Sub-Bottom Profilers

To understand where the different Sub-Bottom Profiler fits into the range of underwater sonar equipment, we will briefly review the types of instruments available.

Types of Sub-Bottom Profilers

At the highest level of generalization, sonar systems are of three types:

- Passive systems
  They use a hydrophone to detect a noise made by the object, be it a submarine, or a transponder implanted in the ocean floor.
- Active continuous wave (CW) systems
  They transmit a sound beam continuously. Sound reflected by objects in the beam path is detected by a hydrophone. this type of equipment is often used in detecting moving objects by measuring the doppler frequency shift of the scattered signal relative to the transmitted frequency.
- Active pulse sonar systems
  They trigger a burst of sound energy (a ping) and detect the returning echo. The amplified echo signal is displayed as a function of a travel time and direction. The Benthos Chirp II SP belongs to this category

Acoustic sub-bottom profiling equipment is defined by two of its principal operating characteristics: penetration and resolution. To a significant degree (but not entirely), both of these characteristics depend on the frequency content and bandwidth of transmitted pulses.

The frequency content of acoustic signals generated by various types of sub-bottom profiling equipment ranges from several tens of Hz to several tens of kHz.

Although frequency, depth and resolution figures are approximate for each type of equipment, the inverse relationship between penetration and resolution is immediately apparent. Higher frequency content is invariably associated with an increase in resolution and a decrease in penetration.

At the low end of the frequency spectrum, below 1 kHz, is a class of seismic devices generally referred to as low-resolution profilers. Water and air guns, sparkers, sleeve exploders, bubble pursers and most boomers share several characteristics. First, these are all energy sources that transmit a signal of broad spectral content. They all require separately towed hydrophone arrays to receive the signal. The output of the hydrophones is generally fed to an amplifier/filter combination. Typically, low-resolution devices achieve deep penetration. The correlation between frequency and penetration is not linear; at frequencies below approximately 800 Hz, penetration increases dramatically.

Systems in the lower frequency ranges have lower resolution. The 400 Hz Benthos Bubble Pulser System has a bandwidth of 400 Hz or 500 Hz, which corresponds to a pulse duration of 2 ms or a resolution of about 3 meters.

High-resolution devices, also referred to as tuned-frequency profilers, have a range of about 1 kHz to 30 kHz. They achieve significantly improved resolution but their penetration is limited. Typically, at 3 kHz they achieve a penetration of 30 to 50 meters in soft materials such as clays and silts, with a minimal penetration of course compact sands and gravel tills.

Tuned-frequency profilers can use the same transducer array to transmit and receive the signal. The source signal (its frequency content as well as its signature) is repeatable from one pulse to the next. In analyzing the data and tracking certain thin layers, it is important to have a predictable and consistent source.

The highest frequency systems are often used in engineering, environmental and other applications in which the goal is to resolve layers in the upper one or two meters.

It is clear from the above that implementing a sonar system involves a trade-off between penetration and resolution. Lower frequencies achieve greater penetration; higher frequencies achieve higher resolution. Although the relation between penetration and resolution is not linear, it is quite constant. Matching the application to the appropriate equipment is essential to obtaining optimal performance and satisfactory results.

Factors Affecting Resolution and Image Quality

The sound pulse is the sonar system's probe. The system's frequency, or bandwidth, determines the fineness of this probe. Naturally, a finer, high frequency, broadband probe is more discriminating.

Sound energy transmitted to the sea floor is reflected off the boundaries between layers of different densities (and hence, of different acoustic impedance). The first such boundary is between the water and the sea floor itself. As layers of clay, sand, and various other sediments succeed each other, they create interfaces from which sound is reflected. It is the energy reflected from these boundaries that the system uses to build the image.

The resolution of an imaging system is measured by its ability to separate closely spaced objects, in other words, to detect discrete echoes returning from the interfaces between layers. The vertical resolution of an acoustic sub-bottom profiler refers to the minimum -distance between adjacent layer interfaces that can be visually distinguished in the image produced by the system. A sonar system with a 10 cm resolution will resolve layers that are at least 10 cm apart. Layers that are spaced closer than 10 cm will be resolved by the system as one layer. In a single-frequency system, the limit of resolution is determined by the frequency and the length of the pulse. In a multi frequency system, such as the CAP-6600 system, it is the bandwidth that sets the system's theoretical resolution.

In addition to the frequency and bandwidth of the insonifying beam, other interrelated factors that affect the system's intrinsic resolution are:

- The width of the beam (transducer radiation pattern)
- The distance between the echo sounder and the bottom
- The nature of the electronic signal processing

A wide-beam transducer that insonifies a large area of the sea floor produces a series of reflections that stretch the returned pulse.

The larger the area that is insonified, the more the return pulse will be stretched. A one ms pulse could be stretched to 1.5 or 2 ms.

The stretching of the pulse results in the smearing of layers that are close together. The transmitted pulse of 1 ms corresponds to a 1 kHz bandwidth; but the received pulse, stretched to 1.5 ms, for example, corresponds to a 675 Hz bandwidth. This pulse stretching effectively reduces the bandwidth and with it the system's ability to resolve layers that are closely spaced together. As with any probing system, narrower beams produce better resolution.

The Chirp II is the only tuned-frequency profiler that uses digital signal processing to improve image quality in several ways. First of all, signal processing improves resolution by eliminating or attenuating beam components that would otherwise degrade the resolution. For example, all transmitted sound pulses produce side lobes. The side lobes contain energy that tends to stretch the pulse. With standard profiling systems, resolution is lost to pulse stretching due to side lobes. With the CAP-6600, the effect of side lobes is reduced through the matched filter process, which attenuates signals that do not correlate well with the transmitted pulse.

The second factor that affects the image quality is the signal-to-noise ratio. As it penetrates the sub-bottom layers of the sea floor, sound becomes attenuated and returning signals quickly fall below the noise level. The CAP-6600 has a standard processing gain of 20 dB to 30 dB that improves signal-to-noise ratio and the quality of sub-bottom images.