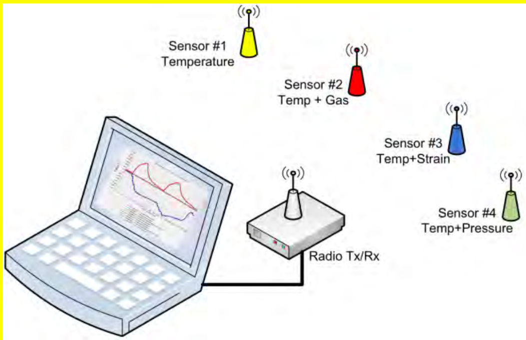
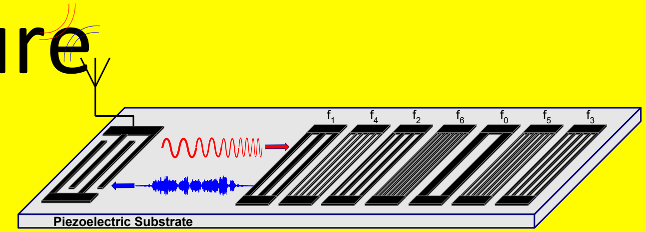

UNIVERSITY OF CENTRAL FLORIDA
COLLEGE OF ENGINEERING
AND COMPUTER SCIENCE

PWST SAW Technology
Challenges & Future





Donald C. Malocha
Pegasus Professor
Electrical & Computer Engineering Dept.
University of Central Florida

- Approximately 4-5 billion SAW devices are produced each year
- If you have a cell phone, you own multiple solid state acoustic devices

2015 IEEE International Conference on Wireless for Space and Extreme Environments

***FAIRWINDS* Alumni Center**, University of Central Florida
Orlando, FL, USA – December 14th-16th, 2015

UCF: Brief Facts

- ***LOCATION:*** 13 miles east of downtown Orlando
- ***STATUS:*** One of Florida's 11 public universities
- ***Fall 2015 Enrollment:*** ~ 63,000 students
- ***Service Area:*** Encompasses 11 counties, such as including Brevard, Citrus, Flagler, Lake, Levy, Marion, Orange, Osceola, Seminole, Sumter, and Volusia Counties
- ***Degrees Offered (212 total):*** 93 BS, 84 MS, 3 Specialist, 31 Doctorate, 1 Professional (Medicine)
- ***Degrees Awarded (281,584 total):*** BS (230,931), MS (46,000), Specialist (603), Doctoral (3,674), Doctoral-Prof (376)

Some Partners in the Community

The world's first industry-led consortium
(501.c.6 non-profit) for the manufacturing of smart sensors

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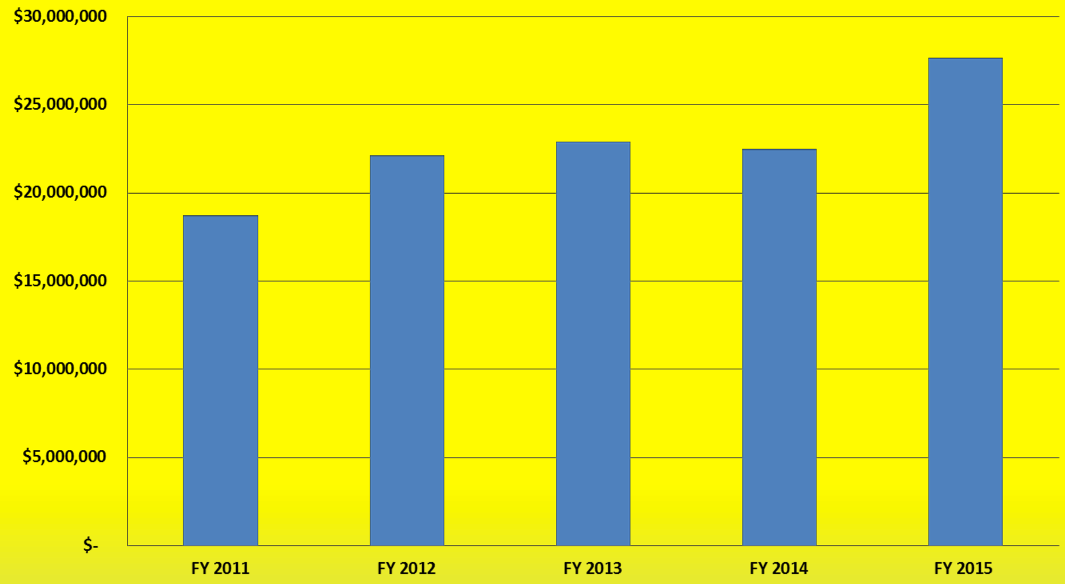
CECS: Brief Facts

- The College houses ***6 Departments***
  - Civil, Environmental and Construction (CECE)
  - Computer Science (CS)
  - Electrical and Computer Engineering (ECE)
  - Industrial Engineering and Management Systems (IEMS)
  - Mechanical and Aerospace Engineering (MAE)
  - Materials Science and Engineering (MSE)
- There are two affiliate ROTC units, Army and Air Force
- The College has ***three buildings*** (Engineering 1 (130,000 sq. feet), Engineering 2 (105,000 sq. feet) and Harris Engineering Center (113,000 sq. feet))
- The College currently has over ***8,300 undergraduates*** and ***1,300 graduates***
- The College has ***awarded*** (up to Spring 2015) more than ***30,000 degrees***
  - 23,420 BS degrees
  - 7,379 Masters degrees
  - 1,175 Ph.D.'s

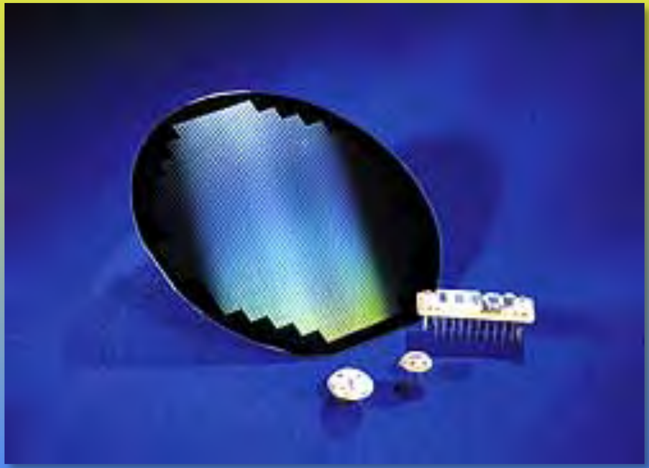
Research Productivity (Funding)



60% funding is from National Agencies

What is a Surface Acoustic Wave Device

- A solid state device
  - Converts electrical energy into a mechanical wave (~4000m/sec) on a high-Q, low-loss, single crystal substrate
  - Provides very complex signal processing in a very small volume
- Approximately 4-5 billion SAW devices are produced each year



Applications:

- **Cellular phones and TV (largest market)**
- **Military (Radar, filters, advanced systems**
- **Currently emerging – sensors, RFID**

My Brief History

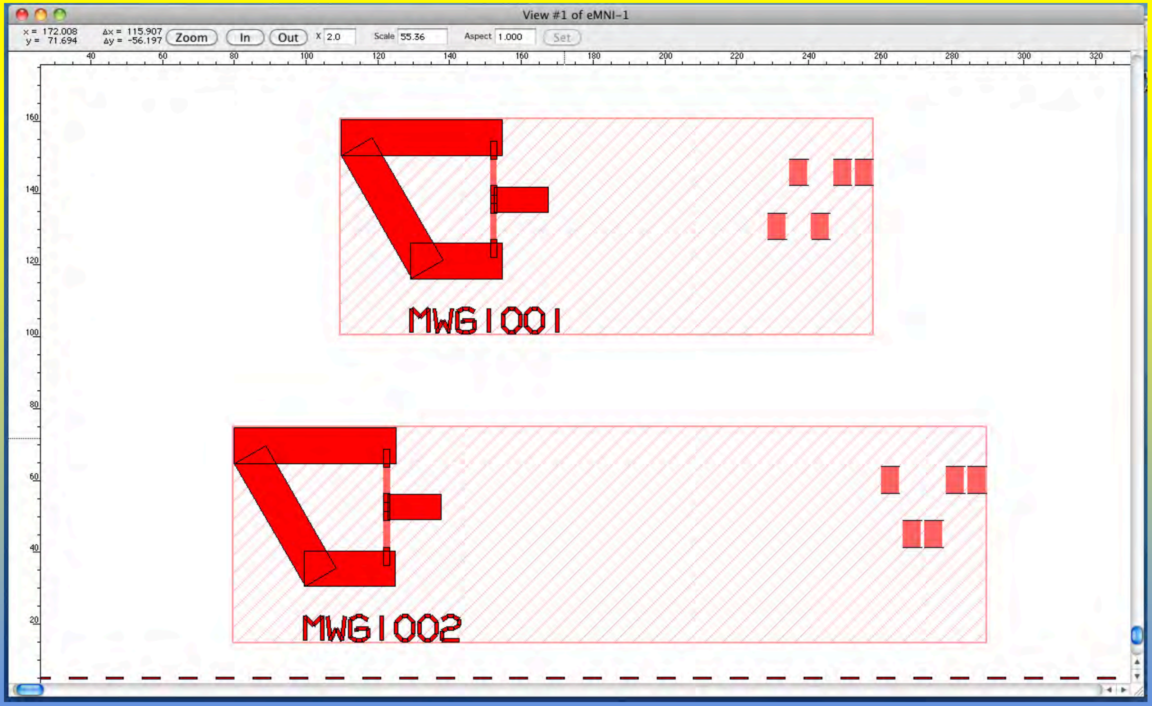
- University of Illinois, UIUC
- Texas Instruments Corporate Research, Dallas
- Joined a tiny, new startup called Sawtek, Orlando
  - Merged with Triquint then merged with RFMD
  - Currently Qorvo ~ $3-4 Billion company
- Joined a small university called UCF, Orlando
  - Started the semiconductor program
  - Started the SAW research activity

My Groups Activity
CAAT: Center for Advanced Acoustic Technology

- 15 Yrs: SAW devices for communications, acoustoelectronics and RF systems
  - Developed and sold SAWCAD design tool
  - Developed date acquisition tools
  - Developed parameter extraction tools
  - Developed analysis and COM modeling

Led to: Accurate and Rapid Device Analysis Design and Layout Tools

- Custom analysis and synthesis tools
- Custom Layout and Pattern Generator (PG) Tools

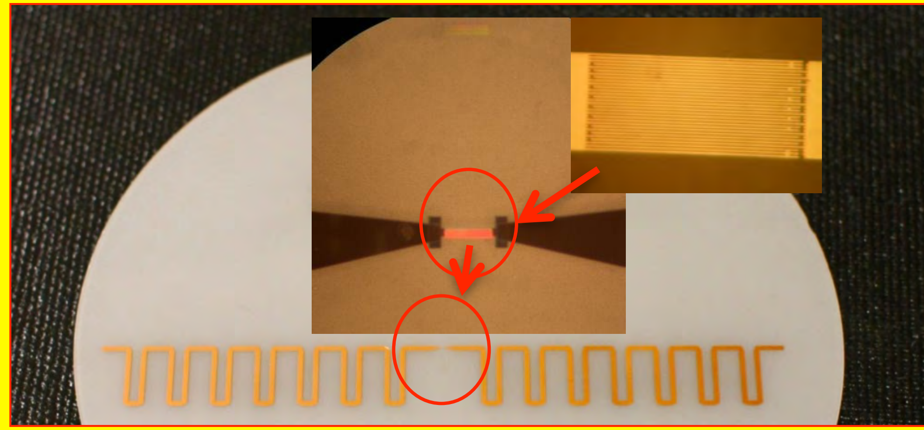


My Groups Activity CAAT

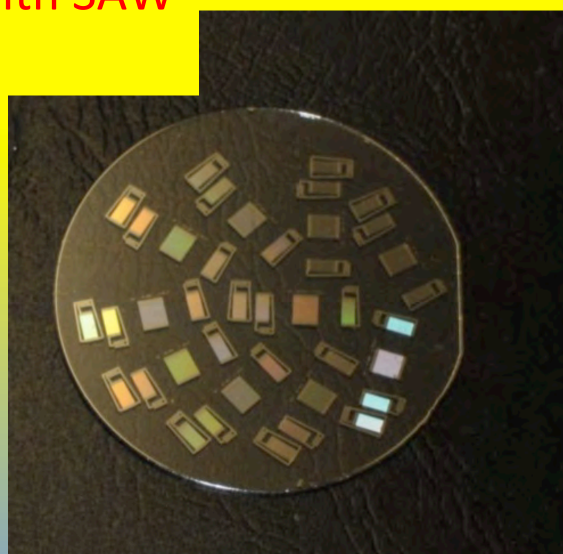
- Next 5 Yrs: Piezo material characterization
  - LGT, LGS and LGN extraction of stiffness, expansion and dielectric constants versus temperature
- Bulk Acoustic Wave Devices

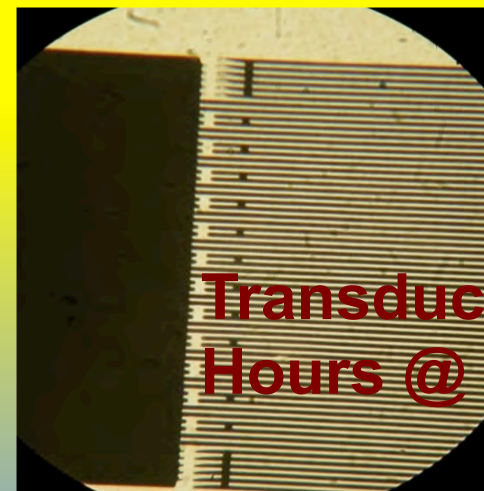
Led to: High Temperature Sensors

- **SAW devices on Langatate (LGT)**
  - **LGT stable up to melting temperature of ~1450ºC**
- **Platinum thin/thick films under investigation**
- **Sawtenna development**



LGT Wafer with SAW pin-wheel





Transducer after 2 Hours @ 700ºC

My Groups Activity CAAT

- Last 15 years: RFID and Sensors
  - Orthogonal frequency coded SAW RFID concept
  - Developed adaptive matched filter, synchronous coherent transceiver concepts
  - Demonstrated first 915 MHz SAW multi-sensor system and continually refining
  - Demonstrated physical, gas, liquid, cryogenic and high temperature sensor embodiments

UCF CAAT Sensor Research since 2004

Major Student Fellowships:

5- GRA Research Program
Fellows: = $410K

2- McKnight: = $160K

1-NSF:= $65K

2-FSGC: = ~$40K

17 Contracts:

8 - STTR/SBIR Phase I = $350K

7- STTR/SBIR Phase II = $1.92M

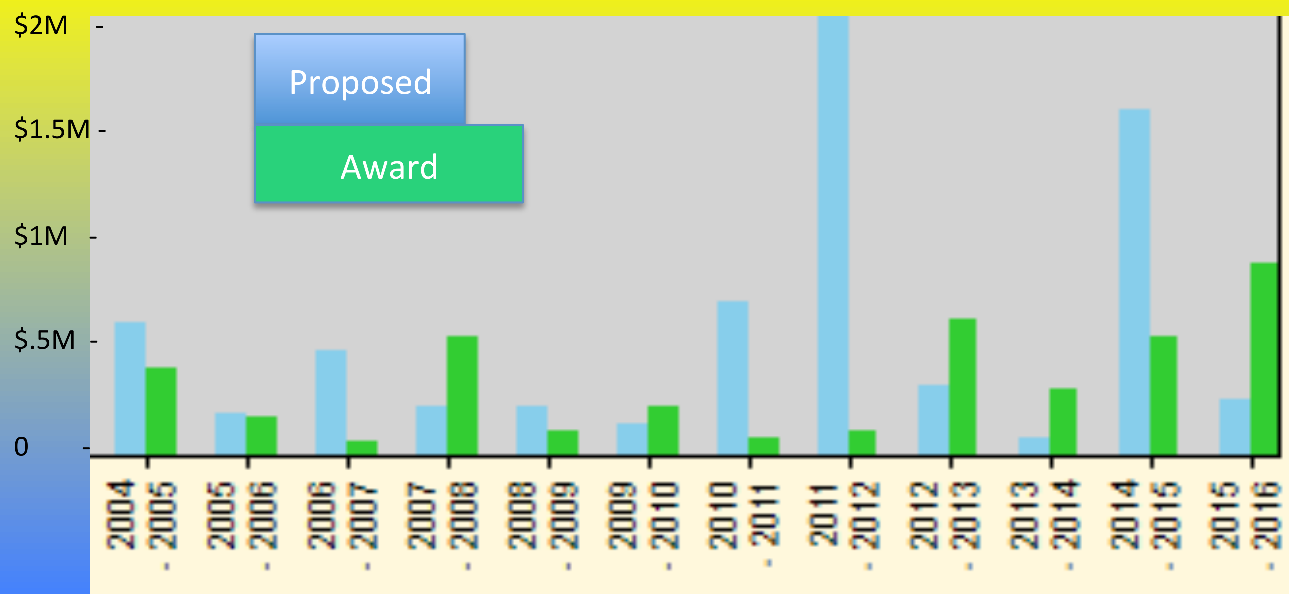
2 – DoD = $1.13M

Other = $750K

7 – UCF Patents on SAW based sensors and systems & several pending

Proposals: $9.47M

Awards: $4.31M



Motivation: Multiplexed, Wireless, and Passive SAW Sensors

This work originated in 2002 with a Shuttle request for passive sensors that could be located under the Shuttle tiles and accessed wirelessly. These sensors would have to survive in space and reentry. No applicable technology existed, so an STTR program was established to seek solutions.

Several universities tried to solve this problem, but the best approach came from the University of Central Florida (UCF) who advocated surface acoustic wave sensors and demonstrated an orthogonal frequency code (OFC) wireless multiplexing scheme in 2005. We at KSC decided to support this SAW approach.

See NASA Tech Brief on SAW Sensor

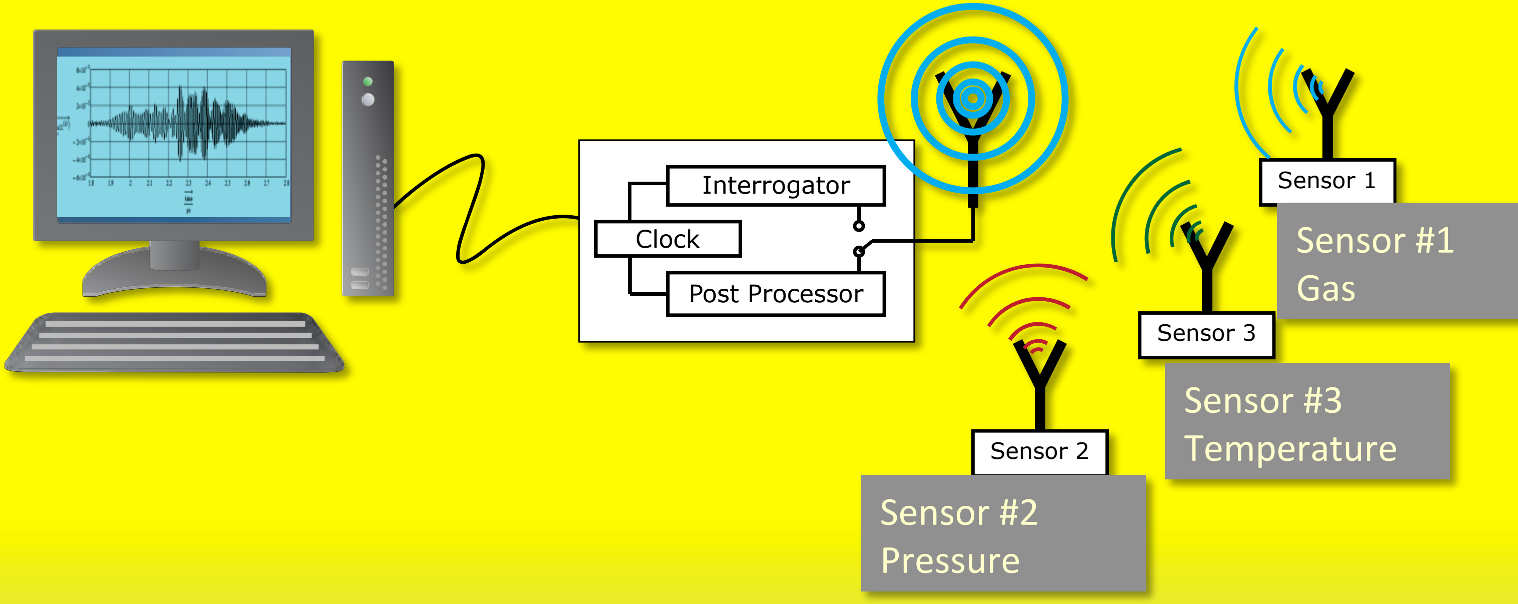
Jim Nichols – KSC/NASA
Licensing Manager
NASA Techbriefs Webinar
Sept 19, 2013

Why SAW Passive Sensors?

- A game-changing approach
- Wireless, “infinite-life”, and multi-coded
- Single communication platform for diverse sensor embodiments
- Broad frequency range of operation and range (. 25-2.5 GHz)
- Many different embodiments
- Can operate over large temperatures, radiation hard and robust in harsh environments
- Multiple sensor operations on a single chip
  - Physical
  - Gas
  - Liquid
  - other

The goal

Basic Passive Wireless SAW System



Basic Goals:

- Interrogation distance: 1< range < 1000 meters
- # of devices: 2 – 100's - **coded and distinguishable at TxRx**
- Single platform and TxRx for <u>differing</u> sensor combinations
- Can operate over a wide temperature range.

Jim Nichols – KSC/NASA
Licensing Manager

NASA Techbriefs Webinar
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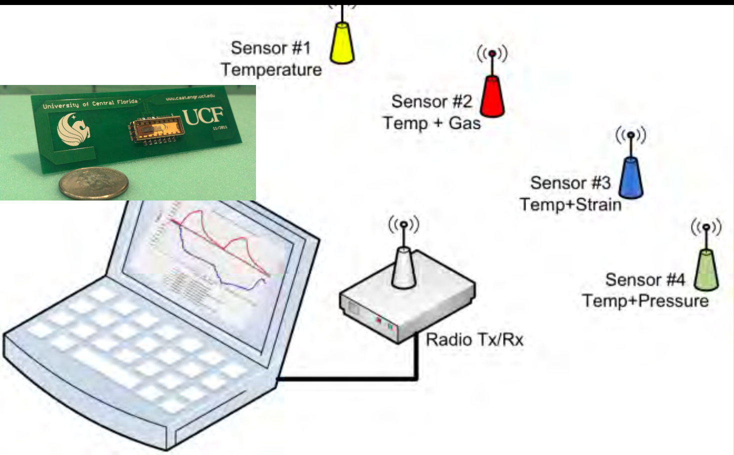
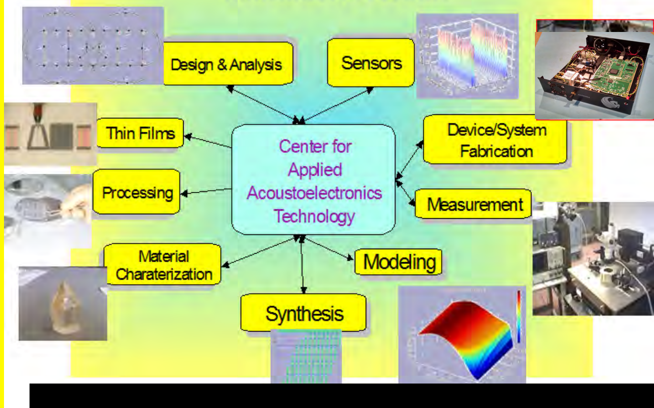
Present: UCF RFID Passive Wireless Sensors

Wireless Multi-Sensor Concept



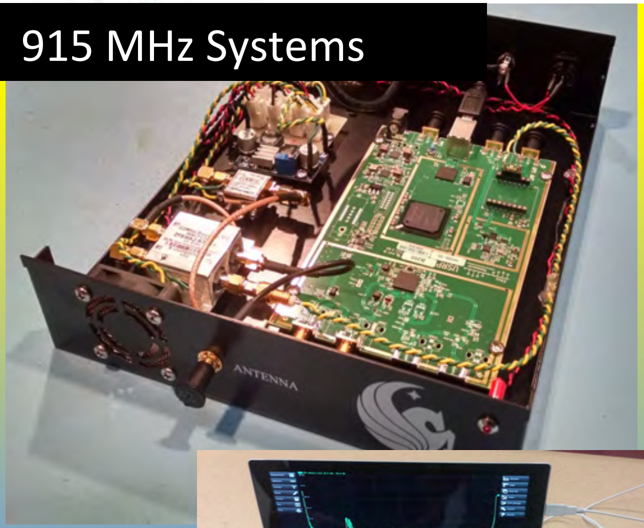
Highlights

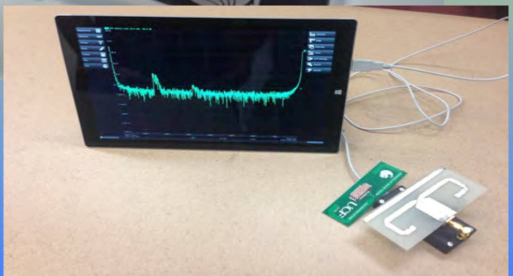
- Solid state
- Piezoelectric
- Freq: 0.7 – 2.4 GHz
- Temp: 0.1 – >1000K
- Rad Hard
- SS-RFID
- Current Sensors: temp, gas, strain, liquid, magnetic



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

915 MHz Systems





Wireless H_2 Gas

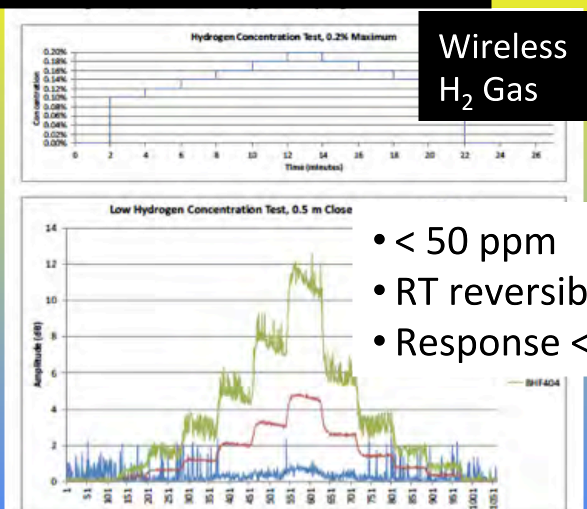
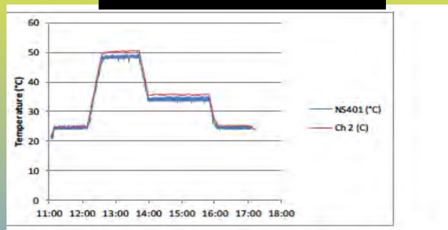


Figure 45. Low hydrogen concentration test, input profile and results

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

Wireless Temperature



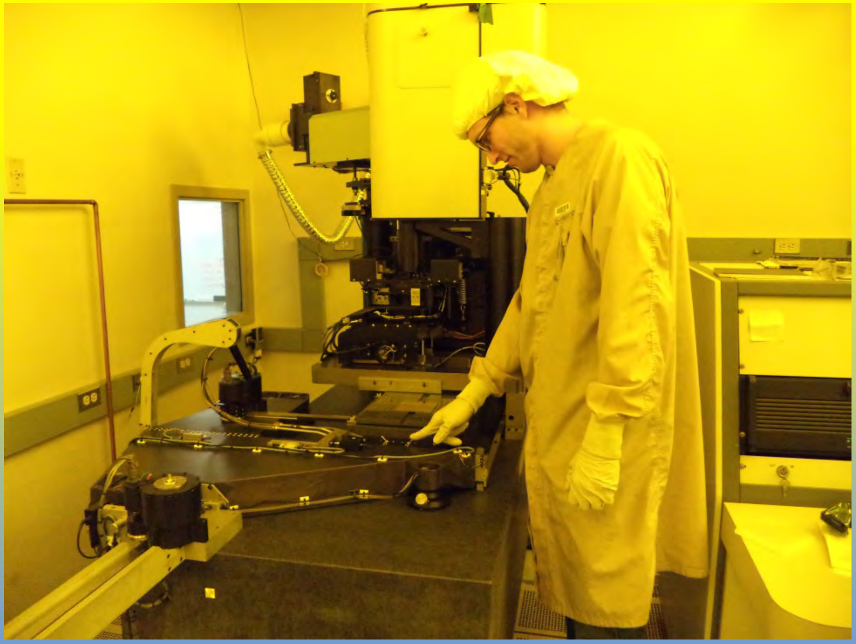
Temperature test results; blue trace: SAW sensor; red trace: thermocouple

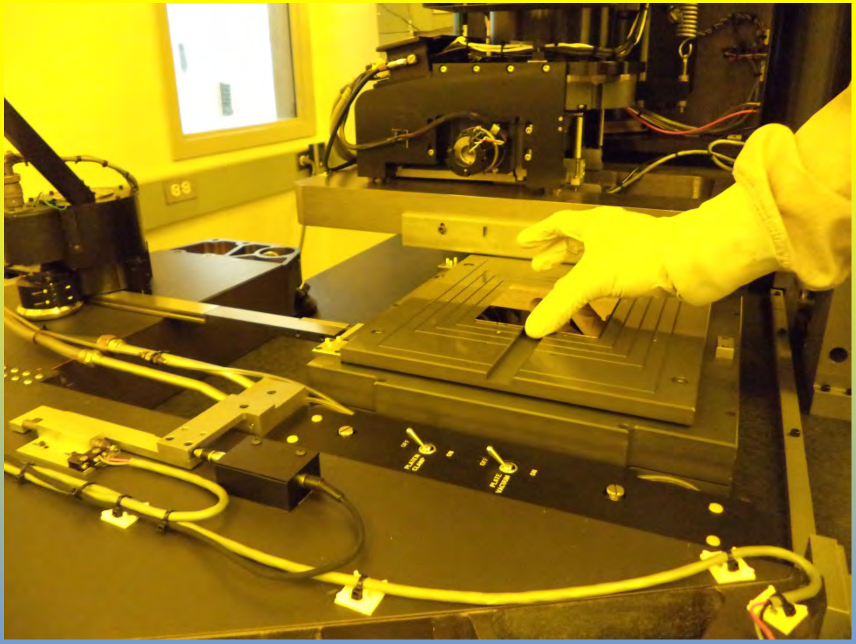
<.01 C acc.
0.1-500 K range

SAW Sensor Fabrication

Mask Fabrication for Photolithography

Pattern Generator - ~0.7 um Resolution



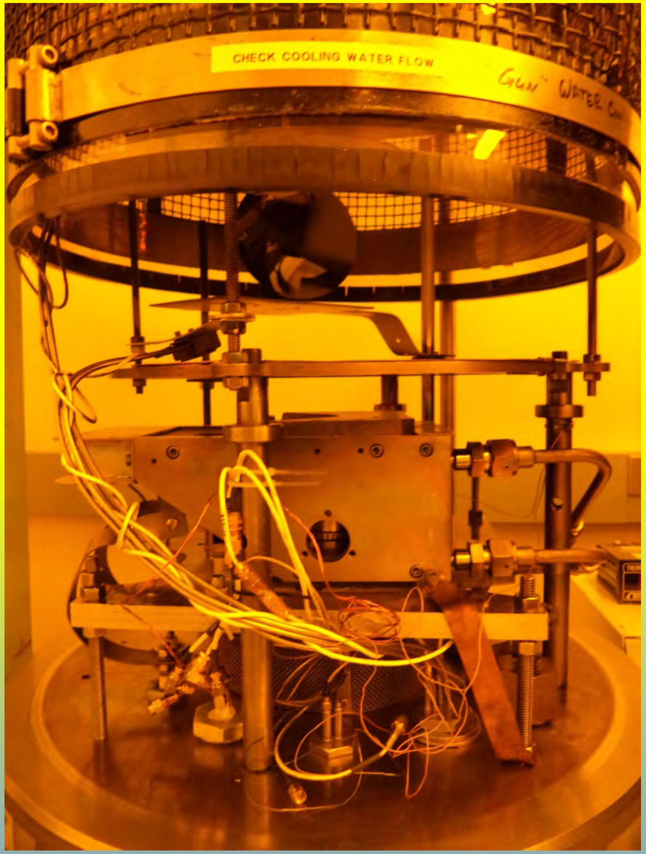


Photolithography

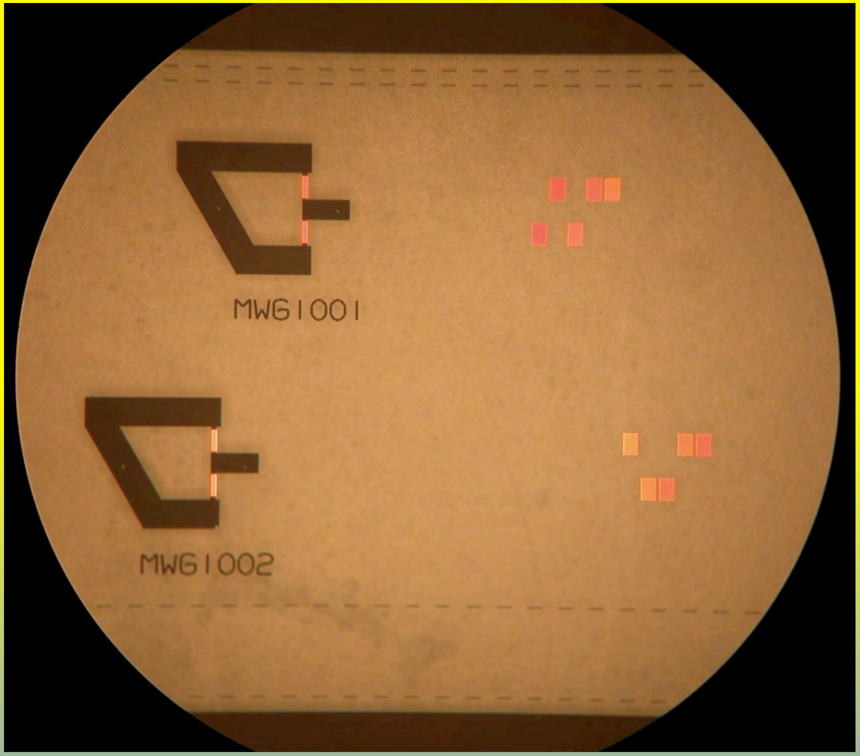
Submicron capability (~0.7um)

Thin Film Deposition

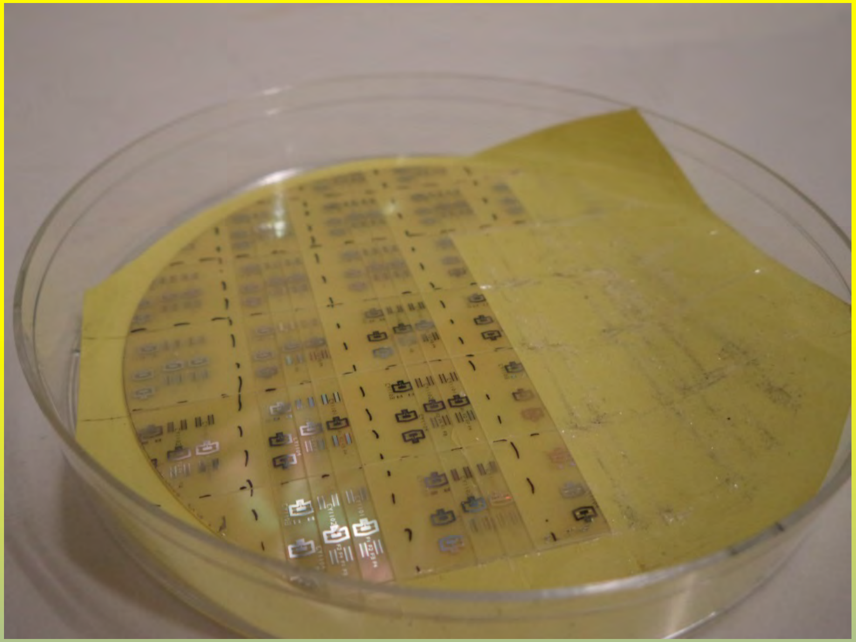
< 50 Ang. Accuracy



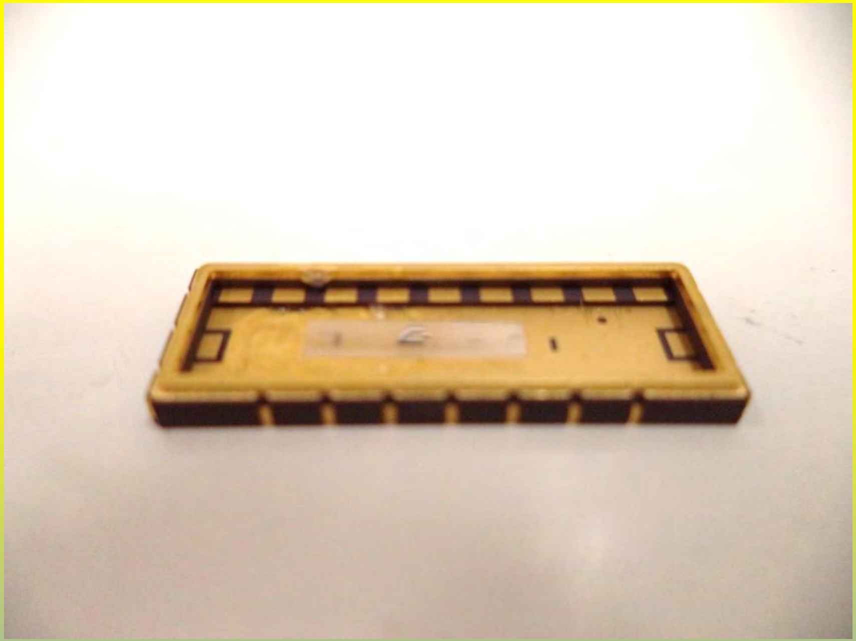
On Wafer Device Probing

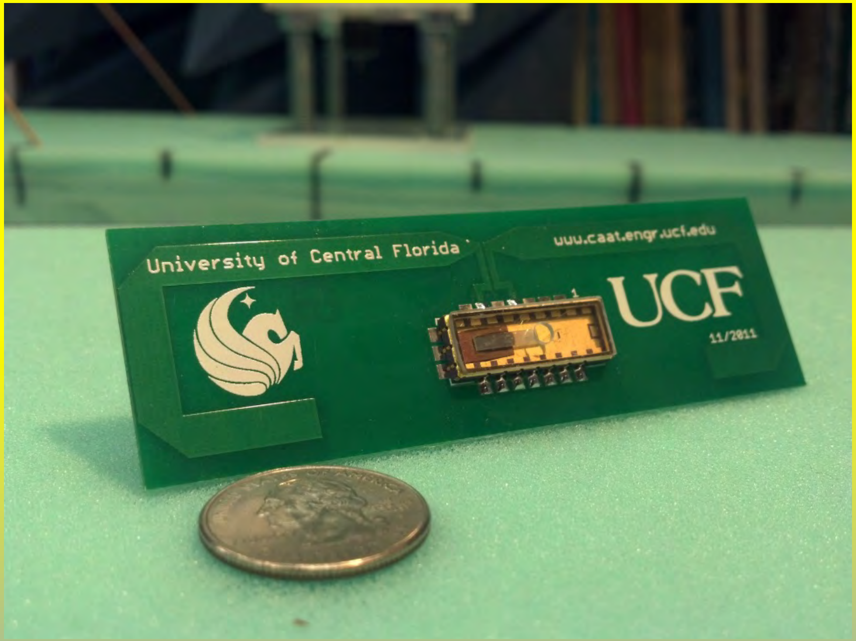


Wafer Dicing

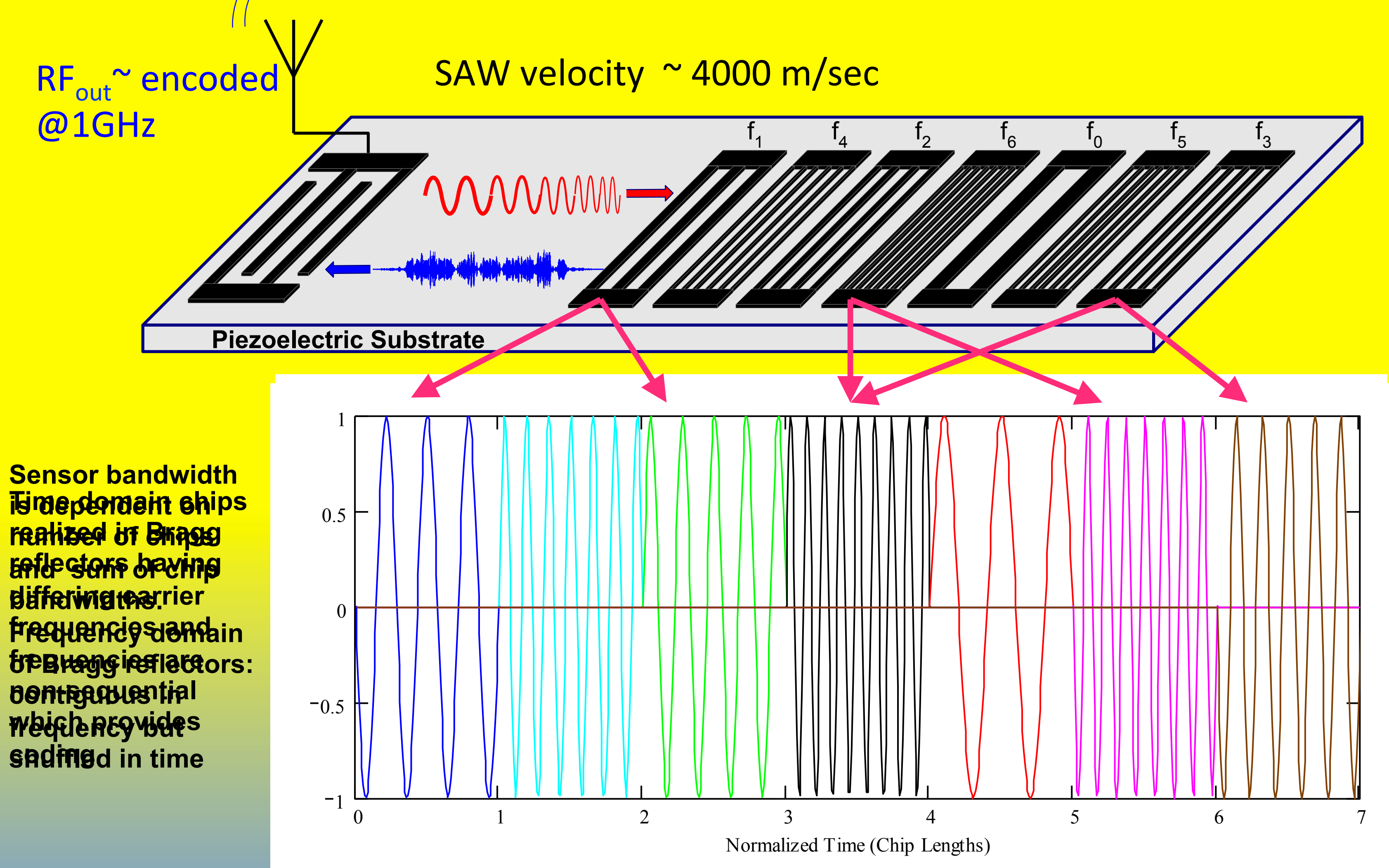


Packaging and Final Device Implementation





Schematic of a typical OFC SAW ID Tag

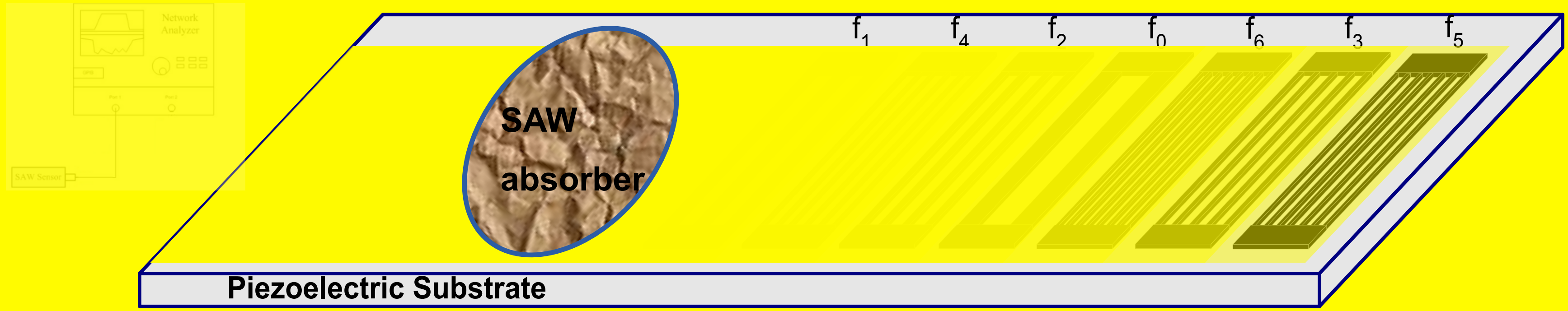


Sensor bandwidth is dependent on number of chips and sum of chip bandwidths.

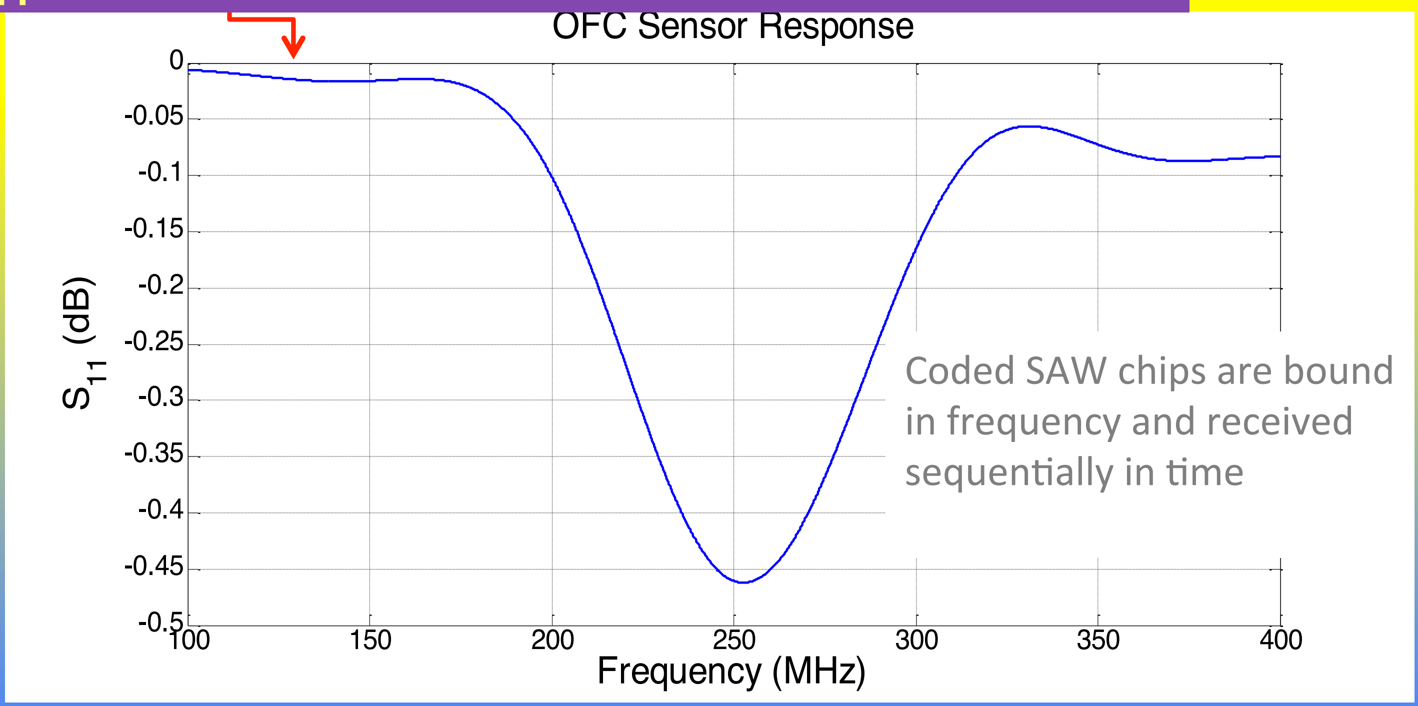
Time domain chips realized in Bragg reflectors having differing carrier frequencies and frequencies are non-sequential which provides coding

Frequency domain of Bragg reflectors: contiguous in frequency but shuffled in time

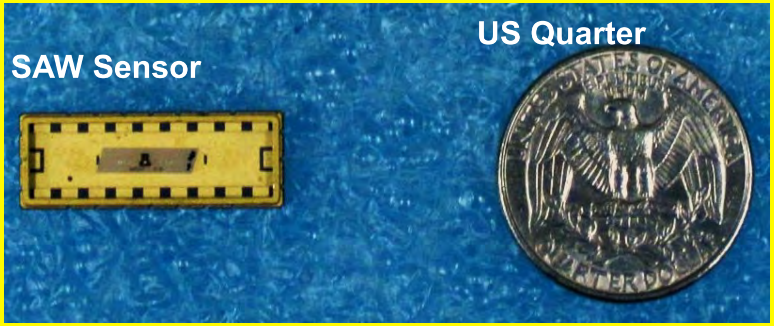
SAW OFC RFID signal – Target reflection as seen by antenna



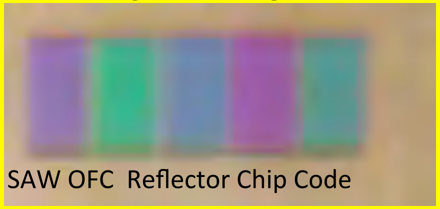
S_{11} w/o absorber and w/ reflectors

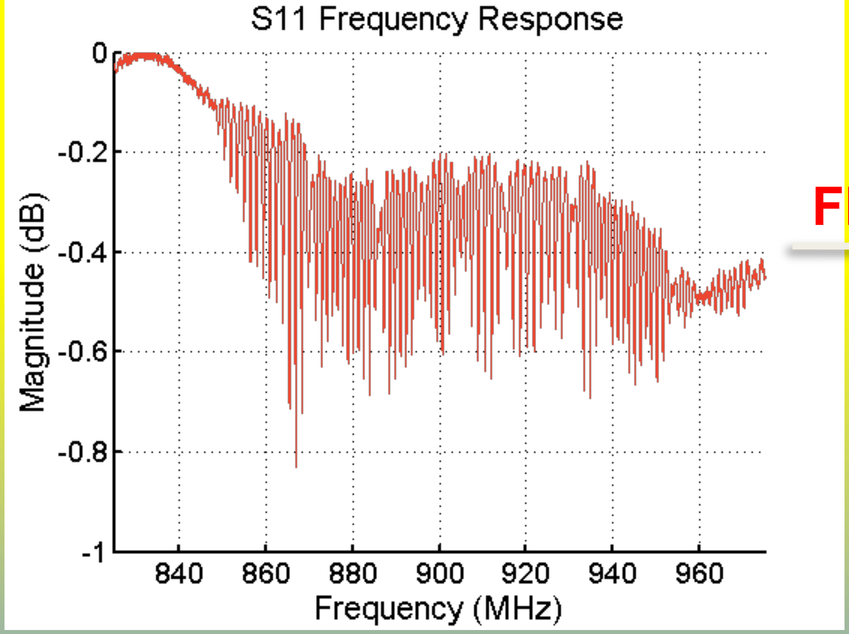


Example 915 MHz SAW OFC Sensor

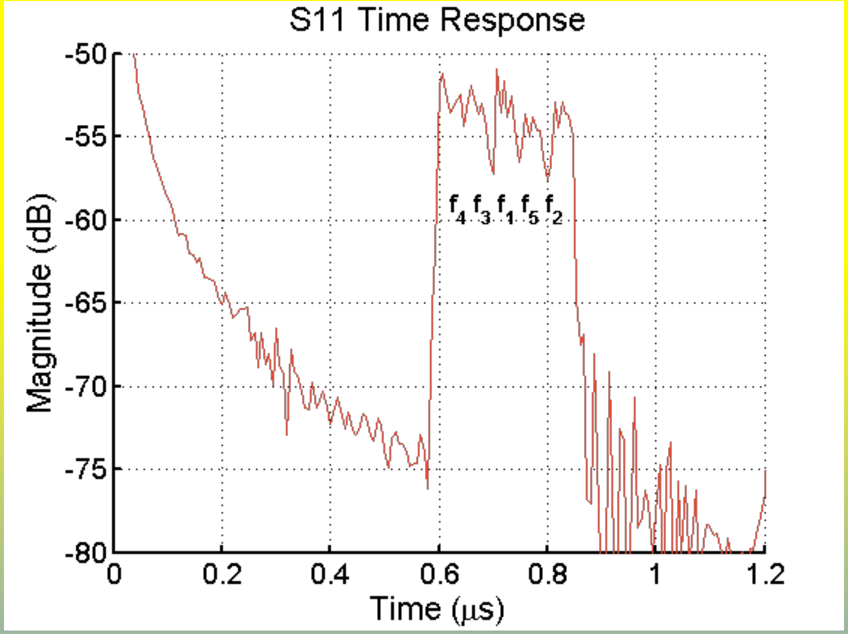


Light Micrograph





FFT



Most Transceiver Developments

It's all about S/N Ratio for any sensor system

- Interrogation signal:
  - –Time windowed, all sesnors frequency bandwidth
- Transceiver:
  - –usually time duplexed mode, opposing on-off state.
  - –usually synchronous mode for switching and integration.
  - – usually ADC to a post-processing software

TxRx Multi-Sensor Concept

- Bandwidth can be either shared or partitioned
  - Output power is Watt/Hz or dBm/Hz
- Time window can be either shared or partitioned
  - Output power is in Watt/usec or dBm/usec
- Sensors can be partitioned either in time, in frequency, or can share both domains
  - Inter-sensor interference is eliminated by partitioning in one domain
  - Inter-sensor interference is problematic if overlap in **BOTH** time and frequency domain occurs

Signal-to-Noise Ratio (SNR)

Condensed Version

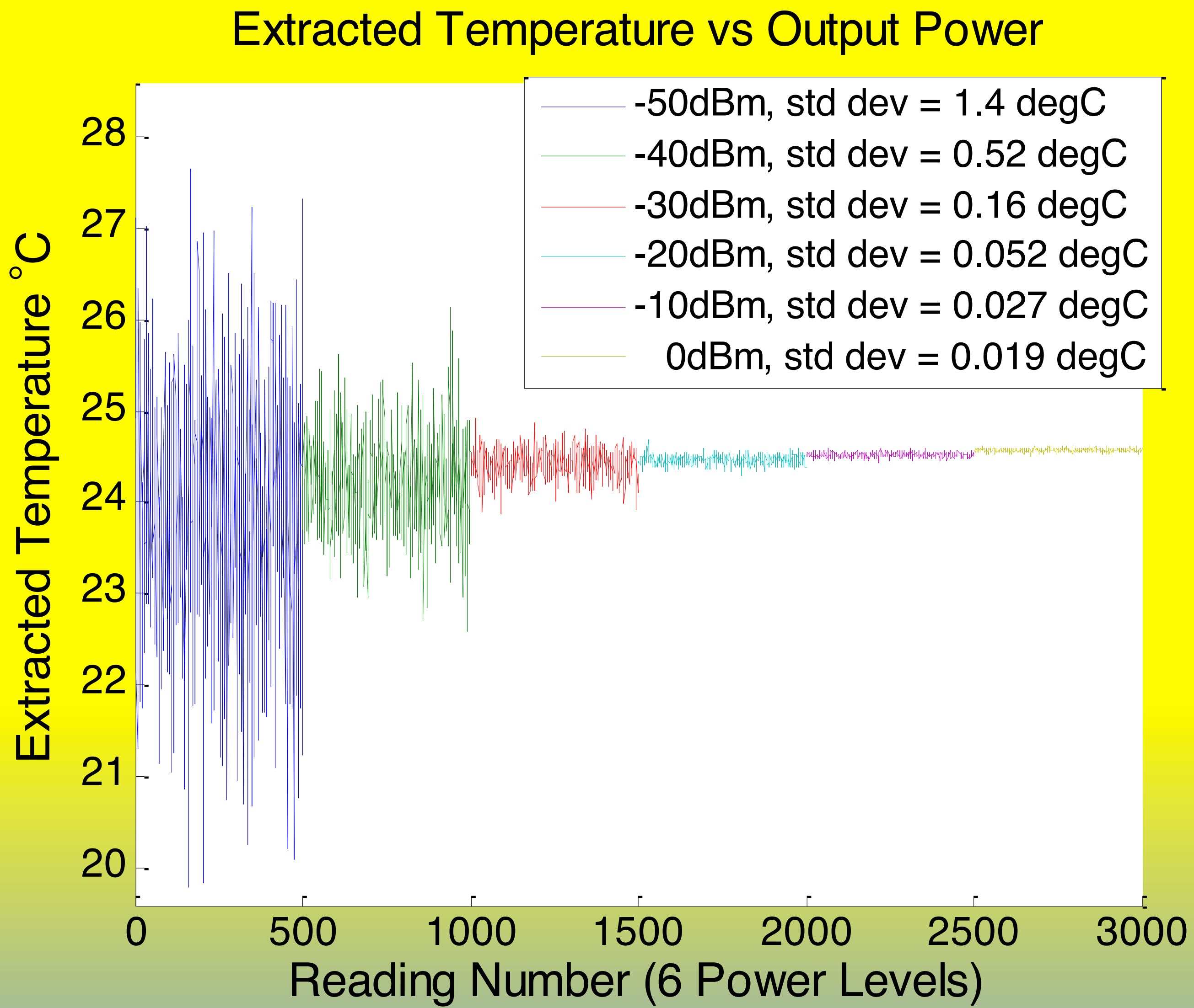
$$SNR=\left[\frac{V_r^{2}\cdot N_{Sum}}{V_{MDS}^{2}}\right]\cdot\left[G_{Sensor}\cdot G_{Tx\text{-}ant}\cdot G_{Rx\text{-}ant}\right]\cdot PL^{-1} \qquad (1)$$

or

$$S/N=G_{TR}\cdot G_P\cdot G_E \qquad (2)$$

where $G_{TR}=\left[\frac{V_r^{2}\cdot N_{Sum}}{V_{MDS}^{2}}\right]$, $G_P=[G_{Sensor}\cdot G_{Tx\text{-}ant}\cdot G_{Rx\text{-}ant}]$
and $G_E= PL^{-1}$.

V_r is the transmit voltage level and V_{MDS} is the voltage level detectable at the ADC, PL =Path Loss= $[v_{EM}/(4\cdot\pi\cdot R\cdot f_o)]^{-4}$, R=range



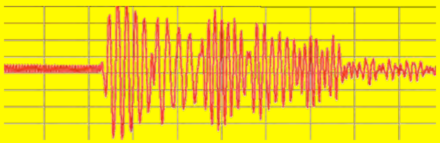
Temperature measurements showing the precision as a function of interrogation signal power in a controlled environment.

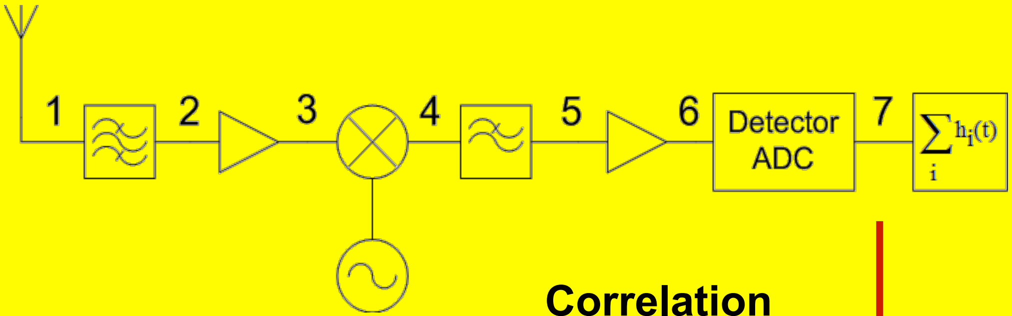
The corresponding reading number (RN) for the 6 power levels are: RN 1-500, -50dBm; RN 501-1000, -40dBm; RN 1001-1500, -30dBm; RN 1501-2000, -20dBm; RN 2001-2500, -10dBm; RN 2501-3000, 0dBm.

UCF Synchronous Correlator Receiver

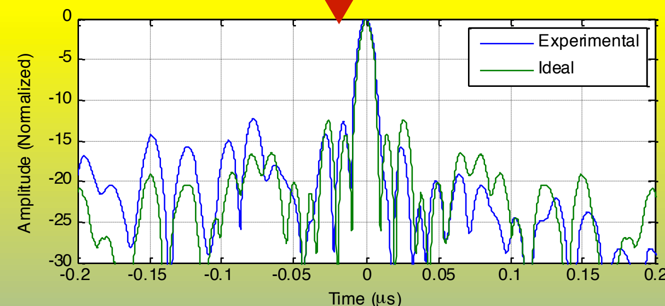
Block diagram of a correlator receiver using ADC

OFC Single Sensor Signal

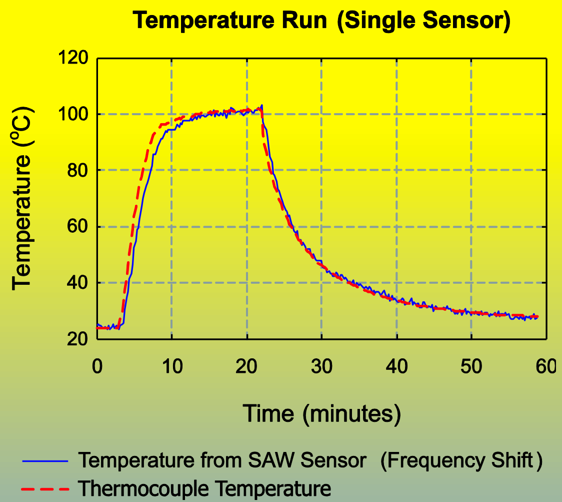




Correlation Output

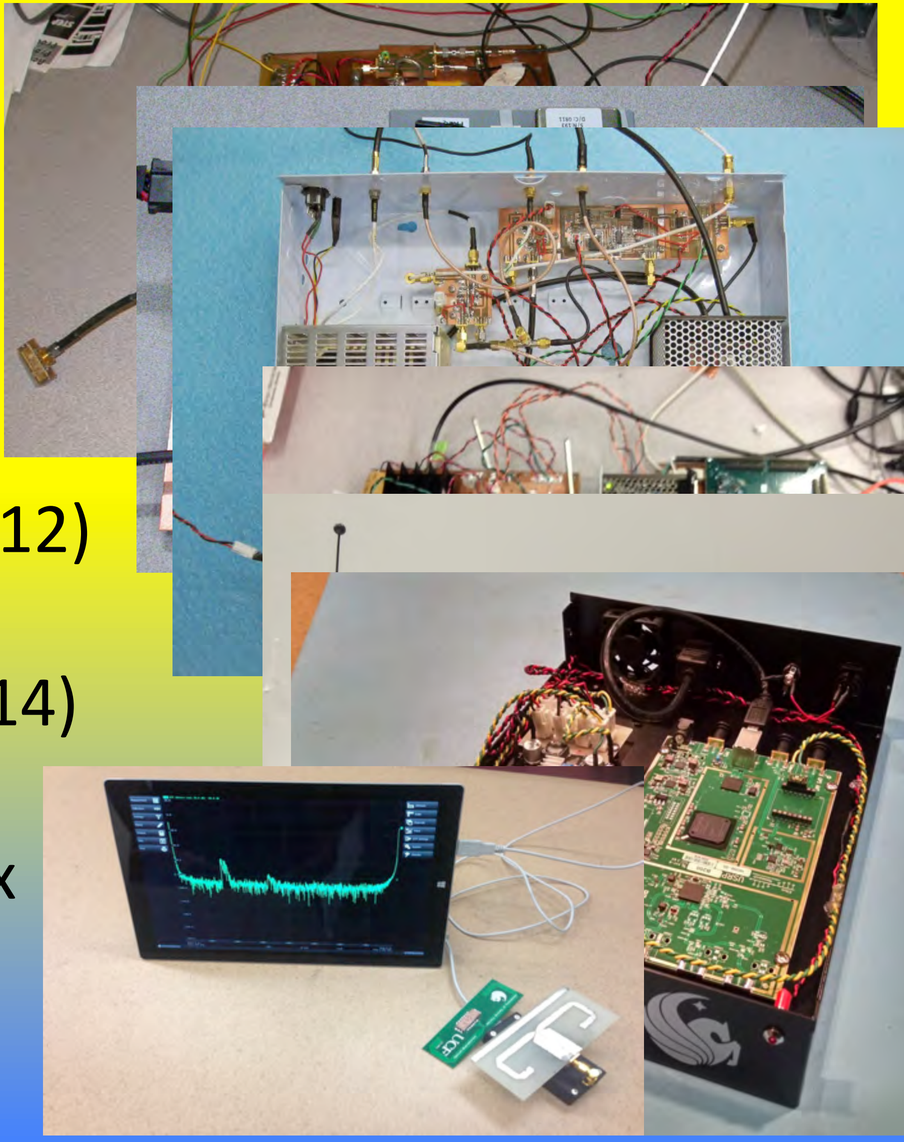


Temperature Extraction



RF Synchronous Coherence Transceiver Prototype Development

- 250 MHz
  - First Prototype (multiple boards) (2008)
  - Second Prototype (two main boards) (2009)
- 915 MHz Pulsed (2011)
- 915 MHz Noise Coherent(2012)
- 915 MHZ Wideband (2013)
- 915 MHZ FCC compliant (2014)
- 915 MHz SDR (2015)
- Wireless handheld mini-TxRx



NASA Tech Briefs

Monday, 01 December 2014

Named in NASA's Hot 100 Technologies: Sensors

Coherence Multiplexing of Wireless Surface Acoustic Wave (SAW) Sensors

This integrated, multi-sensor network quickly identifies gaseous leaks in extreme environments in ground systems, spaceflight, and space exploration by utilizing a chemical sensing film located on a piezoelectric substrate that wirelessly transmits the data collected through pairs of antennas located on the sensor. The multiplexed system is unique because it allows multiple sensors to communicate simultaneously without incurring degradation through returning signal echoes. www.techbriefs.com/2014NASA100/AcousSens

NASA-KSC Wireless Temperature Test Results

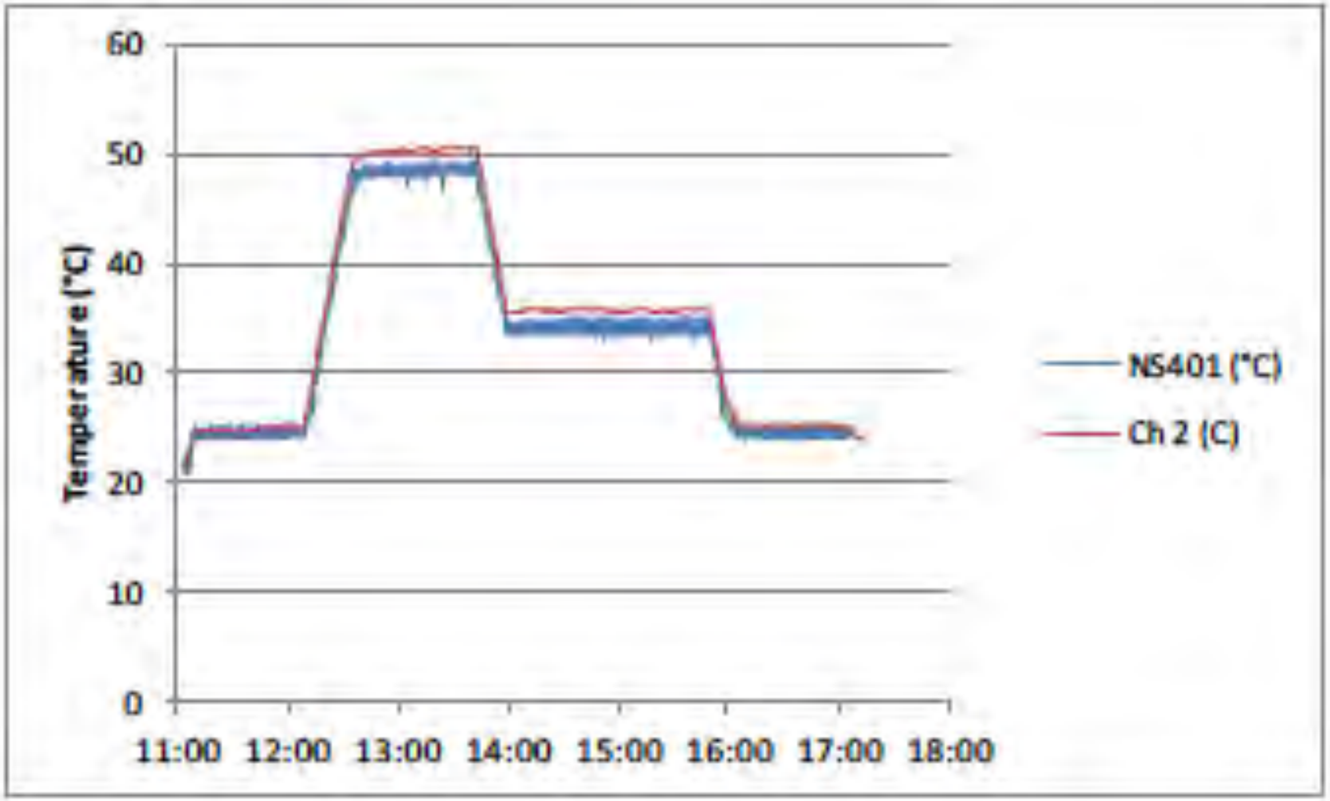
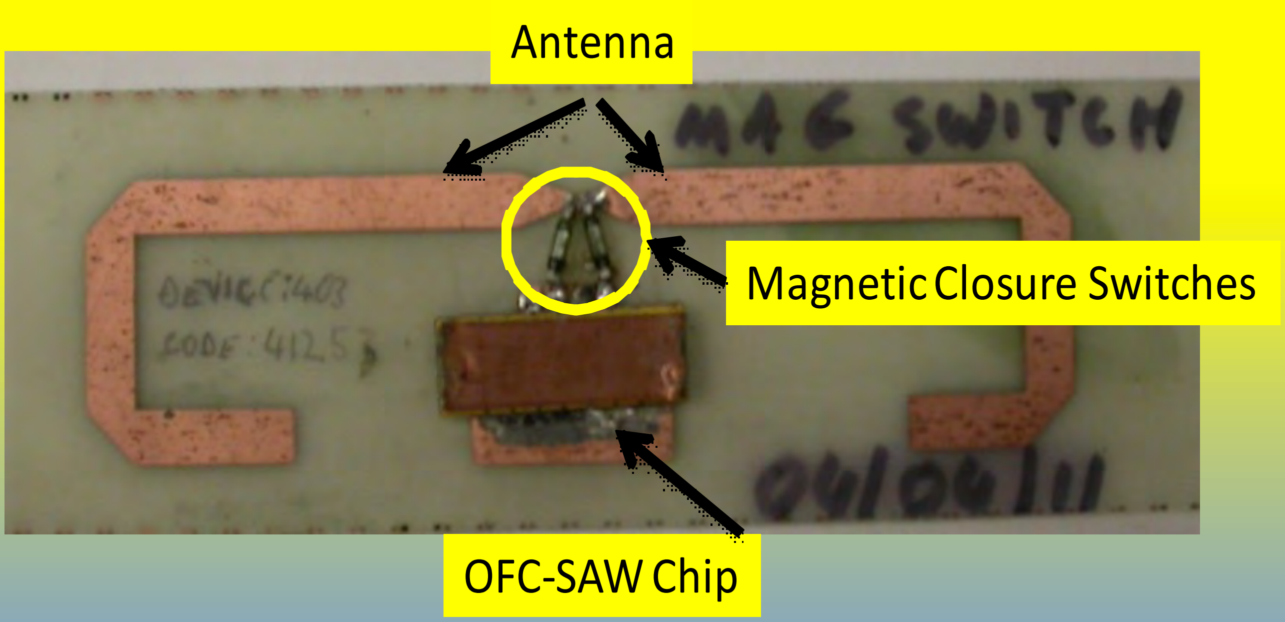


Figure 32. Temperature test results; blue trace: SAW sensor; red trace: thermocouple

Off-die: Wireless Magnetic Sensor

- SAW is used as RFID link and external device provides sensing
- Sensor between antenna and SAW



- **on-off ratio >30dB**
- **Multi-track**

Multiplexed Passive SAW Sensors Liquid Level Applications

NASA needs improved methods for monitoring the liquid level in cryogenic tanks, and wireless passive technology is ideal due to the limited heat load introduced by the sensing system.

Devices operate from ~250C to 0.1 Kelvin

A set of six, coherence multiplexed, liquid level SAW sensors.

NASA-KSC Wireless Test: Hydrogen Gas Sensor 0.2% max H_2 0.02% concentration steps

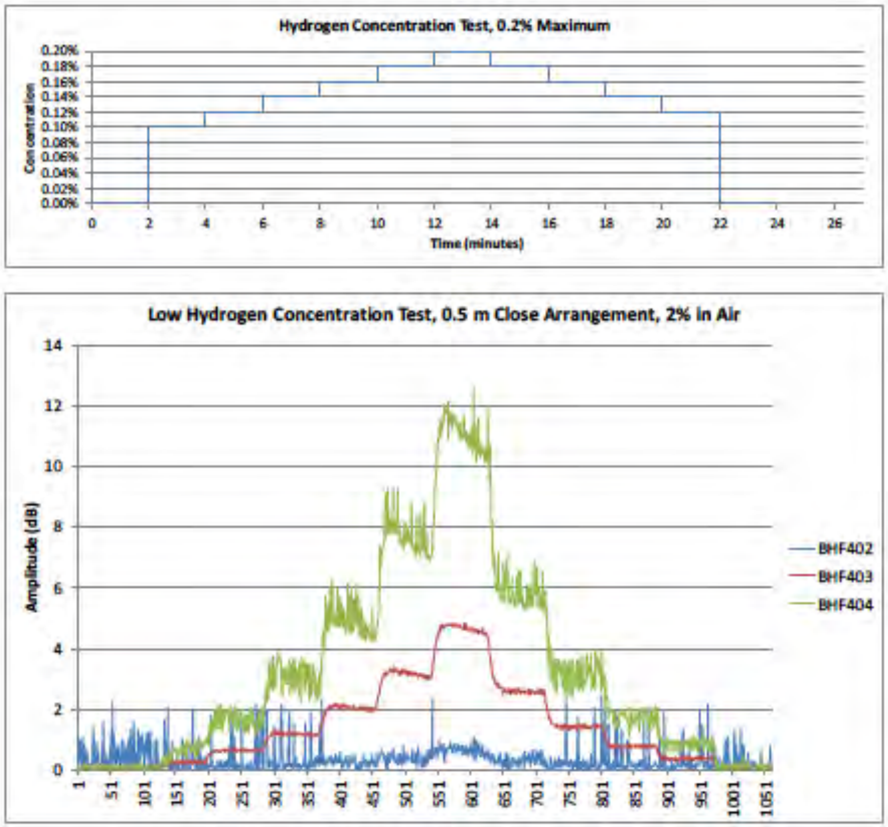


Figure 45. Low hydrogen concentration test, input profile and results

Current Research

- Wireless gas sensing
- Wireless strain sensor
- Miniature low-cost hand-held TxRx
- High data rate acquisition
- Wired handheld POC diagnostics for biological liquid sensing

Future Research

- Higher frequencies
- NASA space qualification
- Hydrogen and gas sensing
- Biological POC handheld system
- Networking of multi-node multi-sensor TxRxs

UCF Office of Commercialization

- SAW Business – for accepting purchase orders, credit cards, etc., for device and system purchases.

<u>Contact person:</u>

- Andrea Adkins: Andrea.Adkins@ucf.edu

<u>Technical contact:</u>

- Don Malocha: donald.malocha@ucf.edu

Thank you for your attention!!