Underwater Vector Acoustic Communication via Particle Velocity Channels: Theory and Experimental Results

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Outline

- Signal Processing Using Vector Sensor Receivers
- Vector Communication Using Vector Transducers
- Scalar versus Vector Communication
- Benefits of Acoustic Vector Communication
- A MIMO-OFDM Vector System
- Vector Transmission Experiments
- Role of a Vector Sensor Equalizer
- Vision for the Future: Underwater Vector Modems
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Signal Processing Using Vector Sensor Receivers

- Used for SONAR, target localization, angle-of-arrival estimation.

- Advantages of vector sensors over scalar hydrophone arrays (some early papers: [1]-[4])
  - Avoiding the left-right ambiguity of linear towed arrays of scalar sensors
  - Significant acoustic noise reduction

- A vector sensor measures the vector components of the acoustic field, such as the three components of the acoustic particle velocity, in addition to the acoustic pressure.

- A scalar sensor measures the acoustic pressure.

Vector Communication Using Vector Transducers

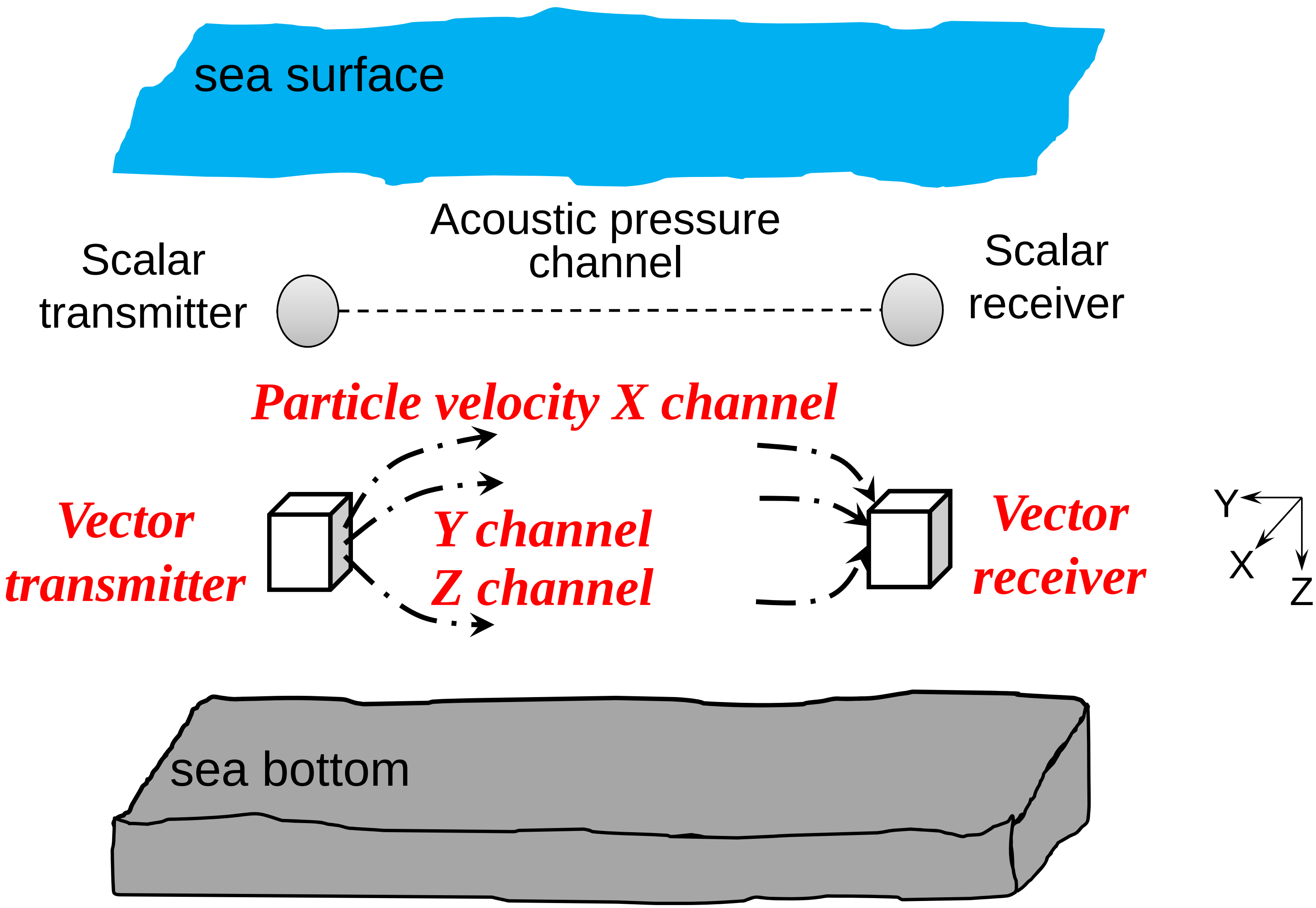
- **Scalar Underwater Communication**
  - Utilizes the acoustic pressure channel.
  - Acoustic pressure is the scalar component of the acoustic field.

- **Vector Underwater Communication Benefits from the Vector Components of the Acoustic Field [5]-[7].**

- **Particle Velocity Channels in Vector Comm. [5]-[10]**
  - They are vector components of the acoustic field.
  - Acoustic particle velocity is spatial gradient of the acoustic pressure.
  - There are three particle velocity channels: x, y and z.
  - Higher order channels such as acceleration channels do exist.

- **Vector Transducers**
  - Excite or measure the vector components of the acoustic field.

Scalar versus Vector Communication

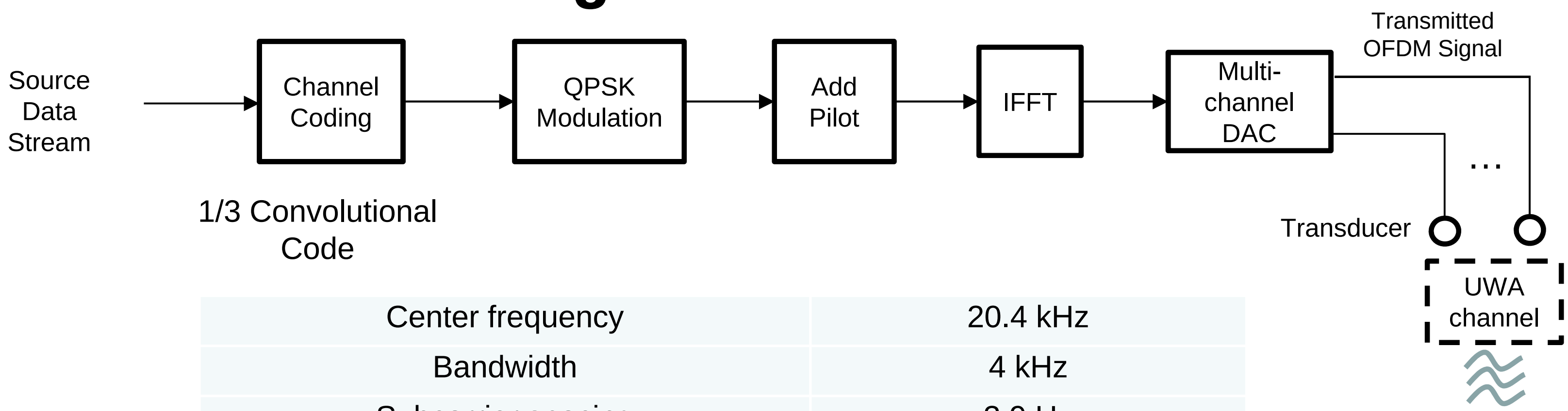


Benefits of Acoustic Vector Comm. Systems

- **Optimum utilization of the limited underwater bandwidth, via multiple channels.**
- **Increased transmission rate using a multi-channel vector projector [7] [11]**
  - **Simultaneous data modulation via vector spatial multiplexing**
  - **Examples: Doubling and tripling the transmission rate using one vector projector**
- **Improved multi-channel equalization using a vector receiver [5] [6] [10] [11]**
- **Compact vector transceivers are particularly useful in small platforms such as AUVs and UUVs.**

A MIMO-OFDM Vector System [11]

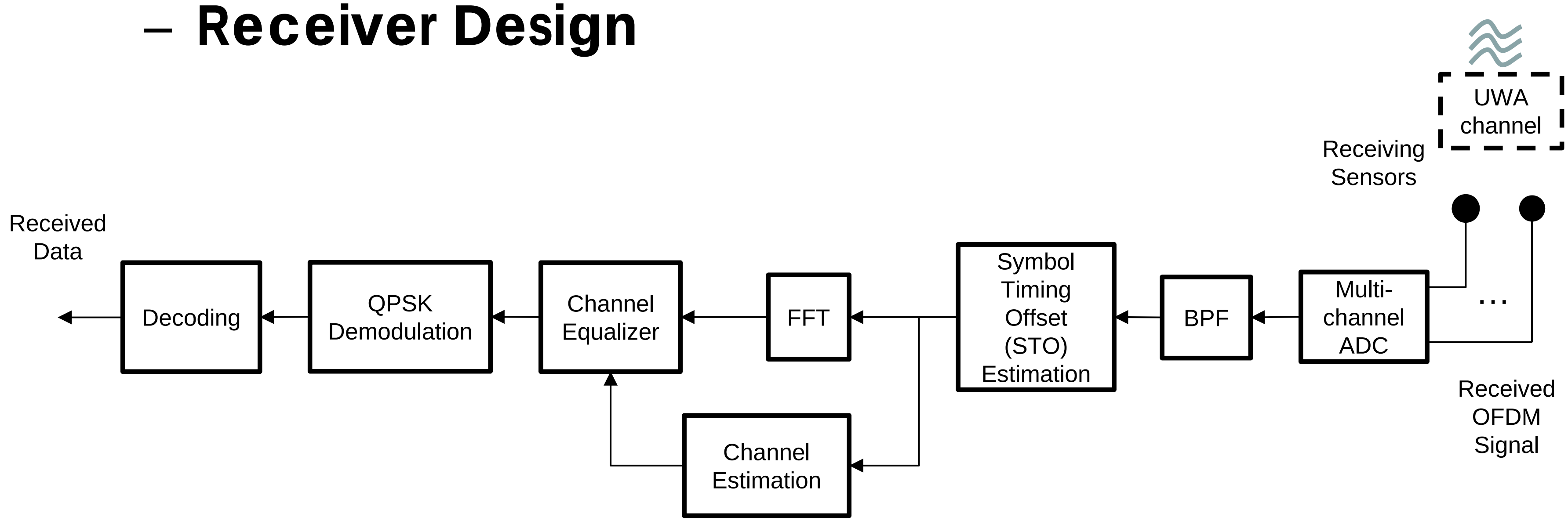
– Transmitter Design



Center frequency	20.4 kHz
Bandwidth	4 kHz
Subcarrier spacing	3.9 Hz
OFDM block duration	256 ms
Number of OFDM blocks	50
Sampling frequency	100 ksamples/sec
Modulation	QPSK
Time guard interval	25 ms
Number of subcarriers	1024
Number of pilot tones	256
Number of null subcarrier	96

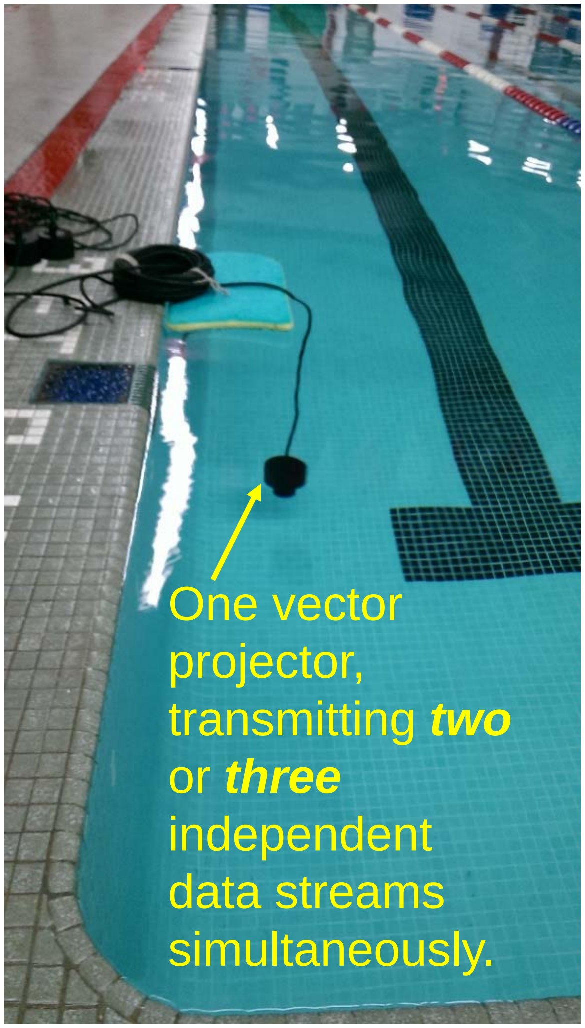
A MIMO-OFDM Vector System (cnt'd)

– **Receiver Design**



- **Symbol timing offset estimation using chirp preamble**
- **Least-squares channel estimation using pilot tones**
- **Convolutional decoding**
- **A MIMO-OFDM scalar system can be found in [12].**

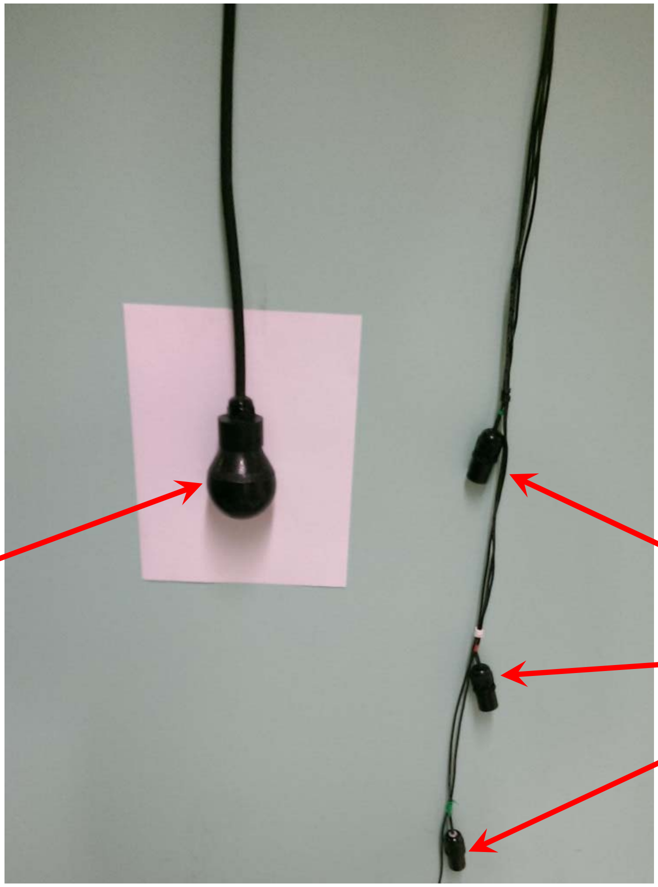
Vector Transmission Experiments



- **What we have done so far using one vector transmitter**
  - **Doubling the transmission rate**
  - **Tripling the transmission rate**
- **Two vector transmitters can be considered as well, for further rate increase.**

Role of a Vector Sensor Equalizer

– **A three-channel compact vector receiver instead of an array of three scalar hydrophones.**



A three-channel vector receiver, measuring x, y and z acoustic particle velocity components.

Three scalar hydrophones, measuring the acoustic pressure.

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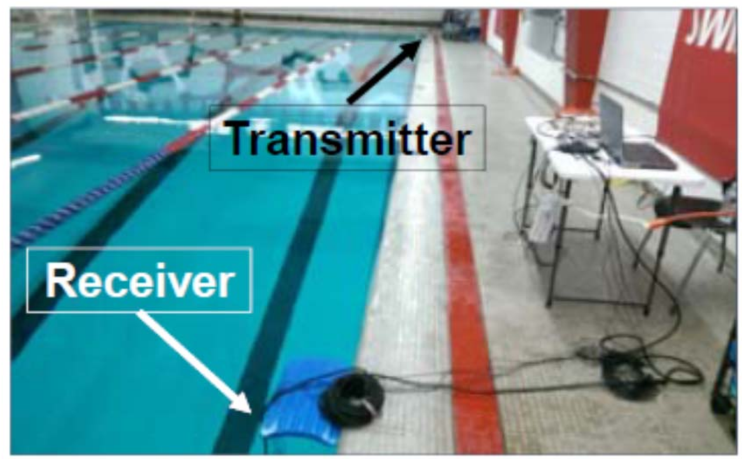
Vision for the Future: Underwater Vector Modems

Vector Transmitter

Vector Receiver

- Successful tests in a large pool with complex multipath propagation.
- Ocean tests are planned.



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Questions?