Low frequency marine acquisition

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Abstract

A low frequency marine towed streamer acquisition experiment was conducted in deep-water offshore Gabon.

Data were acquired during two vessel passes along a 2D test line using a tuned and detuned source and solid streamer towed at 9m and 15m, respectively.

Frequency analysis of shot records and 2D brute stacks clearly show an enhancement of low frequency reception on the receiver side by lowering the tow depth of the streamer from 9m to 15m. This result is as expected. The use of a detuned air-gun array, however, showed a significant increase of low frequency energy on the signal side, even with the streamer at a 9m tow depth.

These results suggest that the source and receiver components of the towed streamer acquisition system can be “tuned” to provide the optimum signal-to-noise in areas where low frequencies are critical to the seismic imaging effort.

Introduction

As seismic exploration for hydrocarbon reserves has moved into deep water ocean basins, seismic image quality is often hampered by the presence of high acoustic impedance boundaries associated with salt bodies, thick carbonate layers, sheets of volcanic rock, and/or very thick stratigraphic sections that highly attenuate mid and high frequency source signals. Over the years the industry has recognized that, in most cases, in these types of terrains only narrow-band low frequency signals (<30 Hz) can be transmitted to and from the targets of interest. Frequencies above about 40 Hz are often reflected, scattered, or absorbed and contribute more to the noise environment then to the useable signal band.

In recent years there has been a lot of attention focused on trying to extend and enhance the low frequency performance of towed streamer acquisition systems by mitigating the effects of the streamer ghost notch. However, if the full response of the integrated acquisition system is taken as whole then dealing with the receiver ghost issue only addresses a part of the problem. Just as critical for improvement of low frequency reception is the noise performance of the receiver platform (i.e. the streamer design) and the amount of low frequency energy that can be generated by the source.

In February, 2011, Polarcus had the opportunity to acquire a suite of 2D test data in a deep-water sub-salt hydrocarbon province offshore Gabon. The test was designed to demonstrate three (3) aspects of low frequency acquisition:

- Enhancements to low frequency signal generation by manipulating the firing times of a conventional air-gun array to shift more energy into the low frequency end of the signal spectrum while attenuating potential noise generating energy at frequencies above about 35 Hz.
- Exploiting the reception gain in selected frequency bands inherent in the receiver ghost response.
- The value of long offsets in capturing low frequency signals from below complex salt bodies.

Method

The experimental configuration was composed of two source arrays, one a conventional tuned array towed at 7m depth and the other a non-conventional detuned array towed at 10m. A single 12km solid streamer was towed between the sources. A pre-selected test line (Figure 1) was shot twice, each time in the same direction, once with the streamer set to a 9m tow depth and the second time with the streamer at 15m. Along each line the sources were alternated at 25m shot intervals to acquire adjacent 2D CMP lines.

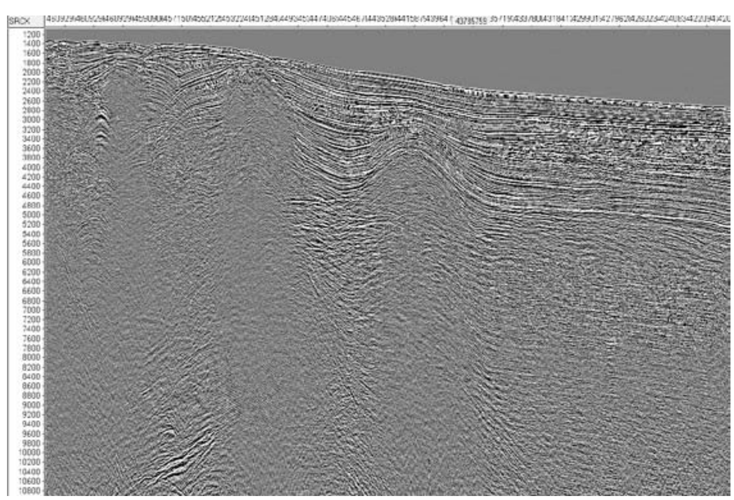


Figure 1: Brute Stack of 2D Test Line

The test set-up and procedures produced four (4) acquisition configurations:

- Tuned source with 9m streamer depth
- Detuned source with 9m streamer depth
- Tuned source with 15m streamer depth
- Detuned source with 15m streamer depth

These four (4) configurations allowed for the controlled evaluation of three acquisition features:

- Frequency content of the source output
- Reception band of the receiver system
- Impact of long offsets on pre-stack imaging.

For this report we will concentrate on the low frequency results of the various combinations of source plus streamer responses.

The evaluation of maximum offsets via pre-stack migrations is currently underway and will be reported when those results are available.

Source Output

The two source arrays were basically identical and were composed of three sub-arrays each containing six pairs of air-guns arranged in 2-gun clusters. The conventionally tuned array was towed at 7m depth and used thirty-three (33) active air-guns and three inactive as spares for a total volume of 4240 in^3. The source controller was programmed to synchronize the firing times of all active elements to align the peak pressure pulses emitted by each air-gun.

The de-tuned array was towed at 10m depth and had all thirty-six air-guns active, for a total volume of 5080 in^3. However, for this array the source controller was programmed to scatter the firing times of the individual elements over a time period of approximately 100ms. The fire time increments were chosen so as to “smear” the primary and bubble pulses and ghost reflections from each element across a time window of about 250ms. Figure 2 shows the modeled time series and amplitude spectra for the vertical signatures from each array.

The spectrum for the de-tuned array signature shows that by staggering the firing times the emitted energy is concentrated in a frequency band between 3 Hz and 40 Hz, which are the -20 dB down points from the peak at 7 Hz. An overlay of the signature spectra from the two arrays (Figure 3) shows the de-tuned array has about 6 dB more output below about 15 Hz while attenuating the mid to high frequencies relative to the output of the tuned array.

Receiver Response

Because of the physics of air gun bubble behavior and source ghosting it is very difficult to generate very low frequency energy with air-gun arrays. Even in a detuned mode the peak frequency is only as low as the longest bubble period from the largest volume element in the array. In this case the peak is at 7 Hz from a 760 in^3 array element. Therefore it is important to have a receiver system that has a reception band capable of recording very low frequencies and a physical design that minimizes tow generated noises at those frequencies.

Figure 4 shows a comparison of measured vibration sensitivity functions for a solid streamer, a gel-filled streamer, and a fluid-filled streamer. Vibration sensitivity is the measure of acoustic noise generated by a streamer hydrophone per unit measure of mechanical excitation, thus the units in dB re 1 uPa/m/sec^2 (Dowle and Maples 2006). As exhibited in the graph the solid streamer generates significantly less noise below 20 Hz than both the gel-filled and fluid-filled designs. This is a very important signal-to-noise issue when we are dealing with low amplitude low frequency signals. For example at 6 Hz, for the same vibration regime (i.e tow environment), vibration sensitivity values indicate that the solid streamer would provide about 20dB better signal-to-noise than either of the measured gel-filled or fluid-filled streamers.

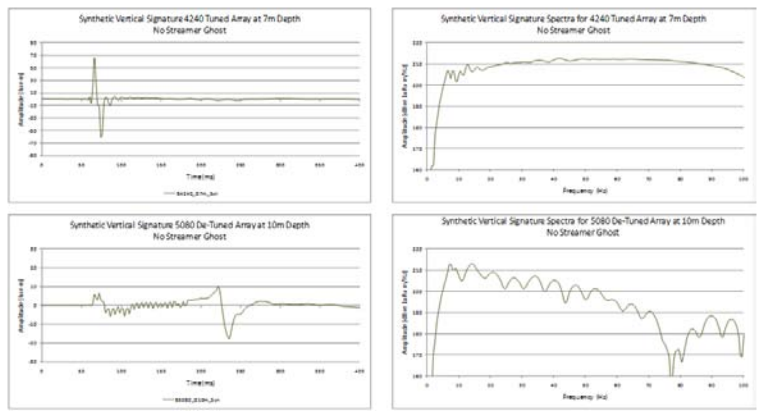


Figure 2: Modeled time series and amplitude spectra for vertical signature from the tuned and de-tuned source arrays.

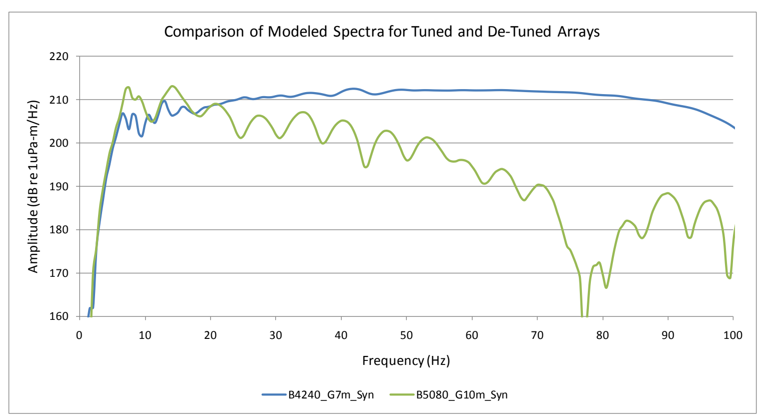


Figure 3: Comparison between tuned array and de-tuned array amplitude spectra

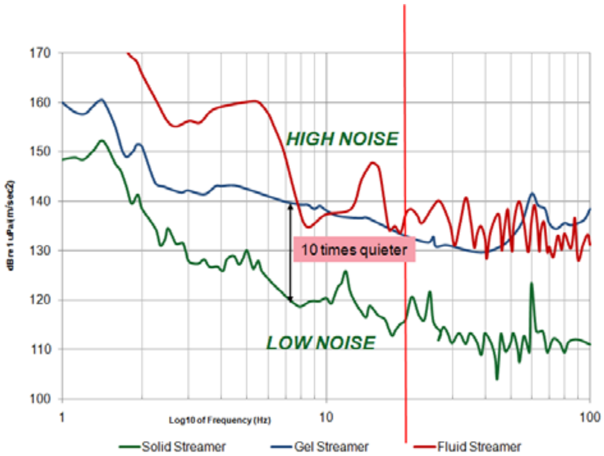


Figure 4: Steamer Vibration Sensitivity Curves (data courtesy of Sercel)

A second important component for marine receiver systems is the receiver ghost function. There has been a lot of effort expended recently in attempting to mitigate the impact of the receiver ghost notch on mid and high frequencies in towed streamer applications. In the narrowband application, however, the receiver ghost can be exploited for its positive reinforcement of peak frequencies in selected low frequency bands.

Figure 5 demonstrates that a receiver ghost for a streamer tow depth of 15m provides about +6 dB of gain to the source signal in the 15 Hz to 30 Hz band.

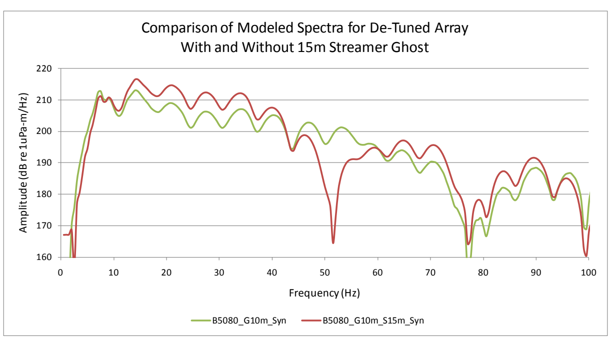


Figure 5: De-tuned array signature spectra with and without 15m receiver ghost.

Data Examples

Figures 6, 7, and 8 show examples of the seismic data recorded from each of the four acquisition configurations for a section near the deep water end of the line. These data were extracted from brute stack sections where minimal processing was applied to produce the stack images. In this area the water is deep and the sub-surface section appears thick with relatively simple structure thus allowing a reliable observation of the frequency response of the earth to each of the source / receiver tow depth combinations. That response would include both primary events and inter-bed multiples. The data in the panels have been filtered to show the broadband response (2 Hz to 80 Hz), the mid to high frequency response (>40 Hz) and the low frequency response (<20 Hz). The same display gain has been applied to each panel in a figure. This allows for a qualitative evaluation of the relative differences in recorded amplitudes for the different acquisition configurations.

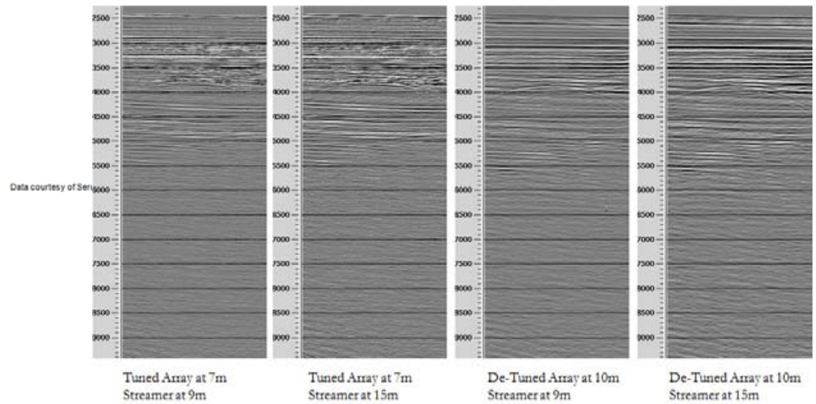


Figure 7: Brute stack sections with 2 Hz to 80 Hz band-pass filter applied

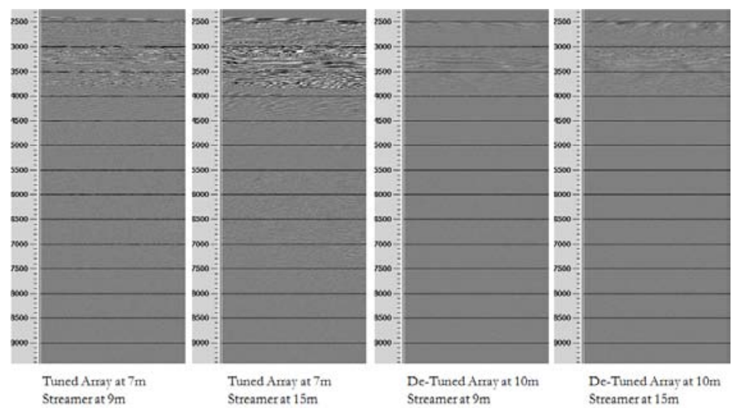


Figure 8: Brute stack sections with 40 Hz high-pass filter applied

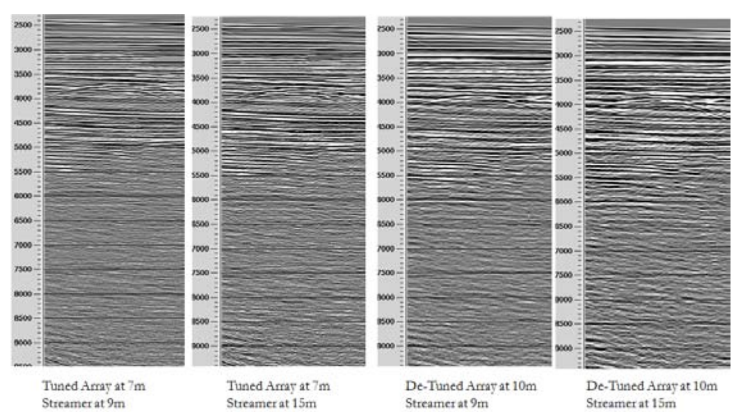


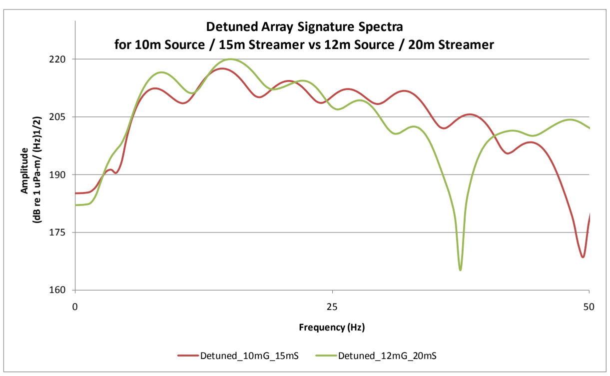
Figure 9: Brute stack with 20 Hz low-pass filter applied

These data clearly show that the acquisition system behaved as modeled, the de-tune source produced more low frequency energy than the tuned source and the deeper cable depth allowed more low frequency reception than the shallower streamer tow depth.

The 40 Hz high-pass data show that there is a broadband response in the first 1.0 to 2.0 sec below the water bottom. Below that the mid and high frequency energy is rapidly attenuated. Conversely, the 20 Hz low-pass data shows high amplitude reflection (and multiple?) data throughout the whole section with the de-tuned source with a 15m deep streamer giving the best low frequency results.

Conclusions

None of these results are really surprising. The frequency characteristics of the four trial acquisition configurations are easily predictable from simple physics. The seismic reflection imaging process starts with the source. There is a fixed amount of potential emitted acoustic output for any given array design and air gun chamber pressure. We have demonstrated that by manipulating the firing times of the different elements in the array we can preferentially position the resulting emitted energy into preferred frequency bands. The same array can be used to emit a broadband signal or a narrowband low frequency signal; we're essentially just moving energy from the mid and high band into the lows. Figure 10 shows that the choice of source and streamer depths can "fine tune" how that energy is distributed.



On the receiver side, the effects of receiver ghosting are well known Over the past several years there has been significant technology developments aimed at mitigating the effects of the receiver ghost in order to widen the bandwidth of marine towed streamer data, at mid and high frequencies as well as low frequencies. We accept that that approach makes sense ***in areas where the earth provides a broadband response***. However, as the data in our test area demonstrates, the earth is generally pretty stingy about passing mid and high frequency signals through a rock section where deep exploration targets may occur. And as stated in the introduction, in areas where there are strong acoustic impedance interfaces, the mid and high frequencies may actually add more to the overall noise environment than to useable signal.

Acknowledgments

We would like to acknowledge the following contributors to this effort:

- Ophir Energy for allowing us to conduct this experiment on their block offshore Gabon. Their assistance was also essential in securing the required government permissions in a short time frame.
- The management and crew of the Polarcus Naila. They were asked on short notice to detour during a transit to acquire this test data. They now lay claim to acquiring the first 2D data in the company's history.
- The senior management of Polarcus for providing the time in a very tight schedule for the vessel.

Additionally, all source signatures were modeled using PGS' Nucleus source modeling software.

References

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Solid streamer noise reduction principles
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