
CommTech Tutorials Series

Chirp Technology

The Chirp Advantage: Range and Resolution, not Range or Resolution

In response to the industry's requirement of a high resolution, extended range/ penetration profiling device, Datasonics (now Benthos), in conjunction with the Office of Naval Research, University of Rhode Island and the United States Geological Survey developed Chirp technology for use in side scan sonar and sub-bottom profiling applications. Although conventional systems have delivered reasonable penetration and resolution, the ability to improve this technology to provide required levels of increased resolution and range has been severely limited. In addition, sediment classification and other quantitative measurements demanded a calibrated energy source. Now, with the advent of digital signal processing these requirements have been met through the implementation of Chirp Technology.



Note – Chirp technology uses digitally produced linear FM acoustic transmissions to produce high-resolution images of seafloor contours and sub-bottom layers.

In all sonar systems, higher frequency content is invariably associated with an increase in resolution and a decrease in penetration. Chirp technology, as implemented in our Chirp systems, reduces the trade-off between signal range and image resolution.

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

For sub-bottom sonar, sound energy transmitted to the seafloor is reflected off the boundaries between layers of different densities. The first boundary is between the water and the seafloor itself. As layers of clay, sand and various other sediments succeed each other, they create interfaces that reflect sound. It is the energy reflected from these boundaries that the system uses to build the image. Likewise, for side scan sonar, backscatter from the seafloor produces an image of the seafloor contours.

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 or targets on the seafloor. The vertical resolution of an acoustic sub-bottom profiler refers to the minimum distance 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. In a conventional single-frequency system, the limit of resolution is determined by the pulse length of the transmitted waveform. In a multi-frequency system, it is the bandwidth of the transmitted pulse that sets the system's theoretical resolution.

The theoretical sonar range resolution, either cross-track in the case of side scan sonar or vertical in the case of sub-bottom profiling, is calculated by multiplying the length of the compressed pulse by the speed of sound, and dividing the product by two to account for the ping's round trip travel time.

$$\text{Range resolution} = \frac{\text{pulse length} \cdot \text{speed of sound}}{2}$$

The duration of the de-chirped pulse equals the inverse of the bandwidth.

$$\text{Pulse length} = \frac{1}{\text{bandwidth}}$$

For example, the duration of a pulse with a bandwidth of 9 kHz (which is the bandwidth of a system configured to operate between 1 and 10 kHz) is approximately 100 μ s ($1/9,000 = 0.0001$). Traveling at about 1,540 m/s, the acoustic signal can travel approximately 15 cm in 100 μ s. Allowing for the round trip, this results in a one-way distance of 7.5 cm.

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

- The horizontal width of the beam
- The tow speed
- The distance between the tow vehicle and the bottom
- The nature of the electronic signal processing
- The transducer produces a series of reflections that stretch the returned pulse width. The system cannot distinguish between pulses returning at t_2 and t_3 from sub-bottom layers.
- The larger the area that is insonified, the more the return pulse will be stretched. A 1 ms pulse could be stretched to 1.5 or 2 ms.
- The stretching of the pulse results in the smearing of features 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 or objects that are closely spaced. As with any probing system, narrower beams produce higher resolution.

The Benthos side scan transducers, such as those used in the SIS-1000, are the only swept frequency profilers that use digital signal processing to improve image quality in several ways.

Digital signal processing improves resolution by eliminating or attenuating beam components that would otherwise degrade the resolution. All transmitted sound pulses produce side lobes which contain energy that stretches the pulse. In standard side scan sonar and sub-bottom profiling systems, the resolution is lost to stretching by the side lobes. The effect of side lobes is greatly reduced through matched filter processing, which attenuates signals that do not correlate well with the received pulse.

The second factor that affects the image quality is the signal-to-noise ratio. As the transmitted pulse travels through the water, its sound becomes attenuated and quickly falls below the noise level. Benthos Chirp systems use matched-filter correlation processing to improve signal-to-noise ratio and as well as the quality of the sonar images.

Resolution for Benthos Chirp Geophysical Systems

System	Band range	Bandwidth	Pulse Length	Resolution
SIS-1000 Side Scan	90-110 kHz	20 kHz	$\frac{1 [s]}{20,000} = 0.00005 [s]$	$\frac{0.00005 [s] \cdot 154,000 [cm/s]}{2} = 3.85 [cm]$
SIS-1000 Sub Bottom	2-7 kHz	5 kHz	$\frac{1 [s]}{5,000} = 0.0002 [s]$	$\frac{0.0002 [s] \cdot 154,000 [cm/s]}{2} = 15.4 [cm]$
SIS-1500	190-210 kHz	20 kHz	$\frac{1 [s]}{20,000} = 0.00005 [s]$	$\frac{0.00005 [s] \cdot 154,000 [cm/s]}{2} = 3.85 [cm]$
Chirp II Low Freq.	2-7 kHz	5 kHz	$\frac{1 [s]}{5,000} = 0.0002 [s]$	$\frac{0.0002 [s] \cdot 154,000 [cm/s]}{2} = 15.4 [cm]$
Chirp II High Freq.	10-20 kHz	10 kHz	$\frac{1 [s]}{10,000} = 0.0001 [s]$	$\frac{0.0001 [s] \cdot 154,000 [cm/s]}{2} = 7.7 [cm]$