Practical Application of the Finite Amplitude Techniques to Narrow Beam Depth Measurement

by

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ABSTRACT

An Acoustic depth sounder using the Finite Amplitude technique for the generation of narrow beamwidths at a relatively low difference frequency has been developed. The primary frequency beamwidth is nominally 2°, resulting in difference frequency beamwidths predicted to vary from 2° to about 5°. Tank testing of the system verifies the lack of side lobes at the difference frequency predicted by theory, despite the presence of large grating lobes at the primary frequencies. The source level of the system at a difference frequency of 12 kHz is estimated at +88 dB/ubar. Experimental results have been obtained showing comparative performance of the finite amplitude depth sounder and a conventional, wider beamwidth, system. Improved resolution of sub-bottom layering results from the narrow beamwidth in a sub-bottom profiling application. High resolution depth sounding is achieved at water depths of 2000 fathoms. Comparisons of the finite amplitude and conventional system performance show source levels which are compatible with predictions based on scaling laws developed by R.H. Mellen. System operation has been demonstrated with both conventional and replica correlation receivers.

INTRODUCTION

A practical system application of non-linear finite amplitude acoustics to a narrow beam echo sounder and sub-bottom profiler has been demonstrated. The system makes use of the parametric array concept originally proposed by Westervelt[1] to generate narrow beamwidth acoustic signals with an acoustic projector aperture approximately sixteen times smaller than that required by conventional techniques. Difference (operating) frequencies have been generated in the range of 3.5 kHz to 12 kHz, starting with primary frequencies of 200 kHz. Source levels are adequate to perform high resolution sub-bottom profiling, and to echo sound at depths up to six thousand meters from typical surface ships. This includes 99% of the world's ocean depths.

An extensive series of laboratory experiments conducted at Raytheon's Marine Research Laboratory during 1968 and 1969 demonstrated the functional relationship of difference frequency source level to primary source level and the actual frequencies used, and showed that the Westervelt model correctly predicts these relationships[2,3]. These experiments also demonstrated the saturation effects observed at high signal intensities. This work, augmented by the scaling rules developed by Mellon[4] based on these and other experiments, showed that the achievable source levels at the difference frequency could be adequate for several potential applications. Preliminary experiments in Narragansett Bay, R.I. in early 1970 confirmed that high resolution, narrow beam sub-bottom profiling could be achieved using the finite amplitude, or parametric array technique. These experiments also demonstrated that large time - bandwidth product signals could be used to provide improved signal processing gain for the system.

As an illustration of the parameters of a high resolution deep water echo sounder, Figure 1 shows the required source level for depth measurement as a function of depth, with operating frequency as a parameter. These curves are based on an average bottom reflection loss of 20 dB, a required signal-to-noise ratio on the display of + 10 dB, an aperture of nominally 0.225 meter, receiver bandwith of2000 Hz, and a receiver noise level 10 dB greater than Sea State 6. This level is considered to represent a rather noisy surface ship installation. The required source level for operation to 6 KM depths at the common depth sounder frequency of 12 kHz is seen to be + 105 dB/ubar at one meter, for the parameters given above. The typical conventional 12 kHz echo sounder has a source level of about + 115 dB/ubar with a beamwidth of 35° at the 3 dB points.

THE FINITE AMPLITUDE DEPTH SOUNDER

It was decided to use the parametric array concept to construct a 12 kHz narrow beam echo sounder within the aperture constraints of the existing 12 kHz system. This aperture is 0.225 meter. The desired beamwidth was 2.5° in sea water, which constrained the primary frequency to be at 200 kHz. The maximum acoustic intensity is limited at this frequency to less than 10 watts per square inch. The expected difference frequency source level with these parameters is nominally + 90 dB/ubar based on the Westervelt model and the experimental measurements made previously. This source level could have been increased significantly only by using a considerably larger aperture and a lower primary frequency.

The discrepancy in achievable versus required source levels was overcome by providing receiver signal processing gain. A replica correlation (pulse compression) receiver had been developed previously which used large time-bandwidth product signals to provide up to 20 dB of signal processing gain at operating frequencies from 3.5 kHz to 12 kHz.[5] The signal is a frequency modulated (FM) slide, or chirp, which is modified to improve the resolution of the signal by suppressing correlation function sidelobes. It has a bandwidth of 2000 Hz and a duration of 65 ms. Extensive at-sea experience with this device has demonstrated that 20 dB of signal processing gain is available, and also, that desirable signal normalization and noise suppression features result from the clipping of the received signals. Figure 2 illustrates the performance of the correlator with a conventional 12 kHz echo sounder. In the center of the figure is the conventional system output showing noise bursts (dark vertical lines); interference from another unsynchronized echo sounder; and a weak bottom echo. This record was made at a power level of 50 watts. The right side shows the output signal of the correlation receiver (CESP) operating at the same 50 watt power level as the conventional system. Note the improved bottom echo signal-to-noise ratio and the suppression of interference and noise bursts. At the left of the figure, the output of the CESP unit is shown with a 20 dB power reduction, to 0.5 watt. The bottom echo signal-to-noise ratio is similar to that of the conventional system for this case, as is expected since the signal energies are equivalent at this power level; however, the correlator is still acting to suppress noise bursts.

The combination of the replica correlator receiver and the parametric array made possible a practical narrow beam echo sounder using a transducer aperture one sixteenth the size of a conventional system aperture. This permits use of this system on small vessels or for semipermanent installations using a towed body for the transducer. The system diagram of the echo sounder is illustrated in Figure 3. The transmitter unit heterodynes the FM slide signal to a band of 205-207 kHz and also transmits a second CW tone at a frequency of 194 kHz. These two signals mix in the water due to the nonlinear propagation effects to produce a narrow beamwidth signal centered at 12 kHz. A separate receiving transducer is used for convenience. The Correlation Echo Signal Processor (CESP) includes the receiver and the replica correlator. The output is recorded on a conventional dry paper precision recorder.

The 200 kHz projector is shown in Figure 4. The active aperture is approximately 0.225 meter. The heavy mounting plate is designed to be an exact replacement for the conventional 12 kHz transducer. The beam pattern of this transducer is shown in Figure 5. The main lobe beamwidth is nominally 2°. The grating lobes result from the mosaic construction of the transducer. These lobes could be eliminated by using either a solid disk design or incorporating amplitude shading into the array.

The beam pattern of the 12 kHz difference frequency, as measured in fresh water, is shown in Figure 6. The beam pattern has a width of 2° and has no observable secondary sidelobes, as predicted by the Westervelt model, despite the large primary frequency grating lobes. The measured freshwater source level of the difference frequency was + 88 dB/ubar. The Westervelt model predicts a level of + 91 dB/ubar.

TESTING AT SEA

The experimental system was initially tested in Narragansett Bay. Figure 7 shows an example of a sub-bottom profile at a frequency of 12 kHz. The left side of the figure was made using the finite amplitude system and the right with a conventional system, also using the CESP. The vertical grid lines are 9.2 meters (30 feet) apart. The multiple bottom traces are due to reflections of the bottom signal by the surface. The narrow beamwidth provides greatly improved sub-bottom profile clarity, and the lack of reverberation due to the narrow beamwidth shows layers which are hidden in the conventional system record. The two areas shown are contiguous. Figure 8 shows the wide frequency range of the equipment. It is interesting to note that approximately the same preparation is obtained at frequencies from 3.5 kHz to 12 kHz. The increased attenuation of the sediments at the higher frequencies is offset by the improved efficiency of the finite amplitude process.

Figure 9 illustrates the performance of the system as a deep water echo sounder. The water depth is approximately 1000 meters. The narrow beamwidth shows improved topographical detail, for example what appears to be rock outcroppings on the side of the slope. The details are usually obscured in wide beam systems. Depth sounding to date has been accomplished at a depth of 3500 meters using a transducer towed from a surface ship. Other deep water records show sub-bottom layering which is buried in bottom reverberation with conventional systems, and improved detail of the structure of the deep scattering layer.

CONCLUSIONS

The parametric array (finite amplitude) technique has been successfully demonstrated for narrow beam echo sounder applications. The combination of a replica correlator receiver provides the signal processing gain required for operation at depths to 6 KM from surface ships. The small apertures required make the finite amplitude depth sounder useful for small vessels and for semi-permanent installations using a towed transducer. The observed source levels based on comparative measurements with a conventional system appears to be in agreement with those predicted by the Westervelt model.

REFERENCES

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3. Konrad, W.L., and P. Abraham; "Study of Finite Amplitude Effects In Underwater Sound Propagation", Raytheon Co.; Portsmouth, R.I.; December 1, 1969. (Prepared for Contract N00140-69-C-0173).

4. Mellen, R.H., and W.L. Konrad; "Parametric Sonar Transmission"; Tech. Memo. 2070-303-70; Naval Underwater System Center, New London, Conn.; Oct. 14,1970.

5. Walsh, G.M. "Final Report: Correlation Echo Sounder Program", Raytheon Co., Portsmouth, R.I.; May 1, 1969. (Prepared for U.S. Naval Oceanographic Office under contract N62306-68-C-0202).

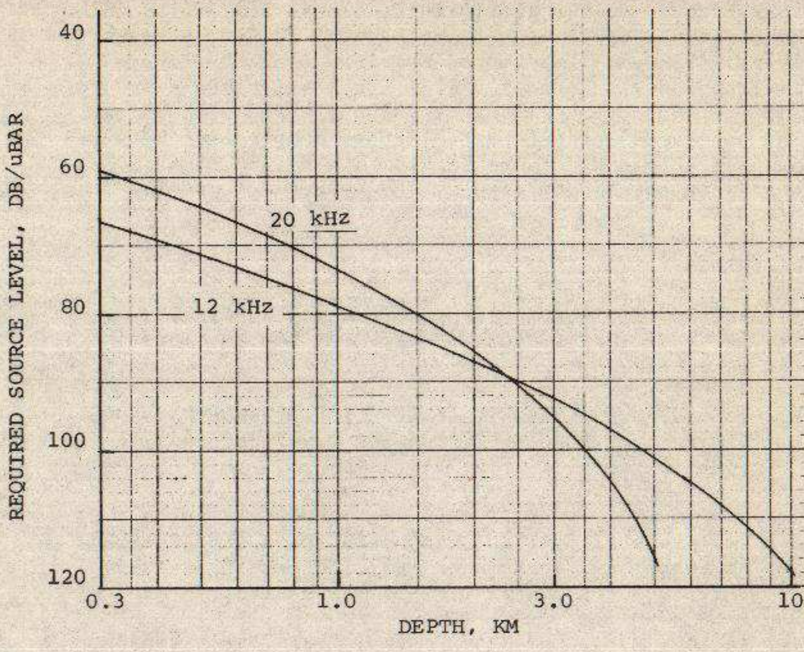


Figure 1. Source Level Requirements for Depth Sounding

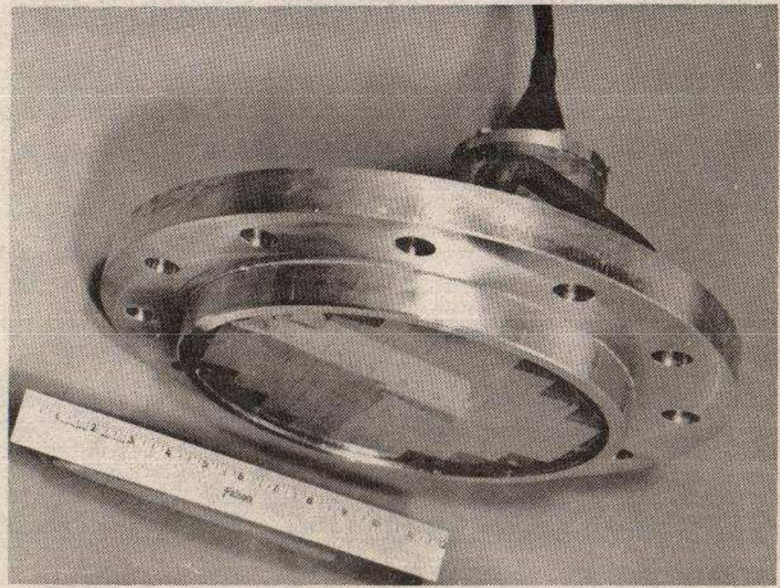


Figure 4. Finite Amplitude Transducer,
200 kHz, 2° Beamwidth

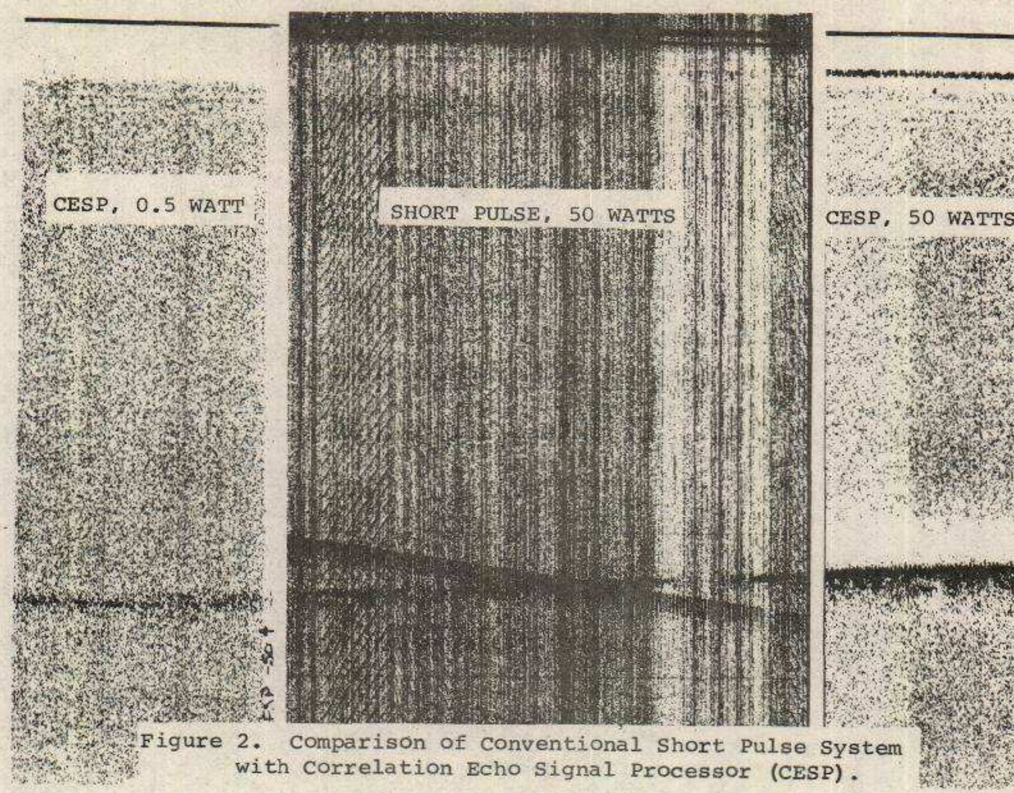


Figure 2. Comparison of Conventional Short Pulse System with Correlation Echo Signal Processor (CESP).

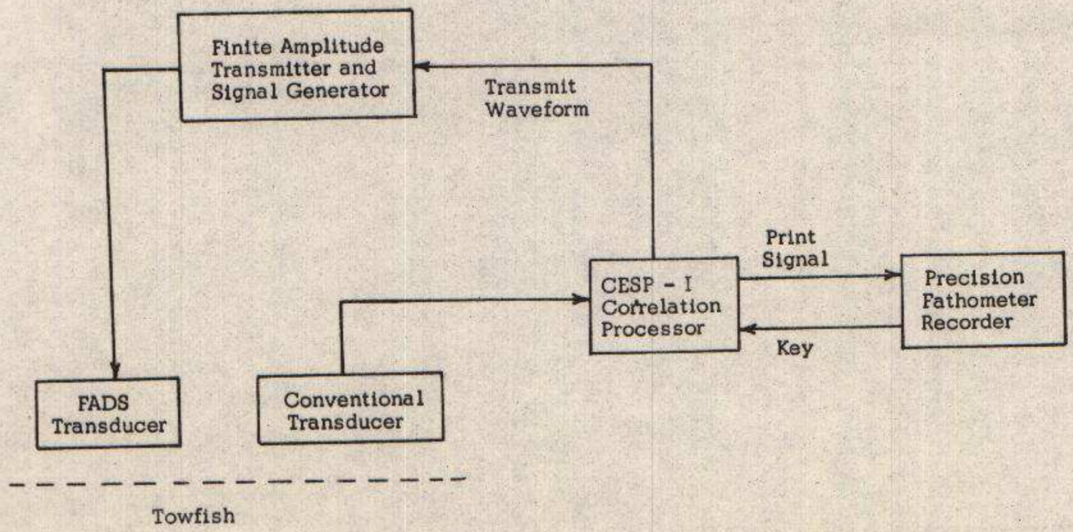


Figure 3. Finite Amplitude Depth Sounder System Block Diagram

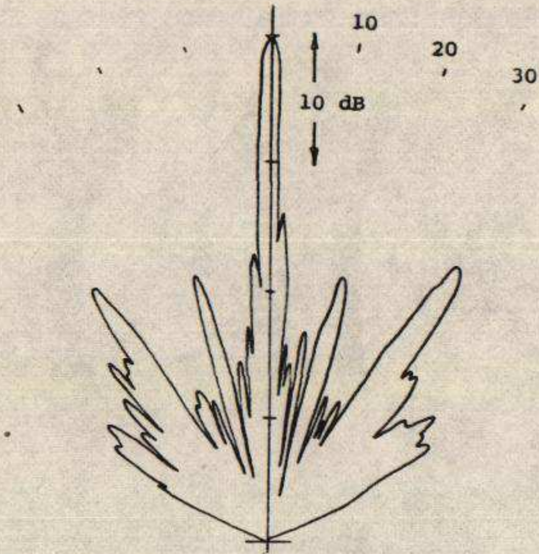


Figure 5. Primary Frequency Beam Pattern, 200 kHz

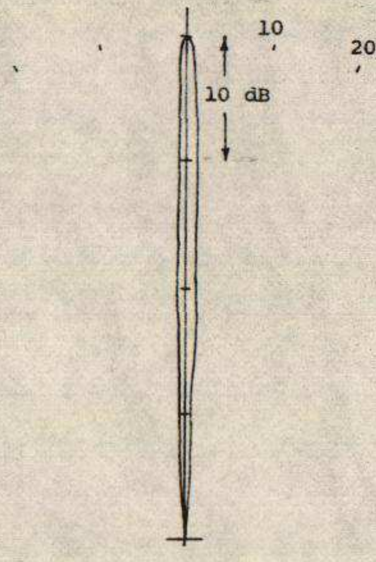


Figure 6. Operating (Difference) Frequency Beam Pattern, 12 kHz

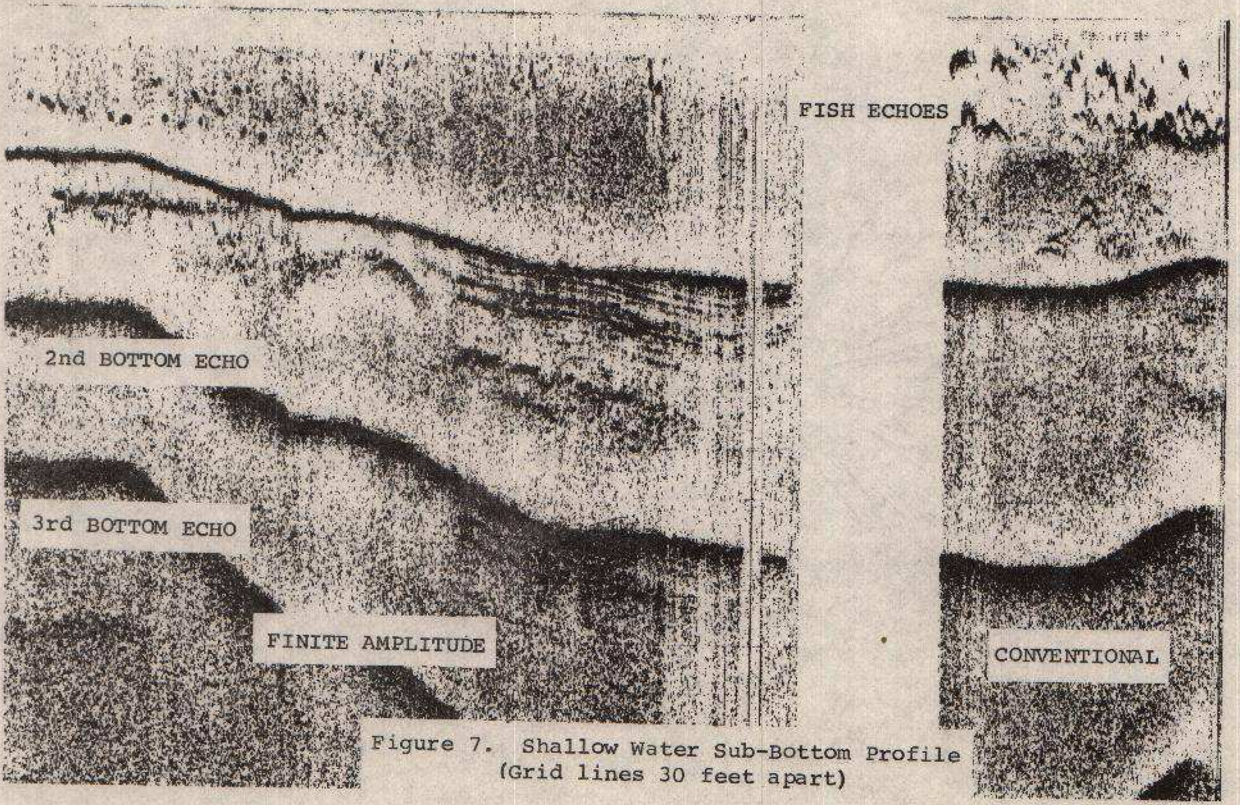
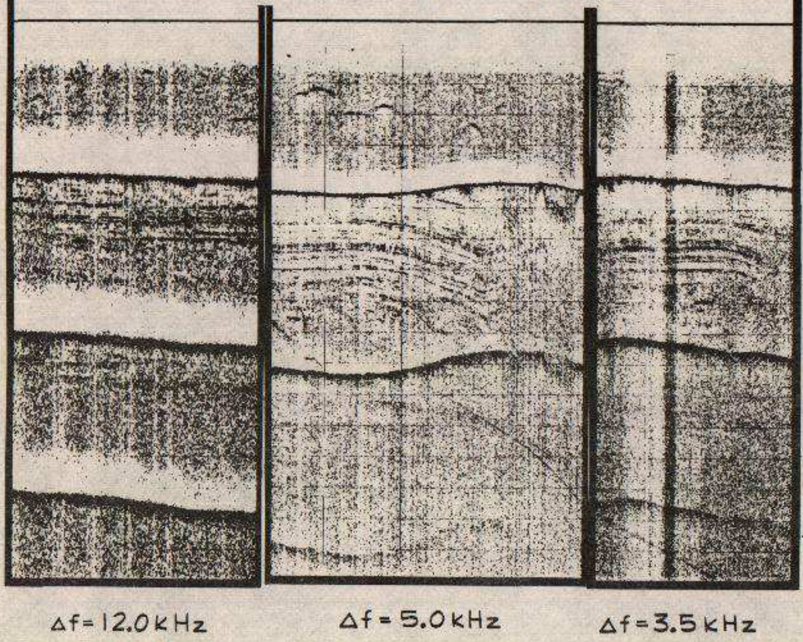


Figure 7. Shallow Water Sub-Bottom Profile
(Grid lines 30 feet apart)

Figure 8. Sub-Bottom Profiles Showing Operating Frequency Range (Grid lines 30 feet apart)



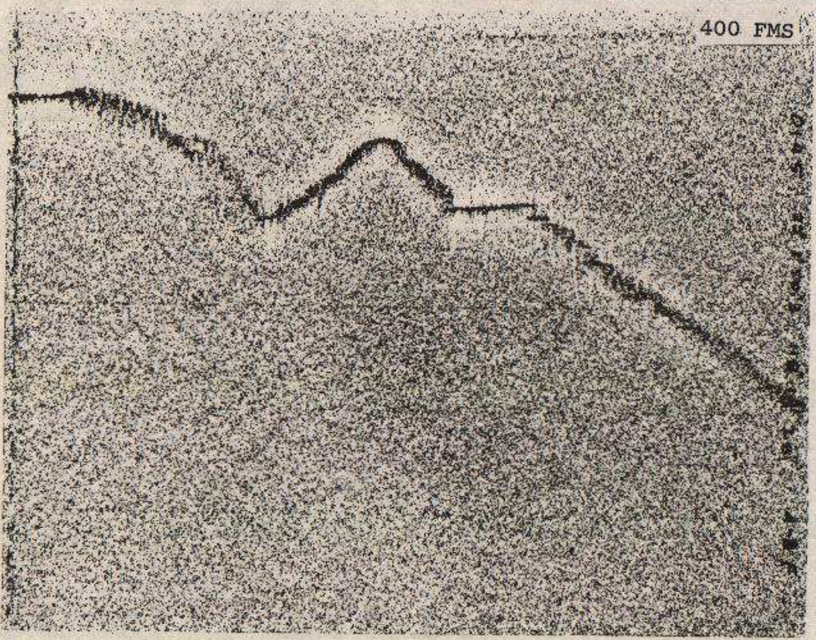


Figure 9. Narrow Beam Finite Amplitude System Depth Profile