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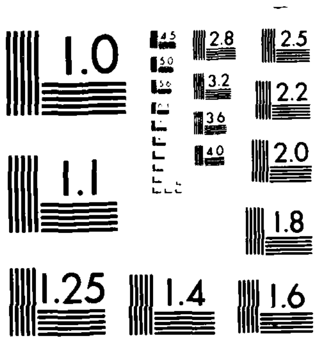

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Monterey, California

THESIS

DEVELOPMENT OF A MODIFIED TIME DELAY SPECTROMETRY TECHNIQUE FOR UNDERWATER ACOUSTIC MEASUREMENTS IN A MULTIPATH ENVIRONMENT

by

Bjoern Brekke

December 1984

Thesis Advisors: O. B. Wilson, Jr.
J. P. Powers

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A measurement technique has been developed which makes possible the determination of the acoustic transmission loss for various paths between a source and a receiver at relatively short ranges in the ocean. The method is based upon a technique called Time Delay Spectrometry (TDS). The theory for utilizing TDS to perform measurements on an underwater test range with

20(cont.). a homogeneous water column is presented. The experimental parameters concerning test geometry together with criteria for the source signal are discussed and the limitations are described. A computer program written in HP BASIC is the tool in a multipath measurement system where analog sound signals recorded on tape are processed by an HP 3561A Dynamic Signal Analyzer.

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Development of a Modified Time Delay Spectrometry Technique for Underwater Acoustic Measurements in a Multipath Environment

by

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Commander, Royal Norwegian Navy
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Submitted in partial fulfillment of the requirements for the degree of

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from the

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December 1984

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ABSTRACT

A measurement technique has been developed which makes possible the determination of the acoustic transmission loss for various paths between a source and a receiver at relatively short ranges in the ocean. The method is based upon a technique called Time Delay Spectrometry (TDS). The theory for utilizing TDS to perform measurements on an underwater test range with a homogeneous water column is presented. The experimental parameters concerning test geometry together with criteria for the source signal are discussed and the limitations are described. A computer program written in HP BASIC is the tool in a multipath measurement system where analog sound signals recorded on tape are processed by an HP 3561A Dynamic Signal Analyzer under program control.

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I. INTRODUCTION

A. BACKGROUND

The Naval Undersea Warfare Engineering Station (NUWES) in Keyport, Washington, has since 1969 been operating a system called T-NAAS (Torpedo Noise Acquisition and Analysis System). This system has later been upgraded and today is called the Noise Recording System (NRS). It is used to measure torpedo radiated noise in the frequency range of 50 Hz to 20 kHz and the results have been used to establish torpedo radiated noise baseline levels, to evaluate noise reduction attempts, and to derive a torpedo radiated noise-proofing criterion and to study parameters affecting torpedo noise. These measurements are now carried out on a routine basis.

The empirical transmission loss model that is currently being used for short range acoustic propagation is based on limited empirical data, but seems to work satisfactorily under normal operating conditions. However, it is possible under unusually rough surface conditions or when a directional acoustic array (Bottom Mounted Array (BMA)) is used that this model would be inappropriate thus leading to unknown errors. Both experimental and theoretical studies have been done over the past years by other students and faculty at NPS to improve the acoustic transmission loss model. Initial experiments performed in Dabob Bay by LT. Elsen and Prof. Wilson showed that at short to moderate ranges the contributions to the signal received by an omnidirectional hydrophone from the bottom and surface reflected paths were a significant fraction of the direct signal level. They also pointed out that if an array were to be used instead of an omnidirectional hydrophone some additional changes to the transmission loss model should be made. Theoretical studies presented by LT. Ward in his thesis (1980) include the development of a computer model which calculates the interference effect in the acoustic pressure sensed by an omnidirectional hydrophone due to multipath propagation. This model, however, has not yet been verified experimentally.

The latest developments in FFT-based dynamic signal analyzers now make it possible to design experiments or routine measurements where multipath propagation effects on the test range may be studied or easily measured and accounted for.

B. SCOPE OF THESIS

In 1967, Richard C. Heyser presented a paper, "Acoustical Measurements by Time Delay Spectrometry" [Ref. 1], describing a new acoustical measurement technique which would "provide a solution for the conflicting requirements of anechoic spectral measurements in the presence of a reverberant environment." He describes the technique, which uses commercially available instruments, where the transmitted signal is a linear swept tone (or Linear Frequency Modulated (LFM) pulse) with constant amplitude. This forcing function, which linearly relates frequency with time, provides the wanted spatial discrimination of different path lengths when the received signal is analyzed by a frequency-tracking analyzer which can be offset in order to "focus" in on the desired path.

Time delay spectrometry (hereafter called TDS) has since been used successfully in areas such as investigation of regenerative sound systems (i.e., probing of the sound pressure field in rooms), free field calibration of microphones in ordinary rooms, calibration and performance evaluation of miniature ultrasonic hydrophones, and attenuation and velocity measurements in tissue as a function of frequency. However, so far as we have been able to determine, nothing has been done in applying this technique in the area of underwater acoustics.

It is the scope of this thesis to use the concept of TDS as the foundation to develop a multipath measurement system which can be applied at the Naval Undersea Warfare Engineering Station (NUWES) test ranges and which could lead to a more accurate computer-controlled model for transmission loss as a function of frequency. In order to accomplish this, the following objectives were set:

(1) Identify a technique for resolving the direct and reflected components of a sound signal received by a hydrophone from a distant source.

(2) Develop the theory and experimental parameters for applying this technique to measurements on NUWES test ranges.

(3) Develop techniques for processing the received signal. This includes identifying suitable hardware and generating necessary software to enable processing of the acquired data.

(4) Verify the technique and processing capabilities that have been developed by using selected data that have been acquired by NUWES during range testing.

NUWES operates several ranges for underwater measurements. Of special interest are the two 3-D tracking ranges, one at Nanoose located in the Straits of Georgia, British Columbia, Canada, and the other, the Dabob Bay range located off the Hood Canal in the state of Washington. Even though the test data that have been used to develop the TDS model was obtained in Dabob Bay, it will be shown that geometrical and environmental parameters are an integrated part of the model and hence it is not tailored to the specific conditions of one particular range.

Another governing factor has been that hardware required for this analysis be compatible with and the software be readily transferable to existing NUWES analysis systems.

The above list provides a logical description of the problem and will be the sequence in which the subjects are treated in this thesis

II. THE MEASUREMENT TECHNIQUE

The "classical" TDS technique as described by Heyser in Ref.1 is based on the use of a sweeping heterodyne analyzer. The same is true for the more specialized implementation in the Bruel and Kjaer Time Delay Spectrometry System Type 9950. In Ref.11, P.A. Levin describes a calibration and performance evaluation system in which a sweeping heterodyne analyzer, Hewlett Packard Model 3585A, with a built in frequency offset unit was used. Common characteristics of these systems are that they provide excellent real time measurement results. However, the systems are either too specialized (B&K Type 9950) or the analyzer becomes too expensive to be cost effective for range tests. Furthermore, implementation of a real time measurement system would involve synchonization problems of the source and the tracking filter in the spectrum analyzer.

For this type of analysis, it is desirable to record the data on magnetic tape during range tests and subsequently perform the analysis on the recorded data in a shorebased facility. This analysis method requires a less specilized (and cheaper) analyzer and the sychronization problem is avoided as will be shown. In addition, the test may be reproduced at any later time when required. This modified TDS technique requires that a Dynamic Signal Analyzer be used to process the input (recorded) signal. Dynamic Signal Analyzers are based on a high speed calculation routine which acts like a parallel filter analyzer with hundreds of filters that are connected to the input signal all the time. These analyzers are fast, but have a limited resolution as will be shown later.

A. DEVELOPMENT OF THE THEORY

The analytical verification of this modified TDS technique is based on the work done by Heyser [Ref.1] and also parts of the theoretical verification of B & K TDS System Type 9950 [Ref.2 and 3]. In this attempt to bring the TDS technique to sea, it will be necessary to state the assumptions that are inherent in this linear systems approach. Also the nature of the repetitive LFM (Linear Frequency Modulated) pulse must be analyzed and finally the validity of identifying the dynamic signal analyzer display with the acoustic spectrum will be discussed.

1. Assumptions

In the modified TDS technique, we consider the propagation of small amplitude acoustic signals in the ocean which can be described bu the linear, inhomogeneous wave equation. Since the wave equation for small amplitude acoustic signals is linear, we can represent the ocean medium as a linear filter. Furthermore, we assume that there is no relative motion between source and receiver during a measurement period and that the water column in homogeneous (i.e., isospeed conditions exist).

2. The Excitation Signal

The excitation signal used in the TDS technique has the characteristic shown in Fig.2.1. It is a linear sweep with constant amplitude over a period of T seconds and then repeats this cycle indefinitely. For convenience, the amplitude can be set equal to unity.

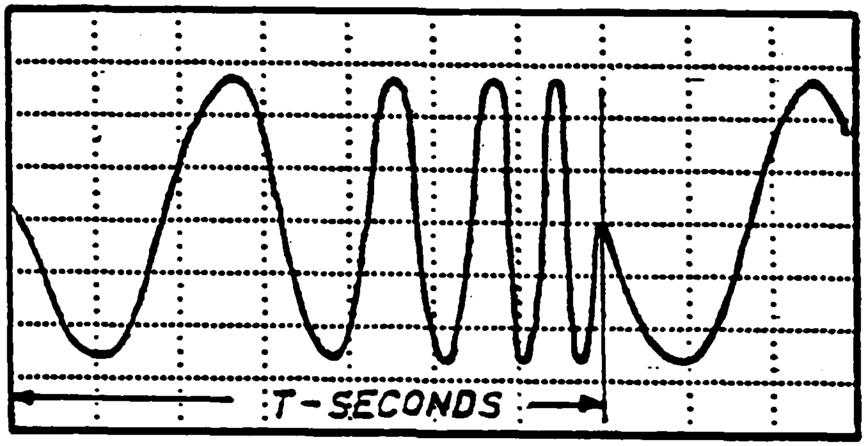


FIG.2.1 THE EXCITATION SIGNAL

Let F be the frequency range starting at f_1 at time t=0 and stopping at f_2 at time t=T, thus the frequency range is $F = f_2 - f_1$. The corresponding angular frequency range or angular dispersion is $D = \omega_2 - \omega_1$. We define the carrier frequency as $f_c = (f_1 + f_2)/2$ or the angular carrier frequency, $\omega_c = (\omega_1 + \omega_2)/2$. The excitation signal may now be written as:

$$X(t) = \cos\,[\phi(t)] = \cos\left[\left[\frac{\pi F}{T}\right]t^2 + 2\pi f_c t\right] \qquad (2.1)$$

The instantaneous frequency f_i is defined as the time derivative of the phase $\phi(t)$:

$$f_i = \frac{1}{2\pi}\frac{d\phi}{dt} = \left[\frac{F}{T}\right]t + f_c \tag{2.2}$$

Note that the constant $\pi F/T$ (or D/2T when angular frequency is used) is often referred to as the phase deviation constant or modulation index. In TDS, the value of the modulation index is normally very large. The sweep rate S is the time derivative of f_i, which upon differentiation yields:

$$S = \frac{df_i}{dt} = \frac{F}{T} \tag{2.3}$$

From Eq. (2.3) it is seen that the sweep rate S is constant and that the instantaneous frequency varies linearly with time. It must be noted that the instaneous frequency f_i is a time domain description of the signal and is not a frequency in the Fourier sense.

In order to study the spectrum of the excitation signal, we first rewrite the signal:

$$X(t) = \frac{1}{2}\left[e^{i\Phi(t)} + e^{-i\Phi(t)}\right]. \tag{2.4}$$

In terms of the angular frequency, the phase $\phi(t)$ is

$$\phi(t) = \left[\frac{D}{2T}\right] t^2 + \omega_c t.$$

In Eq. 2.4, each complex exponential is separable into the product of a steady-state term and a term periodic in T. Hence it is sufficient to expand only the periodic term in a Fourier series. Considering first only positive frequencies:

$$e^{i(D/2T)t^2} = \sum_{n = -\infty}^{\infty} c_n e^{in\omega_o t} \qquad (2.5)$$

$$c_n = \frac{1}{T} \int_{-T/2}^{T/2} e^{i(D/2T)t^2} * e^{-in\omega_o t}\, dt \qquad (2.6)$$

where $\omega_o = 2\pi/T.$

Equation 2.6 can be written as

$$c_n = \frac{1}{T} \int_{-T/2}^{T/2} e^{i[(D/2T)t^2 - n\omega_o t]}\, dt.$$

Completing the square in the exponent, A, gives

$$A = \left[\left[\frac{D}{2T}\right]^{1/2} t\right]^2 - n\omega_o t + \left[\frac{T}{2D}\right](n\omega_o)^2 - \left[\frac{T}{2D}\right](n\omega_o)^2$$

This can be put in the form

$$A = \left\{\left[\frac{D}{2T}\right]^{1/2} \left[t - \left[\frac{T}{D}\right] n\omega_o\right]\right\}^2 - \left[\frac{T}{D}\right](n\omega_o)^2$$

Substituting the expression for the exponent, A, gives

$$C_n = \frac{1}{T} \quad e^{-i(T/2D)(n\omega_o)^2} \int_{-T/2}^{T/2} e^{i\{(D/2T)^{1/2}[t - (T/D)(n\omega_o)]\}^2} dt \qquad (2.7)$$

and changing the variables where

$$X = \left[\frac{D}{2T}\right]^{1/2} \left[t - \left[\frac{T}{D}\right](n\omega_o)\right] \quad \text{and} \quad dx = \left[\frac{D}{2T}\right]^{1/2} dt,$$

we can write the Fourier coefficient after multiplying and dividing by $(2/\pi)^{1/2}$ as:

$$C_n = \left[\frac{1}{T}\right] \left[\frac{\pi T}{D}\right]^{1/2} e^{-i(T/2D)(n\omega_o)^2} \left[\left[\frac{2}{\pi}\right]^{1/2} \int_{-T/2}^{T/2} e^{ix^2} dx\right]. \qquad (2.8)$$

Recalling that the instantaneous angular frequency is given by:

$$\omega_i = \left[\frac{D}{T}\right] t + \omega_c \quad \text{or} \quad t = (\omega_i - \omega_c)\frac{T}{D},$$

By solving for t and substituting this into the expression for x, Eq. (2.8) can be put in the final form:

$$C_n = \left[\frac{1}{T}\right]\left[\frac{\pi T}{D}\right]^{1/2} e^{-i(T/2D)(n\omega_o)^2}\left[\left[\frac{2}{\pi}\right]^{1/2}\int_0^{\omega_o} e^{ix^2}\,dx - \left[\frac{2}{\pi}\right]^{1/2}\int_0^{\omega_2} e^{ix^2}\,dx\right], \quad (2.9)$$

where

$$x = \left[\frac{T}{2D}\right]^{1/2}[\omega_i - (\omega_c + n\omega_o)].$$

Each of the two integrals in brackets consists of the Fresnel cosine integral C(u) and sine integral S(u)

$$\left[\frac{2}{\pi}\right]^{1/2}\int_0^{u} e^{ix^2}\,dx = C(u) + i\,S(u). \quad (2.10)$$

The Fresnel cosine and sine integrals are tabulated in Ref.12 and their behavior is shown in Fig.2.2. Using this result and noting that the argument changes sign in the second integral, we can write the Fourier coefficients as:

$$C_n = \left[\frac{1}{T}\right]\left[\frac{\pi T}{D}\right]^{1/2} e^{-i(T/2D)(n\omega_o)^2}\left\{C(\omega_1) + C(\omega_2) + i[S(\omega_1) + S(\omega_2)]\right\}. \quad (2.11)$$

Fig.2.3 shows how to calculate the n'th coefficient. The Cn's as given by Eq. (2.11) are the side band terms and consist of the product of the quanized spectrum of a continuous swept LFM pulse and a complex Fresnel modifying term which involves the finite frequency limits. The spectrum is symmetrical about the effective carrier and even though there is an overshoot at the band edge, the ripple rapidly approaches zero as the angular frequency is increased. These ripples are not distinguishable to the spectrum analyzer as they are smoothed by the appropriate filter bandwidths and temporal weighting window. This means that the distribution is effectively that of a constant amplitude continuum which is desired in TDS.

The previous derivation has revealed several important properties of the forcing function used in TDS. These properties may be summarized as follows:

- The spectrum is quite well behaved for all modulation indexes (D/2T).
- At the band edges (ω_1 or ω_2) the spectrum level is down 6 dB and falls off beyond.
- Expansion of the negative frequencies yields a similar symmetric spectrum. This ensures that the modulation we are using is valid for TDS even if the sweep goes through zero beat.

2. Response of the Dynamic Signal Analyzer

The signal received by a hydrophone when a linear sweep is being used to excite the ocean medium consists of multiple time-delayed

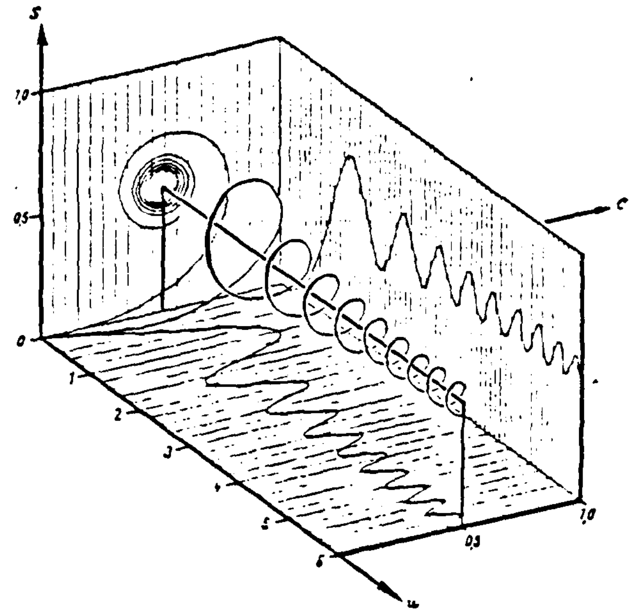


FIG.2.2 THE FRESNEL INTEGRALS, C(u) AND S(u)

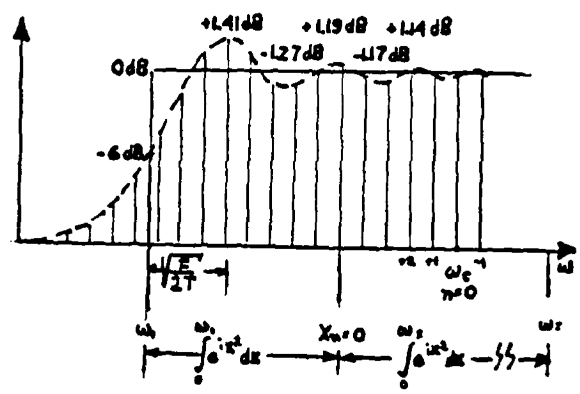


FIG.2.3 METHOD TO CALCULATE THE COEFFICIENTS Cn

responses. In the modified TDS technique the entire signal from the hydrophone is sent to and recorded on magnetic tape as an analog signal. This signal is then in turn analyzed by the Dynamic Signal Analyzer.

Heyser [Ref.1] shows that (in air) any delayed response may be selected by properly adjusting the frequency offset of the analyzer used to process the transmitted LFM pulse. In the modified TDS technique, however, the effect of a frequency offset is obtained by using a trigger which is sent to the analyzer, but which is delayed with respect to the start of the linear swept tone. (Recall that the sweep rate S is the conversion factor.) In deriving the expression for the output of the demodulator in a swept analyzer, Heyser [Ref.1] shows that the proper spectrum is being displayed and that the result is also valid for repetitive sweeps. Furthermore, the spectrum is not only preserved in amplitude but also in phase.

B. EXPERIMENTAL PARAMETERS

When applying the modified TDS technique to measurements in the ocean it must be recalled that we are considering multipath propagation over relatively short distances, i.e., less that 1000 yds (approximately 900 m). As a first approximation the sound speed profile is considered to be isovelocity throughout the water column and the rays will therefore travel in straight paths. The surface and bottom boundaries are considered to be perfectly reflecting surfaces.

Before making measurements on the range, both geometrical and environmental parameters need to be accounted for in order to measure the effects of multiple paths between source and receiver. The a priori knowledge about range geometry and environment will be used in TDS to determine the test geometry when planning measurements, and subsequently to identify the analysis results. As a tool it is therefore necessary to develop a simple multipath model to describe the time delays caused by different path lengths. These results will be used later when criteria for the source signal are derived.

1. Geometrical Considerations

The simple multipath geometry is shown in Fig.2.4. Following the developments of Albers [Ref.13, p.49] it can easily be shown that the reflected signals travelling the extra distances from their "image sources" will reach the receiver at a time later than does the direct path sound.

From the geometry of Fig.2.4 it is seen that the expressions for the direct path (XR), the surface reflected path (XSR), and the bottom reflected path (XBR) are given by:

$$XR = [R^2 + (ZR - ZS)^2]^{1/2} \qquad (2.12)$$

$$XSR = [R^2 + (ZR + ZS)^2]^{1/2} \qquad (2.13)$$

$$XBR = [R^2 + (2H - ZR - ZS)^2]^{1/2} \qquad (2.14)$$

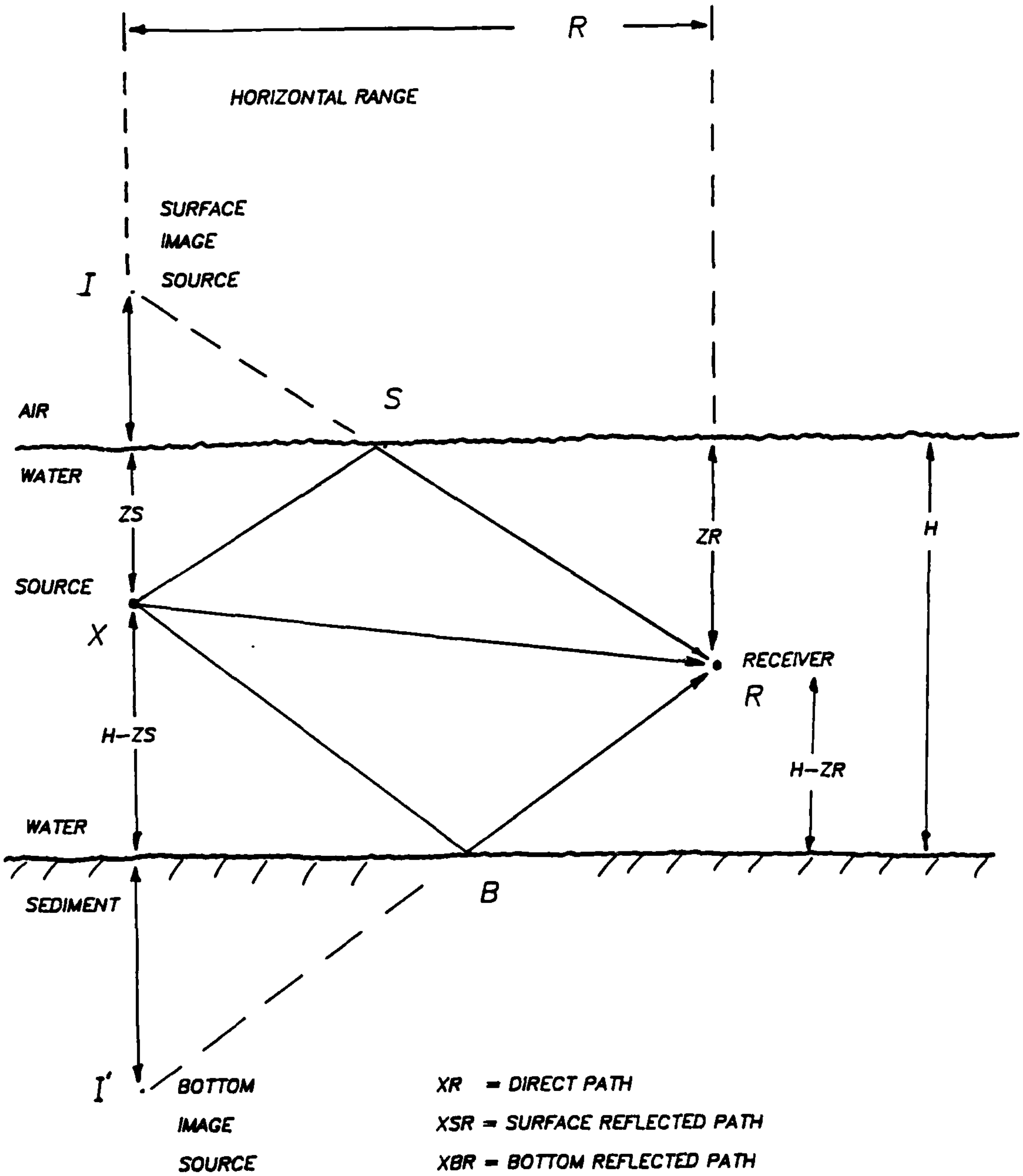


FIG.2.4 SIMPLE MULTIPATH GEOMETRY

If the range is given in yards and the depth is in feet, then the last term in Eqs. (2.12) to (2.14) must be divided by three. The travel time for each path is now found by simply dividing by the speed of sound, c. Furthermore, the time delays between the reflected and direct path are given by:

$$\text{Surface reflected time delay:} \quad t\_s = \frac{XSR-XR}{c} \tag{2.15}$$

$$\text{Bottom reflected time delay:} \quad t\_b = \frac{XBR-XR}{c} \tag{2.16}$$

and finally the delay between the reflected paths:

$$\text{Inter reflected time delay:} \quad t\_r = \frac{XSR-XBR}{c} \tag{2.17}$$

Typical values for arrival times and time delays for a sound speed of 4850 ft/sec (or 1478 m/s) are listed in Tables. I - X in Appendix A on page 77. The values are calculated for a fixed range and receiver depth of 300 feet (91 m) when the source is varied in depth from 50 to 550 feet (15 - 168 m).

2. <u>Environmental Considerations</u>

Oceanographic and acoustic characteristics of both Dabob Bay and Nanoose 3-D test ranges are well documented in Ref.10 and Ref.14. In the TDS multipath model the ultimate goal is to measure transmission loss as a function of frequency for <u>short range propagation</u> Also the contribution from reflected paths will be measured. Data used in this thesis to develop the computer controlled multipath model was taken in Dabob Bay. The areal extent of the range within Dabob Bay basin is shown in Fig.2.5 and the contour of the basin in the measurement area (at the 8000 yard station) is shown in Fig.2.6.

In order to predict arrival times when planning an experiment, information about the sound speed profiles are contained in the previous references. For Dabob Bay five typical profile envelopes have been adopted after an oceanographic data study spanning the years 1971 through 1975. The probability of occurrence for each profile type during a year is shown in Fig.2.7. Due to the lack of the actual sound speed profile for the measurements performed in September 1982, a sound speed profile (envelope) type 4 as shown in Fig.2.11 has been used in the TDS multipath model.

a. Effects of Refraction

As shown in Fig.2.9 - 2.12, there might exist a strong negative gradient above approximately 100 ft (30 m). Only during the winter months, as expected, does one find a positive gradient in the upper layer as shown in Fig.2.8. Another characteristic feature is the positive gradient below 300 ft (91 m) as shown in Fig.2.9, which is most likely to occur during April and May but can also occur in late March or early June.

The assumption about isovelocity conditions was required for the simple multipath geometry and calculation of expected time delays in particular. In TDS it is necessary that a sufficient time delay exist between direct and reflected paths and eventually between reflected paths if the source and receiver are not at the same depth. A quantitative measure of the required time delay will be derived later. In particular, it will be shown that under given conditions the

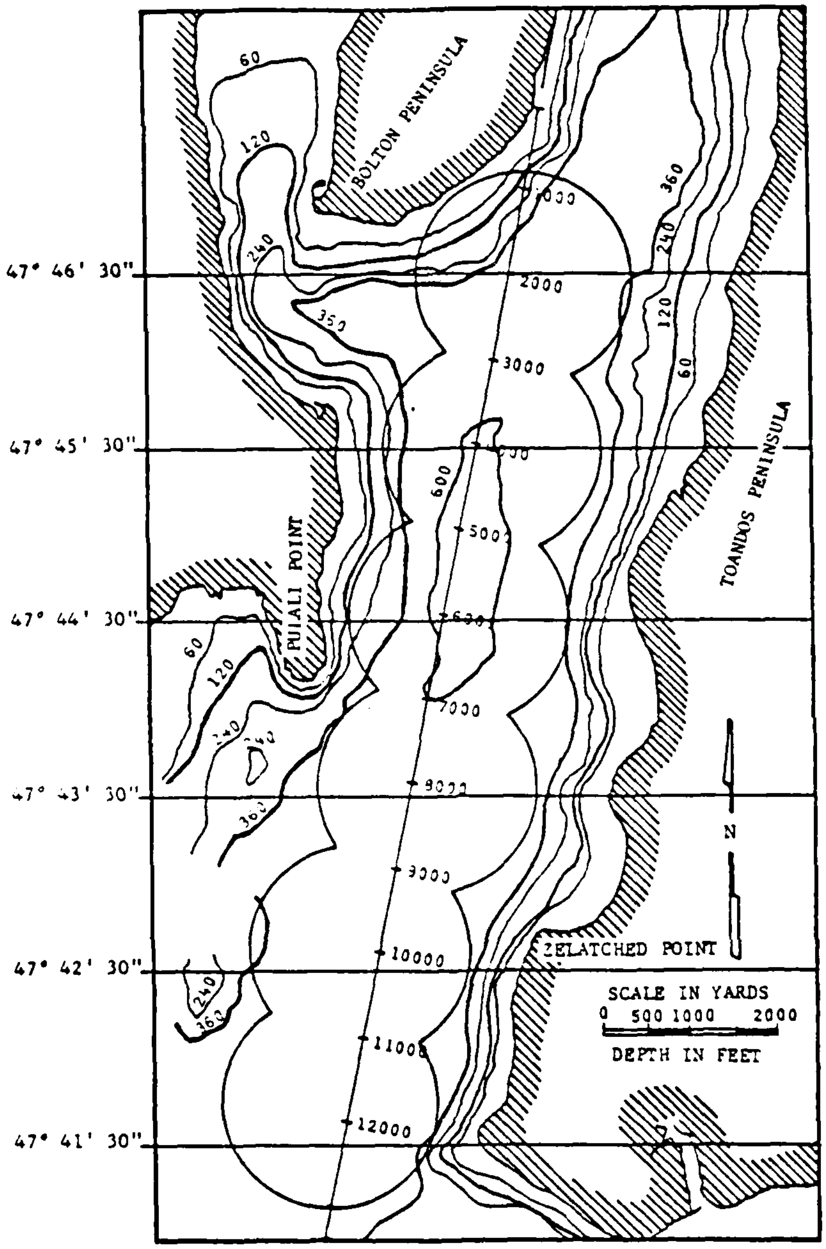


FIG.2.5 MAP OF THE ACOUSTIC RANGE AT DABOB BAY [REF.10]

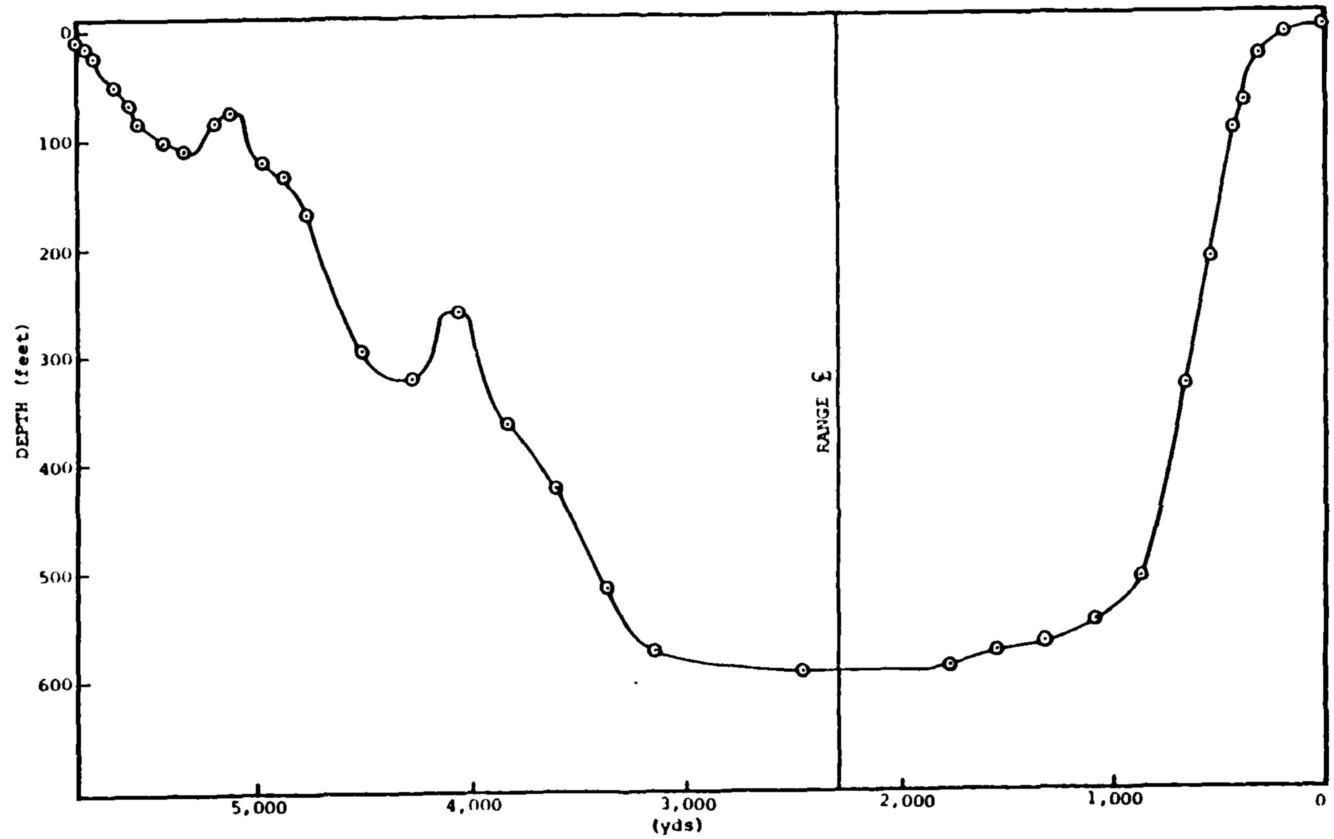


FIG.2.6 DEPTH CONTOUR (AT 47°43'30") [REF.10]

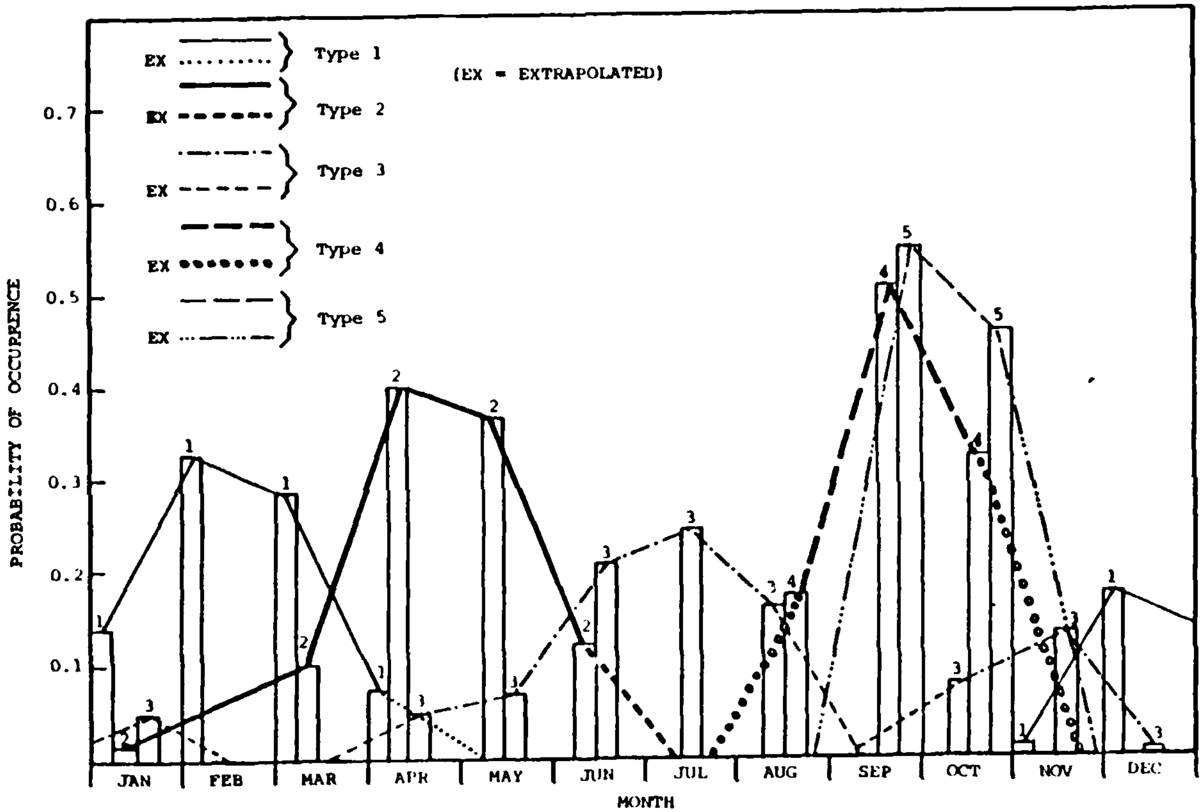


FIG.2.7 PROBABILITY OF OCCURRENCE FOR EACH PROFILE TYPE [REF.10]

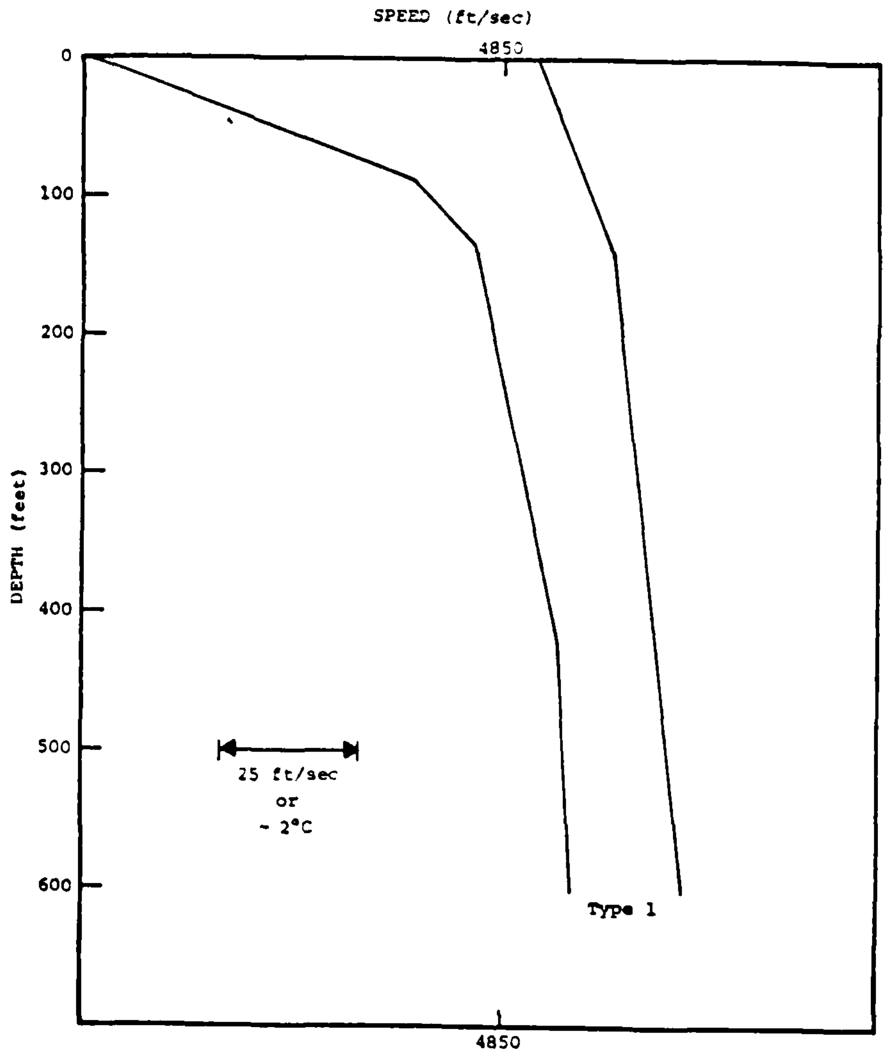


FIG.2.8 SOUND SPEED PROFILE (ENVELOPE TYPE 1) [REF.10]

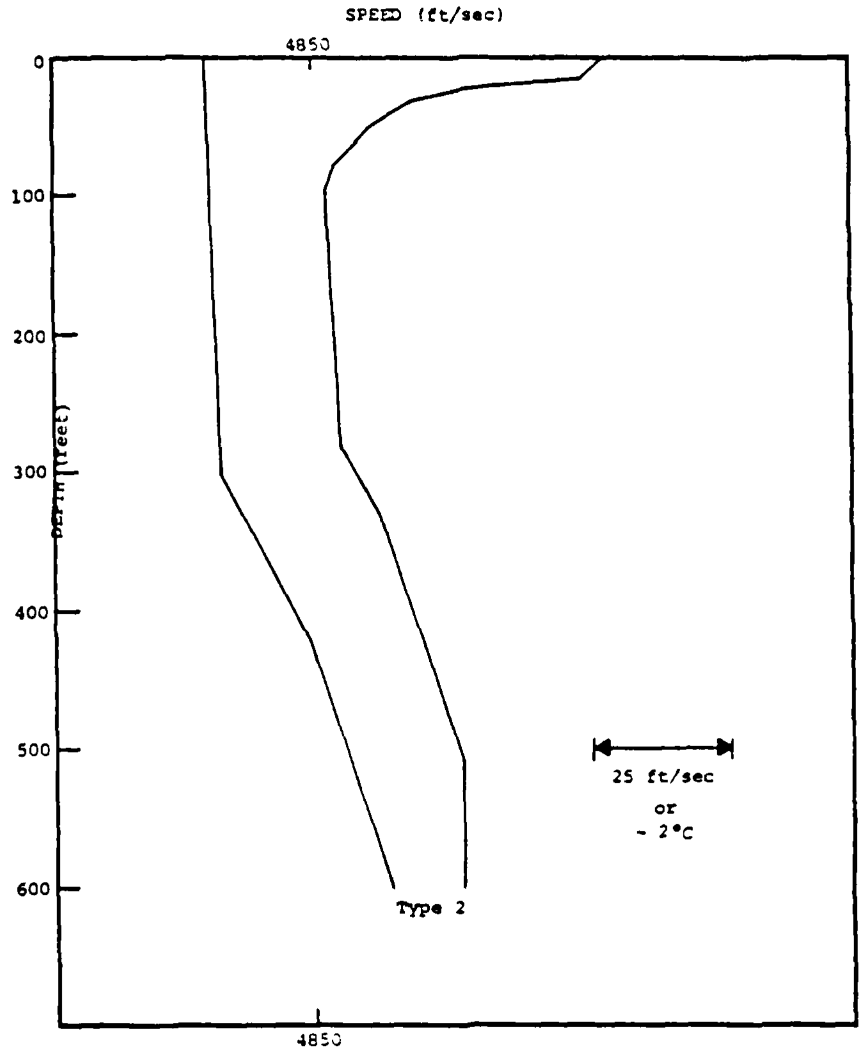


FIG.2.9 SOUND SPEED PROFILE (ENVELOPE TYPE 2) [REF.10]

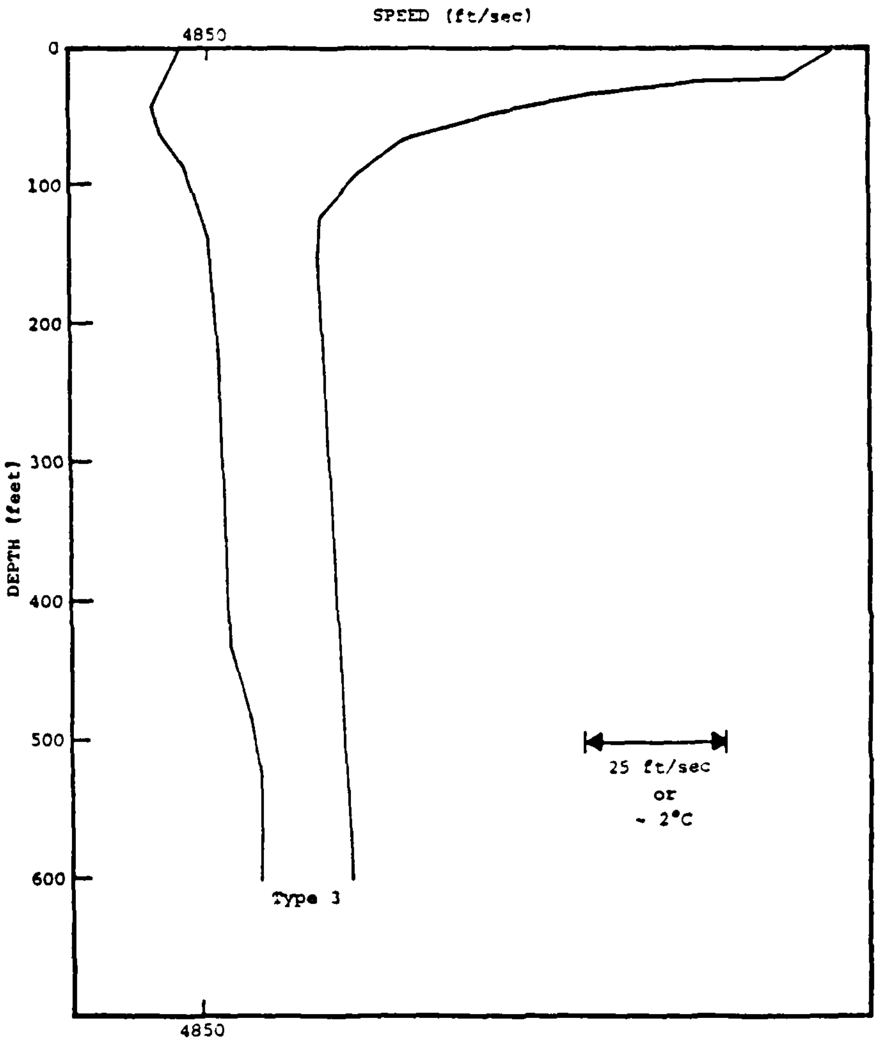


FIG.2.10 SOUND SPEED PROFILE (ENVELOPE TYPE 3) [REF.10]

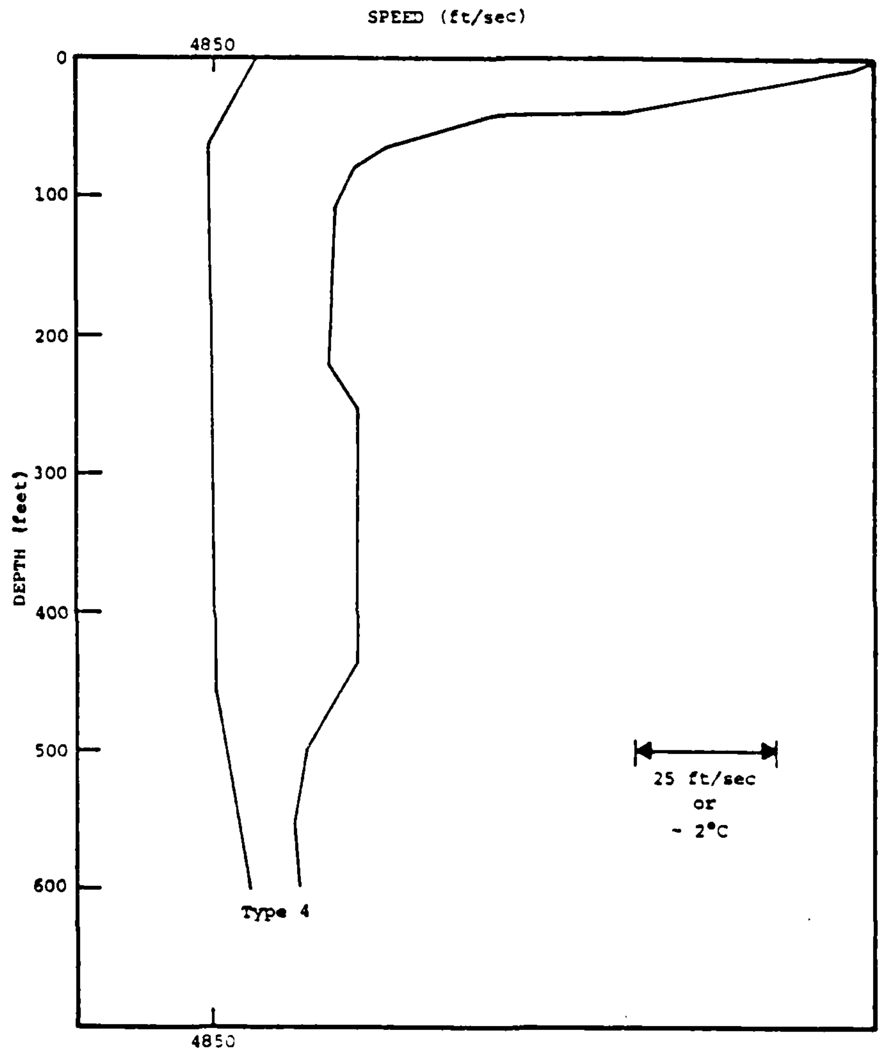


FIG.2.11 SOUND SPEED PROFILE (ENVELOPE TYPE 4) [REF.10]

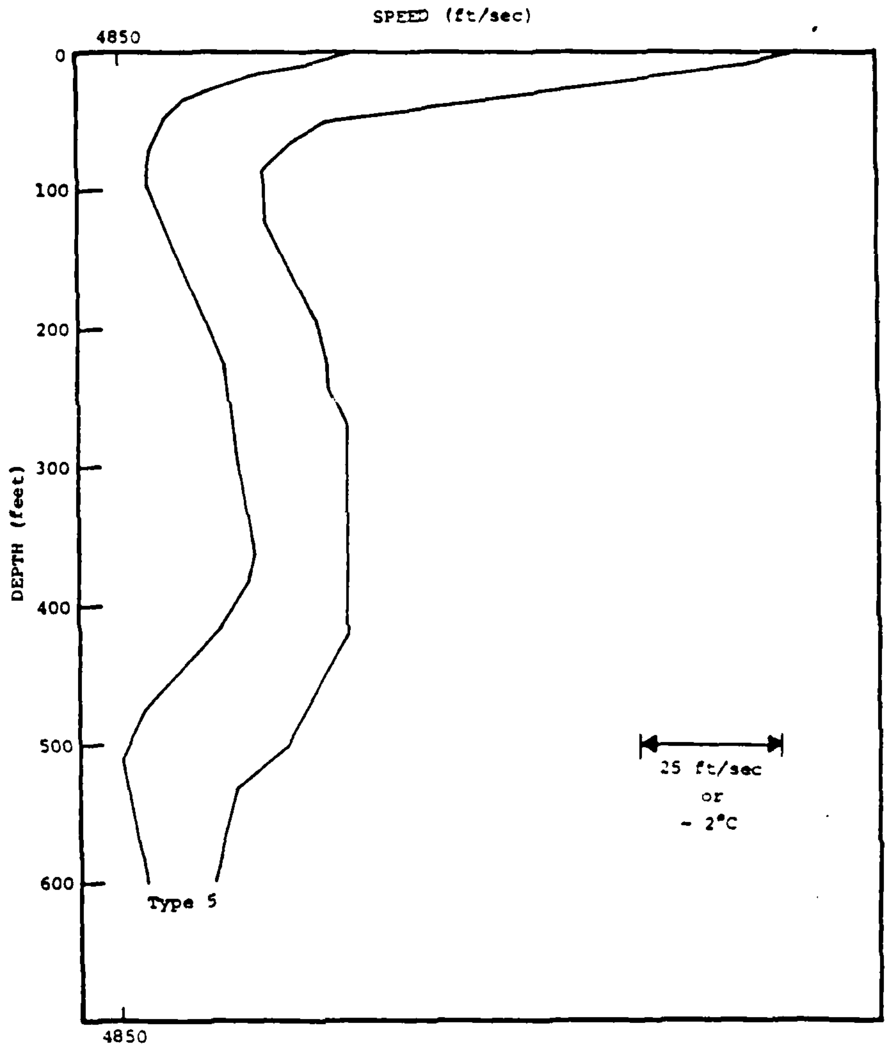


FIG.2.12 SOUND SPEED PROFILE (ENVELOPE TYPE 5) [REF.10]

the measurement range is less than 500 - 600 yds (457 - 549 m). From Fig.2.11 it is seen that a worst case situation will exist if both source and receiver are located at 100 ft (30 m). The sound speed profile and ray diagram are shown in Fig.2.13. The negative gradient above 100 ft (30 m) is:

$$g = (4870 - 4965)/100 = -0.95 \ s^{-1}$$

and the horizontal range travelled by the surface refracted ray is given by [Ref.6]:

$$x = 2\Delta x = 2[2\ (c_o/g)\Delta z]^{1/2} = 2[2\ (4965/0.95) * 100]^{1/2} = 2045 \text{ ft},$$

or $x = 681$ yds (623 m).

As shown the surface refracted ray(s) should not interfere with measurement of the direct path as long as the horizontal separation between source and receiver is kept below 600 yds (549 m).

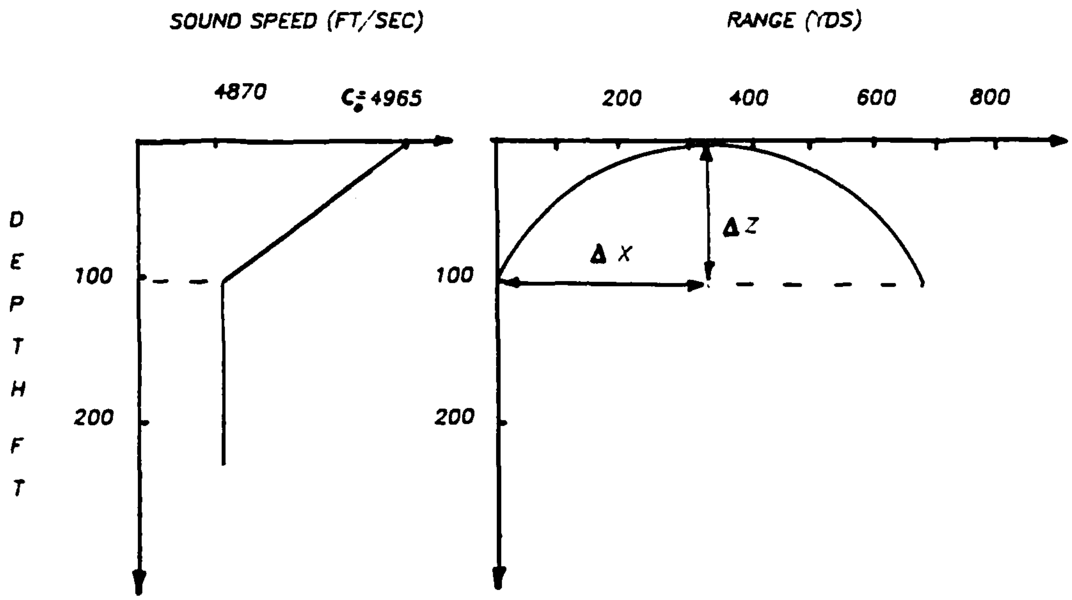


FIG.2.13 SURFACE REFRACTED RAY PATH

III. TDS MULTIPATH MEASUREMENT SYSTEM

In the previous chapter, the LFM pulse with constant amplitude was analyzed and it was shown theoretically that a well behaved spectrum is to be expected and that this spectrum will be correctly measured by a dynamic signal analyzer. The test geometry is important and full advantage can be taken to minimize the effect of unknown parameters by choosing an optimum test area location. The Dabob Bay range has been used in the previous discussion due to the availability of data; however, there are no requirements inherent in the theory that prevents measurements being done at other 3-D test ranges.

The TDS multipath measurement system is characterized by the following subsystems:

- Range and test configuration
- Data processing system

The range and test configuration that is described here have been developed by Mr. John G. Burwell of the Acoustics Division at NUWES, Keyport, and was used during previous TDS measurements. The data processing system consists of both hardware and software required to extract the desired measurement results. The parameters that need to be considered in order to resolve the different paths are directly related to the hardware used to process the data. As a consequence, a description of the experimental setup and the procedure to determine the test parameters will be given. Finally, a complete documentation of the software is presented.

A. RANGE AND TEST CONFIGURATION

Data recorded for this study were obtained with the Noise Recording System (NRS) used by NUWES in routine radiated noise measurements. It consists of three calibrated omnidirectional hydrophones suspended from a surface platform and associated recording instrumentation. The sound source was a projector (Type F-56) suspended from another platform. The location in Dabob Bay was near the 8000 yards (appr. 7300 m) station. The range and test configuration is shown in Fig.3.1. Since the primary objective in these tests was to determine the characteristics of the new Bottom Mounted Array system (BMA), conditions were not optimized for the TDS method.

An IRIG-B time code signal is generated at the computer site and broadcast to all systems used in the test. From this time code signal a trigger pulse can be derived to trigger the source signal which is being generated by a swept ocillator. The period of this trigger signal determines the sweep time T which is one of the parameters to be considered using the TDS technique. As indicated in Fig.3.1 the IRIG-B signal is also sent to the NRS platform where it is recorded on magnetic tape. During post analysis of the recorded data the desired trigger signal can now be extracted (see Chapter III) and hence a common time base has been established.

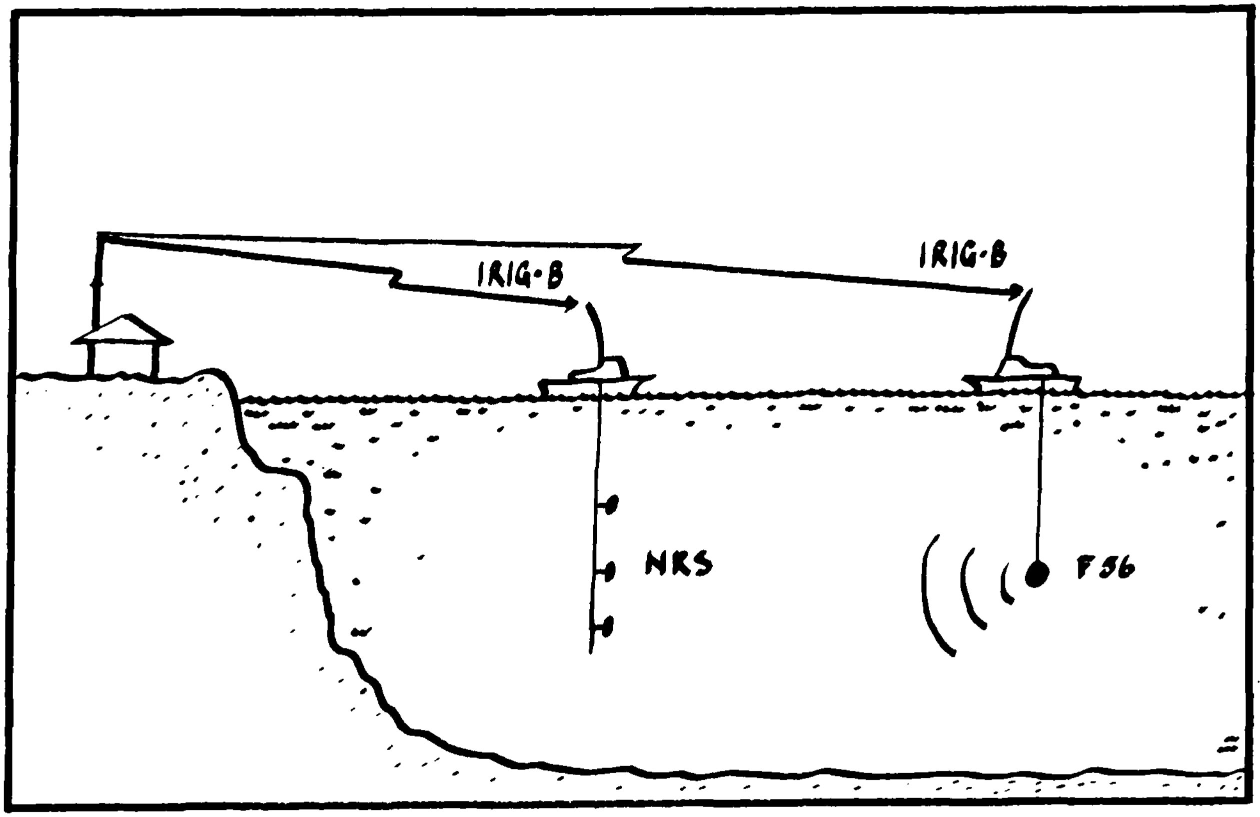


FIG.3.1 RANGE AND TEST CONFIGURATION FOR TDS MEASUREMENTS

B. DATA PROCESSING SYSTEM

1. The Hardware

The experimental setup which was used to implement the modified TDS technique is shown in Fig.3.2. It consists of the following components:

- HP-9836, Computer
- HP-3561A, Dynamic Signal Analyzer
- Datum, Time Code Reader Model 9300
- Honeywell 5600E, Tape Recorder
- HP-7074A, Plotter
- HP-2671G, Printer

During a TDS measurement period analog data are recorded on tape. The complete tape channel configuration and tape log is given in Appendix C. The data includes the individual hydrophone signals and the IRIG-B (time code) signal. In Chapter II, it was shown that the sweep rate, S, is constant and that the instantaneous frequency, f_i, varies linearly with time. Considering the distance of the propagation paths (direct or reflected) between the source and receiver and the speed of sound in the medium, it can easily be shown that a time delay is converted into a frequency shift which is proportional to the sweep rate and the time delay.

The functional relationship between the frequency (instantaneous) of the transmitted signal, f_T, and the received signal, f_R, can then be written as:

$$f_T(t - nT) = f_R(t - nT - D) \qquad \text{where} \quad n = 0,1,2,3,\ldots.$$

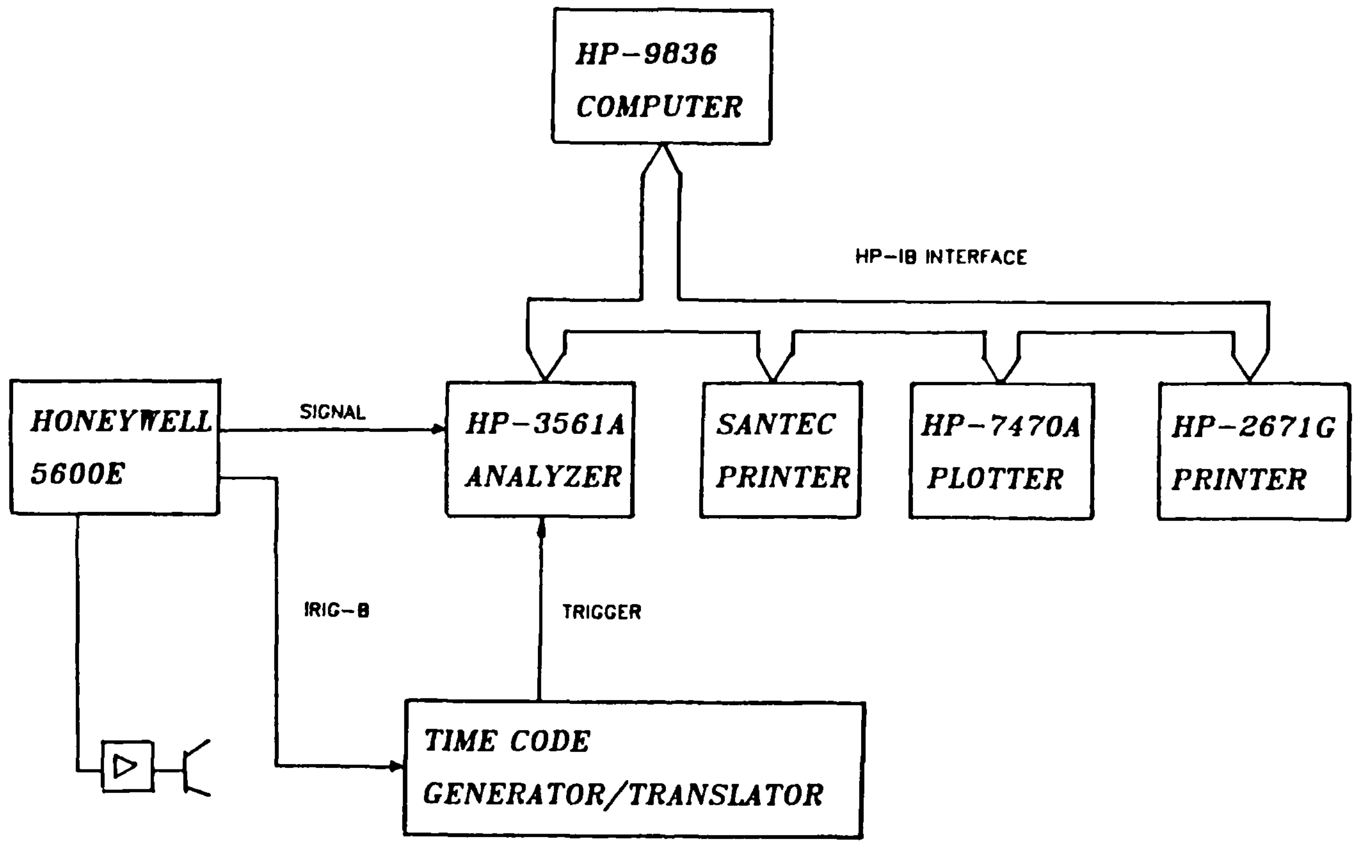


FIG.3.2 EXPERIMENTAL SETUP

and D is the time delay required for the signal to propagate to the receiver. If the relative position between the source and receiver is constant during a measurement period then the time delay D will be constant as well. The instantaneous received frequency f_R is therefore only a function of the time from the trigger pulse. The HP-3561A features a post-trigger which will initiate measurement of the received signal at any desired time (limited to 1023 time records) after the trigger.

The appropriate hydrophone signal to be measured is connected to the analyzer input, and the IRIG-B time code signal is connected to the time code reader where a one pulse per second (1 pps) trigger signal is derived. This signal is then applied to the rear panel external trigger input on the analyzer. The delayed post-trigger is controlled by the computer program and the accuracy of the delay increment is approximately 1/100 ms for a 20 kHz frequency span. (The exact value of the delay increment is determined by the frequency span F and only a span of 100 kHz will result in an exact delay time. This is a feature of the dynamic signal analyzer.) The fact that measurements by the analyzer now can be initiated at a precise time after the trigger and incremented accurately is the key to obtaining the spectral response of the ocean medium by using the modified TDS technique.

a. The TDS Parameters

Constraints on the excitation signal, X(t), discussed in Chapter II are determined by the test geometry and the hardware used to process the received signal. In particular the characteristics of the dynamic signal analyzer are important. The following discusses factors which affect the choice of an appropriate test geometry (i.e., source and receiver depth, maximum horizontal range) based on a desired frequency span F over which the response is to be measured. A lower limit for the sweep rate S will be derived and the effect of an exceedingly high sweep rate will be discussed.

The HP-3561A Dynamic Signal Analyzer is based on a 1024 point FFT algorithm. The resulting spectrum (i.e., frequency and corresponding amplitude) displayed on the analyzer contains 400 points or bins. For a given frequency span F the displayed frequency resolution or bin separation b is then given by:

$$b = F / 400 \quad (\mathrm{Hz}). \tag{3.1}$$

Hence if F = 20 kHz then the bin separation b = 50 Hz. Another important parameter regarding the analyzer is the observation time t_{obs}. The observation time or time record length is the time during which the analyzer acquires data from the received signal and is simply

$$t_{obs} = 400 / F = 1 / b \quad (\mathrm{sec}). \tag{3.2}$$

Typical values for the frequency span and the corresponding observation time using this TDS technique is tabulated below.

TABLE XI. Frequency Span and Corresponding Observation Time Or Time Record Length (HP-3561A)

Frequency Span	Observation Time
5 kHz	80 ms
10 kHz	40 ms
20 kHz	20 ms
50 kHz	8 ms

Fig.3.3 shows a possible spectrum of both reflected paths and the direct path a specific trigger delay. The fact that the reflected paths show up at a lower frequency is due to the positive sweep rate S (i.e., during the sweep the frequency increases). The time delay between the direct and the surface reflected path is t_s. The time t_b is the time delay between direct and bottom reflected path and t_r is the difference in arrival time between the surface and bottom reflected paths.

Data were acquired by the analyzer from the received signal during the observation time t_{obs}. Since the instantaneous frequency is changing with time the spectrum of the signal averaged over this time interval will contain energy in a frequency band which is given approximately by:

$$f_{spread} = S \times t_{obs} \qquad (3.3)$$

Compared to the "classical" TDS technique as introduced by Heyser [Ref.1] and further developed by Bruel & Kjaer [Ref.2 & 3], this frequency spread may be seen as the parameter which determines the

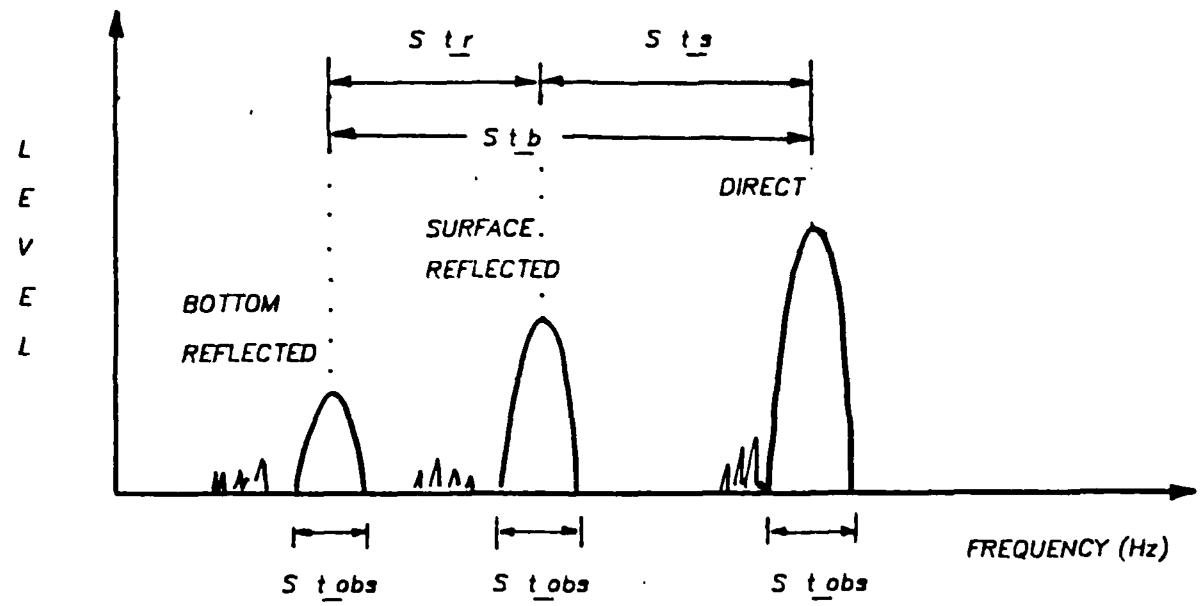


FIG.3.3 POSSIBLE SPECTRUM OF THE RECEIVED SIGNAL

choices of tracking filter bandwidth. From Fig.3.3 it is also seen that separation between the reflected paths and the direct path is determined by the delay in arrival between the three paths and the sweep rate. Hence we may write other sufficient, but not necessary, conditions as:

$$S \times t_s > S \times t_{obs} \tag{3.4}$$

$$S \times t_r > S \times t_{obs} \tag{3.5}$$

and

$$S \times t_b > 2 \times S \times t_{obs}. \tag{3.6}$$

These inequalities must be satisfied individually to resolve <u>all the paths</u> Note that if the surface and bottom time delays are equal we may then write

$$t_{delay} > t_{obs}, \tag{3.7}$$

where t_{delay} is the time delay between the direct and reflected paths.

A measurement window is a weighting function which is applied to the input data in order to reduce errors caused by leakage into adjacent frequency bins. For a sufficiently low sweep rate such that there is no spreading of energy over frequency as measured by the analyzer, there is still a minimum bandwidth that is defined by the frequency span F and the measurement window that is used. This bandwidth is given by:

$$f_{band} = C \times F. \tag{3.8}$$

The constant C is normally given as a percentage of the frequency span. For a Hanning window (HP-3561A) this constant is 0.00375 which gives f_band = 75 Hz for a frequency span of 20 kHz. A second condition to resolve the paths is therefore to ensure that

$$S \times t\_s > f\_band \tag{3.9}$$

and

$$S \times t\_r > f\_band \tag{3.10}$$

and

$$S \times t\_b > 2 \times f\_band. \tag{3.11}$$

In order not to choose the sweep rate too low, we consider the case when t_r = 0. Then the above set of inequalities reduces to:

$$S \times t\_delay > f\_band = C \times F$$

or

$$S > (C \times F) / t\_delay. \tag{3.12}$$

This inequality gives an expression for the minimum sweep rate. For the HP-3561A the constant C, determining the equivalent noise bandwidth, is 0.00955 for a flat top window and 0.0025 for a uniform window. The constraint in Eq.(3.12) does not imply that high sweep rates should be used. This is because exceedingly high sweep rates result in less energy being transmitted in a given frequency band which results in a lower signal to noise ratio at the receiver.

b. Procedure to Determine the TDS Parameters

Based on the previous work a simple procedure may now be developed in order to fix the parameters S, F, R, ZS, and ZR for a given measurement.

1). First the frequency span F over which the data is to be processed must be selected. Fixing F causes the observation time, $t\_obs = F / 400$, to be fixed. For F = 20 kHz the observation time $t\_obs = 20$ ms as given in Table XI on page 47.

2). The next step is then to choose a geometry such that t_s and t_r are guaranteed to be greater than the observation time t_obs. If both source and receiver are located at the middle depth then $t\_r = 0$ ($t\_s = t\_b$). Fig.3.4 shows the relationship between time delay and range for a total depth of 600 ft and sound speed 4850 ft/sec. The receiver is fixed at 300 ft and the source depth is varied between 100 and 300 ft. Note that in this case the plot of range vs. time delay is symmetric about 300 ft.

3). Finally from the selection in steps 1) and 2), the minimum sweep rate must be determined from Eq. (3.12). Fig.3.5 shows a plot to determine the minimum sweep rate based on Eq. (3.12) and C = 0.00375 (Hanning window), for a frequency span F = 5, 10, 20, and 50 kHz.

c. Determining the TDS Parameters -- An Example

Consider a case where it is desirable to cover a frequency span of 20 kHz. From Table II we get the corresponding time record length or observation time $t\_obs = 20$ ms. In order to separate the direct and both the reflected paths a geometry must now be determined so as to guarantee that both t_s and t_r be greater than t_obs and that t_b be greater than 2 t_obs.

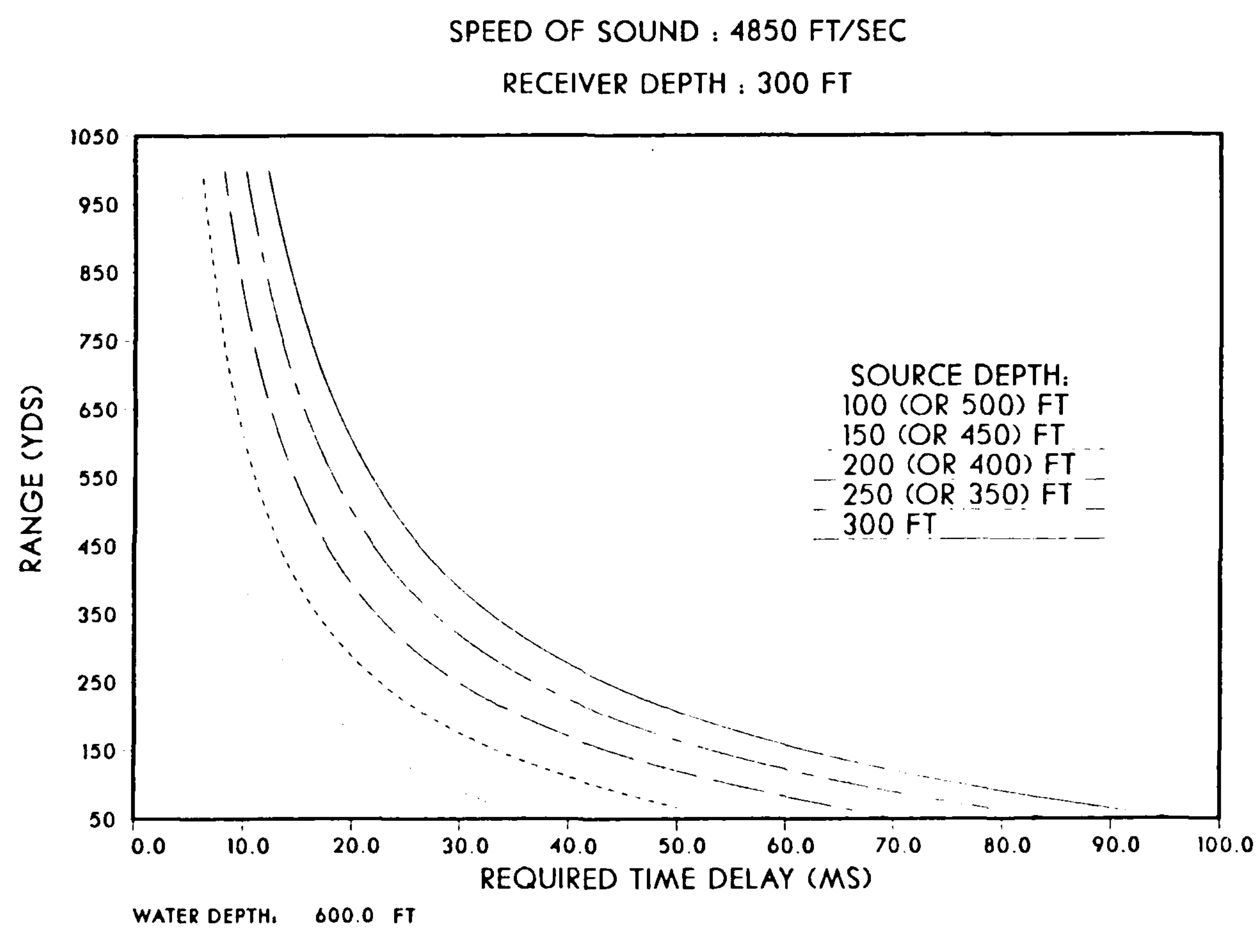


FIG.3.4 PLOT FOR MAXIMUM RANGE.

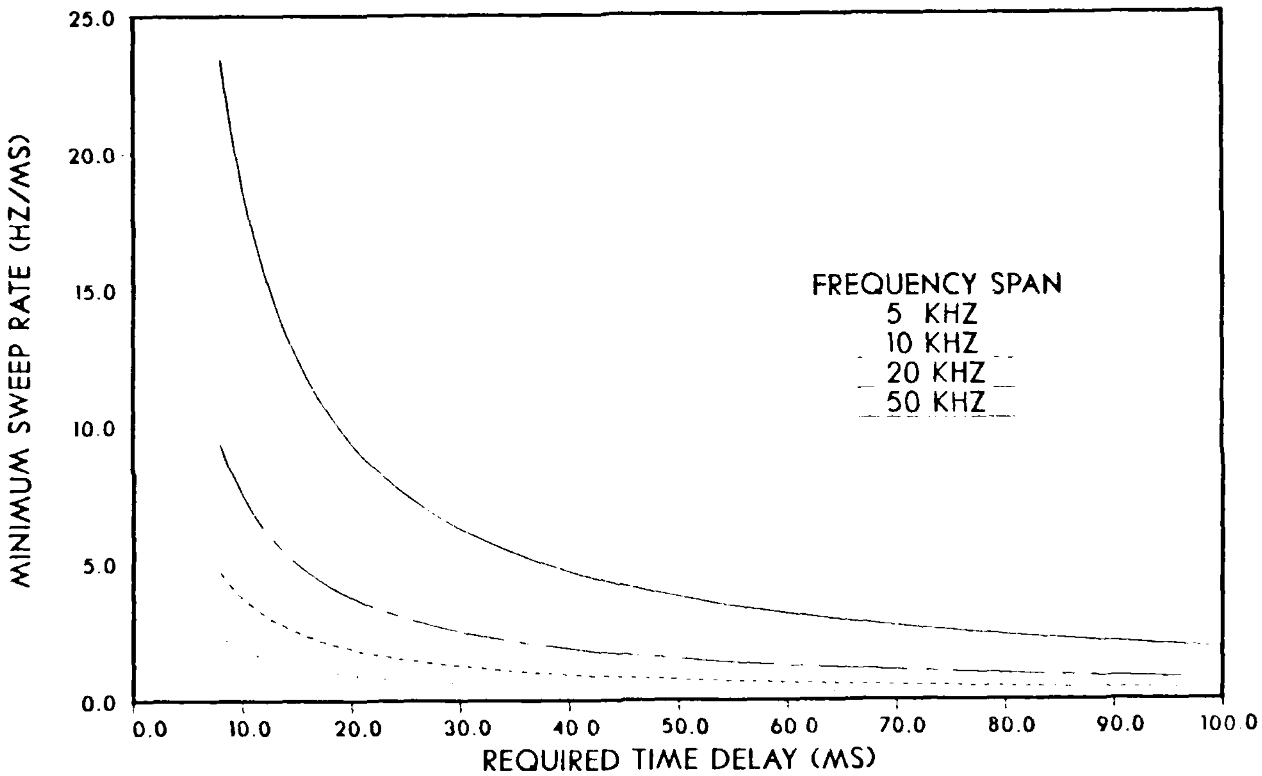


FIG.3.5 PLOT FOR MINIMUM SWEEP RATE

If the receiver is fixed at 300 ft depth then Fig.3.4 gives the maximum range to resolve the direct path and one of the reflected paths For source and receiver at 300 ft the maximum range is approximately 600 yds. At this range, however, both reflected paths have the same time delay and will contribute to the reflected signal. In order to resolve all paths Table I through X of Appendix A may be used to determine the delays. From Table III we see that a range of 300 yds and receiver at 300 ft depth, a sorce depth of either 200 or 400 ft will be required.

The minimum sweep rate is found directly from Fig.3.5. For a required time delay of 20 ms the minimum sweep rate is approximately 4 Hz/ms or equivalently 4 kHz/sec.

2. The Software and its Documentation

The code written to accomplish the measurements in the TDS Multipath Measurement System consists of 2134 lines and is not included in this thesis. The HP BASIC programming language with extension AP2_1 has been used. As shown in Fig.3.2 the program (TDS_1, i.e., version #1)is designed to run on an HP-9836 desktop computer. A modular design structure was chosen in order to reduce the testing time of the code and to increase readability and maintainability. The individual modules are all subprograms that are called upon when required to perform a specific task. In addition to an easily identifiable structure, comments are included in the subprogram headings and throughout the program in order to support readability of the code. In particular mnemonics used to control the HP-3561A Dynamic Signal Analyzer are explained at the first time that they occur in a statement.

The hierachical structure of the TDS_1 program is shown in Fig.3.6. Three major subprograms form the basis of the total program and represent the different analysis methods that can be used to process the recorded data. The Quick_Analysis and Normal_Analysis subprograms are both interactive programs which require an operator to identify the different paths (direct-, surface-, or bottom-reflected) when displayed on the analyzer. Both these subprograms are, however, fundamentally different with respect to the mode of operation of the spectrum analyzer. The Auto_Analysis subprogram is in principle an automated version of the Normal_Analysis subprogram where path identification is done by the program. A description of those subprograms that support all the three major analysis methods will first be discussed followed by a description of each of the major subprograms and their variables.

a. The Structure and General Purpose Subprograms

As shown in Fig.3.6 the only purpose of the main program is to call the TDS_Menu and finally to return the analyzer to local control and terminate the program. The TDS_Menu is a subprogram that initializes the desirable analysis method (i.e., Quick, Normal, or Auto). Before continuing, the following terminology should be kept in mind. The word mode refers to the different modes of operation (i.e., Time Capture Mode, Narrow Band Mode, etc.) of the Dynamic Signal Analyzer. On the other hand, the word method refers to the three different analysis methods implemented in the TDS_1 program.

Regardless of which analysis method is being selected from the TDS_menu, the Set_analyzer subprogram is used by all three major subprograms. Initially the analyzer is put in a known preset state

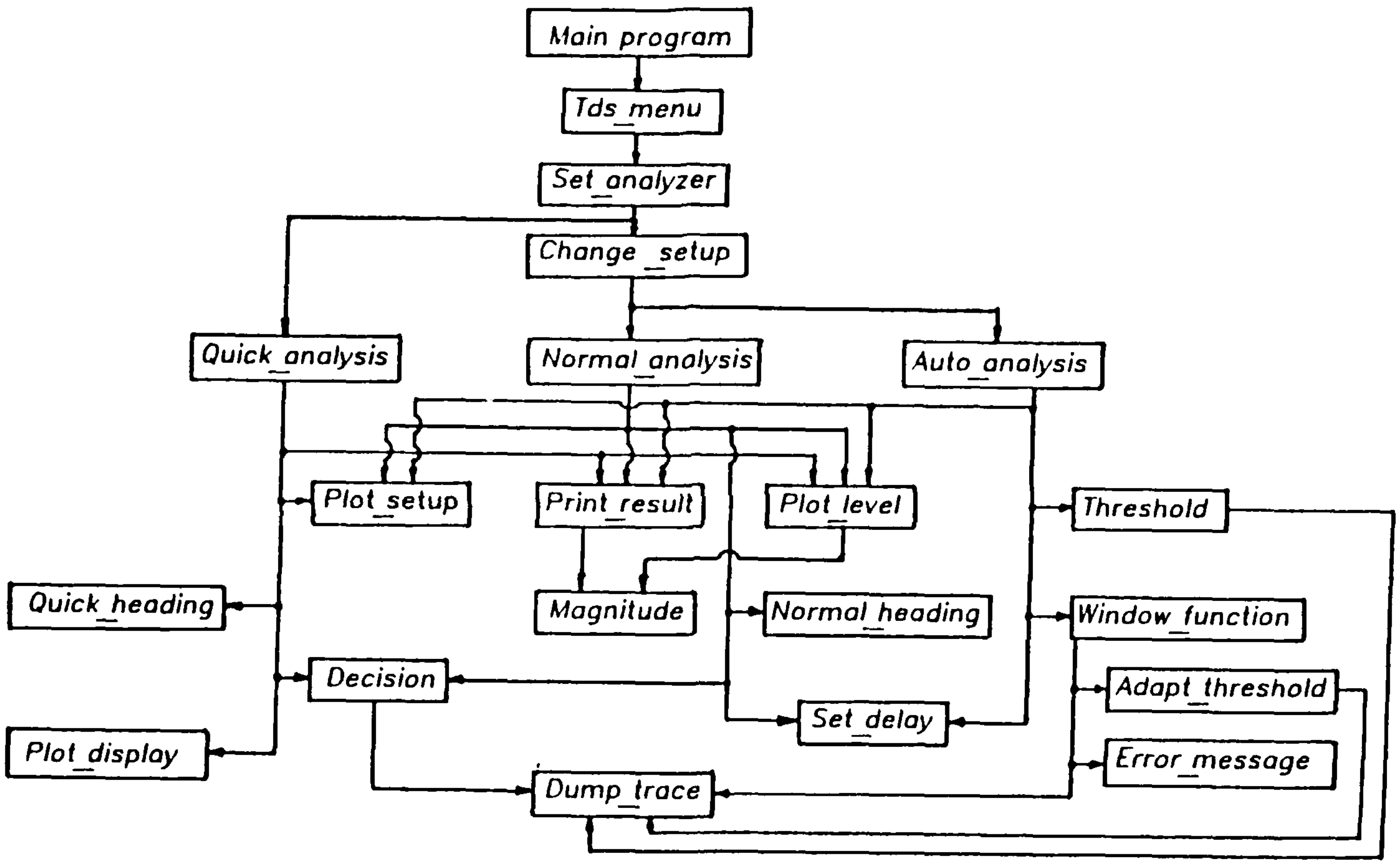


FIG.3.6 THE HIERARCHICAL STRUCTURE OF THE TDS PROGRAM

and then the Time Capture mode which is used in the Auto_analysis is set. If Normal_analysis or Auto_analysis is selected from the TDS_menu then the analyzer is changed to Narrow Band mode in the Charge_setup program. After the HP-3561A is programmed for a particular analysis method the instrument state will be displayed on the analyzer. The Plot_display is at present only called in Quick-analysis, where the 3-D magnitude map initially displayed on the analyzer after a measurement may be plotted on an HP-7470 plotter.

The following subprograms are all used in connection with identification of the received signal(s) and measurements of corresponding frequency and amplitude values. Quick_heading and Normal_heading are called in the Quick_analysis and Normal_analysis subprograms respectively. In these subprograms the signal identification is entered by the operator and the result is passed to the Decision subprogram which measures frequency and amplitude and stores the values in the appropriate variables. Set_delay is called in both Normal and Auto_analysis and is used to increment the delayed trigger signal. Dump_trace records the amplitude values corresponding to the trace that is currently displayed on the analyzer and in addition calculates the average amplitude value. This average amplitude is assigned to the variable Noise_ampl in all three analysis methods. However, in Auto_analysis the Dump_trace subprogram is also used to set an appropriate threshold determined by the subprogram Threshold. When both the direct and reflected paths are present this initial threshold will be raised by Adapt_threshold to account for increased signal levels. The Window_function is only used in Auto_analysis. Here a measurement window is moved across the display and a peak is counted if every amplitude value within the window exceeds the current threshold. Finally identification of the peaks are made based on trigger delay, number of peaks and their relative position on the display. If too many peaks are counted then Error_message is called to notify the operator of this event.

The operator's response to prompts by the TDS_1 program is always tested at the time the input occurs. In case of an incorrect answer the subprogram Wrong_key is called to correct the mistake before the next statement is executed. The measurement results for each analysis method are finally presented in a tabulated form (Appendix B) and if desired a plot of amplitude vs. frequency for both the direct and reflected paths (see Fig.4.3 and 4.4) is made. During the analysis, spectral density levels are measured by the analyzer. Both the print routine Print_result and the plotting routine Plot_level intially call the subprogram Magnitude. In this subprogram the measured spectral density levels are converted to a magnitude level in dB re 1V before the data are printed or plotted.

b. The Three Major Subprograms

In version # 1 of the program both source and receiver are assumed to be located at middle depth. This configuration gives the minimum number of possible states or combinations of the signals (paths) displayed on the spectrum analyzer. The analysis methods have been named to indicate their functional content in the TDS_1 program.

Quick-Analysis is based upon the analysis of data from 40 time records. The appropriate settings are entered by the subprogram

Set_analyzer and puts the analyzer primarily in the Time Capture Mode. It is also important to recognize the following settings: 20 kHz frequency span, 500 Hz start frequency and 20% overlap processing. For a frequency span of 20 kHz the corresponding time record length (or observation time, see Table XI, page 46) is 20 ms. As a consequence the total measurement time is just 40 x 20 ms = 800 ms and therefore only one sweep is processed.

The intention with the Quick_analysis method is primarily to provide a quick overview of the received signal as a function of frequency and time, and to determine the arrival times of the direct and reflected paths. The arrival times can easily be determined by adjusting the start time of the measured data which is stored in the memory of the analyzer. The overview of the received signal is presented in a 3-dimensional magnitude map which consists of 60 traces. When 20% overlap processing is used each consecutive trace is delayed by 4 ms. (Note! If the percentage of overlap is changed in the Set_analyzer subprogram then the constant Delay_step must be changed in the Quick_analysis subprogram since this affects the time interval between successive traces.) Information about the different arrival times is required as input parameters for the Auto_analysis subprogram and must be recorded manually. If desired, the analysis may be continued in order to obtain the standard measurement results.

Normal analysis is an interactive analysis method where the signal identification is done by the operator. After the initial setup is finished, the analyzer is set to Narrow Band Mode in the Change_setup subprogram. A standard 20 kHz span is set in the Set_analyzer subprogram. This corresponds to a frequency resolution on the analyzer display of 50 Hz. As was outlined in Chapter II, the sweep rate (20 kHz/sec in this experiment) is the conversion factor between time delay and frequency. The trigger signal is delayed after each measurement by the value of the constant Delay_step. This constant should theoretically be equal to or greater than 3 ms which will give a frequency increment for each delay of: 3 ms x 20 Hz/ms = 60 Hz. A 2 ms delay step will similarly give a frequency increment of 40 Hz which is less than the resolution of the spectrum analyzer in Narrow Band Mode at a frequency span of 20 kHz.

In the Normal_analysis method eight consecutive sweeps are RMS averaged to increase the signal to noise ratio before a measurement is made. The averaging is also required to reduce the effects of minor fluctuations in the received signal. It is believed that these fluctuations are due to a combination of scattering from surface roughness and small variations in the horizontal range between source and receiver. Measurements are repeated until the value of the variable Trigger_delay is equal to or greater than the variable Limit. The value of Limit is initially 1000 (ms), but may be changed by the operator in order to analyze just the time span in which there is signal present. After the analysis is terminated the result may be viewed on the screen before a hard copy is printed. Finally a plot of the measured levels vs. frequency for both the direct and reflected paths is presented.

Auto analysis is in principle an automated version of the Normal_analysis method where the same settings are used for the spectrum analyzer. In this method, however, the signal identification and measurements are done under program control. Information about arrival times of the direct and reflected paths is required in order to simplify the identification problem. These inputs must be obtained from the Quick_analysis method as explained earlier. Since the analyzer is operated in the Narrow Band Mode, the same considerations about display frequency resolution and choice of the constant Delay_step as described in the Normal_analysis method are valid here as well. Measurements are terminated when the variable Trigger_delay is equal to or greater than the variable Limit which initially may be changed by the operator. Finally the measurement results are presented the same way as described for Normal_analysis.

When frequency and corresponding amplitude of the various paths are measured during an analysis period, the values are assigned to the appropriate variable arrays. In both Normal and Auto_analysis eight consecutive sweeps are RMS averaged before the frequency and the amplitude are measured for a given value of the Trigger_delay. The variable Delay_step determines (approximately) the frequency shift of the next measurement which under stable conditions will result in a monotonic increasing frequency. In case of an unstable spectrum of the received signal it may happen that the frequency measured for one (or both) signal(s) at a given Trigger_delay is less than the preceeding one. Also in the Auto_analysis, errors may occur during identification of the signals due to incorrect arrival time supplied by the operator, or due to the threshold being set too high or too low. In any of these cases the measured frequencies will not be monotonic increasing. The tabulated output from Print_result contains all the measured frequency and amplitude values. In order to make a plot of frequency vs. amplitude for both the direct and reflected paths it is required that the frequency arrays are monotonic increasing. This requirement is initially tested in the Plot_level subprogram. If incorrect measurements are found in this test they will not be plotted.

IV. VERIFICATION OF THE TECHNIQUE AND PROCESSING CAPABILITIES

The data used to develop the TDS_1 program described in Chapter III were obtained in 1982 during verification of the bottom mounted array (BMA) system at the 3-D range in Dabob Bay, Washington. The objective for that test was to determine the directional characteristics of the BMA. The additional data obtained during that test and made available to the author in order to study multipath propagation using the TDS technique, is due to the foresight of John G. Burwell who at that time was interested in applying the concept of Time Delay Spectrometry to underwater acoustic measurements.

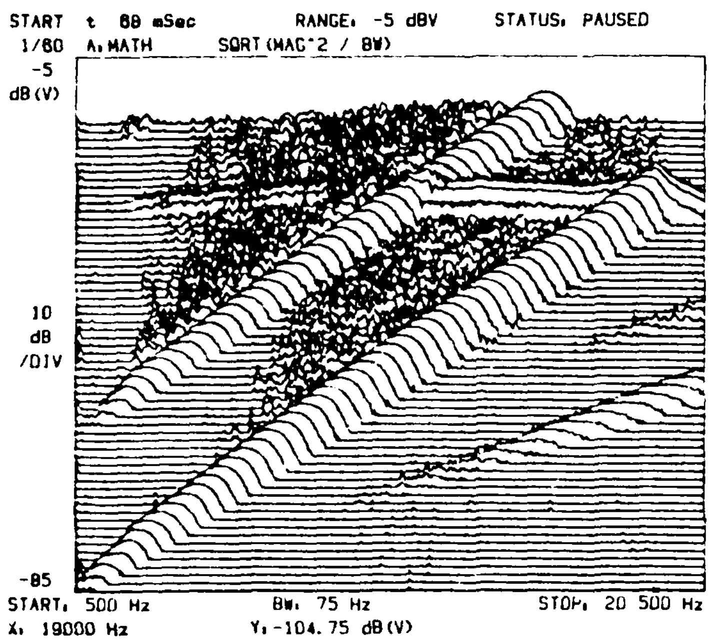
The test configuration shown in Fig.3.1 consists of two systems. The Noise Reduction System (NRS) is the receiving system, which consists of several hydrophones located at different depths. During this experiment the received signal at three different hydrophones located at 240, 300, and 340 ft was recorded on separate channels on the tape recorder. The tape channel configuration and tape log is found in Appendix C on page 91. The source system, an omnidirectional transducer

(Naval Research Laboratory Model F 56) was located at mid-depth about 300 ft. (NRS may also be used to establish transmitted levels.) The horizontal range between source and receiver was kept constant at 300 yds during the experiment. The excitation signal was an LFM pulse at constant amplitude which was swept once each second covering the frequency range from 500 Hz to 20 kHz. The occillator output was not blanked during the fly back.

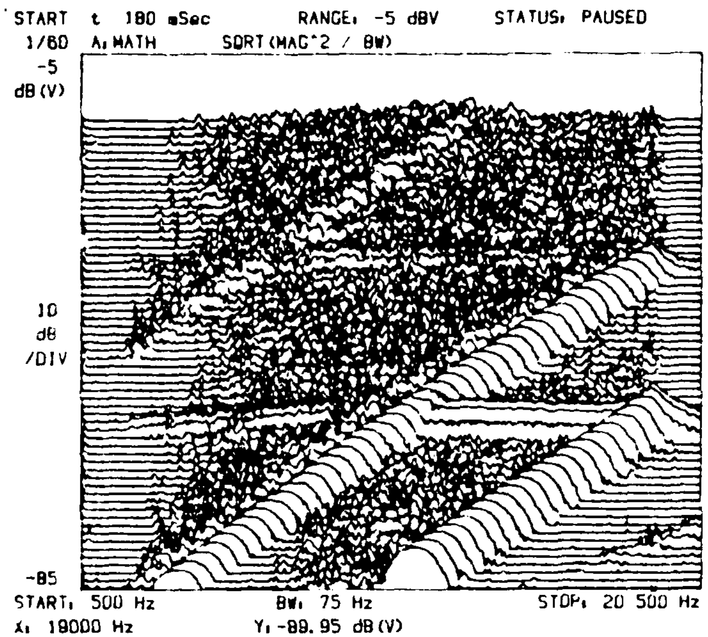
A. THE MODIFIED TDS TECHNIQUE AND ITS ABILITY TO RESOLVE MULTIPLE PATHS

Given the frequency span F of 19.5 kHz swept once every second, it follows that the sweep rate is $S = 19.5$ Hz/ms. Choosing a frequency span of 20 kHz on the Dynamic Signal Analyzer corresponds to an observation time $t_{obs} = 20$ ms as given in Table XI on page 46. For the case when both the source and the receiver are located at mid-depth (300 ft), the time delay relative to the direct path is the same for both the surface and bottom reflected paths. Only separation between the direct path and a combination of the reflected paths can be expected for this configuration of source and receiver. Recall (see Ch.III) that in order to resolve these paths it is required that the time delay, t_{delay}, be greater than the observation time, t_{obs}. From Fig.3.4 this requirement gives a maximum range of approximately 600 yds and hence the geometry is well within the limits. The sweep rate of approximately 20 Hz/ms is however not optimal in this test. From Fig.3.5 the minimum sweep rate is 4 Hz/ms and clearly 10 Hz/ms would be sufficient in this case. The effect of an exceedingly high sweep rate was discussed in Chapter III. However, the lowest possible sweep rate would increase the total measurement time and hence increase the range time required to complete the measurements.

A magnitude map obtained from the Quick_analysis method where the analyzer is set to the Time Capture mode is shown in Fig.4.1 (a) and (b) for two different start times relative to the trigger. Each map contains 60 traces which represent the time delay axis is the 3-D plots. In Fig.4.1 (a) the start time is delayed 68 ms relative to the trigger and shows the direct path as the diagonal signal. The reflected path is displayed above and parallel to the direct path. In Fig.4.1 (b) the start time has been further delayed to 180 ms showing the direct path to the right and the reflected path to the left. The combination of the two figures shows the entire spectrum of each path within the frequency span of the excitation signal. In addition to the two signals, the second harmonic of the excitation signal which has travelled by the direct path is also visible. The presence of the this harmonic is assumed to be caused by nonlinearities in the transducer which might have been driven above its linear range. Another effect that is seen at the end of the direct path is the increased spectral level when the frequency of the excitatin signal flys back to the start value. Ideally, the source should be turned off during this transition when the sweep is restarted. The fast negative sweep in this case results in a signal-to-noise ratio for the reflected spectrum which is significantly lower (approximately 5 dB(V)) at this time delay than earlier or later spectra. Fig.4.2 shows a spectrum of the received signal at a delay equal to 180 ms relative to the trigger. Clearly a sufficient signal-to-noise ratio is obtained for both the direct and the



(a)



(b)

Fig.4.1 MAGNITUDE MAP OF DIRECT AND REFLECTED PATHS FOR SOURCE AND RECEIVER AT MIDDLE DEPTH, 300 FT.
(a) Start time delayed to 68 ms.
(b) Start time delayed to 180 ms.

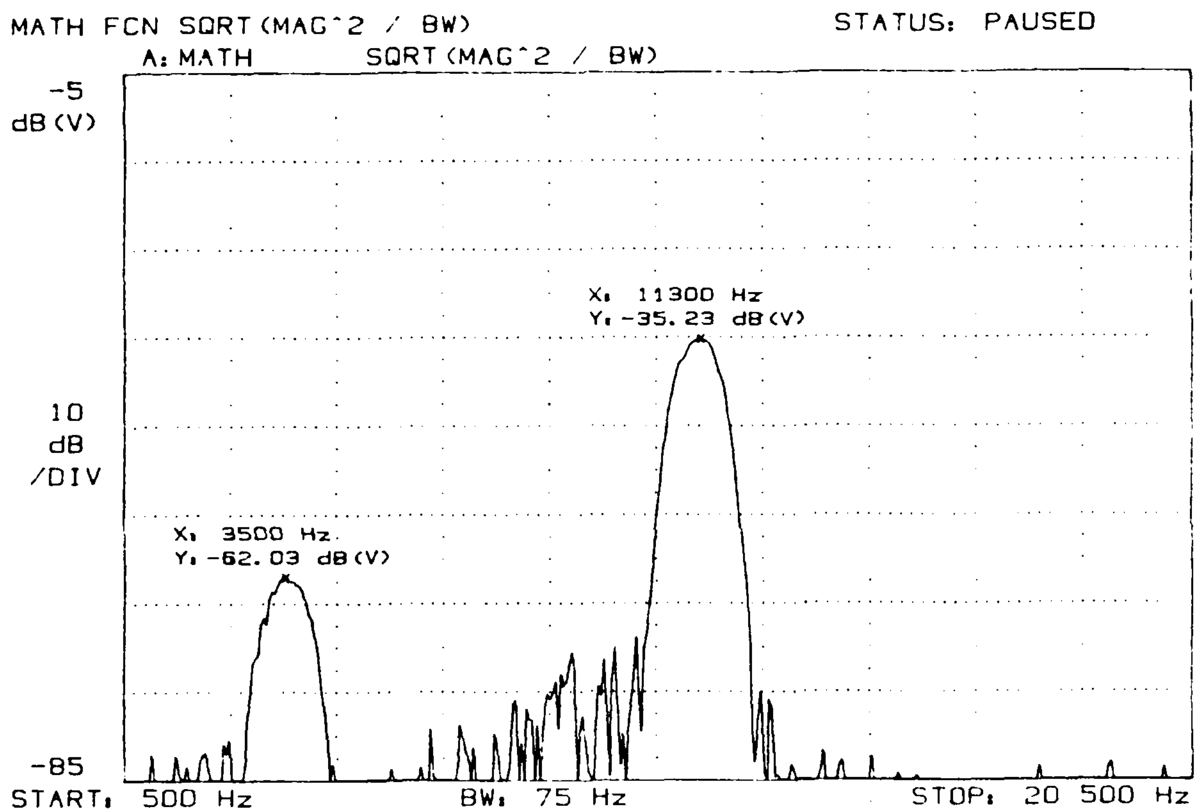


Fig.4.2 SINGLE TRACE PLOT OF DIRCET AND REFLECTED PATHS AT TRIGGER DELAY EQUAL TO 180 ms.

reflected spectrum levels. From Fig.4.2 we see that the signal-to-noise ratio is approximately 35 dB for the direct path (11300 Hz) and 16 dB for the reflected path (3500 Hz) at this trigger delay. As the trigger is further delayed still better signal-to-noise ratios are obtained.

An example used to determine the TDS parameters required to resolve all the paths was given in Chapter III (see page 50). By the use of Tables I - X (Appendix A) it was found that complete separation could be obtained at a range of 300 yds when the receiver was kept at 300 ft and the source positioned at a depth of 200 or 400 ft. For the test considered here, the geometry and hence the spectral separation is marginal and in addition the available data were recorded while the source was being hoisted towards the surface. Due to the constant motion of the source and the lack of precise information about the source depth it has not been possible to obtain a well defined spectrum for this case.

B. THE PROCESSING CAPABILITIES OF THE TDS PROGRAM

In the previous section it was documented that the direct and the reflected paths can be properly resolved. It is the purpose of the TDS_1 program to identify the spectral peaks and to extract the available information concerning level and frequency as the trigger delay (or measurement start time) is increased. The analysis results are presented in the same format for each analysis method and consists of a plot of the measured levels as a function of frequency together with a table of the measured values including the delays at which the data were obtained. In Fig.4.3 and 4.4 the measured levels of both

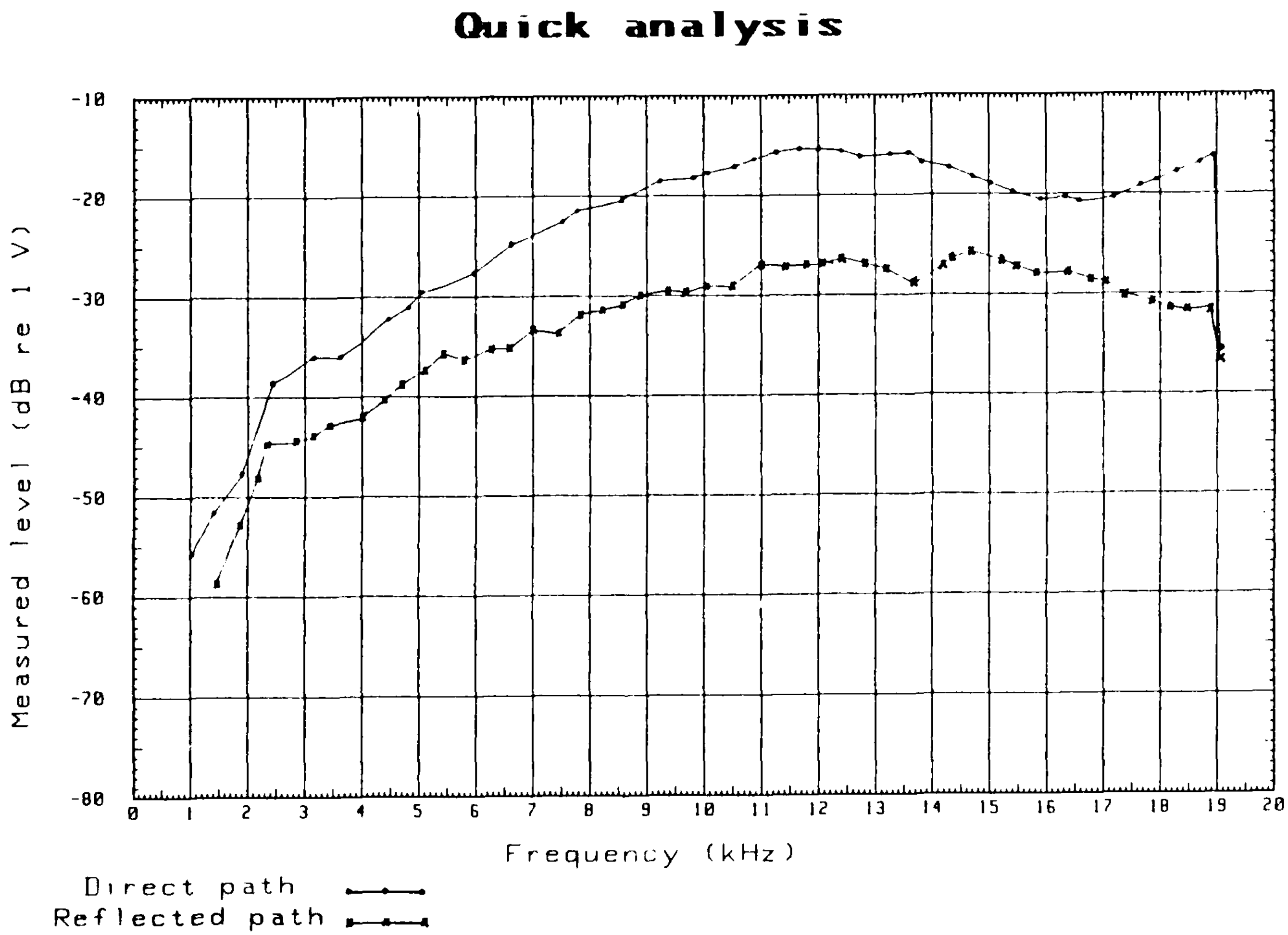


Fig.4.3 PLOT OF MEASURED LEVELS (dB re 1 V) VS FREQUENCY (kHz) FOR THE QUICK–ANALYSIS METHOD.

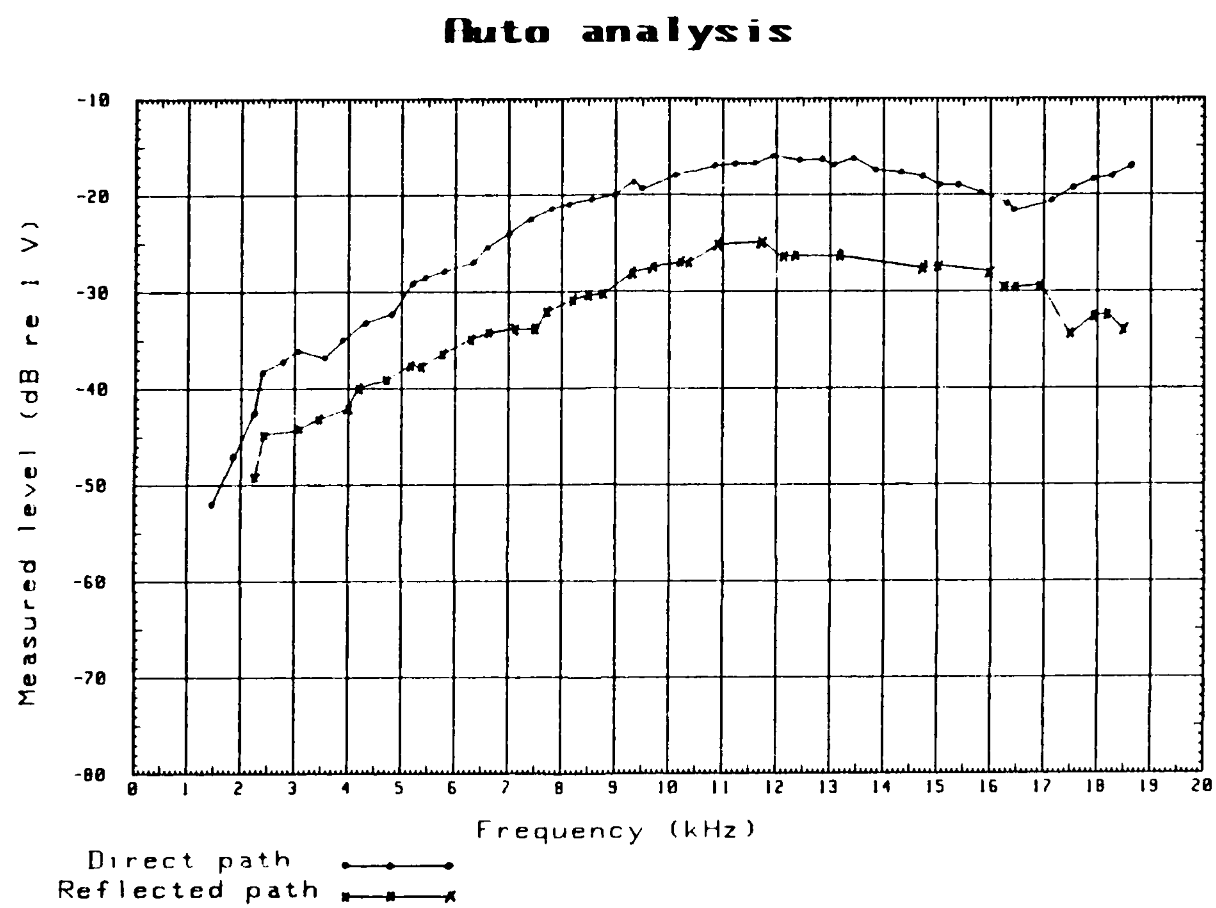


Fig.4.4 PLOT OF MEASURED LEVELS (dB re 1 V) VS FREQUENCY (kHz) FOR THE AUTO-ANALYSIS METHOD.

paths are plotted as a function of frequency for Quick_analysis and Auto_analysis respectively. The corresponding tabulated values are given in Appendix B on page 87.

At this stage in the development of the modified TDS technique a quantitative analysis of the results would not be feasible. First, because important environmental data at the time of the test were not available to the author, and second, because such an analysis should be based on test data for which an optimal geometry and optimal TDS parameters were used. It is, however, interesting to notice that the same general characteristics of the measured levels as a function of frequency were obtained using either Quick_analysis, Fig.4.1, or Auto_analysis, Fig.4.2. It should not be expected that the two methods would give the same results, since the Quick_analysis is based on the capture of 40 time records in less than one sweep, while in Auto_analysis 8 consecutive sweeps are RMS averaged before measurements are made. From Fig.4.2 it is seen that the difference in measured levels between the direct and reflected paths at the same frequency is in the range of approximately 6 - 12 dB (V). However, at the higher frequencies where the signal-to-noise ratio is low due to the sweep fly-back, we see that the difference in the measured levels increases.

An important parameter to be considered is the frequency resolution of the analyzer. The value of this parameter is inversely proportional to the desired frequency span and is also equal to the inverse of the observation time. By decreasing the frequency span a better frequency resolution will be obtained, but at the same time this advantage has to be paid for by an increased observation time. The plots shown in

Fig.4.3 and 4.4 are not continuous functions of frequency, but represent measurements at discrete trigger delays. Furthermore, the frequency shifts between consecutive measurements are determined by the value of the variable Delay_step which increments the delayed trigger signal to the analyzer. In the present version of the TDS program, this step size is constant (may be changed by the operator) during a particular analysis method. If more closely paced data points are required, the value of Delay_step must be reduced, which increases the total analysis time. However, it is not useful to make the delay steps so small that the corresponding frequency shifts are less than or comparable to the frequency resolution of the analyzer. The measurement results presented previously for the Quick and Auto_analysis methods were obtained with constant Delay_step equal to 4 ms.

If we define the effective analysis time as the time required to complete any of the analysis methods without including the time to plot or to print the data, we see that the modified TDS technique is much slower than the "classical" TDS technique which has an effective analysis time equal to the sweep time. This was expected since we initially preferred to record the data on magnetic tape before the final analysis. Using the present version of the TDS program the effective analysis time for the Quick_analysis is found to be 15 minutes. An additional 15 minutes is required to plot the magnitude map and finally 5 minutes are required for the output plot shown in Fig.4.3. In Auto-analysis each data point is based on the RMS average of 8 consecutive sweeps. For this method the effective analysis time was 40 minutes. Including an additional 5 minutes to obtain the output plot shown in Fig.4.4, we get a total analysis time of approximately 45 minutes for this method.

The current version of the TDS program can only handle the case where source and receiver are located at the mid-depth. This test geometry requires the smallest number of possible states or combinations of the received spectra at any given trigger delay. If we let 1 denote the state where signal is present and 0 the state where signal is not present, we may then tabulate the possible combinations as follows:

STATE	DIRECT	REFLECTED
1	0	0
2	1	0
3	0	1
4	1	1

In the general case where the test geometry is chosen to obtain separation of all the paths and in addition include the above simple case for source and receiver at mid-depth, the possible combinations may be tabulated as follows:

STATE	DIRECT	SURFACE	BOTTOM	REFLECTED
1	0	0	0	0
2	1	0	0	0
3	0	1	0	0
4	0	0	1	0
5	0	0	0	1
6	1	1	0	0
7	1	0	1	0
8	1	0	0	1
9	0	1	1	0
10	1	1	1	0

In the above table REFLECTED indicates the case where source and receiver are located at the middle depth. Implementation of the general case is straightforward in both of the interactive analysis methods. In order to account for the surface and bottom reflected paths, four additional variables would be required to store magnitude and frequency values. Since the data are measured in the subprogram Decision, the number of states here would have to be increased to ten. Minor changes would also be required in the subprograms Quick and Normal_heading to include the additional states. In the Auto_analysis method, however, the logic used in the subprogram Window_function to identify and measure the spectral levels and corresponding frequencies would have to be changed completely. Finally, the printed format in Print_result must be changed and re-indexing of the new variables in Plot_level would have to be added for implementation of the general case.

V. CONCLUSION AND SUGGESTIONS FOR FUTURE RESEARCH

In his book, Underwater Electroacoustic Measurements [Ref.5, pp.1], Bobber writes: "Acoustics, particularly underwater acoustics, is not a very precise science. The second significant figure in a measurement usually is in doubt and the the third, usually meaningless. Accuracies of ± 1 dB (or about 10% pressure amplitude) are quite acceptable in most circumstances. At least part of the reason for this is the instability of the medium and unfavorable environment in which the electroacoustic instruments must operate. Except under the controlled conditions that can be achieved only on a laboratory bench, water is not the simple, stable, homogeneous, quiet and harmless medium that the layman imagines."

All transmission loss models, designed for shallow water acoustic propagation, require statistically averaged input parameters describing the sea surface, water column, and ocean bottom. Even at NUWES 3-D test ranges, the statistics are not yet complete. In order to describe any of the test ranges, complicated and expensive measurements would have to be carried out. As an alternative to the currently used transmission loss model(s), it is believed that routine measurements can be carried out on the test ranges in the future using the technique and measurement system described in this thesis.

The multipath measurement system which has been developed is based on the concept of Time Delay Spectrometry. In the classical TDS technique a "real time" response may be measured in a small-scale environment. Implementation of the TDS concept on a larger scale 3-D test range, however, has required the development of a modified TDS technique which is more appropriate for measurements in the field. Fundamental requirements are that the source and the receiving systems remain at a constant range and that the linear sweep be triggered at constant time intervals during a measurement period. Given these requirements and a test geometry which is similar to the one used during torpedo radiated noise measurements, spectral separation of the paths is obtained with a signal-to-noise ratio in the range of 10 to 40 dB. Finally, in the TDS Multipath Measurement System, both the hardware and the software are compatible with already existing analysis equipment at the Acoustics Division in Keyport.

The ultimate goal as outlined in the introduction is to determine the transmission loss along the different paths as a function of frequency. The TDS program may be the tool to accomplish this task. A complete description of the receiving system in terms of calibration insert loss and hydrophone sensitivity is readily available at the Acoustics Division in Keyport. The received acoustic level (RL(f)) at the face the hydrophone referenced to 1 μPa and to the bandwidth of the measurement is found using the following relationship:

$$RL(f) = ML(f) - CAL(f) - HS(f) + IL(f) - 47 - AG$$

where:

ML(f) is measured level (dB re 1 V) in the measurement BW

CAL(f) is measured level of calibration in a 1 Hz BW

HS(f) is the hydrophone sensitivity in dB re 1 μPa

IL(f) is the calibration insert loss in dB

AG is the gain of the autogain amplifier

During calibration of the receiving system a bandlimited (50 kHz) white noise signal is applied. The -47 dB term is therefore simply 10 log(BW). Calculation of RL(f) is not included in the present version of the TDS program. In future work, one should consider including the characteristics of both the receiving system and the source in the computer model. Without any changes in the current TDS program it is further recommended that a "pre-test decision package" be added to the program. This package would be based on the simple formulae for maximum range and minimum sweep rate given in Chapter III. Extension of the TDS program to include an arbitrary source and receiver configuration will require minor changes in both the interactive analysis methods (Quick and Normal analysis). In Auto analysis, however, a complete change in the logic is required. It is therefore recommended that future tests being conducted on the range include data obtained from an optimal source and receiver configuration that will ensure complete separation of all the paths. When such data are available the simple changes should be made first before the logic of the Auto analysis method is decided upon.

A final point to be considered is the transmit response of the source and the frequency span in which data is to be analyzed. It has been shown earlier that a sweep rate of 20 kHz/sec is too high. When still utilizing the 1 pps trigger signal derived from the IRIG-B signal, a reduction of the sweep rate to 10 kHz/sec is readily available if the frequency span is reduced to 10 kHz. Data from a wider frequency range can then be obtained by separate measurements each covering a 10 khz frequency span.

APPENDIX A

TABLES OF SOURCE DEPTH VS TIME DELAY AT FIXED RANGE

TABLE I

SOURCE DEPTH VS TIME DELAY AT FIXED RANGE - DABOB BAY

HORIZONTAL RANGE : 100 (yds)
WATER DEPTH : 600 (ft) RECEIVER DEPTH : 300 (ft)

SPEED OF SOUND : 4850 (ft/sec)

DEPTH (ft)	TXR(ms)	TXSR(ms)	TXBR(ms)	t_s (ms)	t_b (ms)	t_r (ms)
50	80.5181	95.0468	185.853	14.5288	105.335	90.8064
100	74.3413	103.093	176.165	28.7516	101.824	73.0723
150	69.1568	111.512	166.551	42.3551	97.3947	55.0396
200	65.2016	120.226	157.026	55.0242	91.8246	36.8004
250	62.7089	129.175	147.606	66.466	84.8975	18.4315
300	61.8557	138.314	138.314	76.4578	76.4578	0
350	62.7089	147.606	129.175	84.8975	66.466	18.4315
400	65.2016	157.026	120.226	91.8246	55.0242	36.8004
450	69.1568	166.551	111.512	97.3947	42.3551	55.0396
500	74.3413	176.165	103.093	101.824	28.7516	73.0723
550	80.5181	185.853	95.0468	105.335	14.5288	90.8064

TXD = Time delay (ms) for the direct path.
TXSR = Time delay (ms) for the surface reflected path.
TXBR = Time delay (ms) for the bottom reflected path.
t_s = Time delay between direct and surface reflected path.
t_b = Time delay between direct and bottom reflected path.
t_r = Time delay between surface and bottom reflected path.

TABLE II

SOURCE DEPTH VS TIME DELAY AT FIXED RANGE - DABOB BAY

HORIZONTAL RANGE : 200 (yds)
WATER DEPTH : 600 (ft) RECEIVER DEPTH : 300 (ft)

SPEED OF SOUND : 4850 (ft/sec)

DEPTH (ft)	TXR(ms)	TXSR(ms)	TXBR(ms)	t_s (ms)	t_b (ms)	t_r (ms)
50	134.021	143.221	214.522	9.20041	80.5015	71.3011
100	130.403	148.683	206.186	18.2794	75.7824	57.503
150	127.519	154.639	198.035	27.1204	70.516	43.3956
200	125.418	161.036	190.094	35.6183	64.6759	29.0577
250	124.14	167.823	182.39	43.6827	58.2495	14.5668
300	123.711	174.954	174.954	51.2429	51.2429	0
350	124.14	182.39	167.823	58.2495	43.6827	14.5668
400	125.418	190.094	161.036	64.6759	35.6183	29.0577
450	127.519	198.035	154.639	70.516	27.1204	43.3956
500	130.403	206.186	148.683	75.7824	18.2794	57.503
550	134.021	214.522	143.221	80.5015	9.20041	71.3011

TXD = Time delay (ms) for the direct path.
TXSR = Time delay (ms) for the surface reflected path.
TXBR = Time delay (ms) for the bottom reflected path.
t_s = Time delay between direct and surface reflected path.
t_b = Time delay between direct and bottom reflected path.
t_r = Time delay between surface and bottom reflected path.

TABLE III

SOURCE DEPTH VS TIME DELAY AT FIXED RANGE - DABOB BAY

HORIZONTAL RANGE : 300 (yds)
WATER DEPTH : 600 (ft) RECEIVER DEPTH : 300 (ft)

SPEED OF SOUND : 4850 (ft/sec)

DEPTH (ft)	TXR(ms)	TXSR(ms)	TXBR(ms)	t_s (ms)	t_b (ms)	t_r (ms)
50	192.593	199.105	255.246	6.5121	62.6526	56.1405
100	190.094	203.069	248.28	12.9756	58.1867	45.2111
150	188.127	207.47	241.554	19.3437	53.4276	34.0839
200	186.709	212.281	235.088	25.5722	48.3788	22.8066
250	185.853	217.475	228.903	31.6214	43.0501	11.4287
300	185.567	223.024	223.024	37.4568	37.4568	0
350	185.853	228.903	217.475	43.0501	31.6214	11.4287
400	186.709	235.088	212.281	48.3788	25.5722	22.8066
450	188.127	241.554	207.47	53.4276	19.3437	34.0839
500	190.094	248.28	203.069	58.1867	12.9756	45.2111
550	192.593	255.246	199.105	62.6526	6.5121	56.1405

TXD = Time delay (ms) for the direct path.
TXSR = Time delay (ms) for the surface reflected path.
TXBR = Time delay (ms) for the bottom reflected path.
t_s = Time delay between direct and surface reflected path.
t_b = Time delay between direct and bottom reflected path.
t_r = Time delay between surface and bottom reflected path.

TABLE IV

SOURCE DEPTH VS TIME DELAY AT FIXED RANGE - DABOB BAY

HORIZONTAL RANGE : 400 (yds)
WATER DEPTH : 600 (ft) RECEIVER DEPTH : 300 (ft)

SPEED OF SOUND : 4850 (ft/sec)

DEPTH (ft)	TXR(ms)	TXSR(ms)	TXBR(ms)	t_s (ms)	t_b (ms)	t_r (ms)
50	252.735	257.732	303.205	4.99684	50.4699	45.473
100	250.836	260.806	297.365	9.9707	46.5295	36.5587
150	249.348	264.248	291.773	14.8994	42.4243	27.5249
200	248.28	268.041	286.442	19.7609	38.1617	18.4008
250	247.637	272.173	281.389	24.5354	33.7511	9.21573
300	247.423	276.627	276.627	29.2043	29.2043	0
350	247.637	281.387	272.173	33.7511	24.5354	9.21573
400	248.28	286.442	268.041	38.1617	19.7609	18.4008
450	249.348	291.773	264.248	42.4243	14.8994	27.5249
500	250.836	297.365	260.806	46.5295	9.9707	36.5587
550	252.735	303.205	257.732	50.4699	4.99684	45.473

TXD = Time delay (ms) for the direct path.
TXSR = Time delay (ms) for the surface reflected path.
TXBR = Time delay (ms) for the bottom reflected path.
t_s = Time delay between direct and surface reflected path.
t_b = Time delay between direct and bottom reflected path.
t_r = Time delay between surface and bottom reflected path.

TABLE V

SOURCE DEPTH VS TIME DELAY AT FIXED RANGE - DABOB BAY

HORIZONTAL RANGE : 500 (yds)
WATER DEPTH : 600 (ft) RECEIVER DEPTH : 300 (ft)

SPEED OF SOUND : 4850 (ft/sec)

DEPTH (ft)	TXR(ms)	TXSR(ms)	TXBR(ms)	t_s (ms)	t_b (ms)	t_r (ms)
50	313.544	317.586	355.483	4.04147	41.9389	37.8974
100	312.016	320.086	350.516	8.07065	38.5001	30.4295
150	310.821	322.896	345.784	12.0752	34.9628	22.8876
200	309.965	326.008	341.298	16.043	31.3329	15.2899
250	309.45	329.413	337.068	19.9632	27.6175	7.6543
300	309.278	333.103	333.103	23.8246	23.8246	0
350	309.45	337.068	329.413	27.6175	19.9632	7.6543
400	309.965	341.298	326.008	31.3329	16.043	15.2899
450	310.821	345.784	322.896	34.9628	12.0752	22.8876
500	312.016	350.516	320.086	38.5001	8.07065	30.4295
550	313.544	355.483	317.586	41.9389	4.04147	37.8974

TXD = Time delay (ms) for the direct path.
TXSR = Time delay (ms) for the surface reflected path.
TXBR = Time delay (ms) for the bottom reflected path.
t_s = Time delay between direct and surface reflected path.
t_b = Time delay between direct and bottom reflected path.
t_r = Time delay between surface and bottom reflected path.

TABLE VI

SOURCE DEPTH VS TIME DELAY AT FIXED RANGE - DABOB BAY

HORIZONTAL RANGE : 600 (yds)
WATER DEPTH : 600 (ft) RECEIVER DEPTH : 300 (ft)

SPEED OF SOUND : 4850 (ft/sec)

DEPTH (ft)	TXR(ms)	TXSR(ms)	TXBR(ms)	t_s (ms)	t_b (ms)	t_r (ms)
50	374.697	378.085	410.434	3.38855	35.7371	32.3486
100	373.418	380.188	406.139	6.76965	32.7208	25.9511
150	372.42	382.556	402.062	10.1359	29.6415	19.5056
200	371.706	385.186	398.21	13.4801	26.5042	13.0241
250	371.277	388.073	394.591	16.7959	23.3138	6.51788
300	371.134	391.209	391.209	20.0755	20.0755	0
350	371.277	394.591	388.073	23.3138	16.7959	6.51788
400	371.706	398.21	385.186	26.5042	13.4801	13.0241
450	372.42	402.062	382.556	29.6415	10.1359	19.5056
500	373.418	406.139	380.188	32.7208	6.76965	25.9511
550	374.697	410.434	378.085	35.7371	3.38855	32.3486

TXD = Time delay (ms) for the direct path.
TXSR = Time delay (ms) for the surface reflected path.
TXBR = Time delay (ms) for the bottom reflected path.
t_s = Time delay between direct and surface reflected path.
t_b = Time delay between direct and bottom reflected path.
t_r = Time delay between surface and bottom reflected path.

TABLE VII

SOURCE DEPTH VS TIME DELAY AT FIXED RANGE - DABOB BAY

HORIZONTAL RANGE : 700 (yds)
WATER DEPTH : 600 (ft) RECEIVER DEPTH : 300 (ft)

SPEED OF SOUND : 4850 (ft/sec)

DEPTH (ft)	TXR(ms)	TXSR(ms)	TXBR(ms)	t_s (ms)	t_b (ms)	t_r (ms)
50	436.047	438.962	467.114	2.91473	31.0665	28.1518
100	434.949	440.774	463.345	5.82541	28.3954	22.57
150	434.093	442.819	459.775	8.72629	25.6826	16.9563
200	433.48	445.094	456.411	11.6132	22.9307	11.3176
250	433.113	447.594	453.257	14.4813	20.1439	5.66263
300	432.99	450.316	450.316	17.3264	17.3264	0
350	433.113	453.257	447.594	20.1439	14.4813	5.66263
400	433.48	456.411	445.094	22.9307	11.6132	11.3176
450	434.093	459.775	442.819	25.6826	8.72629	16.9563
500	434.949	463.345	440.774	28.3954	5.82541	22.57
550	436.047	467.114	438.962	31.0665	2.91473	28.1518

TXD = Time delay (ms) for the direct path.
TXSR = Time delay (ms) for the surface reflected path.
TXBR = Time delay (ms) for the bottom reflected path.
t_s = Time delay between direct and surface reflected path.
t_b = Time delay between direct and bottom reflected path.
t_r = Time delay between surface and bottom reflected path.

TABLE VIII

SOURCE DEPTH VS TIME DELAY AT FIXED RANGE - DABOB BAY

HORIZONTAL RANGE : 800 (yds)
WATER DEPTH : 600 (ft) RECEIVER DEPTH : 300 (ft)

SPEED OF SOUND : 4850 (ft/sec)

DEPTH (ft)	TXR(ms)	TXSR(ms)	TXBR(ms)	t_s (ms)	t_b (ms)	t_r (ms)
50	497.523	500.08	524.964	2.55685	27.441	24.8841
100	496.561	501.671	521.613	5.11017	25.0518	19.9416
150	495.811	503.469	518.445	7.65762	22.6339	14.9763
200	495.275	505.47	515.464	10.1954	20.1893	9.9939
250	494.953	507.673	512.673	12.7206	17.72	4.99939
300	494.845	510.075	510.075	15.2297	15.2297	0
350	494.953	512.673	507.673	17.72	12.7206	4.99939
400	495.275	515.464	505.47	20.1893	10.1954	9.9939
450	495.811	518.445	503.469	22.6339	7.65762	14.9763
500	496.561	521.613	501.671	25.0518	5.11017	19.9416
550	497.523	524.964	500.08	27.441	2.55685	24.8841

TXD = Time delay (ms) for the direct path.
TXSR = Time delay (ms) for the surface reflected path.
TXBR = Time delay (ms) for the bottom reflected path.
t_s = Time delay between direct and surface reflected path.
t_b = Time delay between direct and bottom reflected path.
t_r = Time delay between surface and bottom reflected path.

TABLE IX

SOURCE DEPTH VS TIME DELAY AT FIXED RANGE - DABOB BAY

HORIZONTAL RANGE : 900 (yds)
WATER DEPTH : 600 (ft) RECEIVER DEPTH : 300 (ft)

SPEED OF SOUND : 4850 (ft/sec)

DEPTH (ft)	TXR(ms)	TXSR(ms)	TXBR(ms)	t_s (ms)	t_b (ms)	t_r (ms)
50	559.082	561.359	583.636	2.27686	24.5541	22.2772
100	558.226	562.777	580.624	4.55109	22.3977	17.8466
150	557.56	564.38	577.78	6.82031	20.2202	13.3999
200	557.083	566.166	575.106	9.0835	18.0236	8.94006
250	556.796	568.134	572.606	11.3376	15.8096	4.47198
300	556.701	570.281	570.281	13.5803	13.5803	0
350	556.796	572.606	568.134	15.8096	11.3376	4.47198
400	557.083	575.106	566.166	18.0236	9.0835	8.94006
450	557.56	577.78	564.38	20.2202	6.82031	13.3999
500	558.226	580.624	562.777	22.3977	4.55109	17.8466
550	559.082	583.636	561.359	24.5541	2.27686	22.2772

TXD = Time delay (ms) for the direct path.
TXSR = Time delay (ms) for the surface reflected path.
TXBR = Time delay (ms) for the bottom reflected path.
t_s = Time delay between direct and surface reflected path.
t_b = Time delay between direct and bottom reflected path.
t_r = Time delay between surface and bottom reflected path.

TABLE X

SOURCE DEPTH VS TIME DELAY AT FIXED RANGE - DABOB BAY

HORIZONTAL RANGE : 1000 (yds)
WATER DEPTH : 600 (ft) RECEIVER DEPTH : 300 (ft)

SPEED OF SOUND : 4850 (ft/sec)

DEPTH (ft)	TXR(ms)	TXSR(ms)	TXBR(ms)	t_s (ms)	t_b (ms)	t_r (ms)
50	620.701	622.752	642.906	2.05096	22.2045	20.1536
100	619.93	624.031	640.172	4.10132	20.2426	16.1412
150	619.329	625.477	637.594	6.1474	18.2645	12.1171
200	618.9	627.089	635.172	8.18842	16.2716	8.08319
250	618.643	628.866	632.909	10.223	14.2661	4.04309
300	618.557	630.807	630.807	12.2498	12.2498	0
350	618.643	632.909	628.866	14.2661	10.223	4.04309
400	618.9	635.172	627.089	16.2716	8.18842	8.08319
450	619.329	637.594	625.477	18.2645	6.1474	12.1171
500	619.93	640.172	624.031	20.2426	4.10132	16.1412
550	620.701	642.906	622.752	22.2045	2.05096	20.1536

TXD = Time delay (ms) for the direct path.
TXSR = Time delay (ms) for the surface reflected path.
TXBR = Time delay (ms) for the bottom reflected path.
t_s = Time delay between direct and surface reflected path.
t_b = Time delay between direct and bottom reflected path.
t_r = Time delay between surface and bottom reflected path.

APPENDIX B

TABULATED MEASUREMENT RESULTS

ANALYIS METHOD: QUICK ANALYSIS

DATE OF ANALYSIS: 11/17/84

RECORDED MAGNITUDE LEVELS (dB re 1V)

DELAY(MS)	DIRECT MAGN	DIRECT FRQ(HZ)	REFL MAGN	REFL FRQ(HZ)	NOISE MAGN
68	-56.13	1000	19.75	0	-75.38
72	-51.70	1400	19.75	0	-74.53
76	-47.79	1900	19.75	0	-73.79
80	-41.91	2250	19.75	0	-73.09
84	-38.56	2450	19.75	0	-72.07
88	-37.80	2700	19.75	0	-70.98
92	-35.96	3150	19.75	0	-70.75
96	-36.08	3600	19.75	0	-71.30
100	-34.51	4000	19.75	0	-71.37
104	-32.50	4400	19.75	0	-70.06
108	-31.13	4800	19.75	0	-69.88
112	-29.58	5050	19.75	0	-70.29
116	-28.87	5450	19.75	0	-70.00
120	-27.65	5950	19.75	0	-69.96
124	-26.71	6200	19.75	0	-69.27
128	-24.77	6650	19.75	0	-68.72
132	-23.93	7000	19.75	0	-67.66
136	-22.61	7500	19.75	0	-67.37
140	-21.40	7800	19.75	0	-66.55
144	-20.95	8200	19.75	0	-65.53
148	-20.46	8550	19.75	0	-64.58
152	-19.30	8950	-58.90	1450	-64.54
156	-18.46	9250	-53.28	1850	-63.85
160	-18.25	9800	-47.89	2200	-62.80
164	-17.75	10050	-44.62	2350	-62.83
168	-17.26	10450	-44.52	2800	-63.06
172	-16.44	10850	-43.92	3150	-63.36
176	-15.70	11250	-42.80	3450	-63.10
180	-15.32	11650	-42.11	4000	-62.68
184	-15.45	12000	-40.63	4350	-61.39
188	-15.58	12400	-38.61	4750	-60.55
192	-16.20	12750	-37.21	5150	-59.63
196	-15.96	13250	-35.65	5450	-58.76
200	-15.79	13600	-36.37	5800	-58.24
204	-16.79	13850	-35.18	6300	-58.26
208	-17.28	14300	-35.23	6600	-58.83
212	-18.31	14750	-33.37	7000	-58.80
216	-18.97	15050	-33.74	7450	-58.67
220	-19.86	15450	-31.77	7850	-58.25
224	-20.61	15900	-31.39	8200	-58.06
228	-20.35	16300	-30.87	8600	-57.49
232	-20.84	16650	-29.90	8900	-56.93
236	-20.35	17200	-29.43	9400	-56.68
240	-19.36	17600	-29.68	9700	-56.15

RECORDED MAGNITUDE LEVELS (dB re 1V)

DELAY(MS)	DIRECT MAGN	DIRECT FRQ(HZ)	REFL MAGN	REFL FRQ(HZ)	NOISE MAGN
244	-18.63	17950	-29.00	10050	-55.98
248	-17.74	18300	-29.11	10500	-55.89
252	-16.88	18700	-26.86	11000	-51.00
256	-16.13	18950	-27.10	11400	-46.46
260	-20.60	18950	-26.92	11750	-47.15
264	-36.05	19050	-26.88	12050	-53.85
268	19.75	0	-26.28	12450	-59.30
272	19.75	0	-26.82	12800	-59.43
276	19.75	0	-27.39	13200	-59.90
280	19.75	0	-28.92	13700	-59.67
284	19.75	0	-27.31	14150	-58.90
288	19.75	0	-26.33	14350	-58.79
292	19.75	0	-25.68	14700	-58.28
296	19.75	0	-26.61	15250	-58.51
300	19.75	0	-27.19	15500	-58.47
304	19.75	0	-27.93	15850	-57.76
308	19.75	0	-27.77	16400	-58.07
312	19.75	0	-28.53	16800	-58.28
316	19.75	0	-28.72	17050	-58.29
320	19.75	0	-30.07	17400	-58.27
324	19.75	0	-30.81	17900	-57.92
328	19.75	0	-31.38	18150	-57.26
332	19.75	0	-31.64	18500	-56.56
336	19.75	0	-31.40	18900	-54.70
340	19.75	0	-36.55	19050	-55.53
344	19.75	0	19.75	0	-59.43

ANALYIS METHOD: AUTO ANALYSIS

DATE OF ANALYSIS: 11/17/84

RECORDED MAGNITUDE LEVELS (dB re 1V)

DELAY(MS)	DIRECT MAGN	DIRECT FRQ(HZ)	REFL MAGN	REFL FRQ(HZ)	NOISE MAGN
68	19.75	0	19.75	0	-73.43
72	19.75	0	19.75	0	-73.20
76	-52.39	1450	19.75	0	-62.65
80	-48.08	1800	19.75	0	-62.65
84	-42.47	2250	19.75	0	-62.65
88	-38.25	2400	19.75	0	-62.65
92	-37.29	2750	19.75	0	-62.65
96	-36.06	3050	19.75	0	-62.65
100	-36.88	3550	19.75	0	-62.65
104	-35.05	3900	19.75	0	-62.65
108	-33.21	4300	19.75	0	-62.65
112	-32.18	4850	19.75	0	-62.65
116	-29.07	5200	19.75	0	-62.65
120	-28.60	5400	19.75	0	-62.65
124	-27.76	5850	19.75	0	-62.65
128	-27.00	6350	19.75	0	-62.65
132	-25.63	6550	19.75	0	-62.65
136	-23.98	7000	19.75	0	-62.65
140	-22.44	7400	19.75	0	-62.65
144	-21.44	7800	19.75	0	-62.65
148	-20.96	8100	19.75	0	-62.65
152	-20.52	8550	19.75	0	-62.65
156	-19.97	9000	19.75	0	-62.65
160	-18.53	9350	19.75	0	-62.65
164	-19.47	9500	-49.40	2250	-62.65
168	-18.03	10100	-44.74	2450	-59.15
172	19.75	0	19.75	0	19.75
176	-16.94	10900	-44.36	3050	-57.68
180	-16.72	11250	-43.17	3450	-57.83
184	-16.73	11600	-42.09	4000	-55.28
188	-15.97	11950	-39.87	4200	-54.06
192	-16.48	12450	-39.08	4750	-53.15
196	-16.33	12850	-37.47	5200	-50.95
200	-16.95	13050	-37.89	5350	-51.19
204	-16.18	13450	-36.53	5750	-48.10
208	-17.47	13850	-34.93	6300	-48.53
212	-17.77	14350	-34.33	6600	-46.41
216	-18.14	14750	-33.83	7050	-46.26
220	-19.05	15050	-33.89	7550	-48.14
224	-19.00	15400	-32.16	7700	-45.90
228	-19.87	15850	-30.73	8250	-45.14
232	-21.03	16350	-30.46	8500	-47.32
236	-21.70	16450	-30.20	8800	-45.80
240	-20.66	17150	-28.00	9350	-45.52

RECORDED MAGNITUDE LEVELS (dB re 1V)

DELAY(MS)	DIRECT MAGN	DIRECT FRQ(HZ)	REFL MAGN	REFL FRQ(HZ)	NOISE MAGN
244	-19.42	17500	-27.59	9650	-45.30
248	-18.31	17950	-26.90	10250	-45.34
252	-18.07	18250	-27.06	10350	-44.49
256	-16.97	18650	-25.08	10950	-40.60
260	19.75	0	19.75	0	19.75
264	19.75	0	-24.85	11750	-37.12
268	19.75	0	-26.44	12100	-37.50
272	19.75	0	-26.33	12250	-43.93
276	19.75	0	19.75	0	19.75
280	19.75	0	-26.34	13150	-47.90
284	19.75	0	19.75	0	19.75
288	19.75	0	19.75	0	19.75
292	19.75	0	19.75	0	19.75
296	19.75	0	-27.66	14750	-48.48
300	19.75	0	-27.33	15000	-46.72
304	19.75	0	19.75	0	19.75
308	19.75	0	-28.01	16000	-48.39
312	19.75	0	-29.61	16250	-47.58
316	19.75	0	-29.64	16450	-47.12
320	19.75	0	-29.33	16950	-46.91
324	19.75	0	-34.56	17500	-47.62
328	19.75	0	-32.49	17950	-47.44
332	19.75	0	-32.38	18200	-47.43
336	19.75	0	-34.02	18500	-47.33
340	19.75	0	19.75	0	-53.30
344	19.75	0	19.75	0	-54.15

APPENDIX C

TAPE CHANNEL CONFIGURATION AND TAPE LOG

CHANNEL	CODE	CONTENT
1 - 7		Not used
8	(D)	Reference
9	(D)	Gain code
10	(D)	Top hydrophone
11	(D)	Middle hydrophone
12	(D)	Bottom hydrophone
13	(D)	IRIG-B
14	(D)	Voice comments

TAPE LOG

	AUTOGAIN
A. Calibration signal	0 dB
B. Ambient noise	70 dB
C. Swept tone, constant depth	10 dB
D. Swept tone, varied depth	10 dB

Receiver depth:	Top	240 ft
	Middle	300 ft
	Bottom	340 ft

Scource depth: (C) 300 ft fixed

(D) Varied from 300 ft to surface

Source/Receiver horizontal separation nominally 300 yds.

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