World Material Forum – June 9-10, 2016 Nancy, France

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Wireless Passive Sensor Technology

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College of Engineering and Computer Science

World Materials Forum

Materials and Sensors

- Sensors are effectively used to affect materials:
  - Process monitoring
  - Material process development
  - Materials and associated energy costs can be reduced by at least 25% through:
    - Conservation
    - Health monitoring of structures, devices or systems
    - Data mining
- Material development and costs will be affected through data acquisition and sharing – accomplished through the IOT

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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.

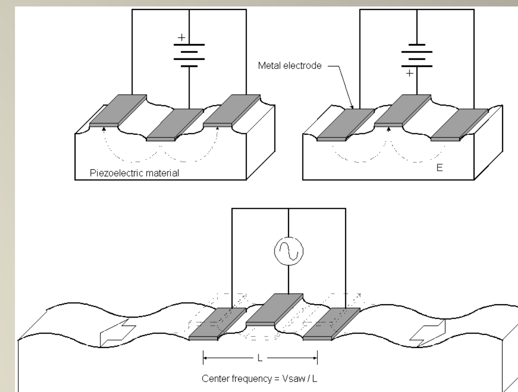
Several universities tried to solve this problem, but the best approach came from the University of Central Florida (UCF) who advocated surface acoustic wave sensors and demonstrated an orthogonal frequency code (OFC) wireless multiplexing scheme in 2005. We at KSC decided to support this SAW approach.

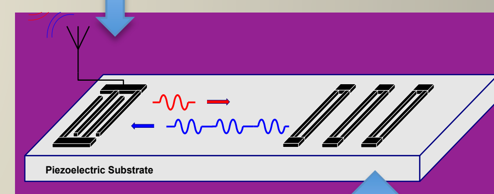
See NASA Tech Brief on SAW Sensor

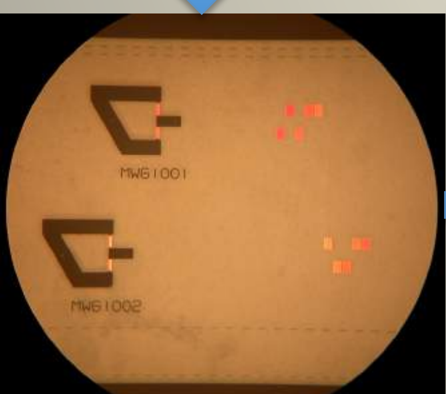
Jim Nichols – KSC/NASA
Licensing Manager
NASA Techbriefs Webinar
Sept 19, 2013

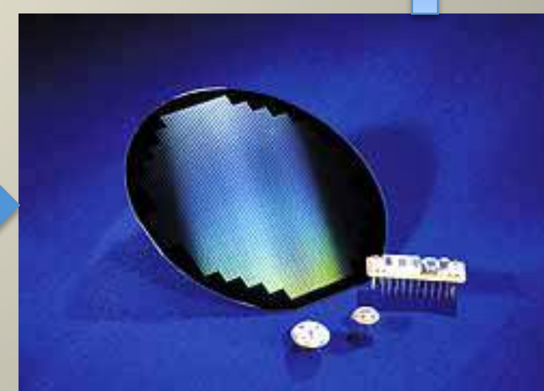
What is a Surface Acoustic Wave (SAW) Device?

- A solid state device
  - Converts electrical energy into a mechanical wave on a high-Q, low-loss, single crystal substrate
  - Provides very complex signal processing in a very small volume
  - Mass produced using IC processing
- 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









Contrasting/Competing Technology

- **Silicon chip** – (non-passive) requires power beyond interrogation signal power but is solid-state having on-board processing, storage and possible gain. Limited temperature and environment
- **Simple L-C antenna** – passive, low-Q, resonant, no processing gain, limited range, not solid-state
- **Solid-State Resonator** – passive, high-Q, but no processing gain, only frequency coded, fading and jamming problems, operates in harsh environments
- **SAW OFC Delay-line**– passive, solid-state, high Q, processing gain, RFID time & frequency encoded, low probability of intercept and detection, immune to fading, operates in harsh environments, long range and precision

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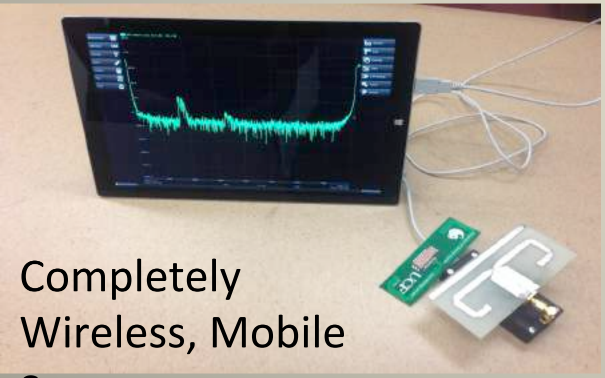
SAW Sensor Advantageous

- External stimuli affects device parameters (frequency, phase, amplitude, delay)
- SAW sensor
    - Passive
    - Wired or wireless
- RFID - Coded devices allow for operation of multiple sensors
- Small, rugged, low-cost sensor solution
- Monolithic structure fabricated with current IC photolithography techniques
- Fabricated on COTS single crystal substrates

SAW Passive Sensors Goals

- A game-changing approach
- Wireless, “infinite-life”, and multi-coded
- Single communication platform for diverse sensor embodiments
- Manufacture sensors < $1.00
- Manufacture transceiver (Reader) < $100
- High volume manufacturing of millions of SAW sensors/year
- Operation over large temperatures in harsh environments
- Multiple sensor operations on a single chip



Completely Wireless, Mobile System

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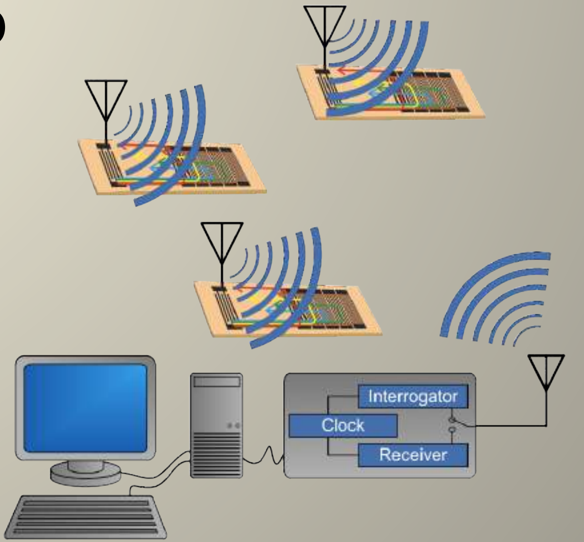
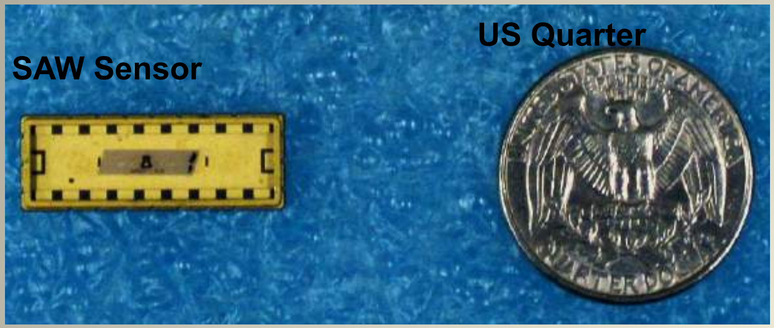
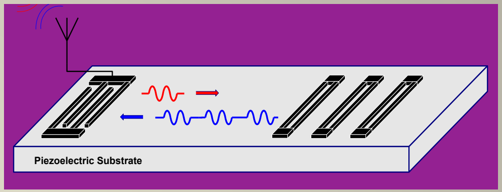


Confluence of Technology

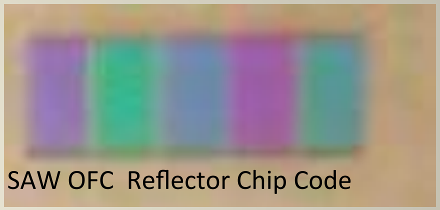
- **RF receiver technology – fast, small & cheap**
- **Digital Hardware – fast, small & cheap**
- **Post-processing – fast, small & cheap**
- **SAW design, analysis and simulation**
- **SAW sensor embodiments**
  - **On-board sensors**
  - **Off-board sensors**

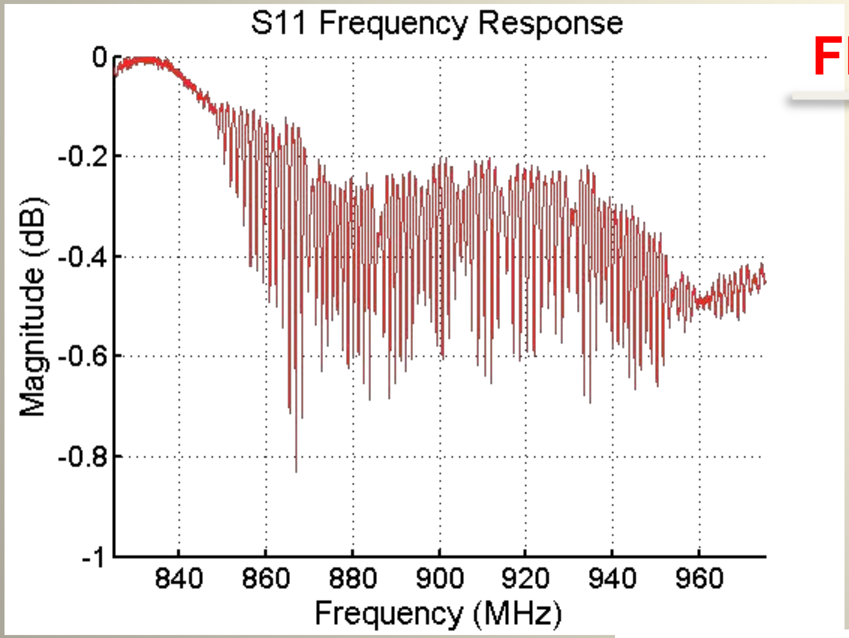
Example 915 MHz SAW OFC Sensor



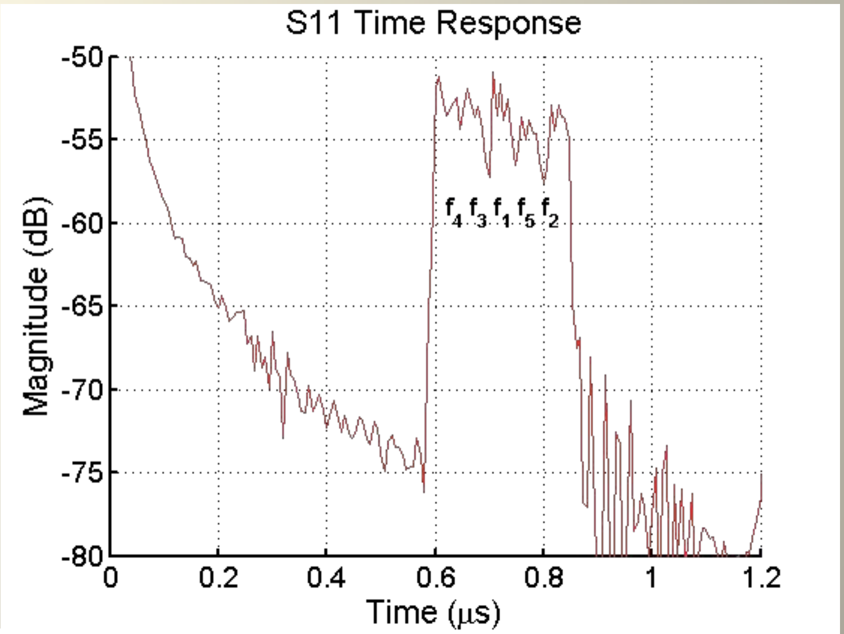


f4 f3 f1 f5 f2

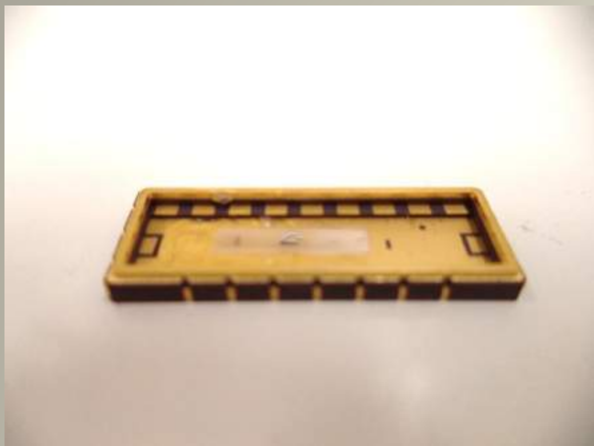


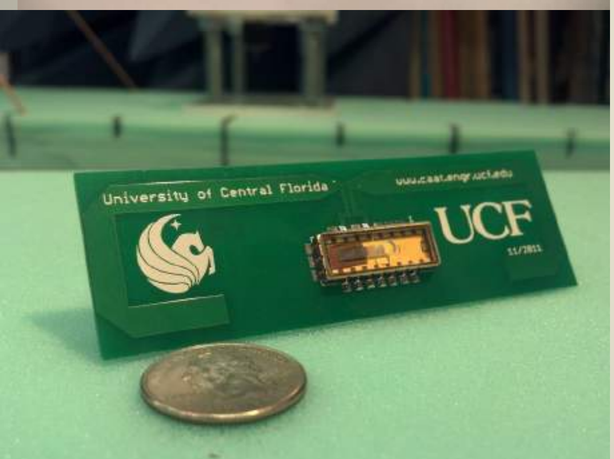


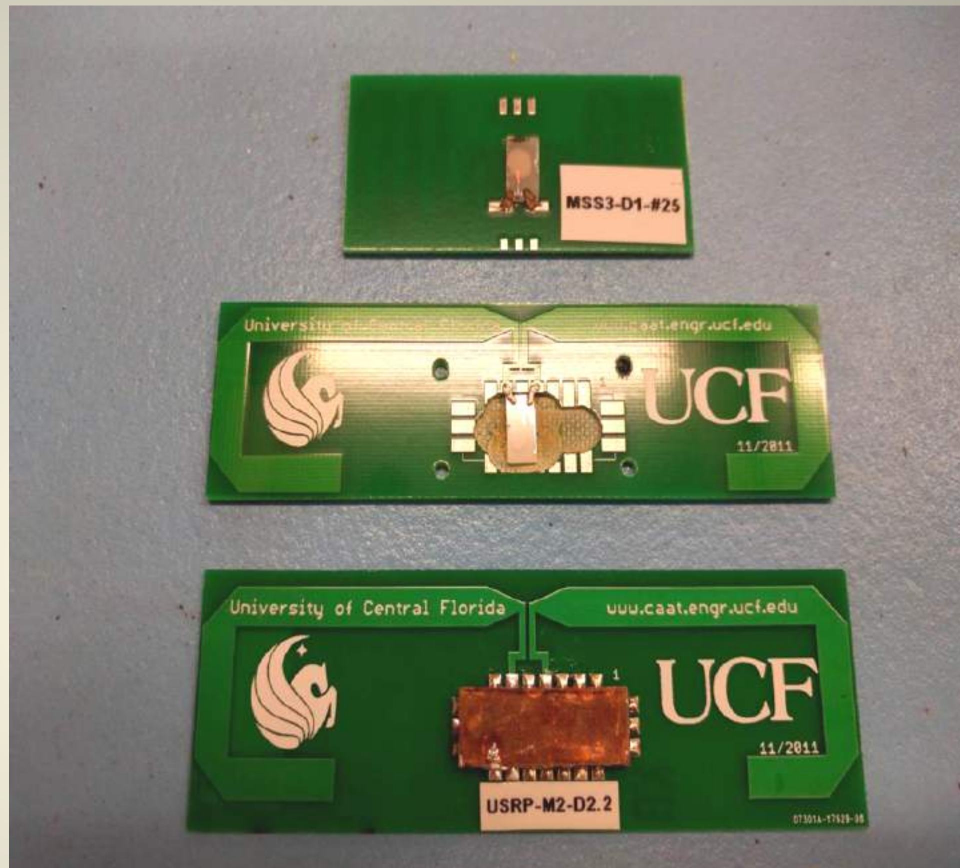
FFT



SAW Sensor + Antenna





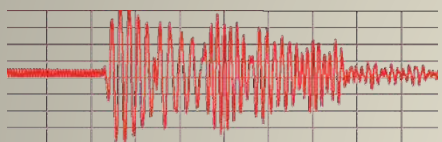


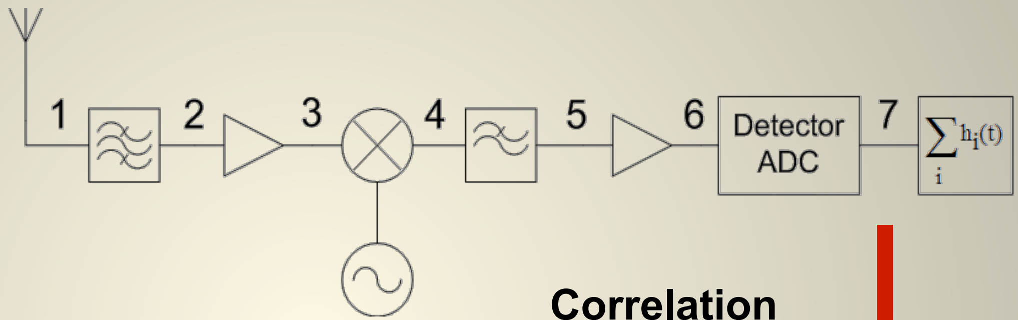
Photograph of various SAW gas sensor embodiments. The design evolution is from bottom to top. The upper device has an embedded sensor and a small PCB antenna. Miniature antenna with exposed device (top), folded dipole antenna with embedded SAW die (middle), and folded dipole antenna with packaged SAW device (bottom).

UCF Synchronous Correlator Receiver

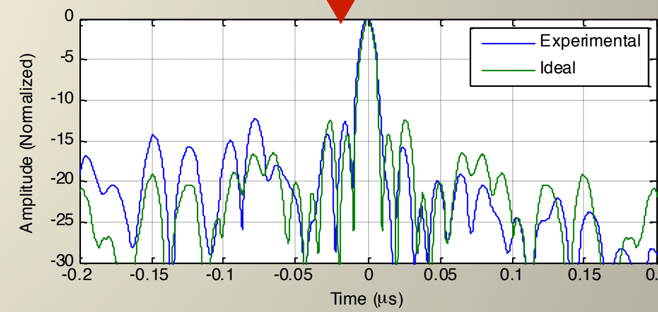
Block diagram of a correlator receiver using ADC

OFC Single Sensor Signal

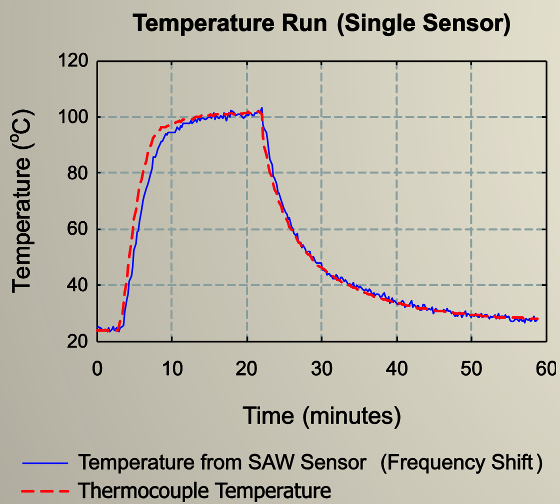




Correlation Output



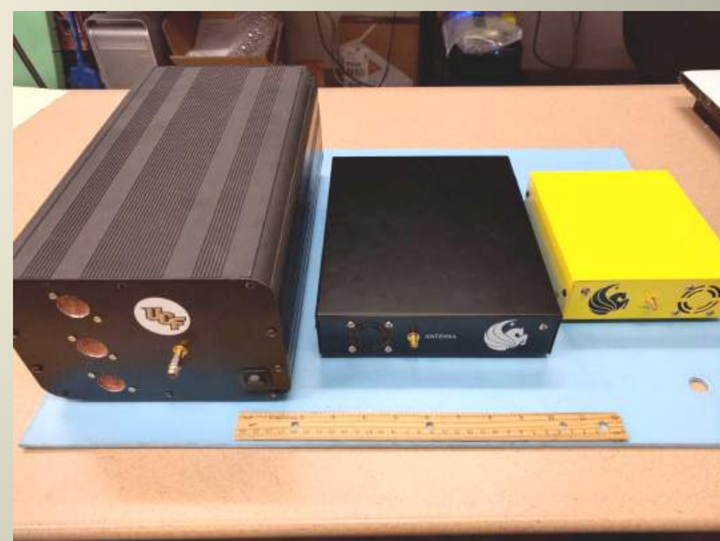
Temperature Extraction



Passive Wireless Sensor Features

- Sensor < $1.00
- Reader (Transceiver) < $1000; moving toward $100 cost
- No power required – infinite life
- Ubiquitous deployment – wide areas, redundancy, millions/year
- Multi-sensing with a single device and transceiver platform
- Mobile Internet device and WiFi connectivity
- Security

- Demonstrated:
  - Ranges 100 ft., 1C Std. Dev.
  - Temperature precision of 0.001K (1mK)
  - Reversible H_2 gas at <50 ppm
  - Closure sensors
  - Cryogenic sensing in liquids and gas
  - Strain and pressure



Evolution of transceiver technology

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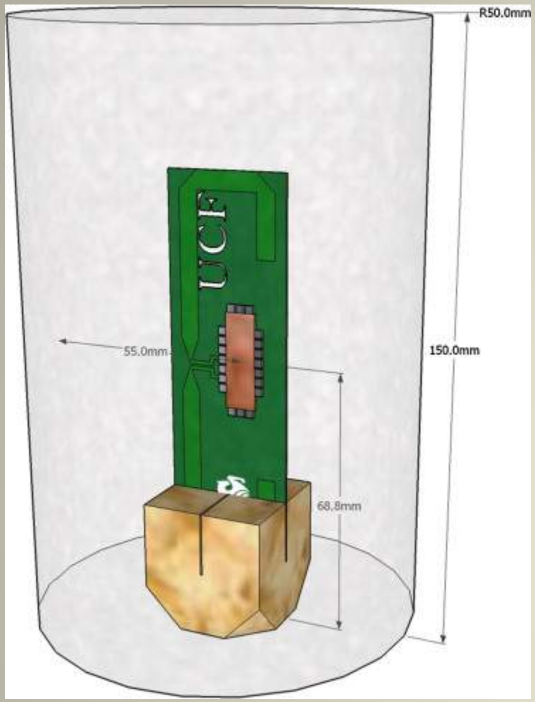
Emerging Applications for Passive Wireless Sensing

- Fossil fuel exploration and gas monitoring
- Power plant gas sensing of exhaust gases
- Engine and turbine sensors – just in-time maintenance
- Massively deployable sensors – hazardous gases
- Search and rescue – planes and people
- Structural health monitoring – bridges, buildings
- Building Monitoring – conserving energy
    - ***Three examples for consideration:***

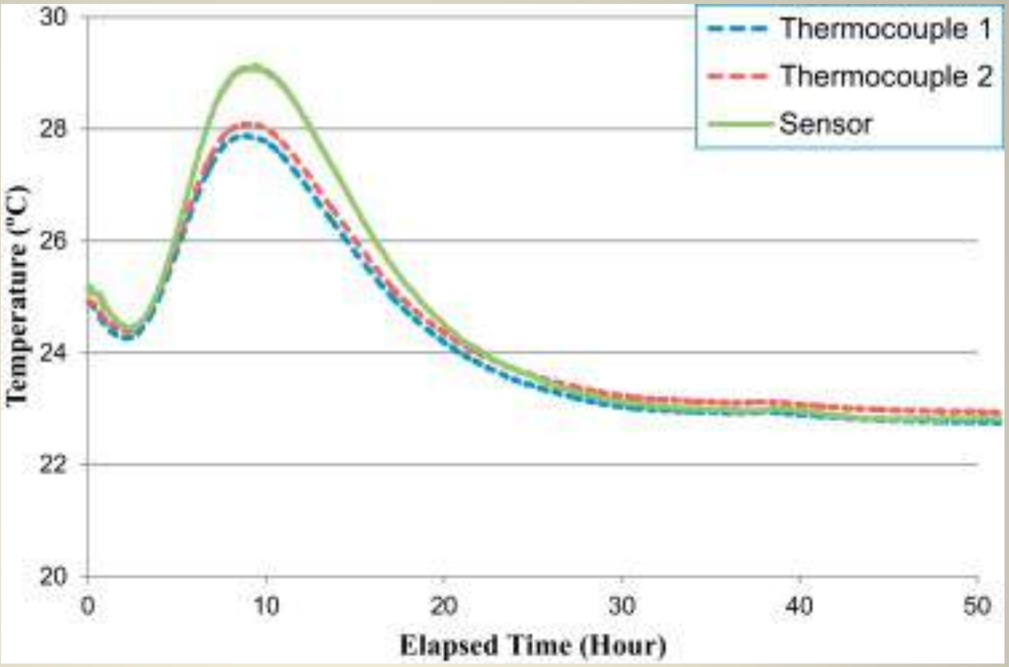
Transportation: Concrete Monitoring

- Bridge and road construction
  - Curing profile
    - Optimum cure time
    - Cement quality and strength
    - Construction productivity and reliability
    - Safety
    - Reduced construction and material cost
  - Post curing
    - Strength
    - Corrosion
    - Safety for bridge and road
    - Long lifetime – no maintenance and passive
    - Multi-sensors and mobile reader
    - Easily verifiable structural health monitoring (SHM)

Example of a SAW wireless sensor embedded in concrete and measured during curing.



Configuration of the SAW temperature sensor embedded in a concrete cylinder.

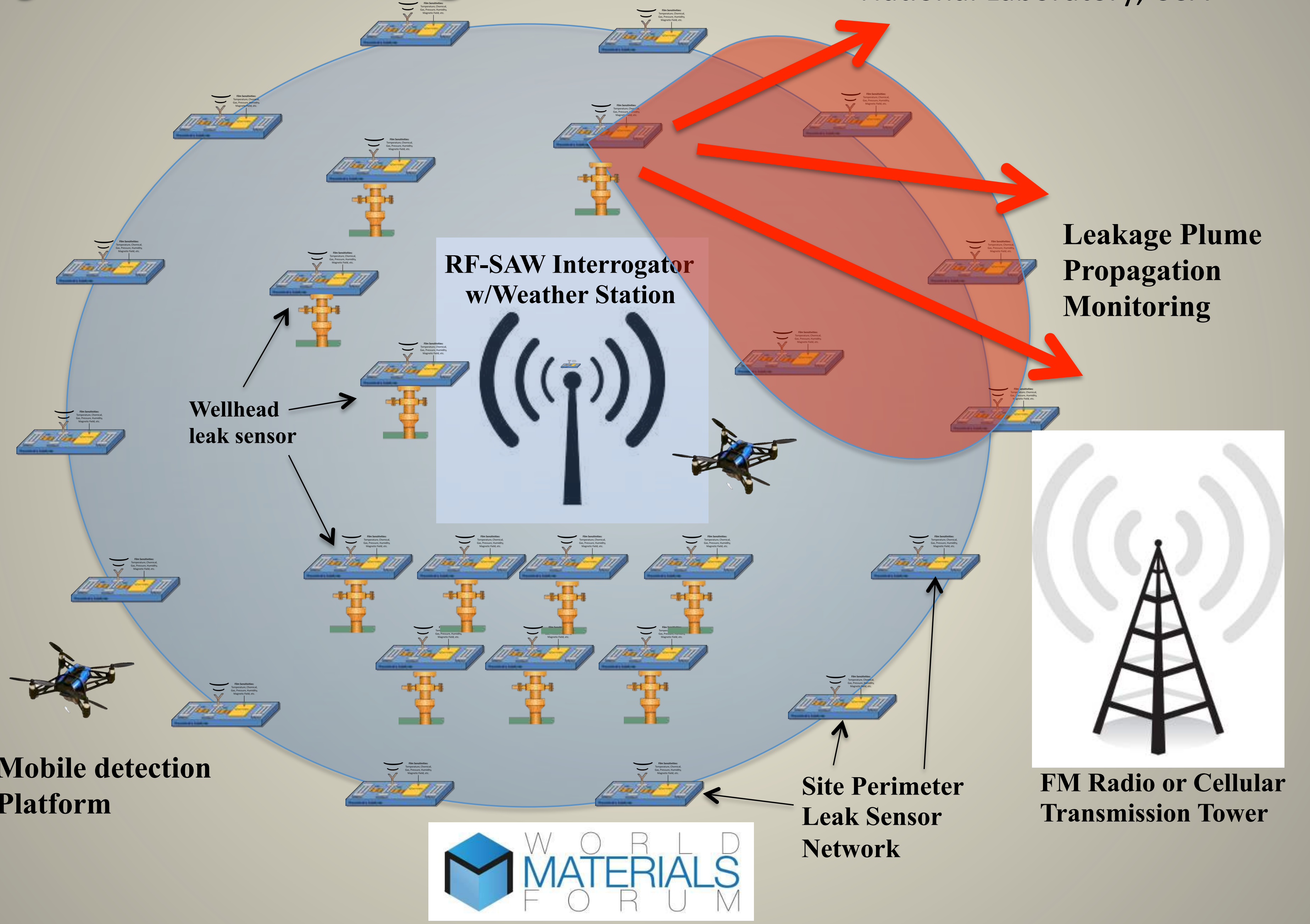


Internal concrete temperature versus time measured during the initial curing of concrete by embedding commercial thermocouples and a SAW sensor.

Jinyoung Kim, Rodriguez Luis, Marshall S. Smith, Jose A. Figueroa, Donald C. Malocha, Boo Hyun Nam, **Concrete temperature monitoring using passive wireless surface acoustic wave sensor system,** Sensors and Actuators A: Physical, Volume 224, 2015, 131–139, http://dx.doi.org/10.1016/j.sna.2015.01.028

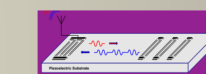
Hydro- fracturing Site

Slide Courtesy of Oak Ridge National Laboratory, USA



Power Grid -Wireless Temperature Monitoring

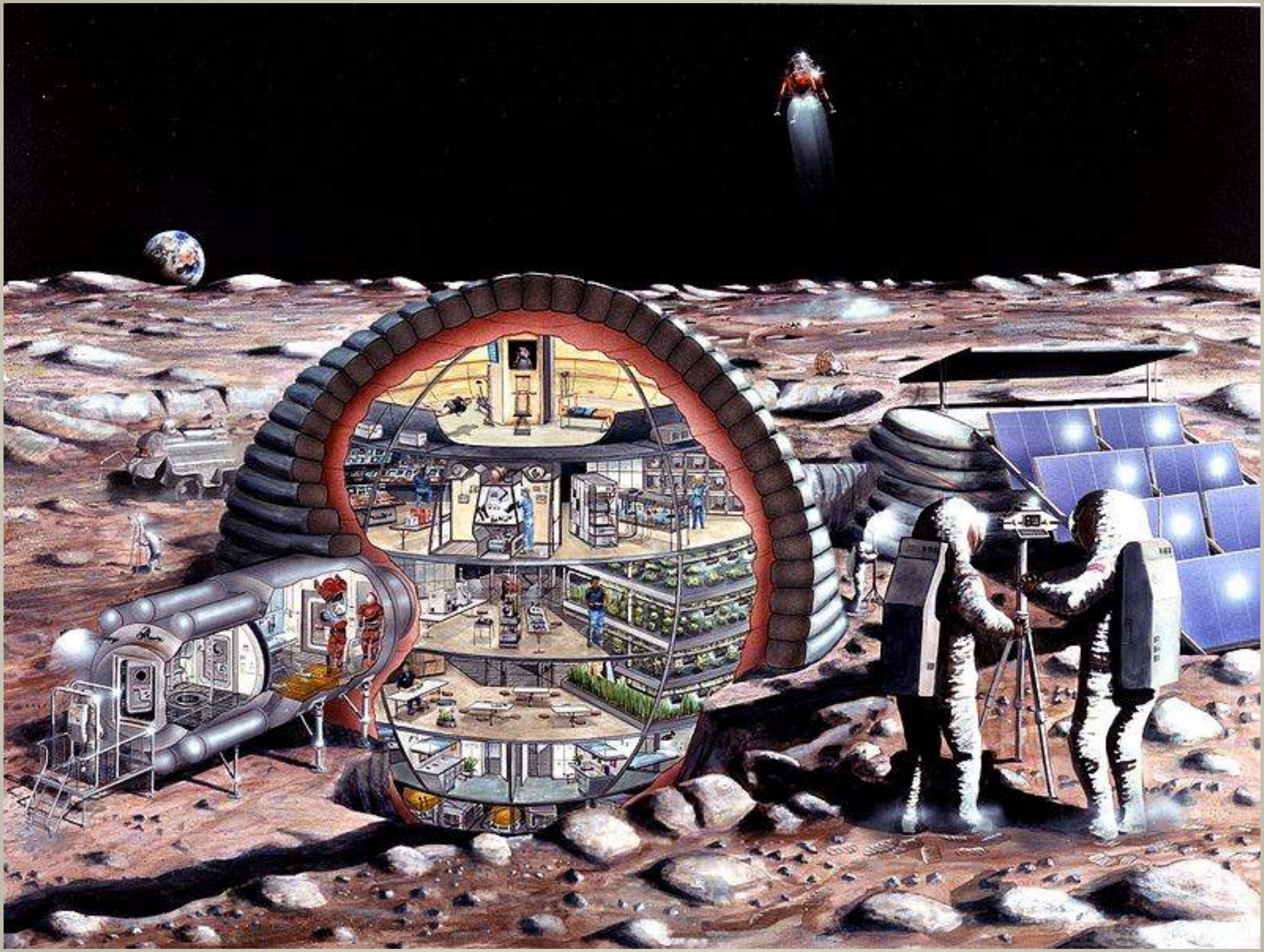
Drone w/ reader/internet



Temperature Sensor

Cellular Tower

Space Exploration



Inflatable Habitat

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Concluding Remarks

- Sensors will be ubiquitous – trajectory of trillions of sensors per year
- RFID sensors < $1.00
- Transceivers (readers) will soon be the size of a tablet and about the same cost (or less)
  - Meters of range
  - Real-time processing
  - Good precision
- SAW sensor technology will fill important application spaces which require passive and demanding specifications
- Wireless interconnectivity allows massive, parallel networking of sensor information that will have significant results on materials, energy and environment