Digital Signal Processing on the KEL 320 BR

The 320BR employs wideband chirp transmit signals - a linear FM sweep - and digital correlation processing in the receiver, on both high and low frequency channels. Some of the implementation details are discussed below, with emphasis on 3.5 kHz.

Transmit Pulse Synthesis

The transmit waveform is synthesized internally in the 320 BR. The start and stop points of the frequency sweep are specified in the firmware as compilation parameters. For a 3.5 kHz channel these are typically set to 2.5 kHz and 5.5 kHz, or 3 kHz and 6 kHz, for a frequency sweep of 3 kHz. We have used chirps as wide as 5 kHz (2 kHz to 7 kHz) with nominal 3.5 kHz arrays, but the practical limits are set by the useful bandwidth of the transducer. Pulse lengths up to 24ms are user selectable to produce time-bandwidth products (T*B) to 72 in these examples.

Software compilation settings permit a number of options. A windowing function (Hamming or raised cosine) may be applied to the transmit pulse as a firmware compilation option (not user selectable). Firmware is normally supplied with a rectangular transmit pulse (no windowing), trading off temporal sidelobe performance for maximum resolution. A choice of square wave or more usually pulse-width-modulated (PWM) drive signals for the switchmode power amplifier is also specified as a compilation option.

Received Signal Processing

The received echo signal is routed through a wideband antialiasing filter prior to digitization. The digitized echo signal is digitally correlated with a replica of the transmitted pulse, using a straightforward transversal implementation. The correlation kernel is synthesized by firmware in the 320BR with compilation options similar to those used for transmit waveform synthesis. The correlation kernel may also be windowed (Hamming or raised cosine) but is normally supplied unwindowed, as the transmit pulse. The output of the correlation filter is then processed with a complex filter which generates the real and imaginary components of the analytic signal, which are squared and summed to produce a square-law detected envelope signal. Another compilation option causes the square root of the square-law detected envelope signal to be taken to produce an amplitude detected envelope.

Two additional processing steps are performed for data which is transferred to the host PC for display and logging in KEL .keb format. First, if the user-selected range (the displayed window in the water column) is very large, the envelope signal is lowpass filtered and decimated to a bandwidth and data rate appropriate to the size of the buffer. And finally, an interpolation filter resamples the data to exactly 1600 samples (16 bits per sample, sign bit always zero). Note that these final steps do not affect data recorded in industry standard SEG-Y format, which is always recorded at full bandwidth and data rate.

A couple of firmware compilation options are available which produce alternative output data formats for SEG-Y files. These are not accessible by the user, but are supplied as firmware which the user can program into the 320BR. These include: 1) 16-bit signed raw data, prior to correlation processing, 2) 16-bit signed data, taken after correlation processing but prior to envelope detection, and 3) 16-bit detected envelope data produced from the analytic signal components. Note that this last option is available in either square-law or amplitude detected form. All three SEG-Y formats contain full-bandwidth data, even when the displayed data may not.

Benefits of Correlation Processing

The correlation processing provides two main benefits: 1) the signal to noise ratio is improved (by 10log(T*B) dB, where T is pulselength and B is bandwidth or frequency sweep), permitting greater depths or greater penetration, and 2) the time resolution of the processed signal is much improved, due to the pulse compression effect of correlation processing. This permits fine details in the sediment layering to be resolved.

The theoretical vertical resolution improvements achieved with chirp technology are well understood. The output of the correlation filter (assuming a rectangular input pulse) has a sin(x)/x envelope with a 3 dB main lobe duration equal to the inverse of the swept frequency. In other words, the processed pulselength is independent of the transmitted pulselength, and is a function only of the swept frequency, which in this example is 3 kHz. Thus the pulselength after correlation processing is about 0.33 ms. The effective range resolution is half of this value (because of two-way signal travel). With a nominal speed of sound of 1.5 m/ms, the effective vertical resolution is therefore about 25cm. Test tank results confirm this theoretical value remarkably well. In the real world, the beam angle of a typical low frequency transducer is quite large, and scatterers are usually distributed so that off axis returns degrade this resolution somewhat. However, this is the value normally quoted by users and sellers of chirp systems.

Higher Frequencies

Chirp and correlation processing are used most often on low frequency systems , such as 3.5 and 12 kHz. However, chirp technology is available as a compilation option on all Knudsen echosounder frequencies, including 200 and 210 kHz, with pulselengths to 3.2 ms and frequency sweep of 8 kHz or more. This can provide a useful improvement in S/N in deep water, and when used with sidescan provides both a range and resolution benefit.

Each channel of a BR system has its own digital signal processor and the two channels operate independently and simultaneously. A third digital signal processor manages communications, data transfers, ping timing and other functions.