High Frequency, Broadband Time/Frequency Spreading for Bistatic Geometries

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Abstract: The overall goal of this work is to develop a functional characterization of, and empirical models for, high frequency, broadband acoustic propagation through a shallow ocean channel. One important aspect of this characterization is the time/frequency (T/F) spread, which quantifies how much signals spread in time and frequency as they propagate. Because time and frequency spread are random quantities that vary from pulse to pulse, time/frequency spread must be characterized by its statistics. T/F spread has been measured in the following ocean environments: sandy gravel bottom, isovelocity sound speed profile (SSP), rough rock bottom, slightly downward refracting SSP, and mud bottom, upward refracting SSP. A statistical model for T/F spread is being developed for these environments based upon radial basis function decompositions of matched filter (MF) output. The ultimate use of a T/F spread model will be in simulation to assess and optimize acoustic receiver performance.

OBJECTIVE

The long-term goal is to develop an empirical, predictive model for the time and frequency (T/F) spread imparted to high frequency, broadband acoustic signals propagating through a shallow ocean channel. Such a model is needed for sonar signal processing optimization and wideband signal design. The environment-driven T/F model will be based upon T/F measurements in shallow ocean channels and concurrently measured environmental parameters (primarily wind speed, sound speed profile, and bottom type). The model will utilize ray tracing to predict the multipath (a major contributor to time spread) and will be consistent with the accepted surface reflection models. To date, several at-sea measurements have been made and the T/F spread is being estimated.

APPROACH

The T/F spread is measured by a transmitting wideband, high-resolution signal through a shallow ocean channel (one-way propagation). The received signals are matched filtered (MF) using replicas generated by compressing/expanding the transmitted signal (wideband processing). The result is one realization of the spreading function (SF) convolved with the signal ambiguity function (AF). The SF can be extracted from the MF output by deconvolution. However, deconvolution is tricky at best and often unstable in the vicinity of small AF values. An alternative approach is to decompose the MF output into the sum of radial basis functions (1) convolved with the AF. Two-dimensional Gaussians are a suitable radial basis function, so that the SF estimate becomes the sum of 2-D Gaussians with variable time and frequency standard deviations and correlation coefficient. In the ocean, the SF is a random quantity that can change significantly with time and position. We cannot predict single realizations of the SF, but instead focus on understanding the statistics of the stochastic process. A model is obtained by observing how SF statistics depends upon geometric and environmental parameters.

AT-SEA MEASUREMENTS

An experiment was conducted during November-December 1996 in the Baltic Sea in 45 m of water approximately midway between the south tip of Sweden and the German island of Rügen. A probing pulse consisting of a pair of 27-chip Costas codes provided about 2.5 Hz frequency resolution, time resolution from 0.2 to 1 ms, and -15 dB sidelobe levels. Approximately 200 pings were obtained for each of the following parameters: .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. Conductivity and temperature vs depth (CTD), wind speed, and wave height measurements were made about every six hours. A detailed bathymetric and sediment survey of the area was made.

MEASUREMENT RESULTS

Received signals have been MF processed, and a basis function decomposition script written in Matlab is used to extract T/F spread estimates. Figure 1 shows one such SF estimate. The top panel shows the MF output for a
single transmission. Source/receiver range, center frequency, and signal bandwidth are 3185 m, 20 kHz, and 2 kHz, respectively. The bottom panel shows the essential resolution of the probing signal. Each plot is normalized by the peak value and expressed in dB. The vertical axis (scale) is equal to $1 + (2v)/c$ ($v = \text{velocity, } c = \text{ocean sound speed}$). Clearly the MF output displays spread and shift in time and scale (or frequency). The middle panel shows the SF estimate for this transmission. The six strongest arrivals have been extracted, and they show varying amounts of T/F shift and spread. The T/F model will be derived from SF estimates such as this.

DISCUSSION

When acoustic signals propagate through a shallow ocean channel, the T/F distribution of energy at the receiver is shifted and extended (spread out) relative to that of the transmitted signal. The principal causes of time spread are multipath (or micropath) and reflections from multiple scatterers. Relative movement between the transmitter, receiver, and the scatterers leads to frequency shift. Multiple scatterers with different velocities cause 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 severely degrades signal coherence and thus signal processor performance. A model for T/F spreading can be used to optimize and test wideband signal processing concepts. Sibul et. al. (ARL/PSU) (2) have formulated an Estimator-Correlator (EC) receiver structure that utilizes SF estimates to optimize signal processing. Also, Ziomek (USNPGS) (3) has derived the Fourier relationship between the SF and frequency-time correlation function, such that spread in time and frequency are inversely proportional to coherence across frequency and time, respectively. Frequency coherence must be known in order to use increased system bandwidth most effectively.

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REFERENCES