HF Broadband Time/Frequency Spreading

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LONG-TERM GOAL

The long-term goal is to provide underwater weapon system designers with a means of testing broadband signals and signal processing algorithms in shallow ocean scenarios where time and frequency (T/F) spread are often significant. This capability is required for sonar signal processing optimization and wideband signal and processor design.

OBJECTIVES

The scientific objectives are to measure T/F spread directly along with relevant environmental parameters (primarily wind speed, sound speed profile and bottom properties) at several shallow ocean regions, and from those data develop an empirical, environment-driven T/F spread model. Essentially, the model will be a correction to ray tracing predictions made using validated boundary scattering and reflection models.

APPROACH

T/F spread over a one-way path may be measured by transmitting a wideband, high-resolution signal into a shallow ocean channel and recording the signal received at a hydrophone spatially separated from the transmitter. The received signals are matched filtered (MF) using replicas which have been generated by compressing or expanding the transmitted signal, an approach referred to as *wideband processing*. The MF output amounts to an instantaneous spreading function (SF) convolved with the signal ambiguity function (AF). The AF may be calculated from the transmitted signal and the processing waveform, and the problem is to extract the SF from the MF output. While deconvolution is the straightforward approach to extracting the SF from the MF output, deconvolution often performs poorly because the method is sensitive to small AF values. The approach we have taken is to decompose the MF output into the sum of basis functions convolved with the AF. If the time resolution of the MF output is sufficient to resolve individual paths, weighted impulses are a suitable basis function. Otherwise, a radial basis function such as the two-dimensional Gaussians is a suitable basis function. In either event, a sum of suitably scaled or weighted, time delayed and/or frequency shifted basis functions is taken as the SF estimate. In the ocean, the spreading function is a random quantity that can change appreciably over time and with change in location. Thus it is never possible predict an instantaneous SF. Instead we focus on understanding the statistics of the process. By observing how SF statistics depend upon geometric and environmental parameters, an empirical, environment-driven model can be developed.

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WORK COMPLETED

During November-December 1996, a spreading function measurement was carried out in the Baltic Sea, in 45 m of water, at a site approximately midway between the southern tip of Sweden and the island of Rügens. The transmit signal consisted of a pair of 27-chip Costas codes which provided about 2.5 Hz frequency resolution, time resolution from 0.2 to 2.5 ms, and -15 dB sidelobe levels. We obtained approximately 200 pings each of signals with roughly 0.5, 1, 1.5, 2, 2.5, 3, 3.5 and 4 km path lengths; 10, 20, 40 and 80 kHz center frequencies; and 2, 4, and 10 kHz bandwidths. Due to dropouts in the recordings, only the lowest resolution (2 kHz bandwidth, 2.5 ms time resolution) signals are useable. To date, the 2 kHz bandwidth recordings have been processed.

A second spreading function measurement was conducted during April-May 1998 in the North Sea, in 32 m of water, at a site approximately 20 miles northwest of the island of Helgoland. This time a 50 ms binary phase shift keyed (BPSK) transmit signal was used, providing low sidelobes and about 20 Hz frequency resolution. Using a 250 msec repetition rate, between 56 and 80 pulses were recorded using each of three center frequencies (25 kHz, 50 kHz, and 90 kHz) and four bandwidths (1.25 kHz, 2.5 kHz, 5 kHz, and 10 kHz). The projector-to-receiver separation was varied from 665 m and 4100 m in approximately 500 m steps. All of these data have been MF processed.

Basis function decomposition scripts have been developed in Matlab and we are currently processing the data to extract T/F spread estimates. Results from the first (Baltic Sea) trial have been published. Preliminary results from the second (North Sea) trial were presented at the ASA meeting in June 1998 in Seattle.

RESULTS

Figure 1 shows data from the North Sea experiment. A single 10 kHz bandwidth BPSK pulse centered at 50 kHz was transmitted over a 665 m range. The projector (or XMTR) depth was 15 m, and hydrophones were located at depths of 8 m, 13 m, 18 m, and 23 m. For each panel, the horizontal axis is time and spans 5 msec, the axis into the page is Doppler velocity and spans about 150 Hz, and the vertical axis is linear. The four panels on the left side show matched filter output, while the four on the right show the spreading function estimate composed of weighted impulses.

Solar warming caused higher sound speed and shorter propagation time near the surface. The matched filter output show two or three distinct arrivals at each phone. The spreading function estimates indicate that a larger number of paths are actually present. Correlation between the matcher filter output and spreading function estimate is excellent, except that the latter better resolves the underlying multipath. Next we will correlate the spreading function estimates with the arrival structure predicted by ray tracing.

IMPACT/APPLICATION

When acoustic signals propagate through a shallow ocean region, the T/F distribution of energy at the *receiver* is shifted and extended (or spread out) relative to that of the *transmitted* signal. The time shift is due to propagation time. The principal causes of time spread are multipath (or micropath) and reflections from multiple scatterers. Relative movement between the transmitter, receiver and the

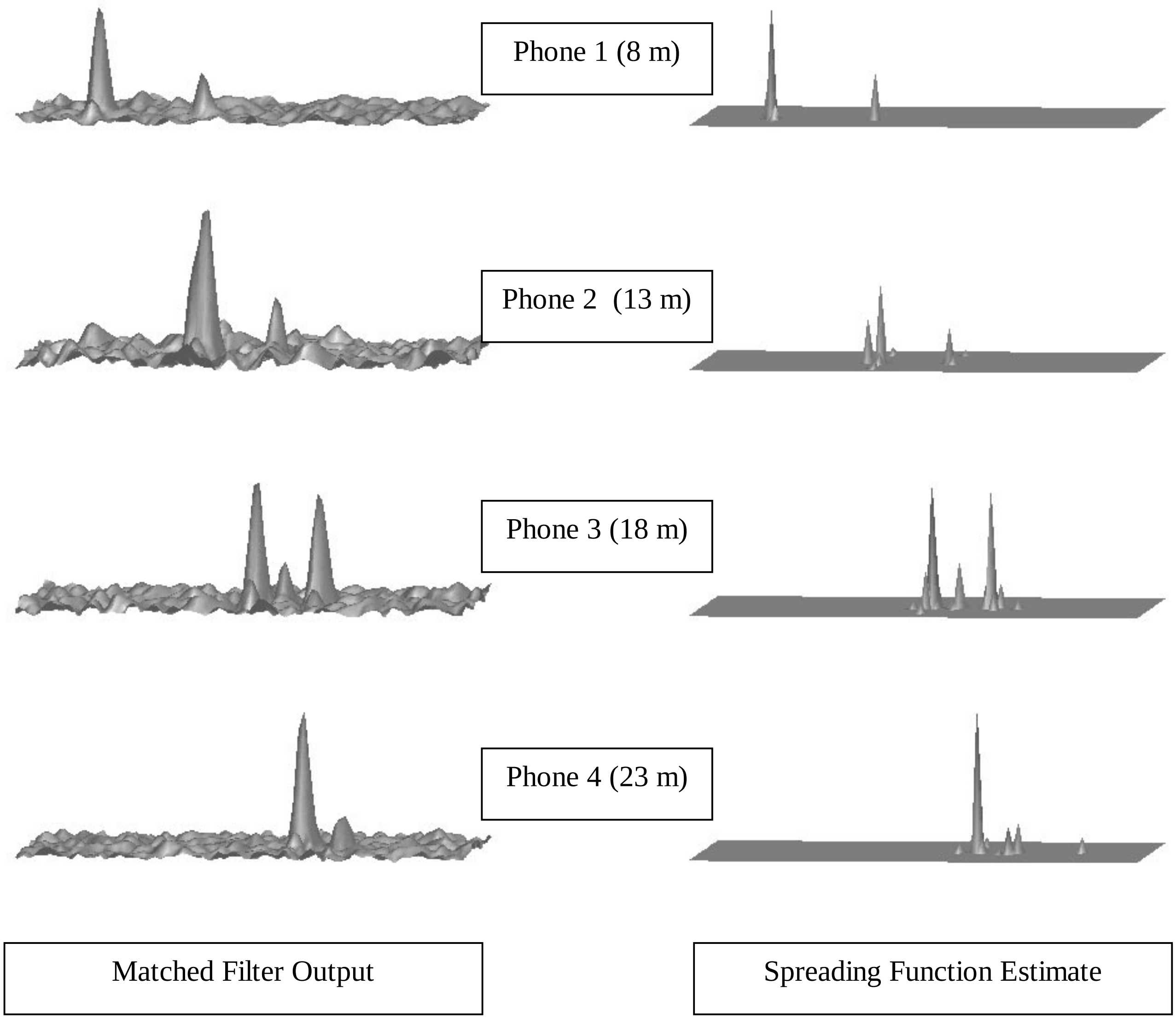

Figure 1.
Matched filter output and corresponding spreading function estimates (weighted impulse basis functions) for a single BPSK transmit. Bandwidth = 10 kHz. Center frequency = 50 kHz. XMTR depth = 15 m. RCV hydrophone depths are 8 m, 13 m, 18 m, and 23 m. XMTR - RCVR range is 665 m.

scatterers leads to frequency shift. Multiple scatterers with different velocities cause the frequency spread wherein the spectrum of the received signal is wider than that of the transmitted signal. It is well known in the signal processing community that T/F spread can severely degrade processing performance.

The entire undersea weapons community is moving toward increased system bandwidth in order to improve signal to interference ratio (SIR), classification performance, and countermeasure resistance. However, the coherence of the propagation channel (and the target echo) across the frequency band, referred to as *frequency coherence*, must be known in order to use increased system bandwidth optimally. Ziomek (USNPGS) has derived the Fourier relationship between the mean square SF and the frequency-time correlation function, mainly that *spread* in *time* and *frequency* are inversely proportional to *coherence* across *frequency* and *time*, respectively. Thus frequency coherence can be estimated from time spread measurements.

TRANSITIONS

The T/F spreading model will be used to optimize and test wideband signal processing concepts. Sibul (ARL/PSU) has formulated an Estimator-Correlator (EC) receiver structure that incorporates mean square SF estimates to optimize signal processing for shallow water and broadband signals. The T/F spreading model will be used to study EC sensitivity to T/F spread in the ONR 6.2 G&C program.

Frequency coherence estimated from time spread data will be used in signal and signal processing design in the ONR 6.2 G&C program.

RELATED PROJECTS

- David Farmer (IOS/BC): High Frequency Propagation Studies in the Coastal Environment
- W.S. Hodgkiss (MPL/SIO): Fluctuations in High Frequency Acoustic Propagation
- Jules S. Jaffe (MPL/SIO): High Frequency Acoustic Propagation Studies
- Frank Symons el. al.: Broadband underwater weapons guidance and control projects

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M.E. Barnoff, R.J. Wilson, *Baltic Exercise Environmental Data,* ARL/PSU Internal Memorandum 97-024, March 1997.

R.L. Culver, *Report of Phase 1,* ARL/PSU Technical Memorandum 97-090, August 1997.

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