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MEASUREMENT OF ACOUSTIC SIGNAL LOSSES AND FLUCTUATIONS VIA REFLECTION FROM THE OCEAN BOUNDARIES

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INTRODUCTION

A parametric array was used, in an adverse shallow water environment, to investigate the statistical properties of acoustic signals reflected from the ocean boundaries. Detrimental effects of multipath interference were virtually eliminated by appropriate signal waveform design, signal processing techniques and, the narrow beamwidth of the array.

Important to the experiment was the measurement of boundary losses at low grazing angles. Also of importance were the statistical properties of the specularly reflected signals.Meteorological and oceanographic measurements were performed in concert with the acoustic tests. Wind speed and direction and the time-varying wave heights of the sea surface were the primary measured parameters.

A brief account is given of the experimental techniques and signal processing schemes pertinent to the determination of the boundary losses, envelope and phase statistics, and power (Doppler) spectrum of the surface reflected (scattered) signal.

EXPERIMENT

The experiment was conducted in Block Island Sound, a body of shallow water off the northeastern coast of the United States; the oceanographic environment has been described previously in a related underwater acoustic experiment.[1] For the measurements described here, a parametric array was mounted on a 7.6 m tower at a depth of 17.7 m below the surface. A second tower supported a hydrophone, at a horizontal range of 203 m, to receive the desired acoustic signals (see Fig. 1). Both the hydrophone and source were separately cabled over 1.5 Km to a shore facility.

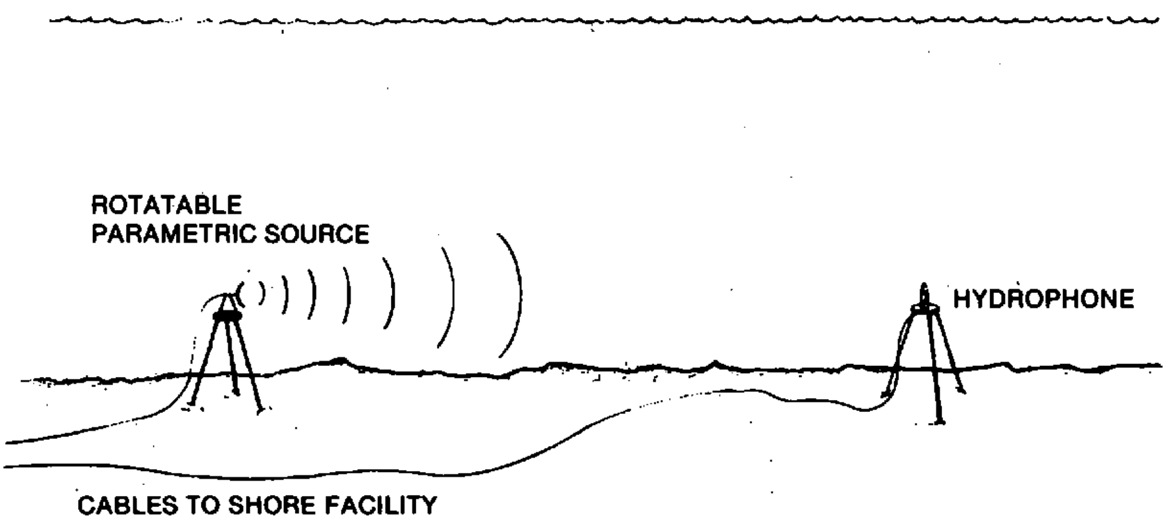

Fig. 1. Parametric Source and Hydrophone Supported Above the Ocean Bottom

MEASUREMENTS OF ACOUSTIC SIGNAL LOSSES AND FLUCTUATIONS VIA REFLECTION FROM THE OCEAN BOUNDARIES

Scuba divers manually aligned the source and hydrophone in azimuth. Because the source was electromechanically controlled in angle of elevation, the acoustic beam could be projected for either a direct path or a surface reflection or a bottom reflection. Grazing angles to both boundaries were approximately 10°.

The parametric source consisted of a 25 cm diameter piston transducer operating at a mean primary frequency of 263 kHz and had a nominal primary beamwidth of 1.5°. A double sideband suppressed carrier signal was power amplified to drive the parametric source over a coaxial cable. Three difference frequencies, -10, 20, and 30 kHz, were generated for the measurements . A typical difference frequency beam pattern is shown in Fig. 2, where it is 10 kHz and the souce level is 177 dB//1 μPam. The beam pattern depicts the familiar characteristic of narrow beamwidth and the absence of sidelobes associated with the parametric array.

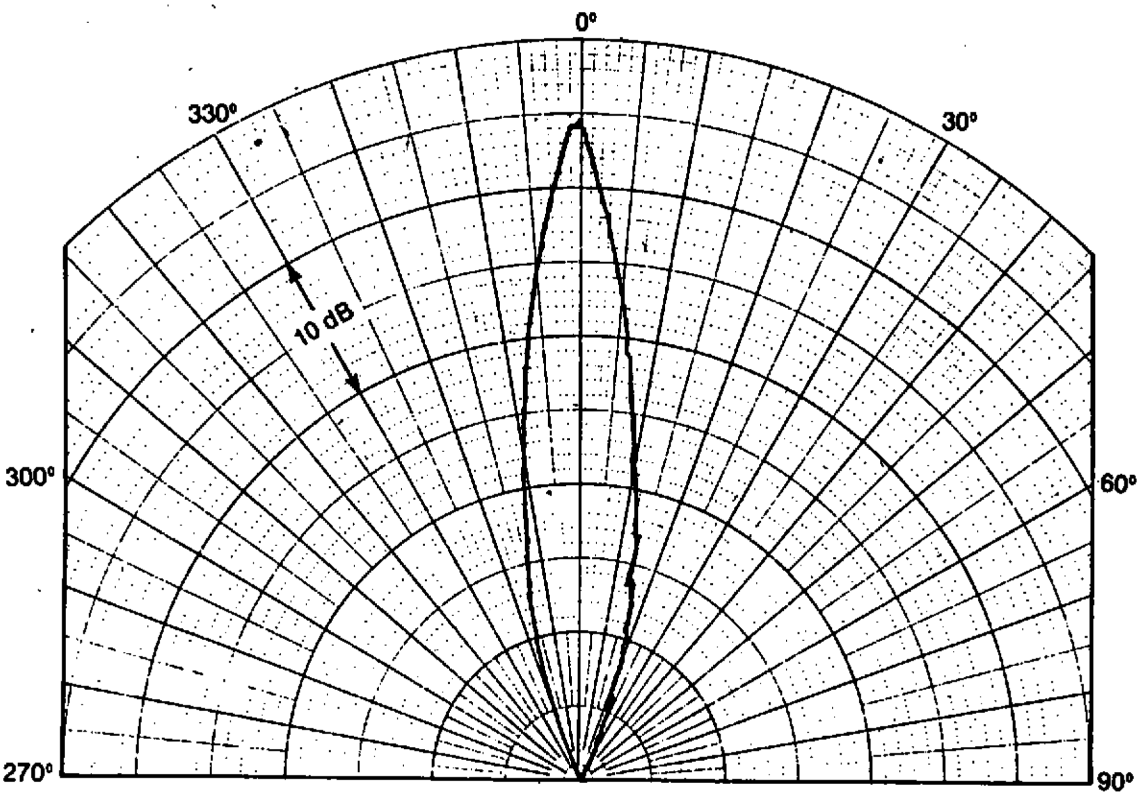

Fig. 2. Difference Frequency Beampattern at 10 kHz

The parametric source could also be rotated to normal incidence to the sea surface. In this mode, it was used as an acoustic wave-height sensing system.[1] With the source operating in a conventional mode, the inverted fathometer insonified a spot size on the surface with a cross sectional diameter on the order of the piston diameter. As with other echo ranging methods, a repetition of short pulses are transmitted. The transducer is gated to receive the echo and the travel time variations are converted to a calibrated voltage that is a linear function of the wave height above the transducer.

MEASUREMENTS OF ACOUSTIC SIGNAL LOSSES AND FLUCTUATIONS VIA REFLECTION FROM THE OCEAN BOUNDARIES

SIGNAL GENERATION AND PROCESSING

The signal generation scheme was based upon computing the envelope, phase, and spectral properties of the received acoustic signals from samples of the quadrature components. To ensure complete isolation of all multipath interference, a CW pulse train was chosen for the transmitted signal. The pulse length and repetition period were carefully selected with consideration for several conflicting requirements.

The 0.7 msec pulse length was short enough to resolve the multipath, while being of sufficient lenght for a steady-state build-up in the surface- and bottom-reflected signals. The steady-state build-up requires the pulse length to be greater than the relative difference in travel time for waves propagating (1) to the receiver via the specular reflection point (shortest travel time) (2) via sloped facets lying on the edge of the insonified area. The edge of the insonified area is defined by waves eminating from the parametric source measured at the half-power points of the beampattern. For a 3° beamwidth, the maximum time spread is approximately 0.1 msec.

The repetition period (18 msec) of the pulsed CW was also equal to the sampling period of the second order sampling signals. That is, two sampling signals were used in the analogue-to-digital conversion process. The first sampling signal sampled at time, t, is given by

$$t = n\Delta, \Delta = \ell/f_o, \tag{1}$$

where

Δ = sampling period,
f_o = transmitted frequency,
ℓ = an integer, and
$n = 0, \pm1, \pm2. \ldots$

A second signal, sampled at a time delayed by a quarter of a cycle of the transmitted signal, is

$$t = n\Delta + k, k = (1/4)f_o. \tag{2}$$

The two sets of sampled data are related to the quadrature components of the received signal,[3] r(t), which can be represented as

$$r(t) = x(t)\cos 2\pi f_c t - y(t)\sin 2\pi f_c t, \tag{3}$$

where x(t) and y(t) are the quadrature components of the signal. It is assumed here that the received signal is narrowband and the bandwidth, W, is less than f_o and $\Delta < 1/W$. The envelope e(t) and phase $\phi(t)$ of the signal can be expressed in terms of the quadrature components

$$e(t) = [x^2(t) + y^2(t)]^{1/2} \tag{4}$$

and

$$\phi(t) = \tan^{-1}[y(t)/x(t)]. \tag{5}$$

The sampled received signal data sets are related to the quadrature components by

$$[r(n\Delta)] = [x(n\Delta)] \tag{6}$$

and

$$[r(n\Delta + k)] = [y(n\Delta + k)]. \tag{7}$$

Thus, for the narrowband assumption, the approximation

$$y(t) \approx y(t + k), k = (1/4)f_o \quad (8)$$

is very accurate and, hence, the envelope and phase can be obtained directly from the raw data sample by

$$e(n\Delta) \approx [r^2(n\Delta) + r^2(n\Delta + k)]^{1/2} \quad (9)$$

and

$$\phi(n\Delta) \approx \tan^{-1}[r(n\Delta + k)/r(n\Delta)]. \quad (10)$$

Referring to Fig. 3, it is seen that the double sideband suppressed carrier signal, with frequency separation f_o, is gated by a tone-burst generator. The gate is controlled by an externaltrigger signal generated from a CMC counter. The 18 msec repetition of the outgoing pulse waveform is an integer multiple of the period of the transmitted frequency.

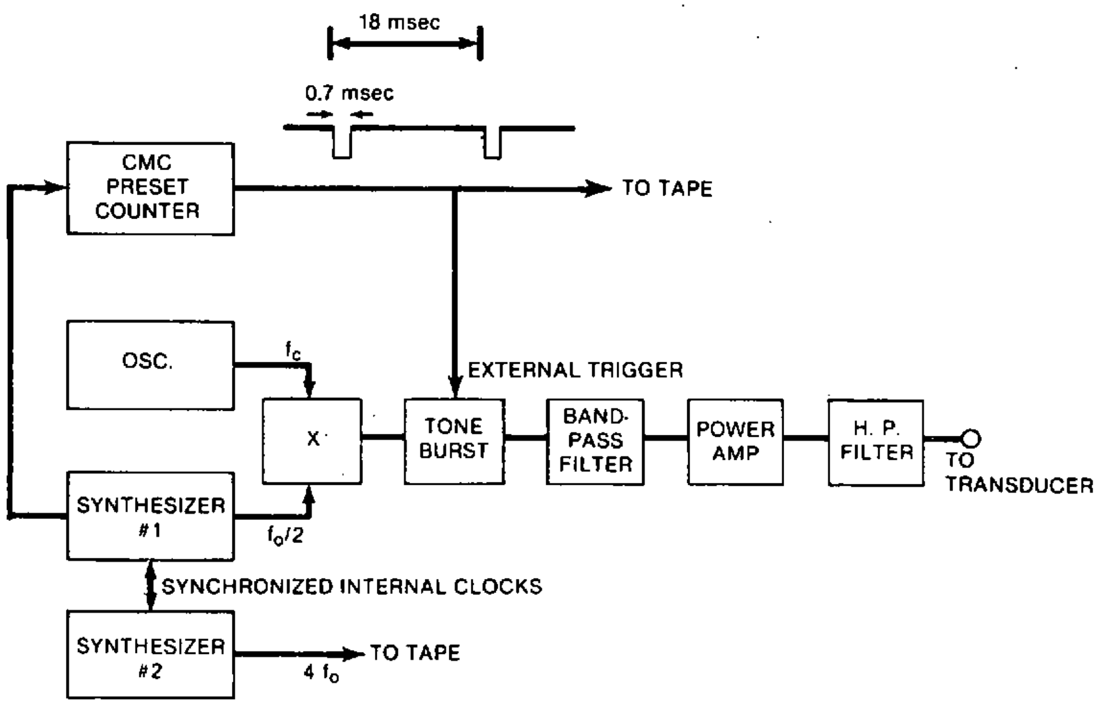

Fig. 3. Transmitting System Block Diagram

The received acoustic signals were amplified, filtered, and further amplified for recording on magnetic tape. A sampling frequency, at four times the transmitted frequency, and the DC pulses controlling the tone-burst generator were also recorded. The gating signal was used to synchronize the analogue-to-digital convesion process. A *window*, which could be either a direct path or boundary reflection, was positioned about the received pulse. This signal was sampled at four times the transmitted signal. Typically, 300 samples of the received signal were obtained every 18 msec for a 30 kHz transmitted frequency.

Envelope and phase could be computed by simple manipulation of the raw data samples. However, the computation of the Doppler spectrum of the surface reflected signal required additional data processing.

The Doppler spectrum was found by using Fast Fourier transform (FFT) techniques on the quadrature components. Two quadrature samples were taken every 18 msec from the center of the received signals. The data samples from each set were Hanning weighted to reduce frequency leakage. An FFT was performed on 28.8 sec of the windowed data and resulted in a 0.05 Hz spectral resolution. Overlaps of 50 percent were used to increase statistical stability in the spectral estimates. Typically, fifteen spectral estimates were ensemble averaged for the computation of the Doppler spectrum. The spectrum can be directly computed from the real and imaginary spectral estimates of the quadrature component spectra.

PRELIMINARY EXPERIMENTAL RESULTS

The boundary losses could be measured by comparing the pressure amplitudes of the boundary reflected paths to the direct path. Because there was a negligible difference in the propagation loss over the boundary reflected and direct paths, the losses could be computed directly

An example of a direct path envelope is shown in Fig. 4. It was obtained at a frequency of 30 kHz with the maximum response axis of the parametric source pointing directly at the receiver. The displayed envelope is an ensemble average of fifty consecutive pulses. The direct path envelope has the same shape as that of the transmitted waveform. Although boundary losses have been computed for the three transmitted frequencies, the environmental data is still under analysis.

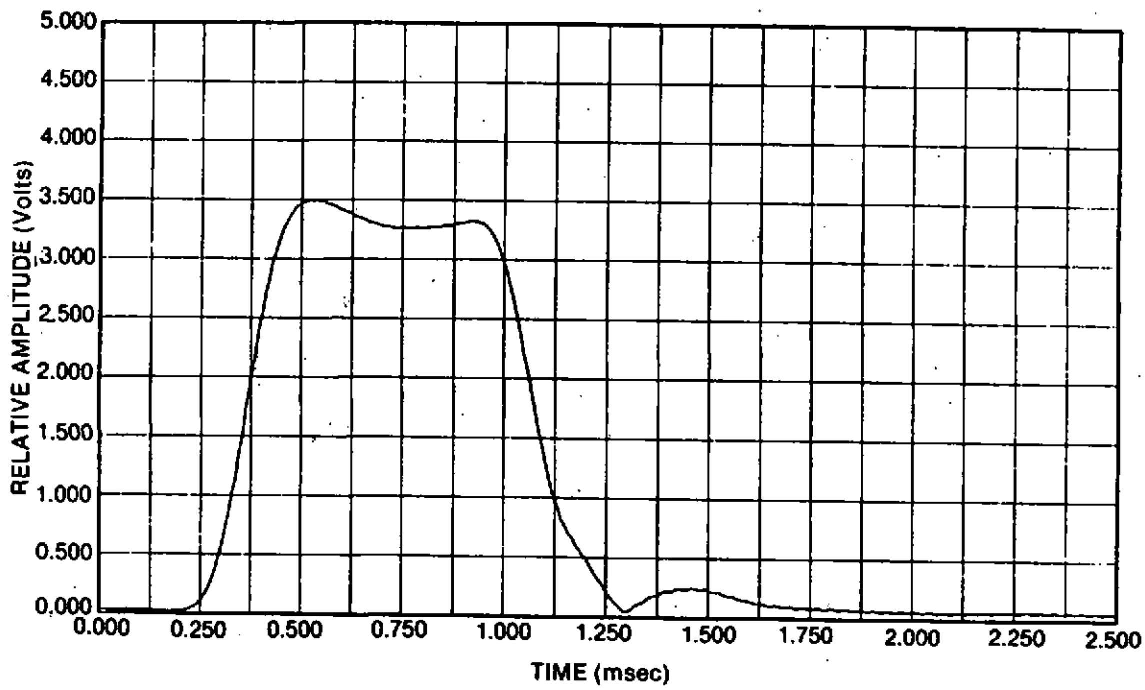

Fig. 4. Direct Path Pulse Envelope

MEASUREMENTS OF ACOUSTIC SIGNAL LOSSES AND FLUCTUATIONS VIA REFLECTION FROM THE OCEAN BOUNDARIES

Prior to computating the Doppler spectra, estimates were obtained for a calibration signal that underwent the same analoge recording and digital processing as the water borne signals. An example of the calibration spectrum for a 30 kHz signal is shown in Fig. 5. The center frequency is referred to 0 Hz. The first order sidelobes are approximately 32 dB from the peak as would be expected with a Hanning weighted signal.

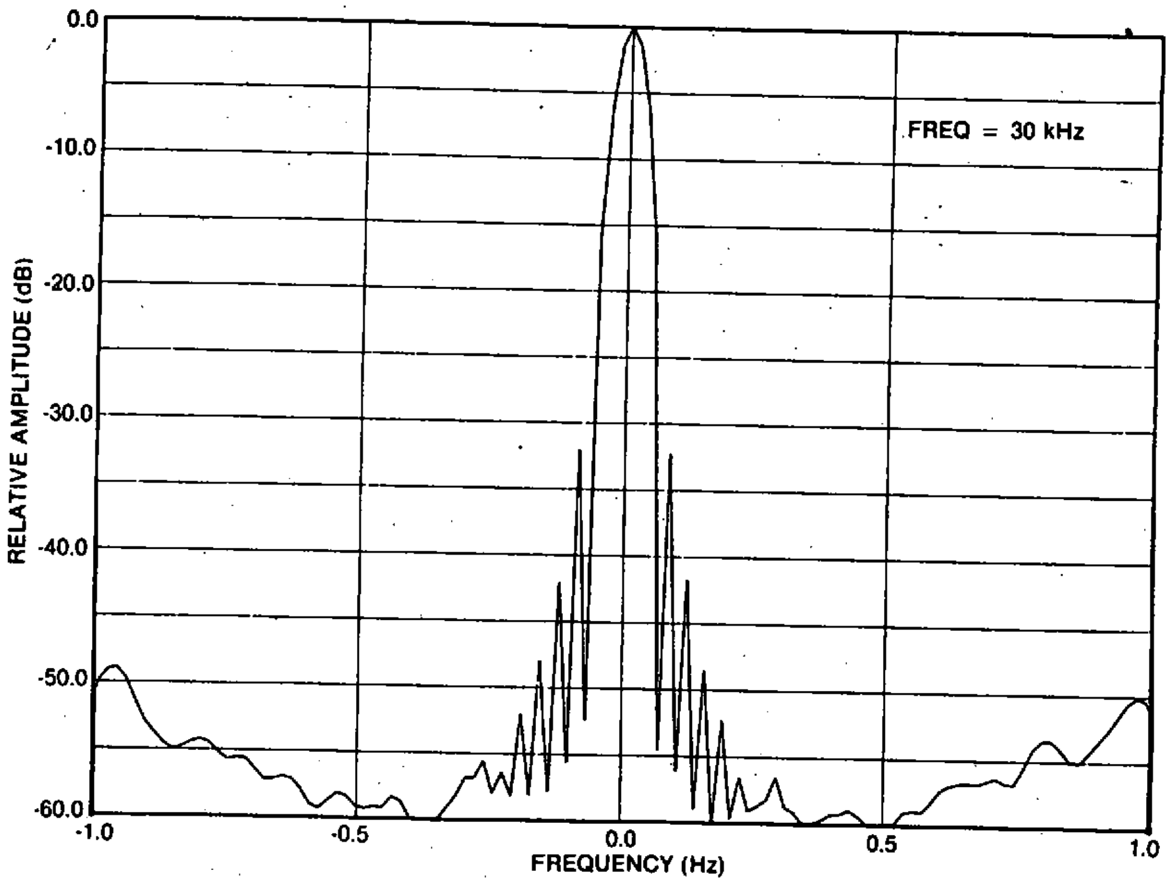

Fig. 5. Calibration Signal Power Spectrum

The Doppler spectrum of a surface reflected signal at a frequency of 30 kHz is shown in Fig. 6. The wind speeds averaged approximately 8 m/sec, with gusts to 11 m/sec. White caps and swell waves were prevalent. There is considerable spectral broadening of the surface reflected signal and the shape of the spectrum is Gaussian with a half-power bandwidth of about 5 Hz. The slight Doppler shift indicates a small misalignment of the parametric array and the specular reflection point. For the rough sea conditions encountered in this measurement, theory predicts a Gaussian shaped spectrum.[4]

MEASUREMENTS OF ACOUSTIC SIGNAL LOSSES AND FLUCTUATIONS VIA REFLECTION FROM THE OCEAN BOUNDARIES

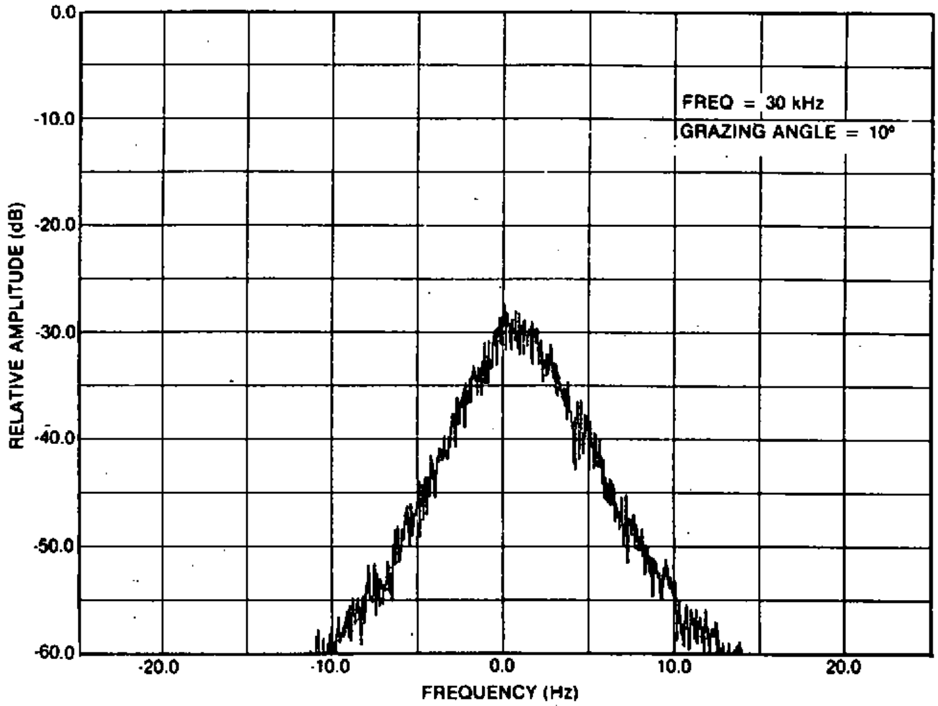

Fig. 6. Surface-Reflected Signal Doppler Spectrum for 30 kHz and 10° Grazing Angle.

CONCLUSIONS

A shallow water experiment using a parametric source to minimize multipath interference has been described. Quadrature sampling techniques were used in the data processing for computation of envelope, phase, and spectral properties. Preliminary results have been obtained for the envelope and spectral properties of direct and surface reflected signals. Acoustic and environmental data processing is continuing.

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