3PHOENIX™

An ISO 9001:2008 Registered Company

INNOVATIVE TECHNICAL SOLUTIONS

Wireless Sensing for Survivable Machinery Control

22-APR-2013

UNCLASSIFIED

Agenda

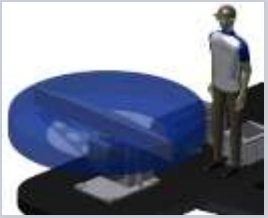
- **3 Phoenix, Inc. Introduction**
- Background – Acoustic Communications and Power Thru Bulkheads
- Data Through Bulkhead
- Power Through Bulkhead

3 Phoenix Overview

- We are an Engineering Company
  - Specializing in Sensor System Development
  - Sonar/Radar/Imaging/Electronic Warfare
  - Application of Low Cost COTS Technology to Rugged Applications
- Design, Development, Integration and Production Capability
  - ISO 9001:2008 Registered
- Small Business - 182 employees
  - Many successful SBIR Technology Transitions
- Offices in Virginia, Maryland and North Carolina

UNCLASSIFIED

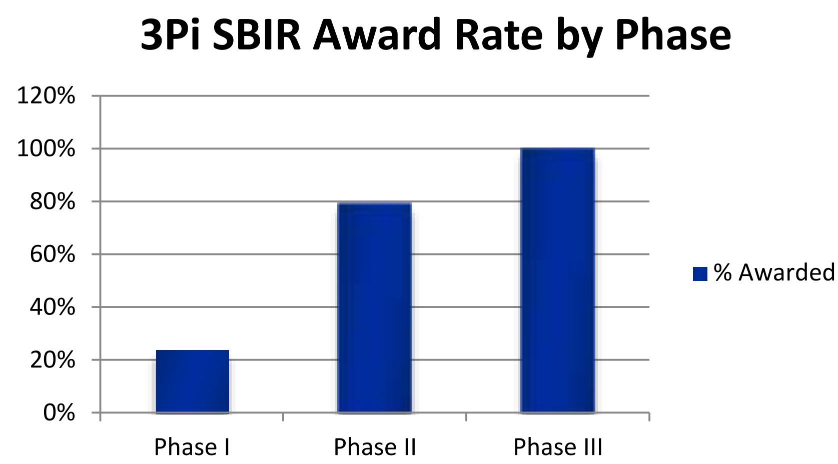
Core Capabilities and Business Overview

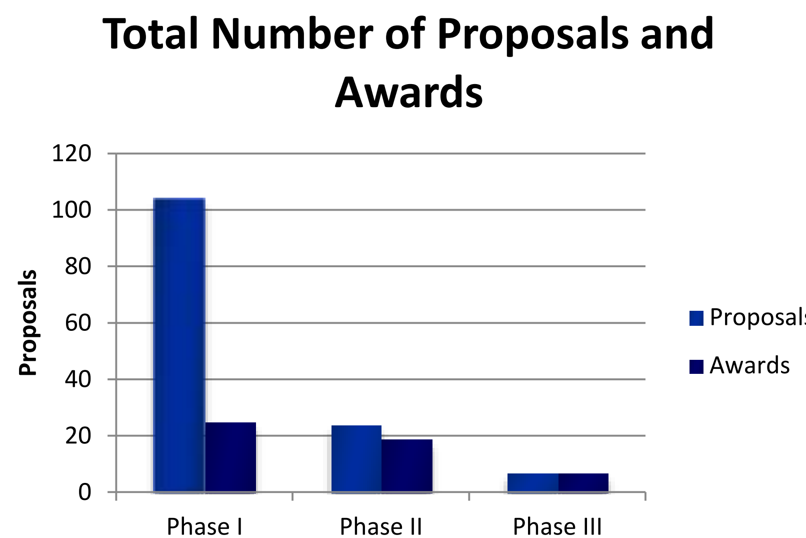
SONAR	RADAR	ISR
		
TWS Receive Array	*MFHR RADAR*	*TIPM*
Products		
• Torpedo Warning System • Towed Arrays • Side Scan SONAR Systems • Deep Ocean Bottom Arrays	• AN/SPS-74(V)1/2 Periscope Detection RADAR (PDR) • Multi-Function High Resolution RADAR (MFHR)	• Technology Insertion Photonics Mast (TIPM)/Zeiss Augmentation Project (ZAP) • Modular Compact Imaging Mast (MCIM) • Compact Covert Periscope • Universal Mast Controller • Next Generation Submarine ESM
Platforms Served/Potential Platforms		
• Carriers (CVN) • LA/VA/Seawolf Subs • Shallow Water Combat Submersible • Cruisers and Destroyers • Littoral Combat Ship	• Carriers • Large Deck • Cruisers and Destroyers • Littoral Combat Ship	• VA Class • Ohio Class Replacement • SEAL Delivery Vehicle • Shallow Water Combat Submersible

UNCLASSIFIED

SBIR's as a Product Development R&D Resource

- 3 Phoenix has bid on 104 Phase I and Phase II SBIRs since company inception
- All bids are product/system centric
  - Focus on developing products that can transition to Program of Record, have direct benefit to the warfighter and can be built cost effectively
- Award Rates:
  - Phase I: 24%
  - Phase II: 79%
  - Phase III: 7





22-APR-2013

UNCLASSIFIED

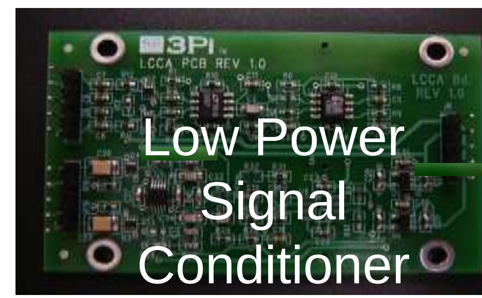
Key Enabling Technologies

- Inverted Passive Optical Network (iPON)
  - Provides low power high data rate communications
  - Supports precision time synchronization and data fusion
  - Scalable open architecture
  - Uses low cost high availability technology
  - Initially developed for Towed Array applications
    - Also enables integration of hull and towed sensors

iPON Optical Network Gateway (ONG)

iPON ONG Packaging

iPON Optical Network Controller (ONC)



Agenda

- 3 Phoenix, Inc. Introduction
- **Background – Acoustic Communications and Power Thru Bulkheads**
- Data Through Bulkhead
- Power Through Bulkhead

Acoustic Communications and Power Thru Bulkheads

Background

- New technology desired for:
  - Ship Installation Cost Savings
  - Increased Survivability of Vital Comms Infrastructure
  - Reduced Manning through automated Ship Operations

- Wireless Sensing Systems Are an Ideal Candidate

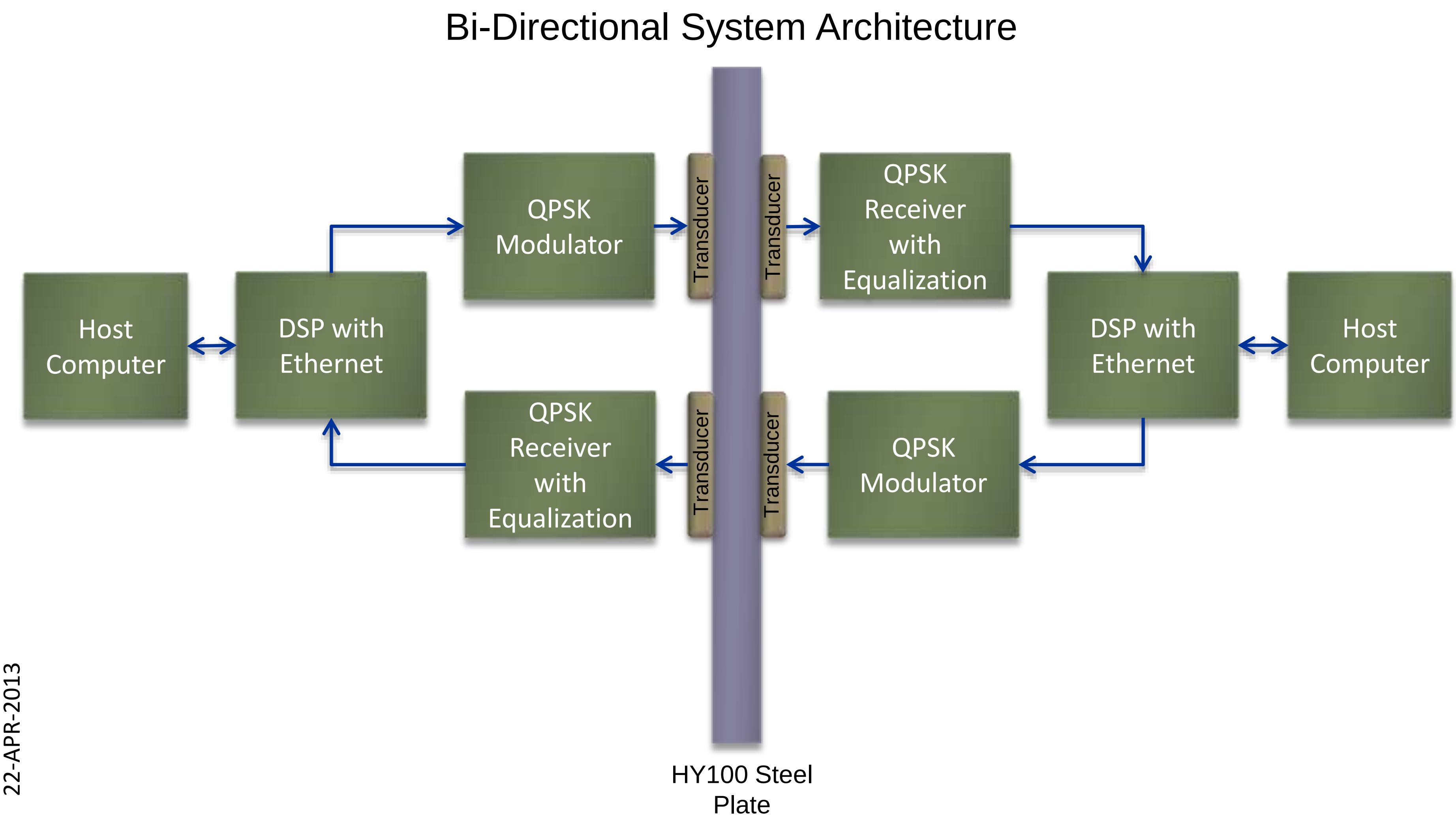
Background

- Design Requirements:
  - Intra-compartment communications
  - Inter-compartment communications
  - Aggregate data bandwidth
- Challenges
  - Communications through and around steel ship compartments
    - Reduce number of thru-hull penetrations where cost, feasibility or safety is a constraint.
  - Secure Software Architecture
  - Minimizing Power Requirements to enable:
    - Parasitic scavenging
    - Wireless Power Conduction

Agenda

- 3 Phoenix, Inc. Introduction
- Background – Acoustic Communications and Power Thru Bulkheads
- **Data Through Bulkhead**
- Power Through Bulkhead

Acoustic Modem Architecture

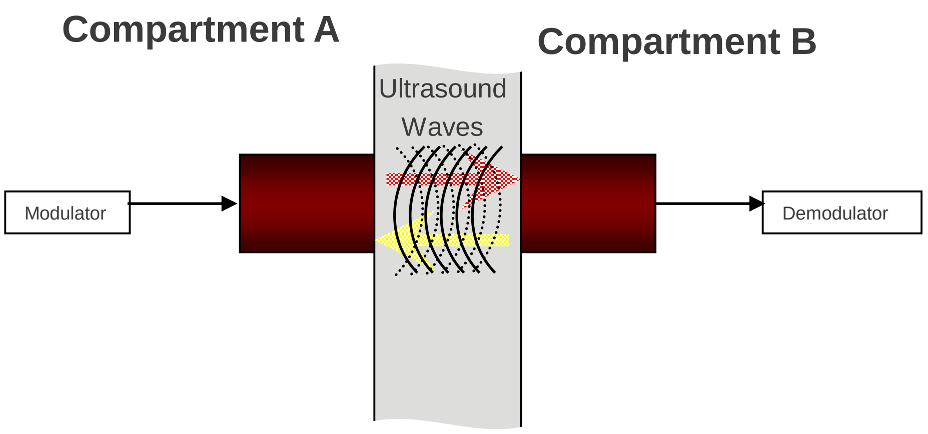


22-APR-2013

UNCLASSIFIED

Multi-path and Resonance Interference

- Signal Distortion and Attenuation Due to:
  - Constructive and Destructive Interference from Multi-path reflections
  - Resonance of Steel
  - Resonance of Transducers



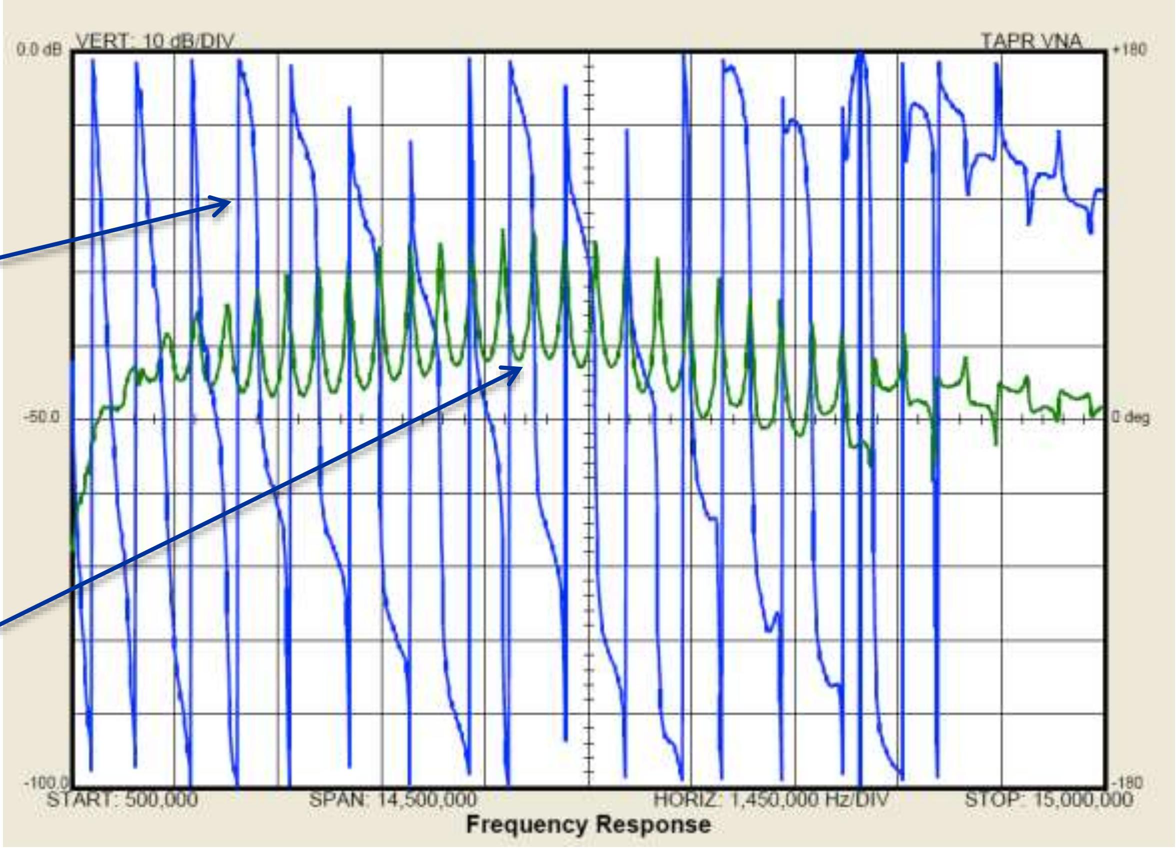
- Conclusion – Signal Distortion severely limits data rate without equalization of the receive signal
- The physical system can be characterized and the distortion can be equalized with a digital filter specifically pre-designed for the frequency and bandwidth of the transmitted signal and thickness/density of the steel.

Effective Electrical Frequency Response

- Green – constructive and destructive interference due to direct and reflected path acoustic signals

Blue – Non-linear Phase Response

"Rainbow" shape due to frequency response of transducers (7.5Mhz)



Equalize the Channel Response

- Given a measured channel response in the time domain, g(n), we want an equalizing filter, h(n):

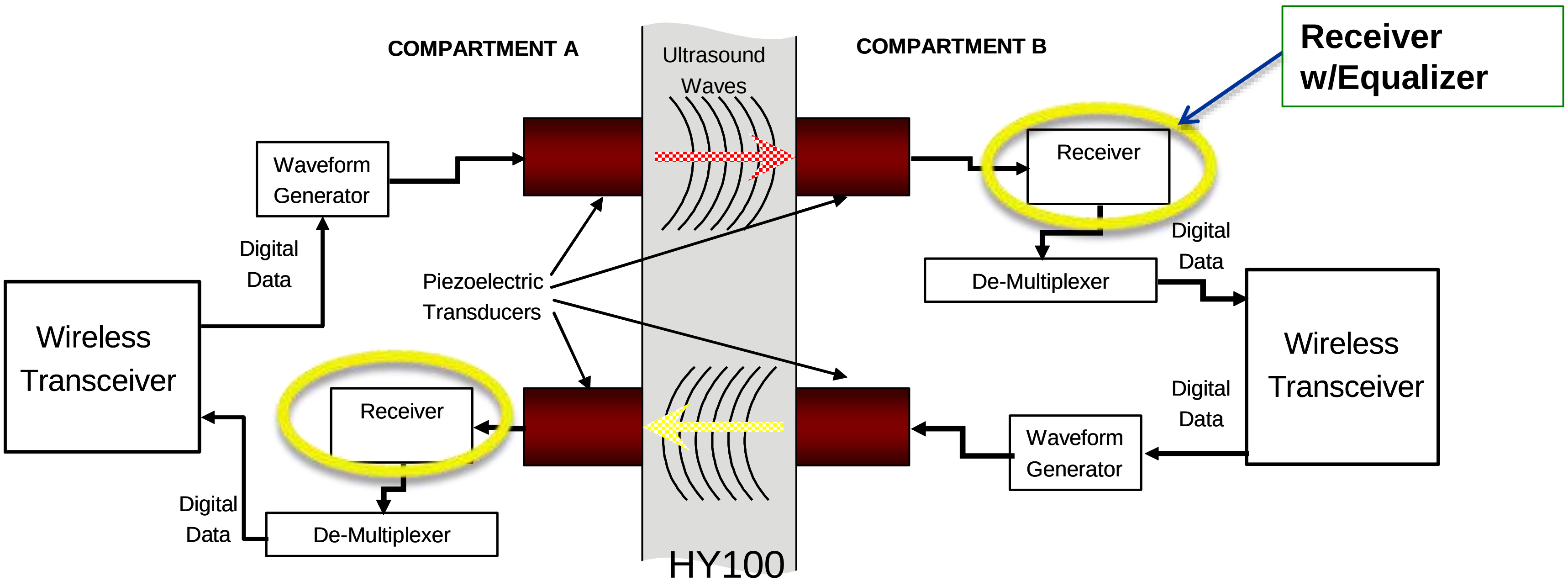
$$h(n) * g(n) = \delta(n)$$

- δ is the impulse function,

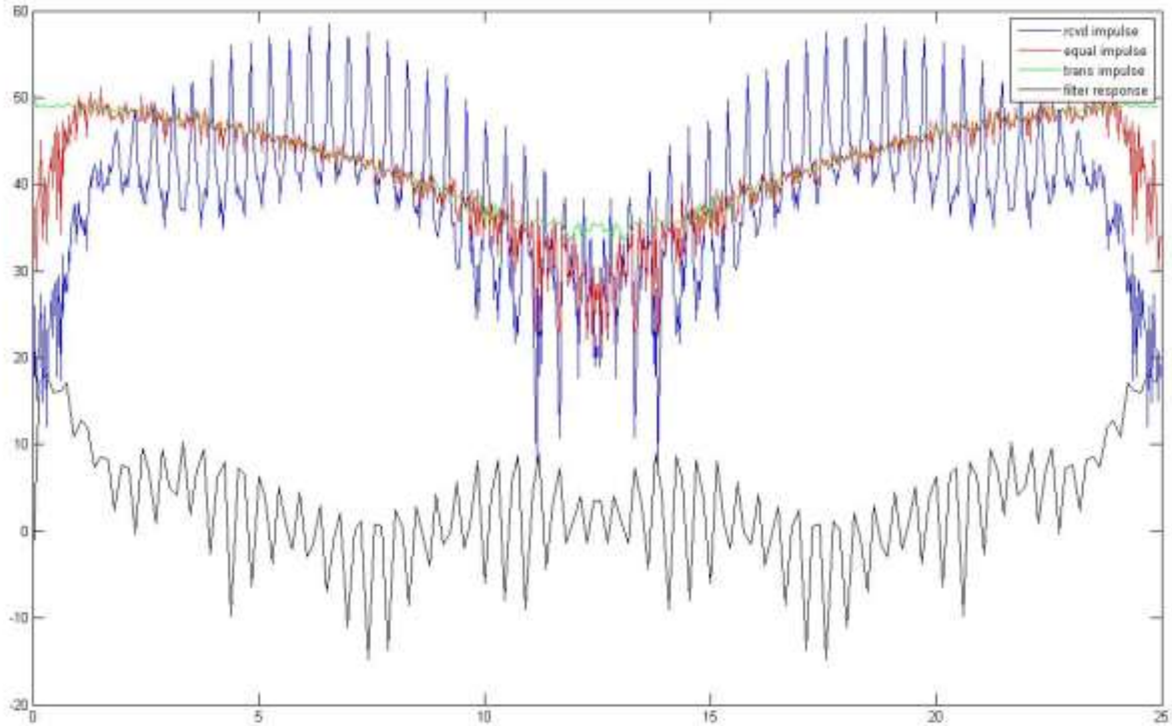
- The solution for the equalizer, h(n) is solved via a least squared error criterion

$$\varepsilon^2 = \sum_{n=0}^{\infty} \left| \delta(n) - \sum_{k=0}^{N-1} h(k) g(n-k) \right|^2$$

Digital Filter Added to the Receiver



Filter Response Design Plots



Notes:

Spectrum (FFT) of the transmit impulse (green) closely matched by the spectrum of the received equalized impulse (red) showing the equalization is working!

Spectrum of the equalizer response cancels shaping due to the channel (transducer-steel-transducer)

The channel has a large insertion lose

Acoustic Modem Features

Modulation:

- QPSK
- Symbol Rate -2.5 MHz
- Bit Rate - 5 MBits/Sec
- Shaping – Root Raised Cosine Shaping

Equalization:

- Calculation Based (least squared error criterion)
- Implementation - 400 Tap FIR
- Fixed Solution (not adaptive)
- Requires calibration at install

Acoustic Modem Features (2)

Data Interfaces:

- Ethernet-In to Ethernet-Out
- Packet Type – UDP
- Software based ‘Flow Control’
- Limits data transfer rate
- Prevents Overflow
- Implemented at transmit end

Transmit Overhead:

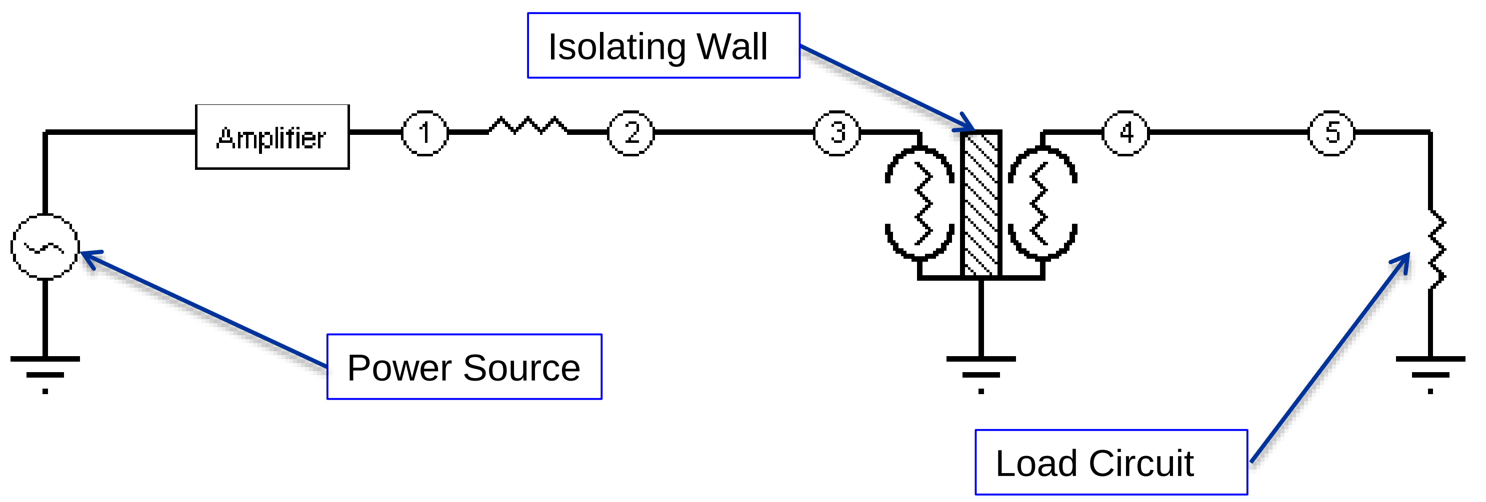
- Embedded Sync words - 3% overhead
- Forward Error Correction (FEC)
- Code Rate = 7/8 giving 12.5 % overhead
- Usable Data Rate (given FEC) = 4.5 MBit/Sec

Agenda

- 3 Phoenix, Inc. Introduction
- Background – Acoustic Communications and Power Thru Bulkheads
- Data Through Bulkhead
- **Power Through Bulkhead**

Transmitting Power thru Steel

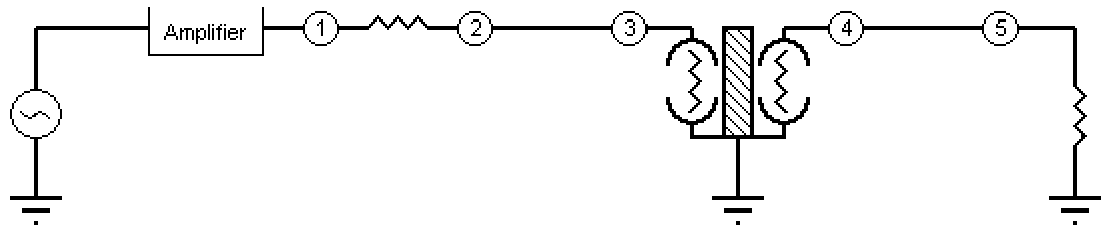
- Demonstrated feasibility to transmit power (electrical energy) through a steel wall using acoustic waves
  - Piezoelectric transducers utilized
  - Effective power transfer useful in shipboard environments when penetrations are prohibitive
  - Allows a load circuit to be placed in power isolated areas



Power Transducer Setup

Transmit Xdcr

Receive Xdcr



Load Circuit

$$I_{\text{driving, RMS}} = \frac{V_1 - V_2}{R_{\text{series}}}$$

$$P_{\text{driving}} = \left(I_{\text{driving, RMS}}\right)\left(V_2\right)$$

$$I_{\text{load}} = \frac{V_{\text{load}}}{R_{\text{load}}}$$

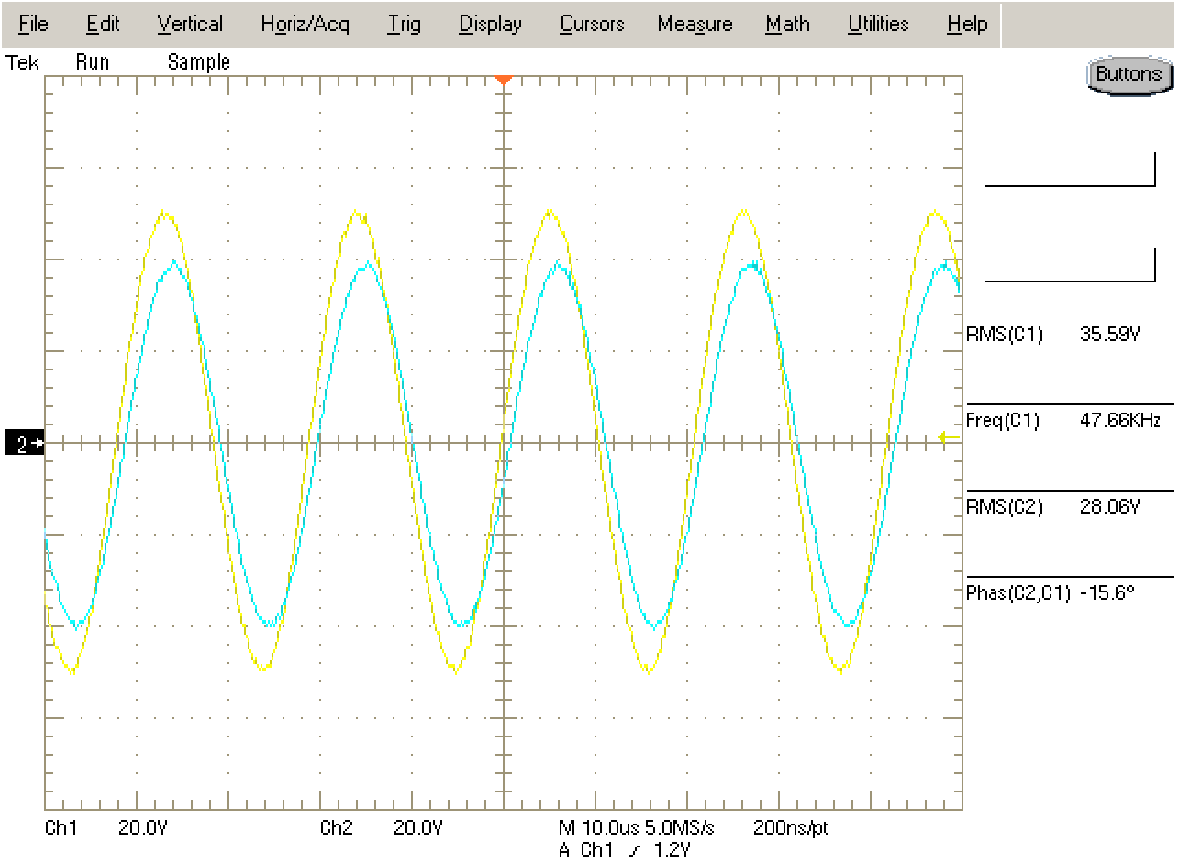
$$P_{\text{load}} = \left(I_{\text{load, RMS}}\right)^2\left(R_{\text{load}}\right)$$

$$\text{Efficiency} = \frac{P_{\text{load}}}{P_{\text{driving}}}\left(100\right)$$

22-APR-2013

UNCLASSIFIED

Transducer Operation



Channel 1 = Input Sinusoidal Signal (green)

Channel 2 = Output Sinusoidal Signal (blue)

Transducer Measurements

V_{in}(p-p)	V_1(rms)	V_2(rms)	$I_{driving}$	$P_{driving}$	V_{load}(rms)	I_{load}	P_{load}	Efficiency
1.00 V	7.11 V	7.03 V	16.12 mA	0.11 W	6.18 V	12.38 mA	0.08 W	67.56 %
2.00 V	14.24 V	14.07 V	33.01 mA	0.46 W	12.40 V	24.84 mA	0.31 W	66.33 %
3.00 V	21.54 V	21.29 V	48.54 mA	1.03 W	18.79 V	37.64 mA	0.71 W	68.44 %
4.00 V	28.72 V	28.37 V	67.96 mA	1.93 W	25.12 V	50.33 mA	1.26 W	65.57 %
5.00 V	35.90 V	35.46 V	85.44 mA	3.03 W	31.55 V	63.21 mA	1.99 W	65.83 %
6.00 V	43.10 V	42.58 V	100.97 mA	4.30 W	37.90 V	75.93 mA	2.88 W	66.94 %
7.00 V	50.43 V	49.80 V	122.33 mA	6.09 W	44.46 V	89.07 mA	3.96 W	65.01 %
8.00 V	57.75 V	57.06 V	133.98 mA	7.64 W	50.95 V	102.08 mA	5.20 W	68.03 %
9.00 V	64.72 V	63.92 V	155.34 mA	9.93 W	57.09 V	114.38 mA	6.53 W	65.76 %
10.00 V	70.88 V	70.01 V	168.93 mA	11.83 W	62.20 V	124.61 mA	7.75 W	65.54 %

V_{in}(p-p) is the voltage of the signal from the Waveform Generator
V_1(rms) is the output voltage of the Power Amplifier
V_2(rms) is the voltage across the Driving Transducer

Conclusions

- Average power transfer efficiency – 65%
- Achieved delivered power levels up to 9 W
  - Power levels of 10-15W should be easily achievable
  - 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