TECHNOLOGY MATURATION OF WIRELESS HARSH-ENVIRONMENT SENSORS FOR IMPROVED CONDITION-BASED MONITORING OF COAL-FIRED POWER GENERATION

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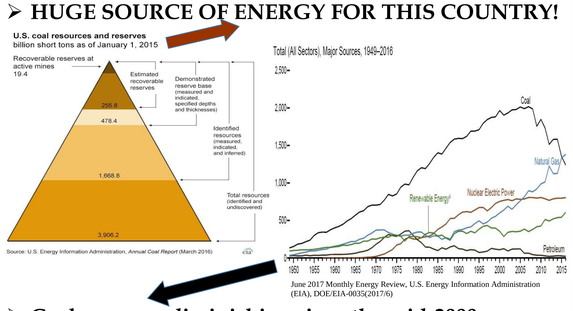
Motivation

COAL: U.S. Energy Information Administration (EIA)

- U.S.A → 21% of the world's proven recoverable reserves of coal (255.8 billion short tons)
- This is only 6.5% of the potential total coal resources
- HUGE SOURCE OF ENERGY FOR THIS COUNTRY!



June 2017 Monthly Energy Review, U.S. Energy Information Administration (EIA), DOE/EIA-0035(2017/6)

- Coal usage → diminishing since the mid-2000s :
  - ✓ Coal-fired Variable Operations and Maintenance (VOM) consistently HIGHER than Natural Gas
  - ✓ Emissions
- High Coal availability in the U.S. calls for:
  - ✓ New Advanced Technologies for use in harsh environments
  - ✓ Advanced Sensors for Condition Based Maintenance (CBM)

Advanced Sensors:
↓ Operating Cost ↓ Maintenance Cost ↓ Emissions

Goals and Objectives

GOALS

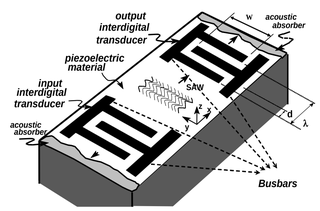
- Usage of Harsh-Environment (HE) High-Temperature (HT) Wireless Surface Acoustic Wave (SAW) Sensor Technology to:
  - ✓ ↑ Reliable maintenance through CBM of critical coal-based power plant equipment
  - ✓ ↑ Cost-effective efficiency of power plant operations
  - ✓ ↑ Power Plant Safety
- ↑ HE/HT Wireless SAW Sensor Technology Readiness Level (TRL) via test & implementation

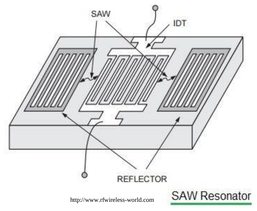
OBJECTIVES

- HE/HT Wireless Surface Acoustic Wave (SAW) Temperature Sensors → CBM in Coal Power Plants
- Improvement in the packaging of SAW temperature sensors & antennas
- Advancement in piezoelectric films and strain sensors
- Wireless communication protocols & signal processing refinements
- Technology validation and transition to coal-based power plants

Surface Acoustic Wave (SAW) Technology

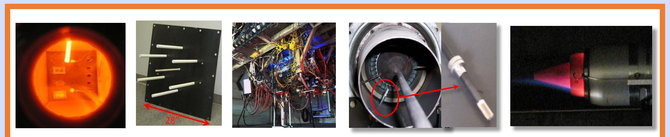
- Class of Micromechanical Systems (MEMS)
- Electronic platform: electrical signal translated into microwave acoustics using a piezoelectric substrate
- Delay line and resonators: typical SAW structures used for sensor applications
- Interdigitated transducers (IDTs) used for wave generation; reflector electrodes used for acoustic wave energy trapping





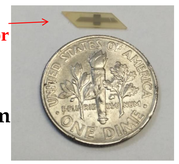
- Typical operating features:
  - ✓ $v_p \approx 3.10^3$ m/s << c= 3.10^8 m/s (5 order of mag. ⇒ size ↓)
  - ✓ Frequency range: ~50 MHz to a few GHz (range determined by size & lithography)
  - ✓ Respective λ (v_p = λ . F) ⇒ from 60μm to 1.5μm
    ⇒ minimum feature size → λ/4 → ~ 15μm to 0.4μm
- Low cost in high volume production
- Reproducible manufacturing based on semiconductor fabrication capabilities

SAW Sensors in Harsh Environments



- SAW technology can be used to measure a variety of sensor parameters: temperature, pressure, torque, strain, gas
- Small sensor footprint
- Robust and stable over long-term
- Varying detection mechanisms: loading, absorption, stress, changes in film thickness or material properties
- Existence of substrates for high temperature applications, such as the langasite (LGS)
  - ✓ LGS : 1470°C Melting point

300 MHz SAW Sensor

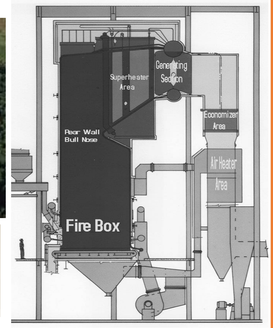


Advantages of SAW Sensors:
Wireless, battery-free, robust, passive operational capability leading to reduced installation & maintenance cost
↓ Complexity ↑ Reliability ↓ Size

UMaine/Environetix Previous Experience

Collaboration with Penobscot Energy Recovery Company (PERC) Power Plant in Orrington, ME

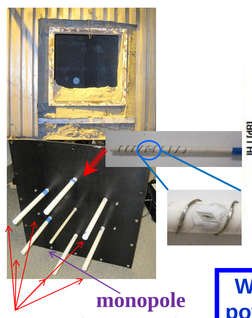
- PERC → Municipal Solid Waste (MSW) Power Plant
- Goal → Implement a Wireless Temperature Monitoring System(s) at the MSW power plant



- Power plant conditions:
  - ✓ Temps ↑ 900°C (1650°F)
  - ✓ Highly erosive/corrosive exhaust gases

¾" Schedule 40 Hastelloy thermocouple tube after ~6 mo

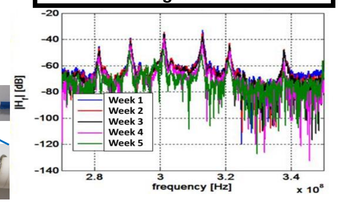
- Wireless HE/HT Sensor Array tested at Economizer



6 dipoles + SAW Sensors

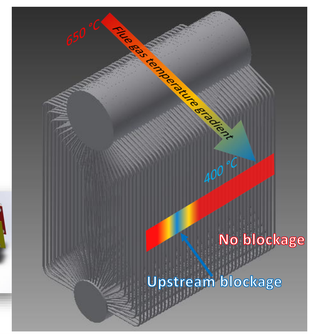
monopole interrogating antenna

Example of wireless temperature monitoring over 5 weeks



Wireless SAW sensor tests in power plant harsh environment carried out over 2 years

- Wireless HE/HT Sensor Array tested in Boiler
- PERC Indicated the need for:
  - ✓ Placement of sensor array on Boiler tubes for CBM
  - ✓ Locate blockage → optimally aim steam/soot blowers



Project Structure & Implementation

- Project Tasks:
  - ✓ TASK 1 – Project Management & Planning
  - ✓ TASK 2 – Technology Transition & Adaptation: High Temperature Wireless SAW Sensor Technology in Harsh Coal-fired Power Plant Environments
  - ✓ TASK 3 – Implementation and Testing of Mature Prototype Wireless Sensor System within Power Plants
  - ✓ TASK 4 – Protective Coatings and Piezoelectric Thin Films for Improved Sensor Packaging & Performance
  - ✓ TASK 5 – Development of Prototype SAW-based Strain Sensor

Milestone	Planned Completion	Milestone Title
M1	1st quarter of Year 1	Kick-off Meeting with DOE / NETL Program Officer
M2	4th quarter of Year 1	Definition of Target Locations to Install Prototype Wireless HE SAW Sensor System
M3	1st quarter of Year 2	Wireless Communication Planning and Testing
M4	3rd quarter of Year 2	Fabrication of Prototype Wireless HE SAW Sensor System
M5	4th quarter of Year 2	Installation of Specific Prototype Sensor System in Identified Power Plant Locations
M6	1st quarter of Year 3	Testing of Specific Prototype Sensor System in Identified Power Plant Locations
M7	4th quarter of Year 3	Refinement of Sensor System Performance and Additional Testing
M8	1st quarter of Year 3	Identification of the Best Thin Film Dielectric Coatings for Packaging of Sensor in Harsh-Environment
M9	2nd quarter of Year 3	Identification of the Best Piezoelectric Materials for Enhanced Sensor Manufacturability and Integration with Sensor Antenna
M10	2nd quarter of Year 3	Field Testing of Wireless Temperature Sensor Arrays in Selected Power Plant Locations
M11	2nd quarter of Year 3	Demonstration of Strain Sensor
M12	4th quarter of Year 3	Final Demonstrations in Coal-fired Power Plants and Final Project Reporting Preparation to DOE / NETL

- Current Activity Status:
  - ✓ Kick-off meeting DOE on February 22, 2018
  - ✓ Environetix subcontract executed on March 21, 2018
  - ✓ Contact & Coordination with Duke Energy / PERC/ Other Coal-based Power Plants
  - ✓ Hiring staff for project support at UMaine
  - ✓ Engaging Grad and Undergrad students

Conclusions

- Project initiated within the past 2 months.
- Presented Project Background: Motivation, Goals, & Objectives
- Provided SAW Technological Overview and HE/HT SAW Sensor Background
- UMaine/Environetix are under current discussions with coal power plant collaborators to be selected as test bed for technology demonstration and advancement
- Described Project Structure & Implementation
  - ✓ Tasks & Milestones
  - ✓ Current Activity Status

DOE / NETL Project DE-FE0031550
Program DE-FOA-0001728:
Advanced Combustion Systems (ACS): Existing Plant Improvements and Transformational Technologies