# Matched Field Processing for Active and Passive Sonar

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## LONG TERM GOALS

The complexity and dynamics of shallow water limit the performance of adaptive array processors. Matched field processors are especially sensitive since they require accurate environmental models to construct signal replica vectors. The long term goals are i) to determine processors performance limits and ii) to develop robust algorithms for adaptive array processing in shallow water for both active and passive sonar systems.

## OBJECTIVES

The first objective is to understand how mismatches impact adaptive array processing. Array processing in shallow water is limited by: i) environmental, ii) scattering, iii) system and iv) stochastic mismatches. Environmental mismatch concerns imperfect knowledge of the propagation medium, such as the sound speed profile and geo-acoustic properties; this leads to signal gain degradation. Scattering mismatch refers to acoustic processes such as internal waves, surface dynamics and fine scale bathymetry which scatter energy into unusable incoherent components. One may consider it the random component of signal gain degradation. System mismatch refers to array calibration errors (such as positions and sensitivities). Finally, stochastic mismatch concerns errors in estimating sample covariance or other ensemble quantities needed for adaption. Mismatch can be reduced by a number of methods including self calibration; however, it is ultimately present at some level due to dynamical oceanography, shipping sources rapidly transiting through resolution cells, or nonstationary reverberation.

The second objective concerns coherence which relates to scattering and stochastic mismatch described above. Spatial coherence has long been an issue for both passive and active systems. There are two types of spatial coherence: i) wavefront coherence, or wavenumber spreading, and ii) ray/mode coherence. The first relates to the aperture of the array where one can do coherent processing while the second relates to coherence among signal components. This makes coherent multipath/mode processing methods such as matched field possible. With active sonar, temporal frequency represents doppler spread, while frequency coherence represents range spread.

# APPROACH

Our approach has been to pursue the following four aspects for adaptive array processing in shallow water:

<u>Environmental parameter estimation</u>: We assess the limits on MFP performance using parameter estimation bounds. The work using Cramer-Rao bounds for source localization has been well

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established; less attention has been given to the uncertainties due to unknown environments. This is addressed by the investigators as cited in the references. There are two approaches; i) extend the Cramer-Rao results to active sonars and ii) identify the "threshold" in parameter estimates using higher bounds such as the Wiess-Wienstein bounds.

Stochastic matched field: Almost all adaptive array algorithms treat noise nonparametrically. However, in many scenarios a few discrete sources dominate the noise field. In radar these components are addressed parametrically using a combination of direction finding and nulling. In sonar, this is more complex since signals are often not well represented by a single vector parameterization. Our approach is to treat the interference as a "noisy" process with more than a single vector representation. This leads to array processing algorithm parallel to the "noise in noise" detection problem in time series analysis.

Adaptive array constraints: With the large arrays now used it is straight forward to demonstrate that nonstationarity of the field is the most significant limitation to adaptive processing. Consequently, one must use reduced degrees of freedom characterizations. We are examining techniques based upon the signal to noise ratio (SNR) on the coordinates of an singular value decomposition (SVD) of the noise field. The issue here is the low order eigenvalues of an SVD are noisy when there are few "snapshots," so the SNR calculations are subject to significant variability.

Broadband processing: The performance gains for broadband processing in the VLF range have been advocated and some experiments has verified this. Nevertheless, broadband processing is hard to exploit for passive systems because of the uncertainties in spectra which then dominate whitening in an adaptive processor. In addition, coherence across frequency due to range spreading is an issue for active systems. Our approach to is to i) investigate passive matched field algorithms which exploit the impact of motion, or doppler, on broadband signals and ii) use data from the recent Santa Barbara Channel Experiment (http://sbcx.mit.edu) to estimate frequency coherence using the wideband waveforms used in the experiment.

## WORK COMPLETED

Work continues on a broadband implementation of the performance bounds and comparing them to experimental data. This work on performance bounds was reported in previous annual reports and the references therein.

The performance of an adaptive sidelobe canceller using a singular value decomposition was evaluated and compared against more traditional adaptive methods such as diagonal loading and subspace techniques.

A method for matched field processing in range-depth and doppler space has been devised and simulated. This method has both an incoherent and coherent formulation depending upon the assumptions made for the temporal coherence of the signal along a range-doppler trajectory. The incoherent approach is an extension of that of Borodin where he stacked MFP outputs along a doppler hypothesis dimension.

## RESULTS

The generalized sidelobe canceller was simulated and compared against the following methods:

Direct form with diagonal loading (DF-DL): This is the standard white noise gain constraint used in matched field processing algorithms with many degrees of freedom. It is well understood and proven experimentally to be quite robust.

Direct form with maximal coherence on subspace (DF-EC): This is a subspace based method which selects the space based upon maximizing the ratio of projection of the signal on the subspace eigenvalue normalized by the eigenvector, a generalized signal to noise approach. It has been used by several others on experimental data. (Lee and Mikhalevsky, Cox)

Generalized sidelobe canceller with subspace reduction by subspace eigenvalue ranking (GSC-PC): This approach reduces the adaption dimension at the output of the blocking matrix in the sidelobe canceller, according to the magnitude of the eigenvalue of the blocked signal.

Generalized sidelobe canceller with subspace reduction by subspace signal to noise ratio (GSC-CS): This approach reduces the adaption dimension at the output of the blocking matrix in the sidelobe canceller according the signal to noise ratio on the subspace dimension, or a cross spectral matrix. This has been proposed for plane wave adaptive array processors and we have extended it to matched field processing. (Goldstein and Reed).

Figure 1 indicates the results for a shallow water, downward refracting water column with a fast bottom. The signal model contained a Kuperman-Ingenito surface noise, a strong surface directional signal at 7000 m and a submerged and weaker target signal. A sixteen element array with 48 snapshots was used. Subspaces with two dimensions were used consistent with the number of directional signals in the field. The figure suggests that the DF-EC approach leads to the clearest resolution of the field. We conjecture the problem with the GSC approach is the noisy estimate of the low order eigenvalues with a small number of snapshots. This results in selecting the incorrect subspace and/or weighting it incorrectly.

We have formulated a matched field processing algorithm which matches in doppler space as well the traditional range-depth dimension. In this we generate a time varying replica waveform for each sensor in a vertical array. This depends upon the instantaneous range and depth of a moving source. If one assumes the signal is incoherent across time, i.e. the bandwidth exceeds the window resolution, one has an incoherent processor; whereas, if the signal were coherent, i.e. the bandwidth is narrower than the inverse of the observation interval, one has a coherent formulation.

Figure 2 illustrates the results of applying this to the environment described above except the surface source is closing with a range of -2.5 m/s and the submerged source is opening at 2.5 m/s. We have matched to the submerged source. One can see the doppler matching highlights the submerged source for both incoherent and coherent processing. Note as well the surface source is suppressed since it has a different doppler. In contrast, when one applies the usual MFP with no doppler compensation, the submerged source is masked by the KI surface noise and the strong directional source. The important result of this is a non-adaptive MFP algorithm, which exploits doppler, one of the more robust parameters in a passive sonar system.

## IMPACT/APPLICATIONS

All the signal processing issues outlined in the approach section are fundamental ones for operational sonars in shallow water.

The role of simultaneous environmental parameter estimation for matched field methods was first raised during the High Gain Initiative (HGI) and has been subsequently pursued in experiments by NUWC and DARPA. It is an issue in the ongoing Santa Barbara Channel Experiments (SBCX) and overall in the limits of passive sonar.

All of beamforming algorithms now used for Navy sonar arrays are based on a matched filter, coherent replica methodology. The introduction of a stochastic approach is applicable when the array dimensions exceed coherence distances and alternative processing algorithms are appropriate. Data from the SBCX program can be used to test stochastic algorithms and the concepts are certainly relevant to large aperture arrays such as the TB-29.

The "snapshot" problem is well known in the array processing literature and will become acute with large aperture, high resolution arrays. The issue has driven aspects of the algorithm design for Twin Line SURTASS (*a priori* covariance models are assumed), the adaptation algorithms in ADS and the forthcoming APB-1 test for the Submarine Superiority Program.

The performance gains of broadband processing in the VLF band for passive systems has been demonstrated in several recent experiments. For active systems the results from recent 6.1 experiments, *e.g.* Heard Island, ATOC (Acoustic Telemetry of Ocean Climate) and TAP (Trans Arctic Propagation) have also demonstrated high coherence for broadband signals over very long ranges. Broadband coherence gains are also fundamental to the limits of passive sonar.

## TRANSITIONS

The software for the reduced degree of freedom algorithm generalized sidelobe canceller for the finite "snapshot" problem has been given to SSC-SD to test on the SWELLEX data. The SWELLEX analysis was reported by Abawe in 1998.

## RELATED PROJECTS

Santa Barbara Channel Experiment, DARPA: We participated in the signal design and execution of the experiment and are now analyzing the vertical array data for sensor localization and broadband matched field processing. This work is being done by Research Assistant, Mr. Peter Daly in cooperation with Dr. Peter Mikhalevsky of SAIC. The Program Manager is CAPT John Polcari of DARPA.

Acoustic Observatory Working Group: This effort was commissioned by ONR/DARPA/N87 as the result of the JASON recommendation to field an acoustic observatory to assess the limits of passive sonar. Points of contact are Dr. Steven Ramberg, ONR, CAPT John Polcari, DARPA and Mr. John Schuster (N87).

Submarine Superiority Technical Advisory Group: This is a panel commissioned by N87 to review their towed array program, especially regarding the software and algorithms for the Advanced Processor Build (APB) effort. The panel is chaired by Mr. James Griffin (N87).

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**PATENTS**

None.

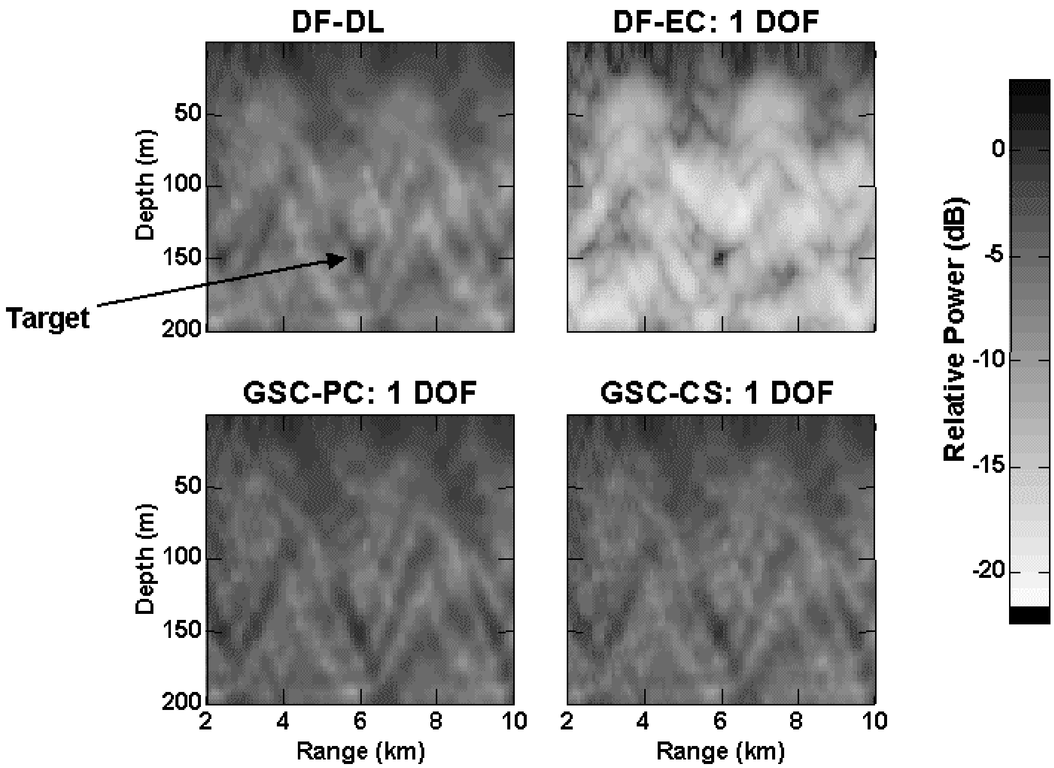


***Figure 1: Comparison of reduced degrees of freedom algorithm for shallow water matched field processing.***

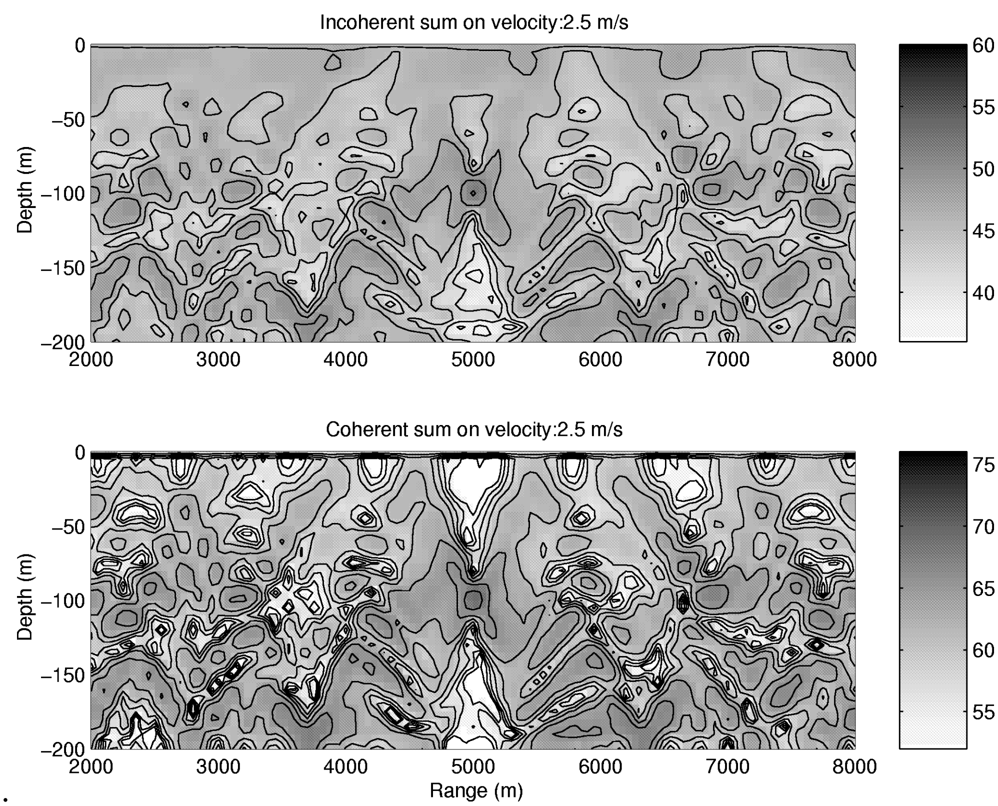


*Figure 2: Incoherent and coherent doppler matched field processing. Replica is based on a source moving at 2.5 m/s.*