

Why not narrowband?

Philip Fontana* and Mikhail Makhorin, *Polarcus*; Thomas Cheriyan and Lee Saxton, *GX Technology*

Summary

A 2D towed streamer acquisition experiment was conducted in deep water offshore Gabon to evaluate techniques to optimize seismic reflection data within narrow low frequency bands through the use of a low frequency source, deep towed solid streamers, and long offsets.

These techniques proved effective and should be applicable in many areas where the primary exploration targets are deep in the rock section and/or are overlain by high impedance low-pass salt, basalt, or carbonate structures.

Introduction

In many exploration provinces potential hydrocarbon bearing geologic formations are located beneath thick layers of carbonate rocks, salt, or basalt. These layers present several challenges to seismic reflection imaging

- The interfaces between the rocks above and below these layers created high acoustic impedance boundaries that reflect a good percentage of the down-going and/or up-going seismic energy.
- The layers can be highly absorptive, attenuating high and mid frequencies and only passing low frequencies.
- In salt provinces, as well as absorbing seismic energy, the movement of salt through the overlying rock layers creates complex geologic formations that require very sophisticated 3D imaging techniques to allow an accurate interpretation of potential hydrocarbon traps.

Given these challenges we submit that during data acquisition the bandwidth of the seismic acquisition system should be tuned to optimize the signal-to-noise at the low frequency end of the signal spectrum and not configured for a broadband response.

In these types of areas attempts to record broadband data can actually be counterproductive in that the frequencies that do not penetrate the problem layers tend to be reflected, refracted, and/or scattered thus contributing to the overall noise environment rather than to signal. So our question, why not narrowband?

On the signal side of the issue the quality of the low frequency data will be dependent on the source output, the low frequency noise performance of the streamer(s), and

exploitation of the low frequency boost the source and receiver ghost responses can provide in targeted low frequency bands. In these cases we want to use the ghosts, not suppress them.

On the imaging side, we consider long offsets to be extremely important for imaging below complex structures that require some form of pre-stack imaging process to provide an accurate 3D picture of the sub-surface.

Recently we acquired a set of data over a 2D test line in deep water offshore Gabon. The objectives of the experiment was to demonstrate that through manipulation of the source and receiver systems we can enhance the low frequency response of a conventional towed streamer system and to evaluate the value of long offsets to the imaging effort. The test line, Figure 1, was in a block operated by Ophir Energy and provided a great laboratory to quantify differences in the low frequency response of different source/receiver combinations in the thick section on the west end (right) of the line and the impact of increasing offset ranges for pre-stack imaging over the complex salt areas on the east (left) end.

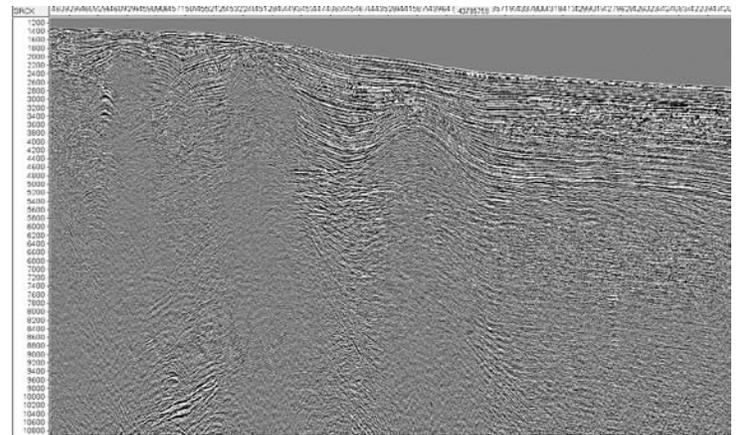


Figure 1: Brute Stack of 2D Test Line

Data Acquisition

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 12 km solid streamer was towed between the sources. The line was shot twice, each time in the same direction, once with the streamer set to a 9m depth and the second time with the streamer at 15m. Along each line the

Why not narrowband?

sources were alternated at 25m shot intervals to acquire adjacent 2D CMP lines.

This configuration and process provided for three primary controlled experiments

- Comparison of data bandwidth as a function of source design
- Comparison of low frequency response of receivers at two different tow depths
- Evaluation of pre-stack migrated image quality as a function of maximum offset used in the migration

For this initial 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. Also, as shown below, the waveform for the de-tuned source is quite complex. We will present a separate report on the stability of the waveform and the signal processing required to shape the signal into a more conventional wavelet.

Source Arrays

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 in³. The source controller was programmed to synchronize the firing time 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 in³. However, for this source 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 the staggered firing times concentrates the emitted energy 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 between 15 Hz and below 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 de-tuned 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 in³ array element.

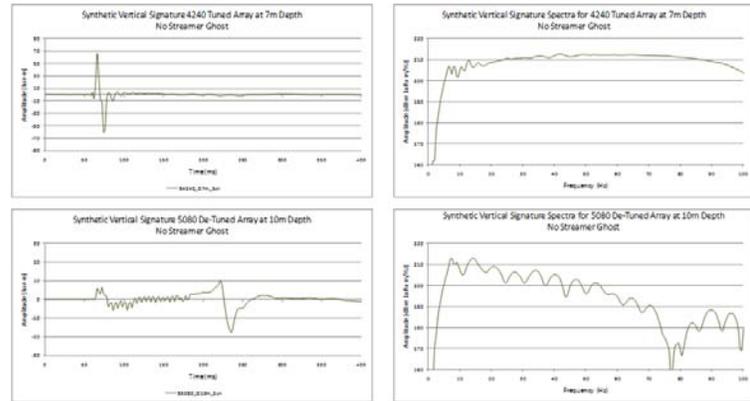


Figure 2: Modeled time series and amplitude spectra for vertical signature from the tuned and de-tuned source arrays.

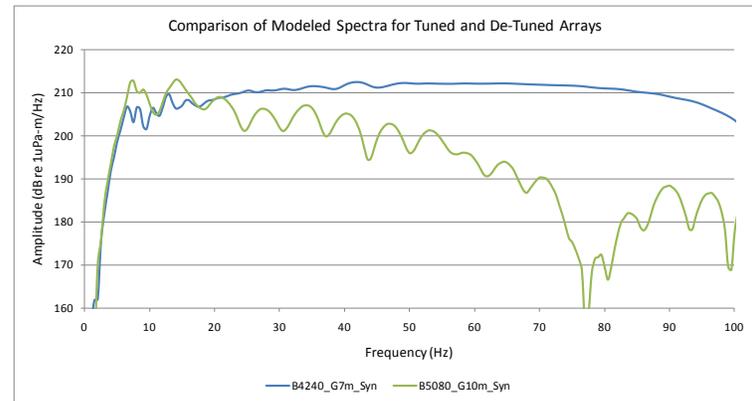


Figure 3: Comparison between tuned array and de-tuned array amplitude spectra

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 frequencies below 20 Hz.

Figure 4 shows a comparison of measured vibration sensitivity functions for a solid streamer and gel-filled and fluid-filled streamers. Vibration sensitivity is the measure

Why not narrowband?

of acoustic noise generated by a streamer hydrophone per unit measure of mechanical excitation, thus the units in dB re 1 $\mu\text{Pa}/\text{m}/\text{sec}^2$ (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.

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 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.

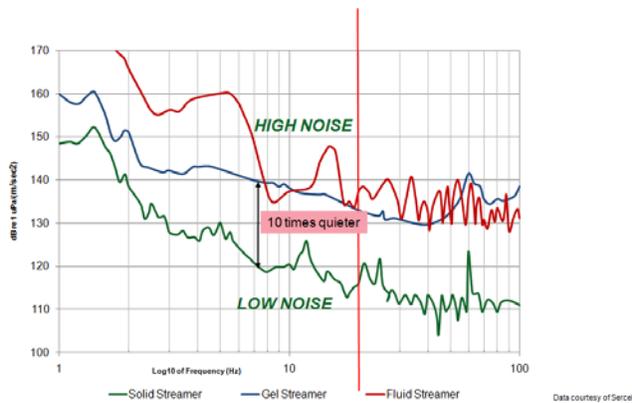


Figure 4: Steamer Vibration Sensitivity Curves (data courtesy of Sercel)

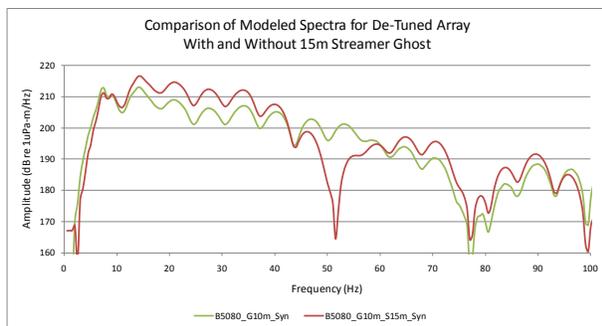


Figure 5: De-tuned array signature spectra with and without 15m receiver ghost.

Figure 5 demonstrates that a receiver ghost for a streamer tow depth of 15m provides about +6 dB of gain in the 15 Hz to 30 Hz band while further attenuating potential noise generating higher frequencies.

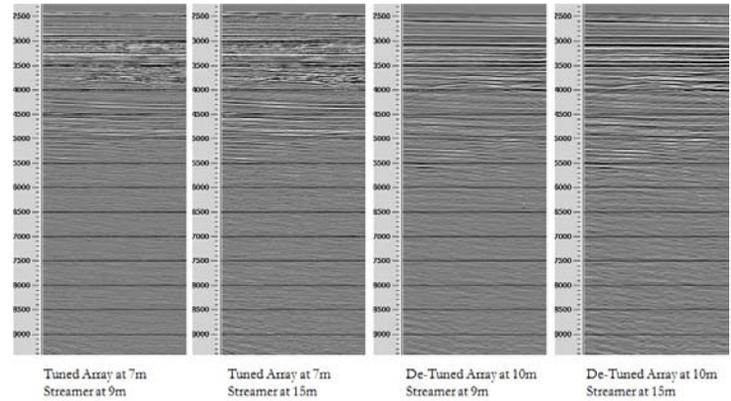


Figure 6: Brute stack sections with 2 Hz to 80 Hz band-pass filter applied

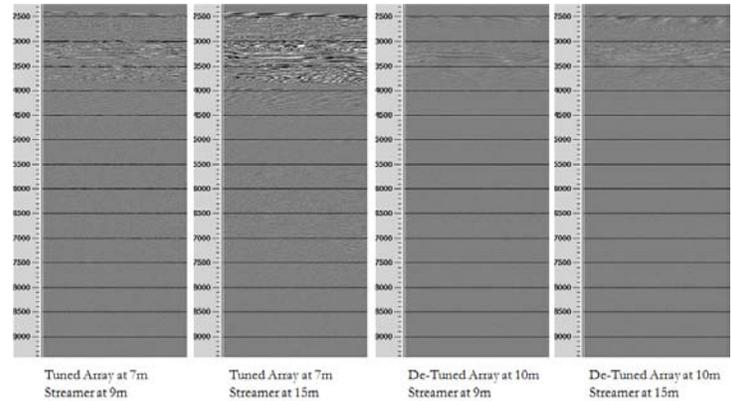


Figure 7: Brute stack sections with 40 Hz high-pass filter applied

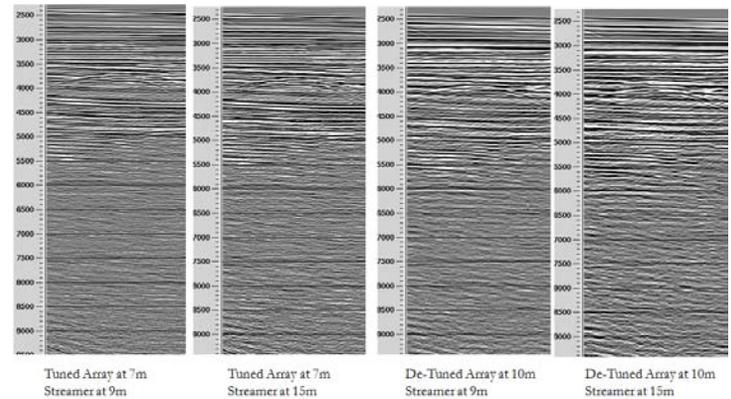


Figure 8: Brute stack with 20 Hz low-pass filter applied

Why not narrowband?

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 west 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.

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.

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.

Therefore we restate our question, why not narrowband?

Acknowledgments

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

- Andy Oldham at Ophir Energy for allowing us to conduct this experiment on Ophir's block offshore Gabon. He was also essential in getting 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.

EDITED REFERENCES

Note: This reference list is a copy-edited version of the reference list submitted by the author. Reference lists for the 2011 SEG Technical Program Expanded Abstracts have been copy edited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

REFERENCES

Dowle, R., and M. Maples, 2006, Solid streamer noise reduction principles: 76th Annual International Meeting, SEG, Expanded Abstracts, 85–89.