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Analysis of Propagation Loss and Signal-to-Noise Ratios from IOMEDEX

[Unclassified Title]

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ABSTRACT

Propagation-loss, noise, and signal-to-noise-ratio (S/N) measurements obtained in the Ionian Basin by using a continuous-wave (CW) projector, towed at a depth of 500 ft for seven days, and five receiving hydrophones, spanning the sound-channel axis at depths ranging from 270 to 2010 ft, are discussed. For these data, it is shown that the received signal level (L_R) is at a maximum when the receiving hydrophone and source are both positioned near the sound-channel axis and that the noise level is lowest at the 1050- and 2010-ft depths. The S/N is optimum for the source-depth hydrophone and becomes progressively unfavorable for receivers positioned farther away from the channel axis.

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INTRODUCTION

(U) In November 1971, acoustic transmission was measured in the Ionian Basin of the Mediterranean Sea during the Ionian-Mediterranean Exercise (IOMEDEX),[1] sponsored by the Long Range Acoustic Propagation Project (LRAPP). For seven days, a continuous-wave (CW) projector, operating at 125 Hz, was continuously towed at a 500-ft depth by R/V NORTH SEAL over the track shown in figure 1. The signals were received by the Naval Underwater Systems Center's (NUSC) Moored Acoustic Buoy System (MABS), a five-hydrophone, self-contained, data-recording system emplanted at measurement site "A" (see figure 1).

(U) This report presents an analysis of the data recorded by MABS. Propagation-loss, noise, and signal-to-noise-ratio (S/N) measurements are analyzed with respect to hydrophone depth, and differences in propagation loss for the different tracks are discussed. Similar data were also collected by the Naval Research Laboratory's (NRL) Ambient Noise Buoys (ANB) at sites A and C.[2]

MEASURING SYSTEMS

PROJECTOR

(U) The acoustic projector, a Honeywell Model HX37 bender bar with a source level of +190 dB//1 μPa* at 1 m, was towed at a depth of 500 ft using a 1-in.-diameter, faired, electromechanical cable. The projector depth was estimated from the amount of cable deployed and the wire angle at the sheave. A frequency synthesizer, accurate to 1 part in 10^8, generated the CW signal. Tow speed, which was dependent on sea conditions, ranged between 8 and 10 knots.

(U) *One micropascal, equal to 10^{-5} dynes per square centimeter, has been adopted by NUSC as the standard reference pressure for acoustic measurements in liquids, superseding the microbar (1 dyne per square centimeter). The effect of the change in reference is a translation of 100 dB in level; e.g., 90 dB//1 μB = 190 dB//1 μPa.

MABS

(U) MABS is a moored, self-contained, programmable, acoustic data-acquisition system that samples the acoustic field in deep ocean areas. Depending on the sampling cycle, MABS can record calibrated underwater acoustic signals as a function of depth in the frequency band from 10 to 5000 Hz, either continuously for 42 h or intermittently for up to 30 days. The system includes (1) a subsurface buoy that houses an instrumentation capsule; (2) an array of five hydrophones spaced along 1770 ft of faired, multiconductor cable; and (3) a clamp mooring arrangement consisting of floats, swivels, and two acoustic releases placed along a length of cable which is dependent on the ocean depth. Figure 2 shows the mechanical arrangement of MABS when it is fully deployed. Depths shown for the subsurface buoy and the hydrophones are nominal.

(U) All timing for MABS is derived from a crystal oscillator that is part of a miniature time-code generator (TCG). (Figure 3 is a block diagram of the MABS electrical system.) The TCG provides an Inter-Range Instrumentation Group (IRIG) B time code for indexing the data on magnetic tape. Timing pulses derived from the TCG are counted in the control circuit until a predetermined number of pulses, corresponding to the required elapsed time between data samples, have been counted. Start commands then energize the other functions of MABS in order to begin a data sample. The hydrophone switching logic, which also derives timing pulses from the TCG, controls the sequential on and off switching of each data input. When all seven data inputs have been recorded (time code, calibration signal,* and data from the five hydrophones), the hydrophone switching logic sends a command to the control circuit to turn off power to all but the time-keeping circuits. The end of the tape is sensed by a phototube, which then signals (1) the recorder to rewind the tape and (2) the record electronics to switch to the next track.

MEASUREMENT TECHNIQUES

(C) The CW projector was towed continuously, at a depth of 500 ft, from 2230Z on 7 November until 1600Z on 14 November over the tracks shown in figure 1. During this tow, the projector was operated at 125 Hz with a source

(U) *The tape recorder has a standard seven-track head but only one record amplifier, which is switched in sequence from tracks 1 through 7. Therefore, to compensate for the impedance variation that occurs when the record amplifier is switched from track to track, the calibration signal is recorded as a part of each data sample; the other data on the track are corrected to this standard before being processed.

level of 190 dB//1 μPa at 1 m. It was turned on for 45 min (from 5 to 50 min after the hour) and turned off for the next 15 min (from 10 min before to 5 min after the hour). The timing, relative to WWV and accurate to 1 s, permitted recording a noise sample on MABS in the CW analysis band on the hour and provided a positive "key" to the ship's navigational log. Navigation was by means of a satellite navigator, with dead reckoning used between position fixes. This navigation system was used to obtain source-to-receiver range as a function of time.

(C) The MABS receiving site is shown in figure 1 as site A. Two MABS deployments (6 to 15 and 17 to 22 November) were conducted, and ambient-noise results from both periods were obtained.[3] Since the CW projector was operated only during the first MABS deployment (6 to 15 November), all measurements described in this report are limited to that time frame. The depths of the five MABS hydrophones during the first deployment are shown in table 1.

Table 1. (C) MABS Hydrophone Depths (U)

Hydrophone No.	Hydrophone Depth (ft)
1	270
2	490
3	1050
4	1550
5	2010

(C) Every 30 min during this deployment, the system sequentially recorded (1) the output of each hydrophone, (2) the time code, and (3) the broadband pseudorandom noise calibration signal. A 5-s "dead time" between hydrophone samples, together with the 25-s data input from each hydrophone, resulted in a 2.5-min overall recording time for the five hydrophones. Therefore, at 10 knots, the projector would travel less than 1/2 nmi in this time interval. However, since the source was off when the sample was taken on the hour, only one CW data point for propagation loss was obtained for every 8 to 10 nmi of ship track. This resulted in a severe undersampling of the transmission versus range characteristics for radial runs. In spite of the undersampling,

a. some significant observations of propagation-loss slopes were made for the radial runs, as well as statements of propagation-loss variability for nonradial runs where the range was slowly varying, and

b. the depth dependence of the received signal level L_R and of S/N for this source depth were obtained for the Ionian Basin as a whole.

(U) The conclusions based on the CW data are presented in the results section.

DATA PROCESSING AND ANALYSIS TECHNIQUES

(U) The CW data were reproduced at a speed-up ratio of 8:1, processed through a 50-Hz filter at 1000 Hz, averaged for 2.5 s, and scaled back down to 125 Hz to yield an effective bandwidth of 6.3 Hz for analysis; noise data for the signal-to-noise study were similarly analyzed. In addition, the analog data were reproduced at a speed-up ratio of 8:1 and processed through 1/3-octave contiguous filters in the frequency range from 80 to 20,000 Hz for the noise-depth-dependence analysis. For processing the speed-up has the advantage (for data recorded directly by MABS) of increasing the system's low-frequency dynamic range by translating the data to a frequency above the 60-Hz noise of the reproduce electronics. For example, 10-Hz data are effectively processed at 80 Hz and then scaled back to 10 Hz for analysis. Even though faster playback speed decreases analysis time, it does not permit audio editing for data quality during the processing.

(U) The effect of the recording system noise on MABS measurements is shown for hydrophones 1 and 5 in figure 4. The curve labeled "MABS NOISE" was obtained by recording with the input to the preamplifier shorted. The curve labeled "REPRODUCE AMP NOISE" was obtained by analyzing the noise at the tape-reproducer output of the processing system with the tape off. The "WHITE NOISE CAL" and "AMBIENT NOISE" curves are typical of those derived from the data tapes. The "spike" on the ambient-noise curve at 125 Hz resulted from the CW signal. The calibration signal consisted of a signal from 0- to 5000-Hz broadband noise generator mixed with a 1-kHz tone. Both the broadband noise level and the tone had recorded levels of -5 dB//1 V.

(U) The system characteristic curves were obtained by processing the data tape at a speed-up ratio of 8:1, digitally sampling the broadband output, performing a 40-Hz analysis using a fast Fourier transform (FFT) on the

Univac 1108 computer, and then scaling the results to a bandwidth of 5 Hz and the true frequency. Although the system has a 10- to 5000-Hz response, the data were low-passed at 2500 Hz to reduce the required sampling rate for the FFT analysis shown in figure 4. The curves in figures 4a and 4b indicate that, up to the cutoff frequency for this analysis, the dynamic range of the system is good for hydrophone 1 and usable for hydrophone 5. The performances of hydrophones 2, 3, and 4 were between those of 1 and 5.

(U) As stated earlier, the data recorded on the hour contained only noise, and that on the half-hour contained signal and noise. For the analysis in this report, the hourly noise sample is considered to be the best available estimate of the noise in the succeeding signal sample. Relative noise amplitudes for 30 min at 125 Hz have a correlation of 0.6, and it takes approximately 5 h for this correlation to go to zero.[3] Propagation loss (N_w) is derived by subtracting the noise energy estimate ($\hat{n}$) from the signal plus noise measurements (s + n) to obtain the best possible estimate of received signal energy (S) in dB, which is then subtracted from the known source level (L_s); i.e.,

$$N_W = (L_S - S)\ \mathrm{dB} \quad ,$$

where

$$S = 10 \log \left[(s + n) - \hat{n}\right] \mathrm{dB}//1\ \mu\mathrm{Pa}.$$

Therefore, the S/N is given as S/N, where

$$N = 10 \log \hat{n}\ \mathrm{dB}//1\ \mu\mathrm{Pa}.$$

RESULTS

(U) The depth dependence of ambient noise[3] is shown in figure 5 for the 6 to 15 November deployment. Figure 6 is a sound velocity profile measured at the MABS site in early November. The depth-dependent noise curve (figure 5) shows a minimum sound energy level at the hydrophone 3 depth in the sound channel and a deep maximum and reversal at 1500 ft. Calculations by T. E. Wing[4] for a similar sound-velocity profile indicate that a deep sound energy maximum resulting from shipping should occur at the critical depth and should monotonically decrease to a sound energy minimum near the sound-channel axis. Unexplainably, the energy inflection at hydrophone 4 is not in agreement with these calculations.

(U) Propagation-loss data for hydrophones 2 and 5 are shown in figures 7 through 10 for the four longest tracks: radial tracks A-E and A-F are shown in figures 7 and 8, respectively (see figure 1), and nonradial tracks E-B and B-D are shown in figures 9 and 10, respectively For the nonradial tracks, propagation loss is plotted as a function of time, and a comparison curve of range versus time is presented. Only two hydrophone results are shown because they represent the lowest (hydrophone 2) and the highest (hydrophone 5) propagation-loss results. Results from hydrophones 1 and 2 are nearly the same, and results from hydrophones 3 and 4 are generally between those from hydrophones 2 and 5. These values were expected because the projector tow depth of 500 ft was near, but generally below, the sound-channel axis, which, in the Ionian Basin, ranges from a depth of 300 to 600 ft (reference 2); hydrophones 1 and 2 were located just above the axis.

(U) The fluctuation in the data at the longer ranges and over deep-water paths is approximately 10 dB. For any given curve, the total range of loss is 15 to 20 dB. For the radial runs, the loss ranged from 80 to 95 dB for hydrophone 2 and from 85 to 105 dB for hydrophone 5; for the nonradial runs, the loss ranged from 85 to 105 dB for hydrophone 2 and from 90 to 110 dB for hydrophone 5. These results are summarized in table 2.

Table 2. (U) Propagation-Loss Summary (U)

Track	Description	Propagation-Loss Range (dB)		Short-Range Propagation Loss Slope (dB/50 nmi)
		Hydrophone 2	Hydrophone 5	
A-F	Radial	80-95	90-105	6
A-E	Radial	80-95	85-105	9
B-D	Nonradial into shallow water	85-100	90-105	N/A
E-B	Nonradial into deep water	90-105	95-105	N/A

(U) The last column in table 2 describes the short-range slope of the spreading loss curve for the radial runs. This slope represents a linear interpolation of the data for the range between 25 and 75 nmi and is the same for all hydrophones during a given event, but is different for different events. For the events shown in figures 7 and 8, this slope is 6 dB for track A-F and 9 dB for track A-E.

(C) Figure 11 compares the S/Ns at hydrophones 2 and 5 as a function of time. (The time axis is keyed to the turning points of the track shown in figure 1.) The S/N is generally better at hydrophone 2 than at hydrophone 5 over the entire track. Figures 12 and 13 are cumulative distribution functions for L_R and S/N, respectively. They show the percentage of time that the measured parameter levels are less than a given level. These distribution functions are for all observations made during the CW tow, 7 to 14 November. Negative S/N values to -10 dB are shown in figure 11 and are included in the statistical analysis. Although the inclusion of these negative values affects the shape of the lower portion of the distribution curve in figure 13, the relative position and slope of the curve in the region above 0 dB are not affected because these S/Ns are definitely negative, even though the processing procedure may be unable to determine their exact values. In figure 12, it can be seen that the L_R s at hydrophone 2 are consistently higher than those at hydrophone 5 and that, at the 60-percent point, the curves are 10 dB apart. An evaluation of the average noise levels (figure 5) indicates that hydrophone 5 is about 6 dB quieter, on the average, than hydrophone 2. Therefore, it is expected that the signal-to-noise advantage at hydrophone 2 for this source will be only 4 dB, and figure 13 shows that, on the average, hydrophone 2 signal-to-noise results are uniformly 4 dB better than the hydrophone 5 results.

SUMMARY

(C) From the results of the IOMEDEX experiments conducted near the sound-channel axis in the Ionian Basin, it can be seen that the propagation loss between a CW projector, towed at a depth of 500 ft, and a receiver is minimized when the projector and the receiver are at approximately the same depth. Moreover, even though the ambient-noise levels are lower, on the average, at the 1050- and 2010-ft depths, the S/Ns (for these tests) are a maximum for the receiver positioned at 490 ft. The S/N is about the same at hydrophones 1 and 3, which are at conjugate points on the sound-velocity profile, and progressively decreases at hydrophones 4 (1550 ft) and 5 (2010 ft).

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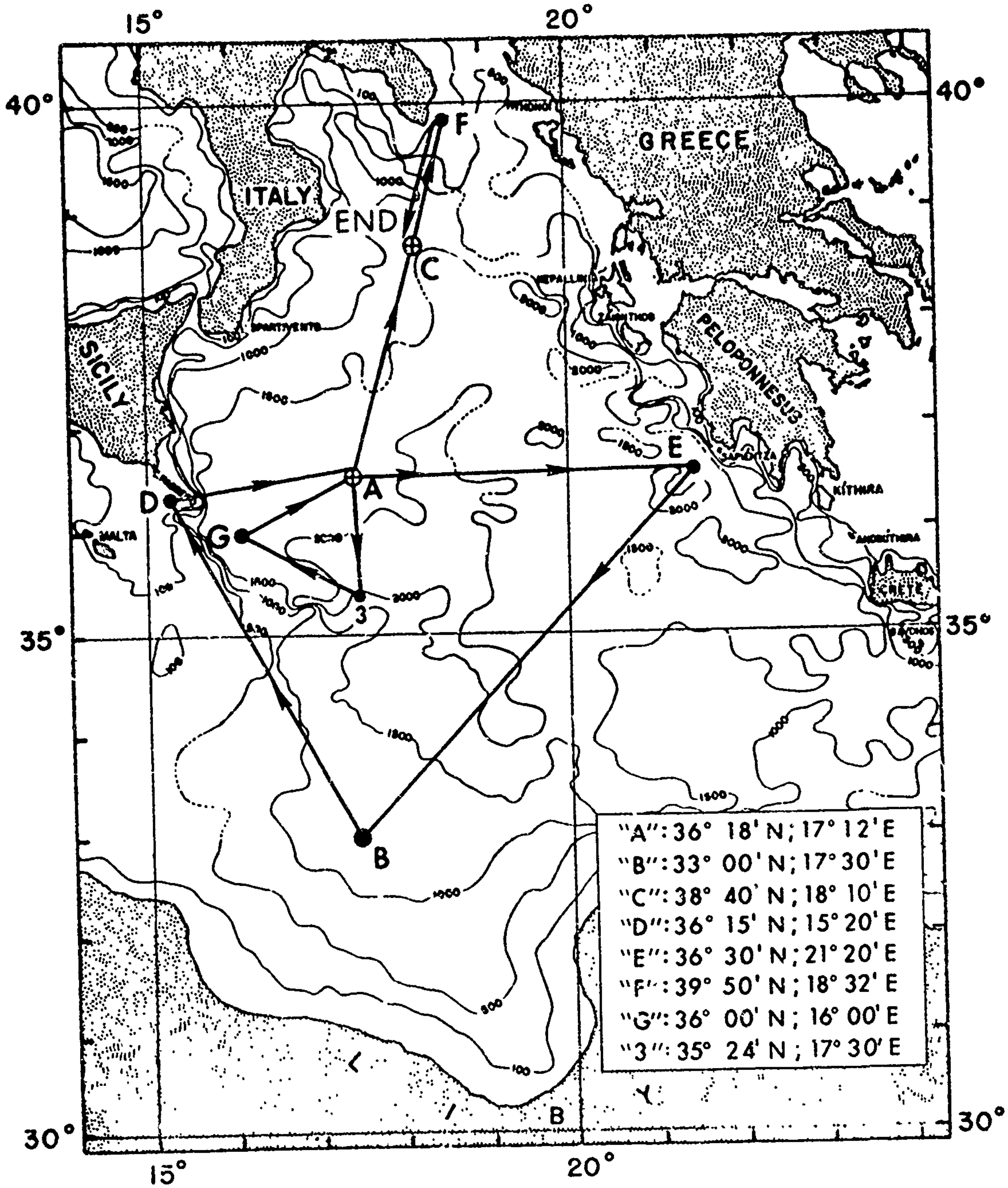
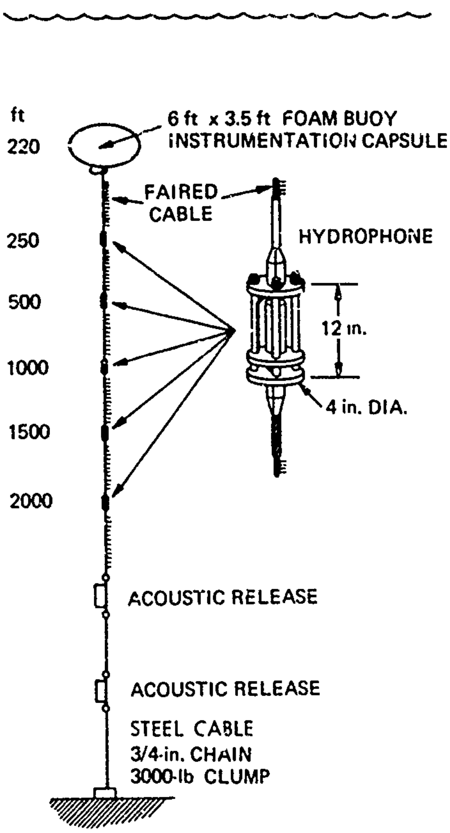


Figure 1. (C) IOMEDEX CW Track Chart (U)



- DEPLOYMENT TIME<2 h
- CAPSULE DEPTH TO 700 ft
- HYDROPHONES TO 2500 ft
- HYDROPHONES SAMPLED SERIALLY
- 42-h DATA CAPACITY
- 30 DAYS IN-SITU SAMPLING
- BANDWIDTH 10-5000 Hz

Figure 2. (U) MABS I (U)

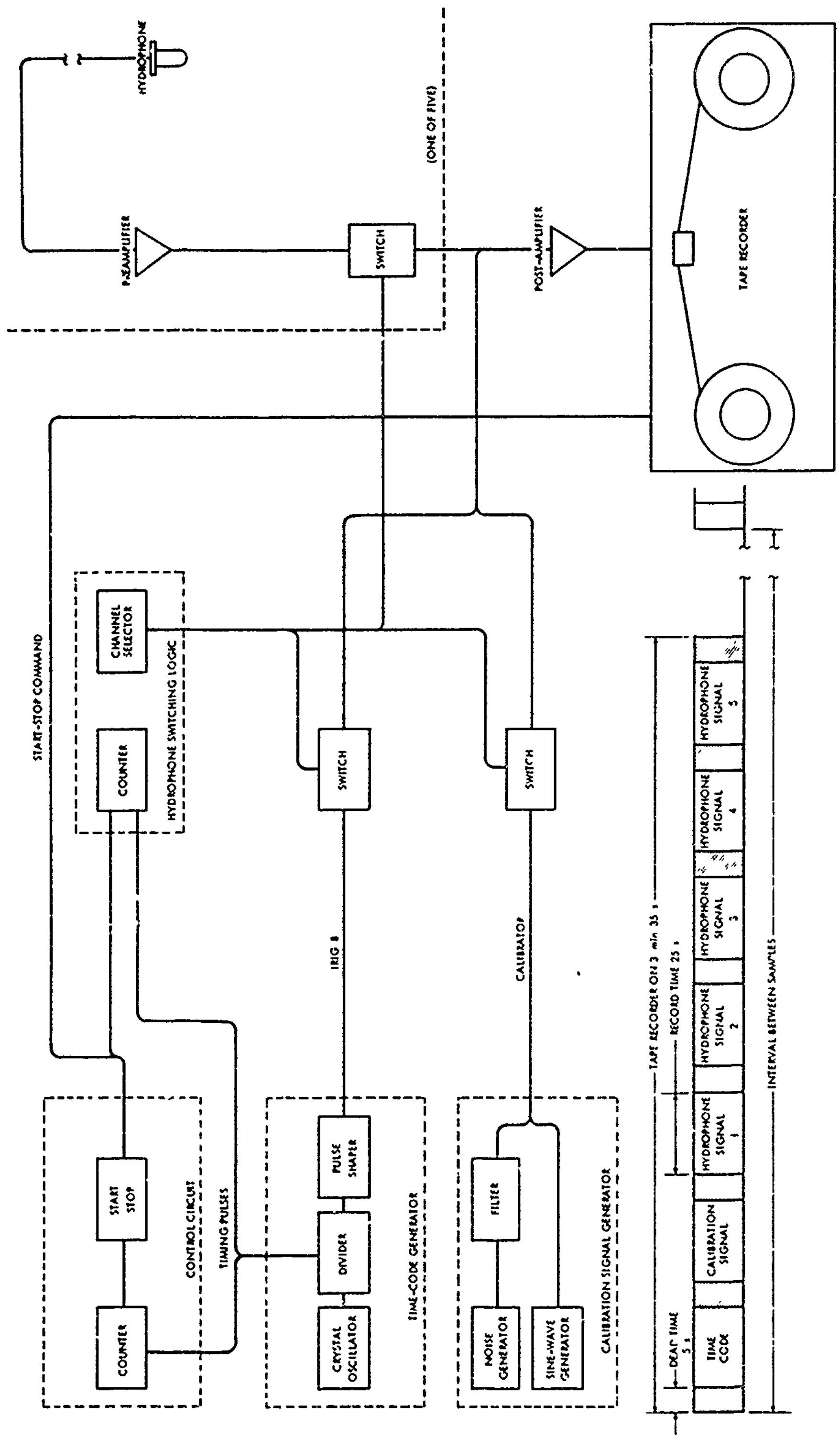


Figure 3. (U) MABS Electrical System Block Diagram (U)

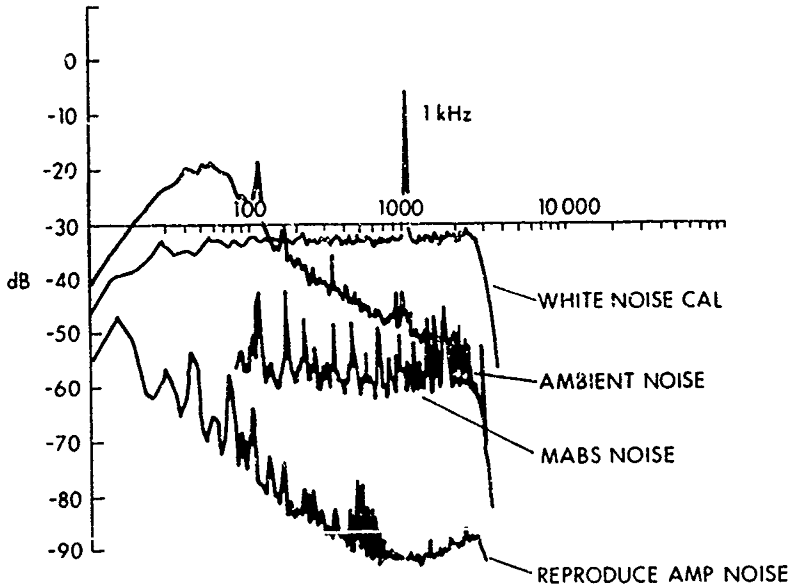


Figure 4a. (U) Recording System Noise, Hydrophone 5 (U)

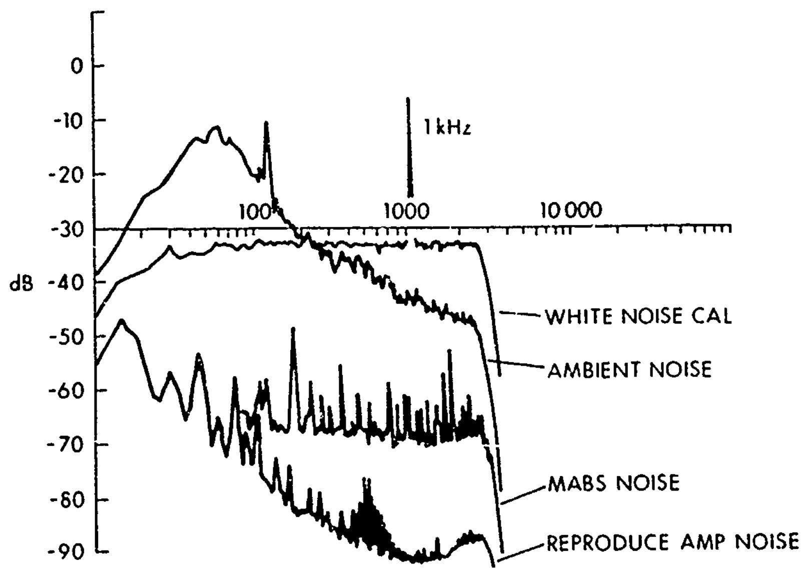


Figure 4b. (U) Recording System Noise, Hydrophone 1 (U)

Figure 4. (U) MABS Recording System Characteristics (U)

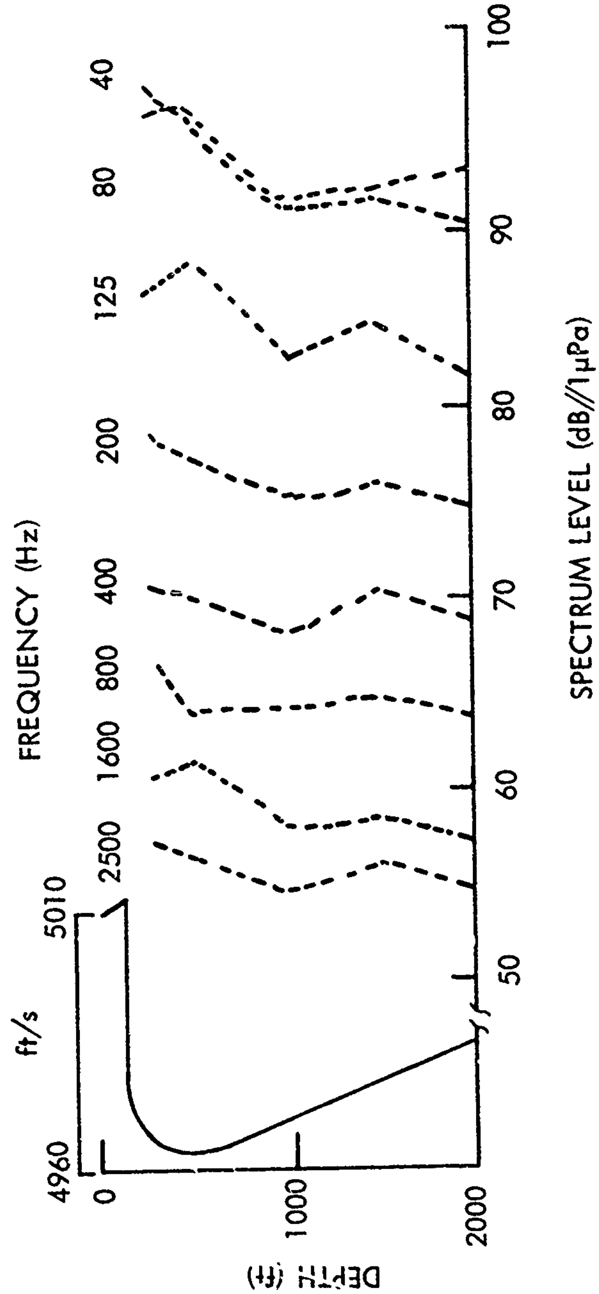


Figure 5. (C) Depth Dependence of Ambient Noise (250 to 2000 ft) (U)

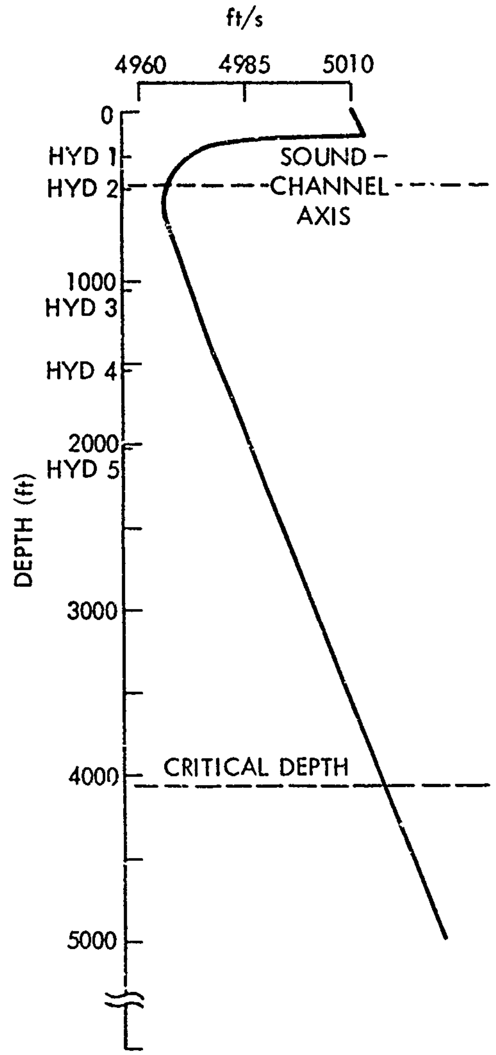


Figure 6. (C) IOMEDEX Sound Velocity Profile (U)

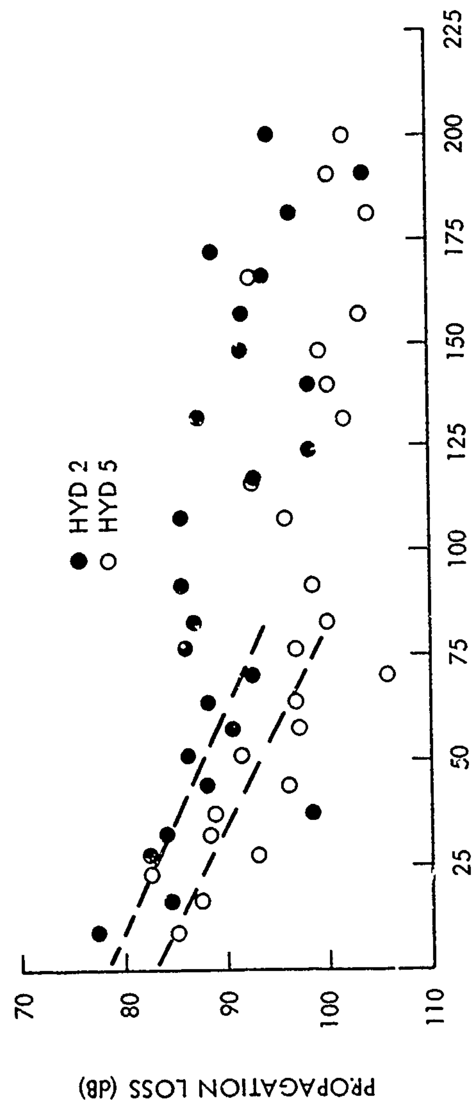


Figure 7. (C) MABS Propagation-Loss Plot, Track A-E (U)

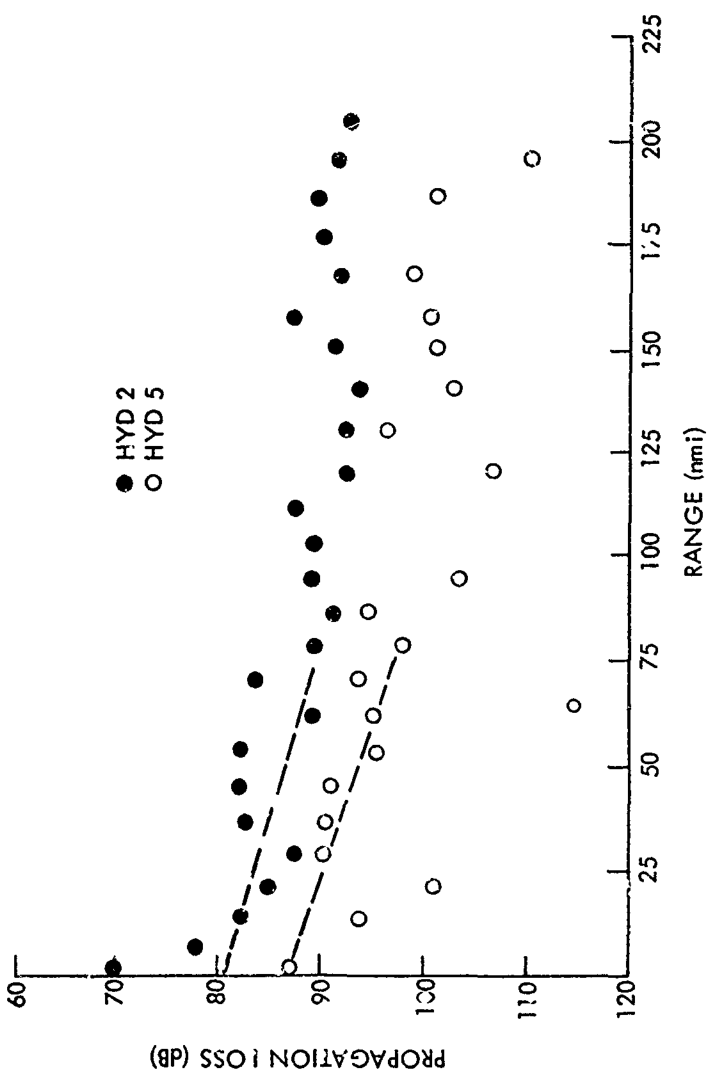


Figure 8. (C) MABS Propagation-Loss Plot, Track A-F (U)

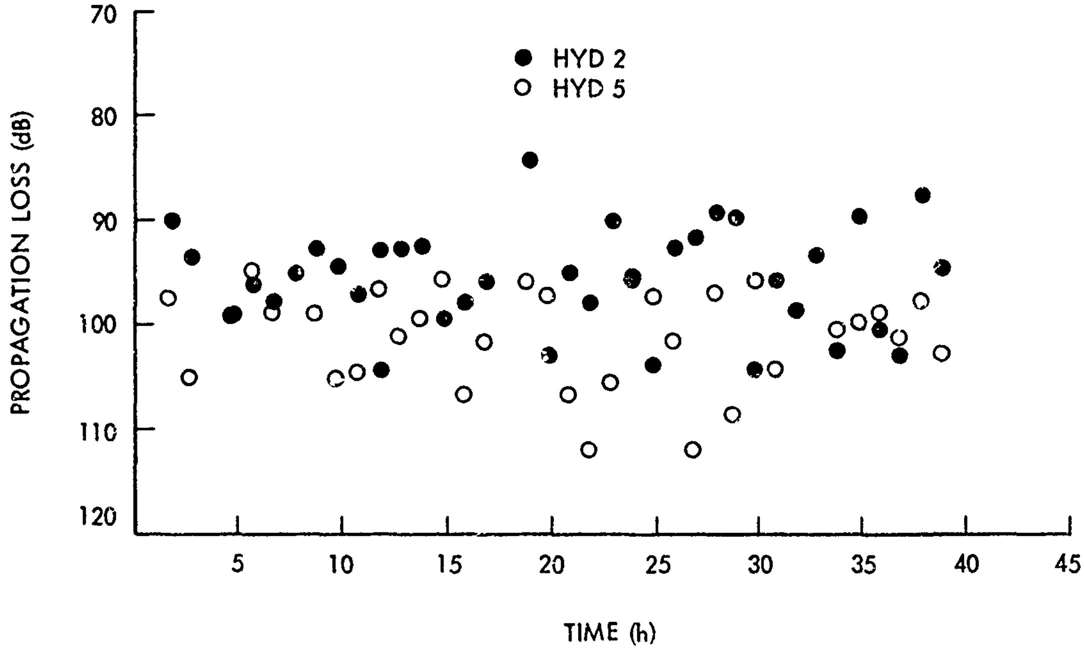


Figure 9a. (C) MABS Propagation Loss, 125 Hz CW Source at 500 ft (U)

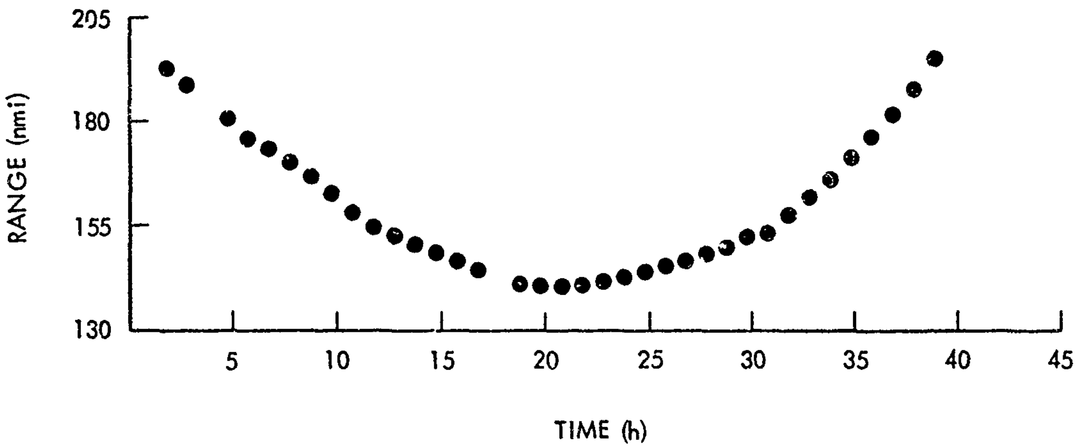


Figure 9b. (C) Range versus Time (U)

Figure 9. (C) MABS Propagation-Loss Plot and Range versus Time Plot, Track E-B (U)

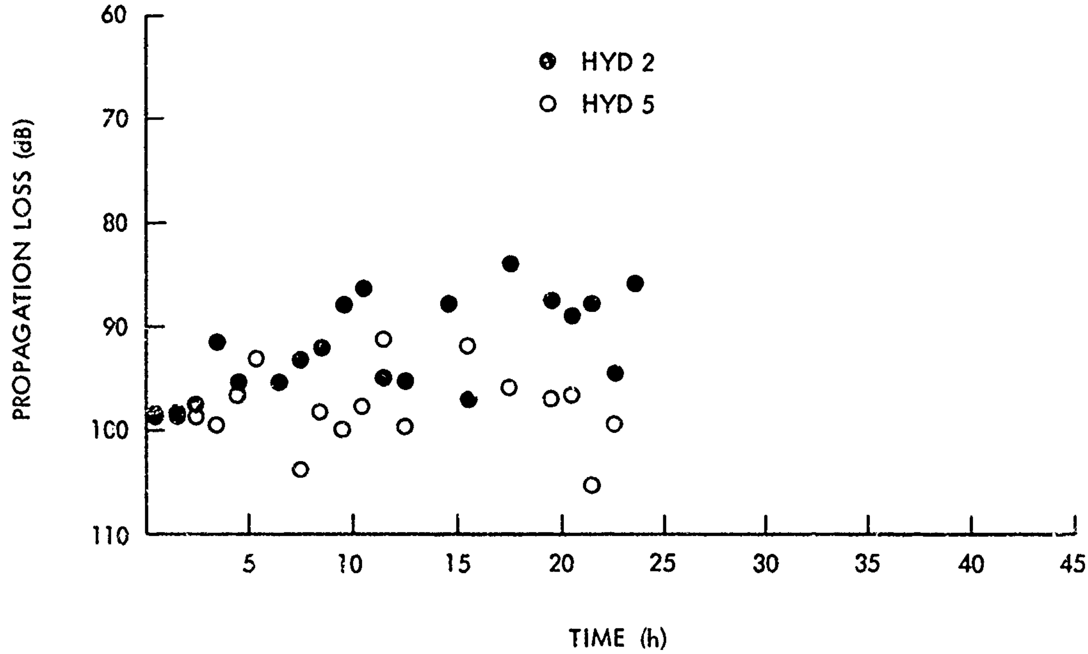


Figure 10a. (C) MABS Propagation Loss, 125 Hz CW Source at 500 ft (U)

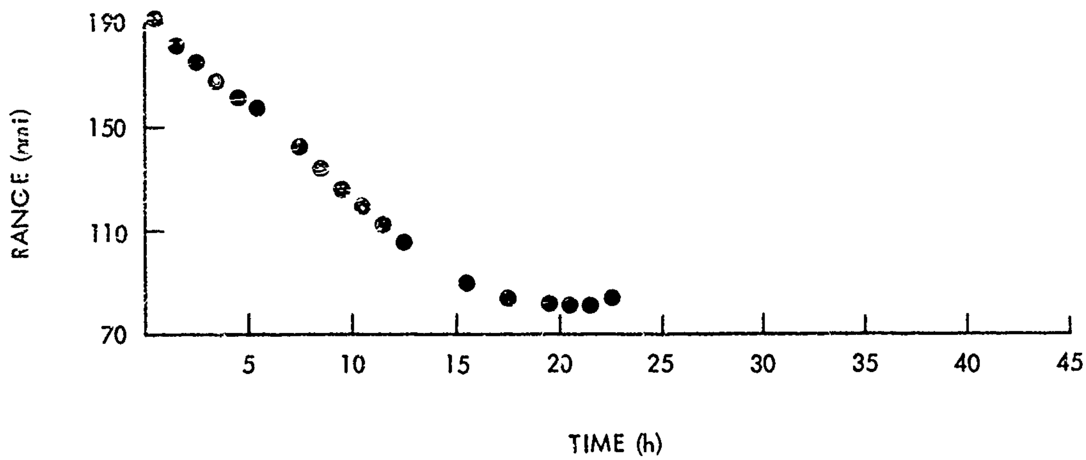


Figure 10b. (C) Range versus Time

Figure 10. (C) MABS Propagation-Loss Plot and Range versus Time Plot, Track B-D (U)

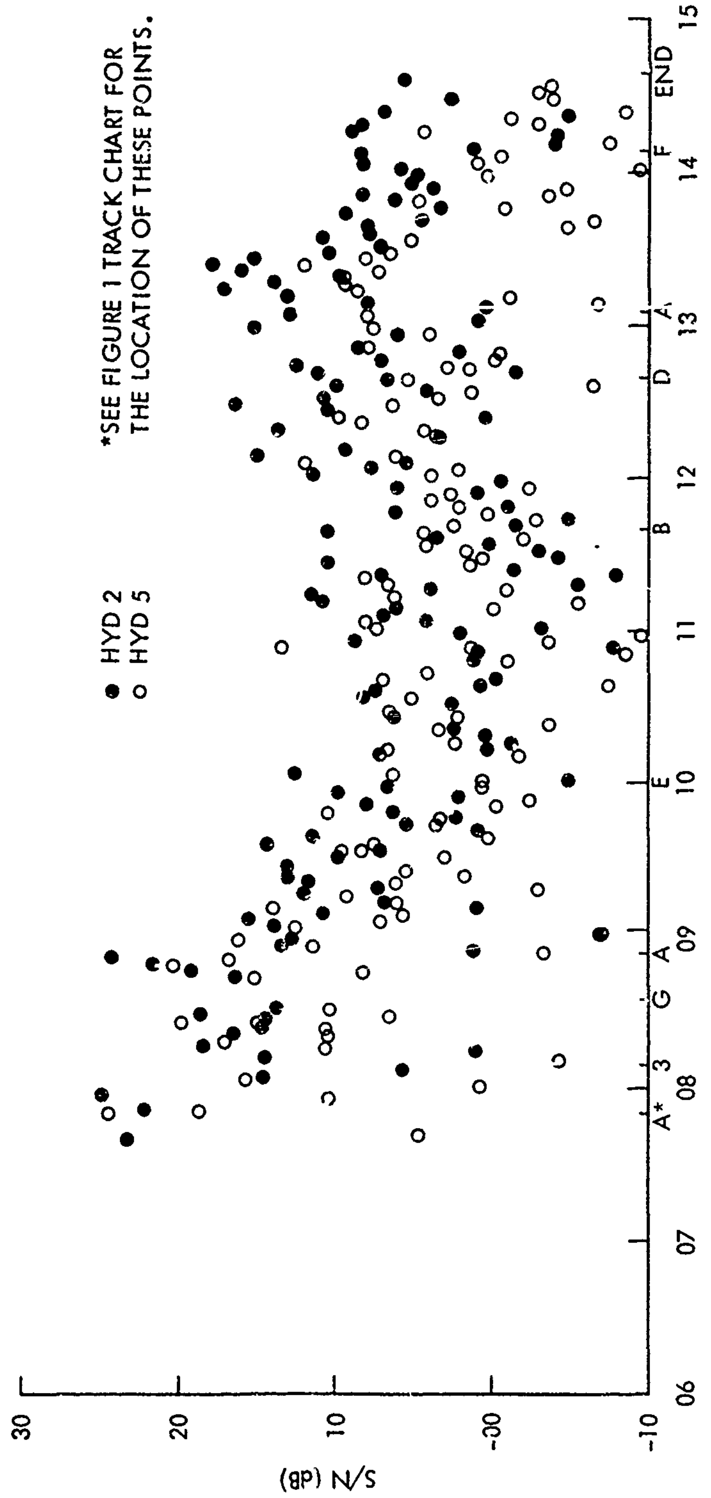


Figure 11. (C) IOMEDEX S/N (U)

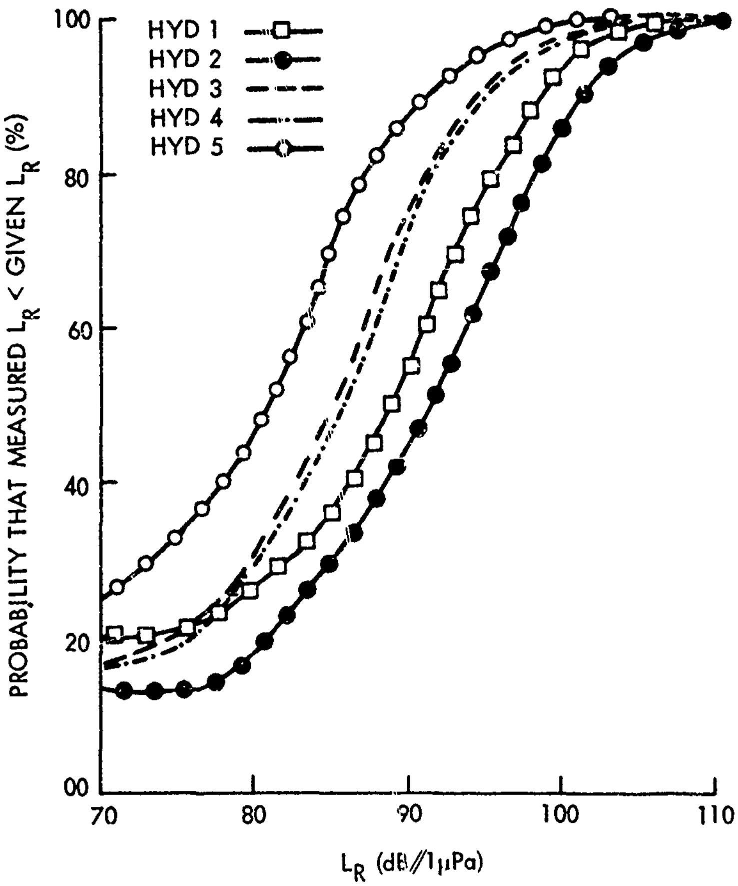


Figure 12. (C) Cumulative Distribution of Received Signal Levels (U)

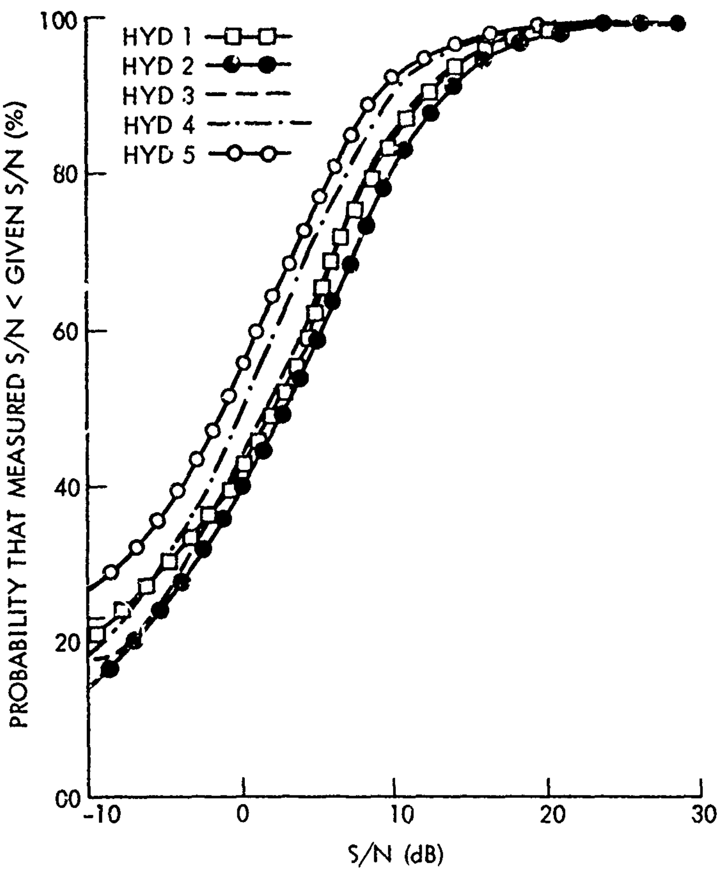


Figure 13. (C) Cumulative Distribution of Signal-to-Noise Ratios (U)

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13. ABSTRACT

Propagation-loss, noise, and signal-to-noise-ratio (S/N) measurements obtained in the Ionian Basin by using a continuous-wave (CW) projector, towed at a depth of 500 ft for seven days, and five receiving hydrophones, spanning the sound-channel axis at depths ranging from 270 to 2010 ft, are discussed. For these data, it is shown that the received signal level (L_R) is at a maximum when the receiving hydrophone and source are both positioned near the sound-channel axis and that the noise level is lowest at the 1050- and 2010-ft depths. The S/N is optimum for the source-depth hydrophone and becomes progressively unfavorable for receivers positioned farther away from the channel axis.

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1. In accordance with reference (a), a declassification review has been conducted on a number of classified LRAPP documents.

2. The LRAPP documents listed in enclosure (1) have been downgraded to UNCLASSIFIED and have been approved for public release. These documents should be remarked as follows:

   Classification changed to UNCLASSIFIED by authority of the Chief of Naval Operations (N772) letter N772A/6U875630, 20 January 2006.

   DISTRIBUTION STATEMENT A: Approved for Public Release; Distribution is unlimited.

3. Questions may be directed to the undersigned on (703) 696-4619, DSN 426-4619.

BRIAN LINK
By direction

Subj: DECLASSIFICATION OF LONG RANGE ACOUSTIC PROPAGATION PROJECT (LRAPP) DOCUMENTS

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Report Number	Personal Author	Title	Publication Source (Originator)	Pub. Date	Current Availability	Class.
Unavailable	Brancart, C. P.	TRANSMISSION REPORT, VIBROSEIS CW ACOUSTIC SOURCE, CHURCH ANCHOR EXERCISE, AUGUST AND SEPTEMBER 1973	B-K Dynamics, Inc.	730101	AD0528904	U
Unavailable	Daubin, S. C., et al.	LONG RANGE ACOUSTIC PROPAGATION PROJECT. BLAKE TEST SYNOPSIS REPORT	University of Miami, Rosenstiel School of Marine and Atmospheric Science	730101	AD0768995	U
NUSC TR NO. 4457	King, P. C., et al.	MOORED ACOUSTIC BUOY SYSTEM (MABS): SPECIFICATIONS AND DEPLOYMENTS	Naval Underwater Systems Center	730105	AD0756181; ND	U
MC-012	Unavailable	CHURCH GABBRO SYNOPSIS REPORT (U)	Maury Center for Ocean Science	730210	ND	U
Unavailable	Hecht, R. J., et al.	STATISTICAL ANALYSIS OF OCEAN NOISE	Underwater Systems, Inc.	730220	AD0526024	U
Raff rept 73-2	Bowen, J. I., et al.	EASTLANT SHIPPING DENSITIES	Raff Associates, Inc.	730227	ND AD~~X~~4627	U
Unavailable	Sander, E. L.	SHIPPING SURVEILLANCE DATA FOR CHURCH GABBRO	Raff Associates, Inc.	730315	AD0765360	U
Unavailable	Wagstaff, R. A.	RANDI: RESEARCH AMBIENT NOISE DIRECTIONALITY MODEL	Naval Undersea Center	730401	AD0760692	U
Unavailable	Van Wyckhouse, R. J.	SYNTHETIC BATHYMETRIC PROFILING SYSTEM (SYNBAPS)	Naval Oceanographic Office	730501	AD0762070	U
MCPLAN012	Unavailable	SQUARE DEAL EXERCISE PLAN (U)	Maury Center for Ocean Science	730501	NS; ND	U
Unavailable	Marshall, S. W.	AMBIENT NOISE AND SIGNAL-TO-NOISE PROFILES IN IOMEDEX	Naval Research Laboratory	730601	AD0527037	U
Unavailable	Daubin, S. C.	CHURCH GABBRO TECHNICAL NOTE: SYSTEMS DESCRIPTION AND PERFORMANCE	University of Miami, Rosenstiel School of Marine and Atmospheric Science	730601	AD0763460	U
MC-011	Unavailable	CHURCH ANCHOR EXERCISE PLAN (U)	Maury Center for Ocean Science	730601	ND	U
Unavailable	Solosko, R. B.	SEMI-AUTOMATIC SYSTEM FOR DIGITIZING BATHYMETRY CHARTS	Calspan Corp.	730613	AD0761647	U
64	Jones, C. H.	LRAPP VERTICAL ARRAY- PHASE II	Westinghouse Research Laboratories	730613	AD0786239; ND	U
Unavailable	Koenigs, P. D., et al.	ANALYSIS OF PROPAGATION LOSS AND SIGNAL-TO-NOISE RATIOS FROM IOMEDEX	Naval Underwater Systems Center	730615	AD0526552	U
NUSC TR 4417	Perrone, A. J.	INFRASONIC AND LOW-FREQUENCY AMBIENT-NOISE MEASUREMENTS OFF NEWFOUNDLAND	Naval Underwater Systems Center	730619	~~ND~~ AD 913668	U
USRD Cal. Report No. 3576	Unavailable	CALIBRATION OF FLIP-CHURCH ANCHOR TRANSDUCERS SERIALS 15 AND 19	Naval Research Laboratory	730716	ND	U