Time-domain beam signals for adaptive beamforming

UDT 2019, Stockholm - 13th May

… a sound decision

ATLAS ELEKTRONIK

Table of contents

Table of contents

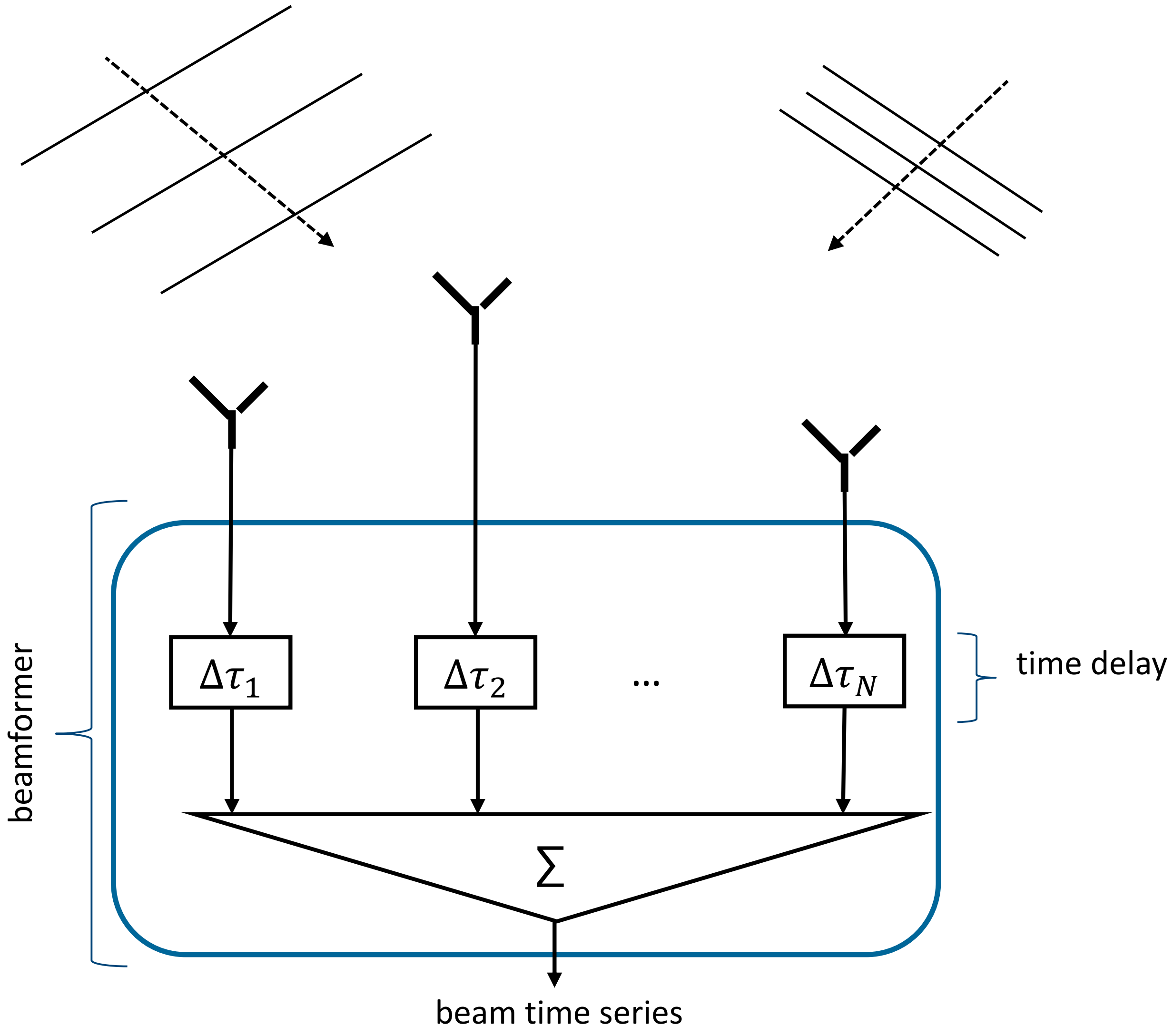
Motivation

Basics of Beamforming

- Joint processing of array outputs:
  - Enhanced detection of weak signals
  - Spatial discrimination of wave fronts

- Spatial sensitivity depends on:
  - Array geometry
  - Frequency
  - Desired look-direction
  - Beamformer (BF)

- Example: „Delay & Sum“ Beamformer
  - BF coefficients = time delays $\Delta\tau_n$
  - Choice of $\Delta\tau_n$ according to desired look-direction



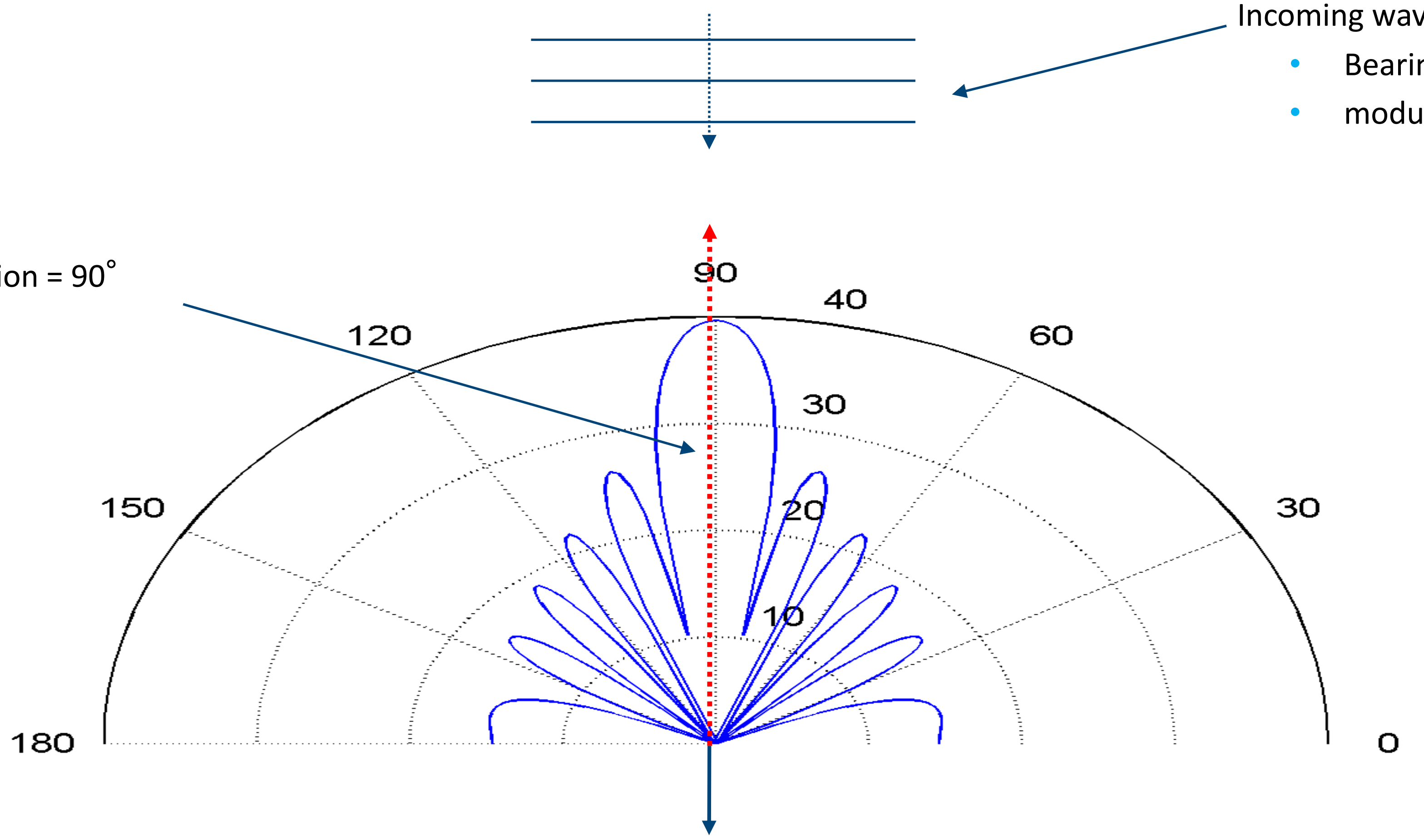
Motivation

Beamforming Characteristics → Beampattern

Incoming wave front

- Bearing = 90°
- modulated by signal $s(t)$

Desired look-direction = 90°



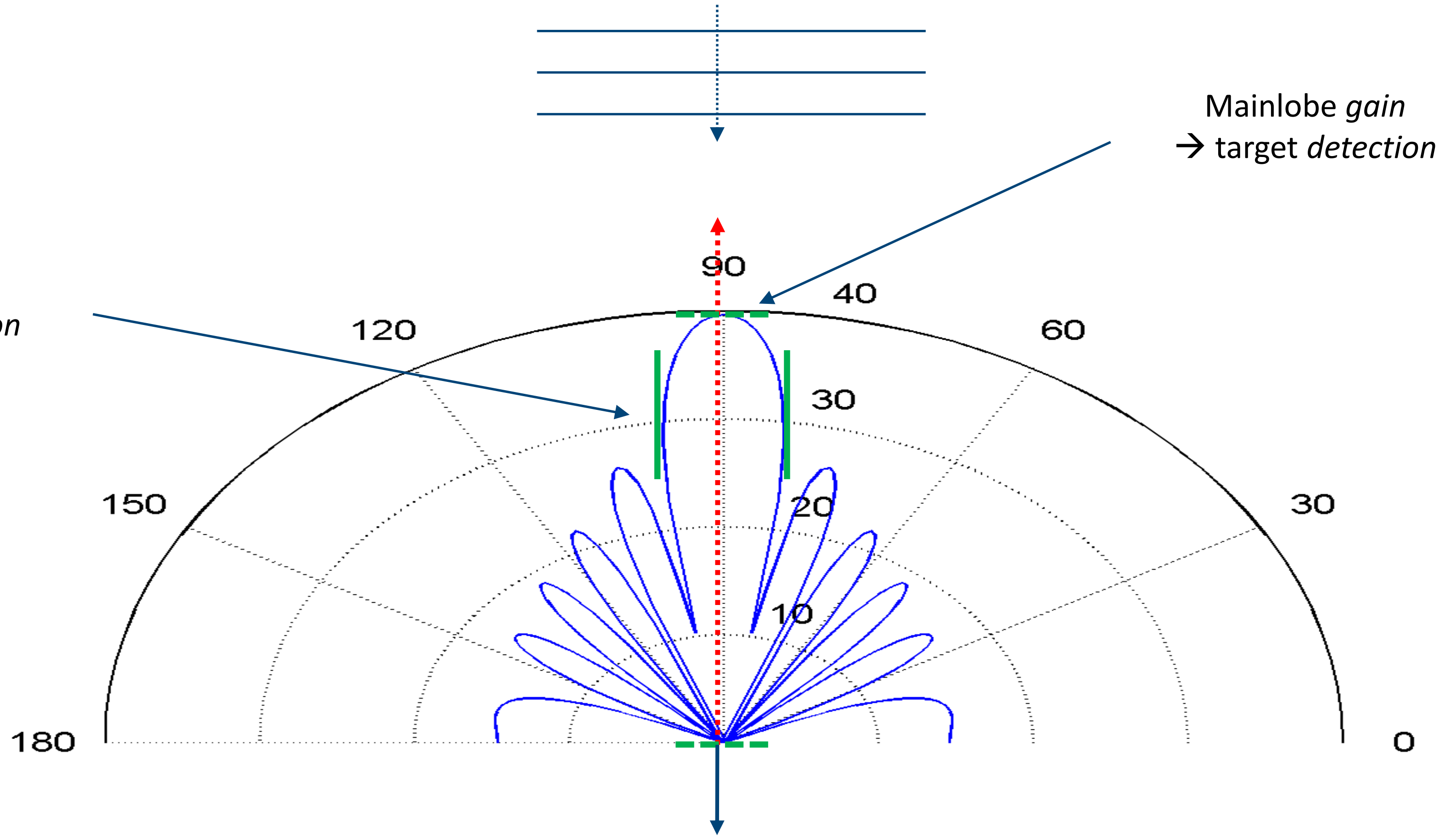
beam time series $\hat{s}(t)$

Motivation

Beampattern – Mainlobe

Mainlobe *gain*
→ target *detection*

Mainlobe *width*
→ target *separation*



beam time series $\hat{s}(t)$

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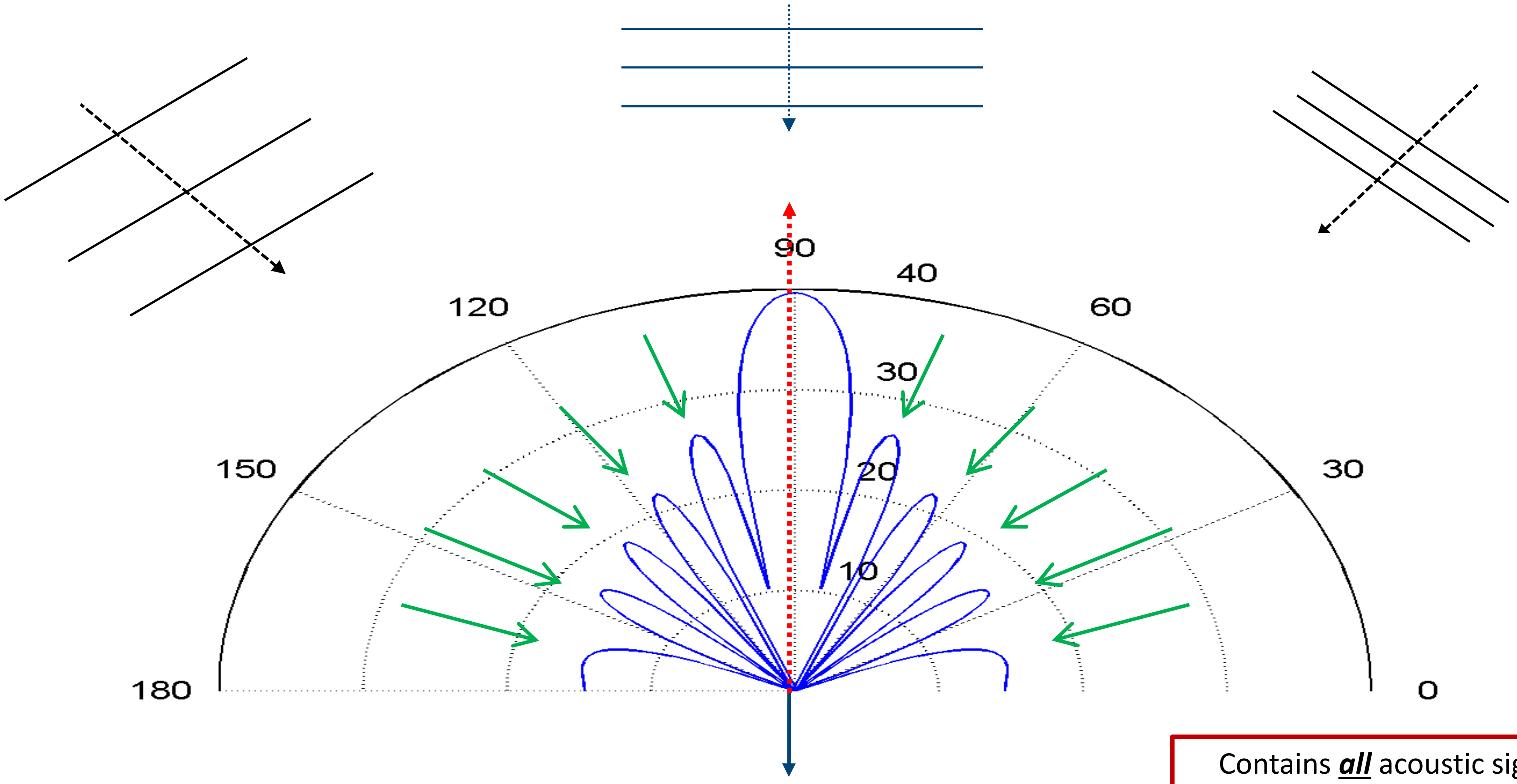
Motivation

Beampattern – Sidelobes



beam time series $\hat{s}(t)$

Contains ***all*** acoustic signatures „collected“ with the beampattern!

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Motivation

Disadvantage of *non*-adaptive Beamformers

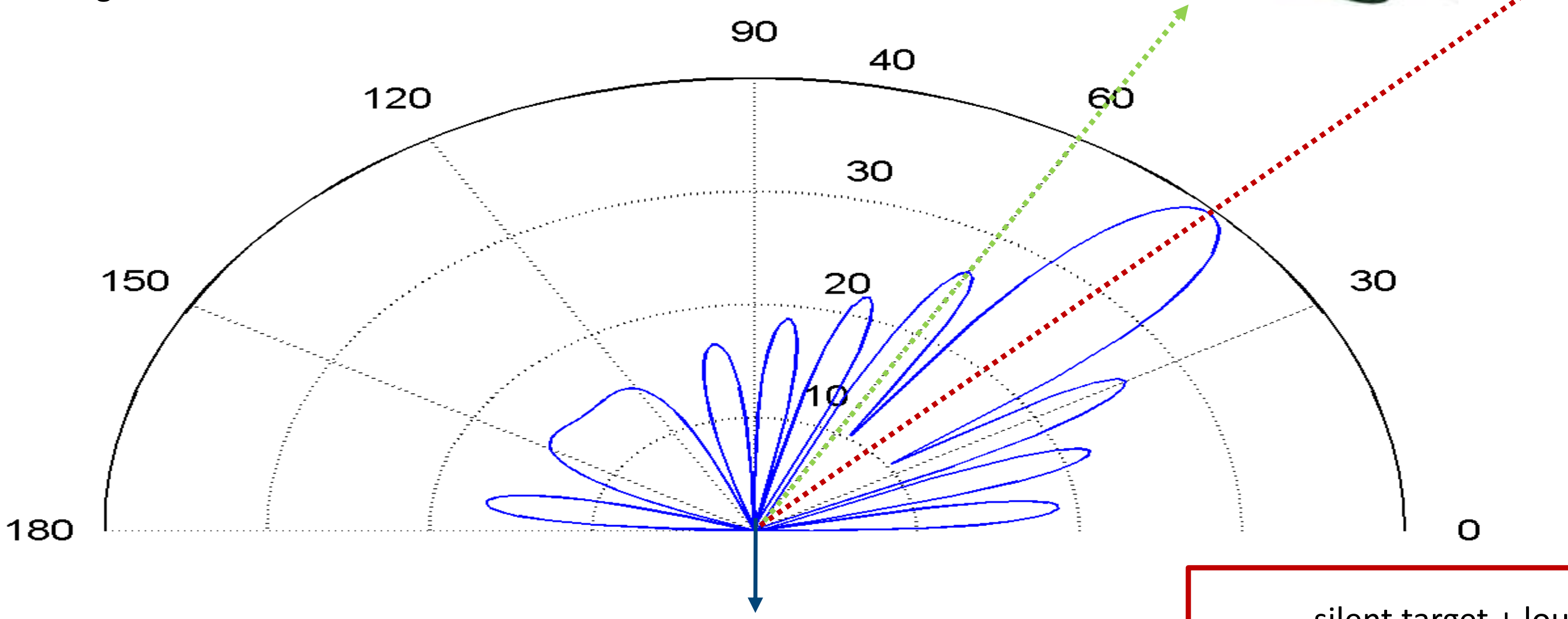
Contributions of loud target received via sidelobe @ 60° …

…mask contributions of silent target in $\hat{s}(t)$
→ silent target might not be detected!

…are erroneously assigned to bearing of 45°
→ incorrect bearing for loud target!

Loud target

Silent target



beam time series $\hat{s}(t)$

silent target + loud target + noise

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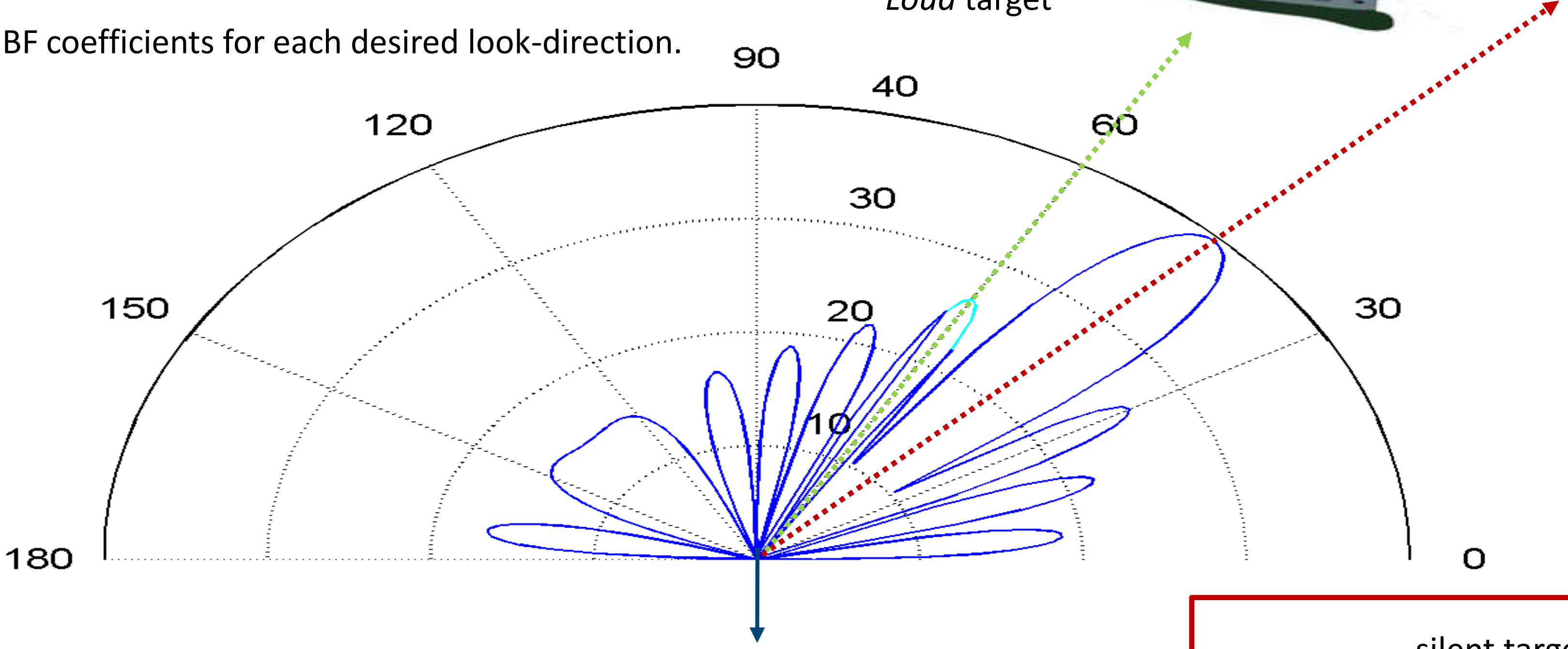
Motivation

Idea of *adaptive* Beamforming (ABF)

- Adapt beamformer coefficients such that directional zeros are formed in directions of interferers.
- Derive information about interferers from data itself.
- Perform adaptation of BF coefficients for each desired look-direction.

Loud target

Silent target



beam time series $\hat{s}(t)$

silent target + noise

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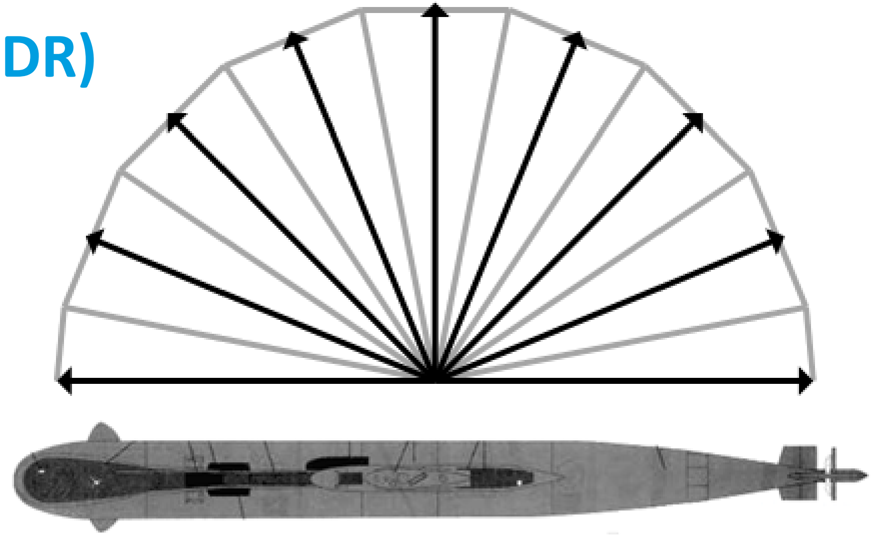
Table of contents

ATLAS Approach

Robust Minimum Power Distortionless Response (MPDR)



Basic idea of MPDR

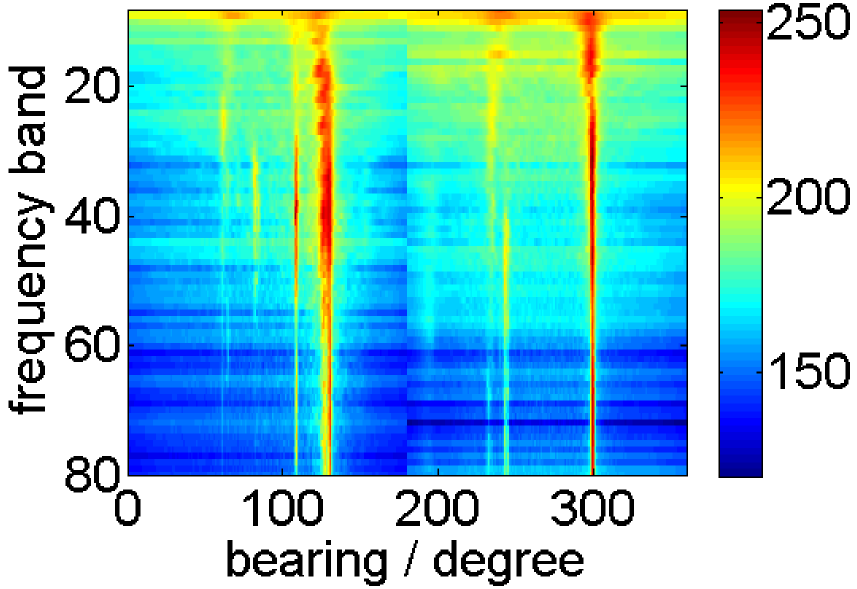
- Select BF coefficients such that:
  - Signal from look-direction remains undistorted
  - Total power of beam time series is minimized

- Required information:
  - Covariance matrix of stave data (correlation of stave outputs)

- Robust design of processing:
  - Introduce tolerance regions such that signals from a sector around look-direction remain undistorted

  → prohibits suppression of targets between two look-directions

- Calculate output power directly from steering vectors:
  - Matrix with dimension #beams x #frequency bands
  - Low time resolution (~ 1 Hz)



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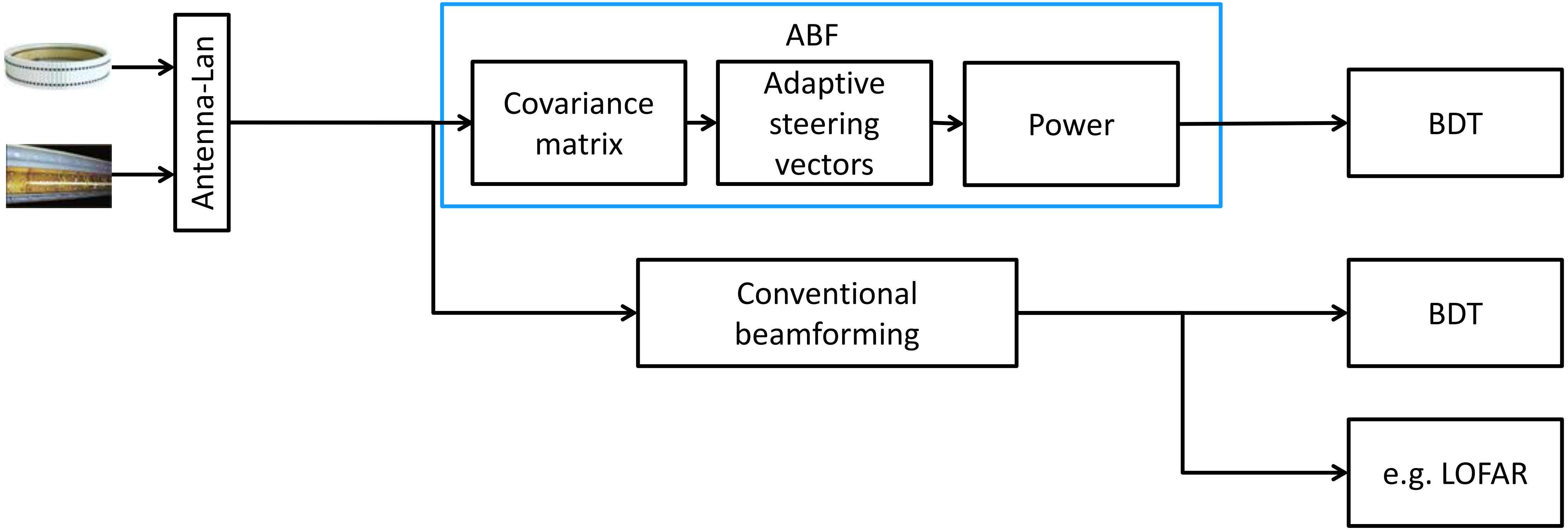
ATLAS Approach

Robust Minimum Power Distortionless Response (MPDR)

Current Version

- ABF for BDT processing
- Conventional beamforming for BDT processing and others



ATLAS Approach

Robust Minimum Power Distortionless Response (MPDR)

New design

- ABF for BDT processing
- Adaptive time-domain beamforming for BDT processing and others

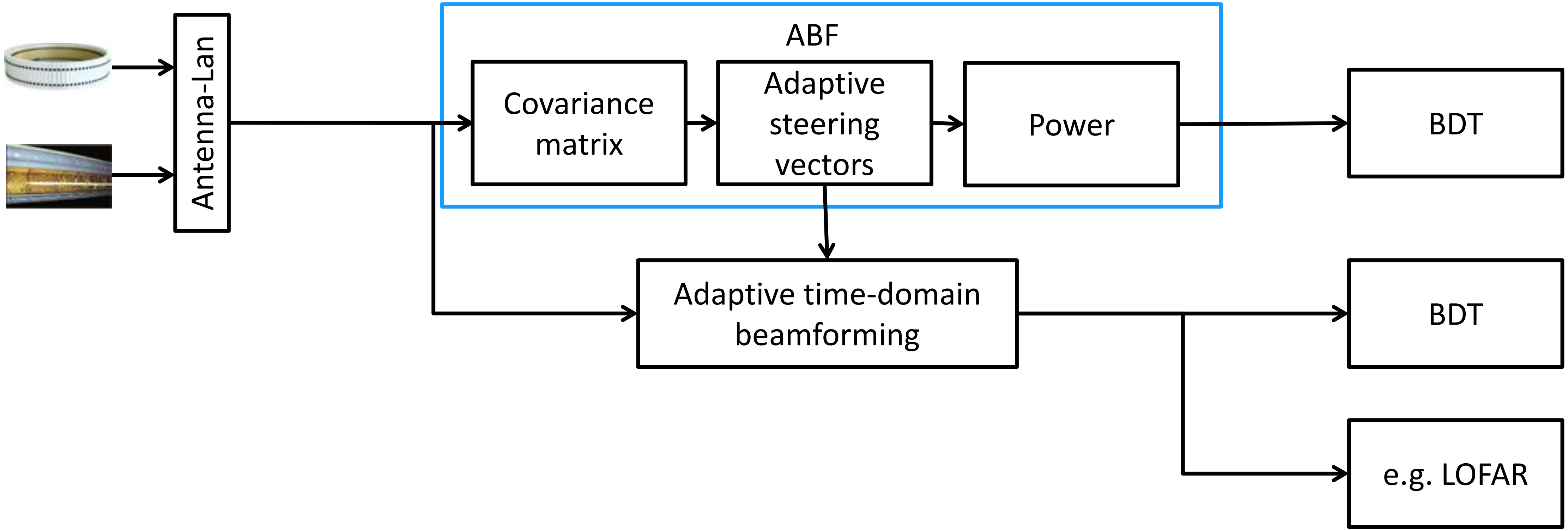


Table of contents

Simulated data

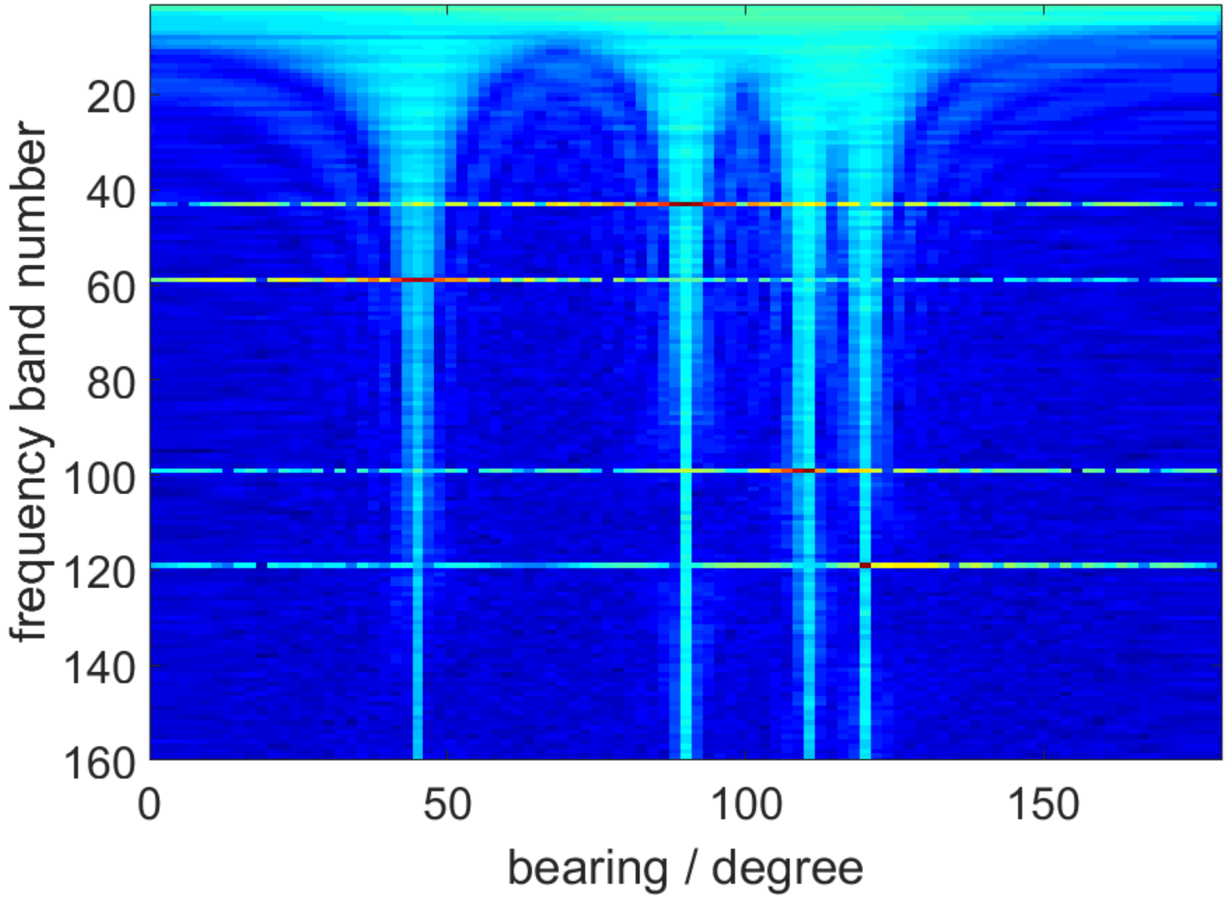
Simple scenario for a flank array sonar

Scenario:

- 4 broadband targets
- Each has a strong frequency line

Conventional Beamforming:

- Target width depends on frequency
- Sidelobes due to broadband signature
- Strong sidelobe structure due to frequency lines



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Simulated data

Simple scenario for a flank array sonar

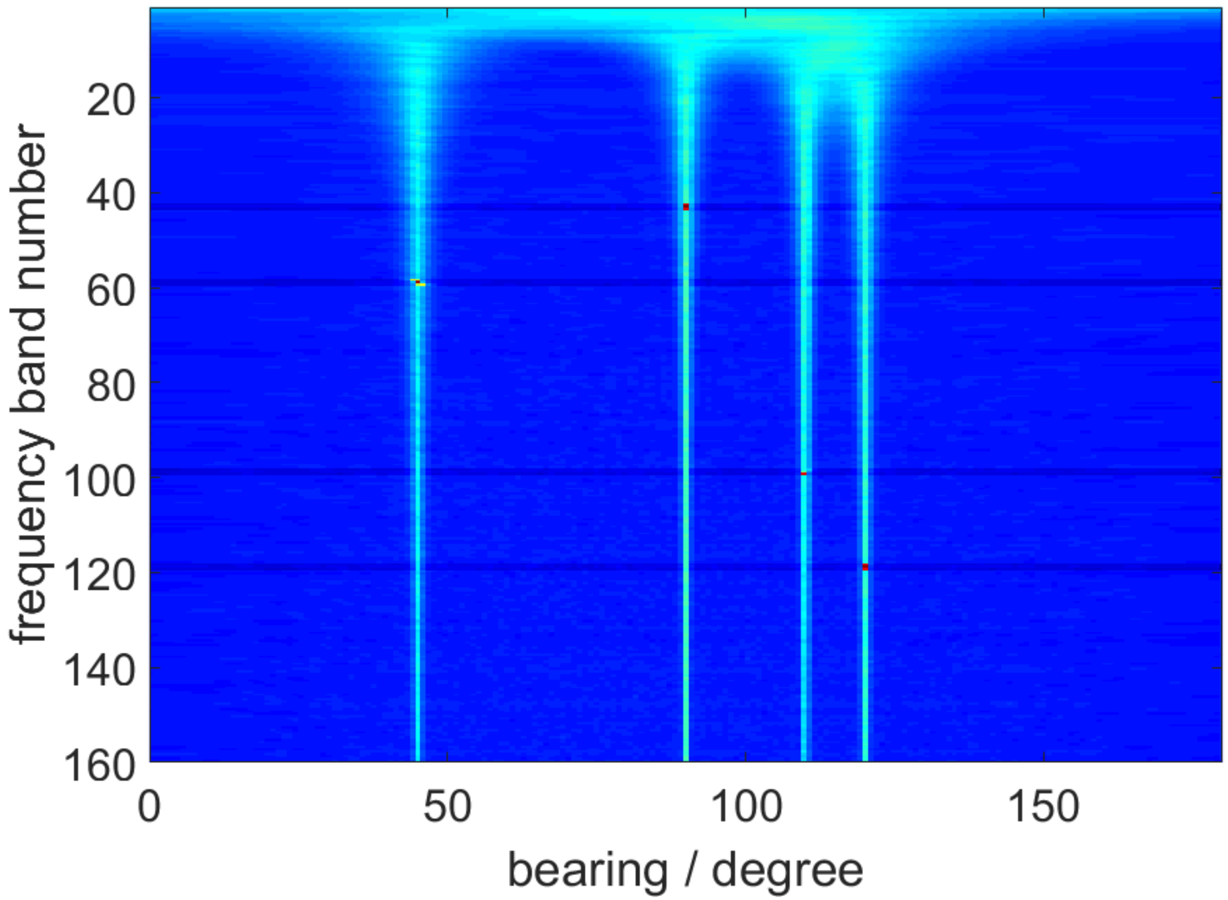
Scenario:

- 4 broadband targets
- Each has a strong frequency line

ABF Beamforming:

- Constant power width for broad frequency range
- No sidelobes for broadband structure
- No sidelobes for frequency lines

- Improved performance
- No time signals



Simulated data

Simple scenario for a flank array sonar

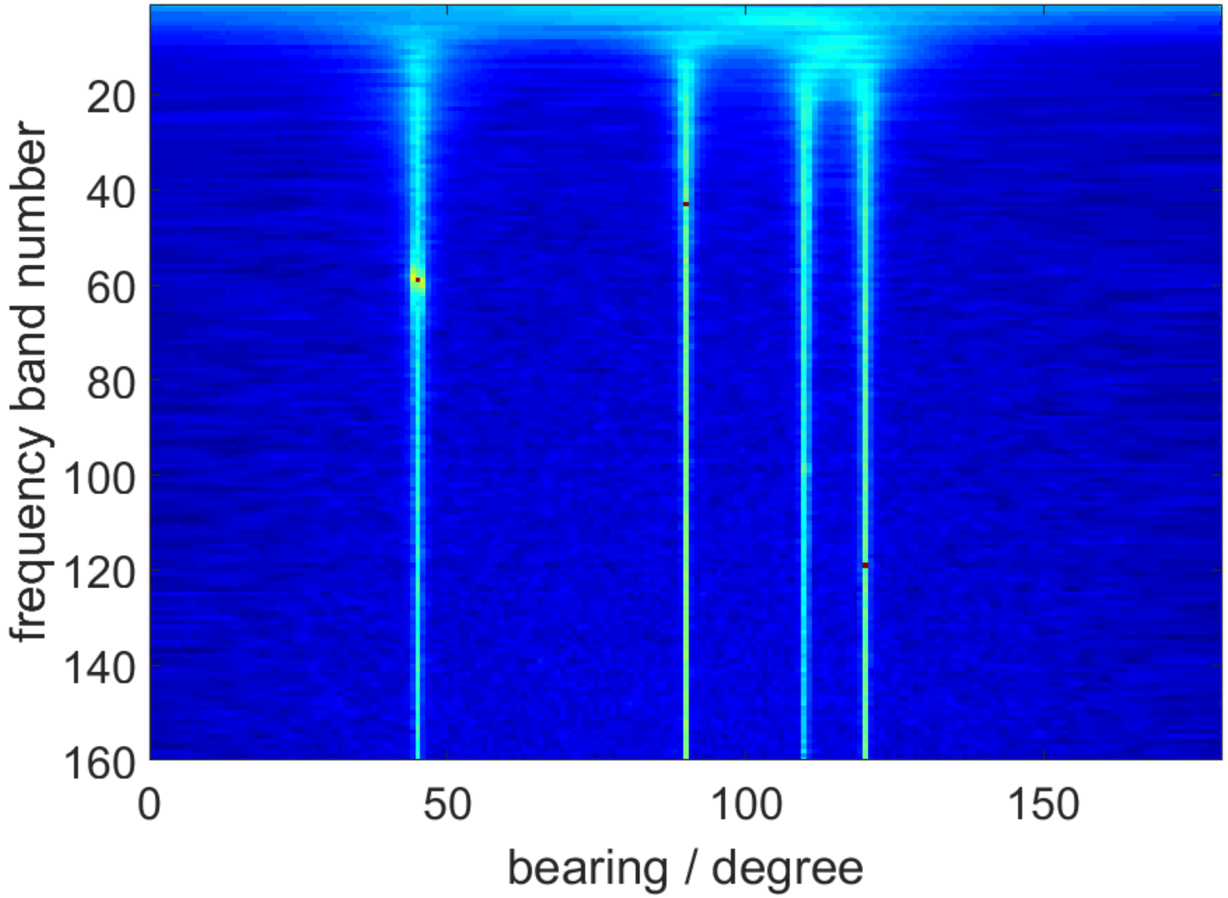
Scenario:

- 4 broadband targets
- Each has a strong frequency line

ABF Beamforming with time signals:

- Constant power width for broad frequency range
- No sidelobes for broadband structure
- No sidelobes for frequency lines

- Nearly same performance as before
- Time Signals are available

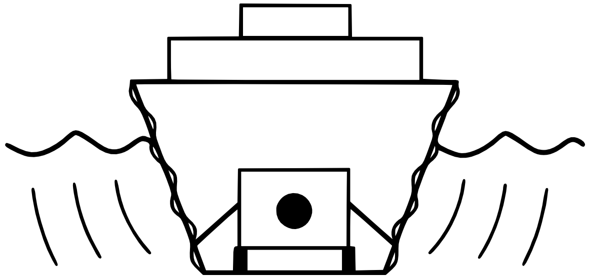


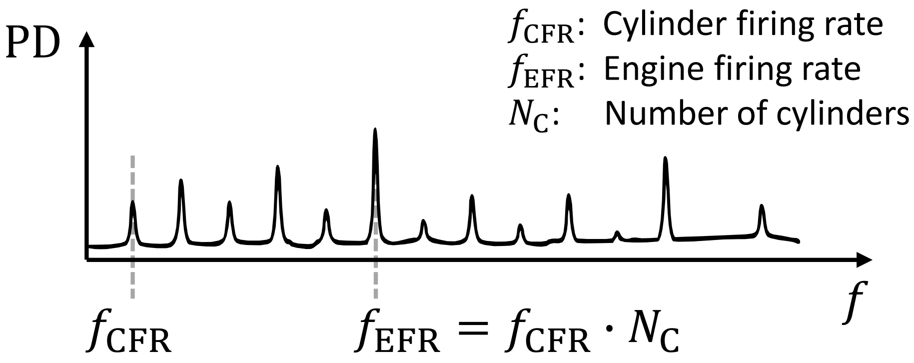
Simulated data

Low Frequency Analysis and Recording (LOFAR)

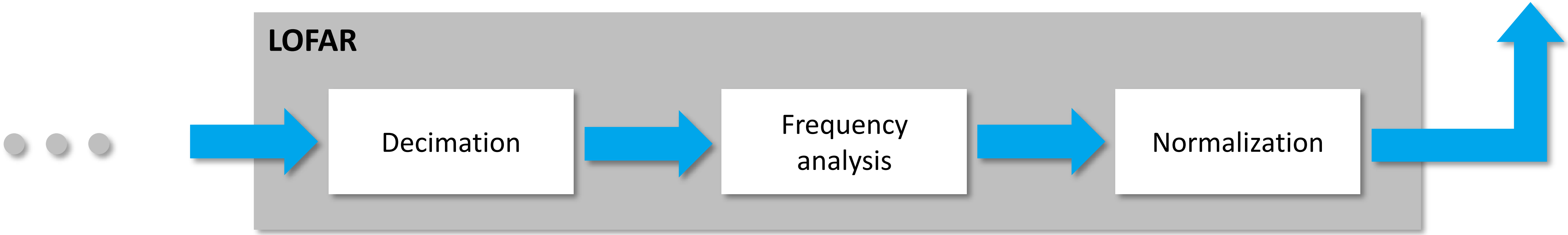
Intention: Analysis of frequency lines

- Engines
- Generators
- Pumps



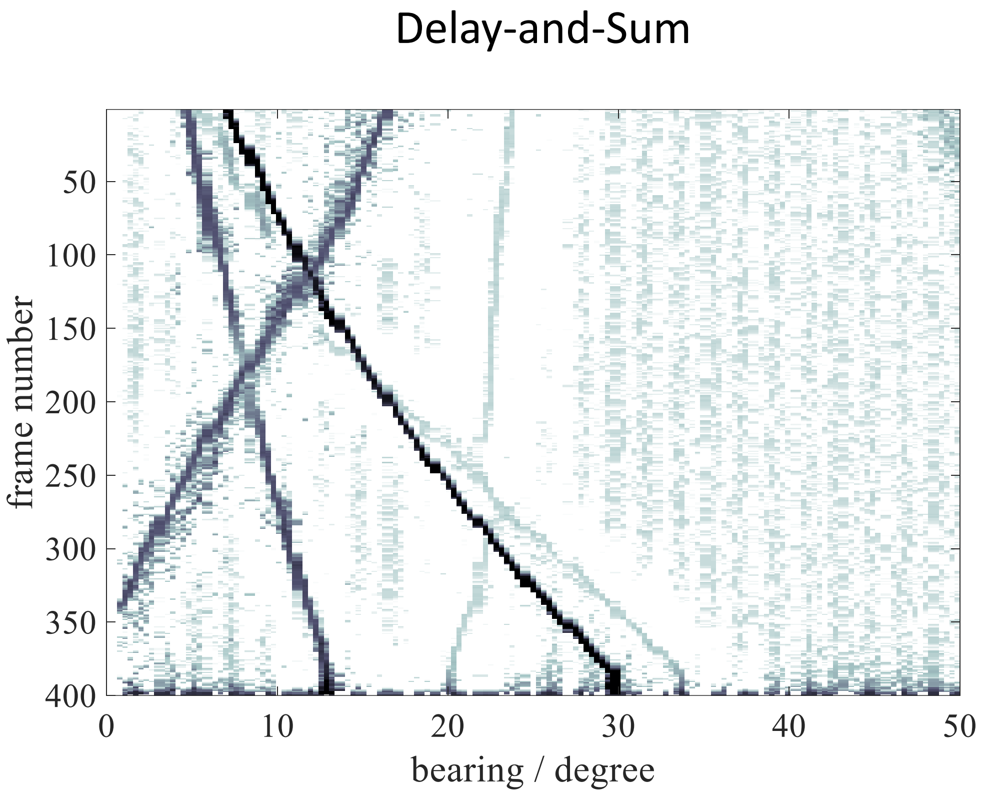


Signal Processing:



Simulated data

LOFAR (bearing information)



5 simulated targets

- Flank Array Sonar
- Multiple target crossings

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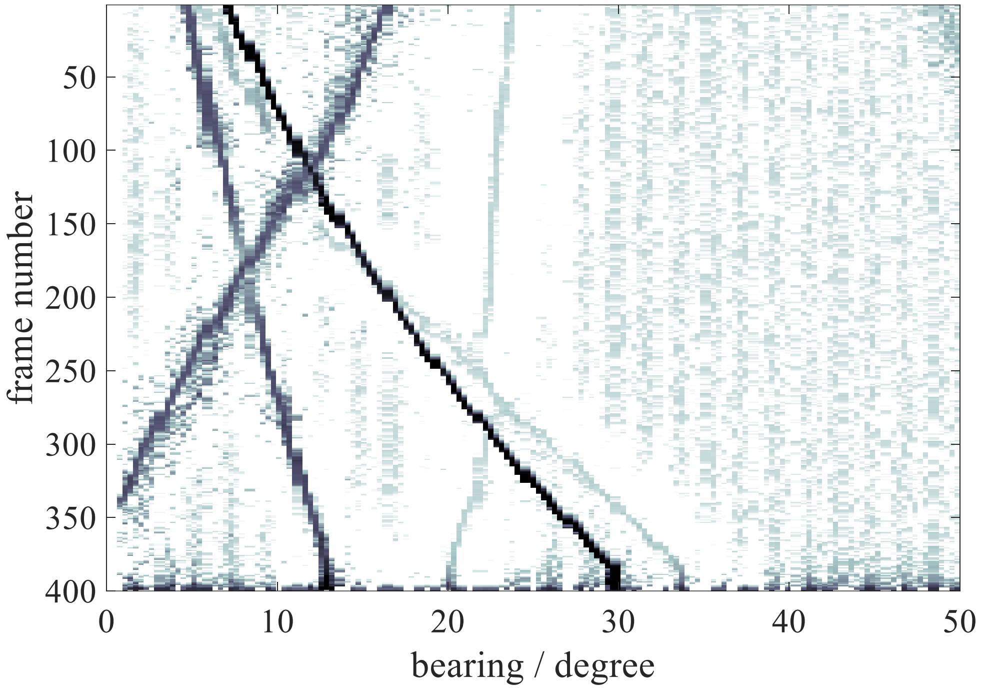
Simulated data

LOFAR (bearing information)

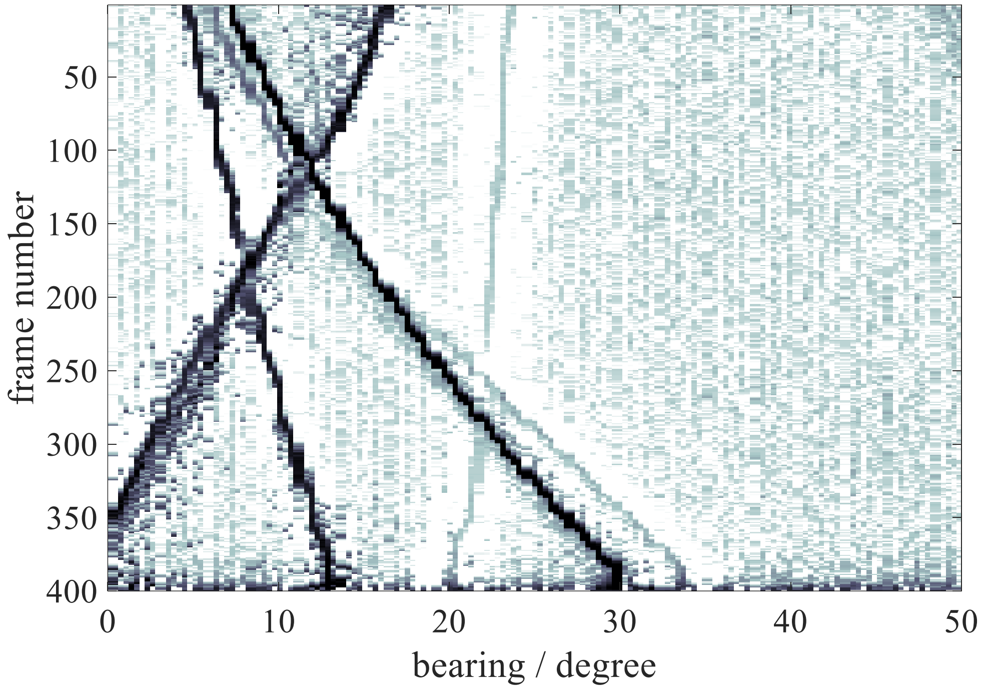
Delay-and-Sum



5 simulated targets

- Flank Array Sonar
- Multiple target crossings

ABF



Improved detection performance:

- Improved target separation

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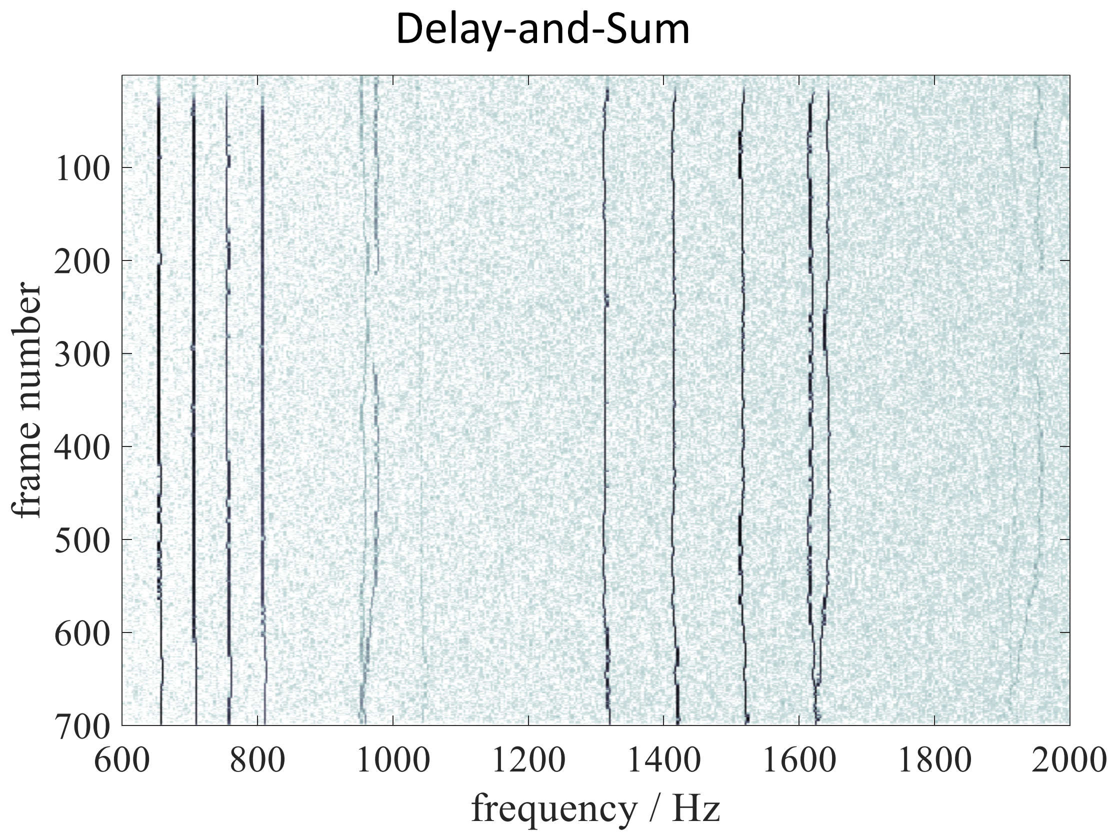
Simulated data

LOFAR (frequency information)

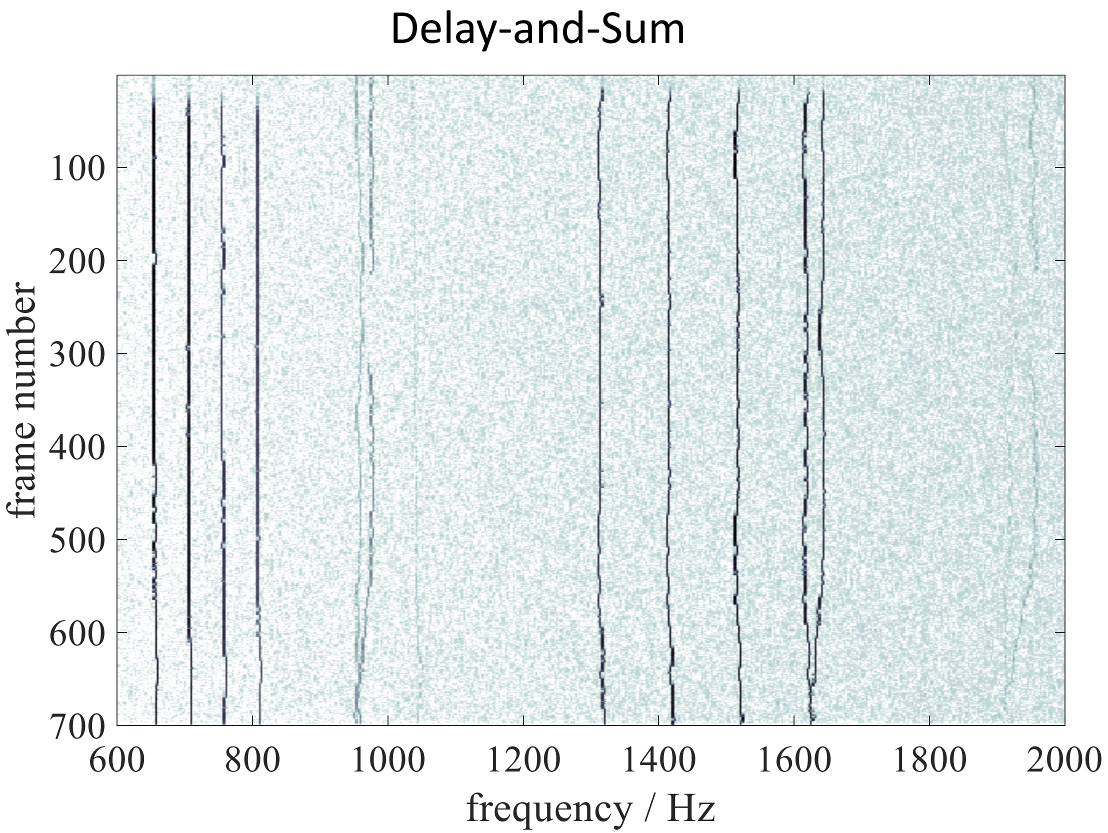


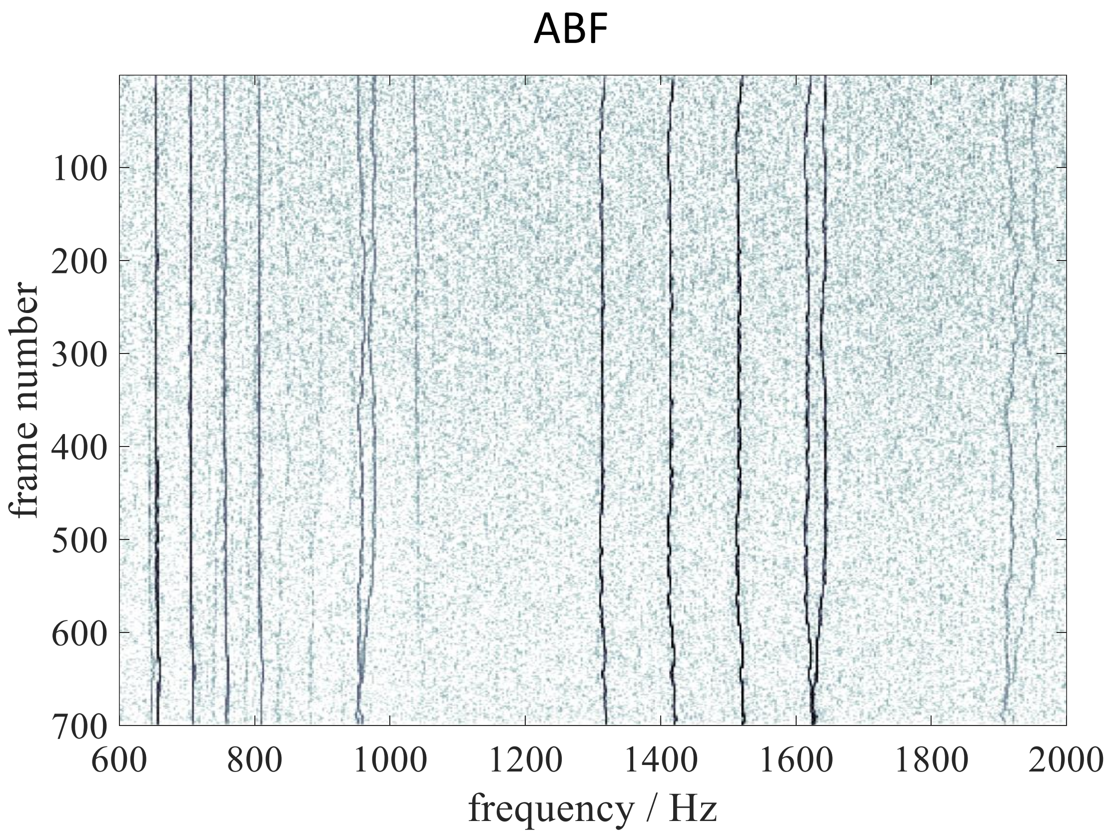
Simulation of frequency lines

- Different SNR
- Stable / unstable lines

Simulated data

LOFAR (frequency information)





Simulation of frequency lines

- Different SNR
- Stable / unstable lines

Improved detection performance:

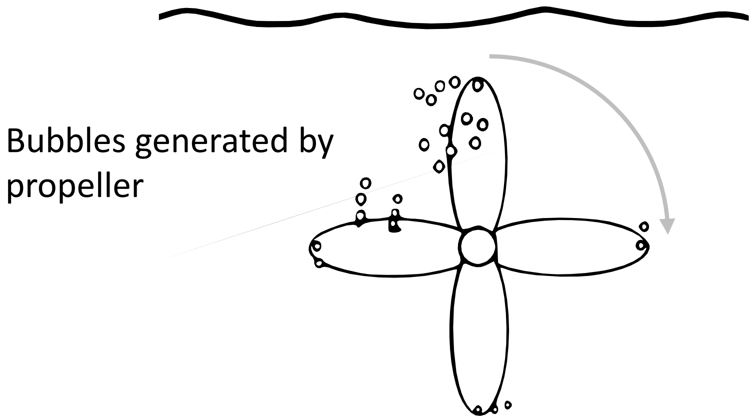
- Higher signal-to-noise-plus-interference ratio
- Detection of more frequency lines possible

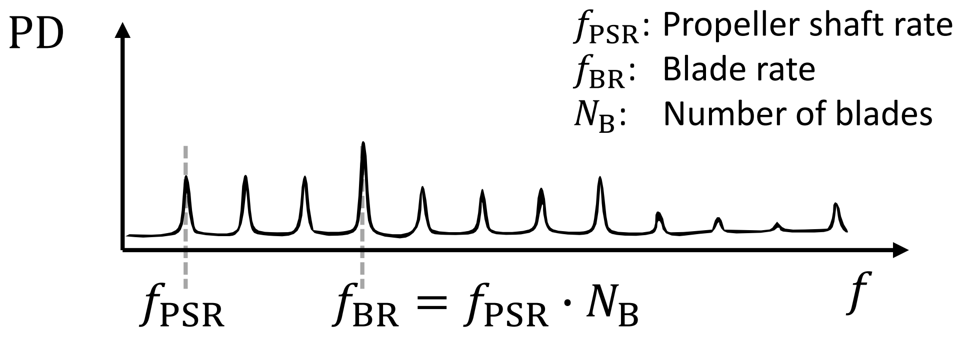
Simulated data

Detection of Envelope Modulation on Noise (DEMON)

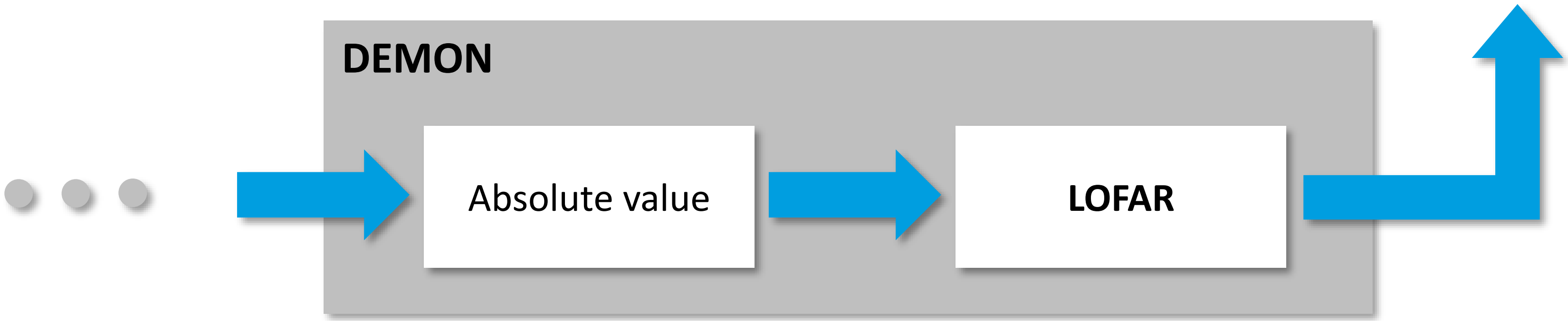
Intention: Analysis of frequency lines from modulation

- Cavitation



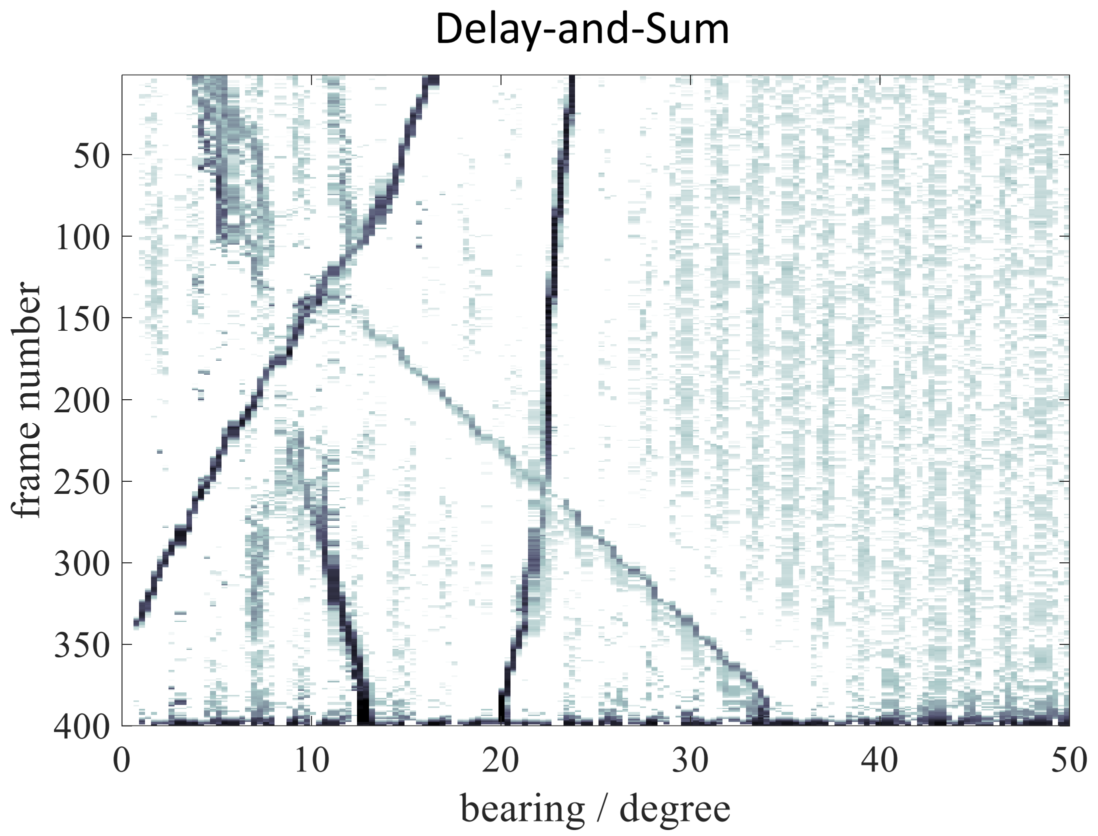


Signal processing:



Simulated data

DEMON



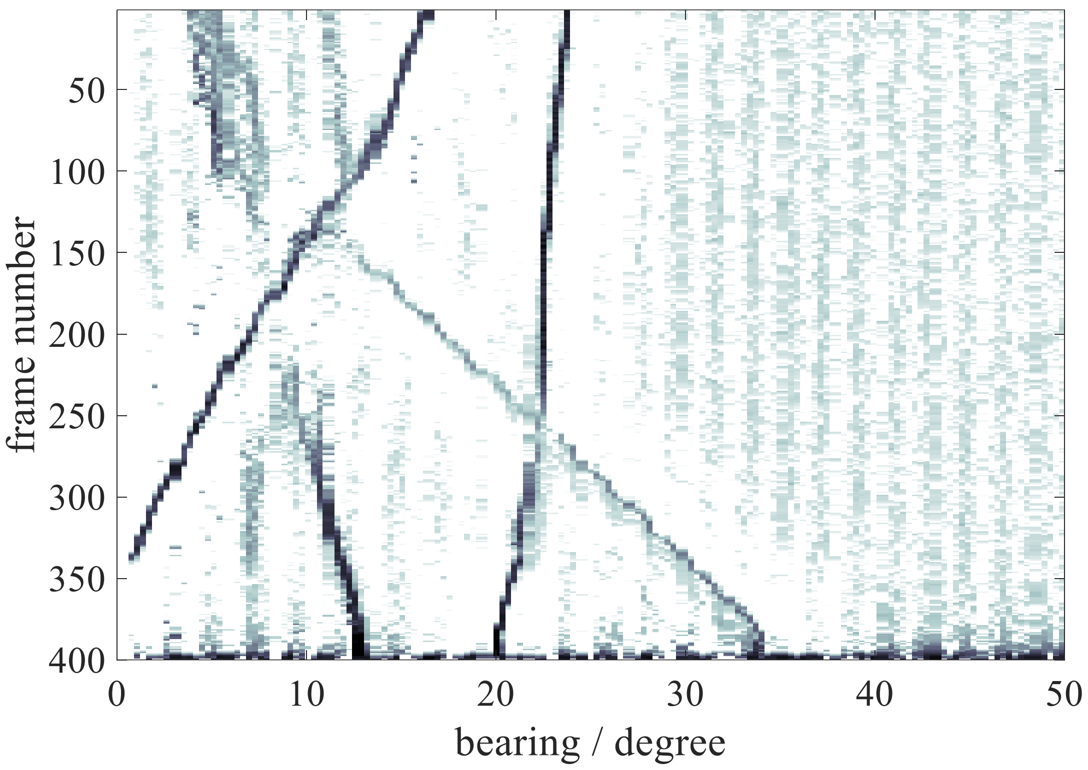
5 simulated targets

- Flank Array Sonar
- Multiple target crossings

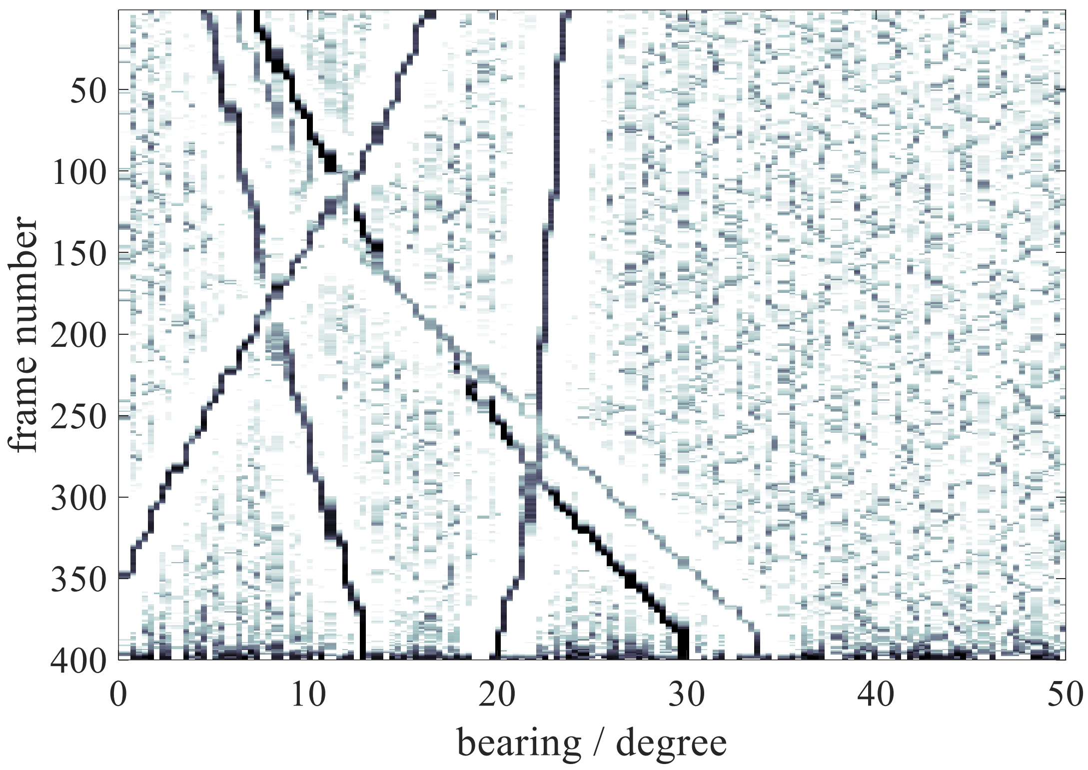
Simulated data

DEMON

Delay-and-Sum



ABF



5 simulated targets

- Flank Array Sonar
- Multiple target crossings

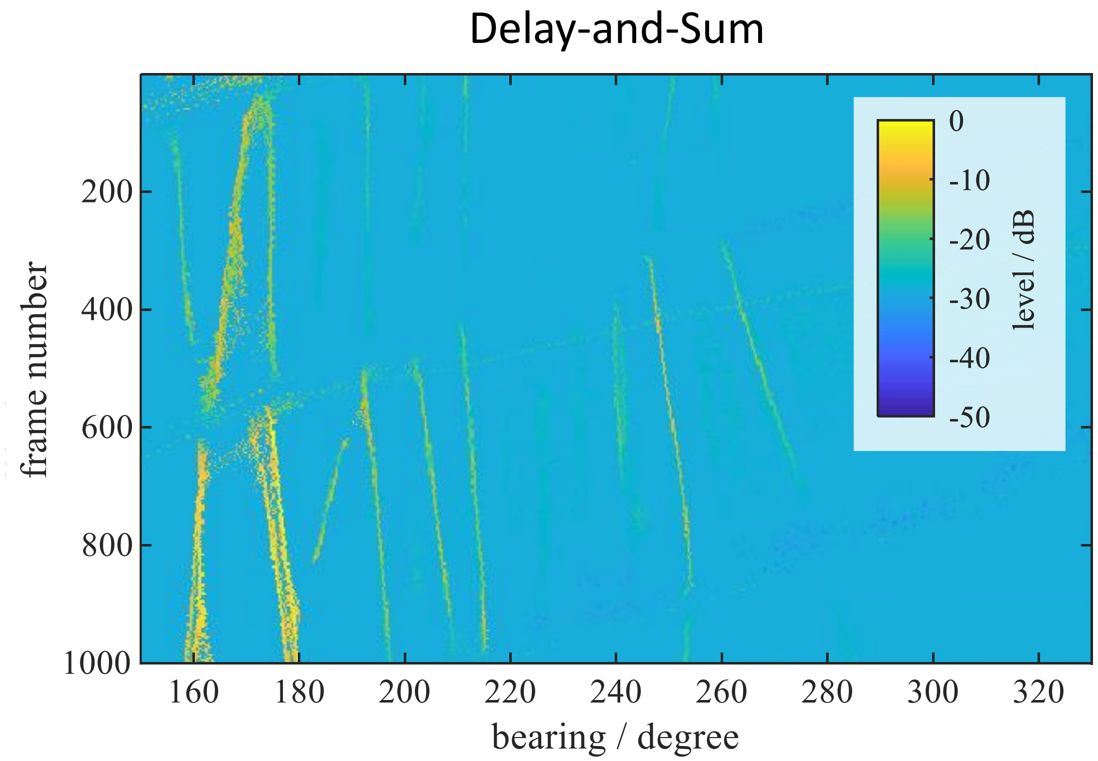
Improved detection performance:

- Superior target separation

Table of contents

Sea trial data

Broadband Detection (BDT)

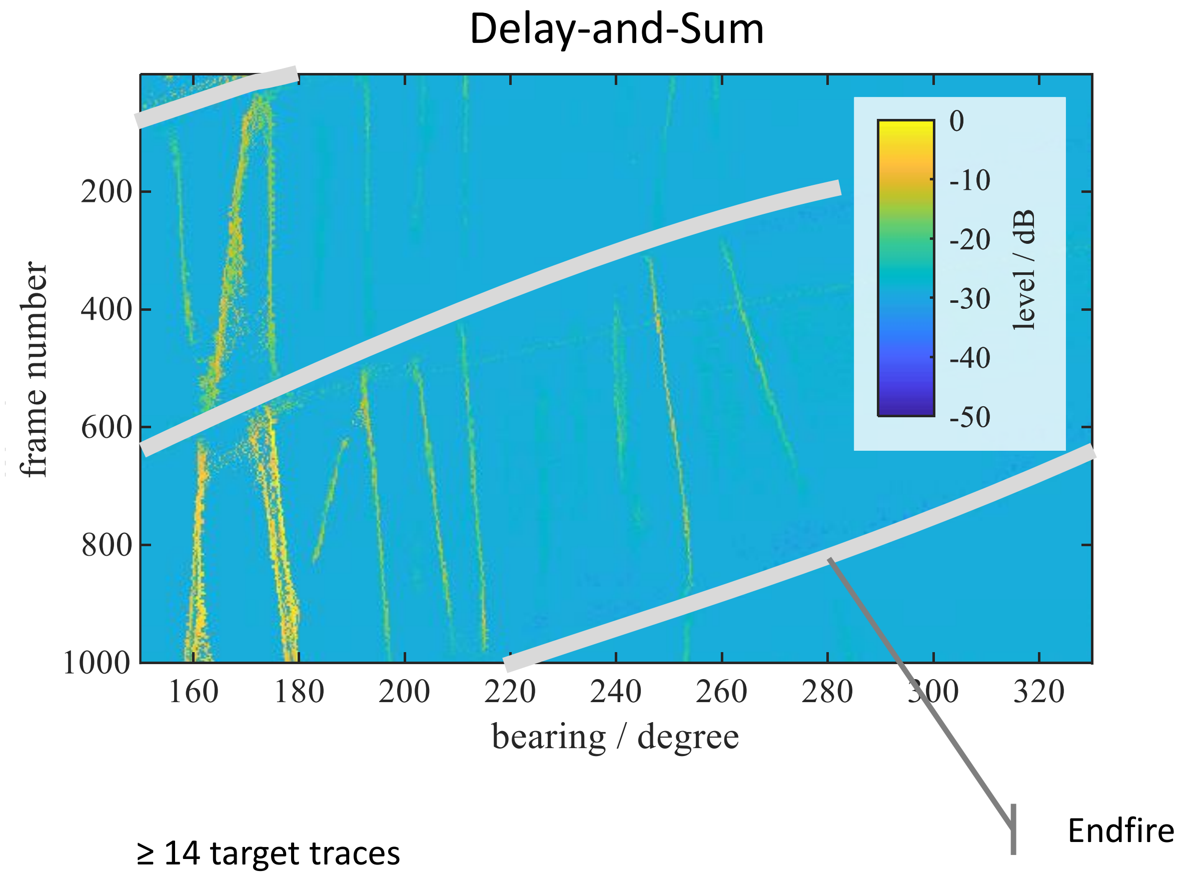


≥ 14 target traces

- Flank Array Sonar
- 360° turn of the submarine
- Reduced performance in endfire

Sea trial data

Broadband Detection (BDT)



≥ 14 target traces

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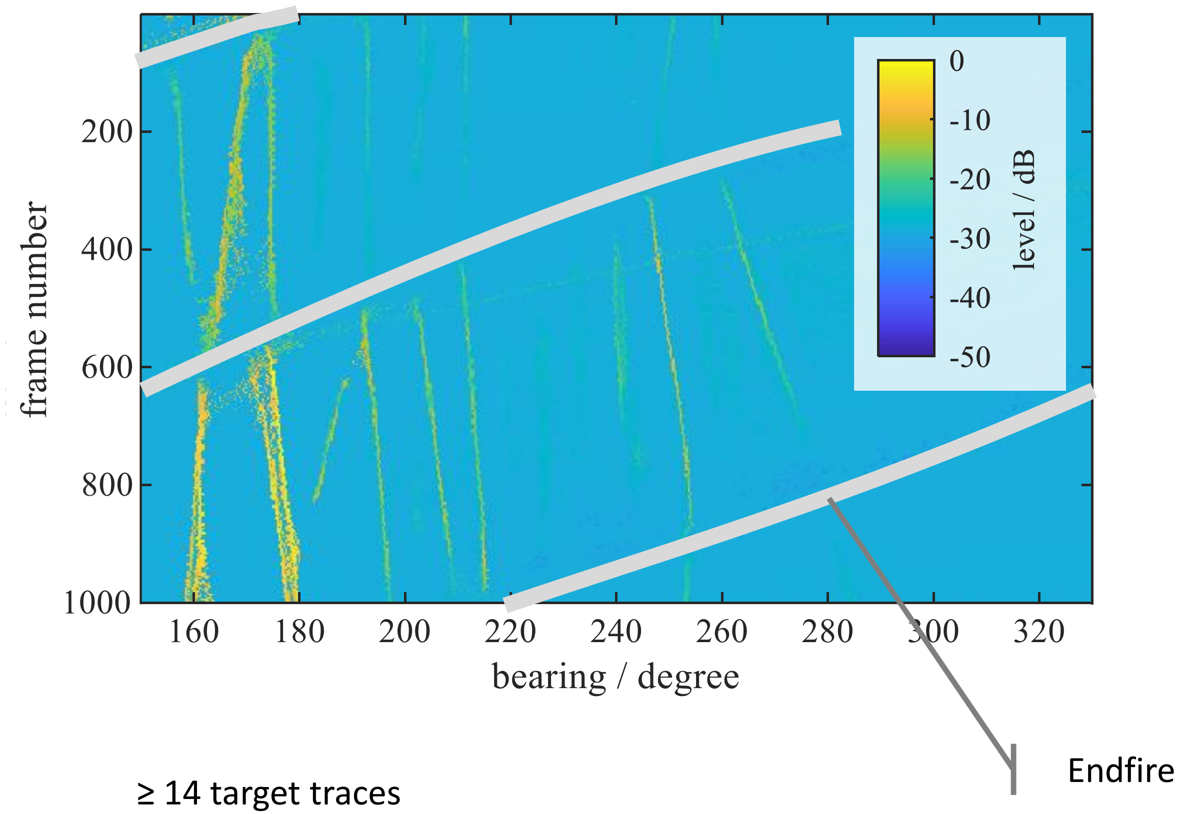
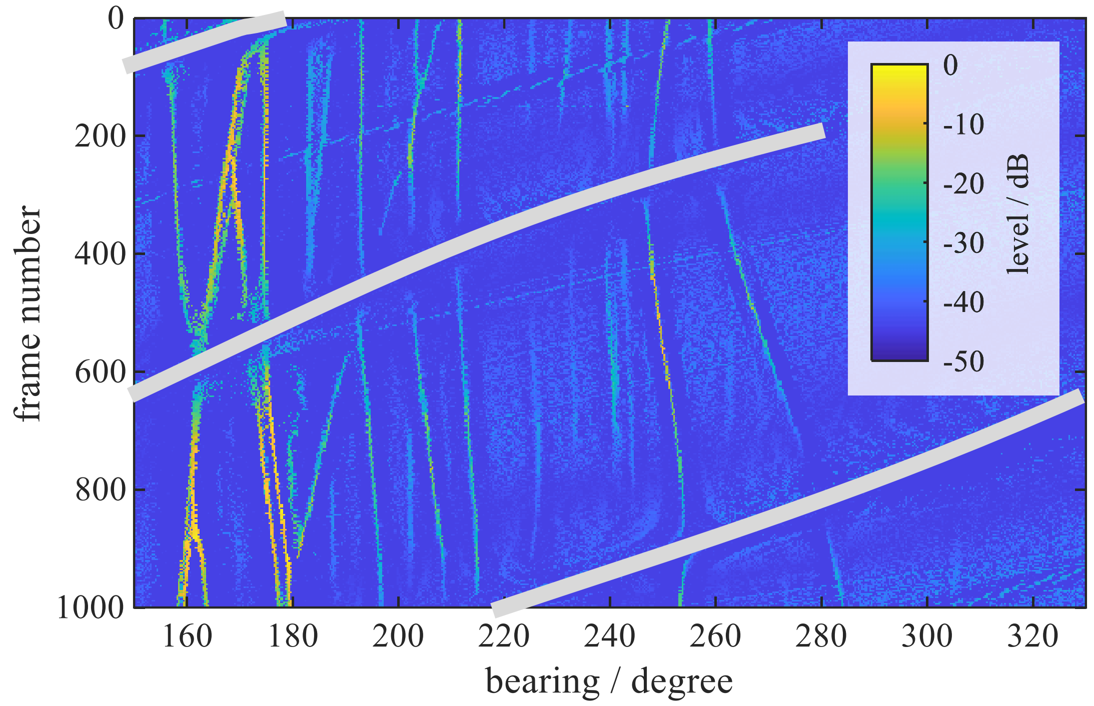
Sea trial data

Broadband Detection (BDT)

Delay-and-Sum



ABF



≥ 14 target traces

- Flank Array Sonar
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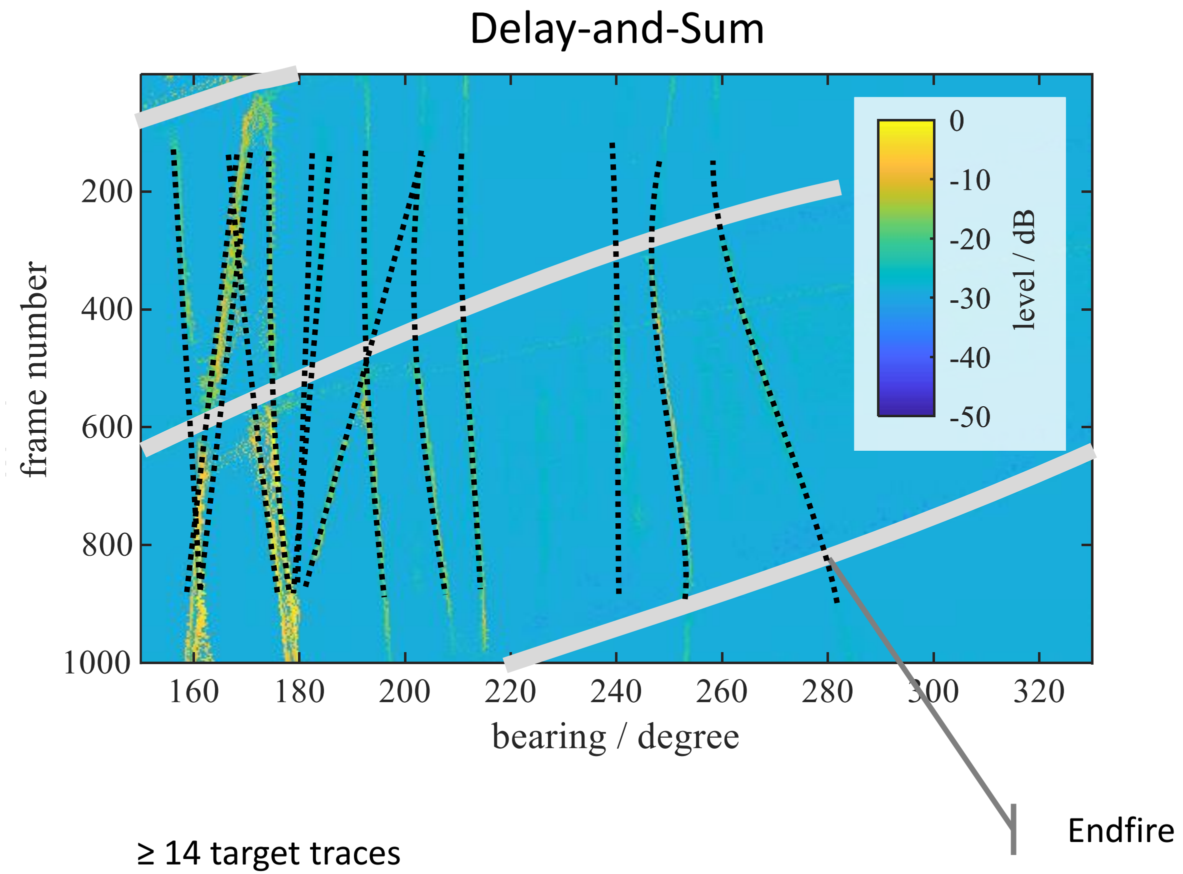
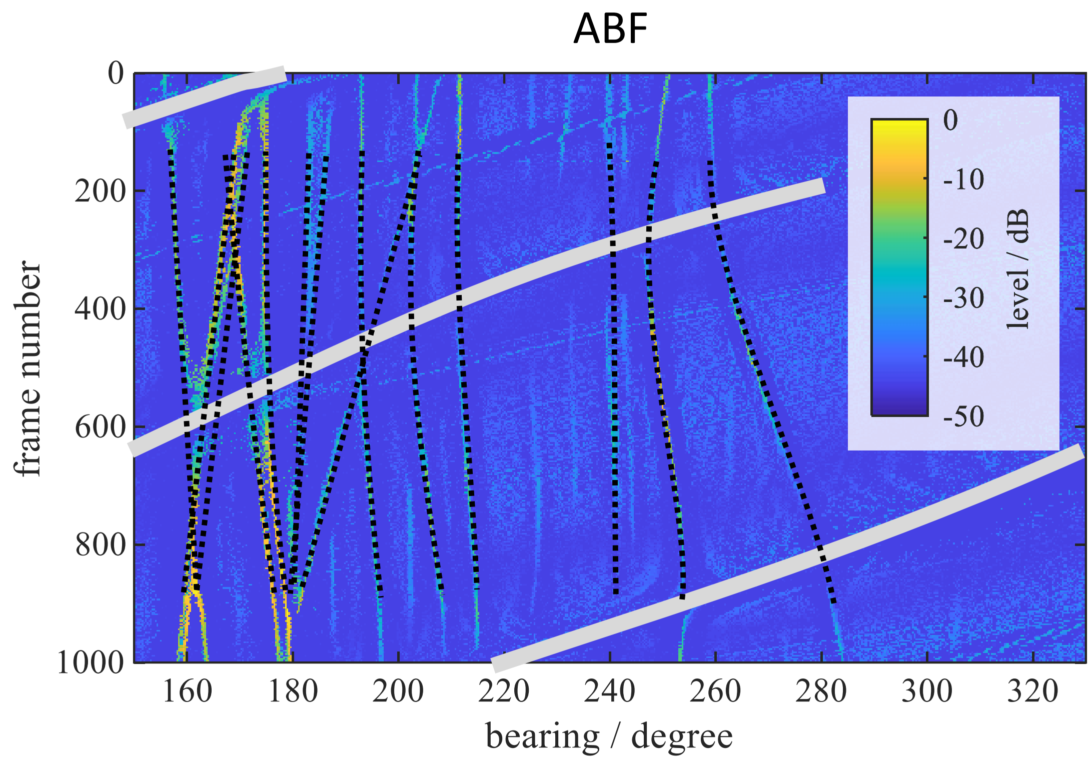
Improved detection performance:

- Higher signal-to-noise-plus-interference ratio
- Improved target separation

Sea trial data

Broadband Detection (BDT)





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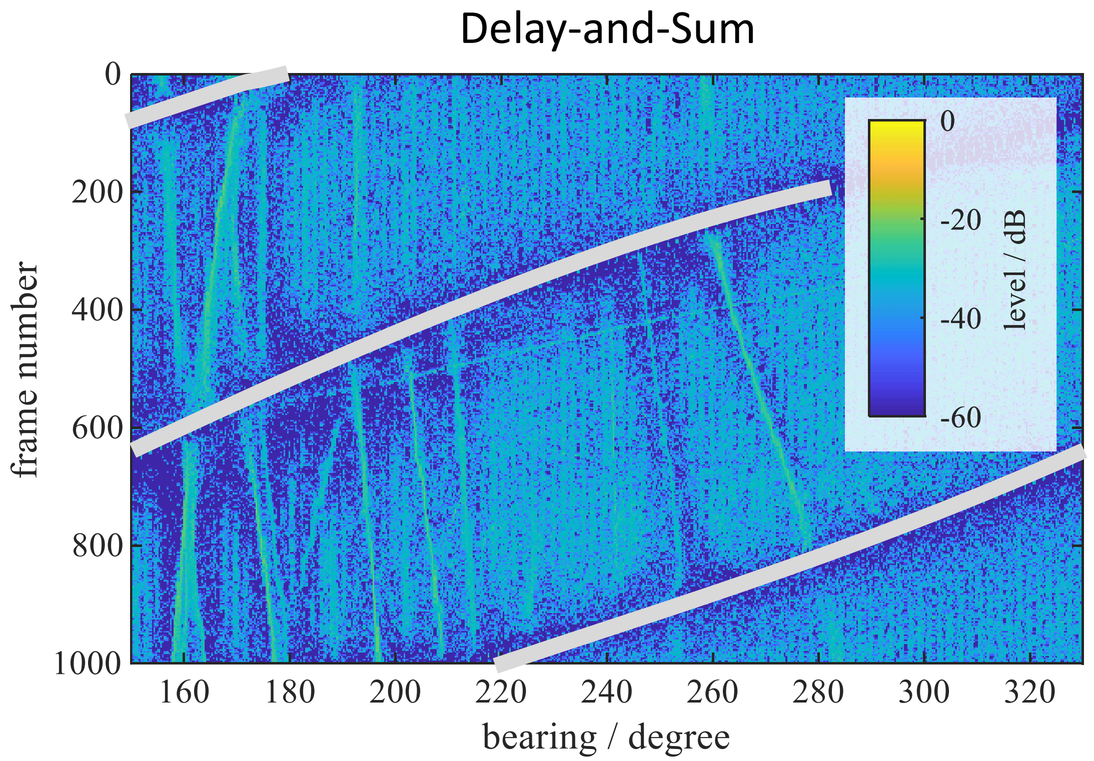
Sea trial data

Low Frequency Analysis and Recording (LOFAR) (Maximum from frequeny domain)



≥ 14 target traces

- Flank Array Sonar
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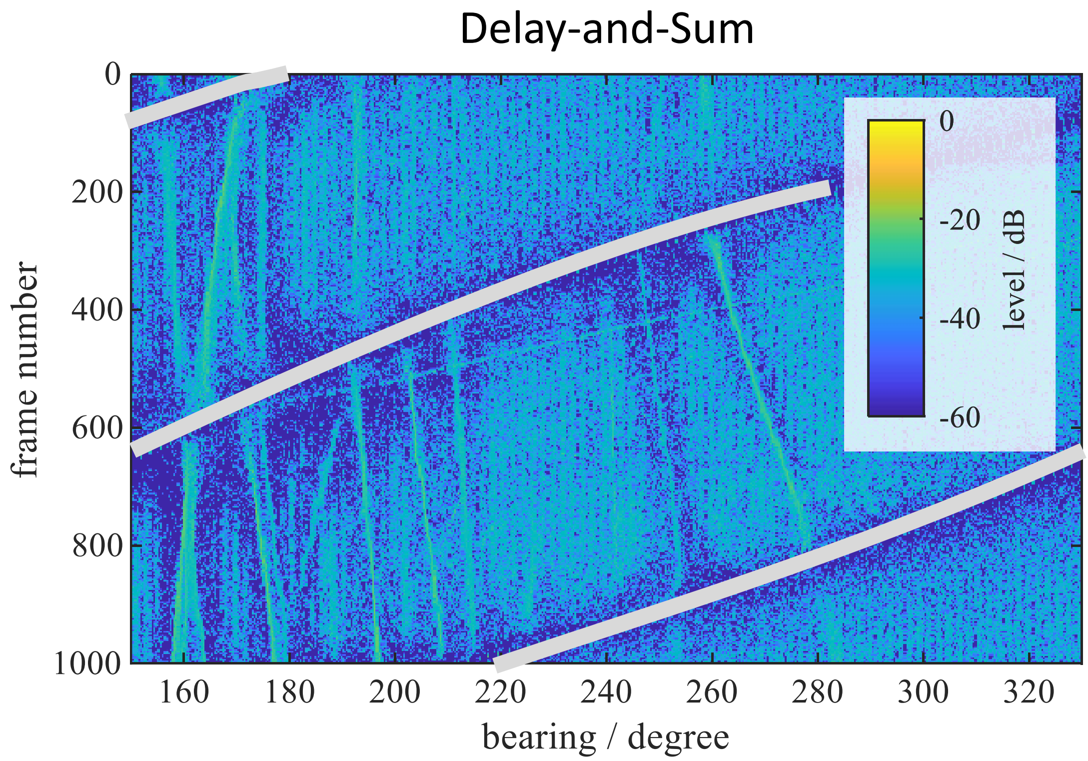
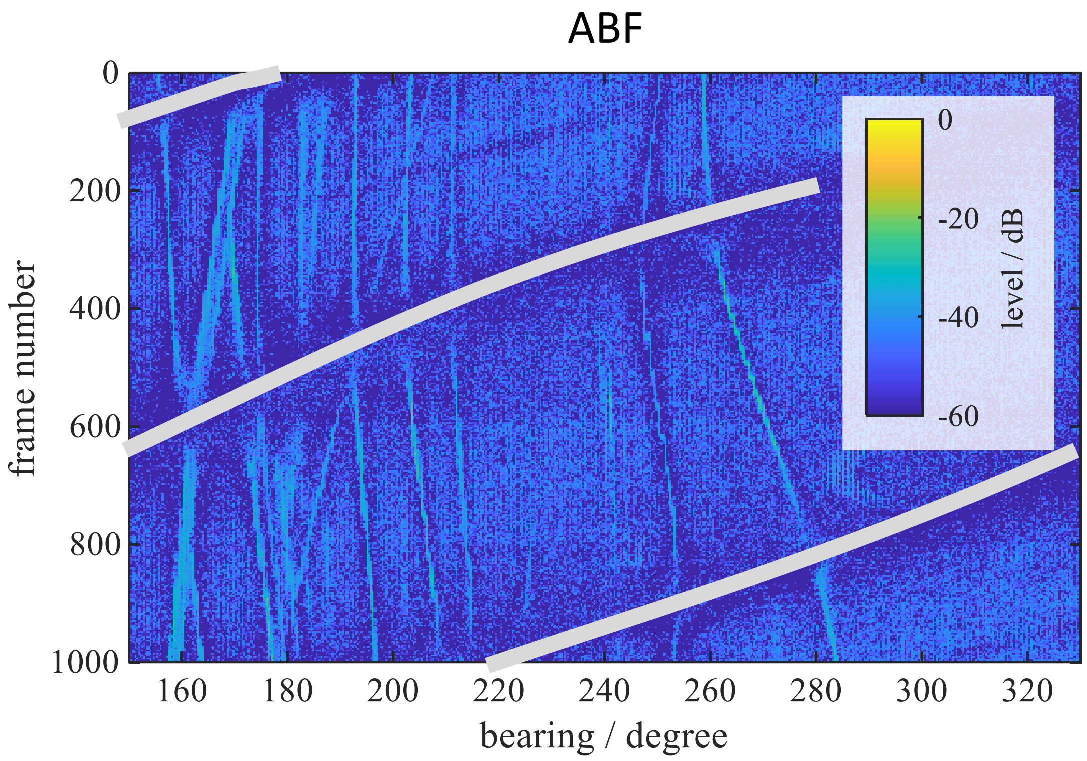
Sea trial data

Low Frequency Analysis and Recording (LOFAR) (Maximum from frequeny domain)





≥ 14 target traces

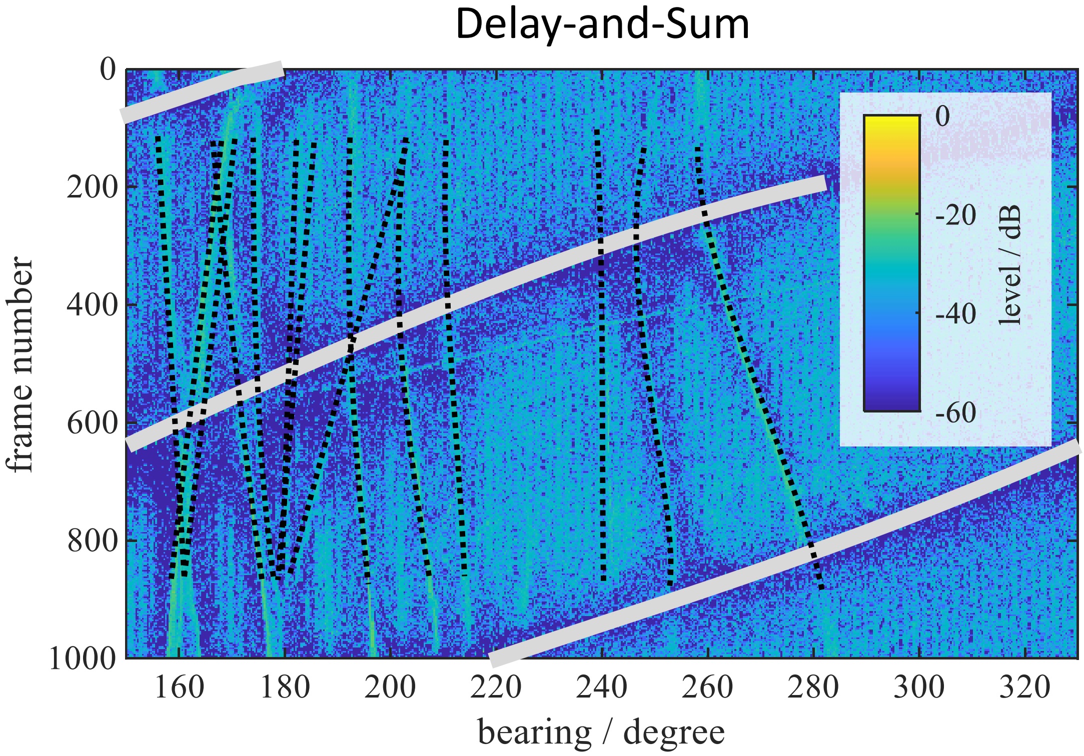
- Flank Array Sonar
- 360° turn of the submarine
- Reduced performance in endfire

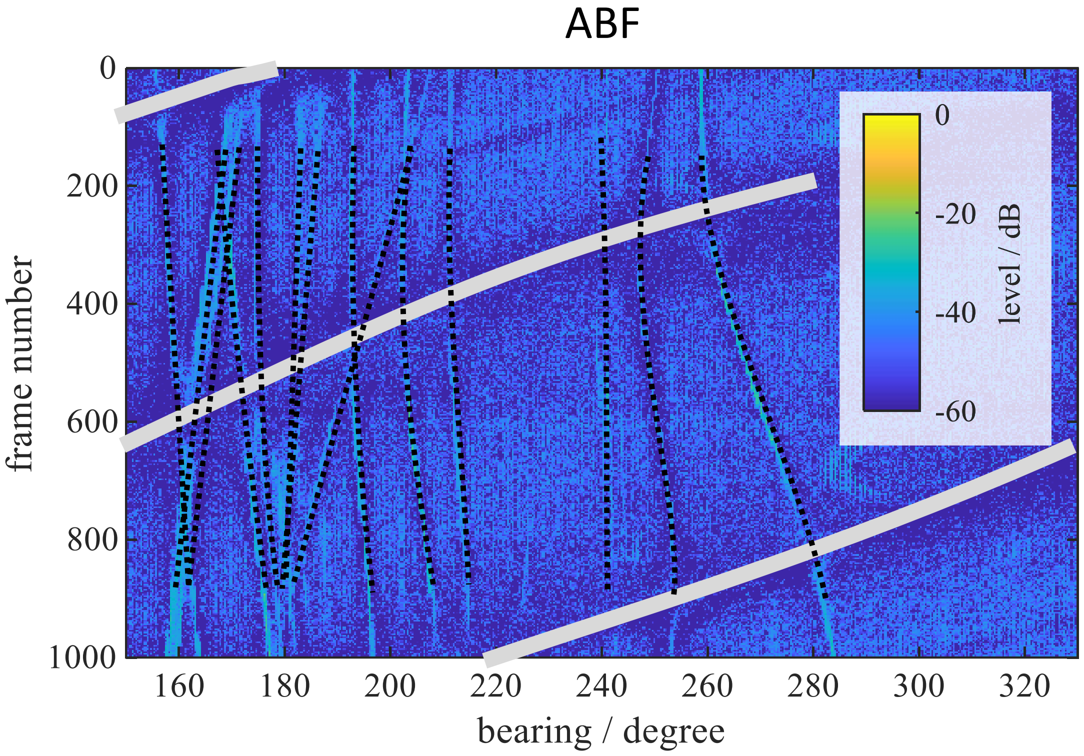
Improved detection performance:

- Higher signal-to-noise-plus-interference ratio
- Improved target separation
- Detection of more target traces possible

Sea trial data

Low Frequency Analysis and Recording (LOFAR) (Maximum from frequeny domain)





≥ 14 target traces

- Flank Array Sonar
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Improved detection performance:

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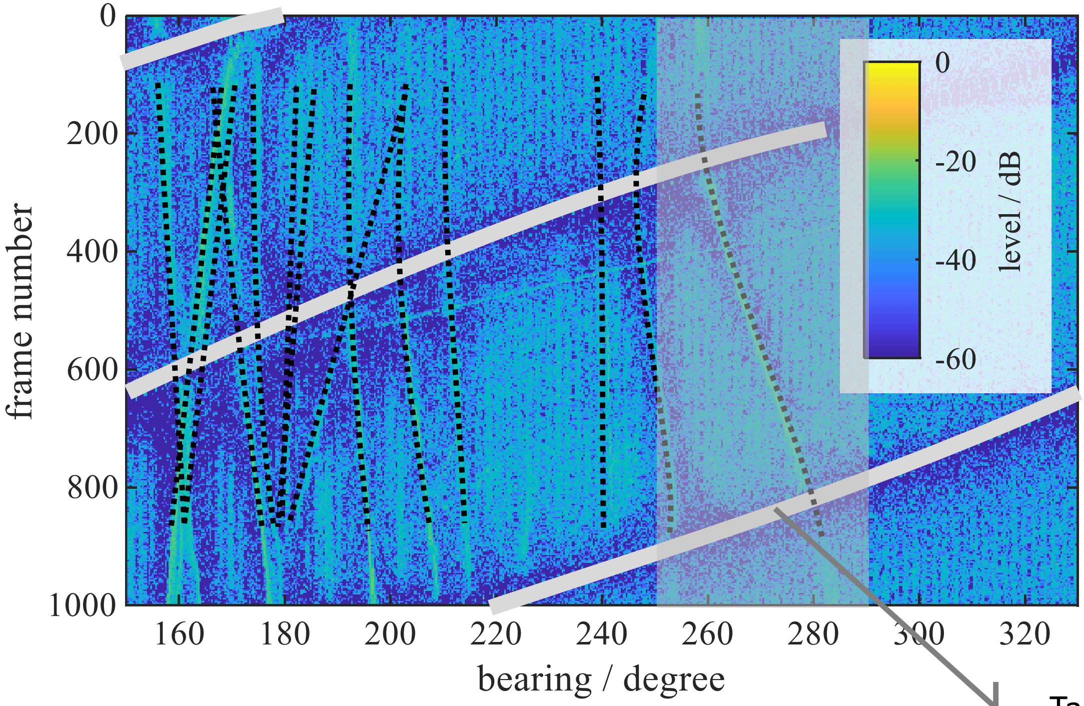
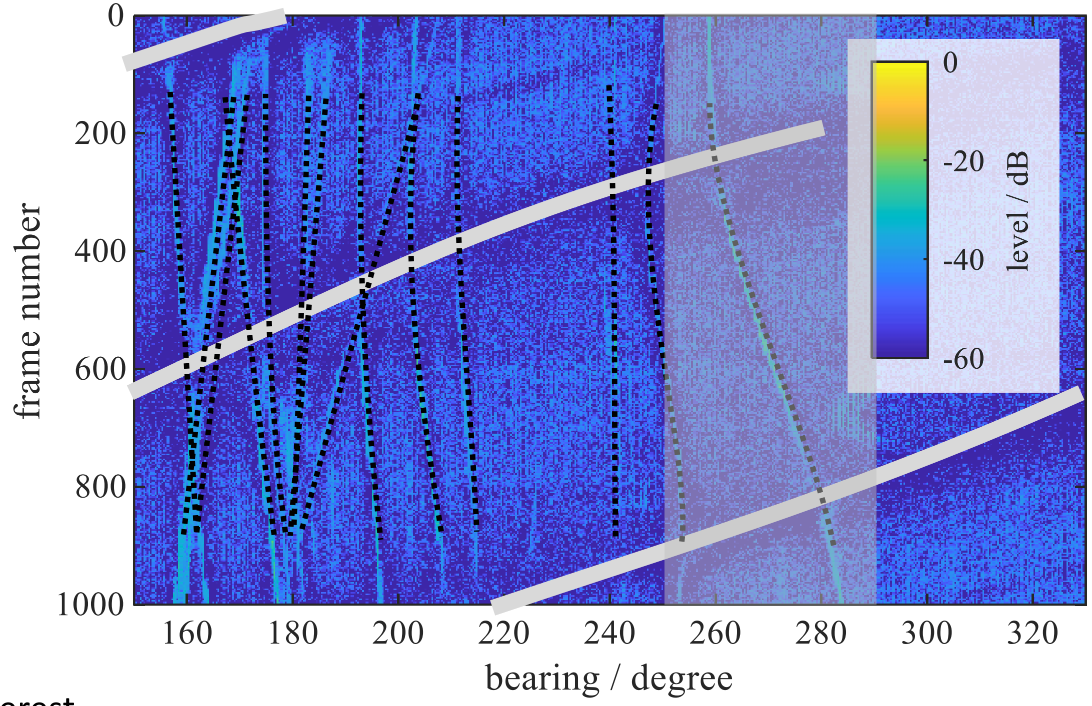
Sea trial data

Low Frequency Analysis and Recording (LOFAR) (Maximum from frequeny domain)

Delay-and-Sum



ABF



Targets of interest

≥ 14 target traces

- Flank Array Sonar
- 360° turn of the submarine
- Reduced performance in endfire

Improved detection performance:

- Higher signal-to-noise-plus-interference ratio
- Improved target separation
- Detection of more target traces possible

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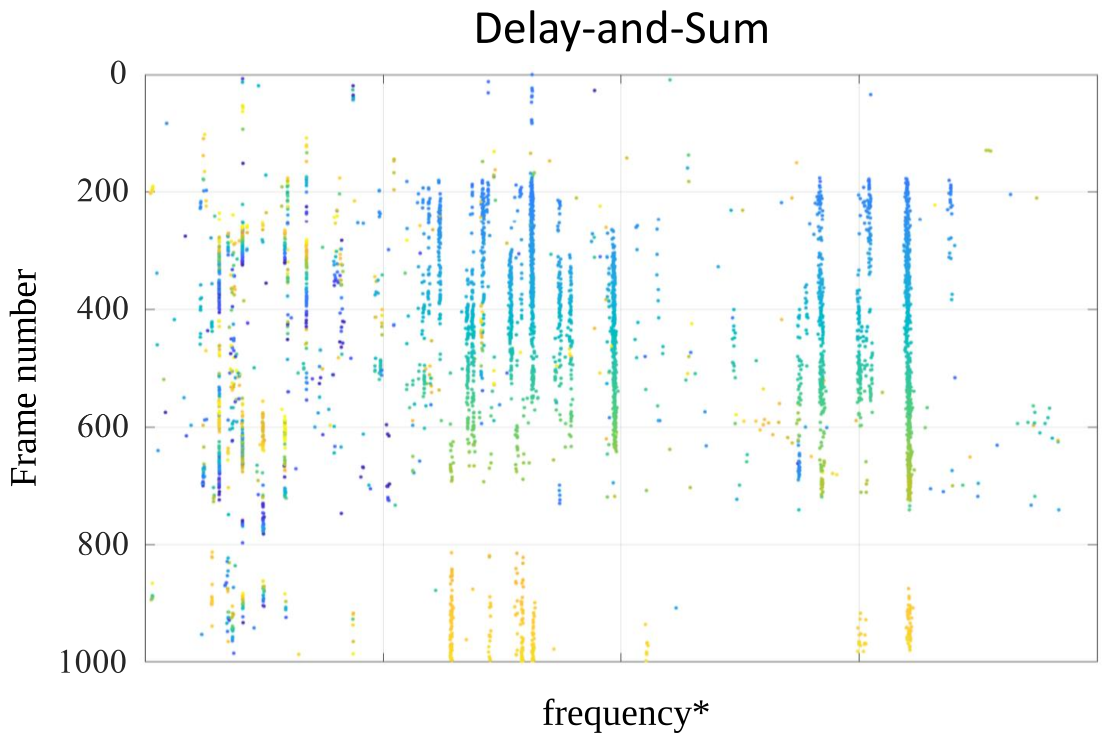
Sea trial data

LOFAR (Frequency detections)

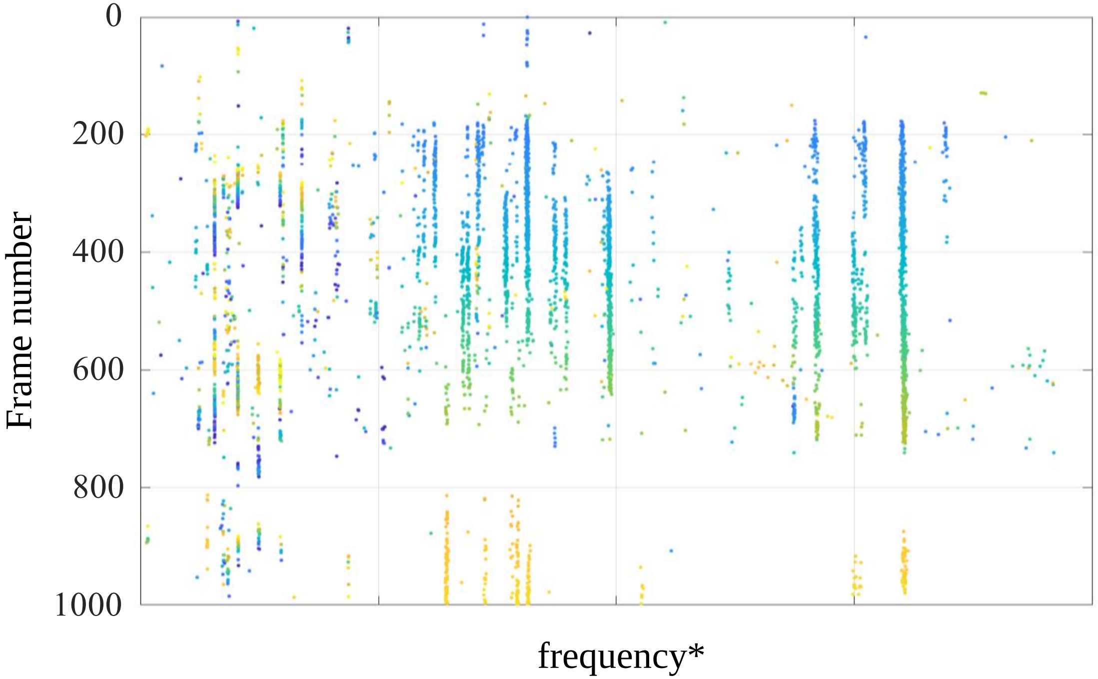


- Frequency information removed

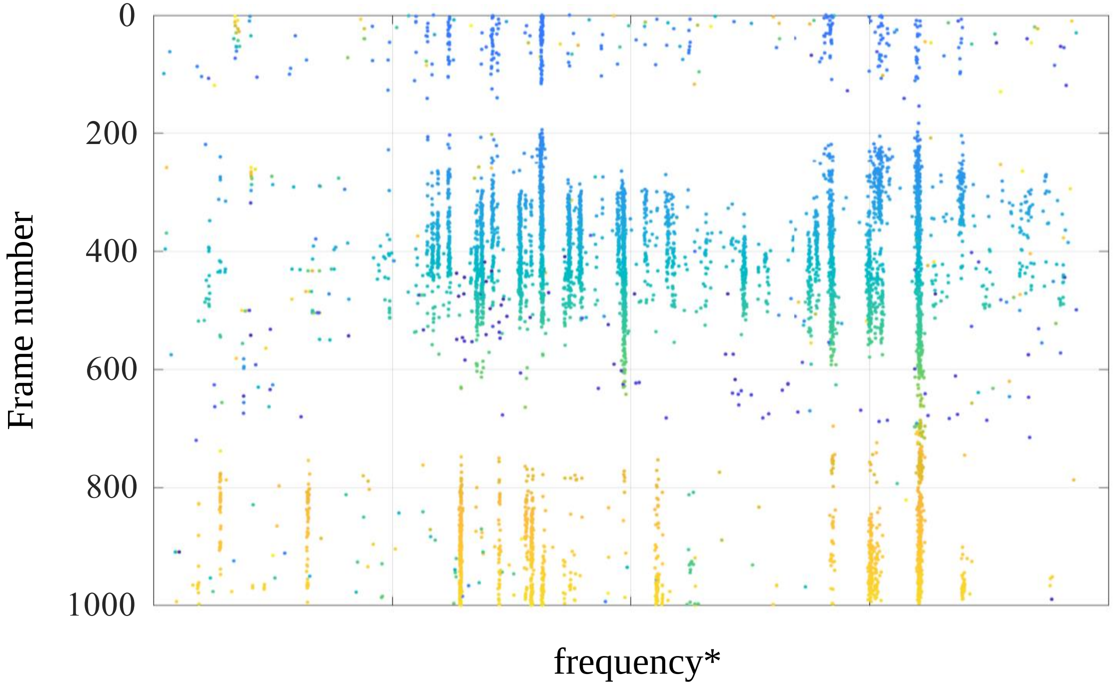
Sea trial data

LOFAR (Frequency detections)

Delay-and-Sum



ABF



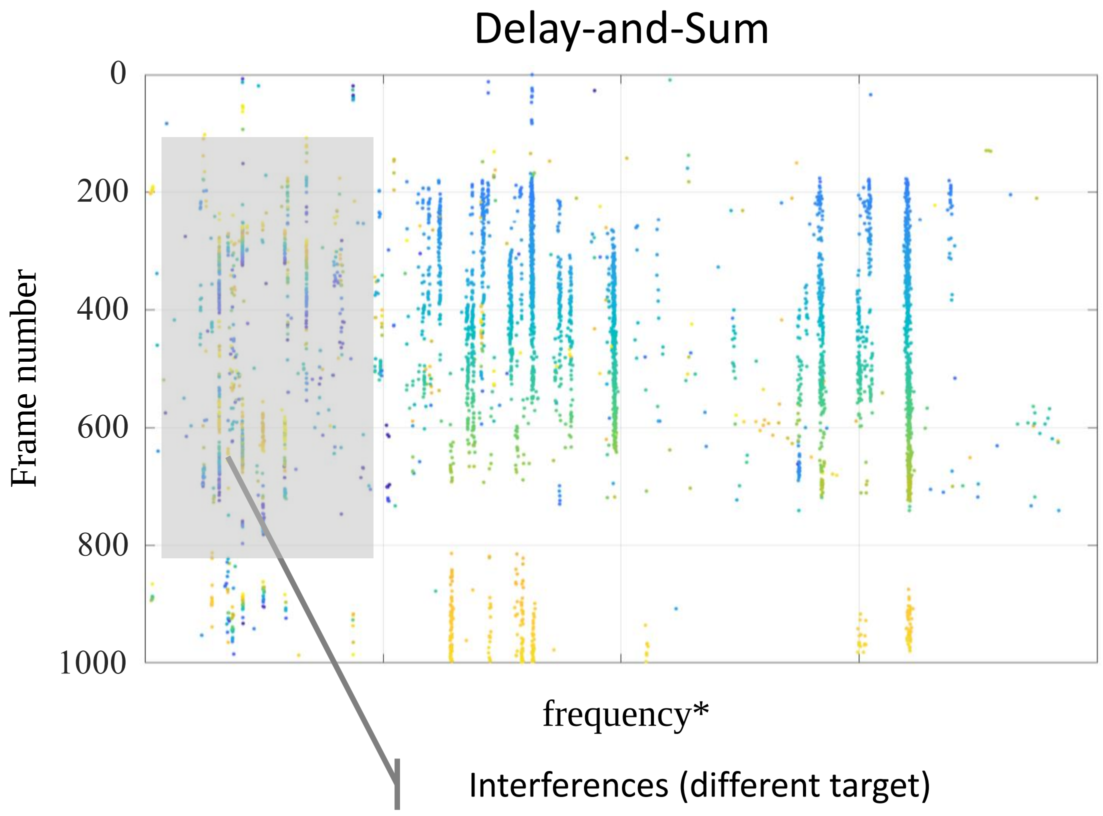
Improved detection performance:

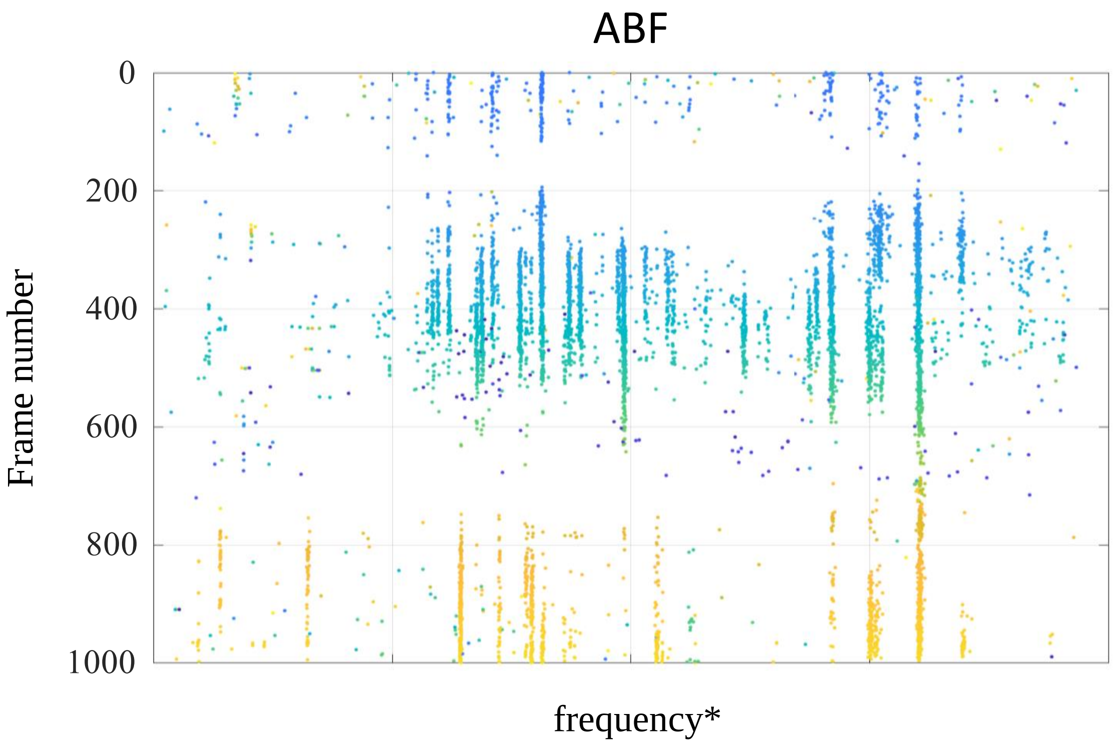
- More frequency lines
- Higher signal-to-noise-plus-interference ratio
- Longer frequency lines

- Frequency information removed

Sea trial data

LOFAR (Frequency detections)





Improved detection performance:

- More frequency lines
- Higher signal-to-noise-plus-interference ratio
- Longer frequency lines
- Suppression of interferences

- Frequency information removed

Table of contents

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Summary

- ATLAS Elektronik GmbH uses an approach to calculate time-domain signals with ABF
- Design is based on existing ABF for BDT
- Advantages of adaptive beamforming with time-domain signals:
  - Sonar operator can listen to the noise of targets only detected in BDT with ABF
  - Superior signal quality for DEMON + LOFAR and other signal processing chains

Contact

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