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SURFACE-DUCT SONAR MEASUREMENTS (SUDS I - 1972) PROPAGATION LOS--ETC(U)

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SURFACE-DUCT SONAR MEASUREMENTS (SUDS I - 1972)

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R. B. GILCHRIST, CAPT, USN
Commander

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Technical Director

ADMINISTRATIVE INFORMATION

During February 1972 the Naval Undersea Center conducted a series of 18 propagation loss experiments in three deep-water areas off the coast of California. These experiments are known as the SUrface Duct Sonar Measurements (SUDS I – 1972). This work was originally supported by the then Naval Ships Systems Command, Sonar Technology Division, PMS-302-4 and partly supported by the Office of Naval Research, code 102-OSC. The preparation of this report began in April 1973 under the sponsorship of the Naval Sea Systems Command, code 06H1-4, problem SF 52-552-602, task 19344. This report covers work from March 1971 to February 1976 and was approved for publication in April 1976.

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The SUDS I program was a coordinated and cooperative effort involving personnel from the Undersea Sciences and the Undersea Surveillance Departments. The program was basically an Acoustic Propagation Division project developed by H. P. Bucker and H. S. Aurand.

The Principal Investigator was J. Cummins. H.P. Bucker was the Senior Scientist for the CW-pulse measurements and D. L. Keir the Senior Scientist for the explosive measurements. Additional contributions were made to experiment planning by J. R. Lovett and J. D. Pugh. Preliminary analysis of acoustical data was done by H. P. Bucker and H. E. Morris. Assisting in the preliminary data reduction and analysis of the acoustic data was J. L. Thompson, an exchange scientist from RANRL, Sidney, Australia, and R. W. Townsen. Preliminary analysis of the environmental data was done by K. W. Nelson.

H. P. Bucker was the Scientist-in-Charge aboard the *DeSteiguer*, D. G. Good was Scientist-in-Charge aboard the *Lee*, and P. A. Hanson was Scientist-in-Charge aboard the *Cape*. Assisting with the acoustic measurements at sea were: T. E. Stixrud, C. R. Lisle, N. J. Martini, D. White, and R. F. Hosmer. The assistance of the officers and men of the *DeSteiguer*, *Lee*, and *Cape* in making the propagation loss measurements program successful is acknowledged.

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During 9-24 February 1972 a series of 18 propagation loss experiments were conducted in three deep-water areas located southwest of San Diego, California. These measurements were designed to measure near-surface continuous wave (CW) pulse propagation losses and propagation losses for explosive sources out to ranges of 45 kyd and to obtain detailed supporting environmental measurements. Measurements were made at CW frequencies of 0.4, 1.0, 1.5, 2.5, 3.5, and 5.0 kHz. The explosive measurements were analyzed at 0.40, 0.63, 1.00, 1.60, 2.50, 3.15, 5.00, and 10.00 kHz.

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This is the second in a series of three NUC Technical Papers reporting the results of these measurements. This report contains the propagation loss measurements. It consists of five volumes. Volume I describes the instrumentation used to make the propagation loss measurements and the data reduction procedures. Volumes II–V are detailed reports containing a summary of the environmental measurements, plots of propagation loss versus range, and comments pertinent to the specific propagation loss run.

SUMMARY

Develop a data base by obtaining near-surface acoustic propagation loss measurements complete with relevant supporting environmental measurements.

Specifically, the SUDS I experiments were designed to measure near-surface continuous wave (CW) pulse propagation losses and propagation losses for explosive sources out to ranges of 45 kyd and to obtain detailed supporting environmental measurements in three deep-water areas off the west coast of southern California. This study contains the propagation loss measurements made during four acoustic stations. During each station either four or five propagation loss runs were made. This report consists of five volumes. Volume I describes the instrumentation used to make the propagation loss measurements and the data reduction procedures. Volumes II-V, one volume for each acoustic station, are detailed reports, each containing a summary of the environmental measurements, plots of propagation loss versus range, and comments pertinent to the specific propagation loss run.

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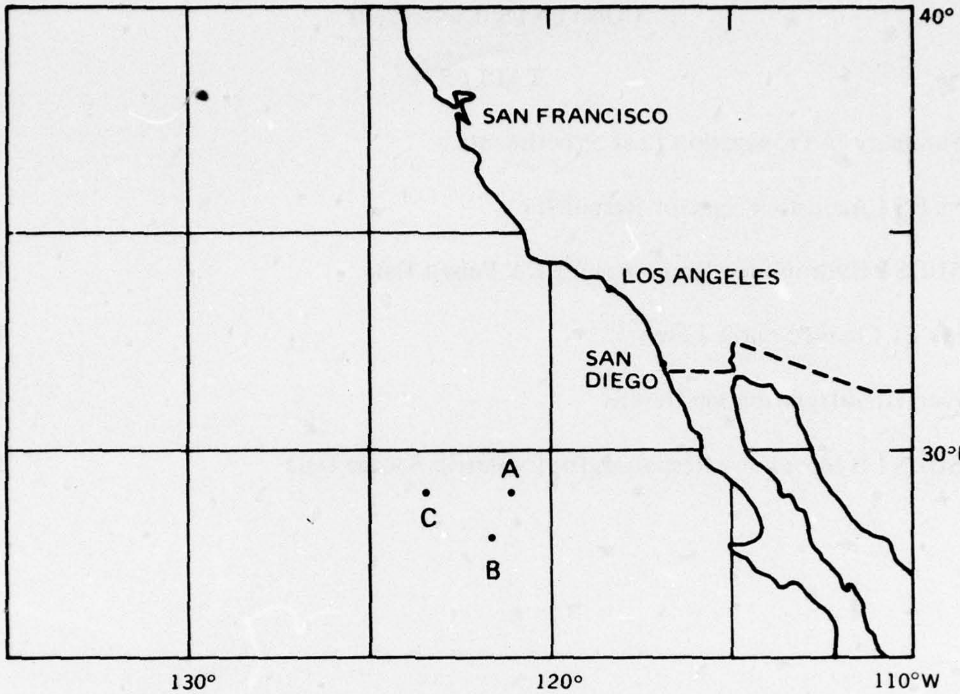

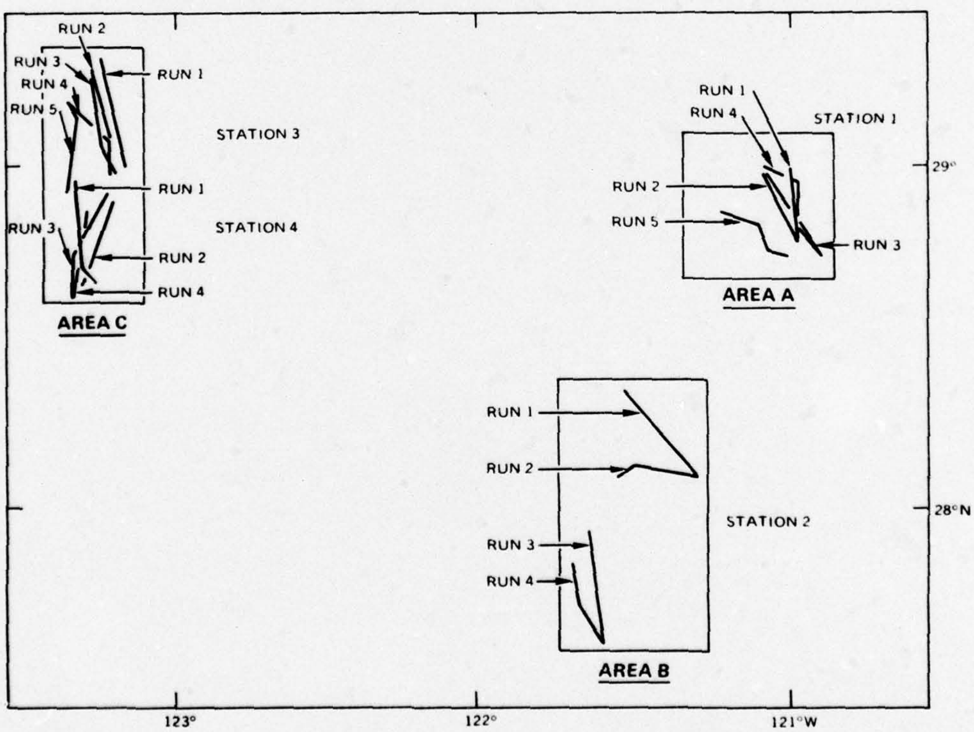

Figure 1. Location of experimental areas.

INTRODUCTION

From 9-24 February 1972 the Naval Undersea Center conducted, at four acoustic stations, a series of 18 propagation loss experiments in 3 deep-water areas off the west coast of southern California. These experiments are known as the SUrface Duct Sonar Measurements (SUDS I - 1972). Figure 1 shows the locations of the experimental areas. Acoustic station 1 was conducted in area A, station 2 in area B, and stations 3 and 4 in area C. At each acoustic station, either four or five propagation loss runs were made. During these experiments propagation losses in near-surface propagation paths (direct, surface channel, and depressed channel) were made as a function of range out to ranges of 25.0 to 43.7 kyd.

This is the second in a series of three NUC Technical Papers reporting on the propagation loss and supporting environmental measurements made during these experiments. The first report (Ref. 1) is a technical report discussing the propagation loss and environmental measurements. The third report (Ref. 2) contains the environmental measurements made in support of the propagation loss measurements. The present report contains the propagation loss measurements made during the four acoustic stations. It consists of five volumes. Volume I describes the instrumentation used to make the propagation loss measurements and the data reduction procedures. Volumes II-V are detailed reports containing a summary of the environmental measurements, plots of propagation loss versus range, and comments pertinent to the specific propagation loss run.

Table 1 summarizes information pertinent to the individual propagation loss runs. Continuous wave (CW) sources (0.4, 1.0, 1.5, 2.5, 3.5, and 5.0 kHz) were used during 15 of the runs and explosive sources during 3 of the runs. CW source depths from 38 to 47 m were used during 12 of the runs and depths of 4 to 9 m used during 3 of the runs. Explosive source depth was 18 m for all explosive runs. During each propagation loss run five receivers were used at depths selected between 4 and 182 m, depending upon the surface layer depth. Additionally, during the explosive runs another receiver was deployed at 38.1 m.

Participating in these experiments were the USNS S. P. *Lee* (TAG-192), the USNS *DeSteiguer* (T-AGOR-12), and the R/V *Cape*. The *Lee* was the source ship, the *DeSteiguer* the receiver ship, and the *Cape* operated and monitored environmental sensors. A summary of preliminary results has been reported by Cummins (Ref. 3). The data contained in this report supercede the data reported in Ref. 3. Comparisons of propagation loss models with the SUDS I experimental data were reported by Morris (Ref. 4).

Table 1. Summary of Propogation Loss Experiments

STATION 1 (10-12 February 1972)

Run	Date/time LST	Range, kyd Minimum	Range, kyd Maximum	Frequency, kHz	Source depth, m	Receiver depth, m
1	10/0251-0647	0.5	27.1	1.5	41	6/24/59/98/148
				2.5	41	
2	11/0052-0515	2.2	26.6	0.4	45	4/17/43/72/112
				1.0	42	
3	11/0721-1330	0.1	38.9	3.5	45	4/17/43/72/112
				5.0	42	
4	11/1438-2119	0.1	43.7	3.5	7	5/19/47/77/120
				5.0	4	
5	12/1125-1400	1.2	30.3	explosive	18	6/23/57/95/145/38

STATION 2 (14-15 February 1972)

Run	Date/time LST	Range, kyd Minimum	Range, kyd Maximum	Frequency, kHz	Source depth, m	Receiver depth, m
1	14/1822-0024	0.2	32.4	1.5	38	5/19/47/77/120
				2.5	38	
2	15/0141-0508	10.7	29.5	1.0	39	4/17/43/72/112
				—	—	
3	15/1328-1940	0.2	25.0	3.5	38	4/17/43/72/112
				5.0	41	
4	15/2031-0052	1.7	28.1	0.4	8	4/17/43/72/112
				1.0	5	

STATION 3 (19-21 February 1972)

Run	Date/time LST	Range, kyd Minimum	Range, kyd Maximum	Frequency, kHz	Source depth, m	Receiver depth, m
1	19/1500-2130	5.2	31.1	explosive	18	6/34/69/112/173/38
2	20/0105-0630	3.9	33.6	1.5	42	6/37/173/119/182
				2.5	42	
3	20/0658-1418	0.1	37.5	0.4	42	6/34/69/112/173
				1.0	42	
4	20/1530-2052	0.1	33.3	3.5	44	6/36/72/117/180
				5.0	47	
5	20/2131/0400	2.9	36.0	3.5	6	6/35/72/115/177
				5.0	9	

STATION 4 (21-23 February 1972)

Run	Date/time LST	Range, kyd Minimum	Range, kyd Maximum	Frequency, kHz	Source depth, m	Receiver depth, m
1	21/2342-0646	0.1	33.3	3.5	43	6/36/73/118/181
				5.0		
2	22/1210-1705	0.1	33.1	explosive	18	6/36/72/117/181/38
3	22/1810-0104	2.3	35.1	1.5	43	6/36/72/117/180
				2.5	43	
4	23/0116-0632	2.6	33.4	1.5	43	6/36/62/117/180
				2.5	43	

CONTINUOUS WAVE (CW) MEASUREMENTS

CW pulse propagation loss measurements were made on 15 of the acoustic runs. Two frequencies were transmitted for each experimental run, except for station 2 run 2, during which only one frequency was used. Three propagation loss runs were made using the 0.4- and 1.0-kHz sources, five using the 1.5- and 2.5-kHz sources, six using the 3.5- and 5.0-kHz sources, and one using only the 1.0-kHz source.

Planned source depths were 0.7 of the measured surface layer depth or 15 m, whichever was the deeper, for 12 runs and 6 m for 3 runs. During each experiment a series of 500-msec pulses, at a 12-sec repetition rate for each frequency, were transmitted by the source ship as it opened or closed range at 3 knots from the receiver ship. Every minute, a pulse was omitted as an aid to later data reduction and processing. At one of the frequencies four pulses were transmitted per minute. During the same minute, a second series of pulses at the second frequency, were transmitted. The second group was structured the same as the first, but was delayed 6 sec relative to the first. The resulting pulsing schedule was a series of eight pulses, alternating in frequency, 500 msec in length, sent each minute, with the first 12 sec silent.

These transmissions were received on five receivers suspended from the receiving ship, which was hove to and drifting. Planned receiver depths were 6 m and 0.4, 0.8, 1.3, and 2.0 times the measured surface layer depth. The data were recorded on two six-channel Brush recorders and a magnetic tape recorder.

Acoustic travel times were obtained from the difference in the time of arrival of the simultaneous radio and acoustic pulses. To obtain a travel time with the required accuracy, the Brush recorder speed was increased from the normal recording speed of 5 mm/sec to 125 mm/sec every 30 min. This permitted a travel time determination accurate to ± 0.01 sec. The acoustic range was obtained by multiplying the travel time by an appropriate average sound speed for near-surface propagation. During these experiments the sound speed varied from 1503.8 to 1507.0 m/sec. This results in a relative acoustic range accuracy of about 15 m, or 16 yd.

Transmitting System (N. J. Martini, T. E. Strixrud, D. White)

Figure 2 is a block diagram of the SUDS I acoustic transmission system. The oscillators, used as sources for signals f_1, f_2, and f_3, are fixed-frequency fork-type units. For any given acoustic experiment frequency, f_1 was either 0.4, 1.0, or 1.5 kHz, and frequency f_2 was either 2.5, 3.5, or 5.0 kHz. Frequency f_3 was always 0.7 kHz and was used to modulate the radio transmitter.

The keyer had two functions. It alternately imposed signals f_1 and f_2 onto the input of a power amplifier, and it switched the appropriate inductors in and out of a series-resonant circuit formed between the inductors and the acoustic transducers. Each frequency is pulsed for 0.5 sec, with a 6-sec delay between f_1 and f_2. Once a minute, one 0.5-sec pulse of each frequency was omitted. Signal f_3 was applied to the radio transmitter whenever signal f_2 was applied to the power amplifier. This caused a 0.7-kHz tone to be sent almost simultaneously to the acoustic receiving system, where it was used as a reference for obtaining acoustic travel times.

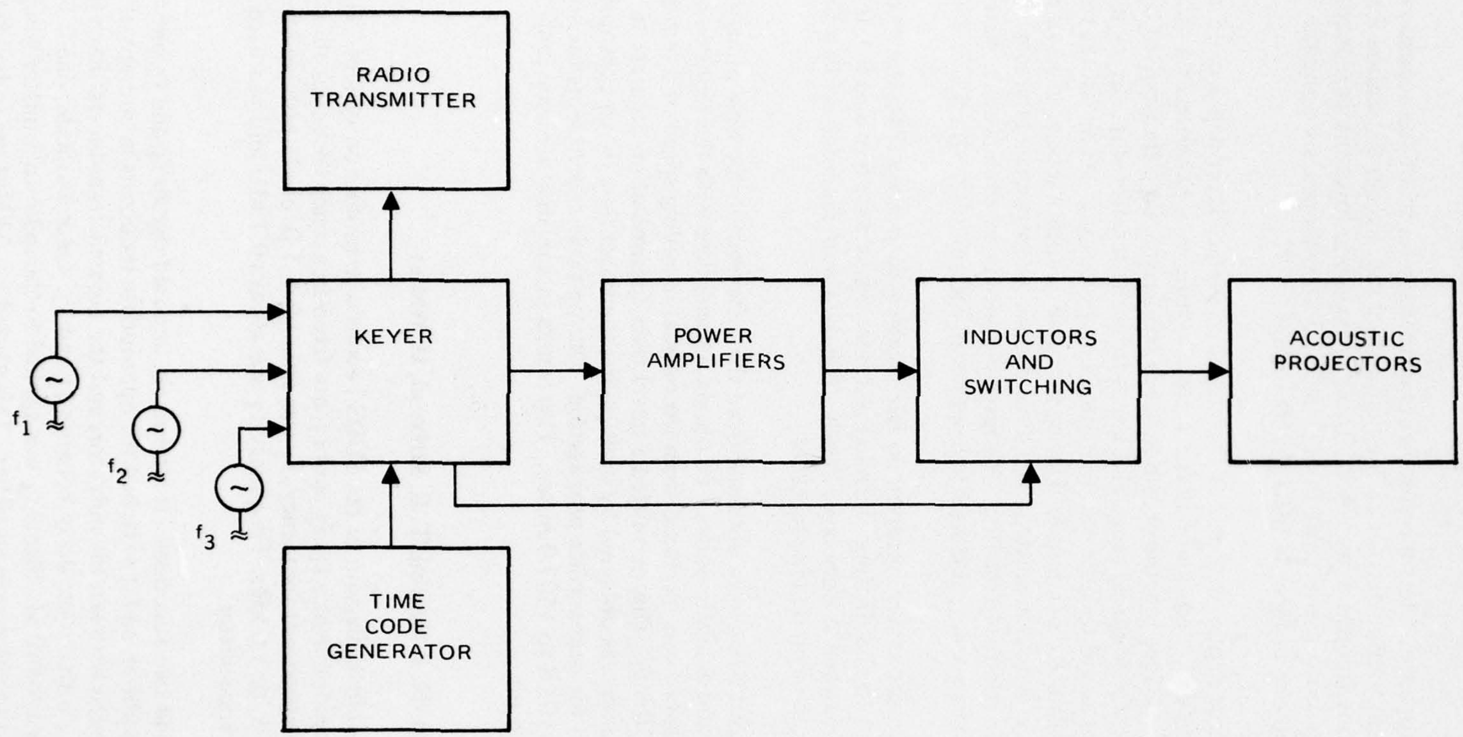

Figure 2. SUDS I acoustic transmission system.

The time code generator provided an accurate clock to pace the keyer in its control sequence. Since the receiving system also had a time code generator, accurate time references were obtained by synchronizing the time code generator to radio WWV.

Four different acoustic projectors were used to generate the six required frequencies. Pertinent information on these projectors is summarized in Table 2. The transmitting responses are in dB re 1 μb/A at 1 m and relate source levels directly to the driving currents recorded during the measurements at sea. These responses were obtained from calibration response curves prepared before and after the experiments. Source levels were measured every 20 min during all propagation loss runs.

Receiving System (C. K. Lisle)

Figure 3 is a block diagram of the SUDS I CW receiving system. Acoustic signals were received on five hydrophones rigged from the receiver ship. To reduce the effect of ship-generated noise, the three shallowest hydrophones were suspended from a buoy, which was floated out about 270 ft from the receiver ship. The two deepest hydrophones were rigged over the fantail of the receiver ship.

The hydrophones were calibrated at TRANSDEC before and after the experiments. Table 3 lists the results of these calibrations for each frequency used in the experiments. These receiver responses are in dB re 1 V/μb and relate sound pressures directly to the calibration voltages injected during the measurements at sea.

The received signal was fed into a preamplifier with a variable attenuator and then into an amplifier. All preamplifiers were adjusted to 80 dB gain on broadband. The amplification was the same for all frequencies. An Ithaca 257A amplifier was used to furnish additional gain from 0 to 80 dB in 1- and 10-dB steps.

The acoustic signals were then fed into a Brush strip chart recorder and an AMPEX FR1300A tape recorder. The acoustic data were recorded on five channels of the Brush recorder with logarithmic amplifiers in the final stage. A logarithmic amplifier was chosen to increase the dynamic range over that of the linear amplifiers. The recorder provided 50-dB dynamic range.

Table 2. SUDS I Acoustic Projector Responses.

Projector Mod-Ser	Type of Response	Frequency, kHz					
		0.4	1.0	1.5	2.5	3.5	5.0
HX90-007	Current	+92.9					
C29JP-1M	Current	+77.5	+82.6	+84.5	+82.6	+76.1	
C29JP-2M	Current	+77.0	+82.7	+84.4	+81.7	+75.6	
C28JP-3M	Current						+89.5

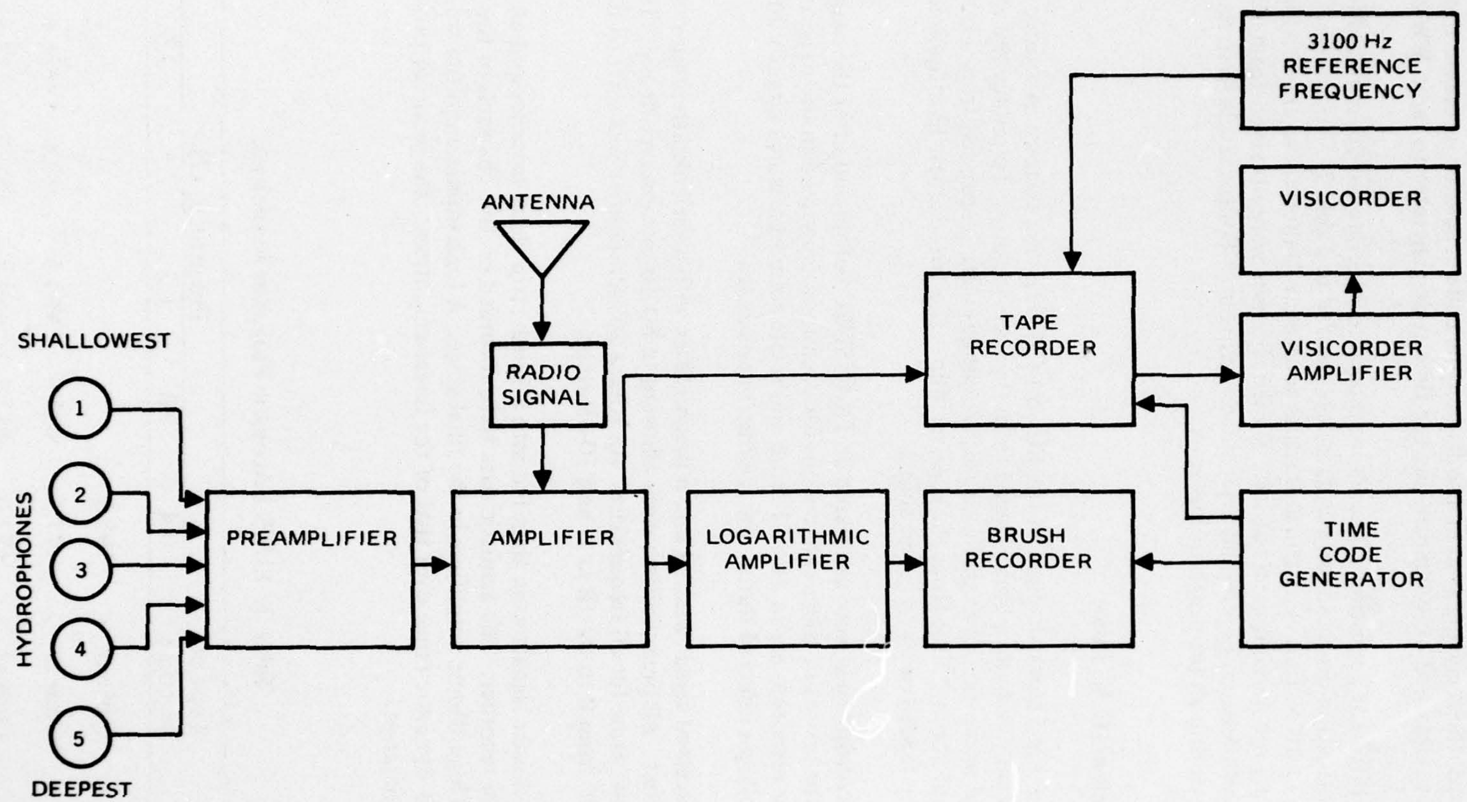

Figure 3. Block diagram for CW receiving system.

Table 3. SUDS I Hydrophone Responses for CW Pulsed Data.

Hydrophone		Frequency, kHz					
No.	Mod-Ser	0.4	1.0	1.5	2.5	3.5	5.0
1	C02JP-2	−116.3	−108.6	−105.6	−101.6	−100.4	−97.7
2	C09JP-3	−105.7	−98.3	−96.0	−93.7	−91.8	−91.4
3	B11JP-1	−104.0	−96.9	−94.3	−93.2	−94.8	−93.8
4	C22JP-2	−106.2	−99.1	−96.1	−93.7	−93.1	−93.0
5	C11JP-1	−106.6	−99.5	−96.9	−94.7	−93.2	−93.3

The radio signal from the transmitting ship was monitored on channel 6 of the Brush recorder and on the tape recorder. The time code generator provided an accurate reference time to the Brush and tape recorders. The time code generator was kept to within ±5 msec of WWV. A 3100-Hz tone was applied to one channel of the tape recorder. This was used for checking tape-speed stability. Before and after each experiment a calibration of the 10 hydrophone channels was made. For each calibration three injected signal levels were used. In addition to the calibration, the logarithmic amplifiers were checked every hour and after a recorder paper change.

Data Reduction (R. W. Townsen)

The Brush recorder record of the acoustic signal arrivals was used as the primary data source. Figure 4 is a 1-min sample of the recorded data. The hydrophone outputs were recorded on channels 1-5, with the shallowest hydrophone recorded on channel 1 and the deepest on channel 5. Generally, three arrivals were recorded for each 0.5-sec pulse. The first arrival traveled via the surface channel path and was the arrival of interest in these experiments. The second arrival traveled via one bottom reflection and the third via two bottom reflections. A radio pulse was transmitted with each acoustic pulse for each frequency, and its arrival was recorded on channel 6 of the corresponding Brush recorder. The travel time of the acoustic energy is the difference in arrival time between the surface channel acoustic pulse and the radio pulse.

Travel time was usually read from channel 2 at the higher of the two frequencies being transmitted unless a period occurred in which the received levels were at the noise level. If travel time measurement pulses were at the noise level, travel time was read from the channel 2 recording at the lower frequency. Because of hydrophone placement and receiver ship drift, the estimated horizontal range accuracy is ±90 yd.

The surface channel arrivals were read as a visual average of the received level at the top of the pulse pedestal. When possible, a corresponding average noise level was also

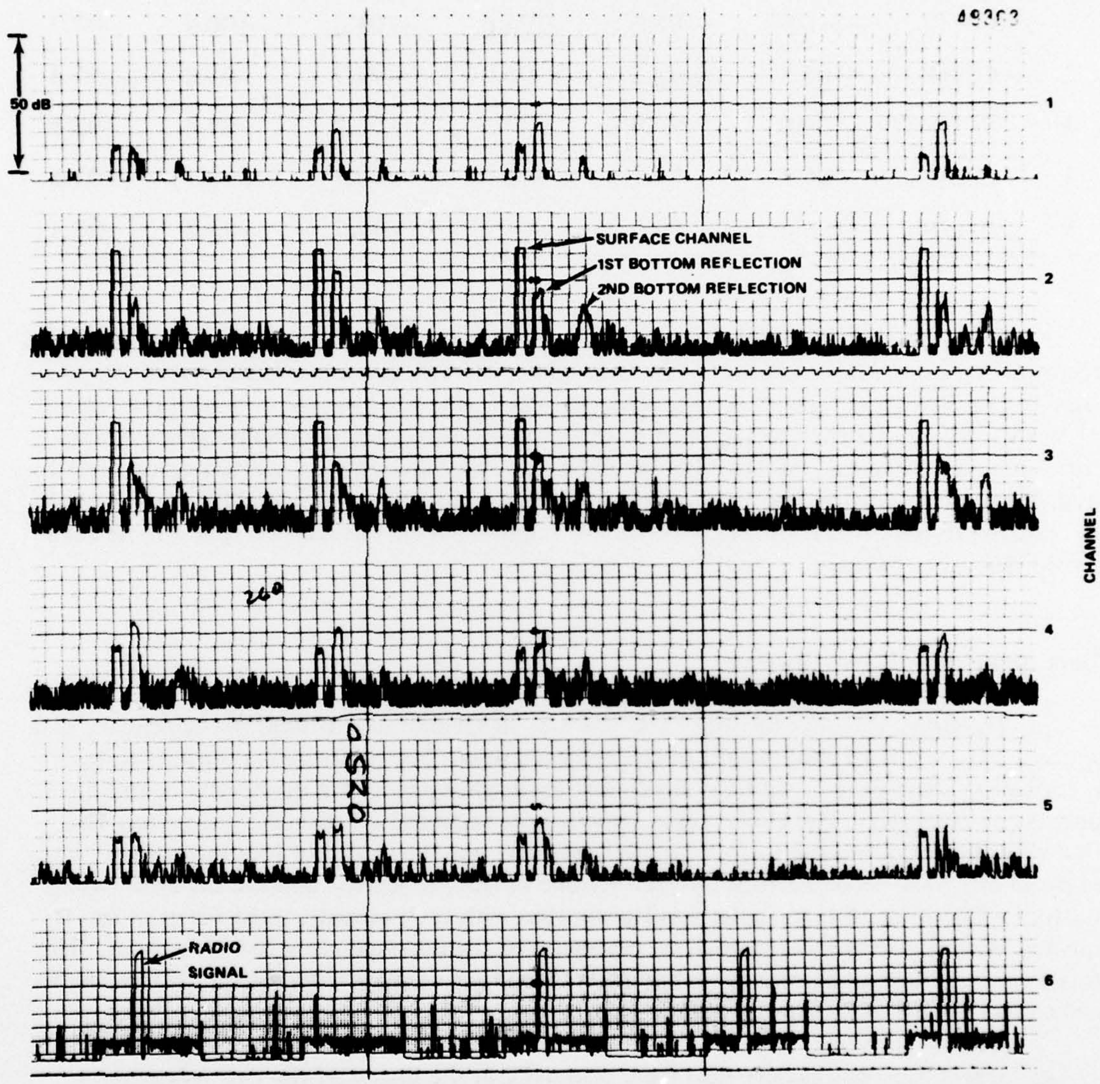

Figure 4. Sample Brush recorder record.

recorded. These levels were transcribed onto keypunch worksheets and then punched onto punch cards. Each deck of punch cards consisted of one set of header cards defining:

a. hydrophone depths and sensitivity

b. source level measurements and their corresponding set number (each set number applies to a 1-min pulsing sequence)

c. amount and time of gain and attenuation changes

d. injected level plus system response (calibration) at the beginning and end of the run for the frequency being analyzed and set number relative in time to data set numbers

e. paper fluctuation and corresponding set number at the calibration points and along the run

f. travel time measurements and corresponding set number

g. sea-surface sound speed

The remainder of each card deck contains the pulse data. The pulse data were grouped by putting three sets (four pulse and noise levels per set) on one card. Since each deck contained five channels of data, cards were ordered by punching the first three sets from channels 1 to 5, then the second three sets from channels 1 to 5 and so on until all data were punched.

A UNIVAC 1110 computer with a capacity of 36-bit single precision was used in the data reduction procedure. The data reduction program handled all computations, storage, and plotting. The program consisted of a main routine and five subroutines, with all necessary data and transfer parameters being passed through a series of common statements. The main routine was designed to call the subroutines, compute the propagation loss for each received pulse, and output the propagation loss and range data. The subroutines handled reading of header cards, reading data cards, computing system loss levels for each pulse, computing acoustic ranges for each data set, and plotting propagation loss as a function of acoustic range for each hydrophone channel.

The variables used in calculating the propagation loss are:

n	set number
m	pulse number in set
D	recorded pulse amplitude
H	system loss level
S	source level
P	paper fluctuation
A	attenuation
G	gain
Q	system calibration
INJ	injected signal level (for recorder calibration)
LEV	system response (for a given signal inject)

R	hydrophone sensitivity
N	recorded noise level
PL	propagation loss

The actual propagation loss is:

$$PL_{nm} = H_{nm} - (D_{nm} - N_{nm}) \quad (1)$$

The system loss level is:

$$H_{nm} = S_{nm} + P_{nm} - A_{nm} + G_{nm} + Q_{nm} + R \quad (2)$$

where

$$Q_{nm} = Q_a + \left(\frac{Qa - Qb}{a - b}\right)\left(n + \frac{m}{5}\right) \quad (3)$$

Let i = a or b, then:

$$Q_i = A_i - G_i + P_i - INJ_i + LEV_i \quad (4)$$

where a̲ is the relative set number of the first calibration, and b̲ is the relative set number of the second calibration with $a \leq n \leq b$. The source level and paper flucation were assumed to be constantly varying functions of set number and were linearly interpolated between successive points. The signal level recorded on the Brush record contains a background noise component. If the background noise was within 10 dB of the recorded signal level, it was subtracted out by means of the following relationship:

$$D_{nm} - N_{nm} = 10 \log_{10} \left[10^{(D_{nm} - 50)/10} - 10^{(N_{nm} - 50)/10} \right] + 50 \quad (5)$$

In order to keep track of set number and for inter-referencing between channel outputs and range outputs, missing data were entered as zero propagation loss. Acoustic range for each set was computed from the surface sound speed and travel time obtained from a linear fit between travel time measurements.

The final results were presented as follows:

a. Printer listings of set number, propagation loss, and the range in kiloyards.

b. Magnetic tape containing propagation losses. One file on the magnetic tape contains one deck of cards. The data were stored in integer form and were 10 times the true value in order to preserve tenths of a dB. The range data were stored in real form. Each file contains five records of propagation loss data (one record per hydrophone channel) and one record of range data in kiloyards.

c. Plots of propagation loss as a function of range.

EXPLOSIVE MEASUREMENTS
(D. L. Keir)

Explosive propagation loss measurements were made on three of the acoustic runs: station 1 run 5, station 3 run 1, and station 4 run 2. The first explosive experiment was made using a 6-knot source-ship speed, while the other two experiments were conducted at 3 knots.

Mk 61 charges set for an 18.3-m explosion depth were used as sources for these experiments. Prior to each experiment, test shots were dropped for setting attenuators on the receiving equipment. During each experiment, in order to achieve a shot spacing of approximately 1 kyd, charges were dropped every 5 or 10 min while the source ship opened or closed range at 6 knots or 3 knots, respectively. The charges were monitored by a hydrophone towed by the source ship. The output of this hydrophone was radioed to the receiver ship to be used for obtaining acoustic travel times.

The acoustic transmissions were received on six hydrophones suspended from the receiver ship. Planned hydrophone depths were 6 m, 38 m, and 0.4, 0.8, 1.3, and 2.0 times the measured surface layer depth. The data were recorded on two six-channel Brush recorders and an AMPEX wideband tape recorder.

Mk 61 Source Levels

Mk 61 explosive charges were used since such charges have a well-known source level over a wide band of frequencies. Source levels for these charges were obtained from curves published by Stockhausen (Ref. 5) scaled according to Weston (Ref. 6). Analysis done by Gaspin and Shuler (Ref. 7) was used to determine the source level at 0.4 kHz. Source levels are listed in Table 4.

Table 4. Mk 61 Charge Source Levels

Frequency kHz	Source Level,* dB	Frequency, kHz	Source Level, dB
0.40	66.2	2.50	64.0
0.63	65.9	3.15	63.0
0.80	65.7	5.00	61.5
1.00	65.6	10.00	58.6
1.60	65.0		

*Source level is dB re 1 erg/cm^2. These values are for a 1.8-lb charge of TNT at a depth of 18.3 m as measured through a 1/3-octave filter scaled to a distance of 1 yd.

Receiving System

Figure 5 is a block diagram of the SUDS I explosive receiving system. The explosive signals were received on six hydrophones rigged from the receiving ship. To reduce the effect of ship-generated noise, hydrophones 1, 2, and 3 were suspended from a buoy, which was floated out about 270 ft from the receiver ship. Hydrophones 4, 5, and 6 were suspended directly from the receiver ship. Table 5 contains the depth, in meters, of the receiving hydrophones for each explosive experiment.

The hydrophones were calibrated at TRANSDEC before and after the experiments. Table 6 lists the results of these calibrations for each frequency used in the analysis. Shown are the average sensitivities over 1/3-octave bands in dB re 1 V/μb for the center frequency. These values need not agree with those used for the CW pulse measurements since it was necessary to average the response over a 1/3-octave band centered at the frequency given in the table.

The explosive signal, received on hydrophones 1-5, was fed into preamplifiers which had up to 78 dB attenuation and a nominal gain of 75 dB. To reduce the low-frequency noise generated by the receiver ship, 160-Hz high-pass filters were used. The output from each of the hydrophone channels was paralleled into two Ithaco model 257A amplifiers, with a 10-dB gain difference between the two channels. A scope was used to monitor the lower gain channel among the five hydrophones to obtain an absolute check on levels at the output of the Ithaco amplifiers.

The signal from the amplifiers was recorded on Brush recorders, using logarithmic amplifiers in the final stage. The signals were also recorded at 15 ips on an AMPEX FR1300A wideband tape recorder. In the FM mode this allowed frequencies up to 10 kHz to be recorded. The Brush recorders also recorded the radio signal of the explosives for travel time purposes and the output of one channel of the high-frequency hydrophone system. The tape output was monitored on four channels with a Honeywell TCGA-600 Visicorder amplifier and a Honeywell 906C Visicorder.

Table 5. Estimated Hydrophone Depths, m

Hydrophone No.	Hydrophone Mod-Ser	Station 1 Run 5	Station 3 Run 1	Station 4 Run 2
1	C02JP-2	5.7	5.7	5.8
2	C09JP-3	23.0	34.4	36.0
3	B11JP-1	57.3	69.0	72.1
4	C22JP-2	94.7	111.8	117.1
5	C11JP-1	144.5	173.2	180.5
6	Clevite CH-18B	36.0	36.0	37.5

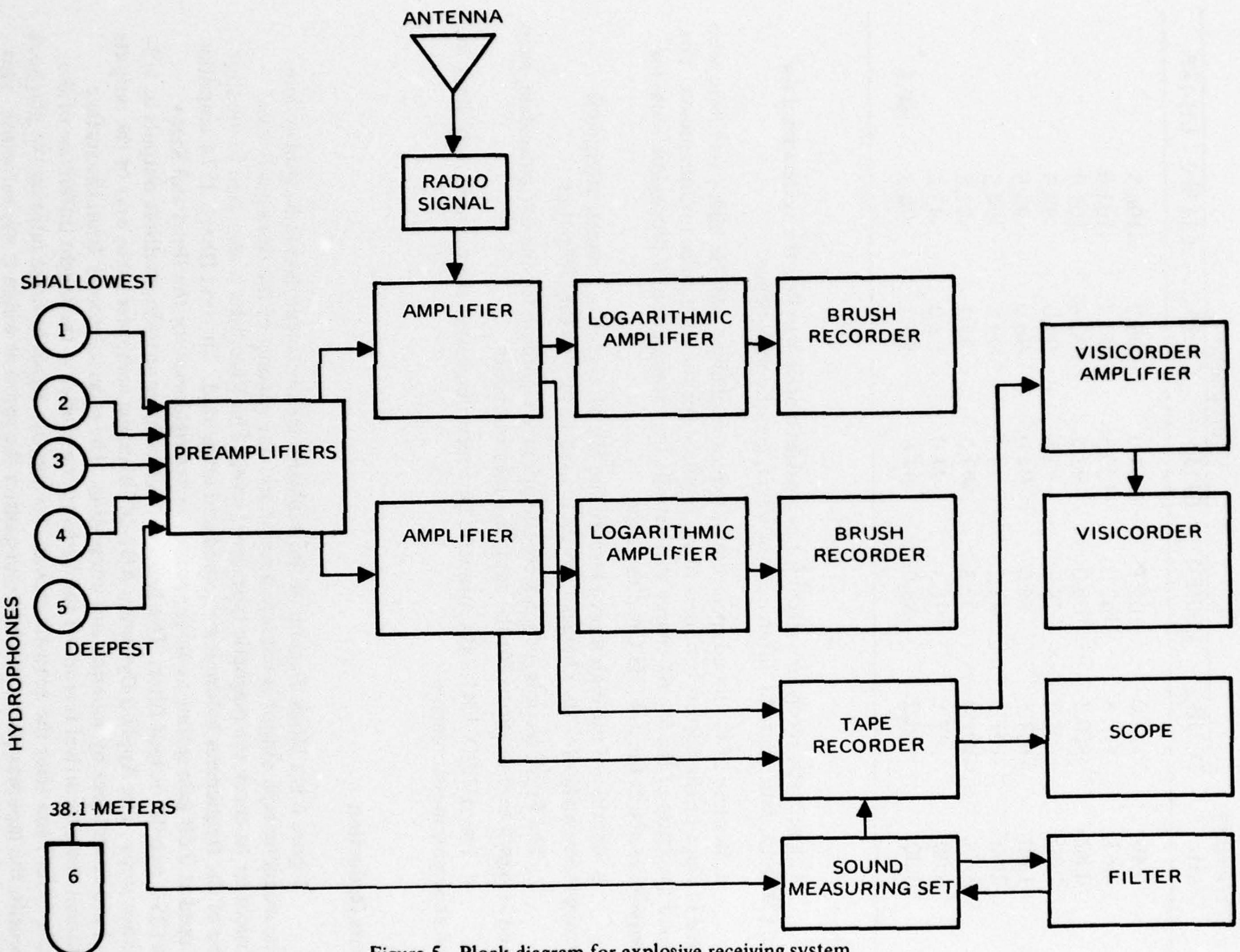

Figure 5. Block diagram for explosive receiving system.

Table 6. SUDS I Hydrophone Responses for Explosive Source Data

Frequency kHz	Hydrophone C02JP-2	C90JP-3	B11JP-1	C22JP-2	C11JP-1	CH-18B
0.40	-116.2	-105.7	-104.0	-106.2	-106.5	
0.63	-112.8	-102.0	-100.3	-102.7	-103.0	
0.80	-110.8	-100.0	-98.5	-100.8	-101.0	
1.00	-108.5	-98.2	-96.8	-99.0	-99.5	
1.60	-104.5	-96.0	-94.0	-96.0	-96.5	
2.50	-101.5	-93.7	-93.2	-93.7	-94.5	
3.15	-101.0	-92.3	-93.0	-93.2	-93.5	
5.00	-97.5	-91.3	-94.0	-93.0	-93.2	
10.00	-96.2	-88.0	-94.8	-90.7	-90.3	-80.5

The acoustic receiving system for explosives closely parallels the system used for the CW pulse data. Certain differences, however, are of consequence:

a. Because of the broad spectrum of explosive charges, 160-Hz high-pass filters were used in place of the narrow bandpass filters required for the tone pulse measurements. The broad spectrum of the Mk 61 charge also permits the examination of propagation loss for frequencies above the 5.0-kHz CW pulse data.

b. Because of the high source level of the Mk 61 explosive charges, attenuator settings were higher for the charges than those used to receive the CW pulses.

c. The Brush records, which were the primary recording for the CW pulse data, were used as signal level monitors for the explosive measurements.

d. The AMPEX FR1300A magnetic tape recordings were the primary recordings for the explosive measurements.

Data Reduction

Figure 6 is a block diagram of the explosive measurement data reduction system. The magnetic tape output is fed into a scope and one channel of the Honeywell 906C Visicorder to check the magnetic tape signal level. The Visicorder is also used to monitor one of the frequencies before it is squared and integrated. The first Ithaco 257A amplifier is used at 0 dB gain setting as an impedance-matching device for the Bruel and Kjaer 16125-1 parallel output filter. The Bruel and Kjaer filter provides multiple outputs in 1/3-octave steps. The Applied Dynamics AD2-24PB analog computer takes four of the outputs and processes them by squaring and integrating. The received energy from the surface channel acoustic arrival is read off the Visicorder recorder as the height difference of the trace before and after the acoustic arrival. To improve signal-to-noise ratio on the playback records, the tape was played back at one-quarter the speed at which it was recorded. This procedure produced an increase of 6 dB in the apparent energy of the arrival and a 6-dB

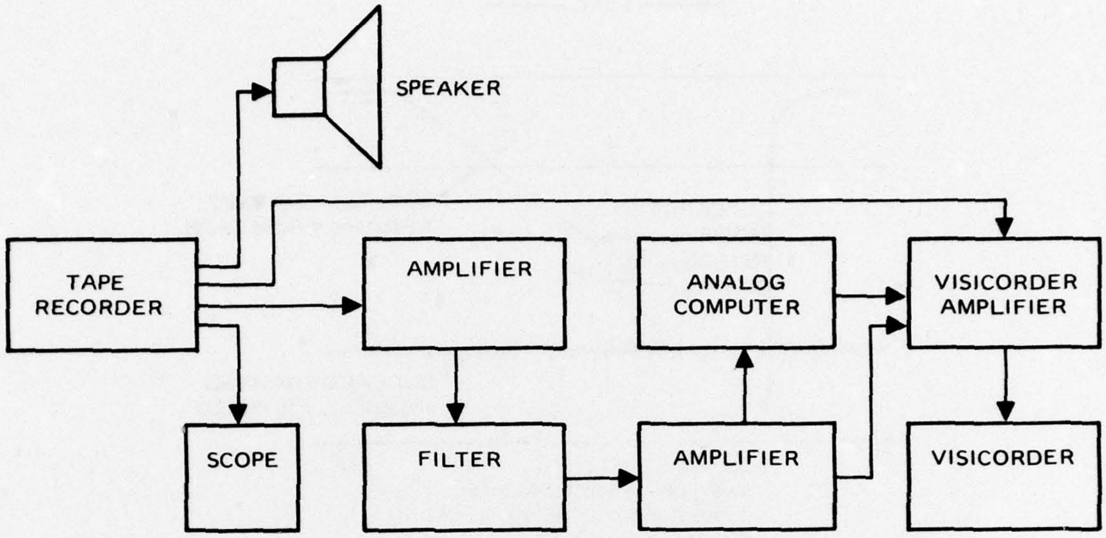

Figure 6. Block diagram of explosive data reduction system.

decrease in 10 log the tangent of the slope for the integrated noise. The Bruel and Kjaer filter outputs were set at one-quarter the original frequencies to compensate for the reduction in playback tape speed.

Figure 7 is a facsimile of a Visicorder record. When the squarer integrator is turned on, noise is integrated to form a line of more or less constant slope. The surface channel arrival results in a sharp increase in slope of the Visicorder trace. After the surface channel arrival has died out, the noise alone continues to be integrated. Analysis is terminated before the bottom reflection pulse returns. The energy of the surface channel arrival, in a given frequency band, is proportional to the height difference of the trace before and after the pulse arrival. Although only one frequency (10 kHz) is shown in fig. 7, four frequencies are analyzed per pass through the tape, with two traces at each edge and two traces in the center of the recorder paper.

Figure 8 shows the calibration signal taken off the magnetic tape as well as the trace of the squared and integrated tone. The tangent of the angle made by this trace is proportional to the power in the calibration signal.

Propagation loss is obtained from the following equation:

$$PL = SL - RL \tag{6}$$

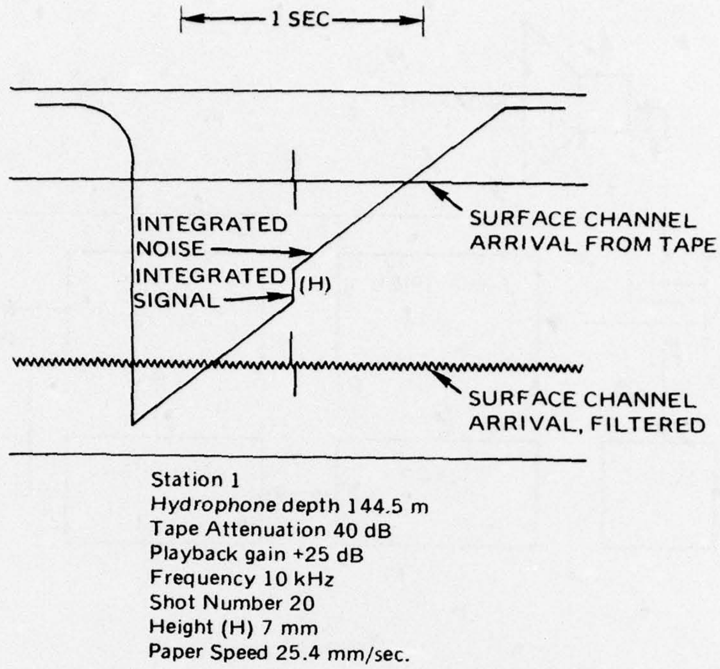

Figure 7. Sample Visicorder record of surface channel arrival.

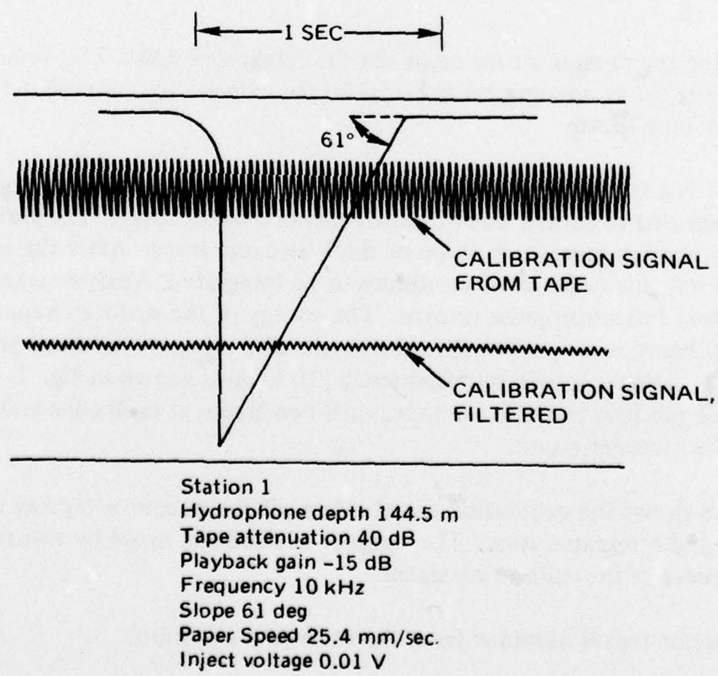

Figure 8. Sample Visicorder record of calibration signal.

where PL is the propagation loss, SL the source level, and RL the received level.

The received level is:

$$RL = 10 \log_{10}(H-6) + A_p + A_t - 10 \log_{10}S_c - 10 \log_{10}V_p - A_{cp}$$

$$- A_{ct} + 20 \log_{10}V_i - 20 \log_{10}K - 10 \log_{10}\rho c \quad (7)$$

The variables are defined as follows:

H	height difference in millimeters of the trace before and after the surface channel arrival. (The −7 dB is a correction for the factor-of-four reduction in the magnetic tape speed upon playback.)
A_p	attenuation in the playback system for the explosive. (Since gain settings are used with this set of equipment, the gain is subtracted from an arbitrary value of 40 dB to obtain A_p.)
A_t	attenuation in the recording system at the time the explosion was recorded.
S_c	tangent of the angle made by the integrated trace of the calibration signal with the horizontal axis of the recorder paper.
V_p	Visicorder paper speed in millimeters per second when the calibration signal on the magnetic tape was processed.
A_{cp}	attenuation in dB in the playback systems for the calibration signal. (Since the playback system uses gain settings, 40 dB minus the gain is defined as the attenuation.)
A_{ct}	attenuation in dB in the record system for the calibration signal.
V_i	voltage injected into the tape recording system.
K	hydrophone sensitivity in dB re 1 V/μb for the frequency being processed.
ρc	acoustic impedance of seawater in cgs units.

The explosive arrivals were analyzed for the nine frequencies listed in Table 6. Noise limited the detectability of both the high- and low-frequency components at various times on all experiments. When this happened, a maximum possible value for the received energy was used in the propagation loss calculation. This resulted in a minimum propagation loss value, which was compared with other propagation loss values near in range. If the noise-limited data point was in reasonable agreement with adjacent non-noise-limited data, it was retained.

For each station, measurements made at 10 kHz by means of the Clevite hydrophone were compared with 10-kHz propagation losses as measured by hydrophone 2. Except for station 4 run 2, a significant lack of agreement was observed for ranges greater than 10 kyd. This lack of agreement was attributed to overloading of the Clevite hydrophone preamplifier. This overloading occurred before the strong low-frequency components of the explosive arrival were filtered out.

The final results were plots of propagation loss versus range for all frequencies analyzed and all receiver depths. On these plots, noise-limited measurements are plotted as triangles. These measurements represent a minimum possible propagation loss. Non-noise limited measurements are plotted as squares.

In conclusion, the following remarks are pertinent:

- The recording system for the high-frequency portion of the explosive spectrum proved inadequate because of overloading the five hydrophone preamplifiers at close ranges and because of a lack of dynamic range to cover the wide differences in propagation loss at different frequencies found at the longer ranges.
- Low-frequency noise generated by the receiver ship limited the detectability of surface channel arrivals at lower frequencies and occasionally at close ranges.
- Some signals were overloaded at close range because of inadequate attenuation in the preamplifiers.

OTHER ACOUSTIC MEASUREMENTS
(J. Cummins)

Other acoustic measurements included bottom-reflection data, reverberation data, and short- and long-pulse fluctuation data as a function of range, receiver depth, and frequency. These data are not scheduled for analysis and reporting in the near future.

Bottom reflection data were collected on both CW pulse and explosive propagation loss experiments. As illustrated by fig. 4, the quality of these data is excellent.

Reverberation data were recorded with the source ship and receiver ship approximately 1000 yd apart. Five-sec pulses at one-minute intervals were used. Since omnidirectional sources and receivers were used, the bottom reverberation obscured the surface channel reverberation after the time requried for the bottom reflection arrival. Thus, these data are not representative of a fleet sonar operating in a surface channel.

The short-pulse fluctuation measurements were made with the source ship hove to while transmitting the pulses. Measurements were made at ranges of 3, 6, 9, 12, and 15 nm for a period of 10 min at each frequency. These data were recorded on Brush recorders and on magnetic tape for later analysis of spectral broadening. Long pulses were also recorded at the same ranges. A 10-min pulse was transmitted at 1.0, 3.5, and 5.0 kHz. The signals were recorded on magnetic tape at 7.5 ips.

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