Project Title: *Wireless Passive Sensors and Systems for Physical Sensors and Hydrogen Sensing Applications*

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Start Date = January 1, 2005
Planned Completion = May 30, 2007

Research Goals and Objectives

1. Develop miniature, light weight, passive remote wireless sensors for physical, chemical, gas and biological applications.
2. Develop a device platform which operates over wide range of operating environments and for various sensing applications.
3. Theoretical and experimental studies on sensor device embodiments to determine sensitivity and limits of operation.
4. Verify SAW sensor can operate at and near liquid hydrogen temperatures.
5. By using multiple devices and/or temperature sensing, liquid level can be determined.
6. Develop a hydrogen gas sensitive film for the detection of hydrogen gas.

Relevance to Current State-of-the-Art

- New use of spread spectrum technique for surface acoustic wave (SAW) sensor
- Orthogonal frequency coding allows lower spectrum emission, coding and processing gain over conventional single carrier SAW devices
- Initiate work on SAW sensor operation at cryogenic temperatures and hydrogen sensing
- Wireless-passive device platform can potentially be used for a wide range of physical, gas, chemo and bio sensors with slight changes in embodiment

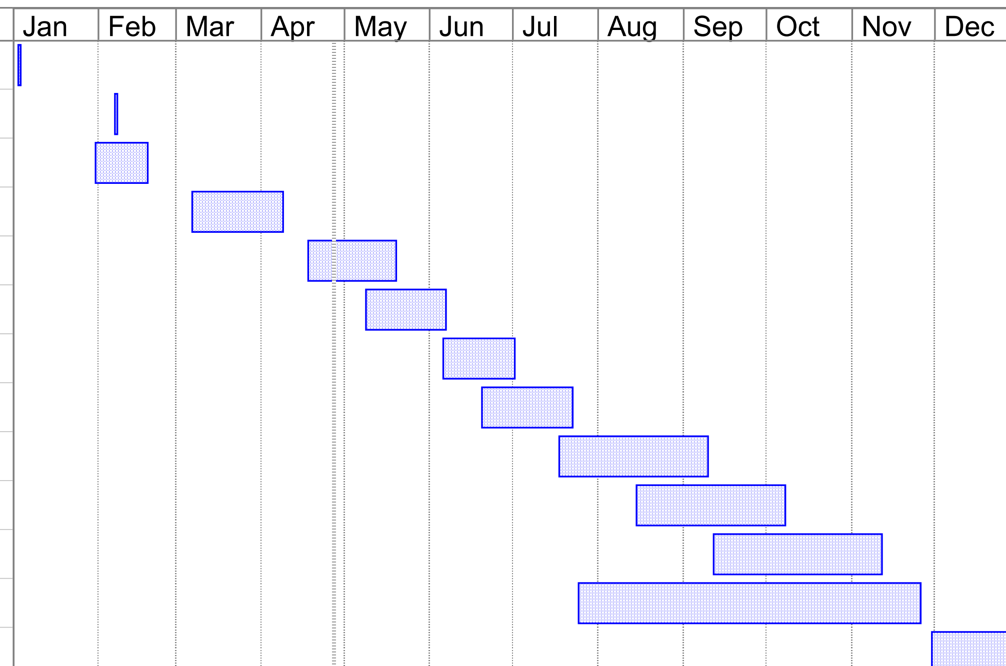
Relevance to NASA

- Hydrogen gas sensor for leak detection
- Hydrogen liquid level sensor by using multiple devices in a linear array-sensor “dip stick” approach
- Temperature sensor
- Tire and other pressure sensor
- Potential use in a wide range of NASA applications in future exploration in remote vehicles and space craft requiring sensors

Budget, Schedule and Deliverables

- Start date delay due to contract setup - 1st Year Funding
- We are on schedule and within this year's budget of $90K
- Deliverables: Qtrly reports, 3 publications, devices fabricated and tested

ID	Task Name
1	Contract Award
2	Project/contract initiation
3	Design Mask 1 Initial testing
4	Fabricate Device #1
5	Measure & Analysis Device #1
6	Design Mask #2 TCD Extraction
7	Fabricate Device #2
8	Measure Device & Analysis #2
9	Design Mask #3 Hydrogen Gas Sensor
10	Fabricate Device #3
11	Measure & Analysis Device #3
12	Antenna Designs and Measurenments
13	Final Report



Anticipated Technology End Use

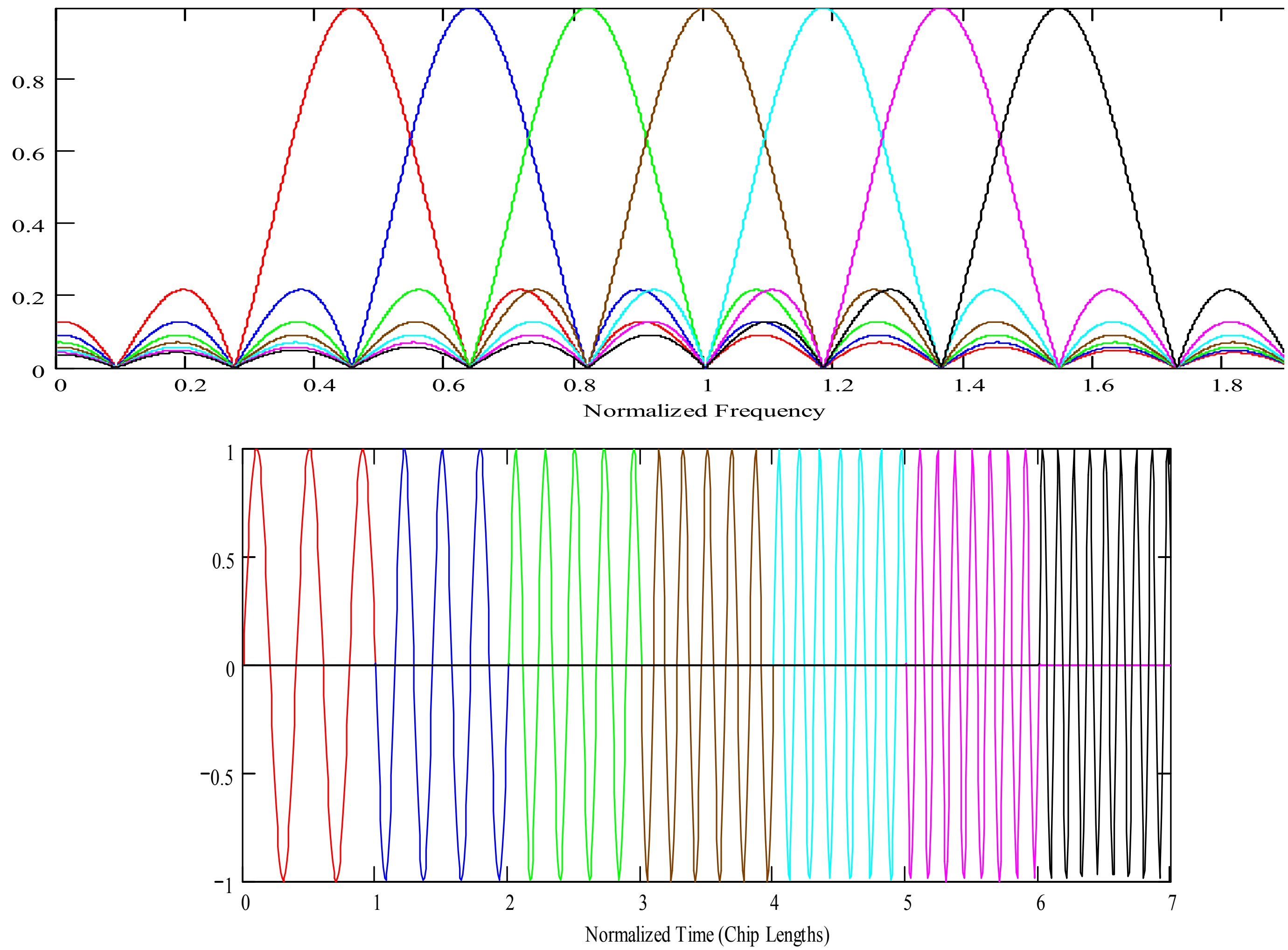
- Hydrogen gas sensor for leak detection
- Hydrogen liquid level sensor by using multiple devices in a linear array-sensor “dip stick” approach
- Temperature sensor
- Tire and other pressure sensor
- Cement temperature curing monitor using a large array of coded SAW sensors
- Small wireless coded strain/ vibration sensor for moving systems
- High temperature remote sensing for turbines or other harsh environment applications
- Bio- and Chemo- sensors can use the current and future progress of other investigators working in the field since the device platform and interrogation system will be developed

Accomplishments and Results

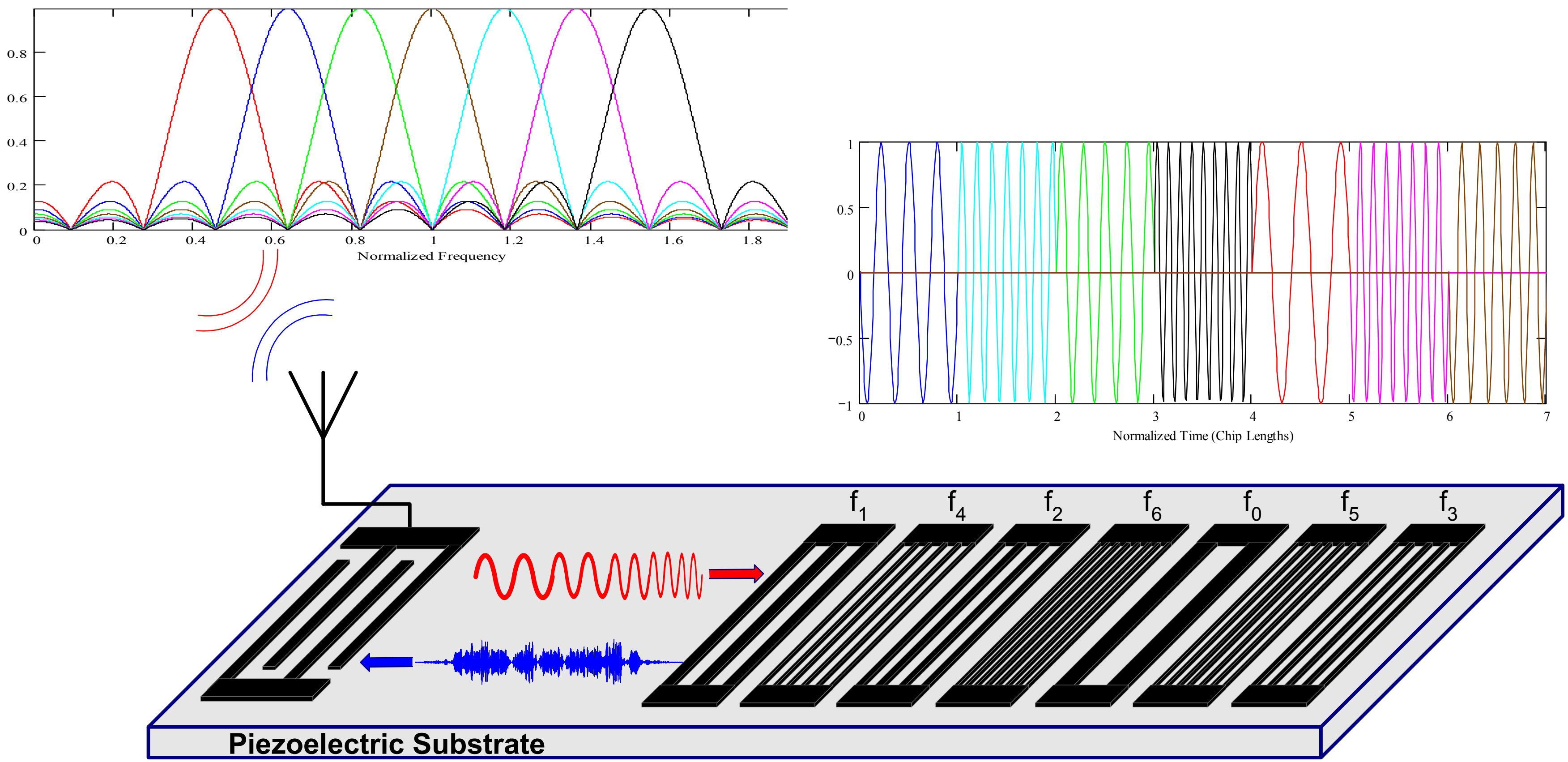
- Demonstrated low temperature operation of SAW OFC Sensor
- Designed and fabricated a 500 MHz OFC SAW sensor with approximately 1um lines using pattern generator
- Designed and are attempting fabrication of .7 um, 1 GHz SAW OFC sensor using ebeam writer– on third iteration of fabrication
- Theory and experiments on SAW reflectivity to account for film thickness and line width vs. period variation
- Expanded interrogation system software and analysis for device evaluation
- Expand analysis and design software, including a 2-D coupling of modes model which allows weighted reflector analysis
- Built several OFC hydrogen gas sensors using palladium thin films and begun characterization
- Initial experiments using the FSEC color changing thin films for integration into OFC sensor devices for detecting hydrogen
- Initial cryogenic temperature testing of $LiNbO_3$ substrates

Basis of Operation

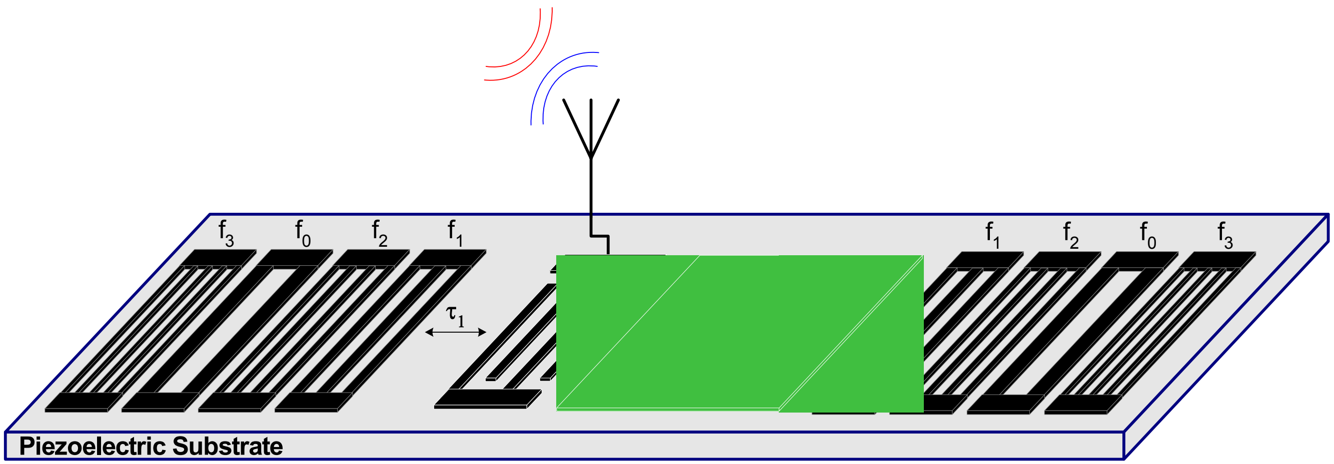
Linear Stepped Chirp Time Response with 7 Chips



Schematic of 7chips/bit OFC SAW ID Tag



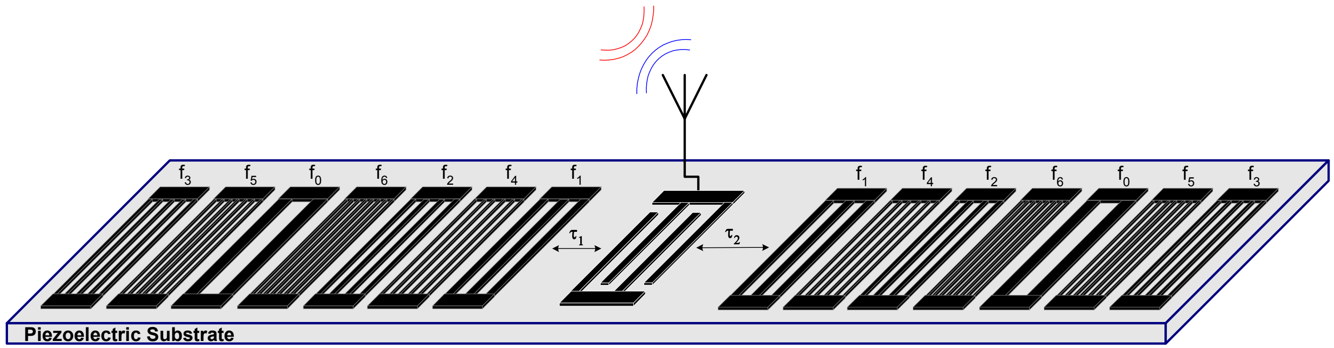
SAW Sensor Implementation

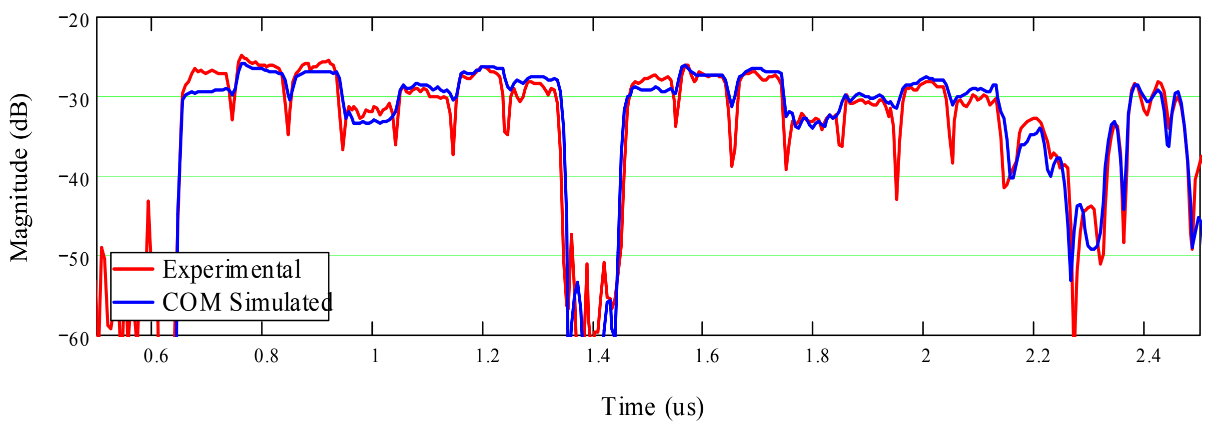


- OFC reflectors repeated on both sides of transducer
- Transceiver yields two compressed pulses
- Pulse separation proportional to sensed information
- Different free space delays ($\tau_1 \neq \tau_2$) yield temperature
- For gas, chemo or bio sensing a sensitive film, such as palladium for hydrogen gas, is placed in one delay path and a change in differential delay senses the gas ($\tau_1 = \tau_2$)

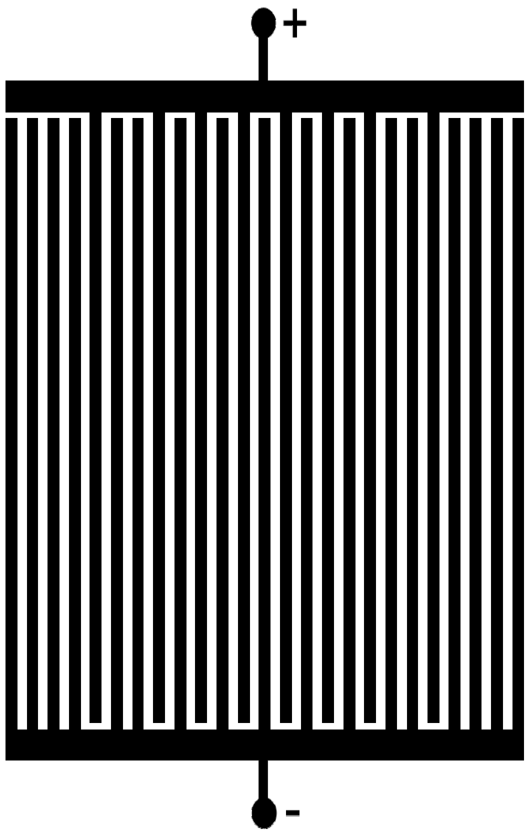
OFC SAW Temperature Sensor

- Seven chips / frequencies
- YZ $LiNbO_3$ substrate
- 250 MHz center frequency
- 25% fractional bandwidth
- Free space delays of 1 μs and 2 μs
- Simulation using coupling of modes (COM) model compared with experimental results

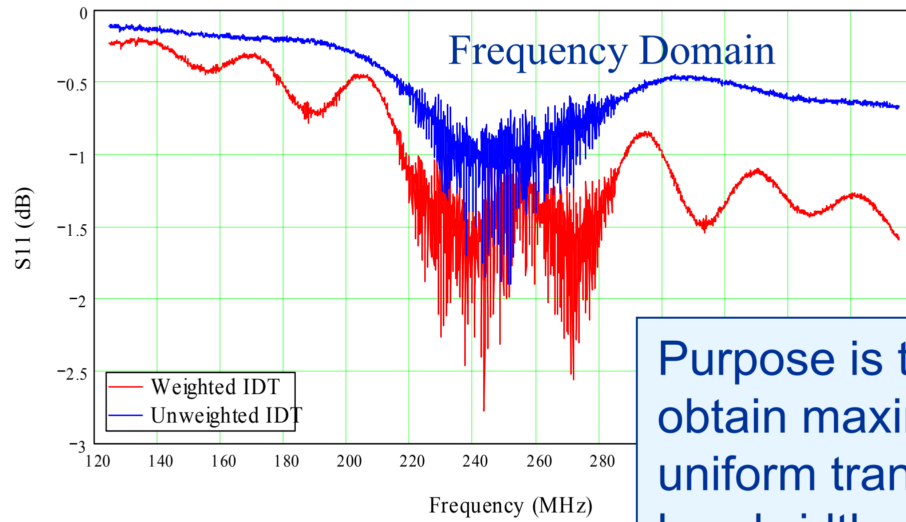




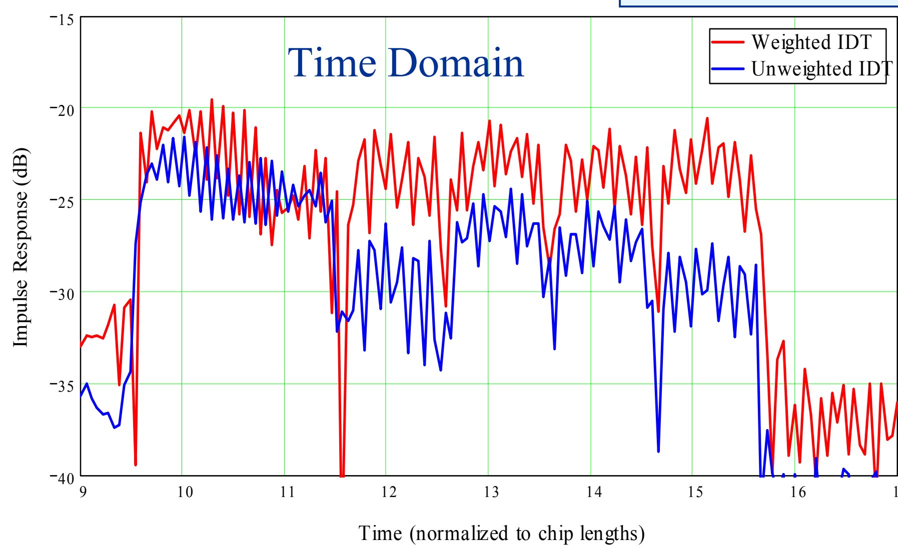
Uniform vs Weighted Input Transducer Results



Weighted transducer

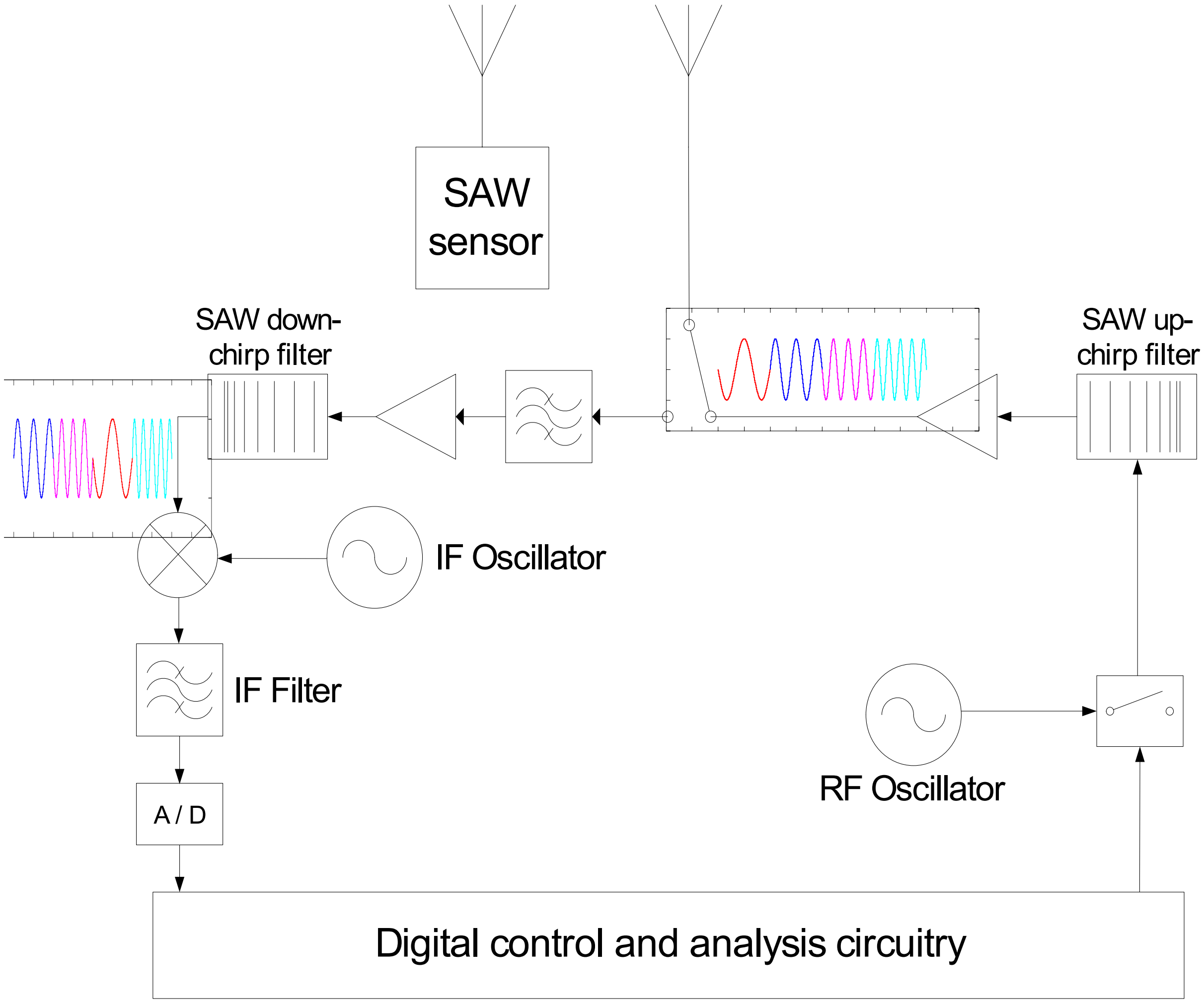


Purpose is to obtain maximum uniform transducer bandwidth

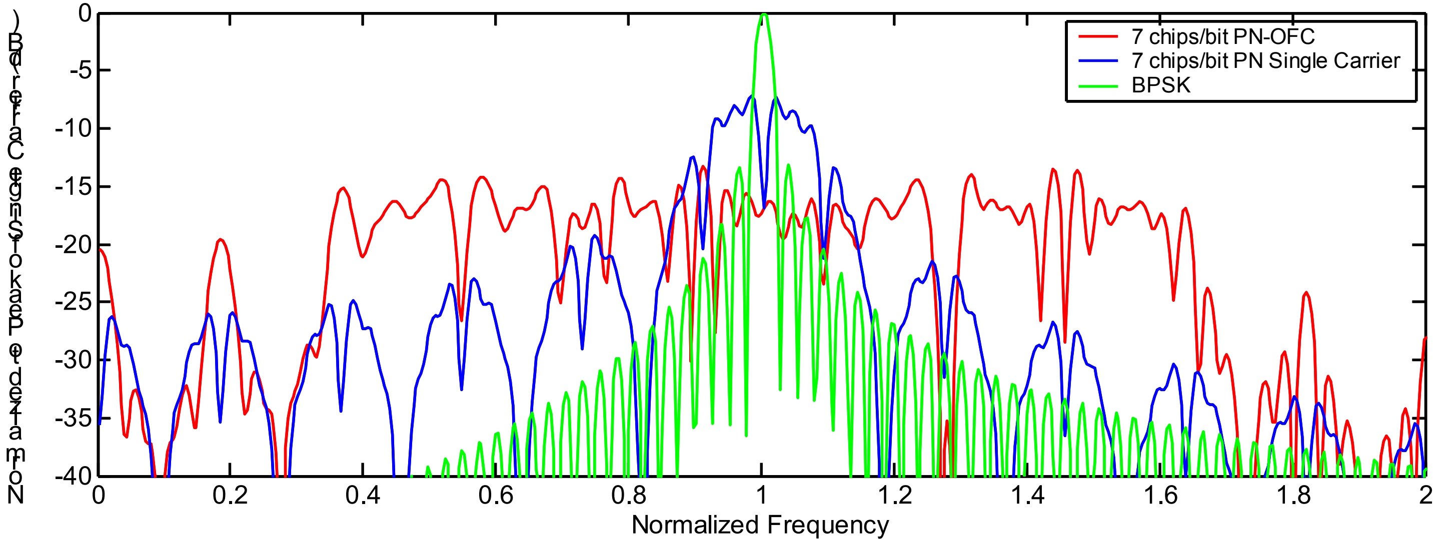


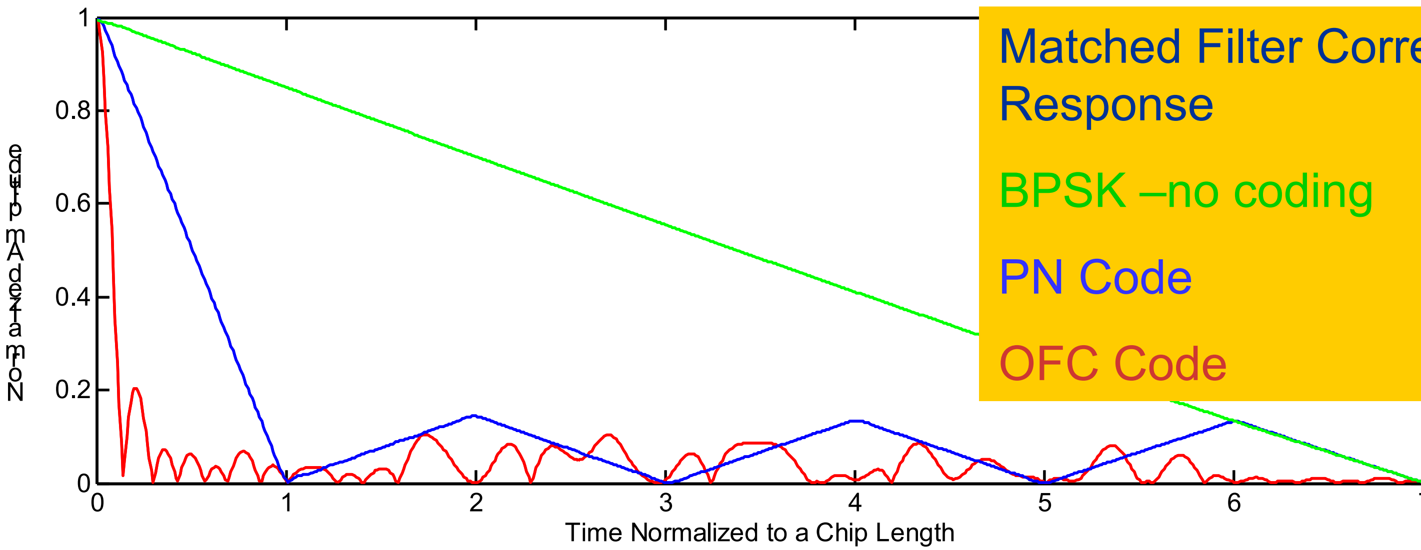
Chirp Interrogation-Transceiver Concept

Currently software simulated



Bit, PN, OFC Signal Comparison





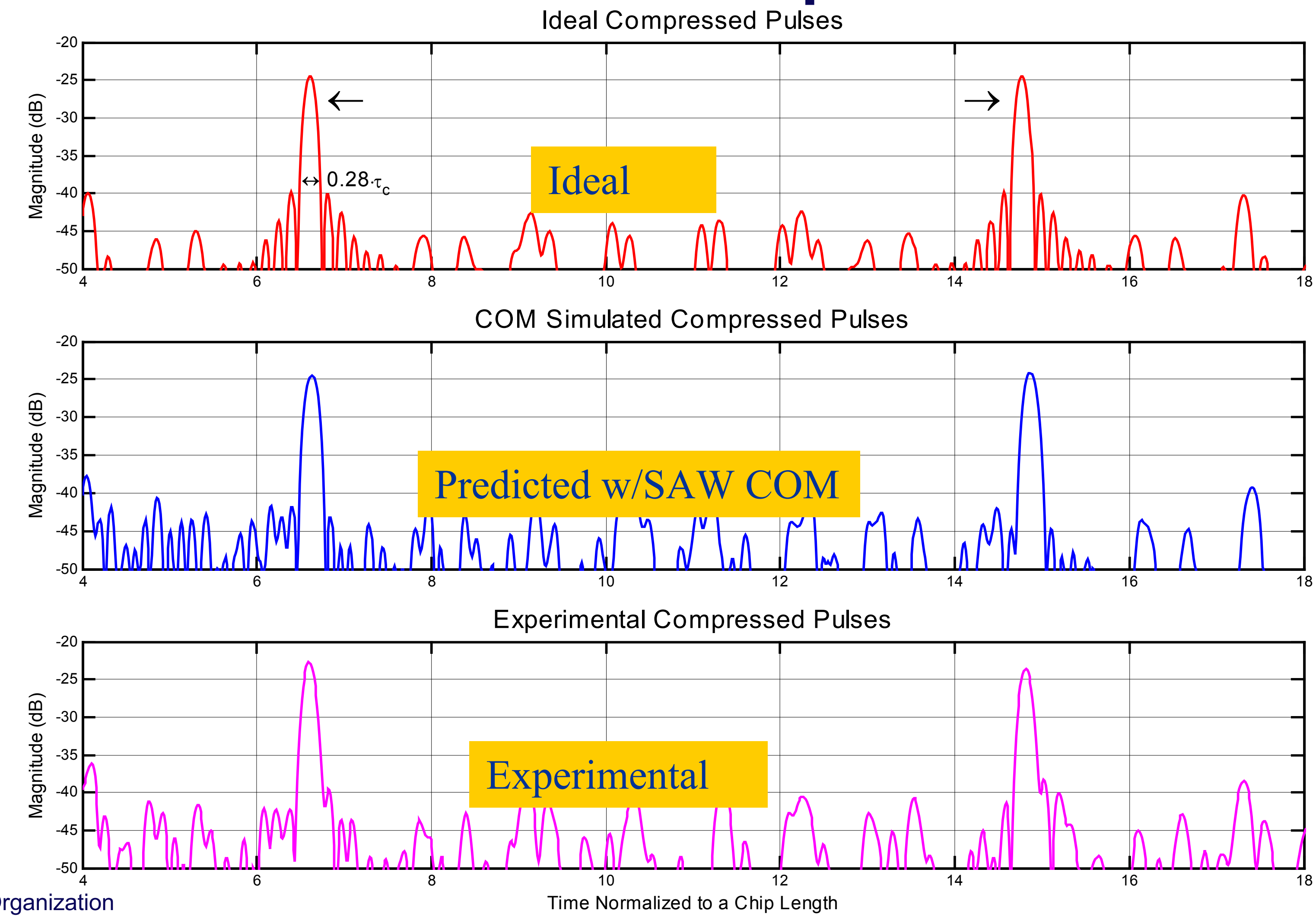
Matched Filter Correlated Response

BPSK –no coding

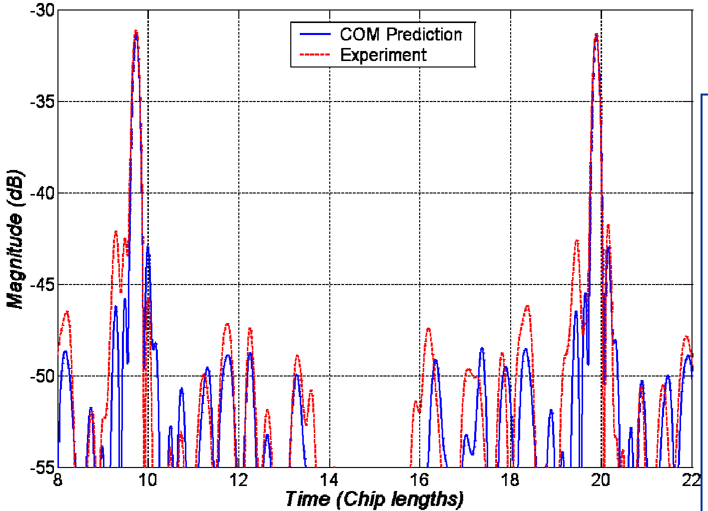
PN Code

OFC Code

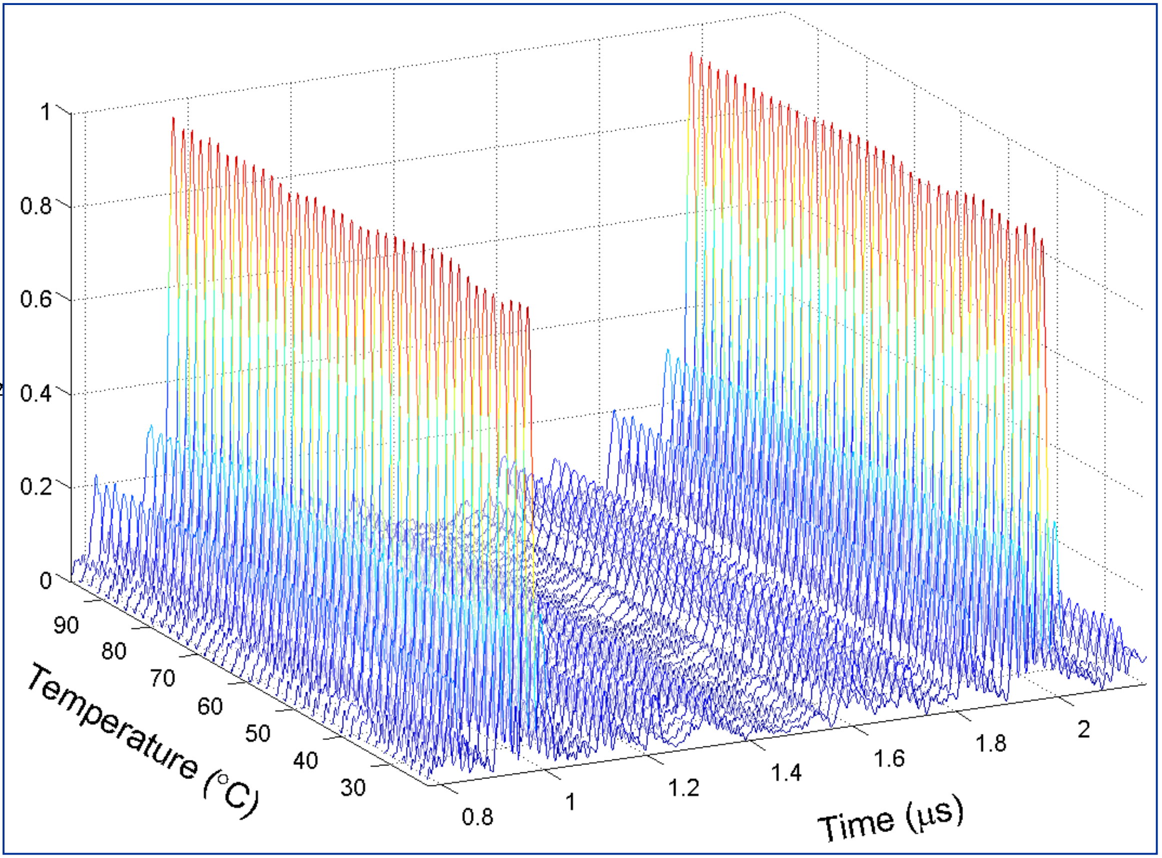
Verification of Predicted Results- Time Correlated Output



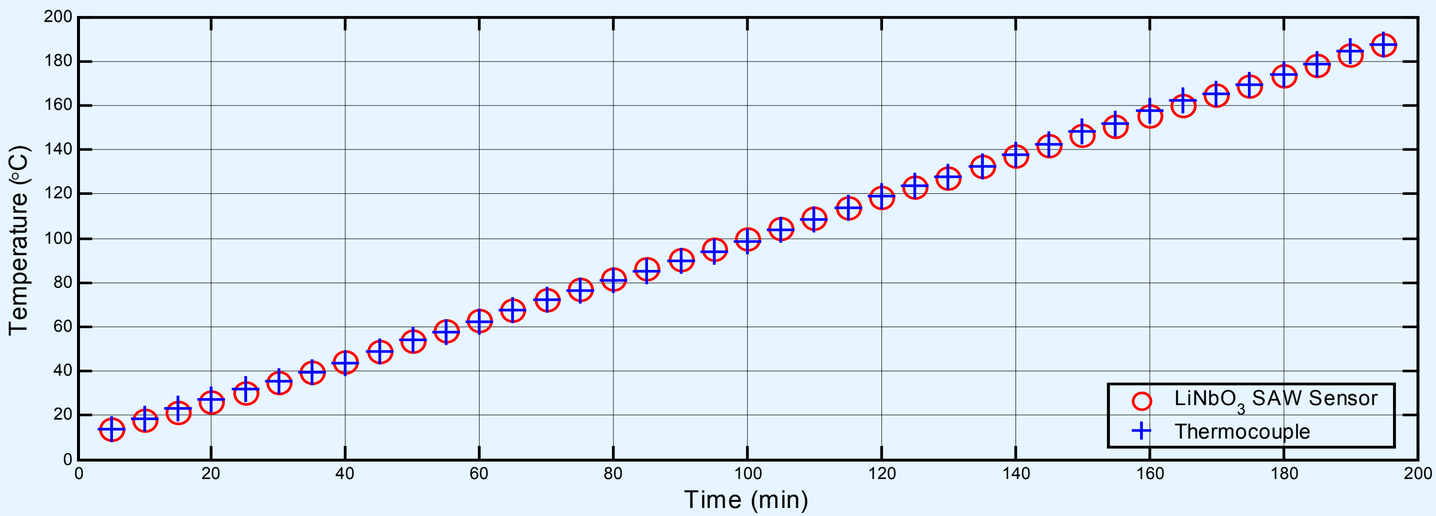
Measured Time Correlated Output Compressed Pulse Responses versus Temperature



Single temperature measurement showing the 2 compressed pulses and differential delay

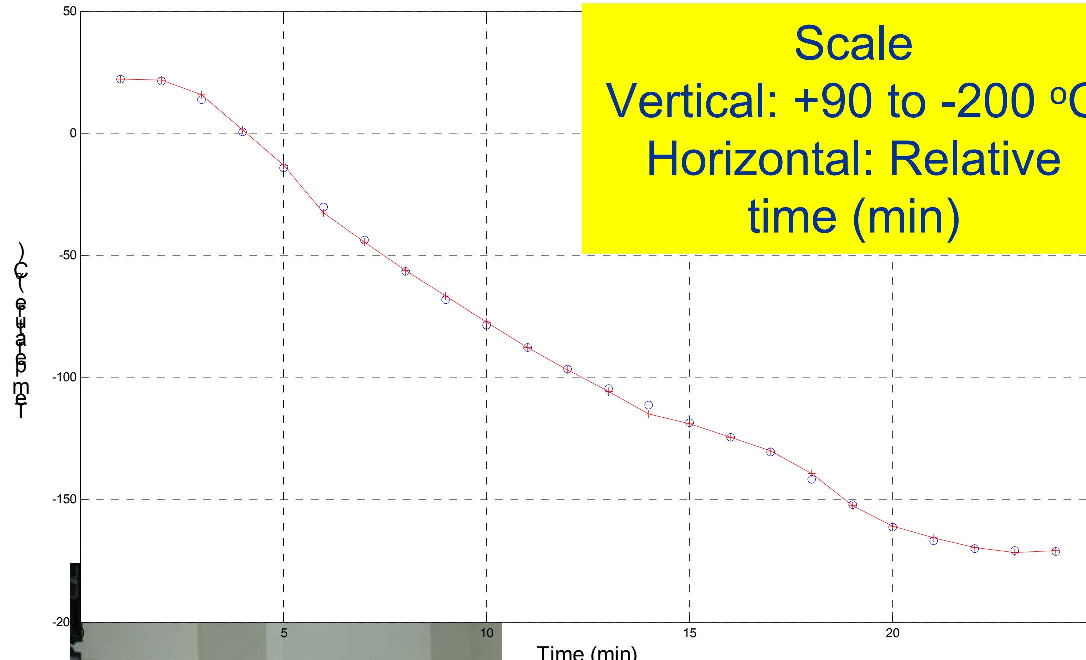


Temperature Sensor Results



- 250 MHz $LiNbO_3$ OFC SAW sensor tested using temperature controlled RF probe station
- Results applied to simulated transceiver and compared with thermocouple measurements

Cryogenic Sensor Results



Scale
Vertical: +90 to -200 °C
Horizontal: Relative time (min)

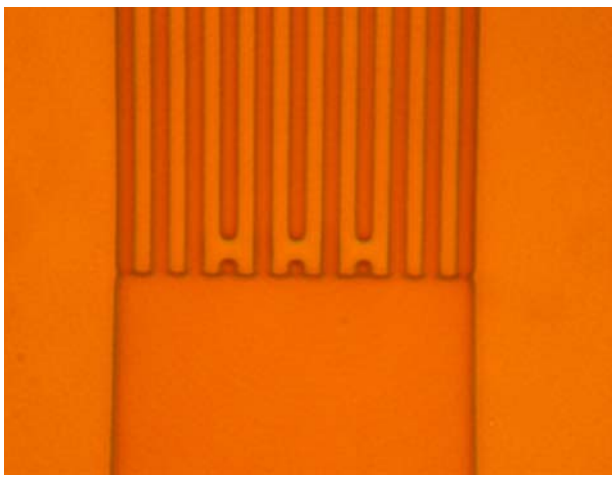
- SAW device feasibility is established
- Initial device design, fabrication and testing completed at liquid nitrogen temperatures
  - Device performed over multiple temperature cycling
  - Initial temperature coefficient of delay (TCD) obtained
  - Using TCD, temperature is predicted and compared to measurement (graph)

Measurement system with liquid nitrogen Dewar and vacuum chamber with DUT

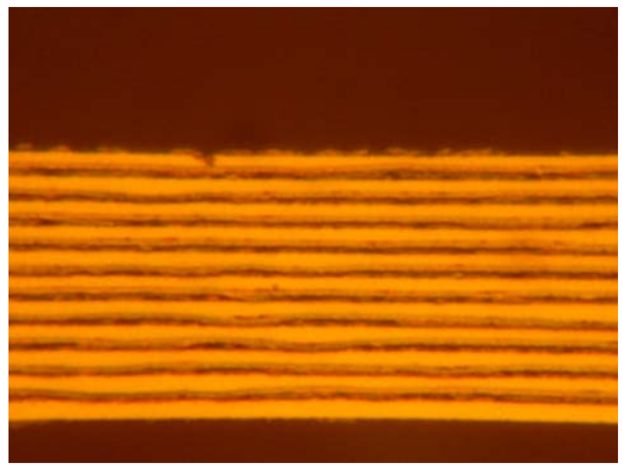
Device Fabrication Progress
push to higher frequencies to reduce antenna size and improve performance

Pattern generator should take us to .7um lines while Ebeam should yield .5 um lines

E-beam

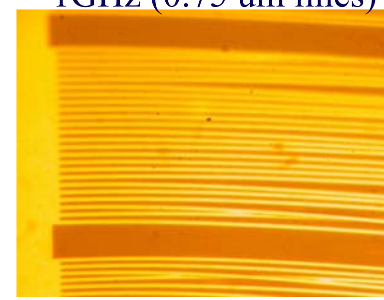


1.27 um line resolved in positive PR on mask plate using PG shows good line definition

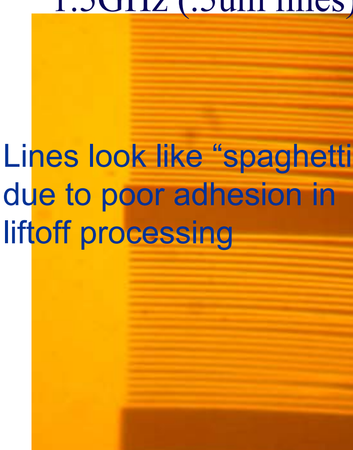


1 um lines after lift off using +ve PR (S1813) by direct on wafer write using Image Repeater, (lines are jagged, lift off needs optimization)

1GHz (0.75 um lines)



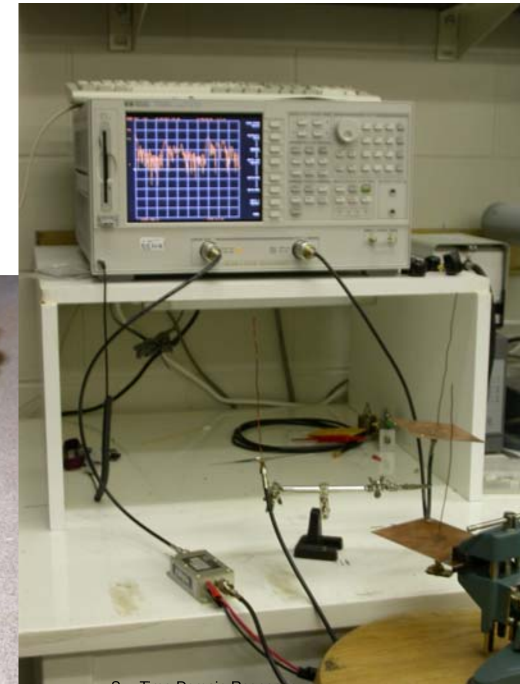
1.5GHz (.5um lines)

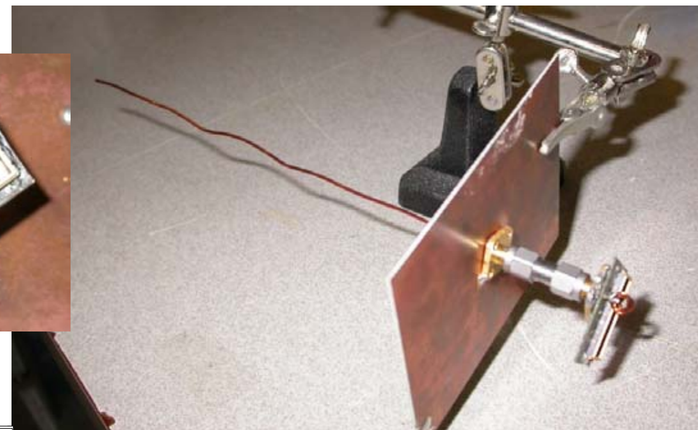


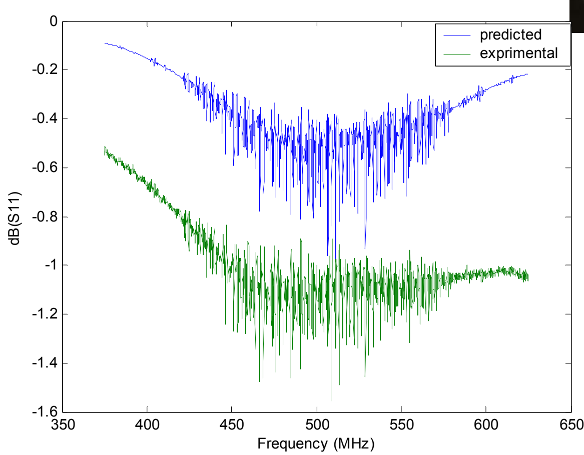
Lines look like "spaghetti" due to poor adhesion in liftoff processing

Wireless Testing of a 500 MHz Sensor

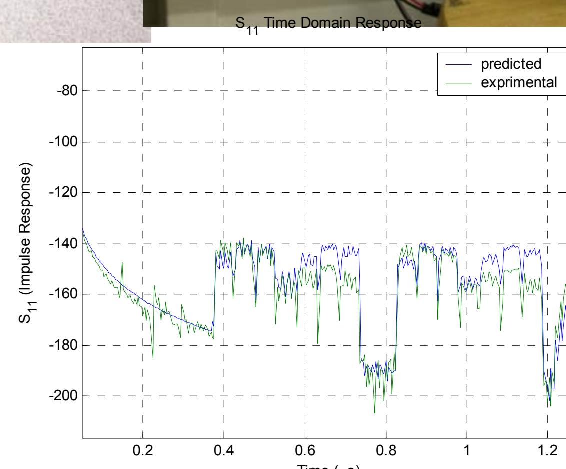
- Simple dipole antenna for wireless transmission
- Demonstrated Tx/Rx at a distance of 2 feet



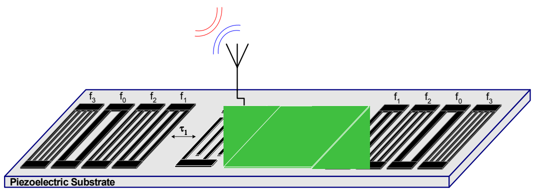




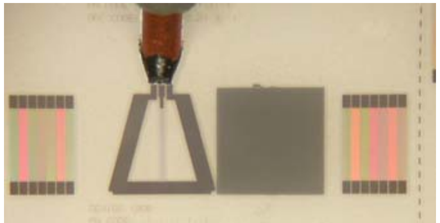
Experimental and COM Predicted 500 MHz sensors



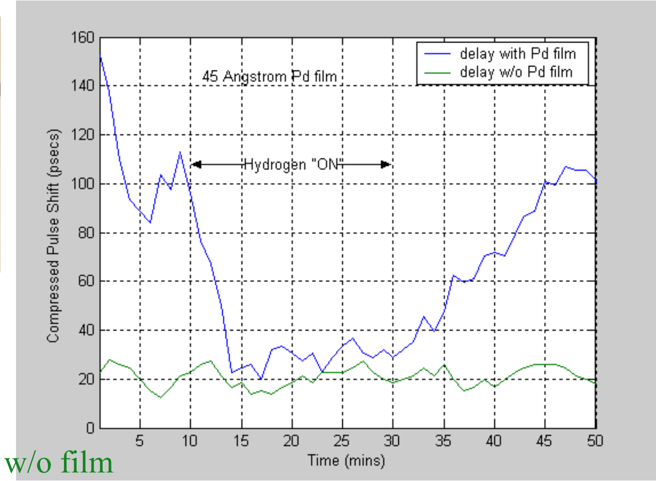
Pd Hydrogen Gas Sensor – Initial Results for 3 films



Schematic



Actual device with probe



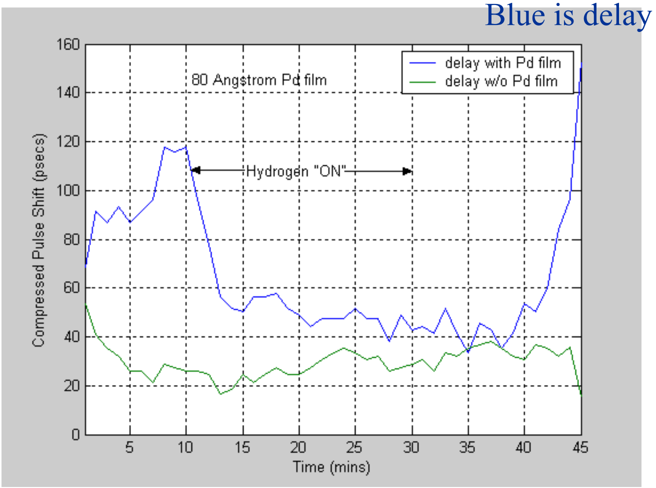
•For palladium hydrogen gas sensor, Pd film is in only in one delay path, a change in differential delay senses the gas ($\tau 1 = \tau 2$)

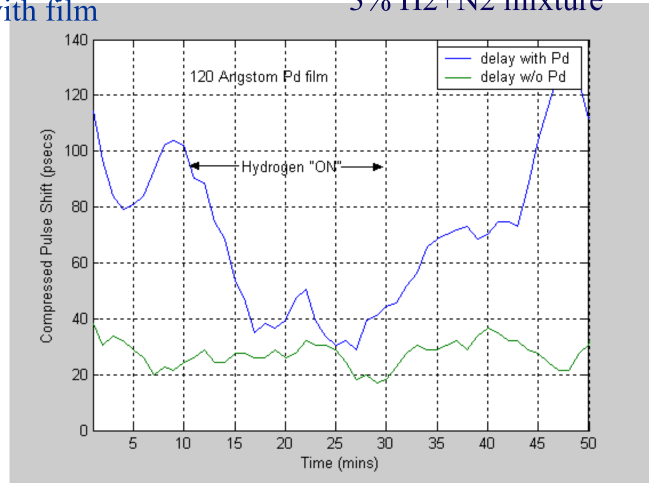
Green is delay w/o film

Blue is delay with film

3% H2+N2 mixture

Gas/probe chamber





Initial results demonstrate device sensitivity to hydrogen gas.

Future Plans

- Fabricate and build a 1 GHz SAW OFC sensor to reduce size and optimize performance
- Build or purchase a cryostat for sensor testing at liquid hydrogen temperatures and build a cryogenic data acquisition system for device testing
- Continue hydrogen gas sensor development using metal and/or oxide thin films and continue application of the FSEC films. Materials evaluation work will need to be conducted to understand the film and SAW interaction
- Analysis, design and fabrication of an interrogation/receiver system for “pinging” the OFC sensor and extracting the received data
- Design antenna and device to optimize performance
- Investigate parallel track embodiments to relax fractional bandwidth requirements of the antenna
- Goal is to have a fully operational proof-of-concept, multi-sensor SAW OFC system within approximately the next 18 months, for hydrogen liquid and gas sensing