Development of Ice Profiler Sonar (IPS) Target Sonar with a Logarithmic Detector

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Abstract— **Upward-looking sonar (ULS) instruments have become the primary source of data for high resolution and long duration measurements of sea ice drafts to support engineering requirements for oil and gas exploration projects in Arctic and other ice-infested areas. ULS instruments, in the form of ASL's Ice Profiler Sonar (IPS), provide accurate measurements for ice draft on a continuous year-long basis and allow detailed characterization of keel shapes and other ice features. The IPS instrument was originally developed in the 1990's and it was last upgraded by ASL Environmental Sciences Inc. in 2007- 2008 through improved instrument design based on more capable microprocessors and more advanced on-board firmware.**

Another upgrade of the IPS instrument platform is presently underway with the design, testing and implementation of a logarithmic detector module in place of the previously used linear detector module which has been used for the past decade in the instrument. The linear detector module involves the use of an echo sounder detector which generates an analog voltage output from the raw transducer input supplied which is constant, i.e. independent of the time elapsed since the acoustic pulse was originally emitted. While this approach has proven reasonably serviceable, it has the disadvantage that the dynamic range of the instrument is curtailed from the alternative approach of using a logarithmic detector module which has previously been implemented in other ASL upward looking sonar instruments. The larger dynamic range of the log detector avoids using approximate TVG compensation. With the logarithmic sonar detector, the use of discrete threshold values for target detection is avoided and the resulting target detection capability is more robust.

The project involved three principal components: (a) construction of a prototype 420 kHz log sonar card; (b) simulations of the response of the IPS log sonar instrument from previous IPS data sets which guided the development of operating firmware; and (c) assembly and field testing of a prototype IPS log sonar unit operated simultaneously with a standard IPS5. The simulations of the IPS5 log sonar outputs derived from previous standard IPS5 data indicate that there are occasional differences in the target detection for borderline cases, but they will not be significant. After iterations to improve the robustness of the target detection algorithm, development of the remaining functions of the IPS5 operating firmware was then carried out and further tested. Finally the prototype IPS5 log sonar instrument unit, along with a standard IPS5 instrument, was field tested in a deep open water environment (to 200 m water depth) in order to test the accuracy of the acoustic range of the sonar targets.

I. ICE PROFILING SONAR (IPS): DEVELOPMENT HISTORY

A. *Introduction and Principles of Operation*

Upward-looking sonar (ULS) instruments have become the primary source of data for high resolution and long duration measurements of sea ice drafts to support engineering requirements for oil and gas exploration projects in Arctic and other ice-infested areas [1]. ULS instruments, in the form of ASL's Ice Profiler Sonar (IPS) continuously collect acoustic data for periods of one year or longer as operated on sub-surface moorings (see Fig. 1). The instruments provide accurate measurements for ice draft on a continuous year-long basis and allow detailed characterization of keel shapes and other ice features. When combined with a companion Acoustic Doppler Current Profiler (ADCP) to measure ice velocities, high resolution ice thicknesses and ice velocities can be obtained along thousands of kilometers of ice which move over the moored ice profiler location. These measurements provide important data for establishing metocean design criteria related to oil and gas operations in areas with seasonal or year-round ice cover.

The IPS instrument operates by emitting frequent short pulses (pings) of acoustic energy concentrated in narrow beams (1.8° beamwidth) and detecting surface returns [2]. Precise measurements of the delay times between ping emission and reception are converted into distances separating the instrument's transducer and the ice undersurface. Contemporary data from the instrument's on-board pressure sensor are then combined with atmospheric surface pressure data and estimates of the mean sound speed in the upper water column (obtained from observations of open water above the instrument) to derive estimates of ice draft from each emitted ping. The IPS can operate continuously for one year at a ping rate of 1 Hz and it provides high precision of approximately ±0.05 m vertical of the underside of the sea ice. When combined with the ADCP instrument located below the IPS instrument, the time series ice draft data can be converted to a quasi-spatial or distances series with a horizontal resolution of approximately 1 m.

B. *Development History*

The ASL IPS is an upward looking sonar device that was purpose-designed for sea ice draft measurements by the Institute of Ocean Sciences (IOS) of the Fisheries and Oceans Canada in the 1990's [3].

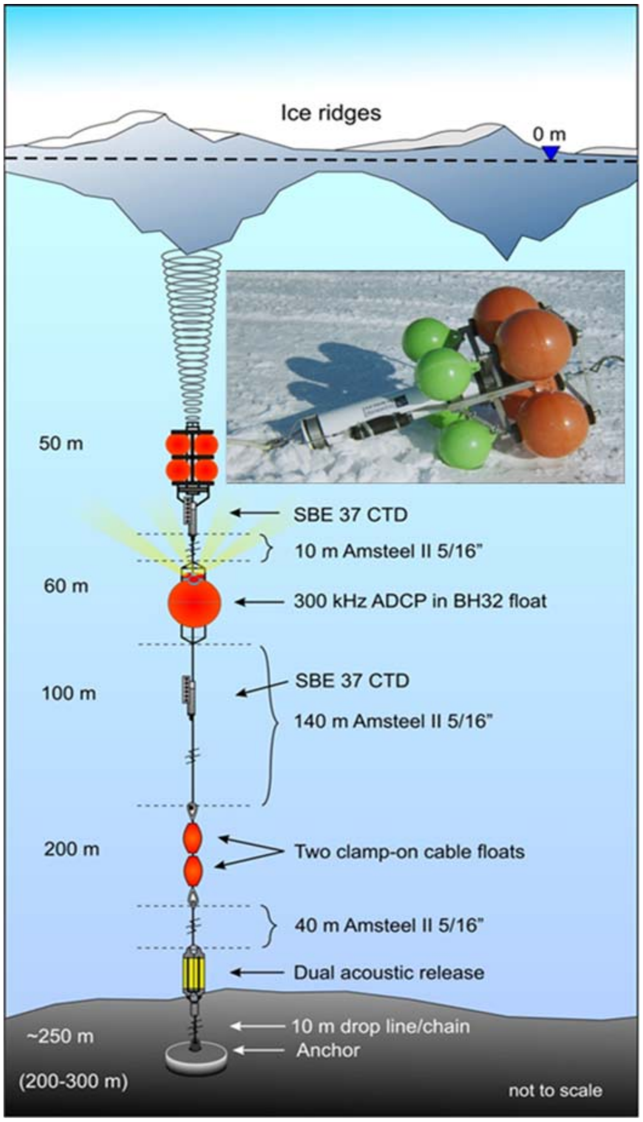

Figure 1 A typical deployment arrangement of an ice profiler and ADCP ice velocity measuring instrument on a single subsurface mooring.

The technology was commercialized by ASL in 1996. It was last upgraded by ASL Environmental Sciences Inc. in 2007- 2008 through improved instrument design based on more capable microprocessors and more advanced on-board firmware [4]. The additional features of the new IPS5 model as given in Table 1 included: expansion of the onboard flash data storage from 69 MB to 2GB, then 4 GB and now 8 GB; allowing for detection of up to 5 targets per ping rather than the single target detected with the IPS4; increasing the total number of individual sequential sampling selections from 8 to 12; and reduction of overall receiving system gain so that thicker ice targets were not at the saturation limit of the A/D converter. Also, the echoes from separately programmed "bursts" of pings can be recorded over the entire water column above the instrument with a vertical resolution of 1.1 cm.

Table 1 The improved features of the Ice Profiler Sonar model IPS5 with comparisons to the model IPS4.

Parameter	**IPS-4**	**IPS-5**
Year Introduced	1996	2008
Sample Rate	up to 1 Hz	up to 2 Hz
Data Storage	68/128 MB	2 to 8 GB
A/D Resolution	8 bits	16 bits
Receiver Gain	fixed	variable
Power Consumption	up to 2 years	improved
Multiple Phases	8	12
Targets per Ping	1	up to 5
Full Water Column Profiles	Limited	User selectable
Wave Measurement Mode	Not Available	2 Hz Burst Sampling

II. IPS LOGARITHMIC DETECTOR: DESIGN OBJECTIVES

An upgrade of the IPS instrument platform is presently underway with the design, testing and implementation of a logarithmic detector module in place of the previously used linear detector module which has been used for the past decade in the instrument.

A. *Present Detector Module*

The existing linear detector module is comprised of three main sections. The first section is an impedance matching pre-amp that provides passive linear gain and bandpass filtering. The second section is a voltage controlled amplifier whose gain is controlled in time relative to the start of the transmitted signal. This Time Varying Gain (TVG) roughly compensates the expected signal loss from attenuation and spreading of the acoustic signal in sea water such that the signal level from identical targets will generate the same DC voltage irrespective of its distance from the instrument. The TVG has four settings, corresponding to different initial gains, with G1 being the lowest and G4 the highest; normally only G1 is used for ice draft measurements. The third section generates an analog DC voltage that is linearly proportional to the peak to peak amplitude of the filtered and gained signal so the 420KHz echo signal can be digitized by the A/D converter at rates up to 64 K samples / second..

The effects of the time varying transmission losses are compensated for through a time varying gain (TVG) circuit which only approximately represents the actual transmission losses. While this approach has been successful, it has the limitation of a relatively small "instantaneous" dynamic range at any point in time. This limited dynamic range makes the setup of the instrument more difficult if the user does not want the water-ice and water-air interfaces to be saturated (clipped at the maximum input of the A/D converter). To overcome the clipping problem, the time varying amplifier and the linear detector have been replaced with a "logarithmic" detector that provides a DC voltage for the A/D converter with an instantaneous dynamic range of over 80dB. The logarithmic detector converts the logarithm of the peak to peak amplitude from the pre-amp/filter into a DC value for the A/D converter. This system was developed for the ASL AZFP product line and is now a "proven" technology for delivering high quality sonar data with low power consumption. [5]. In addition, the new logarithmic sonar detector avoids component obsolesce issues that have been a problem with the older linear detector system and also has manufacturing advantages. The use of the present linear detector module also required the specification of amplitude thresholds for qualifying the detection of targets which were not optimal for short ranges and for very long ranges.

B. Design Objectives and Requirements for the Logarithmic DetectorModule

The log detector has no TVG compensation, instead relying on its large dynamic range to keep the echo signal within the detector's response. In that case, the signal received from a constant strength target will decrease with its range, in accordance with the transmission loss. With the logarithmic sonar detector, the use of discrete user-selected threshold values for detection is avoided and the resulting target detection capability is more robust.

III. DEVELOPMENT AND TESTING OF THE IPS LOG DETECTOR SONAR

The development project involved three principal components: (a) preliminary design and initial construction of a prototype 420 kHz log sonar card; (b) simulations of the response of the IPS log sonar instrument from previous IPS data sets which guided the development of operating firmware for the IPS instrument; and (c) assembly and field testing of a prototype IPS5 unit.

A. Preliminary Design and Initial Construction of a Prototype 420 kHz log sonar detector module

The preliminary design of the IPS5 Log Detector involved an adaptation of the log sonar detection module previously developed for the AZFP [5] to replace the original linear echo sounder electronics circuitry used for sonar target detection.

B. Simulation of the IPS5 Log Sonar Detector In Support of the Firmware Development

Once the prototype log sonar module had a preliminary design for the electronics as per part (a), the development of the operating firmware was undertaken. This involved the use of data obtained from many previously collected IPS data sets (see Table 2) that had a wide range of signal-to-noise and other types of data attributes. These test data from the original IPS instrument digital measurements were converted to the output that would have resulted from the log sonar module (see Figure 2), through a detailed numerical simulation software system developed for this purpose. These converted profiles were then processed using the new algorithm for target detection with the log sonar module and these targets were then compared to those found by the standard algorithm in the original IPS linear detection module. An example of the output of the software simulation is shown in Figure 3.

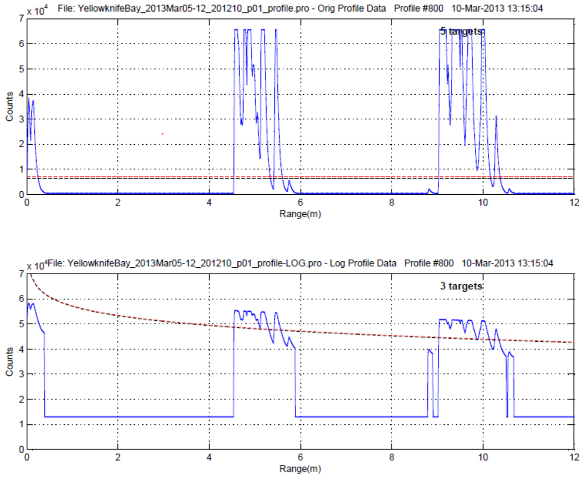

Figure 2 Converted linear data to log

The start and stop amplitudes used in the original data were converted to their logarithmic equivalents (matched at 50 meters range), and the same persistence limits were used. For each set of profiles considered the plots show for the standard and log versions of the IPS, the number of targets found, the difference in the number of targets, and the difference in the index number vs. the profile number. For sample cases where the number of targets detected differed, plots of the signal profile with the start and stop amplitudes are shown for each instrument configuration.

Table 2 Data sets used in detection performance model tests.

Condition	Instrument	Project #	Site Name	Measurement Year	Extracted Date
D,M	IPS5-1107	709	Site H	2009-2010	Feb 09-23
D,M	IPS5-1106	758	Site A1	2010-2011	Feb 26-27
D,M	IPS5-1110	758	Site H	2010-2011	Feb 26-28
D,M	IPS5-1079	776	ShellSite02	2011-2012	Nov 28-29
D,HN,O	IPS5-3019	827	Makavik (SWIP)	2011-2012	Oct 15-16
M	IPS5-3019	827	Makavik (SWIP)	2011-2012	Nov-15
H,M,O	IPS5-1147	793	Site 1	2012-2013	Dec 03-08
H,M	IPS5-1147	793	Site 1	2012-2013	Mar 04-06
M	IPS5-1050	795	Yellowknife Bay	2012-2013	Mar 05-12
M,N	IPS5-1050	701	Site A	2009-2010	Nov-05

M,O	IPS5-1110	758	Site H	2010-2011	Aug 24-28
M,O	IPS5-1107	776	ShellSite01	2011-2012	Sep 15-30
Condition: D - Drop Outs, M - multiple targets, HN – high amp, no target, O - open water, H - high tilt, N - noisy data					

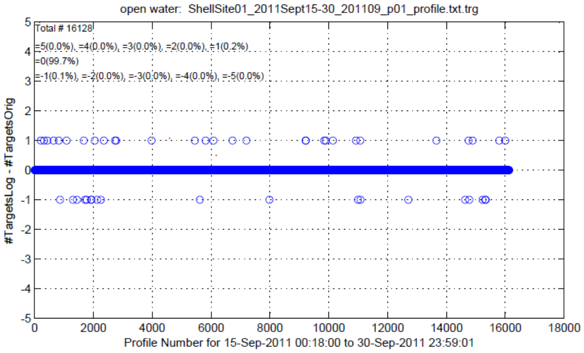

Figure 3 Log Targets - Orig Targets

The threshold curves computed from the transmission loss equation were tabulated in discrete steps in the firmware to make it possible for the processor to run the detection algorithm. The stepwise approximations to the ideal curve will cause occasional differences in the target detection for borderline cases, but they will not be significant. After iterations to improve the robustness of the target detection algorithm, development of the remaining functions of the IPS5 operating firmware was then carried out and further tested. Finally the prototype IPS units are being assembled and field tested in a deep water environment (to 200 m water depth) in order to test the accuracy of the range of the targets detected out to the limits of signal detectability at large acoustic ranges.

C. Field testing of a prototype IPS5- Log Detector unit.

A field test of a prototype version of the IPS5 Log Detector (IPS5L) unit operated alongside a conventional IPS5 (IPS5E) instrumented was conducted in the waters of Saanich Inlet, B.C. Canada near Victoria B.C on June 6, 2014. The IPS instruments were operated on connected sub-surface moorings which were separated by a distance of approximately 150 m over a total measurement period of 5 hours at an operating depth of 195 m below the water surface.

All targets (to the selected maximum of 3 per ping) and the best target (target 1) during the inter-comparison measurements are shown in Figure 4 and Figure 5 for the IPS5L and in Figure 6 & Figure 7 for the conventional IPS5E.Typical returns from the full water column acoustic returns are presented in Figure 8 and Figure 9 for the IPS5L and IPS5E instruments.

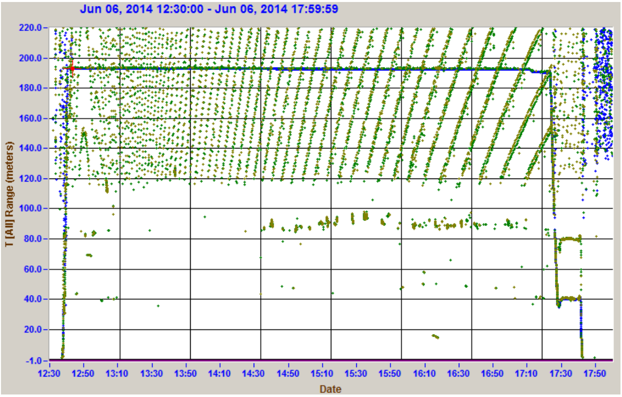

Figure 4 IPS5L All Targets

The IPS5E was operated with the gain alternating between G1 and G4 every 30 minutes, as indicated in Figure 6. The periods with higher gain were included to allow the IPS5E to detect the mid-depth zooplankton scattering layer, the echoes from which were used to do a relative inter-calibration of the two instruments. As may be seen from Figures 5 and 7, the surface is always detected as the primary target by both instruments. The angled lines of targets in Figure 4 are interference from another echo-sounder operating in the vicinity; they are not seen in the IPS5E target record because of its more limited dynamic range the differences in the form of the target threshold in the two instruments.

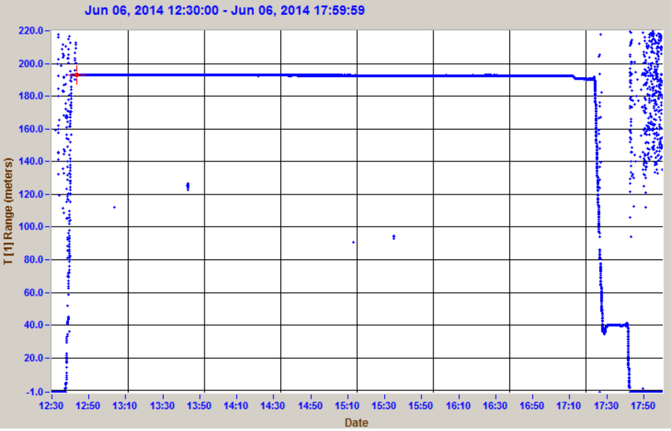

Figure 5 IPS5L Best Targets

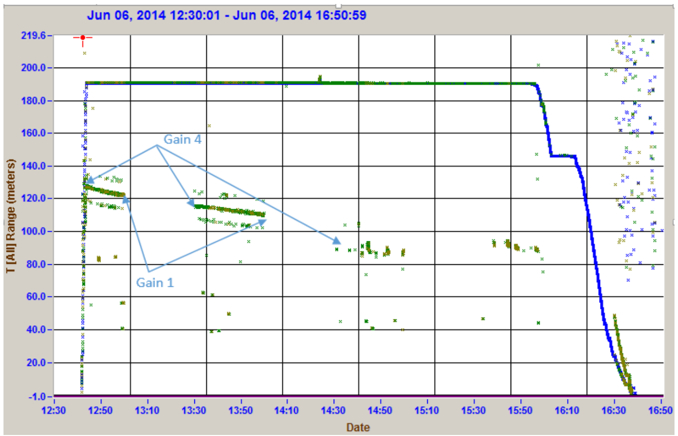

Figure 6 IPS5E All Targets (gain settings shown)

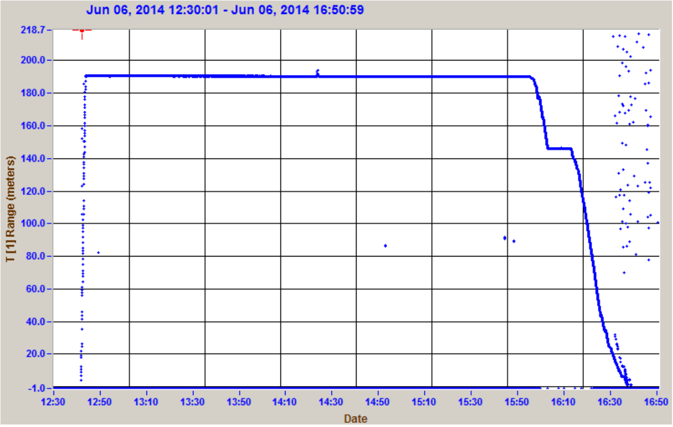

Figure 7 IPS5E Best Targets

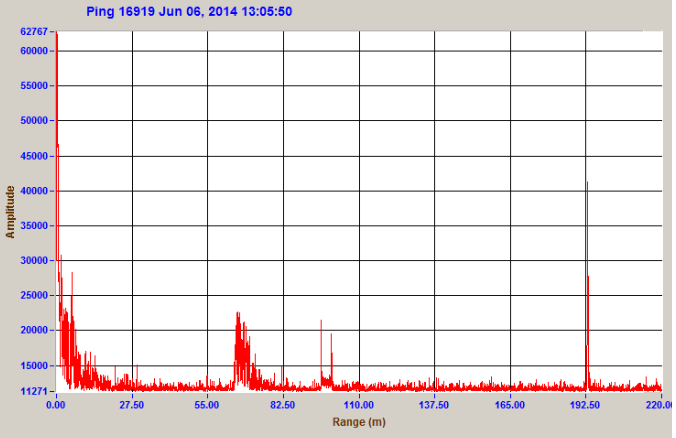

Figure 8 IPS5L Typical Acoustic Return

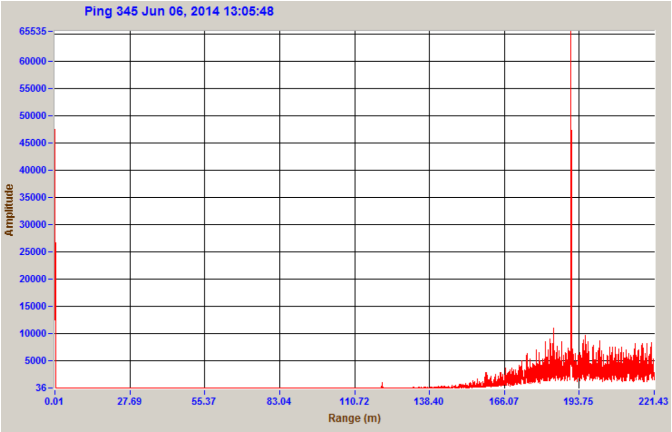

Figure 9 IPS5E Typical Acoustic Return

To quantitatively compare the response of the IPS5L and the IPS5E, the comparison results are further analysed. To allow for an inter-calibration of the IPS5L and IPS5E, the zooplankton acoustic scattering layer at 70-80 m depth allowed an adjustment to computed volume backscattering values (Sv) so that the Sv values for each IPS instrument is directly comparable

A range of backscatter coefficients from -14dB/Sr to 0dB/Sr was chosen to represent the range of echo intensities that could be seen by an IPS deployed under the ice. Using these as max and min values for both models, the difference in instrument response can be shown. Figure 10 shows the response for the current IPS5E. The 0dB line shows the signal at this level from the ice will be clipped out to 240m. The signal from the low end of -14dB will be out of saturation but still above the threshold detection level. The line for the -14dB also shows the error due to the deviation in the TVG response from the theoretical. The line should be flat out to where the TVG no longer is increasing which is just over 180m. The plot of the actual data from the test shows the return from the water surface and the system noise floor. From this it can be seen that the noise floor starts to rise above the detection threshold at around 180m but the low end of the ice signal range should stay safely above the noise until just over 230m. This leaves the possibility for false targets between the range of 180m to 230m.

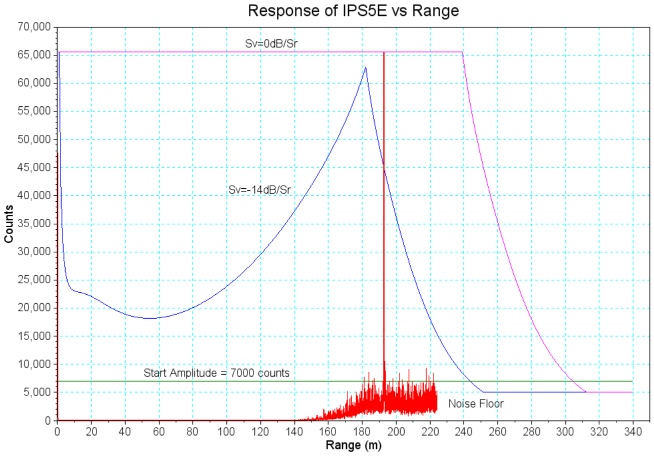

Figure 10 IPS5E Response as a function of range

In Figure 11 the response of the IPS5L is shown. The highest estimated returns from the ice are clipped out to just under 20m while the low returns are out of saturation until the signal drops below the system noise floor out near 270m. It can also be seen that there is enough dynamic range for returns lower than estimated at the short range and stronger signals at the longer ranges.

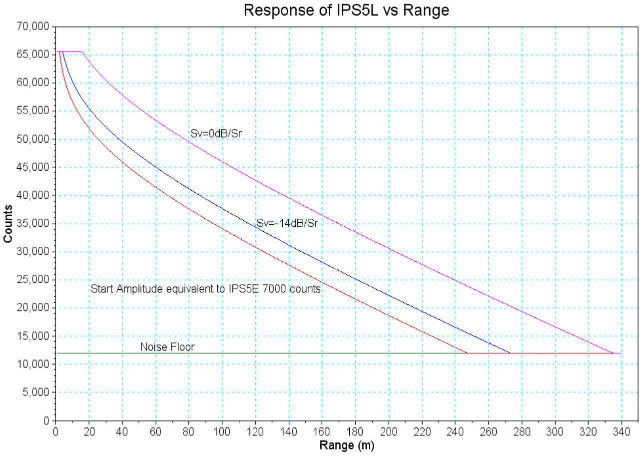

Figure 11 IPS5L Response as a function of range

IV. SUMMARY AND PRESENT STATUS

The project involved three principal components: (a) preliminary design and construction of a prototype 420 kHz log sonar card; (b) development of operating firmware for the IPS instrument; and (c) assembly and field testing of a prototype IPS5 unit. The numerical simulations of profile data of the IPS5 log detector instrument using profile data from the conventional IPS5 instrument proved to be very useful in preparing the initial version of the IPS log sonar detector firmware. The field inter-comparison of the IPS5 with log sonar detector reveals that this version of the instrument will allow detection of non-saturated A/D acoustic returns much more frequently than the conventional IPS5 for sea ice and even for open water returns, allowing greater use of acoustic amplitudes for acoustic ice measurements. Based on an acoustic model of the IPS5 log sonar instrument's target detectability, the IPS5 log sonar instrument also with its greater dynamic range will allow detection of weaker targets in the water column that the IPS5E would not be able to detect.

Operation of the instrument is also simplified as there is no longer any need to select the gains to switch between the ice and wave detection modes. The greater dynamic range should as reduce the importance of, or even the need for, the user specification of amplitude thresholds to detect targets. There is no impact on the instrument power consumption from these changes.

The next step in the development of the IPS5 log detector sonar will be a full year deployment of the IPS log detector instrument alongside a conventional IPS5 to provide extensive direct comparisons of returns from sea ice. This inter-comparison is planned for the period Sept. 2014 to Sept. 2015 in the Canadian Beaufort at a site in a total water depth of 30-50 m.

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