The target detection capability of the Atlantic bottlenose dolphin (*Tursiops truncatus*) in the open waters of Kaneohe Bay, Oahu, Hawaii will be discussed using the noise-limited form of the sonar equation. In Kaneohe Bay, *Tursiops* typically emit short duration transient—like broadband echolocation signals with peak frequencies between 110–130 kHz (Au, 1980). Therefore the generalized or transient form of the sonar equation based on energy flux density instead of intensity must be used (Urick, 1983).
APPLICATION OF THE SONAR EQUATION TO DOLPHIN ECHOLOCATION

Whitlow W. L. Au
Naval Ocean Systems Center
P.O. Box 997, Kailua, Hawaii 96734 USA

The target detection capability of the Atlantic bottlenose dolphin (Tursiops truncatus) in the open waters of Kaneohe Bay, Oahu, Hawaii will be discussed using the noise-limited form of the sonar equation. In Kaneohe Bay, Tursiops typically emit short duration transient-like broadband echolocation signals with peak frequencies between 110-130 kHz in (Au, 1980). Therefore the generalized or transient form of the sonar equation based on energy flux density instead of intensity must be used (Urick, 1983). An example of a Tursiops echolocation signal and its frequency spectrum is shown in Fig. 1. The peak-to-peak source level is shown on the oscilloscope display.

![Fig. 1. An example of an echolocation signal of Tursiops truncatus measured in Kaneohe Bay.](image)

I. GENERALIZED SONAR EQUATION: NOISE-LIMITED FORM

The generalized form of the noise-limited sonar equation applicable to a dolphin can be expressed as (Urick, 1983)

\[ DT = SE - 2 TL + TS - (NL - DI) \]  

(1)

The detection threshold, DT, corresponds to the energy-to-noise ratio used in human psychophysics and is equal to 10 Log (E/N0), where E is the echo energy flux density and N0 is the noise spectral density level. SE is the source energy flux density. TL is the transmission loss, TS is the target strength based on the ratio of the energy in the echo and incident energy. NL is the ambient noise density, and DI is the receiving directivity index.

In order to use Eq. 1, the target detection capability of the dolphin must be measured along with other parameters associated with the animal’s sonar and the environment. Murchison (1980) performed a maximum range detection experiment with two Tursiops, using a 2.34-cm diam. solid steel sphere and a 7.62-cm diam. stainless steel water-filled sphere as targets. The composite 50\% correct detection threshold was at ranges of 72 and 77 m for the 2.34-cm and 7.62-cm spheres, respectively. However, the dolphins performance with the 7.62-cm sphere was affected by reverberation from a bottom ridge located at a range of 73 m.

Au and Snyder (1980) remeasured the maximum detection range in a different part of Kaneohe Bay using one of the same dolphins (Sven) and a 7.62-cm diam. sphere Sven’s target detection performances for the 2.34-cm sphere (Murchison, 1980) and the 7.62-cm sphere (Au and Snyder, 1980) are plotted in Fig. 2 as a function of range. The 50\% correct detection threshold for the 7.62-cm sphere occurred at 111 m, considerably longer range than the 76 m measured by Murchison (1980).

II APPLYING THE SONAR EQUATION

The parameters in the sonar equation (Eq. 1) will now be discussed according to the order they appear in the equation. The first term has to do with the signals used by dolphins. Sonar signals are projected in a beam directed forward of the animal. The composite transmit beam pattern from three dolphins in the horizontal and vertical planes (Au et al., 1978; Au, 1980; Au et al., 1986) are shown in Fig. 3. The 3-dB beamwidth in both planes have similar values, approximately 10°.

![Fig. 2. Target detection performance a Tursiops truncatus as a function of range for two spherical targets (from Murchison, 1980; Au and Snyder, 1980).](image)

![Fig. 3. Transmit (inner curves) and receive (for a frequency of 120 kHz; outer curves) beam patterns for Tursiops in the horizontal and vertical planes.](image)