PWST SAW - Sensor System

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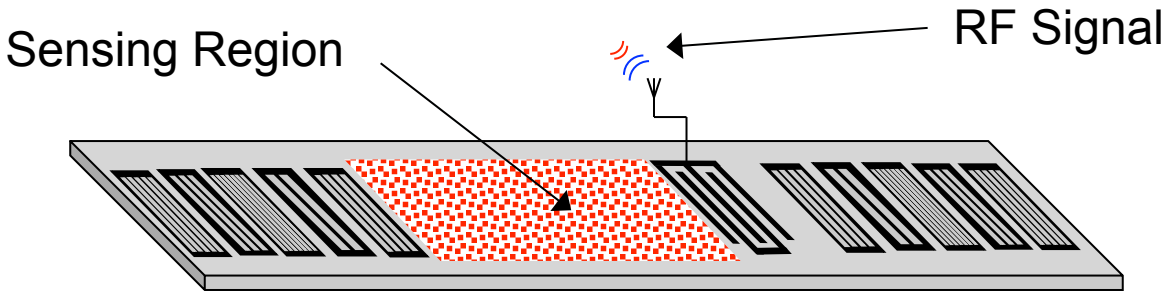
How do SAW sensors work?



Features

- ♦ Operate wirelessly
- ♦ RFID capable
- ♦ Require no batteries
- ♦ Sensitive/accurate measurements
- ♦ Real−time measurements
- ♦ Last for decades
- ♦ Survive & operate in extreme environments
- ♦ Low cost - based on established technology

Benefits

Eliminate wiring harness; Low installation cost
Operate on rotating parts
Individual sensor ID enables multisensor systems
No battery changes; Low maintenance cost
Comparable to wired sensors
Rapid response; Variable sampling rate
Suitable for embedded use and long-term monitoring
Cryogenic to 1000°C+; Measure where Si fails
Radiation hard
Existing manufacturing infrastructure
Enable low cost distributed sensing

Products under development:

> Coded sensor-tag wireless interface devices

> Humidity sensors

> Hydrogen sensors

> Temperature sensors

> Methane sensors

> Hypergol leak detection sensors (MMH, DMH, NTO)

> (Cryogenic) liquid (level) sensors

> Concrete maturity monitor

> Biosensor for infectious agents (CT)

Focus on these today & on recent coding advances

Coded sensor-tag wireless interface devices:

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> SAW device acts as wireless interface to existing sensor

> SAW coded and individually identifiable

> Read SAW code & sensor reading

> Read impedance varying & voltage producing sensors

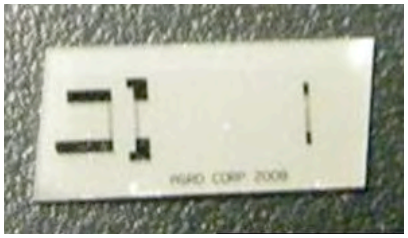
- > Temperature sensors
- > Strain gauges
- > Switch positions
- > Bus voltages
- > Acoustic emission sensors

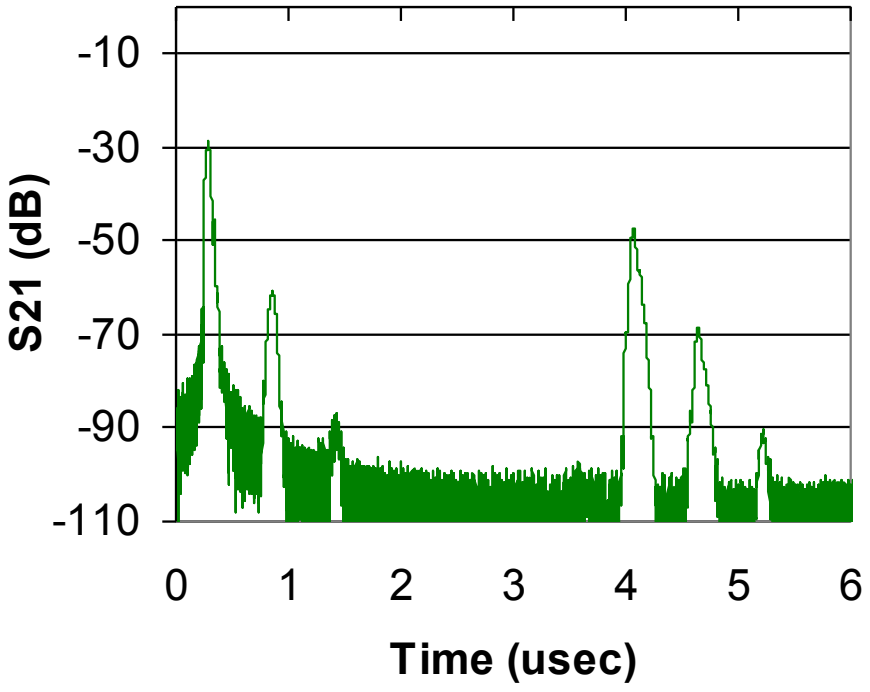
> Goal: Elimination of wiring harness to existing sensors

Overview

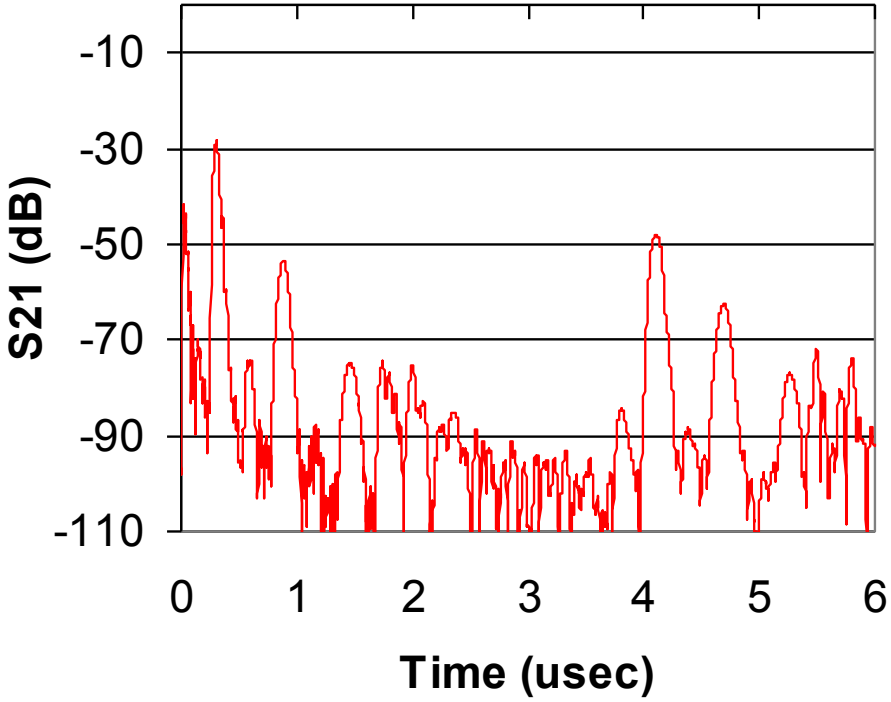
- SAW humidity sensor system with 16 individually identifiable devices
  - Nanoparticle PVP/LiCl-doped TiO_2 films
  - Rapid responses to humidity variation
  - Used time diversity and code diversity (DFC)
- Wireless SAW sensor interrogation system utilizing a differential time integrating correlation approach
- Demonstrated passive wireless measurement of a chemical vapor using film coated SAW sensors
- Advances in code anti-collision
  - Barker Coding with time, frequency diversity – 100 sensor-tags
  - DSSS codes with time, frequency diversity – 32 T sensors
- Conclusions

SAW Test Device - Films



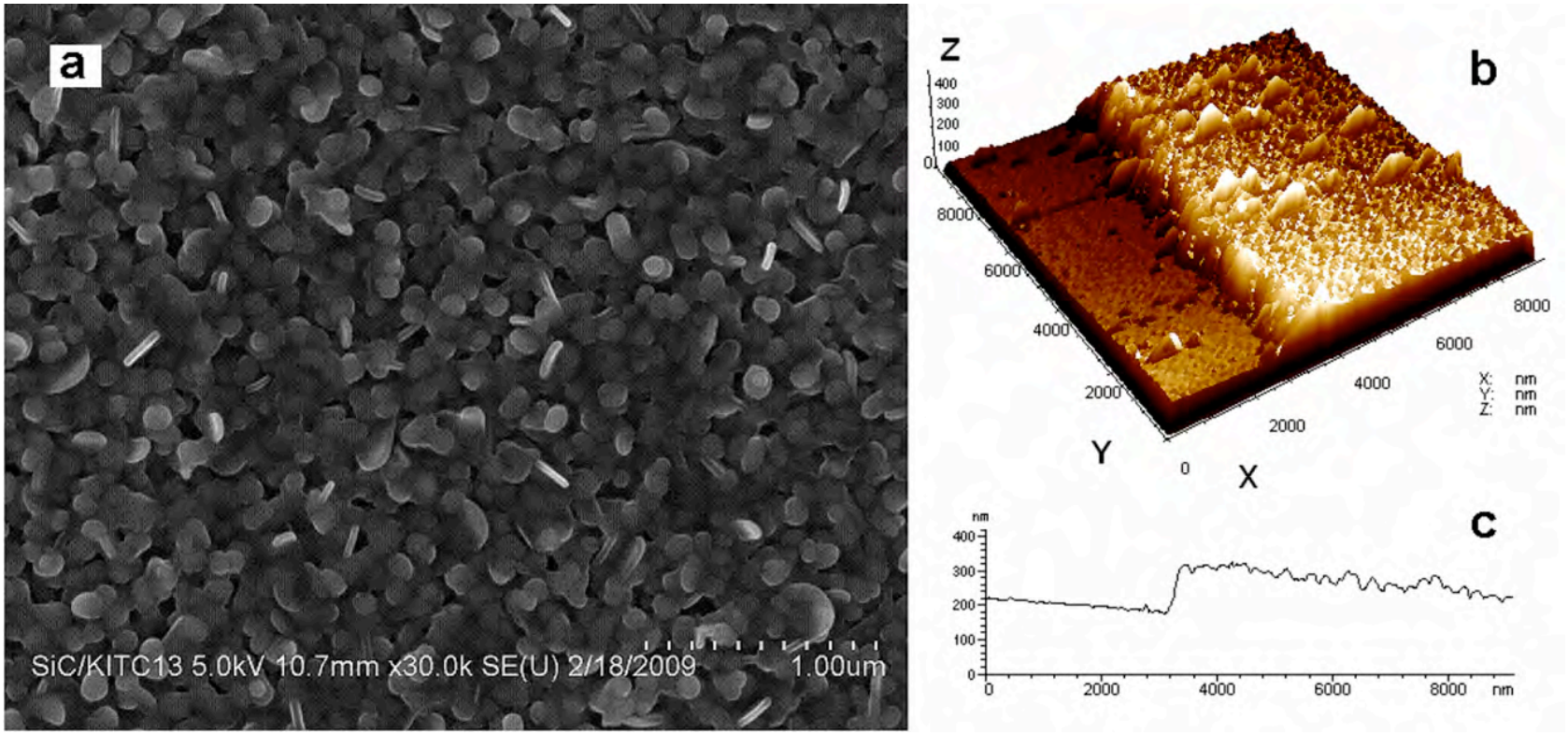


Simulation



Actual Device

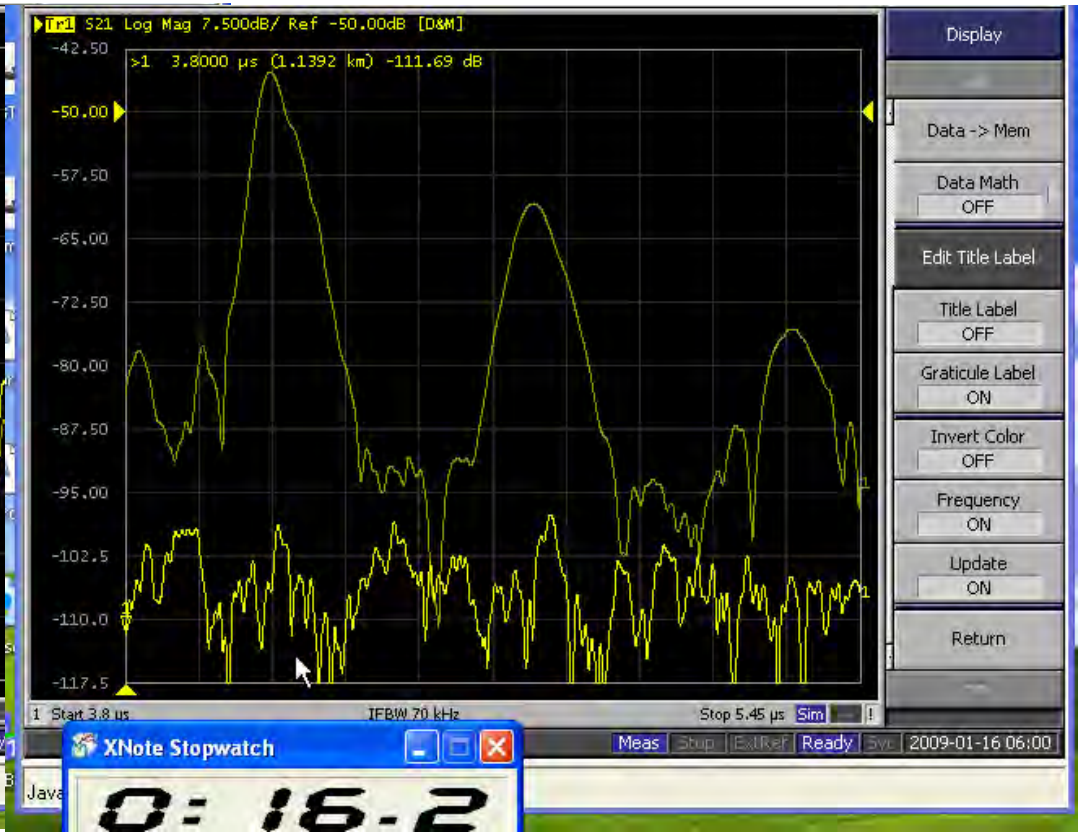
Nanoparticle PVP-LiCl/TiO_2



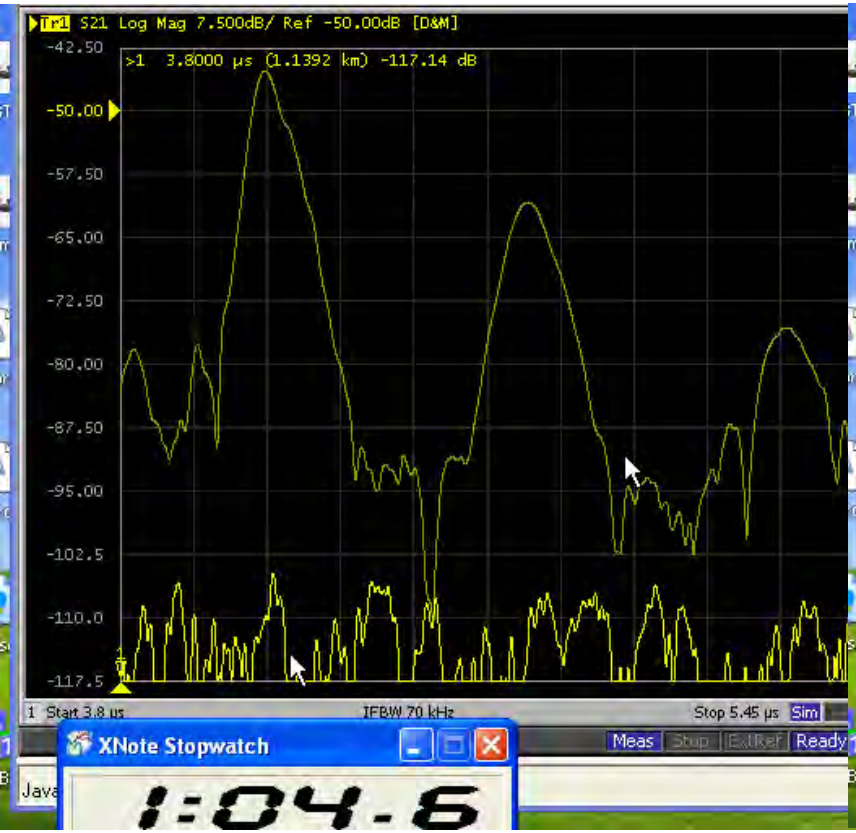
(a) SEM image of TiO-$_2$/LiCl film; (b) typical AFM 3D-image used to determine film thickness; (c) AFM cross-section showing profile of the film edge

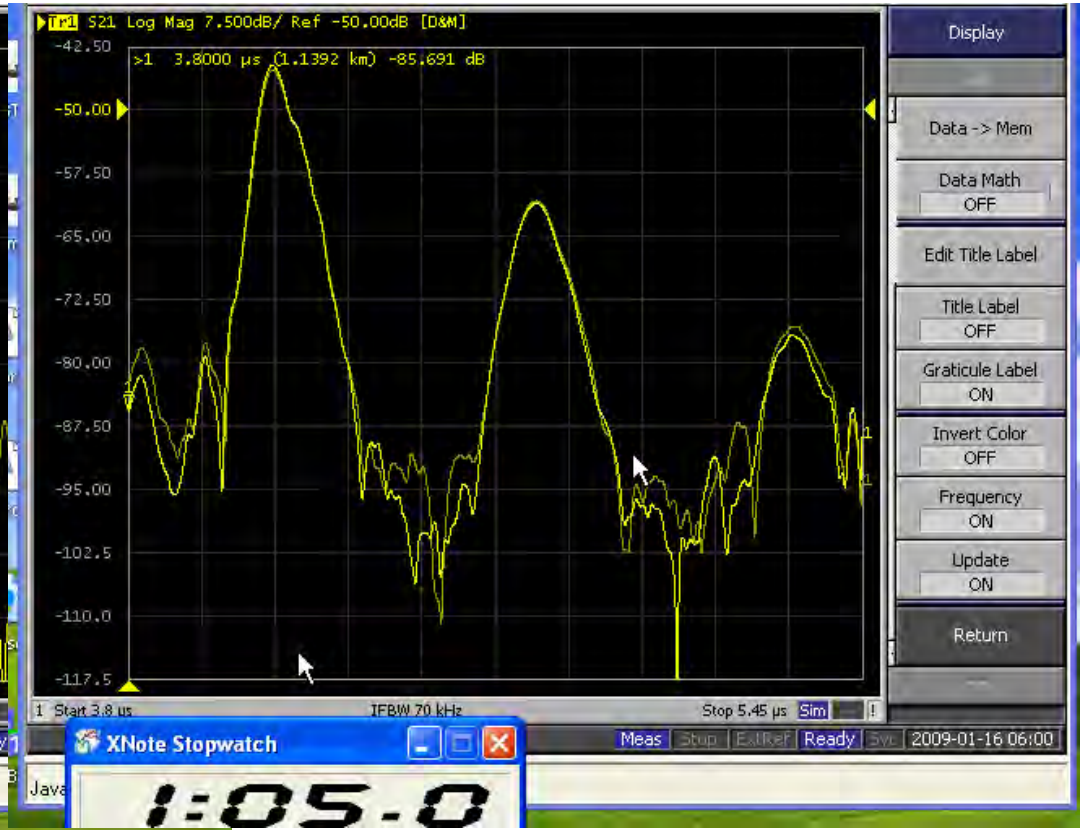
Andrii I. Buvailo, Yangjun Xing, Jacqueline Hines, Norman Dollahon, and Eric Borguet, " TiO_2/LiCl–based nanostructured thin film for humidity sensor applications". ACS Appl. Mater. Interfaces 2011, 3, 528-533.

$LiCl/TiO_2$ Response to Full Humidity

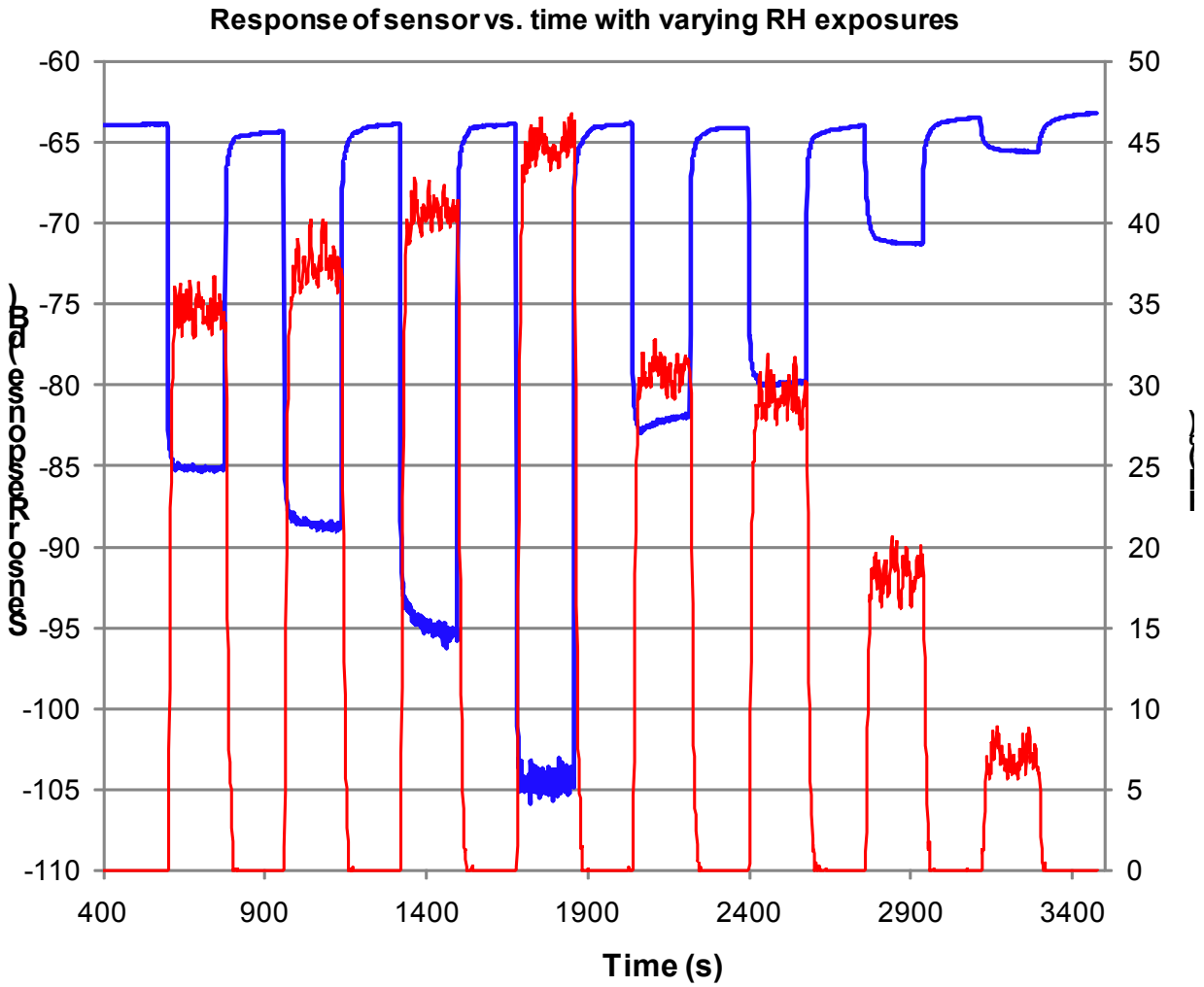


LiCl/TiO_2 Recovery (100% → 20%)

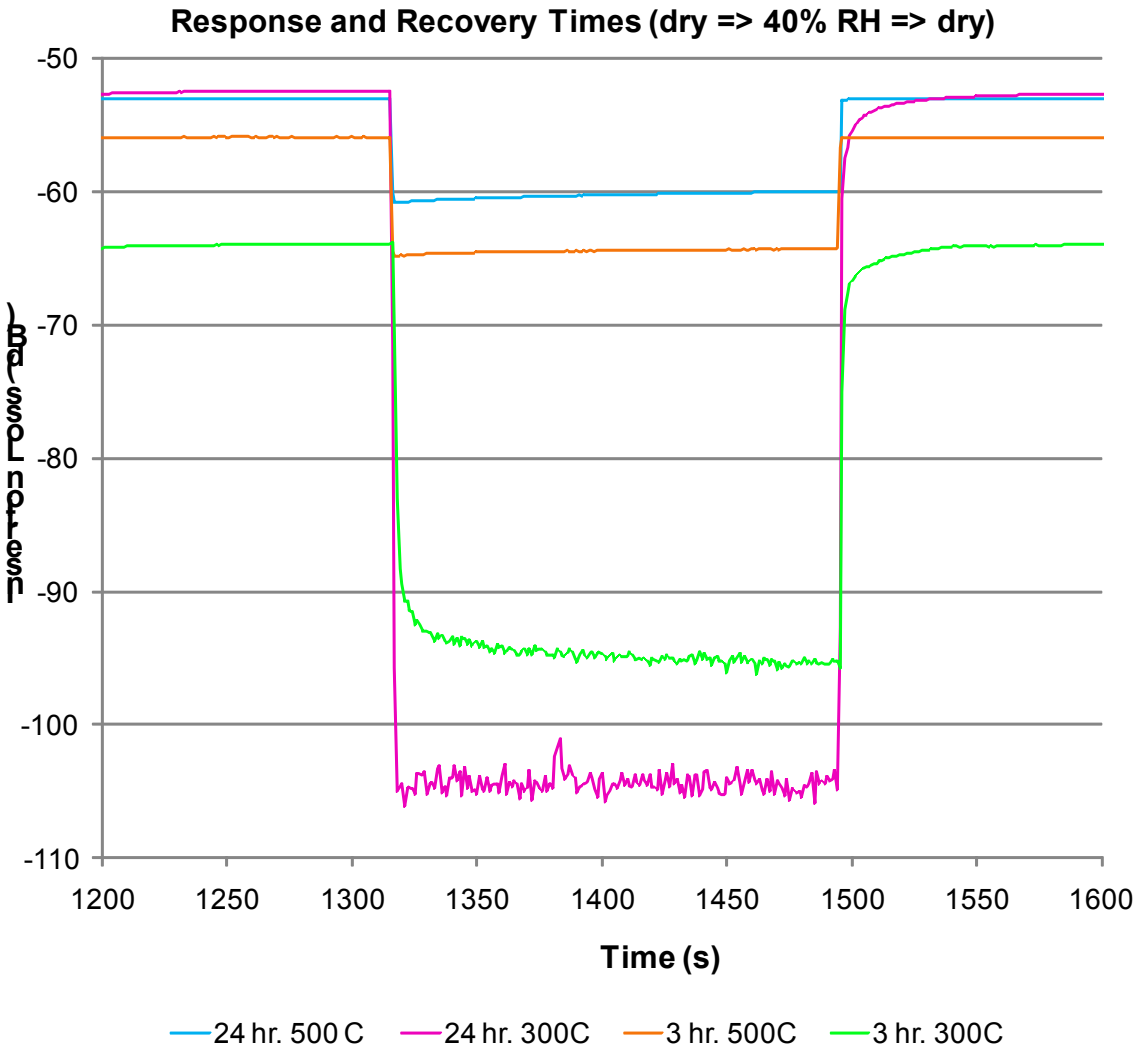




$LiCl/TiO_2$ Response to Humidity



$LiCl/TiO_2$ Response to Humidity

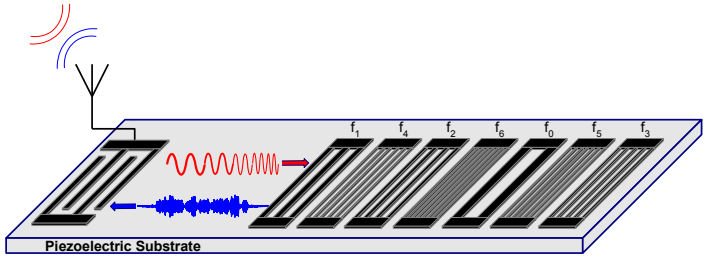


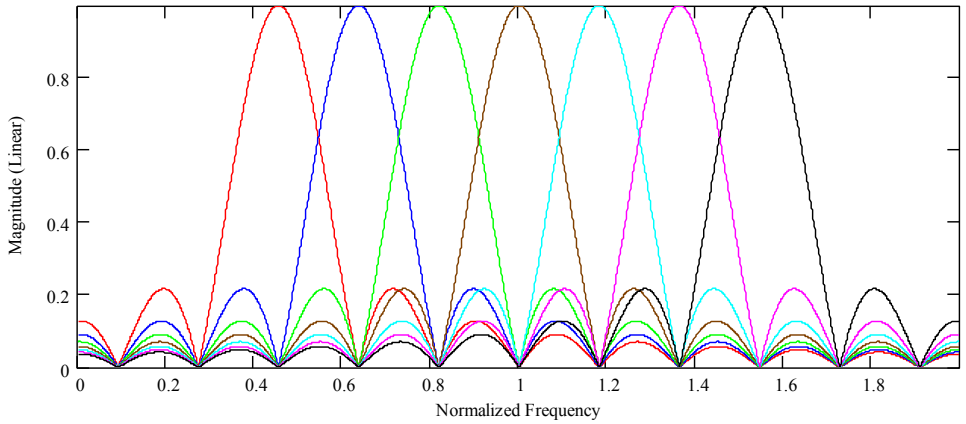
Implementation of Multi-Sensors

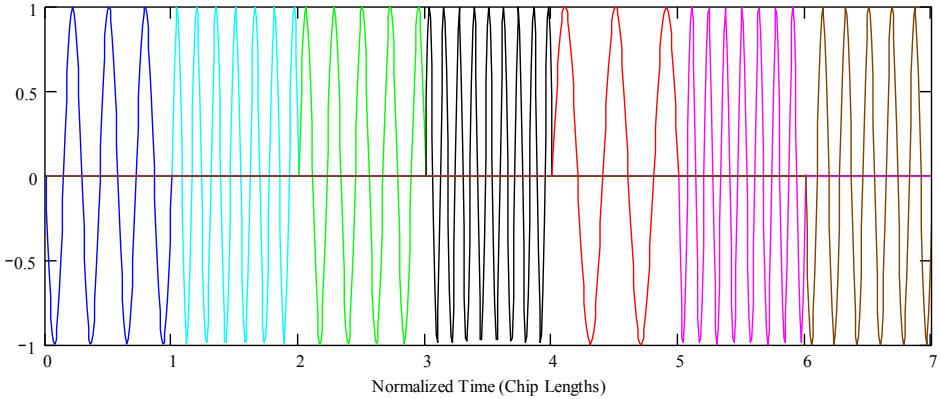
- Designed and manufactured 64 coded SAW humidity sensor devices
  - Used time diversity and code diversity
  - Set of 16 delivered to NASA
- Discrete Frequency Coding (DFC) – code diversity
  - Implemented eight “good” codes
- Time Diversity
  - Re-used each code at eight distinct time delays

Orthogonal Frequency Coding (OFC)

Orthogonal chips at specified frequencies are placed at different delays to produce codes



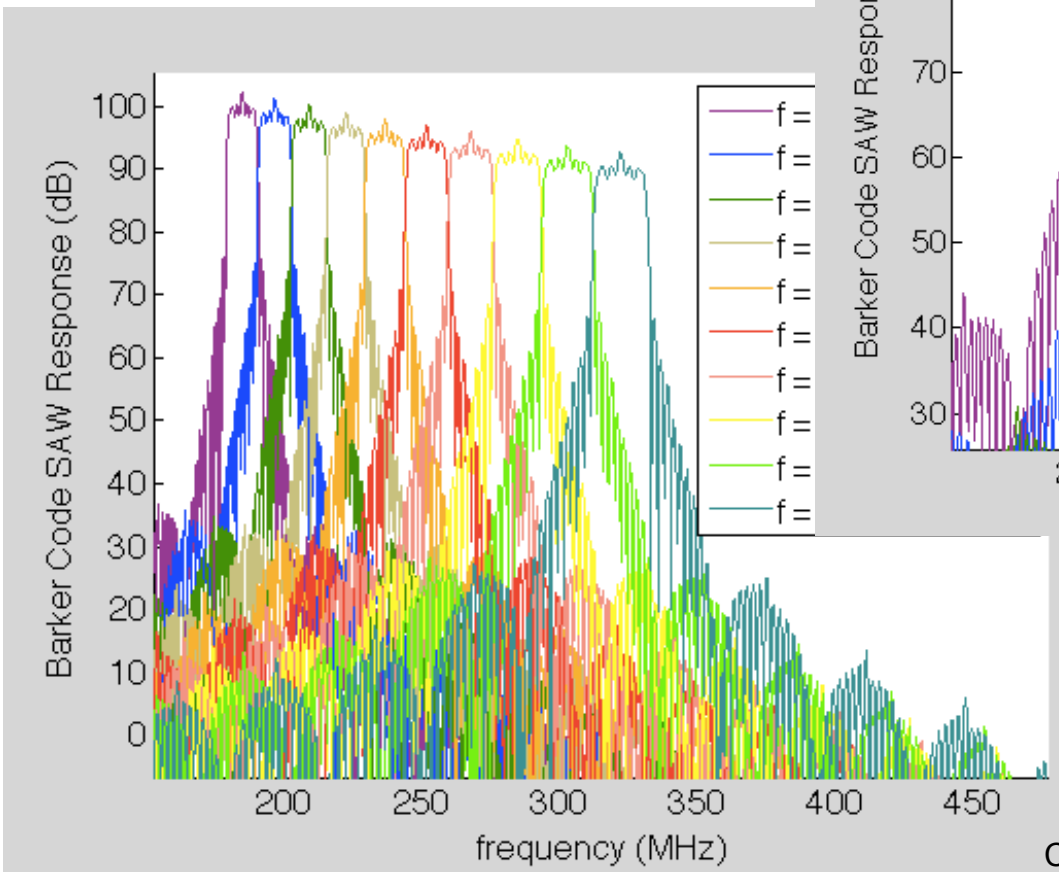


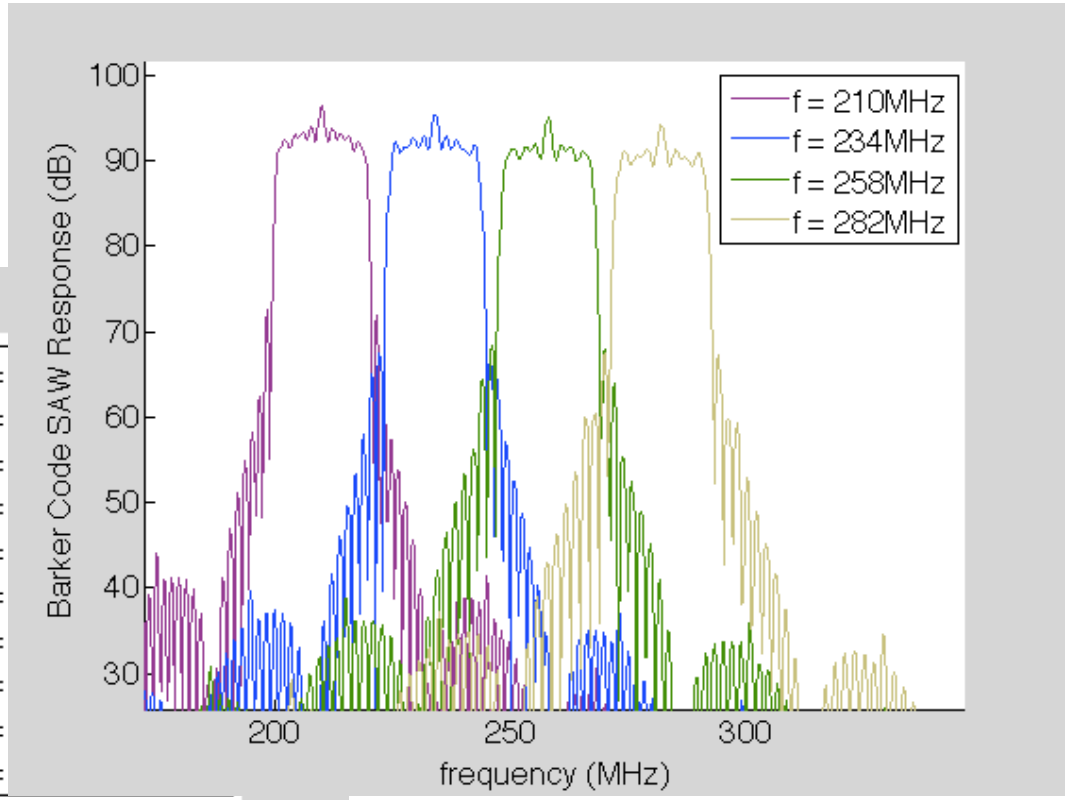


Puccio , D.; Malocha, D.C.; Saldhana, N.; Gallagher, D.R.; Hines J.H. “SAW Sensors Using Orthogonal Frequency Coding", *IEEE Trans UFFC* V 53, No. 2, pp 377-384 Feb. 2006

Discrete Frequency Coding (DFC)

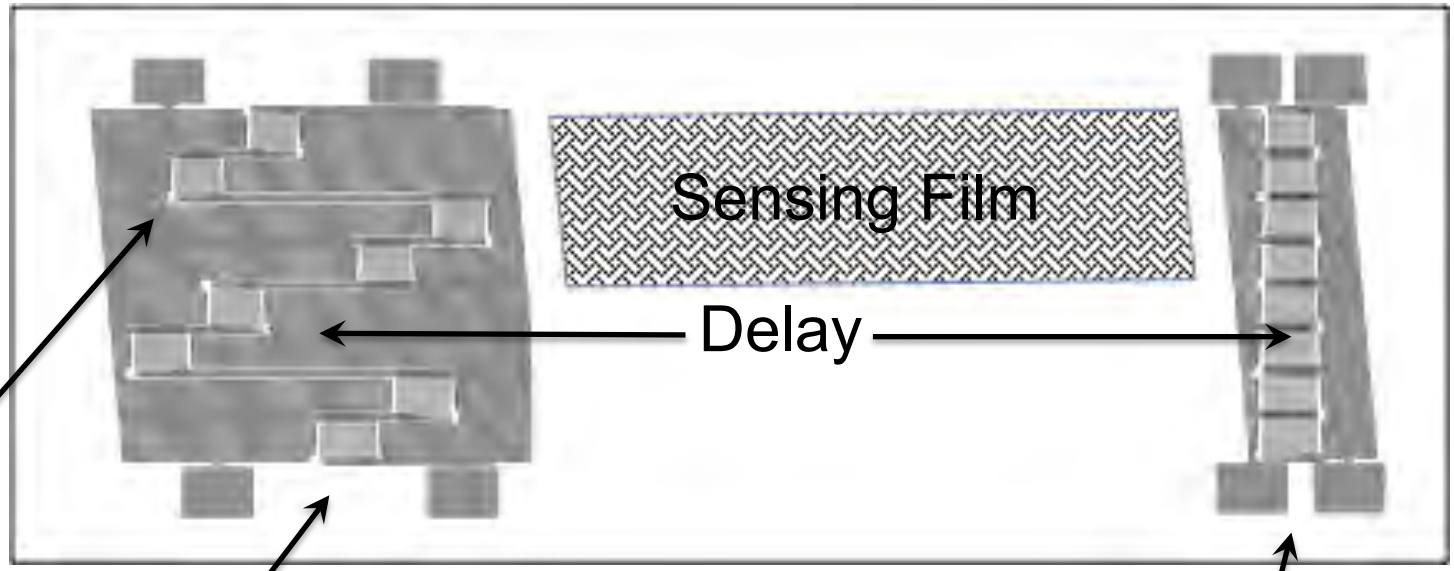
Similar to OFC, but with code “chips” in frequency bands that do not overlap





U.S. 7,791,249 (2010)
"Frequency Coded Sensors Incorporating Tapers",
Hines et. al.

Coded Chemical Sensor Device

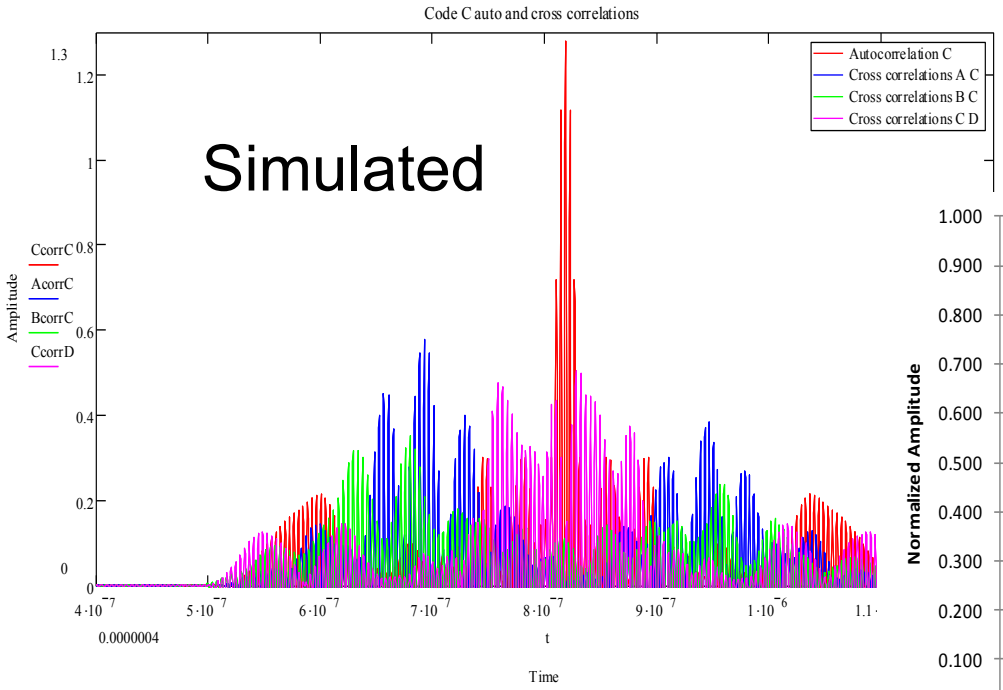


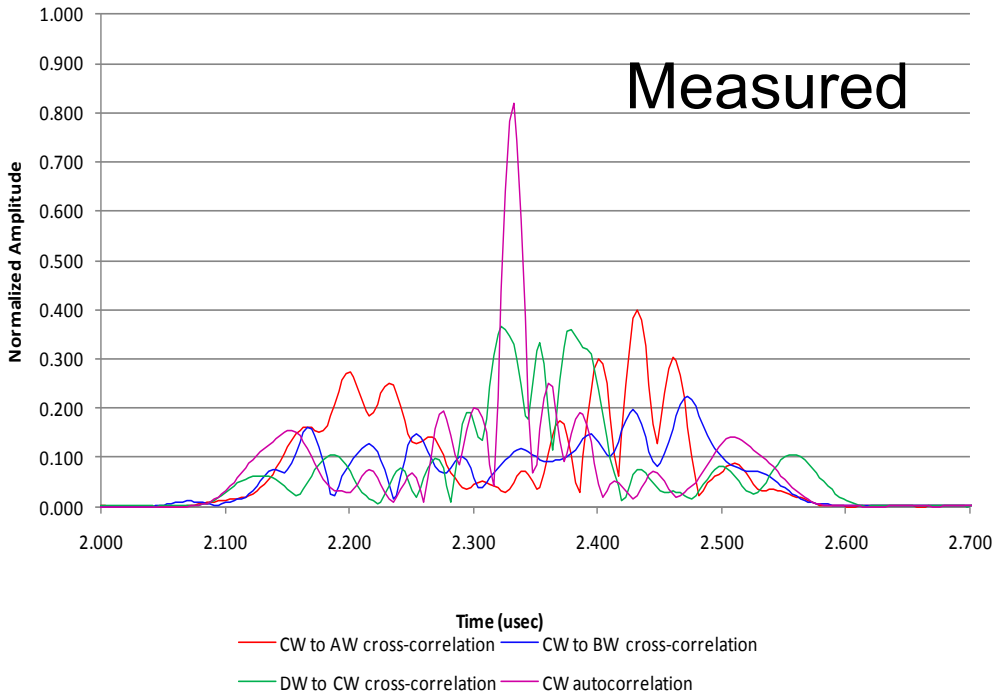
Code Chips

Coded Transducer

Uncoded Transducer

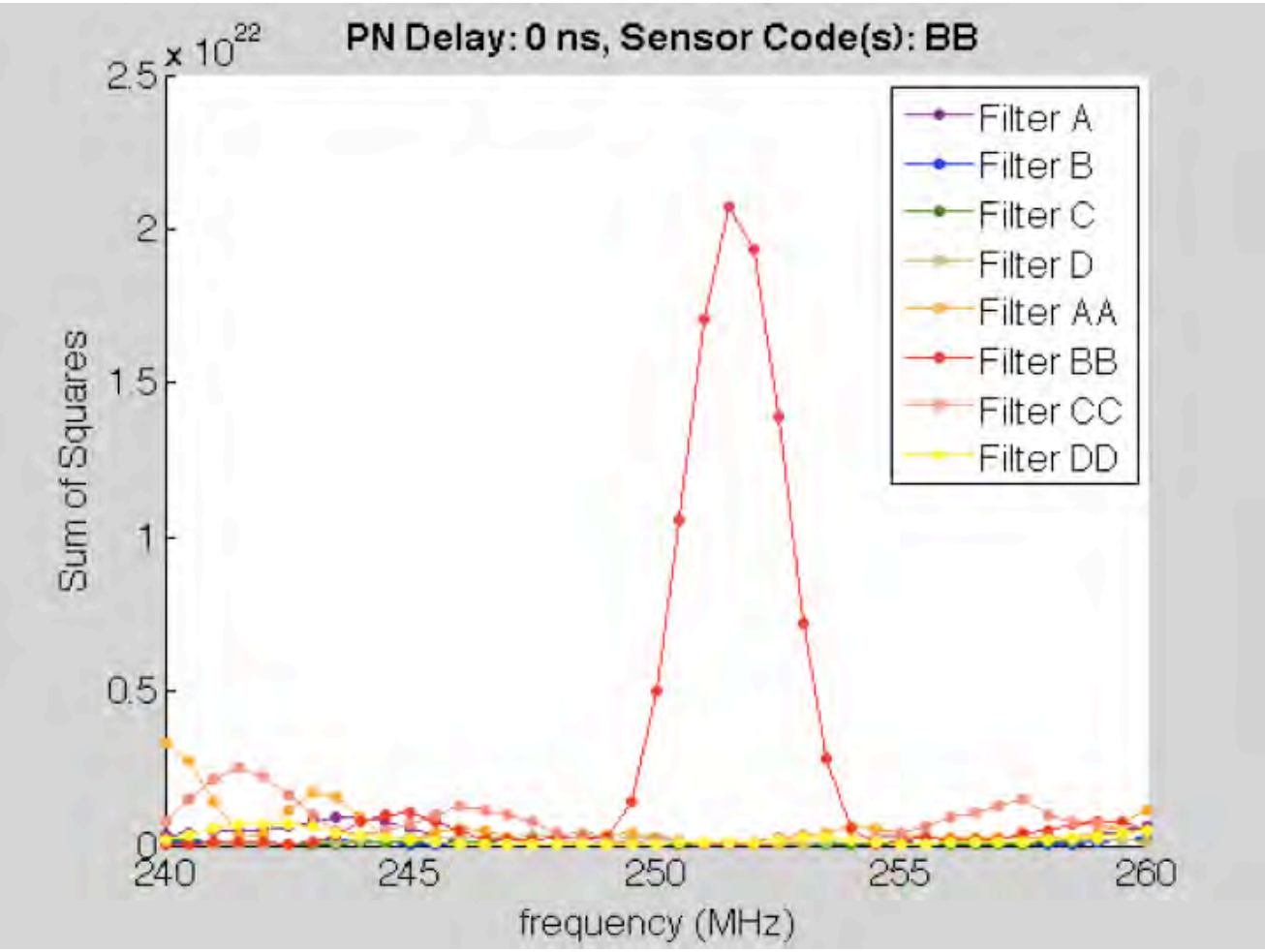
Time & Frequency Coding





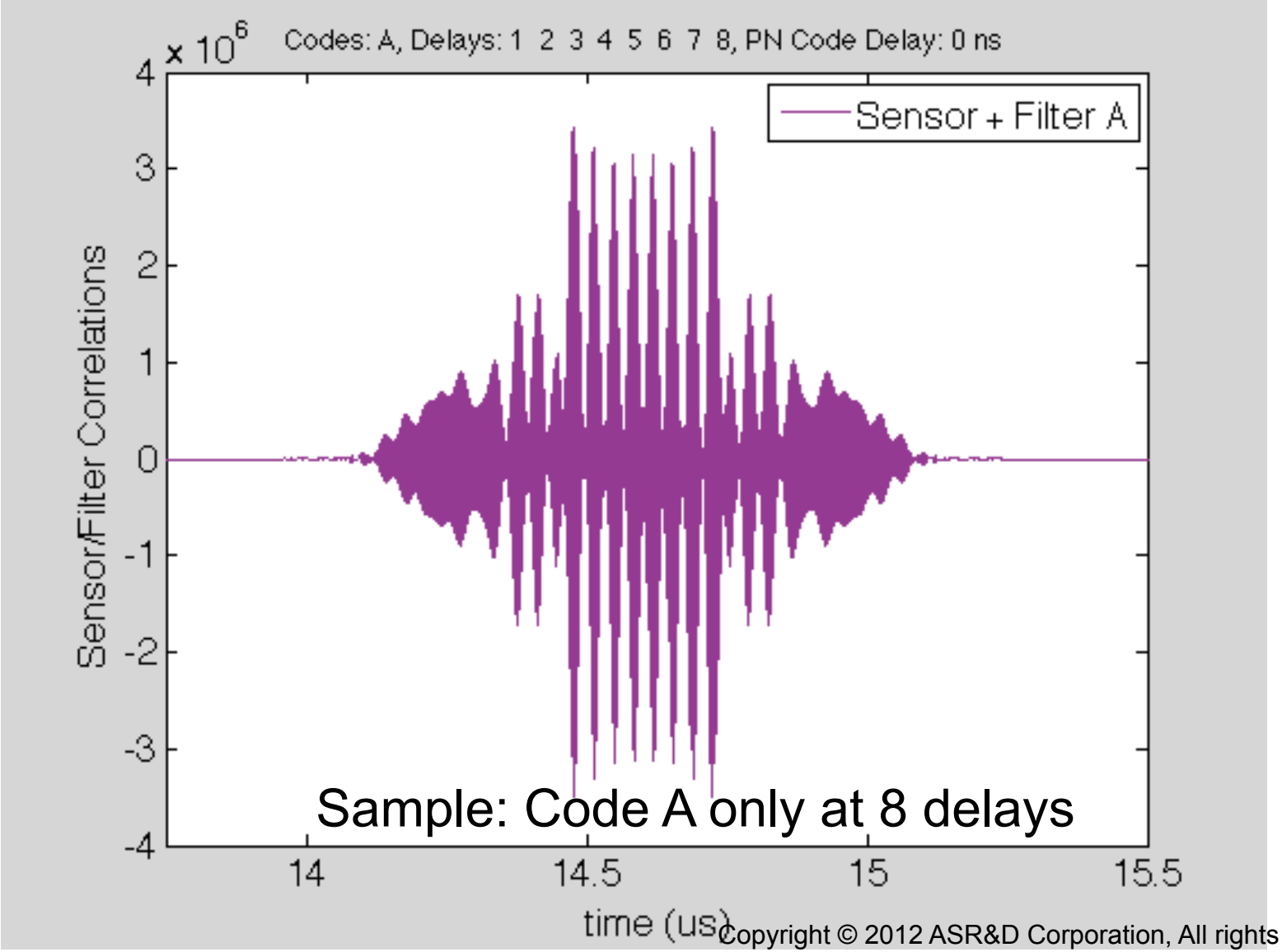
Sample: Auto- and cross-correlation of 4 codes

Simulated System Response

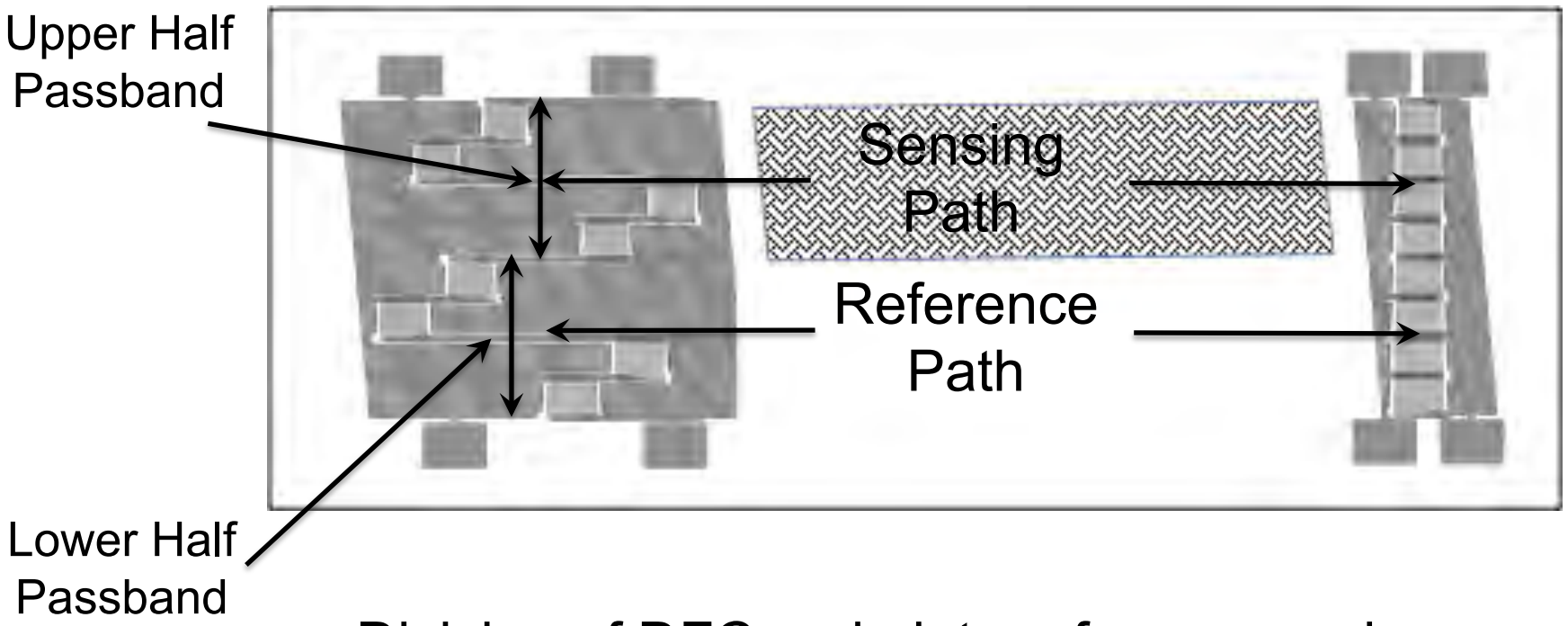


System simulation: Matched filter responses (codes A-DD) to sensor with code A

Time & Frequency Coding



Coded Chemical Sensor Device

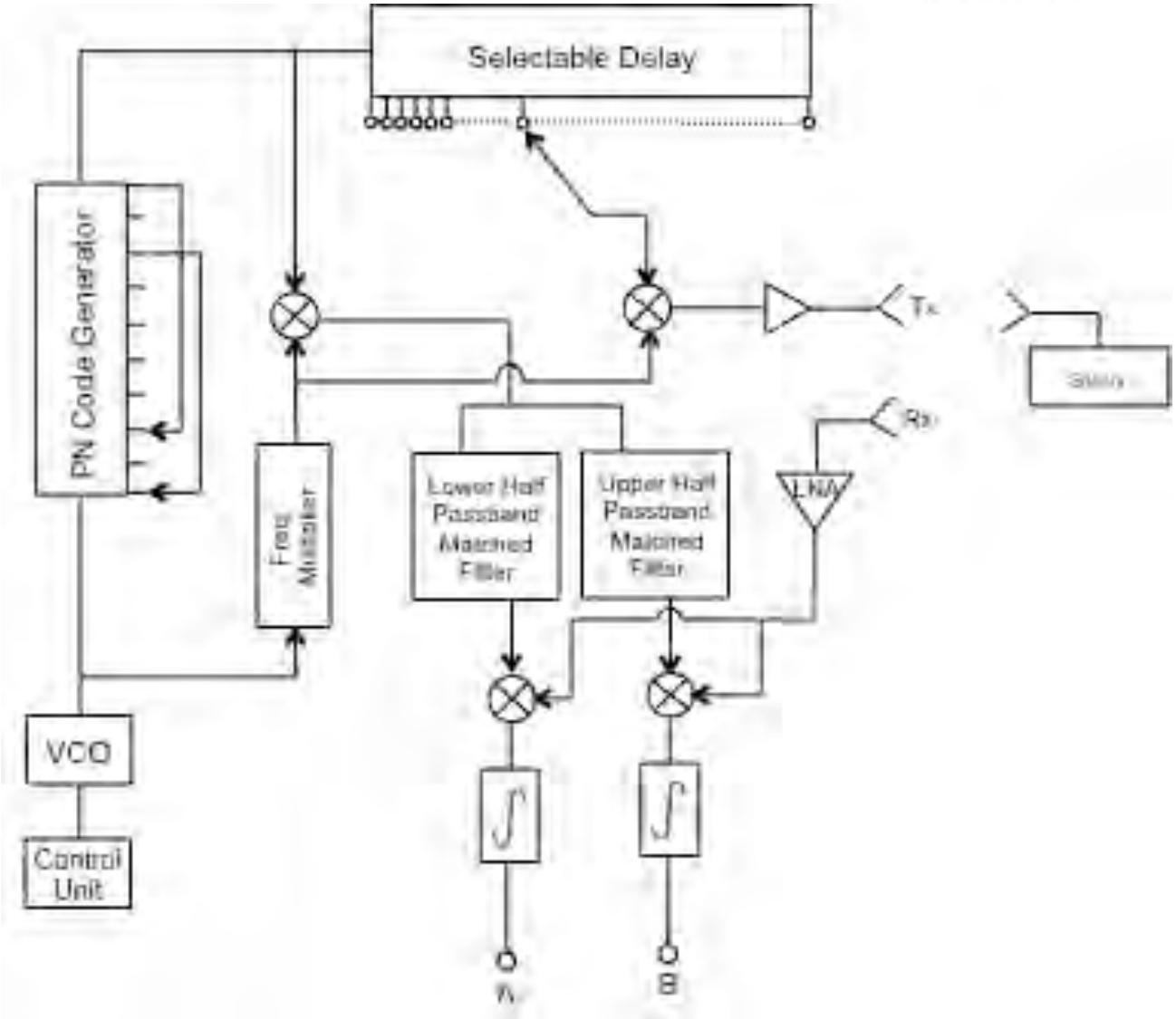


Division of DFC code into reference and sensor path degrades correlation performance

➔ Used only 2 codes for final sensor set

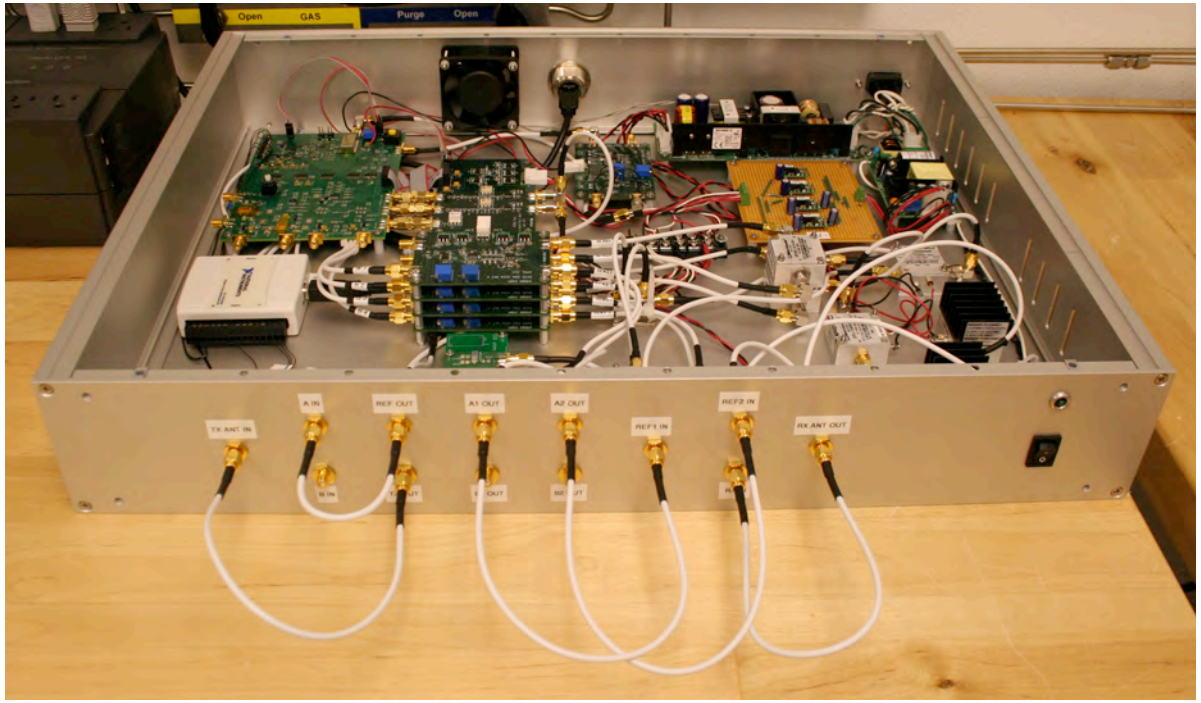
Wireless system

- Time integrating correlator-based transceiver
- Power spectral density of response measured
- Half-passband integrated energy

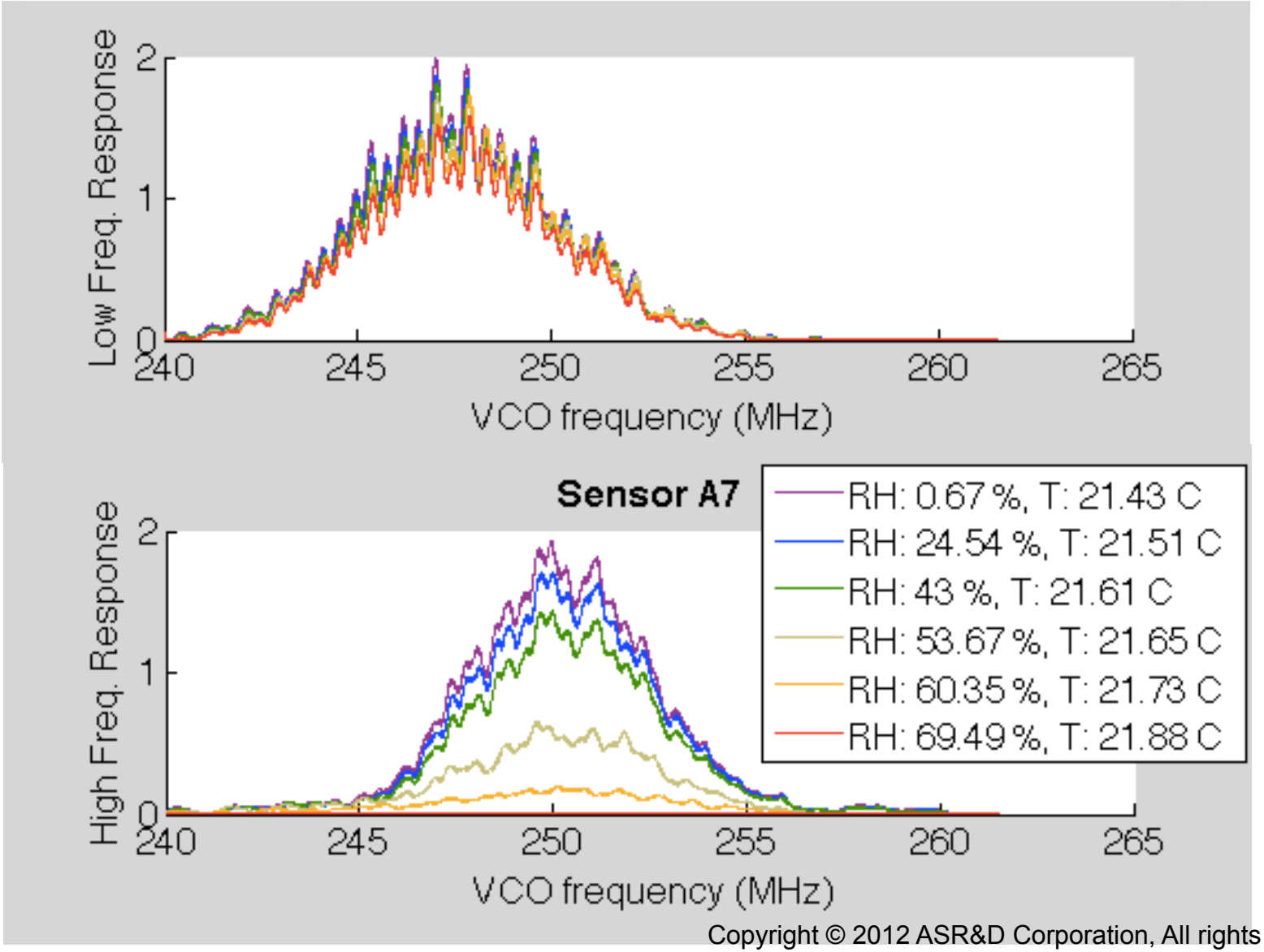


Wireless system

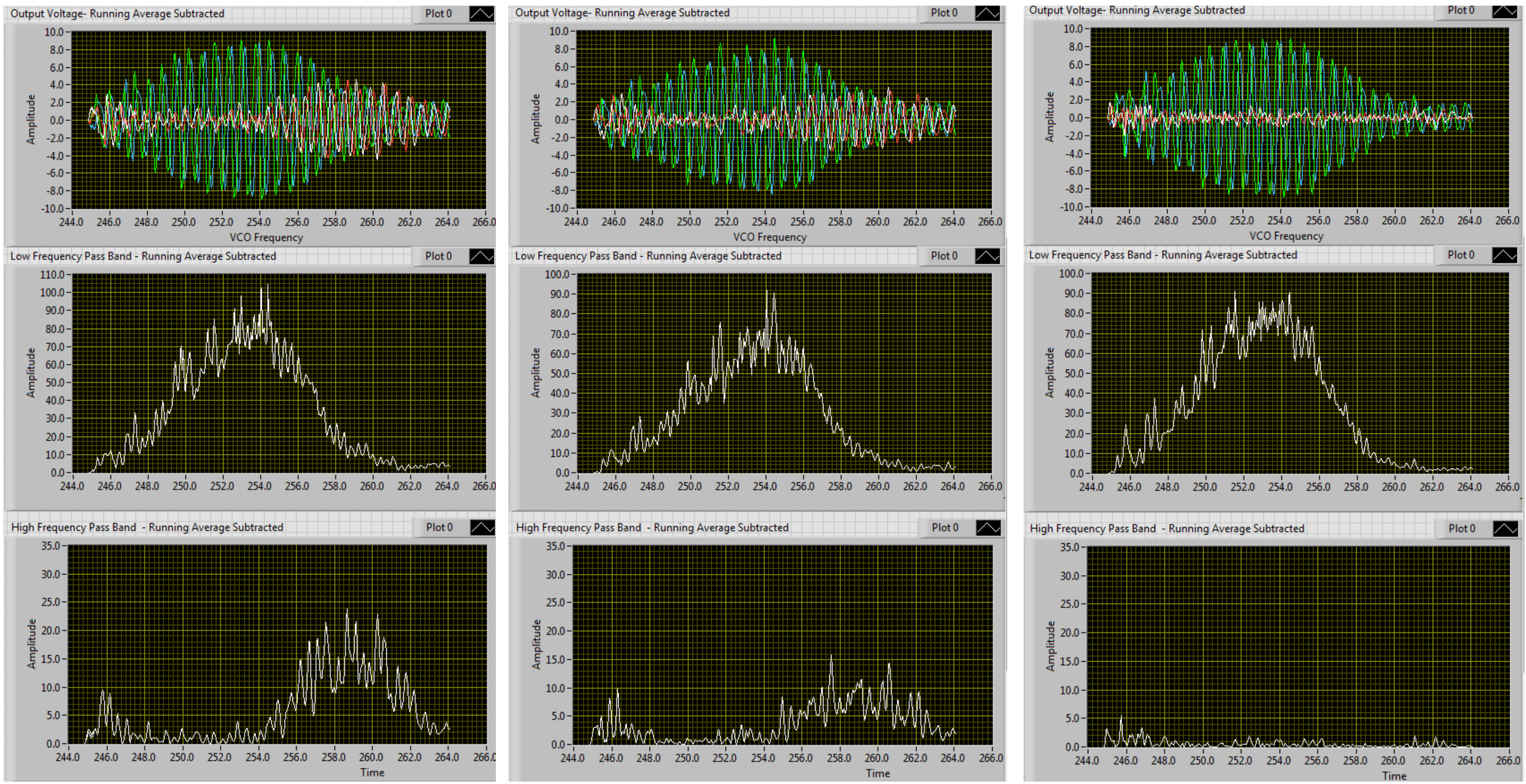
- Room temperature measurement of RH
- 16 individually identifiable sensors
- Passive wireless measurement of humidity
- Need to incorporate temperature sensing to provide calibrated RH



Wired humidity measurements



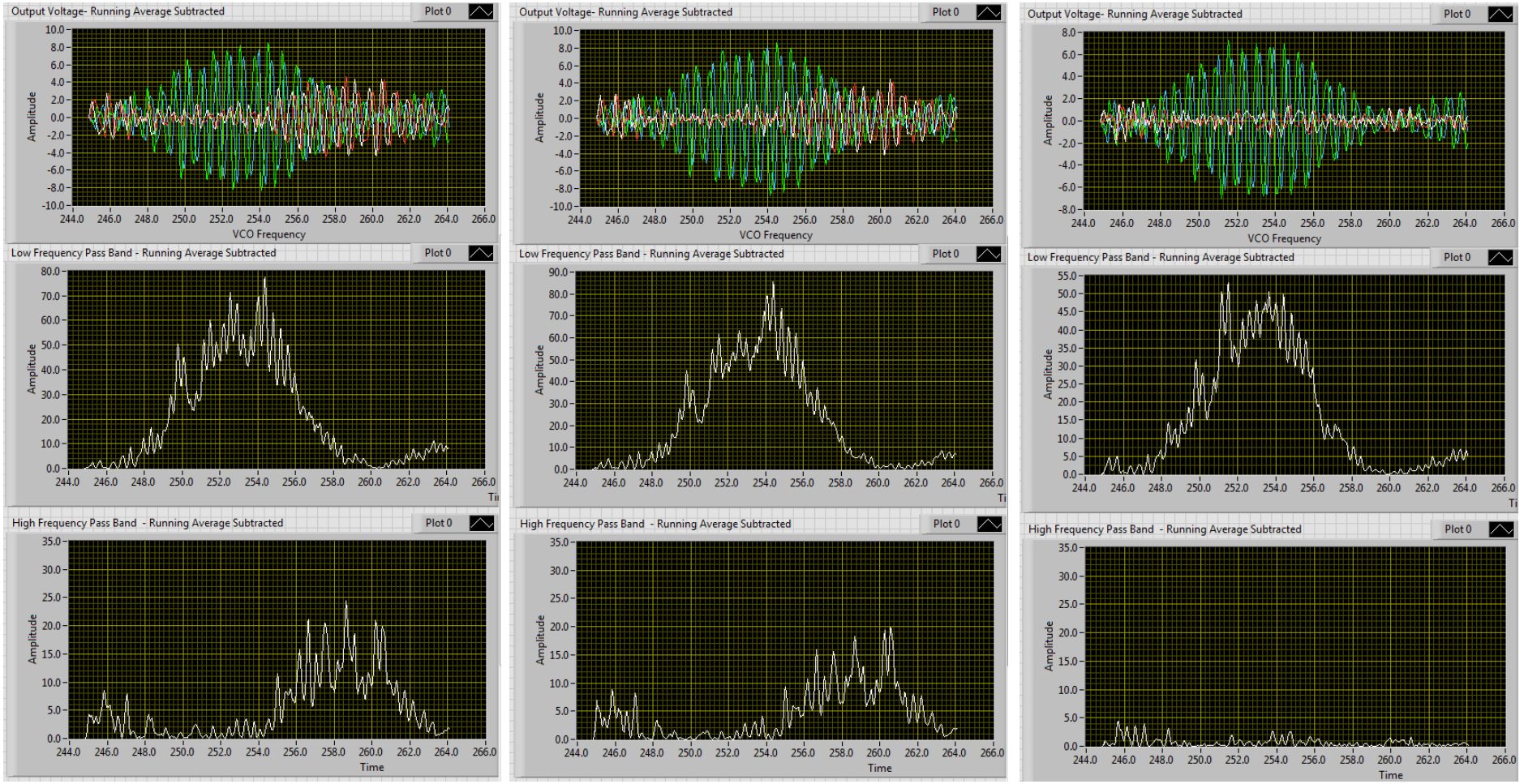
Wireless humidity measurements



Dry **Low RH** **RH~70%**

Sensor B read alone at a distance of 2.5 ft from reader

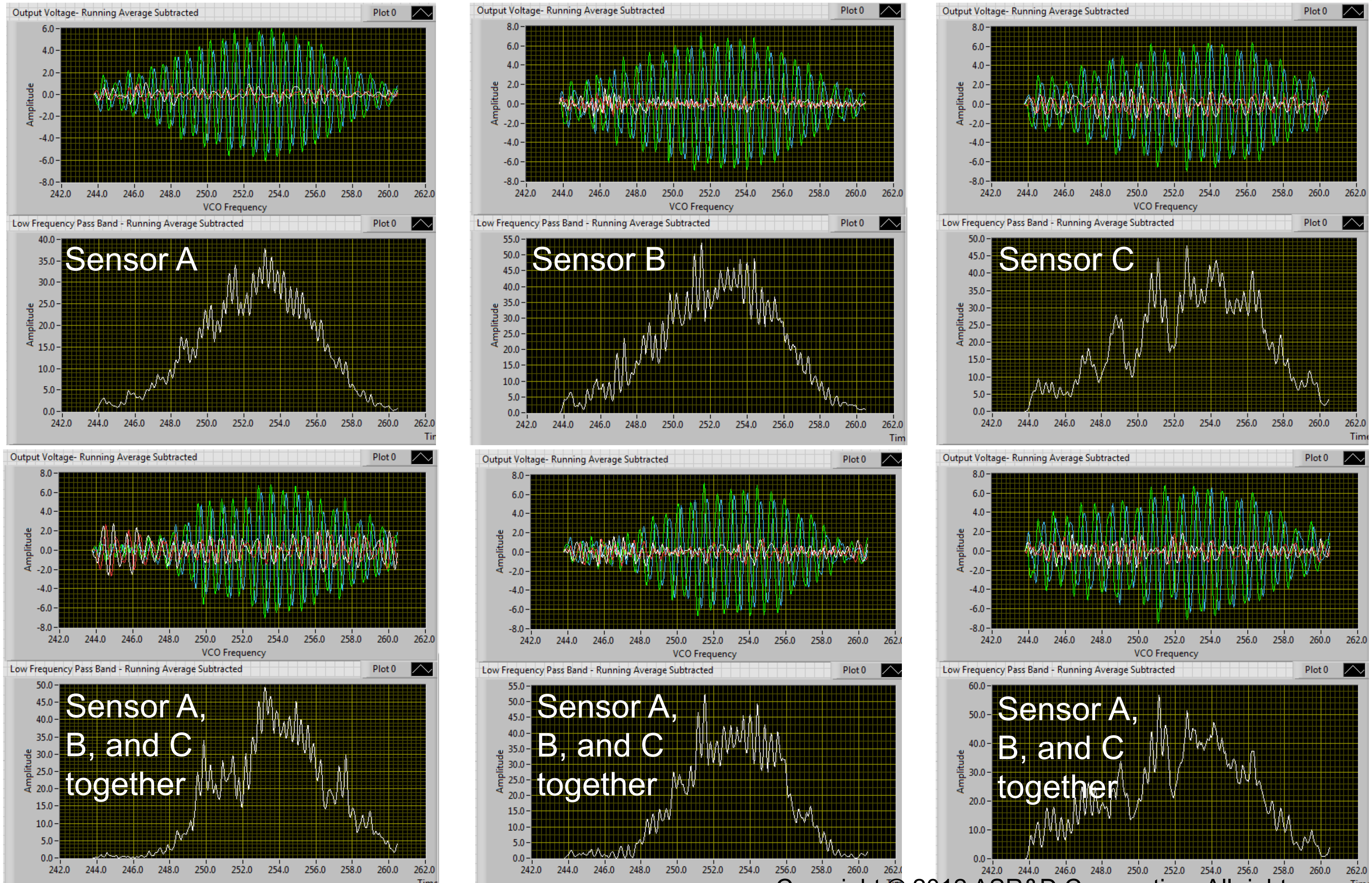
Wireless humidity measurements



Dry **Low RH** **RH~70%**

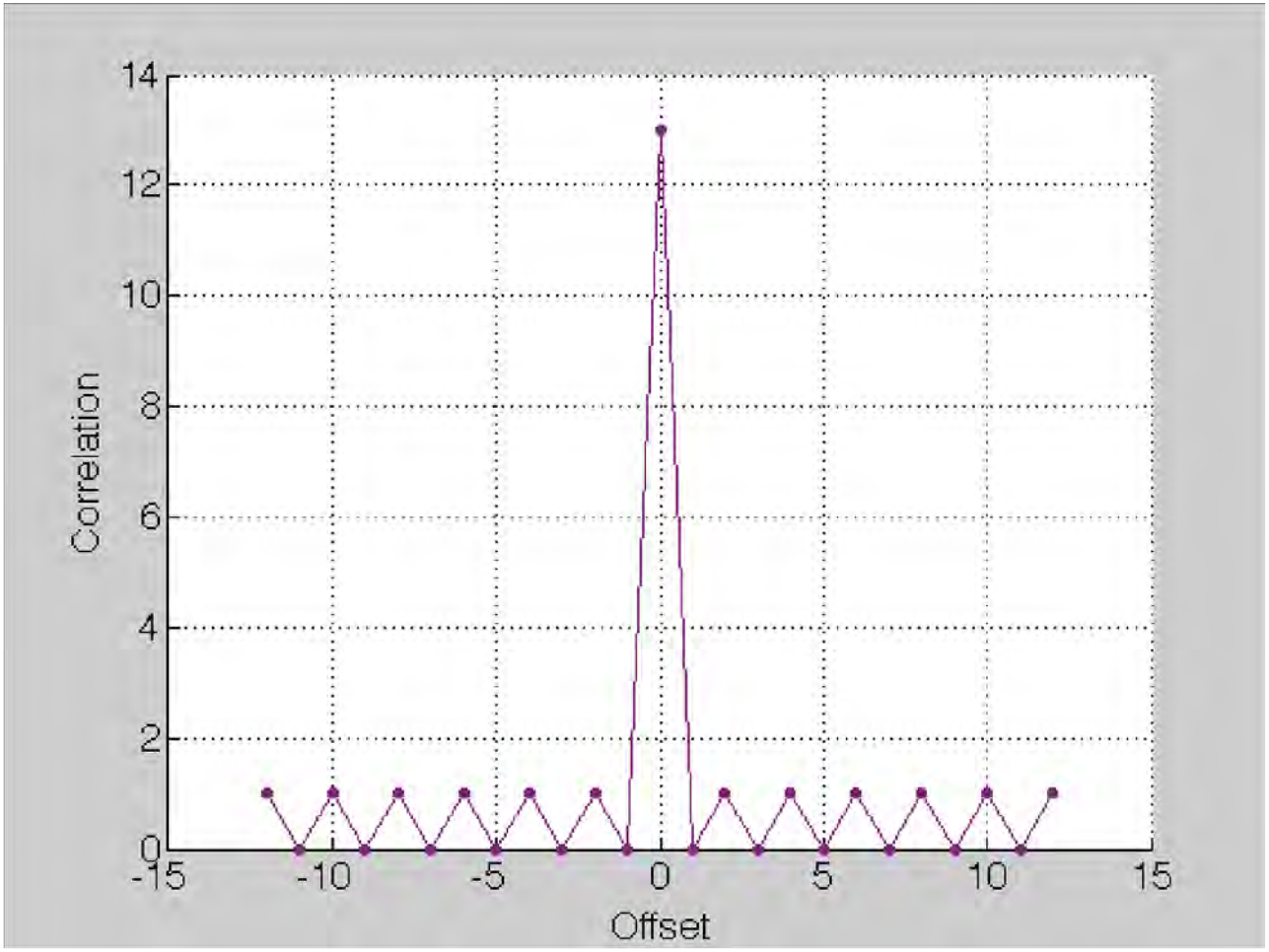
Sensor B read with three sensors in the field of view of reader

Wireless humidity measurements



Advances in Sensor-tag Coding

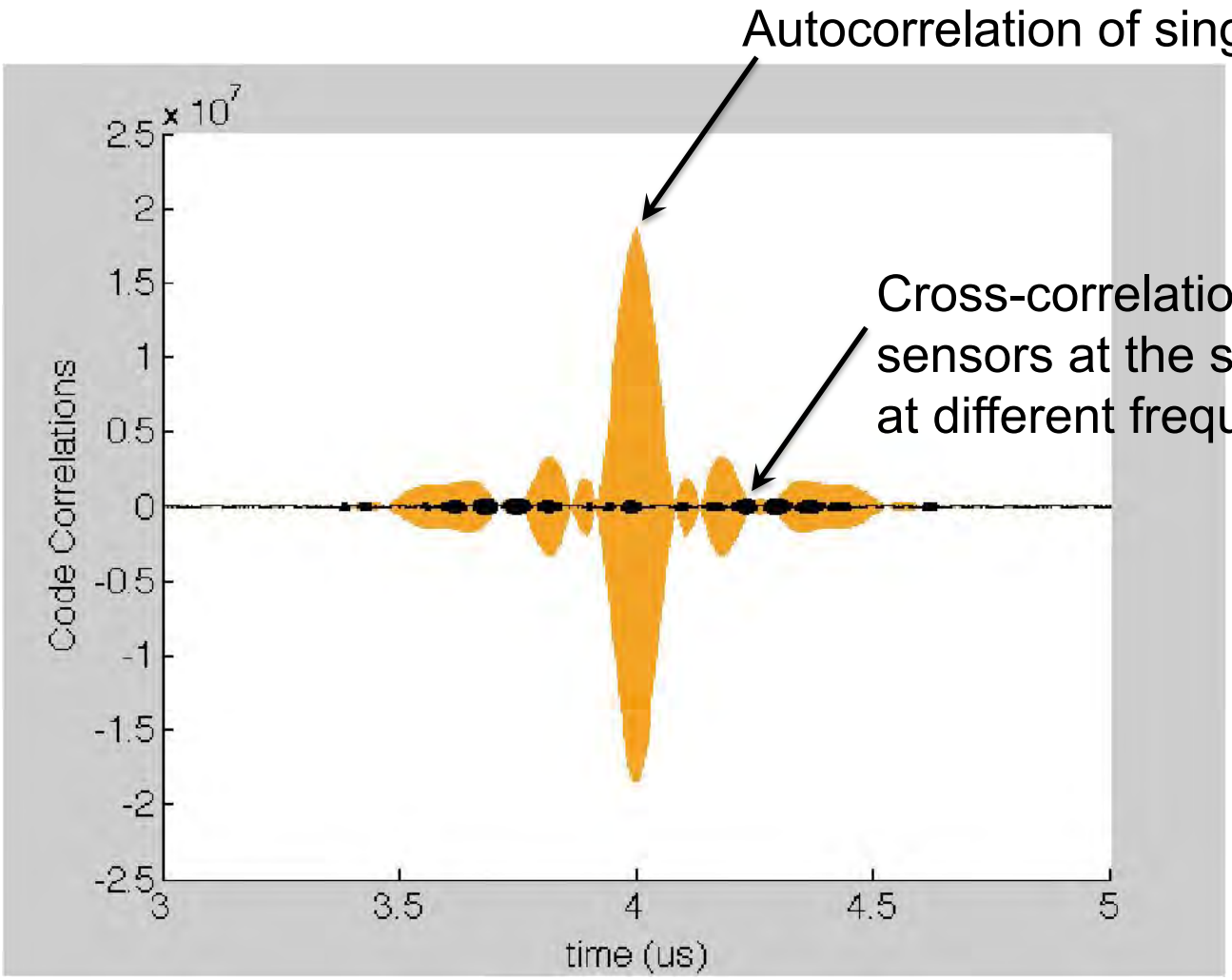
- 13-bit Barker code with time & frequency diversity – 100 sensor-tags



Autocorrelation for13-bit Barker code

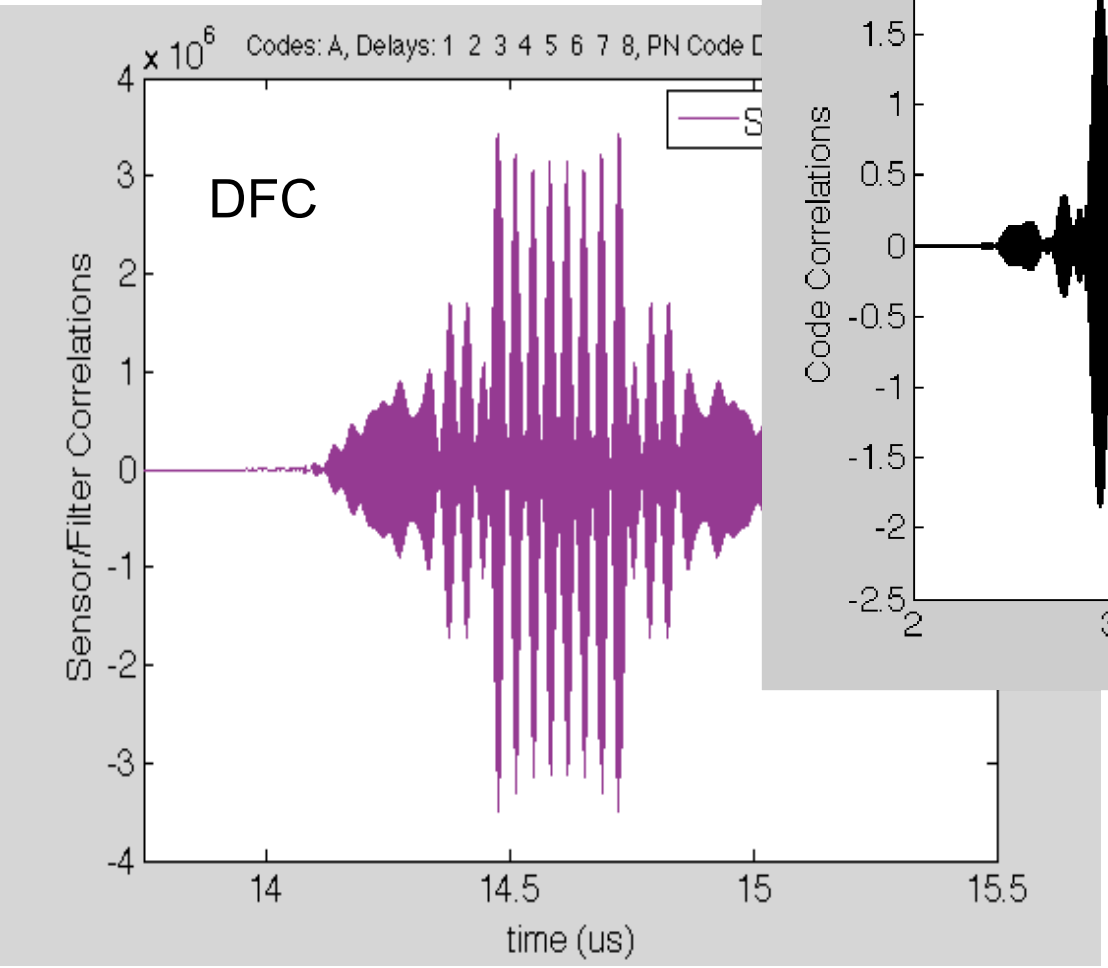
100 Barker coded sensor-tags

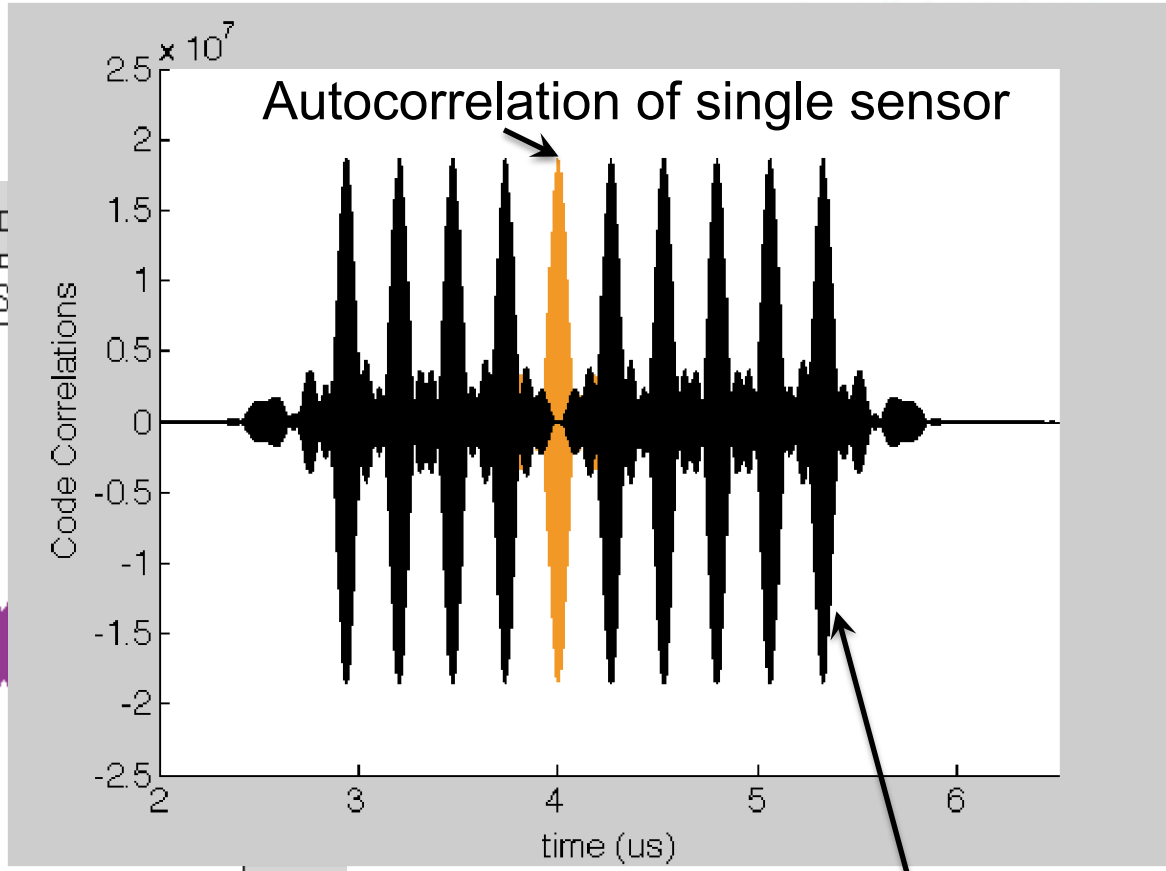
- Frequency Diversity x 10



100 Barker coded sensor-tags

- Time diversity x 10

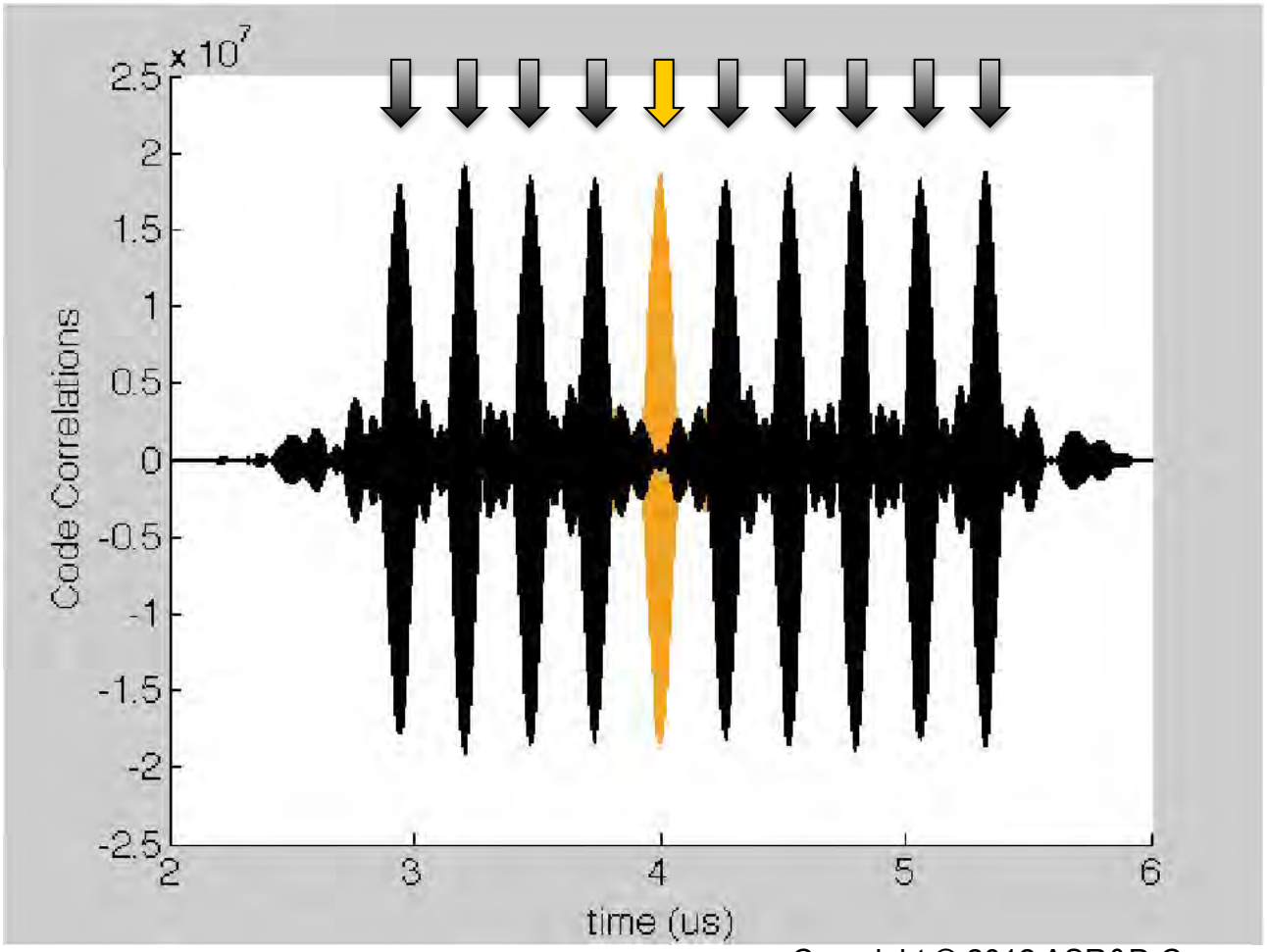




Cross-correlation with 9 other sensors at the same frequency and different delays

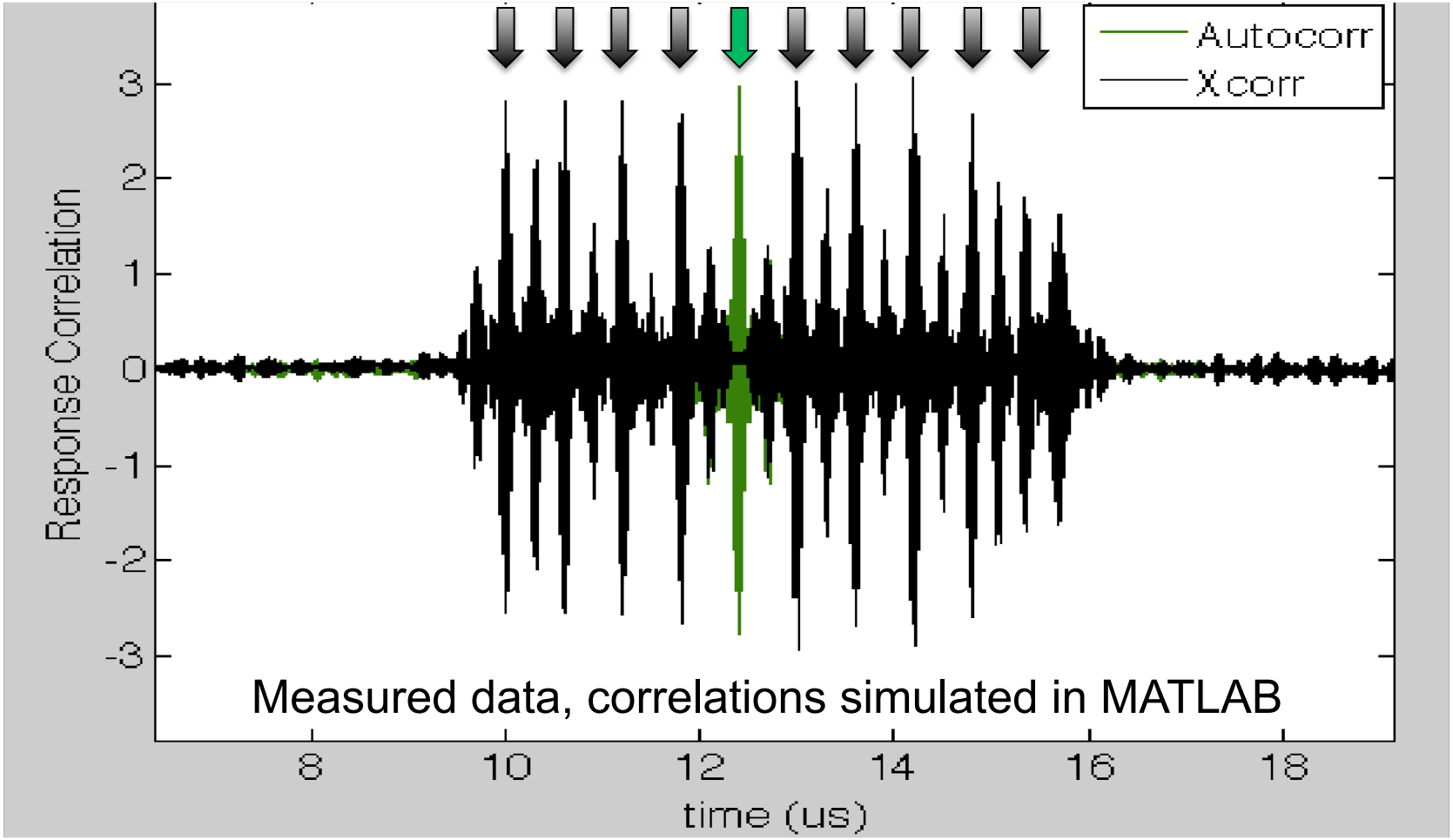
100 Barker coded sensor-tags

- Autocorrelation of 1 sensor (gold) – frequency 3, delay 5
- Cross-correlation this sensor with the 99 other sensors



100 Barker coded sensor-tags

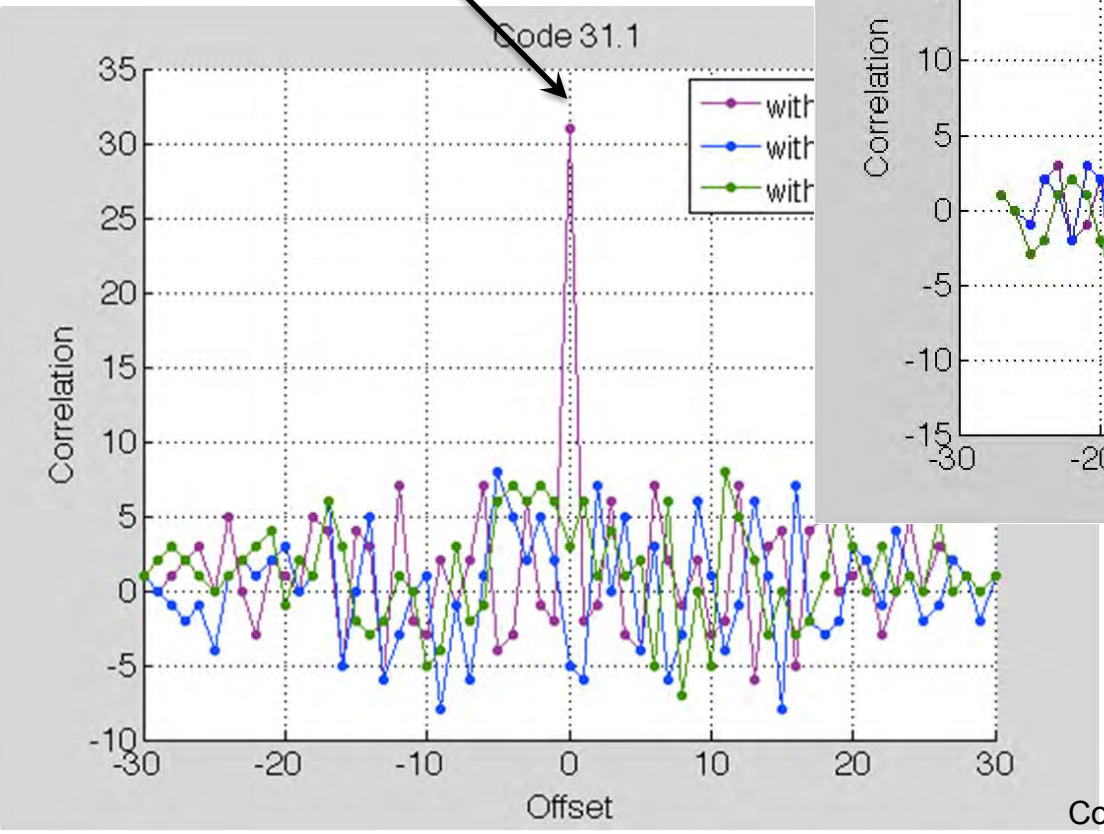
- Autocorrelation of 1 sensor (green) – frequency 3, delay 5
- Cross-correlation this sensor with the 99 other sensors

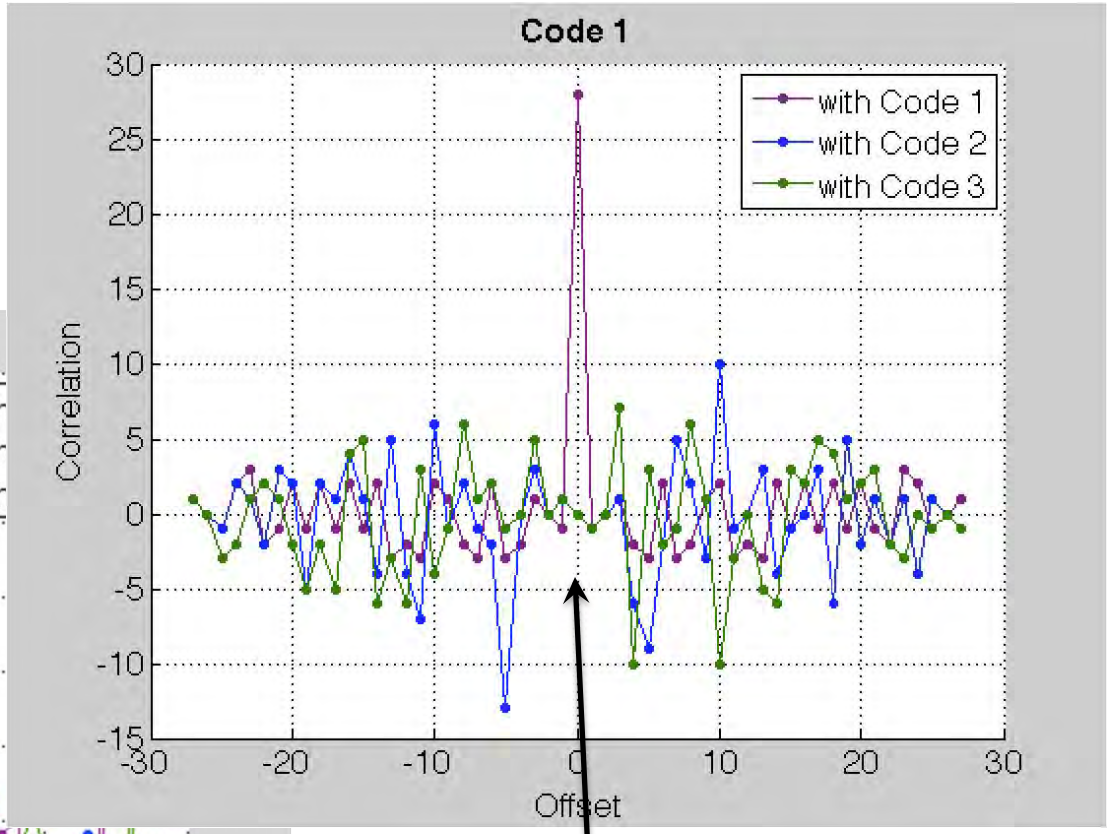


Advances in Sensor-tag Coding

- DSSS code generation

Correlation behavior for a set of three 31- bit Gold codes





Set of three 28-bit codes with improved cross-correlation

Advances in Sensor-tag Coding

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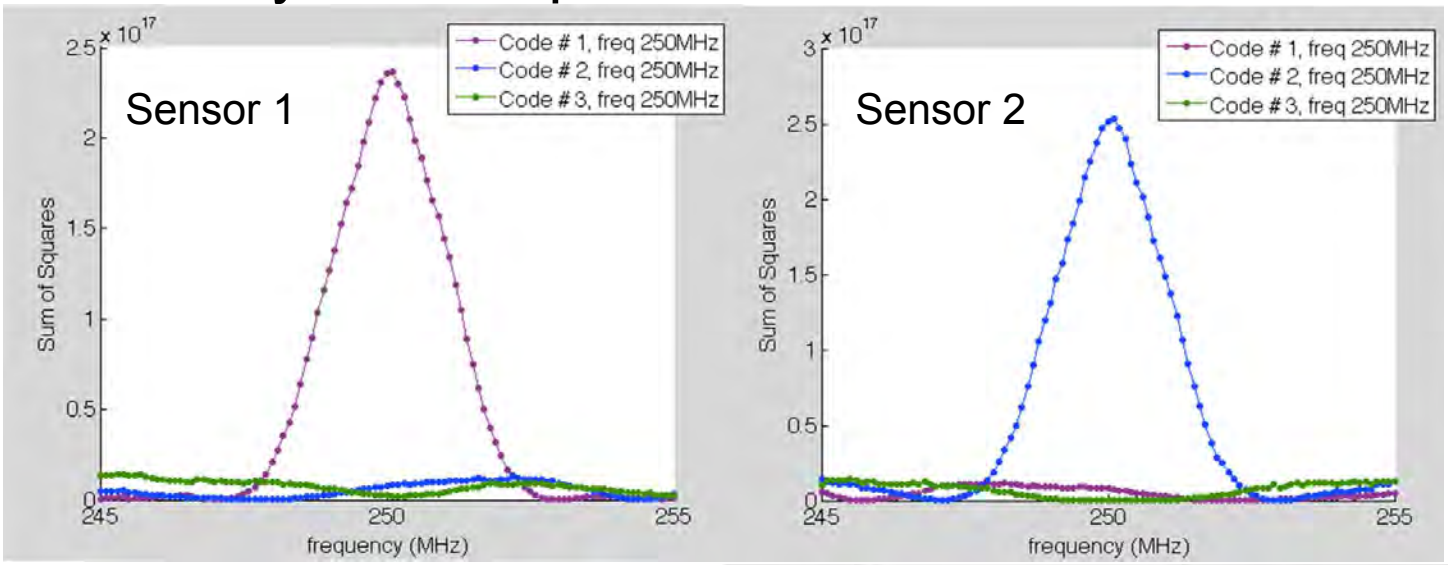
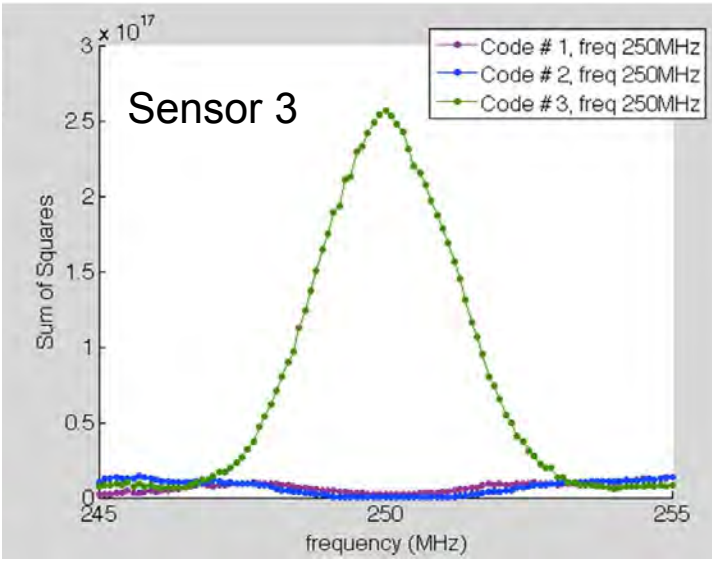
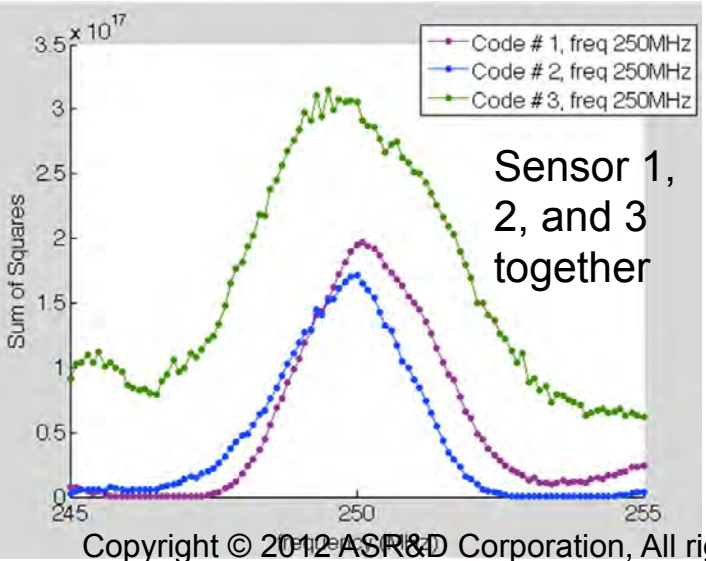
- Simulated system response with three 31-bit Gold codes

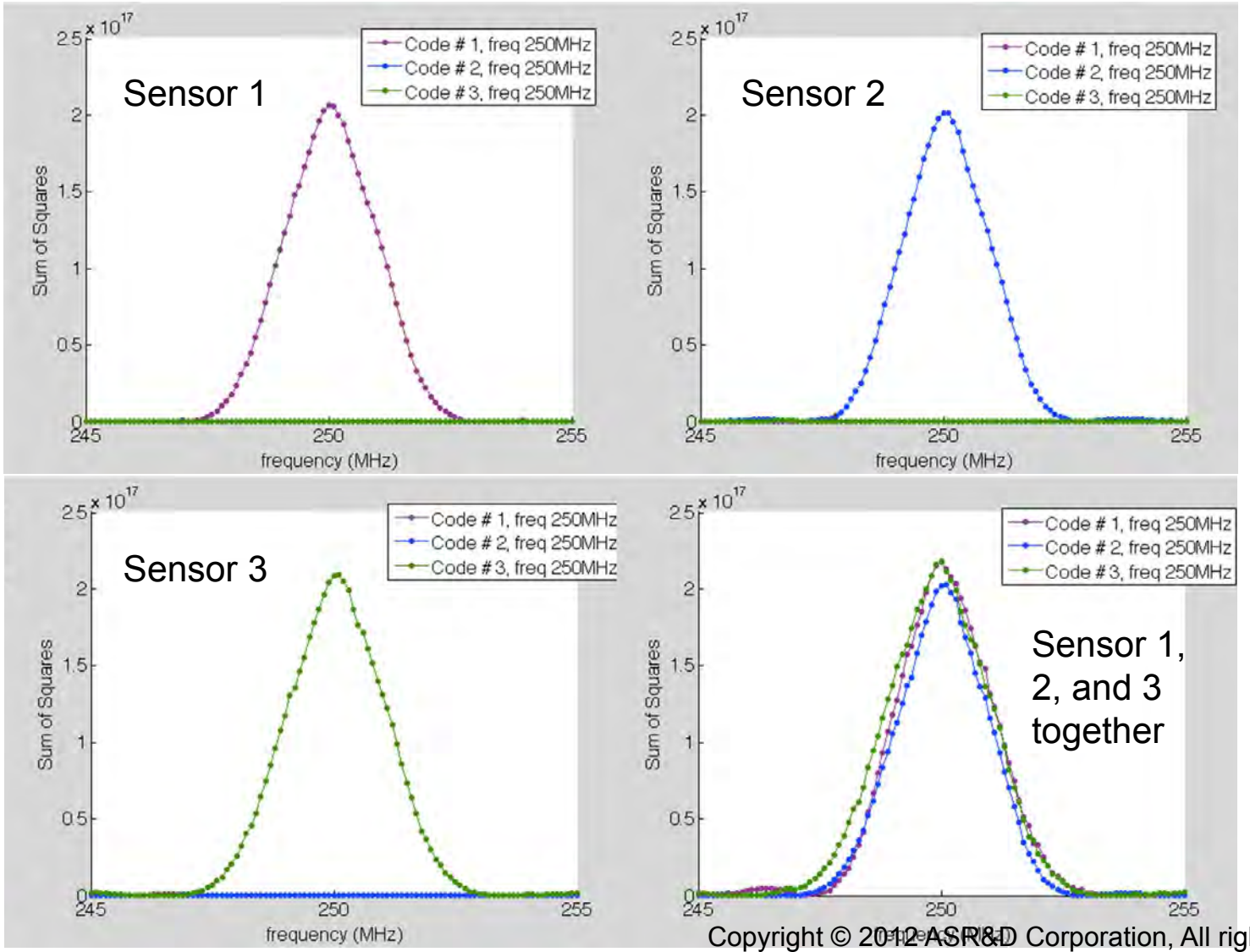






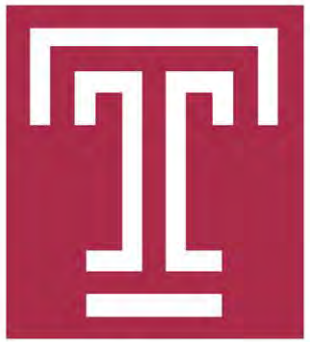
Advances in Sensor-tag Coding

- Simulated system response with three 28-bit DSSS codes



Conclusions

- Designed and manufactured 16 individually identifiable SAW sensor devices with rapid, reversible, quantitative responses to humidity
- Developed novel differential time integrating correlation- based wireless SAW sensor interrogation system
- Delivered 16-sensor system to Kennedy Space Center and demonstrated system operation on Nov. 30, 2011
- Demonstrated (we believe for the first time) the passive wireless measurement of humidity using SAW sensors with integrated nanostructured chemically sensitive films
- Made significant advances in code anti-collision
  - Barker Coding with time, frequency diversity – 100 sensor-tags
  - DSSS codes with time, frequency diversity – 32 T sensors
- Sets of 32 or more sensor-tags operating simultaneously are achievable



Acknowlegements:

This work was supported by NASA STTR Contracts

NNX08CD42P and NNX09CB77C

ASR&D would like to thank Bob Youngquist, NASA KSC

And Temple University colleagues:

Eric U. Borguet

Andrii Buvailo, Yangjun Xing, Devika Sil, Olivier Katz, Nicole Haloupek, Uduak Udeyo, Aseem Malhotra, and Chigozem Oguh

Any questions or comments?

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Thank you