Passive Wireless Sensor Technologies(PWST) & Needs
- a Library of Info“

Workshop Vision and Summary of Past Workshops

NASA Engineering and Safety Center
Avionics TDT
Wireless Avionics Community of Practice
George Studor

Dec 15, 2015

Passive Wireless Sensor Workshop at WiSEE 2015
December 2015

Agenda

- **Motivation for Passive Wireless Sensors,**
  a Tool in the Toolbox for "Fly-by-Wireless"
- **PWS Workshops – Purpose and Objectives**
- **PWS Workshop Summaries (reference)**
  - **2015 PWST – December Workshop Agenda**
  - **2015 PWST - May Workshop Agenda - Presentations**
  - **2013 PWST Workshop Presentation Summaries**
  - **2012 PWST Workshop Presentation Summaries**
  - **2011 PWST Workshop Presentation Summaries**

Space Shuttle Lessons Learned from Wireless Sensor Experiences

- **Technology demo can be funded if also meets strong user need.**
- **Can leverage SBIR/STTR to incrementally increase capability.**
- **Vehicle integration & ops are biggest cost/schedule drivers.**
- **Go for Smart, Standalone, Small SWAP & Foot-print (drawings).**
- **Safety & Communication Reliability concerns can be overcome with engineering.**
- **Batteries are a big limitation for application and operations.**
- **Eliminate wire between the DAQ and sensor(Passive Wireless Sensors).**

Actual Space-flight Wireless Sensor Flight Applications:

- Shuttle-based Wireless Instrumentation Systems for Payload Bay module temperatures
- ISS Assembly – Z1 and P6 temperatures while unpowered prior to mate
- Integrated ISS Structural Loads & Dynamics Model Validation – modules & truss segments
- Shuttle and ISS Temperature monitors – crew middeck, wing, airlock
- Shuttle Structural Loads/Dyn – Cargo Trunnion, SSME struts, SSME feedlines OMS Pods
- Shuttle Wing Leading Edge Ascent and MMOD Impact – STS-114 and subs
- Shuttle RMS (arm with 50' boom) – strain(loads) at SRMS joints; astronaut-induced loads
- ISS Ultrasonic Background Noise – ultrasonic monitoring/location in module walls
- ISS Bigelow Experiment Module – deployment loads/dynamics and impact detection
- ISS External Wireless Network –> External High Definition Camera

What Do the 2 sides of Aerospace Have in Common?

Wires!!

Aviation	← →	Space
Aircraft	← wires →	Manned Spacecraft
Helicopters	← wires →	Launch/Landing Systems
Unmanned Aerial Vehicles	← wires →	Unmanned Spacecraft
Internal/External Robots	← wires →	Internal/External Robots
Balloons	← wires →	Inflatable Habitats
Crew/Passenger/Logistics	← wires →	Crew/Scientists/Logistics
Jet Engines	← wires →	Rocket Engines
Airports/Heliports	← wires →	Launch Sites
Engineering Validation	← wires →	Engineering Validation
Ground Support	← wires →	Ground Support

Energy, Oil&Gas, Internet of Things, Wireless Home, Transportation, Infrastructure, Building, Agriculture & Food, Medical, Security

What do these have in common?

1. **Data, Power, Grounding Wires and Connectors for: Avionics, Flight Control, Data Distribution, IVHM and Instrumentation.**
2. **Mobility & accessibility needs that restrict use of wires.**
3. **Performance issues that depend on weight.**
4. **Harsh environments.**
5. **Limited flexibility in the central avionics and data systems.**
6. **Limited accessibility.**
7. **Need to finalize the avionics architecture early in the lifecycle.**
8. **Manufacturing, pre and post delivery testing.**
9. **Schedule pressure, resource issues, security and reliability.**
10. **Operations and aging problems.**
11. **Civilian, military, academic & international institutions.**
12. **Life-cycle costs due to wired infrastructure.**
13. **Need for Wireless Alternatives!!**

Common Motivations

Wireless Alternatives for Systems, Vehicles and Facilities:

- Cost/Schedule of Wired Infrastructure
- Cost of Change
- Reliability
- Maintainability
- Safety
- Security (some applications)
- System Functionality
- Changes in System Engineering & Integration, Vehicle Architecture and Technology Development/Awareness
- Size, Weight and Power

Active Wireless Sensors:

- Add-on capability/simplicity
- Reduce integration costs
- Distributed sensing/processing
- Reliability from network/backup
- Use other industry momentum
- Battery or scavenge power
- Low transmit power

Passive Wireless Sensors:

- Applications – no wire to sensor
- Sensor Cost - No battery, no radio
  - Manufacture in quantity
- Operations – no battery replacement
- Performance – weight, footprint
  - extreme environments
- Safety – little or no stored power

1. <u>Motivation: Cost of Wired Infrastructure</u>

- **<u>Expenses for</u> <u>Cabled Connectivity</u>** beginning in Preliminary Design Phase and continuing for the entire system life cycle.
- **<u>Reducing the quantity and complexity</u>** of the physical interconnects has a payback in many areas.

  1. **<u>Failures of wires, connectors</u>** and the safety and hazard provisions in avionics and vehicle design to control or mitigate the potential failures.
  2. **<u>Direct Costs</u>**: Measurement justification, design and implementation, structural provisions, inspection, test, retest after avionics r&r, logistics, vendor availability, etc.
  3. **<u>Cost of Data not obtained</u>:** Performance, analyses, safety, operations restrictions, environments and model validations, system modifications and upgrades, troubleshooting, end of life certification and extension.
  4. **<u>Cost of Vehicle Resources:</u>** needed to accommodate the connectivity or lack of measurements that come in the form of weight, volume, power, etc.
  5. **<u>Reliability Design Limitations</u>**: avionics boxes must build in high reliability to “make up for” low reliability cables, connectors, and sensors. Every sensor can talk to every data acquisition box, and every data acquisition box can talk to every relay box -backup flight control is easier.

1. Motivation: The Cost of Wired Infrastructure

6. **Physical Restrictions:** Cabled connectivity doesn't work for monitoring: structural barriers limit physical access and vehicle resources, the assembly of un-powered vehicle pieces (like the ISS), during deployments (like a solar array, cargo/payloads, or inflatable habitat), crew members, robotic operations, proximity monitoring at launch, landing or mission ops.

7. **Performance**: Weight is not just the weight of the cables, it is insulation, bundles, brackets, connectors, bulkheads, cable trays, structural attachment and reinforcement, and of course the resulting impact on payloads/operations. Upgrading various systems is more difficult with cabled systems. Adding sensors adds observability to the system controls such as an autopilot.

8. **Flexibility of Design:** Cabling connectivity has little design flexibility, you either run a cable or you don't get the connection. Robustness of wireless interconnects can match the need for functionality and level of criticality or hazard control appropriate for each application, including the provisions in structural design and use of materials.

9. **Cost of Change**: This cost grows enormously for as each flight grows closer, as the infrastructure grows more entrenched, as more flights are "lined-up" the cost of delays due to trouble-shooting and re-wiring cabling issues is huge.

2. Motivation: Cost of Change for Instrumentation

The earlier conventional instrumentation is fixed, the greater the cost of change.

- Different phases uncover and/or need to uncover new data and needs for change.
- Avionics and parts today go obsolete quickly - limited supportability, means big sustaining costs.
- The greater number of integration and resources that are involved, the greater the cost of change.
- Without developed/test systems and environments, many costly decisions result.

We need to design in modularity and accessibility so that:

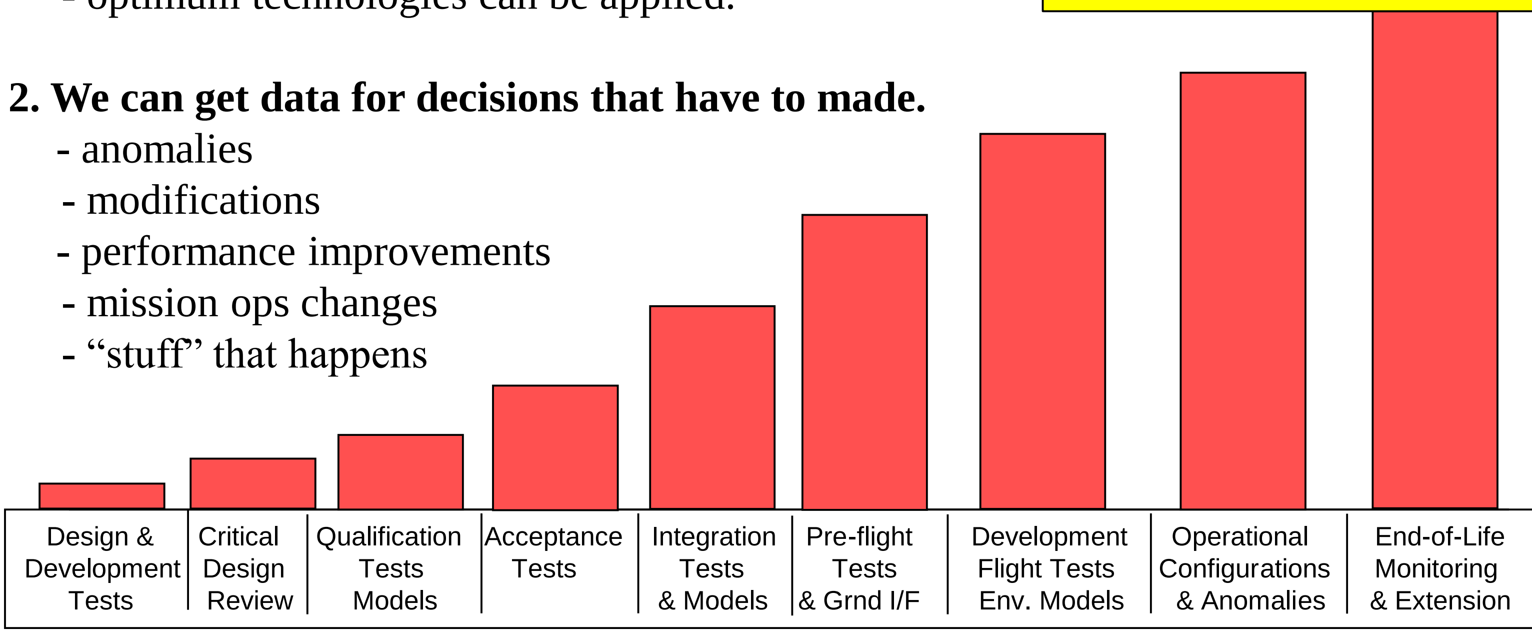
1. We can put off some decisions until:

- sufficient design, tests/analysis can be made.
- optimum technologies can be applied.

2. We can get data for decisions that have to made.

- anomalies
- modifications
- performance improvements
- mission ops changes
- "stuff" that happens

The more complete the vehicle the greater cost of change to the program and the facility used



3. Motivation: Reliability

Vehicle Reliability Analyses must include: the End to End system, including man-in-the-loop operations, and the ability to do effective troubleshooting, corrective action and recurrence control.

With Wireless Interconnects, the overall Vehicle Reliability is Increased:

Through Redundancy: All controllers, sensors, actuators, data storage and processing devices can be linked with greater redundancy. A completely separate failure path provides greater safety and reliability against common mode failures.

Through Structural and System Simplicity: Greatly reduced cables/connectors that get broken in maintenance, must be trouble-shot electronics problems, sources of noisy data and require structural penetrations and supports.

Through Less Hardware: Fewer Cables/Connectors to keep up with

Through Modular Standalone Robust Wireless Measurement Systems: These can be better focused on the system needs and replaced/upgraded/reconfigured easily to newer and better technologies. Smart wireless DAQs reduce total data needed to be transferred.

Through Vehicle Life-Cycle Efficiency: Critical and non-critical sensors can be temporarily installed for all kinds of reasons during the entire life cycle.

Through the Optimum Use of Vehicle and Human Resources: With the option of distributed instrumentation and control managed with much less integration needed with the vehicle central system, both system experts, hardware and software can concentrate on their system performance, instead of integration issues.

Background/Motivation – Why a PWST Workshop?

“Fly-by-Wireless” Vision:

To Minimize Cables and Connectors and Increase Functionality across the aerospace industry by providing reliable, lower cost, modular, and higher performance alternatives to wired data connectivity to benefit the entire vehicle/program life-cycle.

Focus Areas:

1. System engineering & integration methods to reduce cables & connectors.
2. Vehicle provisions for modularity and accessibility.
3. A “tool box” of alternatives to wired connectivity.

What it is NOT:

- A vehicle with no wires.
- Wireless-only for all control systems.

Active Wireless
Passive Wireless
Other Technologies

"Fly-by-Wireless" Focus Areas

(1) <u>System engineering and integration to reduce cables and connectors</u>,
- **<u>Capture the true program effects</u>** for cabling from launch & manned vehicles.
- **<u>Requirements</u>** that enable and integrate alternatives to wires.
- **<u>Metrics</u>** that best monitor progress or lack of progress toward goals.(# cables, length, # of connectors/pins, # of penetrations, overall weight/connectivity, total data moved/lb).
- **<u>Design Approach</u>** that doesn't assume a wires-only approach, but optimizes all practical options, providing for the inevitable growth in alternatives to wired connectivity.

(2) <u>Provisions for modularity and accessibility in the vehicle architecture</u>.
- **<u>Vehicle Zone Accessibility</u> –** Considers standalone sensors along with system assembly, inspections, failure modes/trouble-shooting, system/environment monitoring, remove & repair.
- **<u>Vehicle Zone Modularity</u> –** Vehicle wired buses provide power, two-way data/commanding, grounding and time in a plug-and-play fashion. Wireless networks are standardized by function and are also plug-and-play.
- **<u>Centralized & De-centralized approaches</u>** are available for measurement & control.
- **<u>Entire life-cycle</u>** considered in addition to schedule, performance, weight & volume.

(3) <u>Develop Alternatives to wired connectivity</u> for the system designers and operators.
- Plug-n-Play wireless devises
- Wireless no-power sensors/sensor-tags
- Standalone wireless smart data acquisition
- Standardized I/Fs, networks & operability
- Wireless controls – back-up or low criticality
- Robust high speed wireless avionics comm.
- Inductive coupling w/rechargeable batteries
- Data on power lines, light, structure, liquids
- No connectors for bulkheads, avionics power
- Robust software programmable radios
- Light wt coatings, shielding, connectors
- RFID for ID, position, data, & sensing.
- Various Passive Wireless Sensing Options
- Other power & comm scavenging schemes

“Fly-by-Wireless” Progress

NASA/JSC “Fly-by-Wireless” Workshop	Oct 1999
USAF Reserve Report to AFRL	Nov 1999
DFRC Wireless F-18 flight control demo - Report	Dec 1999
ATWG “Wireless Aerospace Vehicle Roadmap” & ONR Wireless Mtg	Feb 2000
NASA Space Launch Initiative Meeting	Aug 2001
World Space Congress, Houston	Mar 2002
International Telemetry Conference	Apr 2004
VHMS TIM at NASA LaRC	May 2004
CANEUS 2004	Oct 2004
Inflatable Habitat Wireless Hybrid Architecture & Technologies Project:	Sep 2006
CANEUS 2006 “Lessons Learned Micro-Wireless Instrumentation”	Sep 2006
CANEUS/NASA “Fly-by-Wireless” Workshop- investigate common interests	Mar 2007
NASA/AIAA Wireless and RFID Symposium for Spacecraft, Houston	May 2007
AVSI/other intl. companies organize/address the spectrum issue at WRC07	Nov 2007
Antarctic Wireless Inflatable Habitat, AFRL-Garvey Space Launch Wireless	Jul 2008
NASA RFIs for Low Mass Modular Instr	May/Nov 2008
Gulfstream demonstrates “Fly-by-Wireless” Flight Control	Sep 2008
AFRL announces “Wireless Spacecraft” with Northrup-Grumman	Mar 2009
CCSDS Wireless Working Group – NASA & International Space Partners	Apr 2009
JANNAF Wireless Sensor Workshop	Apr 2009
Wireless SAW Symposium – Vienna, Austria	Nov 2010
JANNAF Wireless Sensor Workshop	Dec 2010
ISA-NASA-BP Passive Wireless Sensor Technology Workshop	Jul 2011
International Workshop on Structural Health Monitoring - #8	Sep 2011
JANNAF Wireless Sensor Workshop	Apr 2012
ISA-NASA Passive Wireless Sensor Technology Workshop	Jun 2012
Wireless SAW Symposium – SAWHOT – Villach, Austria	Sep 2012
ISA-NASA Passive Wireless Sensor Technology Workshop	May 2013
IEEE – Wireless for Space and Extreme Environments	Nov 2013
Wireless SAW-Symposium – Villach, Austria	Oct 2014
DOE/Future Instrumentation – NASA Passive Wireless Sensor Workshop	May 2015
World Radio Conf. approves AVSI proposal for WAIC Spectrum 4.2-4.4 GHz	Nov 2015
IEEE-NASA WiSEE Conf & Passive Wireless Sensor Workshop	Dec 2015

Some History of Surface Acoustic Wave (SAW)

– courtesy Sabah Sabah, Vectron - Sengenuity

1880 Piezoelectricity, discovered by Jacques and Pierre Curie in quartz crystals`

1885 Lord Rayleigh characterizes Surface Acoustic Waves (earth quake)

1889 First interdigital electrode design, "Electric condenser" U.S. patent Nikole Tesla

1965 First Interdigital Transducer (IDT's) on a polished piezoelectric plate (White / Voltmer)

1970 First applications: pulse expansion and compression in radar systems

1985 SAW filters replace LC filter in TVs and VCRs

1990 SAW filters allow for miniaturization of mobile phones

1990s Passive Wireless SAW Sensors begin making their presence known(Europe).

2000s Passive Wireless Sensors branch out from SAW, to BAW, NFC, RFID….

2010s **Manufacturing and Demand merge to produce large markets for PWST**

What Is a Passive Wireless Sensor(PWS)?

Attributes:

- No battery/power source at sensor
- No wired connection between sensor and data acquisition unit
- Minimum electronics – extreme environments
- No need for scavenging power over time
- Provides a sensor reading along with a unique tag id
- Can provide range information for location/orientation
- High volume production –> low cost per measurement point (including installation)

Passive Wireless Sensor Types

- EM-coupling: Simple – very short range (RLC, Magnetic Field/Ultrasonic)
- RFID-based: Range: less than a meter
- NFC-based: Near Field Communications – up to a couple meters!
- SAW-based: Surface Acoustic Wave reflection(s) + Antenna
- BAW-based: Bulk Acoustic Wave
- Broadcast Power-assisted: Meets many of the objectives of PWST
- In/Across Metal Barriers: Power & Comm - Magnetic Field - Acoustic Waves

  Antenna Impedance-based – longer range
- Dielectric Resonators: simple, high volume
- 60GHz: V-Band metal dipoles in spray-on patches
- Optical: Active & Passive(Spatial Phase Imaging-no illumination required)
- Visual Light Communications(VLC): Li-Fi , LiFD (Light-based RFID)?
- X-Ray: Backscatter X-ray sensing?

Passive Wireless Sensor Technology Workshops

<u>Purpose</u>:
To bring Passive Wireless Sensor (PWST) technology developers, manufacturers and potential industry end-users together to understand the larger market drivers that will drive costs down and applications up. We will also discuss logical next steps.

<u>Objectives:</u>

- Understand various PWST technologies, actual & potential uses, and maturity.
- Assess the future applications/advantages/limitations in various industries.
- Assess what is needed for high volume production, standardization & communication.
- Precipitate individual & group "next step" thinking to further develop/apply PWSTs.
- Accumulate and Post a library of PWST publicly released presentations and contacts for potential partnering activities for everyone.

<u>Past Presentations and Brochures:</u>

<u>PWST 2011, 2012, 2013</u>
http://archive.isa.org/MSTemplate.cfm?Section=Passive_Wireless_Sensor_Workshop&Site=Computer_Tech__Division&Template=/ContentManagement/MSContentDisplay.cfm&ContentID=92282

<u>PWST May 2015</u>: http://futureinstruments.ornl.gov/pdfs/FIIW-2015-Agenda-Website-Agenda.pdf

Passive Wireless Sensor Technology Workshop Vision

Publicly Released Presentations and Demonstrations
+ Private Conversations

What we enable together at PWST Workshop

Awareness:
- Technologies
- Products
- Integrators
- Other Users
- Applications

+

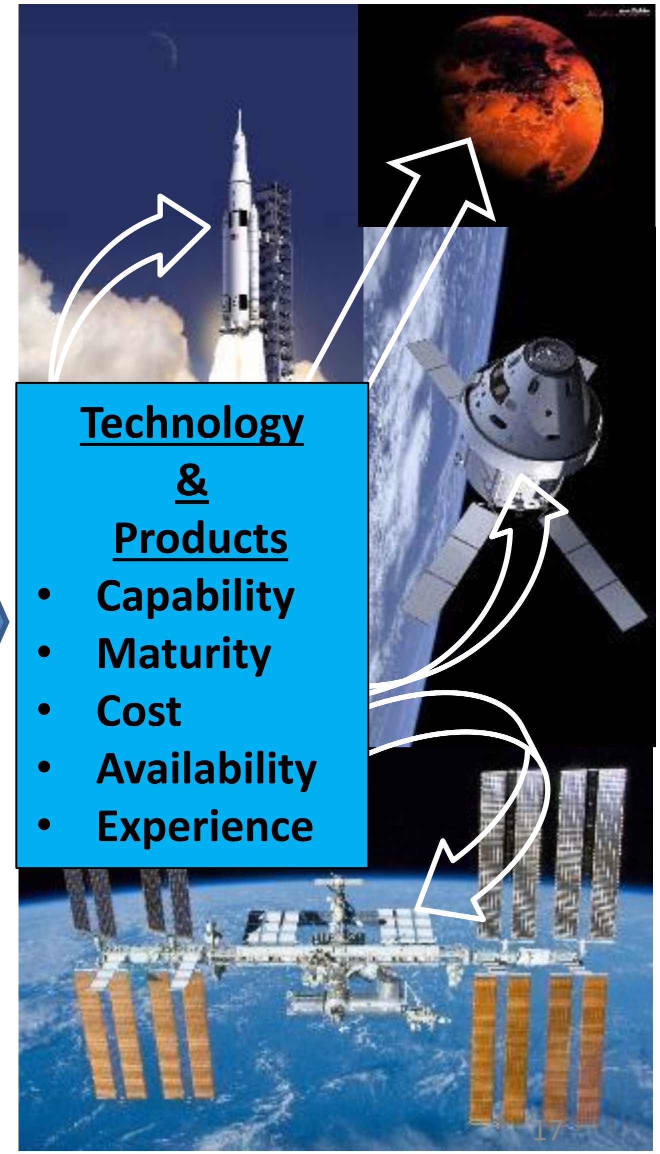
Networking
- With-in NASA
- Other US Gov
- Industry
- Universities
- International

What we produce from a series of PWST Workshops

On-line Library
- Presentations
- Summary
- Brochures
- Contact List

+

In-Person
- Contacts
- Ideas
- Trust
- Pursuits



Technology & Products
- Capability
- Maturity
- Cost
- Availability
- Experience

PWST at WiSEE 2015 Conference

http://sites.ieee.org/wisee/

	December 14	December 15	December 16
Rm A	Wireless for Space & Extreme Environments Sessions		**Passive Wireless Sensor Technologies (PWST) Workshop**
Rm B	Space Terrestrial Internetworking Workshop	Passive Wireless Sensor Technologies	
Rm C	Space Solar Power Workshop		
Lobby	Wireless Sensor Systems – Poster Sessions		

University of Central Florida(UCF)
***FAIRWINDS* Alumni Center**
12676 Gemini Blvd. N.
Orlando, FL

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George Studor
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PWST Workshop - December 15th 2015 Presentations

Green = Keynote or Plenary Speaker

"Wireless Challenges and UCF Solutions"

- Don Malocha, University of Central Florida

"NASA Wireless Mission Support Concepts"

- Steve Horan, NASA/LaRC

"Disruption Tolerant Networking: An Architecture for Challenged Communications"

- Jason Soloff, NASA/JSC; DTN Deployment Kit Demo - Adam Schlesinger, NASA/JSC

"Passive Wireless Sensor Technologies & Needs - a Library of Info"

- George Studor, NASA/NESC

"Overview of SAW technology (UCF) and Demonstration"

- Arthur Weeks, UCF

"On low cost ubiquitous sensor networks: DOE needs and application areas"

- Tim McIntyre, DOE/ORNL

"Inflatable Reentry Vehicles and Instrumentation Needs"

- Robert Dillman, NASA/LaRC

"Aircraft Wireless Tire Pressure Sensing and Harsh Environmental Constraints"

- Bill Andrew, Airbus

"Wireless Avionics Intra-Aircraft Communications(WAIC) for Commercial Aircraft"

- Dave Redman, AVSI

"Partnership Opportunities with AFRC for Wireless Systems Flight Testing"

- Richard Hang, NASA/AFRC

"NASA Aeronautics Strategic Direction and Aeronautical Research Programs"

- Jay Dryer, NASA/ARMD

"NASA Experimental Program to Stimulate Competitive Research (EPSCoR)"

- Jeppie Compton, NASA/KSC

PWST Workshop - December 16th 2015 Presentations

"Optical Wireless, Theory and Applications"

- Mohsen Kavehrad, Penn State Univ

"NASA and LVX System Partnership for Development of Light Communication Technologies"

- Jack Fox, NASA/KSC

"Cryogenic Applications for Wireless Power and Data using Magnetics"

- Garrick Merrill, NASA/MSFC

"Ultrasonic Communication for High-Data Rate Through-Metal Applications"

- Cem Sahin, Drexel Univ

"Acoustic Data and Power Transmission through and Along Solid Structures"

- Kyle Wilt, RPI

"Robust UWB Communication in Large Ship Interiors"

- Farid Dowla, LLNL

"A Spacecraft Backbone - Plug 'n' Play Concepts for a Deep Space Habitat"

- Kimberly Simpson, NASA/JPL

"Software Defined Radio Approach for Passive, Wireless RFID Sensors"

- James"Trip" Humphries, UCF

"Passive RFID Sensing for Harsh Environments - LLNL-Dirac Platform"

- Faranak Nekoogar, LLNL

"Improving Performance of Passive RFID-based Part-DNA for Rotor-head Maintenance Application"

- Maciej Zawodniok, Missouri S&T

"The NASA Sounding Rocket Program and Technology Needs"

- Brian Hall, NASA/WFF

"Aerojet Rocketdyne Propulsion System PWST Needs/Challenges"

- James Larkin, Aerojet Rocketdyne

"Four High Value Wireless Applications at MSFC with their Challenges"

- Leo Fabinski, NASA/MSFC

"Instrumentation Overview of Space Environment Test Facilities at Plumbrook"

- Rich Evans, NASA/GRC/Plumbrook

WiSEE 2015 Presentations - December 14-15 2015 Presentations

“Lifetime and Power Consumption Analysis of Sensor Networks” *- Gholamreza Alirezaei*
“Practical application of the Optical Wireless communication technology (OWLS) in extreme environments” *- Ignacio Arruego*
“Building blocks for an intra-spacecraft wireless communication” *- Patrice Pelissou*
“Wireless Leak Detection Using Airborne Ultrasonics and a Fast-Bayesian Tree Search Algorithm with Technology Demonstration on the ISS” - *Casey Clark*
“An Integrated Remote Monitoring System for Impact Responses of Aerospace Structures” *- Sayan Roy*
“Software Defined Radio Implementation of DS-CDMA in Inter-Satellite Communications for Small Satellites” *- Frank Pinto*
“Adaptive wireless sensor networks for aircraft” *- Pascale Minet*
“Methods and Tools for Assessment of Wireless Networks in Extreme Environments” *- Rue Caldeira*
“A Wireless Technology Assessment for Reliable Communication in Aircraft” *- Murat Gürsu*
“Power Allocation for Distributed Passive Radar Systems with Occasional Node Failure”
- Omid Motlagh
“Metamaterial based Wireless charging system for Wireless Sensor Network with an effective charging algorithm”
- Vikaram Singh
“Standalone SAW Sensor Interrogator Using an Embedded Computer and Software Defined Radio”
- James Humphries
“Carrier Synchronization in Distributed MIMO Satellite Links” *- Pietro Savazzi*
“Millimeter Wave Directional Channel Modeling” *- Amir Torabi*
“Wireless Capacitive Pressure Sensor with Directional RF Chip Antenna for High Temperature Environments” *- Maximilian Scardelletti*

2015 PWST Workshop
May 4 – 6, 2015

Chair: NASA/NESC/George Studor

Location: NRECA Conference Center, Arlington, VA

Sponsor: NASA Engineering and Safety Center

Host: DOE/ORNL Future of Instrumentation and Internet Workshop

Agenda and Presentations available at:

http://futureinstruments.ornl.gov/pdfs/FIIW-2015-Agenda-Website-Agenda.pdf

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PWST Workshop - May 2015 Presentations

“Motivation and Overview of Past PWST Workshops – Needs and Technologies”

- *George Studor, NASA Engineering and Safety Center*

“PWST GHz RF Systems and SAW Sensor Technology”

- *Don Malocha, University of Central Florida*

“Latest Advancements in Passive RFID Sensing with Deployment Examples”

- *Scott Dalgleish, Phase IV Engineering*

“Wireless Sensing in Aerospace and Transportation – Advanced Engineering”

- *Scott Dalgleish, Phase IV Engineering*

“Value of Wireless Technology for Rotorcraft”

- *Brian McCabe/UTRC and Jonathan Hartman/Sikorsky Innovation*

“Passive Wireless Needs at Yokogawa”

- *Penny Chen, Yokogawa*

“Sensors for the Highway Transportation System Today and in the Future”

- *Dave Kuehn, DOT/FHWA/Exploratory Advanced Research Program*

“Passive Optical Sensing Using Spatial Phase Imaging”

- *Scott Ackerson, Photon-X/Quidient*

“Passive, High-Function RFID: Sensors and Bi-stable Displays”

- *Charles Greene, Powercast*

”High Temperature Passive Wireless Sensor Technology for Harsh Environment Applications”

- *Mauricio Pereira da Cunha, Environetix & Univ of Maine*

PWST Workshop May 2015 Presentations

“Passive Wireless Needs/Research at DOE”

- Tim McIntyre,Oak Ridge National Laboratory

“Low Temperature Integration of Thin Films and Devices for Flexible and Stretchable Electronics”

- Pooran Joshi, Oak Ridge National Lab

“Operation of Passive SAW Sensors in Complex Media”

- Jackie Hines, SenSanna,Inc (Formerly ASRDC)

“SAW-Based Strain and Torque Sensor”

- Viorel Olariu, Albedo

“Building Blocks and Challenges of the IoT”

- Allen Nejah, Sunman Engineering

”The Nation’s First Advanced Sensors Manufacturing Development Center: ICAMR”

- Dan Holladay, Executive Director, ICAMR

“Passive Wireless Sensors – Innovations from lab, to fab, to market … and back”

- Bert Gyselinckx, IMEC

“Dielectric Resonators, A New Frontier for Passive Sensing”

- Taimur Aftab, IMTEK – Univ of Freiburg, Germany

“Through Wall Data and Power Delivery Using Ultrasound”

- Kyle Wilt/Gary Saulnier, RPI

“Wireless Power for Low Power Devices”

- J.K. Huang, Ferro Solutions

”NFC Cell Phone Sensors Networks: An Emerging IoT Platform”

- Jim Peeters, Gentag

PWST Workshop – May 2015 Presentations

“BAW Device Platform for Sensors”

- Bryan Bothwell, Qorvo

“NASA/AFRC Flight Test Capabilities & Opportunities for Applications of Wireless Data Acquisition Systems”

- Richard Hang, Armstrong Flight Research Center

“Passive Wireless Sensors for Agriculture and Food Systems”

- Ray Knighton, USDA

“Potential PSWT Applications for Upstream Oil and Gas Equipment”

- Stephen Szpunar, GE Oil and Gas

“IVHM Systems for Solid Rocket Motors”

- Scott Hyde/Derek DeVries, Orbital/ATK

“Spaceflight Experience in applying Smart Wireless Sensors: Implications for PWS Applications”

- Aaron Trott, Invocon Inc

“Wireless Interrogation of SAW Sensors for Advanced Applications”

- Sylvain Ballandras, Frec|n|sys SAS France (remote)

“3GHz-6 GHz SAW Devices: Low Loss SAW Filters, Resonators, Sensors, and Tags”

- Victor Plessky, GVR Trade Switzerland (remote)

“Wireless Cryptographic Keys for Mobile Devices”

- Mark Krawczewicz, Torceo Labs

“Magnetic Field Based Wireless Power, Data and Passive Sensing”

- Corey Jaskolski, Hydrotech

“The Joint Sensor Database for Propulsion and Energetic Systems”

- Ben Hill, Lam/CPIAC-Johns Hopkins

Future of Instrumentation and Internet Workshop(FIIW) 2015

http://futureinstruments.ornl.gov

May 4-6, 2015

NRECA Center - Arlington, Virginia

Green indicates may be applicable for PWST

DOE FIIW May 2015Presentations:

"Small Utilities and Agile, Fractal Grid"

- *Craig Miller, NRECA (National Rural Electric Cooperative Association)*

"Wireless Avionic Intra-Communications for On-Board Safety Networks"

- *Mike Franceschini, Honeywell*

"Let's Instrument Everything…And Trust It"

-Stacy Prowell, Oak Ridge National Laboratory

"Cognitive Radio and Shared Spectrum: Implications for Instrumentation"

- *Jeff Reed, Virginia Tech University*

"Review of Past FIIW's and What is the Future?"

- *Ken Tobin, Oak Ridge National Laboratory*

"Shared Spectrum, the Wireless City and Implications for Secure Grid Communication Innovation"

- *Rangam Subramanian, National Telecommunications and Information Administration*

"Backhaul Network Architectures for Secure Industrial Communications"

- *Penny Chen, Yokogawa/ISA Comm Division*

"Next Generation Communications for Tailored Fracking Sensors"

- *Sterling Rooke, X8 Systems*

"NEON: Sensors and Communications Needs"

- *Brian Wee, National Ecological Observatory Network (NEON)*

"Communications Requirements for Energy Efficient Buildings"

- *George Hernandez, Pacific Northwest National Laboratory / DOE*

DOE FIIW - May 2015 Presentations

"NIST's Wireless Platform Project"

- Kang Lee, National Institute of Standards and Technology

"NASTCN: An Overview"

- Nada Golmie, National Institute of Standards and Technology

"Wireless Spectrum Research and Development (WSRD) Activities: Past, Present, Future"

- Wendy Wigen, Networking and Information Technology Research & Development

"Driving Innovation and Investment for a More Resilient Electric Grid"

- Stewart Cedres, Office of Electricity Delivery and Energy Reliability, U.S. DOE

"3D Integrated Low Power FPGAs for Edge Computing with Extreme Power Efficiency"

- Aravind Dasu, USC/ISI

"HVAC-Embedded Connected Devices to Provide Transactive Energy Services"

- Teja Kuruganti, Oak Ridge National Laboratory

"Convergence of FDD, IoT, & Cloud-Based Services in Supermarkets & Small Format Retail Locations"

- John Wallace, Emerson Climate Technologies

"BEMSS: An Agent Platform to Facilitate Grid-Interactive Building Operation with IoT Devices"

- Manisa Pipattanasomporn, Virginia Tech

"Data Storage and Services for Accessing Data from IoT"

- David Resseguie, Oak Ridge National Laboratory

"Data-Science Solutions for Advanced Manufacturing/Production-line Systems in the 'Internet of Things' Era"

- Sreenivas Sukumar,Oak Ridge National Laboratory

DOE FIIW - May 2015 Presentations

"Sensors and Networks for Environmental Intelligence"

- Tim McIntyre, Oak Ridge National Laboratory

"Thermoelectric Generator for Efficient Power Harvesting for Self-Powered Wireless Sensor Nodes"

- Vivek Agarwal, Idaho National Laboratory

"Flexible Data Acquisition Architecture for Novel Sensor Development and Deployment"

- James Smith, Idaho National Laboratory

"Evaluation Of A Consumer Electronics-Based Data Acquisition System For Equipment Monitoring"

- Randall Wetherington, Oak Ridge National Lab

"Unique Virtual Test-Bed Requirements to Simulate Internet of Things"

- Srikanth Yoginath, Oak Ridge National Laboratory

"Design Considerations for Wireless Sensor Networks in Nuclear Power Applications"

- Dwight Clayton, Oak Ridge National Laboratory

"Functional Materials for High Temperature Sensing in Power Generation Applications"

- Paul Ohodnicki, National Energy Technology Laboratory

"Harsh Environment Fiber Sensing for Advanced Energy Systems"

- Zhihao Yu, Virginia Tech University

"Embeddable Sensors and Smart Components for High Temperature Advanced Energy Systems"

- Lei Yuan, Jia Huang, Hai Xiao, Clemson University

"Investigation on Smart Parts with Embedded Piezoelectric Sensors via Additive Manufacturing"

- Yirong Lin, University of Texas El Paso

"Additive Manufacturing Enabled Ubiquitous Sensing in Aerospace and Integrated Building Systems"

- Joseph Mantese, United Technologies Research Center

"Sensor Placement for Fault Diagnosis, Condition Monitoring, and Efficiency Maximization"

- Debangsu Bhattacharyya, West Virginia University

2013 PWST Workshop
May 21 - 22, 2013
<u>Summary</u>
NASA/JSC/George Studor
Location: Georgetown Melrose Hotel, DC
Sponsor: ISA Communications Division

2013 PWS Workshop Agenda
May 21, 2013 – Day 1

Intro	8:00am - 8:15am	Univ of Central Florida	Workshop Intro	Don	Malocha
S1-P2	8:15am - 9:00am	NASA/JSC	Vision/PWS Workshops/SHM	George	Studor
S1-P3	9:00am - 9:30am	Canadian NRC - IVHM-DPHM	Canada-India Aerospace IVHM	Prakash	Patnaik
S1-P4	9:30am - 10:00am	NAVAIR- TDA, Inc.	Rotorcraft Metal-rich zones	Nagaraja	Iyyer
Break	10:00am-10:15am				
S2-P1	10:15am-10:45am	DOE-Oak Ridge Nat. Lab	Low Cost Wireless at ORNL	Wayne	Manges
S2-P2	10:45pm - 11:15pm	DOE-EERE-Building Tech Off	Low Cost Meter Challenge	Jason	Koman
S2-P3	11:15am -12:00pm	OnRamp Wireless Inc.	Connecting Anything	Ted	Myers
Lunch	12:00pm - 1:00pm				
S3-P1	1:00pm - 1:30pm	Rahrig Pacific Company	Environmental Services Tech.	Joe	Delaney
S3-P2	1:30pm - 2:00pm	Rahrig Pacific Company	Supply Chain Solutions	Kaley	Parkinson
S3-P3	2:00pm - 2:30pm	TMI USA, Inc.	Expanding Data Logger Uses	Chris	Hough
S3-P4	2:30pm - 3:00pm	Tufts University	Micro UAV Platforms	Usman	Khan
Break	3:00pm - 3:15am				
S4-P1	3:15pm - 3:45pm	GE Global Research	Multi-variable Sensors	Radislav A.	Potyrailo
S4-P2	3:45pm - 4:15pm	RFMicron Inc.	Self Tuning RFID	Shahriar	Rokhsaz
S4-P3	4:15pm- 4:45pm	Univ of Louisville	Physical Switch Sensors	Cindy	Hartnett
	4:45pm - 5:00pm	Day 2 Plan - Wrap-up	Encourage Dinner Match-ups	Don	Malocha

2013 PWS Workshop Agenda
May 22, 2013 – Day 2

S5-P1	8:00am - 9:00am	Univ of Central Florida	PSW Technology – Today & Tomorrow	Don	Malocha
S5-P2	9:00am - 9:30am	ASR&D Corp	PWST-SAW Sensor Systems	Jackie	Hines
S5-P3	9:30am - 10:00am	TriQuint Semiconductor	Bulk Acoustic Wave Sensors	Josh	Zepess
Break	10:00am - 10:15am				
S6-P1	10:15am - 10:45am	GVR Trade SA	UltraWBSASensors&Tags	Victor	Plessky
S6-P2	10:45am - 11:15am	Univ of Maine	Smart Interrogators	Ali	Abedi
S6-P3	11:15am - 11:45pm	Gentag Inc.	NFC Sensors	John	Peeters
S6-P4	11:45pm - 12:00pm	CPIAC, Johns Hopkins U	JANNAF Sensor Database	Nick	Kiem
Lunch	12:00am - 1:00pm				
S7-P1	1:00pm - 1:45pm	Hydro-Tech	Magnetic Field PWS	Corey	Jaskolski
S7-P2	1:45pm - 2:15pm	3Phoenix	Thru Wall Comm & Power	Pat	Jordan
S7-P3	2:15pm - 2:30pm	Feedback/Wrap-up	Talk to Don/attendees	Don	Malocha
Break	2:30pm - 3:00pm	Re-Arrange Room for One-on-One Sessions			
	3:00pm - 5:00pm	One-on-One Sessions	1-on-1 Scheduled User - Developer discussions (Developers Signup for 15minutes blocks of time on User Schedules)		
	NA	Univ of Maryland	PWS Workshop Admin	Maice	Costa
	NA	George Mason Univ	PWS Workshop Admin	Hossein	Roufarshbaf

9:00am, May 21- Day 1 **Session 1 Presentation 3**

Dr. Prakash Patnaik

"Sensor Applications to IVHM in Aerospace Systems"

prakash.patnaik@nrc-cnrc.gc.ca **National Research Council(NRC) Aerospace**

613-991-6915 **Principal Research Scientist Lead-Air Defence System Program, Ottawa, CA**

Goal: Canadian Government stimulation of Infrastructure and industry through a **Complementary IVHM Demonstration Program**

- Levels: Vehicles - Systems/Structures – Enabling Technologies
- Complementary Non-Aerospace Partners/Applications

How: Technical Action Teams, Industry Action Teams
NRC Targeted Sector-wide IVHM Program
Target Consortia to facilitate – TIER 1 Companies, Research Centers and Industry Canada

NRC-CANEUS IVHM Workshop - August 2012- Many Aerospace players present

Approach: Work Backwards from the Problem and Decisions to find the best sensor system
Roadmap for Health Usage Monitoring
Test facilities support increasing complexity

Wireless SHM: **Failure precursors & monitor damage: lowest Cost, Weight, Complexity**
Facilitate IVHM technology applications
Address both Technical and Regulatory(Certification) issues

Wireless Engine **Performance, Prognosis, and Health Management – Data-Driven Models**
Thin Film Sensors – design, fabrication, test and application

Flight Test Aircraft: **Numerous**

Energy Harvesting

9:30am, May 21 - Day 1 Session 1 Presentation 4

“Exploring Passive RFID System in Metal Rich Environments Application to Rotorcraft Dynamic Component Tracking”

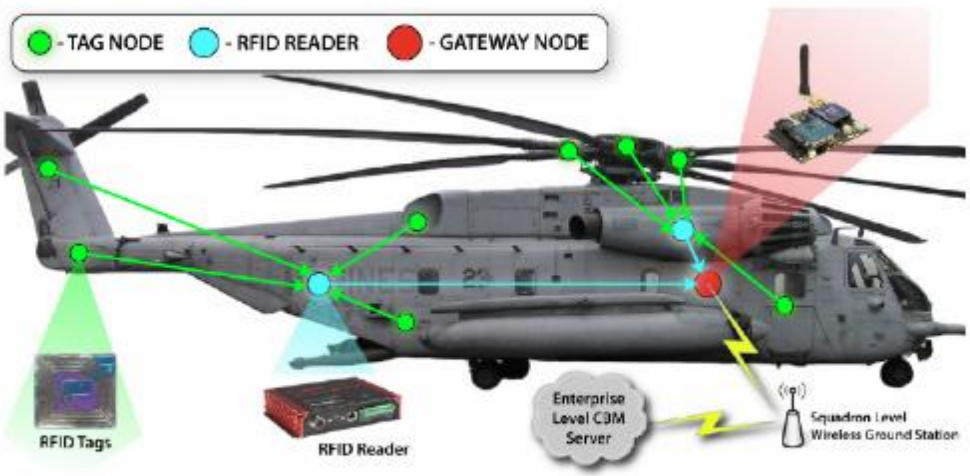
Nagaraja Iyyer
niyyer@tda-i.com
703 226 4070
http://www.tda-i.com
Technical Data Analysis, Inc; Falls Church, VA
Director of Engineering

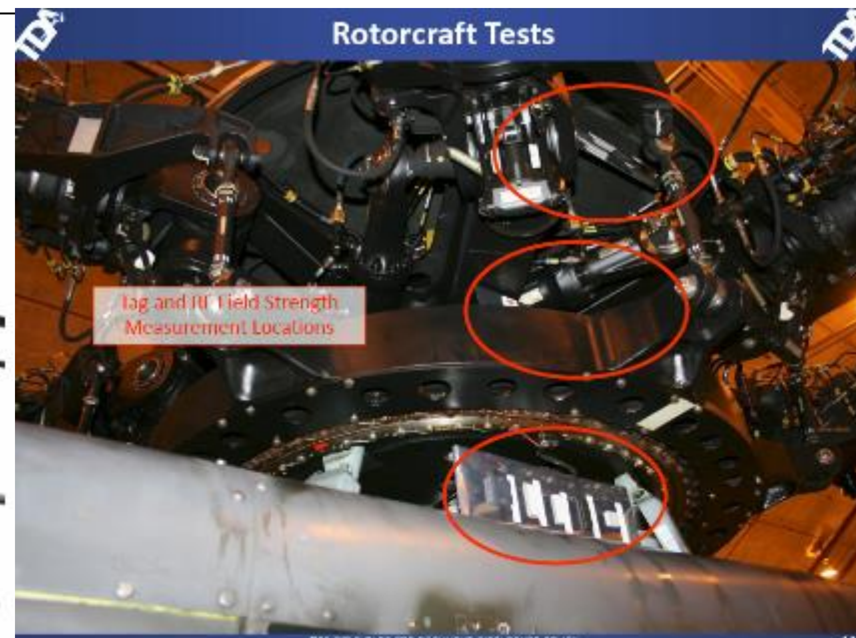
NAVAIR Customer – Driving Technology Needs; Multiple partners in R&D

1) Rotorcraft dynamic component structure life tracking with Passive RFID.
2) Improve passive wireless tag readability in a complex metal-rich environment
   - Dynamically adjust the scattering properties vs redesign
   (a) boosting the back-scatter signal from passive tags with beam-forming and impedance matching techniques,
   (b) boosting the back scatter signal from an auxiliary powering method
   (c) developing a smart placement algorithm involving tag & reader-antenna.

- **Objective:**

  “Develop an innovative system for tracking the structural life of rotary wing dynamic components in support of condition based maintenance (CBM) and unique identification (UID) mandates.”





10:15AM, May 21 - Day 1 Session 2 Presentation 1

Wayne Manges

865-574-8529

mangesww@ornl.gov

“Low Cost Wireless Sensor Network Research at ORNL”

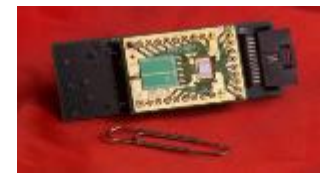
Manager, Oak Ridge National Laboratory Industrial Wireless Program

Oak Ridge, TN

Co-Authors: Wayne Manges, Peter L. Fuhr, T. Kuruganti and T.J. McIntyre

Building Energy Efficiency needs Ultra-low Cost Wireless Sensor Networks

Low Cost? - <$5/mote



- Developed custom chip set: includes sensors, electronic readout & telemetry
- Implemented Integration Architecture for Sensors, Controls and Building Automation Systems at CERL
- Supervisory Model Predictive Control Integrates Sensor Data, Control Set Points, Weather Conditions and Occupancy profiles

2012: ORNL deploys **“wireless suitcase”** at Alcoa ($43 ea)

1) STM32F103 processor (two processor parts, pin & function compatible)
STM32F103VET6, 64K RAM, 512K Flash
2) Ethernet interface (RJ45)
3) NRF24L01 wireless interface (50m w/ 2dBi external antenna)
4) 2.8" TFT LCD and touchscreen
5) SHT10 temperature & humidity sensor
6) Li-poly battery with onboard charger circuit
7) 6x Analog inputs; JST 3 pin side entry connectors
8) RT-Thread operating system
9) realtime clock (RTC) with battery backup

Open Source Software
8 Servers x 6 Units/Server = 48 Sensor Nodes

2013: Wireless Suitcase at
- Ft. Stewart, Ft. Campbell, and Dover AFB
- Environmental Sensing

2013: Growth Areas
- **Printable Electronics, Antennas & Conductors**
- **PARC Sensor Tape**
- **Passive Wireless SAW**
- **Passive RFID Sensors**

10:45AM, May 21 - Day 1 **Session 2 Presentation 2**

Jason Koman **DOE/EERE**

"Low-cost Wireless Meter Challenge"

Jason.Koman@ee.doe.gov **BTO Building Technology Office**
202-287-1578 **http://www1.eere.energy.gov/buildings/commercial/bba_wireless_metering.html**

DOE Building Technologies Office: Commercial Building Integration Team

Input from Several Federal Agencies
and
Better Buildings Alliance: 200 Members, 9 Billion Square Feet
Working with Better Building Alliance Technology Solutions Team

DOE Challenge Process: Identify the Issue -> Deployment Campaign
Build on Successful "Rooftop Unit Challenge"

Premise: Building Energy Efficiency Improvements need to be Measured Efficiently

Wireless Metering Challenge: reduce the price of **panel level sub-metering**
- Sub-meter monitoring is more focused and occupants can be more aware

Goal: 2% Savings = 71 trillion BTU/yr and $1.7 billion/year all US Commercial Bldgs

Participants: **Technology Developers** provide prototype systems
Building Owners to host the Technology Demos

Formal Kick-off - May 20, 2013

11:15AM, May 21 - Day 1 Session 2 Presentation 3

Ted Myers
On-Ramp Wireless, Inc
Ted.Myers@onrampwireless.com
www.onrampwireless.com
858 592 6008
Co-founder, Chief Technology Officer

"Connecting Anything, a M2M Revolution"

Connecting Things that are Unconnected

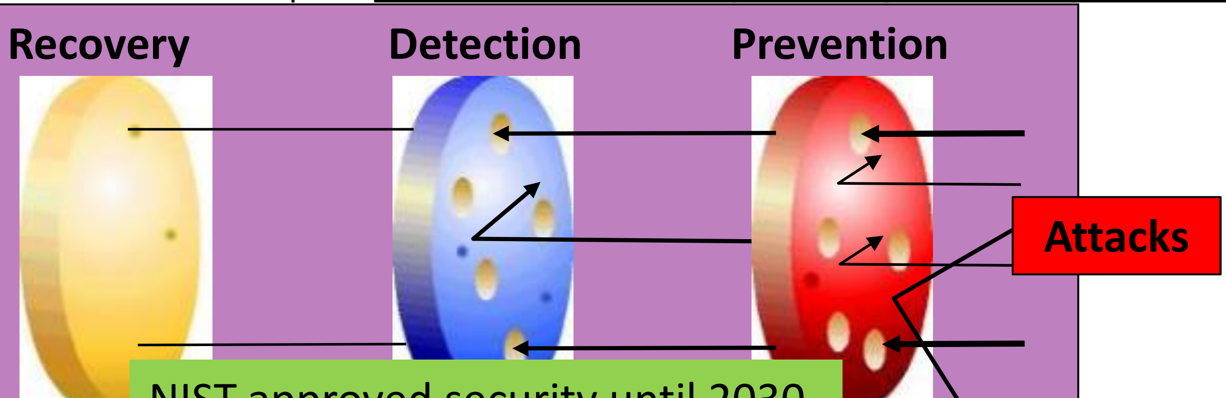
Maximize Intelligence via Wide Area Automation

Random Phase Multiple Access (RPMA)
Coverage - > 1 access point can ocer 400 Sq Mi
35 access points for 4,100 Sq Mi
Capacity - > 2000 nodes, uplink 100MBytes/day
Multiple Sensing Applications Operational
Electric/Gas Meters – above and below ground
RFID-GPS Real-Time Location System Tracking
Collection nodes for many types of sensing

Coexistence

Spreading factors 8192 chips/symbol - up to 39 dB of **processing gain – 172 dB of Link Budget**
Receiver sensitivity is -133 dBm on downlink and -142 dBm on uplink

DOE Paper: "*Smart Grid Automation for Underground Utility Assets Wireless System Trade Study*"



NIST approved security until 2030

1:00PM, May 21 - Day 1 **Session 3 Presentation 1**

Joe Delaney **"Challenges in Solid Waste Collection Operations"** **Rehrig Pacific Co**

jdelaney@rehrigpacific.com **National Operations Technical Manager, Los Angeles, CA**

315-727-1608 **www.rehrigpacifc.com**

Better Asset Management can:

- Reduce costs
- Increase revenues
- Improve Customer service
- Positive impact on Sustainability

Current Technology: Millions deployed
Bar Codes, RFID tags, GPS tracking,
Asset Tracking SW, Customer Service SW

Current Uses:

Service Verification: Late Set outs, Overage, Improper set out, Contamination

Lost Containers = Lost revenue, Overage, Servicing extra, larger or non-revenue containers

Inventory Management, Ordering by demand, Min Container Loss, Scrap/Warranty Management

Collection Routing Efficiency: Inventory accounting, Time between trips, Various Statistics/Data

Recycling Participation - Reduce Fuel, Contamination, Educate Customers, Volume driven service

New Technology Needs:

Beyond Bar Codes and Current RFID(Passive Wireless Sensors?); Creative Service Verification ; Improved Asset Management; Volume or Weight tracking technology; Materials recognition capability; Improve Customer Accountability – Since the Customer is always right!

1:30PM, May 21 - Day 1 Session 3 Presentation 2

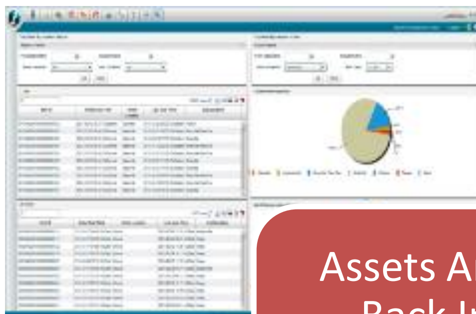
Kaley Parkinson "[Intelligent RTI's for the Supply Chain]" Rehrig Pacific, Los Angeles, CA

kparkinson@rehrigpacific.com Director, Supply Chain Technology Services

925-360-1950 www.rehrigpacifc.com

Intelligent Reusable Packaging for Real World Supply Chain

- Cost per Trip Management
- Reduce Lost Containers



Assets Utilization Data is Made Available via the Web

Items are Picked and Loaded Into Assets for Transport

Asset is Read During the Pick Process at Manufacturing and Sent into the Market

Assets Are Scanned Back Into Plant Inventory via Readers on the Inbound

Can Passive Wireless Sensors help with <u>Real World Challenges?</u>:

- Traditional reader networks on all gateway points
  - **too high a cost barrier** (100's of portals)
- **Too long of a payback** for cash-flow poor companies
- Scanning at the destination **too costly** (1000's of locations)
- Trading partners **unwilling to share costs**
- Third party distribution creates **information barrier/"hole"** in the network
- **Disruption** of current process flow
- **Costly integration** into existing systems
- **Information overload**

2:00PM, May 21 - Day 1 Session 3 Presentation 3

Chris Hough TMI USA, Inc.

chris.hough@tmigi.com Reston, VA

703-668-0116 www.tmi-orion.com

"Expanding Data Logger Applications"

High Performance Data Loggers for Industrial Strength Applications

Zigbee 802.15.4 comm at 2.4GHz ISM

Variables:

Temperature
Pressure
Humidity
Air speed
Force
Electrical Current
Resistance
Distance
Water Activity

Industries:

Food processing
Pharmaceutical, Health care
Chemistry
Ceramic & Tile
High Heat – Brick, Foundry, Electronics
Aeronautics/Aviation
Manufacturing – Automotive, Mechanical

Brick/Ceramics

How to integrate Passive Wireless Sensing with current offerings?

Aviation

2:30 PM, May 21 - Day 1 Session 3 Presentation 4

"Micro-UAV Platforms for Structural Health Monitoring and Inspection"

Usman Khan, Assistant Professor E & CE, Tufts Univ., Medford, MA
khan@ece.tufts.edu http://www.ece.tufts.edu/~khan
617-627-5299 http://spartn.ece.tufts.edu

http://www.youtube.com/user/SPARTNatTufts

1. Wireless Accelerometers Monitor Dowling Foot Bridge at Tufts Univ
2. Sensors in each Substructure Transfer Relevant Info to RFID Tag

Can PWST Tags augment this monitoring scheme?

3. Quadrotor uses Optical Targets to Navigate to Substructure RFID Tag

https://www.youtube.com/watch?v=0AuF_Xj_Xms

RFID Tag

4. Quad-rotor Interrogates RFID Tag
5. Wipes RFID Data
6. Sends monitoring program changes
7. Proceeds to next substructure tag

3:15 PM, May 21 - Day 1 Session 4 Presentation 1

"Meeting Demanding Field-performance Requirements with Multivariable Flexible and Printed Gas Sensors"

Radislav Potyrailo Principal Scientist, General Electric Global Research Center
potyrailo@crd.ge.com Niskayuna, NY
(518) 387-7370 http://ge.geglobalresearch.com/profiles/radislav-potyrailo/

Multivariable sensors:

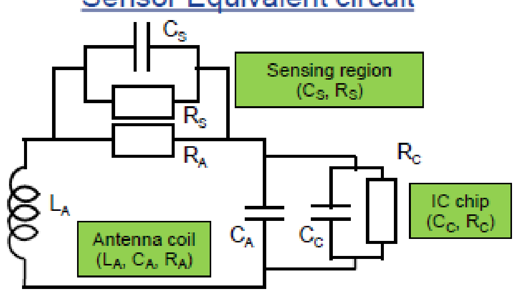
- 16-bit sensing resolution resides in sensor reader, not in disposable sensor
- Common platform for:
  - Phys/chem/bio sensors
  - Asset tracking
  - Storage of sensor calibrations

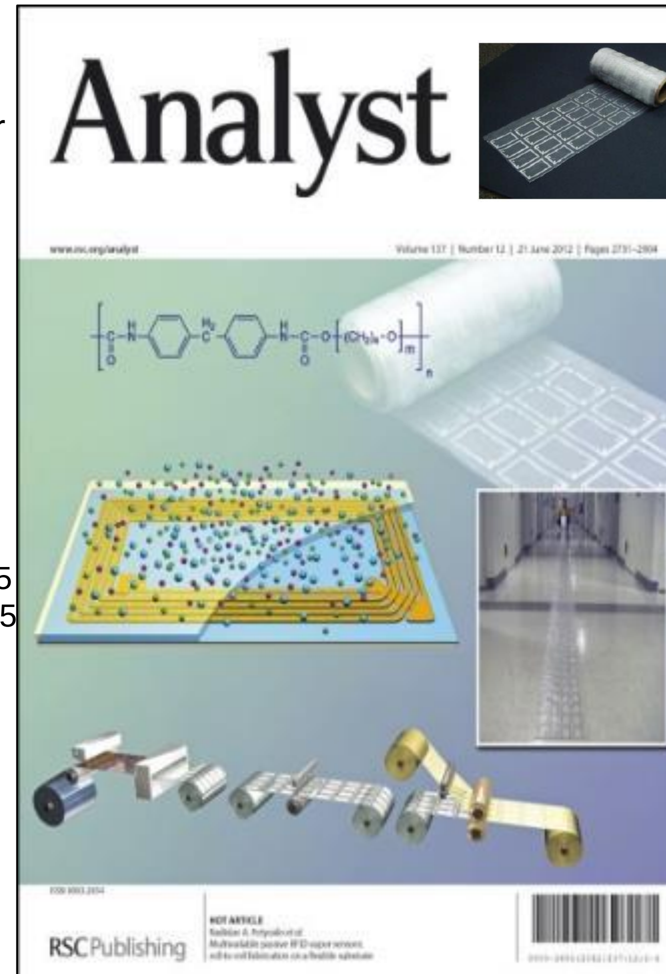
Markets $ Billions	
In vitro diagnostics	20
Clinical diagnostic instr & reagents	10
Chemical sensors and biosensors	4
Pathogen sensors	0.5
Food safety testing products	0.25
Environmental monitoring	0.05

Custom IC chips with Sensor Inputs:
Passive RFID
Smartphone with NFC Sensor

GE Strategy:
Individual Multivariable Sensors:
- Simplified manufacturing
- Reduced number of noise sources
- Simplified device packaging
- More predictable sensor aging

Sensor Equivalent circuit





3:45PM, May 21 - Day 1 Session 4 Presentation 2

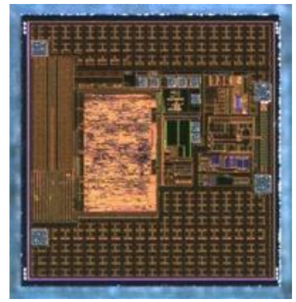
"Passive Wireless Sensing Powered by Chameleon™, a Self-Tuning Technology"

Shahriar Rokhsaz Pres. and CEO, RF Micron

shahriar.rokhsaz@rfmicron.com www.RFMicron.com Austin, TX

Magnus Chip:

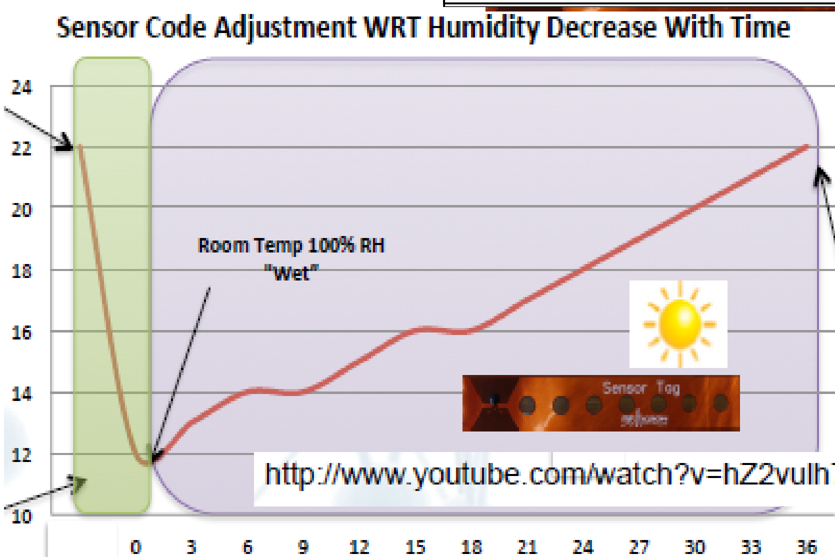
- Wireless Comm
- Sensor Engine
  - location
  - environment
- RF Programmable, non-volatile Memory



Printable Antenna for sensing based on Impedance Changes

- **Relative Humidity sensor:**
  - Senses several wetness levels
- **Pressure sensor**
- **Low cost Wet/Dry sensor**
  - Reliable comm in deep water
- **Proximity sensing**
- **Temperature sensing**

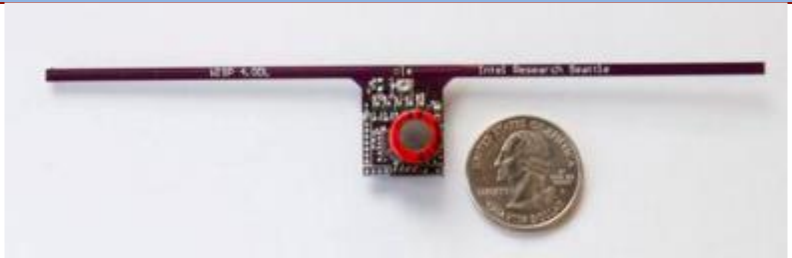
Central Intelligent Unit RFM-Hermes – based on UHF Gen 2



http://www.youtube.com/watch?v=hZ2vulh7r8U&feature=youtu.be

5:15PM, May 21 - Day 1
Session 4 Presentation 3
Cindy Hartnett
University of Louisville, KY
cindy.harnett@louisville.edu
Associate Professor, E and CE
(502) 852-0689
http://harnettlab.wordpress.com

“Physical Switch Sensors”



WISP: Wireless Integrated Sensing Platform

- 1 mW for 1 ms.
- No battery but uses a capacitor

Presentation Topics:

- Design rules for creating bi-stable sensor elements for a given bend angle/size/wt range.
- A power-efficient method for scanning these flexible switch arrays with the with the microcontroller on WISP.
- MEMS and larger-scale fabrication methods for these devices.
  - Ohmic Contact Switches
  - Variable Capacitor AC Switch(memtronics.com)
- Algorithms for reconstructing a shape from an array of digital switch states.

Applications: **flexible electronics and smart textiles.**
shape of deployable structures

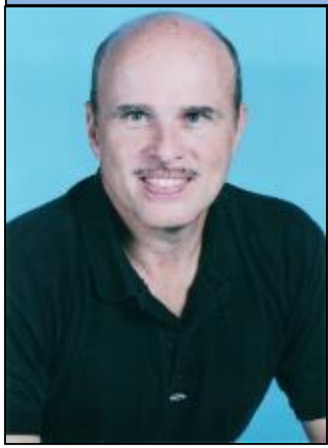
8:00 AM, May 22 - Day 2 Session 5 Presentation 1

Don Malocha

"Passive Wireless Sensor Technology: Device & System Perspective"

donald.malocha@ucf.edu E & CE, University of Central Florida, Orlando

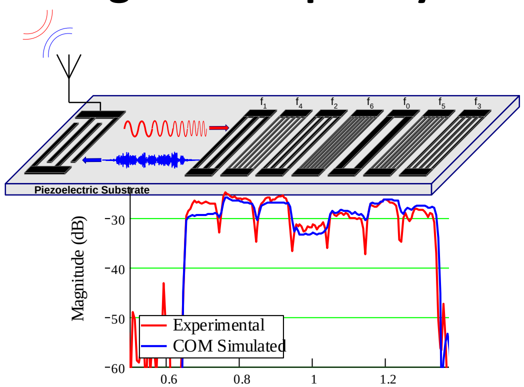
407 823-2414 http://caat.engr.ucf.edu



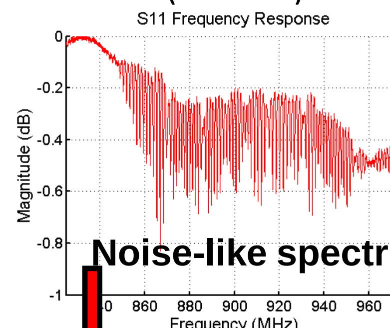
This is a 78 page Tutorial on Passive Wireless SAW Sensors

SAW Resonator Tag(Frequency), CDMA Tag(Time)

Orthogonal Frequency Coding (Time & Frequency Diversity) - UWB

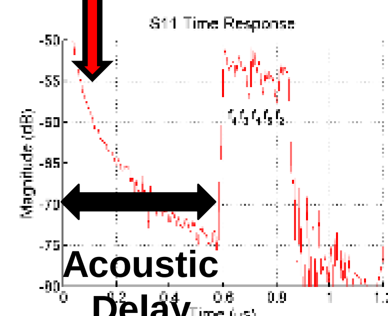


- Multi-frequency (7 chip example) - large number of codes
- Long chips, high reflectivity
- Orthogonal frequency reflectors –low loss (6-10 dB)



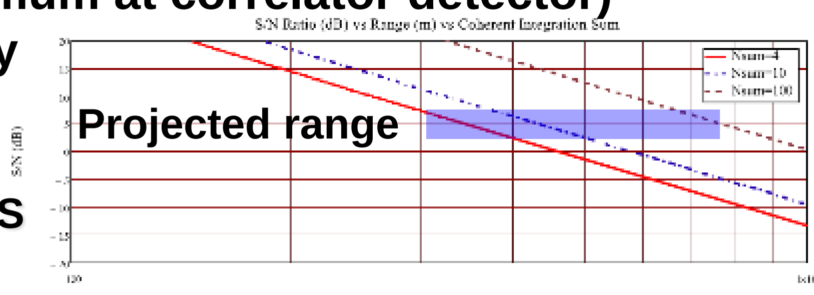
Noise-like spectrum

FFT



Acoustic Delay

- **Synchronous Correlator Transceiver - Software Radio**
- **Novel Coherent Multiplexed Receiver – with NASA/KSC**
  - **Applies Optical Coherent Technology (at coherence, output is maximum at correlator detector)**
- **Correlator Time Delay Extraction (CTDE)**
- **FUTURE FOR SAW SENSOR SYSTEMS**



Projected range

11:00AM, May 22 - Day 2 | Session 5 Presentation 2

Jackie Hines — President, ASR&D Corp

jhines@asrdcorp.com — Arnold, MD

410-544-4664 — www.asrdcorp.com

"PWST SAW-Temperature Sensor Systems"

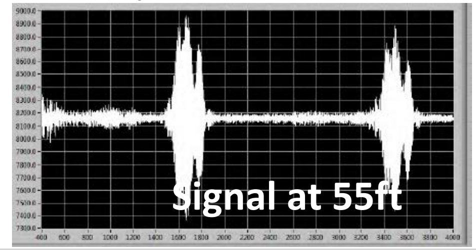
Experience:

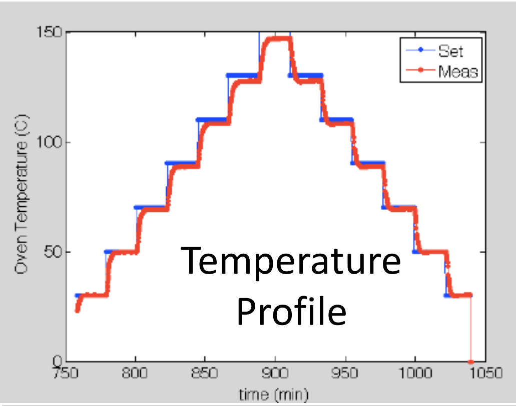
Passive Wireless SAW Sensors – ID & Value – calibration & accuracy

- Sensors that produce variable impedance and voltage
- Temperature comes "free"
- Strain, AE, Switch position, voltage

SAW-based Sensors: Humidity(reported PWST 2012),

- Hydrogen, Methane, Hypergol
- Cryo-liquid-level, concrete maturity
- Biosensor for infectious agents

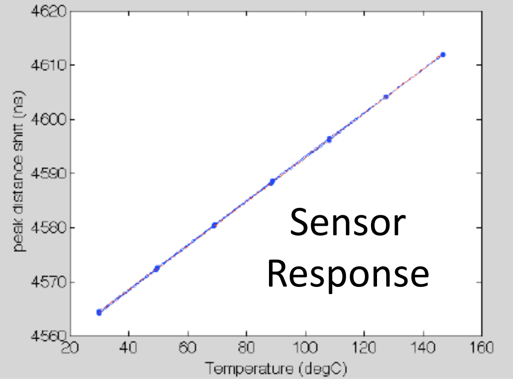




New Temperature Sensor System: NASA-MSFC SBIR

- Software Radio
- Simultaneously reads 32 sensors
- 8 to 55 foot range – antennas not optimized
- Time, Frequency(200-400MHz), & Code/Chirp Diversity
- In-situ Calibration of sensors needed.
- < 0.1 Deg C precision

Credit: MSFC/Jim Miller – NASA Retired



9:30 AM, May 22 - Day 2

Session 5 Presentation 3

Joshua Zepess

TriQuint Semiconductor, Inc.

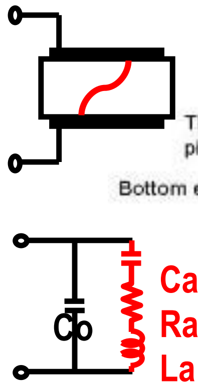
josh.zepess@tqs.com

Bend, OR

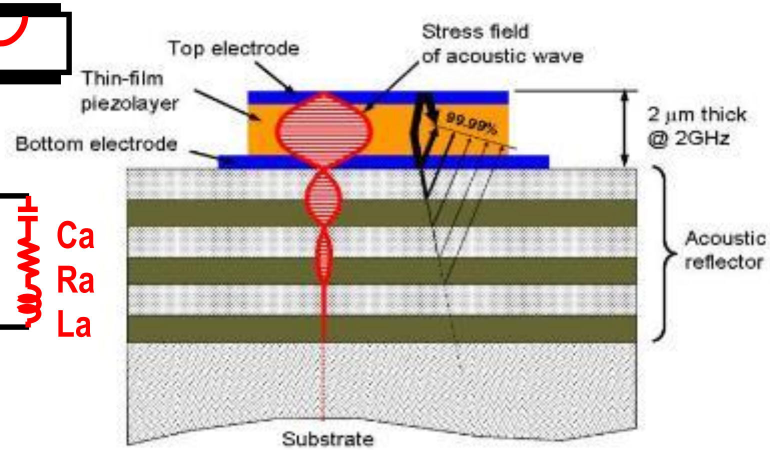
541-382-6706

www.TriQuint.com

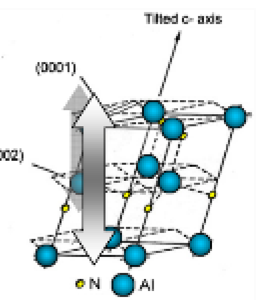
"Bulk Acoustic Wave Sensors"



SMR = Solidly Mounted Resonator

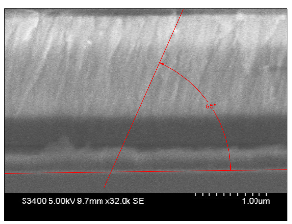


	Quartz QCM	BAW 2 GHz	BAW 10 GHz
Res.Freq. (Hz)	30 x 10^6	2 x 10^9	1 x 10^{10}
Area (cm^2)	1.0	6.25 x 10^{-4}	2.5 x 10^{-5}
Density (g/cm^3)	2.7	3.3	3.3
Shear M. $g/cm*s^2$	2.9 x 10^{11}	9 x 10^{11}	9 x 10^{11}
Sensitivity ($\Delta f/\Delta m$)	**2 x 10^9**	**7.4 x 10^{15}**	**4.6 x 10^{18}**



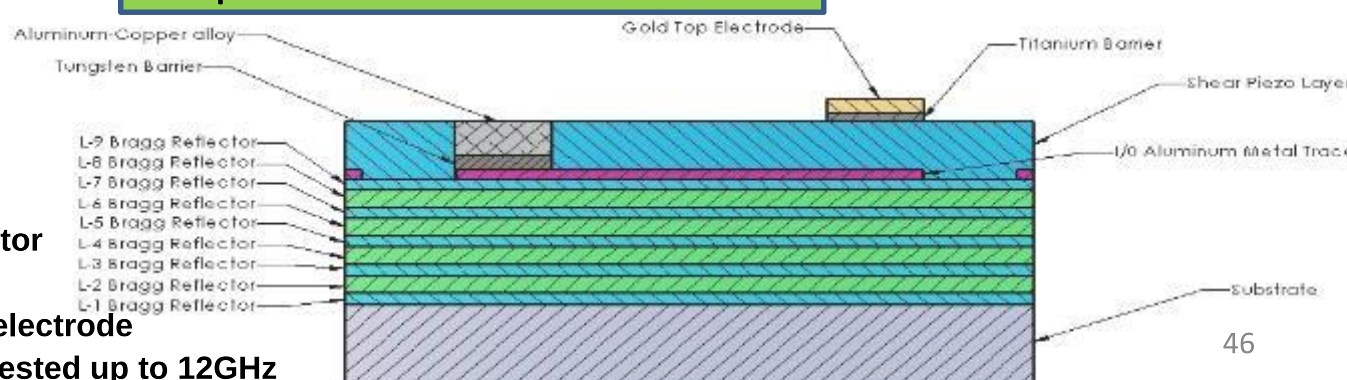
Shear AlN

50deg optimal



Future:
- **Better Film quality**
  - **Increase Q/sensitivity with more complex structures and novel materials**
- **Adapt to use with Std RFID**

SMR BAW Sensor
- **100mm Si substrate**
- **SMR BAW resonator**
- **Standard eight layer oxide reflector**
- **Aluminum bottom electrode**
- **Titanium/Gold or aluminum top electrode**
- **Operating frequency of ~2GHz; tested up to 12GHz**



10:15AM, May 22 - Day 2 Session 6 Presentation 2

Victor Plessky “Ultra-Wide Band SAW Sensors and Tags” victor.plessky@gmail.com

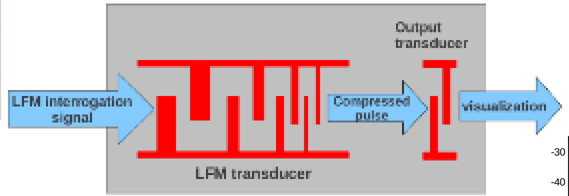
+41 32 8463039 Owner/Director, GVR Trade SA - Gorgier, Switzerland

Co-Authors: M. Lamothe, V.Plessky, T. Ostertag, J.-M. Fried, and S. Ballandras www.gvrtrade.com

UWB Advantages:
More information
Signal processing
Small size
Low EM radiation

200 MHz to 400 MHz

Linear Frequency Modulated (LFM).



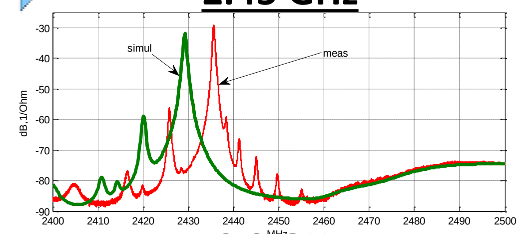
Temperature Sensors
-5° C to 130° C
0.1 - 0.2° C precision

Research & Development

500 MHz

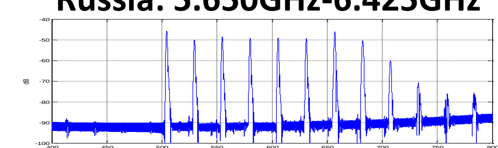
1m Range => US EM limits OK
Working on improved range

2.45 GHz

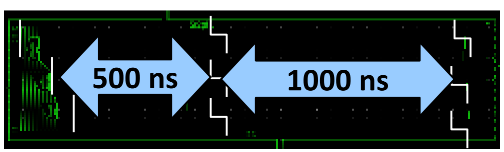


6.0 GHz

Russia: 5.650GHz-6.425GHz



UWB 2.0-2.5 GHz

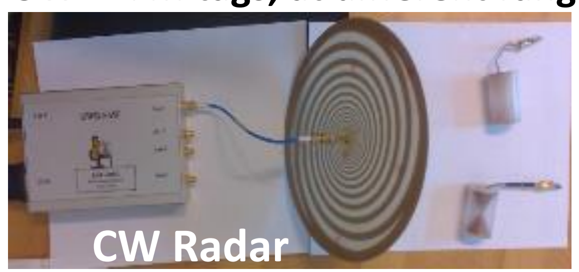


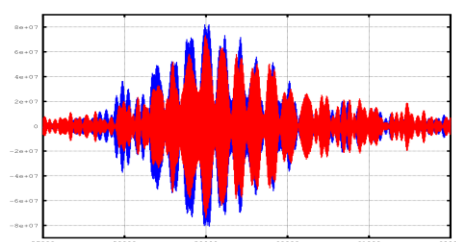
- **Constant pitch transducer in parallel.**
- **Each sensor-tag has a 100MHz channel.**
- **Each channel is sized for his frequency.**

Test Results:
- **Reduced losses over LFM technique**
- **High side-lobes addressed by cross-correlation**

CW Radar interrogates

2 UWB LFM tags, at different ranges





Reflective Environment :

-Sensor in metal can
-Measure spectral response
-Pulses from time-reversal method

Test Results:

-Sensor response is visible
-Compressed pulses are wide/noisy but identifiable-> **Cross-Correlation avoids Phase ambiguity problem.**

Ali Abedi
ali.abedi@maine.edu
207-581-2231
University of Maine, Orono, ME
Wisenet Lab, Professor & Director
http:// wisenet.eece.maine.edu

"SMART Interrogators"

Spectrum **M**anagement **A**nd **R**esource **T**iming **(SMART) interrogators** make efficient use of idle spectrum while allocating optimum power to the wireless interrogators.

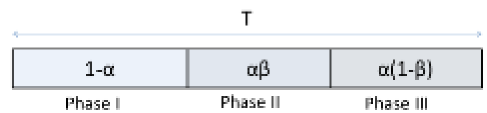
Licensed Spectrum is idle 70% of the time.
Wireless network efficiency improvements
Concept: Allow, but manage interference
 - Interrogate all, one or some sensors.
Challenges: Spectrum measurement
Time synchronization

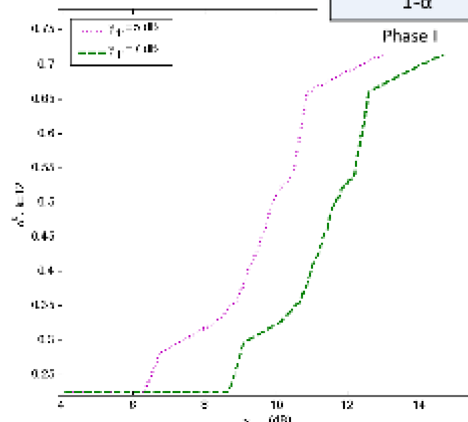
124 wireless tags (900 MHz) and 16 temp/humidity
s (2.4 GHz)

70 Member Team (2008-2011)

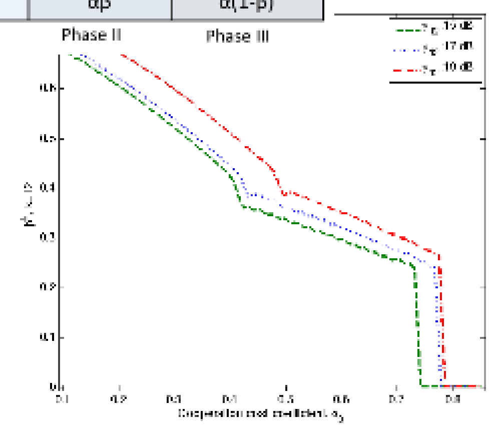
- Network Coding
- Coding Map
- Robustness
- Passive Wireless options
- Interrogate all, one, some
- Distributed Coding
- Cooperative Relays
- Latency Reductions
- Cooperative Cognition

Some Results:





Effect of relay channel quality



Effect of cooperation cost coefficient

11:15AM, May 22 - Day 2
John Peeters
john.peeters@gentag.com
240-994-2236

"NFC Sensors"

Session 6 Presentation 3
Gentag, Inc.
President and CEO
www.Gentag.com

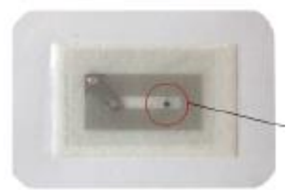
Biosensors:

- Drug Toxicity
- Pathogens
- Allergens
- OTC Tests
- Cancer Detection
- Biomarkers
- Food Safety

Printable Pharma Sensors (pills)

Diagnostic Skin Patches

- Drug Delivery
- UV (sun) Exposure
- Skin Moisture
- Infections
- Diabetes
- Fever
- Cardiac

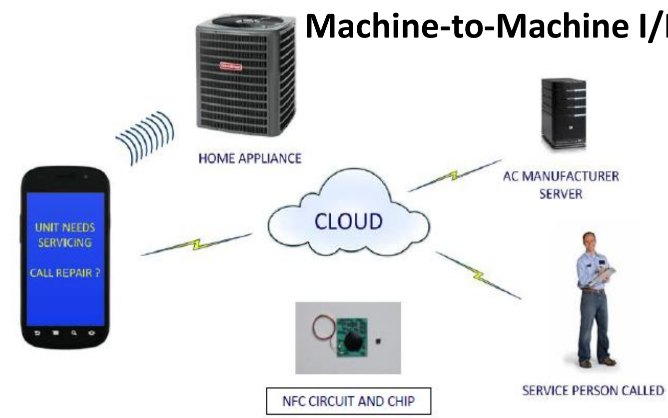


GENTAG NFC PATCH

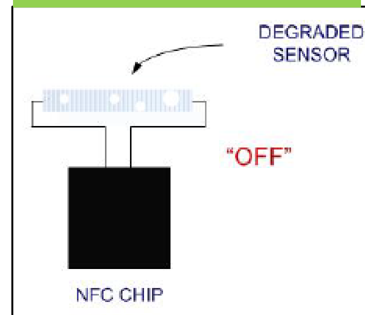
NFC Micro-controller (Custom ASIC)

- 13.56 MHz – Medical band
- NFC and ISO Standards
- No Battery for sensor
- Printable Sensor
- Read Range w Cell Phone(0.1W) = 8 cm
- Power to Sensor: 100microW & 1-3V
- Sensor Resistance change: 2K Ohm

Machine-to-Machine I/F



Physical Sensors (resistance change)



Long Range Radar-Responsive Sensor-Tags

11:45AM, May 22 - Day 2 **Session 6 Presentation 4**

Nick Keim
443-718-5005
nkeim@cpiac.jhu.edu
Chemical Propulsion Information Analysis Center, Johns Hopkins University

"JANNAF Joint Sensors Database"

May 2010 DoE NETL and JANNAF Integrated Health Management (IHM) and Engine Health Management (EHM) panels agreed to cooperate on a Joint Sensors Database

Goals:

- An online database for information on sensors with aerospace applications
- Collaborative data collection (users provide sensor information)
- Secure – For US Government and their US contractors
- Searchable based on criteria of interest
- Generation of side-by-side comparisons

Data to include:

Specifications – one set of specifications for a single sensor
Applications – many user provided application specific notes (eg: environments a sensor has been successfully used)

Here's a way to share Passive Wireless Sensor info. with high tech potential applications.

Benefits:

- Identify available sensors and successful implementations.
- Identify gaps in sensing technology.
- Leverage knowledge across agencies and industry on available sensors.
- Cross-pollination of sensor success from propulsion systems to energy generation.
- Identify & update TRL for particular sensors.

1:00PM, May 22 - Day 2 Session 7 Presentation 1

Corey Jaskolski President

cjaskolski@hydro-tech.com

Hydro Technologies, Inc, Windsor, CO

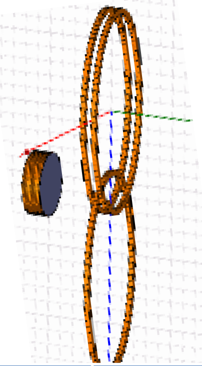
970-686-6200, 970-672-6616

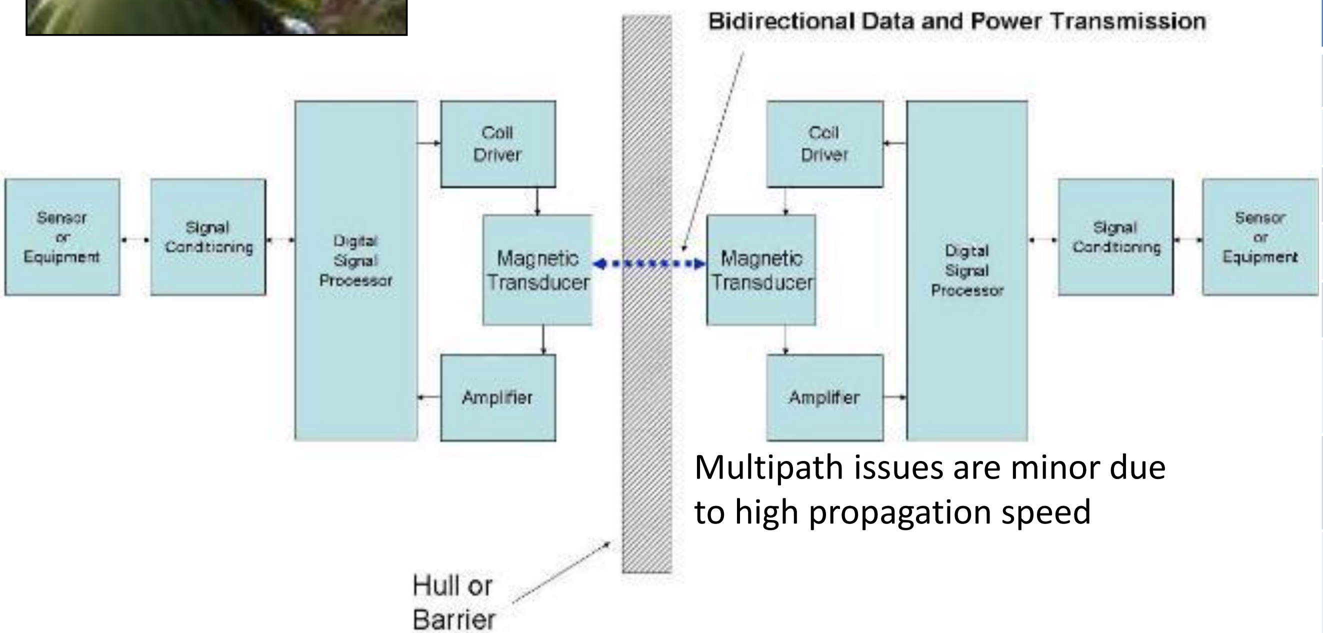
www.hydro-tech.com

"Passive Sensing through Metal Barriers"

- Modulation of magnetic fields to transmit data and power.
- Works through metals (X65, 1010, Inconel, Super Duplex, Al), seawater, concrete, air, layers of multiple materials.
- Deployed on US Navy Los Angeles class submarine as part of a mission and safety critical system.
- Recent specific oil/gas applications & technology improvements.

Passive Sensor "Puck"





Multipath issues are minor due to high propagation speed

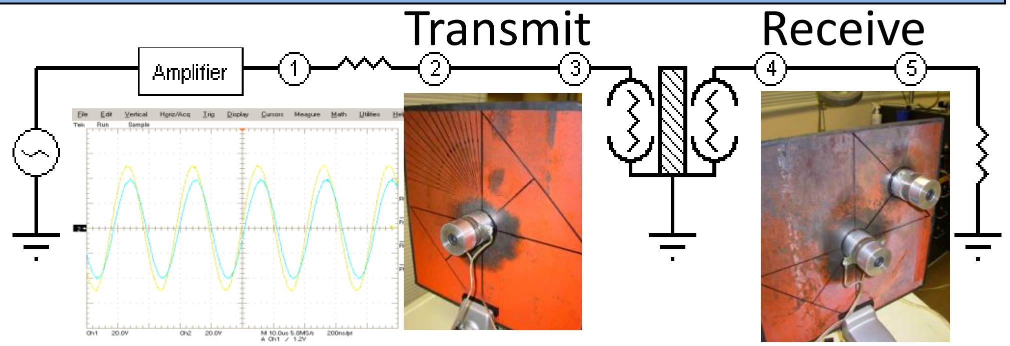
Material	Thickness	Data R (kbps)	Power Xfer
304 S Steel	0.5"	500	5W
	1"	100	1W
Titanium	0.5"	500	5W+
Inconel	0.5"	500	100W
Aluminum	0.5"	100	<1W
Plastics low conductivity	0.5"	1,000+	5kW+
Steel (1010, X65, 4130)	1"	1	~1mW *
Steel (1010, X65, 4130)	7"	10 bps	-

http://www.nationalgeographic.com/explorers/bios/corey-jaskolski/

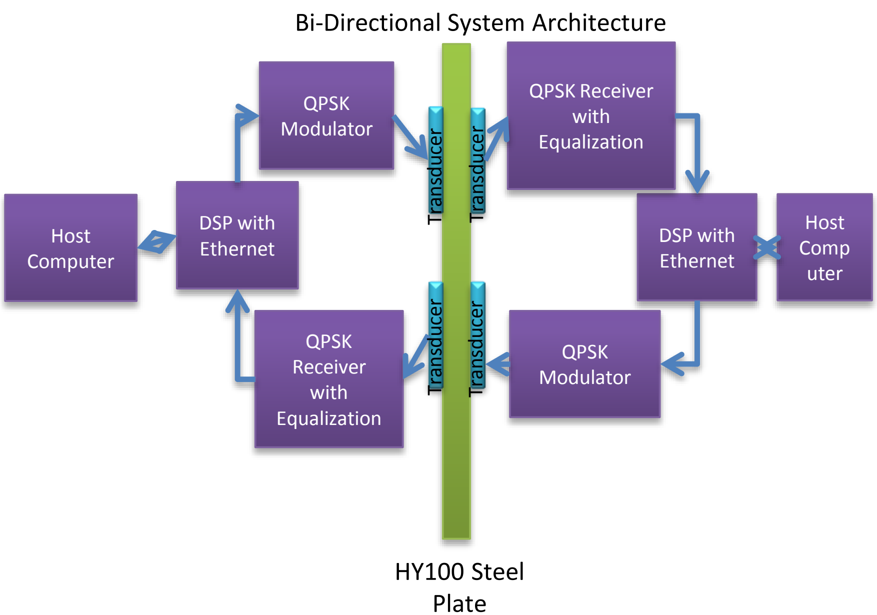
1:30PM, May 22 - Day 2 Session 7 Presentation 2
Patrick Jordan
Patrick.Jordan@3Phoenix.net Director of Surface Sonar Systems, 3Phoenix, Inc
(730) 956-6480 http://3phoenix.com Chantilly, VA

"Wireless Sensing for Survivable Machinery Control"

Acoustic Communications and Power Thru Bulkheads



Comm at 4.5 MBit/Sec



Power:

- Average power transfer efficiency – 65%
- Achieved delivered power levels up to 9 W
  - Power levels of 10-15W easily achieved
  - 3-5W load power will provide longer life
- Operating transducers in parallel doubles the power delivered
  - Transducers will larger areas increase power levels
- Low to moderate power level requirements should result in long life applications
- Sinusoidal wave input power showed 5-8% improvement over square wave input

Passive Wireless Sensor Workshop
Day 2 One-on-One Session Opportunities

<u>Table - End User</u>

1 Shell
2 Canadian NRC - IVHM
3 ORNL Wireless Research
4 NAVAIR - TDA
5 Rehrig Supply Chain
6 DOE Low $ Meter Challenge
7 Tufts Univ: micro-UAVs
8 TMI Data Loggers
9 Rehrig Solid Waste Cont.
10 On-Ramp Wireless

2012 PWST Workshop
Summary
NASA/JSC/George Studor

June 6-7, 2012

Location: La Jolla, CA

Sponsor: ISA Communications Division

2012 PWST Workshop Presenters

#	Name	Organization	Role	Location	Phone	Email	Title/Technology/Interest
1.1	George Studor	NASA JSC	Project Engineer	Minneapolis, MN	(763) 208-9283 (281) 415-3986(c)	george.f.studor@nasa.gov	"Passive Wireless Sensor Technology(PWST) 2012 Workshop Plan"
1.2	Daniel Sexton	GE-Global Research	Project Engineer	Niskayuna, NY	518-387-4121; 518-424-5728	sextonda@ge.com	"ISA107.4: Wireless sensor for turbine instrumentation working group"
1.3	Sanjay Bajekal	UTRC		East Hartford, CT	(860) 610-7700	BajekaS@utrc.utc.com	"Wireless for Aerospace Applications"
1.4	Robert Pritchard	Naval Air Warfare Center/WD	Senior Scientist	China Lake, CA	760-939-7504	robert.w.pritchard@navy.mil	"Naval Applications of PWST from the End-user's Perspective"
2.1	Dave Lafferty	BP	BP - Chief Tech Office	Houston, TX	(281) 504-8852 (630) 853-7625(m)	david.lafferty@bp.com	"Passive Sensor Needs at BP"
2.2	Ron Cramer	Shell	PACO Americas	Houston, TX	281-544-4411 713 894 9141(m)	Ronald.Cramer@shell.com	"Oil and Gas Integrity Monitoring"
2.3	Fred Faridazar	DOT/FHWA	Research Engineer (Highway)	McLean, VA	(202) 493-3076	fred.faridazar@dot.gov	"Wireless Sensors for structural monitoring during extreme events"
3.1	Cliff Whitehead	Rockwell Automation	Manager, Business Development	Mayfield Heights, OH	440.646.3779 216.288.9269(m)	cjwhiteheadjr@ra.rockwell.com	"Machine-to-Machine Interfaces in Factory Automation"
3.2	John Fraley	Arkansas Power & Electric	Lead Wireless Engineer	Fayetteville, AR	(479) 443-5759	jfraley@APEI.net	"High Temperature Wireless Sensor Systems"
3.3	Penny Chen	Yokagawa Industry Automation	Princ. Systems Arch, IA Global Marketing	San Jose, CA	(408) 636-8544	penny.chen@us.yokogawa.com	"PWST needs at Yokagawa"
4.1	Michael Mets	Savanah River Nuclear Systems	Nuclear Materials Org. & Eng Support	Aiken, SC	(803) 952-9578	michael.mets@srs.gov	"PWST/RFID Technology for Material Control and Accountability at the Savannah River Site"
4.2	Jake Rasweiler	On-Ramp Wireless	Chief Strategic Officer	San Diego, CA	858 312-8397 516 761-2235(cell)	jake.rasweiler@onrampwireless.com	"Ultra-Link" High Capacity, Long Range, Low Power Technology/Applications
4.3	Chris Gibson	VTI Instruments	Mgr Mktg &Business Development	Irvine, CA	949-955-1894 425-508-0887	cgibson@vtiinstruments.com	"Integrating passive wireless sensors with existing data acquisition systems"
4.4	Radek Zakrzewski	WAIC - Goodrich	AVSI-WAIC Project Lead	NH	802-877-4757	Radek.Zakrzewski@goodrich.com	"Protected Spectrum for Wireless Avionics Intra-Communications"
5.1	Bruce Montgomery	Syntonics Corp	President	Columbia, MD	410-884-0500 x201 410-913-2907(c)	Bruce.Montgomery@syntonicscorp.com	"Passive Wireless Sensing in a High-Multipath, High-Doppler Environment"
5.2	Fred Gnadinger	Albido Corp	President & CEO	Colorado Springs, CO	719-337-4318	fred@gnadinger.com	"Wireless Passive Strain Sensors Based on Surface Acoustic Wave (SAW) Principles"
5.3	Mauricio Pereira da Cunha	Environetix	Vice President and CEO	Orono, ME	207-581-2384	mdacunha@environetix.com	"Harsh Environment Wireless Sensor System for Monitoring Static & Rotating Components in Turbine Engines and Other Industrial Applications"
5.4	Mike Newton	nScript	Dir. Strategic Tech	Orlando, FL	407-275-4720	mNewton@nscryptinc.com	"Passive Direct-write Sensors"
6.1	Paul Hartmann	RFSAW	Vice Pres. for Engineering	Richardson, TX	(469) 227-0322	phartmann@rfsaw.com	"Advances in SAW devices for Sensing and RFID Applications"
6.2	Jackie Hines	ASRDC	President	Arnold, MD	(410) 544-4664	jhines@asrdcorp.com	"PWST SAW - Sensor System"
6.3	Don Malocha	UCF – Univ Ctl FL	Professor	Orlando, FL	(407) 823-2414	malocha@mail.ucf.edu	"SAW PWST: 915 Mhz Sensor System and Demonstrations"
7.1	Heimo Mueller	Carinthian (CTR)	Sr Accnt Mgr R&D	Villach, Austria	43 (0)4242 56300 213	heimo.mueller@CTR.at	"SAW Sensors: Explore New Measurement Horizons"
7.2	Sabah Sabah	Vectron	Product Mktg Mgr	Hudson, NH	(603) 577-6751	sabah@sengenuity.com	"Vectron Wireless Temperature Monitoring Solutions"
7.3	Isaac Ehrenberg	MIT Auto ID Labs	Research Assistant	Cambridge, MA	201-390-6168	yitzi@MIT.EDU	"RFID Tag Antenna-Based Sensing"
8.1	Kourosh Pahlavan	TagArray	CEO & CTO	Palo Alto, CA	(650)251-4400 x 202	kourosh@tagarray.com	"Passive UWB: long range, low cost and precise location"
8.2	Don Kimball	MaXentric		LaJolla, CA	858-272-8800	dkimball@maxentric.com	"60 GHz Comm, RFID - moving to Passive Sensors"
8.3	John Conkle	Wireless Sensor Tech	President	Encinitas, CA	(408) 234-3741	jrconkle@att.net	"Wireless Temperature Sensors for Gas Turbine Engines"
8.4	Scott Hyde	Aerojet	Mktg Manager for Strategic Propulsion	Clearfield, Utah	801-774-2474 801-745-7449	Scott.Hyde@Aerojet.com	"A System Engineering Simulation Tool and Data Base Proposal for Optimizing the Application of Wireless Sensors"

2012 PWST Workshop other Attendees

Name	Company	Role	Location	Phone	Email
Doyle Carr	ATA		Arnold AFB		doyle.carr@arnold.af.mil
Elizabeth Adams	BP		Munster, IN	(219) 218-2375	addamseg@bp.com
Scott Marston	Boeing	Wireless Cabin Systems	Bellevue, WA	(425) 256-0991	scott.e.marston@boeing.com
Bob Lad	Environetix	President	Orono, ME		rlad@environetix.com
Kirk Galier	GE				kirk.gallier@ge.com
Nilesh Tralshawala	GE Global Research		Shenectady, NY	518-385-1928	nilesh.tralshawala@ge.com
Raj Singh	Honeywell		Golden Valley,MN	763-954-6341	rajan.singh@honeywell.com
Rama Budampati	Honeywell		Golden Vallley, MN		ramakrishna.budampati@honeywell.com
Aaron Trott	Invocon		Conroe, TX	281-292-9903	atrott@invocon.com
Chuck McConaghy	Lawrence Livermore Nat Lab				mcconaghy1@llnl.gov
Mark Cmar	NASA	Plumbrook			mark.d.cmar@nasa.gov
Nekheel Gajjar	Panduit Corp		Tinkley Park, IL		nsg@panduit.com
Kevin Thompson	Perpetua Power				KT@perpetuapower.com
Peter Flanagan	Rosemount - Emmerson		Chanhassen, MN		peter.flanagan@emerson.com
Thanh Vu	Savannah River Nuclear Solutions		Aiken, SC		thanh.vu@srs.gov
Joshua McConkey	Seimens	Seimens	Orlando, FL		Joshua.McConkey@siemens.com
Brian Schaible	Sporian				brian@sporian.com
Farokh Eskafi	Tagarray				farokh@tagarray.com
Paul Fortier	Univ of Massechusetts				pfortier@umass.edu
Haydn Thompson	Univ of Sheffield		Sheffield, UK		h.thompson@sheffield.ac.uk
Tom Birnbaum	Wireless Sensor Technologies				tbirnbaum@att.net
Steve Noro	Yokogawa				shuichiro.noro@us.yokogawa.com

1.2 ISA107.4 Wireless Sensors for Turbine Instrumentation Working Group

Daniel Sexton - RF Instrumentation and Systems Laboratory
GE Global Research Niskayuna, NY - sextonda@ge.com

Scope: **Wireless Instrumentation forTurbine Engine Test Cell** :

Scalable architectures, system components, protocols, secure reliable wireless connectivity for test cell-based, multi-tier, active data transmission and passive wireless sensing, harsh environments

Basis for **future on-wing** engine health monitoring or control systems.

Purpose:

- Define Wireless interfaces, physical and RF environment
- Develop Multi-vendor interoperability support for various applications
- Develop co-existence support – possibly with other network standards

Future Activities:

- Technology Assessment and Gap Analysis
- Develop Needs Areas for Standards and Best Practices
- Users/Develop community develops Documents

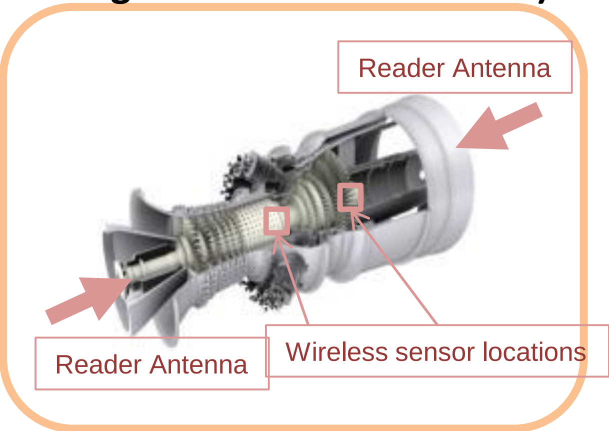
Benefits of Creating a Standard:

1. System simplification
2. Compatibility between vendor equipment
3. Consistency in measurements
4. Reduced testing time and costs

Wires are
a Common Problem

Level 0 - Engine
(On/In-Engine – 1 ft)

Level 1 – Test Cell
(Interrogators & Network – 50ft)



1.3 Wireless Technology for Aerospace Applications

Sanjay Bejekal – UTRC East Hartford, Conn. - BajekaS@utrc.utc.com

Wireless Needs:
- Long term health monitoring of the airframe and structures
- Short term health monitoring of targeted/specific issues using peel & stick sensors
- Security – resistance to intentional RF interference & protection from eavesdropping

Countermeasures:
- Frequency Hopping systems over large frequency bands (>500 MHz)
- Antenna Gain pattern (fixed and adaptive phased arrays)
- Adaptive Tx power control (burn through)
- Coding
- Novel Technologies (Magnetic comm, Free space optics, Higher freq > 40 GHz)
    - Mag comm can have 3 orders of magnitude less susceptibility to eavesdropping vs RF

Energy Harvesting:
- Combine sources – PV, Mechanical, Remote RF
- Power Storage – Ultra Capacitors or thin film rechargeable – Printed Zinc batteries

System Integration:
- Communication Range
- Protocols: Physical and Software Stacks

Passive Wireless Potential: Low Cost - Short & Long Term Health Monitoring, Security

1.4 Naval Applications of PWST from the End-user's Perspective

Robert Pritchard – Navair, NAWCWD China Lake **robert.w.pritchard@navy.mil**

Potential Uses of PWST:

- **Condition-based Maintenance**
  - Energy Autonomy – e.g. thermal scavenging for external skin sensors
  - Event Monitoring – e.g. munitions comm link integrity –voltage drop at umbilical
  - Energy Harvesting – e.g. helicopter blade damage, pitch link dynamic loads
- **Health Management/Monitoring and Inventory Management**
  - -Ext Environment where munitions have been -Temp, Humidity, Vib, Shock, Chem, etc
  - Internal Conditions – Temp, Press, Humid, Stress/Strain, Chem, Corrosion, Leak, etc.
  - Detection, Identification, Location, Remote Sensing(Encryption for Security)
- **Anti-Tampering(DOD and DHS)**
  - disable LIVE/DUD munitions – remotely commanded or self-destruct
  - sense tampering
- **Power Systems**: Improve Isp, Mass Fraction, Cost, Uncertainty, Reliability
  - Novel Ocean(Thermal) Powered Underwater Vehicle – NASA/JPL
  - Energy Mgmnt/System Control: Press, Temp, Power, RPM, Fuel Flow, Vol, Haz Gas
- **JANNAF sponsored Space and Military Wireless Sensor Systems Workshops**
  - Co-chairs: Pritchard and Dr. Tim Miller/AFRL - EAFB
- **OPNAV Ordnance RFID Implementation Policy(Aug 2008)**
- **List of Challenges, Approaches, Critical Measurements, “Low Hanging Fruit”**
- **Desirable Wireless Sensor Features and Approaches**

2.1 Passive Sensor Needs at BP

Dave Lafferty – Chief Technology Office - david.lafferty@bp.com

BP: Worldwide – Down-hole, Transport, Refine, Market – 80,000 employees

Fundamentals of Sensing: Deploy > Measure > Communicate > Take Action

PWST Applications that work/should work:

- Rotational Equip/ Shafts, Flames, Cement, Turbine Tips, Gas Detection,

Specific PWST Use Cases needing solutions:

- Corrosion Under Insulation (Indicators – Moisture, Humidity, Ph)
- Down-hole Cement between casing and rock(level, temp, strain)

Potential PWST Use Cases:

- Difficult to inspect locations
- Operating in hostile environments
- Extend the service life of assets beyond their designed life
- Reducing and managing risk via measuring the environment

2.2 Oil and Gas Asset Integrity Monitoring: the Needs and Challenges

Ron Cramer - Ronald.Cramer@shell.com

- Safety, Sustainability, Security, Ubiquitous Sensors
- Remote Sensing
- Health Care
- MEMS: versatile, powerful, reliable, cheap
- Measure any variable under multiple conditions
- Bring Cost Down, Performance Up
- Sub-Sea Integrity and Leak Detection

Approach

- Prior applications in other industries
- Conversion to O&G – Algorithms to convert signal to info
- Integration into a functional system
- Partnership with technology suppliers: industry & academia
- Quick route to failure – Game-changer

Sensor Elements

- MEMS for Vibration, acoustic detection, temperature
- SONAR, RADAR
- Magnetic detectors
- Ultrasonic

Common Systems

- Existing and emerging sensors
- Power generation and storage
- Signal conditioning and transmission
- Networking
- System architecture
- Data analysis

Systems

- Autonomous underwater vehicle
- Fixed subsea sensor networks
- Fixed acoustic/temperature/chemical/US sensors network onshore
- Versatile and expandable framework

2.3 Wireless Sensor Monitoring of Structures During Extreme Events

Fred Faridazar - Turner-Fairbank Highway Research Center (TFHRC) McLean, VA fred.faridazar@dot.gov
http://www.fhwa.dot.gov/advancedresearch/index.cfm

Exploratory Advanced Research Programs
David.Kuehn@dot.gov; terry.halkyard@dot.gov

- **Integrated Highway System Concepts**
  - International approaches: vehicle automation
- **Nano-scale Research**
  - Measurement of dispersion
- **Human Behavior and Travel Choices**
  - Dynamic ridesharing
  - Vision assisted technologies
- **Energy and Resource Conservation**
  - Sustainable underground structures
  - Electric vehicle commercialization
- **Information Sciences**
  - Video decoding, feature extraction
  - Probabilistic record linkage (data mining)
- **Breakthroughs in Materials Science**
  - "Self-healing" materials
  - Cement hydration kinetics
- **Technology for Assessing Performance**
  - "Smart balls" for autonomous culvert inspection
  - Pressure sensitive paints for aerodynamic testing
  - Remote sensing for environmental processes

Infrastructure

- Pavement Materials
- Pavement Design and Construction
- Long Term Pavement Performance
- Bridge and Foundation Engineering
- Hazard Mitigation
  - - Flood, Seismic, etc.
- Infrastructure Management

Operations and Safety - david.yang@dot.gov

- www.fhwa.dot.gov/research/tfhrc/programs/safety
- Human Factors
- Intersections
- Pedestrian & Bicycles
- Roadway Departure
- Speed Management
- Comprehensive Safety – Predicting Societal and
- Complex Natural Systems

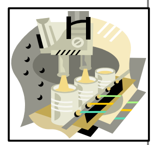
3.1 Machine-to-Machine Interfaces in Factory Automation

Cliff Whitehead – Rockwell Automation - cjwhiteheadjr@ra.rockwell.com

<u>What if machines could report:</u>

their “health”?

- vibration of rotating equipment
- motor winding temperature
- oil or lubricant temperature or quality

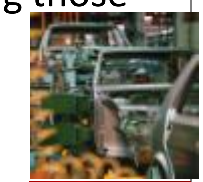


their production?

- good parts or batches
- substandard parts or batches
- scrap or waste
- consumable materials used
- energy or utilities consumed

their “inventory”?

mechanical components
electrical components – including those inside control cabinets
changeover parts
spare part requirements



their “location”?

work cell name
work cell unique identity
physical location inside the plant
operational status
safety status
upstream and downstream interfaces

<u>Wireless in Automation Today:</u>

Most prevalent in higher latency, non-deterministic monitoring applications

- Temperature, Flow, Vibration

Attractiveness stems from:

- Standard interfaces to well-established industrial network protocols (e.g., EtherNet/IP)
- Field-based devices for wireless interrogation and data translation

Challenges arise when speed is important

<u>Summary:</u>

Passive wireless sensing <u>has promise</u> for Factory Automation applications

The challenge is <u>competing for mindshare</u> with other wired and wireless technologies, and “the way it’s always been done”

<u>Standards</u> play a role by exposing user and technical requirements that can <u>challenge our industry</u> to advance our efforts to meet those requirements that are currently unmet is important

3.2 High Temperature Wireless Systems

John R. Fraley/Byron Western – Arkansas Power Electronics - jfraley@APEI.net

Why High Temperature Wireless?
- Data Collection from Rotating Components
- Increased SNR from Sensors
- Reduced Weight from Cabling
- Distributed Systems
- Improved Process Controls

Overview:

Motivation

Applications:

Aerospace: HM for Bearings & Gearbox
Distributed Engine Controls

Geological Exploration: Temp, Press, Flow
Wireless Drill Head Control

Power Generation: Turbine Blades, Condition-based maintenance, Smart Turbine Control

Industrial Processes: Manufacturing and Chemical Process Monitoring

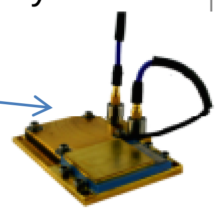
Technical:

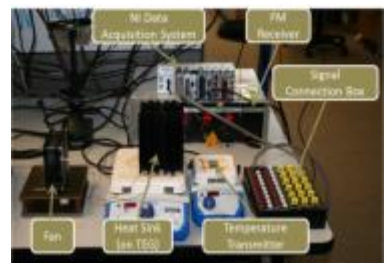
Enabling Technologies:

HTSOI: rated 225 °C and operable to 300 °C.
Wide Band Gap semiconductors up to 600 °C
Low Temp Co-fired Ceramic – multi-layer circuit
Energy harvesting Vibr, RF, TEG

Bearing Sensor Design

Blade Sensor Design

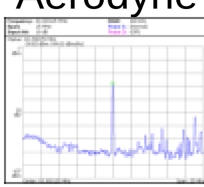




Testing Facilties:

Bearing Tests-AFRL

Spin Tests-Aerodyne

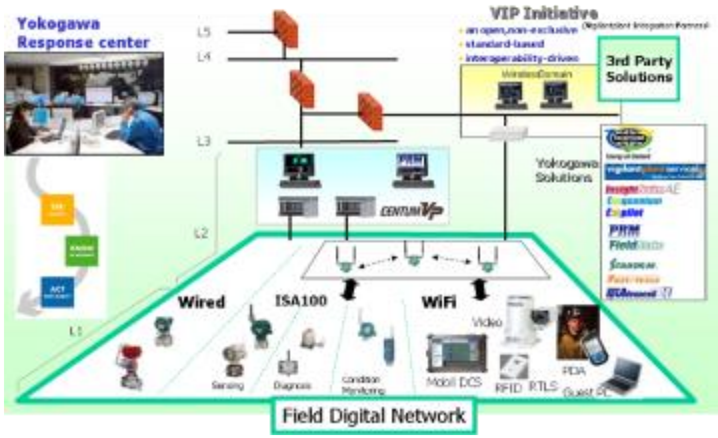


What's Next?

- Energy Harvester & Transmitter in Single Package
- HTSOI and SiC ASICs
- Integrated Sensors
- Improved Power Conditioning

3.3 PWST Needs At Yokagawa

Penny Chen – Yokagawa Corporation of America -
penny.chen@us.yokogawa.com



Future PWST Measurement Needs:

Corrosion
Humidity
Optical, Infrared
Pressure, Tension
Gas, CO_2, Smell
Vibration
Acoustic Emission
Temperature
PH, Liquid Level, Flow
Location, Proximity
Valve position

PWST Challenges:

-Industrial environment :
- Life reliability & stability
- System scalability
- Robust, secure wireless
- Large Data Volume
- Low initial entry cost
- Variety of sensor types
- Coexistence w/wireless
- Open standards

Vigilantplant:

See Clearly
Know in Advance,
Act with Agility

	Requirements	Key technologies	Our Solutions
4:Application	-Full Automation -Full Navigation -Opt. Performance	-Simulation -Advanced HMI (3D, MM, VR) -Production Traceability	- Scenario-based Operation - Augmented Reality - Predictive Navigation - Advanced Optimization
3:Control	- Robustness - Integrity - Flexibility	- Asynchronous Control Algorithm -Predictive control	-palc-PID for continues control block -Shadow function block -APC, Opt. controller
2:Connection	- Reliability, Robust - Deterministic - Min. Latency, Jitter - Scalability - Interoperability	-Full Redundancy (Duo cast, Gateway) - TDMA scheduling - FB communication	- Redundant Gateway - Star topology by Duo cast / dual BBR -MM comm. On BBR - Reliable/long range Radio Comm.
1:Device	- Long Battery life - Growing Intelligent - Function block	- Higher battery Capacity - Low power consumption -Energy Harvesting -Diagnostics -Intelligent Application	-Standard battery case/pack with long life -Zone1 replaceable battery -Extending antenna cable -High gain antenna

4.1 Passive Wireless Sensor Technology for SRS Material Storage

Michael Mets - Process Controls and Automation Technology,
Savannah River Nuclear Solutions, LLC - michael.mets@srs.gov

SRNS: M&O Contractor, DOE Savannah River Site, Aiken SC Nuclear Materials Storage Mission:

- Handling, Storage & Surveillance of Plutonium and other NM

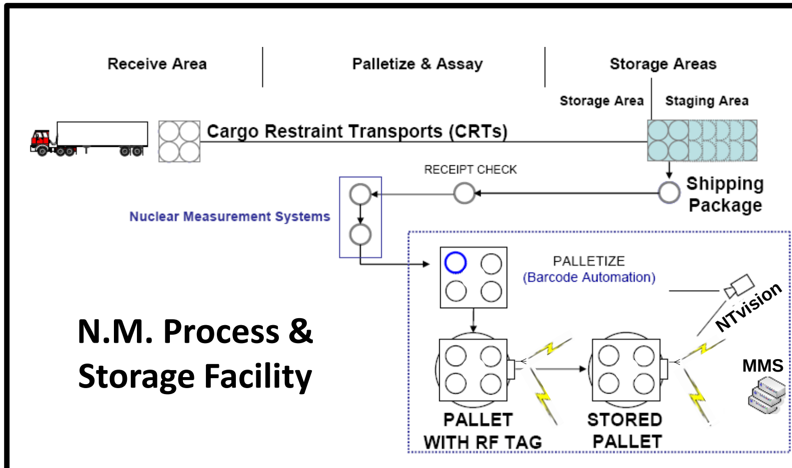
Challenges for RF Systems:

Regulatory Environment
- Spectrum Supportability Auth.
- Procurement Authorization
- Risk Assessment
- Security and Test Plans

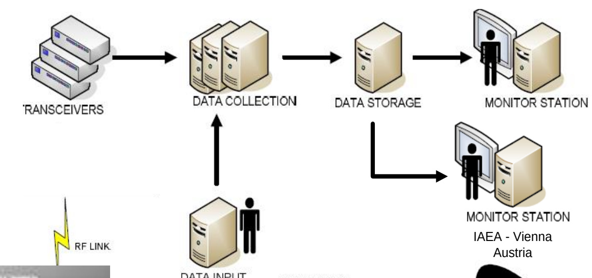
Physical Environment
- Reflective & Attenuating Surfaces
- Various Sources of EMI
- Coexistence with Legacy Equip.
- Harsh Environmental Conditions
- Significant Radiation Levels

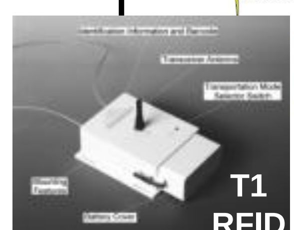
Passive Wireless Sensor Wish List

- Low cost <$500
- -40° to +85° C ambient ops
- RF low power
- Security (AES 128-bit encryption) - NIST
- Authentication (AES 128-bit CMAC) - NIST
- Store messages locally
- Fiber optic loop (up to 50m)
- Remote data collection
- Real time clock
- Tamper detection
- Radiation Monitoring and Reporting
- Temperature & Humidity Monitoring



Current Wireless Monitoring (fromSNL)





T1 ARFTID (Tampering)

NEW: Remotely Monitored Seal Array(RMSA) - 902MHz – Sandia N. Lab

ARG-US RFID - Argonne N Lab

4.2 Introduction to On-Ramp Wireless

Jake Rasweiler – On-Ramp Wireless - jake.rasweiler@onrampwireless.com

"Ultra-Link" Technology

Applications:

- Utilities, Smart Grid
- Process Industries
- Personnel and Asset Tracking
- Critical Infrastructure

System Goals:

- Lowest Total Cost of Ownership
- Best Coverage in Industry
- Connectivity in Hardest to Reach Areas
- Immense Capacity
- Seamless Support for Battery Devices
- Robust Operation in Noisy ISM Band

Application Type	Data/ Day	#Nodes per AP*
Electric AMI Meter	2.4 KB	20,000+
Hazardous Alarms	100 bytes	100,000+
Pressure Sensor	100 bytes	100,000+
Cathodic Protection	100 bytes	100,000+

AP Simultaneous Up & Down-link

AP Up-Link of User Data:

- 100 Mbytes/day
- 2,000 Nodes simultaneously

AP Down-link of User Data:

- Unicast: 72 MBytes/day
- Multi-cast: 144 kBytes/day
- Broadcast: 72 kBytes/day

Performance Metrics:

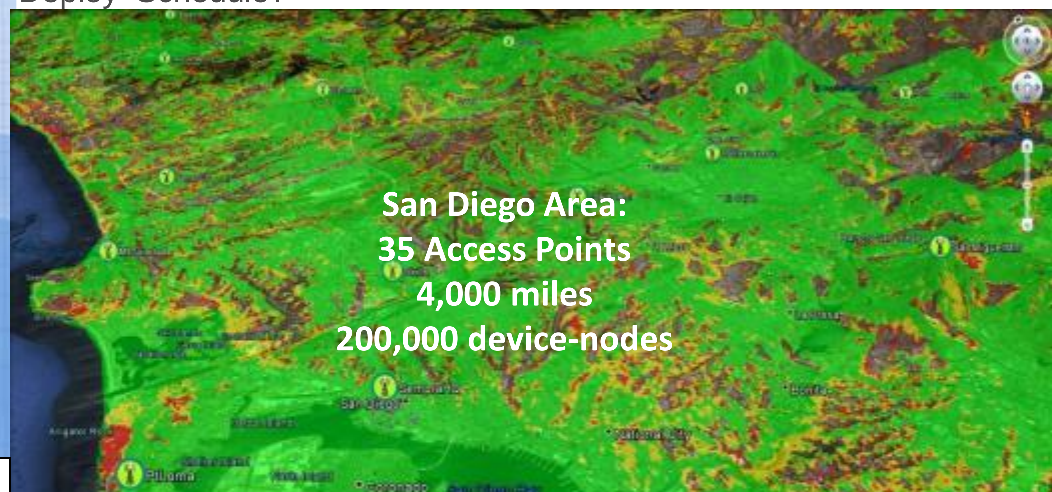
Coverage
Capacity
Coexistence
Power
Security
Cost
Deploy Schedule?

Installations: stationary during RF Ops, underground, in containers or Indoors, wide area coverage

Device Nodes:

-90 kBytes/day - 2.7% throughput for Electric meter – DSSS works fine

DSSS: Spreading factors up to 8192 chips/symbol gets up to **39 dB of processing gain**
Receiver sensitivity is -133 dBm on downlink
-142 dBm on uplink



Also: Niger Delta Oil/Gas Pilot Deployment
10,000 km2 area **Avoid theft/leaks**
challenging terrain **Battery operated**

4.3 Integrating Wireless Sensors with Existing Data Acquisition Systems

Chris Gibson –VTI Instruments, Irvine CA - cgibson@vtiinstruments.com

What is important to End Users?

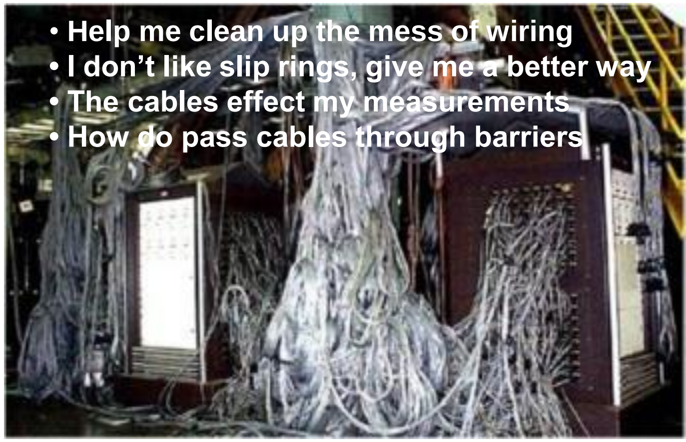
(Wireless Opportunities in Red - Bold)

Gen Purpose/High Speed Data Acquisition

- Cost/channel
- Accuracy
- **Ease of Use**
- **Quick test setup and teardown**
- Ability to distribute across large area
- Turnkey software, or min development effort
- Software tools to roll their own application
- Data processing done post test
- Continuous sampling important (no gaps)

Typical VTI Test Sites

- Jet engine Test Cells
- Rocket engine Test Cells
- White Good Manufacturers
- General Automotive Testing
- Battery/Solar Cell Testing



Modal Ground Vibration Testing

- Distribute the measurements close to the structure
- **Cables add mass and damping, I need to manage this**
- Simultaneous sampling -eliminate channel/channel phase skew
- The ability to move lots of data is very important
- Turnkey software is historically required
- Data is analyzed in the frequency domain
- Move raw data and have the PC do the analysis/processing

Rotational Machinery and Order Analysis

(Turbine Generators, Drive Train, Transmissions, Windmills)

- Repeatability of measurements is a must
- High performance Tachometer inputs simply setup
- **I need to measure rotating mass**
- Data will be re-sampled for order domain analysis
- Phase angle/sampling , Tach accuracy important for balance ops
- Turn key software solutions are desired
- Distributed Sensing
- Software tools that they can use to roll their own application

Static Structural and Fatigue:

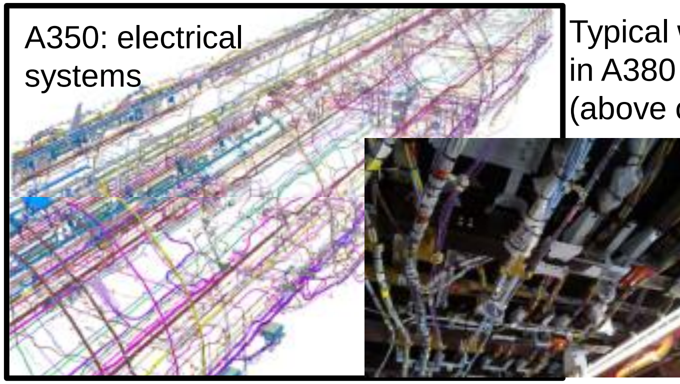
- **The ability to place the instruments close to the structure to minimize cable lengths**
- Synchronization for improved data understanding in the event of a failure
- Front end configuration flexibility, support multiple transducer types (load, strain, pressure, displacement)
- **Scalability is critical - these can become very large tests**
- Turnkey software is preferred, ease of use
- **Help me manage channels for large test configurations**

Temperature Testing/Test Cells

- Repeatability of measurements is a premium
- Temperature accuracy
- **Easy connectivity, mini-TC simplifies setup**
- OTD shows failed channels before critical testing
- Measurement stability, some tests last for a long time
- Distributed measurements ease setup and reduce noise
- Real time limit checking with alarm or shutdown capability
- Software tools that they can use to roll their own application

4.4 Protected Spectrum for Wireless Avionics Intra-Communications

Radek Zakrzewski – AVSI Project AFE73 Chair - radek.zakrzewski@goodrich.com



Typical wiring installation in A380 crown area (above ceiling panels)

About 30% of wiring can be potentially substituted by wireless

A380-800 wiring:

- Total wire count: ~100 000
- Total wire length: 470 km
- Total weight of wires: 5 700 kg
- Add 30% more for **wire mounting**

Motivation:

Reconfigurability: Efficient cabin or other changes/upgrades(e.g. Wireless – relocatable-Oxygen Supply Unit)
Safety: Dissimilar or Added redundancy, Fewer mechanical failures
Efficiency/Environmental: Less fuel burned due to reduced weight
Reliability: reduce aging wiring, data for aging aircraft

Challenge: Obtain Protected RF Spectrum World-wide needed for aircraft OEMs to install RF systems
(License-free – ISM – bands not suitable for safety-critical uses)

Aerospace Vehicle System Institute(AVSI) Consortium – www.avsi.aero – David Redman

WAIC – Wireless Avionics Intra-Communications – On-board, not air-to-ground, air-to-air, air-to-space

Project AFE73 – began in 2008 – **Members**: Airbus, BAE Systems, Boeing, Bombardier, Embraer, Goodrich, Gulfstream, GE Aviation, Honeywell, NASA, Sikorsky

Goals:

- Develop Technical justification and broad support for Protected Spectrum request - ITU-R
- Receive Protected Frequency for WAIC systems world-wide at World Radiocommunications Conference

Progress: WRC-12 (Feb 2012) adopted and Agenda Item for WAIC, WRC-15 will vote on proposal in 2015

ITU-R M.2197 Report: http://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-M.2197-2010-PDF-E.pdf

WRC15 Agenda Item: http://legacy.icao.int/anb/panels/acp/wg/f/wgf26/ACP-WGF26-WP13_WAIC%20AI%201.17%20draft.doc

Next: Detailed Sharing Studies must be accomplished in preparation for 2015.

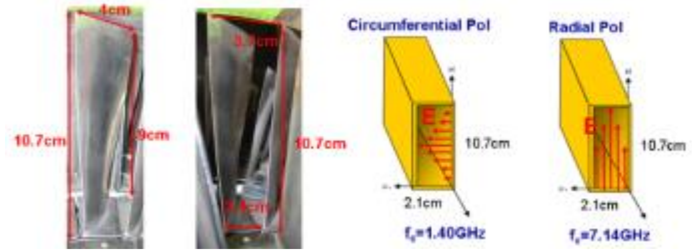
5.1 “Passive Wireless Sensing in a High-Multipath, High-Doppler Environment”

Bruce Montgomery – Pres. Syntonics Corp - Bruce.Montgomery@syntonicscorp.com

RF Propagation in Jet Engines:

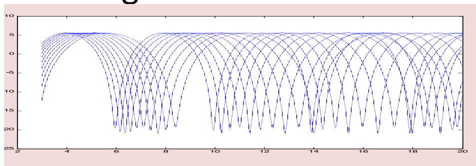
RF Transmission Testing:

- GE CF6-50 at WPAFB
- Small: GD F-16 engine, Large Boeing 747 engine
- Circular Polarization and Radial Polarization
- Signal loss can be less than in free space’s 1÷R2
- Signal Energy is spread out in time: initial and reflections
- Investigated EM “Windows”
- Multiple reflection time corresponds to 3x compressor size
- Time domain: Discerned Individual stages, not blades
- Internal compressor propagation is axial, not circumferential or spiral
- “Cutoff” frequency – for F16, 30db losses below 5.2 GHz



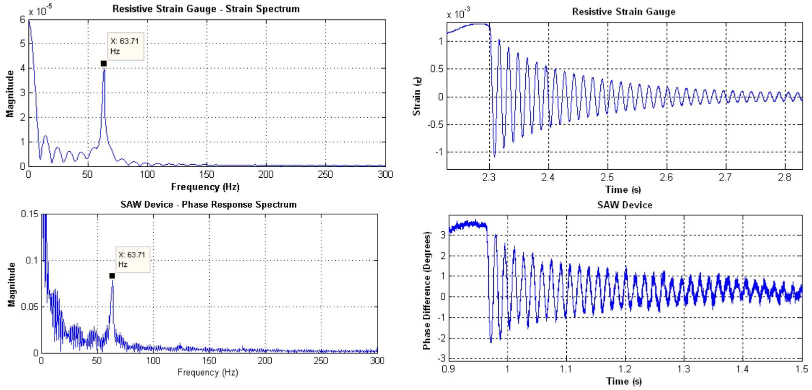
RF Modeling:

- Inserted “scatterers” at several points between transmitter-receiver
- Added waveguides to Model

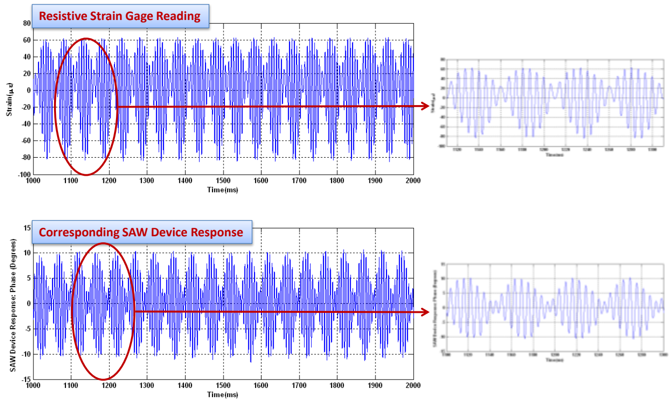


RF Passive Sensor Testing:
SAW device and resistive strain gauge Measurements the same

- Cantilever Strain Measurements



- Harmonically Driven

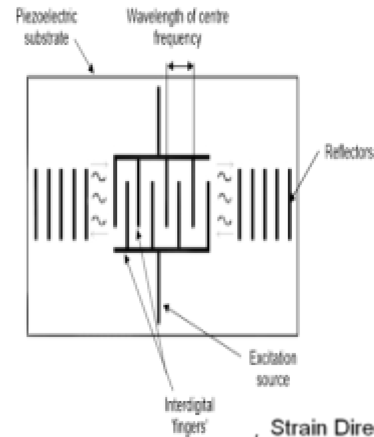


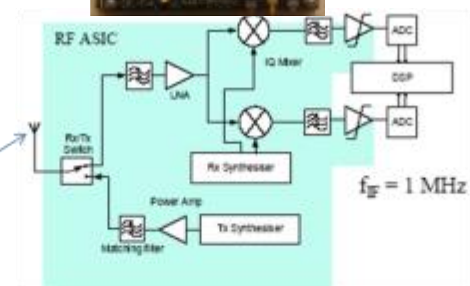
5.2 "Wireless Passive Strain Sensors Based on Surface Acoustic Wave (SAW) Principles"

Fred Gnadinger – Pres&CEO Albido Corp - fred@gnadinger.com; www.albido.com

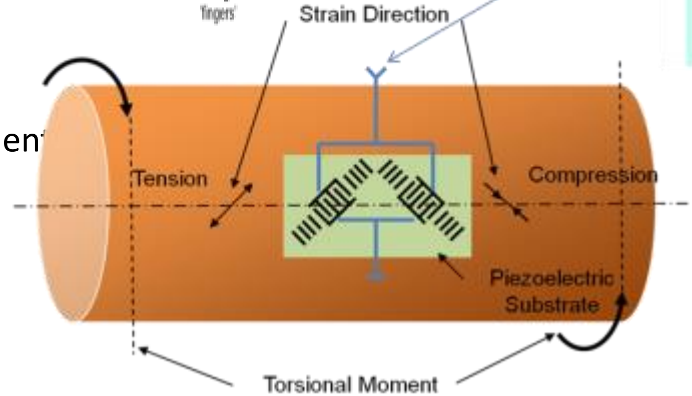
Navy STTR Program
ONR COTR – Scott Coombes

<u>Albido Passive Wireless SAW Sensors</u>
Coded
Large bandwidth, high speed
Large read range
Small, rugged, cheap
Noise tolerant, no cross sensitivity
Low loss and variable frequency
Radiation hard for space applications
Physical, chemical and biological parameters
Wide temperature range and harsh environment
- new temp compensation method



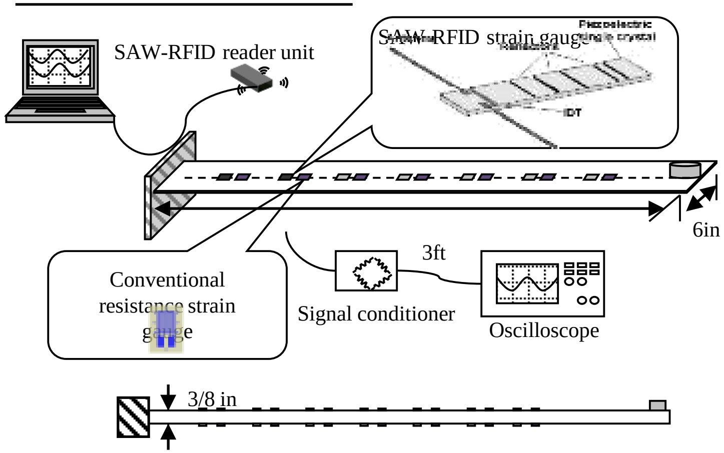


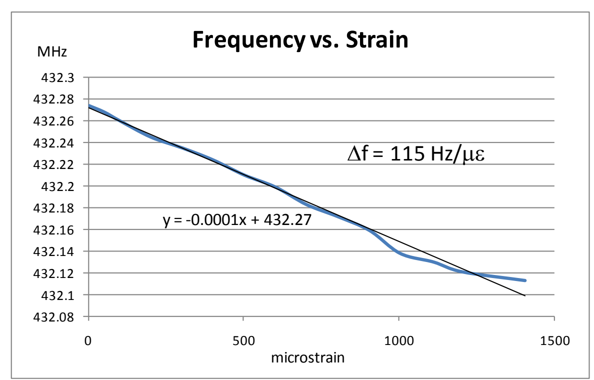
Reader



1cm x 1cm
Strain Sensor

<u>Cantilever Strain Test:</u>





5.3 “Wireless Microwave Acoustic Sensor Systems for Harsh Environments”

Mauricio Pierera da Cunha –Environetx- mdacunha@environetix.com www.environetix.com

<u>Environetix Passive Wireless SAW Sensors</u>

- Stable and reliable operation up to 900oC (1650oF)
- Wireless RF interrogator electronics
- Custom installation on rotating or static parts
- User-friendly data output on laptop PC
- Proprietary sensor packaging and attachment
- Multiple strain and temp sensors - integrated RF antennas
- Dyn Strain, pressure, corrosion , pressure sensors in work
- RF Frequency: 100MHz to 1GHz depending on need
- LANGASITE LA3GA5SIO14 Piezoelectric crystal
  - -Stable up to 1400oC - Thermal shock resistant

<u>Demo s at</u> Power Plants, Furnaces, Engine Exhausts
- up to 1200oC (2200oF)

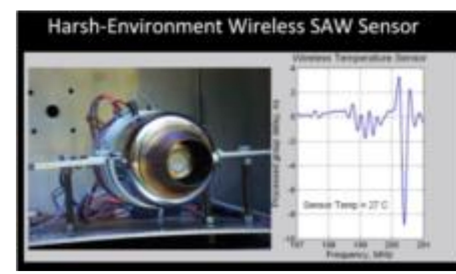
90,000rpm
53,000 G

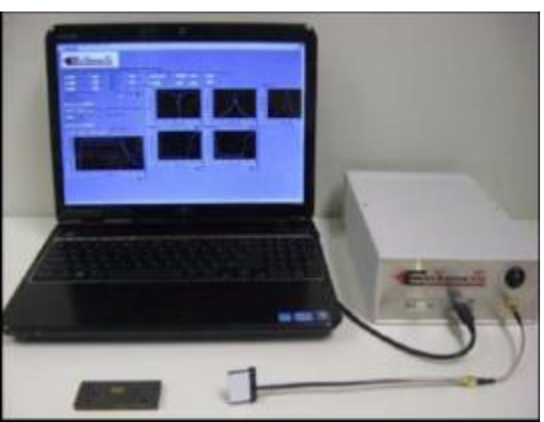
ARMFIELD CM-4

GE CT7 / T700

<u>EVHT-100</u> for multiple Temperature Sensors

TMC85-1





temperature range:	150oC (300oF) to 900oC (1650oF)
accuracy:	±10oC over full range
resolution:	within ± 5oC
long term drift:	< 1oC / 150 hours
operating life:	> 500 hours
insensitivity to press:	0 to 750 psi with < 1oC error
operating frequency:	100 MHz to 1 GHz
sampling rate:	1 Hz to 100 kHz
rotation:	up to 53,000g’s

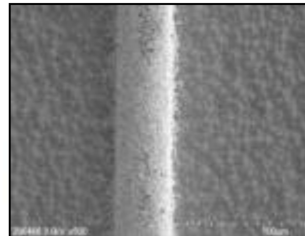
JETCAT P-70 & P-80

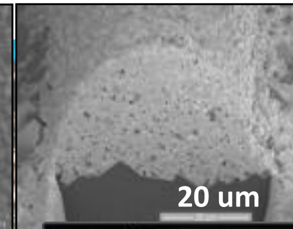
5.4 “Passive Direct-write Sensors”

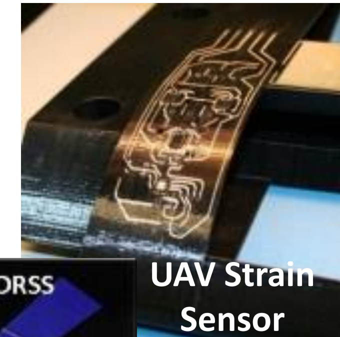
Mike Newton – nScript- mNewton@nscryptinc.com - www.nscryptinc.com

Printed Electronics + 3D Additive Manufacturing = Direct Print Additive Manufacturing

Print what you can….place what you can’t.







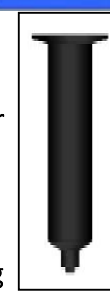
<u>Micro-Dispensing/direct printing:</u>

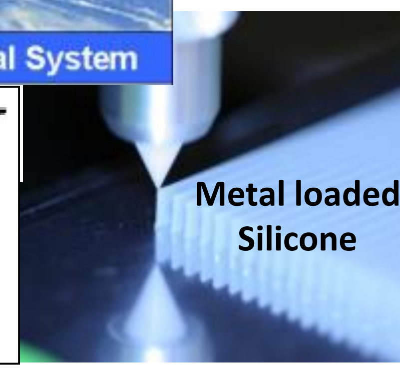
- High speed
- As fast as 500mm/sec.
- Wide range of material choice:
- Viscosity from 1cps to >1 million cps.
- Many Types of materials
- Capability of high resolution and accuracy
- Pico-liter level column control
- Line as small as <u>20um</u>, dot as small as 75um.

3D Print n Play Monolithic Satellite

<u>Mixture,</u> by volume:
25% DSM Somos 11122
75% Ceramic powder

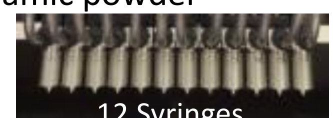
<u>Syringe</u> for Loading, mixing, storing, dispensing

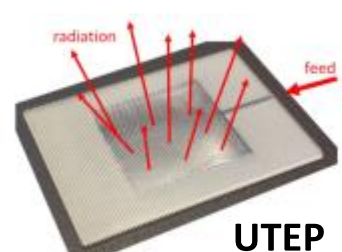




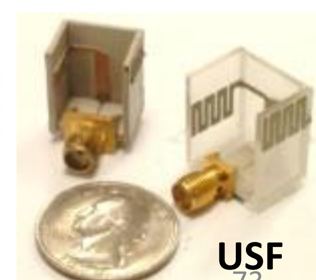
<u>Applications:</u>

- 2nd Generation TDRSS
- Print and Play Monolithic Satellite
- UAV monolithic strain sensor
- Magnetometer
- Vibration Sensor
- Electronic Circuits
- Solar Cell Mfg
- Metal loaded silicone
- Passive Wireless Sensors??





UTEP Antenna



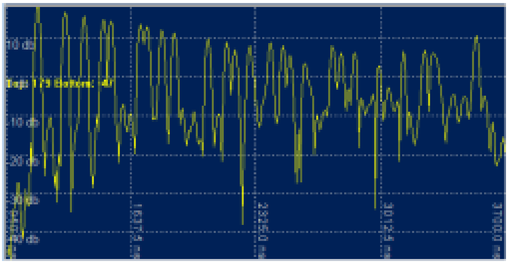
USF

6.1 “Advances in SAW Devices for Sensing and RFID Applications”

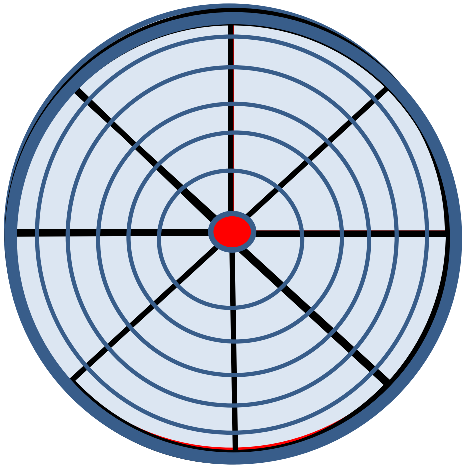
Paul Hartman – RFSAW Inc. -phartmann@rfsaw.com - www.rfsaw.com

Global SAW Tag (GST) - SAW-based passive RFID – 2.44GHz

- **Longest passive sensor reading range**
- **HERO certified for safe use on munitions**
- **Anti-Collision Matched Filter Processing**
- **Temperature tolerant Codes with Cross-correlation (i.e. anti-collision)**
- **Range-dependent zones – group similar tag response magnitudes using times of arrival**



Actual 96-Bit Wireless Tag Waveform



<u>Potentially 240 SAW Temperature Tags:</u>

- 5 Codes
- 6 Ranges
- 8 Directions(Antennas)
- Reader switches from one antenna to the next

.

8 Port Reader

6.2 "PWST SAW - Sensor System"

Jackie Hines – VP ASRDC Corp. jhines@asrdcorp.com - www.asrdcorp.com/
Applied Sensor Research & Development Corporation

Wireless SAW Sensor Advantages:

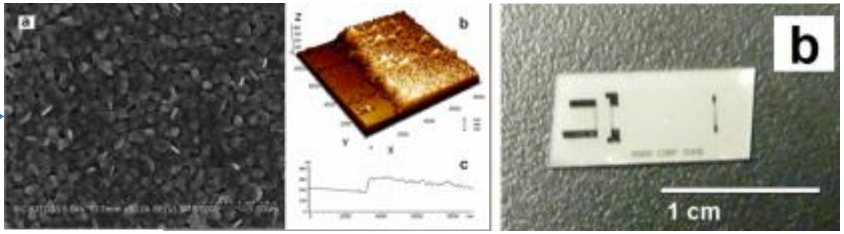
Operate wirelessly RFID capable
RF signal activates sensor,
Require no batteries Sensitive/accurate
Perform multiple real–time measurements
Last a long time (decades)
Survive & operate in extreme environments
Cryo to 1,000°C RadHard to > 10 MRad
Low cost
Established technology
High Volume - Billions of devices sold/year for cell phones
=> Enable low cost distributed sensing

SAW Sensors under development @ ASRDC

- Coded sensor-tag wireless interface devices
  - use variable impedance input from Std sensors
- **Humidity - Today's Focus**
- Hydrogen
- Temperature
- Methane
- Hypergol leak detection(MMH, DMH, NTO)
- (Cryogenic) liquid (level)
- Concrete maturity monitor
- Biosensor for infectious agents (CT)

Passive Wireless SAW Humidity Sensor System

- Temple developed quick response sensor from Nanoparticle PVP/LiCl-doped TiO2 films



DSSS codes with time, frequency diversity – 32 T sensors
Discrete Frequency Coding (DFC) – 8 good codes
Time Diversity - Re-used each code at eight distinct time delays
Orthogonal chips at each freq. have different delays to produce codes
Similar to OFC, but with code "chips" in frequency bands that do not overlap
Relative Humidty measured, need to add temperature compensation
System Delivered to NASA KSC, making improvements – deliver Nov 2012

-Time integrating correlator-based Transceiver
-Power spectral density of response measured half-passband integrated energy

Advances in Sensor-tag Coding
13-bit Barker code with time & frequency diversity – 100 sensor-tags
DSSS codes with time, frequency diversity – 32 T sensors
SBIR Phase 2 Temperature Sensor System(32) to NASA/MSFC – 2013

6.3 “"SAW PWST: 915 Mhz Sensor System and Demonstrations“

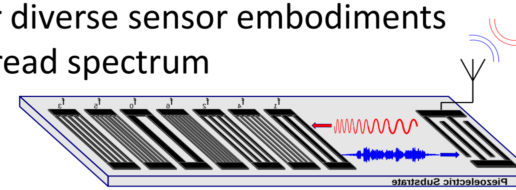
Don Malocha – Univ of Central Florida - malocha@mail.ucf.edu

Acknowledgements *NASA/KSC Dr. Bob Youngquist*
Florida High Tech Corridor Council
Florida Space Institute
Mnemonics(MNI)

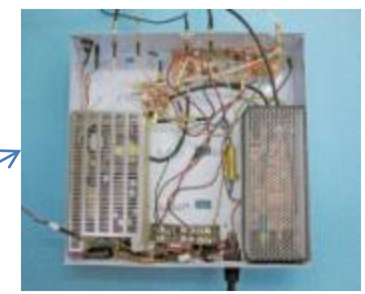
UCF Progress:

Year	Hardware	# Sensors	2 dBi antenna Isotropic Range (m)	Data Transfer Rate (sec)	Post Processing Rate (msec)/sensor	Plotting and Overhead (sec)
2008	UCF	1-2	< 1	5	>1000	2
2009	UCF	1-2	1-3	2	>1000	2
2010	UCF & MNI	1-4	1-4	0.5	500	2
2011	MNI	1-6	1-5	0.5	100	2
2012	MNI	1-8	1-7	0.5	10	2
2013	MNI and ?	1-16	1-10	0.5	5	?
2014	MNI and ?	1-32	1-50	0.001	1	?

Orthogonal SAW Frequency Coding(OFC):
- Frequency & time offer great coding diversity
- Single communication platform for diverse sensor embodiments
- Spread spectrum

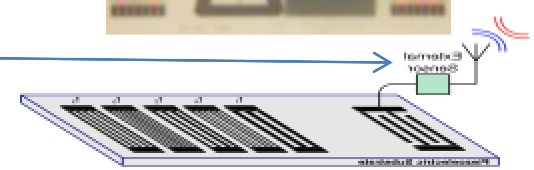


Sensors: temperature, range, strain, hydrogen, magnetic, liquid, cryogenic
Environments: isotropic, hallways (60m), faraday cage (.5x.5 m), anechoic
UCF Fast Prototyping <1 week from idea to device prototype
RF Transciever – more parts are making it faster and cheaper to develop
UCF Correlator Synchronous Transceiver- Software Radio (2004-2010)
- **Pulse Interrogation: Chirp or RF burst**
- **Integration of multiple “pings” OFC processing gain**
- **915 MHz sync transceiver(Mnemonics, Inc) to NASA/KSC – STTR**



Dual Track Gas Sensor: (On-board Sensor) Ref to left and thin film sensor to right)

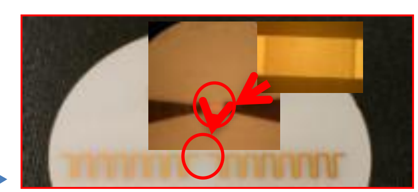
Magnetic Puck for Closure switch sensor (On-board)
Antenna used as Closure sensors (Off-board)



Matched Filters to reduce noise, Correlator Time Delay Extraction(CTDE)
- **S/N determines the precision and accuracy**

Adaptive Temperature Correlator
Range: Current: 5meters; Future: 250m – 800m
High Temperature SAW devices on Langatate (LGT) - stable up to ~1450ºC
- **Platinum thin/thick films under investigation**

Sawtenna development



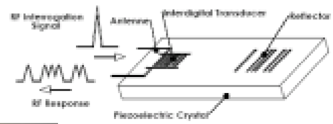
7.1 “SAW Sensors: Explore New Measurement Horizons”

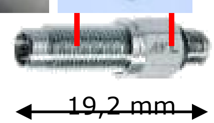
Heimo Mueller – CTR Carinthian Tech Research, Villach, Austria - heimo.mueller@CTR.at – www.ctr.at

Wireless SAW Sensor Symposium, Villach, Sep 20 & 21, 2012 www.saw-symposium.com

➢ **CTR SAW System Sensor-Tags**

Temp	C	F
Range	-55°C to +400°C	-67°F to +752°F
Accuracy	±2°C	±3.6°F
Resolution	0.1°C	0.18°F
Read range	**Meters**	**Feet**
9 dBi antenna	up to 2m	up to 6.6ft
18 dBi antenna	up to 4.5m	up to 14.8ft





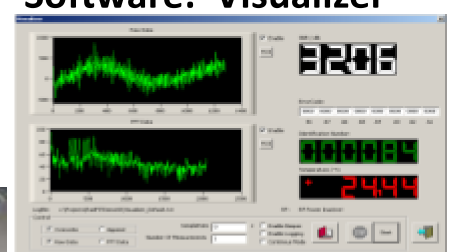
Readers

	Standard	Fast	Handheld
Read Time	300msec	100µsec	100msec
Channels	4	1	1
Frequency Bandwidth	2,45 GHz 80 MHz	2,45 GHz 80 MHz	2,45 GHz 80 MHz
Interface	LAN	LAN	Bluetooth
Power Source	EN 300440, FFC Part 15, JP	EN 300440	Battery life > 10.000 reads

➢ **SAW Applications**

- **Automotive: Pressure, Varnish lines**
- **Food: Baking Plates – ID, Temp & Pressure**
- **Oil: Drill Pipe – ID - www.hmenergyllc.com**
- **Steel – Slag Vessels, Slide Gate Plates – ID**
  - **Refrac Drying & Mold Temps**
- **Energy – Transmission Line Temps**

Software: Visualizer



Panel

Rotating Machine Elements – Temps

Trying:
Al Nitride thin film on Sapphire 1100°C (2012°F)

CTR SAW R & D

Beam-based 7 Membrane-based pressure

Strain - Tensile & Lateral strain

- Temperature compensation

High Temp - 600°C (1112°F) working temp

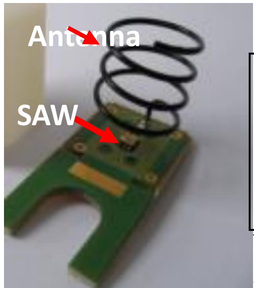
- 800°C (1472°F) short term

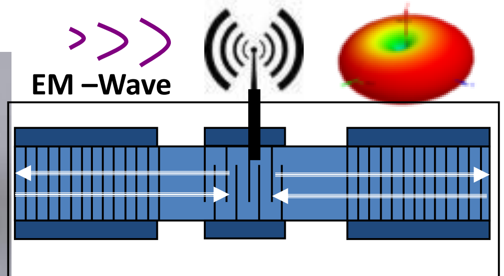
Housings: Ceramic & Metal housing needs

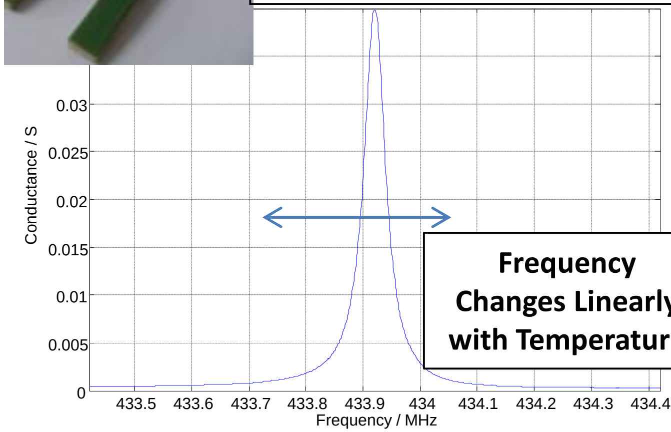
7.2 “Vectron Wireless Temperature Monitoring Solutions

Sabah Sabah – Vectron-Sengenuuity - sabah@sengenuity.com – www.sengenuity.com

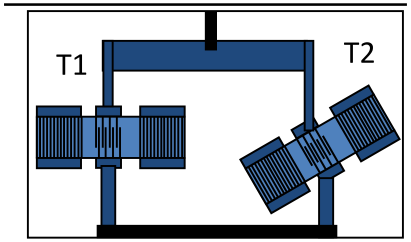
Single SAW Resonator: Absolute Measurement

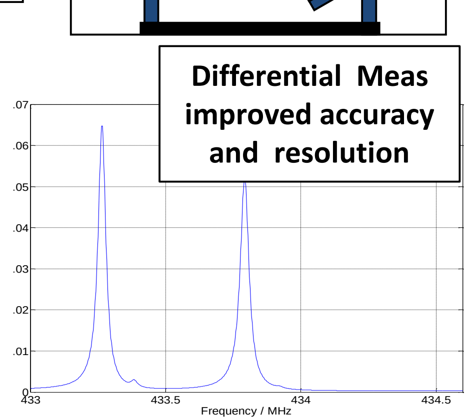






Double SAW Resonator: Differential Measurement





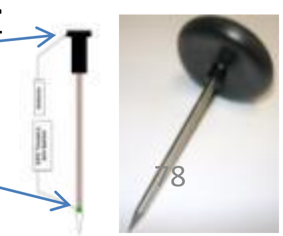
Temp Trackr™

Six Temperature Measurements At 6 Frequencies 428 to 439 MHz

- ***Passive*** and ***Wireless,*** non-invasive and no active electronic circuits
  - Save 20%-80% of industrial wire installation costs (est. US $130 – $650 /m)
- ***Medium*** & ***High*** temperature operating ranges: -20°C to 120°C & up to +260°C
- ***Reading Distance***: 0.1 to 3 Meters (depend on the antenna and RF environment)
- ***System accuracy***: ± 2°C (temperature operating range -20°C to 120°C)
- ***Robust, reliable , stable and suitable for harsh***, hazard and inaccessible hot-spots
- ***Multi- Communication Protocol***: RS485, RS232, USB, CAN. Analog-Output, MODBUS
- ***User Friendly***, ease of installation, simple to use Interfaces and data logging
- ***Real-Time*** and Continuously Thermal Monitoring – 24/7/365
- ***Miniature:*** small and light, low cost
- ***Low Maintenances***
- ***Low ageing degradations*** (± 2°C <12 years)
- ***Environmental*** and green technology – no recycling of battery

Applications:
Switching Temps for Smart Grid
Food Thermometer
Rotating Equipment Temps
Tire pressure
Fluid Viscosity

Food Thermometer



7.3 ““RFID Tag Antenna-Based Sensing”

Isaac Ehrenberg – MIT Auto-ID Labs - yitzi@mit.edu; Rahul Bhattacharyya - rahul_b@mit.edu
Prof Sanjay Sarma

- **Keeping Tabs on Things:**

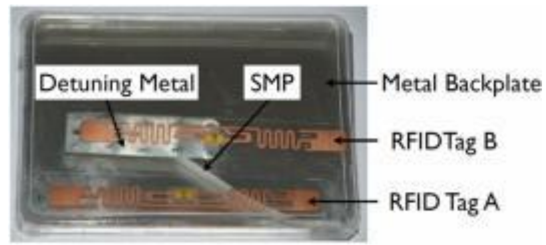
KSW semi-passive RFID temperature logger (>$3)
www.variosens.com

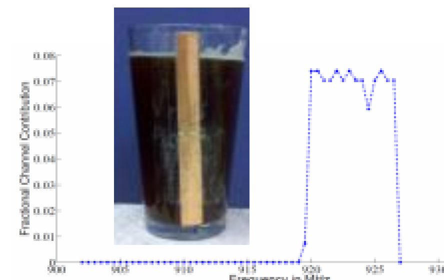
- **Why RFID?**

• Proven track record of pervasive deployment
• Low cost RFID tag manufacturing
• Standardized reader-tag communication
• Free adoption in RFID-enabled processes

Applications:

Temperature: perishables in cold chain
Temperature, Humidity and Shock on large scale

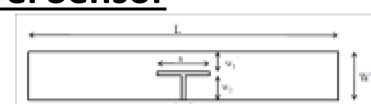


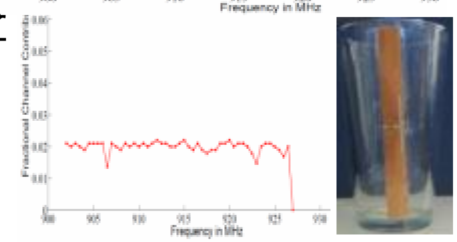


- **2 Concepts:**

Use <u>Reader-Tag Signal Parameters</u> for Sensing
AM: Use Reader Power or Tag Backscatter
FM: Use Freq shift in Tag Response

- <u>Temperature Threshold Sensor</u>
- <u>Fluid Level Sensor</u>





<u>Low-cost, non-electric</u> Memory

Normally, Passive RFID Tags can’t record events when unpowered
- Permanent Change to Antenna(e.g. damage) = memory - Temp Threshold Sensor

- Temporary Change: Shape Memory Polymers – Glass Transition Temp – flexible vs rigid
Diaphragm or Antenna Detuning metal – changes Tag Backscatter (AM)
Fluid in a glass(Deavors 2010)
Note: Other Inventions Potyrailo 2010, Siden 2007, Caizzone 2011

8.1 "Passive UWB: Long Range, Low Cost and Precise Location"

Kourosh Pahlavan – TagArray - kourosh@tagarray.com www.tagarray.com

Motivation:

-Cost Effective: Total cost of ownership 100x less than GEN2 or active RTLS
- Zero Watt Passive Transceiver: Tag consumes < 2µW when communicating
- Accurate Location and Long Range: 2-3 inch resolution from 100 meters away

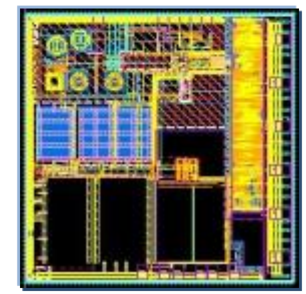
Applications:

- RTLS & Indoor tracking
- RFID
- Sensors
- Surveillance

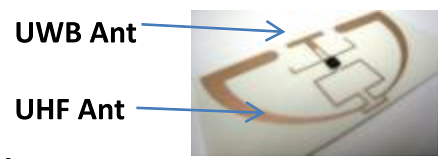
How it Works:

1. Beacon is a Narrowband UHF Transmitter
2. Narrowband signal powers Tag, initiates query session - 4W EIRP: 10m range
3. Receiver harvests RF power and wakes up
4. Tag transmits UWB impulses - 6dBm: 50-100m range
5. UWB Receiver(Single Chip/ Very Low Cost) uses Digital Antenna

Tag 1mm x 1mm



Reader 1mm x 1mm

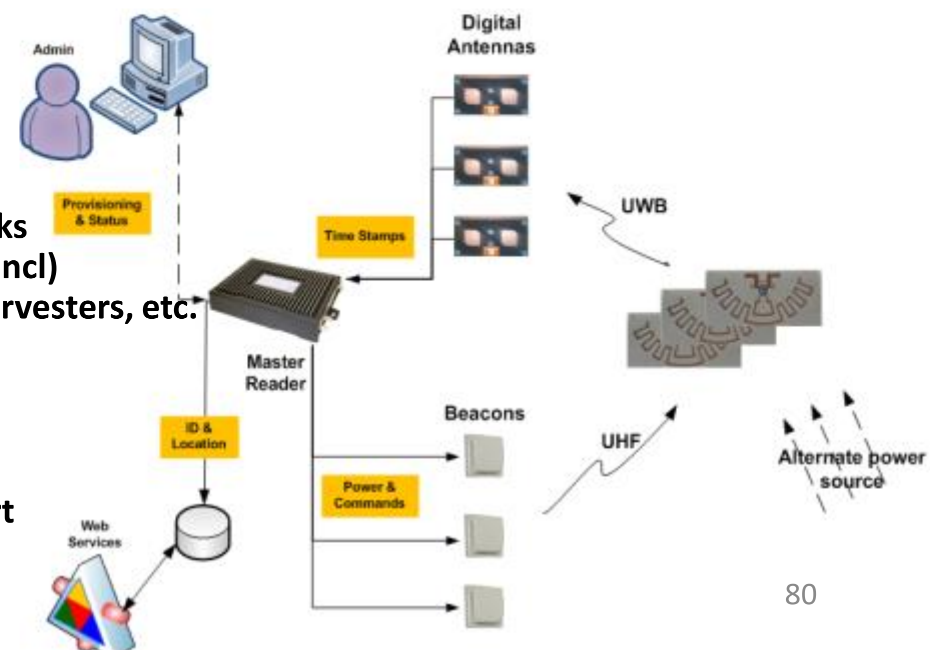


Advantages:

- Small Cost & Size: UWB Readers are100x and 20 times smaller than Gen2
- Read Range: 50-100 meters
- Resolution: 2-3 inches
- Sample Rate: 1000s of reads per second per reader
- Multi-path Immunity:
    - Robust tag detection/location determination
    - Signal propagates through openings and cracks
- Low Power: Tag chip consumes ave of 2µW (memory incl)
    - Alt power options: micro solar cell, MEMS harvesters, etc.

Status:

- Available: Tag, Reader and Software
- Next: Increase DA sensitivity to achieve 100m range
- Tag Antenna, Reader, Software for many tags, FCC cert



8.2 “60 GHz Comm, RFID - moving to Passive Sensors”

Don Kimball – Maxentric - dkimball@maxentric.com www.maxentric.com

<u>ViFi- V-band wireless Fixed and Mesh Network</u> -

Unlicensed at 59-64 GHz in many countries -

Low SWaP at high freq -

Directional Antenna

- Highly Reflective inside metallic enclosures like spacecraft

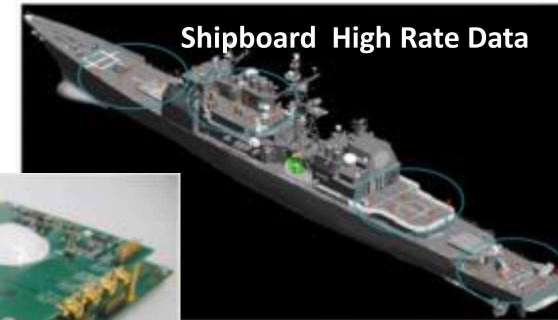
Order of magnitude better than 2.4GHz in satisfying HERO (Hazards of Electromagnetic Radiation to Ordnance)

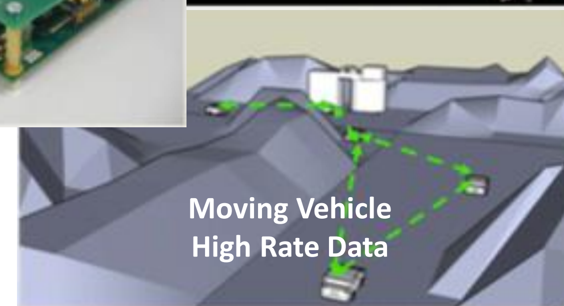
atmospheric resonance attenuates signal beyond 100-300 ft

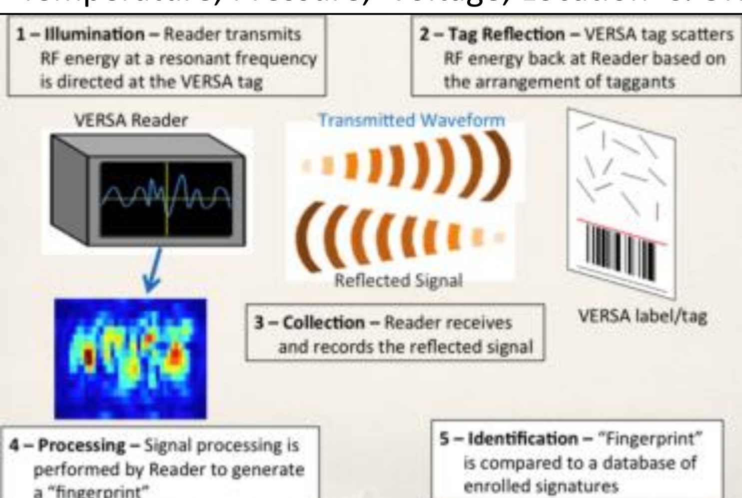
Mesh Network: Ad-hoc Mesh, ⍰ High Data Rate(>Gbps), Delay Tolerant (Memory-based),⍰ Ethernet Compliant - 1.3 Gbps and adjustable to 10 Mbps

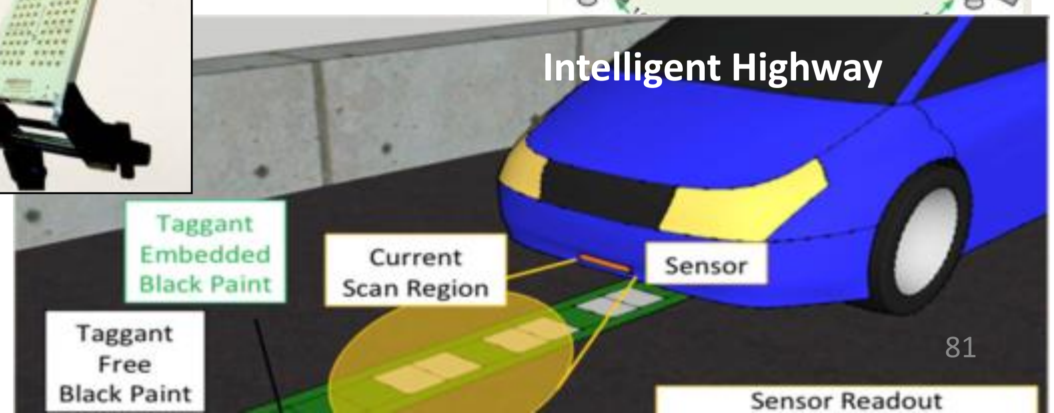
<u>VERSA - V-band Enhanced RFID/Sensing</u> - Thin metal dipoles called Taggants – tiny for high freq

- Tag-response based on: Taggant orientation & Relative positions - Temperature, Pressure, Voltage, Location & Orientation









8.3 “Wireless Temperature Sensors for Gas Turbine Engines”

John Conkle - Wireless Sensor Technologies - jrconkle@att.net

Problem:

- Catastrophic Failure caused by degradation and damage to hot section components
- Poor characterization of degradation process affects the development of durable components

Users:

Jet Engine Developers, Users, Maintenance

Other harsh environment applications - control and CBM applications in carbon, steam, or nuclear-fueled power plants.

Requirements:

• _Accurate temperature measurement

– 10^{o} C accuracy, Range of -60 to 1300C

• Long-term reliability

– ‘00’s of hours for developmental testing

– “000’s of hours for PHM and CBM application

• Easily mount on turbine blade or target surfa

• Not alter the blade dynamics (weight, gas flo

– “Massless” and “Zero” height

WST Solution:

-Sensor Printed like an IC out of Alumina

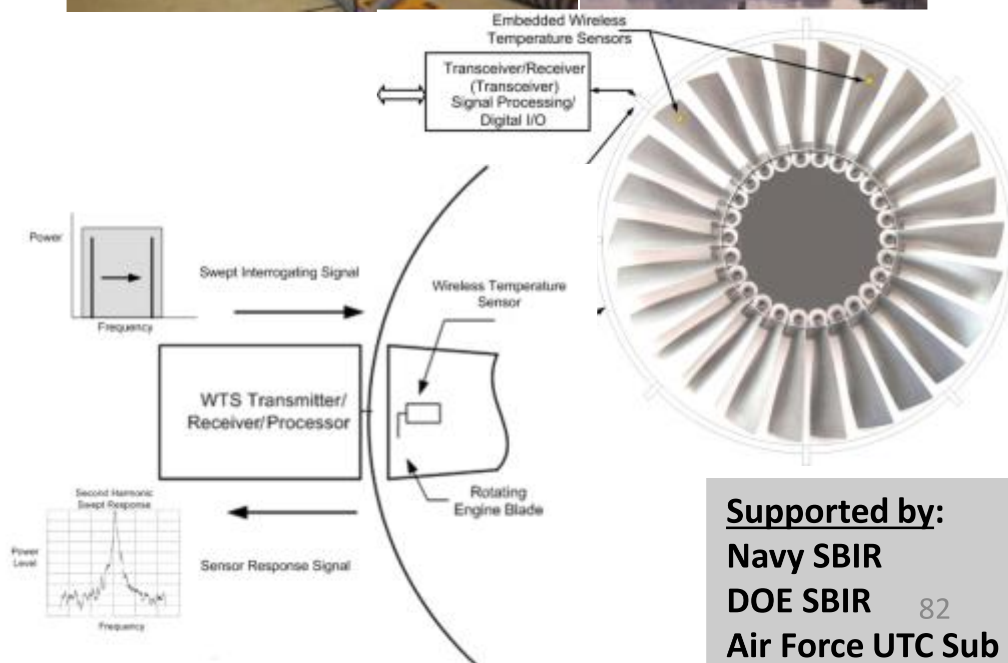
- Antenna,
- Ceramic Dielectric, AZO Schottky Diode
- TRL5 in Fall 2012

In-Engine temperature surface data critical for:

– Propulsion Health Monitoring (PHM)

– Condition-based Maintenance (CBM) that has been mandated for use by the DoD

– Developmental testing of new engine designs



Supported by:

Navy SBIR

DOE SBIR

Air Force UTC Sub

8.4 "A System Engineering Simulation Tool and Data Base Proposal for Optimizing the Application of Wireless Sensors"

Scott Hyde – Aerojet - Scott.Hyde@Aerojet.com www.aerojet.com

Machine-to-Machine (M2M) Market Lesson's Learned

- M2M communications consists of using a device to capture an "event" relayed through a network to an application, translating the captured event into meaningful information.
- Similar problems to Aerospace: too much to communicate, systems are inflexible, system cost

http://www.machinetomachinemagazine.com

Power of Simulation and its Role with Wireless Sensing

Simulation Reduces Upfront Costs and Pays Off Through the Systems Life-Cycle by Facilitating Assessment of Change Requirements, Impacts Due to Obsolescence and Software/Hardware Upgrades

Elements of a System Architecture can be Simulated with High Fidelity Enabling Management of System Complexity and Communication Congestion – Physical Level, Logical Level, System Level

CPIAC Sensor Database :

- Chemical Propulsion Information Analysis Center (CPIAC) is developing a secure, online, portal for the collaborative collection and dissemination of sensor related information.
- Access has ITAR restrictions (U.S. Citizens only)
- Sponsors: NASA , US Air Force and US Department of Energy
- CPIAC to Design, Implement and Host/Maintain an Online Tool for JANNAF to:
    - Allow the secure exchange and collection of information on sensors
    - Wiki-like functionality: Users create new entries based on standard forms
    - Documents can be attached as references for each sensor
    - Search capability based on keywords or filtering by criteria
    - Data reviewed prior to posting by an approving authority
    - CPIAC to perform initial data population using NASA sensors database

Include Active and Passive Wireless Sensors?

Add an ISA or other External database to complement it?

Potential Future Areas of Emphasis Next Workshop 2013?

Technology Developers

- Progress in Technology and Applications since 2011/2012 Workshops
- Near Field Communications
- RFID Sensors
- Mechanical Sensing
- Manufacturing Advances
- Embedded sensing and Nano-materials
- Hybrid Systems
- Systems Integration
- International Developers

End User/Stakeholder Needs

- Consumer Products
- Aerospace
- DOD and Security
- Energy, Efficiency and Environments
- Automation and Machine-to-Machine Interfaces
- Health Monitoring
- Test Instrumentation
- Facility and Vehicle Architecture Changes

Coordination:

- Communication
- Research and Education
- Community of Practice
- System and User Needs Data Base

2011 PWST Workshop
<u>Summary</u>
Chair: NASA/JSC/George Studor

July 27-28, 2011

Westlake Club (BP Hosted), Houston, TX

Sponsor: ISA Communications Division

2011 PWST Workshop Speakers: Day 1

1-1	Lafferty	Dave	Welcome from BP - Interest, Facilities, Safety, etc	BP - Tech Office - host	Houston, TX	Chief Technology Office - Technology Advisor
1-2	Studor	George	"Fly-by-Wireless and the Passive Wireless Sensor Workshop"	NASA/Workshop Vision	Houston, TX	Staff, Strategic Planning and Partnership Opportunities Office
1-3	Malocha	Don	"Wireless Passive SAW Sensors using Coded Spread Spectrum Techniques"	Univ of Central Florida	Orlando, FL	Prof, Dep Electrical & Computer Eng, Harris Engineering Center (HEC 346)
1-3	Belkerdid	Madjid	Joint Presentation - Demonstration	Mnemonics	Melbourne, FL	Principal Systems Engineer
2-1	Surman	Cheryl	"Multivariable passive RFID sensors: From detailed laboratory evaluations to pilot-scale manufacturing"	GE Global Research Center	Niskayuna, New York	Bioanalytical Chemist- Chemical Sensor Laboratory
2-1	Bloch	Peter	Joint Presentation - Demonstration with GE	Avery Dennison	Madison, WI	Sr. Mgr of Strategic Alliances, RFID Div
2-2	Matthews	Robert Dr.	"Compliance Independence– is this the passive revolution?"	West Wireless Health Institute	La Jolla, CA	Chief Technology Officer
Lnch Spkr	Reindl	Leonhard	"History, Applications, and Market Overview of Passive Wireless Sensors"	Imtek,Institute for Microsystem Tech	Freiburg, Germany	Head, Dept of Electrical Instrumentation, Imtek
3-1	Hartmann	Clinton	"Advanced SAW Devices for RFID and Sensing Applications"	RFSAW	Richardson, TX	Founder and President
3-2	Hines	Jackie	"SAW Sensor and Sensor-tag Developments at ASR&D"	ASRDC	Arnold, MD	President
3-3	Woods	Brian	"VERSA: V-band Enhanced RFID/Sensing Architecture"	MaXentric	LaJolla, CA	R & D Engineer - Note: Also accompanied by the Chief Technology Office Don Kimball
3-4	Brown	Jeffrey K.	"Seeing Through the Fog: Collecting PWST Data in a Harsh Environment"	Radient360	St. John's, Newfoundland	Executive Vice President
3-5	Abedi	Ali	"Location and Temperature Passive Wireless Sensor Tags"	Univ of Maine/CANEUS	Orono, ME	Associate Professor Electrical and Computer Eng.
4-1	Trelewicz	Jason	"Integrated Diagnostics Using Direct Write Sensors"	Mesoscribe	St. James, NY	Program Manager
4-2	Conkle	John	"Wireless Sensors for Gas Turbine Engines"	Wireless Sensor Technologies	Encinitas, CA	Founder and President
4-3	Krawczewicz	Mark	"A New Class of Passive Secure ID Display Card"	Tocreo Labs	Annapolis, MD	Founder and CEO
4-4	Kalinin	Victor	"Wireless Resonant SAW Sensors for Automotive Applications"	Transense	Upper Heyford, Oxfordshire, UK	Chief Scientist
4-5	Ostaffe	Harry	"High-Function, Long-Range PWST"	Powercast	Pittsburgh, PA	Vice President of Marketing & Business Devel

2011 PWST Workshop Speakers: Day 2

5-1	Lafferty	Dave	"Potential Passive Wireless Sensor Tag Applications"	BP - Tech Office - host	Houston, TX	Chief Technology Office - Advisor
5-2	Chow	Ivan	"Proceed with Caution with Disaster Recovery Applications Nuclear Power Plant Control System"	Doosan/HF Controls	Plano, TX	V&V Manager at Doosan HF Controls
5-3	Stieger	Ron	"RFID Sensors in Transportation"	Zonar Systems	Seattle, WA	Director of Engineering
5-4	Faridazar	Fred	"Intelligent Multi-Sensor Measurements to Enhance Pavement Monitoring and Safety"	DOT-FHWA - Turner-Fairbank Admin	McLean, VA	Office of Infrastructure Research and Development - Pavement Design and Construction Team
5-4	Lajnef	Nizar	"A Sub-Microwatt Long-term Monitoring Sensor"	Michigan State Univ	East Lansing, MI	Ass. Prof, Dir. Comp Sensors Lab/Civil&Env. Eng
5-5	Mrad	Nezih	"Potential Applications of PWST"	Department of National Defence (DND)	Ottowa, CA	Defence Scientist,Air Vehicles Research Section (AVRS)
6-1	Gemdjian	Ed	"Passive Wireless SAW Temperature Sensors"	Kongsberg Maritime	Northvale, NJ	Mechanical Engineer
6-2	Hernandez	George	"Sensors and Controls Enabled Solutions"	DOE/PNNL - Building Sensors	Richland, WA/Wash DC	Staff Engineer - detailed to DOE HQ
6-3	Salour	Al	"Use of Passive RFID and Networking Technology in Aerospace Manufacturing"	Boeing – Aerospace Manufacturing Sensors	St. Louis, MO	Enterprise Leader for the Boeing Research & Technology's Network Enabled Manufacturing (NEM) initiatives
6-4	Safa-baksh	Robab	"Passive Wireless Sensors, Vehicle Health Management Applications"	Boeing Research and Technology	Philadelphia, PA	Asso. Tech Fellow for VHM & SHM
Lunch Spkr	Sirico	Louis	"What Works in the World of Wireless Sensors"	The RFID Network	Campbell, CA	Host of The RFID Network, a TV video series dedicated to RFID and wireless sensor technologies
7-1	Vega	Victor	"Interactive Gen2 | Bridging the Gap between Passive RFID, Sensors and Electronics"	NXP Semiconductors	San Jose, CA	Business Development Manager, Marketing Director, RFID Solutions
7-2	Plourde	Rich	"Aerosol Jet Direct Write Technology – A Tool for Printed Electronics"	Optomec - Headquarters	Albuquerque, NM	Aerospace & Defense Business Liaison
7-3	Wilson	William C.	"NASA Testing of PWST"	NASA-LaRC	Langley, VA	LaRC-SAW Device Design, COTR
7-4	Fisher	Fred	"AVSI Cooperative Research in Intra-Aircraft Spectrum Usage"	AVSI - Assist Dir; TEES -Dir Eng& Comp	College Station, TX	Assistant Director, AVSI
7-5	Pimprikar	Milind	"Bridging the Mid TRL Gap through Coordinated Technology Development"	CANEUS	Montreal, CA	Founder and Chairman
Intro	Fuhr	Peter	Motivation and Explanation of Splinter Sessions	DOE/ORNL	Knoxville, TN	Future ISA Comm Chair
Mtg	Splinter Sessions Meet in Separate Locations					
Sum	Splinter Spokesperson		5 minute Report from Each of 7 Splinter Groups			

2011 PWST Workshop Attendees
(Presenters and Listeners)

Last	First	Position	Organization	Location	Type
Adams	Elizabeth	Technology Project Leader - Wireless	BP	Naperville, Il	Ind
Adkins	Andrea	Assist Dir. Commercialization: Tech Transfer	UCF	Orlando, FL	Univ
Bachtel	Russel	Engineer	NASA-JSC - EC	Houston, TX	Gov
Bain	Mark	Systems Engineering Electrical	Space Systems Loral	Palo Alto, CA	Ind
Barton	Rick	Wireless Communication Engineer	NASA- JSC/EV4	Houston, TX	Gov
Baumann	Wolfgang	Sales Engineer	R. STAHL INC	Houston, TX	Ind
Bonneau	Walt Jr.	President & General Manager	Cubic Security Systems, Inc	San Diego, CA	Ind
Chen	Penny	Principal Systems Architect	Yokagawa	Palo Alto, CA	Ind
Citrano	Joseph	Global Product Marketing Manager	Honeywell	Golden Valley,MN	Ind
Cote	Andrea	Chief Technology Officer and VP of PM	Omni-ID	Rochester, NY	Ind
Cramer	Ronald	Senior Advisor	Shell	Houston, TX	Ind
Cuartas	Wilson	Engineer	AW ELECTRONICA	Houston, TX	Ind
Daniel	Alan	Sr. Research Engineer	Southwire Company	Carrollton, GA	Ind
Dodds	Kevin	Land Geological Integrity `	BP	Houston, TX	Ind
Drobshoff	Alex	Engineer	Lawrence Livermore National Lab	Livermore, CA	Gov
Ferguson	Dana	Business Development	Ventyx	Houston, TX	Ind
Goodenow	Debra	Instr. for Heavy Lift Launch Vehicles	NASA - GRC	Cleveland, OH	Gov
Griggs	Steve	Engineer	Weatherford	Houston, TX	Ind
Haines	Mark	Director of Engineering	Mnemonics	Melbourne, FL	Ind
Hartmann	Tom	Director Brand Security & Electronics	Topflight	Glenn rock, PA	Ind
Hartmann	Paul	Vice President, Engineering	RFSAW	Richardson, TX	Ind
Hedtke	Bob	Director of Technology	Rosemount Inc	Chanhassen, MN	Ind
Hines	Andy	Technician	ASRDC	Arnold, Maryland US	Ind
Hines	Jackie	President	ASR&D	Arnold, Maryland US	Ind
Ho	Stephen	Research Scientist	MIT Auto-ID Labs	Cambridge, MA	Univ

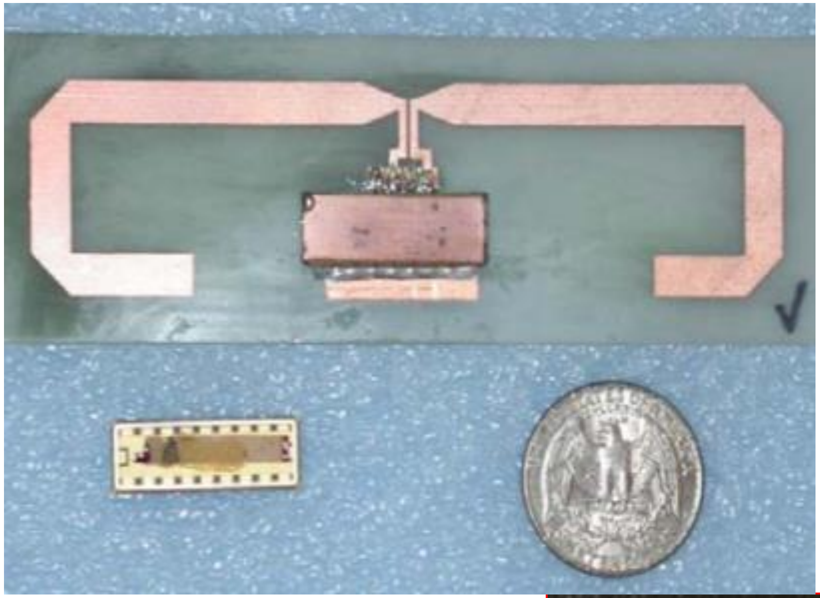
2011 PWST Workshop Attendees (All – continued)

Hyde	Scott	Marketing Manager for Strategic Propulsion	Aerojet	Clearfield, Utah	Ind
Kimball	Don	Chief Technology Officer	MaXentric	LaJolla, CA	Ind
Krisel	Robert	Engineering Manager	Panduit Corp	Tinkley Park, IL	Ind
McIntyre	Timothy	Leader, Sensors and Controls Research Grp	DOE/ORNL - Sensors & Controls	Knoxville, TN	Gov
Montgomery	Bruce	President	Syntonics LLC	Columbia, MD	Ind
Nadler	Gerry	President	Wihart systems	Acton, MA	Ind
Oberle	Larry	Instr. For Heavy Lift Launch Vehicles	NASA - GRC	Cleveland, OH	Gov
Oeste	Tom	Technician	ASRDC	Arnold, Maryland US	ind
Ogai	Takashi	Mgr, Gr. Space Dev., Aero Eng & Space Ops	IHI Corporation	Japan	Ind
Oluwatosin	Adedeji	Shell Global Solutions International B.V.	Shell	Rijswijk,S.Holland NL	Ind
Pahlavan	Kourosh	CEO & CTO	TagArray	Palo Alto, CA	Ind
Patterson	Mark	Propulsion Dir., Turbine EngResearch Center	AFRL /RZTE	WPAFB, OH	Gov
Saito	Hiroki	Staff Member - Aero Engines & Space Ops	IHI Corporation	Japan	Ind
Schoenborn	Renee	Senior Instrument Engineer	Shell Global Solutions(US)	Houston, TX	Ind
Scoggins	Doyle	STPNOC Metrology Supervisor	STP Nuclear Operating Company	Wadsworth, TX	Ind
Scott	Jeffrey	Technologist - RFID	Pacific Northwest National Labs	Richland, WA	Gov
Smith	William	Project Engineer	Mesoscribe	Huntington Beach, CA	Ind
Smith	Richard	Shell SEIP	Shell	Houston, TX	Ind
Solie	Leland	Senior Scientist	ASRDC	Arnold, Maryland US	Ind
Song	Gangbing	Director, Smart Materials/Structures Lab	Univ of Houston	Houston, TX	Univ
Struble	Ed	Vice Pres Avionics, Weapons & Sensor Sys	Mnemonics	Melbourne, FL	Ind
Tran	Thanh	NMO Process Engineer	Savannah River Nuclear Solutions	Aiken, SC	Gov
Trott	Aaron	Program Director	Invocon	Conroe, TX	Ind
Wagner	Raymond	Sr. Research Development Scientist	NASA - JSC	Houston, TX	Gov
Ward	Justin	Sr Business Systems Associate	EOG Resources	Fort Worth, TX	Ind
Willoner	Terry	Engineer	Savannah River Nuclear Solutions	Aiken, South Carolina	Ind
Zipay	John	Structural Engineer	NASA/JSC - ES	Houston, TX	Gov

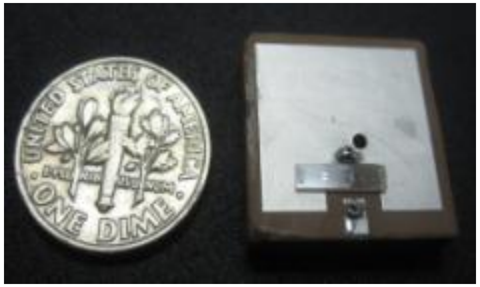
1-3 Wireless Passive SAW Sensors using Coded Spread Spectrum Techniques

Univ of Central Florida/Mnemonics

Don Malocha http://caat.engr.ucf.edu/ - Madjid Belkerdid http://mnemonics-esd.com



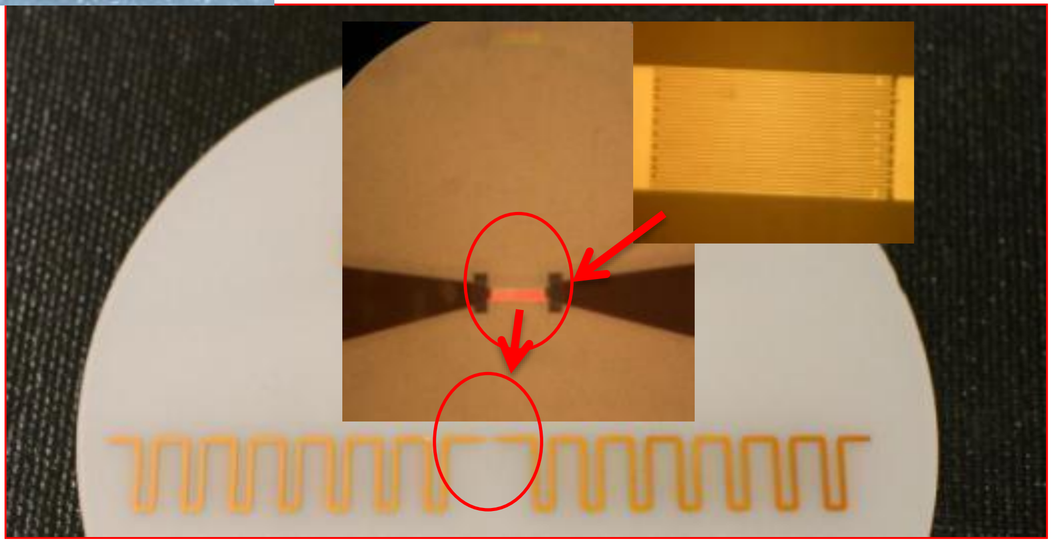
915 MHz Wideband Folded Dipole Antenna



Miniature 915MHz Integrated OFC SAW-Patch Antenna

OFC=Orthogonal Frequency Coded

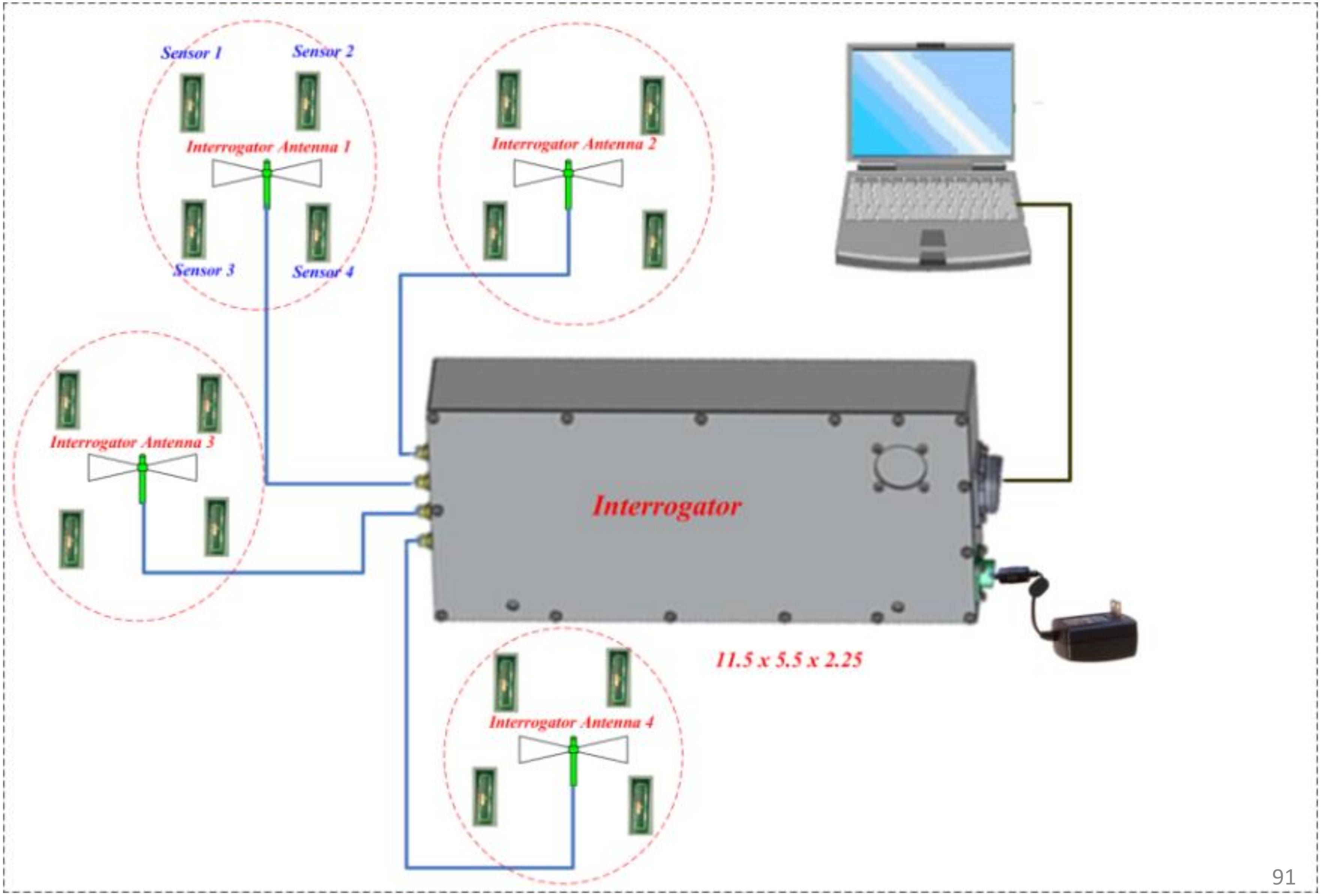
SAW=Surface Acoustic Wave



Fully integrated on-wafer SAW OFC sensor and antenna

1-3 Wireless Passive SAW Sensors using Coded Spread Spectrum Techniques

Univ of Central Florida/Mnemonics
Don Malocha http://caat.engr.ucf.edu/ - Madjid Belkerdid http://mnemonics-esd.com



1-3 NASA Phase 2 STTR Award
UCF & Mnemonics
10-2 T7.01-9980
Wireless SAW Sensor Strain Gauge & Integrated Interrogator Design
Awarded – Apr 27, 2012

TECHNICAL ABSTRACT

The proposed Wireless, passive, SAW sensor system operates in a multi-sensor environment with a range in excess of 45 feet. This proposed system offers unique features in two (2) important areas. The first is in the development of a new sensor type, a strain gauge that is based on OFC techniques and implemented with the low loss characteristics of SAW Unidirectional transducers. The second is in the design of an integrated interrogator system that has DSP-based embedded signal processing. Interrogator will also be capable of rapidly performing multiple interrogations which can them be used to make ibration measurements or averaged to extend the operational range of the system. This proposal extends the Phase I and previous work in two major areas; developing a SAW strain sensor, and dramatically increasing interrogation range, which is applicable to both the new strain sensors and the previously developed temperature sensors. In order to increase SAW sensor range, sensitivity and accuracy, the most important device parameters were identified and initial investigation begun in Phase I and will be put into practice in Phase II. To reduce SAW sensor loss and minimize multi-transit acoustic echoes, low loss unidirectional studies were initiated. Phase I produced three alternative low-loss approaches that will be evaluated in the Phase II work. Success will lower the insertion loss by approximately 15 dB, and multi-transit echoes are predicted to be less than -40 dB from the main signal; doubling the system range and reducing the sensors self-noise. Advanced coding techniques were investigated in Phase I that have led to longer delay path lengths, and shorter codes with less inter-sensor interference.

During Phase II, the interrogator will improve the following critical capabilities: onboard-fully-integrated DSP, extended connectivity options to customer's computer, and rapid interrogation capabilities. This will allow vibration sensing and signal integration.

2-1

Multivariable passive RFID sensors: From detailed laboratory evaluations to pilot-scale manufacturing

GE Global Research/Cheryl Surman(surman@ge.com)
Avery Denison/Peter Bloch(peter.bloch@averydennison.com) - http://ge.geglobalresearch.com

How it works:

- GE RF Sensing utilizes the complex waveform of an existing high-frequency (HF) RFID technology as a signal transport.
- The reader interrogates the sensor tags, interprets the waveform, and determines measurement value.

Handheld Reader Energizes Tag

Passive Sensor Tag 'wakes-up' & Responds

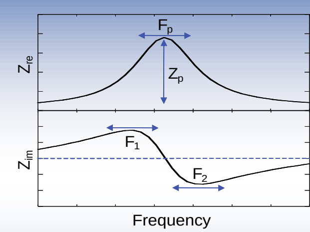
1

Tags incorporate standard 13 MHz HF antenna configurations

2

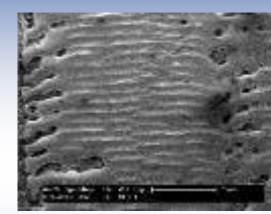
Application-specific sensing films are applied to standard RFID tags

3



A baseline RF signature is captured and stored

4



As the analyte interacts with the sensor film, the RF properties are altered

5

A read is taken and the altered RF signature is compared to baseline

Webinar: http://www.rfid.averydennison.com/rfid-sensor-technology-hf-inlay.php

2-1 Feb 2012 Analyst: "Multivariable passive RFID vapor sensors: roll-to-roll fabrication on a flexible substrate" Radislav Potyrailo, Andrew Burns, Cherly Surman, D.J. Lee, Edward McGinniss

We demonstrate roll-to-roll (R2R) fabrication of highly selective, battery-free radio frequency identification (RFID) sensors on a flexible polyethylene terephthalate (PET) polymeric substrate. Selectivity of our developed RFID sensors is provided by measurements of their resonance impedance spectra, followed by the multivariate analysis of spectral features, and correlation of these spectral features to the concentrations of vapors of interest. The multivariate analysis of spectral features also provides the ability for the rejection of ambient interferences. As a demonstration of our R2R fabrication process, we employed polyetherurethane (PEUT) as a "classic" sensing material, extruded this sensing material as 25, 75, and 125-**μ**m thick films, and thermally laminated the films onto RFID inlays, rapidly producing approximately 5000 vapor sensors.

We further tested these RFID vapor sensors for their response selectivity toward several model vapors such as toluene, acetone, and ethanol as well as water vapor as an abundant interferent. Our RFID sensing concept features 16-bit resolution provided by the sensor reader, granting a highly desired independence from costly proprietary RFID memory chips with a low-resolution analog input. Future steps are being planned for field-testing of these sensors in numerous conditions.

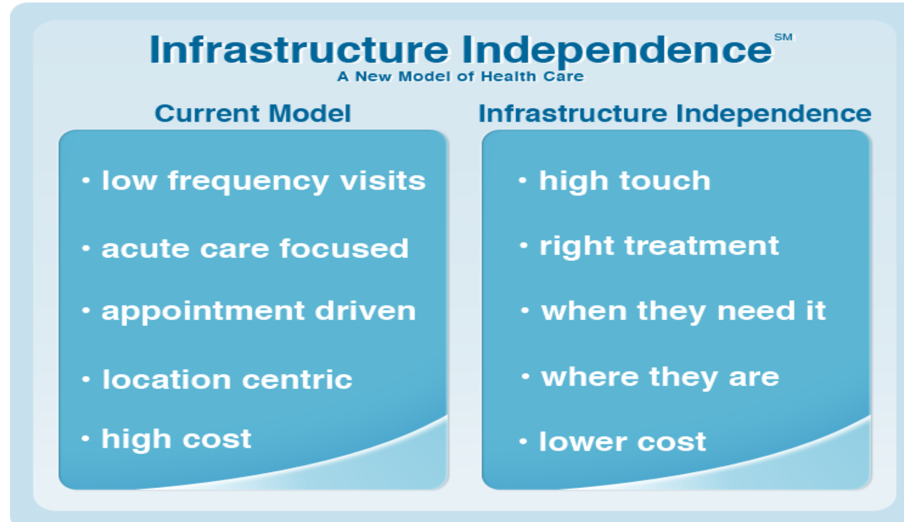
2-2 Compliance Independence– is this the passive revolution?

West Wireless Health Institute/Robert Matthews - CTO

http://www.westwirelesshealth.org/ rmatthews@gmwhi.org

- **Primary Mission:**

Lower Health Care Costs



PWST Application Areas:
- Smart patient ID
- In home/office sensors
- On body sensors
- Medication compliance

Sensors in the bed:
Pressure – management of bed sores
Weight – identify weight gain (fluids)
Heart rate – various diseases
Motion -- various diseases
Wetness – need to change bedding

Patient ID – Once a day, some patient is mis-identified.
Patient Info: Who, what, when
- Allergies, genetic information
- What and when medications were take
- What batch of blood etc

Desired PWST Attributes:

Very Cheap -- cents (disposable)	HIPPA compliant
Long range (100's ft)	Very small, Mechanically flexible
Non-trivial power for sensors without risk to patients	Reliable/Robust
Buffer power for use whilst not being illuminated	Configurable
Store significant amounts of data (both read and write)	Easy to integrate

West Wireless Health Institute 2012 Update(from website)

West Wireless Health Council

SAN DIEGO – February 15, 2012

A new coalition of hospital and health system leaders to create a standard approach to installing wireless infrastructure in health care settings and develop innovative solutions that will enable the full potential of wireless health technology to be realized in health care delivery settings, and ultimately lower health care costs.

https://s3.amazonaws.com/wwhi.org/WWHC_Release-02142012.pdf

Sense4Baby:

Late Term Home Monitor connects to medical experts via Smartphone tablet Bluetooth and internet. Other functions

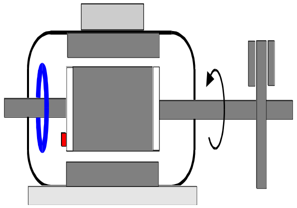
http://www.westwirelesshealth.org/index.php/sense4baby

History, Applications, and Market Overview of Passive Wireless Sensors

Day 1 Lunch Speaker

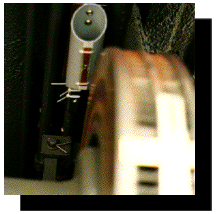
IMTEK - Leo Reindle – Dept Head, Electrical Instrumentation
reindl@imtek.uni-freiburg.de - http://www.imtek.de

- 1st Passive Wireless Sensors: Wolf-Eckhard Bulst
- 1st Chirped Wireless Sensors: Franz Seifert
- 1st Phase Information Basis: Valentin Magori
- 1st Interrogator(Siemens): Patric Heide, Frank Schmid
  433 MHz by Univ. Vienna
- Tollway Application in Norway – 500,000 tags
- 1st Pulse Position Coding: Victor Plessky
- SOFIS on SIEMENS rail – Munich Subway (2.45GHz)
- Temperature Sensors:

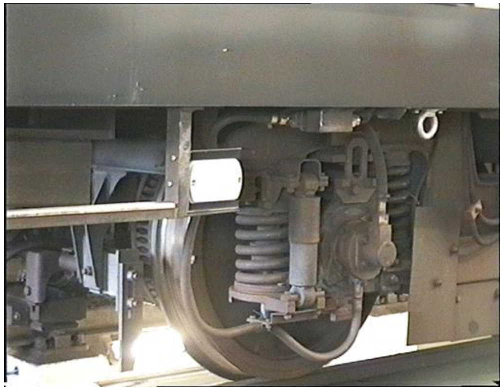


Motor Rotor

HV Surge Arresters



Train Brakes



- High Temp SAW Sensors with Platinum Electrodes on Langasite
- Tire Pressure Sensor(Siemens): G. Schimetta
- SAW Sensor for Tire Friction Control(Siemens +)
- Torque – Sensor Technology's Torquense System

SEIMENS Got out of SAW busyness due to assignment of it to EPCOSS

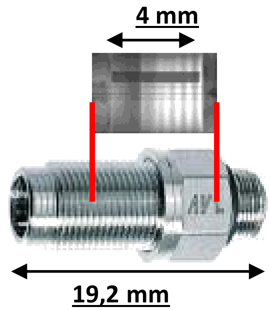
- SAW Accelerometer – Dart Demo

- SAW Current Sensor
- SAW Water Content Sensor - Alexander Kiermayer

IMTEK - Leo Reindle: European Company Products

Mobile Readers:

AVL – Pressure Sensor with Integrated ID:



RSSI GmbH   &   Carinthian Technologies

http://www.ctr.at/carinthian_tech_research_english

RHI - RFID and Sensing in a Steel Plant(+1400C)

CTR - Doble Lemke -Temperature Monitoring of Power Transmission Lines

CTR – Temperature Monitoring of Rotating Machine Elements
Up to 15,000 RPM

Day 1 Lunch Speaker

IMTEK – Leo Reindle: European Companies

<u>SENSeOR</u> - Unique Features for High Value Applications

Revolutionary sensors

- ➢ **Wireless**
- ➢ **Passive**
- ➢ **Robust**

➔ Enabling measurements

- ➢ On moving and rotating parts
- ➢ In confined or inaccessible spaces
- ➢ Where cabling costs too much or is impossible
- ➢ In harsh environments – like: strong fields, explosive, corrosive

➔➔ For measurable benefits

- ➢ **Improved productivity**
- ➢ **Performance optimization**
- ➢ **Security enhancements**

Day 1 Lunch Speaker

IMTEK – Leo Reindle: European Companies

SAW Temperature Evaluation Kit EVAL KIT T01

Pressure sensor chip

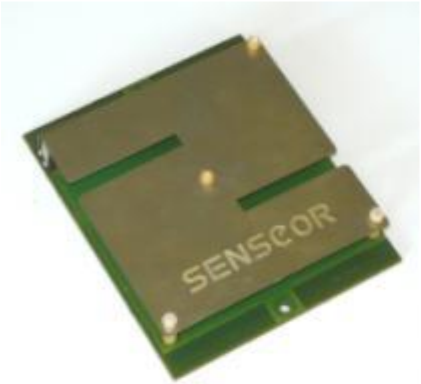
Packaged temperature sensor TSE AS10

Fixture mounted temperature sensor with antenna TSA D031

SENSeOR offers to partner with anyone such as to industrialize such applications and to make the technology known.

Once we find strong applications and/or partners in the US then SENSeOR will establish an office in the USA.

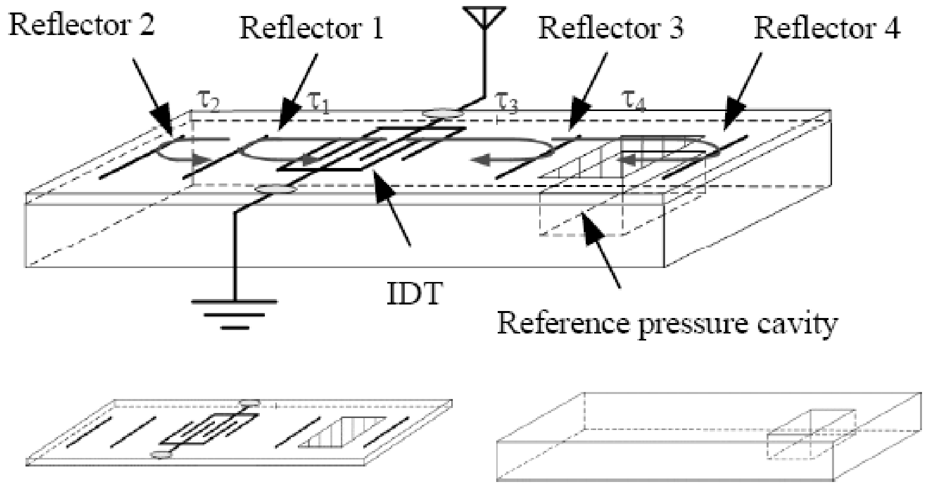
Thermowell packaged temperature sensor TSM D100



PIFA antenna mounted temperature sensor TSA D003

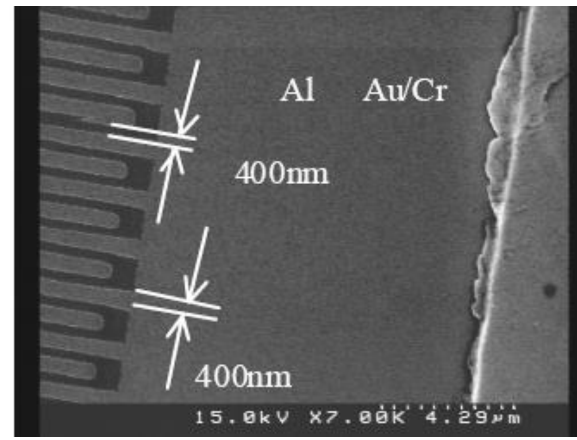
IMTEK – Leo Reindle: Other Offerings

Nissan pressure sensor

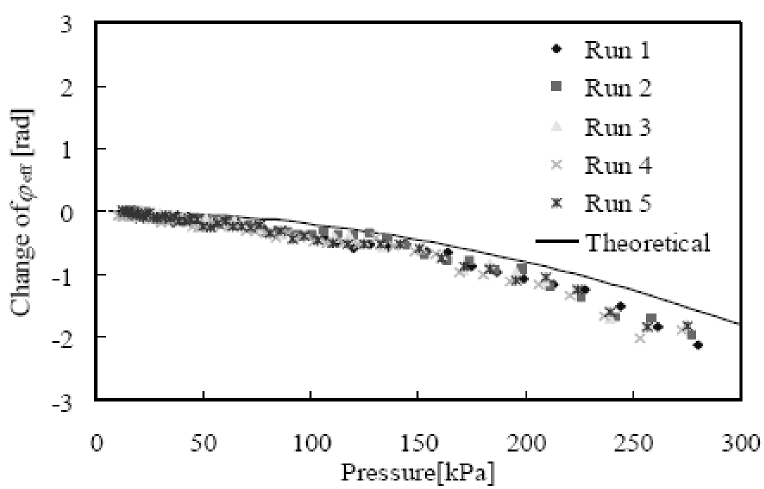


(a) First layer (b) Second layer

Schematic structure of the SAW delay line pressure sensor



Fabricated interdigital transducer

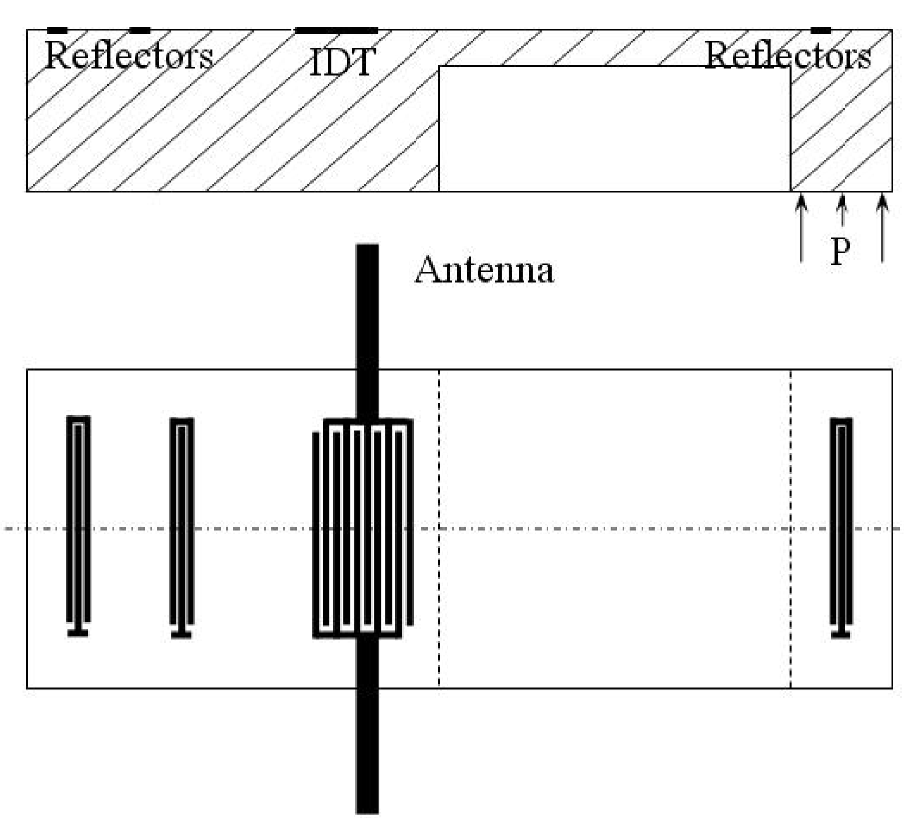


Change of the effective phase φ_{eff} by pressure change

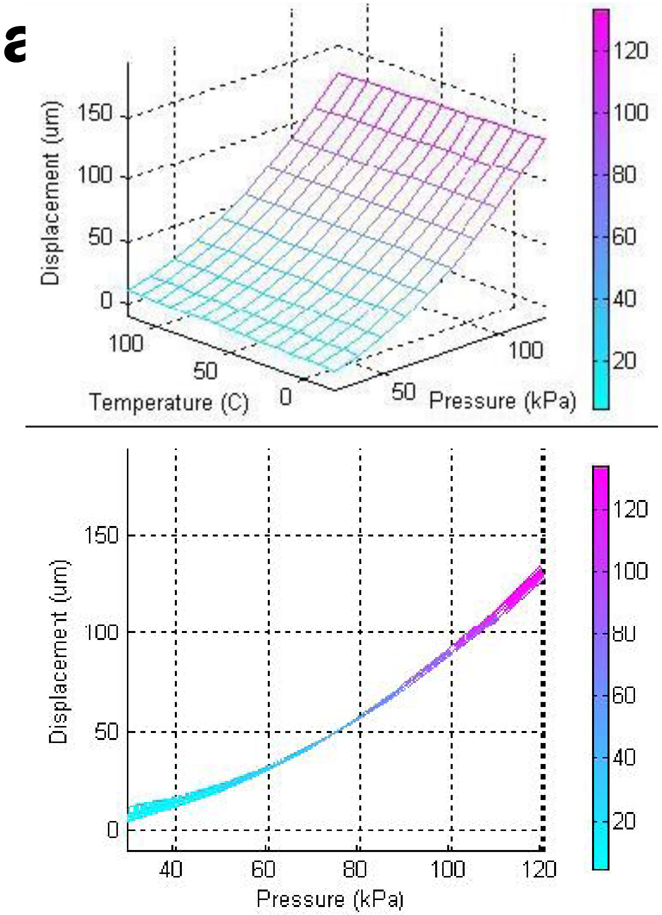
S. Hashimoto, J. Kuypers, S. Tanaka, M. Esashi, „Design and Fabrication of Passive Wireless SAW Sensor for Pressure Measurement “, 2008.

IMTEK – Leo Reindle: Other Offerings

Harbin Institute of Technology, China



The structure of the wireless passive SAW sensor



Displacement affected by the temperature and pressure after data processing.

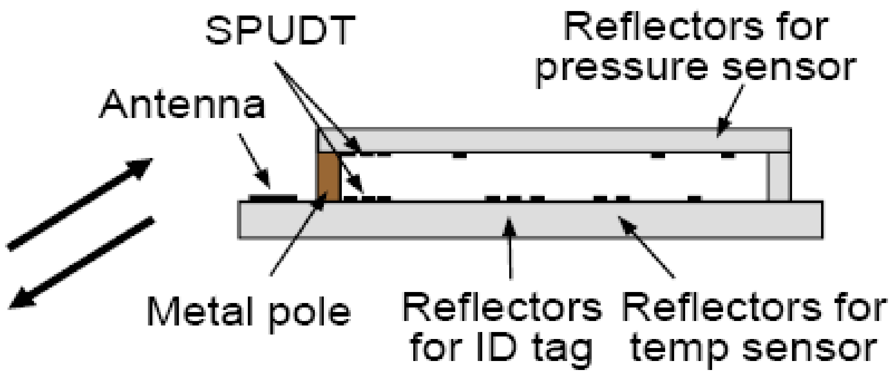
T. Li, L.Zheng, H.Hu, „A Novel Wireless Passive SAW Sensor Based on the Delay Line Theory “, Proc. 3rd IEEE Int. Conf. on Nano/Micro Engineered and Molecular Systems, Sanya, China, 2008.

Day 1 Lunch Speaker

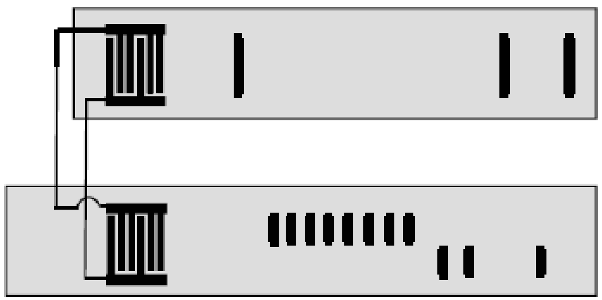
IMTEK – Leo Reindle: Other Offerings

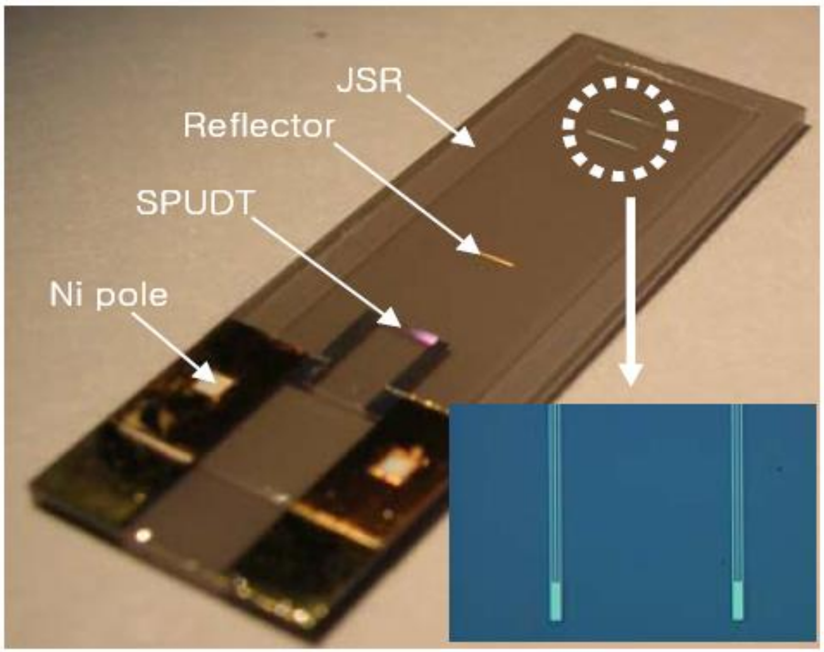
Anyun University, Korea, wireless SAW sensor for simultaneous measurement of pressure, temperature & ID

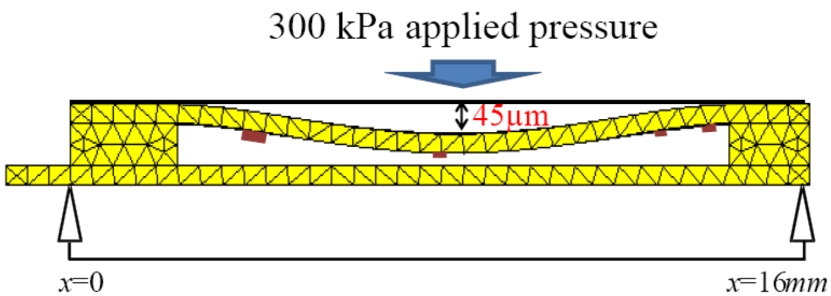
Cross-sectional view of the fabricated microsensor



views of the top and bottom devices







Calculated diaphragm bending under applied pressure of 350kPa using FEM analysis

Haekwan Oh, Weng Wang, Keekeun Lee*, and Sang Sik Yang
Division of Electronics Engineering, Ajou University, Suwon, S. Korea, 443-749
Email: keekeun@ajou.ac.kr, Tel:+82-31-219-1848, Fax:+82-31-219-1848

Day 1 Lunch Speaker

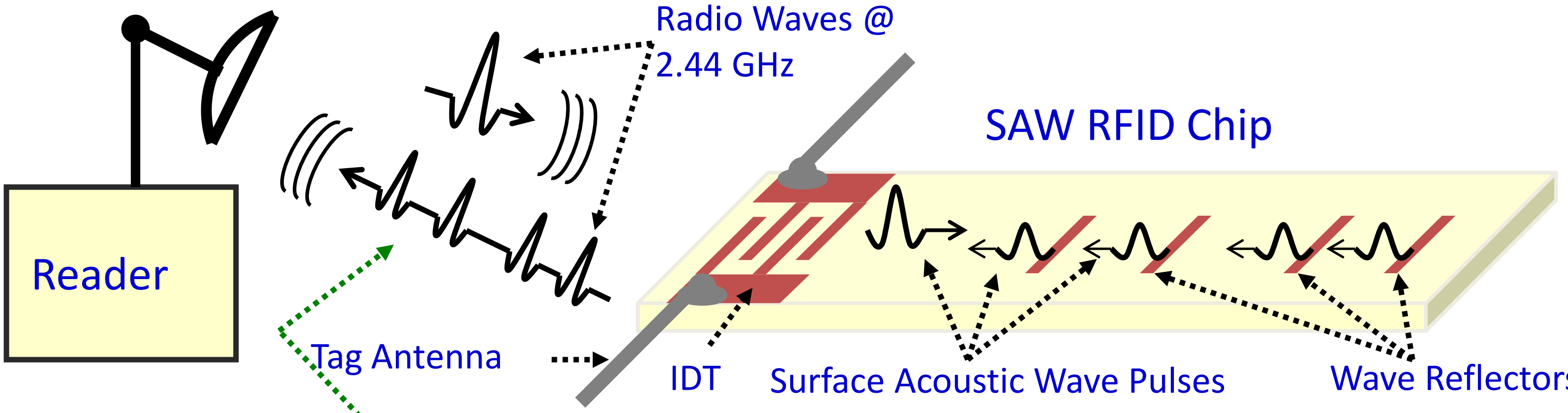
Leo Reindle: Rack-up of SAW Sensor Sources

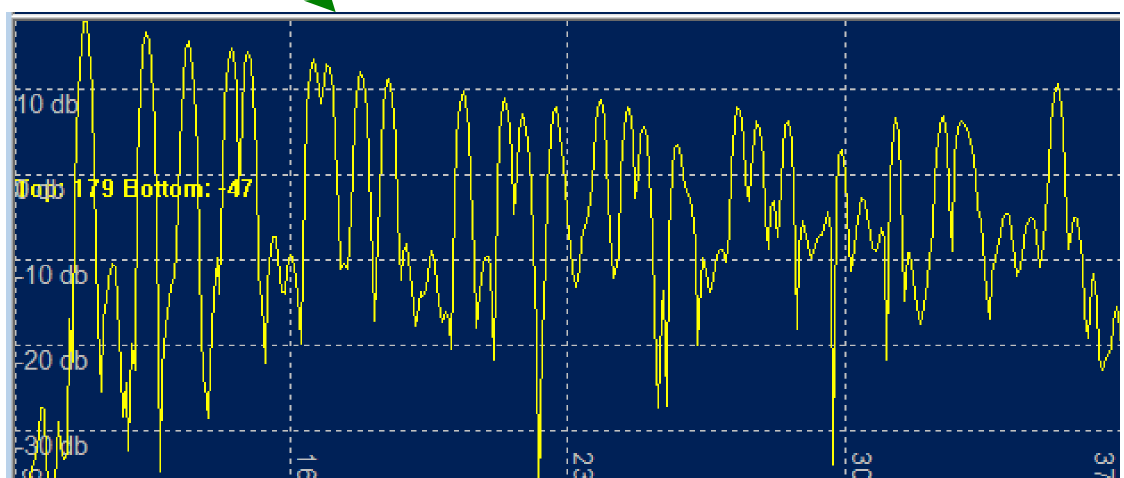
Company	Temp	Pressure	Stress	Torque	Bio/Chem
Applied Sensor R&D (USA)	☻		☻		☻
Avianamolecular (USA)					☻
Bürkert (D)					☻
CTR (A)	☻				
Doble Lemke (D, CH)	☻				
Electronic Sensor Technology					☻
GVR Trade (CH)	☻				
Heinz (D)	☻	☻	☻		
Honeywell (USA)	☻	☻			
Promicron (D)	☻		☻	(☻)	
SAW Instruments (D)					☻
Sengenuity (USA)	☻		(☻)	(☻)	
sensAction (D)					☻
SENSeOR (D,F)	☻	☻	☻	(☻)	☻
Siemens / GE / NG / Honeywell	(☻)	(☻)	(☻)	(☻)	(☻)
Transense (UK)		☻	☻	☻	
	10	4	5	3	8

RF SAW's Global SAW Tag System

Clinton Hartman/RFSAW - CHartmann@RFSAW.com - www.rfsaw.com

More than 100 sensors with a single reader





Actual 96-Bit Wireless Tag Waveform

GST Features

- Trillions of Trillions of ID Numbers
- Inherent Temperature Sensing
- Inherent Tag Localization

SAW Sensor and Sensor-tag Developments at ASR&D

Jackie Hines/ASRDC
jhines@asrdcorp.com - www.asrdcorp.com

Demonstrated sensor devices for:

♦ Temperature ♦ Liquid (level) ♦ Humidity
♦ Hydrogen ♦ Sensor-tags (strain, T, V, etc.)

Products under development:

- Coded sensor-tag wireless interface devices
- Humidity sensors
- Hydrogen sensors
- Temperature sensors
- Methane sensors
- Hypergol leak detection sensors (MMH, DMH, NTO)
- Cryogenic Liquid (level) sensors
- Concrete maturity monitor
- Biosensor for infectious agents (CT)

Systems:

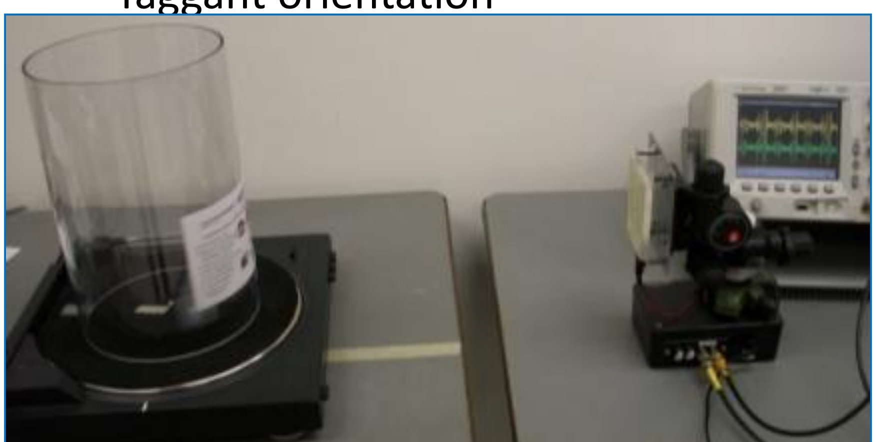
- 32 tag humidity sensor to KSC Sept 29, 2011
- 32 tag temperature sensor system SBIR Phase 2 – begun June 2011 to MSFC

“VERSA” Resonant Passive Tags

MaXentric – Brian Woods
bwoods@maxentric.com - www.MaXentric.com

V-band Enhanced RFID Sensing Architecture(VERSA) Tags: 24 or 60 GHz

- VERSA tags are completely **passive**
- **Potentially** 1-2cents increase in label/tag production cost
- VERSA tags are embedded with **thin metal dipoles called taggants**
  - Length of the taggant and type of material determine resonant frequency (60GHz=2.5mm), several micrometers wide, and hundreds of nanometers thick
- Can be **manufactured on a variety of materials**: paper, wood, plastic
- At 60GHz ISM Band, system uses 7GHz of freq band
- **60GHz is in the Oxygen absorption region** – allowing natural security
- **Unique RF signature** depends on many parameters and pattern
  - Taggant orientation



Business/Use Case Assessments

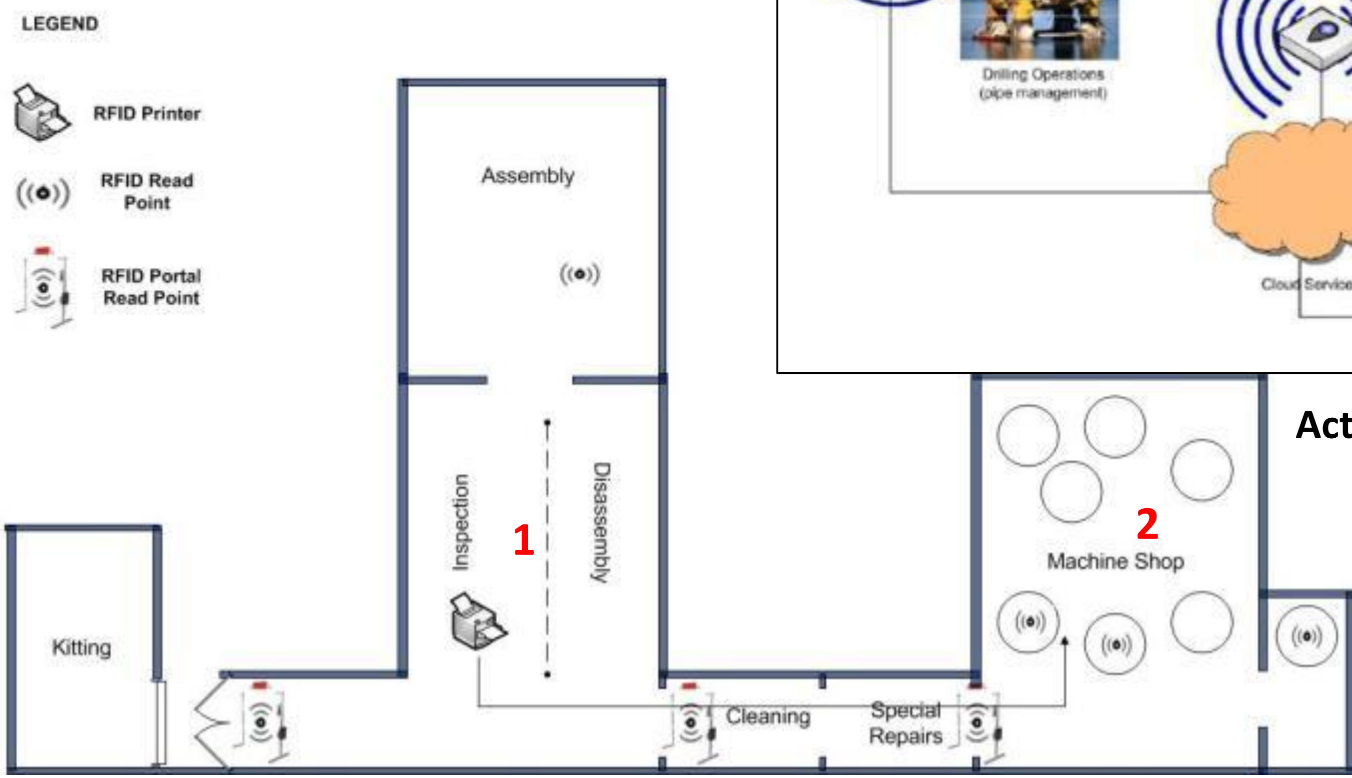
Jeff Brown/Radient360

jeff.brown@radient360.com - www.radient360.com

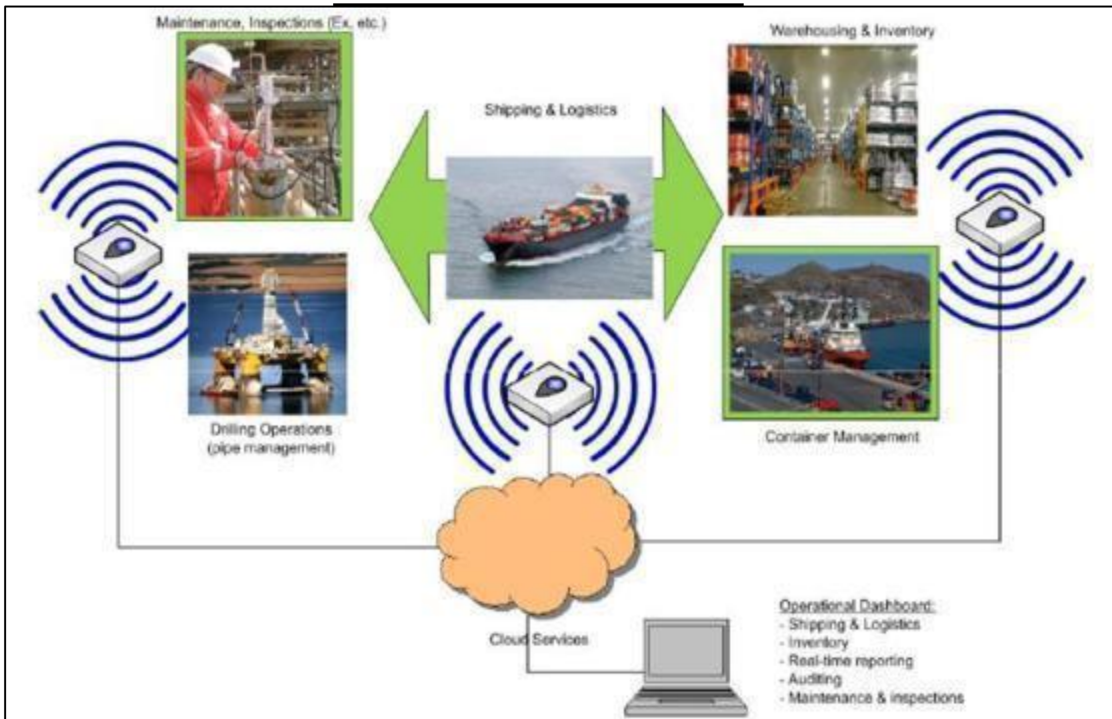
Tracking Aircraft Engine Parts

Aircraft Engine Parts Repair Process:

1. Tag applied to work order at Inspection (based on activity performed 'business as usual')
2. Part is 'read' instantaneously as it moves through out the facility



Offshore Oil and Gas

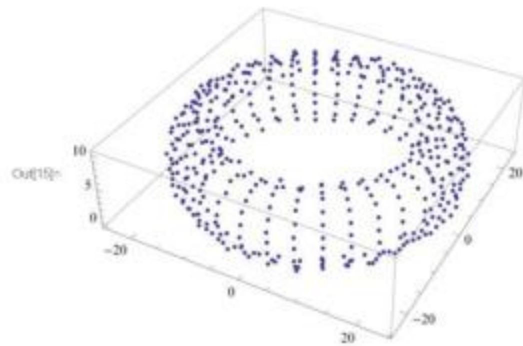


Active and Passive RFID & GPS In Harsh Environments

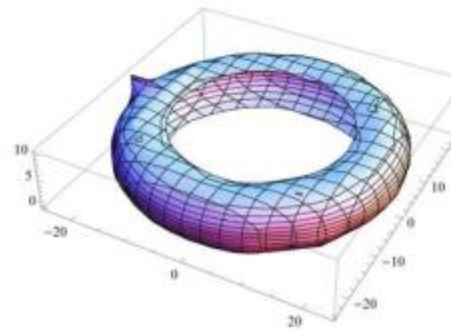
3-5

Location and Temperature Passive Wireless Sensor-Tags

Univ of Maine/Ali Abedi http:\\wisenet.eece.maine.edu - ali.abedi@maine.edu



2D Shape Reconstruction

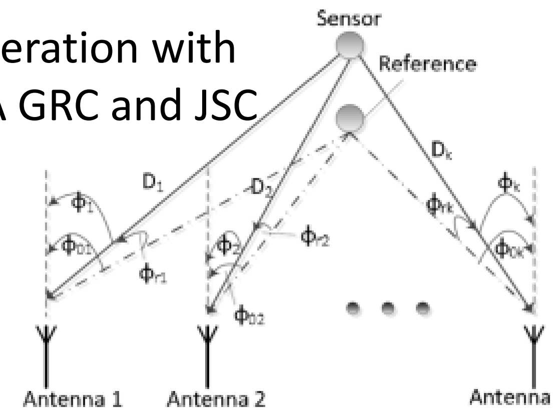


3D Shape Reconstruction

Passive SAW Tag for Location/Shape

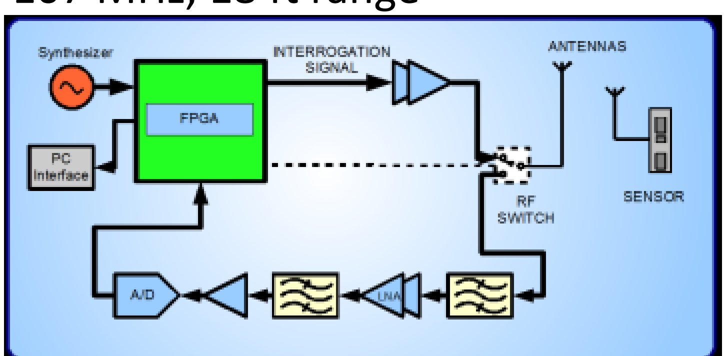
- 860-960 MHz -10 ft read range
- Passive – no battery
- EPC Global Gen 2 / ISO 18000-6C Standard
- Motorola Reader with 70 degree field of view

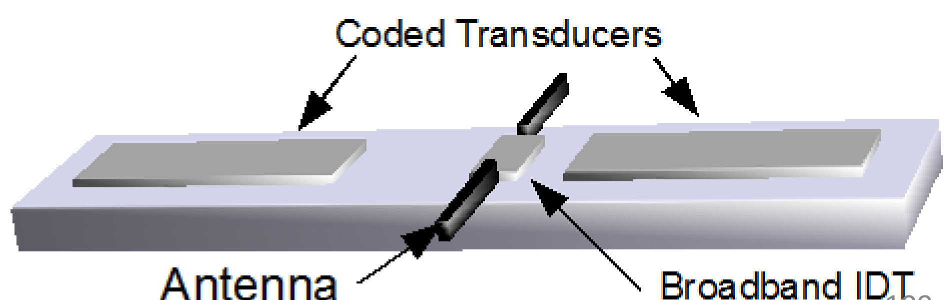
Cooperation with NASA GRC and JSC



Passive SAW Temperature Tag

- Designed and built at Umaine/Prof Mauricio Pierra da Cunha
- 107 MHz, 18 ft range



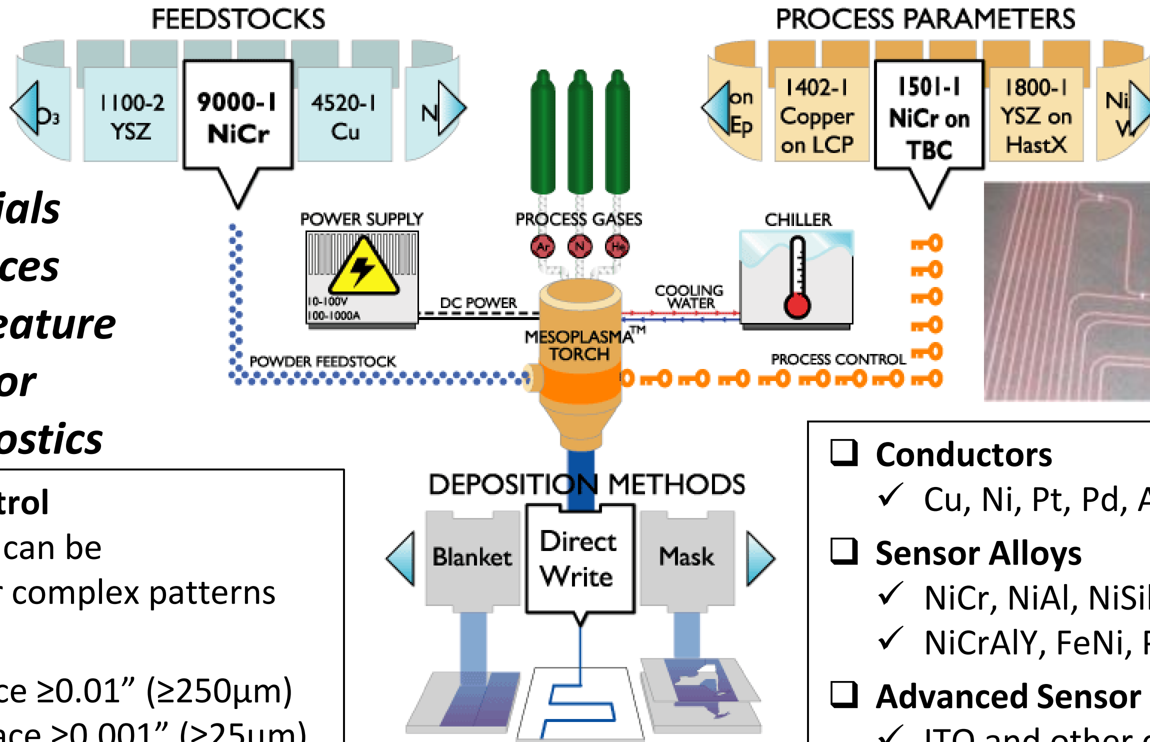


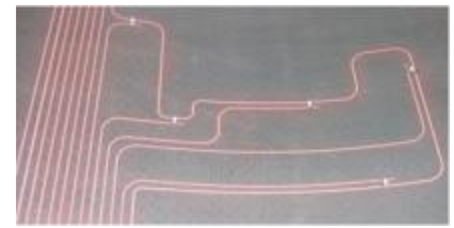
4-1

MesoPlasma^{TM} Direct Write Fabrication of Conformal, Harsh Environment Sensors

Mesoscribe/JasenTrelewicz www.mesoscribe.com - JTrelewicz@mesoscribe.com

Direct Write:* "print" *functional materials on complex surfaces to produce fine feature sensor patterns for integrated diagnostics



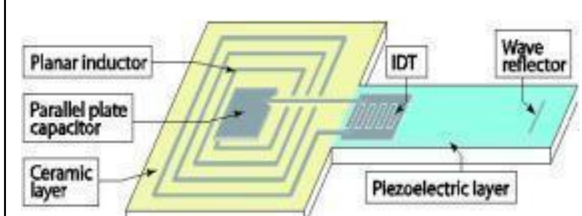


- ❑ **Dynamic trace control**
  - ✓ Trace geometry can be actively tailored for complex patterns
- ❑ **Trace width**
  - ✓ Direct Write trace ≥0.01" (≥250µm)
  - ✓ Laser Scribed trace ≥0.001" (≥25µm)
- ❑ **Trace thickness**
  - ✓ Generally ≥0.001" (≥25µm)

- ❑ **Conductors**
  - ✓ Cu, Ni, Pt, Pd, Ag
- ❑ **Sensor Alloys**
  - ✓ NiCr, NiAl, NiSil, NiCrSil, CuNi
  - ✓ NiCrAlY, FeNi, PdAg
- ❑ **Advanced Sensor Materials**
  - ✓ ITO and other ceramic TE oxides
- ❑ **Dielectrics**
  - ✓ YSZ, $MgAl_2O_4$... proprietary matls

- ❑ Component Health Monitoring
- ❑ Integrated Wiring
- ❑ Structural Energy Storage
- ❑ Damage Detection
- ❑ Antennas
- ❑ Active Control and SHM

Phs 2 SBIR PWST – NASA LaRC



Wireless Temperature Sensor for Gas Turbine Engine Applications

Wireless Sensor Technologies/John Conkle jconkle@wisen-tech.com

Close Proximity Interrogation – Rotating Turbine Blades
Components of Wireless Temperature Sensor - RLC Circuit + Diode Frequency Multiplier – Resonance varies with Temperature

1. Antenna
   - Enables the interrogating signal to be received
   - Sets the frequency of operation of the sensor
   - Enables the return signal to be transmitted back the the Tx/Rx/Signal Processing

2. Diode
   - Causes the generation of RF harmonics of the interrogating signal(as filtered by the antenna) which allow the return signal to be easily separated from the interrogating signal by the Tx/Rx/Signal Processing

3. Alumina or TBC Dielectric
   – possesses temperature-dependent electrical properties(DK, dielectric constant) which alters the antenna center frequency as the temperature changes

Also Developed Wireless Heat Flux Sensor

Supported by SBIRs in Navy, DOE and Air Force

4-3 **Thin Film Secure Display Inlay: A Revolutionary new Class of ID card**

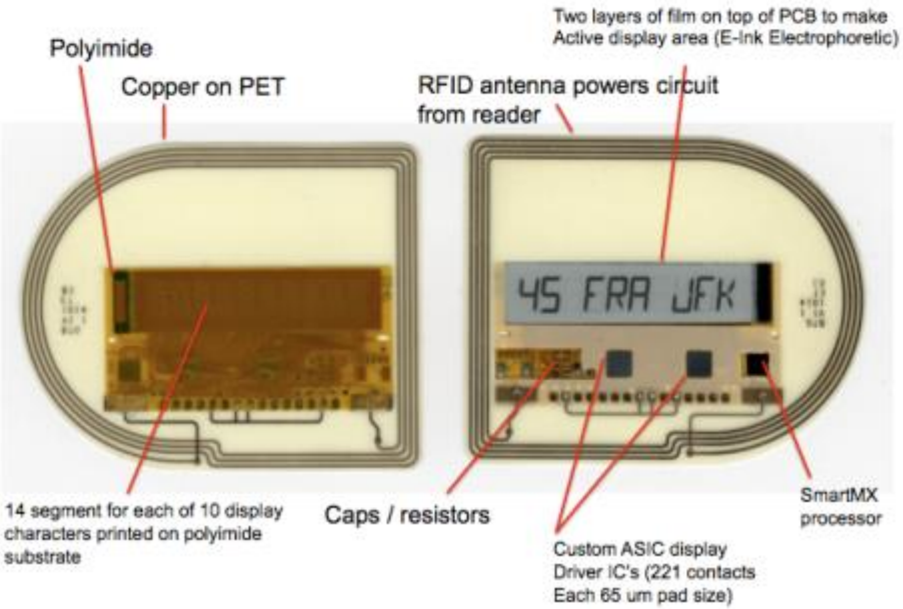
Tocreo Labs/Mark Krawczewicz
mark.kraz@tocreo.com - **www.tocreo.com**

Simple technology: **On-card display – Extraordinary Security - Chain-of-Trust – batteryless**
Applications: **Physical & Logical Access Control, Remote log-in, & Mobile Device Unlock**
Huge Market: **need strategic partners for system integration in Aviation, Transit, National & Commercial network**

Applications for Passive Wireless Sensors used with Near Field Communications???

Capabilites:
Dynamic Bi-State Display
- Users Access **-day / hour / privileges / remaining balance** can be written to the display defining role or access period by access control station
- Display can also show pending **authentication, cryptographic, transactional , or other security process**
- **Visual passport –** user carries auditing trail

Both an visual ID credential and a secure "Container" for data like photo, ID number, name, medical certificate, biometric, audit file, etc. **.**
Extraordinarily secure – same security processor as in 250 million passports
Uses only reader power – will last indefinitely
Maintains the Chain of Trust - (Users can verify at one terminal and then at a later time, facility, or secured area, prove it} – **Virtual Fence**
Single card bridges physical & network access worlds



SAW Resonant Passive Wireless Sensors for Automotive and Industrial Applications

Transense/Victor Kalinin

victor.kalinin@transense.co.uk - www.transense.co.uk

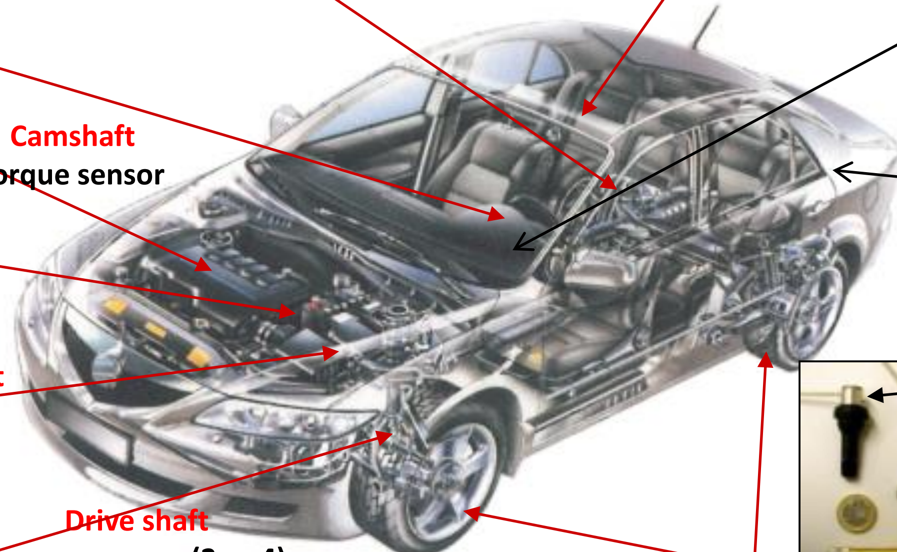
Over 8 SAW systems per vehicle

4WD torque splitter sensor

Kinetic Energy Recovery System (KERS)

EPAS torque sensor (2)

Camshaft torque sensor

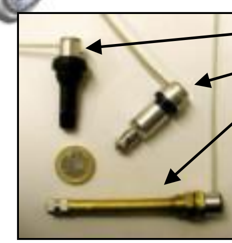


Display and Interrogation Electronics

Crankshaft or Flexplate torque sensor

Transmission output torque sensor

Drive shaft torque sensors (2 or 4)



Snap-In rubber valve for cars

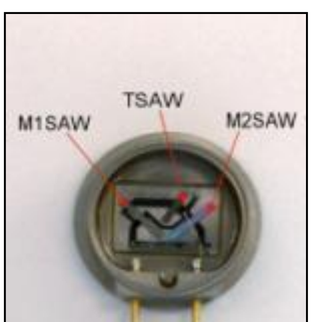
Screw-in metal valve for cars

Long reach truck valve

TPMS sensors (4 or 5)

Torque/Temp: 433-437 MHz sensing element (2005)

- Simultaneous measurement of torque & temperature to achieve temperature compensation.



Transense – GM Flexplate Project

Announcement Sep 26, 2011

http://www.transense.co.uk/news/235-gm-transense-flexplate-project

The Torque drive-line 'flexplate' sensor was “ originally developed for eight-cylinder engines and is now being adapted for 4 and 6 cylinder engines.

“ As part of this process Transense has successfully negotiated a variation of the otherwise exclusive licence to Honeywell, permitting Transense to deal directly with various named companies including GM preferred Tier 1 suppliers. Since then discussions about the technology have commenced between Transense and a Tier 1 supplier permitted under the Honeywell variation agreement.

The flexplate is an integral part of the vehicle powertrain control system and has the potential to improve vehicle driveability, reduce fuel consumption and improve transmission shift quality. This will be the first time a propulsion system has been able to measure engine torque 'live', enabling optimal control to be maintained throughout a vehicle's life. Current torque management systems rely on simulated models derived from production engine testing which can differ from the actual engine torque output over time. The new flexplate technology provides continuous real-time torque measurement allowing actual torque measurement on a per-vehicle basis for maximisation of engine efficiency.

GM is currently evaluating further applications of the technology for real-time vehicle control.”

High Function, Long Range Passive Wireless Sensor Tags

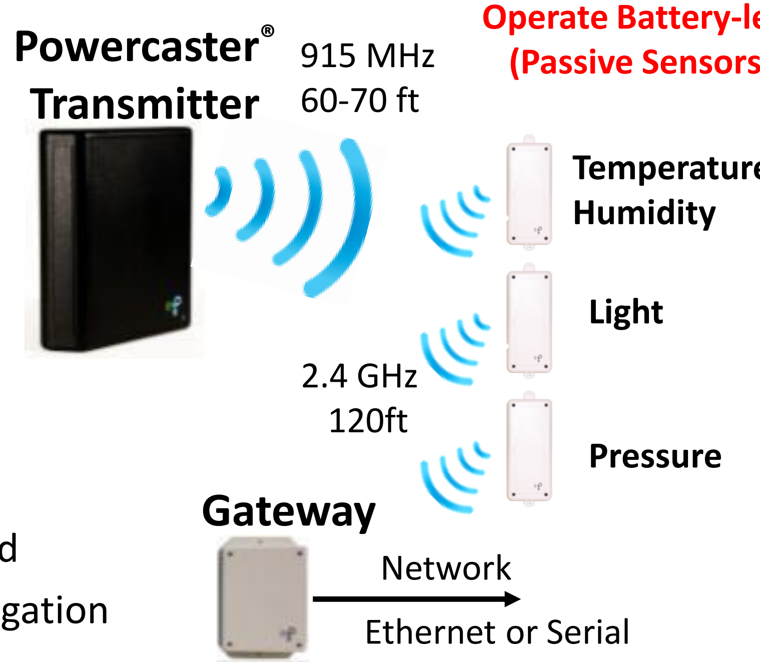
Powercast – Harry Ostaffe

hostaffe@powercastco.com - **www.powercastco.com**

Use to Charge Battery
or
Operate Battery-less (Passive Sensors)

Scavenge Power alternatives:

- Light / solar energy not always sufficient
  and rechargeable batteries are required
- Temperature requires large ΔT 915 MHz
- Vibration has narrow bandwidth, moving parts
- **RF-based wireless power**
  - Send power over distance - µW, low mW
  - One-to-many, any-to-any topologies
  - Overcomes lack of light, temp diff., or vibration
  - Controllable: continuous, scheduled, on-demand
- **Future**: Smart Phone-based wireless power - interrogation



P1110

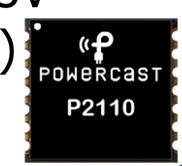
Continuous Power Output

- RF range: -5.0dBm to 20dBm
- Output voltage: 1.8V to 4.2V (configurable)
- Range of at least 3 meters

P2110

Pulsed Power Output

- RF range: -11.5dBm to 15dBm
- Output voltage: 1.8V to 5.25V (configurable and regulated)
- Range of at least 10 meters



5-2

Proceed With Caution: Disaster Recovery (PWST) Applications in Nuclear Control Systems

Ivan Chow - Doosan, HFControls - ivan.chow@doosan.com

www.HFControls.com

Measurement Types

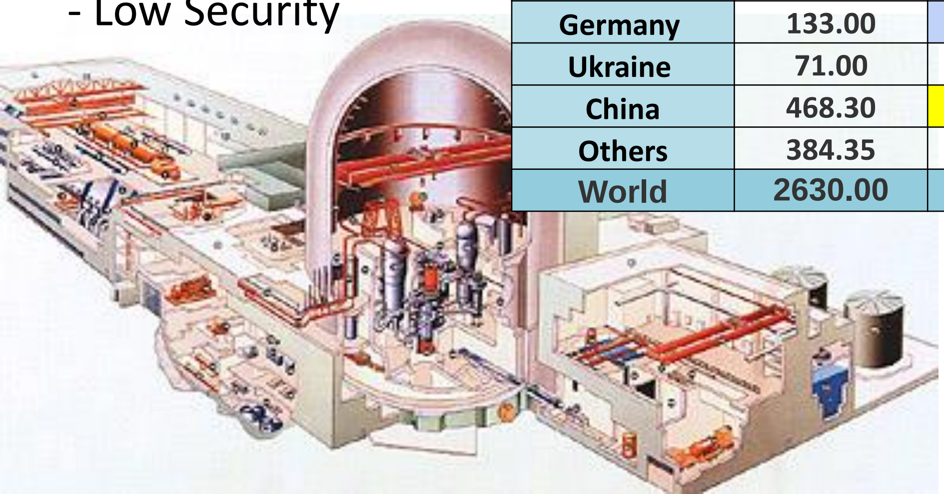
- Temperature
- Radiation
- Others TBD

Use Cases:

- After "Shutdown" sequences initiated
- With or without main power source
- Cover All plant units
- Low Security

Worldwide Nuclear Power Plants

COUNTRY	Nuclear Electricity 2010	Reactors							
		Operable 1 July 2011		Under Contruction 1 July 2011		Planned July 2011		Proposed July 2011	
	billion kWh	No.	MWe net	No.	MWe gross	No.	MWe gross	No.	MWe gross
USA	807.10	104	101421	1	1218	6	7200	28	38600
France	410.10	58	63130	1	1720	1	1720	1	1100
Japan	280.30	51	44642	2	2756	10	13772	5	6760
Russia	155.40	32	23084	10	8960	14	16000	30	28000
South Korea	141.90	21	18716	5	5800	6	8400	0	0
India	20.50	20	4385	5	3900	18	15700	40	49000
Canada	85.50	18	12679	2	1500	3	3300	3	3800
United Kingdom	56.90	18	10745	0	0	4	6680	9	12000
Germany	133.00	17	20339	0	0	0	0	0	0
Ukraine	71.00	15	13168	0	0	2	1900	20	22800
China	468.30	14	11271	26	28710	52	59990	120	123000
Others	384.35	72	52842	9	8770	38	36783	87	106295
World	2630.00	440	376422	61	63334	154	171445	343	391355



Data from World Nuclear Association as of July 1, 2011

RFID Sensors in Transportation

Ron Stieger – Zonar - Director of Engineering ron.stieger@zonarsystems.com
www.zonarsystems.com

Truck Inspection Integrity

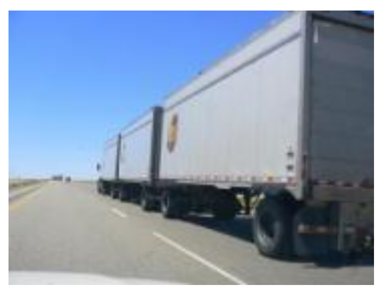
Tag placed at inspection locations - add sensors

Odometer from Tire Rotations needs calibration

Payload Weight

Trash Pick-up Management

Battery Voltage on Trailers



Temps in Refrigerated Truck

Engine Temperature

Brake Stroke

Fluid Levels: Fuel, Oil, Others

5-4

Intelligent Multi-Sensor Measurements to Enhance Pavement Monitoring and Safety

Fred Faridazar - Federal Highway Administration

Turner-Fairbank Highway Research Center

http://www.fhwa.dot.gov/research/; http://www.tfhrc.gov

fred.faridazar@dot.gov

1. **Exploratory Advanced Research**

2. **Pavement Sensors**
   - **Pavement Monitoring**
   - **Self-powered Pavement Monitoring Sensor**
   - **Carbon Nanotube Based Self-sensing Concrete for Pavement Materials Tracking**
   - **Applications of RFID Technology to Asphalt Paving**

3. **Roadway Renewable Energy**

4. **Stay-in Lane**

5. **Additional Application Need**

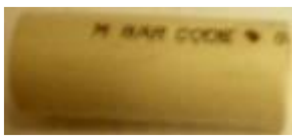
Turner-Fairbank Highway Research Center
Radio Frequency Identification (RFID)

The Solution?

HMA from Plant

Haul Truck

Paver



Encapsulated RFID Tag

Add PWST Temperature?

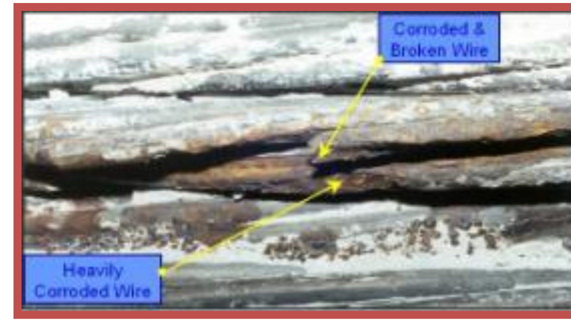
Compaction

Identifying where loads of material end up in the pavement

Finished Pavement

Tags scanned when convenient after construction

Federal Highway Administration
Turner-Fairbank Highway Research Center



Corrosion of Post-Tensioned Bridge Tendons

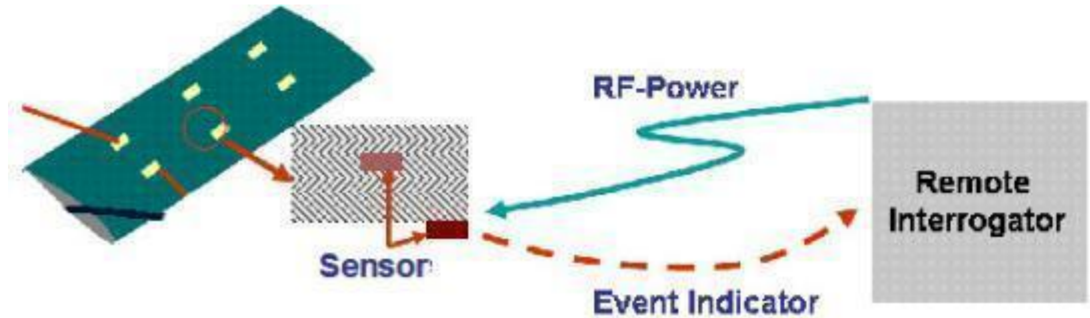
Staying in Lane - Intelligent Fusion of Vehicle Sensor Data

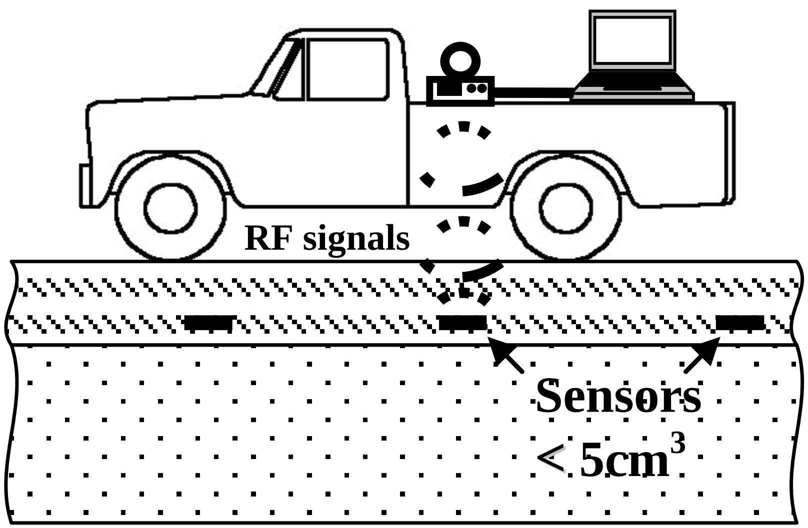
Long Term Pavement Monitoring

- UMD Pavement Monitoring - RFID and active Intelligent Automation Inc. Sensors
- **Kinetic to Electric Energy Conversion (KEEC) – VPI/VSU**
- **Univ of Minn**
    - **Carbon Nanotube (CNTs) Based Self-Sensing Concrete**

A Sub-microwatt Long-term Monitoring Sensor

Nizar Lajnef, Ph.D., Michigan State Univ. for FHWA
lajnefni@egr.msu.edu - http://www.egr.msu.edu/cee/people/lajnef.html





Pavement

Potential Applications of PWST

Nezih Mrad, Ph.D.
Defence R&D Canada (DRDC), Air Vehicles Research Section (AVRS)
http://www.drdc-rddc.gc.ca - Nezih.Mrad@drdc-rddc.gc.ca

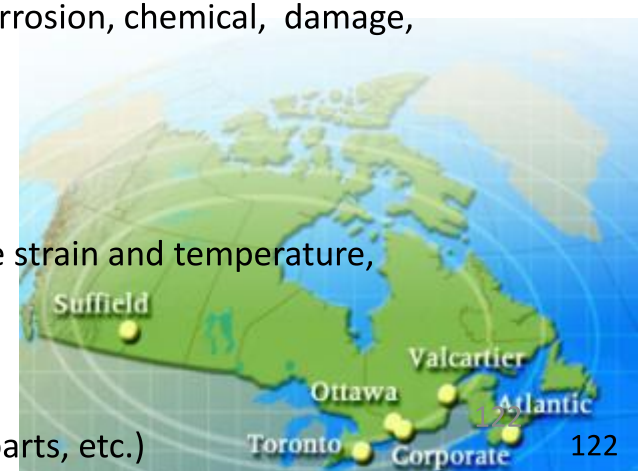
Mission:

To ensure the Canadian Forces are technologically prepared and operationally relevant.

- Advise on Science & Technology
- Conduct Defence research, development and analysis
- Assess technology trends, threats, and opportunities
- Engage industrial, academic and international partners in the commercialization of technology
- Conduct S&T projects for non-DND clients

PWST Interest Areas:

- Advanced Health Monitoring Capability Development and Demonstration
  - Sensors development, evaluation and demonstration (strain, load, corrosion, chemical, damage, cracking, etc.)
  - Modeling, simulation and analysis
  - Experimental capability development
- Engine PHM Capability Development and Demonstration
  - Sensors development, evaluation and demonstration (H/L Temp blade strain and temperature, blade damage and erosion, oil quality/debris monitoring and leak
  - Data fusion and mining, etc.
- Asset monitoring and tracking
  - Materials visibility and condition assessment (e.g. ration, fuel, spare parts, etc.)



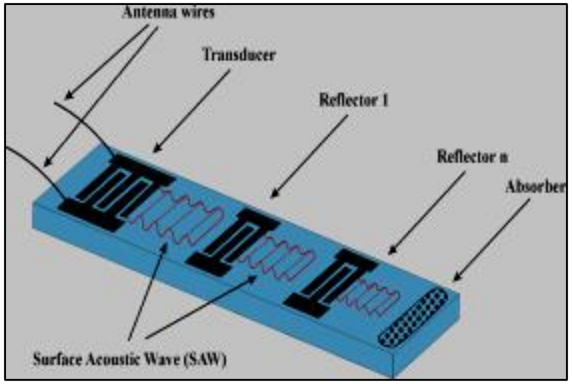
Passive Wireless SAW Temperature Sensors

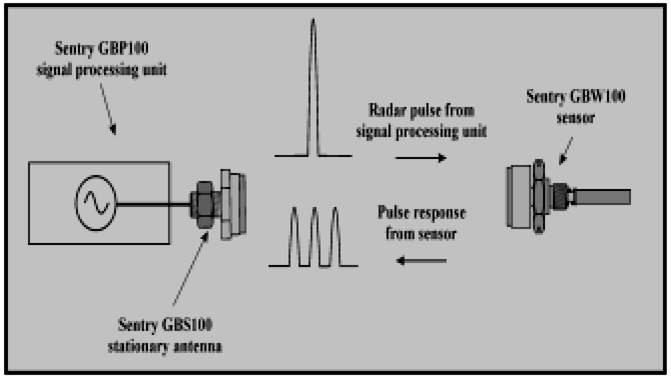
Kongsberg Maritime NJ (Sensors) - Ed. Gemdjian

www.km.kongsberg.com - KongsbergNJ@verizon.net

SENTRY Wireless Temperature Monitoring – Technology – in use for a decade!

- Fast and reliable temperature monitoring of moving or rotating bearings
- Improved overall operational safety for crew and machinery





SENTRY Applications: "Radar Sensor" Temperature Monitoring of Large Rotating Machinery

- **Diesel Engines and Reciprocating Compressors** – new and retrofit
  - main, wrist/cross pin, crank pin, connecting rod(small end, big end, crosshead) bearings
- **Wind Turbine Gears -** the roller bearings in the planetary unit of the gearbox
- **Paper Machines' Drum** – paper roll shell temps – 6 read by 1 antenna - ID by rpm counter
- **Electric Motors & Generators** – rotor windings
- **High Voltage Power Transformers**
- **Hydraulic Clutches – Oil temps**

Sensors and Controls Enabled Solutions

George Hernandez – DOE/Energy Efficiency and Renewable Energy
Pacific Northwest National Laboratory
eere.energy.gov; George.Hernandez@ee.doe.gov

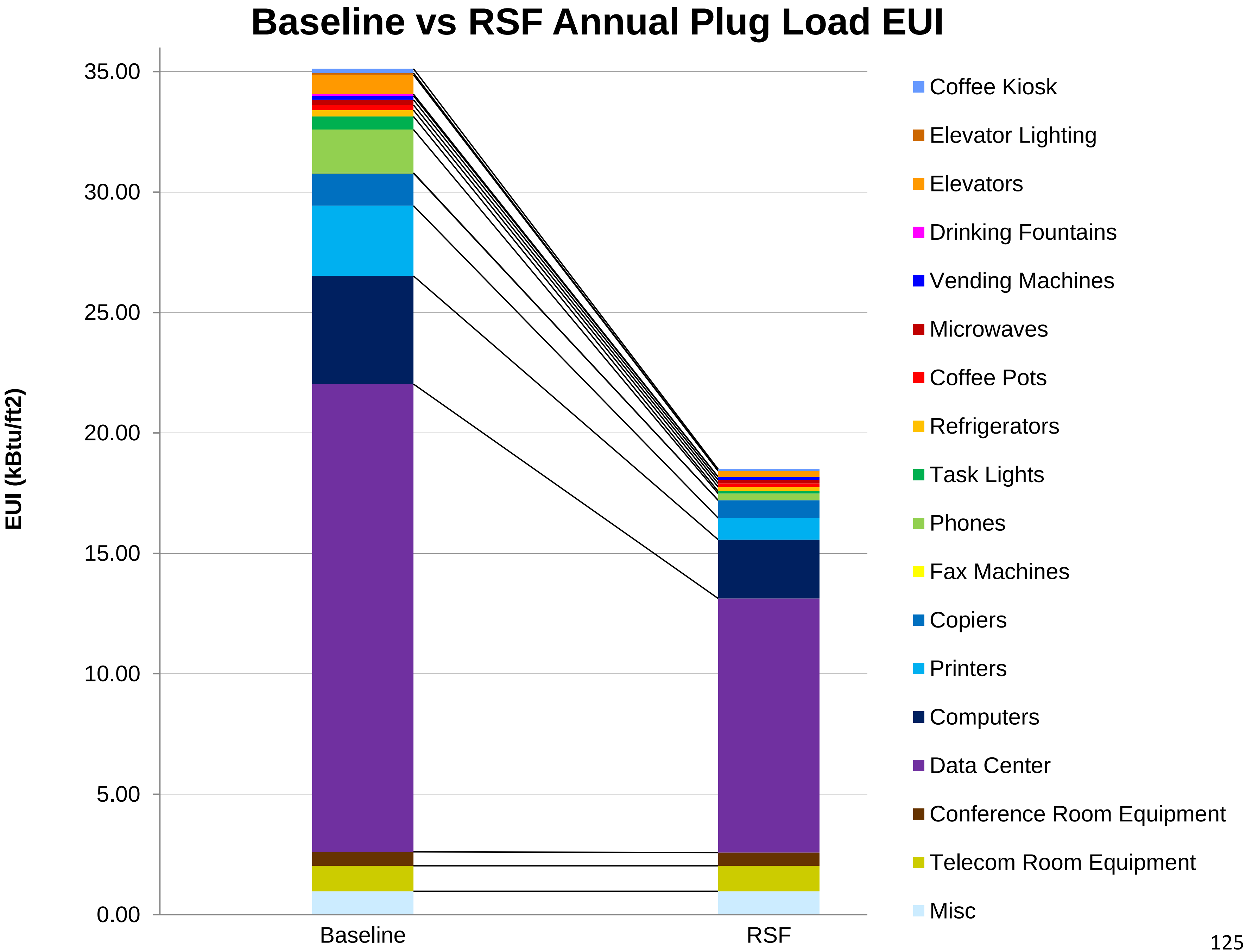
Target Applications:

- Advanced Controls and Diagnostic Packages for Packaged Air Conditioners
- Self-Correcting and Self-Configuring HVAC Controls
- Proactive Building Energy Management – automation and occupant participation
- MEL(Miscellaneous Equipment Loads) Management

Attributes Needed:

- Temperature, Relative Humidity, CO2, Flow (air and liquid), Pressure, Power, Light
- Occupancy Sensors - Image Processing-Based – motions sensors don't work well
- Inexpensive – much less than $100 typical per measurement location
  - Cost is the main deterrent for commercial buildings not installing Efficiency Monitoring/Control sensors
- Accurate (+/- 1 deg C is not good enough for diagnostics) - minimum drift
- Common interfaces
- Relocatable
- Location provided

6-2


Baseline vs RSF Annual Plug Load EUI
EUI (kBtu/ft2)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Baseline
RSF
Coffee Kiosk
Elevator Lighting
Elevators
Drinking Fountains
Vending Machines
Microwaves
Coffee Pots
Refrigerators
Task Lights
Phones
Fax Machines
Copiers
Printers
Computers
Data Center
Conference Room Equipment
Telecom Room Equipment
Misc

Network Enabled Manufacturing(NEM) & Passive Wireless Technologies

6-3

Al Salour, Ph.D. – Technical Fellow
Boeing Research & Technology
al.salour@boeing.com 314-232-1743

NEM Considerations:
- Multi-disciplined technical skills development team
- Serve the customer needs in changing environment
- Emphasis in Composites materials and processes
- In-house fabrication core competencies "Metallic and non-Metallic"
- Supplier management "Increases in the third party material suppliers"
- Wireless secured networks
- Multi-site manufacturing & replication opportunities
- Latest advancements in real time plug & play autonomous systems

NEM Technology Needs:
- **Sensors:** Location, illumination, temperature, humidity, pressure, flow, vibration, proximity, etc.
- **RTLS:** Chokepoint, Presence, Location
  - Battery powered,
  - $40 per sensor -> apply to <u>high value</u> assets
  - UWB indoor & outdoor system for Tool Kits
- **pRFID (passive RFID): Material Management**
  - Commonly used on <u>high volume</u> items
  - No power source (*No batteries*)
  - Inexpensive ($0.50 or less)
  - Minimal data storage
  - EPCGlobal Standard Passive RFID Tag Inlay
  - Gen 2 Class 1 – WMRM (Write Many-Read Many)

pRFID Applications:
Time & Temperature Sensitive Material - Sealants inventory
-Walk in freezer composite material out time / inventory
Paint - Paint mix room
Receiving - Incoming materials
Shipping - UID Bar codes on selected shipments
Work in process – Tube shop
Tool number, serial number, shelf location
Handheld reader for localization and ID – Biomark tag test

6-4

Passive Wireless Sensors Vehicle Health Management Applications

Robab Safa-Bakhsh - robab.safa-bakhsh@boeing.com
Associate Technical Fellow , Boeing Research and Technology

Customers: Boeing Commercial Aircraft, Military Fixed and Rotary Wing aircraft
Objectives: Life-Cycle Cost, Mission Reliability, Availability, Operational Plans, Supply Chain
Life Cycle Applications: Design & Development; Manufacturing, Operation & Sustainment

Sensors:
Flight Control: Electro-Mechanical Actuators, Hydraulic Actuators, Linkage, Hydraulic System
Electrical System: Generators, Converters, Contactors, APU, Batteries, Cooling System
Propulsion: Blades, Bearing, Gas path, valves
Avionic: Power Supply, Electronics
Rotor System: Rotor blades, Rotor hub, Tie bar, Rotor shaft
Fuel System: Fuel Pumps, Motors, Valves
Structures: Airframe Structure, Dynamic Components
Drive System: Gears, Bearings, Shafts, Lubrication, Housing
Electrical Wiring: Wiring insulation, Pins connections
Under Carriage: Landing Gear, Tires, Wheels, Brakes

Challenges: Reliable Comm/cross-talk, EMI, Reliable installations, Harsh environments, Sensor accuracy, life Stability

Passive Wireless Sensor Tag Research Focus:
- Meet min requirements for resolution, accuracy, repeatability & durability of traditional sensors
- System expandability & communication quality as the number of interrogated sensors increases
- EMI for long range interrogation
- Out of sight sensors implementation
- Synchronization of multiple sensors
- Synchronization of multiple interrogators
- Minimize size, weight and power of the interrogators
- Reliable installation and operation over the life of monitored component

Day 2
Lunch Speaker

What Works in the World of Wireless Sensors

Louis Sirico (Louis@RFID.net), **Host & CTO of The RFID Network, Campbell, CA**
http://RFID.net and www.Rfidwikipedia.org

- **Responsible RFID Benchmarking in a web-based TV Video Series & info source for Wikipedia**
  "We don't publish what people tell us, we make them prove it"
  http://rfid.net/applications/energy/289-passive-wireless-sensor-tags-benefit-energy-aerospace-transportation-a-industry

- **We show you** how Radio Frequency Identification and wireless RF sensors can improve your business. We provide information, tools, and advice that help you decide what to buy and how to get the most out of RFID.
  - Install, Implement and Integrate RFID

- **Durable RFID Tag Benchmarking:**
  - Defining 'Durability' and the RFID Tags Evaluated
  - Vibration Survival TestsSupply Chain Logistics Operations Tests: *Mixed Pallets with an RFID Enabled Portal & Handheld RFID Reader*
  - Asset Tracking Tests: *Maximum Read Range Outdoors with a GPS enabled Handheld RFID Reader*
  - Manufacturing Work-In-Progress Tests: *Maximum Read Range Indoors with a Fixed Position RFID Reader*
  - Overall Benchmark Test Analysis
  - Important Considerations When Selecting RFID Tags

RFID Net Website:
1. Use
2. Benefit
3. Compare / Evaluate / Buy
4. Install / Implement / Integrate
5. Back to #1 – Repeat

RFIDWikipedia Website:
1. Define
2. Explain
3. Educate

- **Call for Content: RFID Network is Looking for Subject Matter Experts(SME's) for RFIDWikipedia.org**

✓ **SAW**
✓ **Wireless Sensors**
✓ **RFID**

NXP Interactive Gen2

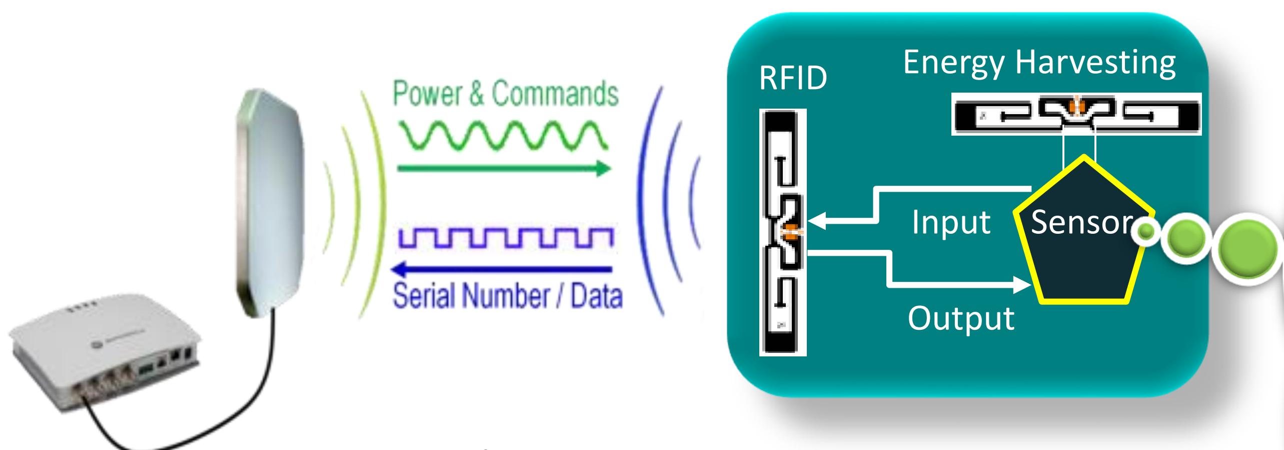
"Bridging the Gap between Passive RFID, Sensors and Electronics"

Victor Vega - Marketing Director, RFID Solutions

www.NXP-RFID.com

UCODE G2iL+ &G2iM+ series ICs **add a digital input / output to RFID**

- Input enables tamper or level detection for simple digital sensors
- State change is transmitted via RF to reader, along with device's unique s/n
- Output may be used as digital switch to assert a remote action
- Use cases may include alerts – for example, if bearing temperature threshold is exceeded



- Tamper
- Temperature
- Humidity
- Light
- Ph
- CO_2
- Pressure
- Vibration
- Tilt
- etc.

- I²C & RF data interface (independently enabled)
- TID/UTID: 96-bits
- EPC Memory: 160-bits
- User Memory: 3,328-bits
- High capacity memory, dual analog front end, read protect, interrupt flag, bidirectional I²C, RF / I²C bridge, digital switch

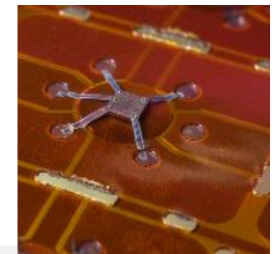
7-2

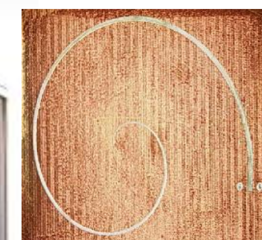
Aerosol Jet® (AJ) Direct Write Technology
A Manufacturing Tool for Printed Electronics

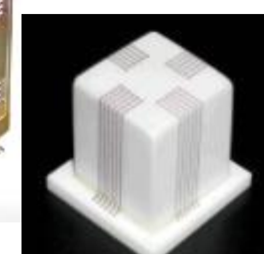
Optomec - Rich Plourde
rplourde@optomec.com

Note: Optomec does not design SAW, RFID, Antennas or Circuits
Contract Mfg: Quest Integrated Inc., Jonathan Kniss, http://www.qi2.com

- **Patented Material Deposition Kernel (atomizers, PCMs, print modules)**
  - Configurable for wide range of Feature Sizes & Multiplexing for volume production
- **Development Platforms Successfully Fielded**
  - for material, process & application development / prototyping
  - Configurable Atomizers, Heads, Motion, etc.
- **High Throughput Multiplexed Heads for Production**
  - ie: 40 nozzle head prints 2400 silicon solar wafers / hour
- **Platform Independent Modular Print Engines**
  - for high volume manufacturing
  - Standardized communications protocols & interfaces
  - Easily integrated with 3rd Party Manufacturing Systems
    - Manz Automation: print 80 solar collector lines on silicon wafers in 2.5 seconds
    - Speedline Technologies: print 20+ die stack interconnects / second


Die Attach


1cm GPS Antenna


3D Interconnects

NASA Testing of PWST

NASA LaRC/William C. Wilson william.c.wilson@nasa.gov
with support from KSC/Emilio Valencia, JSC/Richard Barton, LaRC/Jay Ely

NASA has the capability for most forms of testing!

Transducer characterization

Cryostat

Strain Characterization – COPV

RF Testing

Functional testing

Compliance Testing

Industry, MIL Spec, Space Qual

Flight Testing

- **MLAS**
- ***747&A320 Cargo Bays***
- ***747 Landing Gear***
- ***Intl. Space Station***

Aerospace Vehicle Systems Institute

On-Aircraft Wireless Communications Research at AVSI

A part of the Texas Engineering Experiment Station at Texas A&M

Dr. Fred Fisher, Asst. Director, AVSI www.avsi.aero; Ffisher@avsi.aero

Full Members
- Airbus
- BAE Systems
- Boeing
- DoD
- Embraer
- GE Aviation
- Goodrich
- Honeywell
- Lockheed Martin
- Rockwell Collins
- UTC

Liaison Members
- FAA
- NASA

Associate Members
- Bombardier
- Gulfstream

WAIC Project Status will Presented at 2012 PWST Workshop

Common problem-Cooperative solution-Immediate need

RFID Relevant Research Projects:

- AFE14 - Wireless Communications for Aircraft Systems
- AFE41 - Mitigating the Impact of RF Emissions from PEDs to Airplane Systems through Aircraft Hardening
- AFE50 - Energy Harvesting Potential Assessment
- AFE 56: Feasibility of Intra-Aircraft Wireless Sensors
- AFE54 - RFID Study
- AFE56s1 - Feasibility of Intra Aircraft Wireless Sensors + Supplement
- AFE73 - Wireless Avionics Intra-Communications (WAIC)

AVSI - RFID Relevant Research Projects

AFE 14: Wireless Communication for Aircraft Systems

- Develop and validate a performance model of wireless comm. within aircraft environment.
- Determine viability of using wireless comm for essential or critical aircraft systems.
- Validate model using a ground based aircraft
- Evaluate the impact of passive and active components within the aircraft (structural components, engines, and existing electronic and electro-hydraulic subsystems) at both physical and protocol layers.

AFE 41: Mitigating the Impact of RF Emissions from PEDs to Airplane Systems thru A/C Hardening

- Determine practical aircraft hardening techniques for mitigation of airplane system susceptibility to RF energy from portable electronic devices .
- Use results of this effort may be to support protective regulatory requirements .
- Select approaches for mitigating the impact of PEDs and experimentally evaluate effectiveness of the approaches.

AFE 50: Energy Harvesting Potential Assessment

- Quantify available energy on aircraft for potential energy harvesting.
- Survey one or two types of aircraft to determine the type and amount of energy that is available for harvest.
- Look at vibration/strain, thermal & RF energy levels.
- Assess energy levels for all status of the aircraft i.e. storage, docked, taxi, climb, cruise, decent, etc., to produce an available energy profile.

•AFE 56: Feasibility of IntraAircraft Wireless Sensors

- Evaluate Current aircraft RF certification process
- Evaluate RTCA SC 202 working group and draft DO-294 T-PEDS status as extensible to wireless sensors.
- Evaluate European work in this area.
- Determine Suitability of the ISM band, Possible alternative bands,
- Determine need for encryption.
- Define next steps and or work needed to fill holes/gaps - in coordination with the FAA
- Collect &evaluate existing Channel Modeling work

AVSI - RFID Relevant Research Projects

AFE 54: RFID Study

Deliver: A quantitative model of tag & interrogator emissions

Activities:

- Select representative tags /interrogators for analysis
- Survey existing work (NASA & others)
- Develop catalog of quantitative tag & interrogator models
- Install tags & interrogators in and around selected aircraft
- Measure tag and interrogator performance on the aircraft at selected locations and correlate with previously developed models
- Develop an avionics interference model for the tag/interrogator emissions
- Measure and quantify levels of interference with aircraft avionics

AFE 56s1: Feasibility of Intra Aircraft Wireless Sensors/Supplement

Prepare an info package to start formal frequency allocation process:

- Perform economic analysis on different band classifications
- Characterize potential usage profile envelope for wireless sensors: bandwidths, data rates, power levels, modulation techniques
- Down select frequency candidates from the already identified list.
- Cost and availability of commercial radio devices that operate in the candidate frequency band shall be included as factors in down-selection.
- Establish on-going contact with FAA spectrum office, FCC WTB and OET, NTIA. Contacts with any regulatory agencies/Washington DC offices shall be coordinated in advance w/AVSI PMC member companies' reg. offices.
- Evaluate pros and cons of the RTCA route
- Involve NASA, European contacts, other industry members (possibly as additional members of this PMC)
- Define and prepare a suitable information package including detailed roadmaps for each of the different band classifications (licensed dedicated, licensed shared, unlicensed dedicated portion) use by a third party to lobby the appropriate authorities (e.g. for licensed dedicated, the FCC and NTIA)

Prepare a specific certification strategy for information assurance:

- Determine actual impact of DoD Directive 8500.1
- Study and recommend strategies to certify security approaches that use randomized techniques
- Study and recommend approaches to facilitate upgrade-able encryption/security solutions with minimal FAA re-certification effort
- Study likely characteristics of jamming and denial of service attacks
- Study likely decrypting capabilities of an information interceptor
- Define a reasonable threat model for information assurance requirements

AVSI - RFID Relevant Research Projects

AFE 73: Wireless Avionics Intra-Communications (WAIC) - http://waic.avsi.aero/

• Use of wireless communication technology in safety-critical systems requires that appropriate frequency bands will be available with sufficient regulatory protection against unwanted interference.

• Interact with ITU-R through its Working Party 5B to get their recommendation for an allocation proposal.

• Perform technical studies and analyses necessary to formulate and justify a proposal.

• Formalize previous industry working group / ITU-R interactions.

• Establish a WRC 2015 Agenda Item relative to protected spectrum during the World Radio Conference in 2011.

• Perform all necessary follow-up activities to support allocation of the protected spectrum through regulatory organizations.

• The project serves as an important stepping-stone on the road towards allocation of protected spectrum for wireless avionics system.

- Pending project topics
  - WAIC band sharing studies
  - WAIC/PED/RFID/WiFi coexistence
  - WAIC protocol standard
  - Active/Passive Sensor Networks
  - System architecture virtual integration
  - Integrated reliability processes
  - Certification of RFID applications

Bridging the Mid TRL Gap through Coordinated Technology Development

Milind Pimprikar, Founder & Chairman, CANEUS International

www.caneus.org; milind.pimprikar@caneus.org

CANEUS' Sole Purpose: Enable Productive Public-Private Partnerships

CANEUS Proven Capabilities:

- **CANEUS brings together** technology developers, End-users, Governmental policymakers and investors from across the world.
- **CANEUS provides** a public/ private platform of transitioning emergent technologies rapidly and efficiently from concepts to the aerospace systems / products / missions.

CANEUS' Public/Private Consortia:

1. **Fly-by-Wireless Wireless (FBW)**
2. **Small (Nano/Pico/Micro) Satellites** for Civilian and Defence Applications
3. **Reliability** Testing
4. **Devices-** Harsh Environment Sensors,
5. **Nanomaterials** for Aerospace Applications including **Micro-energetic** for power generation, energy conversion, and micro-rockets

Benefits from joining the CANEUS FBW Consortium:

1. Cost/Risk Mitigation: Access to jointly developed pre-competitive technology & proprietary product development.
2. Participation in a collaborative technology, product and business development environments.
3. Licensing access to a fair and equitable IP-brokering service.
4. Reduced time-to-market and rapid system-level product deployment through supply chain collaboration.
5. Participate in the development of global standards in cooperation with leading aerospace corporations & agencies.
6. CANEUS will "harmonize" various National Policies controlling collaborative international technology development and frequency band allocations.
7. Access to CANEUS forums/conferences as key networking platforms for Fly-by-Wireless project members to address the relevant issues.
8. Access to CANEUS' global "technology portal" that identifies state-of-the-art and the technology developers and suppliers.

7-5

Industry Canada – Opportunities for Collaboration

Jim Castellano - Aerospace, Defence and Marine Branch,
Government of Canada - Ottawa, Ontario
Jim.Castellano@ic.gc.ca - 613-954-3747

Canada

- **Industry Canada** - Mandate is to help make Canadian industry more productive and competitive in the global economy, thus improving the economic and social well-being of Canadians.
  Website: http://www.ic.gc.ca/eic/site/ic1.nsf/eng/h_00000.html?OpenDocument

- **Strategic Aerospace & Defence Initiative (SADI):** http://ito.ic.gc.ca/eic/site/ito-oti.nsf/eng/h_00023.html
  - To encourage strategic research and development (R&D) that will result in innovation and excellence in new products and services;
  - To enhance the competitiveness of Canadian A&D companies;
  - To foster collaboration between research institutes, universities, colleges & the private sector.

  Note: A US company could be treated as a subcontractor under a SADI agreement with a Canadian company but it is difficult to justify.

- **Industrial and Regional Benefits (IRB's):** http://www.ic.gc.ca/eic/site/042.nsf/eng/00029.html
  - Obligates Prime Contractors who have successfully won defence contracts to place economic activities in Canada

- **Defence Development Sharing Agreement (DDSA):**
  - IC Industrial Technology Office is the contact point for DDSA projects - www.ito.ca