Towed streamer data bandwidth – A ghost story

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Summary

The bandwidth of towed streamer data is first and foremost a function of how deep the source(s) and streamer(s) are towed in the water column. The delay time of the sea-surface reflections from the sources and at the receivers (i.e., the ghosts), relative to the primary pulses, determines the fundamental pass-band of the recorded data. Current streamer technology *"only"* provides the means for efficiently exploiting the ghost responses to increase the high frequency content of data by towing streamers at shallower depths.

A set of streamer depth test data was recently acquired with solid streamer cables in the Gulf of Mexico. These data show excellent correlations between modeled and measured bandwidth responses for streamers at different depths.

Further to that, the enhanced signal-to-noise and streamer depth control achievable with solid streamer technology allows for a more cost effective means of exploiting the potential increase in bandwidth at shallow tow depths compared to fluid filled streamers.

The Physics of Ghosting

Ghosting is a term that simply equates to the location on the frequency spectrum at which the reflected signal has become 180° out of phase with the primary signal. At this point, the two signals add destructively and amplitudes sum to zero. This phenomena occurs at both the source and receiver and thereby yields two notches which denote the upper limit of the available bandwidth in any marine streamer seismic set-up. The equation for determining the notch is shown in Equation 1.

$$f_{Ghost} = V_{fluid} / (2 \cdot d_{Source})$$

Equation 1: Definition of the ghosting effect.

Upon application of the above formula, it is readily apparent that only changes in depth (d_{Source}) will change upper limits of the data bandwidth and it should be stressed that no physical characteristics of the streamer sections will increase or decrease this available bandwidth.

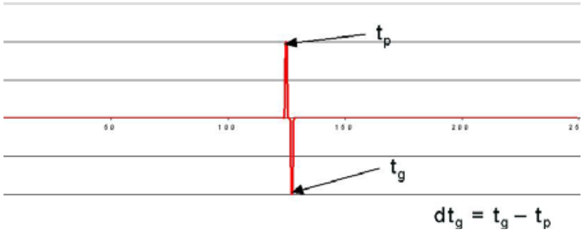

Figure 1: Time series of the primary and ghost signals (180° out of phase)

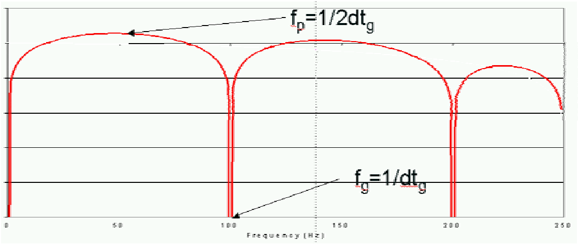

Figure 2: Frequency spectra illustrating the ghost notch

Alaminos Canyon Streamer Depth Test

In November of 2002, Veritas DGC Inc. conducted a test line targeted at assessing the impact on bandwidth by configuring streamers at three different depths. Of the eight streamers in tow, two were set to 7-m, two at 8-m and the remaining four were set to 6-m. Data for the test line were acquired using dual source arrays at 6-m depths with a 37.5-m flip-flop shot interval. At the end of acquisition, 468 shot stations with 5184 channels were recorded.

Environmental conditions during the test were considerable with wave heights between 2.5 to 3.0 meters and Beaufort scales between force 5 and 7.

Analysis of the data consisted of the following.

1. Generate modeled spectra
2. Generate measured spectra
3. Comparison of modeled and measured spectra
4. Verification of cable depth profiles

The spectra for item 2 above was generated using a window positioned in the primary signal and extending nearly half of the cable length (Figure 3).

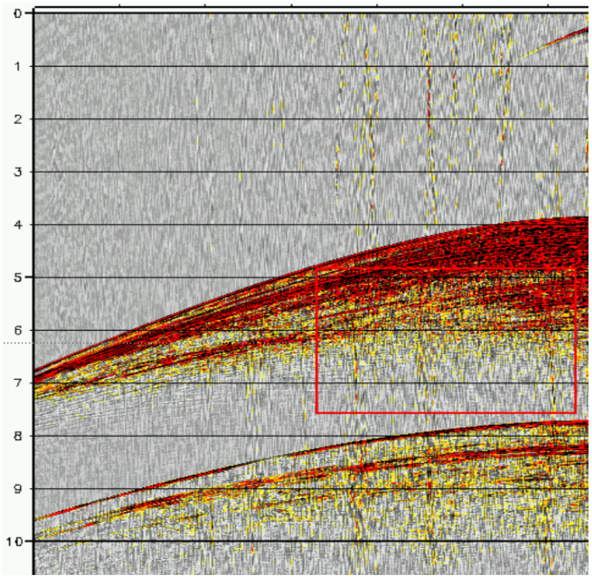

Figure 3: Spectral analysis window for depth test

Analysis of the depth profiles were conducted using two methods. It should be noted that the vessel deployed 29 to 30 depth controllers over the 8100-m active streamer length.

Method 1 examined one depth controller for each of the five defined coverage offset zones at each shotpoint down the line (Figure 4).

Method 2 was a spatial approach which plotted each depth controller for two randomly selected shotpoints on the line (Figure 5). Additionally, the fin-angle of each depth controller was displayed in order to determine the amount of work the depth controller was applying to keep the streamer at depth.

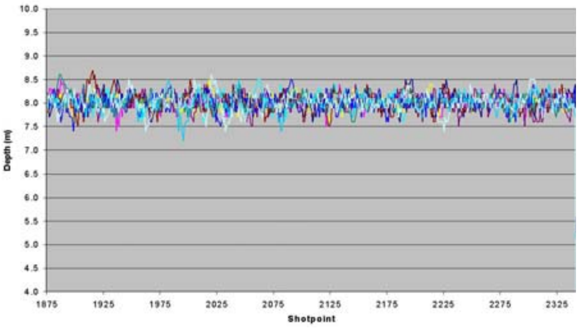

Figure 4: Method 1 – Streamer depth profile analysis

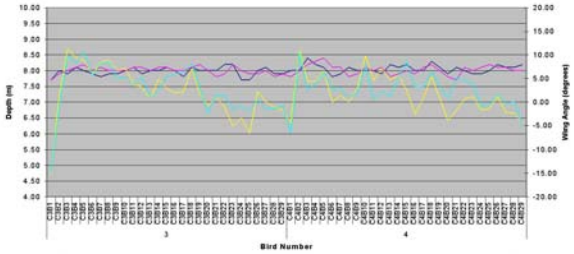

Figure 5: Method 2 – Streamer depth profile analysis

Results of the depth analysis indicated that cable depths could be easily maintained within a +/- 0.5 meter window for any of the three streamer depths. Further to that, any individual sensor deviation was within +/- 0.25 meters.

Spectrum comparisons were as expected and further demonstration of the measured data indicated good correlation to the expected bandwidth (Figures 6 and 7). Of significant importance is that this result could not have been achieved without the steady depth profile as the difference in achievable bandwidth from the modeled results were only 4 and 2 dB respectively at the 80hz requirement specified in the project tender (Figure 8).

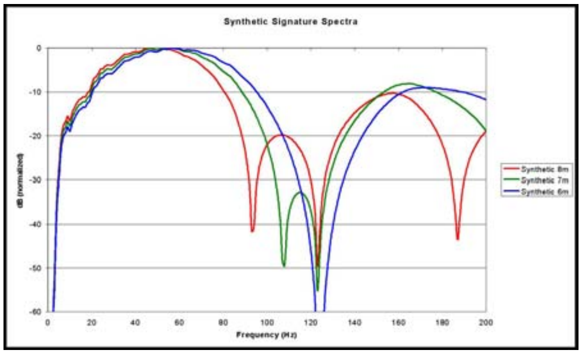

Figure 6: Overlay of the modeled spectrum data at 6, 7 and 8 meter streamer depths

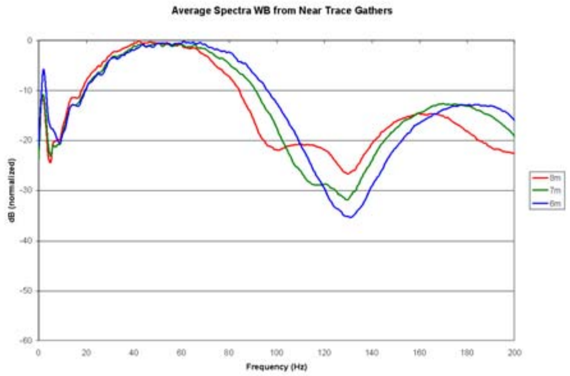

Figure 7: Overlay of measured spectrum data recorded simultaneously at 6, 7 and 8 meter streamer depths

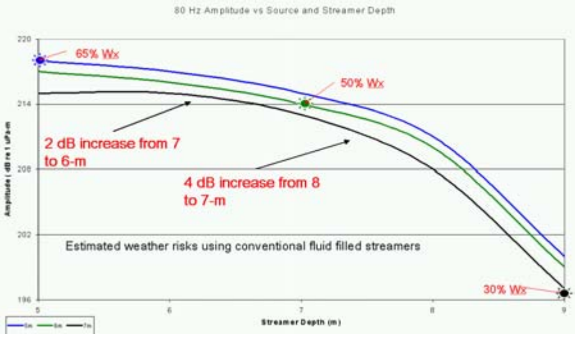

Figure 8: Risk-Benefit assessment at 6, 7 and 8 meter streamer depths

Towed Streamer Technology

One of the driving forces in the development of new streamer technology is noise reduction and increased operation time in marginal weather conditions. To accomplish this, the vibration sensitivity of the streamer sections must be minimized. Vibration sensitivity is a measure of how much acoustic noise is generated in a streamer section per unit of mechanical vibration - the lower the vibration sensitivity the lower the noise levels generated by mechanical excitations. Although this paper does not go into the engineering methodology of solid streamers, it can be demonstrated that solid streamers have a lower vibration sensitivity than fluid filled streamers (Figure 9). The shot record presented in Figure 3 shows that the solid streamers used in these tests have very low levels of sea state induced noise. This is very impressive considering the 2.5 to 3m sea conditions in effect during the acquisition of the test data.

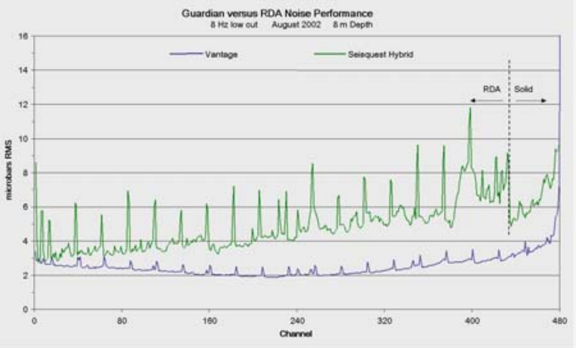

Figure 9: RMS noise comparison between Guardian Solid streamer and Syntron RDA-II fluid-filled streamer

Solid streamer technology presents another key advantage over other fluid filled technology in the fact that ballast is very precise as defined in Equation 2 below in which M_B represents a mass applied to the section in the form of evenly spaced weight collars. Fluid streamer ballast is based on a specific volume of isopar oil. Once a section is released from the factory, the volume can not be controlled or measured accurately. Additionally, as sections are damaged in the field or in transit, the volume becomes even more uncertain often resulting in the addition of weight applied directly to the skin. Since the weight is not specifically designed to fit the fluid-filled section, over time it will fall-off thereby creating a continual process of ballast work for the vessel crew and ultimately reducing operation time. Further to that, damaged sections can leak isopar resulting in environmental concerns.

$$M_B = \left[V_{Sect} + K_T\left(T_W - T_0\right)\rho_W - M_{SectAir} - M_{\mathrm{Re}serve}\right]$$

Equation 2: Guardian Solid streamer ballast formula

A further advantage of solid streamer is the robustness. Due to the nature of the material, it can handle large abrasions to the outer coating while still supplying a sufficient amount of protection for the electronics inside.

Conclusions

The bandwidth of towed streamer data is ultimately determined by the tow depth of the source(s) and streamer cables. Additionally, the accuracy with which these depths can be maintained will directly impact how potential bandwidth enhancements can be ultimately exploited.

Modern solid streamer designs have been aimed at allowing streamers to be towed at shallower depths in rougher weather than previously possible with conventional fluid filled streamers.

Solid streamer technology has consistently demonstrated lower noise performance and greater ballast control than fluid filled streamers.

Acknowledgements

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