Acoustic Data and Power Transmission Through and Along Solid Structures

The Ultrasonic Through-Wall Communications Group at

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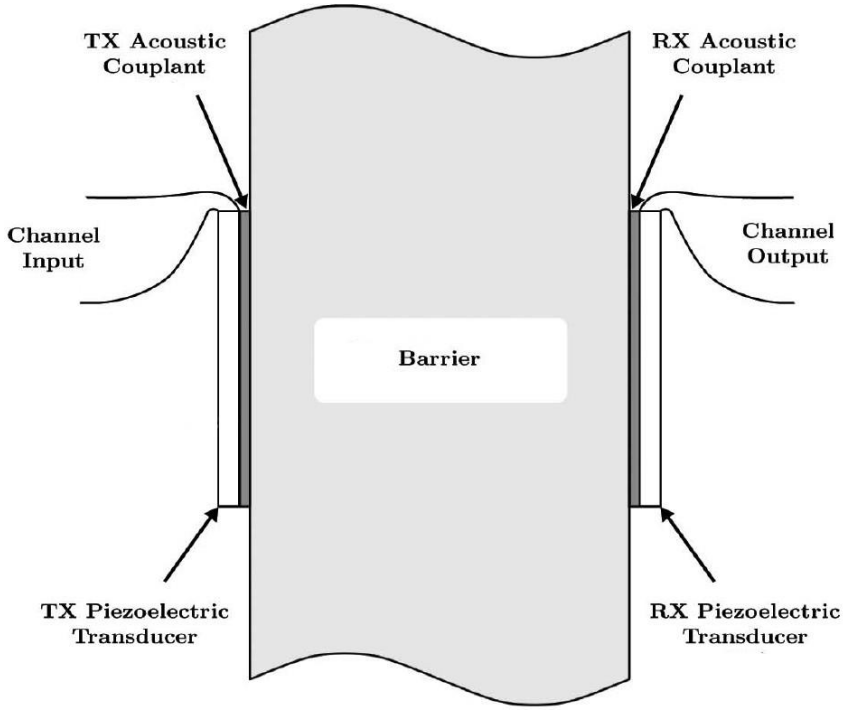
Basics

- Vibrations/Ultrasonics employed to wirelessly transmit both power and data

- Target applications:
  - Through single- or multi-layer barriers
    - Nuclear containment vessels or structures
    - Surface or subsurface vessel hulls
    - Chemical storage tanks
    - Aero- and Astronautical vehicles
    - Oil and Gas wells and pipelines (restricted)
  - Along solid structures
    - Across pipe obstructions
    - Along the skin of vehicles
      - Allows bypass of bulkheads and other obstacles

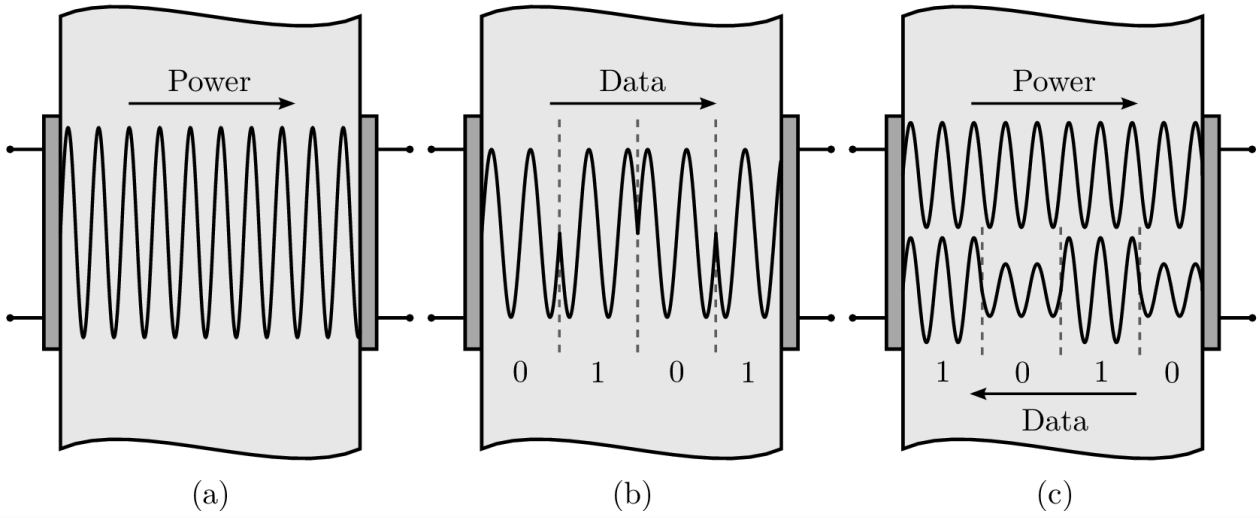
Basics

- Ultrasonic energy is generated and received by piezoelectric transducers
- Transducers coupled to barrier using an acoustic couplant
- Uses same energy conduction mechanisms as ultrasonic non-destructive testing (NDT) → Safe for use on critical components



Basics

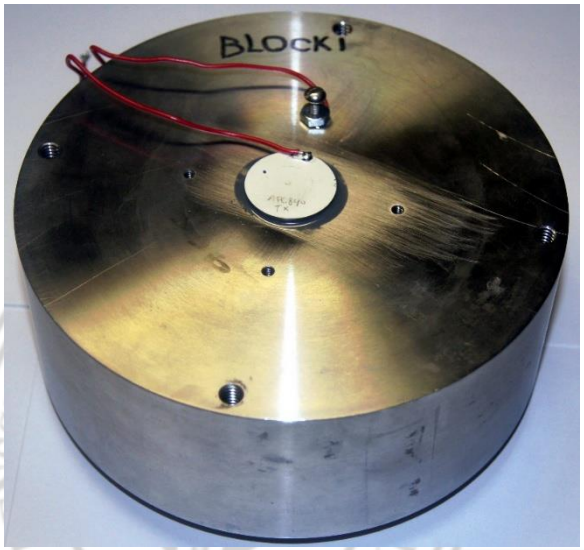
- Three basic system configurations for a single pair of transducers
  a. Dedicated power transmission
     - High-energy throughput requirements
  b. Dedicated data transmission
     - High-data-rate communications
  c. Shared power and data
     - Ideal for low-power and low-rate sensing applications



Dedicated Power Transfer Systems

- Highly efficient transfer efficiencies have been demonstrated on thick metallic barriers:

Barrier Material	Barrier Thickness	Output Power (AC)	Efficiency
Carbon Steel	2.5 in	50.1 W	51 %[1]
HY80 Steel	0.38 in	81 W	55 %[2]
↓ St. Steel 316	2.6 in	141 W	67 %[3]



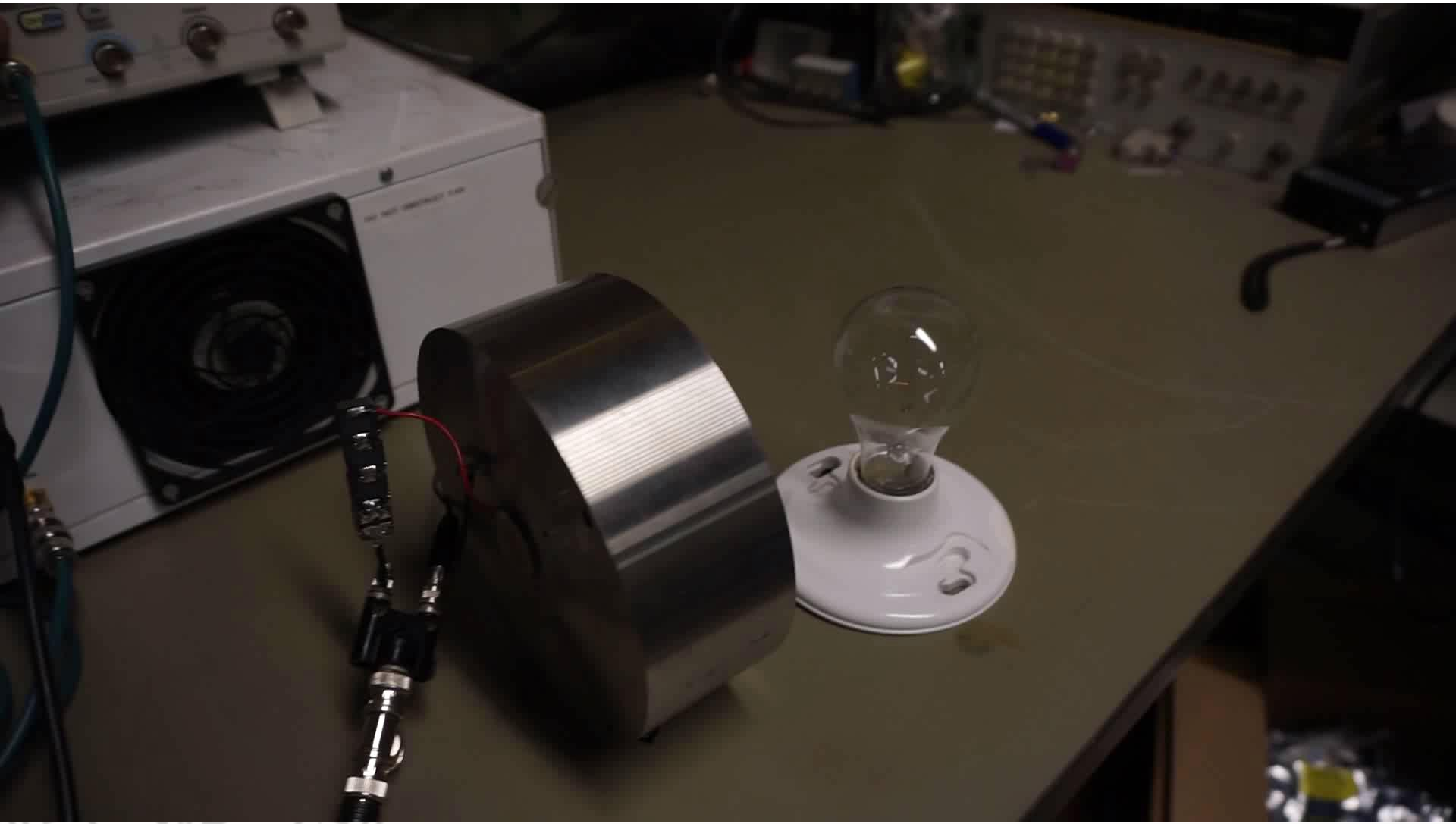
- Energy is focused between transducers
- Extra-high power transfer may be achieved using larger transducers and/or more specialized transducer designs

[1] Lawry, et al., 2013, IEEE UFFC 60(1)

[2] Lawry, et al., 2010, Proc. SPIE Energy Harvesting and Storage

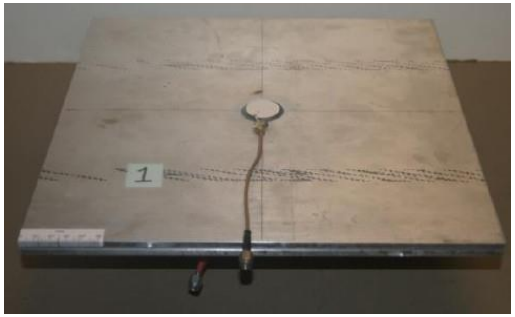
[3] Wilt, et al., 2012, Proc. ASME IMECE

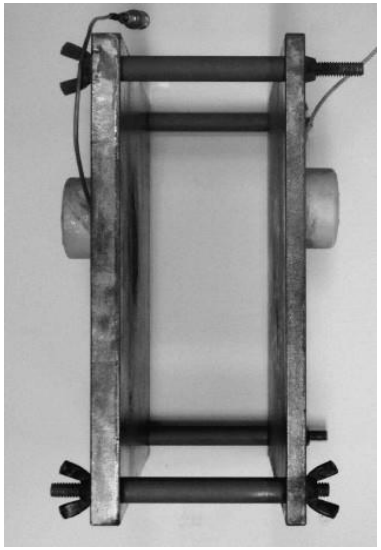
Dedicated Power Transfer Systems



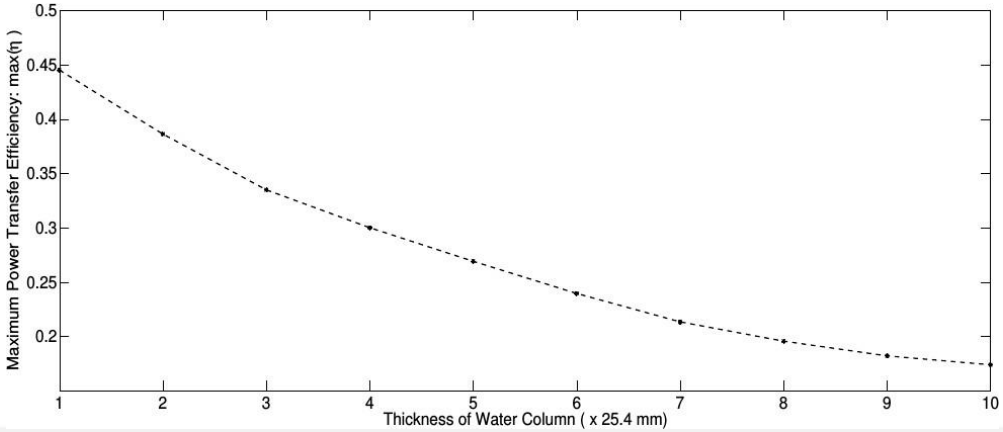
Dedicated Power Transfer Systems

- Less efficient power transfer shown to be possible through layered structures, E.g.:
  - Steel-Water (thick)-Steel → ~10-30 %[1]
  - Aluminum-Water (thin)-Aluminum → ~50 %





- Water thickness effects on efficiency[1]→

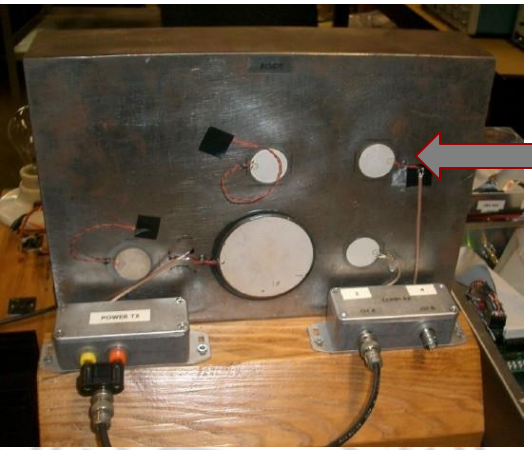


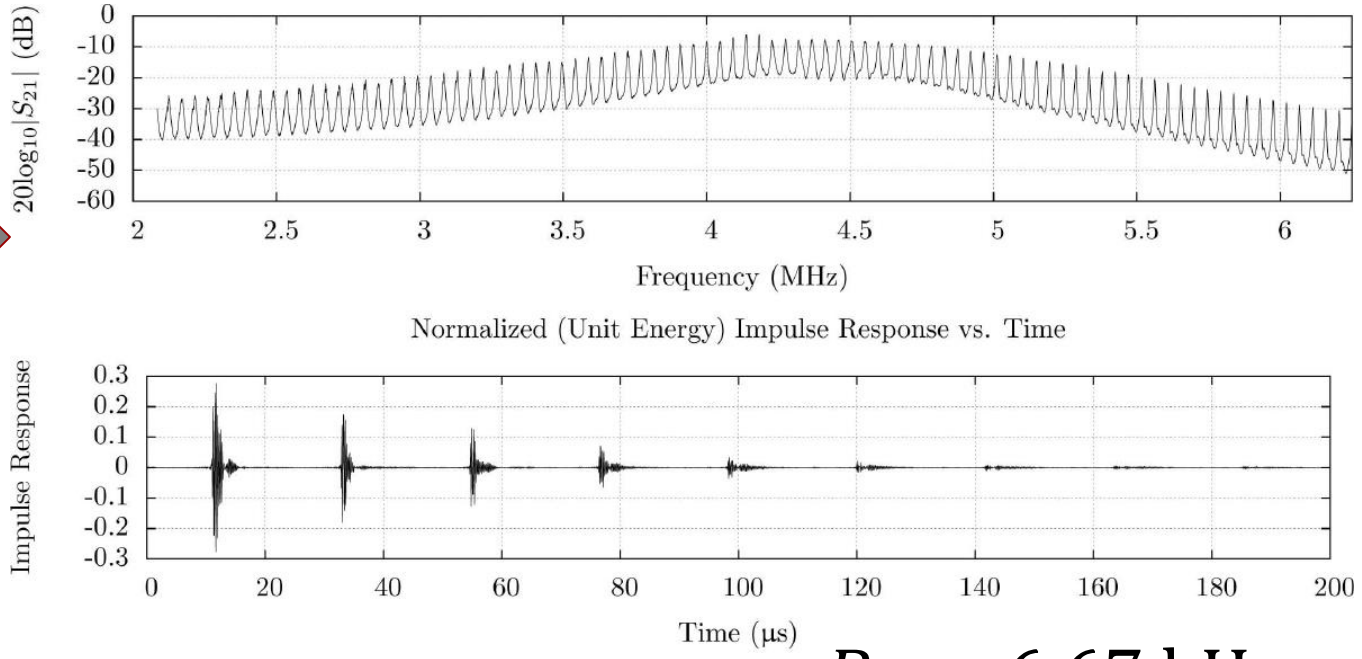
[1] Chakraborty, et al., 2013, Proc. SPIE Wireless Sensing, Localization, and Processing

Dedicated Communication Systems

- Acoustic systems are inherently reverberant, resulting in significant multipath
  - Unequalized, single carrier systems limited to bit rates lower than the coherence bandwidth (100s to 10,000s of bps)

2.5 in Steel



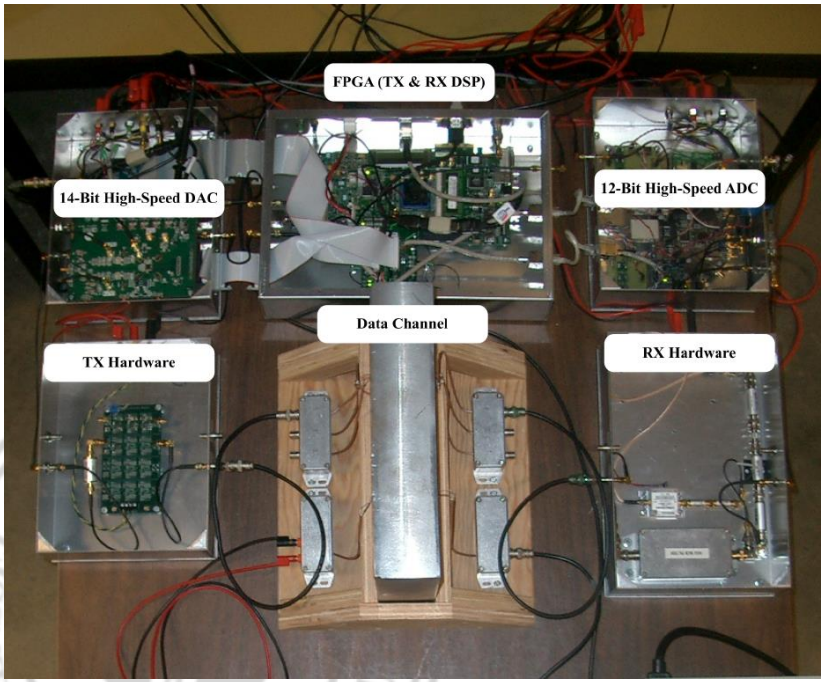


$$B_C \approx 6.67 \text{ kHz}$$

[1] Lawry, et al., 2013, IEEE UFFC 60(1)

Dedicated Communication Systems

- Acoustic systems are inherently reverberant, resulting in significant multipath
  - High data-rate systems possible using equalization or frequency-division multiplexing (e.g., OFDM)



- Demonstrated: 17.37 Mbps through 2.5 in thick steel[1]:
  - OFDM with Bit-Loading: 4096 subcarriers

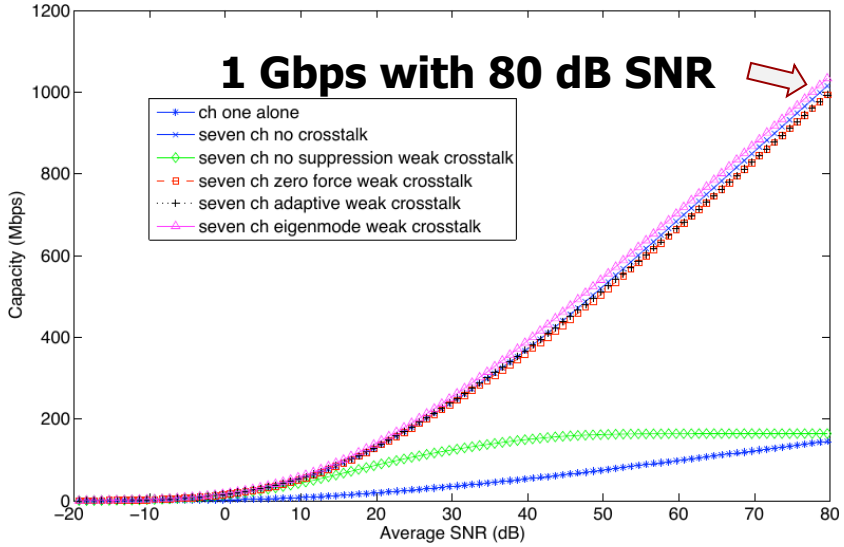
m^2QAM level	# Carriers
4	2766
16	1080
64	213
none	37
Total	4096

  - Frequency range: 2 - 6 MHz
  - Bit error rate: 1×10^{-6}

[1] Lawry, et al., 2013, IEEE UFFC 60(1)

Dedicated Communication Systems

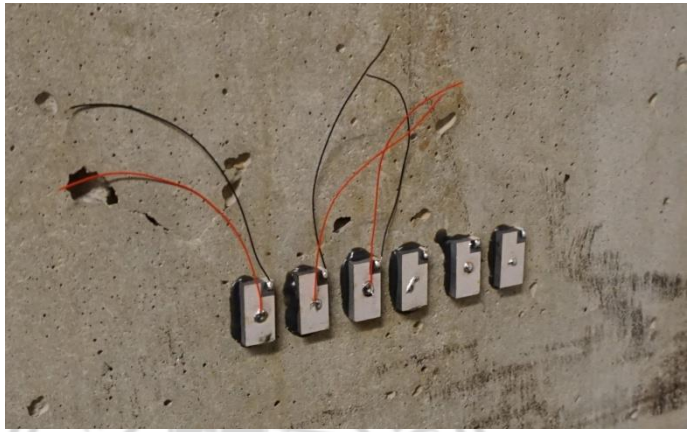
- Acoustic systems are inherently reverberant, resulting in significant multipath
  - Higher data-rates possible by implementing MIMO communication schemes
    - 100s to 1,000s of Mbps possible using NxN transducer arrays[1]
    - Array elements need not be isolated→ May be tightly packed
    - Example: 7x7 arrays, 1.6 in thick steel:

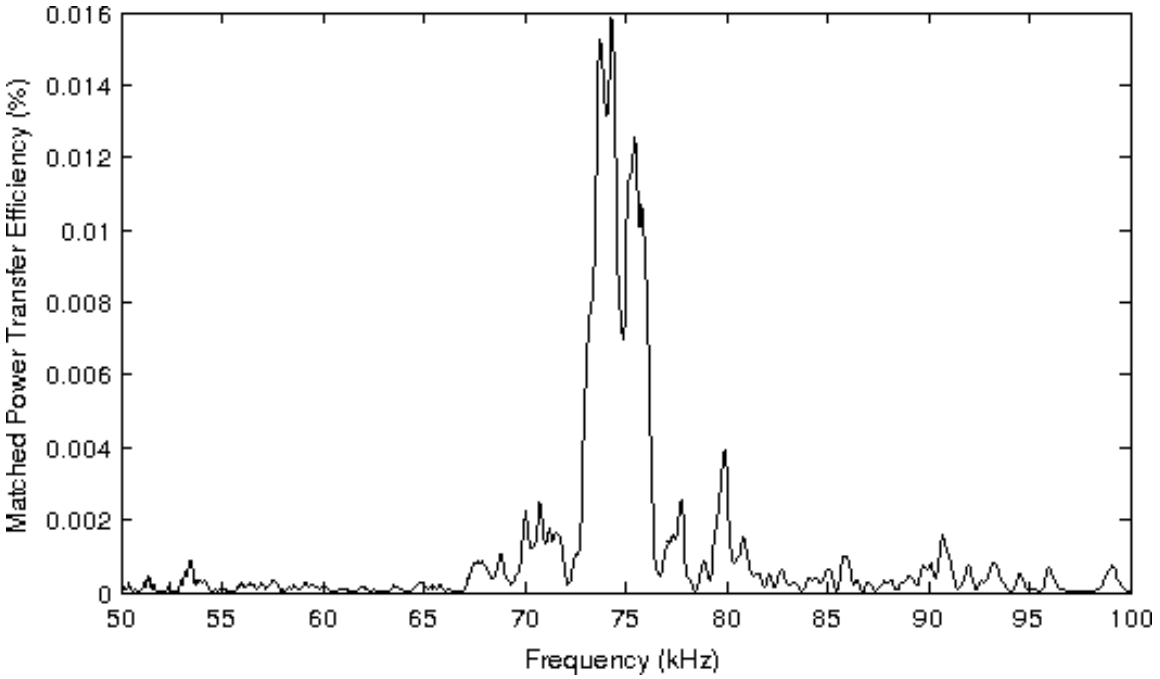


[1] Ashdown, et al., 2013, Proc. MILCOM

Dedicated Communication Systems

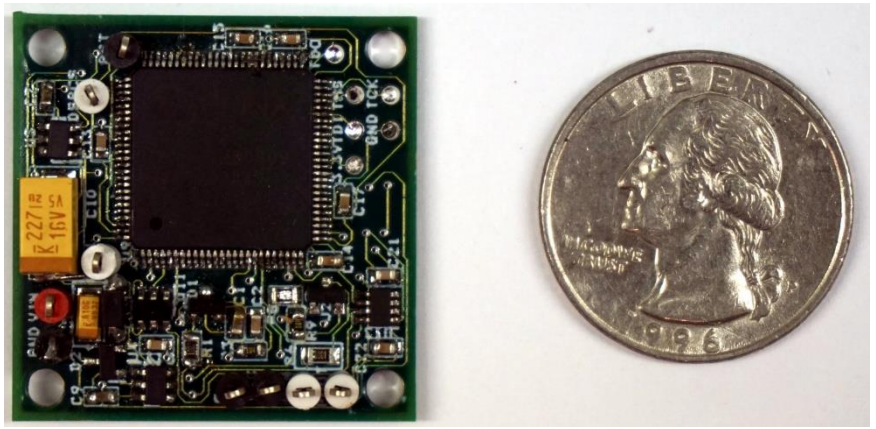
- Experiments on transmission through thick concrete structures with embedded rebar shows capabilities in high rate transmissions
  - Measurements through a 1 m thick concrete structural column
  - Would likely require MIMO schemes to achieve Mbps rates





Shared Power and Data Systems

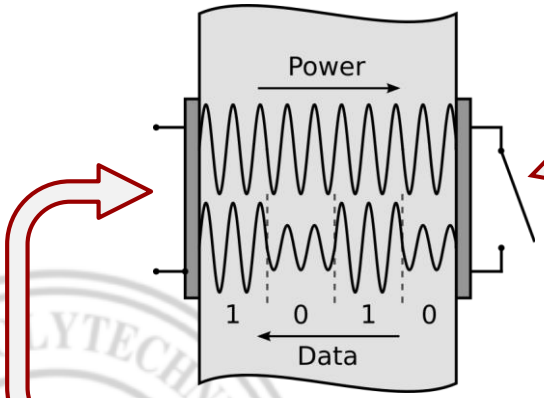
- Power and data is transmitted over a single pair of transducers
- Data may be uni- or bi-directional (half- or full-duplex)
- Useful for low-rate, low-power sensing.
  - 100s to 10,000s bps
  - Delivery of 10s milliwatts to several watts
- When paired with a rechargeable battery:
  - Capable of long-term data collection without power input
  - Battery recharged during data download
- Small footprint

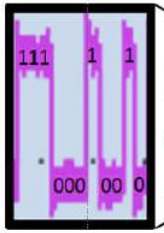


[1] Ashdown, et al., 2013, Proc. MILCOM

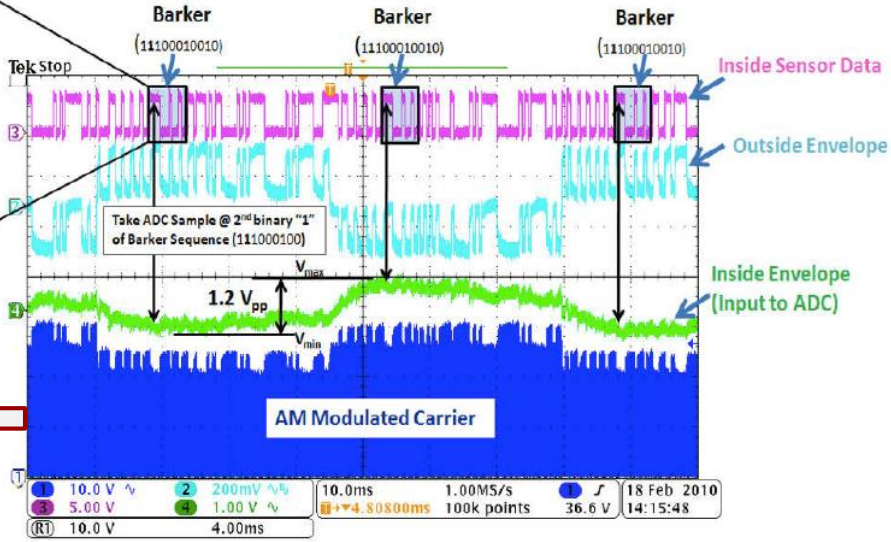
Shared Power and Data Systems

- Powering and Communication methods similar to passive RFID tags:
- Power is transmitted using a continuous wave carrier, as in the dedicated power systems
- Data sent back via modulation of the electrical load applied to the power receiving transducer
- Modulation detectable by transmitter as varying envelope
- Data can be sent to wireless module by modulation of input carrier

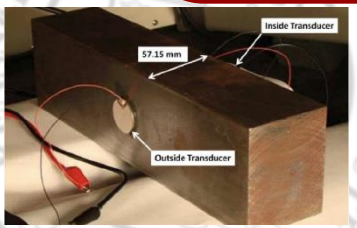




2.12 kbps



Nominal 1 MHz carrier

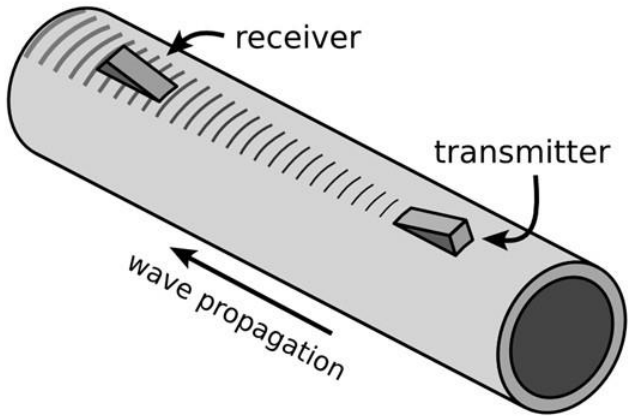


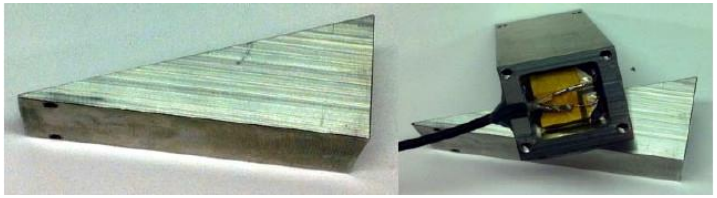
2.25 in carbon steel

[1] Ashdown, et al., 2013, Proc. MILCOM

Axial Power/Data along Pipes

- Preliminary development shows ultrasonics may be used to transmit both power & data along planar/curved structures
- Vibrations sent in either guided wave or bulk wave modes: geometry dependent
- Efficiency strongly influenced by transmission length and pipe boundaries
- Experiments on liquid/liquid boundaries:
  - 10" diameter steel pipe, ¾" wall thickness
  - 4 ft separation:
    - Efficiency: ~1 %
  - 15 ft separation:
    - Efficiency: ~0.1 %
  - 100 bps demonstrated for each case

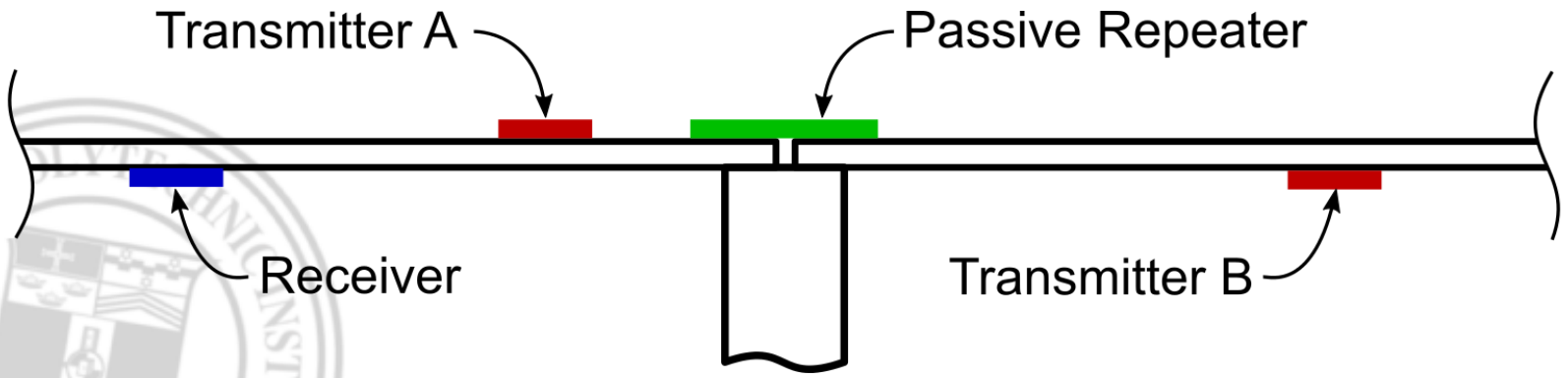




[1] Litman, et al., 2014, Proc. ASME IMECE

Vehicle Skin Communication

- Initial work has started on enabling acoustic communication of data along the skin of a structure
  - Purpose to avoid required bulky and complicated wiring harnesses
  - Prevents penetration of bulkheads
  - Data may be transmitted and/or received on either side of skin
- Transducers are low-profile
- Intended for low-rate sensing (e.g., 1 samples/second)



[1] Litman, et al., 2014, Proc. ASME IMECE

Summary

- Wireless capabilities include:
  - Low power, low rate sensing
  - High power transmission
  - High rate communication
- High power system may be used to power high communication rate systems as well as other devices
- Low acoustic signatures
  - Operation in ultrasonic range limits audible artifacts
  - Bulk of transmitted energy for high efficiency systems contained between transducers → Low leakage
- May be retrofitted onto manufactured structures