Passive Wireless Sensor Technology Workshop (#9)
at
Wireless for Space and Extreme Environments(WiSEE2019)

October 16-18, 2019

Overview

Omar Torres, George Studor, Don Malocha

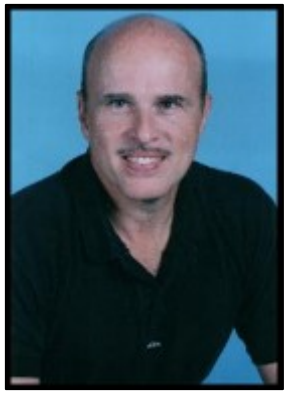
https://attend.ieee.org/wisee-2019/Program/Workshops

PWST Co-Chairs

- **Omar Torres (NASA)**
  - NASA Engineering & Safety Center
    - https://www.nasa.gov/offices/nesc/home/index.html
  - Lead, Wireless Avionics Community of Practice

- **George Studor (NASA/NESC/AMA)**
  - NASA Engineering & Safety Center, Hampton VA.
  - Retired NASA-> Initiated:
    - NESC Wireless Avionics Community of Practice (2011)
    - PWST Workshops (2011) ->
    - In-Space Inspection Workshops (2012)->
    - INCOSE Natural Systems Working Group (2013)->

- **Donald Malocha (Pegasense/UCF)**
  - University of Central Florida, Orlando FL.
  - Prof Emeritus Electrical & Computer Engineering Dept.
  - Dir. Consortium for Applied Acoustoelectronic Technology
  - CTO of Pegasense, LLC
  - IEEE Ultrasonics, Ferroelectronics & Freq Control(UFFC)



PWST Workshop Objectives

- **Objectives**
  - *Promote PWS technology maturation and encourage new applications*
  - *Build Relationships between users/stakeholders and technology developers*
- **Approach**
  - Leverage interests of industry, academia, and governments
  - Facilitate “next step” thinking through one-on-one sessions
  - Broaden PWST workshop usefulness:
    - Introduce new material & focus at each workshop
    - Maintain a library of past PWST workshop programs & presentations

Past PWST Workshop Index and Full Presentations:

WiSEE 2019 Website: https://attend.ieee.org/wisee-2019/program/workshops/

PWST Workshop

- **Big Thanks**
  - WiSEE 2019 & IEEE Organizers and Sponsors
    - Organization, website, keynote speakers, tours
  - University of Ottawa
  - PWST speakers and participants adding to the library of knowledge
- **For 2019**
  - 14 Technical sessions + One-on-One sessions
  - 47 Technical presentations (mix of user needs and technology development)
  - 14 speakers from government
  - 17 speakers from academia
  - 16 speakers from industry
  - 5 countries from 3 continents represented

PWST 2019 Program

- 14 PWST sessions
- 25 min talks + 5 min Q&A
  - Help session chairs keep us on schedule
- PWST in rooms A & B
- ***Late updates to PWST agenda are only reflected on the PWST booklet of speaker summaries***
  - WiSEE program has outdated PWST information
- Program available online:

  https://attend.ieee.org/wisee-2019/program/workshops/

Passive Wireless Sensor Technology Workshop Sessions			
Wednesday, October 16, 2019			
	Room A		**Room B**
S0 **9:30-10:00**	**S0-PWST Worskhop Overview**		
S1 **10:00-11:30**	**S1-A Propulsion & Flight Test:** *Jacob Adams*		**S1-B Optical & EM Backscatter:** *Raymond Rumpf*
S2 **13:30-15:30**	**S2-A Industry & IoT:** *Jin Mitsugi*		**S2-B Flexible Sensors & Antennas:** *Darren Boyd*
S3 **16:00-17:30**	**S3-A Aircraft & Helicopter:** *Aaron Singer*		**S3-B EVA & Surface Systems:** *Richard Evans*
Thursday, October 17, 2019			
S4 **9:00-11:30**	**S4-A Unmanned Vehicles:** *Zach Seibers*		**S4-B SAW, BAW, MEMS:** *Tim McIntyre*
S5 **13:30-15:30**	**S5-A WAIC Systems (4.2-4.4 GHz):** *Gary Hunter*		**S5-B Thru Structure:** *Eduardo Rojas*
S6 **16:00-17:30**	**S6-A Spaceflight Sensors:** *Kristen Donnell*		**S6-B Medical & Flight Crew:** *Ami Yang*
Friday, October 18, 2019			
S7 **9:00-10:30**	**S7-A MISC PWS:** *Juan Romero*		**S7-B Industry:** *Richard Evans*
S8 **10:45-12:00**	**S8-A One-on-One Sessions**		**S8-B One-on-One Sessions**

PWST One-on-One Sessions

- Friday October 18, 10:45a-12:00p
- Process:
  - User/Stakeholder sit at a table – can request developers to sign up
  - Technology Developers – decide who to meet
  - Developers sign up to talk to users in 15 minute time slots

- Make it Work:
  - Be Proactive – Missed a presentation? Got questions?
  - Be respectful – Don't need to meet after all? Erase your name from sign-up sheet
  - Be Prompt – start and finish on time
  - Be Courteous – quiet as practical so everyone can hear
  - Be Practical – get the most out of the 15 minutes, arrange your follow-up

One-on-One Session Sign-up Spreadsheet

Room A One-on-One Sign-up							
	Name	Organization/Topic	10:45	11:00	11:15	11:30	11:45
S-1 A-0	Torres, Studor, Malocha	NASA NESC, Pegasense Wireless, PWST 2020					
S-1 A-1	Aaron Comis	NASA/JSC/EG5 Parachute Challenge					
S-1 A-2	Richard Hang	NASA Armstrong Flight Test Capabilities/Needs					
S-2 A-1	Tim McIntyre	DOE Oak Ridge National Lab PWST R&D					
S-2 A-2	Mustafa Salehi	Giatec Wireless Concrete Sensors					
S-2 A-3	Ali Abedi	University of Maine Wireless R&D					
S-3 A-2	Marco Aimi	GE Global Research Various Interests in PWS					
S-4 A-2	Ian Glenn	Ing Robotic PWS for UAV & Remotely Piloted Aircraft Systems					
S-4 A-3	Aaron Singer	Automodality Autonomous Robotic Systems					
S-4 A-4	Brian Banker	NASA/JSC Seeker Inspection Spacecraft					
S-5 A-4	Dave Redman	AVSI Director,Texas A&M WAIC Project Status					

One-on-One Session Sign-up Spreadsheet

Room B One-on-One Sign-up							
	Last	Organization/Topic	10:45	11:00	11:15	11:30	11:45
S1 B3, S5 A2	Eduardo Rojas	Embry Riddle University WAIC testing & PWS Sensor R&D					
S-2 B-2	Ami Yang	NASA/JSC Flexible Antenna for Next Gen EVA Suit					
S-2 B-3	Curtis Hill	NASA/MSFC In-Space Additive Manufacturing					
S-3 B-1	Chris Gerty	NASA/JSC/EV3 Lunar EVA Suit Sensing					
S-3 B-2	Michael Evans	NASA/JSC/XI Lunar Lighthouse for Surface Navigation + more					
S-4 B-3	Jackie Hines	Sensanna Corp PWS for Electrical Power Grid					
S-7 B-2	Chris Cook	ECM Space - Ottawa PWS Spaceflight Business Develepment					
S-6 A-1	Gary Hunter	NASA/GRC High Operating Temperature Tech(HOTT) & Venus Mission					
S-6 A-2	Doug Litteken	NASA/JSC/ES2 Inflatable Spacecraft					
S-6 A-3	Richard Evans	NASA/GRC - Plum Brook Spacecraft Test Facilities					
S-7 A-3	Zach Seibers	Georgia Tech - REVEALS Radiation Effects + Sensing					

Announcements

- ***Per IEEE policy, video or photos are not allowed***

- ***All PWST presentations will be publicly available*** (let co-chairs know if proprietary information needs to be removed)

- Make your voices heard for PWST 2020
- Talk to us at our One-on-One table
- Discussion opportunity: Friday Oct 18, 1:00p – 3:00pm (room A)

Passive Wireless Sensor Technology Workshop
The Basics
(George Studor)

- **Shuttle Wireless Lessons Learned => AFRL paper and**

  First "Fly-by-Wireless" Workshop October 1999 at JSC
  - **To Reduce Wires, Connectors and Penetrations**
  - **To Add sensing where it was impractical/impossible before**
- **FBW Workshop in 2007 Dallas => Outcomes**
  - **Protected Spectrum World-wide pursued by Commercial Aircraft OEMs to enable the business opportunity(AVSI-WAIC).**
  - **Passive Wireless Sensor Technology Workshops started to draw out developers and users – hosted by multiple orgs.**

<u>Today</u>:

- **1400 Workshop Contacts**
- **286 presentations since 2011 - available on-line.**
- **Types and Maturity of PWS Technologies is at least 4x.**
- **Users and Stakeholders in many categories.**

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

Relationship
- Synergy with WiSEE Conf.
- 1-on-1
- Panels
- Tours

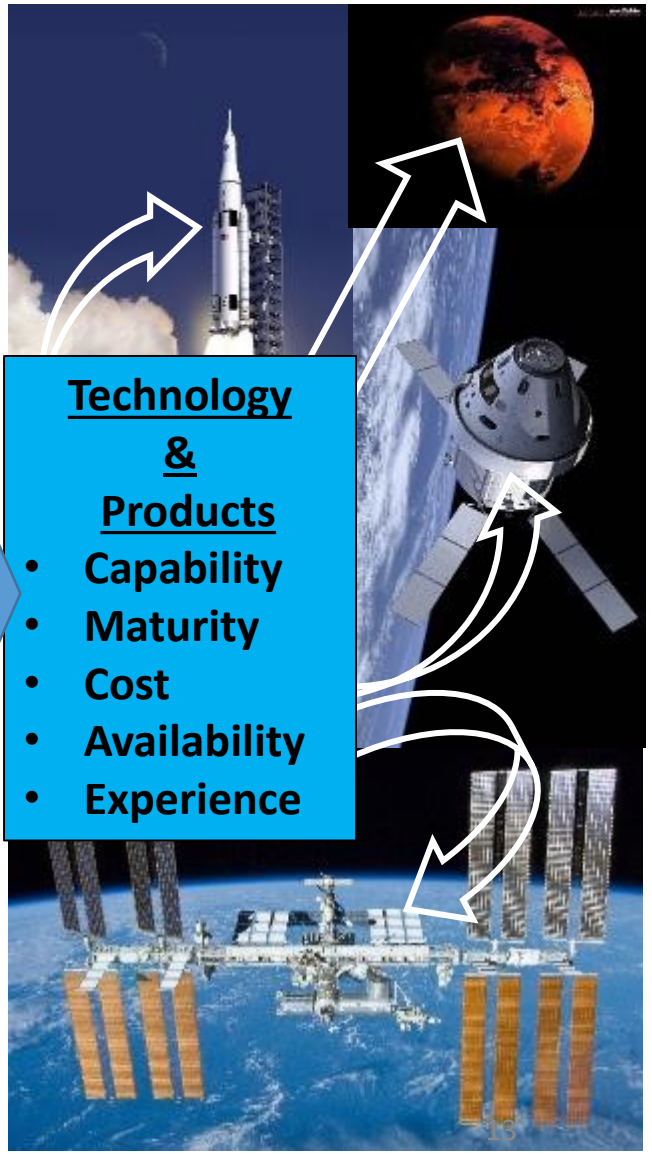
What we produce from a series of PWST Workshops

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

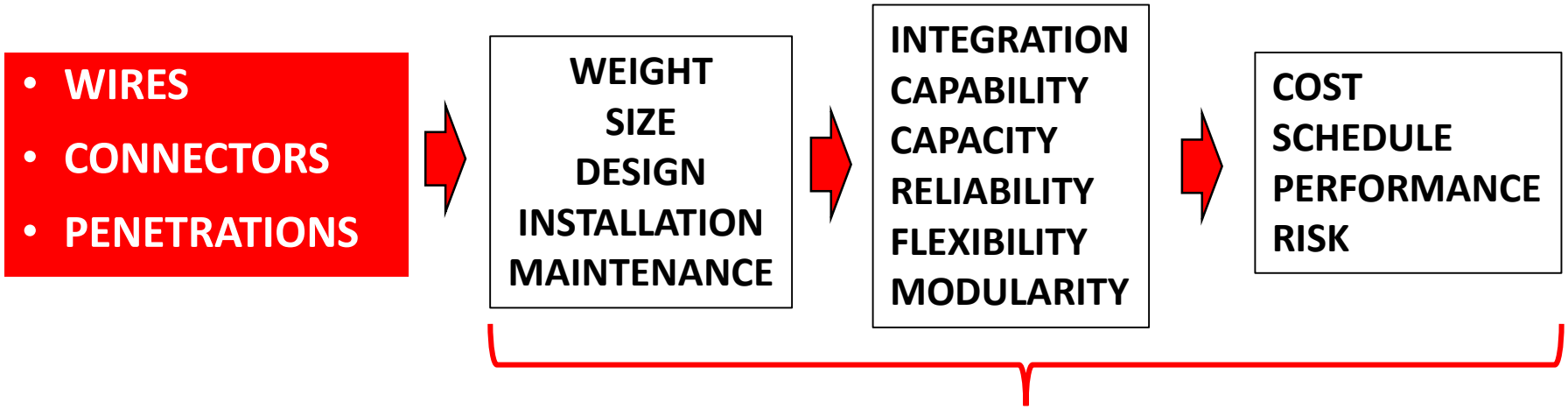
+

In-Person
- Contacts
- Ideas
- Trust
- Pursuits

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



What's the Problem?
"Wired" Connectivity

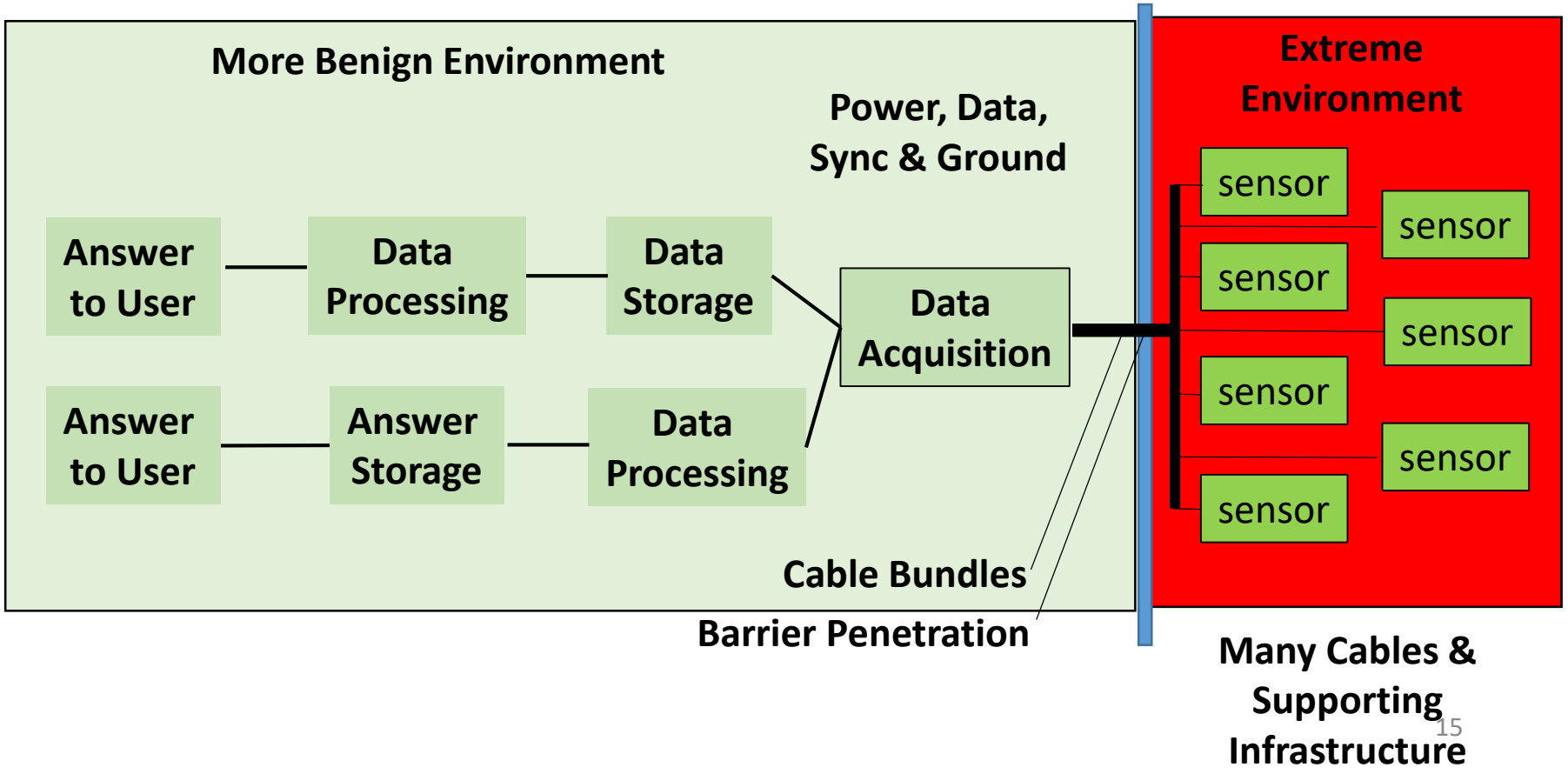


1. Mission Cost/Performance
   - Increasing each year
   - Increasing with missions beyond LEO
2. Contractors LOVE Change Traffic
   - Not incentivized to accommodate change
   - All past programs exhibit this problem

What's the Problem?
"Wired" Connectivity

- Wires – most are to the sensors
- Connectors – most everywhere
- Penetrations – very costly/adds risk

Barriers and Extreme Environments just make the problems WORSE:
Enter
Passive Wireless Sensor Technology



"Fly-by-Wireless" Progress - 20 years!!

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
WiSEE2016 and Passive Wireless Sensor Workshop; also SAW-Symposium Oct 2016
WiSEE2017 and Passive Wireless Sensor Workshop Oct 2017
WiSEE2018 and Passive Wireless Sensor Technology Workshop Dec 2018
WiSEE2019 and Passive Wireless Sensor Technology Workshop Oct 2019

Passive Wireless SAW Sensors Reindle, Hartman, Malocha + others

PW SAW Sensor NASA "false start"

PW SAW Sensor NASA -> Sandia Demo

1st PWST Workshop

PWST Sensors for WAIC band?

9th PWST Workshop

WAIC Systems Approval Regulations System Development

Passive Wireless Sensors

Generally:

- **No battery/power source at sensor**
- **No wired connection between sensor and data acquisition unit**
- **Minimum electronics – can be good for 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/measurement point(including install)**

Benefits:

- **Low Size, Weight and Integration**
- **Low Production cost – especially in volume**
- **Low Operations cost – no battery**
- **Low Safety concerns – little or no stored or transmit power**
- **High Modularity – few interfaces**
- **Extreme Environments – Temperatures, Accel/Shock, Pressure, Radiation**
- **3D Printable, flexible options**
- **Imbeddable in various materials**
- **Wide Applications in industry, government and IOT**

Some Passive Wireless Sensor Technologies

- **SAW-based: Surface Acoustic Wave reflection(s) + Antenna**
- **RFID-based: Including Tuned and remotely "powered"**
- **NFC-based: Near Field Communications – Cell Phone Apps**
- **EM-coupling: RLC, Magnetic Field/Ultrasonic**
- **BAW-based: Bulk Acoustic Wave**
- **Antenna Impedance-based**
- **Dielectric Resonators**
- **Backscatter RF**
- **Radar Response Tags – Long Range, Very Long Range**
- **Optical: Active & Passive(Spatial Phase Imaging - no illumination required)**
- **Software Defined Radios and COTS devices (eg Cell phones)**
- **Broadcast Power-assisted: Meets many of the objectives of PWST**
- **"Thru-wall" Power/Comm In+Across Metal: Mag Field, Acoustic, Ultrasonic, mmwave**

What's Next?

- **Flexible PWS Antennas and Sensors –> liquid metal in fabric PWS**
- **3D Print/Additive Manufacturing adding tailoring and imbedded PWS**
- **Hybrid – Active Wireless Nodes with Passive Wireless Interrogators**
- **X-Ray: Solid State "Thru Wall" Xray Comm -> Backscatter X-ray PWS?**
- **Visual Light Communications(VLC): Li-Fi -> LiFD (Light-based RFID)?**
- **EFI: Electric Field Imaging – materials and sensors**
- **60GHz: V-Band metal dipoles in spray-on patches, coatings, embedded composites**

What Wireless?

- Active
- Passive
- Hybrid
- Thru Wall

Fewer Connectors

Passive Wireless Sensor Systems:

- 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

Hybrid Sensor Systems

Active Wireless Sensor Systems.

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

Fewer Penetrations

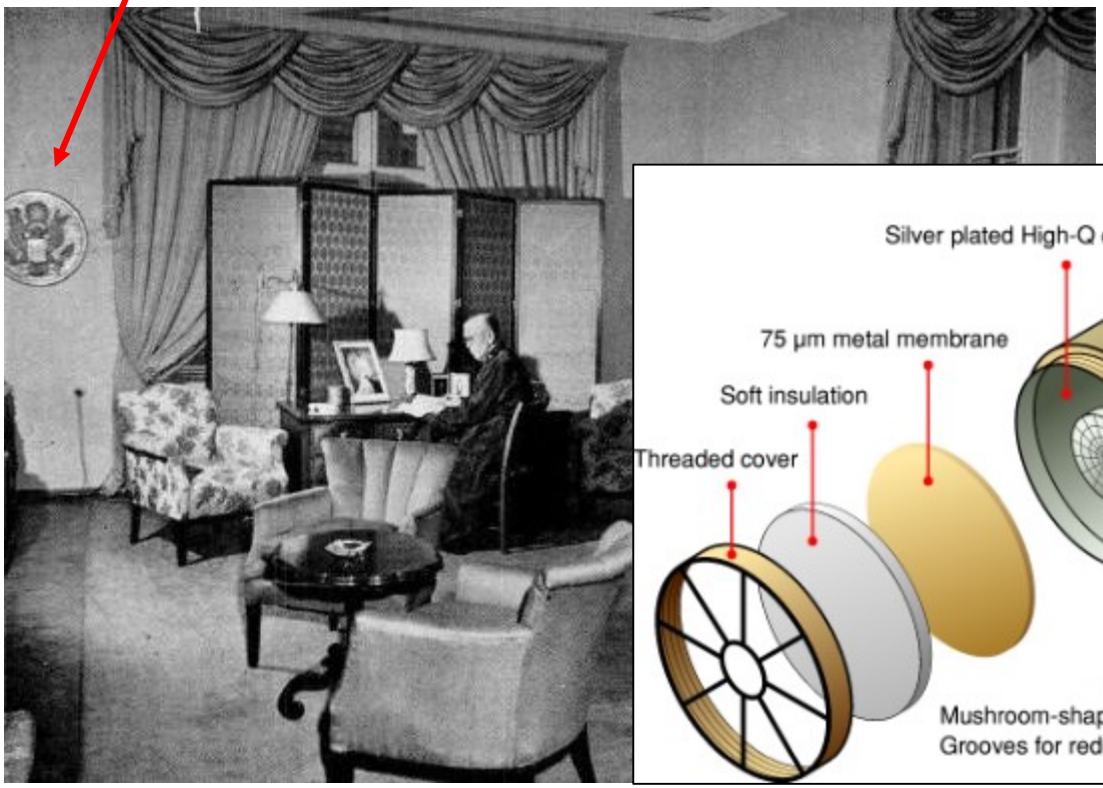
- Thru-Wall Comm/Power
- Remote power sources

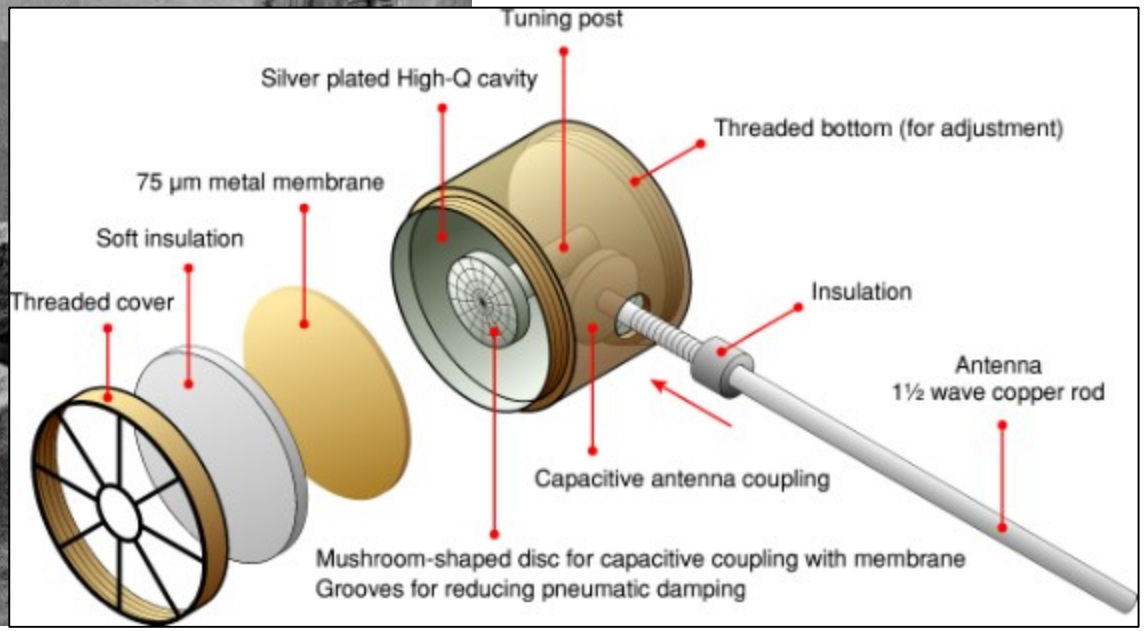
Some Passive Wireless Sensor Technology Actual Applications

Passive Wireless Sensor Technologies
Let's Explain a Couple Examples
(Dr. Don Malocha)

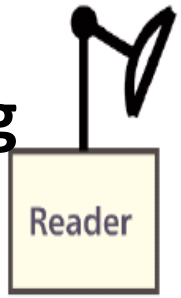
A Passive Wireless Sensor?

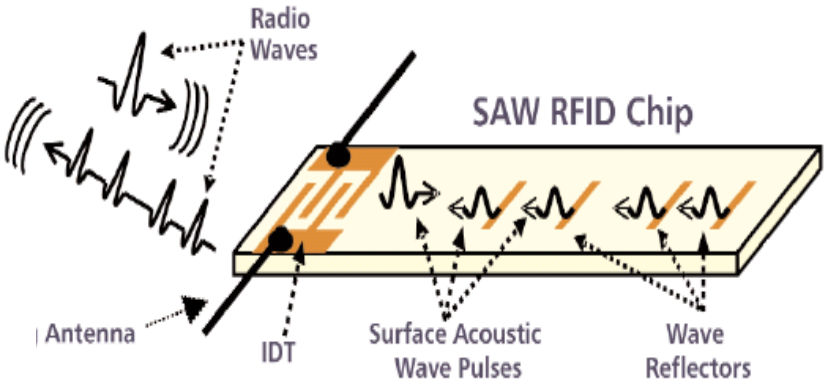
- **Ever heard of "The Thing" installed in the US Embassy in Moscow?**
- **The passive wireless (resonant cavity) microphone hidden in the Great Seal (http://www.cryptomuseum.com/covert/bugs/thing/index.htm)**





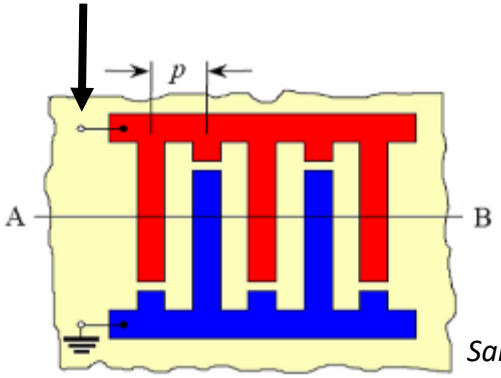
Surface Acoustic Wave Passive Temperature Sensing



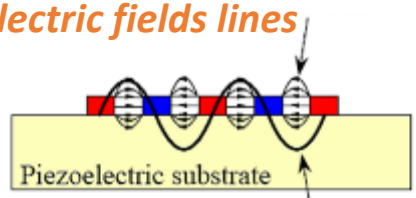


Gnadinger – Albido Corp

Electrical power

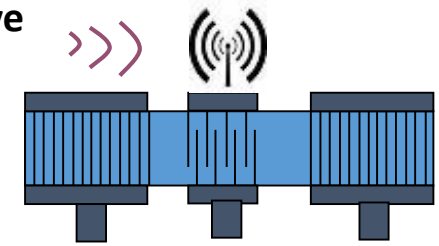


Electric fields lines



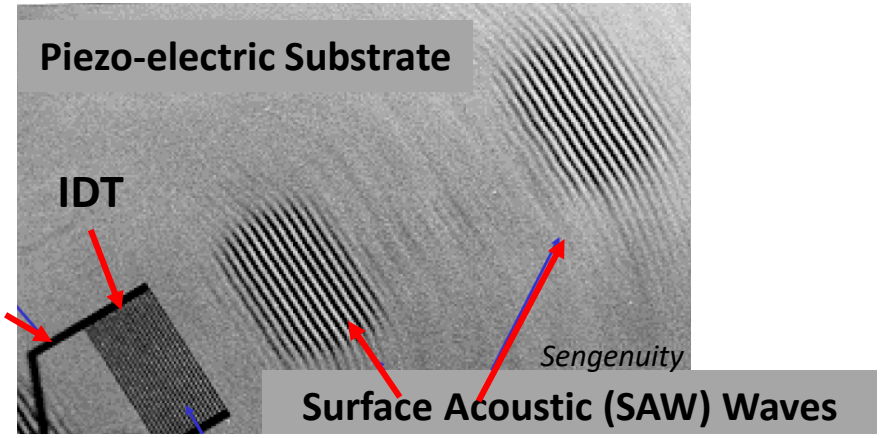
Sabah - Sengenuity Corp

EM –Wave (power)

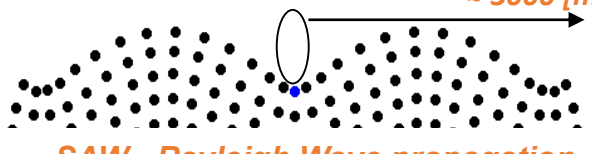


SAW Resonator on piezoelectric substrate

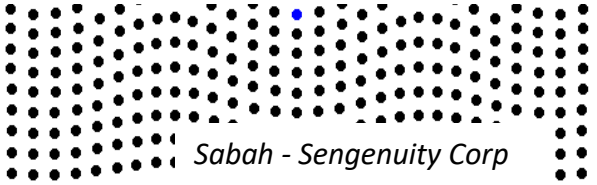
Sabah - Sengenuity Corp



≈ 3000 [m/s]



SAW - Rayleigh Wave propagation



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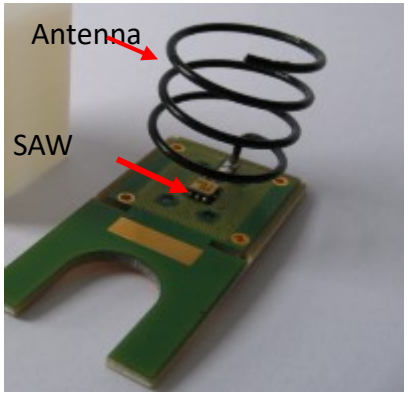
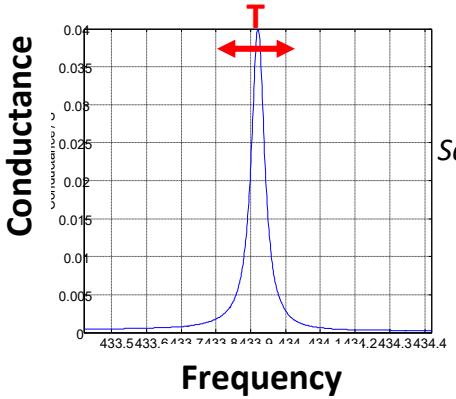
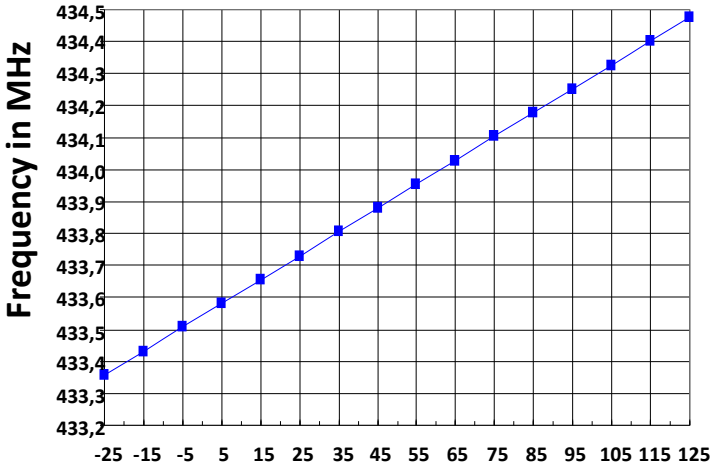
- **Surface Acoustic Wave velocities are dependent on:**
  - **Temperature**
  - **Material type and orientation**
- **Energy Harvesting (EM-Wave)**
  - **can be very low power to excite the acoustic wave**
  - **Much faster than SAW waves (300,000,000 m/s vs 3,000 m/s)**

Single SAW Resonator: Absolute measurement







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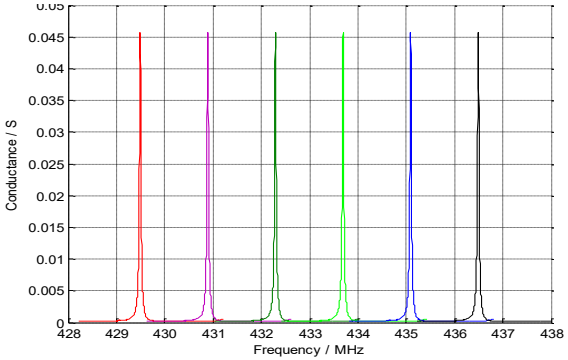
6 sensors at separate frequencies (frequency diversity)



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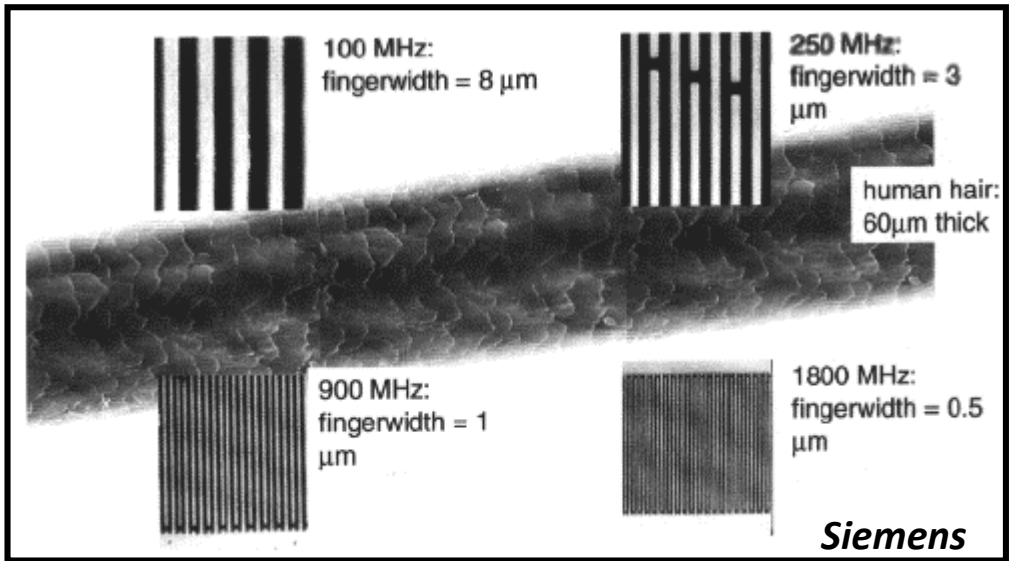
Fabrication Challenge with Higher Frequencies:

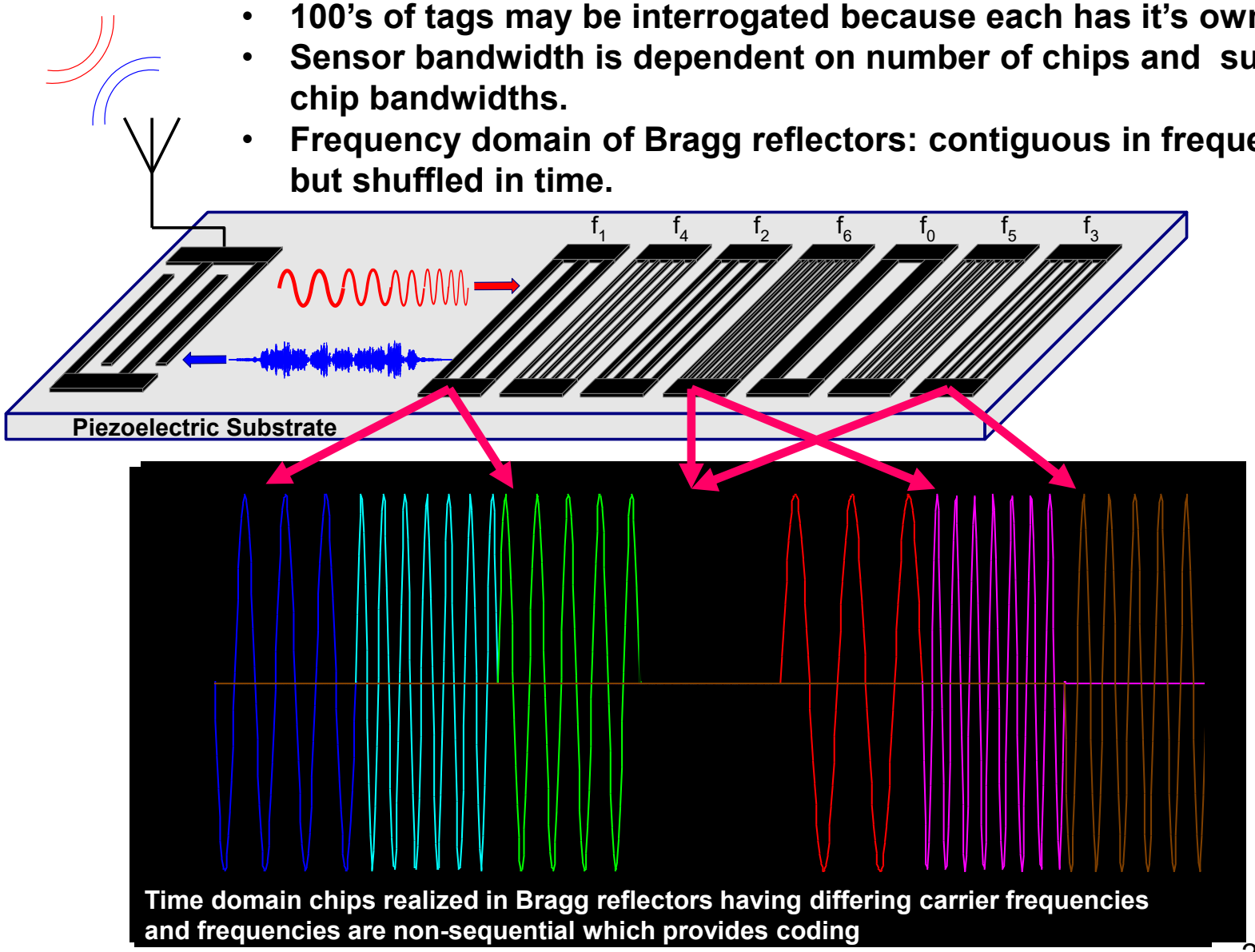
EM Frequency	Fingerwidth
100 MHz	8 um
250 MHz	3 um
900 MHz	1 um
1.8 GHz	0.5 um



Schematic of OFC SAW ID Tag – UCF

(OFC = Othogonal Frequency Coded)

- 100's of tags may be interrogated because each has it's own ID.
- Sensor bandwidth is dependent on number of chips and sum of chip bandwidths.
- Frequency domain of Bragg reflectors: contiguous in frequency but shuffled in time.



2020 PWST Workshop

- **2020 PWST Workshop: Vincenza, Italy – Oct 12-14, 2020**
  - **Make Your Plans to Join Us Now!**
- **Co-Chairs:**
  - **Don Malocha + NASA/Richard Evans + Ariane Group/Johannes Sebald**
- **Need Your Input:**
  - **Our One-on-One Table: 10:45 – 12:00pm (or before)**
  - **Discussion Opportunity: Friday Oct 18 – 1pm – 3pm – PWST Room A**
- **Candidate List: Your Input?**

Technologies	Applications
• SAW & BAW	Smart City and Smart Agriculture
• WAIC Systems(4.2-4.4GHz)	Commercial Aircraft
• Long Range PWS	Lunar Surface
• Standards & International	Cell-phone based
• Optical & Imaging	Spacecraft and Cubesats
• 3D Printed	Drone augmentation
• Through-wall	Launch Vehicles
• Remote/scavenge Power	Helping 3rd World Countries
• "Off-the-Wall" PWS	High Temperature
• "Off-the-Shelf" PWS	Local Italian Interests and Research