A Brief Overview of Sonar Operation

by
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Sonar is an acronym for **so**und **na**vigation and **r**anging. Since electromagnetic radiation does not propagate well in the ocean and sound does, sonar is used underwater instead of radar. Sound waves are used in different sonar systems for a wide variety of applications, including depth determination, bottom mapping, navigation, communication, target detection and classification for Anti-Submarine Warfare (ASW) or anti-mine warfare, etc.

In order to analyze and simulate a sonar system, mathematical models must be developed of all portions of the system, the propagation medium, and the target. The sonar system consists of an electronics package that first applies an appropriate electrical excitation to the sonar transducer. The transducer receives the electrical energy and transforms it into acoustic energy which radiates through the liquid ocean medium. The sound wave will propagate with the three dimensional radiation pattern based on the physical size of the transducer as compared to the wave length of sound for the frequency used. The wavelength is related to frequency and sound speed by

$$c = f\lambda \tag{1}$$

Where: c is the speed of sound in meters
f is the frequency in Hz
λ is the wavelength in meters

The radiating transducer can be designed to have a beam pattern of any shape, such as omni-directional, conical, or fan-shaped. The characteristics of the beam pattern will determine the Directivity Index (DI) of the sonar system. The acoustic Sound Pressure (SPL) produced by the system is a function of the electrical power applied to the transducer, the efficiency of the transducer, and the DI of the radiating beam angle. The Source Level (SL) of the sonar system is defined as the SPL at 1 meter from the transducer. As a reference, 1 Watt of acoustic energy radiating in an omni-directional pattern will produce a source level of 170 dB//1μPa at 1 meter.

The sound pulse travels through the ocean at a nominal velocity of 1,500 m/sec., but the actual sound speed varies as a function of salinity, temperature, and depth. As the sound propagated through the medium, the intensity is reduced by spherical spreading and absorption. The higher the frequency, the greater the attenuation due to absorption. For example, at 10 kHz the attenuation of sound in the ocean is approximately 100 dB/kyd; at 10 kHz it is approximately 100 dB/kyd; and at 1 MHz it is approximately 1,000 dB/kyd.[5]

In addition, sound is scattered as it propagates through the medium. This produces a back-scatter acoustic signal called reverberation. This reverberation signal can be caused by particles and air bubbles in the water column (volume reverberation), back-scatter from the ocean floor (bottom reverberation), and back-scatter from wave action (surface reverberation).

When the sound beam hits a target, a reflected echo is produced. The intensity of the reflected acoustic wave is a function of the incident sound pressure and the reflection characteristics of the target. Every target has a Target Strength (TS), which is a measure of the reflected sound pressure level at one meter from the target as compared to the actual incident sound pressure of the acoustic wave. The TS of an object is a function of its size and shape. Large targets such as submarines can produce positive target strengths of greater than 30 dB, which smaller objects produce negative target strengths below -20 dB.

The reflecting echo travels back to the sonar system loosing intensity again due to spherical spreading and absorption. The echo sound pressure pulse that arrives at the sonar system is then converted into an electrical signal by the transducer. In some systems, the same transducer is used for both transmitting and receiving. In other systems, a separate transducer is used for receiving. A transducer used only for receiving is called a hydrophone. The received electrical signal is then amplified and processed by the receiving circuitry of the sonar system. [1,3,4,5]

It is straightforward to simulate the operation of the electronic portions of the sonar system using any number of circuit analysis programs. The transducer can also be defined by an equivalent circuit for computer analysis. [2,4,7,8,9]

The sound propagation in the medium is defined by

$$EL = SL - 40\log R - 2\alpha R + TS \tag{2}$$

Where:
- EL is the echo level of the target in dB//1μPa
- SL is the transmitting sound level in dB//1μPa at 1m
- R is the target range in meters
- α is the attenuation in dB//in.
- TS is the target strength in dB

$$SL = 170.8 + 10\log W - DI \tag{3}$$

Where:
- SL is the transmitting sound level in dB//1μPa at 1m
- W is the total acoustic power radiated by the transducer in Watts
- DI is the transmitting transducer Directivity Index in dB

The background acoustic noise is

$$N_A = NL + 10\log BW - DI \quad (4)$$

Where: N_A is the total received background acoustic noise in dB//1μPa
NL is the acoustic noise in the ocean in dB//1μPa/Hz
BW is the receiving bandwidth of the system in Hz
DI is the receiving transducer Directivity Index in dB

The calculation for reverberation is not as simple, since it is a function of the type of reverberation in being considered (bottom, surface, or volume), the incident angle of the acoustic pulse, the beam angles of the acoustic pulse, and the reflecting characteristics of the bottom, surface or volume causing the reverberation. Therefore, a simulation program must contain a number of possible reverberation scenarios that can be specified and accessed during the simulation run. [1,3,4,5]

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