Chirp Sub-Bottom Profiler Processing—A Review

Chirp Signals May be Recorded as Correlates, Analytic or Envelope

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Hull-mounted and towed sub-bottom profilers have become common within the U.S. academic community. While these systems may be marketed as "echosounder" or "bathymetric," they are far more powerful and complex than the depth finders of years ago. Echosounders typically used a constant waveform signal of 3.5 or 12 kilohertz, measuring the two-way travel time to the seafloor and sometimes penetrating the sub-bottom. The replacement sub-bottom profilers emit a chirp signal that is usually several kilohertz wide and often penetrates the bottom 100 meters or more.

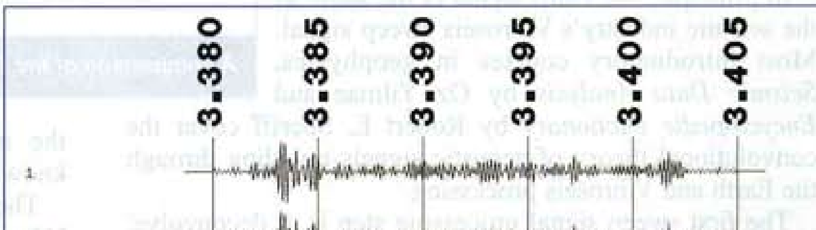
In the early days of chirp sub-bottom profiler development, the profilers required specialists or experts in order to operate them. These days, the chirp profiler is considered just another underway data acquisition device, and the shipboard technician may not have had much training in its use.

The chirp profiler operator must choose recording and display parameters, such as gain and chirp frequency. Hull-mounted profilers are more than likely found on oceanographic ships with a multibeam echosounder mapping system operating at 12 kilohertz and a current profiler operating at 50 kilohertz. Sub-bottom profilers get more depth penetration with low frequency, thus, a chirp center frequency near the old 3.5 kilohertz is generally used.

Many of the chirp recording and processing parameters are similar to the old echosounder parameters. Some chirp systems even use the same transducers, so the transducer transmit and receive gain functions are the same. The display on the old echosounders consisted of burning a spot on a piece of paper so that an increase in seismic amplitude caused a more intense burn spot. Today's profilers create grayscale plots of the signal envelope on computer monitors and thermal raster plotters.

Variable Velocity

The old echosounders were used mostly to measure seafloor depth, and periodically recorded the depth as a number in addition to the paper record. These systems used a single velocity value (750 meters per second) to convert two-way travel time to depth. Expendable bathythermographs (XBTs) were, and still are, deployed to measure the velocity of sound in water, but the old depth systems applied the varying velocity after the fact—in the shoreside laboratory months later. Today's bathymetric multibeam mapping systems allow the full XBT velocity function, and allow this to vary spatially in real time. There could/should be a whole article written just on the different types of velocity functions used to convert time to depth. A marine technician must know which system uses which velocity function for which purpose. A technician also has to educate everybody onboard as to why there is a difference among the depth readings from the different systems.



1. Correlate from a Knudsen 320B profiler
2. Reals from the analytic or complex signal (the correlate itself)
3. Imaginaries from the analytic or complex signal (the Hilbert transform of the correlate)
4. Envelope formed from the complex modulus of the analytic signal

A comparison of the time domain of the correlate, analytic and envelope signals.

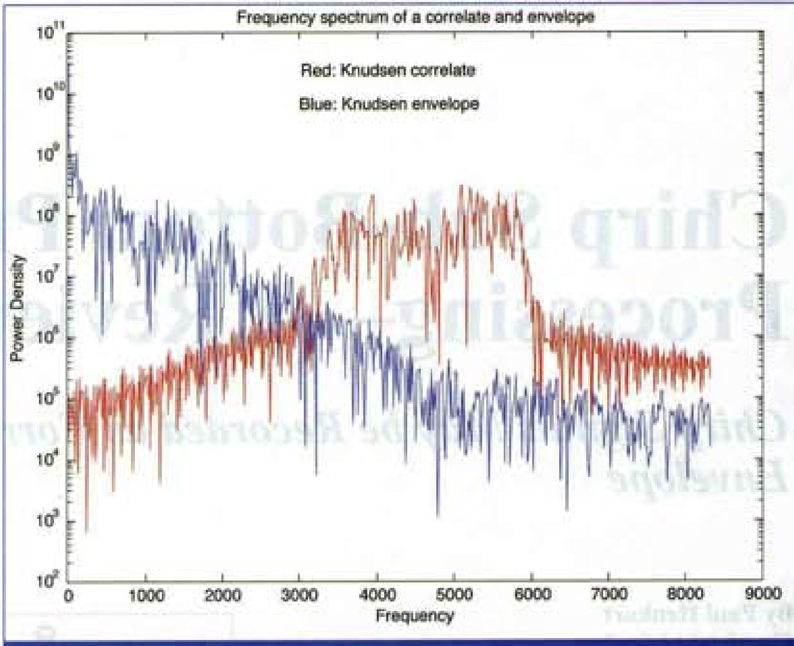
Types of Signals

The modern sub-bottom profiler chirp signal is typically 20 to 50 milliseconds in length and sweeps three to four-kilohertz frequencies in that time. One hull-mounted profiler manufacturer uses a four-kilohertz-wide signal with a center frequency of 3.5 kilohertz (sweeping from 1.5 to 5.5 kilohertz) and another sweeps from three to six kilohertz (a three-kilohertz bandwidth with a center frequency of 4.5 kilohertz). Increasing the length of the outgoing signal increases the power of the outgoing signal.

Generally, the chirp signal takes the following path or steps: it is generated by the transducer, it reflects back off of some object, it is received by the transducer, it is digitized and processed, and it is written to some storage medium and displayed.

The gain, or signal power, may be adjusted at the transducer during send and receive stages, as well as during the processing stage, usually just prior to display. The transmit/receive gain adjustments are independent of each other, but are a constant shift in power. All signal amplitudes are adjusted by the same amount. The gain adjustment during processing may vary with two-way travel time, and usually start from a selected water bottom time (i.e., they are "hung" from the seafloor). Time varying gain (TVG) is inadequate when the water bottom can not be picked, so automatic gain control may be an option.

In principle, the chirp signal is the same as the seismic industry's Vibroseis sweep signal. Most introductory courses in geophysics, *Seismic Data Analysis* by Oz Yilmaz and *Encyclopedic Dictionary* by Robert E. Sheriff cover the convolutional theory of acoustic signals traveling through the Earth and Vibroseis processing.



A comparison of the frequency domain of the correlate and envelope signals.

The first sweep signal processing step is to deconvolve, correlate or match filter the transmitted signal with the received signal. This way, the long outgoing sweep signal is compressed and the resulting signal is similar to the conventional seismic signal. The correlation step is best left to the manufacturer's recording device, since it requires knowledge of the exact outgoing signal.

The marine sub-bottom profiler is different from the land Vibroseis system in that Vibroseis sweeps are much lower in frequency (often less than 100 hertz), while the marine chirp systems are more than several kilohertz. The marine chirp systems use additional signal processing techniques to lower the frequency content so that the signals can be displayed the particular manner the seismic user is accustomed to seeing them.

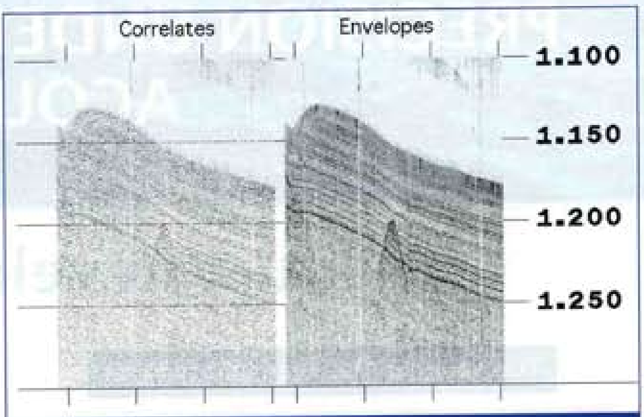
The next processing step is to divide the correlated signal (the correlate) into two parts. The first part is untouched and the second one is phase shifted by 90º. The phase-shifted signal is called the Hilbert transform, or quadrature.

The untouched signal and the Hilbert transform are then merged into a new single signal to form the analytic, or complex signal. The analytic signal resembles a complex number in that each sample has two computer words, similar to a complex number. The real part of each sample is the original signal, and the imaginary part of each sample is the corresponding Hilbert transform. The analytic signal has twice the number of computer words, or bytes, as the correlate because each sample has two words: the real and the imaginary.

The complex modulus (square root of the sum of squares of the real and imaginary) of each sample is formed from the analytic signal and becomes the envelope, or instantaneous amplitude. The envelope contains only positive numbers, and no longer has any phase information, but it is much lower in frequency and can be displayed as the geologist/geophysicist is accustomed to. The envelope is the same length and has the same sample interval as the correlate.

What to Record

Sub-bottom profilers offer digital output in addition to a real-time display of the envelope data. The digital output is often formatted similar to the Society of Exploration Geophysicist (SEG)-Y standard. But, the output may be from any of the intermediary processing steps. The SEG-Y file may contain one of the following signals: the raw



Plotted sections of correlates and envelopes.

uncorrelated signal, the correlated signal, the analytic signal, the envelope signal or the envelope with TVG.

The raw uncorrelated signal requires significant further processing and should be left for the expert signal processor.

The correlate is required when advanced seismic processing is conducted that requires the phase of the signal to be present (e.g., seismic migration). The correlated signal should be converted to the envelope and TVG applied before display.

The analytic, or complex, signal must be converted back into a real signal (the correlate) before it can be used in most seismic processes, since it has the signal phase. The analytic signal must be converted to the envelope and TVG applied before it can be displayed.

The envelope signal is ready for TVG and display, but it should not be used in advanced seismic processes that require the phase of the signal. Seismic migration and the waveform attribute theory require the full waveform, including the phase. Computer software may work on envelope data, but the results should be questioned.

There is not much that can be done with envelope data with TVG applied, other than just display, because the signal's phase is missing and all seismic amplitude relationships have been altered.

Modern sub-bottom profilers are yielding superb high-resolution images of the shallow sub-bottom, but an operator needs a lot of technical knowledge to make the most of them.

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