AMULET: Acoustic Metastructure for Direction-of-Arrival Estimation Underwater using a Single Hydrophone

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Introduction

- Autonomous vehicles and other devices which need spatial information are deployed underwater
- Acoustics are dominant underwater because electromagnetic waves are severely attenuated
- Directional heading is typically found using hydrophone arrays which use up limited space and power on these platforms
- We developed **a bio-inspired air filled acoustic metastructure** that allows a **single hydrophone** to accurately **estimate the angle of arrival** of cooperative sound source

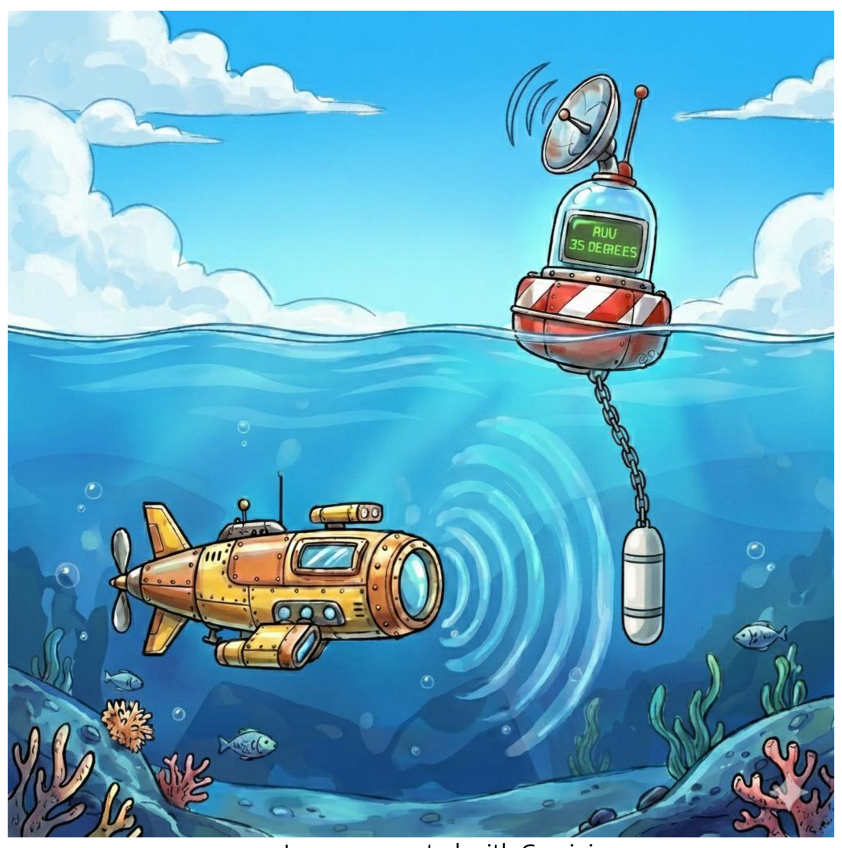
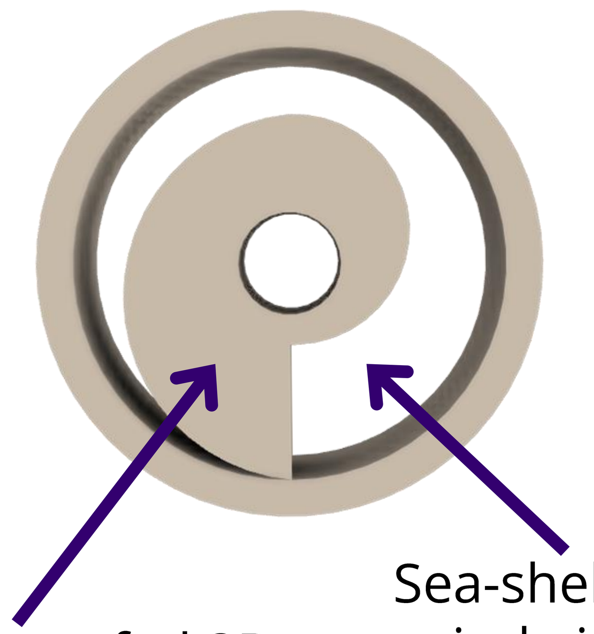


Image generated with Gemini

Metastructure Design

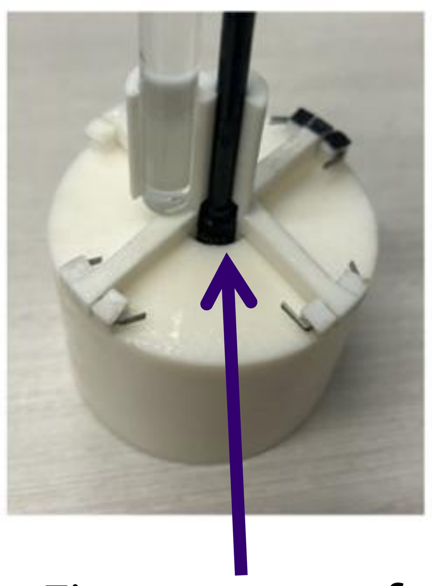
Internal Cross Section:



Waterproofed 3D printed PLA

Sea-shell inspired spiral air cavity

3D Structure:

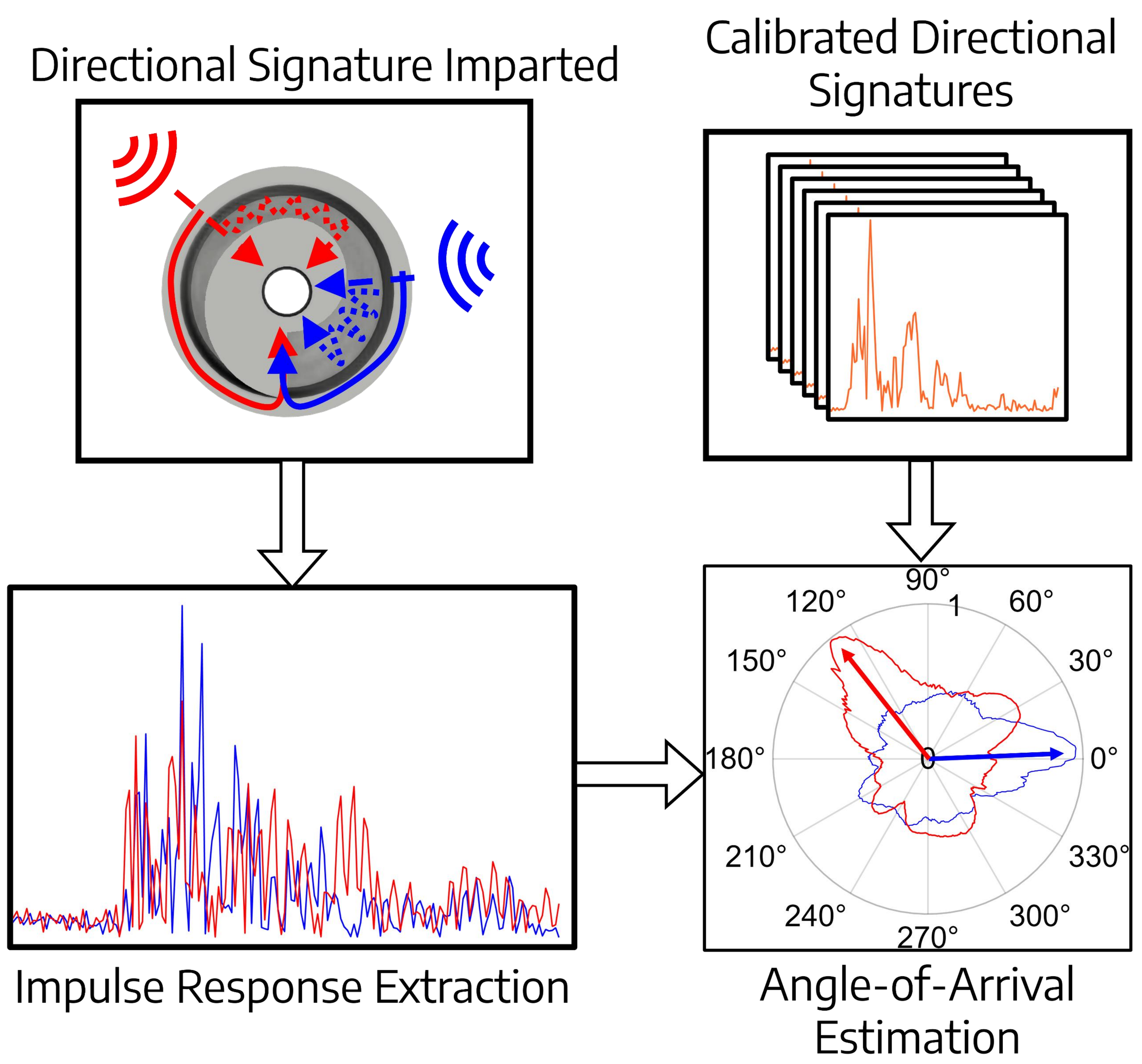


Fits overtop of a single off-the-shelf hydrophone

How it Works

Acoustic Interaction

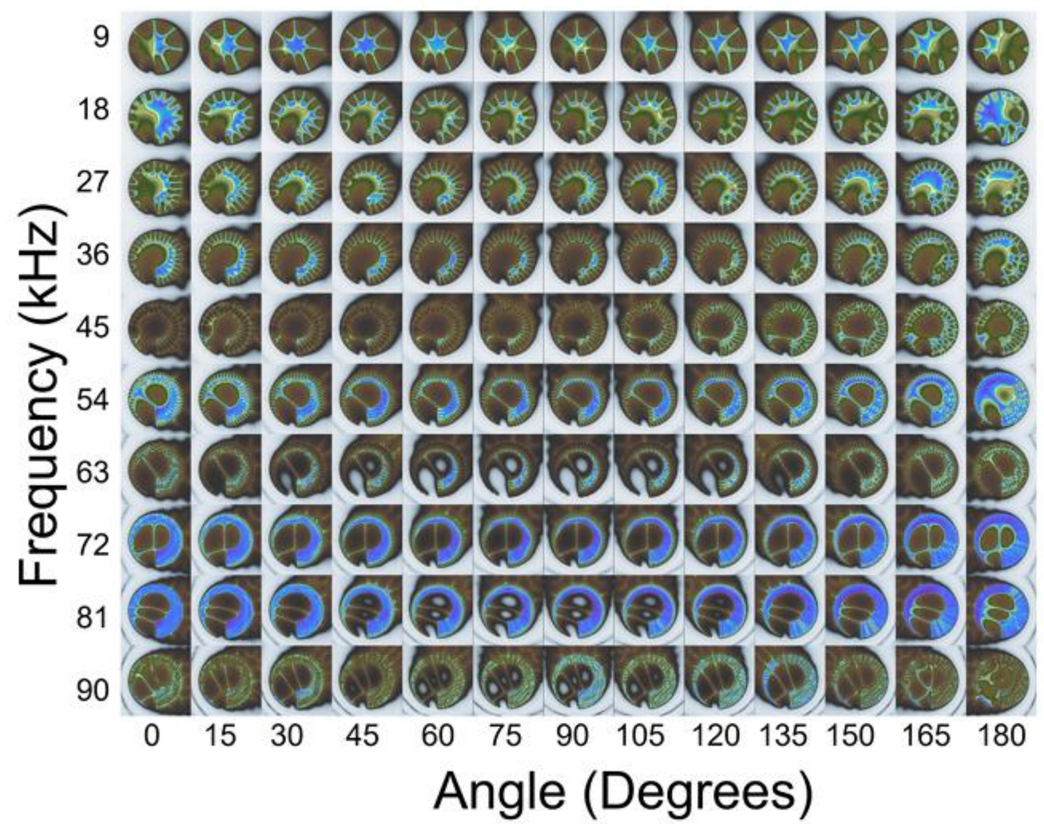
- The structure interacts with incoming sound differently at all incoming angles
- Different paths through the structure create unique delay patterns and frequency dependent responses
- Air trapped inside the structure creates an acoustic impedance mismatch



System Architecture

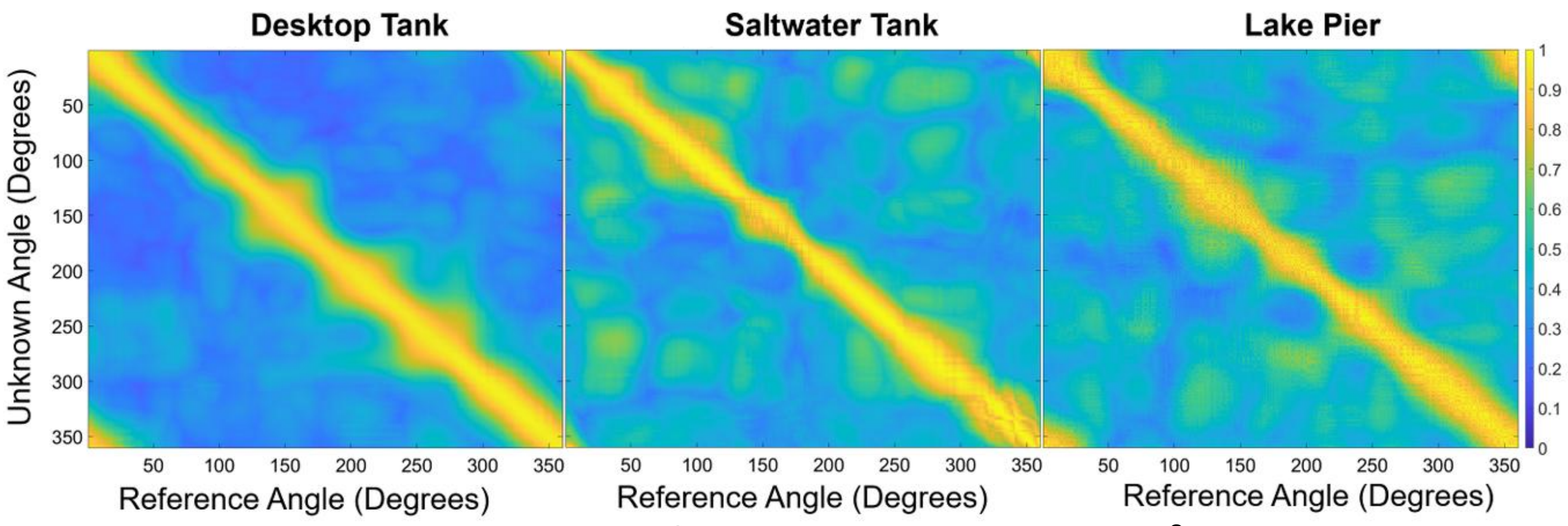
- We perform a 1-time calibration by rotating the structure 360 degrees sending a known signal at each angle to learn each signature (impulse response)
- When deployed the system estimates the angle of arrival of a transmitter sending a known signal (1-88kHz chirp in our evaluation)

Simulation

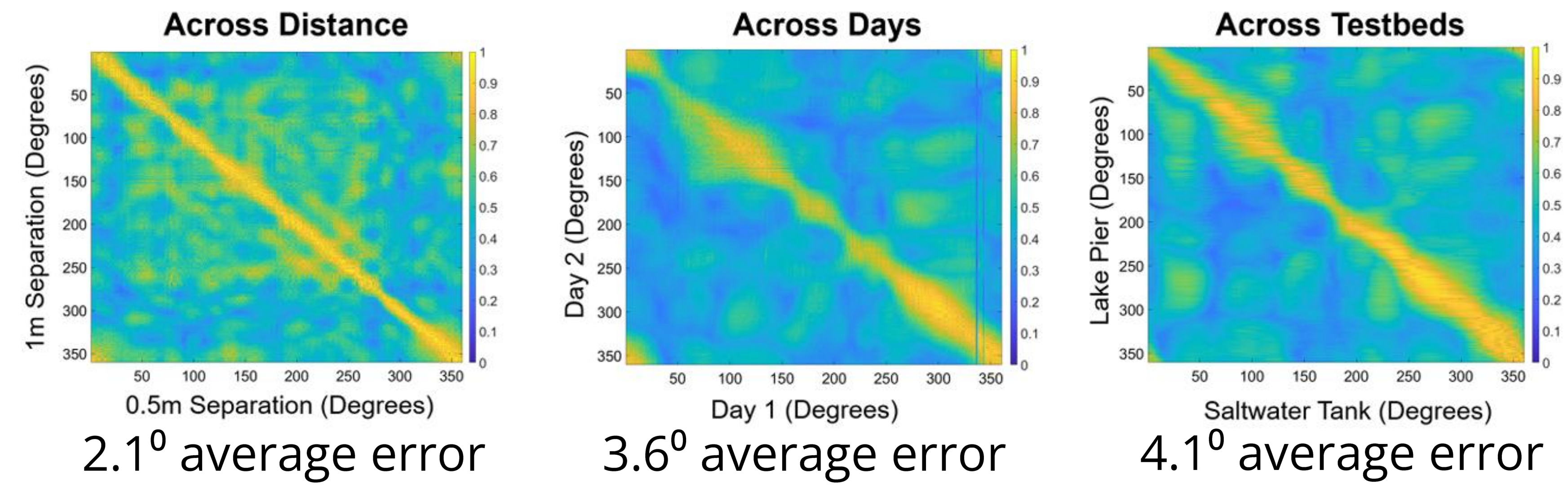


Simulations show different standing wave patterns depending on incident angle and frequency.

Baseline Results



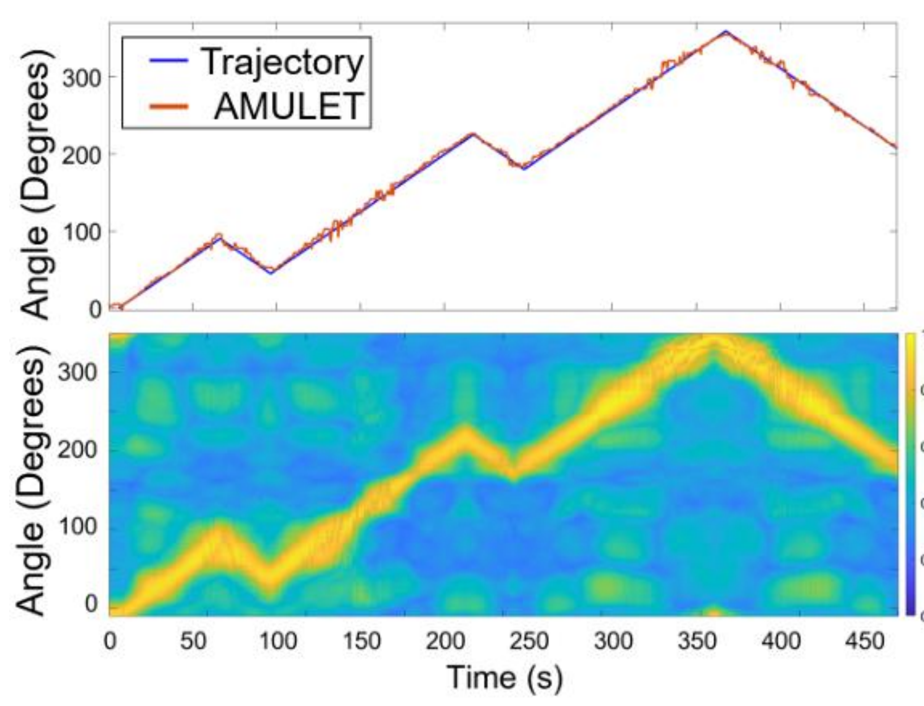
1.1^0 average error | 1.7^0 average error | 2.2^0 average error



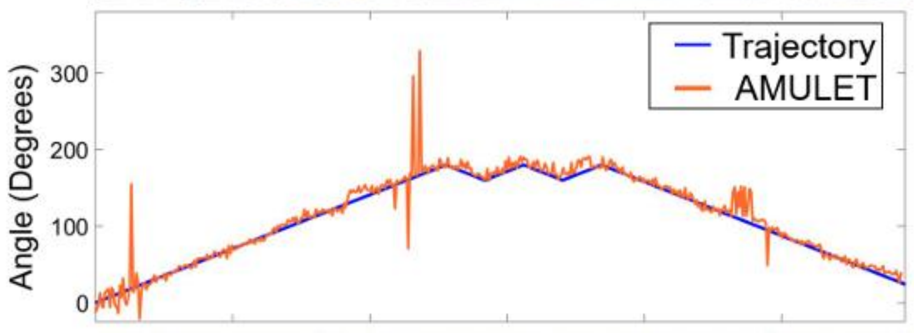
2.1^0 average error | 3.6^0 average error | 4.1^0 average error

Across the various testbeds and even calibrating the system in an indoor tank and deploying it in a lake, the system has an average angular error of 4.1^0 or less.

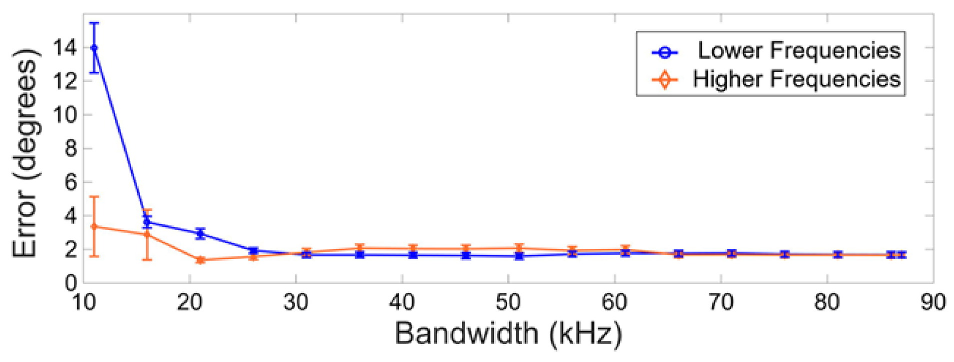
Tracking Results and Bandwidth Analysis



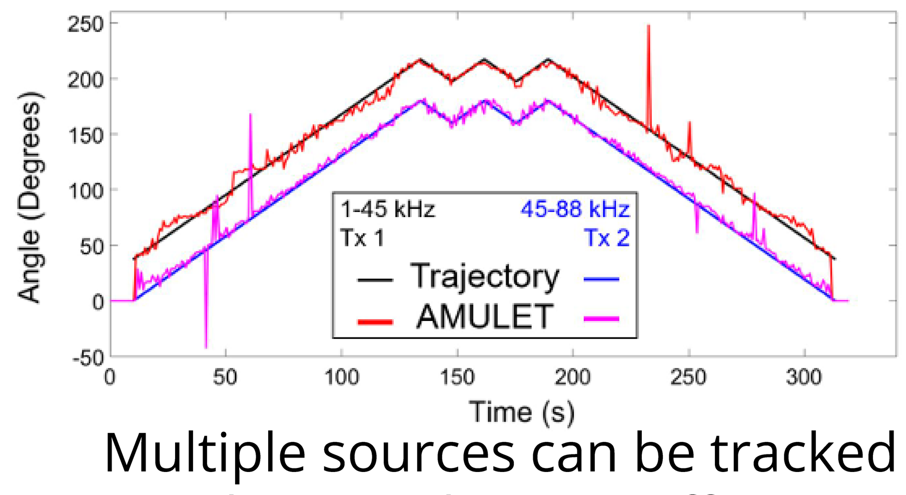
Across 10 test trajectories, the median error was 2.9^0.



Spanning two floating docks 8m apart, the average tracking error was 6.8^0.



The average error remains under 4^0 with at least 16kHz of bandwidth.



Multiple sources can be tracked simultaneously using offset frequency bands.

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