ULTRASONIC COMMUNICATION FOR HIGH-DATA RATE THROUGH-METAL APPLICATIONS

DREXEL UNIVERSITY
College of
Engineering
Wireless Systems Laboratory

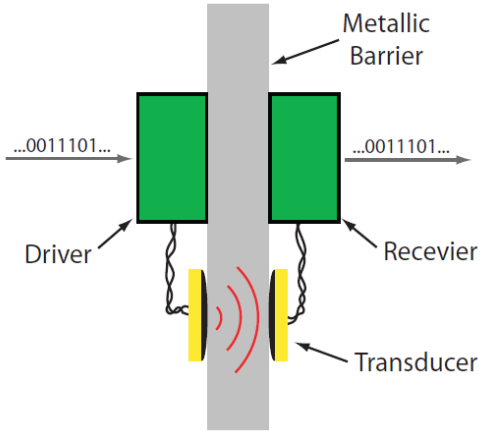
Drexel University
Electrical and Computer Engineering Department

Wireless Systems Laboratory
Data Fusion Laboratory

Motivation

- Many industrial environments can make reliable RF coverage harder to obtain
- Airtight / watertight structure
- Drilling holes is not allowed
- Harder to access the interior to take measurements
  - Need to remove many bolts

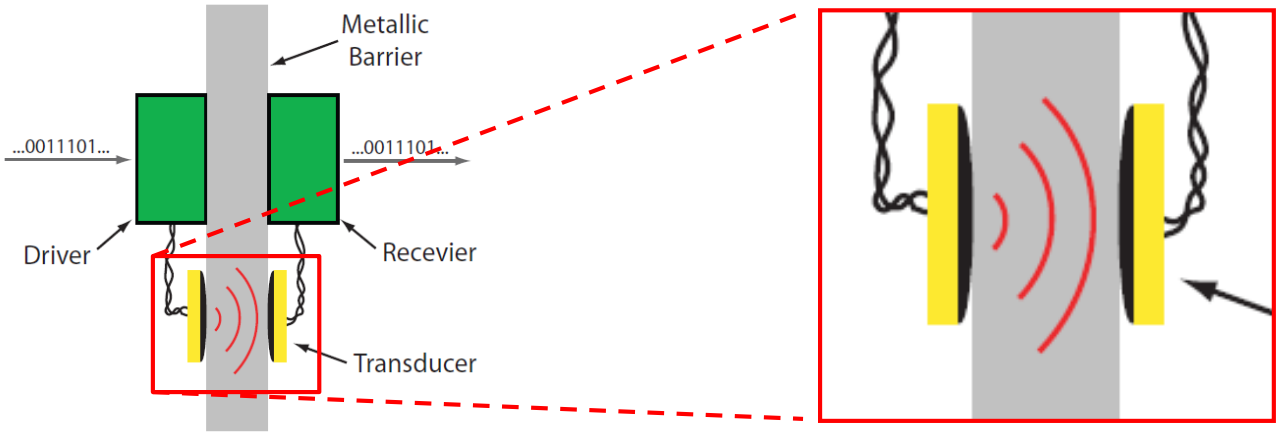
Ultrasonic Communication for High-Data Rate Through-Metal Applications



- Data enters the transceiver on the transmitting side of the barrier (through a wired or wireless connection).
- The data is modulated onto a waveform that drives the transmitting ultrasonic transducer.
- On the opposite side of the bulkhead, a second transducer receives the ultrasonic energy and recovers the transmitted data sequence from it.

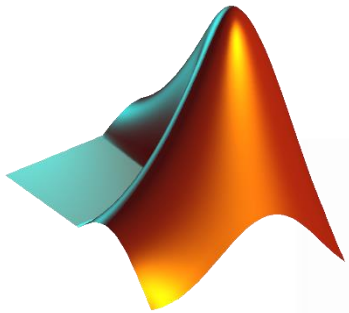
Application of Ultrasonic Communication

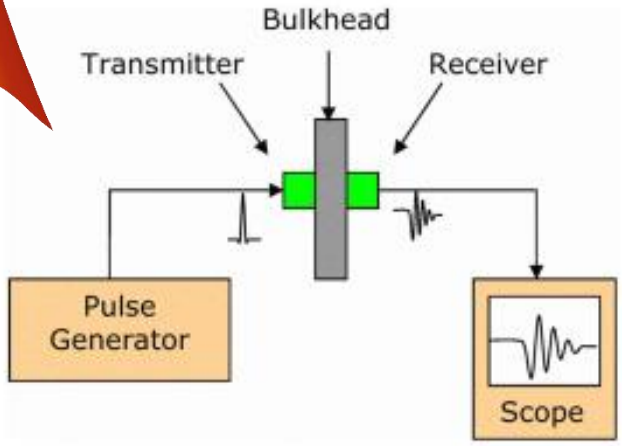
- Ultrasonic signaling **maintains the mechanical integrity of the metallic barrier**.
  - Blast rated, hermetically sealed, or high pressure applications.
  - Temporary or intermittent monitoring, e.g. transmission across drill casings or pipe walls

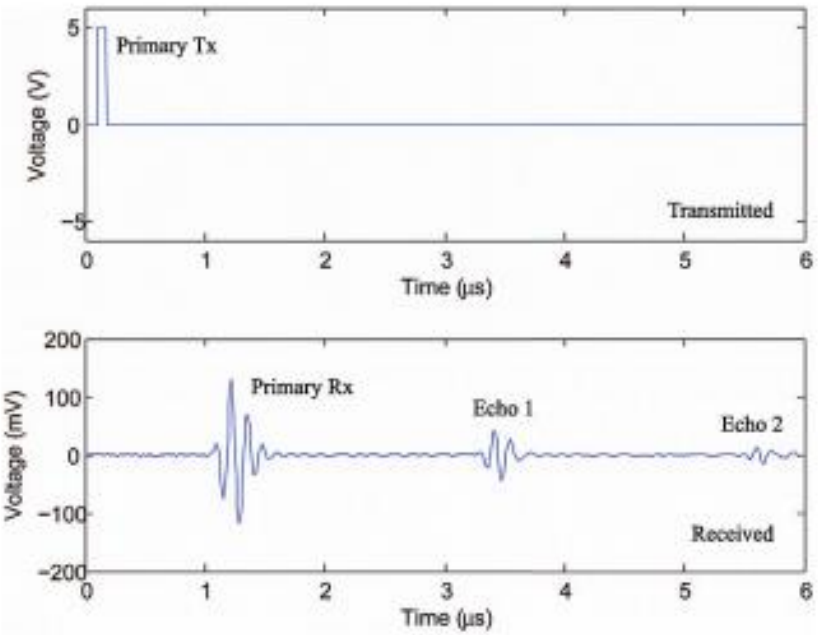


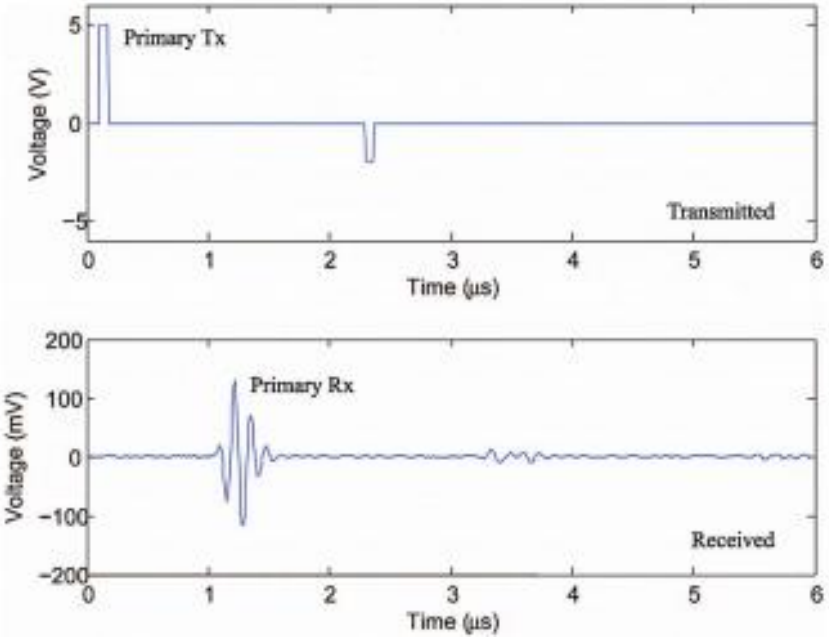
Ultrasonic Communication Through Metal Channels

- Previous research has shown that it is possible to get message across metal channels
- Acoustic echoing is a challenge
  - Intersymbol interference (ISI) at higher data rates (~ >10ksps)
- Echo cancellation
  - Predistortion filter
- ¼” thick steel plate
- Couplant gel
- Function generator at TX
- Oscilloscope at RX
- Post processed using MATLAB

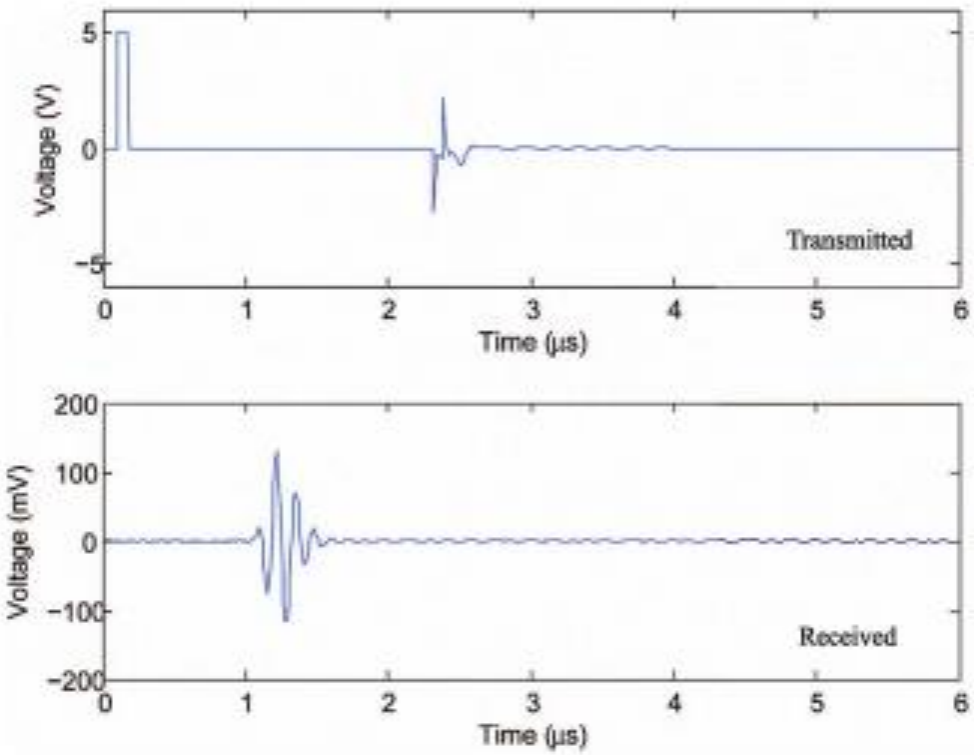





Primary Tx
Transmitted
Voltage (V)
Time (µs)
Primary Rx
Echo 1
Echo 2
Received
Voltage (mV)
Time (µs)


Primary Tx
Transmitted
Voltage (V)
Time (µs)
Primary Rx
Received
Voltage (mV)
Time (µs)

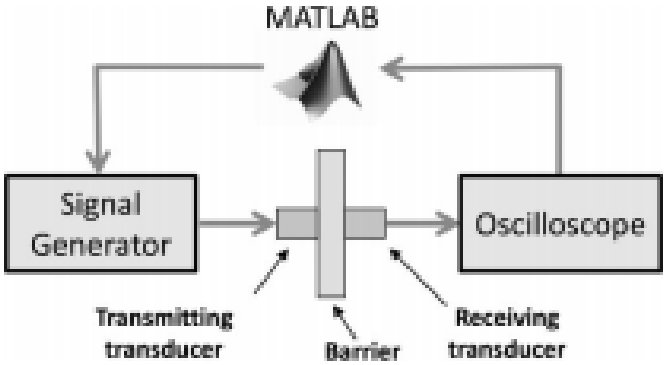
- Upon further tuning…
  - 20x better results



- Data rates ~ 5Mbps

Moving on to OFDM-like Systems

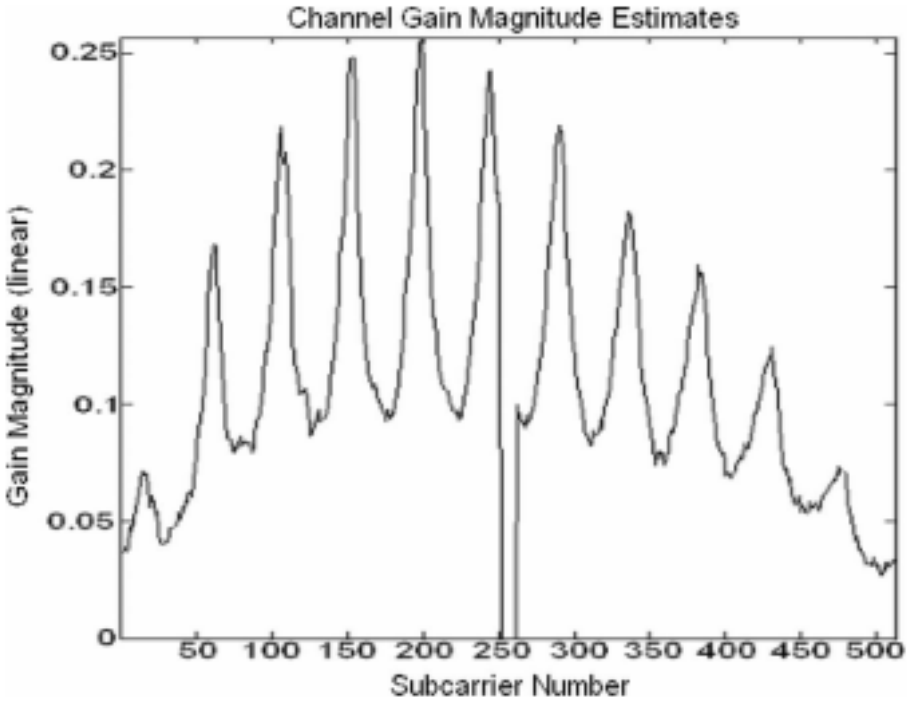
- Narrowband systems are limited with their data rates
  - 5 Mbps
- Link-adaptive Orthogonal Frequency Division Multiplexing (OFDM)
- Two 6-MHz, 0.25-in (6.35-mm) contact transducers (A112s non-destructive testing contact transducer, Panametrics NDT, Waltham, MA)
- Couplant gel (D-12 gel-type Couplant D, Panametrics NDT)



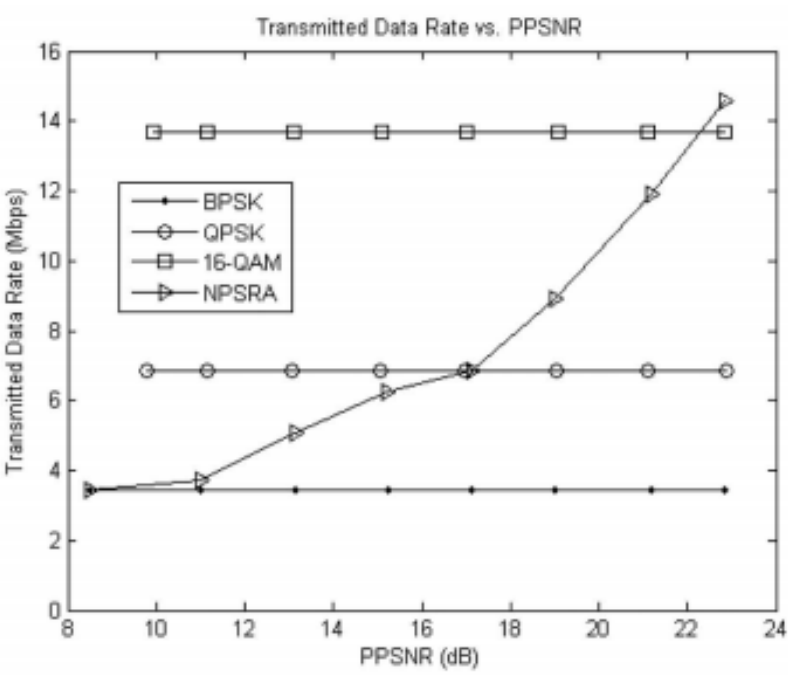
Moving on to OFDM-like Systems

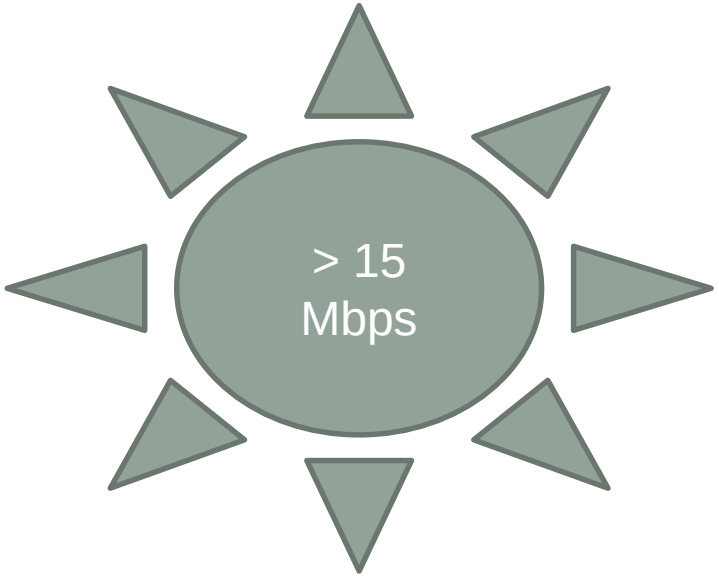
- 512 orthogonal subcarriers
  - 496 data subcarriers
  - 6 pilot tones for carrier frequency offset (CFO) correction
  - 10 guard bands
- QAM modulation
- A cyclic prefix of 128 samples, or 25% of each OFDM word, is appended to each OFDM word to capture ISI from channel echoing.
- The bandwidth of transmissions is 5 MHz at a center frequency of 8.3 MHz.

- Peak transmit power of 3dBm
- Channel is highly frequency selective
- Periodic nature of channel fading
  - Physical thickness of the material



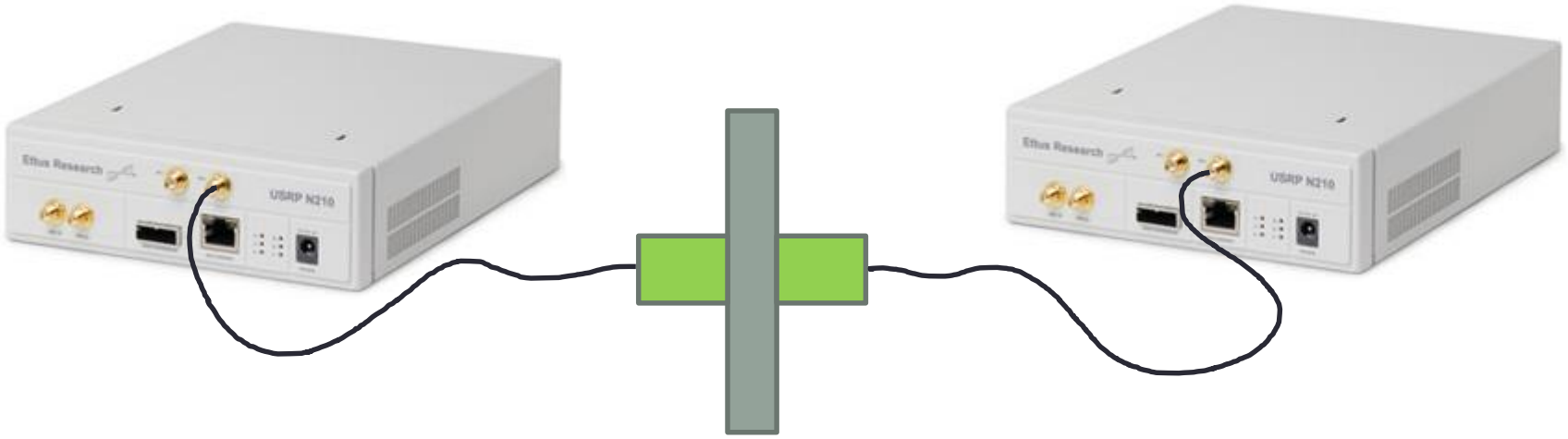
- BPSK, QPSK, N-QAM yields static data rates as the PPSNR increases
- Single constellation order across all subcarriers might be inefficient
  - Non-Power-Scaled Rate-Adaptive (NPSRA) bit loading algorithm
  - Train to estimate channel gains and EVM
  - Lookup table to select the modulation for the specific subcarrier





Ultrasonic Communication Test Bed

- Transmitter and receiver are software defined radios (Ettus Research USRP N210) with some additional amplification circuitry.
- This setup allows us to easily test new equalization schemes, transducers, and barrier materials.
- The system is portable, allowing remote testing and demonstration.



Ultrasonic Communication Research

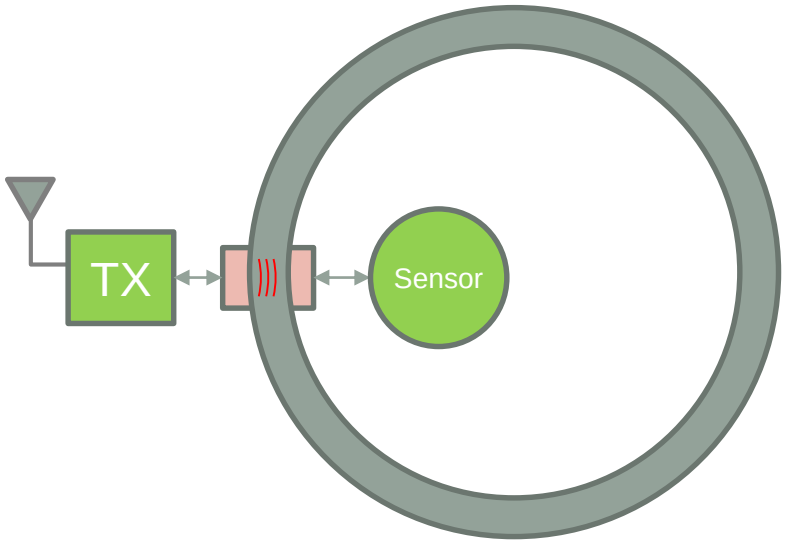
- Our group has been active in through-metal communication research since 2006 [1-7].
- Much of our work has been in developing techniques for high data rate (> 5 Mbps) communication
- At high data rates, ultrasonic echoing causes *intersymbol interference* (ISI) leading to significant data corruption.
- Several channel equalization techniques have been developed to allow for high data rate communication.
- We have demonstrated rates **in excess of 30 Mbps** through ¼” steel plate using commercially available transducers.
- Successful communication has also been demonstrated in barriers of other material and thickness, e.g. ¾” aluminum.

Areas of Active Research

- Down pipes and rods
  - We have demonstrated transmission down 1 meter aluminum rod.
  - High-speed transmission will require adaptation of our existing equalization techniques.
  - Ranges of 10's of meters appear possible.
- Communication across curved barriers
  - Pipes, pressure vessels, drill casings
- Coupled data and power
  - Acoustic energy can transmit power across barriers in the milliwatt and watt range.
  - Allows placement of sensors within sealed metallic envelopes, without the need for internal batteries.
- Non-contact transducers EMATs
  - Non-contact ultrasonic generation and sensing transducers.
  - Well suited for applications where surface corrosion or irregularities are present.

Communication Across Curved Barriers

- Techniques to address angular alignment issues have been developed.



Pipe cross-section

Research Capabilities

- Drexel has a significant body of IP and know-how in design of ultrasonic communication for through-metal applications.
- We *seek opportunities* to work with partners to *apply and extend* IP and know-how.
- New application area can quickly be tested using our ultrasonic communication system test bed.

- Research capabilities include
  - Design of transceiver, modulation and signal processing algorithms
  - Tools and facilities for prototype design and optimization
  - Accurate simulation models
  - Test chambers and instrumentation

- Provisional patent application - composition of matter
  - Drexel can provide more information available under confidentiality
  - Provisional application, analysis of prior IP, additional details as requested

Working with us

- Co-operative education employer
- Hiring of Drexel graduates
- Intellectual property licensing
- Consulting
- Collaboration on joint funding opportunities
- Gift / equipment donations
- Sponsored research agreement

Ultrasonic Communication Team

Kapil Dandekar: Associate Professor, Electrical Engineering, Drexel University. He is Director of the Drexel Wireless Systems Laboratory (DWSL). His research interests include electrically reconfigurable antennas, Printed antennas, MIMO and smart antenna networking, Software defined radio and cognitive radio prototyping and field-testing. He received a BSEE from the University of Virginia, and M.S. and Ph.D. degrees in Electrical and Computer Engineering from the University of Texas at Austin.

Richard Primerano: Assistant Professor in Drexel University's Received his Ph.D. from Drexel University in 2010 and is currently an assistant professor in Drexel University's College of Engineering. Dr. Primerano's research interests include signal processing, robotics, and control system design.

Moshe Kam: Dean of the Newark College of Engineering at the New Jersey Institute of Technology and the 2011 IEEE President and CEO. Dr. Kam is the director if the Data Fusion Laboratory (DFL). His research interests include decision fusion, robotics and controls, and forensic document analysis.

Drexel University and the College of Engineering

Drexel University:

- **Founded :**1891 by financier and philanthropist Anthony J. Drexel
- **Location:** five campuses: 3 in Philadelphia, 1 in Mt. Laurel , NJ, 1 in Sacramento, CA
- **Student Enrollment:** 13,484 undergraduates 9,009 graduate and professional students
- **Student Geographic Distribution:** Students come from 50 U.S. states and 130 foreign countries - nearly 8% are international.

Electrical and Computer Engineering Department at Drexel University:

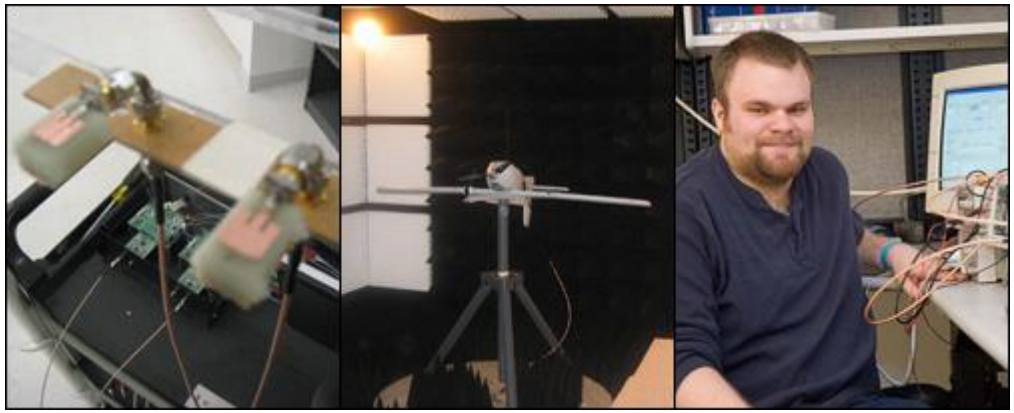
- **Faculty:** 32 full-time
- **Research Expenditure:** ~$10M annual
- **Bossone building:** Home to College of Engineering labs

Drexel Wireless Systems Laboratory (DWSL)

- Founded by Professor Kapil Dandekar at Drexel University's Department of Electrical and Computer Engineering in 2001.

- Research spans multiple communication modalities:
  - Ultrasound, free space optics, radio frequency techniques, PHY-layer security

- Over the past decade, DWSL has:
  - Designed, constructed, tested, and characterized several prototypes of advanced wireless hardware and software solutions



Drexel Wireless Systems Laboratory (DWSL)

Our current work focuses on:

- A software defined radio testbed for the academic and industrial research community capable of using ultra wide band (UWB) radio and optical communication modalities.

- Antenna technologies for advanced MIMO communications systems including:
  - Electrically reconfigurable antennas
  - Transparent antennas
  - Metamaterial-permeability enhanced antenna substrates
  - Metamaterial transmission line antennas
  - Fabrication techniques for non-traditional antenna substrates (e.g., fabric, glass, kevlar)

- PHY-layer security (authentication, encryption, jamming-resistance)
- Cognitive MIMO systems
- Ultrasonic communications
- Free space optical communications
- Environmental sensor networks

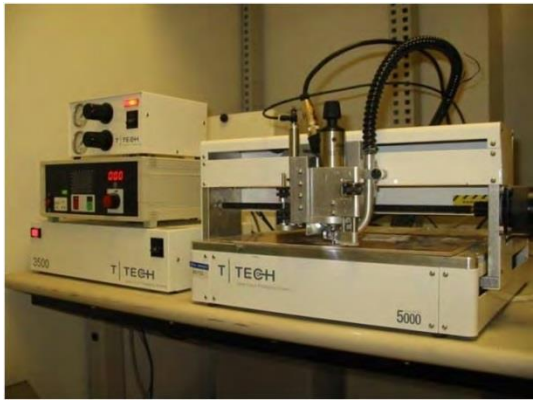
Facilities and Capabilities

- DWSL is equipped with state-of-the-art facilities including
  - A 3M fully anechoic chamber
  - A complete in-house circuit board fabrication facility
  - Materials printer facility
  - Programmable software defined radio testbeds
  - An extensive assortment of high frequency testing equipment
  - Several microwave and wireless systems analysis software packages

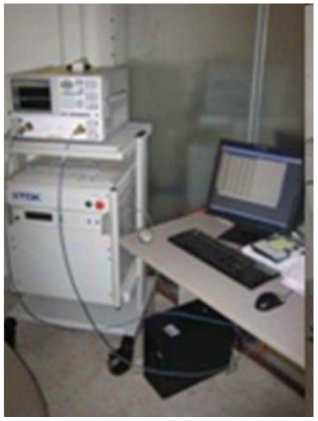
- DWSL has been supported by:
  - Industry, military and government
    - Corporate sponsorship from large equipment vendors and solution providers
    - Grants from National Science Foundation (NSF)
    - National Security Agency (NSA)
    - U.S. Office of Naval Research
    - U.S. Army CERDEC
    - Naval Research Laboratory

Facilities and Capabilities

FABRICATION AND TESTING FACILITIES

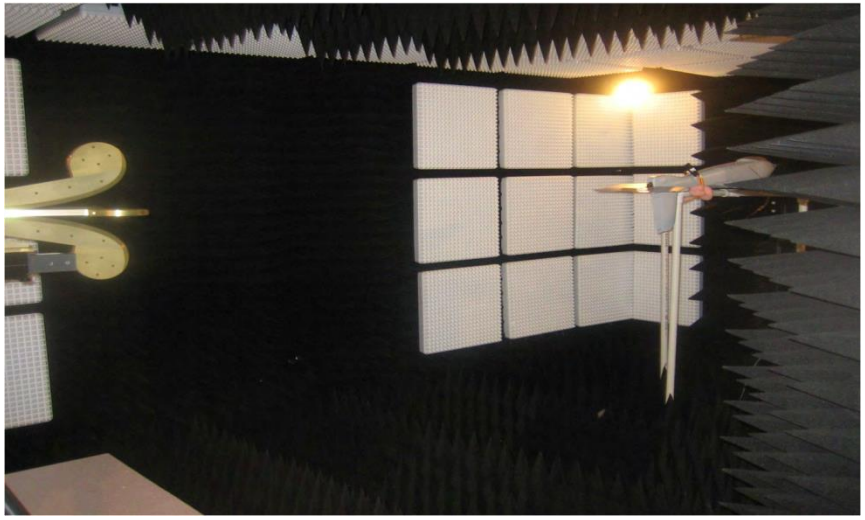


Left: T Tech Quick Circuit desktop prototyping system can produce accurate and quick analog, digital, or RF/microwave board prototypes directly from CAD drawings



Left: 2/4 port PNA Series VNA 6 GHz Inifiium oscilloscopes Signal Generators

Below: LPKF MultiPress for creating multilayer antennas and circuit boards



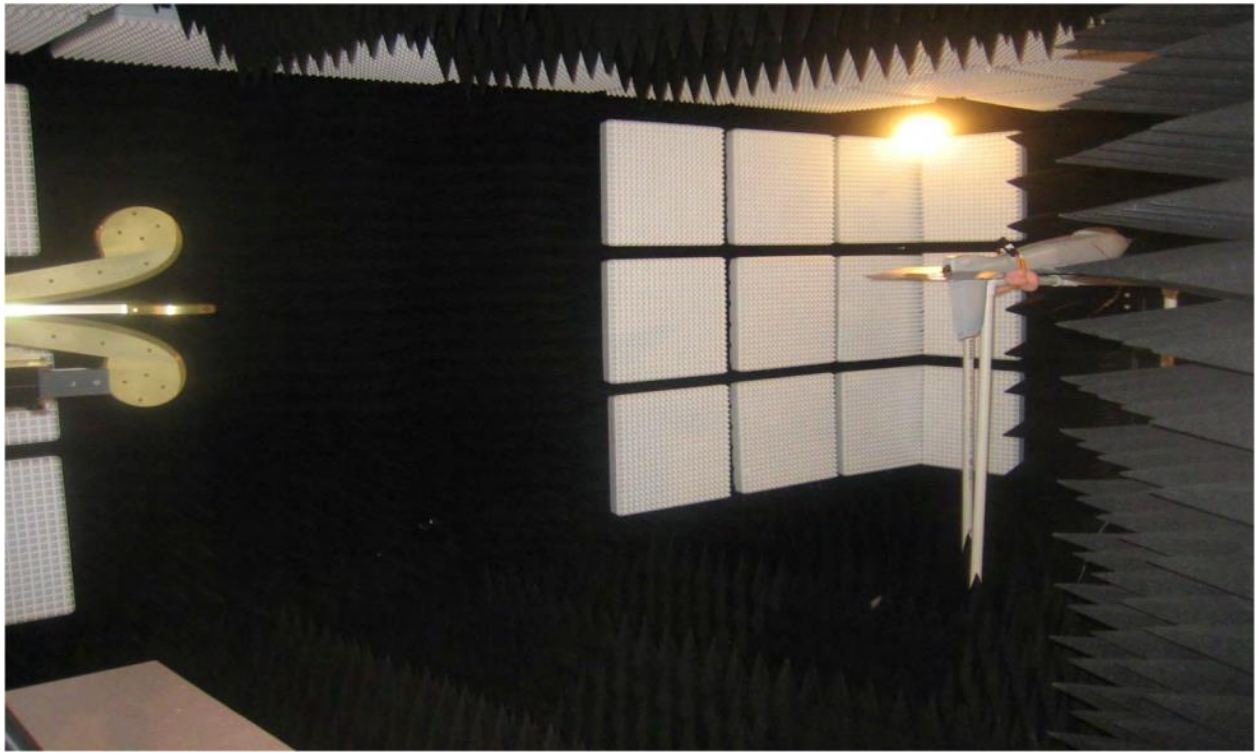
Left: Fully Anechoic Chamber Rated for testing systems operating at frequencies up to 23 GHz systems

Right: T Tech Quick Plate for thru-hole plating of antenna prototypes and circuit boards

Facilities and Capabilities

MAJOR FACILITIES

• Custom designed room that is isolated from external electromagnetic radiation sources and prevents the internal reflection of electromagnetic waves

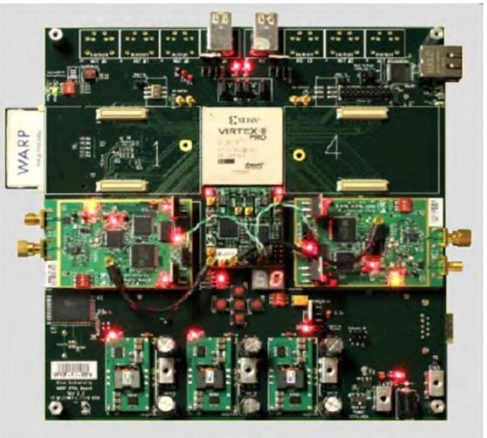


- Used to perform antenna and radiating system characterization
- Rated for testing systems operating at frequencies up to 23 GHz systems
- RFID metrology equipment also available

Facilities and Capabilities

TESTING AND MEASUREMENT PLATFORMS

Drexel SDR capabilities include WARP (v1.2, v3), HYDRA, and USRP2, USRP N210 platforms



WARP

- Modular FPGA/DSP design
- Daughtercards with 802.11 radios
- Variety of transceiver front ends planned
- Each node can perform real-time 2x2 communication with potential expansion to 4x4

HYDRA

- 2 x 2 MIMO orthogonal frequency division multiplexing (OFDM) software defined communication testbed system in an indoor environment
- Nodes consist of frequency agile transceivers operating in the ISM & UNII radio bands & a baseband processing computer

References

1. K. Wanuga, M. Bielinski, R. Primerano, M. Kam, and K.R. Dandekar. High-data-rate ultrasonic through-metal communication. Ultrasonics, Ferroelectrics and Frequency Control, IEEE Transactions on, 59(9):2051-2053, Sept. 2012
2. R. Primerano, K. Wanuga, J. Dorn, M. Kam, and K. Dandekar. Echo-cancellation for ultrasonic data transmission through a metal channel. Information Sciences and Systems, 2007. CISS '07. 41st Annual Conference on, pages 841-845, March 2007
3. K. Wanuga, D. Dorsey, R. Primerano, and K. R. Dandekar. Hybrid ultrasonic and wireless networks for naval control applications. Proceedings of the 2007 ASNE Intelligent Ships Symposium, May 2007
4. R. Primerano, M. Kam, and K. Dandekar. High bit rate ultrasonic communication through metal channels. In Information Sciences and Systems, 2009. CISS 2009. 43rd Annual Conference on, pages 902-906, 2009
5. M.M. Bielinski, K. Wanuga, R. Primerano, M. Kam, and K.R. Dandekar. Application of adaptive ofdm bit loading algorithm for high data rate through-metal transmission. In Global Telecommunications Conference (GLOBECOM 2011), 2011 IEEE, pages 1-5, December 2011
6. M. Bielinski, K. Wanuga, R. Primerano, M. Kam, and K.R. Dandekar. High data rate adaptive ultrasonic OFDM physical layer for through-metal communications. In Intelligent Ship Symposium (ISS 2011), 2011 American Society of Naval Engineers, May 2011
7. M. Bielinski, K. Wanuga, G. Sosa, R. Primerano, M. Kam, and K.R. Dandekar. Transceiver design for high data rate through-metal communication in naval applications. In Proceedings of the American Society of Naval Engineers Fleet Maintenance and Modernization Symposium, 2012, September 2012

Questions?

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