SAW Sensor and Sensor-tag Developments at ASR&D

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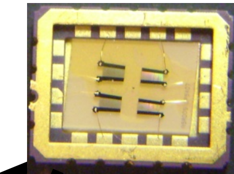
APPLIED SENSOR RESEARCH & DEVELOPMENT CORPORATION

Outline

- ASR&D company summary
- SAW sensor basics
- ASR&D programs/products being developed
- Temperature sensor demo
  - Coded devices with time diversity
  - Design-controlled sensor sensitivity
- Discussion of potential applications
- Wrap-up

ASR&D is developing a platform sensor technology – SAW



To serve multiple markets

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Aerospace

Infrastructure

Heavy Industrial/
Harsh Environment

POC Diagnostics

Company history:

> Founded in August 2005

> Currently 8 employees + University partners & consultants

> 12 NASA SBIR/STTR contracts (8 complete)

> 3 Commercial customers

> Industrial partnership established for device manufacturing

> 2 MD Industrial Partnerships (MIPS) awards

> 1 MD Nanobiotechnology research grant

> 4 U.S. Patents issued, several pending

> Demonstrated sensor devices for:

- ♦ Temperature
- ♦ Liquid (level)
- ♦ Humidity
- ♦ Hydrogen
- ♦ Sensor-tags (strain, T, V, etc.)

> Under development:

- ♦ Other sensors
- ♦ Interrogation electronics

ASR&D team & Facilities:

Jackie Hines – President
- B.S. Applied & Engineering Physics, Cornell, M.S., Ph.D. EE, UCF
- > 20 yrs in the SAW device industry, >10 yrs R&D manager for Sawtek Inc.

Leland P. Solie – Senior Scientist
- B.S. Electrical, M.S., Ph.D. Applied Physics – Stanford
- Over 40 years in the SAW industry
- Over 38 issued U.S. Patents

Dana Tucker – Research Scientist
- B.S. Electrical, M.S.,
- Ph.D. Electrical Engineering (pending) U. Maine
- 3 patents pending

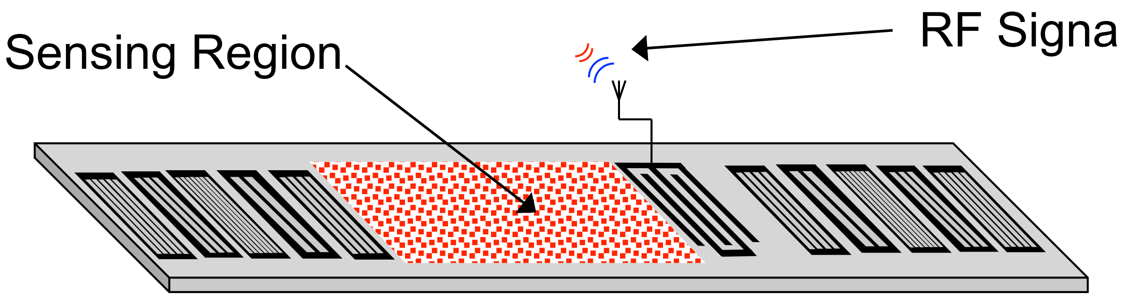
Glenn O. Cote – Principal Engineer

Jerry Corey – R&D Engineer

Andrew J. Hines – CFO
- B.S. Neurobiology Cornell, MBA Rollins College
- Naval Aviator turned banker (>15 yrs)

2200 sq. ft. facility near Baltimore
- Class 10,000 clean room
- SAW device design, fabrication, and testing capabilities
- Complete PCB prototyping capability

How do SAW sensors work?



Features	Advantages	Benefits
♦ Operate wirelessly	Eliminate wiring harness	Low installation cost Operate on rotating parts
♦ RFID capable	Multisensor systems	Individual sensor ID
♦ Require no batteries	No battery changes!	Low maintenance cost
♦ Sensitive/accurate		
♦ Real−time measurements	Rapid response times	Use on
♦ Last for decades	Suitable for embedded use	Long-term monitoring
♦ Survive & <u>operate</u> in extreme environments	Cryogenic to 1000°C Radiation hard	Measure where Si fails
♦ Low cost - based on established technology	Existing manufacturing infrastructure	Enable low cost distributed sensing

Products under development:

> Coded sensor-tag wireless interface devices

> Humidity sensors

> Hydrogen sensors

> Temperature sensors

Focus on these today

> Methane sensors

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

> (Cryogenic) liquid (level) sensors

> Concrete maturity monitor

> Biosensor for infectious agents (CT)

Coded sensor-tag wireless interface devices:

> SAW device acts as wireless interface to existing sensor

> SAW coded and individually identifiable

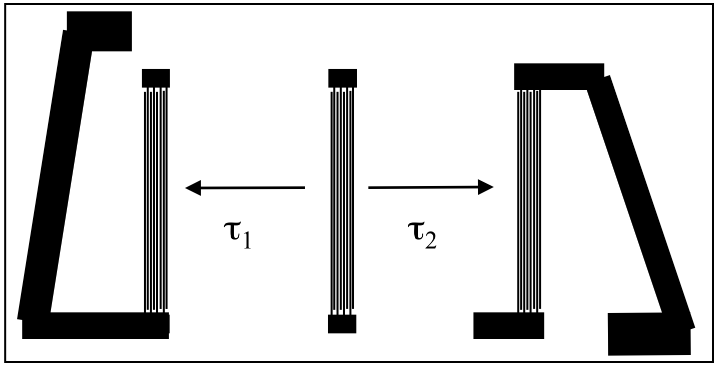
> Read SAW code & sensor reading

> Read impedance varying & voltage producing sensors

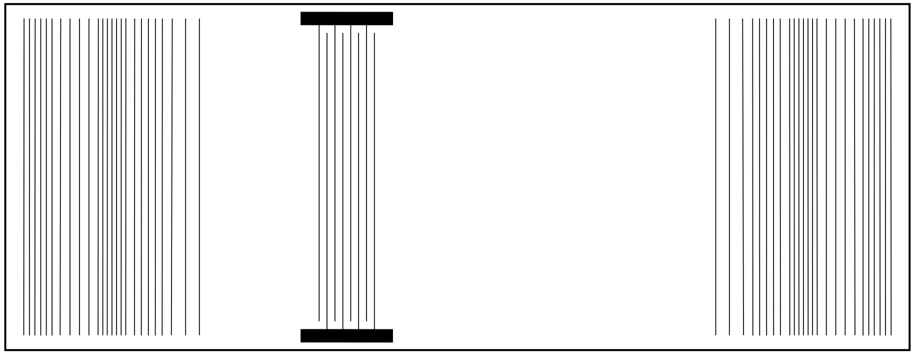
> > Temperature sensors
>
> > Strain gauges
>
> > Switch positions
>
> > Bus voltages
>
> > Acoustic emission sensors

> Goal: Elimination of wiring harness to existing sensors

Tag device structures evaluated:

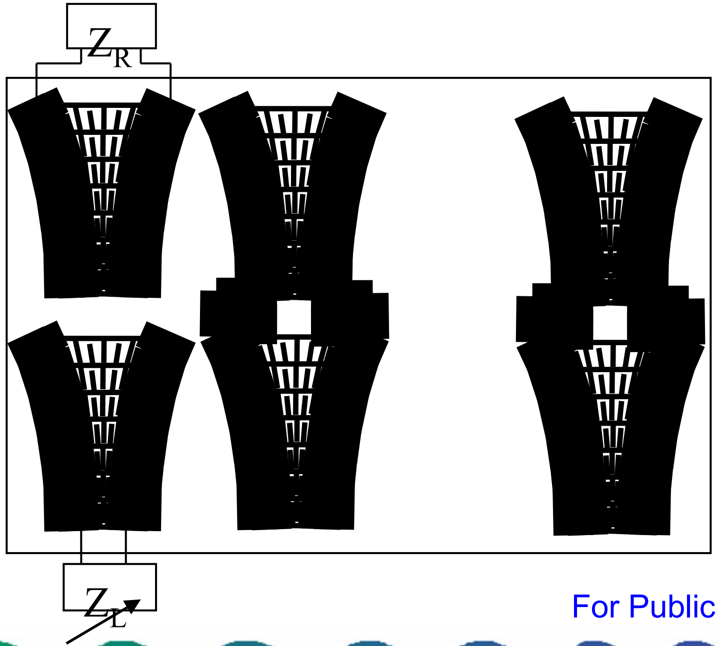


RDDL/PSD Reflective
Differential Delay Line

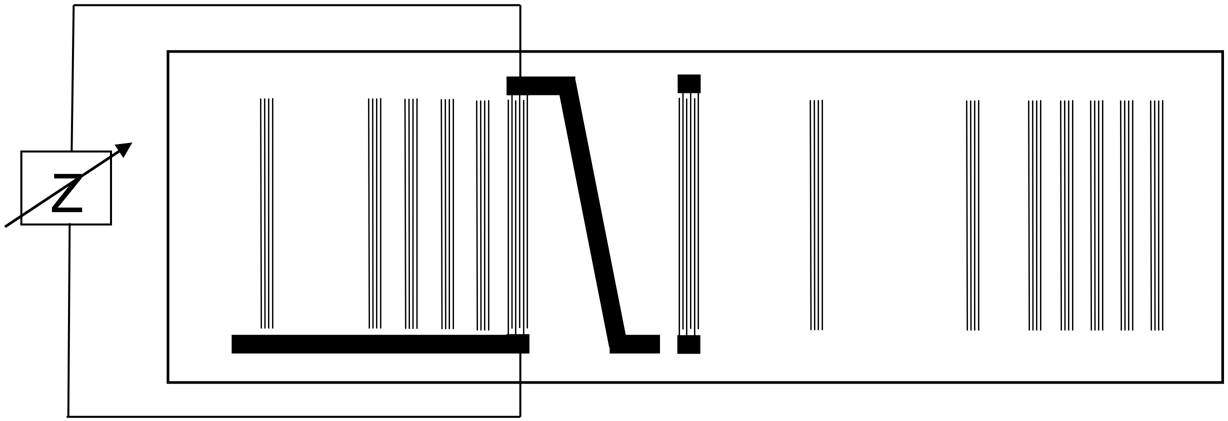


Frequency Coded Tag
OFC/PMFC/DFC

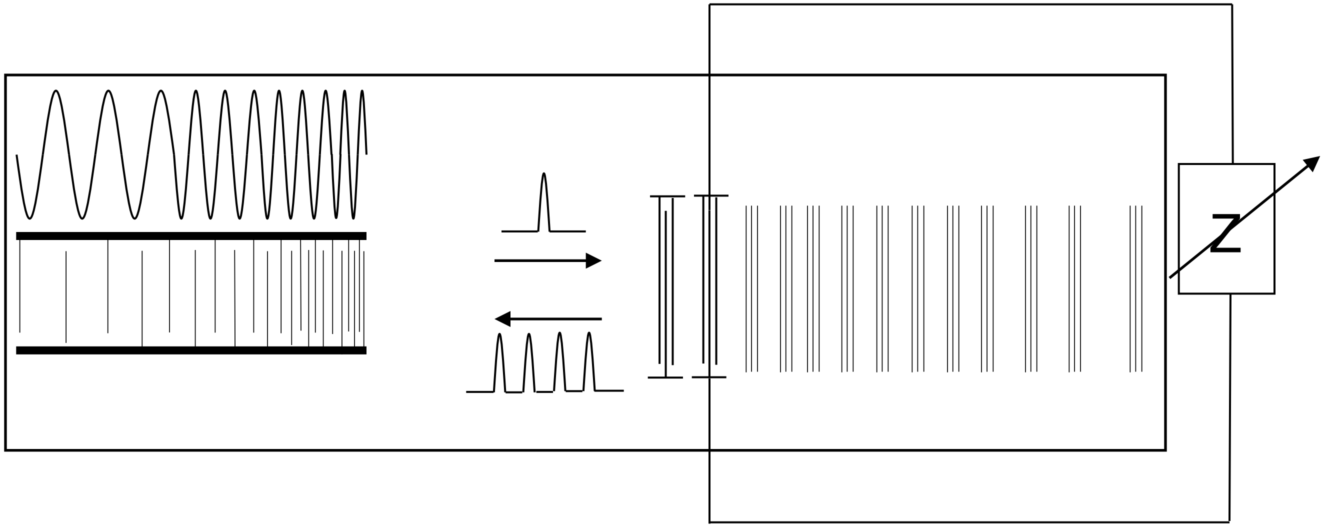
Tapered Reflective
Differential Delay Line



Tag device structures evaluated, contd.:

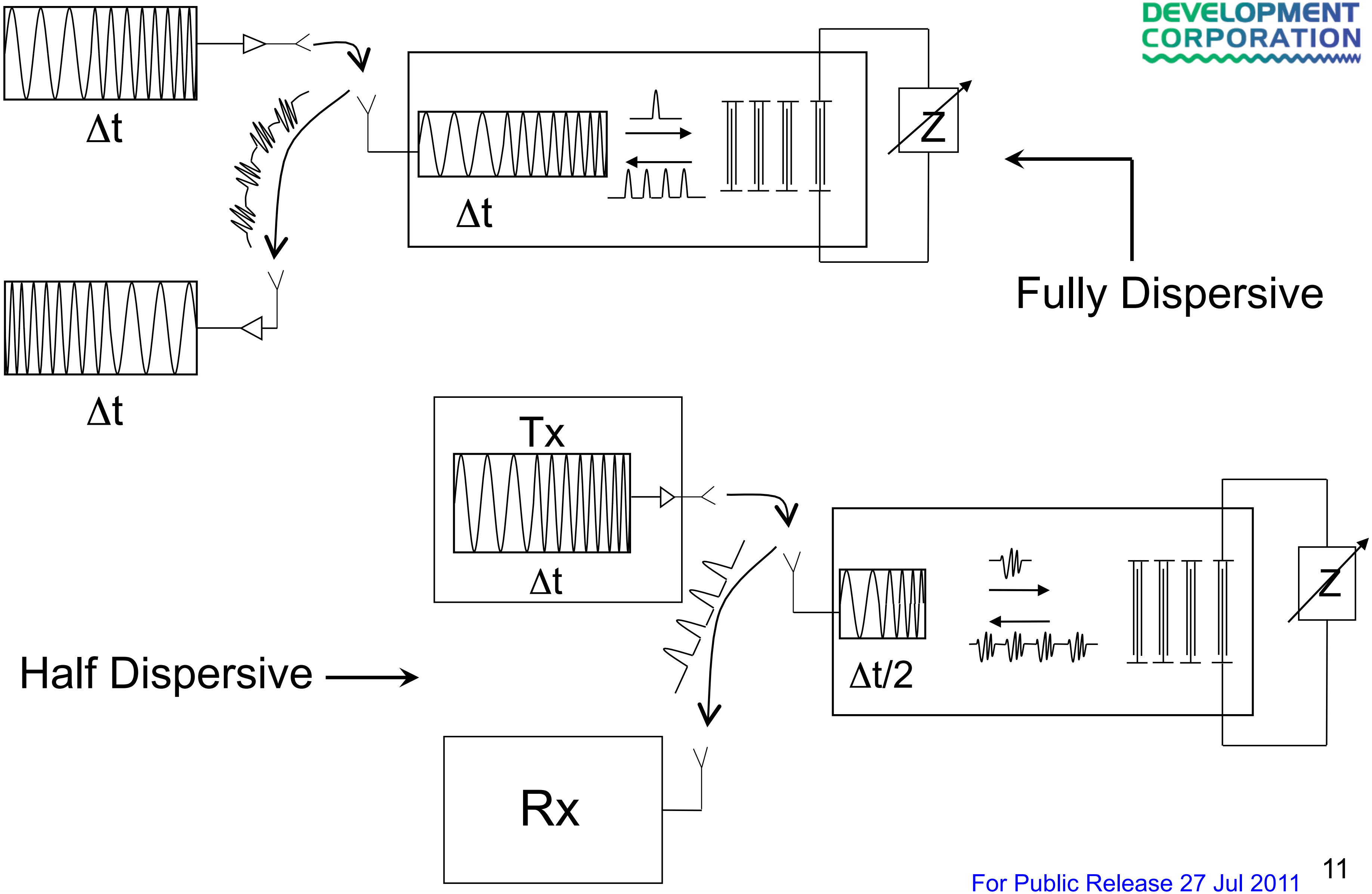


Non-dispersive
RFID tag



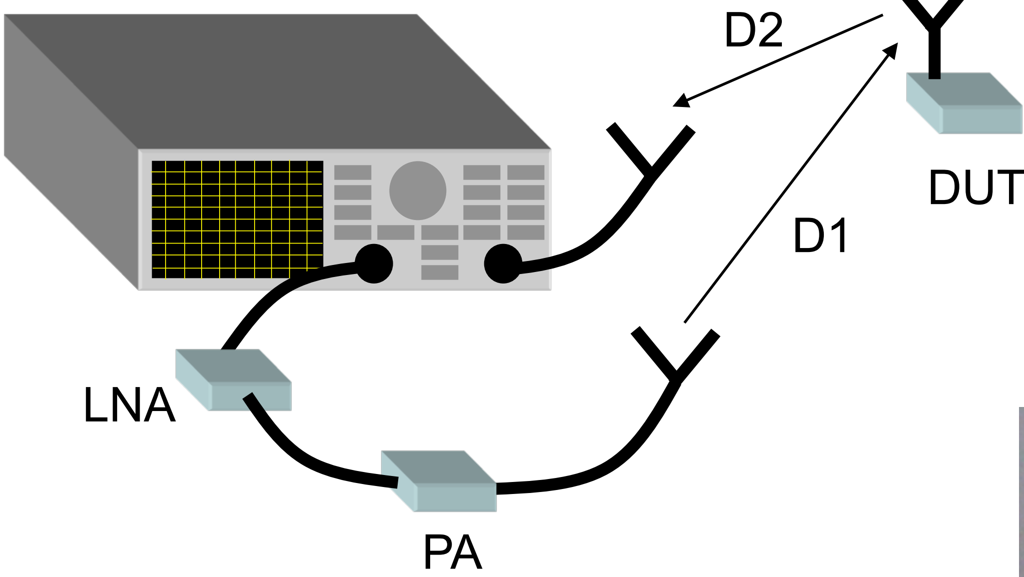
Dispersive
RFID tag

Tag device structures evaluated, contd.:



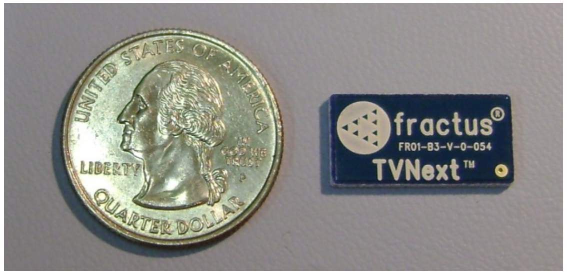
Test Setup: Wireless

Agilent E5070B
Network Analyzer



S21 Transmission
Measurement

Antenna

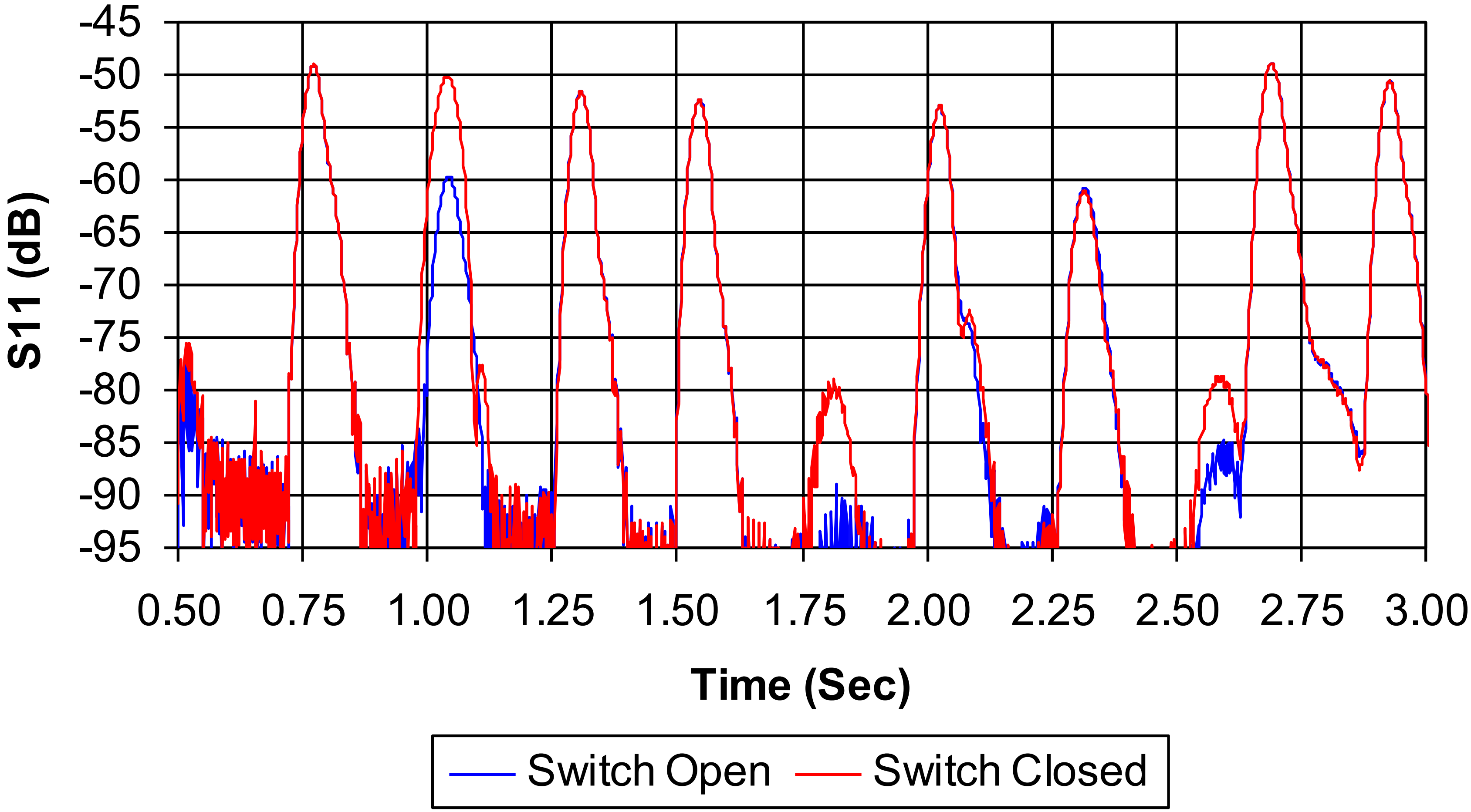


Loss approx. 40 dB

Wireless Test Fixture

Switch load testing (OC/SC): non-dispersive RFID

Wired Testing

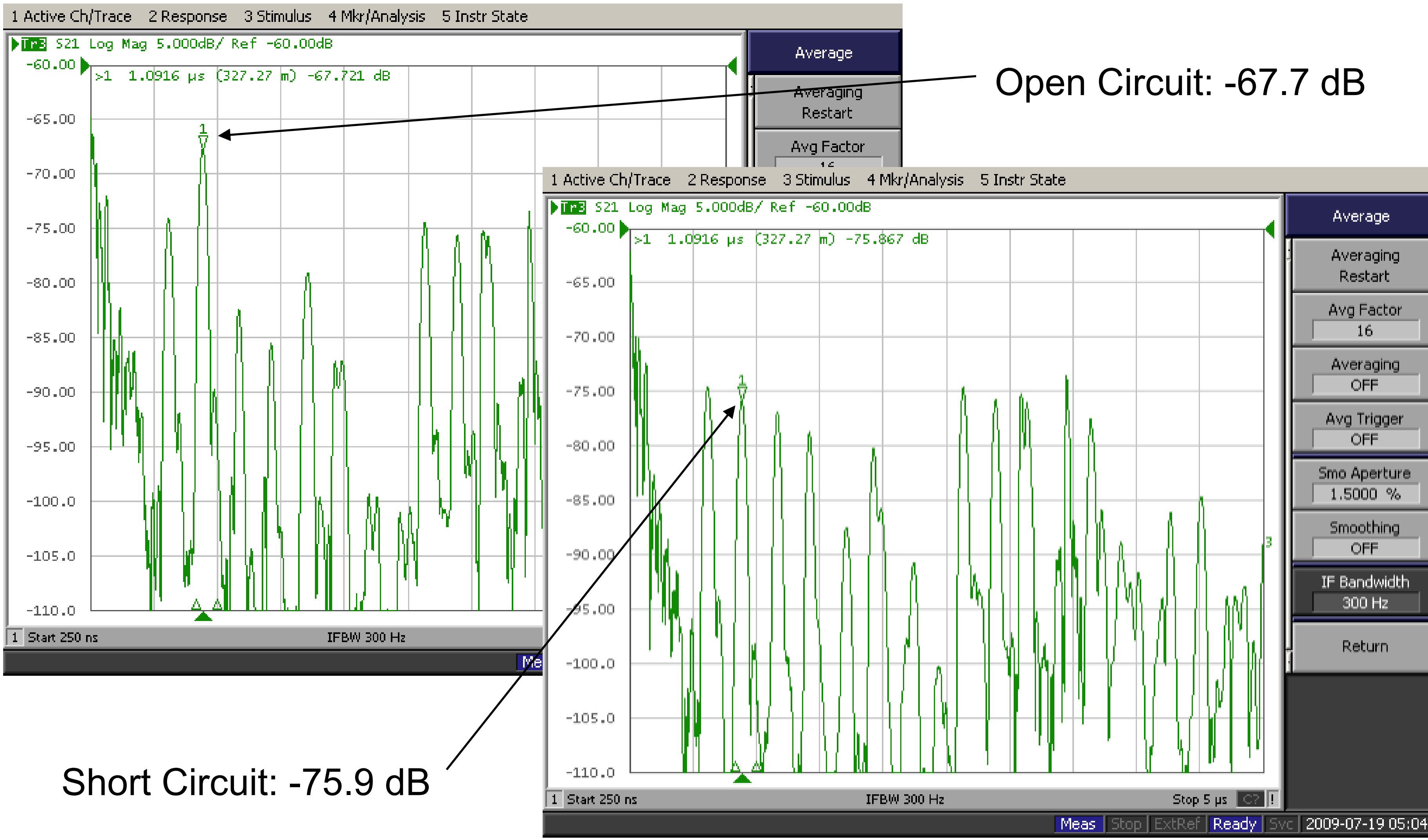


Second tap is load tap – note almost 10 dB change in response

Switch testing: Non-dispersive RFID

Wireless Testing

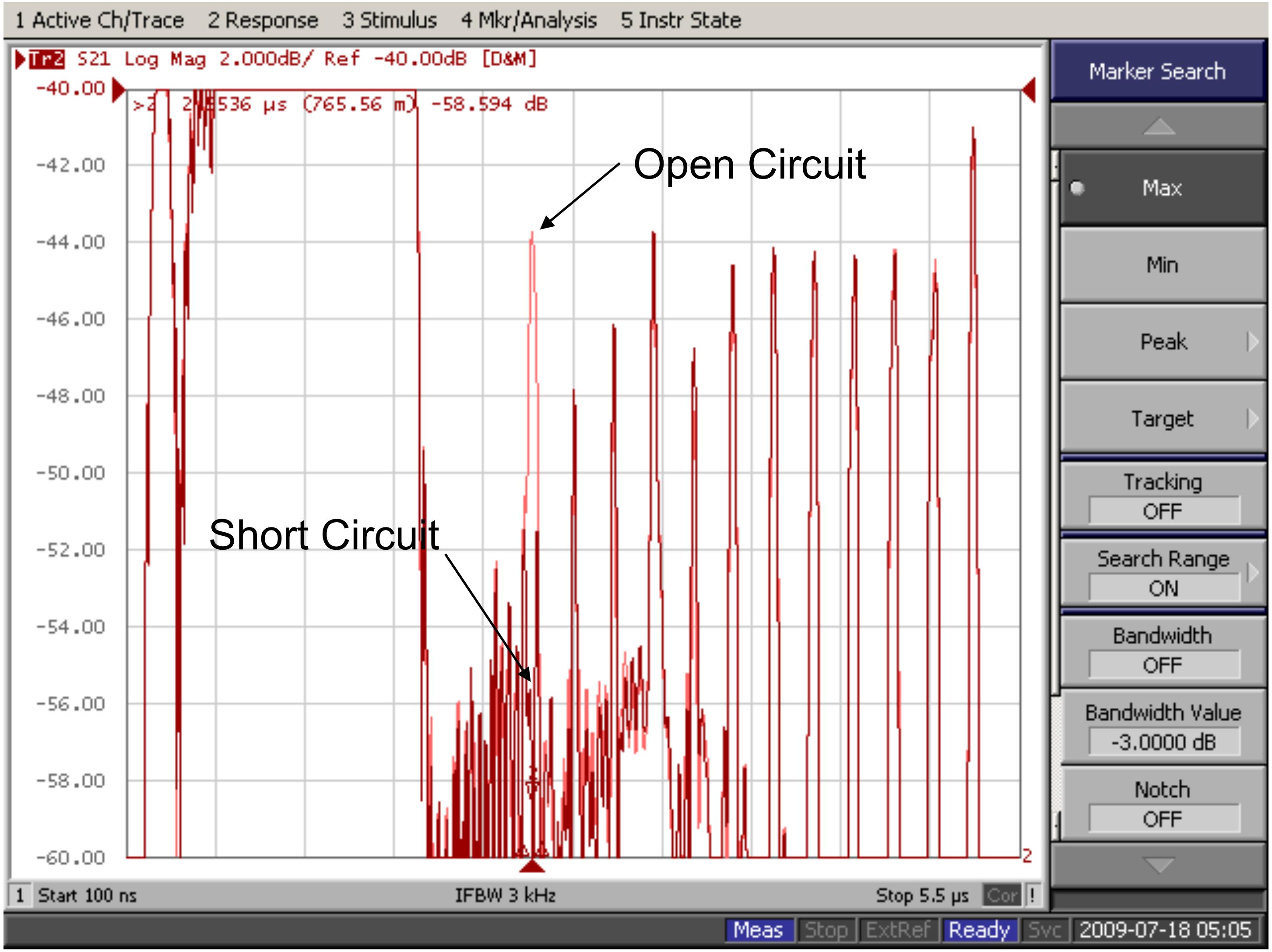
Open Circuit: -67.7 dB



Short Circuit: -75.9 dB

Switch load testing (OC/SC): Half-dispersive RFID

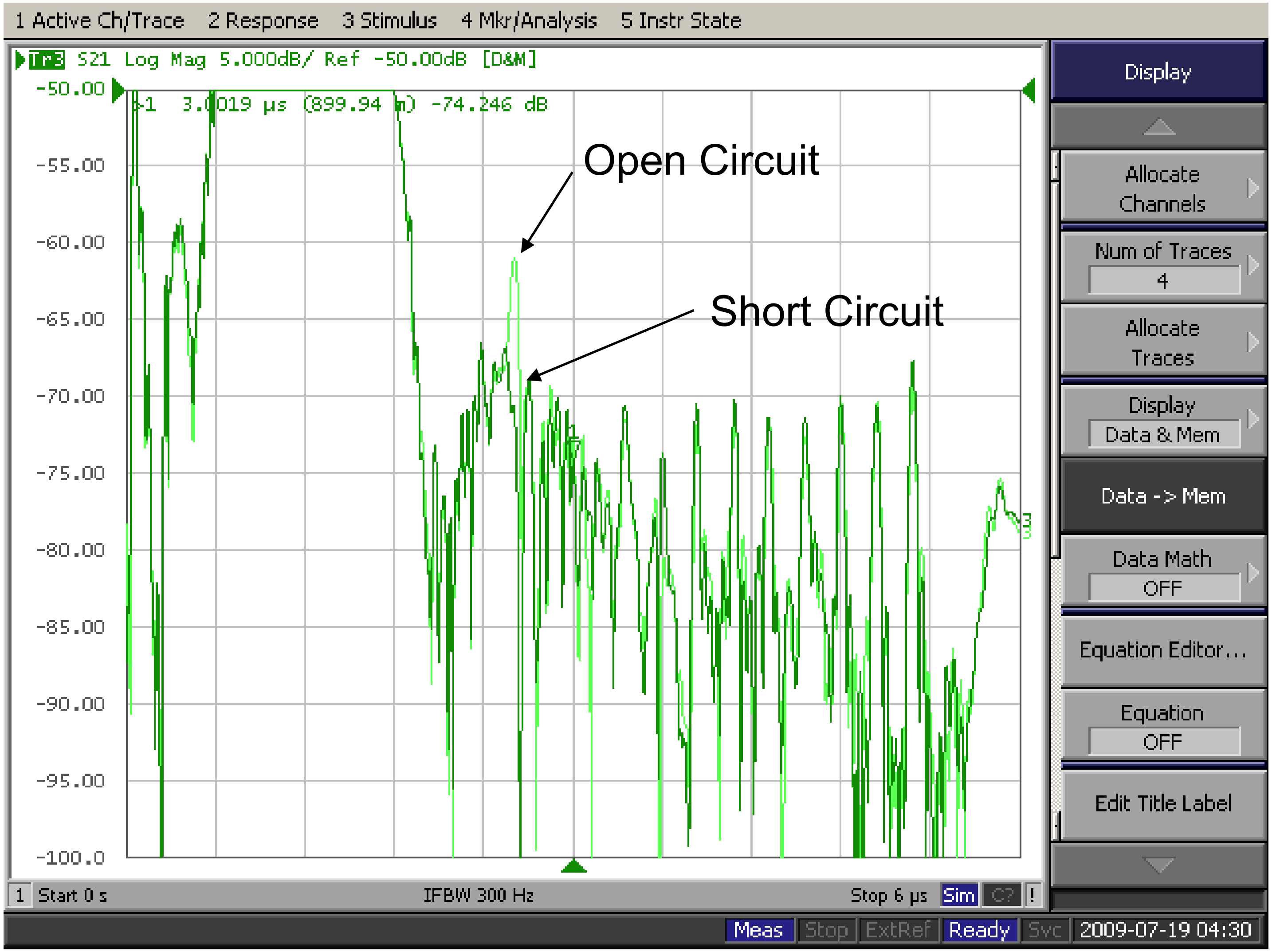
Wired Testing



Change from OC to SC of about 15 dB

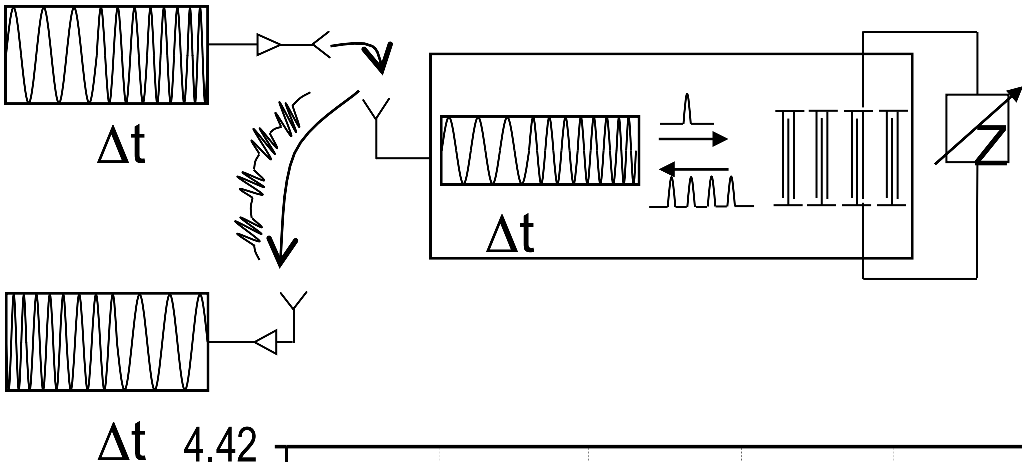
Switch testing: Half-dispersive RFID

Wireless Testing

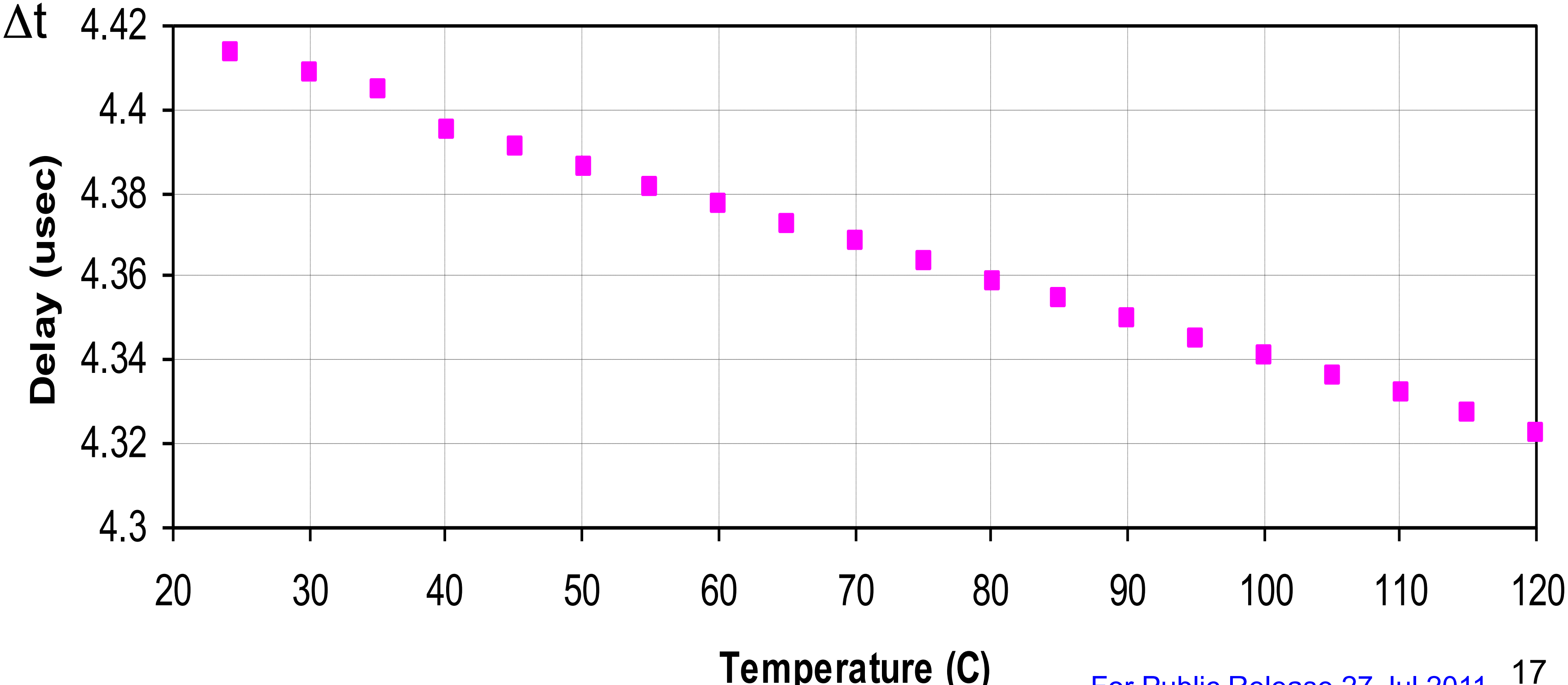


Change of
> 13 dB

Sensor-tag interface device example:



Fully dispersive RFID tag attached to thermistor



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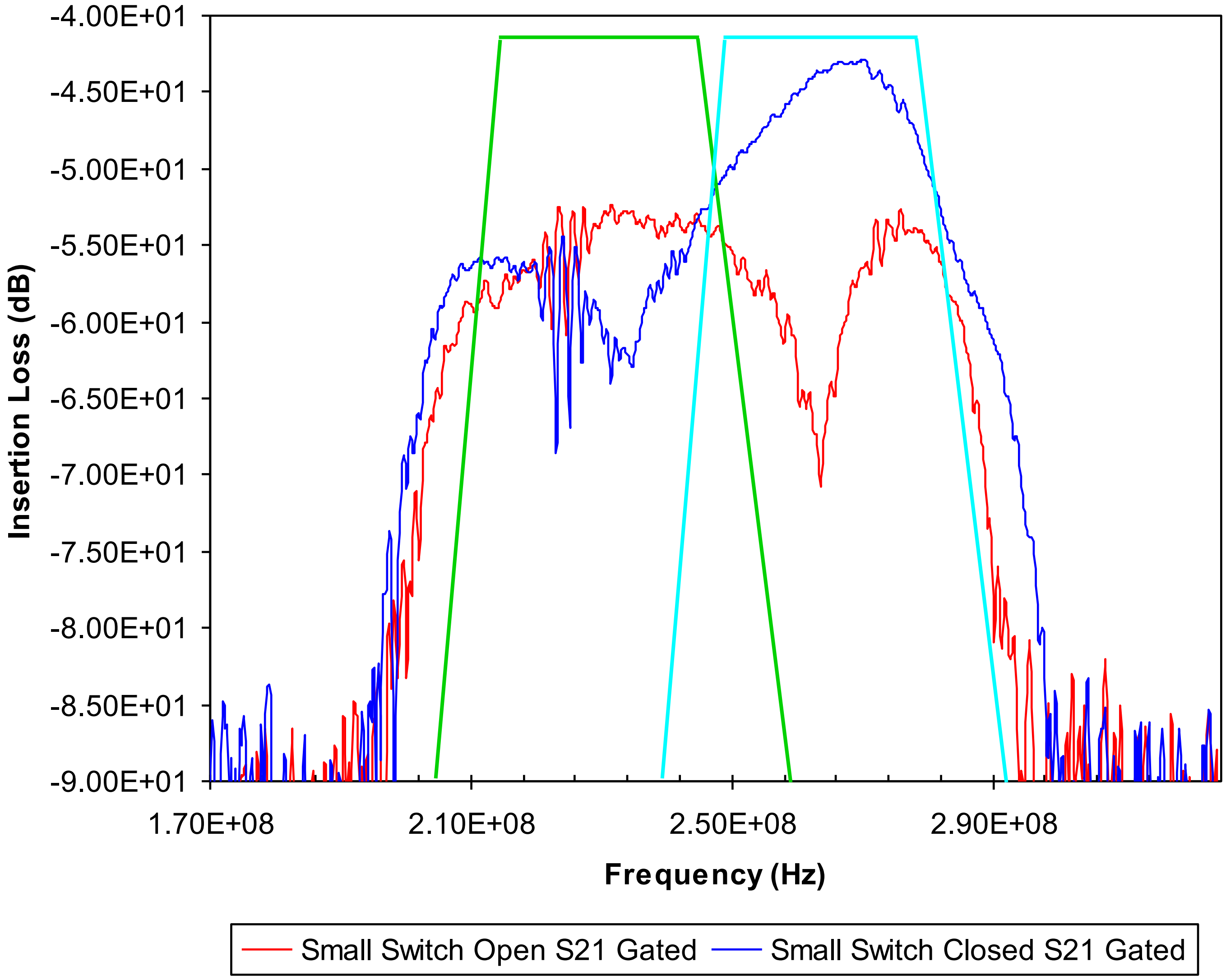
Switch load testing (OC/SC): Tapered PSD

Wired Testing



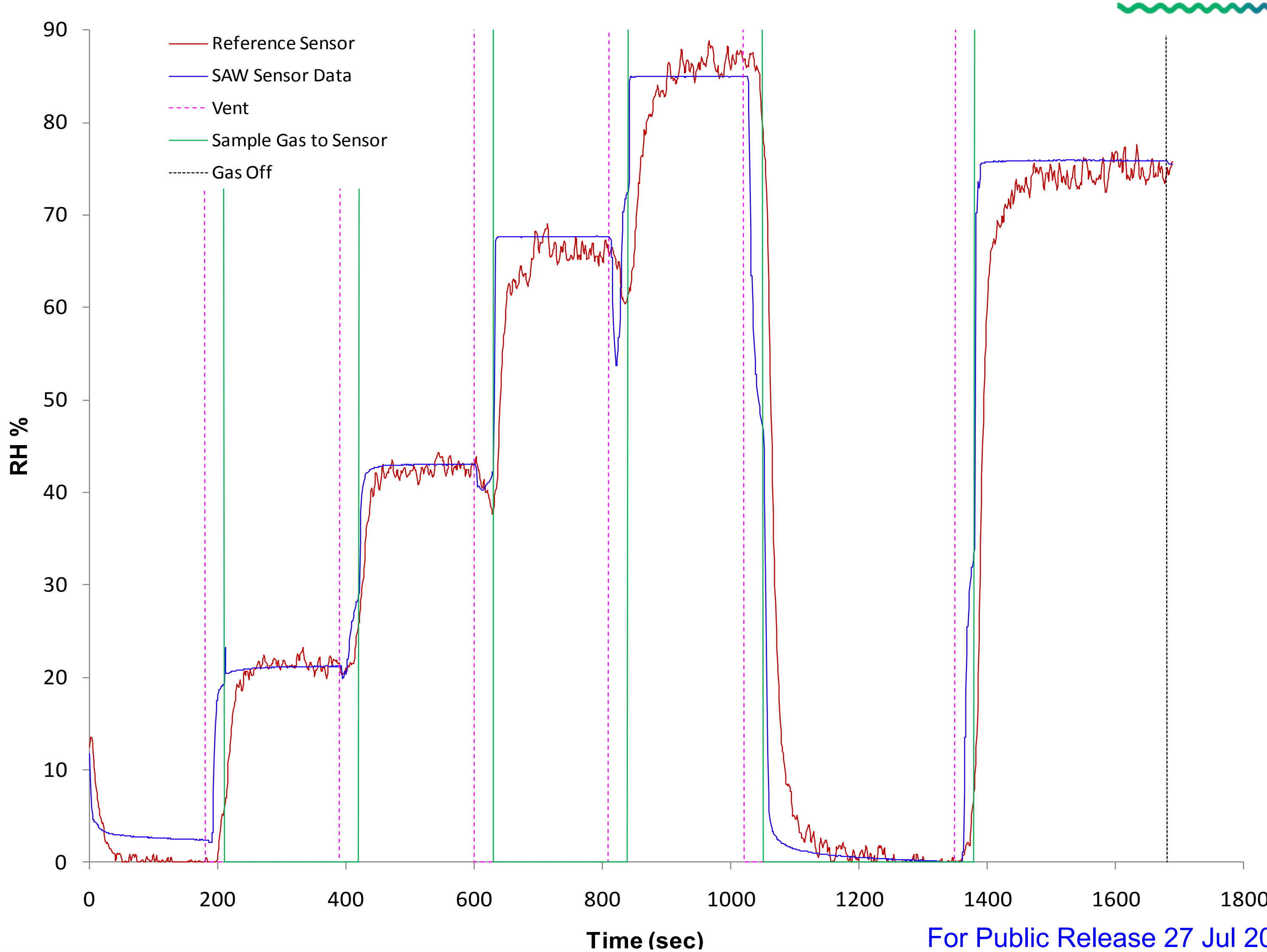
Large response change in notch

> 35 dB and
> 30 MHz
change

measure with PSD system

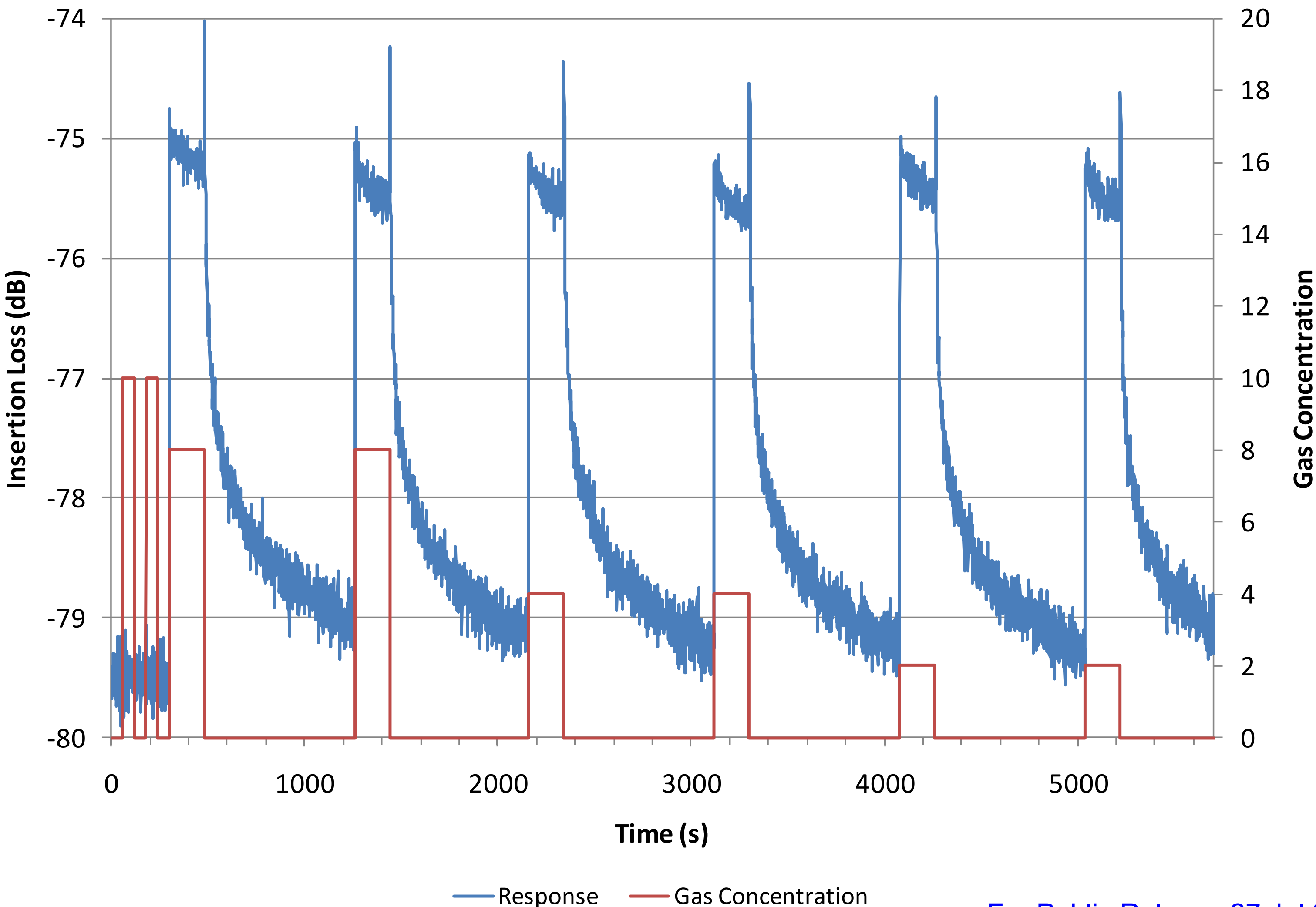
Humidity Sensor example:

LiCl doped TiO_2 film



Hydrogen sensor example:

Nanocluster Pd film on OTMS SAM



Coded wireless temperature sensors with design specified sensitivity

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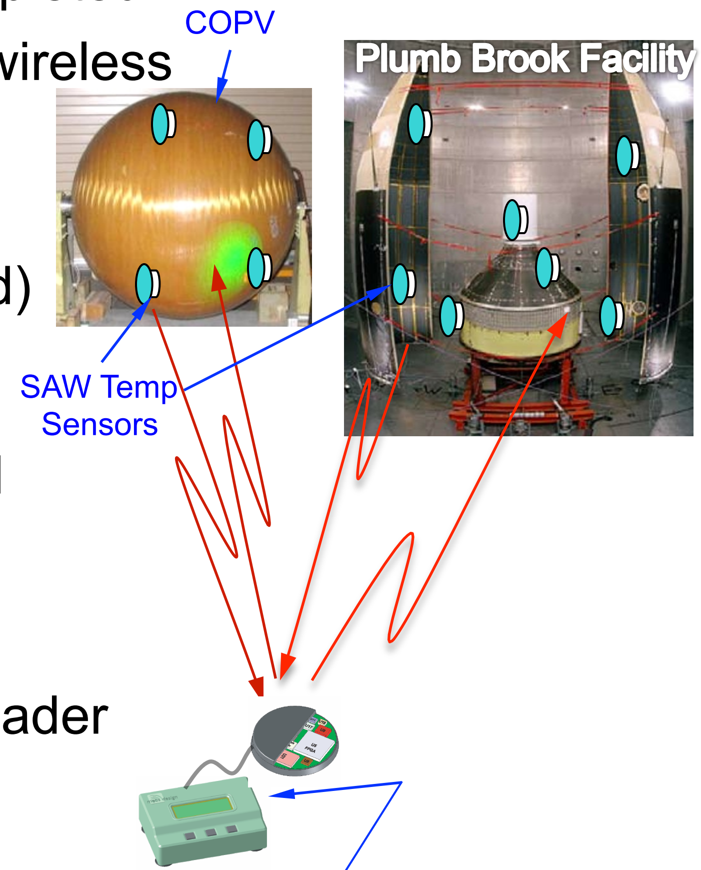
Phase I SBIR – 6 month feasibility study: Completed

Goal was demonstration of a set of 32 coded wireless temperature sensors that can operate simultaneously and be read individually.

- New high sensitivity device (design controlled)



MDC Data Acquisition System with integrated wireless reader (planned)

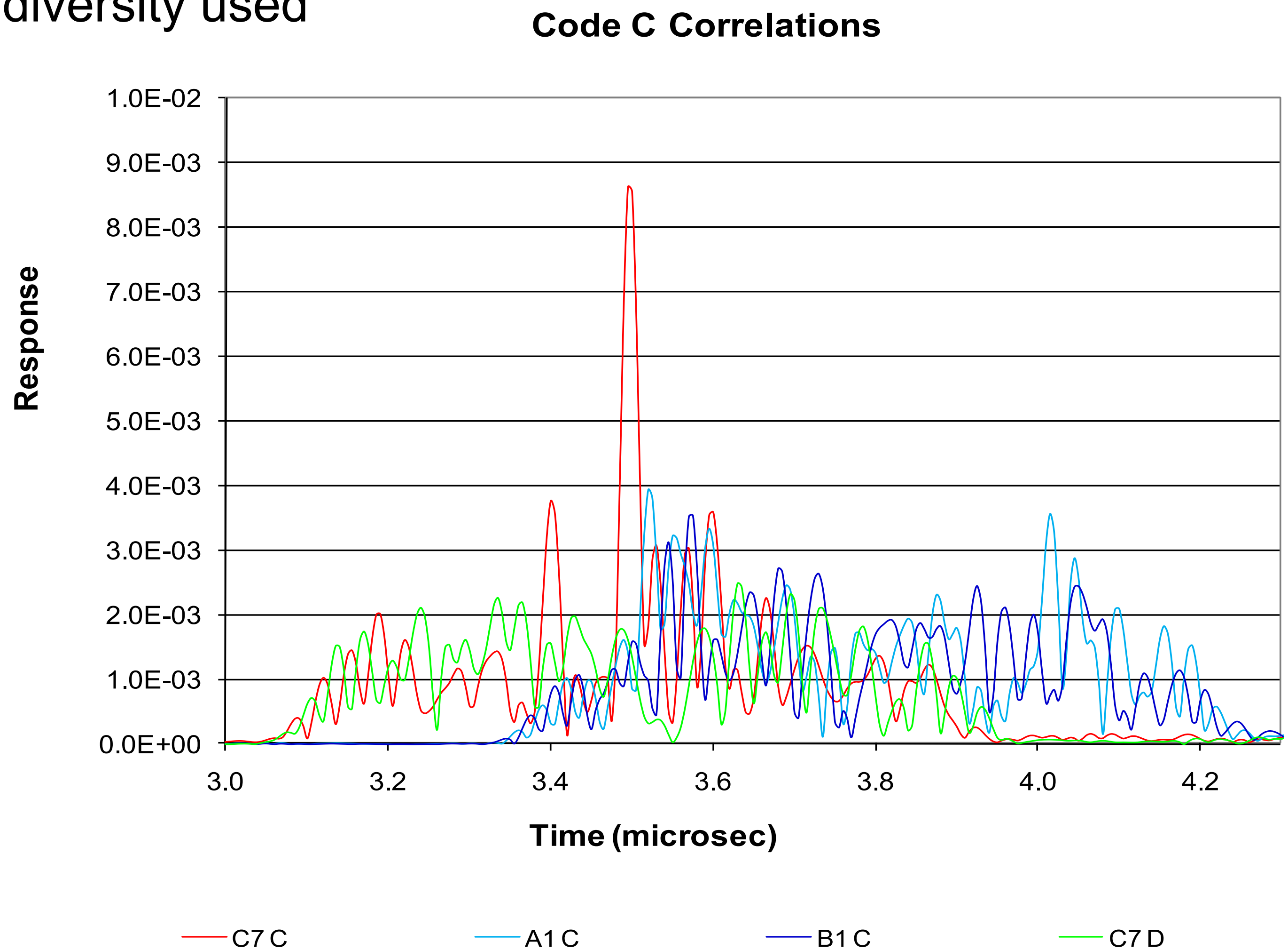
Phase II SBIR – started in June 2011:

- Wireless RF interrogation with enhanced S/N
- Multi-sensor system with increased range
- Ability to read 32 sensors in one FOV
- Teaming with industry partners for wireless reader electronic system integration/DAQ hardware development and size reduction

Goal: Multisensor system including miniaturized wireless reader and 32 temperature sensors

Phase I Accomplishments:

Designed, fabricated and tested set of 32 individually identifiable coded SAW temperature sensors - Combination of code diversity and time diversity used



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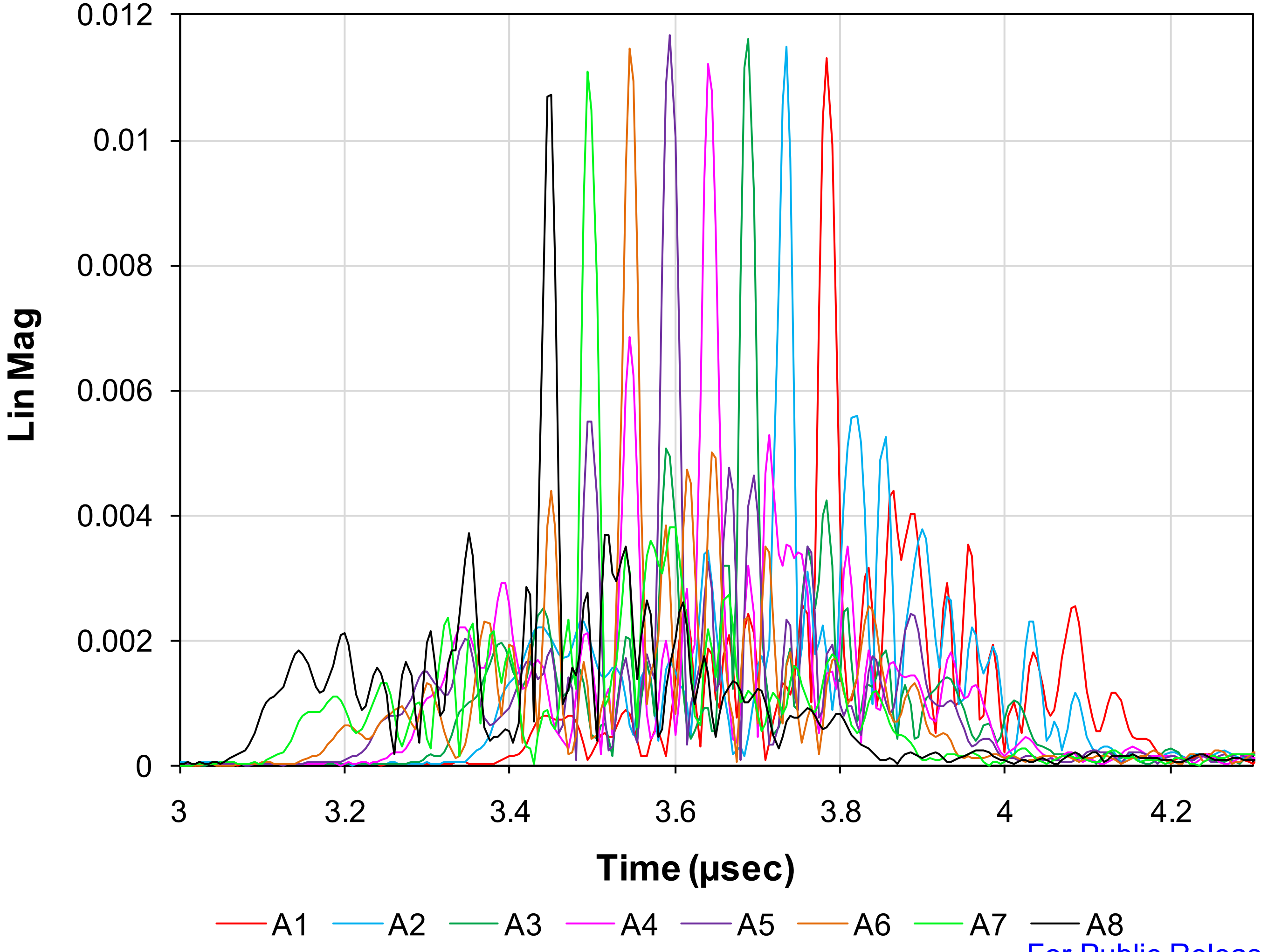
Phase I Accomplishments:

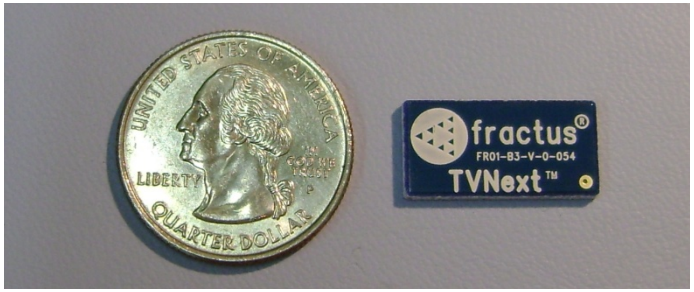
Example: Autocorrelation of a single code at 8 discrete delays



Phase I Accomplishments:

Initial wireless tests confirm ability to selectively measure individual sensors

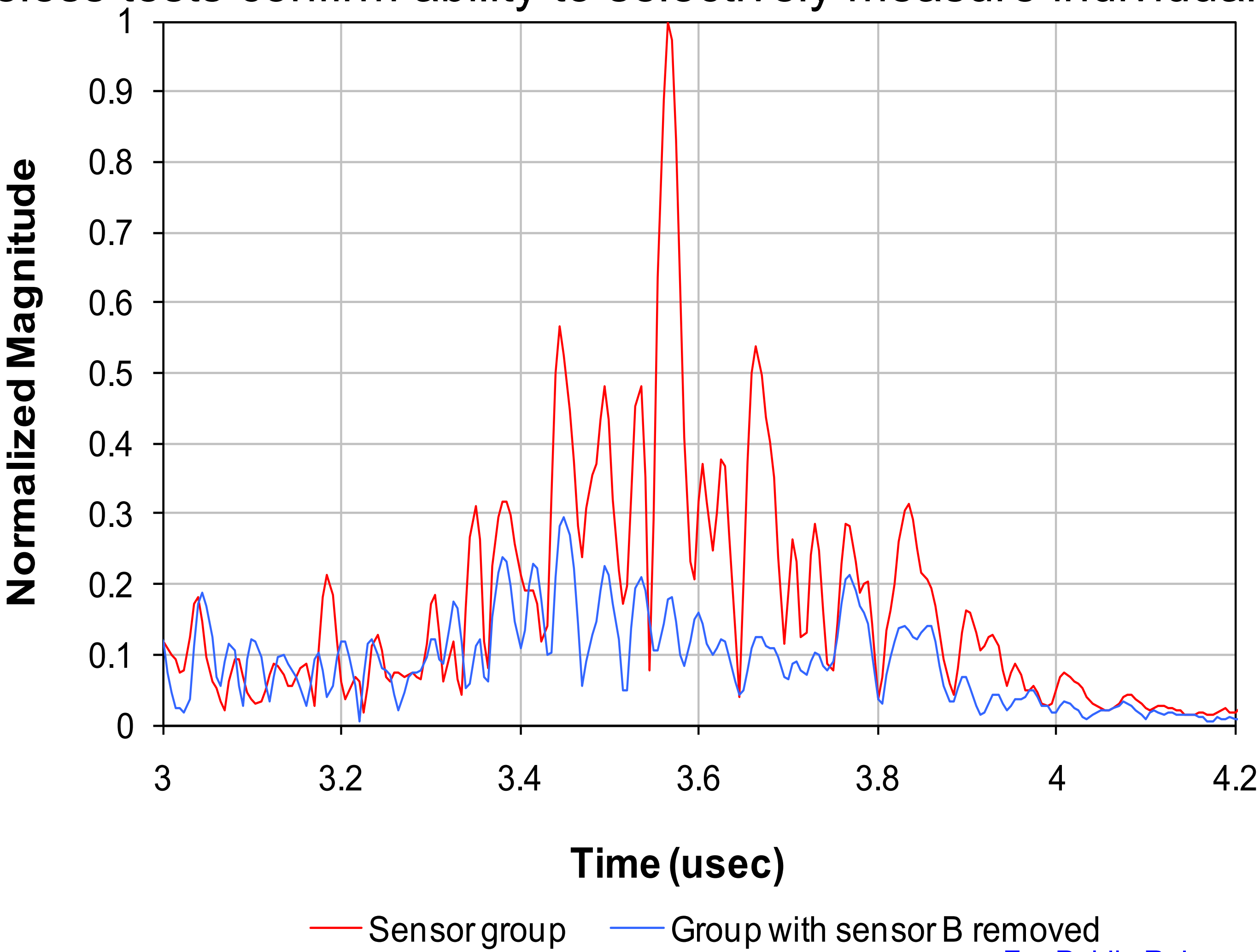
- Network analyzer used as interrogator for these measurements
- Fractal antenna at 250 MHz used (Tx/Rx)
- Group of sensors radiated with interrogating pulse (not coded)



- All sensors respond at random delays
- Coded response with measurement(s)
- Receiver selects sensor of interest
- Confirm proper sensor selection, extract measurement

Phase I Accomplishments:

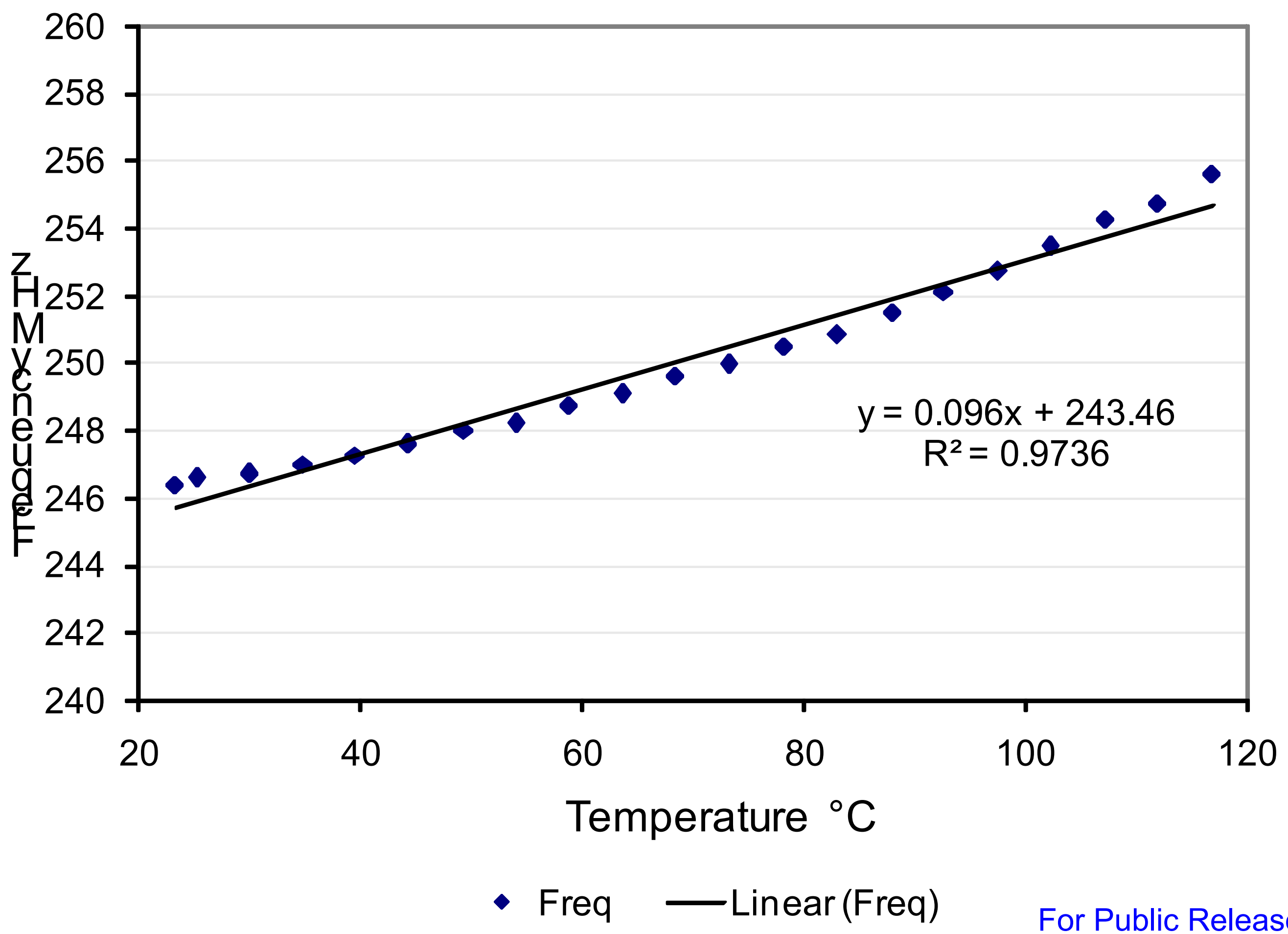
Initial wireless tests confirm ability to selectively measure individual sensors



Phase I Accomplishments:

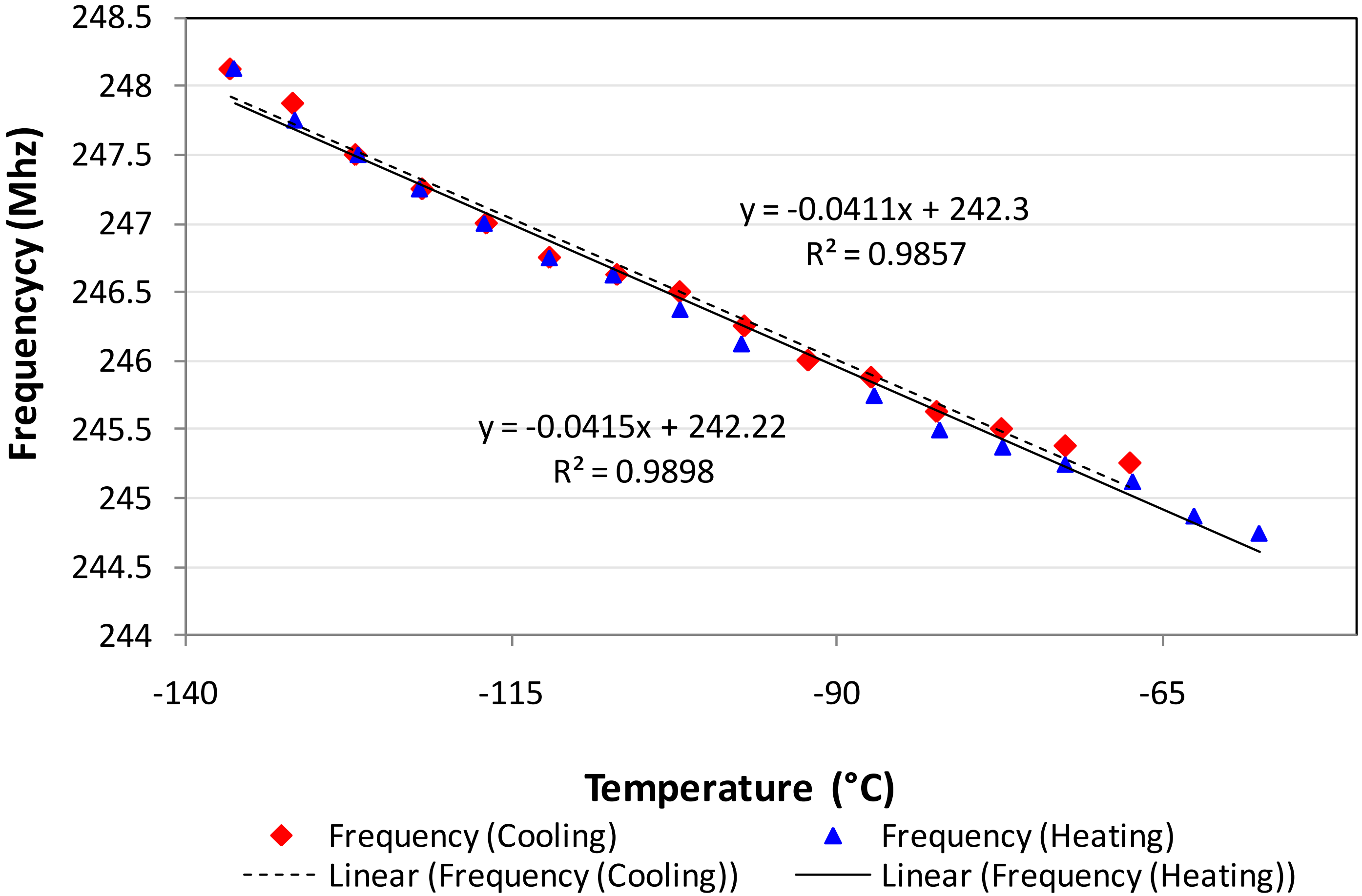
Demonstrated capability to design sensors with target temperature sensitivity:

Example 1: SAW sensor on YZ-$LiNbO_3$ with TCF of +384ppm/°C.



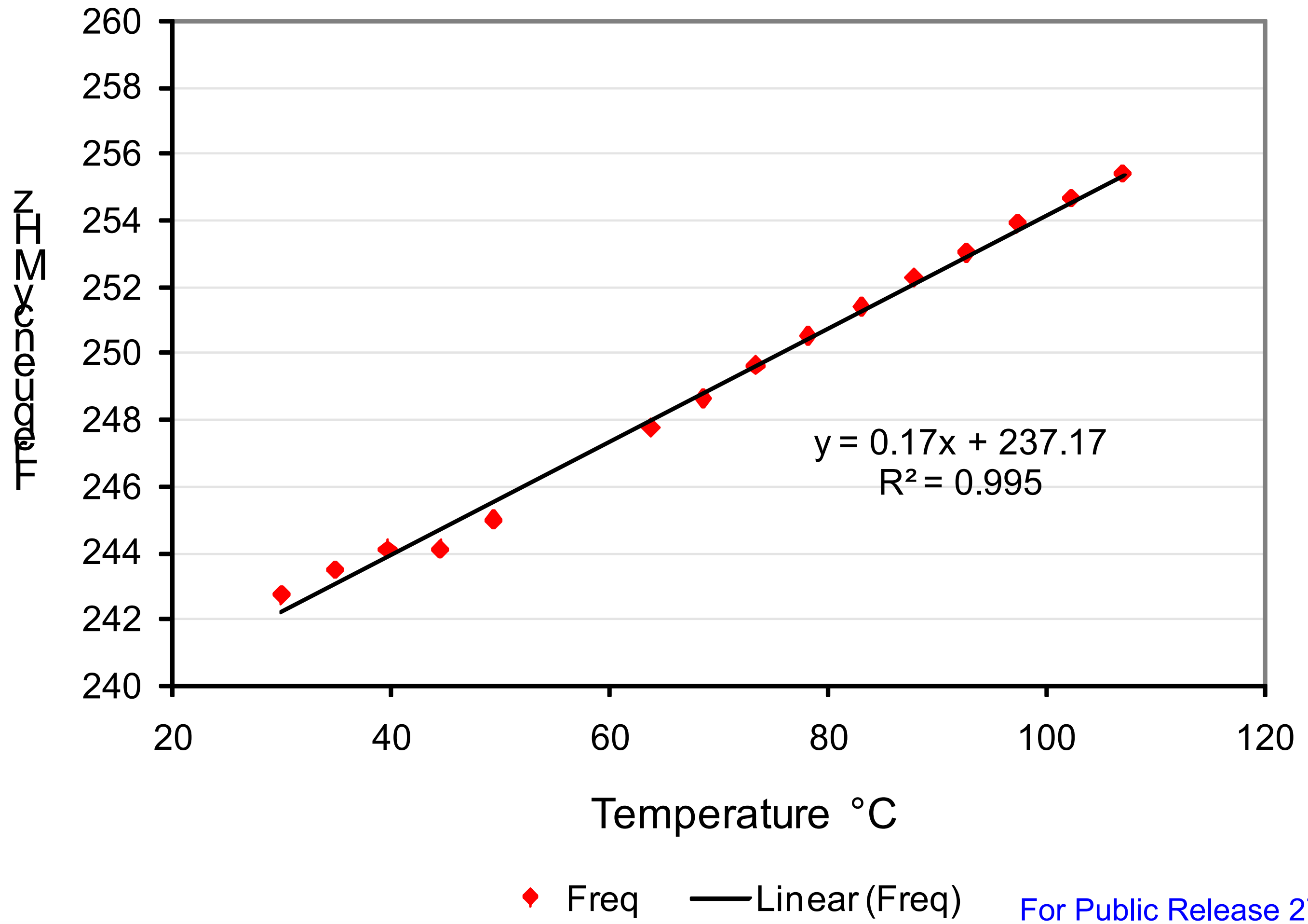
Phase I Accomplishments:

Example 2: Temperature response of a SAW sensor on YZ-$LiNbO_3$ during heating and cooling tests, showing a TCF of -165.2 ppm/°C.



Phase I Accomplishments:

Example 3: Temperature response of another SAW sensor on $YZ\text{-}LiNbO_3$ shows a TCF of +680ppm/°C.



Wireless reader development:

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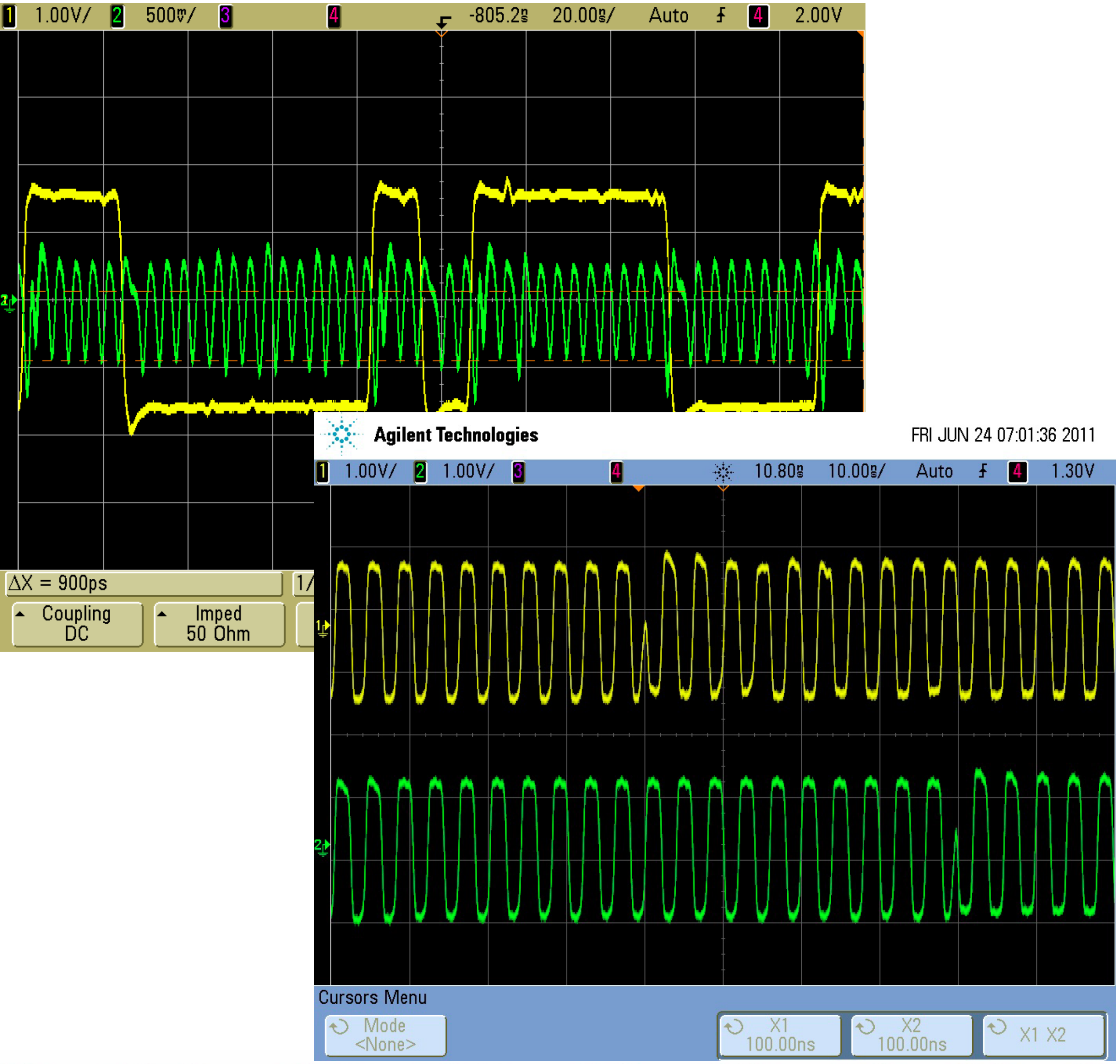
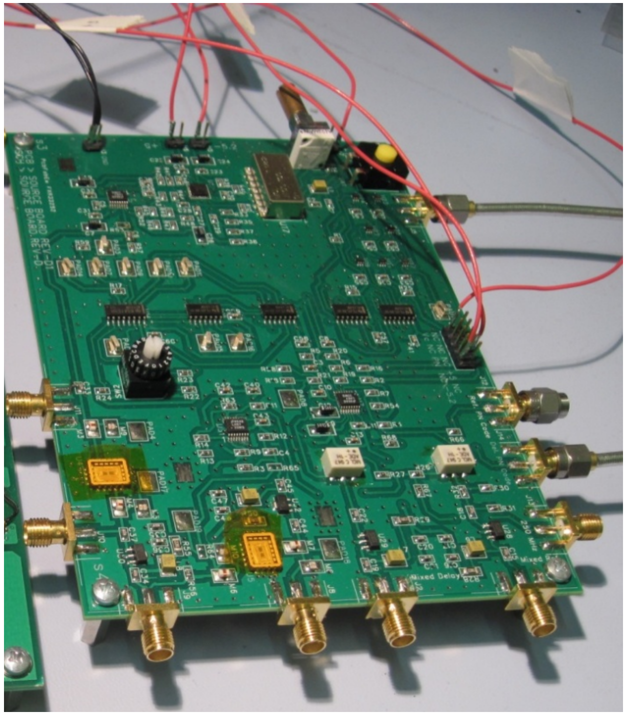
Transmitter board (right) operational

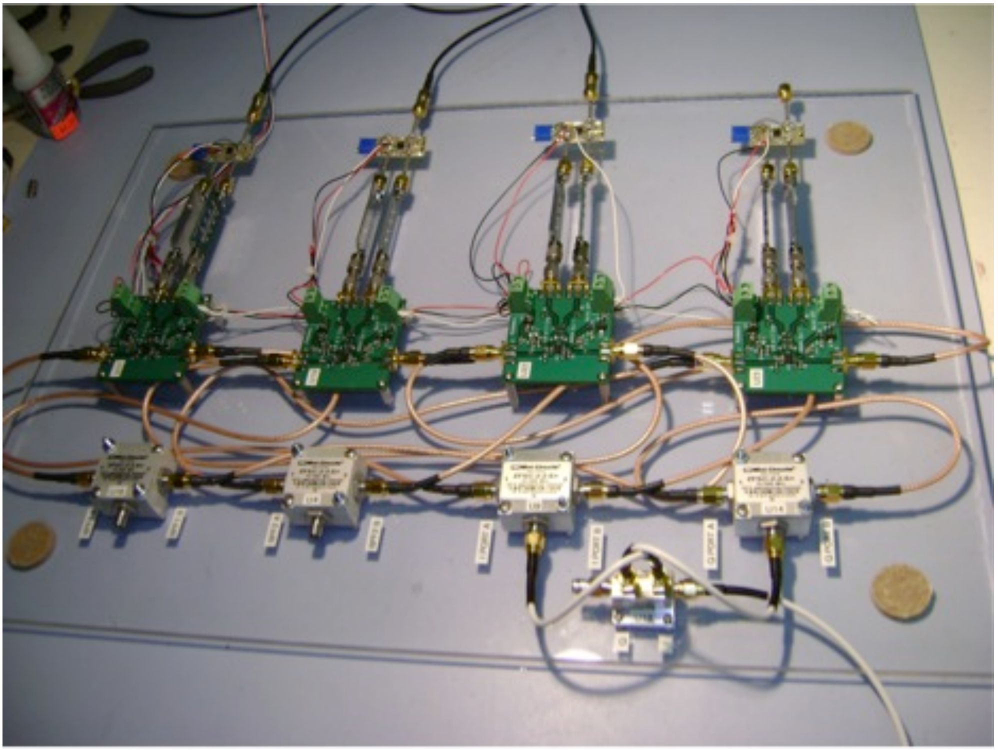




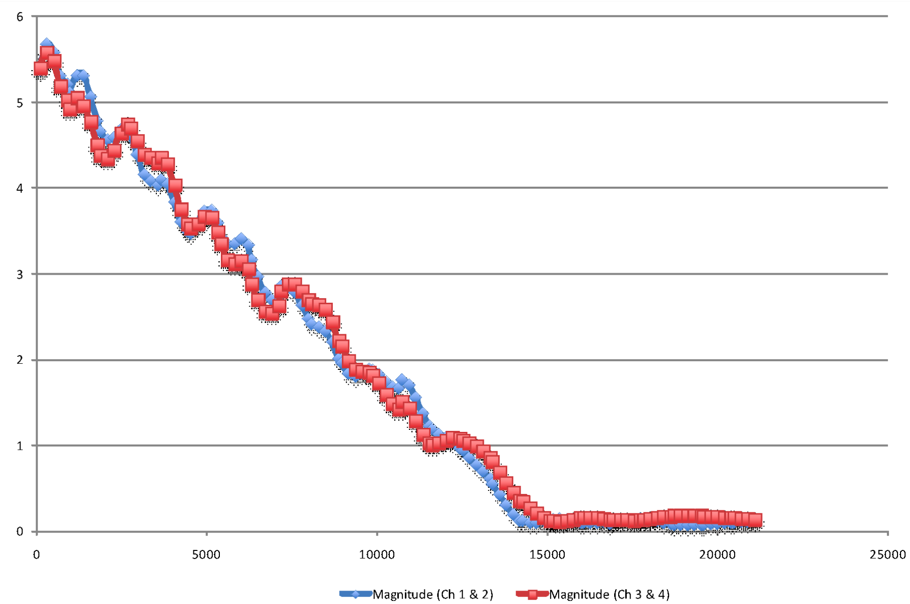
PN-modulated signal generated as interrogation signal

Wireless reader development:

Modular receiver board (also operational)



Clear correlation-based sensor signals obtained



Currently reading output of four channels on analog meters – need A/D conversion and PC interface. ASR&D will deliver a system to KSC Sept 29, 2011 with 32 humidity sensors.

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Potential applications:

Applications are primarily those that cannot be satisfied with Si-based RFID/sensor products due to radiation, temperature, or other environmental parameters and/or requirement for intrinsic safety. Potential apps. include:

- Industrial process monitoring (T, P, chemical vapors, etc)
- Machine tool monitoring (temp, torque, strain, pressure, etc)
- High value asset tracking
- Industrial/military vehicle health monitoring (Oil quality, T, stress, etc.)
- Automotive (torque sensing for electronic power steering, TPMS)
- Harsh environment (Oil & Gas, mining, marine, etc.)
- Aerospace: Commercial, Military, and Space
    - Structural health monitoring (T, P, stress, etc)
    - System health monitoring (voltages, hydraulic pressures, etc)
    - Hard to access/rotating component monitoring (engine, gear box, etc)
    - Reduction of wiring to existing sensors, relays, etc. (sensor-tags)
    - DFI/test facilities – reduction in wiring
    - Leak detection (H_2, CH_4, other vapors)
    - Humidity detection in composite structures

Conclusions:

- SAW wireless sensors are emerging in industrial applications
- Advantageous where Si fails
- Numerous potential aerospace and industrial applications
- No complete solution exists COTS – need end-user involvement
- ASR&D has demonstrated several advances in device & system technology
- We are actively seeking partners to bring sensor solutions to market for a range of applications
- Questions?

THANK YOU FOR YOUR ATTENTION

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