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SOUND PROPAGATION E.'PERIMENTS CONDUCTED UNDER THE POLAR ICE PACK DURING THE SUMMER OF 1958

Navy Underwater Sound Laboratory
New London, Connecticut

9 February 1960

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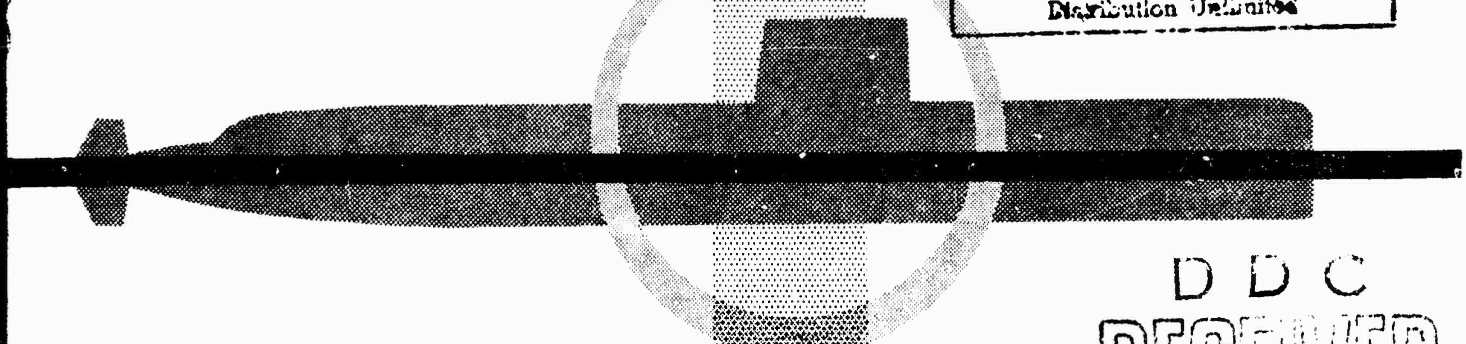
[Title UNCLASSIFIED]

Richard J. Hecht

USL RESEARCH REPORT NO. 465



U.S. Navy Underwater Sound Laboratory
Fort Trumbull, New London, Conn.

[redacted]

1-502-00-00 9 February 1960

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by

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Approved for Distribution

J. W[illegible]ren Horton	H. E. Ruble, Captain, USN
Technical Director	Commanding Officer and Director

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ABSTRACT

During the summer of 1958 the U. S. Navy Underwater Sound Laboratory made sound propagation measurements in the Arctic Ocean. The group velocity of the shots over an average range of 790 kyds appears to change with time, being highest in early and late summer and lowest in midsummer. The spectrum energy curves for various-sized charges show an average slope of -17 to -24 db per octave above 30 cps. It is probable that the pack ice acting as a band rejection filter accounts for the presence of only low frequencies. The transmission loss over a range of 790 kyds averaged 103.5 db.

FOREWORD

This report is based on material presented by Richard J. Hecht at the Seventeenth Navy Symposium on Underwater Acoustics, at the U. S. Naval Air Development Center, Johnsville, Pa., 27-29 October 1959. Limited publication of the material is made at this time and in this form in order to satisfy immediate requirements for the information. It is anticipated that the material as presented at the symposium will be given broad distribution in a future issue of the U. S. Navy Journal of Underwater Acoustics.

ADMINISTRATIVE INFORMATION

The work described in this report is being undertaken under USL Project No. 1-502-00-00, entitled "Underwater Acoustic Research in the Arctic Ocean" and NE No. S-R011 01 01.

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SOUND PROPAGATION EXPERIMENTS CONDUCTED UNDER THE POLAR ICE PACK DURING THE SUMMER OF 1958

INTRODUCTION

The U. S. Navy Underwater Sound Laboratory, in connection with the International Geophysical Year, undertook sound transmission studies in the Arctic Ocean during the summer of 1958 from two observation posts known as Ice Stations Alpha and Bravo. Figure 1 shows the position of these stations in August 1958, the distance between them at that time being about 790 kyds. Station Alpha was established on sea ice about 10 feet thick and Station Bravo on a floeberg, known as Ice Island T-3, that had become frozen in the Arctic ice pack. This island had an area of 36 square miles and was 160 feet thick.

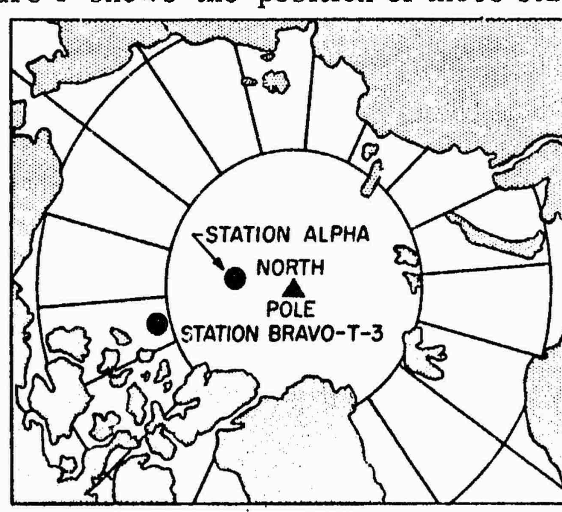

Fig. 1 - Locations of Ice Stations during August 1958

Data were collected by detonating 2-1/4-lb charges of C-3 and 55-lb charges of TNT at a depth of 200 feet at prearranged times. The detonations were observed with a DT-98 hydrophone also at a depth of 200 feet and recorded on a Magnecorder and an Offner Oscillograph versus time. Arrival times and detonation times were recorded together with time signals from a chronometer, which in turn was checked against WWV or JAY. The positions of the two stations were determined at frequent intervals by taking fixes on the sun. A block diagram of the recording system is shown in Fig. 2. The recording system was calibrated daily at frequencies ranging between 22.4 and 8910 cps.

Two hundred feet was selected as the optimum depth for the studies as the result of experiments conducted during the first part of July. At that time, the depths of the detonations were varied from 50 feet to 1000 feet and those of the hydrophone from 30 feet to 450 feet.

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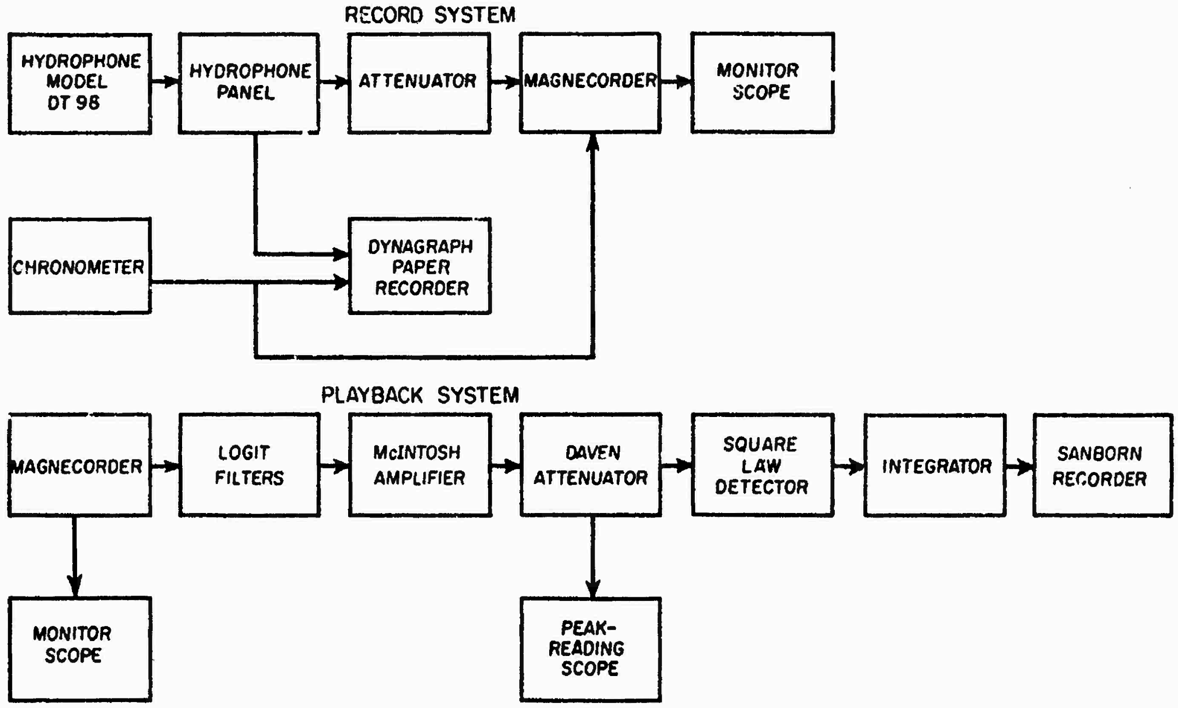

Fig. 2 - Block Diagram of Record and Playback Systems Used in Gathering and Analyzing

At various times during August unidentified signals were received at T-3. It is assumed that these signals were caused by operations of scientists aboard the USS BURTON ISLAND who were studying the bathymetry of the southern Beaufort Sea with one-half pound charges of TNT.

GROUP VELOCITY

Figure 3 shows the nominal horizontal sound velocity or group velocity observed between Alpha and T-3. This velocity was obtained by dividing the great circle distance between the two stations by the observed travel time. The travel time is considered accurate to ±1/10 second.

As shown in Fig. 3, the apparent horizontal velocity is higher in the spring and autumn than in the summer. The range in velocities is approximately 270 ft/sec. There probably is some variation in velocity or path, but the large amount of scatter about an observed mean in Fig. 3 is most probably due to extrapolation errors in determining positions, in turn causing range errors. An error of one mile will cause a change in velocity of about 12 ft/sec at these distances. It is claimed that the positions are accurate to ±1/2 mile, but possibly an accuracy of ±1 mile at each station

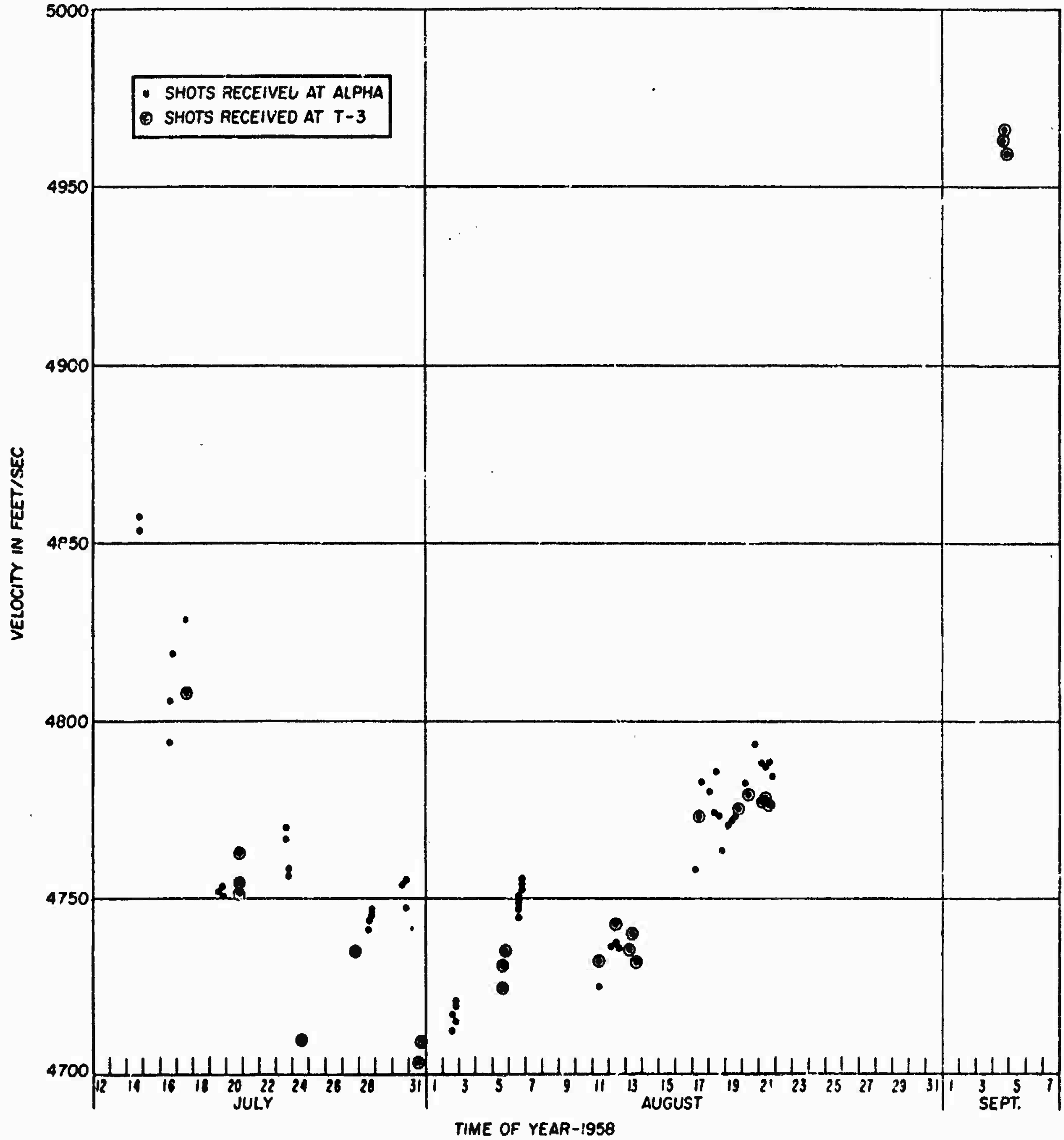

Fig. 3 - Apparent Horizontal Sound Velocity vs. Day of Year Observed between Alpha and T-3

would be more realistic. Two-thirds of a mile was added to all calculated ranges to adjust for the differences in location of the acoustic station and main camp at T-3.

The observed velocity-change with time may show that the mode of transmission changes. However, the same apparent velocity curves could be obtained by a changing velocity profile between T-3 and Alpha or by an error in the refraction correction for the solar position. The two last objections seem to have no justification at the moment so we will assume the velocity curve versus time to be accurate. Between 12 July and 21 August the group velocity ranges from 4700 to 4860 ft/sec. The high velocities observed on 4 September indicate one of two things: either a depressed sound channel near the ocean bottom was developed at this time of year or else there was a gross error in the positions for this period.

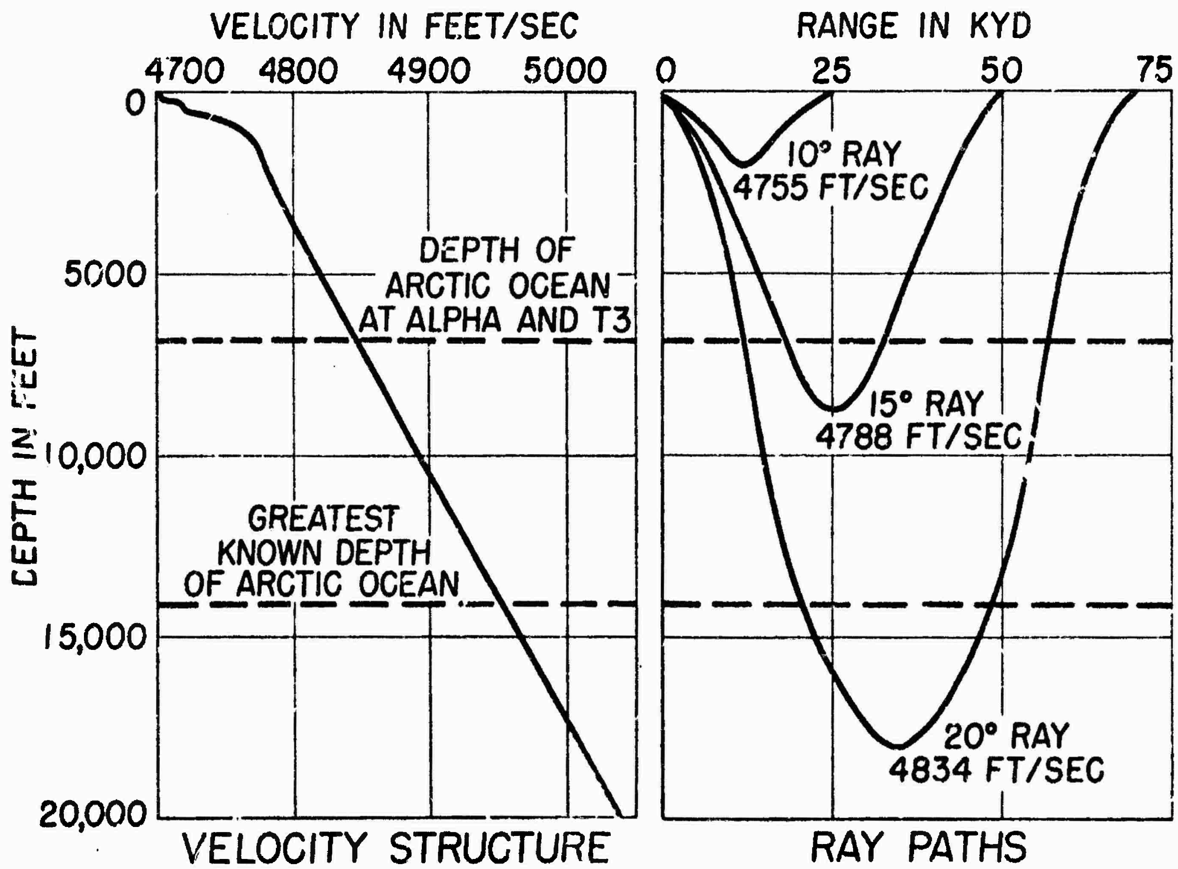

Fig. 4 - Velocity Structure and Computed Ray Paths for Arctic Ocean Summer 1958

The velocity profile of the Arctic Ocean during the summer showed a positive gradient, with no significant variation except near the very top; this variation is thought to be insignificant at frequencies below 100 cycles. The velocity structure presented in Fig. 4 is an average curve of several computed velocity profiles at Alpha and T-3. The ocean was generally about 7000 feet deep at both stations; however, the velocity curve is extrapolated to 20,000 feet for analysis purposes only, using pressure as the only factor affecting velocity. The deepest known point in the western Arctic basin is about 14,000 feet, but bathymetry of the ocean is relatively unexplored.

The loop length and group velocity of rays of various initial angles were computed by the V_x method. When the group velocities of the various rays are compared against the observed velocities, the different modes of transmission can be determined. The number of bounces off the surface range from 31 to 11 for the 10° and 20° rays respectively. In the Arctic Ocean a convergence zone covering about 200 yards in range exists at 12 miles. The initial angles for the rays making up this zone are 9.88° to 10.02°.

SPECTRUM LEVELS

The signals recorded on magnetic tape were processed by playing them back through a logit filter set. The signal from the filter output was rectified and squared using a square law detector and then integrated over the length of the shot. (By spectrum energy flux-density level we mean the integral of the pressure squared over the time divided by the acoustic impedance of the ocean and the bandwidth of the filter.) The calibration signals were replayed through the same system and compared with the signals received from the bombs, thus giving absolute levels. The calibration necessary to evaluate the data at the mean logit filter frequencies of 11.2, 14.1, and 17.8 cps, for which no recorded calibration was available, was obtained in the following manner. A complete calibration of the same type of system, differing only in specific components, was made at the Laboratory and compared with the original calibrations. The difference between the field and laboratory calibration curves was constant, and the new calibration was assumed to hold for the low frequencies. These corrections were applied to the new calibration, and then the 11.2, 14.1, and 17.8 cps frequencies were treated as part of the original calibration. Some of the signals were also processed by reading the peak voltage from the filter output and computing the spectrum energy flux level.[1] The agreement between the two methods was good.

The analysis of twelve shots received during August at station Alpha and fifteen shots received at station T-3 are reported here. These shots are considered to be representative. Of the analyzed shots received at T-3 two were from 2-1/4-lb charges, eight from 55-lb charges, and one from a 330-lb charge, all detonated at station Alpha, and four were from 1/2-lb TNT charges detonated by the USS BURTON ISLAND off the coast of Alaska. Of the analyzed shots received at station Alpha, six were from 2-1/4-lb and six from 55-lb charges, all detonated by station T-3. Signals from fourteen 55-lb , nine 2-1/4-lb charges, and one 330-lb charge

[1] R. W. Hasse, "Some Comments on the Analysis Techniques Used for Analyzing Transient Acoustic Signals," USL Technical Memorandum No. 1170-054-56, 4 January 1957 (CONFIDENTIAL).

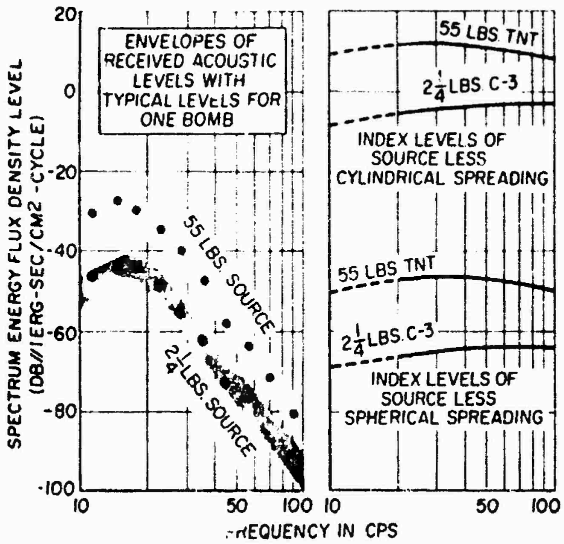

Fig. 5 - Levels of Bombs Received at T-3 and Alpha

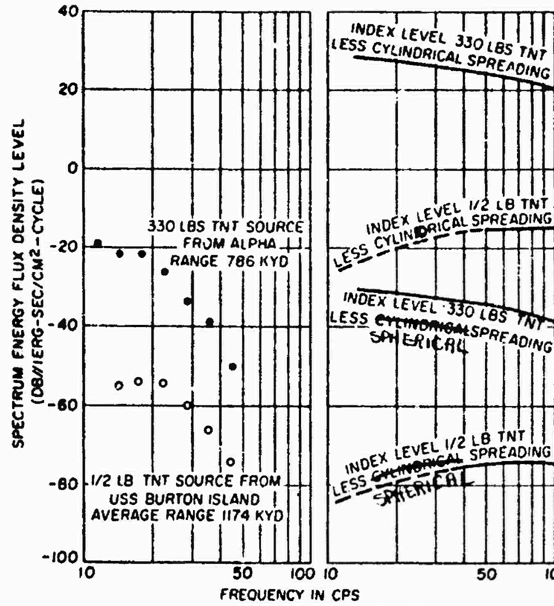

Fig. 6 - Levels of Bombs Received at T-3

were analyzed, the results agreeing fairly well, as shown in Figs. 5 and 6. To the right of the shot levels the index level of each shot minus spherical and cylindrical spreading losses is shown for comparison purposes.

The index level of 2-1/4 pounds of C-3 is that of 3 pounds of TNT given by D. E. Weston.[2] The energy output of C-3 is not known, but it was assumed that its acoustic properties on detonation were in direct relation to its destructive properties.

An interesting aspect of the energy flux density level curves is the apparent peaking between 15 and 20 cycles. However, not too much can be said about the levels below 20 cycles because the record and playback amplifiers both have poor response below 20 cps. The median levels of the 55-lb. charges at 22 cps were -35 db//1 erg sec/cm^2 cycle and of the 2-1/4-lb. charges -47 db//1 erg sec/cm^2 cycle at a range of 790 kyds. These levels correspond to a transmission loss of 100 db for the 2-1/4 lb. charges and 106 db for the 55-lb. charges, at 22 cps. The difference in transmission loss was not reconciled, but we will say 103.5 db is the average loss. It is interesting to note that the energy flux-density level of the 330-lb. charge at T-3 compares with the 55-lb. charges as the cube root of the charge weight.

The median energy flux-density spectrum level at 22 cps of four 1/2 lb. charges of TNT detonated on the USS BURTON ISLAND at an average range of 1174 kyds is -54 db//1 erg sec/cm^2 cycle, as shown in Fig. 6. The range in level is -53 to -54 db//1 erg sec/cm^2 cycle. The index spectrum level of 1/2 lb. TNT at 22 cps is +45 db//1 erg sec/cm^2 cycle. This results in a

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[2] D. E. Weston, "Underwater Explosions as Acoustic Sources," ARL/R20/J, April 1956 (CONFIDENTIAL).

transmission loss of 99 db between the USS BURTON ISLAND off the coast of Alaska and T-3 off Prince Patrick Island. The slope of the spectrum energy flux-density level curve is -17 db per octave.

It appears from the travel times that propagation during the latter part of August was by the 12° ray. By this method of interpretation, the angles of the rays transmitted ranged from 10° to 17° during July and August. Over a range of about 790 kyds, the change of initial angle from 10° to 17° gives a travel time change from 486 sec to 480 sec. Although the total change in travel time is small, it seems justifiable within the accuracy of the data to say that the mode of transmission changed during the summer from initial angles near 17° to those near 10°. It is entirely possible and even quite probable that the larger initial angle rays may undergo one or more bottom reflections.

Assuming the ray most likely to be propagated between Alpha and T-3 to be in the neighborhood of the 12° ray, judging by travel time, we have the ray making 21 bounces off the ice between Alpha and T-3. Assuming spherical spreading for the first 1000 yards and cylindrical spreading thereafter gives about 2/3 db loss per bounce. Although this seems to be a low figure, it must be remembered that the rays being propagated arrive at the ice water interface at more than twice the critical angle where the index of refraction is about 1/2.

Above 30 cps the slope of the energy flux density spectrum curve is -24 db per octave for the 55-lb. charges and -20 db per octave for the 2-1/4-lb. charges. The slope of the spectrum curve shows the strong filter effect of the Arctic Ocean. In comparison, Bermuda area data taken in November 1958 between Bermuda and Eleuthera using 2-1/2-lb. TNT charges show a spectrum slope of -4 db per octave between 40 and 300 cycles. The most notable difference in the environments is the harmonic reflecting surface that the ice presents to the acoustic waves. According to Miles,[3] such a reflector acts as a band rejection filter, which in this case can be considered a low-pass filter, where the longest wavelength or lowest frequency attenuated for the sinusoidal case is $1 - \sin\theta$ times the wavelength of a corrugation, where θ is the angle of incidence. For example, if we take the wavelength of the sinusoidal ice surface to be 180 feet, then the greatest wavelength attenuated at the angle of incidence of 70° is 349 feet or 13.6 cycles. However, we know that the ice surface is only approximately sinusoidal and probably could be represented more exactly as a compound harmonic surface. This has not yet been attempted.

The ambient noise of the Arctic Ocean was found to be generally low (of the order of zero-sea-state broadband) except when there were high winds and ice movement.

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[3] J. W. Miles, "On Non-specular Reflection at a Rough Surface," Journal of the Acoustical Society of America, vol. 26, no. 2, March 1954.

[redacted]

RECORD AND PLAYBACK SYSTEM ANALYSIS

The responses of the record and playback systems were studied between 10 and 150 cps. Figure 7 is a plot of the overload level versus frequency of a system similar to the one used in experiment. Overload level is deter-

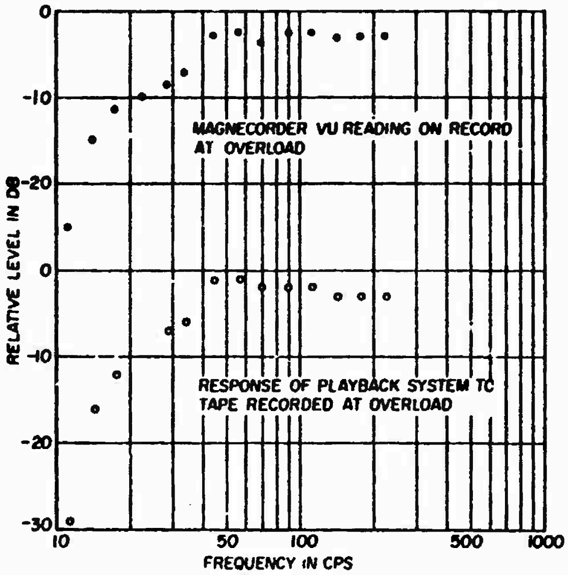

Fig. 7 - Overload Characterics of Record System and Response of Playback System to Tape Recorded at Overload

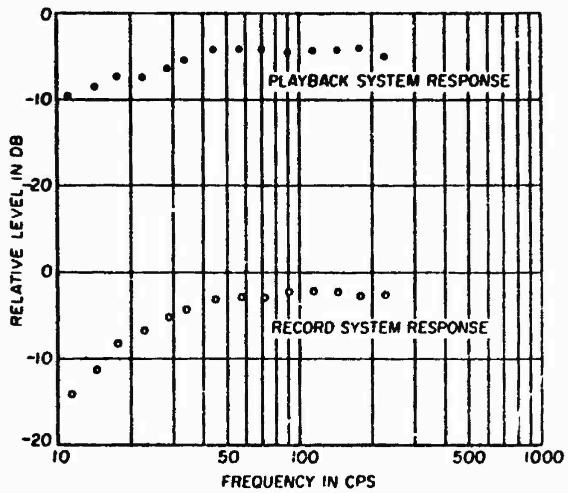

Fig. 8 - Response of Record and Playback System

mined by the visual observation of deformation of a sine wave on an oscilloscope. The estimate of accuracy is ± 1 db.

From Fig. 7 it is apparent that signals recorded near the overload point of the record system would be fairly well reproduced in the playback system. In an experiment, an 11-cps signal was used to calibrate a similar record system at a level of 0 VU on the Magnecorder. The tape was then analyzed on the Western Electric 3A-4A Sound Frequency Analyzer. The third harmonic was found to be only 9 db lower than the fundamental. The fifth harmonic was masked by the 60-cps power frequency inherent in the system and the seventh harmonic did not appear. The frequency response of the playback and record systems at constant inputs below overload is shown in Fig. 8.

[redacted]

CONCLUSIONS

The following conclusions can be drawn from the data analyzed up to this time:

a. The transmission loss between Alpha and T-3, a distance of 790 kyds, is 103.5 db at 22 cps.

b. A spectrum analysis of bomb shots received at a distance of 790 kyds shows a strong filtering action in the Arctic Ocean which may possibly be attributed to the roughness of the undersurface of the ice.

c. The group velocity of sound transmission appears to vary with the season.

d. The velocity profile of the Arctic Ocean changes very little throughout the summer except near the very top.

Thus, sound transmission in the Arctic Ocean at a range of 790 kyds can be described with our present knowledge, as neither poor nor exceptional at 22 cps; above 22 cps the filter action of the Arctic ice canopy becomes increasingly severe until at 100 cps virtually no usable signal-to-noise remains.