2016 Crosscutting Research Review Meeting

High-Temperature Wireless Sensor Array for Harsh-Environment Power Plant Condition Monitoring Applications

Presenter: Mauricio Pereira da Cunha

Dept. of Electrical and Computer Engineering
Laboratory for Surface Science and Technology
University of Maine, Orono, ME 04469 USA
Environetix Technologies Corporation
Orono, ME 04469 USA
mdacunha@maine.edu

Topics

I. **Background**
   - Project Relevance and Goals

II. **Review of Project Achievements & Impacts**
   - List of significant contribution to HT wireless sensor operation
   - Review of preliminary technology test in power plant site

III. **Project Progress and Experimental Validation**

IV. **Current effort: *Wireless SAW Array deployed on Boiler tubes for Condition Maintenance***

V. **Conclusions & Acknowledgements**

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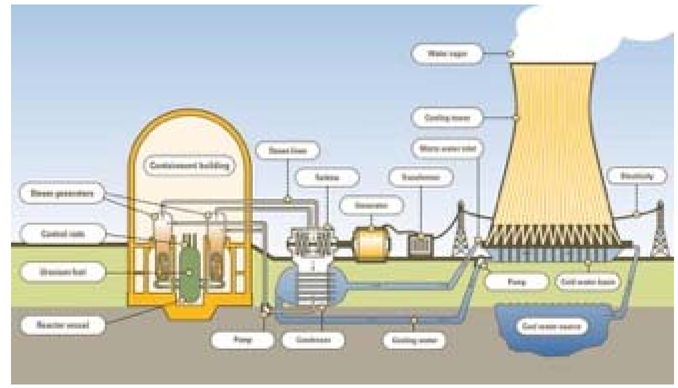
I. Background

Project Relevance and Goals

Power Plants, aerospace, industrial environment:

Need to better monitor & control

- ✓ Fuel burning efficiency
- ✓ Process dynamics & gases concentration
- ✓ Health of the power plant structures



Imagine . . .

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Project Relevance and Goals

Harsh Environment Sensors: better monitoring & control

Imagine . . .

Wireless monitoring temperature, torque, strain, gases, vibration, pressure inside the harsh environment

No Wires! Easier installation, movable parts, improved reliability, improved safety.

NO batteries: Maintenance free sensor in harsh environment

CONDITION BASED MAINTENANCE:

Predictive, Mitigate Defect & Redesign, Increase Safety, Operational Life & Precision, Reduce Work

Planned, scheduled coordinated, preventive as opposed to Down time, breakdown & high-cost

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HE Wireless Microwave Acoustic Technology

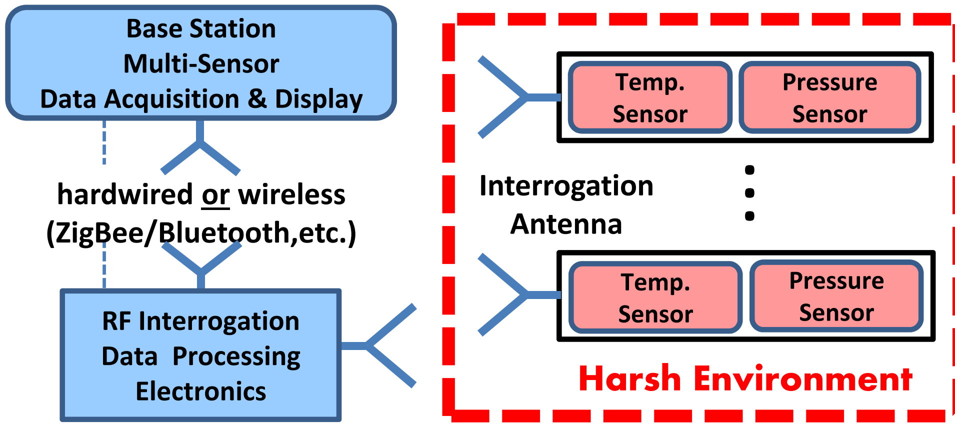
Wireless Microwave Acoustic Sensor Systems for High Temperature Harsh Environments

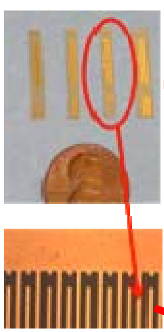
LANGASITE $La_3Ga_5SiO_{14}$

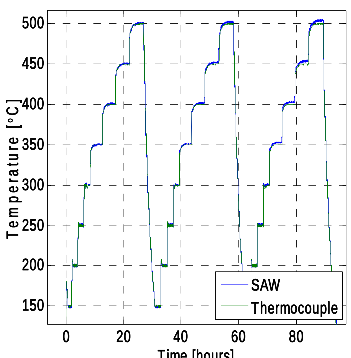
PIEZOELECTRIC CRYSTAL

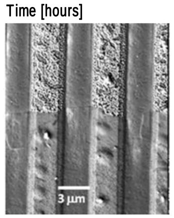
✓ Stable up to 1400°C

✓ Thermal shock resistant

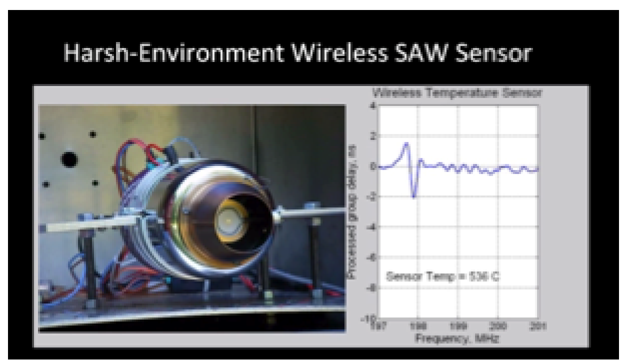








Repetitive, accurate, stable sensor response at least as good as thermocouple used to measure



SAW SENSOR & ANTENNA

Low profile package

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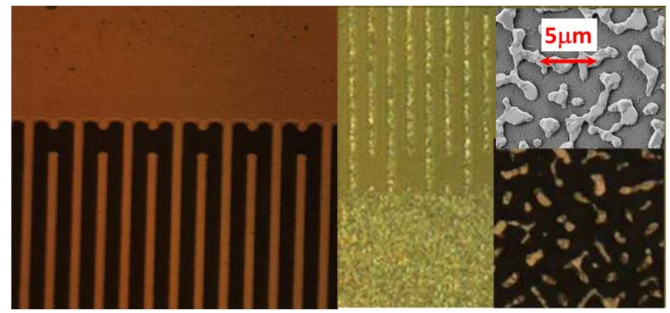
II. Review of Project Achievements & Impacts

Summary of Previously Reported Accomplishments

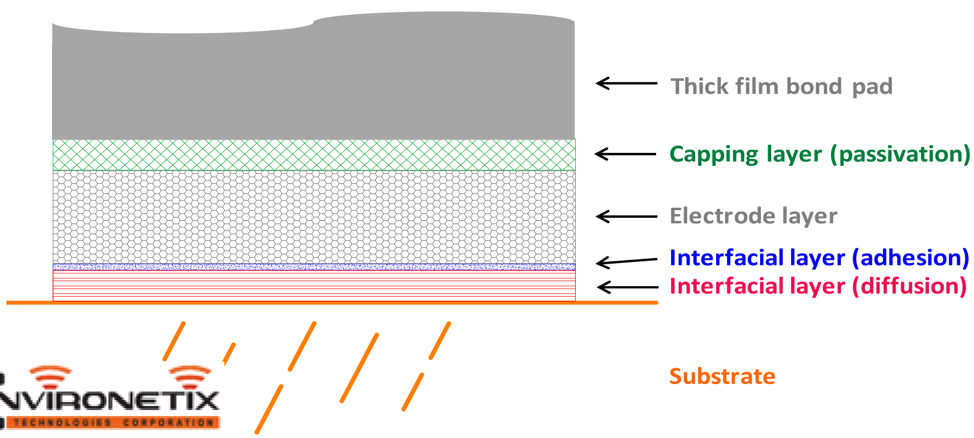
1. Research of multiple HT thin films electrodes to be used with the wireless SAW sensors

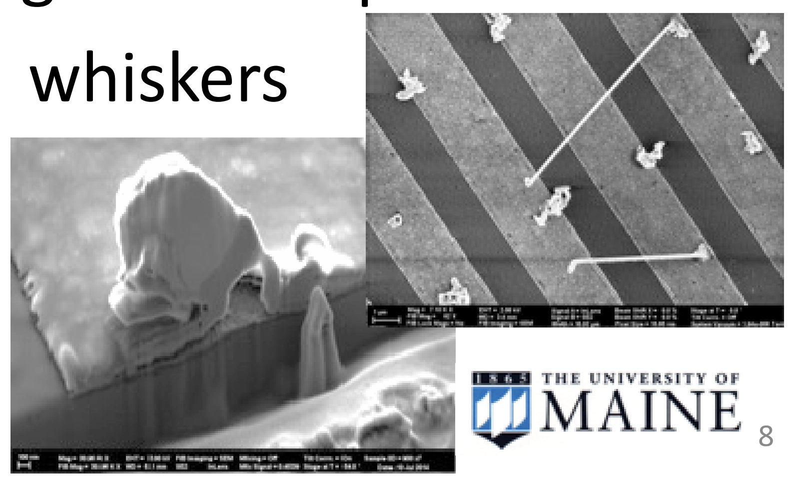
PtRh/ZrO_2, PtCo, PtRh/CoO, PtNi, PtRhNiO, PtCr, PtAl, Pt-Al/Pt/ZrO_2, PtAl/Pt/Nb, Pt-Al/Pt/Cr, PtAl/Pt/ZrO_2, Pt/Al_2O_3, PtRh/HfO_2, Pt/Al_2O_3, and PtNi|PtZr.



- ✓ Operation up to 1100°C achieved

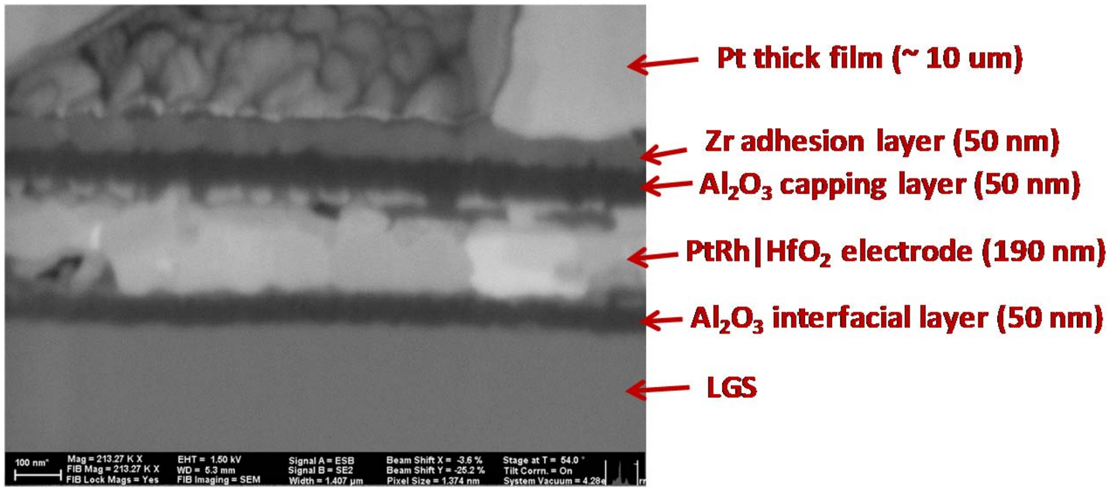
2. Capping & Interfacial layers developed as means of extending max. temp. & avoid whiskers

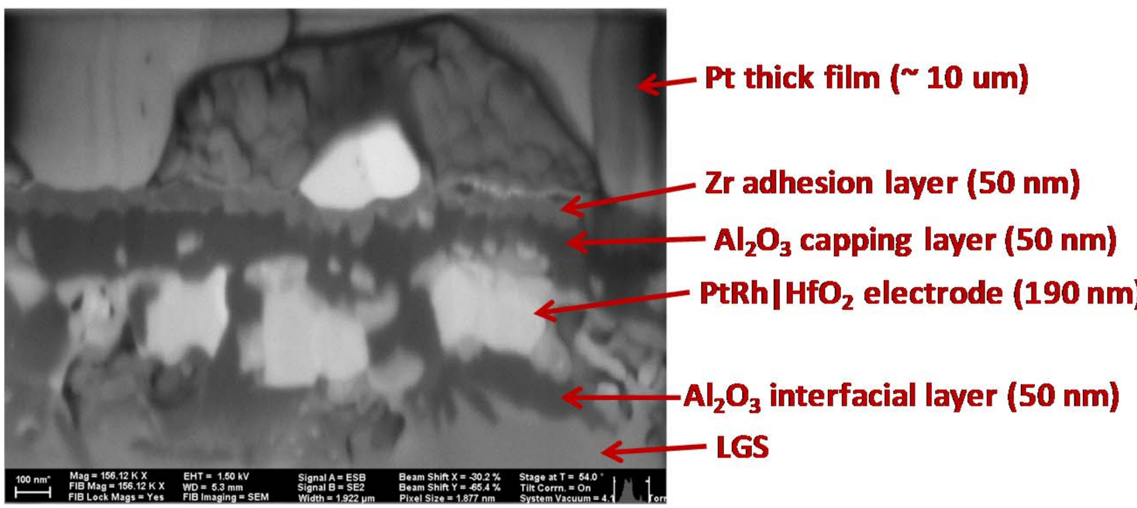




Capping & Interfacial Layers

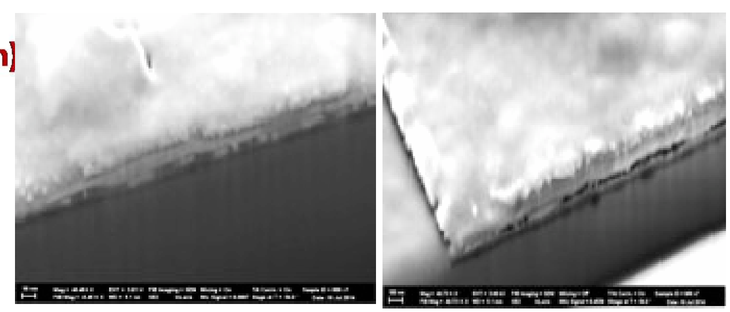
- Used with different film types





- Top-left fig.: as deposited
- Bottom-left figure: After heating at 1000°C for 4 hrs

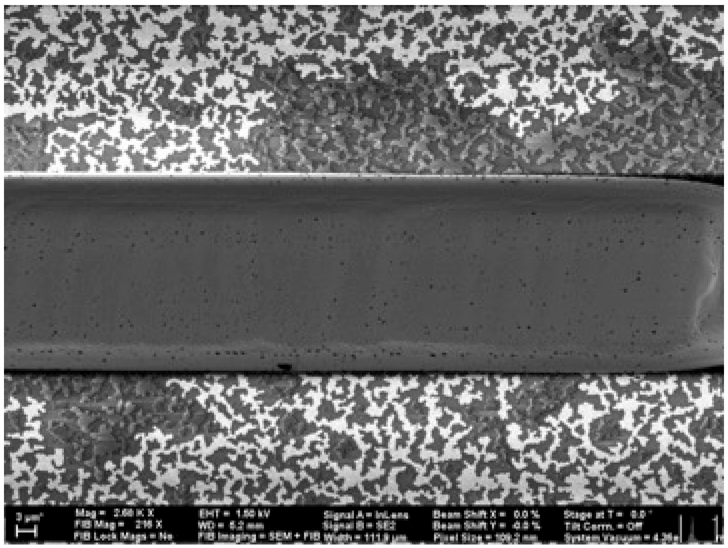
  Note: capping layer still continuous, but electrode agglomeration and interaction with substrate visible
- Bottom-right: delamination after cycling for certain electrode types (film stress)

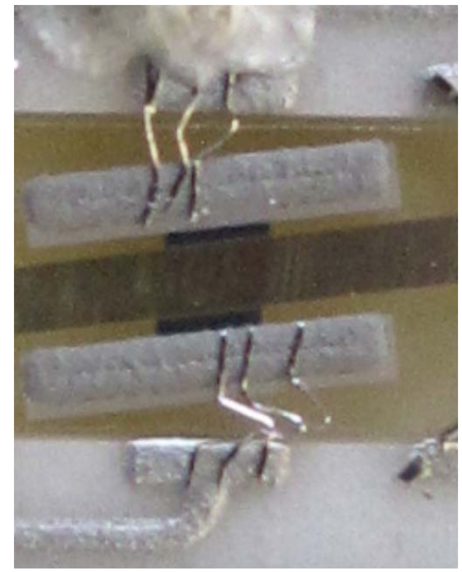


Capacitive Coupling

- ➢ Bonding Pt wire to thin-film → Pt diffusion

(bonding degrade before actual film degrades)





3. Capacitive coupling: Avoid breaking through the capping layer (which compromise bonding and contact reliability)

   - ➢ Thus: contact alternative for HT operation

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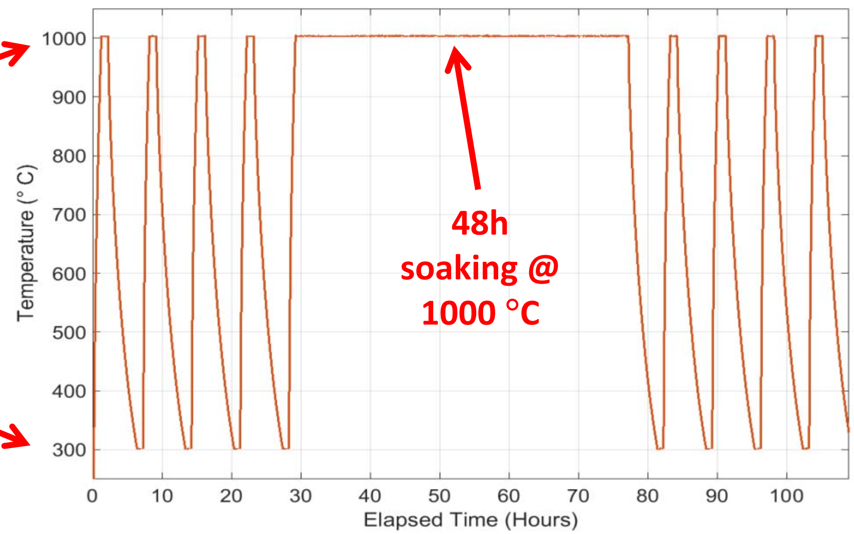
Endurance & Stability Tests

4. PtNi|PtZr Electrodes: cycling test rounds up to 1000°C

4 x 1h soaking @ 1000°C

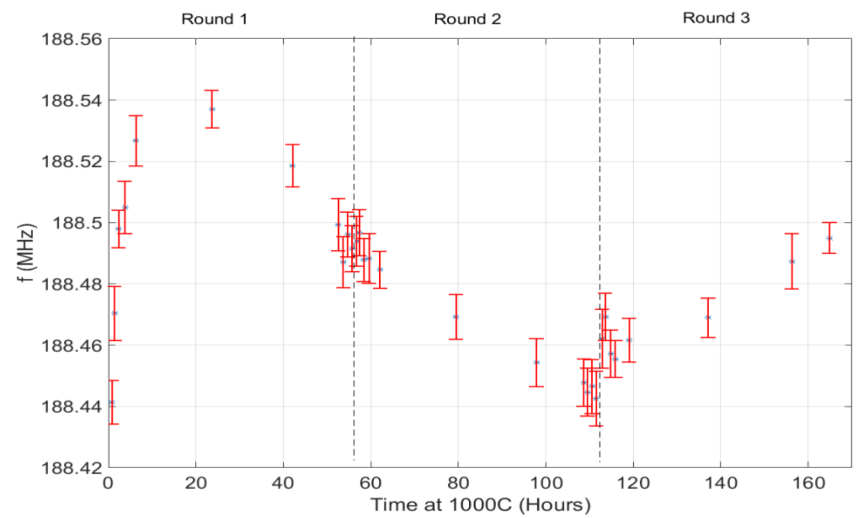
4 x 1h soaking @ 300°C



4 initial cycles repeated

- ➢ Multiple rounds (3 shown)
- ➢ 60KHz fluctuation

$\rightarrow \pm 3°C$



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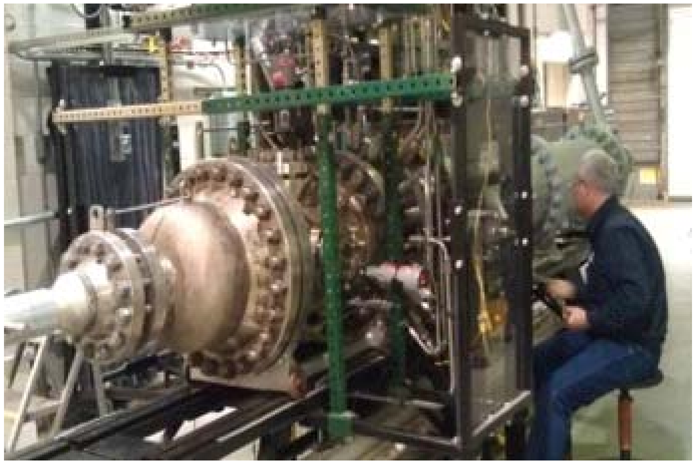
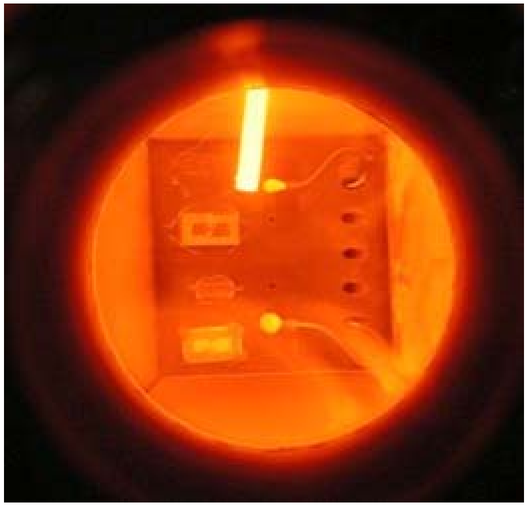
Tests at NETL Aerothermal Facility

- Aerothermal Facility → natural gas combustor
  National Energy Technology Laboratory, NETL/DOE, USA
  - Gas temp. → up to 1100°C; Wall temperatures → Up to 850°C
  - Pressure up to 60psi; Sudden pressure bursts
- Coupon installed directly in the gas flow (1100°C)
- Integrated antenna exposed to 1100°C
- Eight sensors: embedded in two coupons & exposed to environment

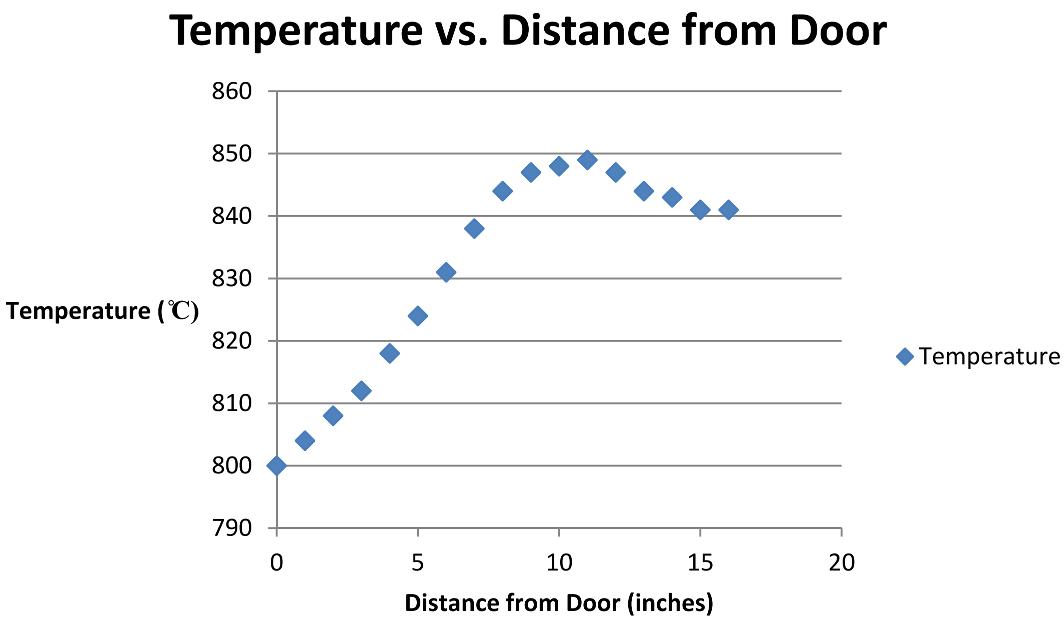




Wireless Position Furnace

5. Custom made furnace: Temperature variation (position)

- ➢ Wireless interrogation
- ➢ LGS SAW wireless sensor response compared to thermocouple response



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Power Plant Tests: PERC

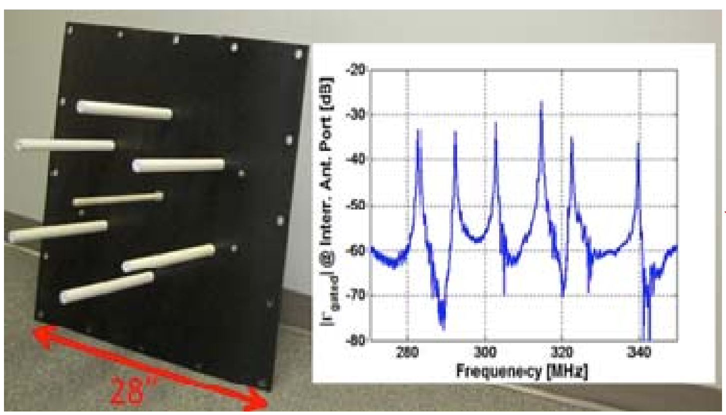
6. Penobscot Energy Recovery Company (PERC)

(Orrington,ME)

Municipal Solid Waste (MSW) Power Plant

Garbage is burned to release energy

- ➢ Testing undergoing for two years
  - Materials testing, sensor units, antennas
  - Wireless Temperature Sensor Array



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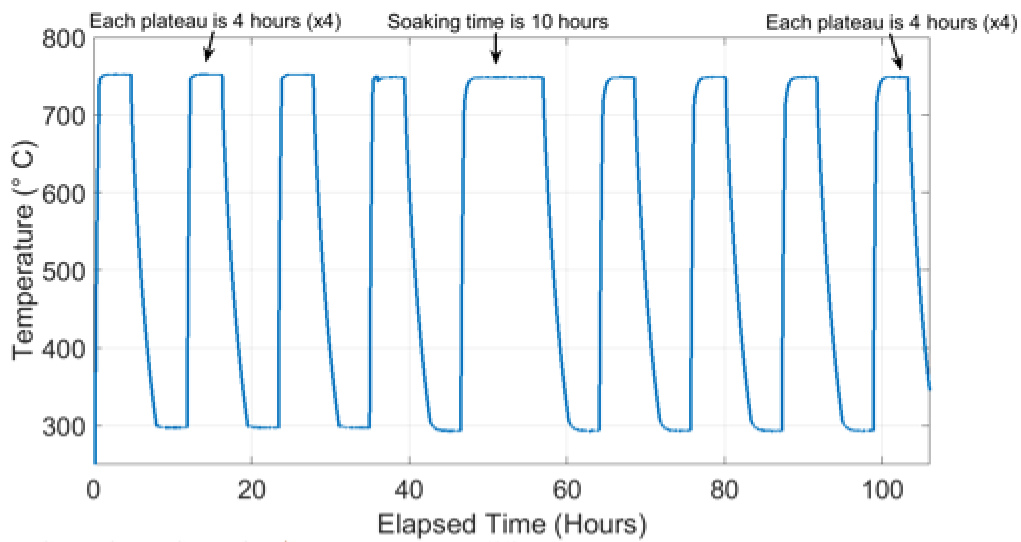
III. Project Progress and Experimental Validation

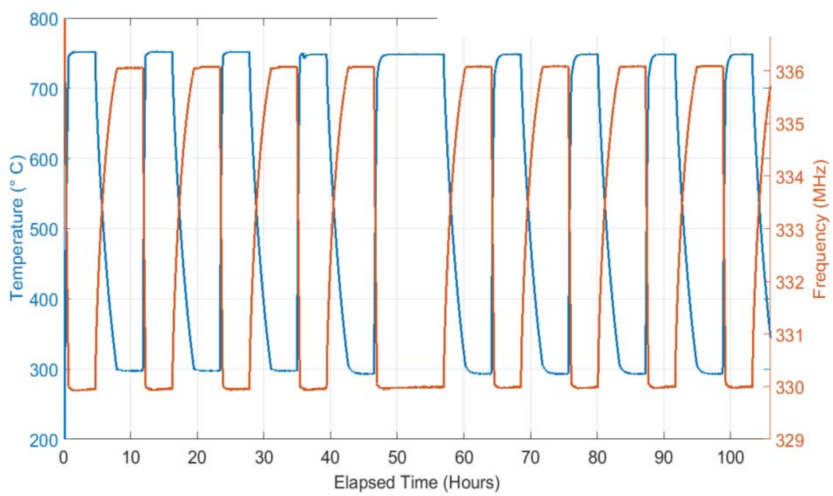
LGS Pt-Al_2O_3 SAW Sensor: STABILITY TESTS

- SAW sensors cycled for six round btwn 300°C and 750°C

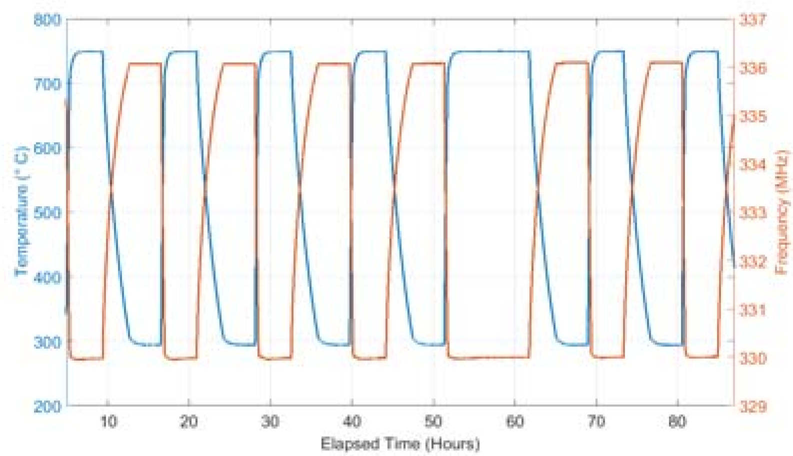
Each round → (~ five-day Test)



Round 1



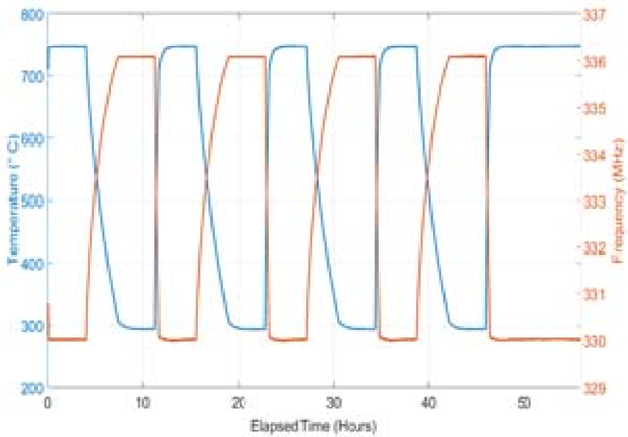
Round 2



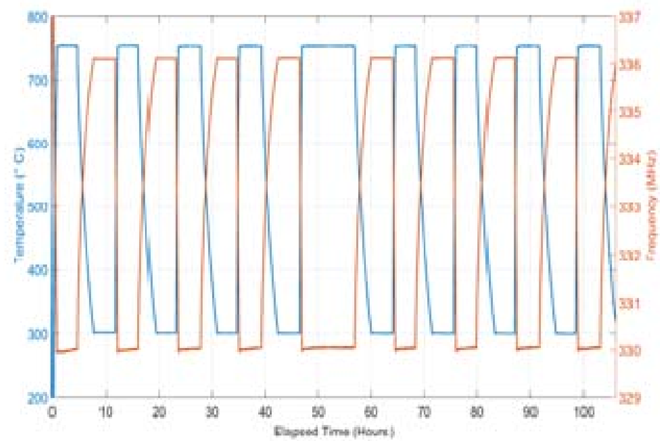
LGS Pt-Al_2O_3 SAW Sensor: STABILITY TESTS

- Rounds 3 to 6: extreme sensor reliability

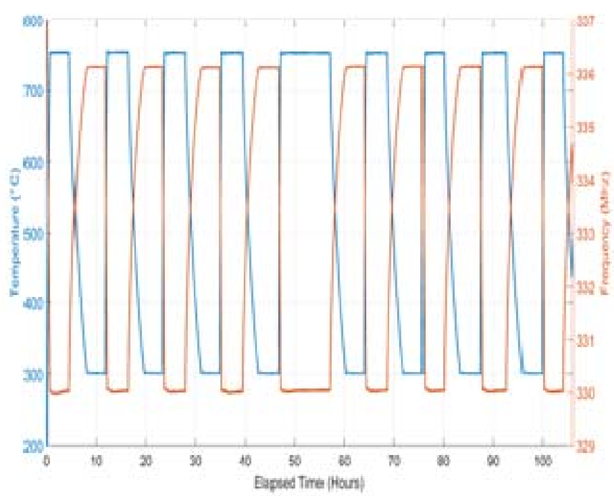
Round 3



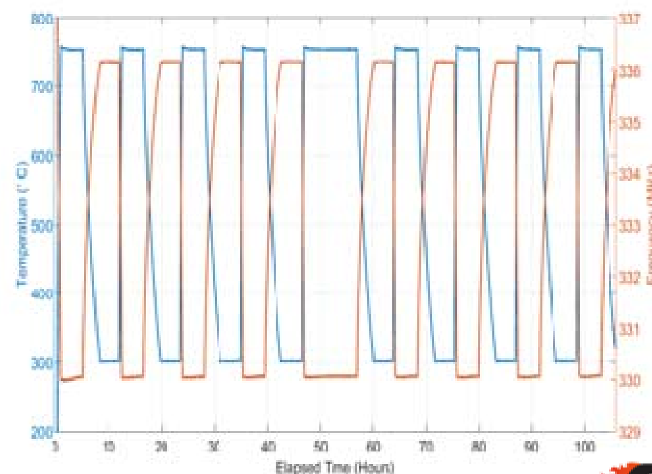
Round 4



Round 5



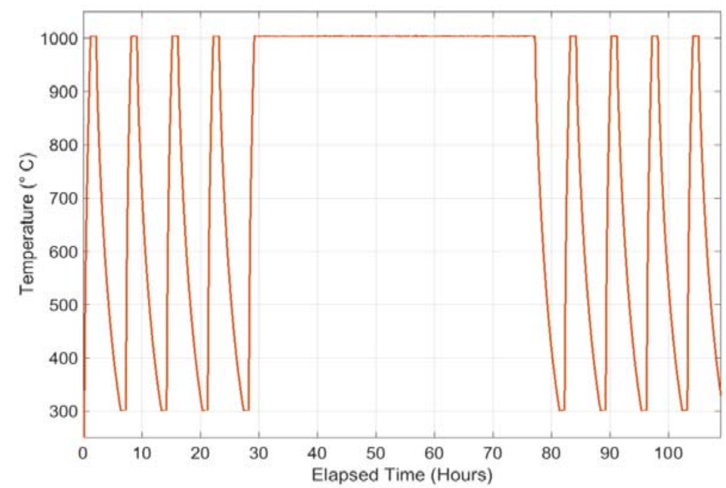
Round 6



Sensor Endurance

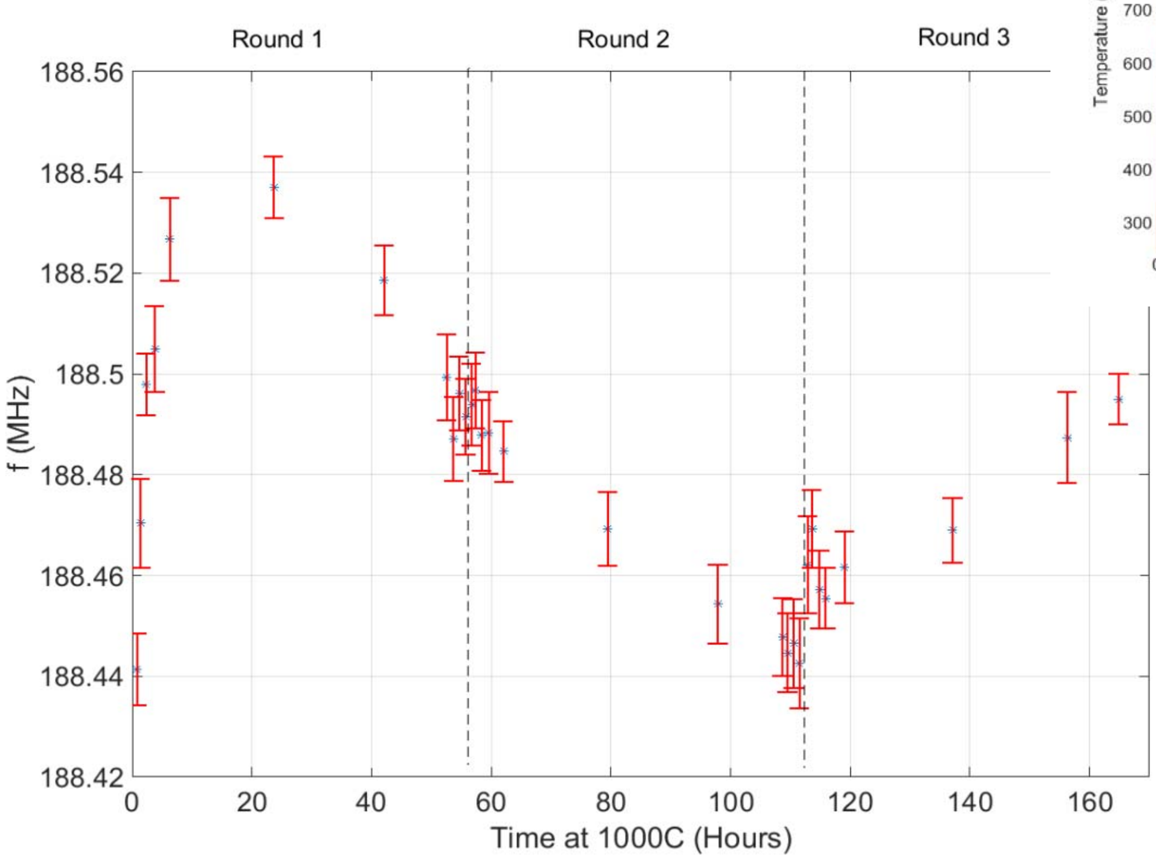
- PtNi|PtZr Sensor stability verified up to 1000°C → ± 3°C (mentioned above

  & reported 2015)



↓

Each round (~ five-day test)



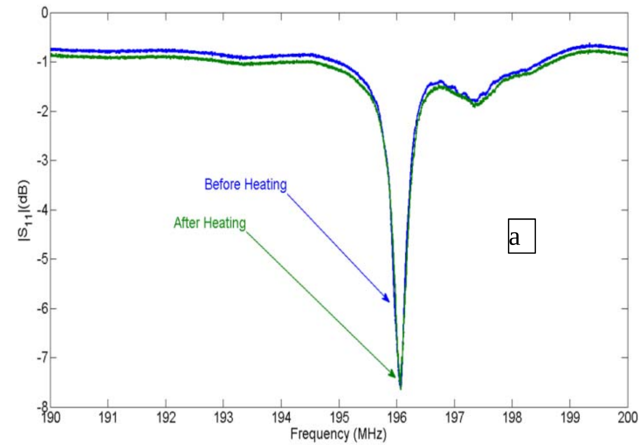
PtNi|PtZr Electrodes on LGS SAW: further cycling

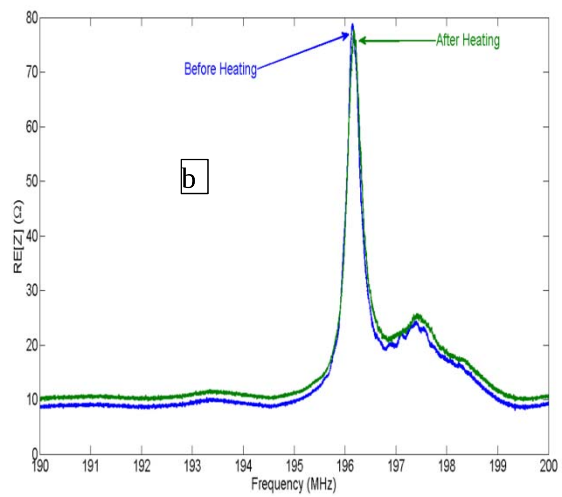
- Six cycles between 350°C and 800°C: stability of frequency response

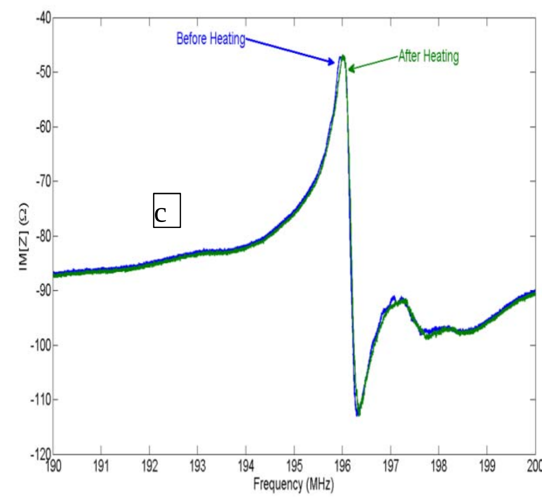
(a) |S11|

(b) Resistance

(c) Reactance







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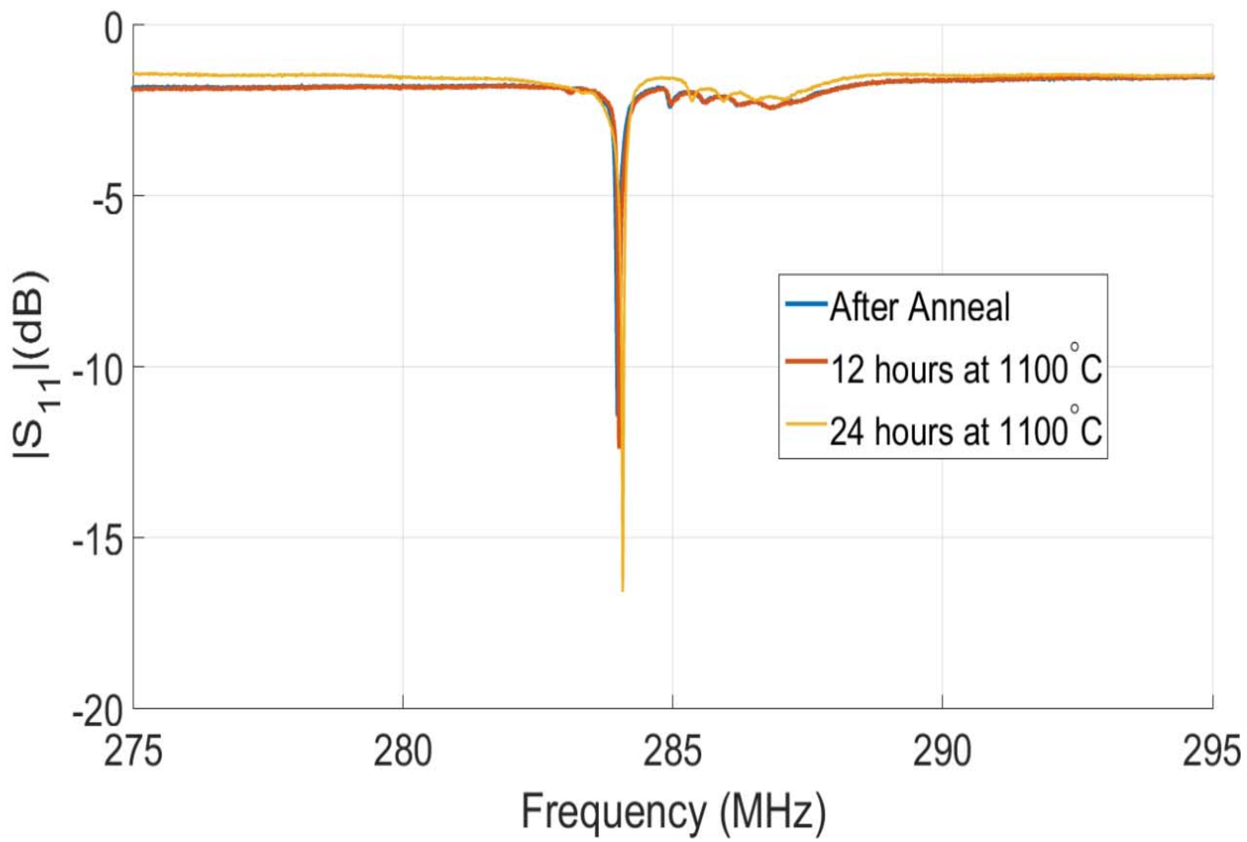
PtNi|Zr Electrodes on LGS SAW: 1100°C

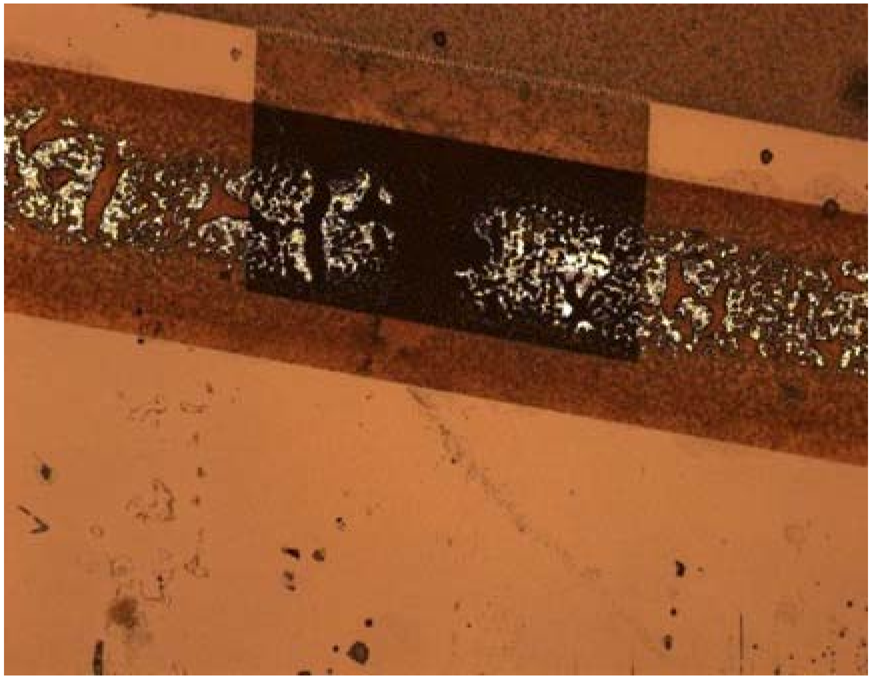
- Sensor tested up to 1100°C
  - PtNi|PtZr → 12h; PtNi|Zr → 24h.

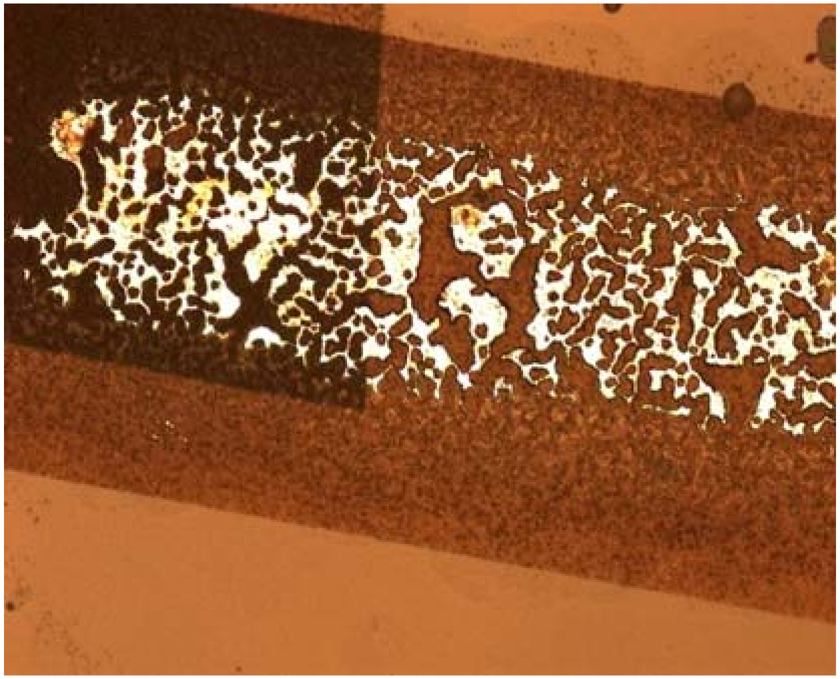


Contact Verification

➢ Contacts (Pt-based thick paste):

- Used in the capacitive coupling to SAW sensor transducer
- Exposed to 1200°C for 104 hours: paste volatilization





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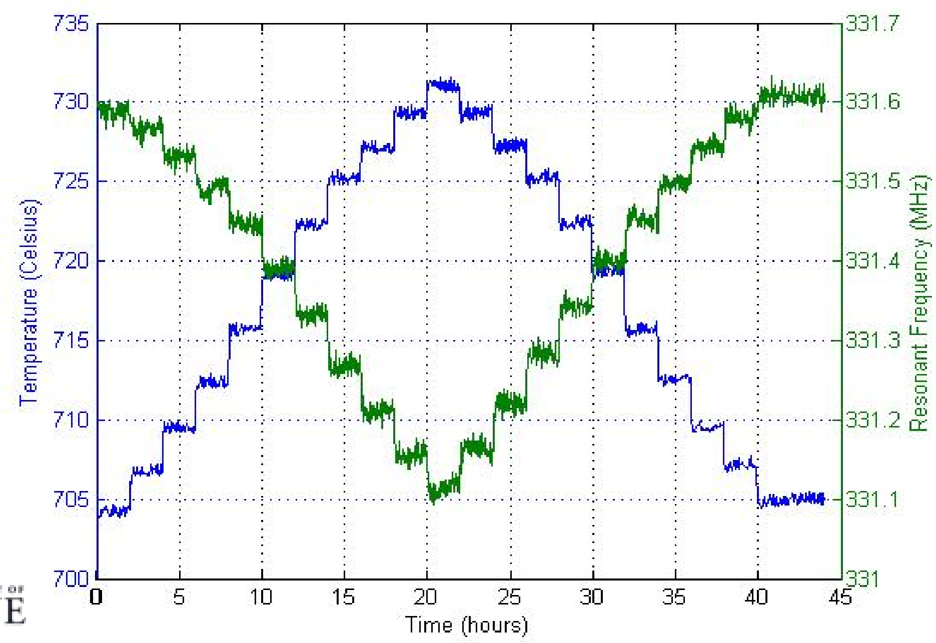
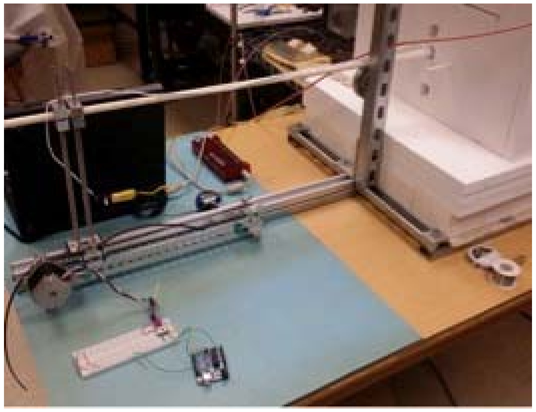
Positioning Furnace: Temp. Tracking

- Wireless sensor interrogation: tracking temperature in the position furnace
- Temperature span of 25°C @ 700°C (fluctuation furnace control: ~1°C)
- Test repeated several times: repetitive
- Calibration & analysis: paper being prepared





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IV. Current Effort: Wireless SAW Array Deployment on Boiler Tubes for Condition Based Maintenance

Motivation

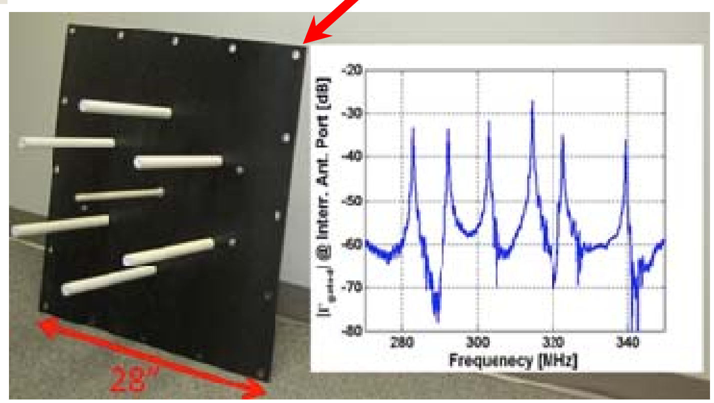
➢ Upon proof that UMaine/Environetix sensor array
- Achieved successful operation in Power Plant Economizer
- Wireless sensor array response: stable (six sensor array used)
- Packaging stable in such environment
- Tests performed throughout 2 years

➢ PERC was inquired → practical usage

Wireless / Battery free / HE sensor array

➢ Indicated the need for:

Placement of sensor array on Boiler tubes for condition based maintenance



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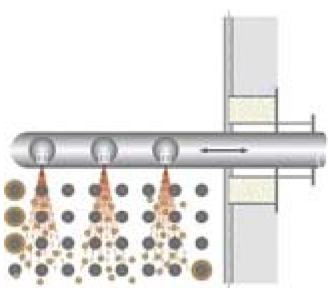
Power Plant Application: Boiler Tubes

- Formation of soot:
  - Due to Municipal Solid Waste burning
  - Also applies to coal power plants
- Soot →
  - Clogs the superheaters & boiler (slagging)
  - Restricts gas flow
  - Diminish heat exchange
  - Reduce power plant efficiency
  - Soot fires: damage the tubes
- Sootblower used to dislodge soot

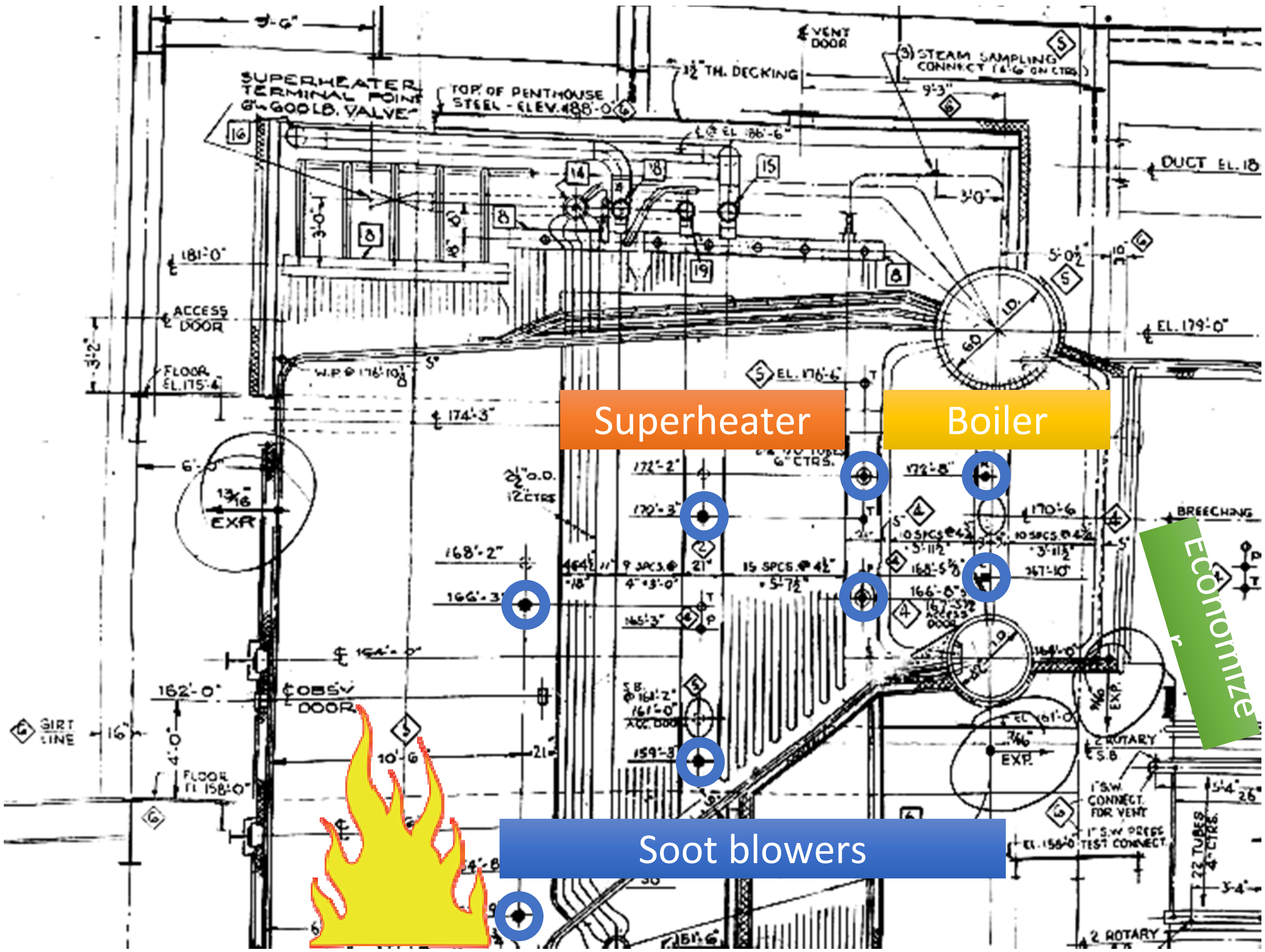


Power Plant Application: Boiler Tubes

- **The questions are:**
  - **When should the soot blowers be activated?**
  - **In which location is the slagging more significant?**
  - **For how long should they be activated?**
- **If too late:** difficult to remove soot → Power plant down
- **Timing & relevance of removing the soot:**
  - **Improve power plant efficiency**
  - **More efficiency → less pollution → Environmental effect**
  - **Prevent soot fires**
- **Thus → Condition Based Maintenance**

PERC Plant Layout

➢ **WHEN SHOULD THE SOOT BLOWERS BE ACTIVATED?**

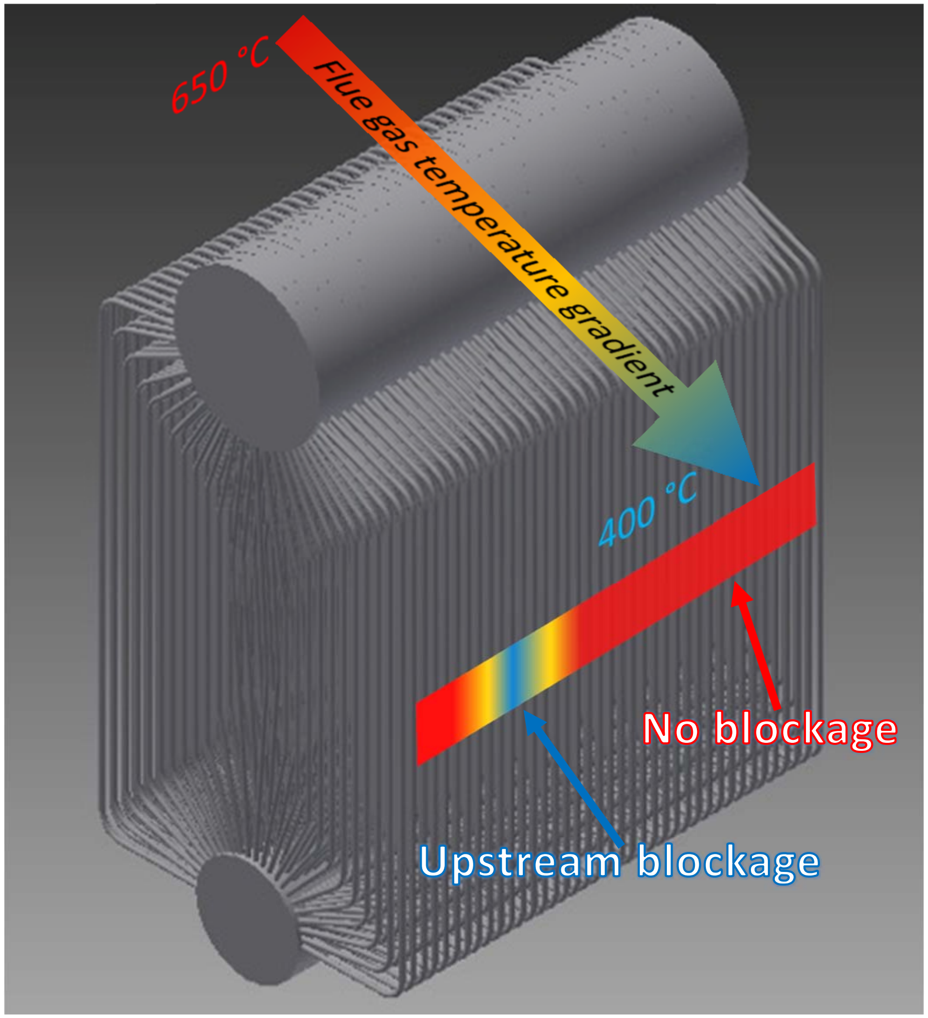


Project Goal

_Q_: How can we locate the blockage in order to optimally aim the steam blowers?

A: Wireless battery-free (maintenance free) **SAW Harsh environment temperature sensors positioned at the boiler tubes** can be used to obtain a temperature profile.

Cooler zones **indicate airflow blockage**.



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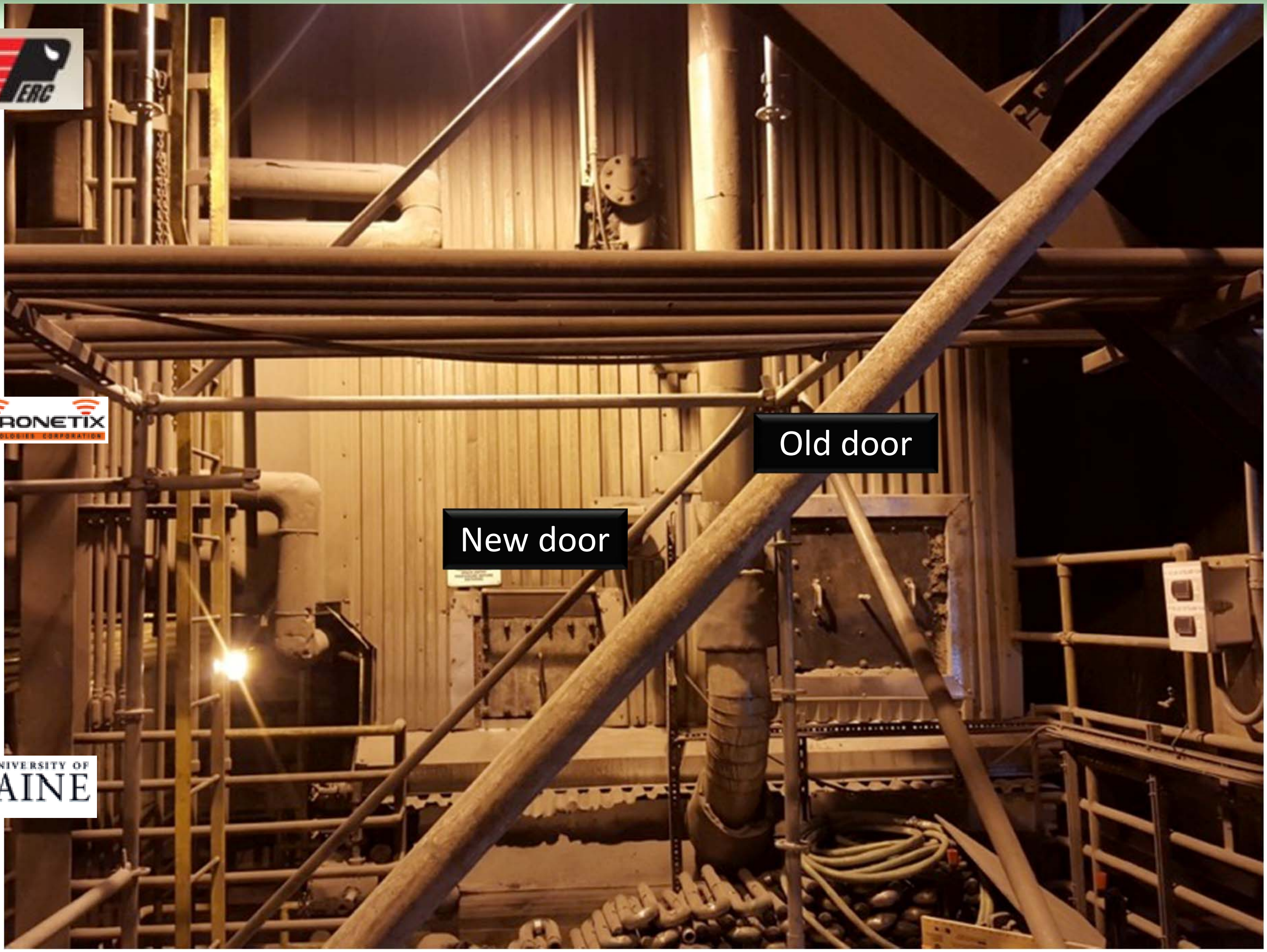
Access to economizer/boiler



Boiler tubes seen from the economizer

- Yearly maintenance: March 2016

Previous Array Revision

- Previously employed monopoles and dipoles not appropriate for the boiler tubes
  - Vertical polarization: significant attenuation
  - Horizontal polarization: block airflow
- Another solution devised & implemented :
  - High-Temperature Suspended Inverted F-antenna (SIFA)
- Encouraging preliminary tests at Environetix's laboratories

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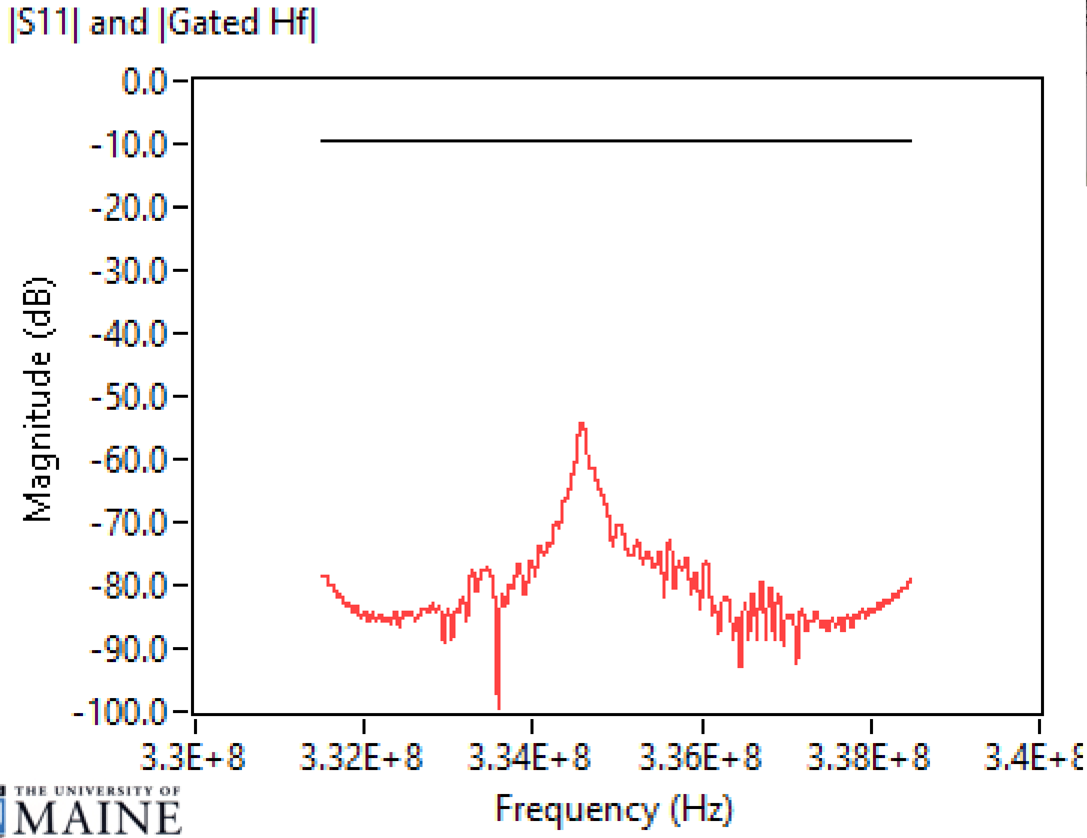
Prototype Testing

- Encouraging tests → Led to the development of:
  - Prototype HT antennas connected to battery-free sensors
  - SAW sensor interrogated: > 3 meters (room temperature)
  - Ceramic packaging to protect sensor and radiating element



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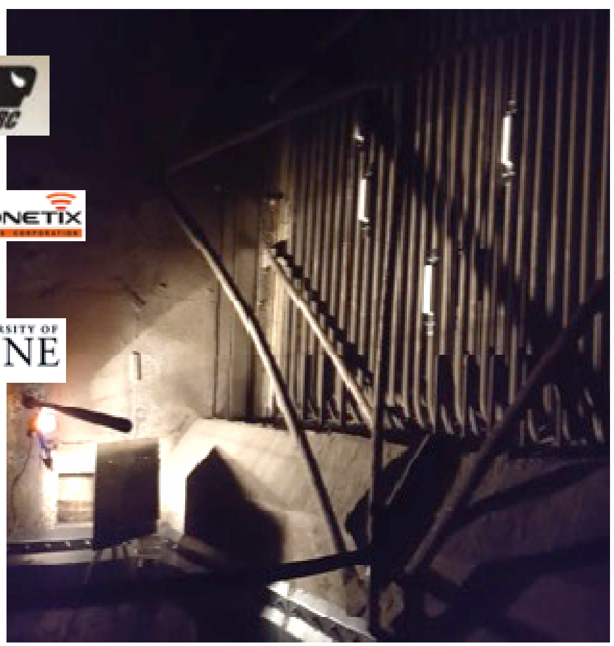
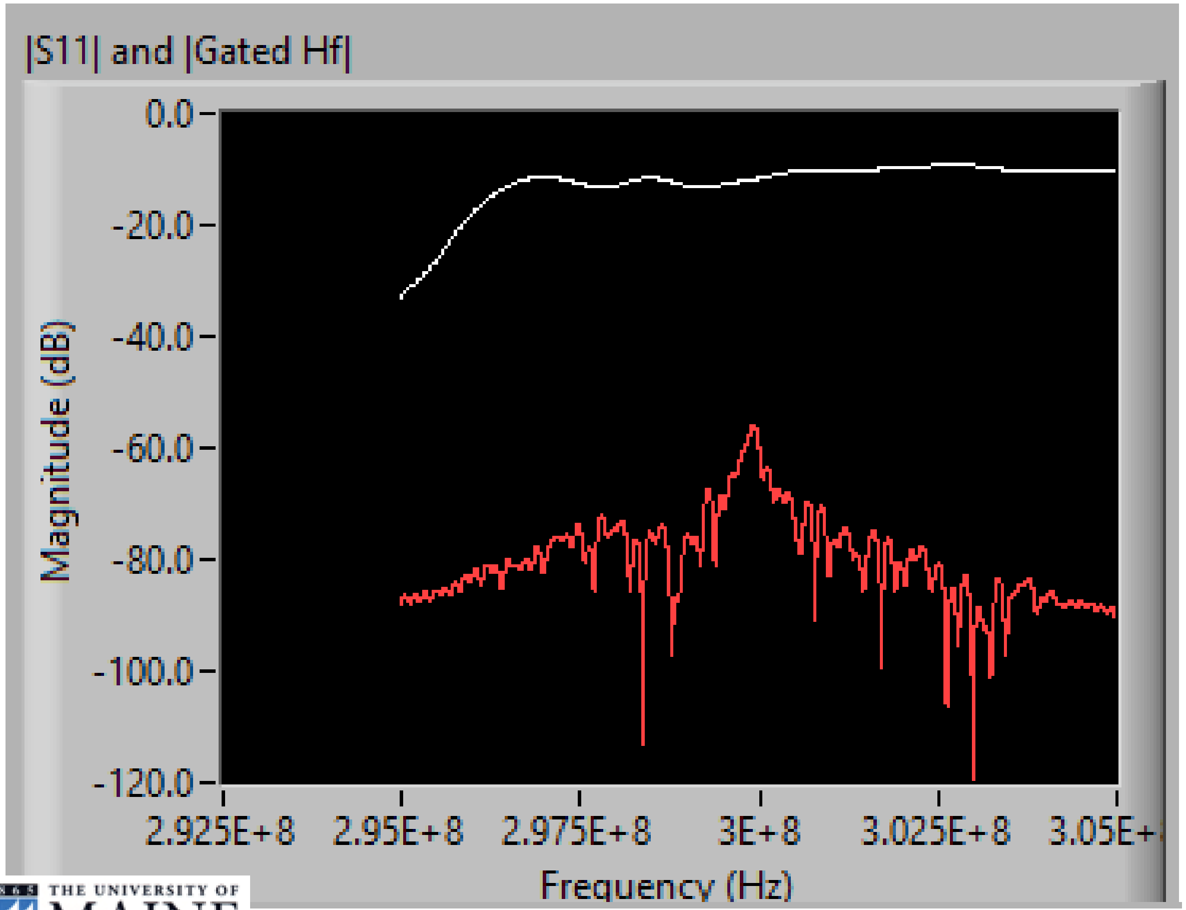
Sensor Array Deployed at PERC

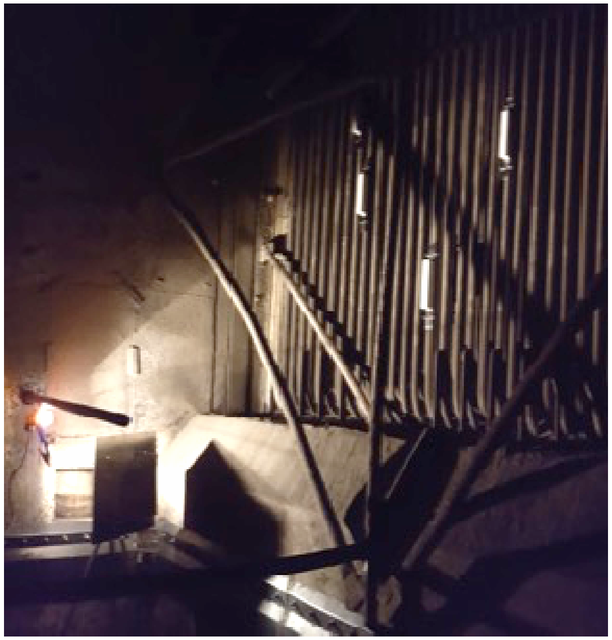
- Four sensor packages were assembled & installed at PERC during the March 16 shut down
- Their relative placement is shown in the figure
- Preliminary Interrogation antenna (lower corner) used to test the installed sensors.



Sensor Performance

- Typical sensor response obtained after signal processing
  - Room temperature antenna on tripod used





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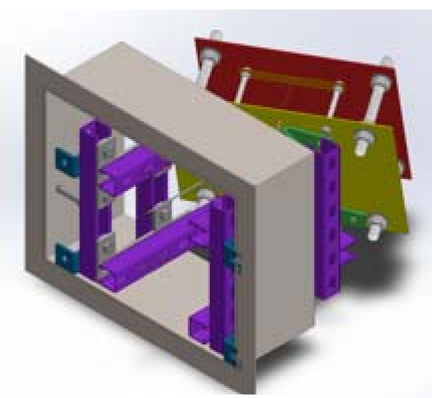
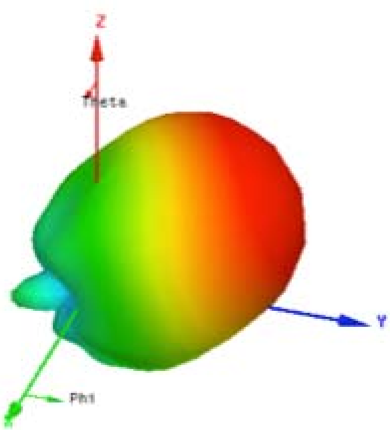
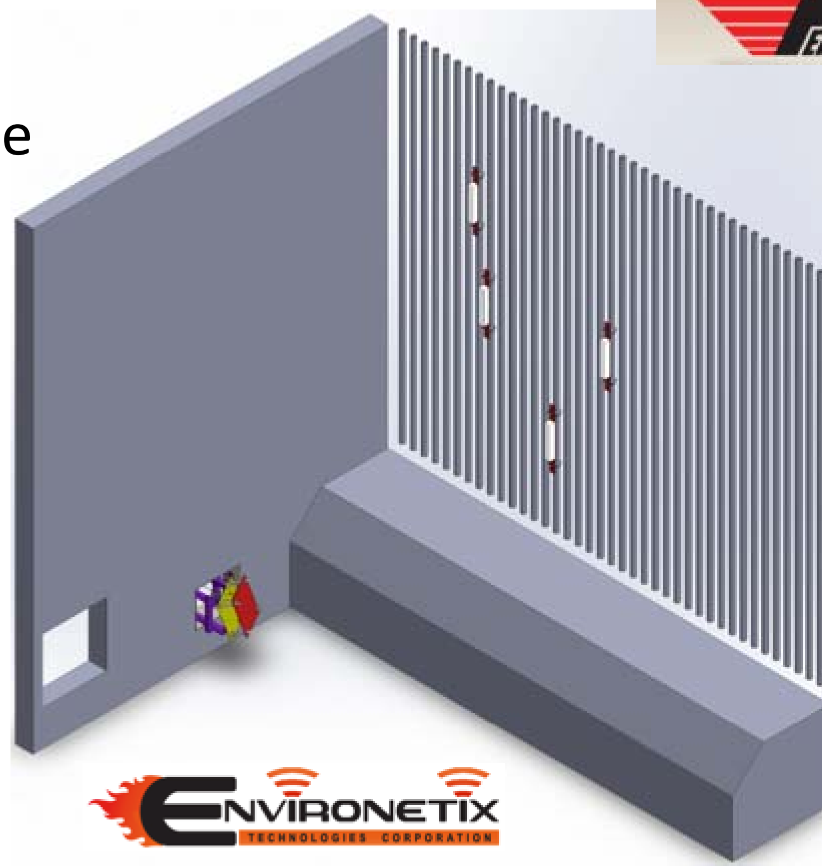
At PERC: Relative Location

- Initial approach: least invasive to PERC as possible
- Attempt to work with the available points of access
- Interrogation antenna: wall at 90° with boiler
- Current phase:

  Design a tilted structure to provide the appropriate radiation pattern to access the wireless sensors







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IV. Conclusions & Acknowledgements

Summarizing …

- This presentation reviewed:
  - The project motivation and goals
  - The majors accomplishments:
    - ✓ List of prior major progresses & findings
    - ✓ Contribution to the area of High-Temp. Harsh-Environment Sensors
    - ✓ Both academically & reduction to practice
- Discussion of achievement during the past year:
  - Confirmation of thin film electrode best performance
  - Confirmation of sensor device stability
  - Progresses of wireless interrogation of HT position furnace
- The description of current project effort:
  - Transition technology → Power Plant boiler tubes monitoring

Current Project Publications (1 of 2)

1. Scott C. Moulzolf, Roby Behanan, Robert J. Lad, and Mauricio Pereira da Cunha, "Langasite SAW Pressure Sensor for Harsh Environments," IEEE International Ultrasonics Symposium Proceedings, 2012, Dresden, Germany, pp.1224-1227.

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Additional Dissemination

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2. M. Pereira da Cunha, "*Technology and Product Update: Wireless Sensors for Extreme Environments*," WEB Conference with ExxonMobil, Feb. 02, 2012.
3. M. Pereira da Cunha, "*High-temperature wireless sensor design solutions*," Invited to sit on the panel and motive discussion on the Wed. session of the Wireless workshop at the International Instrumentation Symposium (IIS), La Jolla, CA, June 6, 2012.
4. M. Pereira da Cunha, "*Industrial Insertion of Wireless Microwave Acoustic Sensors and Systems for Harsh Environments*," Strategic Advisory Board (SAB) of the Propulsion Instrumentation Working Group (PIWG), June 06, 2012.
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M. Pereira da Cunha[1,2], R.J. Lad[1,2], Anin Maskay[1], D.J. Frankel[1], S.C. Moulzolf[1], J. Simonsen[1], P. Davulis[1], R. Benahan[1], M. Breen[1], M. Call[1], G. Bernhardt[1], Robert Dunning[2], Paul Wilson[2], Greg Harkay[2], Suzie Sharrow[2], and Praveen Gunturi[2].

[1] Laboratory of Surface Science and Technology, University of Maine, Orono, ME, U.S.A.
[2] Environetix Technologies Corporation, Orono, ME, U.S.A.

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