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

Ali Abdi
advanced Communication And Signal Processing (aCASP) Research Lab.

Electrical & Computer Engineering Dept.
New Jersey Institute of Technology, Newark, NJ

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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
- References
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

Scalar transmitter → Acoustic pressure channel → Scalar receiver

Particle velocity X channel

Vector transmitter → Y channel → Vector receiver

Z channel

sea surface

sea bottom
Benefits of Acoustic Vector Comm. Systems

- Optimum utilization of the limited underwater bandwidth, via multiple channels.

  - Simultaneous data modulation via vector spatial multiplexing
  - Examples: Doubling and tripling the transmission rate using one vector projector


- Compact vector transceivers are particularly useful in small platforms such as AUVs and UUVs.
**A MIMO-OFDM Vector System [11]**

**Transmitter Design**

- Source Data Stream
- Channel Coding
- QPSK Modulation
- Add Pilot
- IFFT
- Multi-channel DAC
- Transmitted OFDM Signal

**Table:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Center frequency</td>
<td>20.4 kHz</td>
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<tr>
<td>Bandwidth</td>
<td>4 kHz</td>
</tr>
<tr>
<td>Subcarrier spacing</td>
<td>3.9 Hz</td>
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<tr>
<td>OFDM block duration</td>
<td>256 ms</td>
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<tr>
<td>Number of OFDM blocks</td>
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<td>Sampling frequency</td>
<td>100 ksamples/sec</td>
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<td>Modulation</td>
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<tr>
<td>Number of subcarriers</td>
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<tr>
<td>Number of pilot tones</td>
<td>256</td>
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<tr>
<td>Number of null subcarrier</td>
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</tbody>
</table>

**Transducer**

**UWA channel**
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.
Vision for the Future: Underwater Vector Modems

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

Questions?