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A passive receiver for exploiting high-frequency broadband acoustic emitters for improving situational awareness

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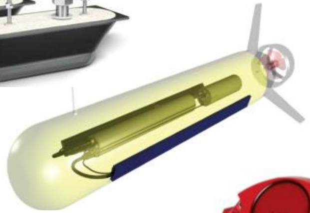
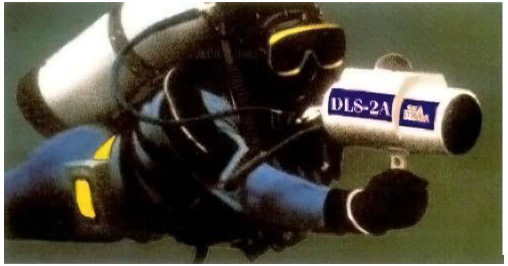
The number of military/commercial/recreational broadband HF emitters is rapidly increasing

- Fathometers
- Fish Finders
- Trawl Net Monitoring
- Sidescan Sonars
- Obstacle / Terrain Avoidance
- Bottom Mapping Sonars
- Underwater Navigation
- Current Monitoring
- Harbor Defense Sonars
- Acoustic Modems





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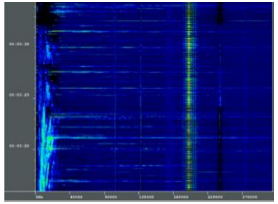
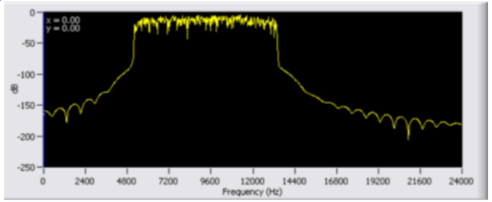
Most platforms can't detect very high frequency signals or signals without narrowband content

- Pulsed CW – Where it all started
  - Easy to generate and process
  - Limited information
  - Optimal counter-detection using spectral analysis



- FM – Current military, commercial and recreational standard
  - Not hard to generate or process
  - Range-Doppler ambiguity can be resolved with up/down sweeps
  - Optimal counter-detection using FM detectors

- Spread Spectrum – The future
  - Harder to generate and process
  - Thumbtack ambiguity diagram
  - Optimal counter-detection requires generalized cross correlation
  - Claims to be LPI but detectable at long range with broadband detector



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Signal types
Any signal can be pulsed or continuous

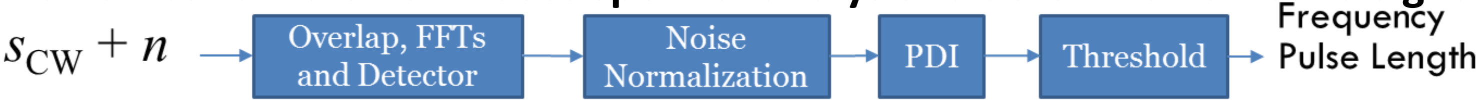
- Continuous Wave (CW)
- Amplitude Modulation (AM)
- Frequency Modulation (FM)
- Phase Modulation (PM)
- Spread Spectrum (SS)
- Pseudorandom Noise (PN)

Detector types

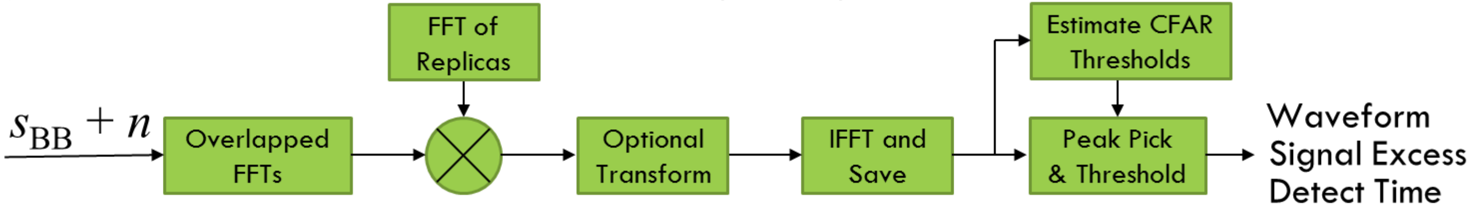
- Narrowband detector
  - Based on spectral analysis
  - Requires search over only one parameter, bin BW = 1 / Period
  - Provides classification features
- FM detector
  - Can be based on modified spectral analysis or replica correlation
  - Requires search over frequency limits and pulse length
  - Provides classification features
- Broadband detector
  - Based on Generalized Cross Correlation (GCC)
  - Requires selection of time and frequency limits
  - Provides very limited classification features
  - Nearly optimal for counter-detection

Detector types

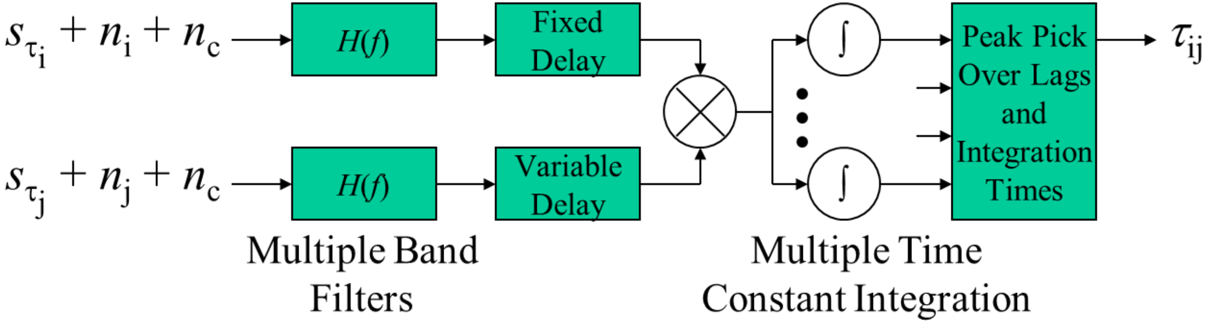
Narrowband Detector – Uses spectral analysis to detect narrowband signals



Replica Correlation Detector – Beats signal against known replica



Generalized Cross Correlation – Beats signal against an unknown replica



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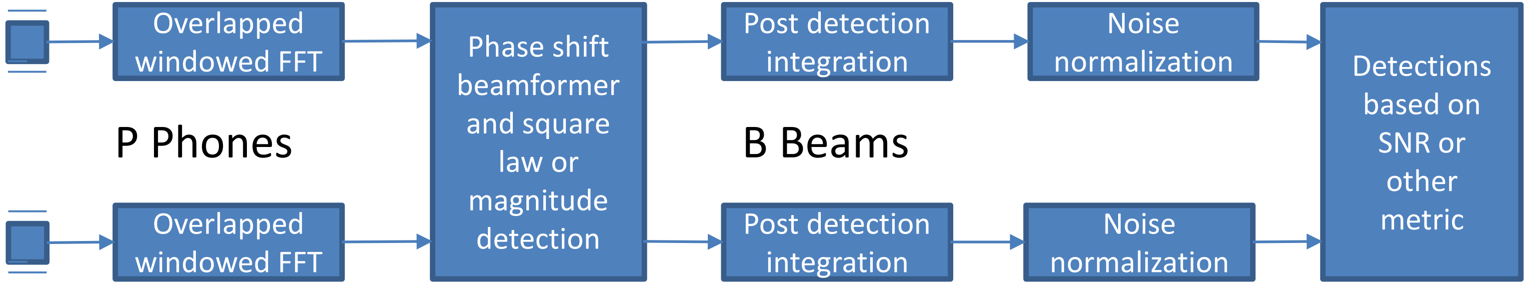
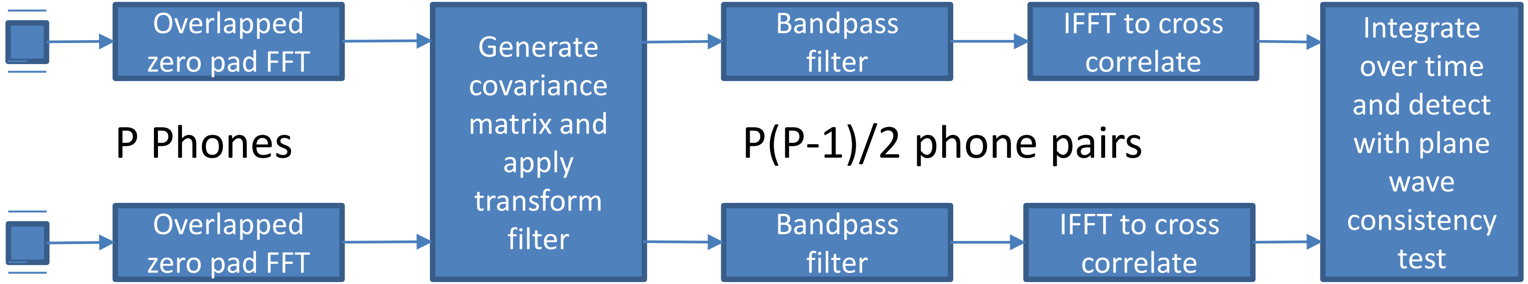
Narrowband and broadband detector implementation

Narrowband Detector – Variable Pulse length and PDI



Broadband Detector – Variable start and stop frequencies and pulse length



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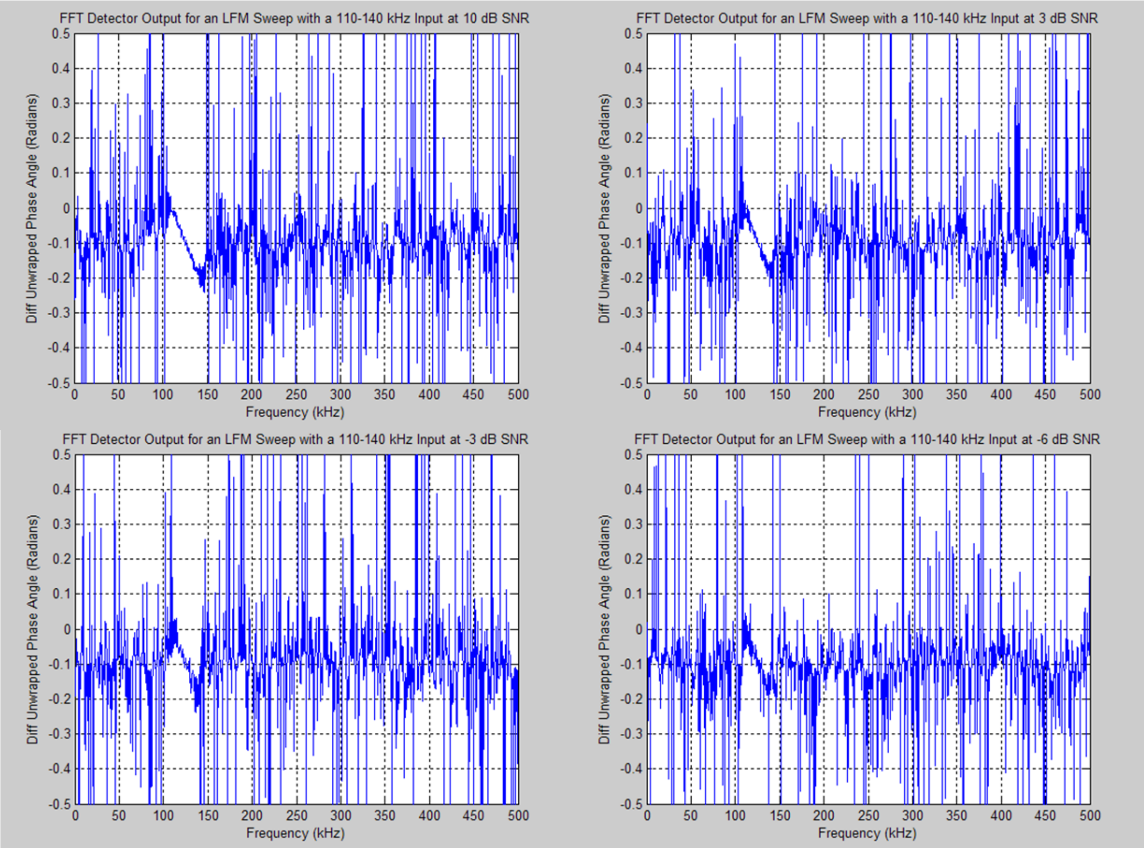
FM detector based on narrowband processing 10dB, 3dB, -3dB and -6dB SNR examples



Today’s sonar primarily use LFM or HFM signals because they provide broadband benefits with reasonable processing.

These figures shows an LFM signal with a TB product of 600 and known duration being detected using differential unwrapped phase.

A true broadband detector would detect the same signal with ten dB less SNR.

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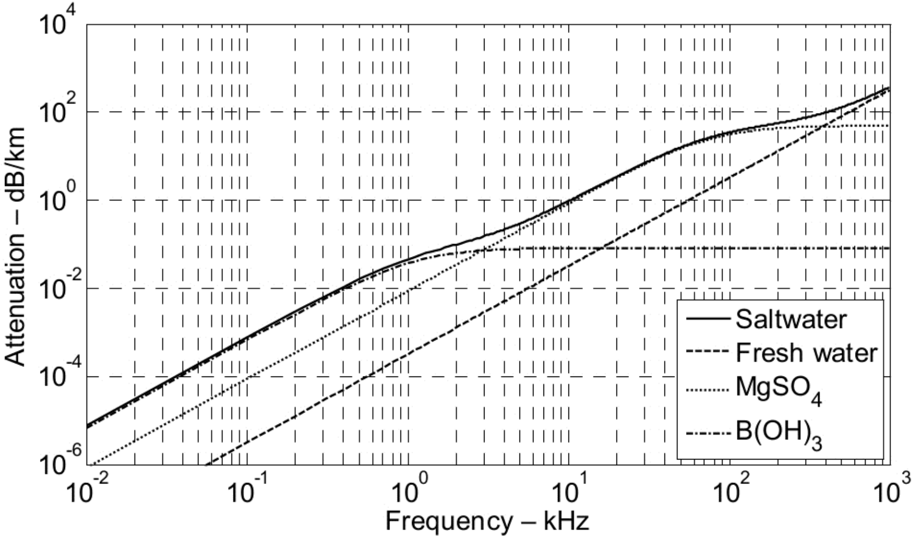
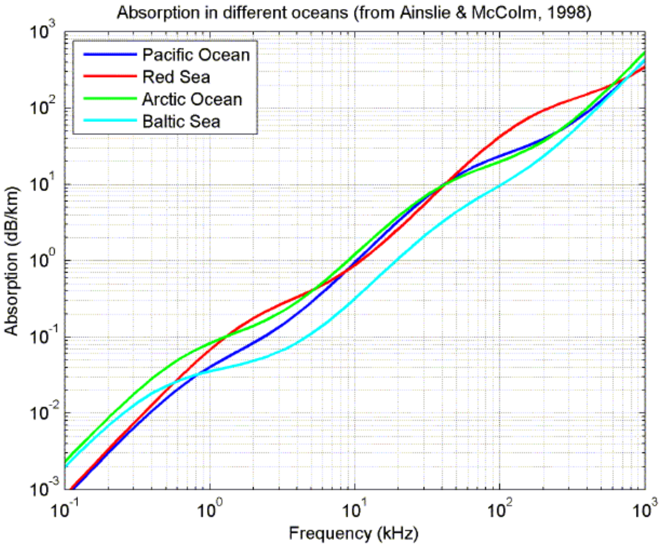
Absorption loss frequency dependence

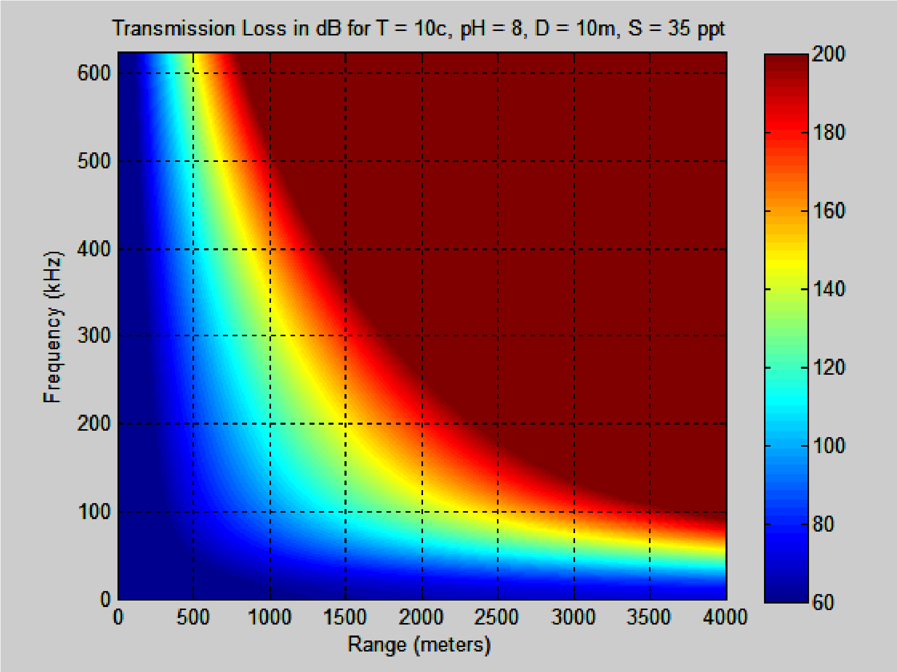




Maximum detection range of high frequency signals is limited by absorption loss. In fresh water this is a function of frequency, temperature, depth, salinity and pH. The figure on the left shows Boric Acid is responsible for most excess loss at frequencies below 1 kHz, while Magnesium Sulfate is responsible for most excess loss at frequencies between 1 kHz and 500 kHz.

Counter-detection of high-frequency signals occurs at tactically useful ranges

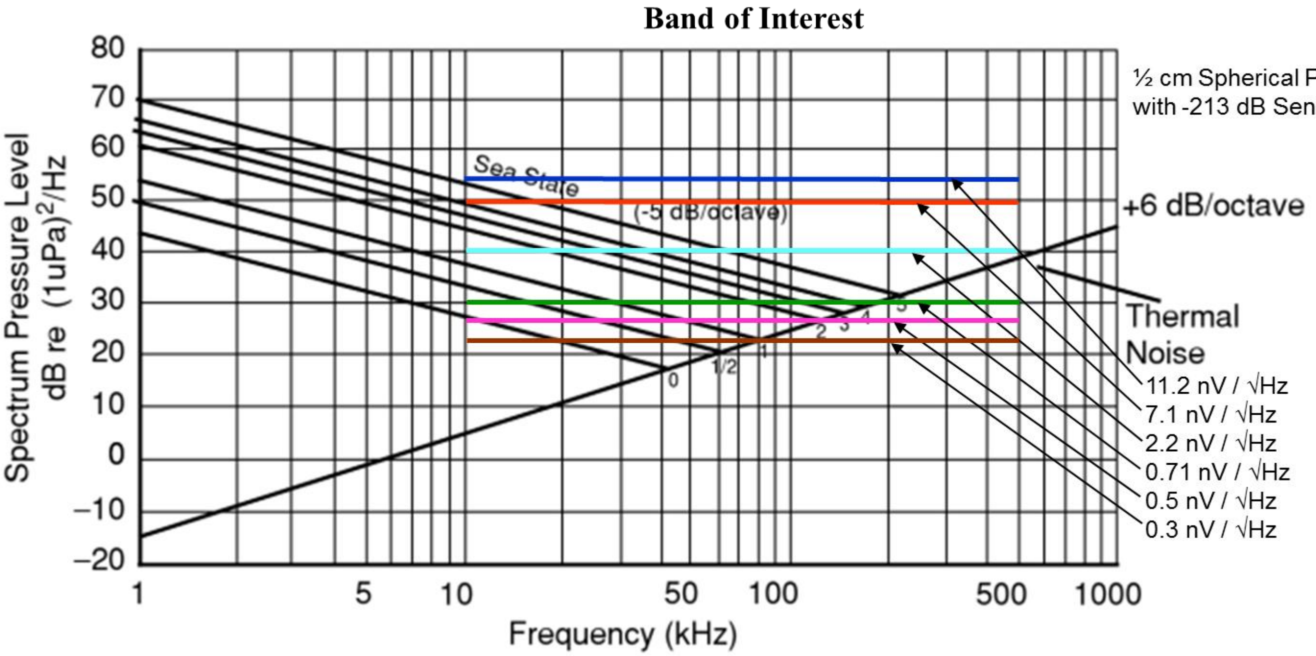
One-Way Transmission Loss (dB)



- Transmission Loss (TL) is estimated by adding spherical spreading and absorption loss.
- One-way range where TL equals 140dB, as a function of frequency:
  - @ 100 kHz: 2.3 km
  - @ 200 kHz: 1.5 km
  - @ 300 kHz: 1.2 km
  - @ 400 kHz: 900 m
  - @ 500 kHz: 700 m
  - @ 625 kHz: 500 m

Minimizing preamp noise level is critical for good performance with low sensitivity hydrophones

Reducing electronic noise in the preamp is the most cost effective way to improve system performance. The goal is an electronic noise floor at least 10 dB below the ambient noise.



½ cm Spherical Phone with -213 dB Sensitivity

Critical sensor metrics and Current system performance

Frequency coverage	1 kHz – 625 kHz
Spatial coverage	Close to 4π Steradian
Counter-detection ratio	>2.5X
Signal clipping level	>180 dB re 1μPa @ sensor
Electronic noise floor	<30 dB re 1 μPa per √Hz
RMS bearing error	<3° @ MDL + 15 dB SNR
Dynamic range	>120 dB 1 tone, >108 dB 2 tone
Platform data I/F	Gb Ethernet
Power	<5 Watts
Weight	<3 kg in air
Cost	<$20K
Detected modulation	CW, FM, AM, PM, SS, PN

Legacy high frequency sensors developed for marine mammal detection

AD&D four ½cm spherical hydrophones on an A-size faceplate in a star configuration.

AD&D four ½cm disc hydrophones behind an A-size faceplate in a star configuration.

AD&D variant with Reson phones.

Calibrated Omni phones for Liquid Robotics WaveGlider.

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Recent blade sensor design for the T-AGOS (X) CLFA ships using seven ½cm spherical hydrophones

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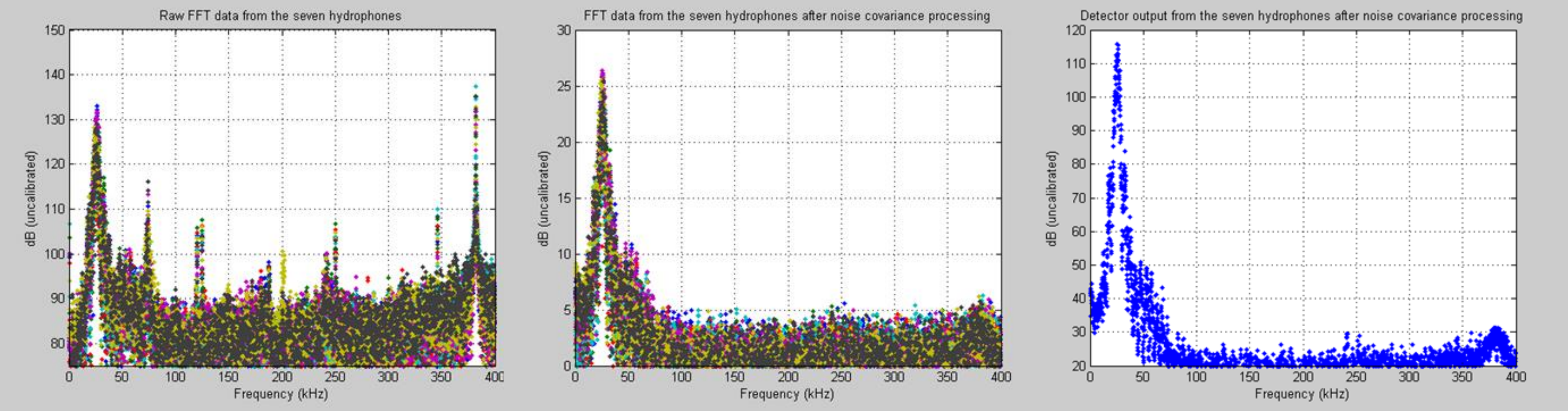
Removal of narrowband stationary noise and efficient detector

- Noise covariance for the seven element array was estimated in the test tank during a noise only collection.
- Mahalanobis whitening, $Y = R^{-1/2}X$, was performed on rotator data with 1ms pulsed test signals.
- $Y = X^T R_n^{-1} X$, is used to efficiently detect signal presence.



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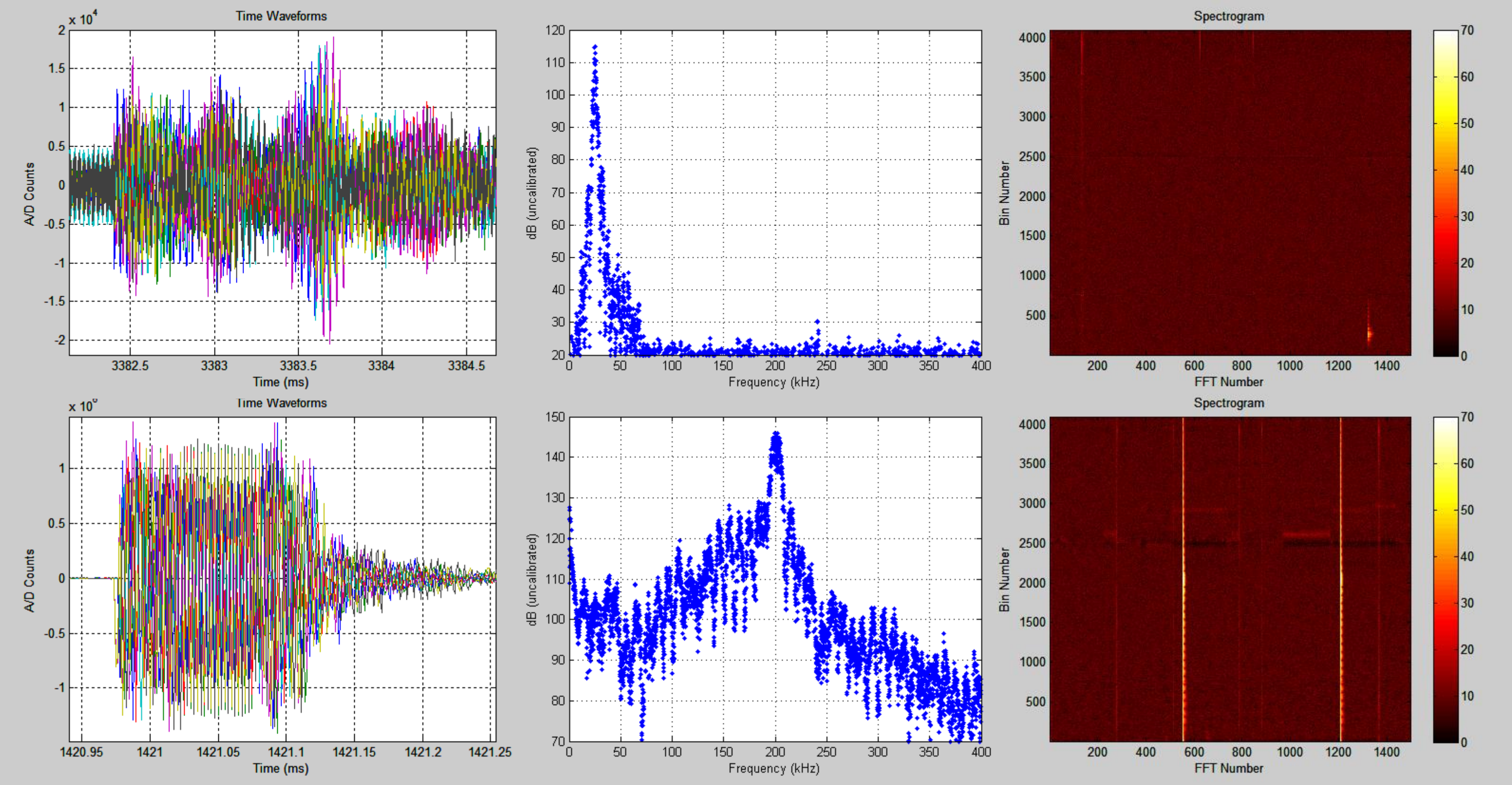
Tank test 25 kHz and 200 kHz pulses



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Strengths and weaknesses of broadband processing

STRENGTHS

- Almost all high frequency signals are broadband
- Detects millions of commercial and recreational sonars which operate above 100 kHz
- Separates signals based on TDoA at phone pairs allowing detection of multiple signals in the same frequency band
- Detects many so called LPI signals

WEAKNESSES

- Requires a lot of processing
- High frequencies may have AoA ambiguities due to sparse array
- Doesn't provide classification features other than frequency band, time duration and angle of arrival
- Doesn't lend itself to audio assisted classification because the human ear is a narrowband receiver

Summary

Millions of acoustic emitters currently being used for military, commercial, and recreational applications can't be detected by many platform because they are either too high in frequency or lack narrowband content.

GCC techniques must be used to detect broadband acoustic emissions with 'near optimal' performance. An accurate Angle of Arrival can be obtained which can be used for localization, tracking and post-detection beamforming.

High frequencies limit detection range, but not as much as generally believed. Many supposedly covert platforms use high frequency broadband sonars that can be detected and localized at ranges of 1 to 2 NM.

Low-cost, high-frequency passive receivers with broadband processing covering up to 625 kHz with close to 4π steradian coverage can provide increased situational awareness by detecting currently overlooked signals.