RECENT ADVANCES IN DOPPLER SONAR TECHNOLOGY FOR SUBSEA NAVIGATION AND CURRENT PROFILING

Oceanology International, China
September 3-5, 2013

Alan Kenny
Teledyne RD Instruments
San Diego, CA
Agenda

• Doppler Sonar – Fundamentals
• Historical Perspective
• Early Limitations and Overcoming Challenges
• Current State-of-the-Art
• Advancements and Next Steps
Origin of Doppler Sonar


Doppler Sonar
How it works

- The Doppler sends out a 4-beam “Ping” and measures the resulting response in terms of frequency shift. (i.e. Doppler Shift)
- This translates to a Velocity relative to the reflection point (e.g. the bottom or a water layer)
- Velocity is measured in three directions (two horizontal (x,y) and one vertical (z))
- Allows Calculation of position while underwater (Doppler Velocity Log (DVL))
- Allows Measurement of Currents (Acoustic Doppler Current Profiler -ADCP)
Current: Conversion of Doppler shifts measured from the scatterers on each beam into east, north, and vertical velocity components.

Two beams combine to yield vertical and horizontal velocity profiles in this plane.

Second pair of (orthogonal) beams yields orthogonal horizontal velocity and another measurement of vertical velocity.
Profiler: Returned echoes from the outgoing transmit pulse are time gated and stored into “depth cells” as the transmit pulse moves through the water column resulting in a current profile.
Doppler Sonar

Purpose

• Measures water current velocities
  – *Water in Motion*

• Measure velocity of a surface or subsea platform through water
  – *Motion in Water*
Induced Doppler Effect

300KHz ADCP: \( F_s = 307200 \text{Hz} \); \( C = 1500 \text{m/s} \); If \( V = 4 \text{ knots} (2 \text{m/s}) \) and \( \theta = 70 \) degrees:

\[
FD = 2 \times 307200 \text{Hz} \left( \frac{2 \text{ m/s}}{1500} \right) \times \cos(70) = 288 \text{ Hz} \text{ Doppler Shift}
\]

The DVL uses beam angles that are tilted 20 or 30 degrees from the vertical. This allows it to sense a Doppler shift when it is pointing downward.

\[
Fd = 2 \times F_s (V/C) \cos(A)
\]
Original Doppler Sonar

Original (clockwise) Sonar, Doppler Sonar, and Speed Log systems required large top-side power and computing sources. And very large hull mounted transducers.

*Could only be used on surface vessels or Submarines.*
## The Challenge

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Range - Profiling</th>
<th>Range – Bottom Track</th>
<th>Single Sensor Size</th>
<th>Weight</th>
<th>Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>38 kHz</td>
<td>800 - 1,000 meters</td>
<td>2,100 + meters</td>
<td>92 cm</td>
<td>400 lbs.</td>
<td>1400 Watts</td>
</tr>
<tr>
<td>75 kHz</td>
<td>560 – 700 meters</td>
<td>1,000 meters</td>
<td>40 cm</td>
<td></td>
<td>300-1,400 Watts</td>
</tr>
<tr>
<td>150 kHz</td>
<td>375 – 400 meters</td>
<td>560 meters</td>
<td>22 cm</td>
<td>25 lbs.</td>
<td>20-35 Watts</td>
</tr>
<tr>
<td>300 kHz</td>
<td>80-100 meters</td>
<td>250 meters</td>
<td>13.75 cm</td>
<td></td>
<td>8-66 Watts</td>
</tr>
<tr>
<td>600 kHz</td>
<td>35-40 meters</td>
<td>90 meters</td>
<td>7.5 cm</td>
<td>4-</td>
<td>2 - 21 Watts</td>
</tr>
</tbody>
</table>
Range vs. Temperature

Range is also dependent on temperature. Thus, the warmer the water, the lower the frequency required for a given range.

Range of 15 kHz Phased Array Sensor for Bottom Tracking (Lt. Blue) and Current Profiling (dark blue)
The Challenge  Size, Weight, Power

Lower Frequency Sensors are generally limited to large fixed or stable platforms

75 kHz piston Array

Higher Frequency Sensors allowed for smaller platforms, but with shorter range.
The Phased Array

Advantages

Size
- Size of only a single Piston sensor

Reduced Weight

Extended Range for same footprint
- Same Size, increased accuracy, greater range
- Smaller size sensor at same accuracy and range

Additional Benefits
- Reduced Flow Noise
- Flexibility in Beam forming/steering
ADCPs & DVLs operate in countless oceanographic applications where performance matters!
Navigation Applications

- Autonomous Waypoint Navigation of UUV’s
- Station Keeping for ROV’s
- Velocity Feedback for Vehicle Control
- Dynamic Positioning
- Dead Reckoning - Tracking of route traveled (UUV, Diver, ROV, Surface Vessel)
- Stabilization of platforms for Hydrographic Survey and Imaging (Side Scan)
- Obstacle Avoidance
- Terrain Following
- Diver Waypoint Navigation
Latest Developments
Small Phased Array (Explorer 600 kHz)

Small AUV and ROV Platforms
Latest Developments
Medium Phased Array (PAVS-150)

Submarine, MCM Ship, Large, and Medium AUV and ROV
Shown also with modified housing for Submarine and MCM Ships
Latest Developments
Large Phased Array Sensors

Deep-Rated PIONEER-38 – Oil Filled
Large, long range DVL /ADCP for Submarines Ships, Oil Wells, Deep Ocean Currents
Conclusion

- Doppler Sensors have enabled maritime navigation with precision and allowed for underwater vehicle autonomy
- Physical principles are at odds with the need to maintain large range while preserving small size, low power, and limited weight.
- Enhancements in the computer industry enabled self-contained systems for long deployments and for vehicle autonomy.
- Phased Array sensors allowed for reduced size, weight, and power consumption.
- Now, virtually every major underwater platform can accommodate a DVL or ADCP.
- Extended Range, Better Power Management,
Discussion...

Teledyne RDI State-of-the-Art Doppler Navigation – Don’t Navigate Without It!