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# Definition of the Acoustical Structure of Echolocation Pulse Trains of an Atlantic Bottlenose Dolphin in Captivity

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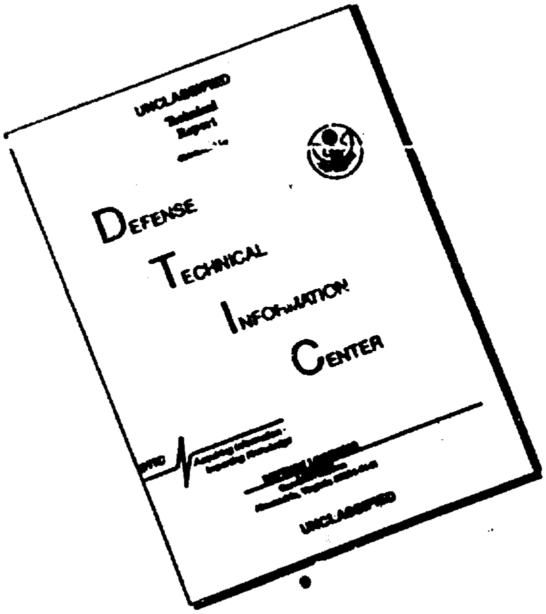

# PREFACE

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Echolocation capabilities of an Atlantic bottlenose dolphin, Tursiops truncatus, were observed in a target detection experiment. Pulse trains occurring during the echolocation sequence were then analyzed in an effort to determine the animal's average frequency range, choice of center frequency, bandwidth, pulse repetition rate, pulse duration, amplitude, and signal-to-noise-ratio (SNR). The animal was trained to detect a polypropylene ring measuring 14.34 centimeters in diameter. Target ranges of 11.582 meters and 15.85 meters were used. Signal-to-noise-ratio (SNR) was determined as a function of pool ambient noise and reverberation characteristics at each target range. The animal was observed to be consistent in its performance at the correct response threshold of 75 percent.

Atlantic bottlenose dolphin   Tursiops truncatus   target range
bandwidth   frequency range   bandwidth   amplitude
pulse repetition rate   signal-to-noise ratio   ambient noise

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## INTRODUCTION

Many experiments have been conducted to study the echolocation capabilities of odontocetes; however, little has been done to actually define the acoustic structure of echolocation signals as a holistic model representation of a typical echolocation task. It is as yet unknown how specific environmental parameters affect the animal's sensory thresholds. Differences in environmental systems as well as experimental designs and procedures have made modeling studies difficult. In addition, the bias of training must be accounted for as much as possible since psychophysical methods are principally used to determine animal sensory thresholds. This was clearly demonstrated by Watkins and Wartzok (1985).

As a baseline for this work, the acoustic environment of the pool system in which this animal lived and worked was characterized by a series of tests designed to yield an "acoustical fingerprint" or descriptive model of the area. The primary acoustic environmental parameters measured during the testing consisted of the ambient noise level, reverberation levels, and standing wave or "dead" zone areas in the acoustic path of the animal. Because other animals were also present in the same pool system their presence was accounted for by a comparison of the amplitude of signals emitted by the group of animals (which were kept in an adjoining holding pool) and the working animal in the main pool. Each pool was monitored on separate channels with independent hydrophones.

Cetaceans are capable of using a wide variety of sounds depending upon the task being performed (Watkins and Wartzok, 1985). Au et al (1974) has suggested that bottlenose dolphins change their signals to compensate for differences in ambient noise levels. Individual experiments have been conducted to determine the levels of specific parameters of dolphin echolocation signals (Au and Turl, 1983). In the present study a holistic representation of typical acoustic parameters of an Atlantic bottlenose dolphin's echolocation sequence on a stationary target was defined. These baseline parameters facilitate the determination of how the animal might change its signal structure in other environments (Scheifele, 1989).

The description of this animal's acoustic structure was accomplished by digitizing its pulse trains during the first two seconds of an echolocation task over fifty trials. The first two seconds were chosen as the time of interest because it was confirmed by video footage and simple geometry that the animal was initially scanning for the target when she was in a position where her beam was normal to the target.

To allow the animal to echolocate in as "natural" a manner as possible, she was allowed to perform the entire sequence from search to target acquisition in a manner of her choice and in any amount of time she wished to take. It was hoped that this would cause her to perform the task in a manner that closely approximated her natural tendencies and thus decrease the bias in signal detection due to training in this experiment.

## MATERIALS AND METHODS

This target detection/acquisition experiment was conducted in the main performance pool at Mystic Marinelife Aquarium, Mystic, Connecticut, using an adult female bottlenose dolphin, Tursiops truncatus, designated (KTT-08). The test enclosure was a concrete, nearly elliptical pool with a depth of 6.096 meters, width of 12.192 meters, and major axis length of 21.336 meters. The experimental configuration with the dolphin at the starting position for both the 11.58 meter and 15.85 meter targets is shown in figure 1.

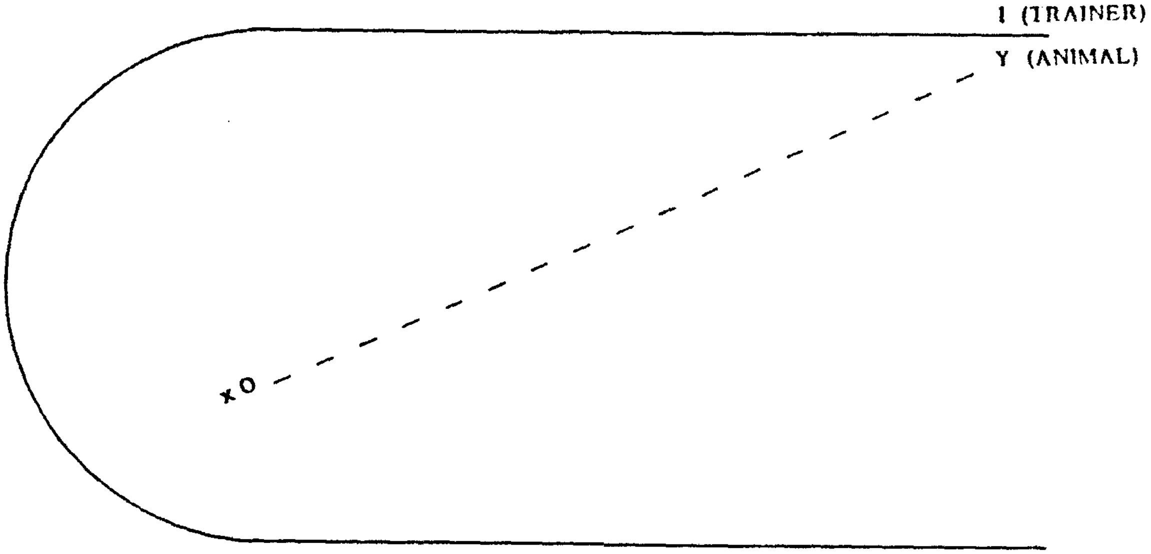

Figure 1. Target Detection/Acquisition Experiment Configuration

The dolphin was fitted with soft rubber, opaque eyecups as the target was simultaneously placed in a position either directly in front of or behind the hydrophone. Once the eyecups were both securely in place on the animal she was allowed to proceed with the task in the manner and time of her own choosing. Time was started when her head submerged and she was facing in the general direction of the target. Only the first two seconds of the "search" phase were used as data, even though the entire task, from search up to and including acquisition, was analyzed.

Targets were thin-walled polypropyline, air-filled circular rings and weighted with water in one side to allow the ring to lie vertically in the water. The targets were suspended directly in-line with the hydrophone, either in front of or behind the hydrophone. The hydrophone was suspended at a depth of 0.83 meters.

Data collection consisted of blocks of echolocation sequences all performed on the same day. Over a two year period, 150 sequences were performed; however, only 50 sequences were validated for use in this experiment. These 50 sequences were all similar in that the animal was at the proper orientation with respect to the hydrophone (that is beam directed normal to the hydrophone axis) and that the animal was actually in "search" (pulsing) for the initial two seconds of the search. The animal participated in blocks of echolocation sequences one day per week.

The data acquisition system consisted of a USRD/NRL MODEL H52 hydrophone (with an accuracy of within +2/-1 dB from 50 Hz to 150 kHz); Lockheed Electronics Model STORE 4D tape recorder (operated at 30 ips); Ithaco Model 455 amplifier; and Hewlett-Packard Model 3562A Spectrum Analyzer. In addition, closeup video photography of the animal was taken using a Cannon Model VC-30A video camera system.

Once the data was collected, an initial power spectrum analysis was completed using the same equipment with which the data was collected. Frequency versus amplitude (power) spectrums were plotted. The data was then digitized on a VACS 11/780 computer, using a sample frequency of 25 kHz with a 0.00000125-ms lapse between samples.. Each pulse of interest over the two-second real time was then plotted and Fast Fourier Transforms (FFTs) completed to completely analyze frequency content. The animal's choice of center frequency was derived by inspection of the FFT plots. Other acoustic structural parameters were analyzed through cross-correlation and statistically effective bandwidth methods. Figure 2 shows a block diagram of the analysis equipment.

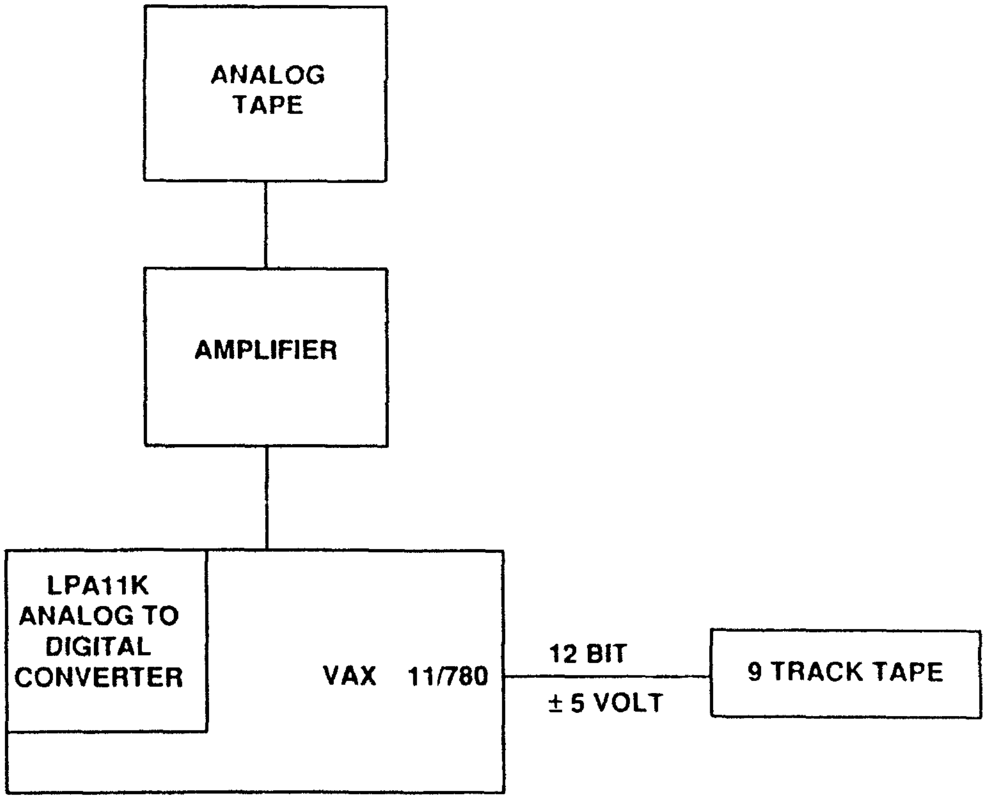

Figure 2. Analysis Equipment Block Diagram

# RESULTS

## SIGNAL-TO-NOISE RATIO

The animal showed fairly large fluctuations in its emitted source levels. The greatest variation between the maximum and minimum signal levels was 10 dB. The actual signal level that the animal used to detect the target is unknown; however, using the maximum signal level found during all of the trials, the maximum source level can be calculated as $S_r$ (Au and Penner, 1981). The signal-to-noise ratio is then given by

$$(S_r/N_0)_{max} \simeq SNR.$$

Because dolphin signals are transient, they may produce echoes that may be many times longer than the transmitted signal (Au, 1989). The equation must then be changed to the more generalized form involving the energy flux density (Urick, 1983). It appears as

$$I = 1/T \int_0^T p^2(t)dt/\rho c = E/T \ ;$$

TS = 10 log echo intensity 1m from target/incident intensity.

Assuming that dolphins detect signals in noise as an energy detector having a specific integration time of $_{int}$, then a transient form of the sonar equation is applicable to the dolphin (Au, 1989) as follows:

$$DT_E = DT\text{-}10 \log {}_{int} = SE\text{-}2TL\text{+}TS\text{-}(NL\text{-}DI).$$

The detection threshold, $DT_E$, corresponds to the energy-to-noise ratio used in human psychophysics and is equal to the maximum source energy flux density. Thus,

$$10 \log (E_e/N_0) = DT_E$$

where $E_e$ is the echo energy flux density and $N_0$ is the noise spectral density level. DT is the SNR used in sonar engineering. Using this equation, a maximum source energy flux density of 10.5 dB re(1 uPa)$^2$s was calculated at a range of 15.85 m. This compares well with the data accumulated by Au (1988) for his subjects prior to the time that their performance levels indicated that they might be "guessing" at the highest noise levels during target detection experiments.

Our test animal appeared to use two specific types of pulses routinely when performing this task. Enlargements of each of these and the FFTs of each are shown in figures 3 and 4. Over the course of the trials analyzed, the typical center frequency chosen ranged from 50 kHz to 130 kHz in this enclosure. The mean frequency appeared to be 85 kHz.

Pulse trains were recorded in two-second increments per trial. The two seconds were recorded when the animal initially scanned for the target with its head oriented approximately normal to the target. This was verified through slow-motion video footage taken coincidentally with the acoustic data. During these times, the animal's pulse rate varied from 88 pulses per second to as high as 150 pulses per second.

Using the digitized waterfall plots of each sequence, the data showed the average pulse duration to be 0.032 m/sec. Because the target and animal were shallow (3 ft), there was some question as to whether the trailing edge of the recorded pulses were actually surface reflections of the true animal pulse. In most cases, the pulse was truncated to clip off the reverberation, thus leaving only the signal itself.

This animal performed 105 trials. Each of these trials was used for analysis. Only the first four seconds of acoustical data were analyzed. It is interesting to note that the animal performed reliably, that is, completed the sequence by actually retrieving the target object 75 percent of the time. This was identical to the response threshold of animals used in similar experiments in Hawaii.

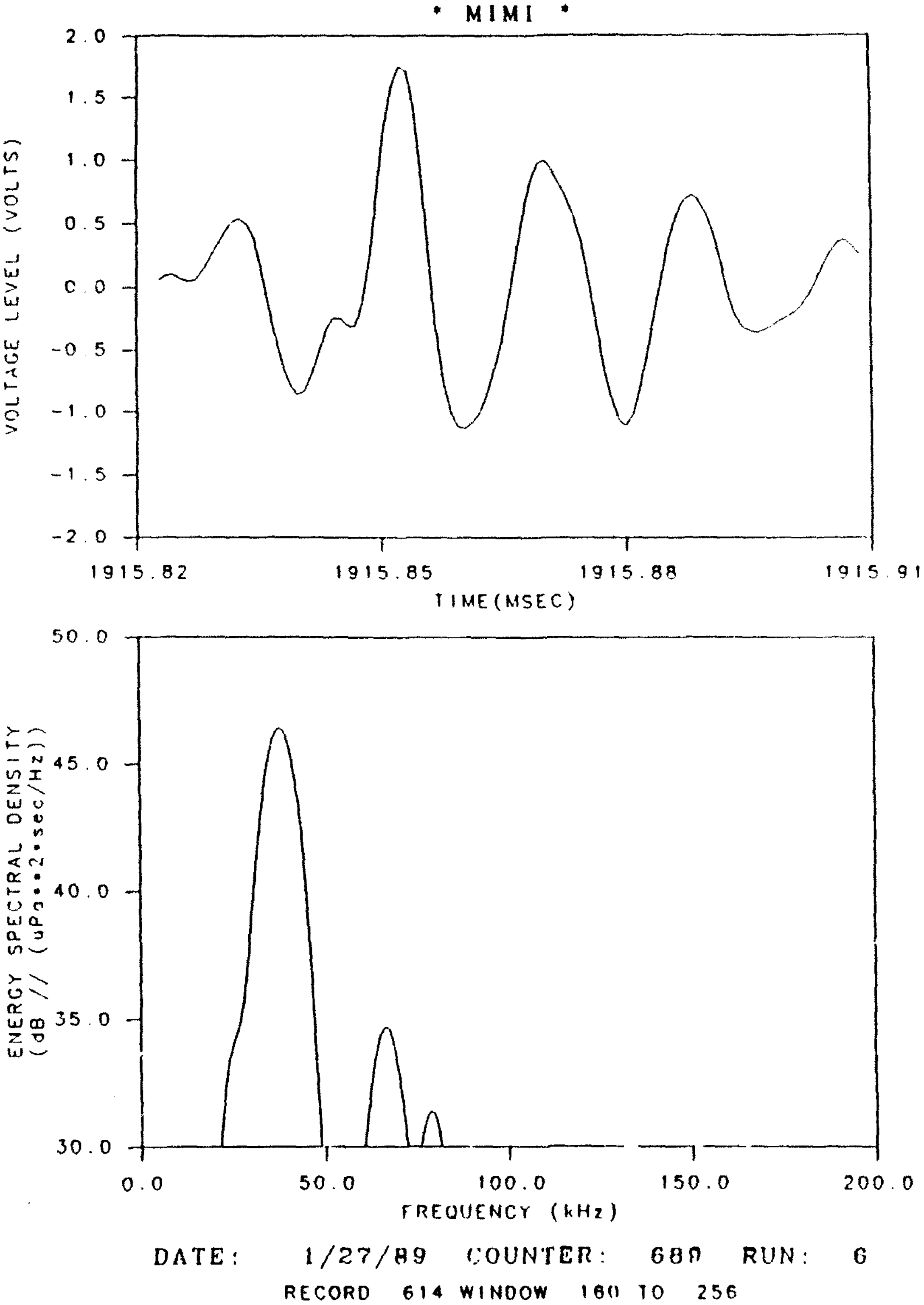

**Figure 3.** Animal Pulse Trains (88 pulses per second)

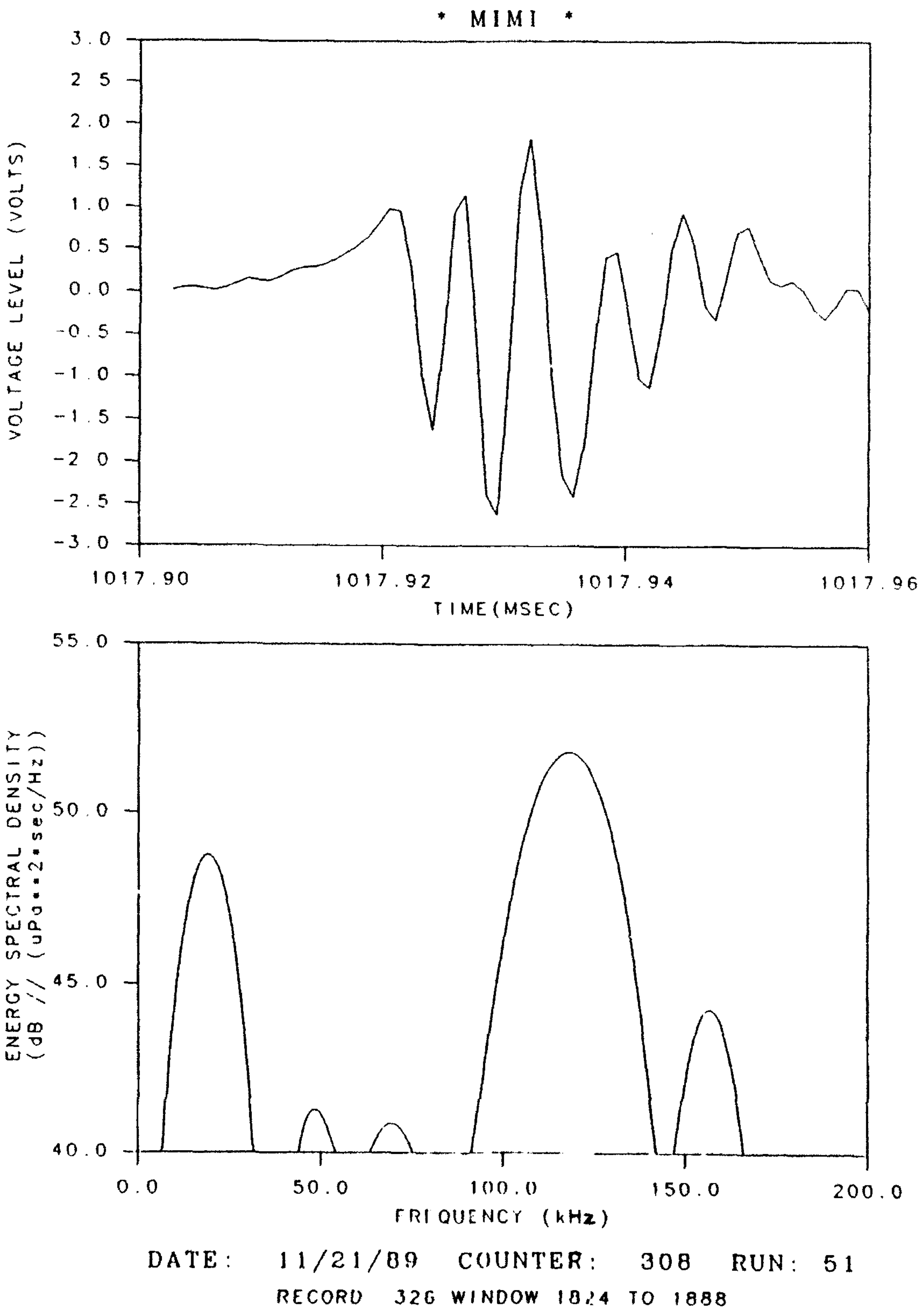

**Figure 4. Animal Pulse Trains (150 pulses per second)**

## CONCLUSIONS

As it appears that the animal routinely employed two specific pulse types during this broadband search, it seems to indicate that her search acoustics are nearly the same as those employed in current conventional sonar systems that operate using different bandwidths. The broader band pulse may be used to determine the target's position; the narrower band, to calculate relative speed with respect to the target. In a pool environment, there would be no true Doppler but simply a stretching or compression of the frequency.

Pulse duration and pulse repetition rate were probably related to the animal's relative distance from the target as well as the movement of the target across the beam of the animal. In only three cases out of fifty sequences was the animal ever still in relation to the target.

It is acknowledged that Tursiops truncatus is capable of controlling boundary layer flow. This dolphin is also capable of transmitting echolocation pulses while swimming at high rates of speed (5 knots). It is possible, therefore, that the low self-noise produced by the dolphin's hydrodynamic structure may be a significant factor in the acoustic performance of the species. It is our intent to compare the data from this study with the same parameters found in echolocation pulses from a stationary animal.

Finally, it is prudent to conduct comparison studies involving other species (e.g., Beluga whales). The data base may then be expanded to allow a better understanding of target recognition by marine mammals in general, a capability which is directly related to the Active Classification Program.

Clearly, comparison studies of other species would be beneficial to the design of conventional sonar, especially as it relates to acoustic detection and classification program. Applications to hydrodynamics may made by comparing the acoustical structures of a single species of stationary versus moving animals. Knowledge of low self-noise compliant surfaces may be responsible for the dolphin's level of acoustic performance, that is, low self-noise due to dolphin hydrodynamic structure may be a significant factor in the acoustical performance of this animal. These studies would have direct application to sonar and hull design.

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