Low-Cost Underwater Wireless Communications and Applications

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Underwater Wireless Communications

- Applications:
  - Unmanned Underwater Vehicles (UUV)
  - Divers, Robots, and Sensors
- Possible communication means:
  - Optical beams: high BW, very short range < 2 m
  - Radio Frequency (RF): limited BW, short range
  - Magneto-Inductive (MI) Communications: low BW, short range (100 meters at 125 kHz)
  - Ultra-Sound (Acoustic Communication):

    Short range (<1 km): 100 kHz (HF)

    Medium range (1-100 km): 10 - 40 kHz (MF or HF)

    Long range (1000 km): < 2 kHz (LF)

Works Done at Missouri S&T

- MI underwater communications:

  Fc=125 kHz, BW = 300 Hz~4 kHz, OOK

  Low power, MCU implementation; 3-Coil Antenna

  Short range 50 ~ 60 m, RSSI localization.

- Acoustic underwater communications:
  - Medium range shallow water ocean applications:

    Fc= 20 - 40 kHz, BW = 4 – 10 kHz, moving or fixed Tx.

    Ranges: 60 m ~ 5 km, channel length: 80 ~ 200 taps

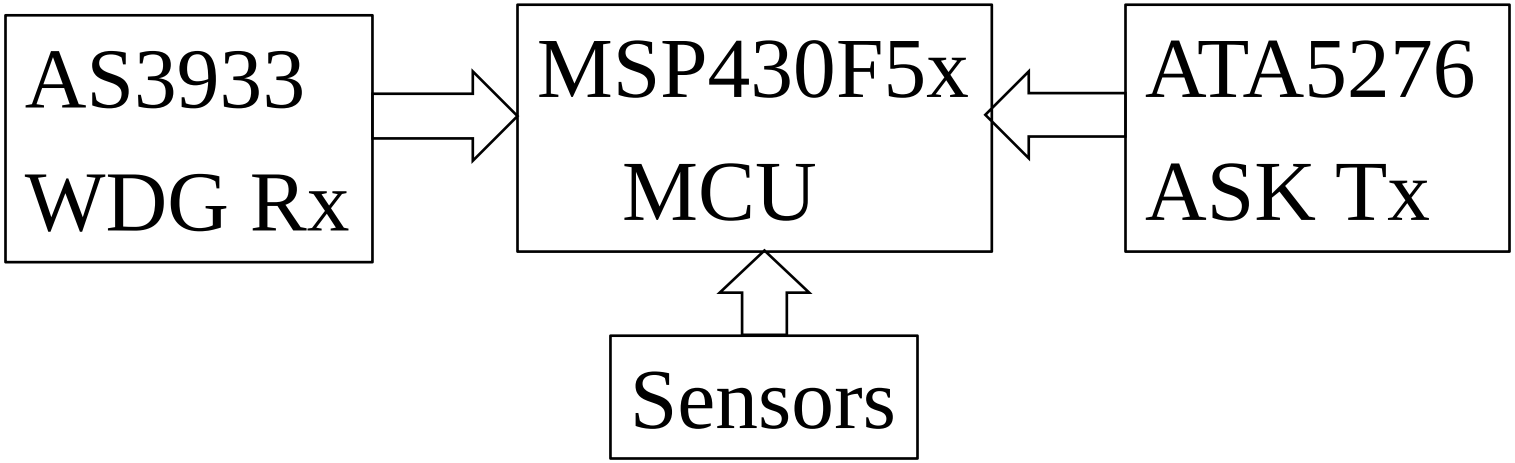
    MIMO (2-by-4 to 4-by-24), QPSK to 16 QAM
  - Short range shallow water river applications:

    Fc= 115 kHz, BW = 5 kHz, OOK or BPSK, SISO or MIMO, Range ~100 m, DSP or MCU, TDOA localization

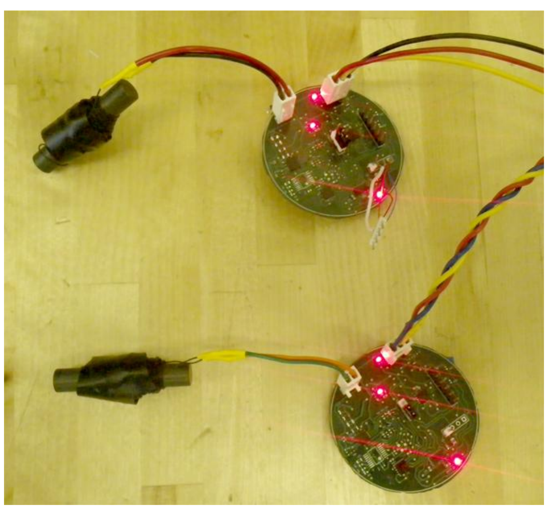
Applications of Short Range Systems

- Bridge Scour Monitoring
- Levee/Water Dam Monitoring
- River Bank Monitoring
- Oil/Water Pipe monitoring
- Underwater robots (Fish bot)

The MI System Implementation



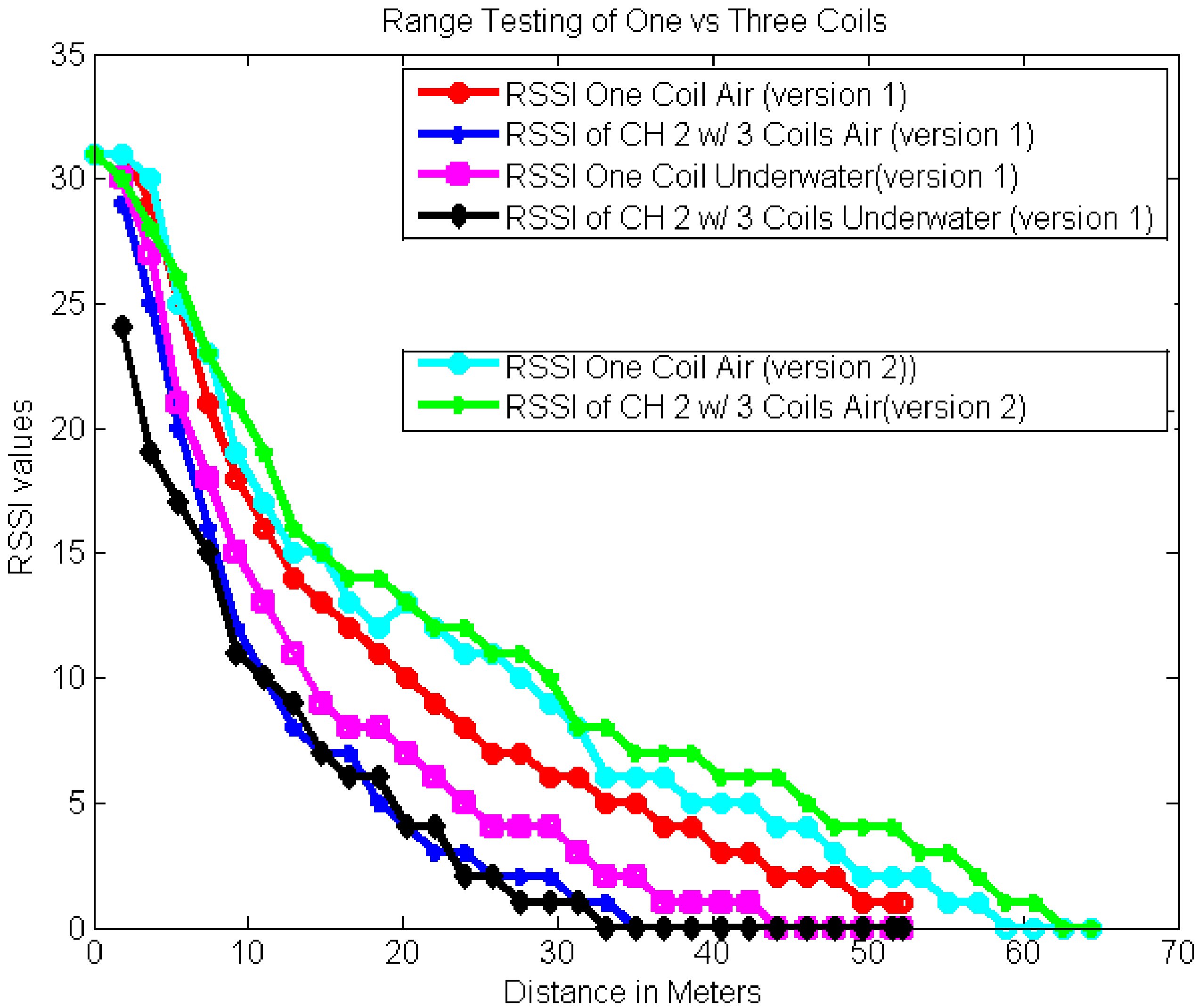
Ver 1 w/ small coil



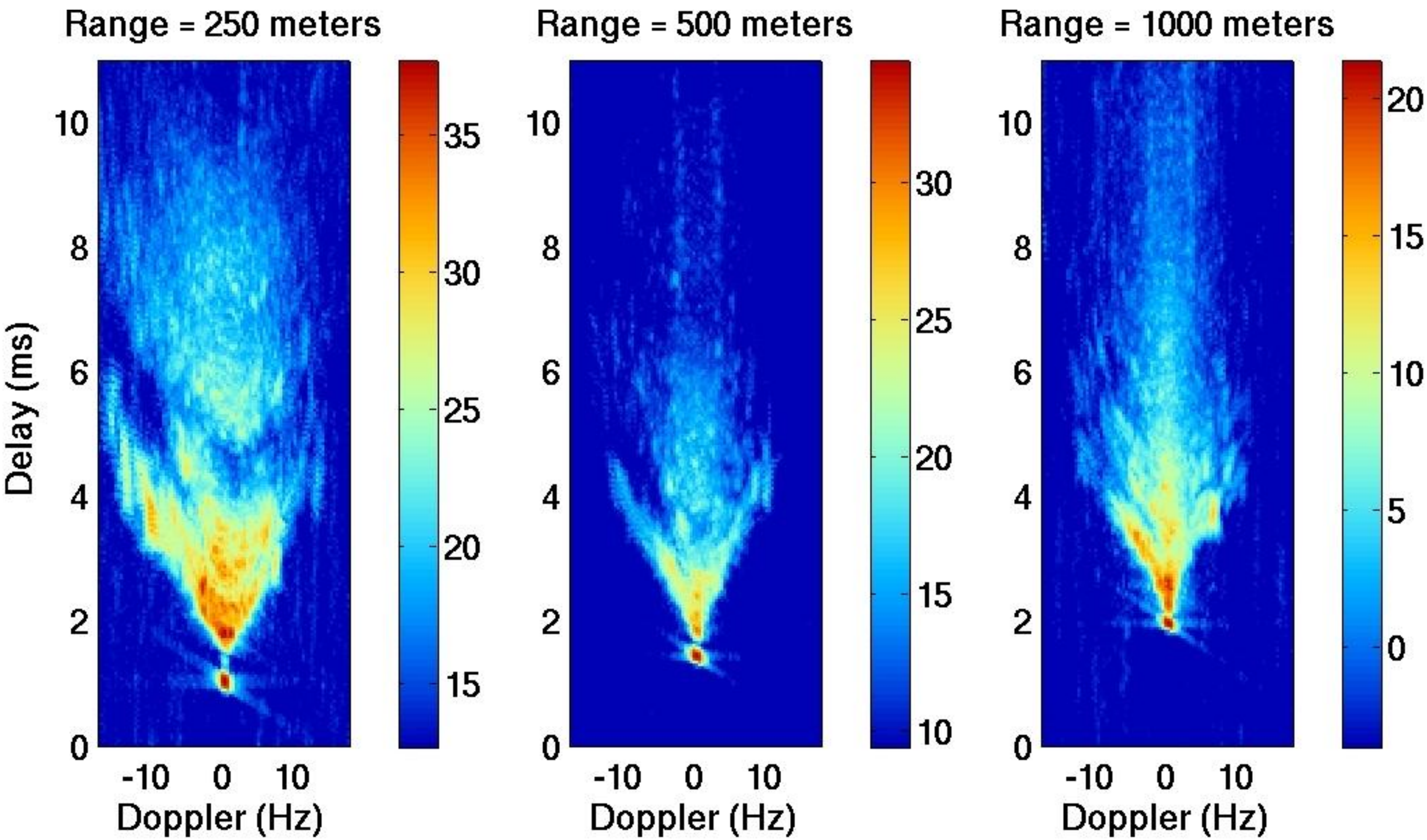
Ver 2 w/ large coil

Ver 3 w/ 3-D multi coils

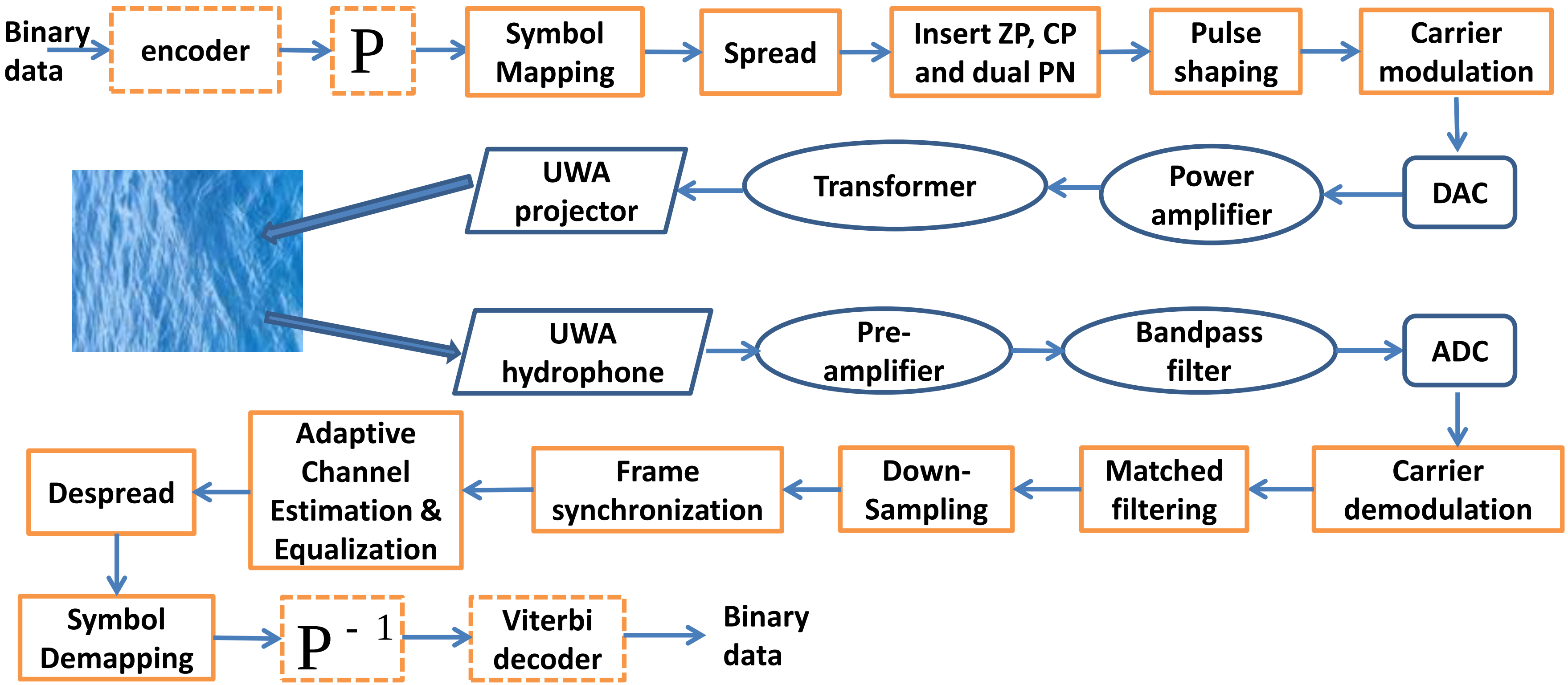
Field Test of MI System



Acoustic Communication Channels

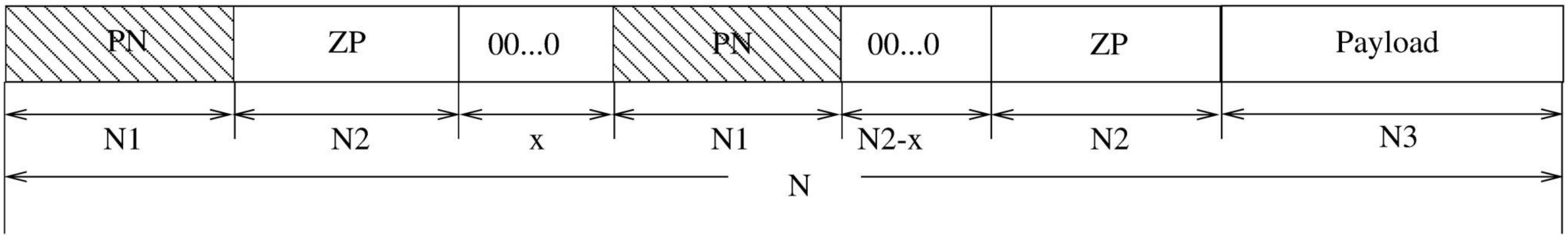


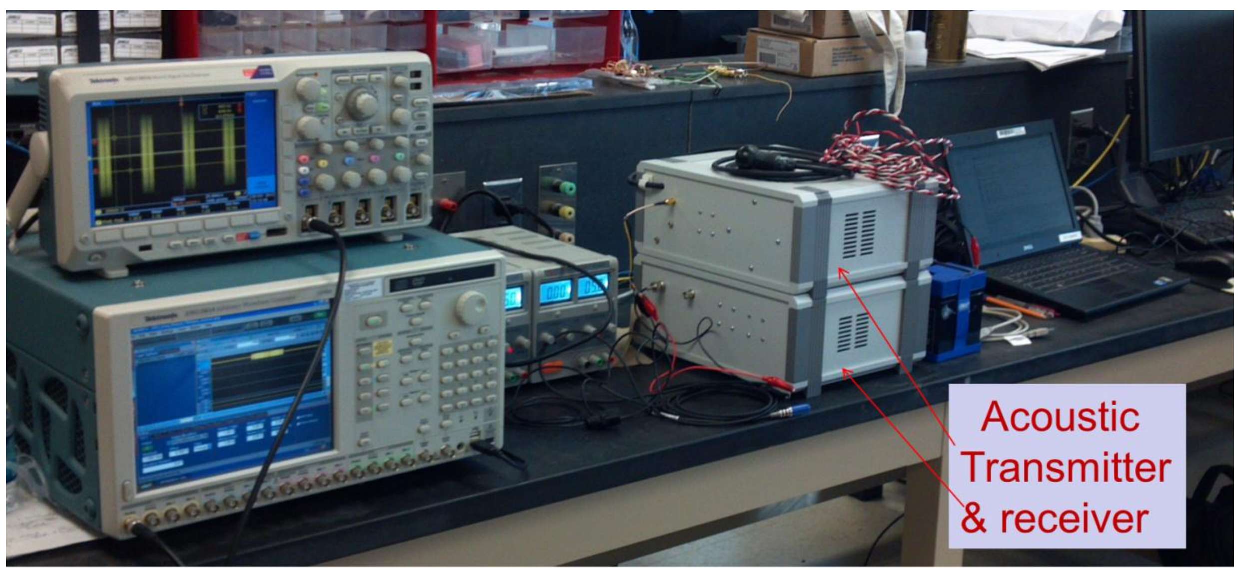
Acomm Communication Systems



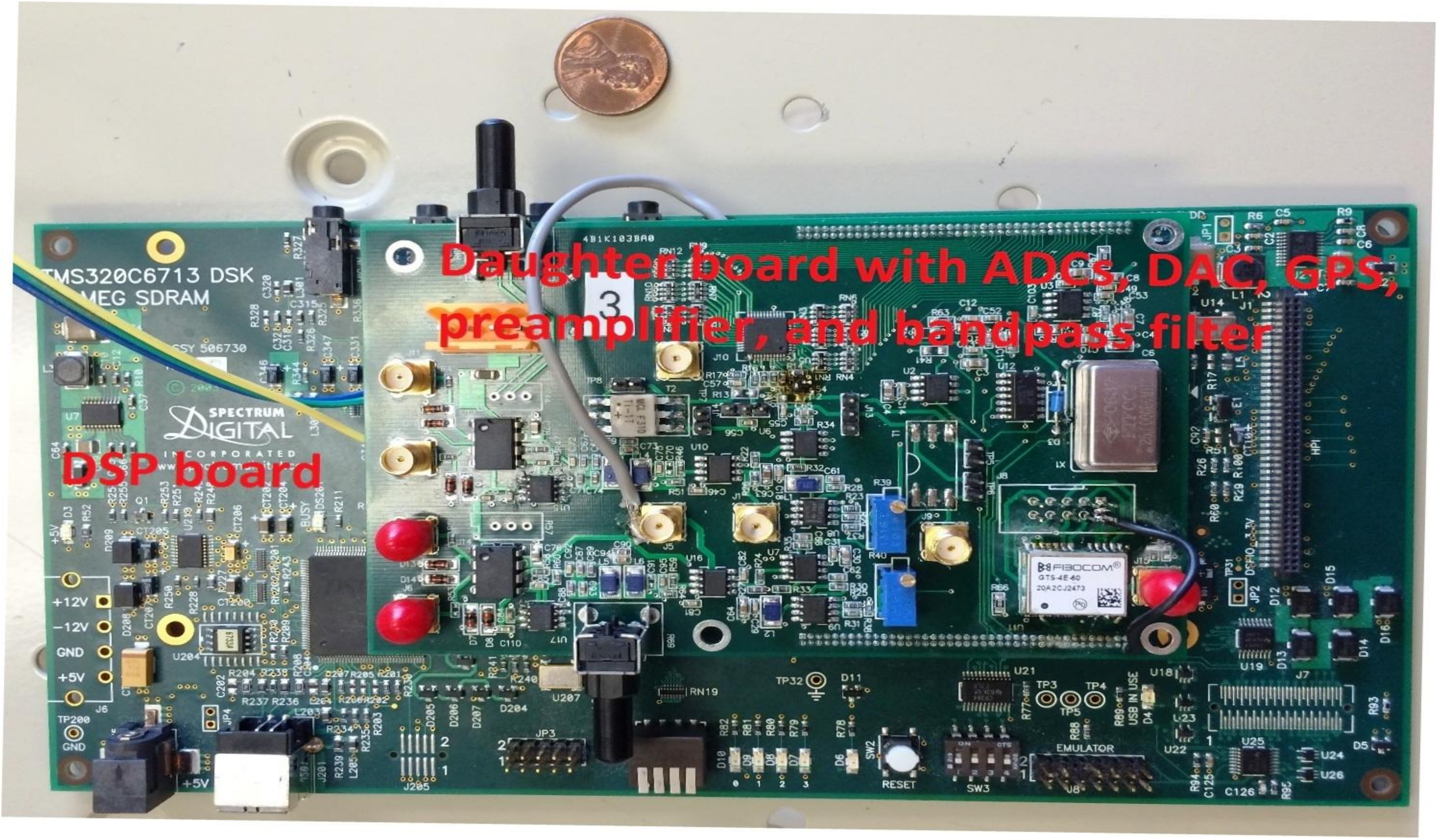
Acomm System: DSP Implementation

Transmitter/receiver hardware





DSP Hardware

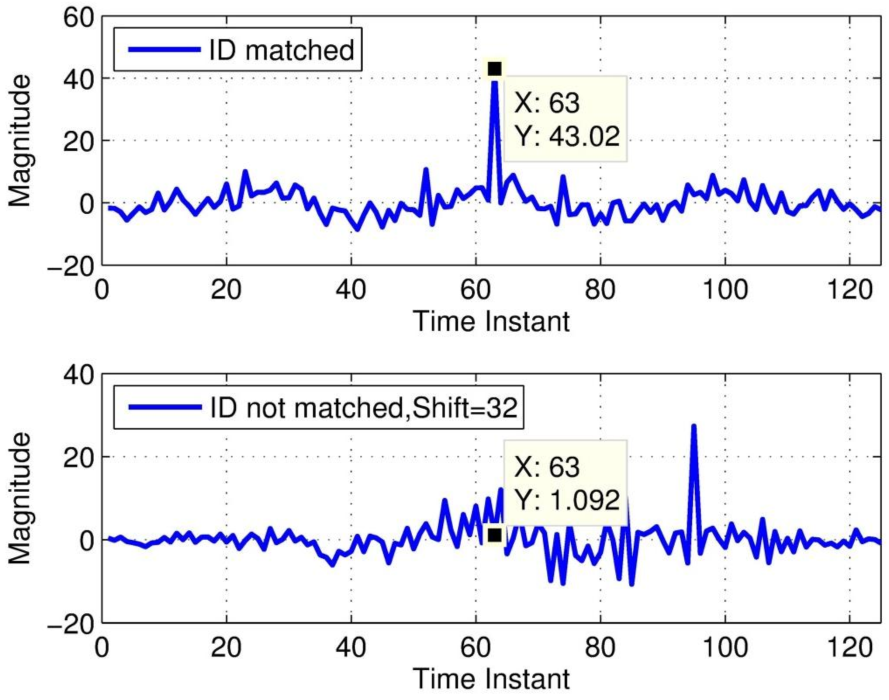


Design Challenges

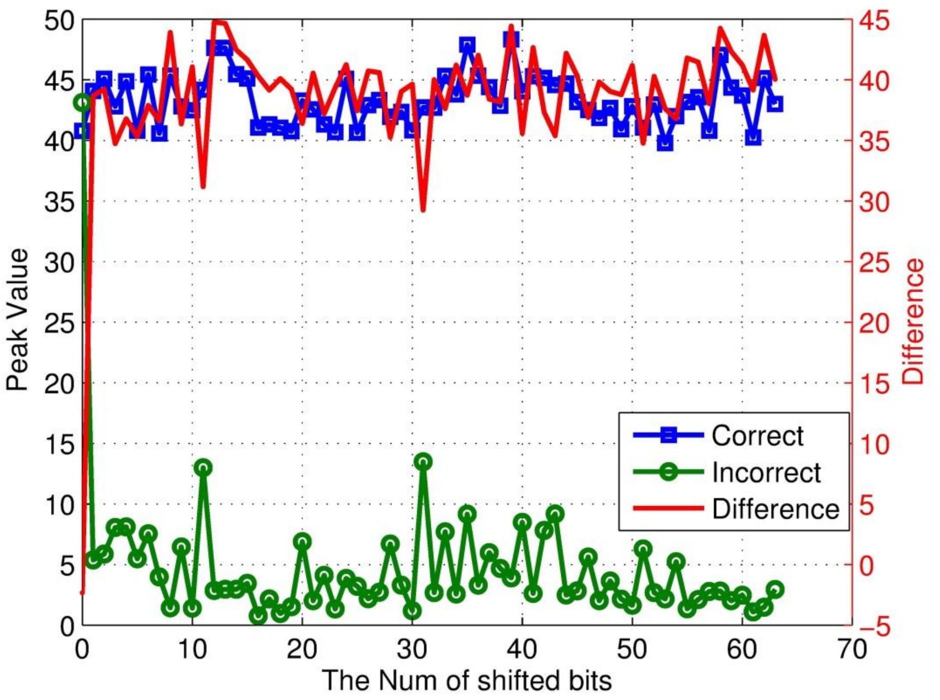
- Timing referencing among different receivers installed at two sides of the river
  - Atomic clocks: on-chip module $3000/piece
  - GPS timing module: $300/module
  - Radio clocks sync to NIST clock reference: $30 but not useful
- Severe multipath propagation: the strongest signal may not be the direct path – causing ranging and communication errors.
- Low cost, low power consumption, small form factor

Field Test Results - ID Detection

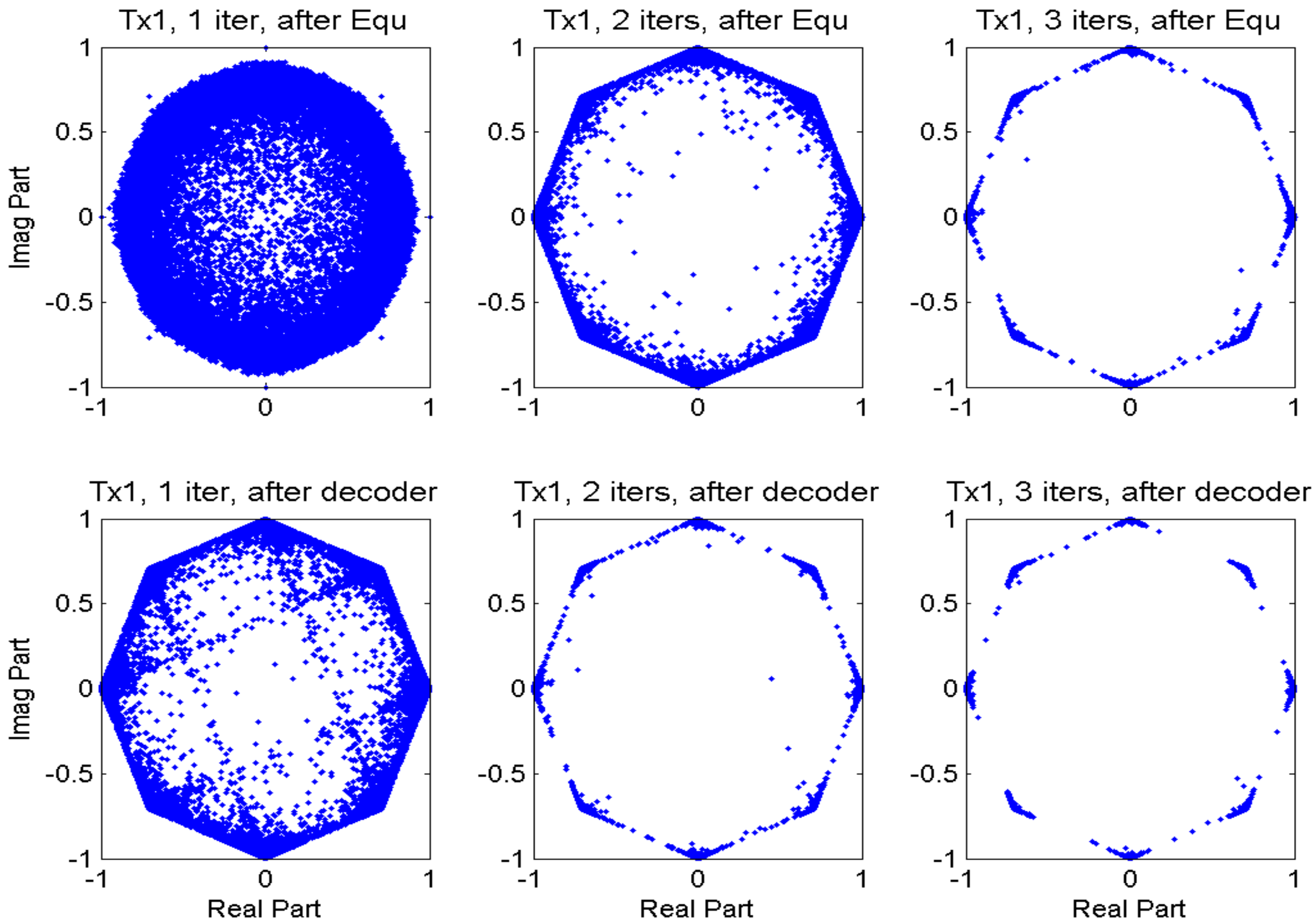
Correlation of 2 PNs



Correlator Output



Communication Performance



River Test Results – Localization

Tx/Rx	(x,y) coordinates (m)	Distance to Tx (m)
Rx1 ch1 (point 2)	(-6.1673, -26.3122)	6.7168
Rx1 ch2 (point 1)	(-11.8589, -35.7277)	6.1316
Rx2 ch3 (point 3)	(0.5304, -29.6561)	7.6654
Rx2 ch4 (point 4)	(-3.0279, -40.9669)	8.6093
Tx (point 5)	(-6.3545, -33.0263)	0

Estimated Tx location $\hat{\mathbf{x}} = (-6.1203, -33.2003)$

Rx-Tx ranges	ground truth	measured mean	variance
Ch1-Tx and Ch2-Tx	0.5852 m	0.6177 m	0.000736 m^2
Ch1-Tx and Ch3-Tx	-0.9486 m	-1.3053 m	0.0019 m^2
Ch3-Tx and Ch4-Tx	-0.9438 m	-0.8236 m	0.0065 m^2

$$\left.\begin{aligned} d_{12} &= ||\hat{\mathbf{x}} - \mathbf{x}_{ch1}||_2 - ||\hat{\mathbf{x}} - \mathbf{x}_{ch2}||_2 \\ d_{13} &= ||\hat{\mathbf{x}} - \mathbf{x}_{ch1}||_2 - ||\hat{\mathbf{x}} - \mathbf{x}_{ch3}||_2 \\ d_{34} &= ||\hat{\mathbf{x}} - \mathbf{x}_{ch3}||_2 - ||\hat{\mathbf{x}} - \mathbf{x}_{ch4}||_2 \end{aligned}\right\} ||\hat{\mathbf{x}} - \mathbf{x}||_2 = 0.29\text{m}$$

River Test of Smart Rocks