Practical Considerations for SAW Sensor and Tag Deployment

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Outline

- Company – status & recent changes
- Brief overview of prior work
- General considerations for deployment
  - Application engineering considerations
  - Customer priorities
  - Adoption rate
- Complex media operation study – oil & gas
- Manufacturing
- Power line monitoring
- Conclusion

Company – status & recent changes

As of Nov. 15, 2014:

ASR&D CORPORATION

SenSanna

Sensanna:

- Is a passive wireless sensor application engineering firm that designs, manufactures, and sells passive wireless sensor systems
- Provides custom RFID/sensor-tag system development
- Actively partners with system integrators and end-use customers to develop solutions for challenging measurement problems

Company – status & recent changes

New facility near BWI

- Assembly manufacturing
- System test

Increased technical & management staff

Currently seeking seed capital of up to ~ $2 million for product development and 2019 launch of SenSanna's

PowerFree™ LineSense™

Wireless Power Line Monitoring System

Overview of prior work*

Developed laboratory prototype:

- Coded sensor-tag wireless interface devices
  - Read SAW code & sensor reading
  - Impedance varying & voltage producing sensors
    - Temperature sensors
    - Strain gauges, AE sensors
    - Switch positions, bus voltages
- SAW sensors for:
  - Temperature
  - Hydrogen, methane, hypergolic fuels (MMH, DMH)
  - Humidity
  - Volatile (cryogenic) liquid (level)
  - Strain
  - Concrete maturity/curing
  - Chlamydia elementary bodies (in urine samples)

* Supported by multiple NASA SBIR/STTR projects & other grants

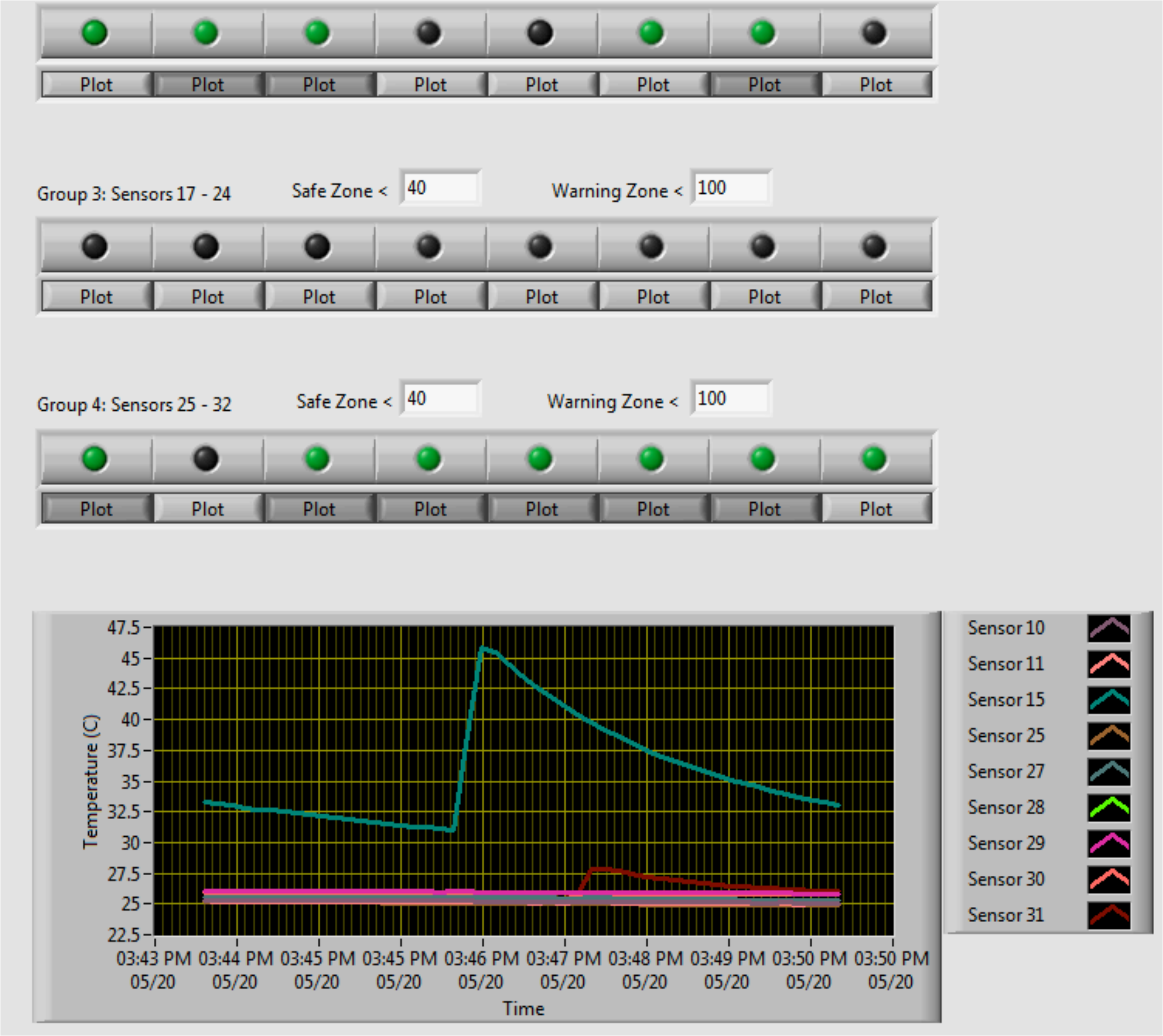
Key issue: Extracting calibrated responses

- Demonstrated 16-device humidity sensor system
  - Mixed signal wireless transceiver system, manual sensor selection
  - Quantitative (not calibrated) responses dependent on sensors used
- Observations led to an emphasis on developing ability to:
  - Identify each sensor
  - Calibrate sensor responses
  - Maintain accuracy with sensors operating simultaneously
- Code anti-collision work: 32 unique temperature sensors
- Developed software defined radio transceiver
  - Identifies and reads all sensors simultaneously in the field of view
  - Output data rate of up to 1.2 kHz – application dependent
  - Measurements out to 55 feet (thus far) – application dependent
  - Performance comparable to reference sensors observed

Demonstrated multisensor calibrated output capabilities

Overview of prior work (continued)

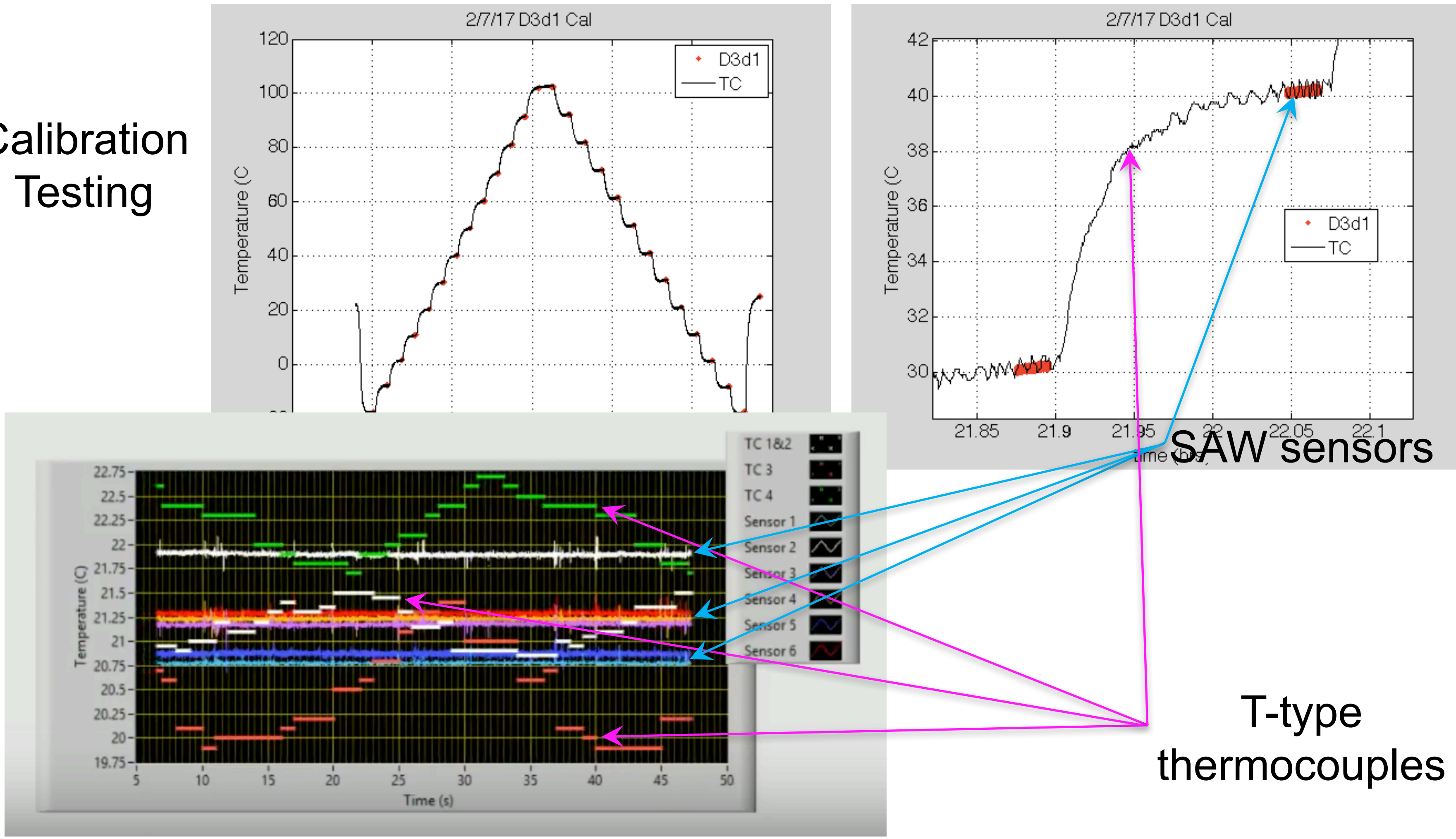
Multi-sensor heating test – 32 sensor set (12 shown)



Overview of prior work (continued)

Temperature measurement using SAW temperature sensors compared to a reference T-type thermocouple

Calibration Testing



General considerations for deployment

Having solved the code-collision problem – SenSanna now focuses on application engineering for customers

- Application engineering considerations
  - Most of the rest of this presentation will discuss this…
- Customer priorities
  - Asset health monitoring – diagnostic & prognostic monitoring
  - Condition based maintenance, prediction of incipient failures
  - Operational efficiency/optimization
  - Safety (personnel & asset)
  - Liability avoidance
  - Cost savings
  - What is the return on investment (ROI) for use of such systems?

Business case: understand the value drivers for your customer

General considerations for deployment, contd.

Adoption rate issues:

- Adoption rate strongly industry dependent
  - Oil & gas – 7-10 years after demonstration (minimum)
  - Electric power generation & distribution – 3-5 years typical
  - Manufacturing
- A successful technology demonstration does not mean your system will be adopted for use in the field
- Almost all applications involve integration with large enterprise systems
  - What do we do with all this data?
  - Application specific models feed into complex control systems
  - Partnering with system integrators is necessary in general

Data is not enough..... Actionable intelligence is needed for adoption!

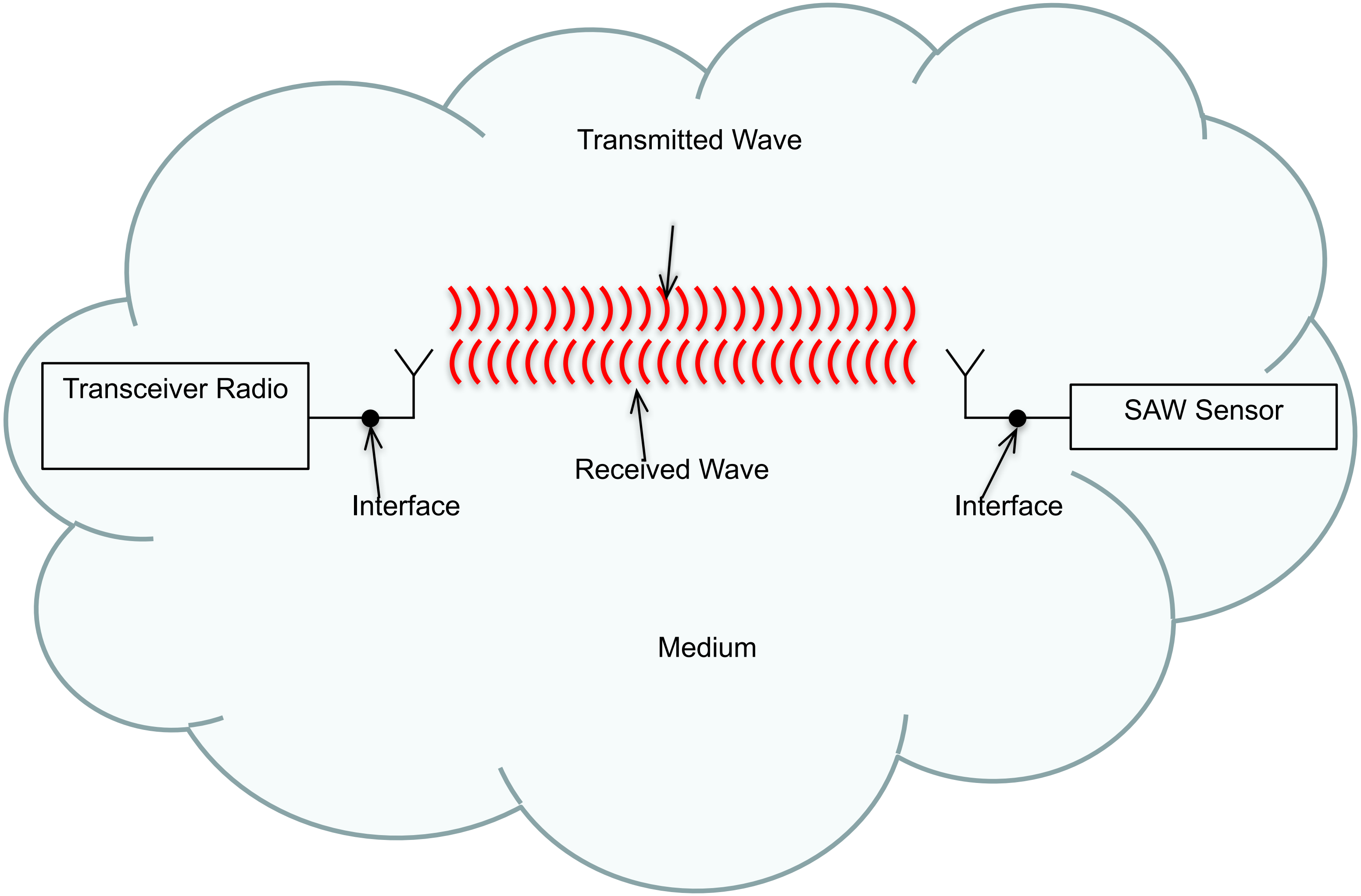
Application engineering considerations

Industrial applications involve specific requirements

- Physical: dimensions, temperature, packaging, mounting, lifetime
- Operational: accuracy/precision, data rate, protocols, integration
- Complex, time-varying RF environments and various media
  - Highly metallic environments
  - High voltage environments
- Relevant media for the industries we address include:
  - Air (with or w/o conductive sprays or chips)
  - Pure and salt water
  - Oil-like fluids
  - Wet cement
  - Cured cement
- Sensor performance is dependent on RF propagation and antenna performance, which are impacted by the media

Operating considerations in complex media

RF Communications channel



Operating considerations in complex media

- Media properties influencing RF propagation
  - Magnetic permeability (μ) $\mu \approx \mu_0 = 1$
  - Dielectric permittivity (ε) $\varepsilon(f) = \varepsilon_r(f)\,\varepsilon_0$
    - Speed of light in a vacuum: $c = 1/sqrt(\varepsilon_0\mu_0)$
    - Speed of light in a medium: $c_m = 1/sqrt(\varepsilon\mu) = c/sqrt(\varepsilon_r)$
  - Conductivity (σ) – contributes to $\mathrm{Im}(\varepsilon_r(f))$
- Impact on RF propagation
  - High conductivity increases attenuation significantly
  - Attenuation is frequency dependent (increases at high f)

Operating considerations in media, cont'd.

- Impact on antenna performance
  - Antenna designs are generally based on wavelength, for operation in air
  - The free space wavelength defined by $\lambda = c/f_0$

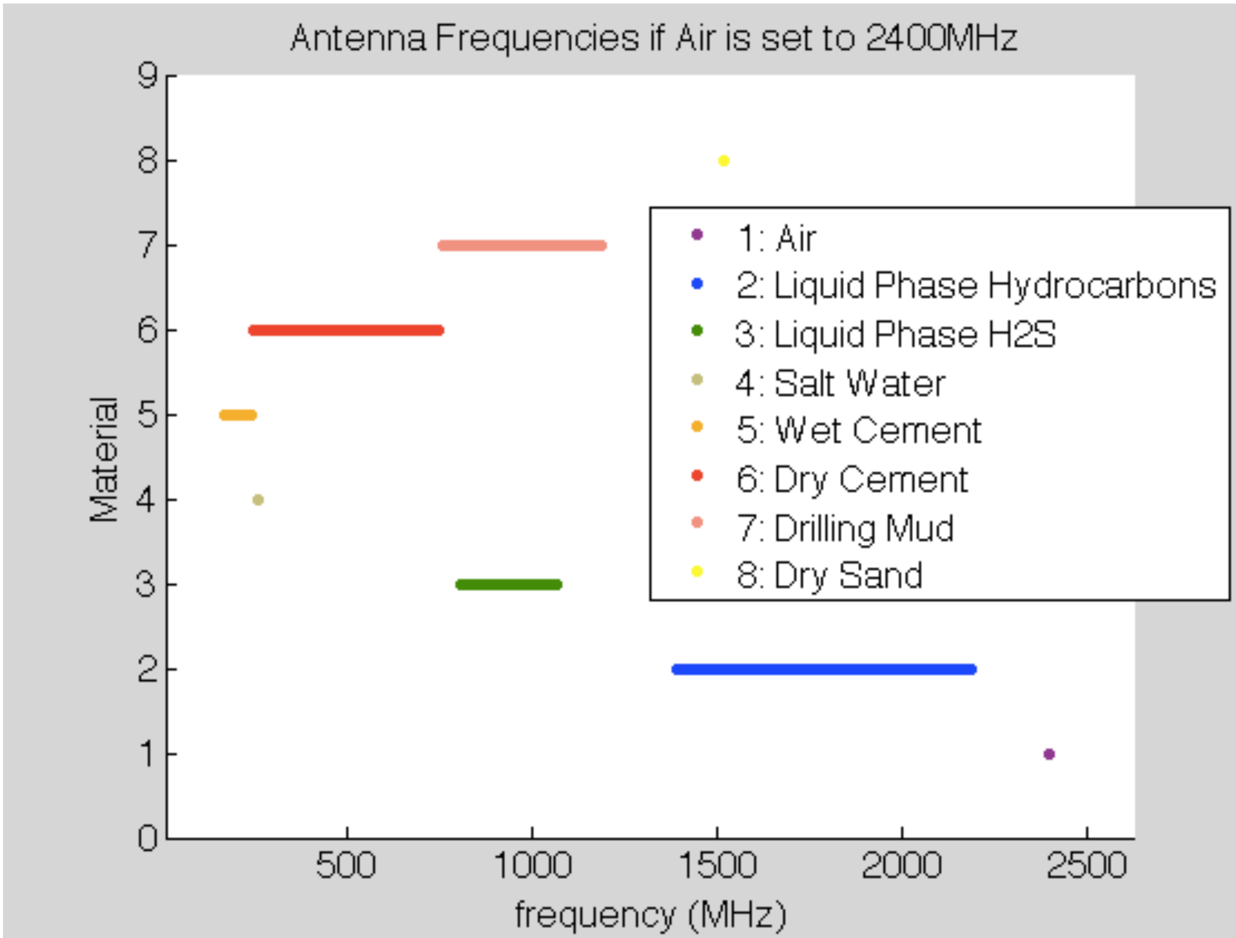
    where f_0 = antenna passband center frequency
  - In media other than air, c is replaced by c_m
  - An antenna designed to operate in air at one frequency has a different effective electrical size (in λ) in other media

    ➡ causes a frequency shift of the antenna passband
  - If the designed passband center frequency of the antenna in air is f_0 then the center frequency in a medium is

$$f_m = f_0/\mathrm{sqrt}(\varepsilon_r)$$

Operating considerations in media, cont'd.

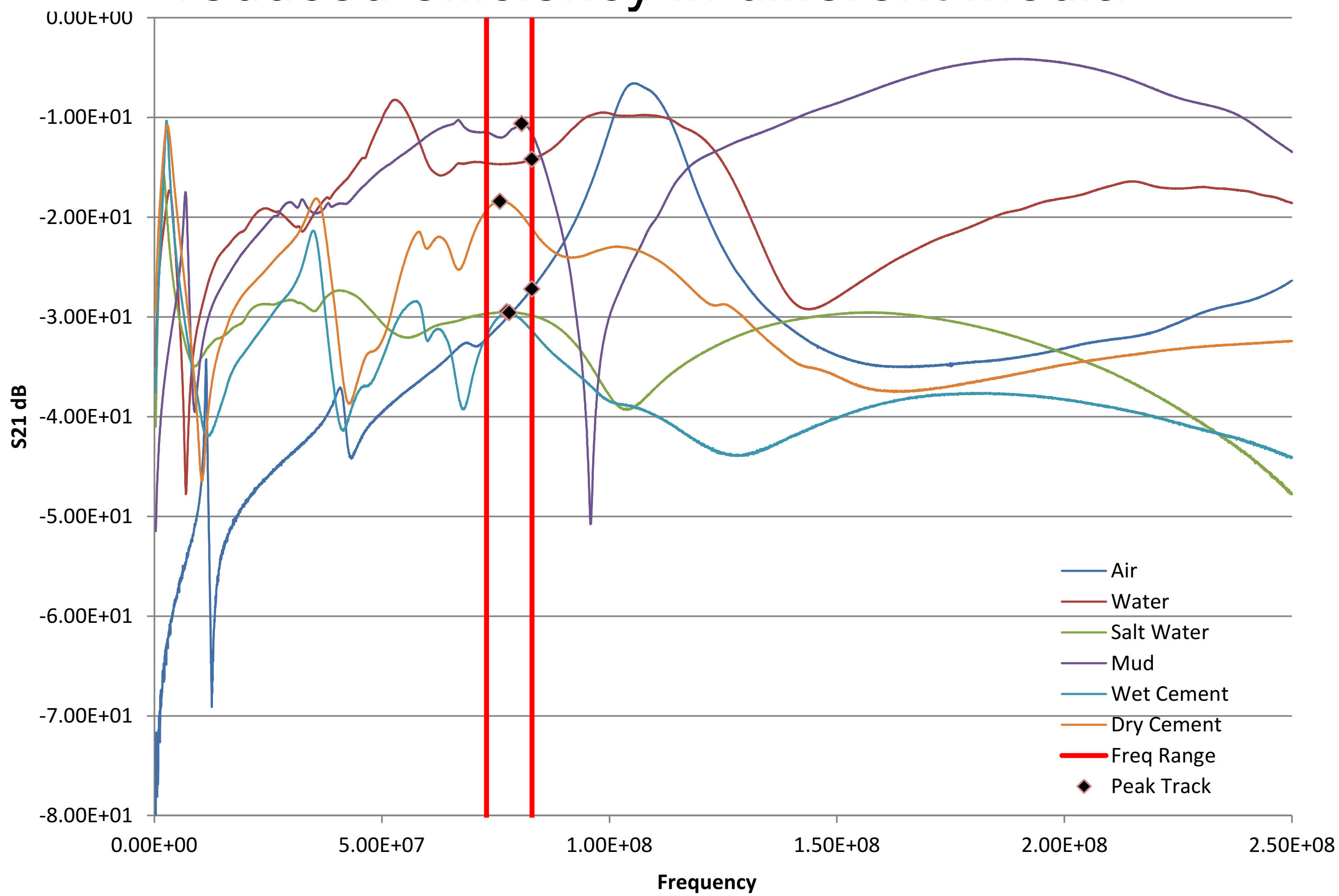
Example: Designed 2.4 GHz antenna (in air)



But - Sensors are designed at one frequency, not media dependent

Operating considerations in media, cont'd.

Antennas can operate outside their passbands at reduced efficiency in different media



Operating considerations in media, cont'd.

- Design of antennas for operation in one medium is simpler than the case where media can change
- If media change over time, antenna can be selected to function with acceptable efficiency in the media of interest in a specific application
- Metal environments impact antenna design
- Many applications place antennas in the near field

Conclusion ➡ All these factors must be taken into account - custom antenna development for each application may be necessary – and it can be done!

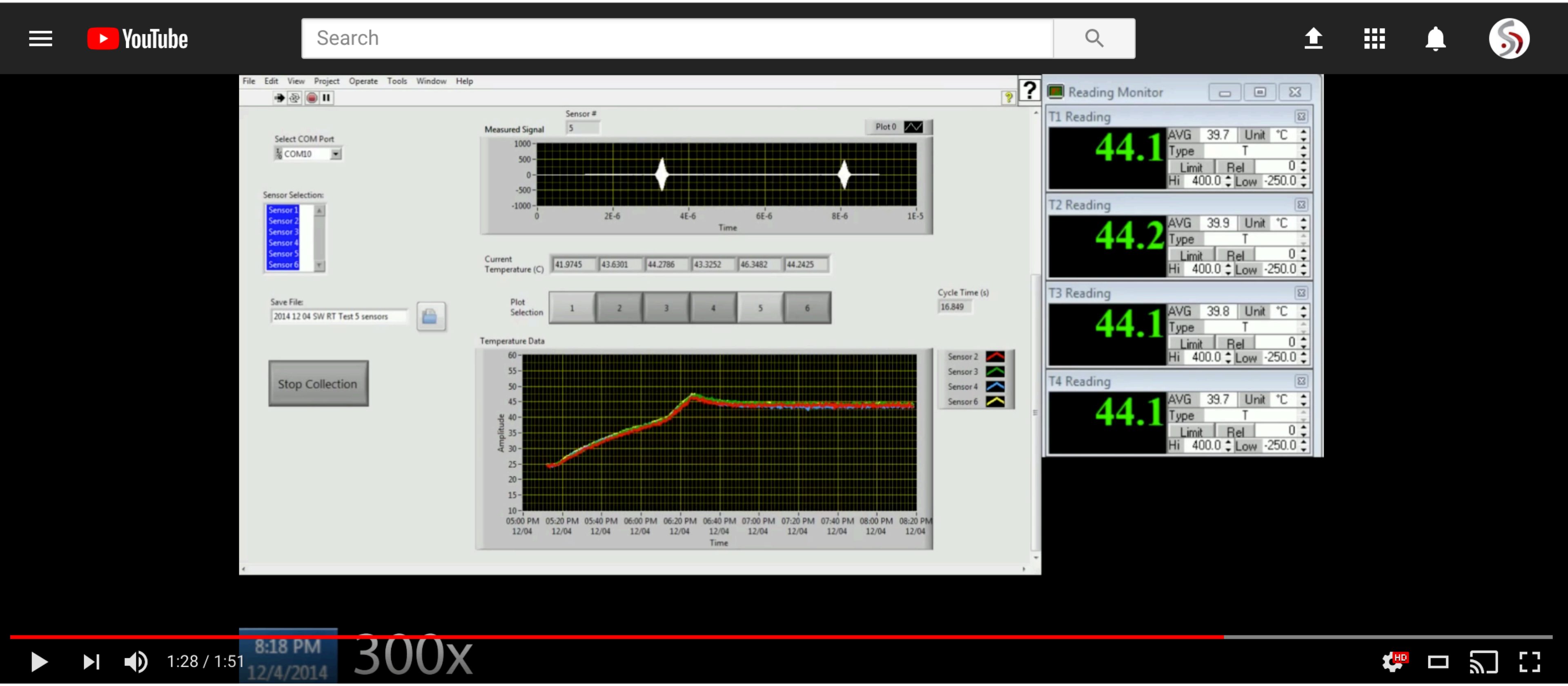
Operation of Passive SAW Sensors in Complex Media

A study conducted for BP North America

2014-2015

Video of SAW sensor operation

Available online at: http://youtu.be/FnNSo26bTsA



Operation of Passive SAW Sensors in Manufacturing

Customers prefer to remain anonymous

2015-present

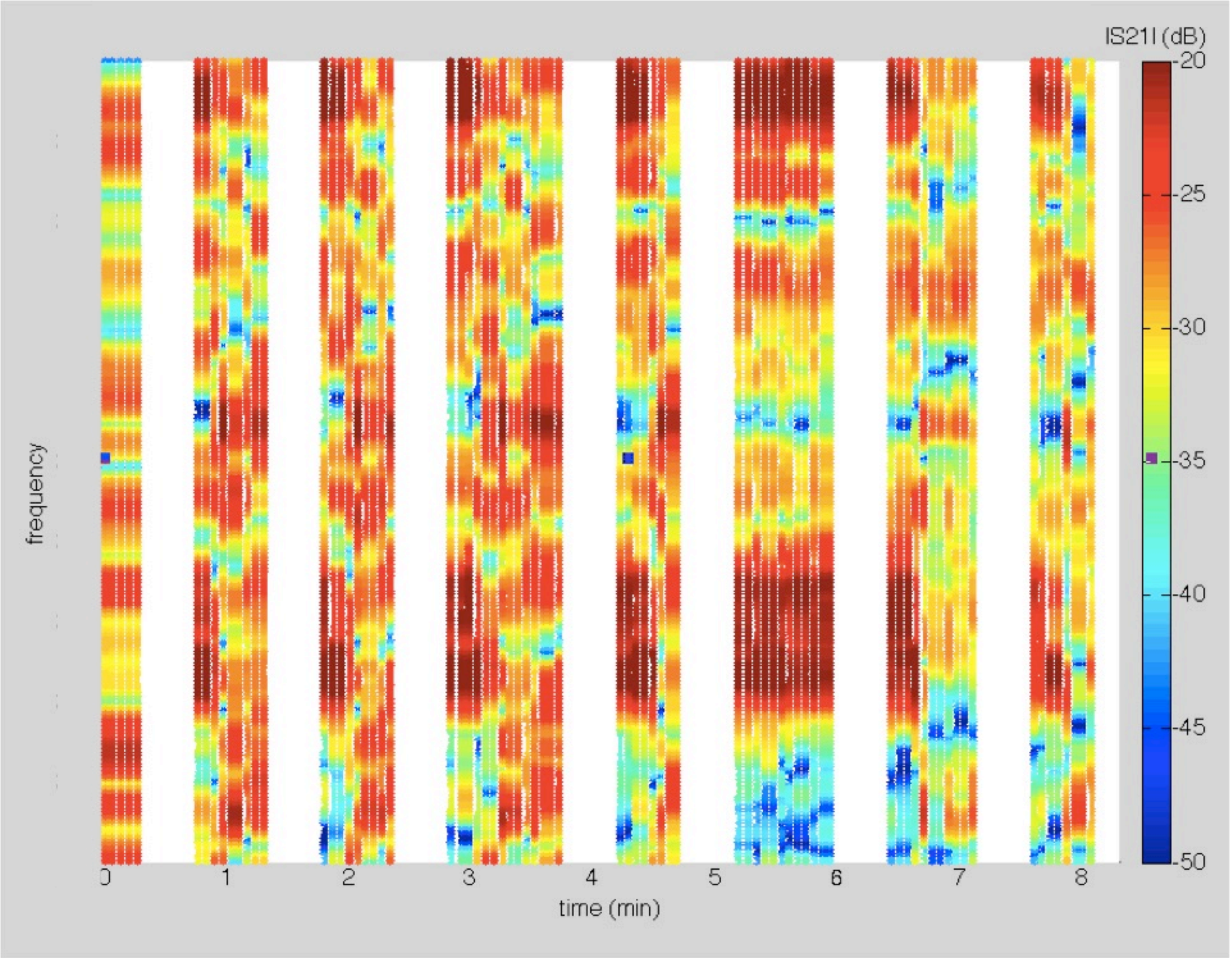
Manufacturing

- Rotating & translating machinery
- Complex RF environment – time dependent RF link

Observe better RF propagation in certain frequency bands

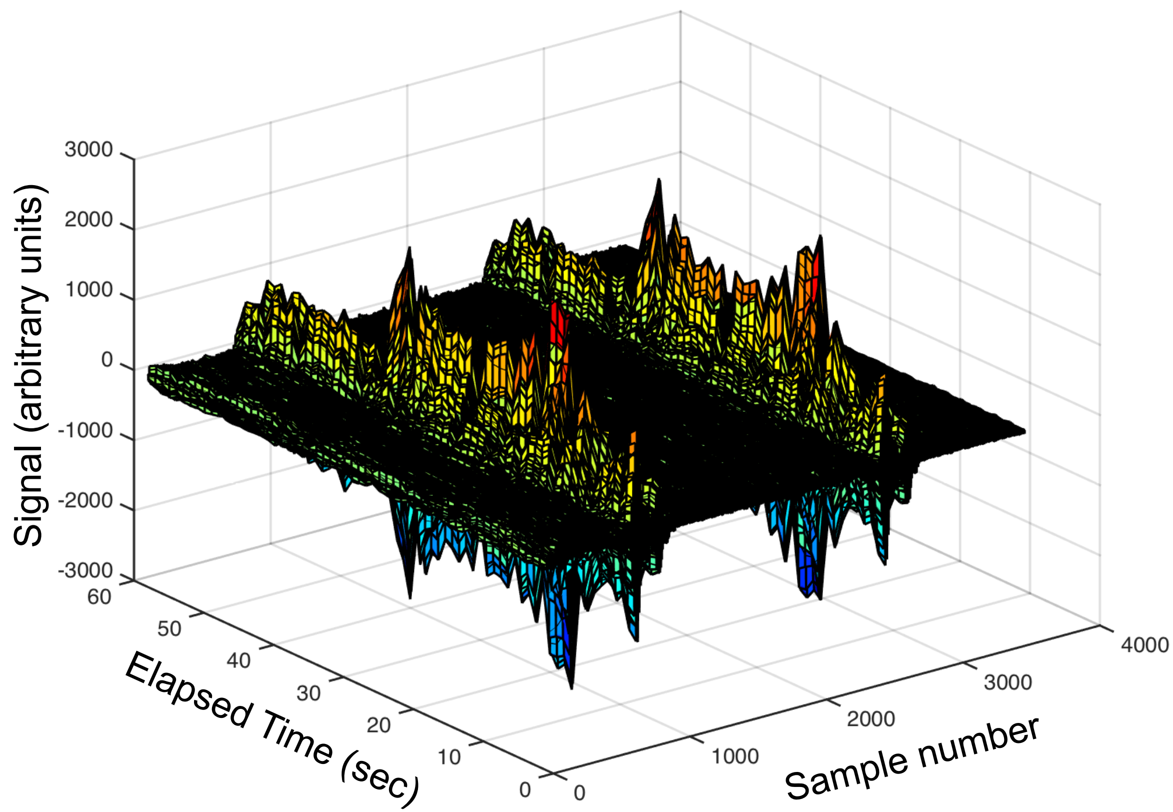
Movement of metal and fluids causes randomized RF link strength that varies with time

SAW sensor design can compensate by including adequate bandwidth for link



Manufacturing

- SAW sensor response strength varies with time



Powered by SunShot
U.S. Department of Energy

Operation of Passive SAW Sensors on Power Distribution Lines

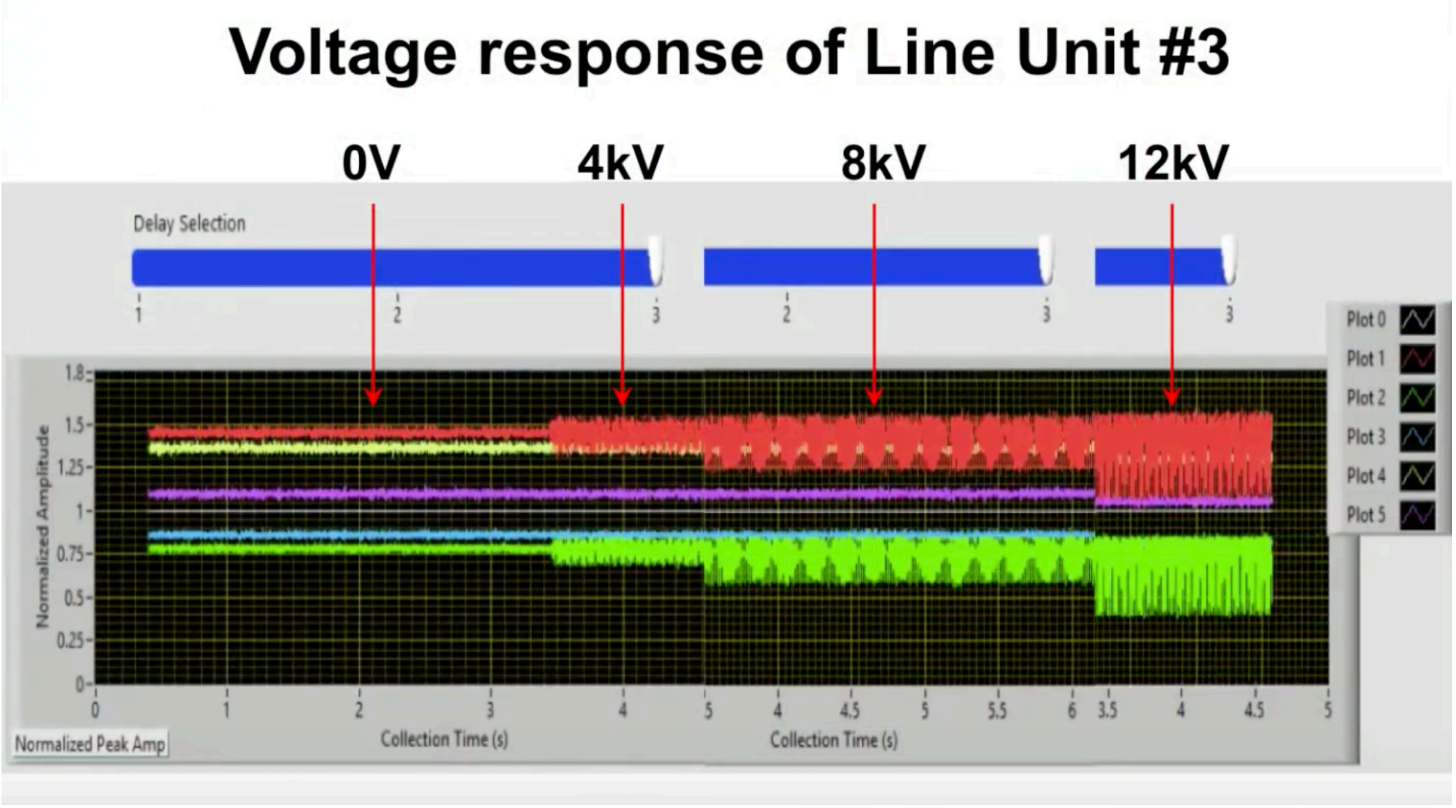
Supported by the

U. S. Department of Energy SunShot Initiative

2015-2019

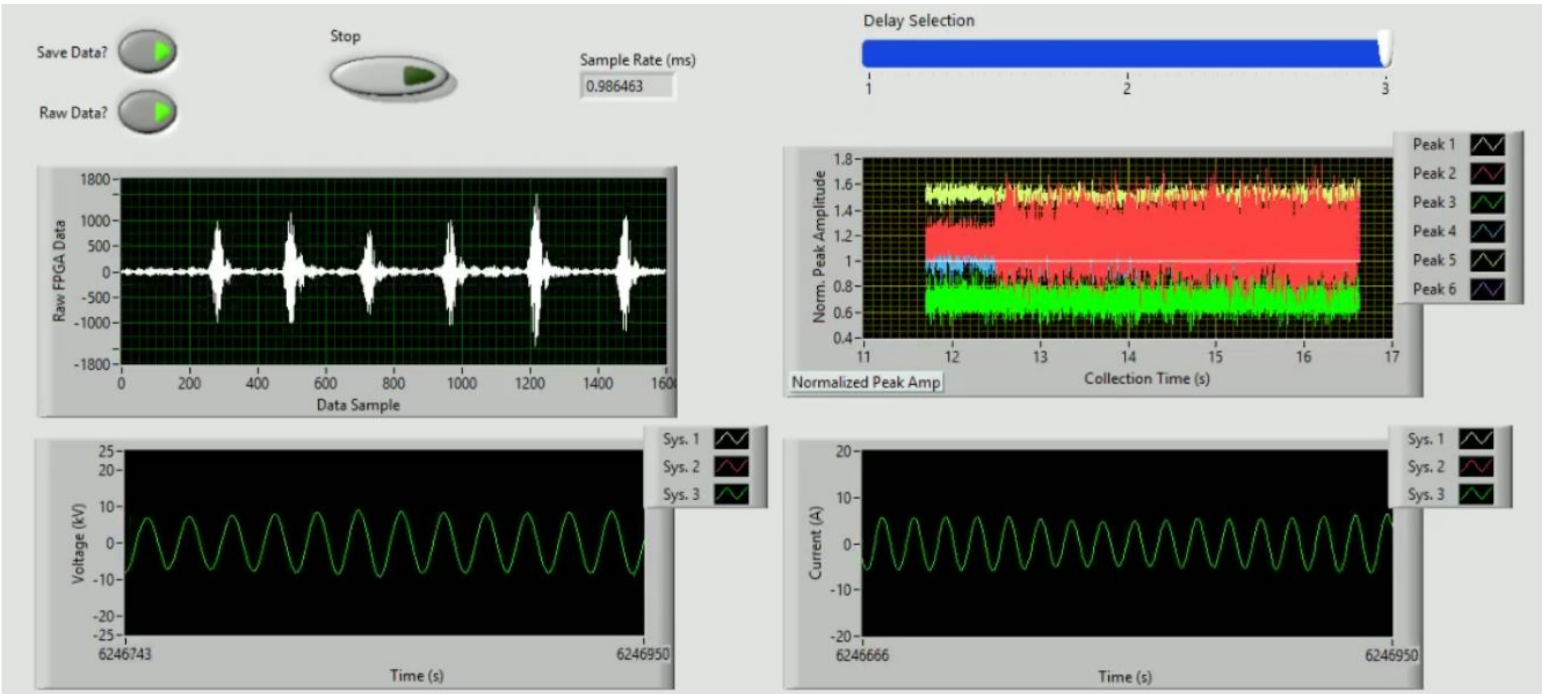
Power line monitoring

Current and voltage ramping at: https://youtu.be/TKSXdqz8ntQ



NREL MV Power line testing:

Current & voltage waveforms, phase lead/lag, and temperature



LabView user interface showing:

- Raw sensor data (top left plot)
- Measured voltage waveform (lower left)
- Voltage and current responses (top right)
- Measured current (lower right)

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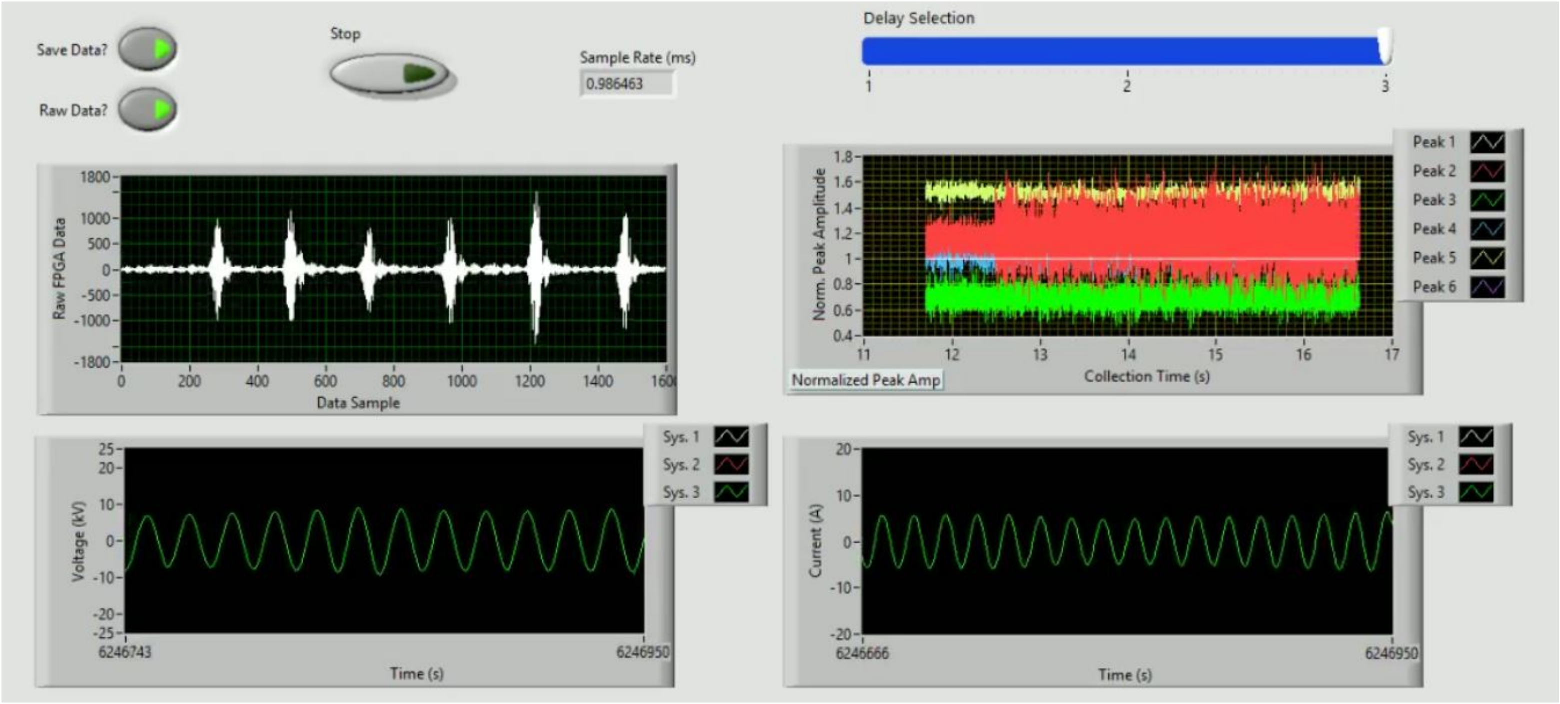

LabView user interface showing:

- Raw sensor data (top left plot)
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Advantageous LineSenS™ Features

- Simple & rugged – no radio in the line mounted unit
  - Pole mounted radio can read multiple local line units
- Operates even at zero line current and zero voltage
  - Enhances line worker safety – detects stray voltage/current on nominally isolated lines
- Synchronous data accumulation
  - Potential for a low-cost synchrophasor–like system
  - GPS module can be incorporated into radio
- Low cost - $1,500 - $2,500 per point monitored
  - Cost effective enough for widespread distribution grid monitoring
  - Widespread adoption could drive prices lower

Conclusion

Calibrated wireless operation of multiple sensors and sensor-tags operating in complex environments is achievable

- Careful design of sensors and antennas is required to provide operation in multiple, complex, or time varying media
- Metallic environment also impacts antenna design
- Near-field antenna interactions may dominate response

Industrial deployment of sensors requires:

- Application engineering to meet operational requirements - each application is unique
- Understanding & addressing customer priorities
- Collaboration with system integrators & end users
- Patience – commercial adoption may take years

Customized application engineering is key to commercial success

Acknowlegements:

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Powered by SunShot U.S. Department of Energy

+ other industrial customers who prefer to remain anonymous

Questions, comments, collaboration, business development, or investment interest?

Please contact me:

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Thank you

