SIO 209: Signal Processing for Ocean Sciences
Class 18

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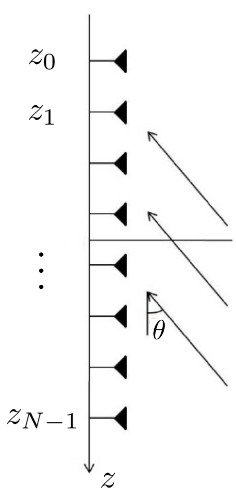
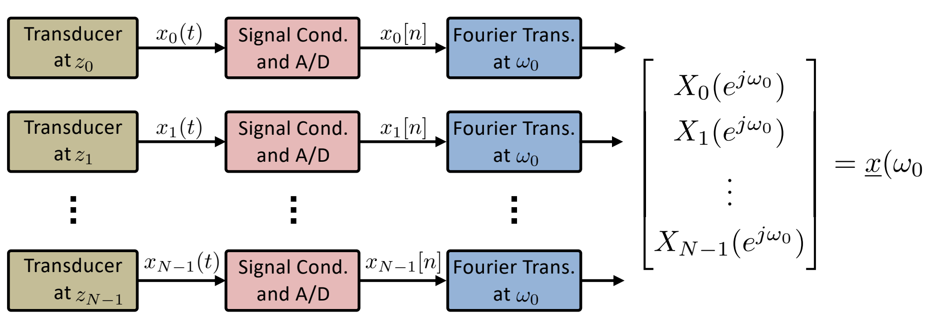
The Narrowband Beamformer

Uniform Line Array
(oriented along the z-axis)



Narrowband Array Measurement Vector



Fourier Trans. at ω_0 $\longrightarrow$ Compute FFT and take desired frequency bin

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The Narrowband Beamformer

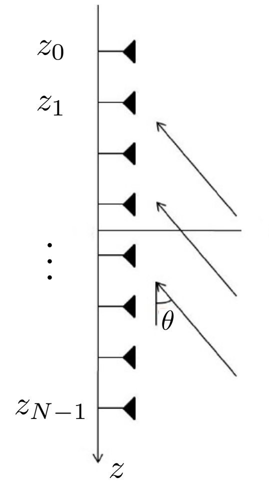
- The narrowband beamformer takes the narrowband array measurement vector and produces a scalar output

$$\underline{\boldsymbol{x}}(\omega_0) \longrightarrow \boxed{\underline{\boldsymbol{w}}_\theta(\omega_0)^H} \longrightarrow \underline{\boldsymbol{w}}_\theta(\omega_0)^{\boxed{H}}\underline{\boldsymbol{x}}(\omega_0)$$

Hermitian Transpose

weight vector

scalar output



Goal: Design $\underline{\boldsymbol{w}}_\theta(\omega_0)$ such that signal with angle of incidence θ and frequency ω_0 adds constructively and signals from other directions add destructively

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How to Choose Beamforming Weights

$$\underline{\boldsymbol{x}}(\omega_0) \longrightarrow \boxed{\underline{\boldsymbol{w}}_\theta(\omega_0)^H} \longrightarrow \underline{\boldsymbol{w}}_\theta(\omega_0)^H\underline{\boldsymbol{x}}(\omega_0)$$

Normalized Plane Wave Replica

$$\underline{\boldsymbol{w}}_\theta(\omega_0) = \frac{1}{N}\underline{\boldsymbol{v}}_\theta(\omega_0)$$

Narrowband Plane Wave

$$\underline{\boldsymbol{x}}(\omega_0) = a(\omega_0)\underbrace{\begin{bmatrix} e^{j\frac{\omega_0 z_0}{\boxed{c}}\cos\theta} \\ e^{j\frac{\omega_0 z_1}{\boxed{c}}\cos\theta} \\ \vdots \\ e^{j\frac{\omega_0 z_{N-1}}{\boxed{c}}\cos\theta} \end{bmatrix}}_{\underline{\boldsymbol{v}}_\theta(\omega_0)}$$

Propagation Speed

scalar amplitude

Phase shifts in $\underline{\boldsymbol{v}}_\theta(\omega_0)$ correspond to phase shifts in planewave with frequency ω_0 and angle of incidence θ

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Bank of Beamformers

- A single beamformer provides output for a single "look direction" θ

$$\underline{\boldsymbol{x}}(\omega_0) \longrightarrow \boxed{\underline{\boldsymbol{w}}_{\theta}(\omega_0)^H} \longrightarrow \underline{\boldsymbol{w}}_{\theta}(\omega_0)^H \underline{\boldsymbol{x}}(\omega_0)$$

- Scanned response consists of bank of beamformers to look in M directions

$$\underline{\boldsymbol{x}}(\omega_0) \longrightarrow \left.\begin{array}{l} \boxed{\underline{\boldsymbol{w}}_{\theta_1}(\omega_0)^H} \longrightarrow \underline{\boldsymbol{w}}_{\theta_1}(\omega_0)^H \underline{\boldsymbol{x}}(\omega_0) \\ \boxed{\underline{\boldsymbol{w}}_{\theta_2}(\omega_0)^H} \longrightarrow \underline{\boldsymbol{w}}_{\theta_2}(\omega_0)^H \underline{\boldsymbol{x}}(\omega_0) \\ \\ \boxed{\underline{\boldsymbol{w}}_{\theta_M}(\omega_0)^H} \longrightarrow \underline{\boldsymbol{w}}_{\theta_M}(\omega_0)^H \underline{\boldsymbol{x}}(\omega_0) \end{array}\right\} \boldsymbol{W}^H \underline{\boldsymbol{x}}(\omega_0)$$

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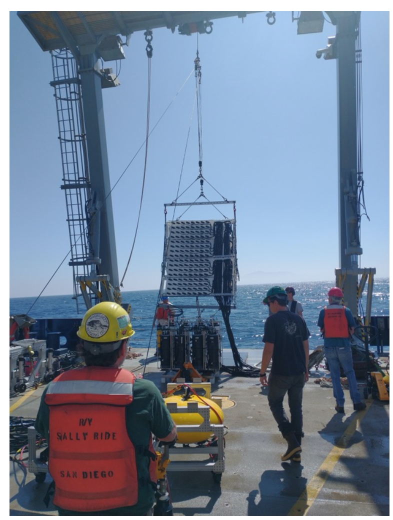
SWMFEx21 Experiment

- Performed on research vessel Sally Ride
- Mid-frequency vertical line array with 64 elements
- Moored and towed acoustic sources



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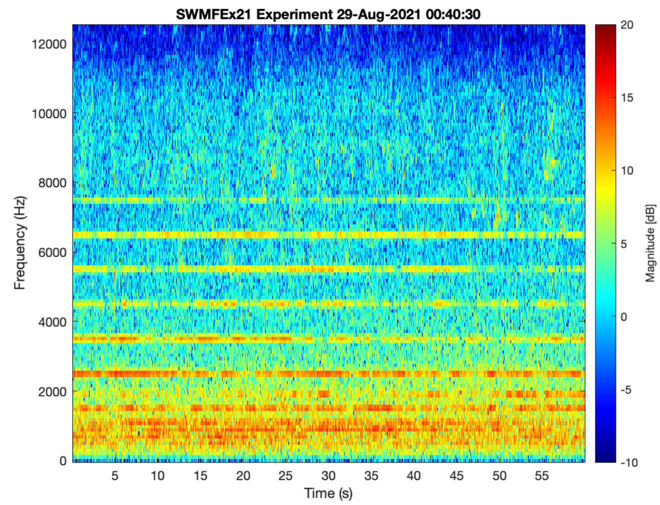
SWMFEx21: Spectrogram Example

- 1 minute of data
- Sampling frequency is 25 kHz
- Distance source array is approx. 3 km
- Middle of array is 130 m deep
- The source transmitted 7 tones at frequencies 1503 Hz, 2503 Hz, 3503 Hz, 4503 Hz, 5503 Hz, 6503 Hz, and 7503 Hz



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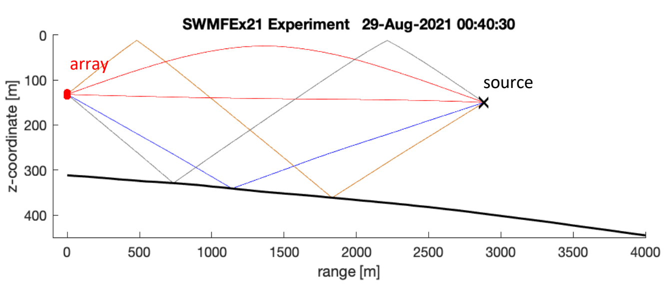
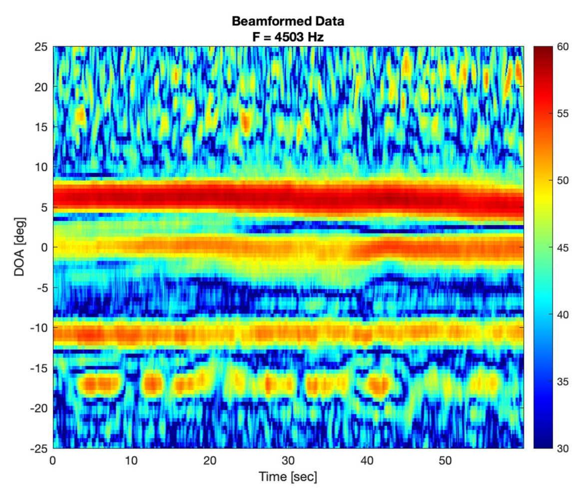
SWMFEx21: Propagation Model and Beamforming

- Beamforming
  - perform FFT ``across array elements''
  - see class SIO207D/ECE251D: Array Processing
- Propagation model makes use of
  - seabed information
  - sound speed profile





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SwellEx-96 – Source Localization Results

- Bayesian Estimation
  - compute source and velocity estimates from direction of arrival measurements
  - see class ECE275A: Parameter Estimation
- Data from SwellEx-96 experiment
  - available online (swellex96.ucsd.edu)