DISTRIBUTED ANTENNA SYSTEM FOR WIRELESS DATA COMMUNICATION IN NUCLEAR POWER PLANTS

Presented By:

Chad Kiger, Ph.D, PE

Principal Investigator, AMS Corporation

10/23/2019

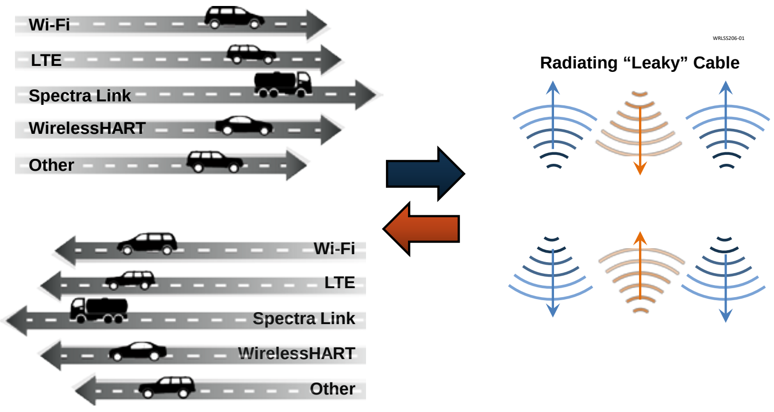
U.S. DEPARTMENT OF ENERGY | Office of NUCLEAR ENERGY

Distributed Antenna System for Wireless Data Communication in Nuclear Power Plants

SBIR Phase I/II

Technology Summary

The goal of the Phase II project is to identify the optimal system components and installation practices that should be used when implementing a distributed antenna system in a nuclear power plant with the goal of maximizing coverage and performance, minimizing electromagnetic and radio frequency interference, and addressing wireless coexistence and other installation considerations. The research will also develop wireless sensor technologies that meet the needs of the nuclear industry for equipment condition monitoring using commercial wireless transmitters.



High Speed Data Highway Capabilities of a DAS

Key Personnel

Chad Kiger, David Jackson, Gary Harmon, Ryan Kettle, Phil Zarb, Tyler Gavin, Morgan Berg, Nathan Dungan, Jonathan Caughron, Mehrad Hashemian, Ryan O’Hagan

Program Summary

Period of Performance:

Start Date: 6/12/2017 End Date: 8/26/2020

Key Milestones & Deliverables	
Year 1 Phase I	• Characterize the RF properties of DAS cables • Evaluate aging characteristics of DAS cables • Determine obstacles to DAS implementation
Year 2 Phase II	• Resolve obstacles for DAS implementation • Determine EMI/RFI and Coexistence Risks
Years 3 Phase II	• Develop DAS compatible wireless sensors • Demonstrate wireless sensors in an NPP

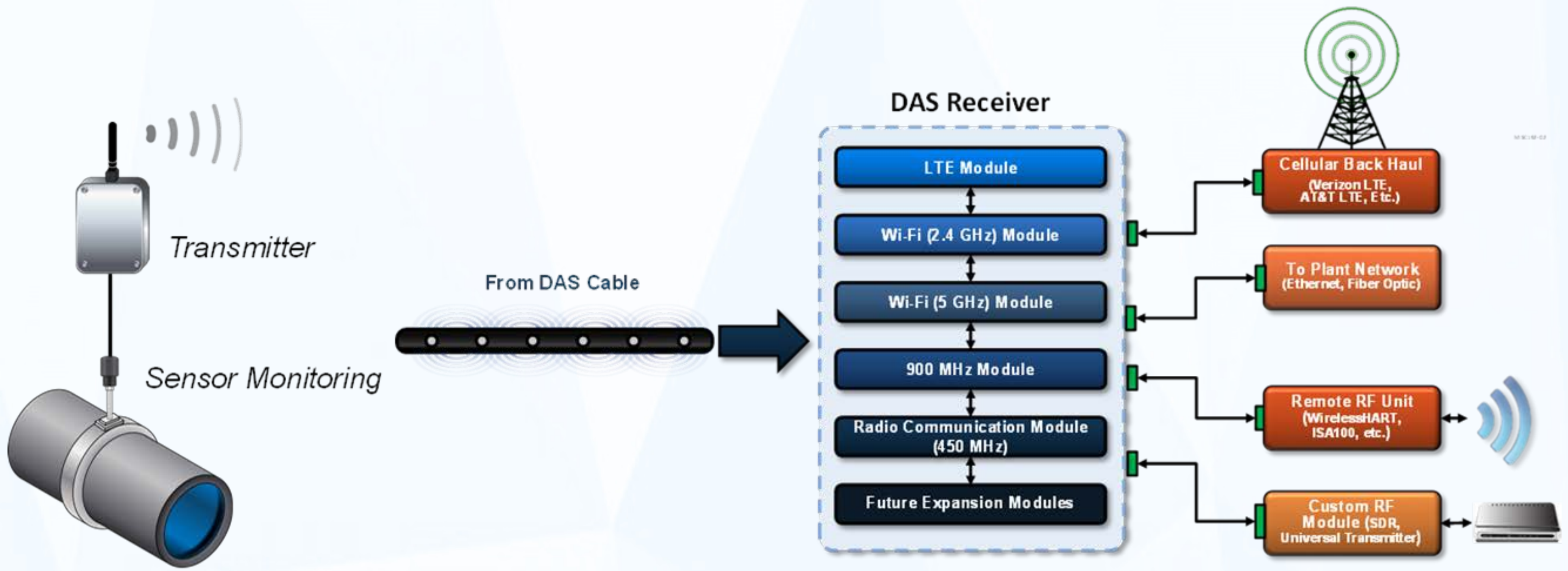
Technology Impact

The implementation of a distributed antenna system as a backbone for wireless communications will not only save nuclear power plants millions of dollars in reduced equipment and installation costs, but will also enhance communication and data access throughout the entire plant. This technology is cross-cutting and benefits the existing fleet of nuclear facilities and new reactors including SMRs and advanced designs.

Support the Implementation of Wireless Technologies into Nuclear Power Plants

What is DAS?

- DAS technology is one enabling technology that can help provide a wireless infrastructure for numerous wireless protocols across a wide range of frequencies
- Can allow plants to implement wireless sensors and data communications efficiently and effectively



Example Benefits of Condition Monitoring

Fleet-Wide Monitoring Perspective

Southern Company Generation

- Average Investment at a typical 10 GW fleet ≈ $10M
- Average Benefits in replacement power cost avoidance, revenue gained from assets & avoided repairs ≈ $17M
- Average Payback Period < 1.5 years

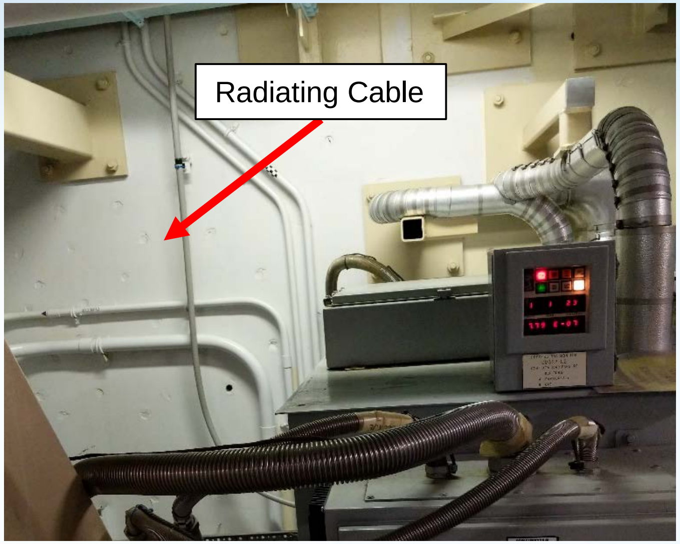
Site Implementation Perspective

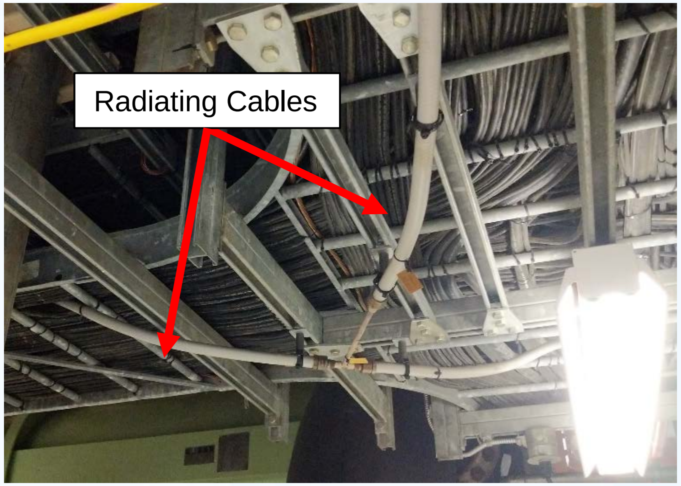
Diablo Canyon Power Plant

- Diablo Canyon Power Plant Estimates 50,000 man-hours per year saving per two unit site through widespread use of wireless devices for voice and data communication.
- This amounts to $6M dollars of savings/gains in efficiency.

Challenges of DAS in Nuclear

- Challenges
  - EMI/RFI Concerns
    - Antennas and radiating cables are often installed near potentially sensitive plant equipment and cables
  - Determining Coverage
    - Existing coverage evaluation methods only evaluate mainstream protocols (i.e. Wi-Fi, GSM, LTE)
  - Lack of Operation Experience
    - Plants don’t know what should be addressed prior to installation
- This research will develop
  - Guidance for optimizing DAS performance
  - Procedures for installation, testing, and monitoring
  - Software and Hardware to identify
    - Faults with DAS and/or wireless networks, Adequate coverage
    - Performance of the system across its entire operating frequency range.
  - Strategies for handling electromagnetic interference and coexistence



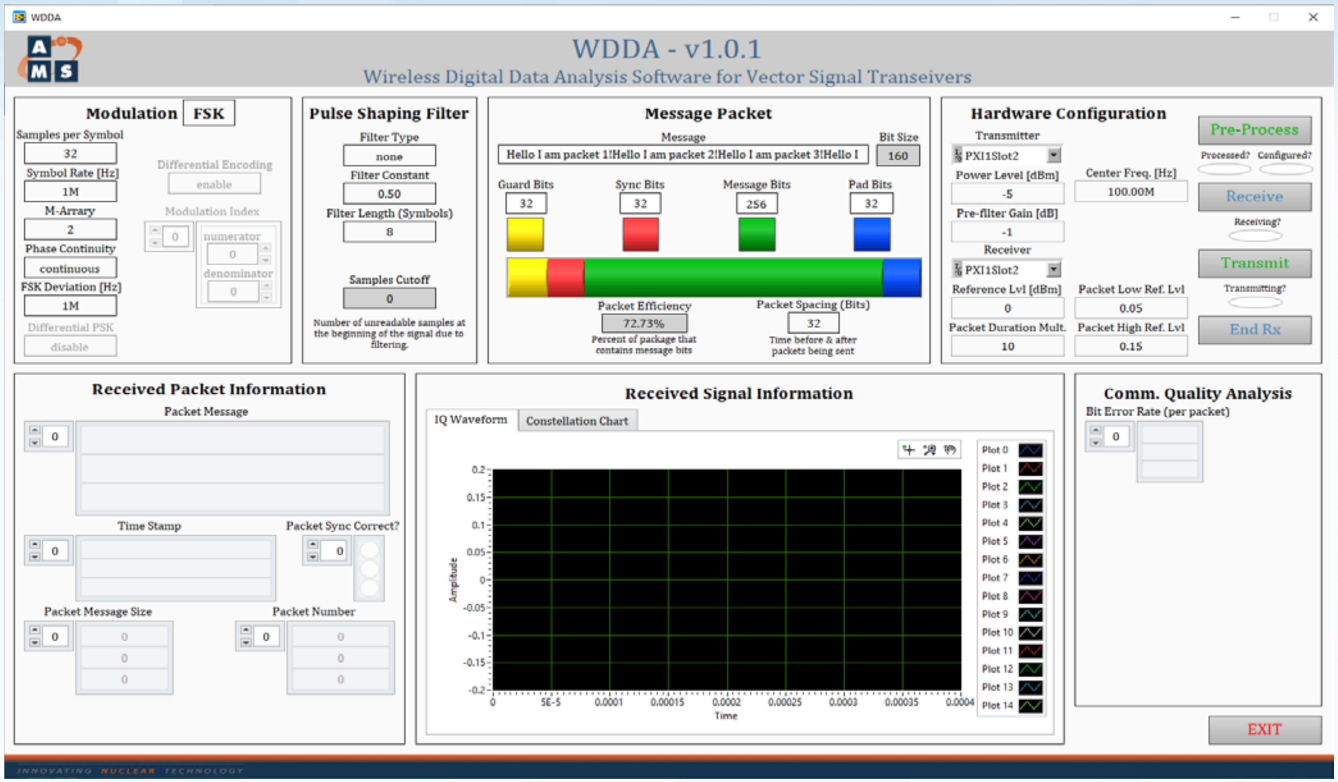


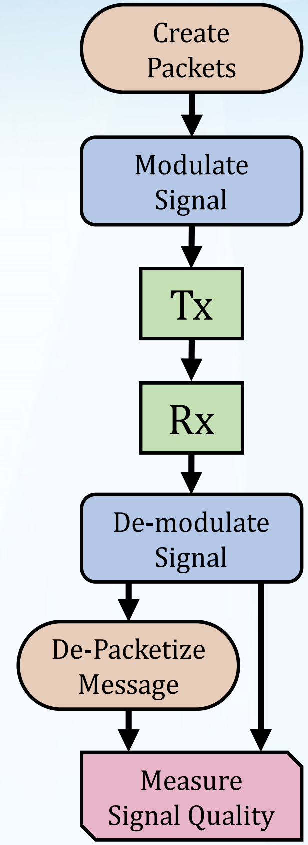
DAS Performance

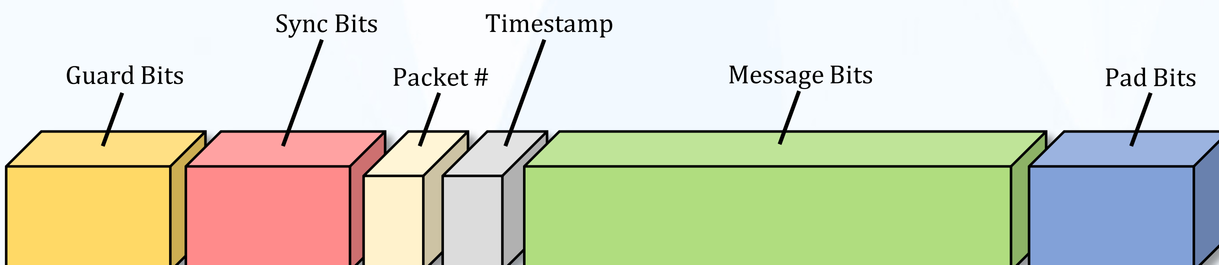
- Determining DAS path quality for any protocol
  - DAS is protocol Agnostic
    - Solutions exist for LTE and Wi-Fi
    - How do you determine path quality for proprietary protocols?
  - Simulate the physical layer to measure the path effects on signal parameters
    - Frequency
    - Amplitude
    - Phase

MODULATION	FULL NAME	PHYSICAL PARAMETER CHANGED TO MODULATE
FSK	Frequency Shift Keying	Changes in frequency represent data
PSK	Phase Shift Keying	Changes in phase represent data
ASK	Amplitude Shift Keying	Changes in amplitude represent data
QAM	Quadrature Amplitude Modulation	Similar to ASK, but acts on the in-phase and quadrature component of the signal
MSK	Minimum Shift Keying	A type of FSK with changes meant to minimize the sidebands (unwanted) power
PAM	Pulse Amplitude Modulation	Similar to ASK but uses a pulse train
CPM	Continuous Phase Modulation	A type of PSK with changes meant to minimize the sidebands (unwanted) power

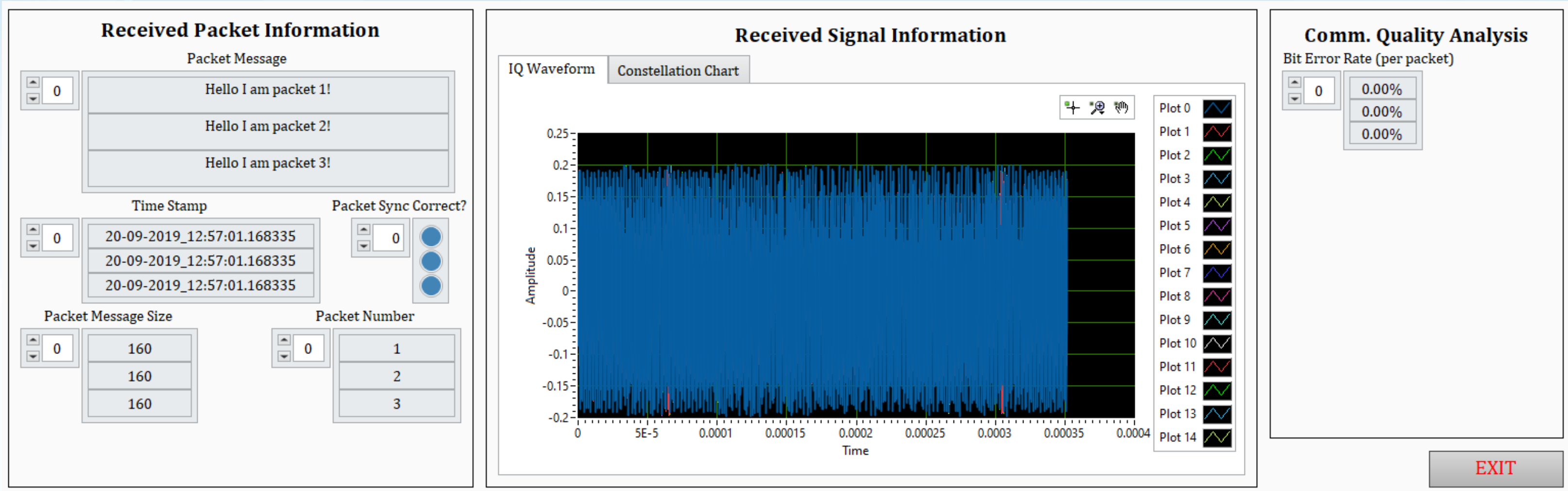
Simulating Protocol Physical Layers



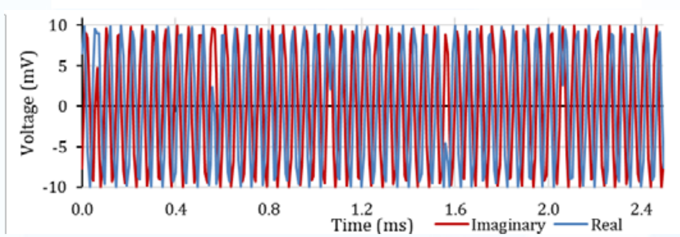




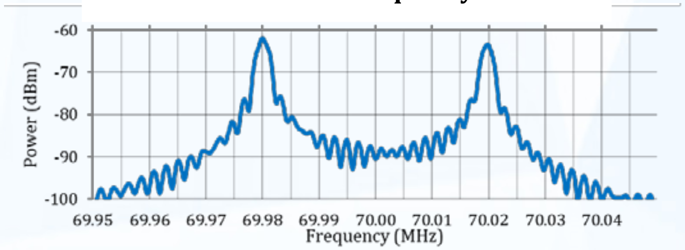
Evaluating Received Signals

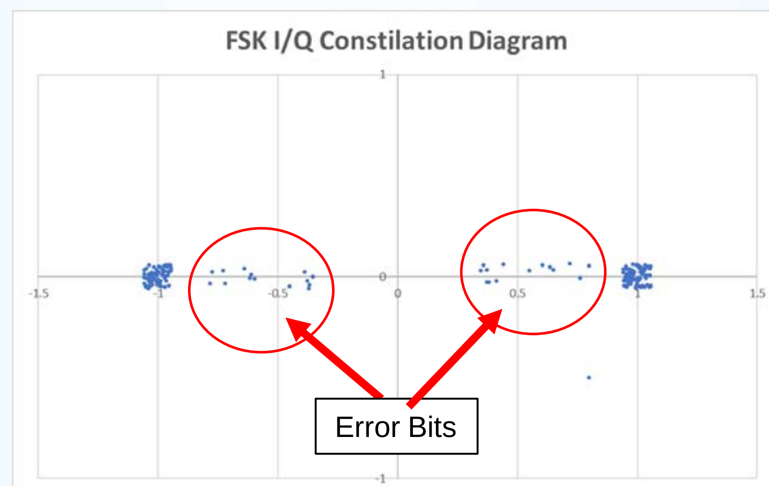


Received FSK I/Q Data Time Domain



Received FSK FFT Frequency Domain





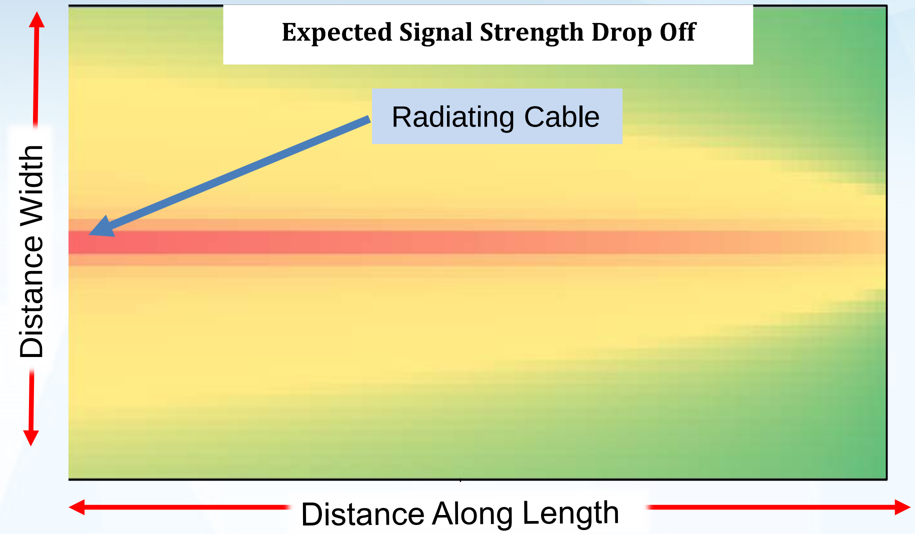
Simulating Plant Installations

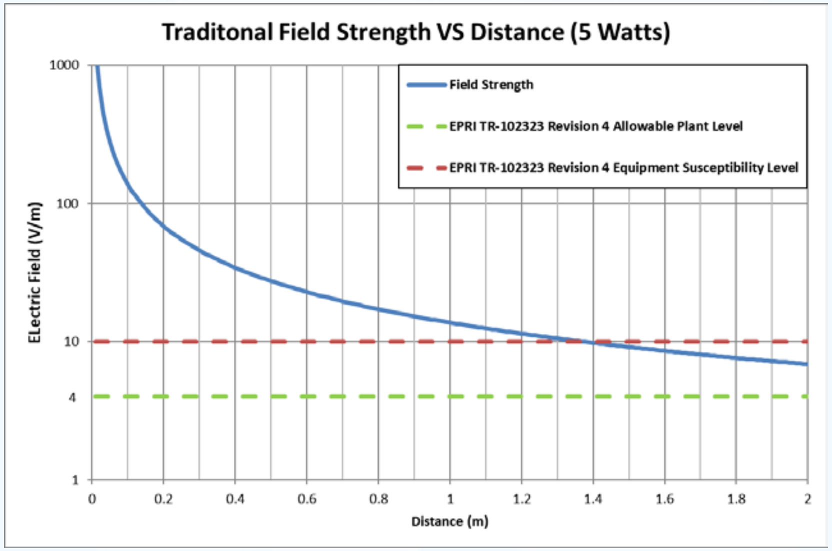
Installation of DAS Cables within a Nuclear Power Plant

DAS Testbed at AMS

Broadband Signals transmitted over DAS Testbed

- Broadband transmission Setup:
  - Frequency Shift Keying over
    - 10 MHz band
  - Spectrum Measurements:
    - Measurements every 1.5 ft
    - Maximum hold trace
- Expected Results
  - Frequency
    - No changes in signal frequency content
  - Amplitude
    - Amplitude drop off consistently over the length of cable
  - Phase
    - No phase distortion

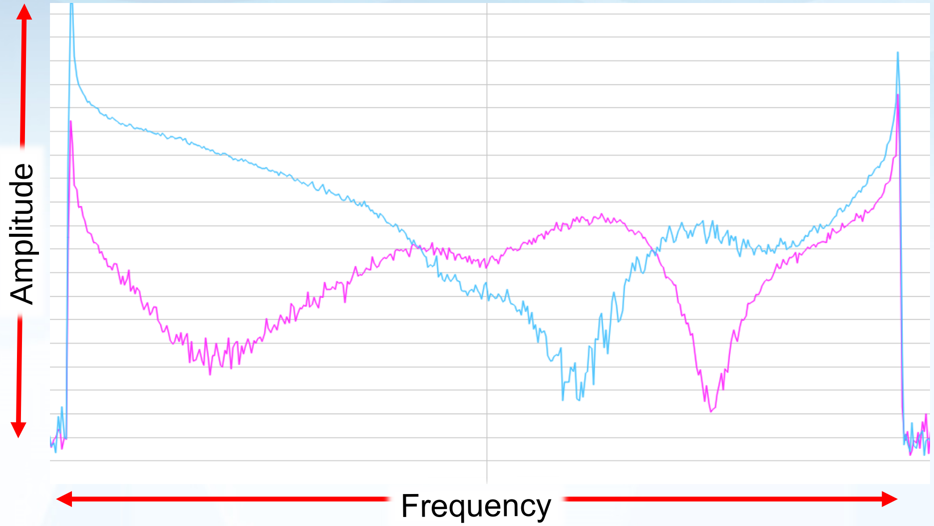


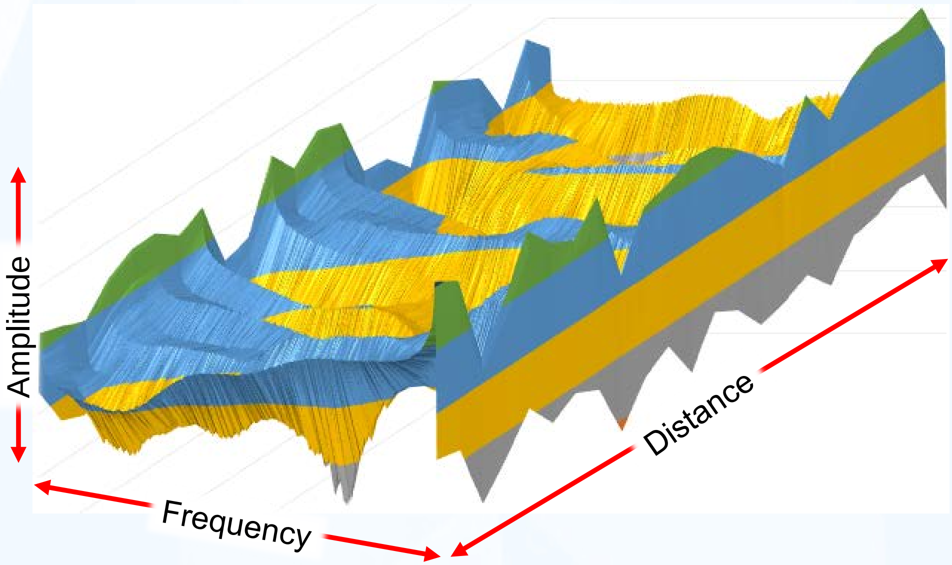


DAS Effects on Broadband Signals

Results

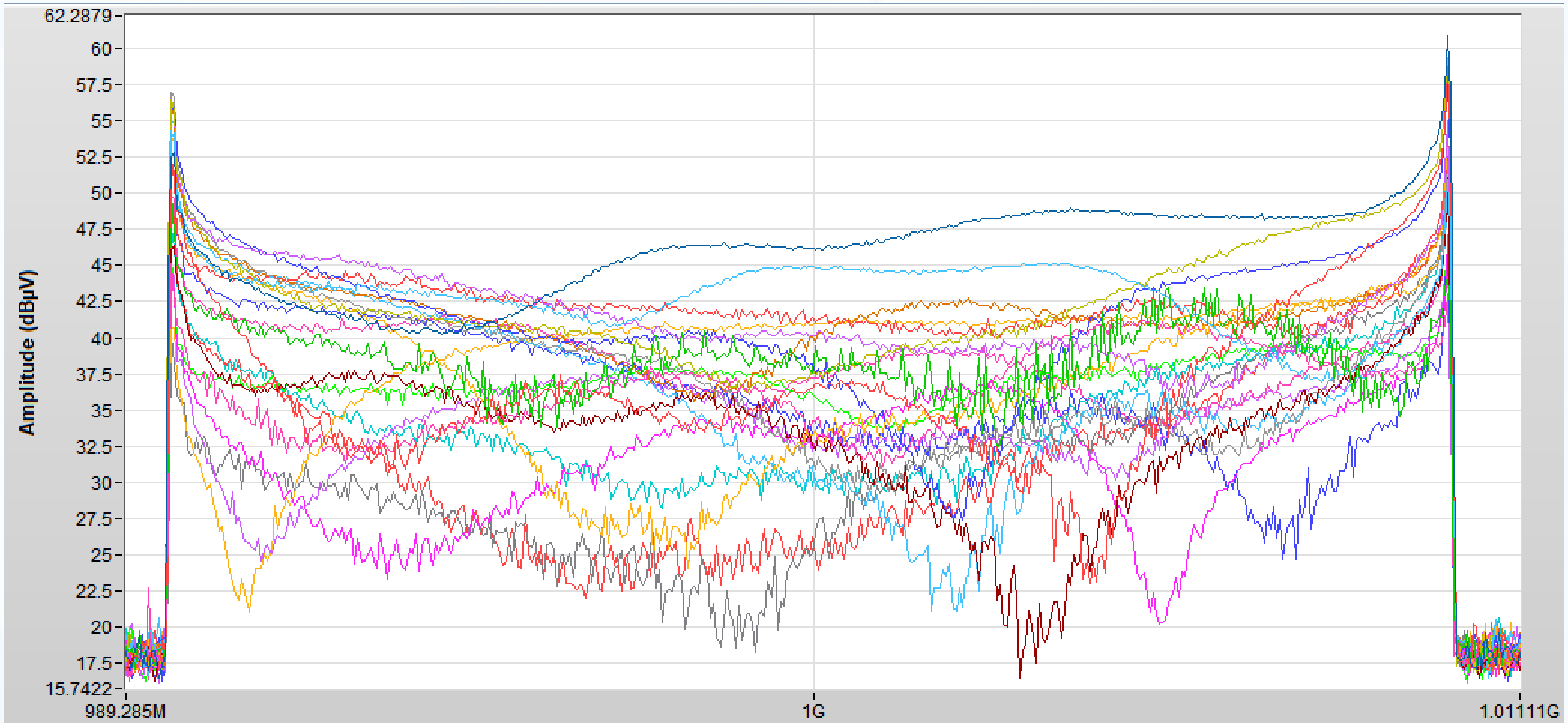
- Frequency
  - No changes were noted in frequency content
    - No effect on frequency modulations (FSK, MSK)
- Amplitude
  - Significant shifts in signal amplitude across the frequency and over distance
    - Negative effect on amplitude modulations (ASK, QAM, PAM)
- Phase
  - Nodes and Nulls caused by phase shifts along the length of the cable
    - Negative effect on phase shift modulations (PSK, QAM, CPM)





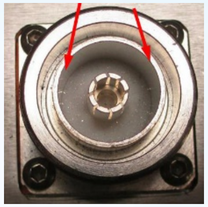
Broadband Transmission Results

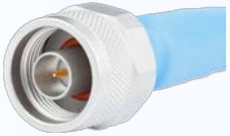
- Signal amplitude did not decrease in a uniform, predictable manner

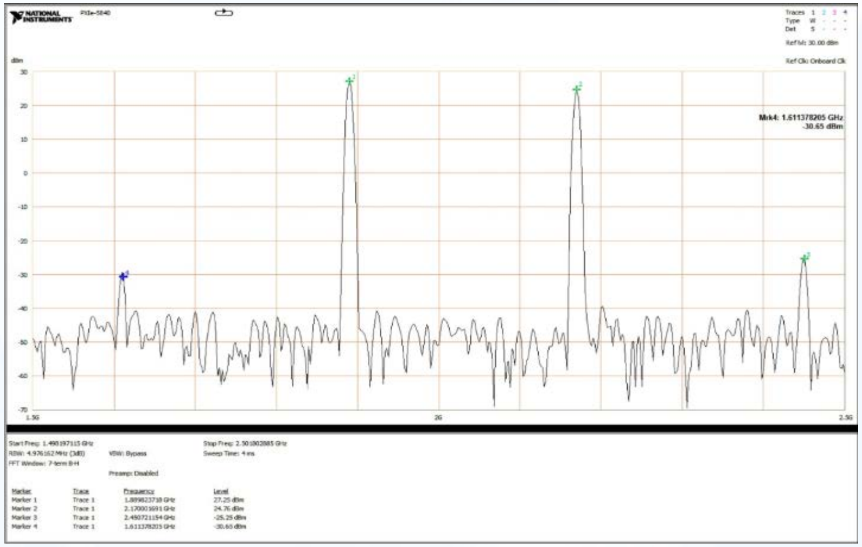


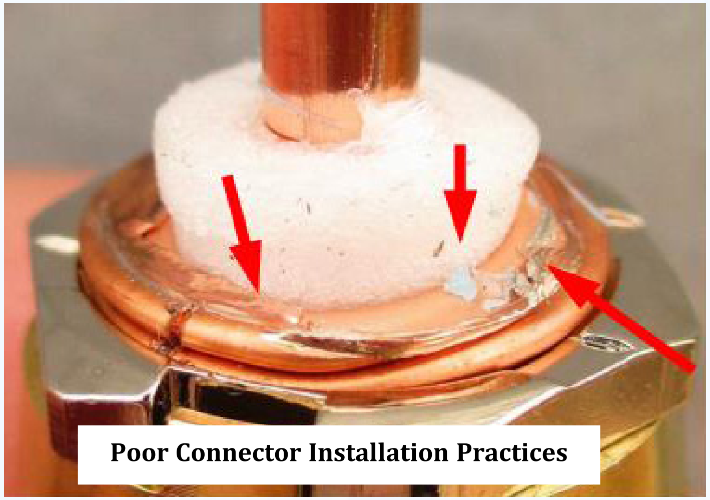
Interference Caused by Faults in DAS Cables and Connectors

- Examples Faults that cause Passive Intermodulation (PIM)
  - Loose metal flakes
  - Rough / irregular metal edges
  - Poorly made components
  - Poorly installed connectors
  - Bad terminations
  - Under/Over Torqued connections





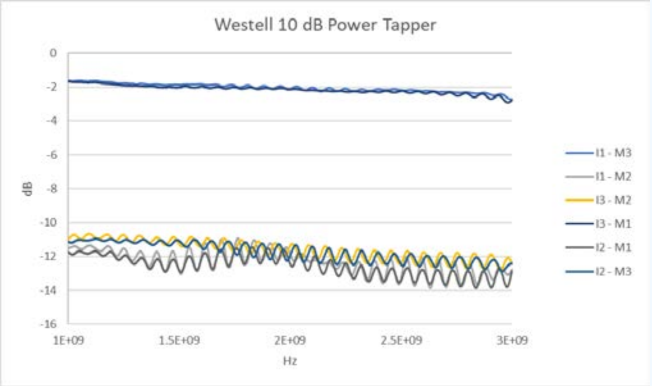


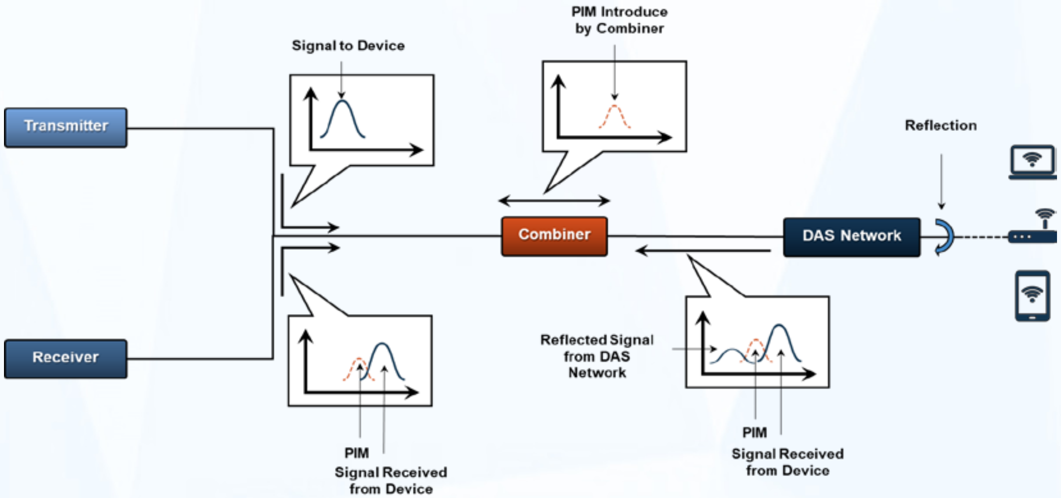


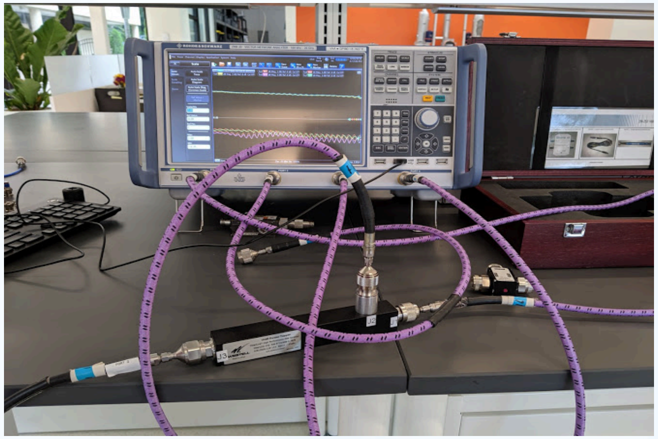
Poor Connector Installation Practices

Detecting DAS Faults

- Can be identified using traditionally impedance measurements
  - Poorly installed connectors
  - Bad terminations
  - Under/Over Torqued connections
- New methods are being researched to identified the following using non-invasive measurement techniques
  - Loose metal flakes
  - Rough / irregular metal edges
  - Poorly made components

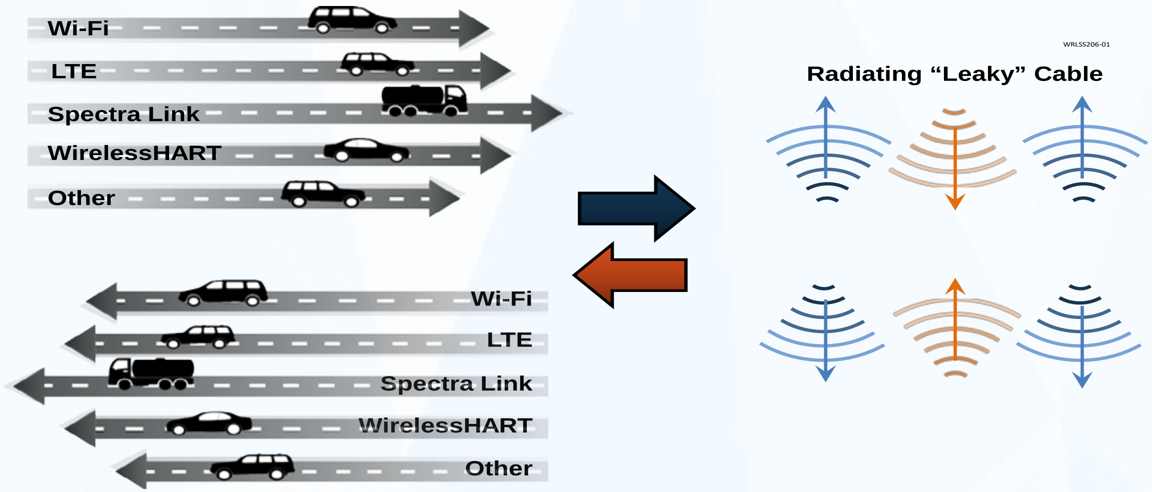






High Level Research Goals

- Nuclear Industry Goals:
  - Establish reliable wireless connectivity within nuclear power plants
  - Enable wireless monitoring of many, currently unmonitored plant systems
  - Find wireless sensors suitable for NPP environments
- Research Goals:
  - Address implementation concerns with the use of DAS technology
  - Develop system hardware and measurement techniques for identifying aging/degradation of DAS components
  - Provide commercial wireless technology integration services to nuclear power plants and other industries



Thank You!

Questions?