INTEGRATED HARSH ENVIRONMENT GAS/TEMPERATURE WIRELESS MICROWAVE ACOUSTIC SENSOR SYSTEM FOR FOSSIL ENERGY APPLICATIONS

Project DE-FE0026217

DOE / NETL Program:

Support of Advanced Coal Research at United States Colleges and Universities

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OUTLINE

1. Project Background
   - Technology & Applications
   - Achievements under other projects
   - UMaine, Environetix & PERC
2. Current Project
   - Integrated Gas / Temperature Wireless Microwave Acoustic Sensor System for Fossil Energy Applications
   - Tasks, Timeline & Milestones
   - Participants
3. Summary Statement

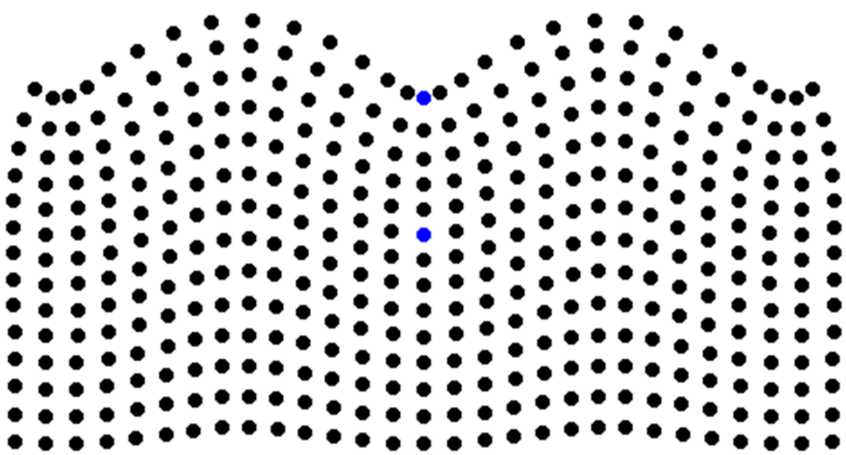
1. Project Background

Technology & Applications

Technology Fundamentals

Surface Acoustic Wave (SAWs)

- SAW $\rightarrow$ guided wave $\rightarrow$ prop. @ the surface
  - Fields decay exponentially inside the material
  - Energy: ~ 90% in 1 λ_{SAW}
  - Ex: Rayleigh mode (elliptical particle trajectory)



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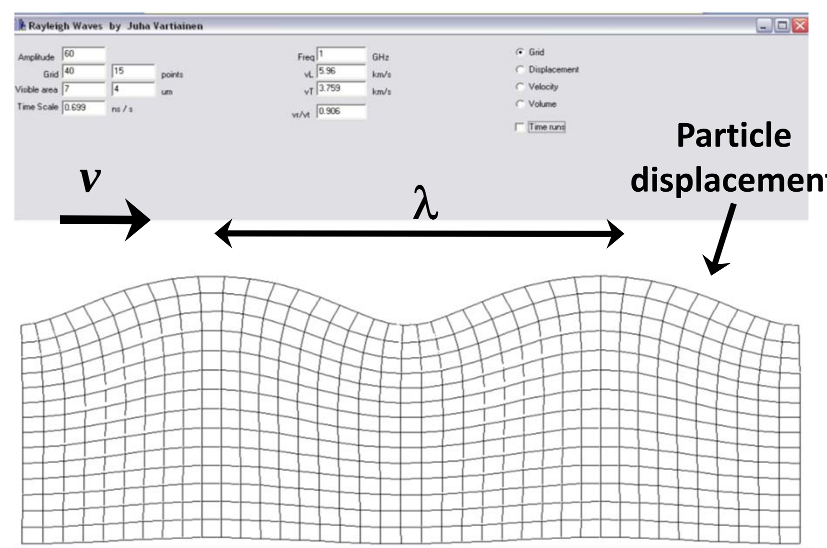
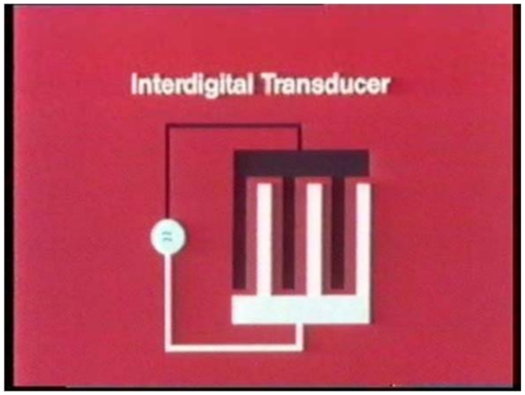


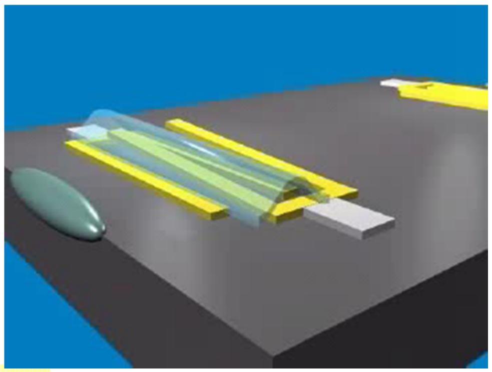


SENSORS

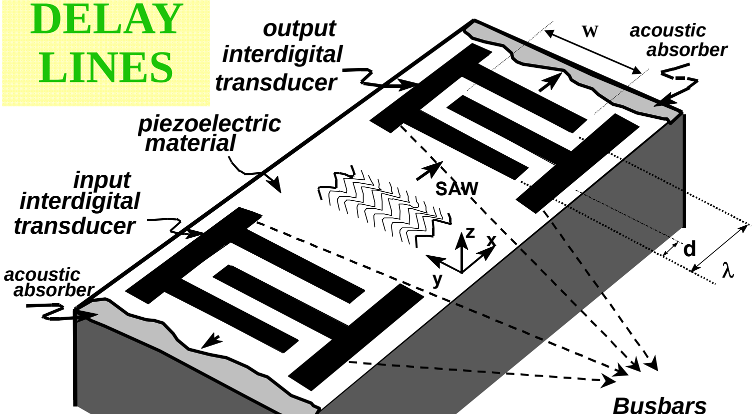
- Phase vel.: 1 to 6 Km/s ⇒ 10^5 x < than EM waves

COMPACT DEVICES

- Piezoelectric material: electrical signal ⇒ acoustic wave

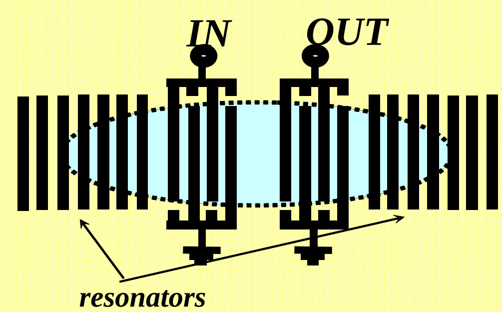


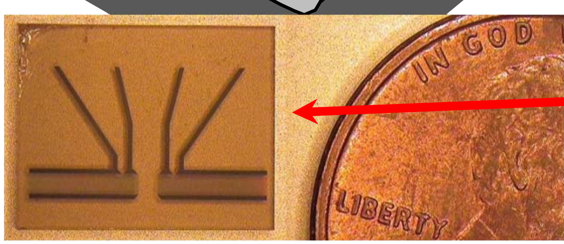
DELAY LINES



Sensing: device response (delay, freq.) ⇒ depend on crystal orientation, surface perturbation (thin film, temperature, pressure, strain, corrosion, gases, vibration)

TWO PORT RESONATOR



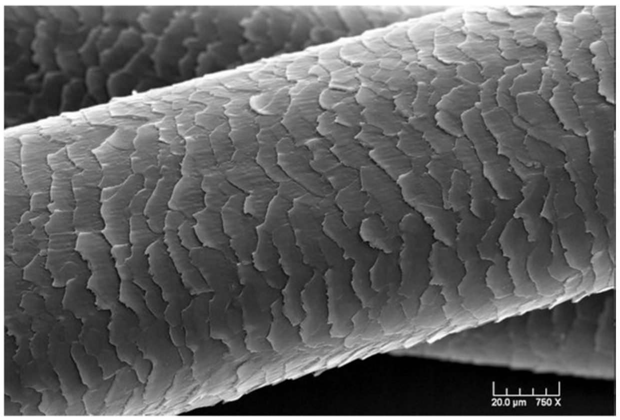


Delay line and two-port resonator fab @ UMaine

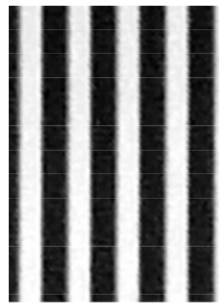
Critical Dimension $\rightarrow$ Fab. Challenge

- Ex: v quartz ST-X = 3,158 Km/s $\Rightarrow \lambda$saw = 3,158 μm (@ 1 GHz)

  $\Rightarrow \lambda$saw /4 fingerwidth



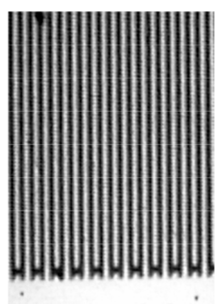
human hair: 60 to 80 μm thick

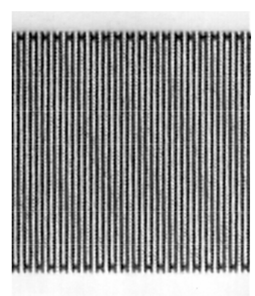


100 MHz:
fingerwidth 8 μm

250 MHz:
fingerwidth 3 μm

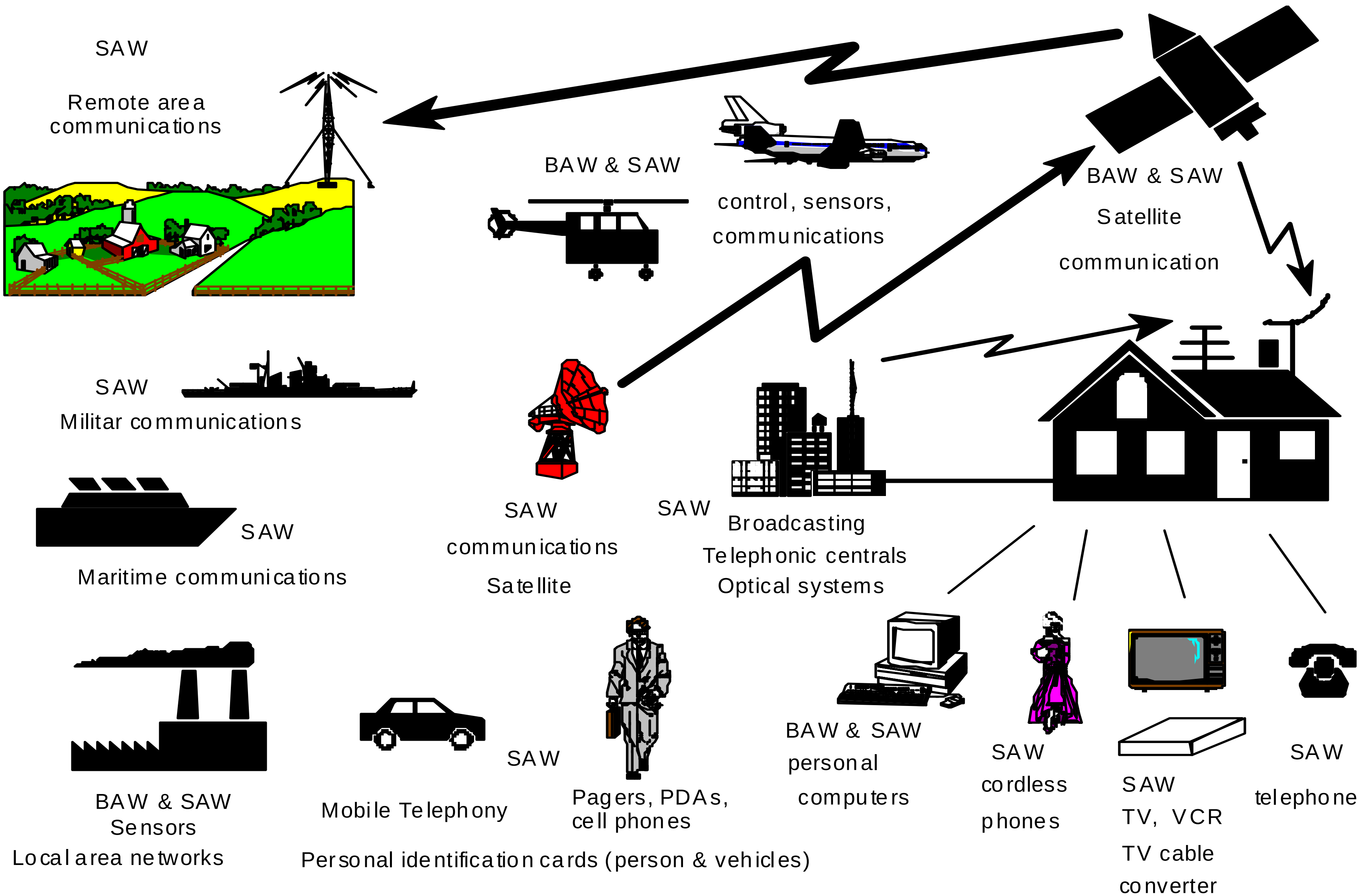
900 MHz
fingerwidth 1 μm
(GSM band)





1800 MHz
fingerwidth 0.5 μm
(PCS, PCN band)

SAW Applications



Harsh Environment (HE) Sensors

- Harsh Environment Sensors
  (temperature, pressure, strain, corrosion, vibration)

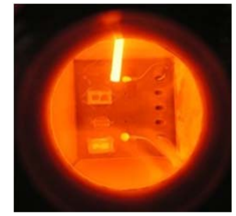
Required → Monitoring (diagnostics & prognostics) & Control

  - Power Plants
  - Turbine Engine
  - Aerospace Industry
  - Industrial Processes
  - Gas/Oil extraction

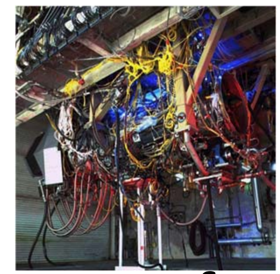
- In particular for Power Plant Environments:
  - Fuel burning
  - Gases composition and properties
  - Reaction Processes
  - Turbine Engines
  - Equipment Integrity and Safety

- Better Temp. monitoring & control translates into:
  - Longer term operation before maintenance
  - Better efficiency
  - Reduced pollution
  - Lower operational costs

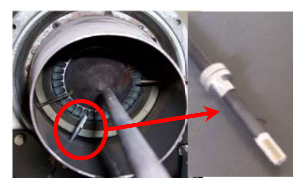
High Temp. (HT) / Harsh Environment



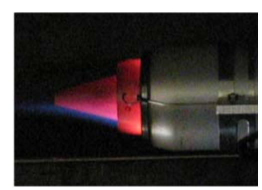
- **Surface Acoustic Wave** technology $\rightarrow$
  Very attractive for HT / HE applications :
  - **Sensitive** & **stable** crystal based platform
  - Capable of **Wireless** Operation in harsh environment
  - **Battery-free** in Harsh Environment
  - **Robust** device: take extreme shocks in temperature (hundreds of °C in a few seconds)



  - **Simple** device: thin film electr. & protective layers on top of a crystal
  - **Easy installation** (the closest to the concept of “leak & stick”)



  - **Reduced** $\downarrow$ (or no) **maintenance**
  - **Reduced** $\downarrow$ (or no) **safety concern**



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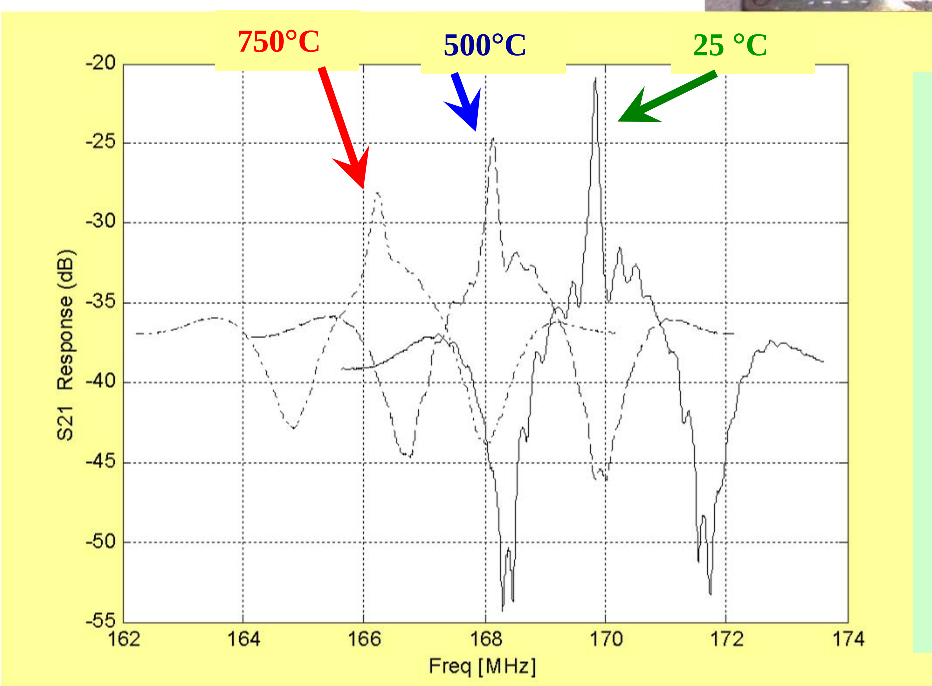
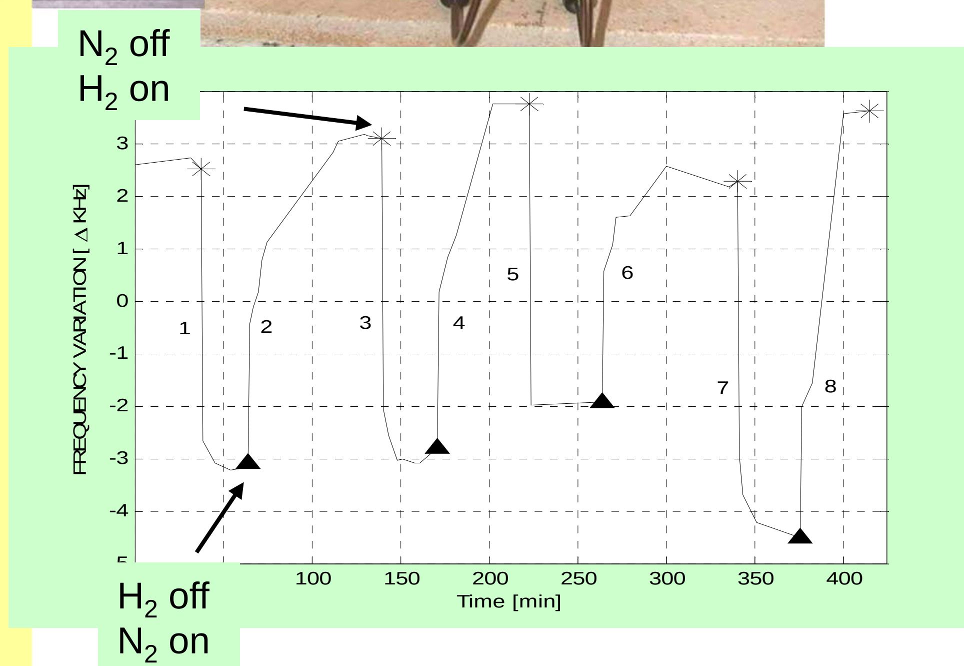
1. NASA: Gas Sensor

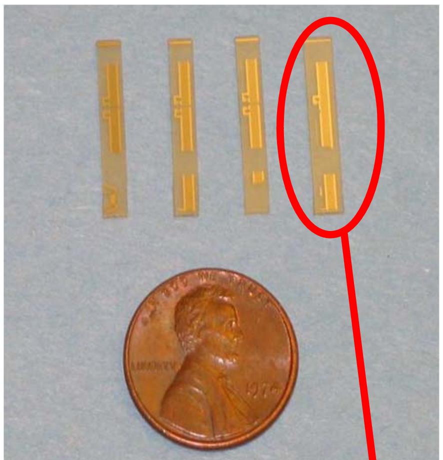
- **High Temperature μ~ Sensors for NASA (2002-05)**
  - LGS H_2 and hydrocarbon HT gas sensors





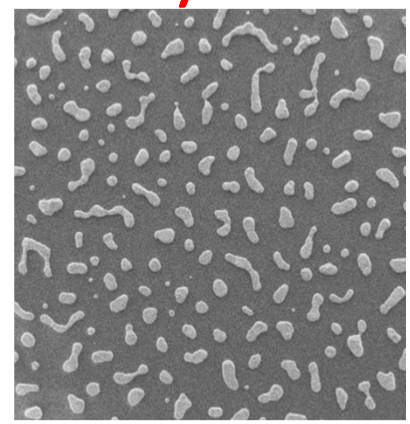
2a. Air Force: Thin Film

- ➢ High Temperature μ~ Sensors turbine engines applic.
- ➢ Major challenges overcome (state-of-the-art):
- ✓ Stable thin film electrode > 650°C (operation up to 950°C)

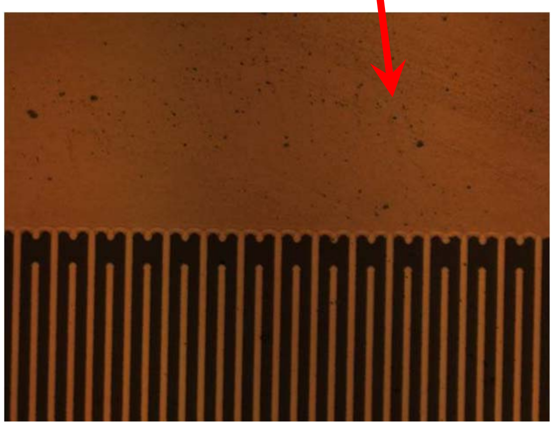


Rapid recrystallization & dewetting of Pt electrodes at ~ 700°C in air leading to loss of continuity

Critical problem that limited high T thin film technology

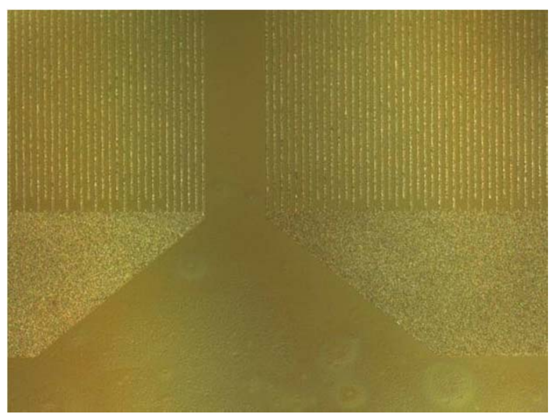


10 μm SEM Image



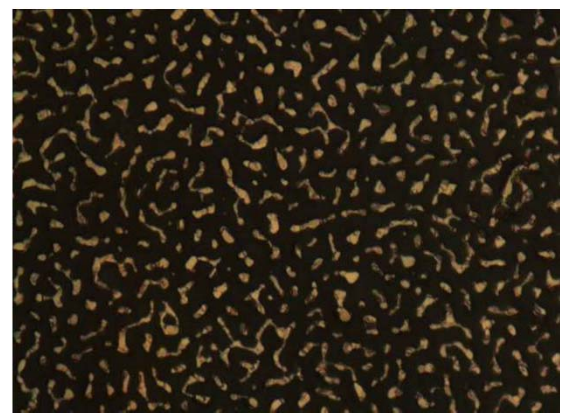
As fabricated

⇒



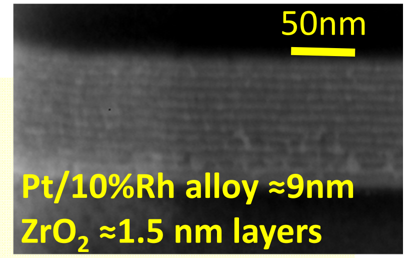
After heating to 1000 °C

⇒

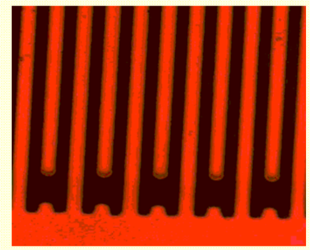


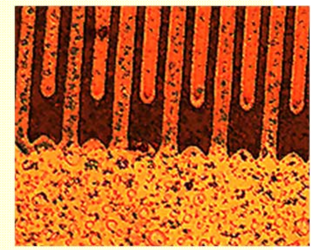
100x magnification

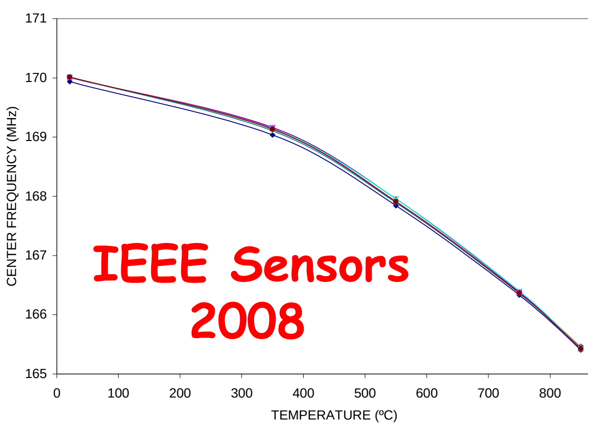
2b. Air Force Devices

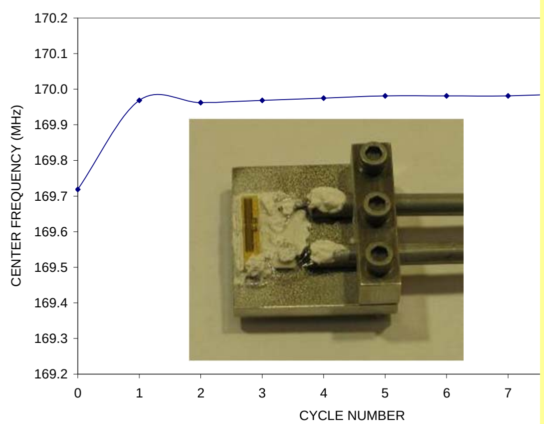


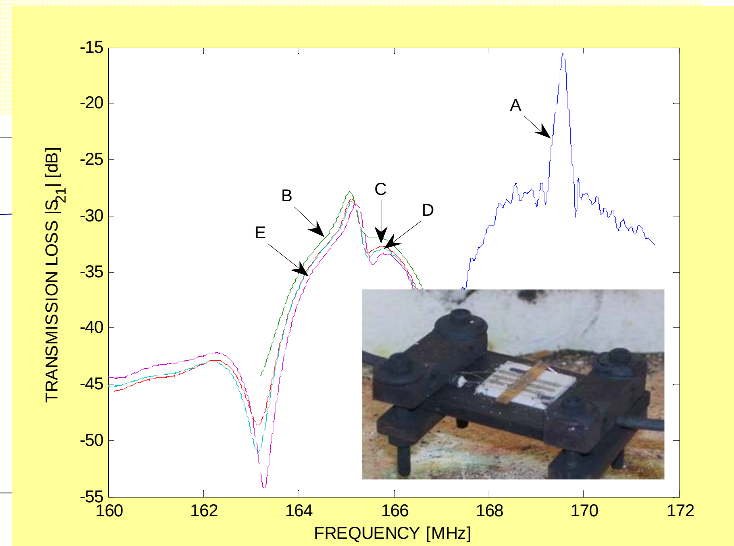
- Electrode and Protective Films Developed
  - $Pt/Rh/ZrO_2$ patented electrode technology
  - Ultra thin (up to 100nm) oxynitride passivating coatings
- Long Term HT Sensor Performance
  - **Tested @ 800°C for 5½ months**
- Thermal Cycling
  - **Multiple cycles (>8) reported btwn RT and 850 °C**
- Temperature Sensor Sensitivity
  - **9.1 KHz/°C around 800°C**











2c. Air Force: Shock

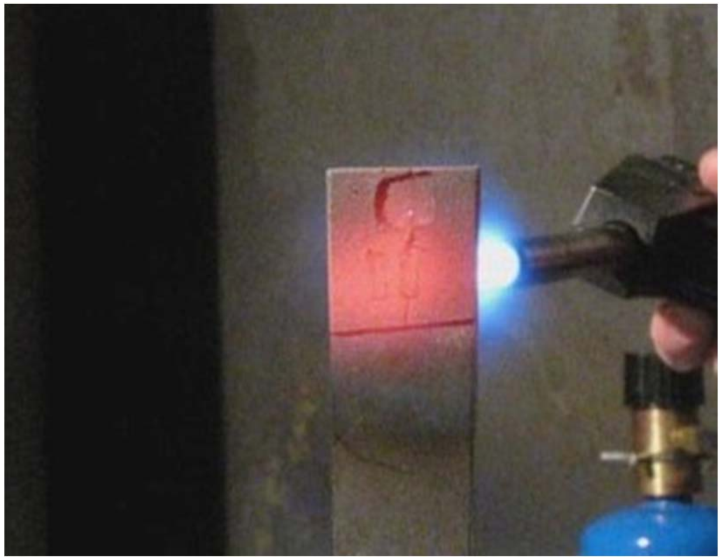
TEMPERATURE SHOCK TEST 1:

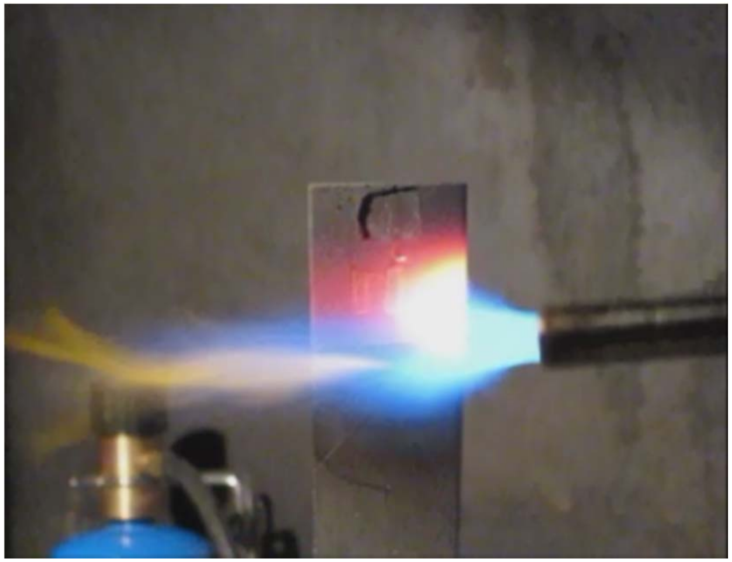
FURNACE TEMPERATURE SHOCK TEST

- Crystal 700°C pre-heated furnace & allowed to stabilize (≈8 min)
- Removed & cooled to RT (21°C) with an air gun
- No sign of device damage: tested repeated 3 times @ UMaine and HPI

TEMPERATURE SHOCK TEST 2

PROPANE TORCH & NITROGEN QUENCH



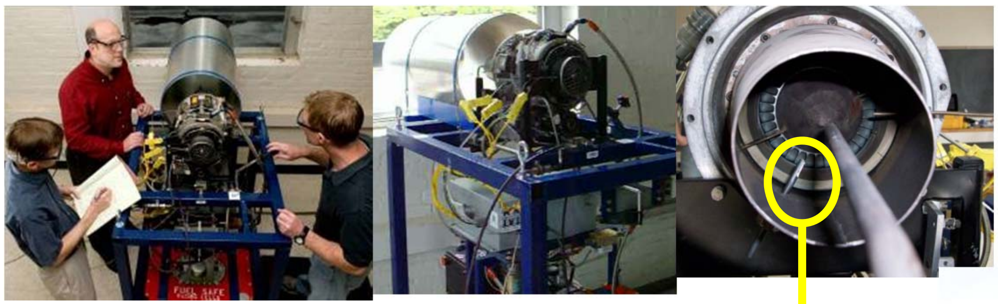


2d. Air Force: Packaging

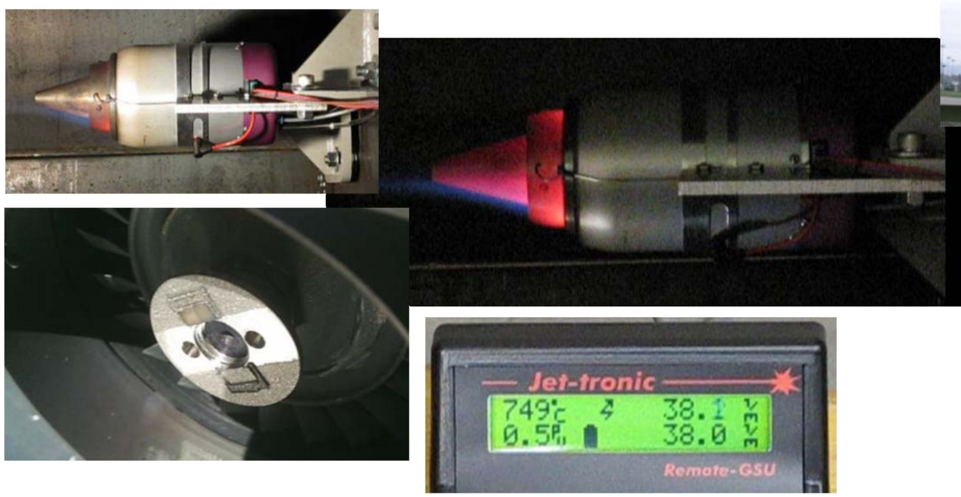
Attachment to Parts of Jet Engine: Static & Rotating

- Rotation up to 90,000 rpm & tangential loads up to 53,000 g's

Armfield CM-4 turbine engine
at UMaine Mechanical Engineering



SAW sensors mounted on probes
inserted into engine exhaust



TMC85-1 gas turbine engine
at Air National Guard, Bangor, Maine

JetCat engine test facility at UMaine

2e. Adhesion Tests on Bladed Turbine Rotor by VEXTEC (external)

Round 1: Two minute g level progression test

g Levels = 14k, 26k, 40k, and 58k

Performed at 800°F (425°C) and 1200°F (650°C)

Round 2: Operational dwell test

Durations = 10, 30, and 60 minutes

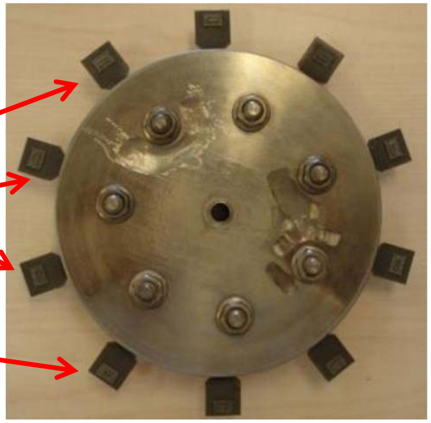
Operational Conditions → 1200°F at 24,300 rpm

Round 3: Snap action test

Temperature snap (10 snaps, inspect, then 16 snaps)

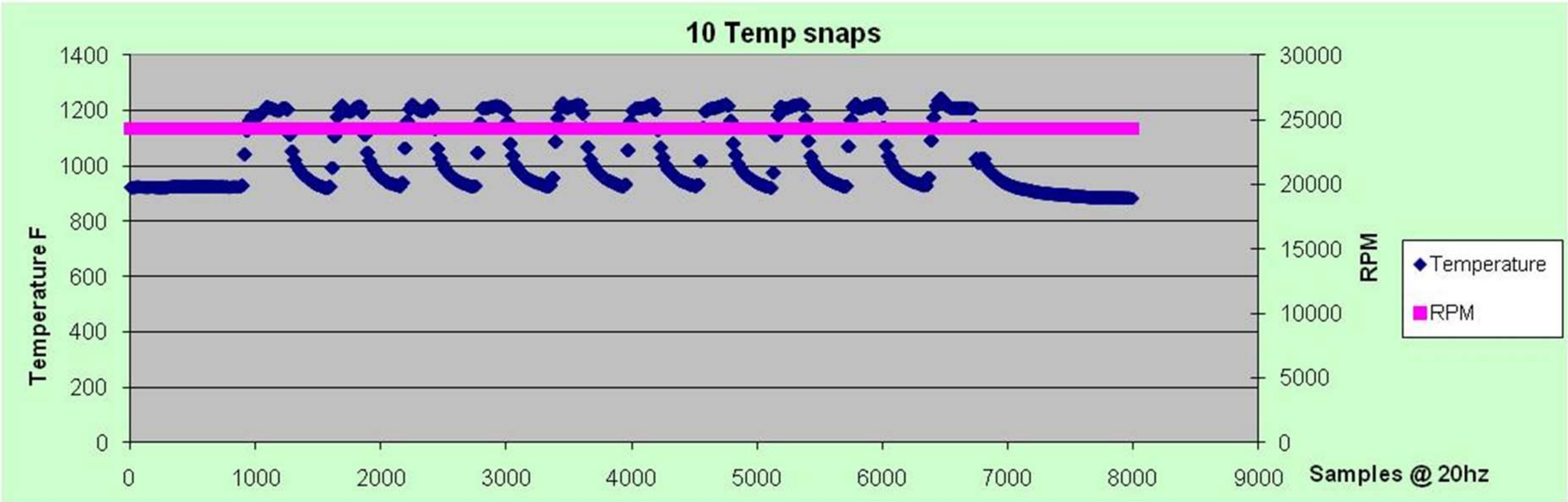
No Failures

SAW sensors adhered to Inconel blade



VEXTEC

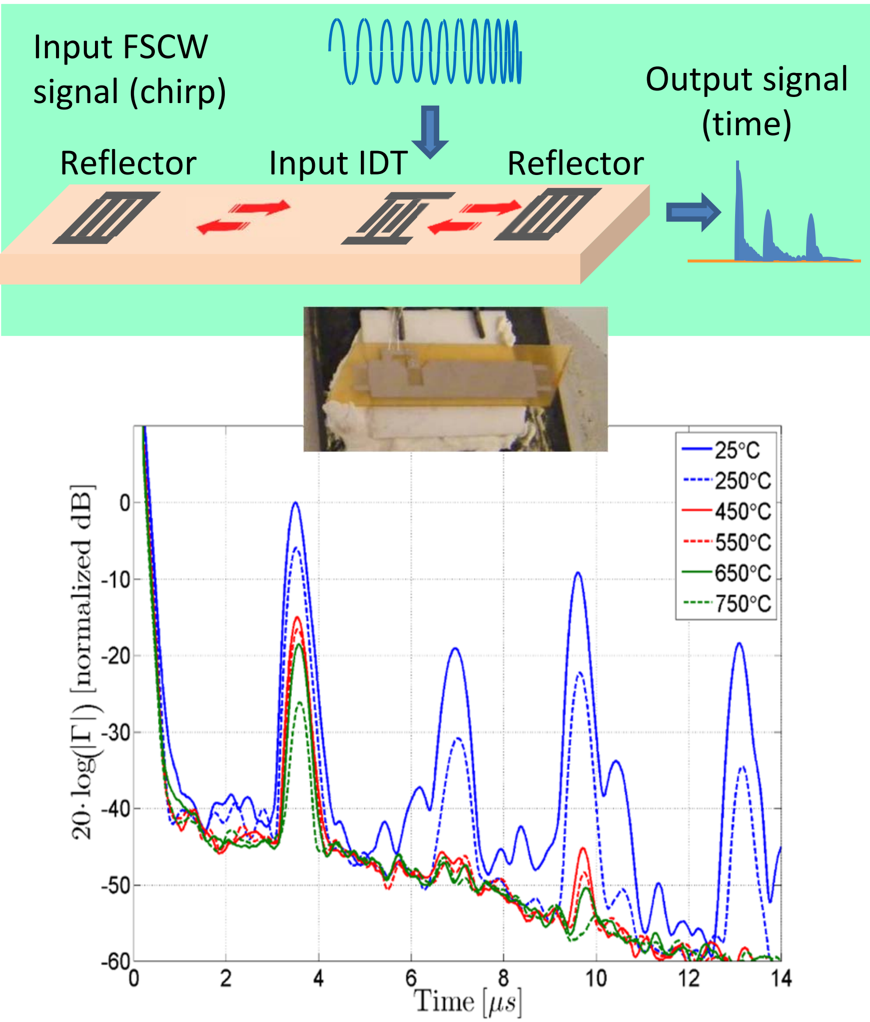
Integrated 4” radius bladed turbine rotor



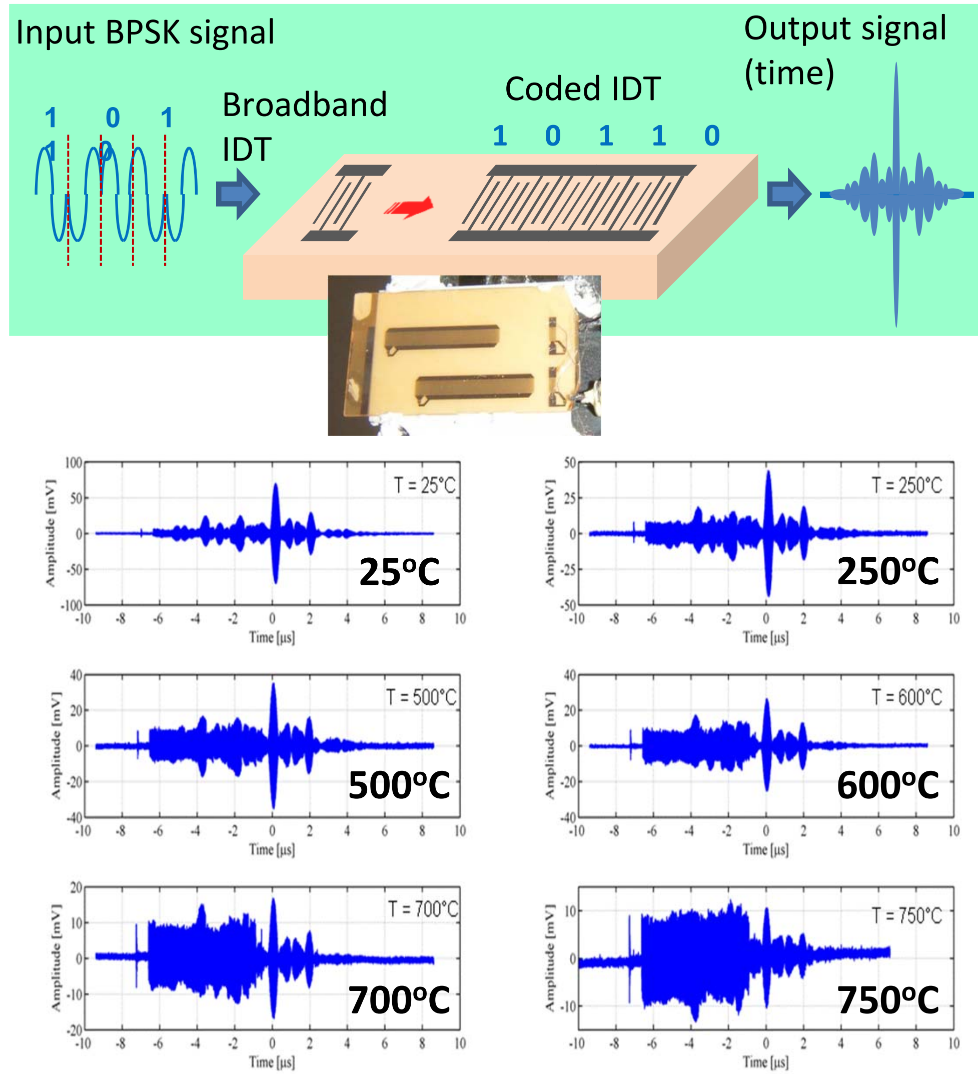
2f. Wireless Systems for Harsh Environment SAW Sensors

Multiple Sensor Interrogation or Multi-Sensing

1) Time Domain Frequency Scanning Continuous Wave (FSCW)



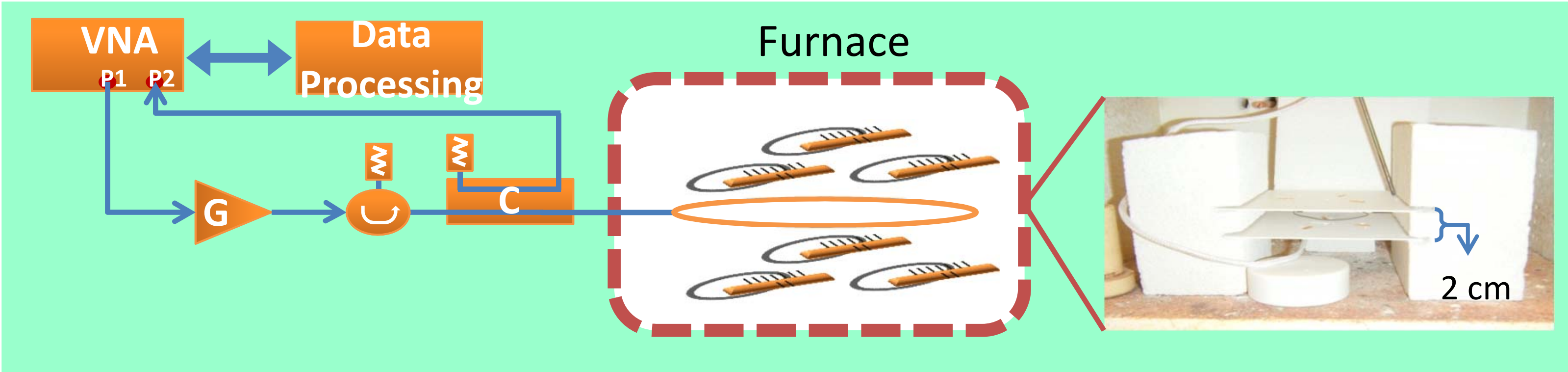
2) Code Division Multiple Access (CDMA)

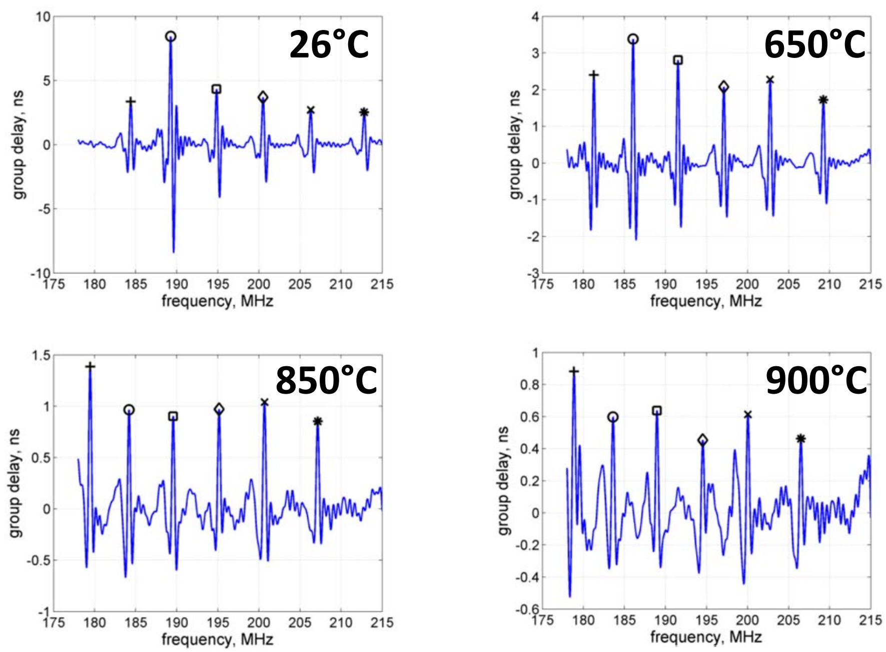


2f. Wireless Systems for Harsh Environment SAW Sensors

Multiple Sensor Interrogation or Multi-Sensing

3) Frequency Domain Multiplex (FDM)

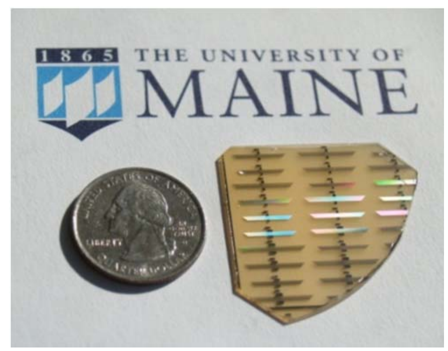




Allows sensing at different locations using a single interrogating antenna

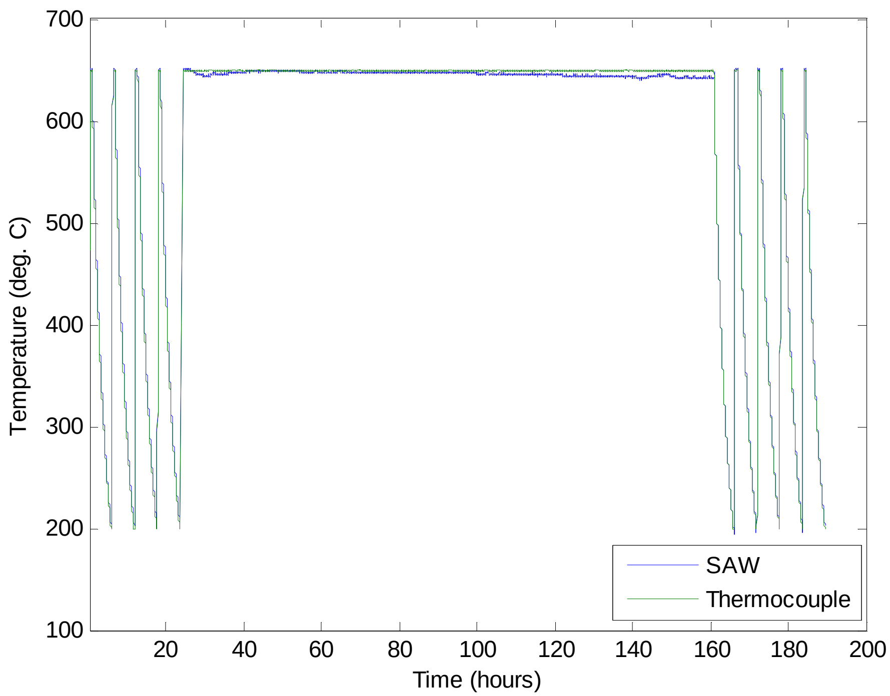
Multiple sensors with integrated antennas

Interrogation in frequency, time, or code domains

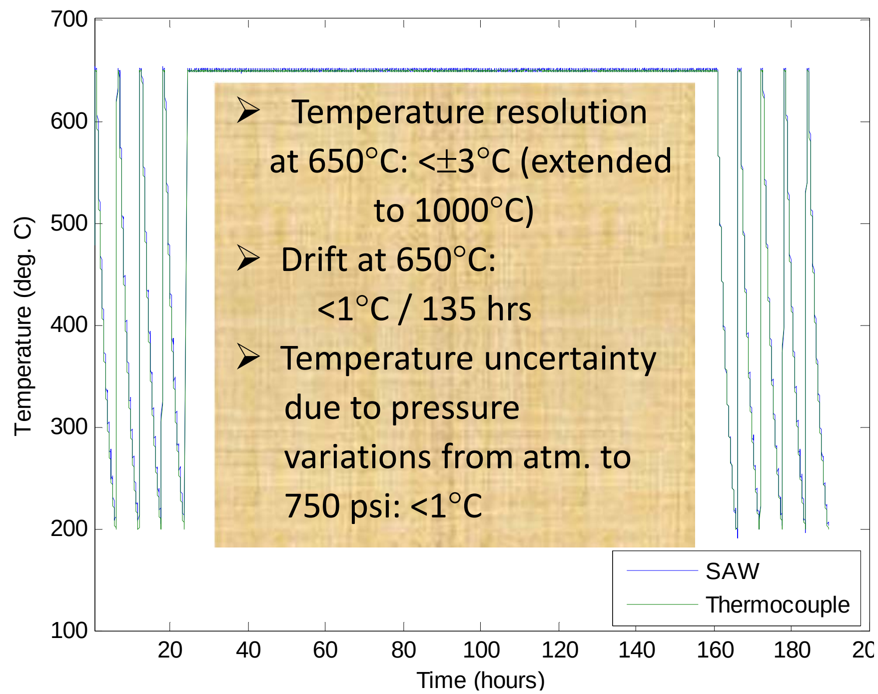


2g. Reliability, Resolution, & Accuracy of T Sensor

Temperature measured by thermocouple and Wired sensor



Temperature measured by thermocouple and Wireless sensor



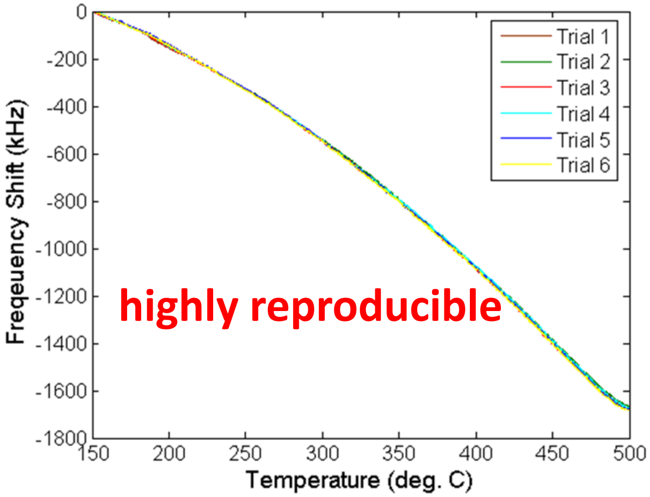
- Temperature resolution at 650°C: <±3°C (extended to 1000°C)
- Drift at 650°C: <1°C / 135 hrs
- Temperature uncertainty due to pressure variations from atm. to 750 psi: <1°C

No sign of degradation or aging for Wired or Wireless Sensors

- **Wireless sensor measures true metal temperature (rotor, blade, casing, etc.)**
- **Thermocouple measures temperature in the heat path of surrounding environment**

2h. UMaine/Environetix Extensive Tests

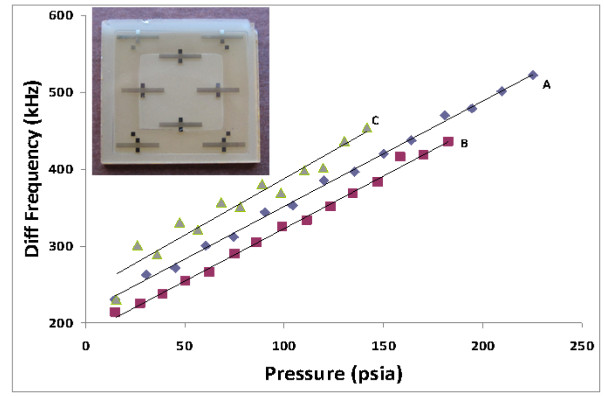
LGS SAW temperature sensor cycling over a period of 2 weeks



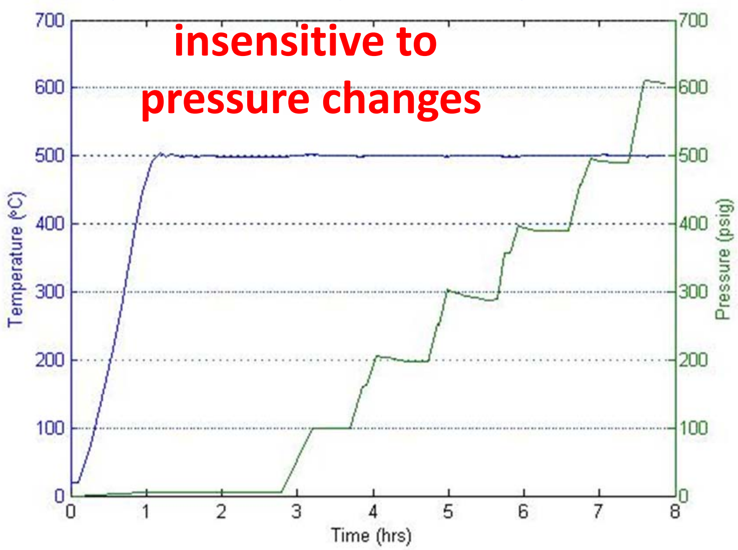
highly reproducible

Pressure Sensor: RT to 515°C / 225 psia

(A) 17°C - 26°C
(B) 234°C - 258°C
(C) 488°C - 516°C



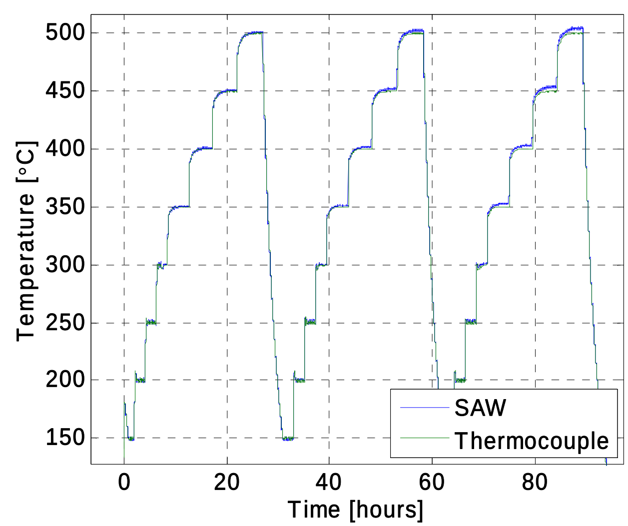
Temperature & pressure profile



insensitive to pressure changes

SAW & thermocouple temperature measured during temperature ramp cycles

Accuracy and drift at least as good as thermocouple



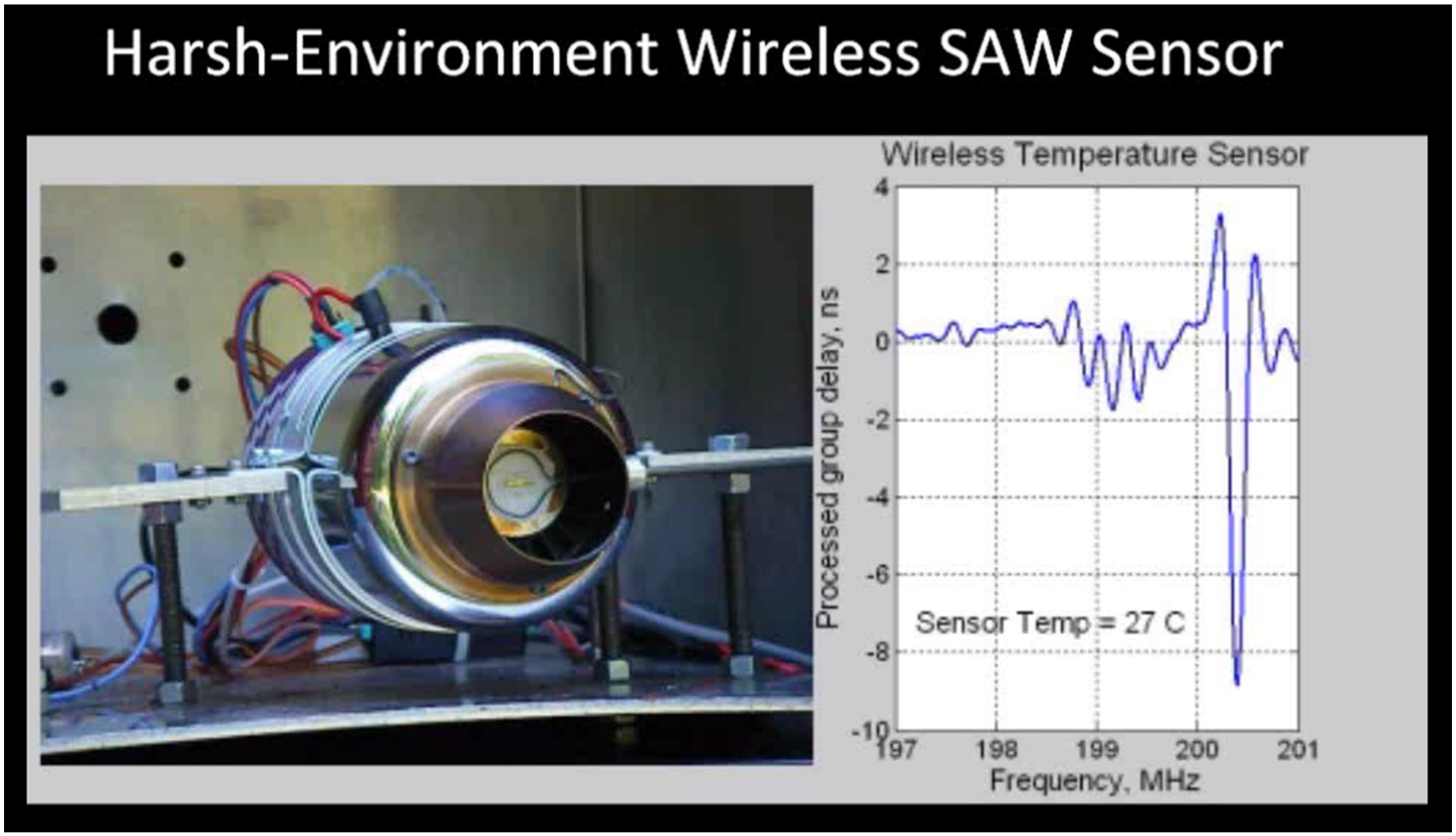
HIGH T / HIGH P FURNACE

Up to 1500°C / 750 psi

20

2i. *In Situ* Wireless Temperature Sensor on Rotating Parts in JetCat Engine

First demonstration of a wireless SAW sensor interrogation on the integrally bladed rotor (IBR) of an operating turbine engine

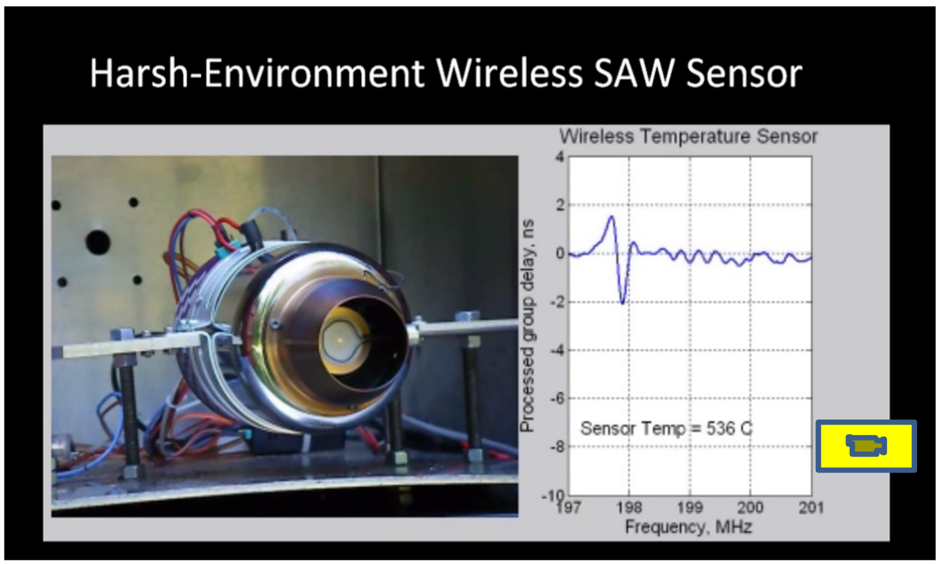


8. UMaine/Environetix JetCat & Blowtorch

Static & Rotating Applications

JETCAT P-70 TURBINE ENGINE TEST

Demonstration of Wireless SAW Temperature Sensor Interrogation on an Integrally Bladed Rotor (IBR)



BLOWTORCH DEMONSTRATIONS

Real time temperature measurement employing a Wireless SAW Sensor under exposure to a blowtorch

3. Penobscot Energy Recovery Company (PERC)

- Power plant: burns municipal **SOLID WASTE**
- Boiler conditions:

Temps ↑ 900°C (1650°F)

Highly erosive/corrosive exhaust gases

⇐ **¾" Schedule 40 Hastelloy thermocouple tube after ~6 mo**

- **GOAL:** **Demonstrate an array of wireless harsh environment temperature sensors in operational power plant**
- Steps:
  - Material tests
  - Array ⇒ sensors & antennas design, implementation, installation
  - Test in the power plant

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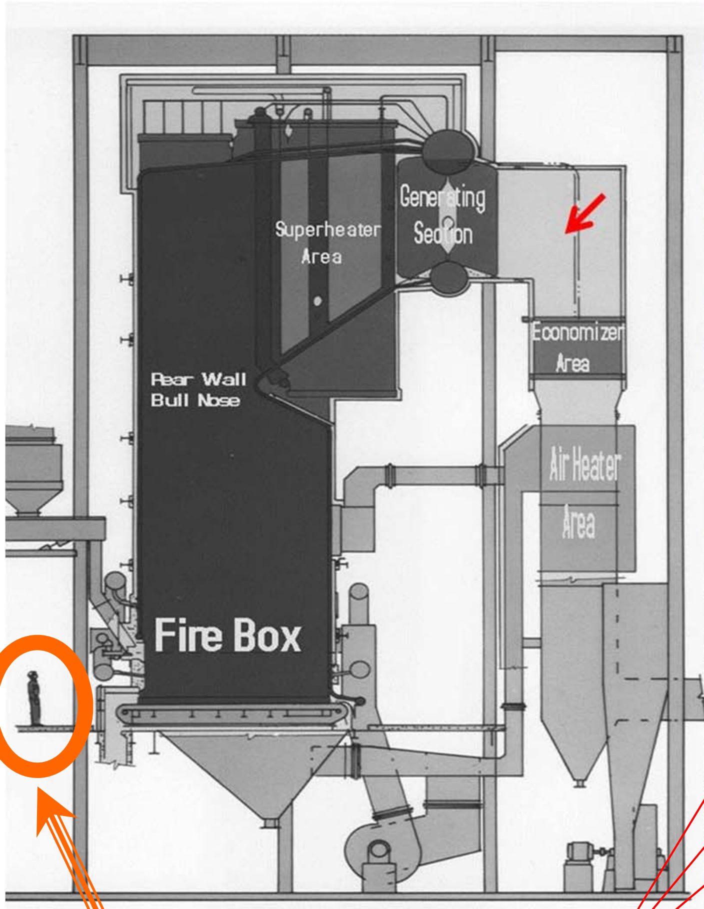
3. Penobscot Energy Recovery Company (PERC)

Array ⇒ Sensors & Antennas Design, Implementation, Installation



- Economizer area: easy access → Power plant in operation
- **6 tuned helical dipole antennas + SAW sensors + external sealing package**

Relative dimension

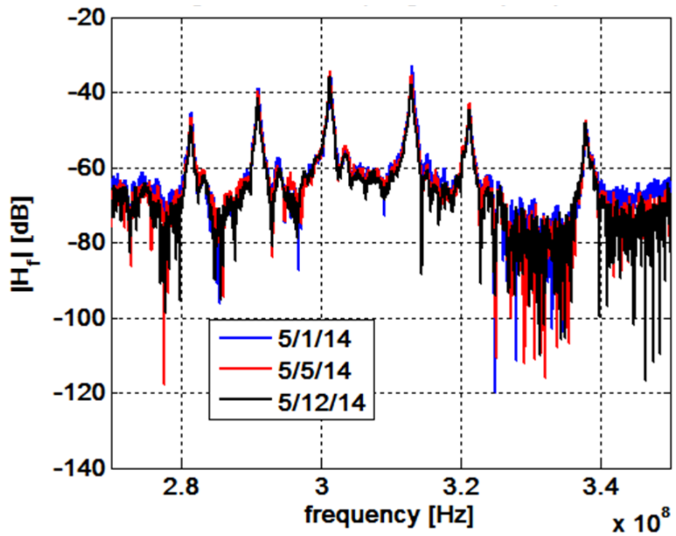
6 dipoles + SAW sensors

monopole interrog. ant.

3. Penobscot Energy Recovery Company (PERC)

Test in the power plant

- Sensors tested from May 1, 2014 to today: August 27, 2015
  - Measurements being performed periodically
  - Array of wireless sensors improved in performance

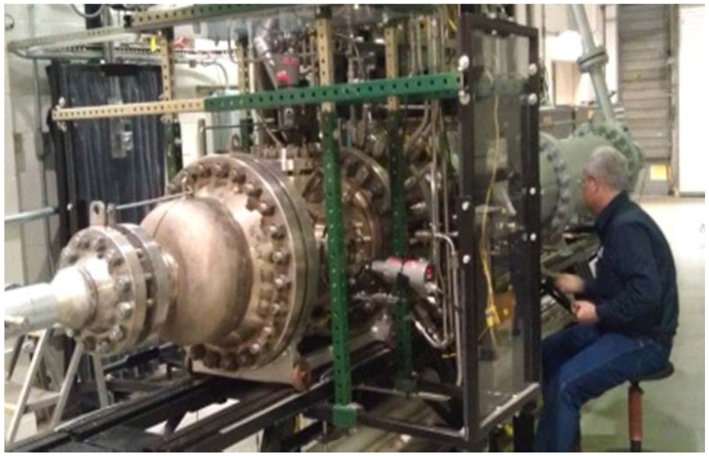


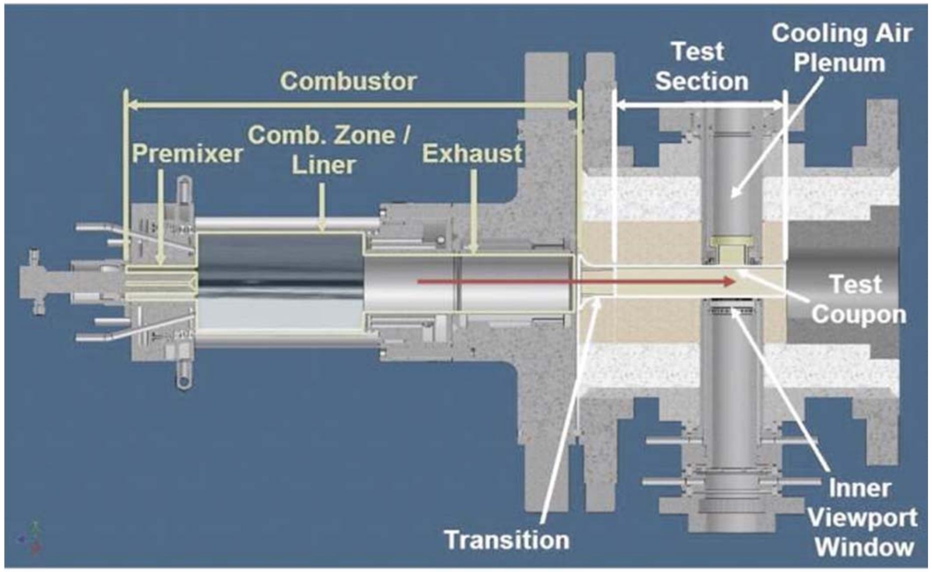
- PERC reference thermocouple ~10' from array

Date	Sensor 1 (°F)	Sensor 2 (°F)	Sensor 3 (°F)	Sensor 4 (°F)	Sensor 5 (°F)	Sensor 6 (°F)
5/1/14	684.3	673.2	683.7	678.9	680.1	695.6
5/5/14	694.2	684.3	695.0	696.0	688.0	705.8
5/12/14	706.2	690.7	701.5	704.8	687.7	711.1

4. Power Plant Environment: NETL Aerothermal Facility

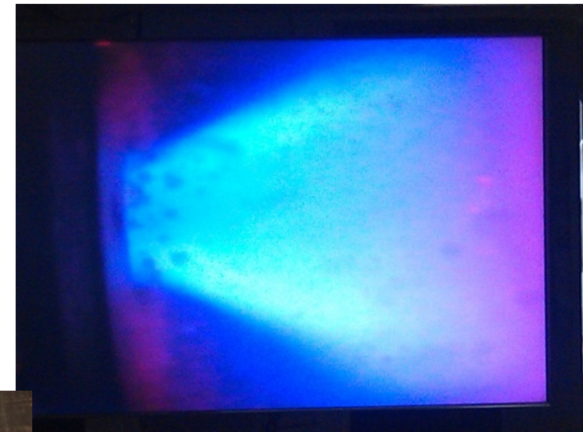
- Aerothermal Facility → natural gas combustor
  National Energy Technology Laboratory, NETL/DOE, USA
- Gas temperatures → up to 1100°C; pressure up to 60psi
- Wall temperatures → Up to 850°C
- Sudden pressure bursts; ceramic particulates; several hundred °C gradient with mm of the wall

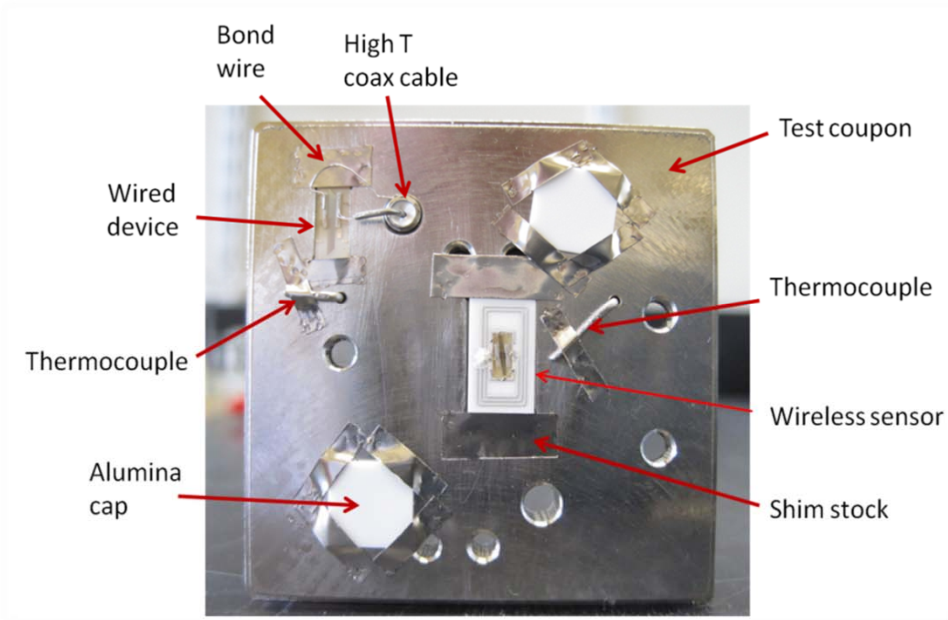


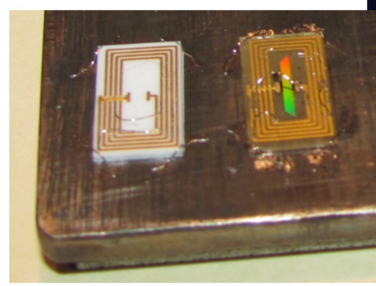


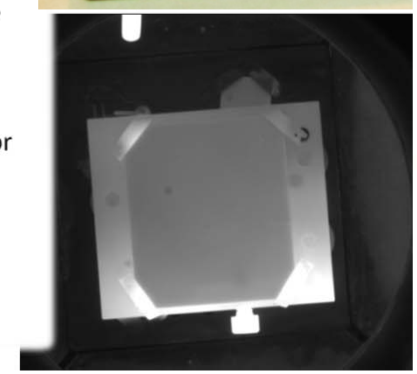
4. NETL Aerothermal Facility Tests

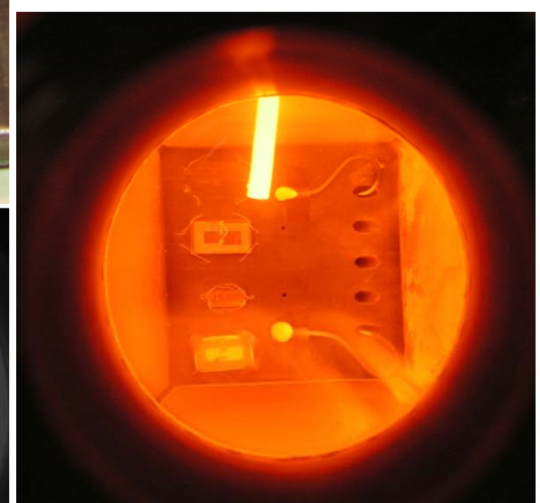
- Coupon installed directly in the gas flow (1100°C)
- Antenna exposed to 1100°C
- Sensors exposed to environment & also embedded in the coupon
- Eight devices packaged in two coupons







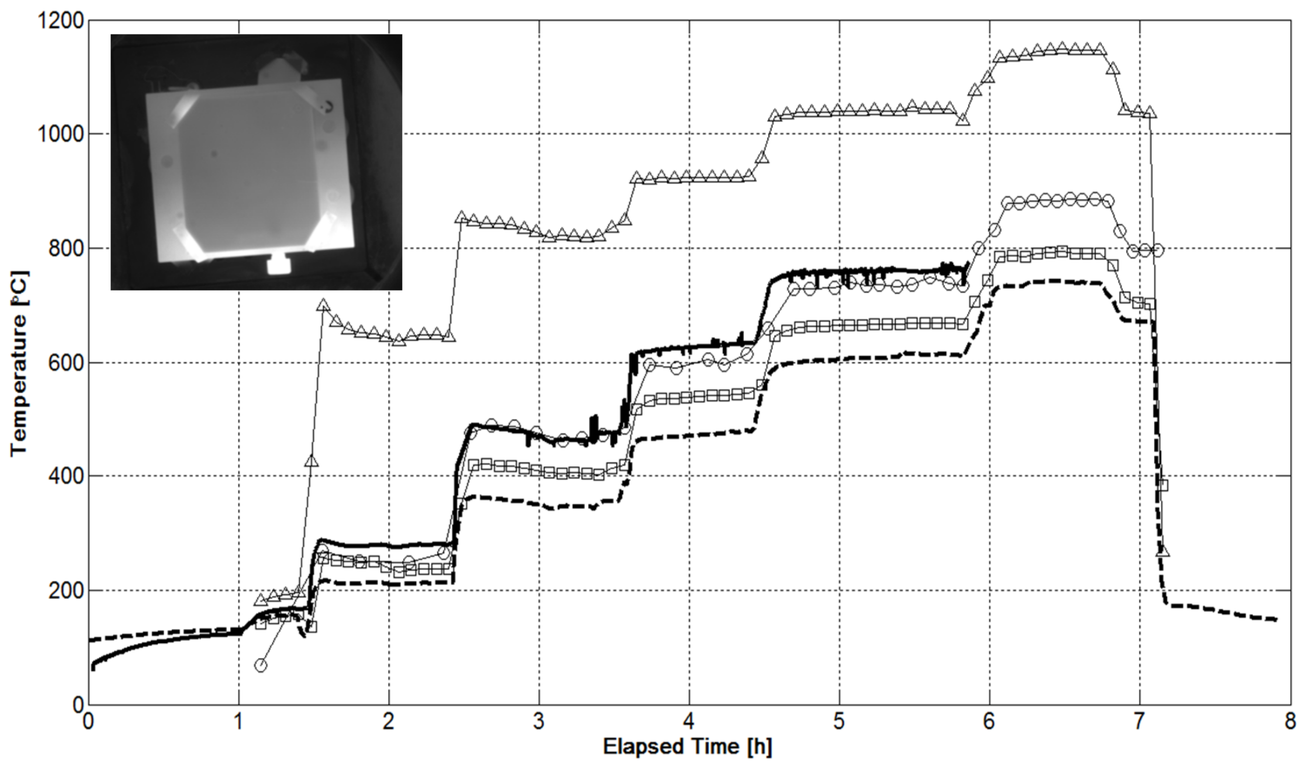




THE UNIVERSITY OF MAINE LASST Laboratory for Surface Science & Technology ENVIRONETIX

4. NETL Aerothermal Facility Tests

- Test results for a wireless and a wired LGS SAW sensors in the coupon fixtures.
- Two days tests (7 hours each day): Sensors & Packaging responded as expected to the variations in Temp. & Pressure



- Δ : gas thermocouple;
- Solid line: wireless SAW sensor;
- dashed line: wired 3.5µm SAW sensor;
- ○ : thermocouple near wireless SAW sensor;
- □ : Thermocouple near wired 3.5µm SAW sensor.

5. Maine Energy Recovery Company

INSTALLATION OF ENVIRONETIX SENSORS IN MERC POWER PLANT

Maine Energy Recovery Company (MERC)

casella

power plant that burnt municipal solid waste

ENVIRONETIX WIRELESS SENSOR PROBE IN MERC WATER WALL

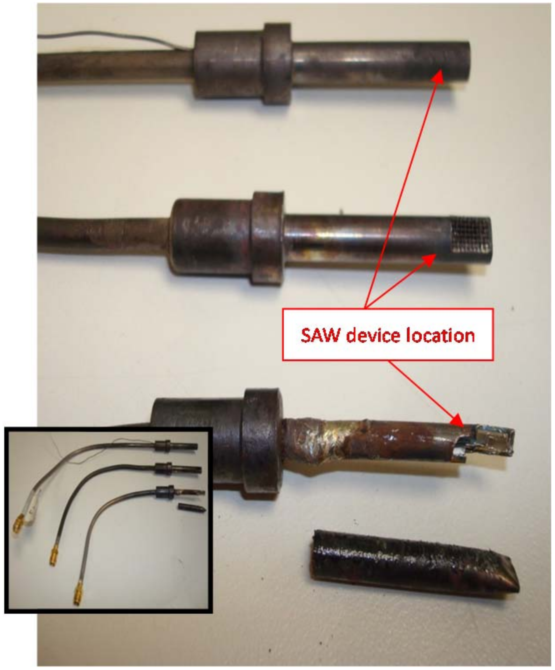
- Target: Condition based maintenance
  - Furnace tubes, piping, superheater / re-heaters tubes, heavy wall piping
  - Boiler operating conditions: erosive/corrosive exhaust gas up to1200°C (2200°F)
- Environetix EVHT-100 Sensor System: water wall & boiler temperatures
- Five wireless sensors installed at MERC
  - Survived 3 rounds of TNT boiler cleaner
- Tests performed for six months (plant closed 2012)

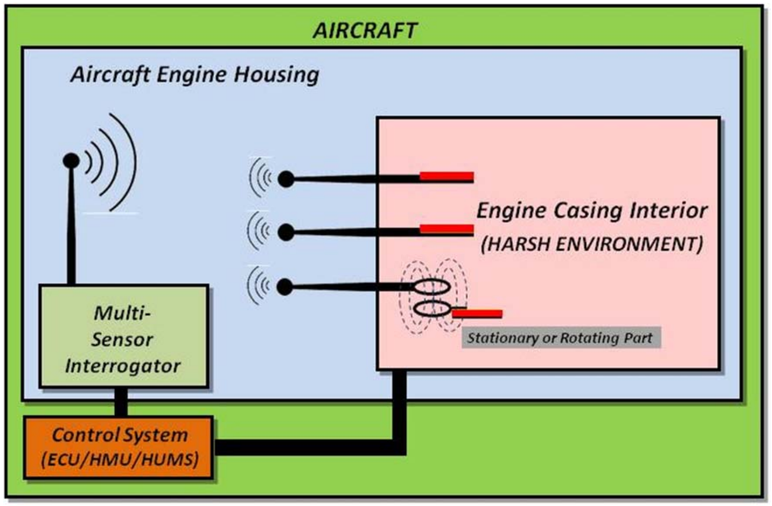
ENVIRONETIX TECHNOLOGIES CORPORATION

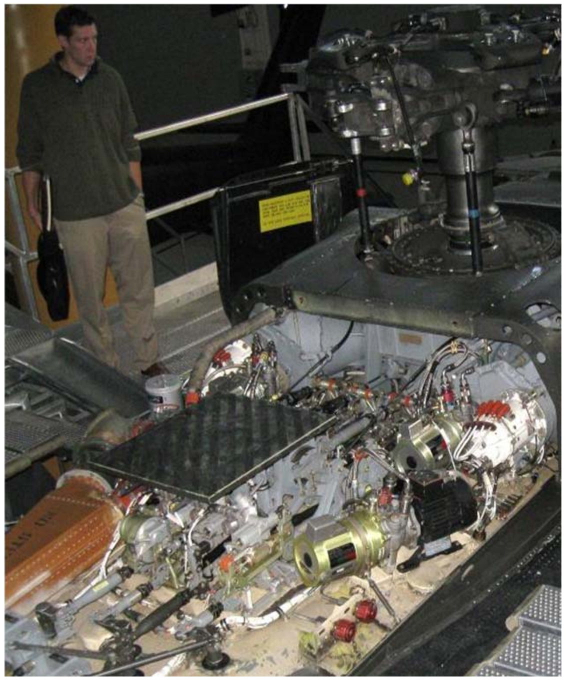
6. Tests at GE Research Center

- Tests inside a helicopter GE CT7 turbine Engine
- Location: last compressor section
- Packaging developed:

  Wireless sensor probes sealed & exposed to environment
- Temperature sensors (insensitive to pressure: ≤ 1°C for full range of pressure variation)





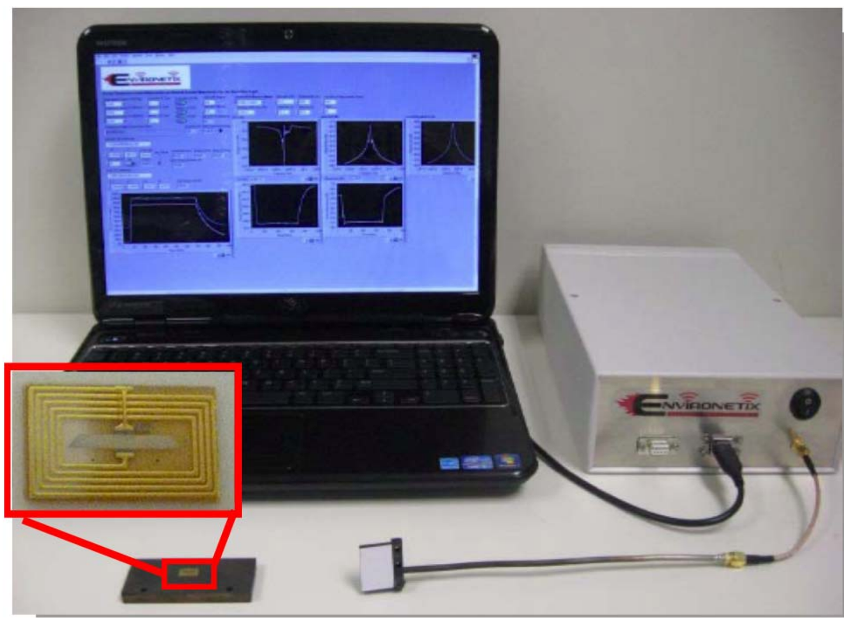


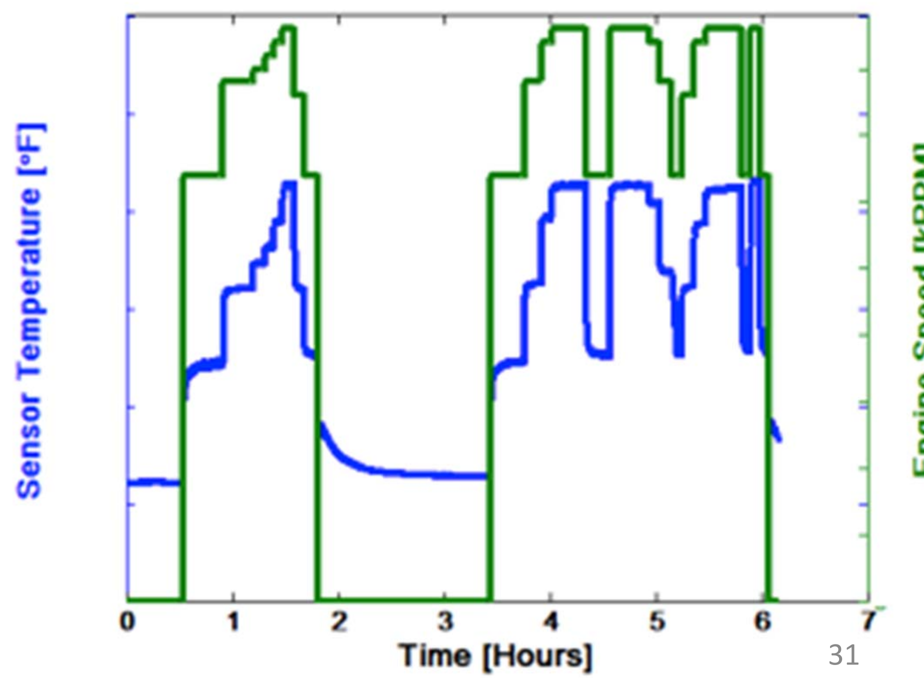
6. Tests at GE Research Center

- Environetix: EVHT-100 interrogator system

Dedicated Wireless Interrogator & Data Acquisition Software

- Test results for wireless sensors (330 MHz) comparing variations in engine rotation with variations in engine temperature measured by the wireless SAW sensors

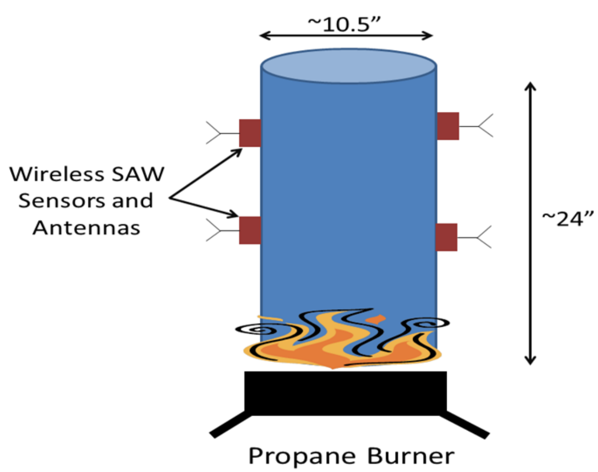




7. Prototype Pipe Structure: Industrial Settings

- Six sensors mounted on a steel pipe
- Temperatures up to 700°C
- Environetix EVHT-100 interrogator system used

SAW sensors: interrogation up to 45 feet



8. Sensor Testing at Rolls-Royce

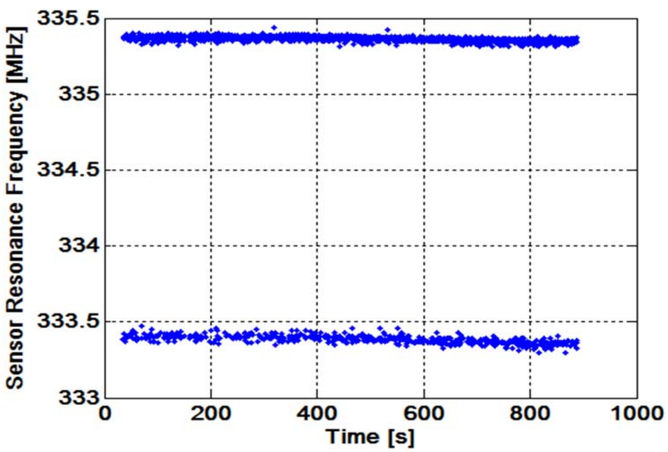
- ➢ Environetix's SBIR Air Force Research Laboratory project
- ➢ Tests performed in R&R, Derby, UK

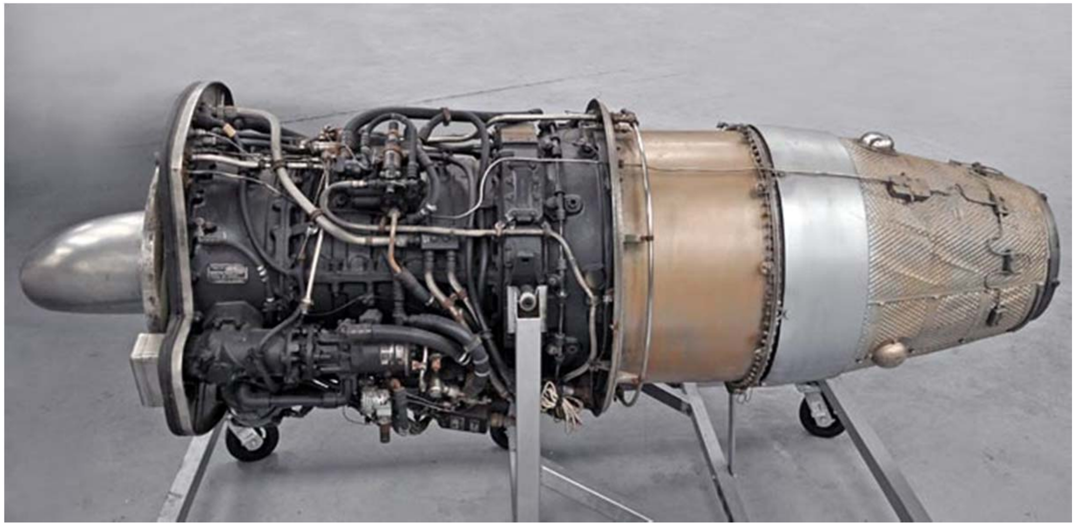
Laboratory Tests:

- ✓ SAW sensors monitored by thermocouples

Wireless test on Rolls-Royce Viper Engine

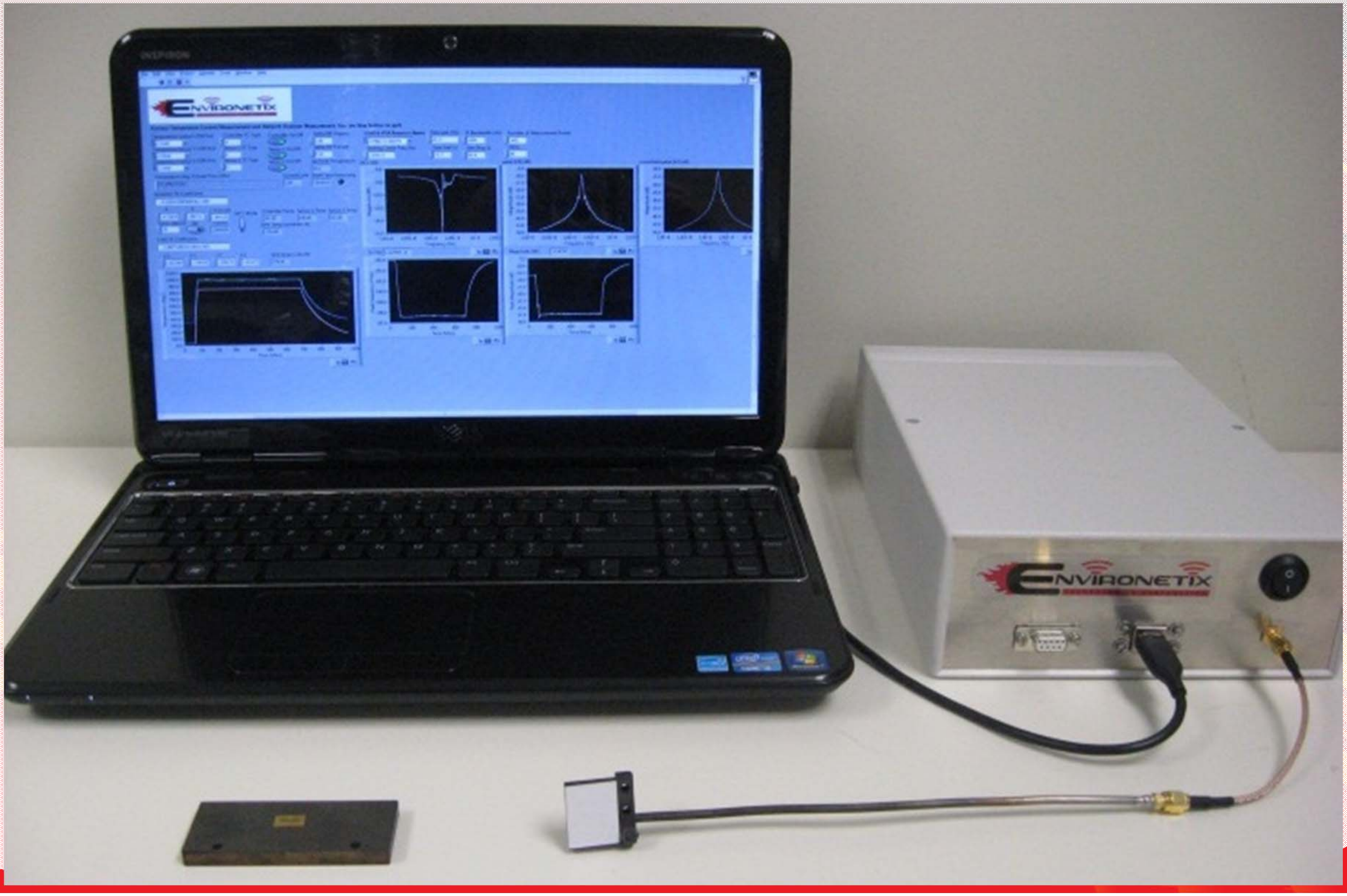
- ✓ "Cold test" → engine spun with compressed gas
- ✓ Spin rig disk tests





EVHT-100

EVHT-100: *Passive, Wireless Sensor System for Harsh Environments*



OUTLINE

1. Project Background
   - Technology & Applications
   - Achievements under other projects
   - **UMaine, Environetix & PERC**
2. Current Project
   - Integrated Gas / Temperature Wireless Microwave Acoustic Sensor System for Fossil Energy Application
   - Tasks, Timeline & Milestones
   - Participants
3. Summary Statement

- Maine Team → working on HT μ~ technology since 1999
- Topics include:
  - Microwave acoustic material characterization & device design
  - Thin film R&D for HT applications
  - Wireless communication: in turbine engine & harsh environments

- Interdisciplinary Research Center
  - Physics, Chemistry, Electrical & Computer Engineering, Chemical & Biological Engineering
  - 2005 Research Building (18 M$) with 3500 ft^2 micro/nano fab clean room
  - Well instrumented for Materials Science and RF work
  - Over 70 people: faculty, tech staff, graduate /undergrad students

ENVIRONETIX TECHNOLOGIES CORPORATION

- UMaine spin-off high tech company (June 09)
  - Currently six employees + administrative support
  - Located Target Technology Center, Orono, ME
  - Funded by DoD SBIRs, Maine State, Customers
  - Wireless product/services for harsh environments

Device Fabrication &Test At UMaine Facilities

Laboratory for Surface Science & Technology

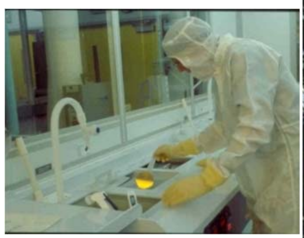
ELECTRICAL & COMPUTER ENGINEERING

Orono, Maine

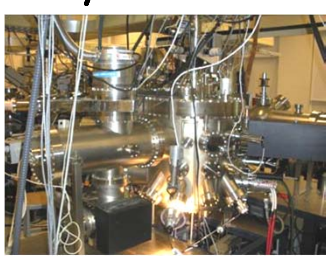
photolithography

thin film deposition

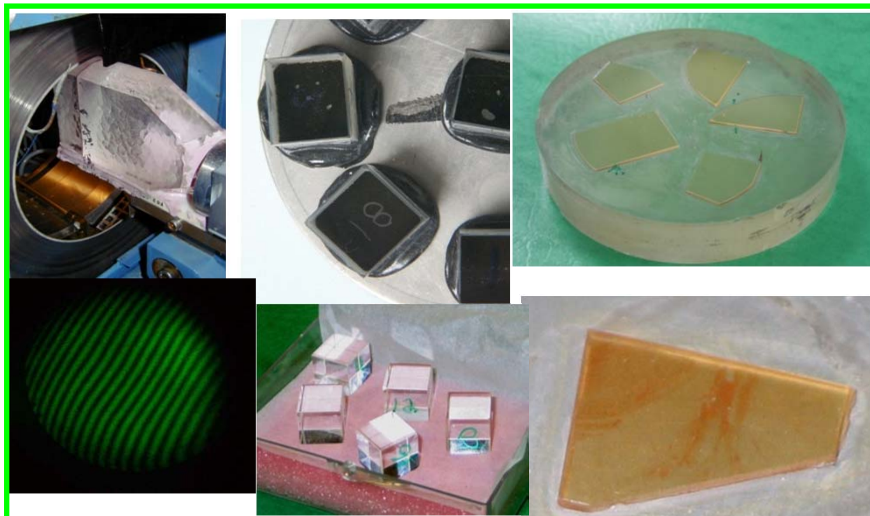
dry etch



wet etch

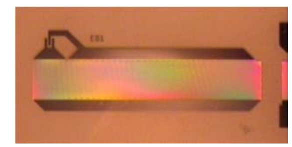


Film Characterization



Cutting, grinding and polishing

device packaging

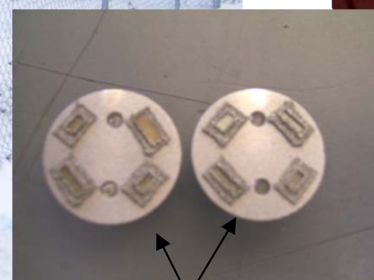


High Tech Testing Facility

Device design, fabrication, and Test

Field Testing: UMaine / Environetix Facilities

Long Term Multi-Sensor Test System

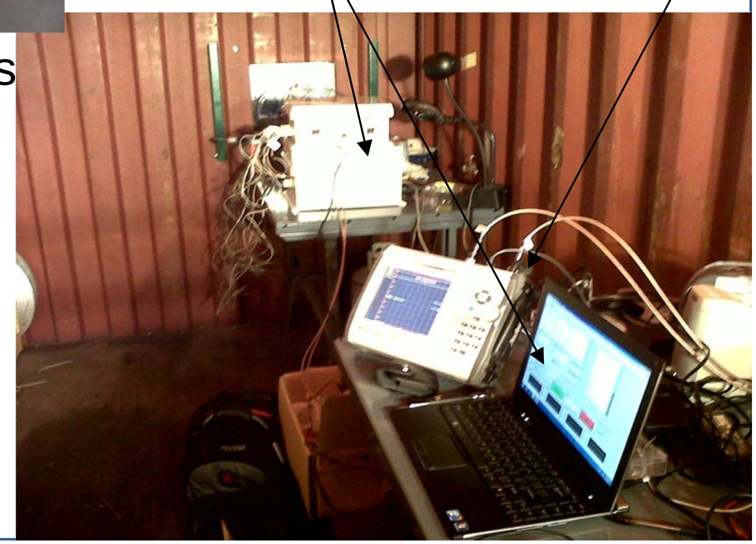


Fuel Sources

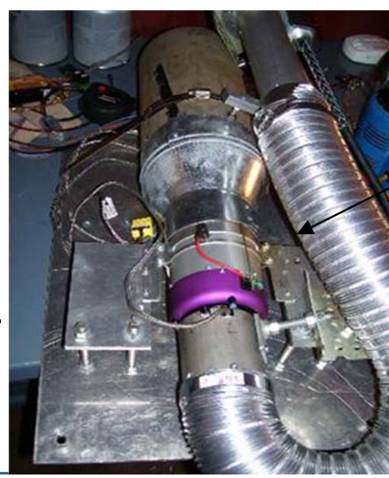
-Rotating discs

-Fixtures, support electronics for up to 8 devices, and Jetcat engine

VNA



-Facility can be operated year round.
-With K-1 fuel source an engine can be run Continuously for over 73 hours at 120,000 rpm



-Scaled Turbine Engine w/ duct heater

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Monitoring Power Plant Environments

- Project objectives:
  - Develop & demonstrate performance of:

Wireless & No-battery Microwave Acoustic Gas / Temperature Sensors

For HT (350 ℃ to 1000 ℃) Fossil Energy Applications →

  - ✓ Coal gasifiers, combustion turbines, solid oxide fuel cells, advanced boiler system, steam headers, reheat lines, water walls, and burner tubes.

- Identify best applications through interactions w/ NETL, power plant users, OEMs.
- Design, fabricate, & test sensor platform →
  - ✓ Langasite piezoelectric crystal with Pt / Pd interdigital electrodes and yttria-stabilized zirconia (YSZ) films doped with Pd, Pt, or Au nano-catalysts
  - ✓ Expected operation within the 300°C to 1000°C range
- Employ developed platform to:
  - ✓ Detect H_2, O_2, and NO_x gases and to also monitor the gas temperature in the harsh environment
- Develop appropriate packaging for the applications identified
- Development of integrated gas & temperature wireless microwave acoustic sensor arrays
- Test prototype sensor / arrays and wireless interrogation system in power plant environments

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Tasks

Project contains 4 major tasks / subtasks, as follows:

1. **TASK 1 – Project Management & Planning**
2. **TASK 2 – Design, fabrication, and characterization of wireless SAW sensors with Pd / Pt electrodes and Au, Pt, Pd doped YSZ films to detect H2, O2, and NOx gas at high temperatures**

2.1 LGS SAW gas sensors using interdigital Pd / Pt electrodes

2.2 LGS SAW gas sensors with integrated Au, Pt, or Pd doped YSZ films

Tasks (cont.)

3. **TASK 3 – Integration and characterization of the dual gas / temperature sensor**

3.1 Two channel LGS SAW sensor with and without gas exposure to extract gas / temperature data

3.2 Use of combined LGS SAW gas & temperature sensor signal from two or more sensors to extract gas / temperature data

4. **TASK 4 – Design, implementation, and characterization of the wireless interrogation systems for the integrated gas / temperature sensor**

4.1 Verification of the wireless signal integrity for the integrated gas / temperature sensor

4.2 Confirmation of sensor packaging adequacy for gas / temperature exposure to harsh-environment

Project Timeline

PROJECT TIMELINE In red: Milestones in accordance with Section C	YEAR 1 (Sep 2015/Aug 2016)				YEAR 2 (Sep 2016/Aug 2017)				YEAR 3 (Sep 2017/Aug 2018)			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
TASK 1: Project Management & Planning	X M1											
TASK 2: Design, fabrication, and characterization of wireless SAW sensors with Pd / Pt electrodes and Au, Pt, Pd doped YSZ films to detect H2, O2, and NOx gas at high temperatures												
Subtask 2.1 - LGS SAW gas sensors using interdigital Pd / Pt electrodes	X	X	X	X								
Subtask 2.2 - LGS SAW gas sensors with integrated Au, Pt, or Pd doped YSZ films		X	X	X	X M2							
TASK 3: Integration and characterization of the dual gas / temperature sensor												
Subtask 3.1 - Two channel LGS SAW sensor with and without gas exposure to extract gas / temperature data			X	X	X	X						
Subtask 3.2 - Use of combined LGS SAW gas & temperature sensor signal from two or more sensors to extract gas / temperature data					X	X	X	X M3				
TASK 4: Design, implementation, and characterization of the wireless interrogation systems for the integrated gas / temperature sensor												
Subtask 4.1 - Verification of the wireless signal integrity for the integrated gas / temperature sensor						X	X	X				
Subtask 4.2 - Confirmation of sensor packaging adequacy for gas / temperature exposure to harsh-environment							X	X	X M4			
TASK 5: Technology adaptation and transition to power plant sites and investigation of alternative applications								X	X	X	X	X M5

Project Milestones

Project Milestone	Planned Completion Date	Milestone Title
M1	Q1 of Year 1 (Nov. 2015)	Kick-off meeting with DOE / NETL Program Officer
M2	Q1 of Year 2 (Nov. 2016)	Characterization of wireless LGS SAW sensors with Pd / Pt electrodes and Au, Pt, Pd doped YSZ films to detect H2, O2, and NOx gas at high temperatures
M3	Q4 of Year 2 (Aug. 2017)	Characterization of the integrated gas / temperature sensor unit
M4	Q1 of Year 3 (Nov. 2017)	Characterization of the designed and implemented wireless interrogation system for the integrated gas / temperature sensor
M5	Q4 of Year 3 (Aug. 2018)	Technology transition to power plant sites and report on alternative power plant applications

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PI's

- **Mauricio Pereira da Cunha**, *Professor of Electrical & Computer Engineering and Member of LASST (PhD in Electrical Engineering, McGill University, 1994).* Principal Investigator who is responsible for overseeing the entire project. Areas of expertise include microwave acoustic materials research and characterization, wave propagation, wireless communication, and sensor development.
- **Robert J. Lad**, *Professor of Physics and Member of LASST (PhD in Materials Science, Cornell University, 1986).* Co-Principal Investigator responsible for assisting in monitoring the project. His area of expertise includes ceramic and semiconductor thin film growth and characterization, electrical transport measurements, and high temperature materials.

UMaine Technical & Support Staff

- **George Bernhardt**, *LASST Research Scientist (PhD in Physics, U.Maine 1994).*
- **Anin Maskay**, *Ph.D. Student (BS in Electrical Engineering, U.Maine 2013).*
- **Michael Call**, *LASST Research Technician (MS in Electrical Engineering, U. South Dakota, 2005).*
- **Tracy Richardson**, *LASST Administrative & Financial Officer*
- **Nathan Dacy**, *Undergraduate Student*

UMaine Students

- **Ph. D. Student at UMaine***:*
- *Proficiency in microwave techniques and with thin film technology & characterization.*
- *Be involved in* $\rightarrow$
  - ✓ *Design, fabrication, and testing of HT SAW sensors for integration of thin sensing films*
  - ✓ *Research, Fabrication, Characterization, & Integration of the novel HT SAW sensor gas detection films into the* $\mu\sim$ *acoustic (SAW) device,*
  - ✓ *Performing wireless interrogation experiments on temperature / gas sensor arrays in laboratory furnace environments*
  - ✓ *Performing embedding of prototype sensors into targeted power plant components*

- **Undergraduate Students at UMaine.** *The selected candidates will also be trained in microwave technology, thin film deposition and sensor fabrication. It is expected that the undergraduate students will assist in:*
  - ✓ *Research and characterization of thin films for the targeted gases species at elevated temperatures (up to 1000℃).*
  - ✓ *Research and fabrication of prototype temperature and gas sensors for operation at elevated temperatures (up to 1000℃) and for the targeted gases species.*
  - ✓ *Performing wireless interrogation experiments on temperature / gas sensor arrays in laboratory furnace environments and participate in the field test experiments in operating power plant environments.*
  - ✓ *Field test experiments in operating power plant environments*

Environetix & PERC
Technical & Support Staff

ENVIRONETIX

- **Gregory Harkay,** *Project Engineer & Project Manager (MS in Physics, Penn State, 2013; BE in Engineering, Dartmouth's Thayer School of Engineering, 2008)*
- **Paul Wilson**, *Project Engineer (B.S in Electrical Engineer, U.Maine 2012).*
- **Jason Harris**, *Project Engineer (Old Dominion University, 2014).*
- **George Harris**, *Technical Engineer (BS in Engineering Physics, U.Maine 1978).*
- **Suzanne Sharrow,** *Financial Administrator (BS in Education, UMaine, 1980; AS Health Information Technology, U.Maine 1986)*

PERC

- **Richard Kelley**, *Plant Manager (Penobscot Energy Recovery Co.)*

Current Progress

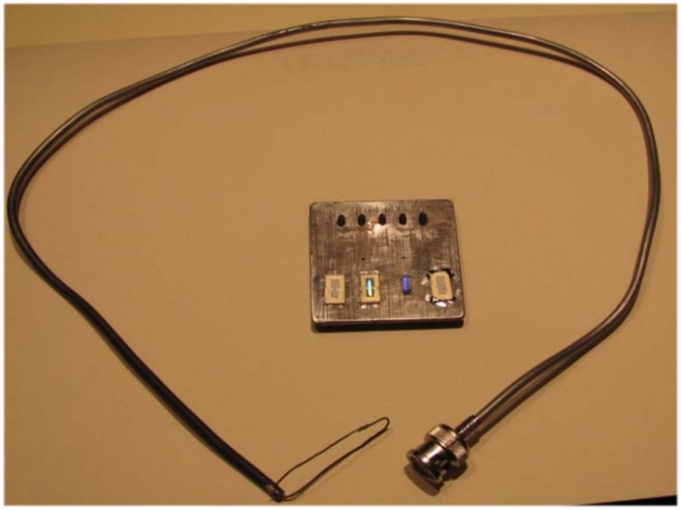
- Project Started Sept. 01st, 2015.
- Task 1 – Project Management & Planning
  - Review of Project Management Plan (PMP) with program officer
  - Kick-off meeting (This presentation)

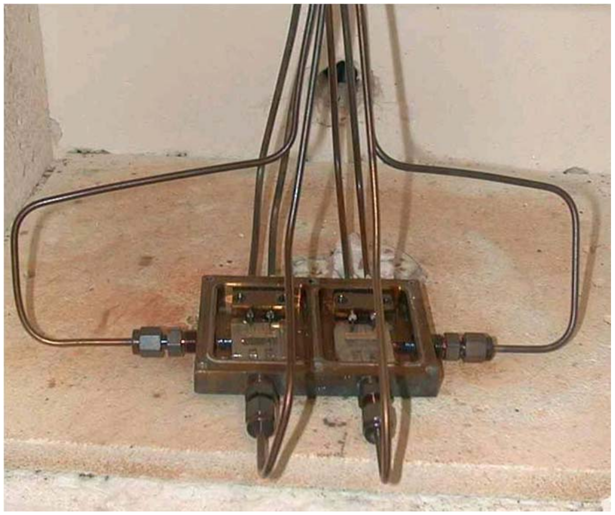
Current Progress
(cont.)

- Task 2 - Design, fabrication, and characterization of wireless SAW sensors with Pd / Pt electrodes and Au, Pt, Pd doped YSZ films to detect H2, O2, and NOx gas at high temperatures
  - Subtask 2.1: LGS SAW gas sensors using interdigital Pd / Pt electrodes
    - ✓ Pt / Pd electrode devices planned for fabrication
  - Subtask 2.2: LGS SAW gas sensors with integrated Au, Pt, or Pd doped YSZ films
    - ✓ YSZ target → Material purchase under way as planned
    - ✓ Blanket deposition tests planned

Current Progress (cont.)

- Task 3 - Integration & characterization of the dual gas / temperature sensor
  - Subtask 3.1: Two channel LGS SAW sensor with and without gas exposure to extract gas / temperature data
    - ✓ In progress: discussions with NETL on possible technical alternatives and current exchange of parts and design info
    - ✓ Packaging alternatives & details under consideration → wired and wireless sensor tests at NETL & transition to power plant environments





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Summary

This presentation addressed:

1. **Overview $\rightarrow$ technology state-of-the-art & accomplishments**
2. **Targeted applications for NASA, Air Force, Army, Industrial Applications, and Power Plants / NETL / DOE Energy sector**
3. **Introduced UMaine capabilities and Environetix/PERC contacts and technical support to the project**
4. **Discussed the current project**
   - ✓ **Objectives**
   - ✓ **Tasks, Timeline, and Milestones**
   - ✓ **UMaine & supporting group (Environetix & PERC) personnel**
   - ✓ **Current activities and progresses**

END / QUESTIONS?

mdacunha@maine.edu