Tu-12-10

Slanted-Streamer Acquisition - Broadband Case Studies in Europe / Africa

B. Webb (WesternGeco*), D. Hill (WesternGeco), S. Bracken (WesternGeco) & C.L. Ocampo* (WesternGeco)

SUMMARY

In 2012, two offshore Africa slanted-streamer acquisition pilot surveys were acquired, as well as one circular acquisition with slanted streamers offshore northern Europe. This technique uses a linear slant streamer in order to produce a sliding notch over offsets. This is an exploration tool as it uses a typical towed-streamer spread with all cables slanted. Receiver deghosting is applied upfront in the processing sequence to narrow the receiver ghost notches. Post deghosting, the processing sequence is similar to any other dataset taking into account the enhancements in both low and high frequencies. We will briefly discuss the acquisition technique and then present the deghosting algorithm. We will then show the results on two case studies in Europe and Africa. The West Africa pilot consisted of three 2D sequences overlapping a large 3D survey acquired in this area. The Europe project consisted of a circular acquisition using slanted streamers. This is currently being processed and we present some preliminary results. The latter gives a combination of full azimuth and broadband data in shallower waters. We will be showing the results of the deghosting up to and including migration and we will be comparing it with the legacy data.
Introduction

In 2012, two off-shore Africa slanted-streamer acquisition pilot surveys were acquired and processed as well as one circular acquisition with slanted streamers in offshore northern Europe. The aim of these acquisitions was to evaluate the acquisition technique operationally as well as evaluating the deghosting processing algorithms. By combining this technique with the circular shooting acquisition method, we are able to create a fully illuminated data set coupled with a broadband solution.

These surveys covered acquisition in deep water (West Africa) as well as in shallower water (Europe). The approach adopted for the deghosting was to complete this step at the beginning of the processing sequence. Prior to deghosting, there is some limited preconditioning to remove noise and direct arrivals. With this early intervention approach to deghosting, the remainder of the processing is undertaken in a way that is similar to that of any towed-streamer data set. This acquisition technique is suited for exploration with all the cables deployed with linear slant geometry and a typical acquisition spread configuration can be used. The processing time will not be affected by issues related to the variable tow depth and associated receiver ghost, as this aspect of the data will be dealt with upfront in the sequence.

Data acquisition

Since 2011, surveys have been acquired using this method throughout the world in a variety of geological settings.

An advantage of this acquisition technique is that existing marine single-sensor streamers are used. It is an efficient acquisition technique as standard marine towed-streamer spread widths are used. Moldoveanu (2012) describes this technique in detail. By using a slanted streamer, the receiver notch varies with offset as the cable depth varies from near to far offsets. A survey evaluation and design study may be performed to determine the optimal cable depths required to meet the geophysical objectives. Typically, we have been recording data where the minimum and maximum cable depths vary from 5 to 50 m. In recent projects in Europe and Africa, the depth ranges used are from 8 metres at near offset and 24 m at the far offsets. Figure 1 is a cartoon illustrating the technique.

A 1.5Hz low-frequency system response ensures the high-fidelity recording of the bandwidth extension towards the low frequencies enabled by this type of acquisition. The data are recorded at the 3.125 m single-sensor spacing which helps to measure the majority of the noise unaliased, such that it can be easily attenuated as coherent energy. We have seen that by retaining a fine receiver spacing, we minimise the effects of spatial aliasing. From experience in recent surveys, the data have been recorded at single sensor-spacing of 3.125 m and, at this spacing, an initial noise removal is applied onboard the vessel. The data are then group formed at 6.25 m so that the deghosting can also be performed at a fine spacing.

![Cartoon of the acquisition technique.](attachment:figure1.png)

**Figure 1** Cartoon of the acquisition technique.
Applications of this acquisition

This technique can be used in conjunction with all towed-streamer geometries from linear sail–line geometries including narrow and wide-azimuth acquisitions. Recently, it was also deployed in curved sail-line geometries such as circular acquisition. This type of survey accomplishes two geophysical objectives:

- Enhancement of the low frequencies to create a broadband dataset.
- Improvements of the imaging with fully illuminated data.

Preconditioning of the data for deghosting

An initial noise removal step is applied on the single-sensor measurements, and the data are then digitally group formed at 6.25 m trace spacing. However it is accepted that there will still be some residual noise. This noise may be linear, seismic interference, or any other noise related to the activities near the acquisition. Prior to deghosting, we only remove the highest amplitude noise in order to prevent any smearing in subsequent processing. Residual noise is then addressed subsequent to deghosting as it would be in a standard processing sequence.

Additionally, the direct arrival energy is removed prior to deghosting because it does not contain any ghost information and could potentially harm the deghosting process.

The shot-to-shot variations are addressed by using a calibrated marine source in which near-field hydrophone measurements are used to determine individual source signatures, such that these variations do not impact the wavelet. All processes prior to deghosting are carefully applied so that they do not modify the ghost information. For example any zero phasing is applied after deghosting, however debubble is applied in a prior step as it does not introduce any artefacts.

Single-streamer deghosting

Single streamer deghost (SSD) is used to attenuate the receiver ghost of data acquired with receivers at variable depths along a given streamer whilst also broadening the data bandwidth (spectrum flattening). In addition, SSD can redatum the cable to a user-defined flat depth.

The deghosting and redatuming is done early in the processing sequence using prestack spectral reconstruction.

The data set obtained after this process has low frequencies enhanced and a flatter spectrum. A conventional processing sequence is tuned to preserve the broadband data.

It is established that the recorded dataset is a combination of the upgoing and downgoing pressure on a variable-depth streamer in space and frequency domains. However, in processing we ideally want the upgoing pressure at a defined depth with minimal ghost response.

Hence, for each shot, we read the variable cable depths from the trace headers and build the 2D theoretical ghost response. As it is difficult to relate downgoing or total wavefield as measured directly on a slanted streamer to the upgoing wavefield on the same slanted streamer in the TX domain, it is necessary to use an indirect relationship by performing the wavefield separation in a different domain.

In this domain, we forward model the upgoing and downgoing wavefield at zero depth. At this depth, the downgoing wavefield is now reverse polarity of the upgoing. Following this, the upgoing and downgoing wavefields are redatumed to a specified constant depth.

To make the transform more stable, constraints are applied such as coloured noise and a variable reflection coefficient with frequency. Experience has determined that we deghost the data at a fine receiver spacing to improve the results.
Case study 1 – Deep water: West Africa

This first case study is located offshore West Africa in a deep-water setting. These 2D lines were acquired over a 7124 km² 3D survey collected between October 2011 and May 2012. The same spread was used with streamers towed 100 m apart, with in-streamer point receivers located at 3.125 m intervals and a cable length of 8000 m. The depth of the cables was at 8 m for the 3D survey and was between 8 m at near offset and 24 m on the far offsets for the slanted-streamer acquisition. The survey was acquired with dual flip-flop sources at a 25m pop interval. A 3147 cu. in air-gun source array was deployed at a depth of 6 m.

To evaluate the results in comparison to a conventional non-slanted streamer acquisition, one of the sequences was positioned to be a repeat of one of the lines from the 3D volume. Additionally, two sequences were shot perpendicular to the first one as shown in Figure 2.

![Figure 2](image1.png)

*Figure 2* 2D lines overlaid on a timeslice.

The processing sequence onshore included a residual noise removal followed by 2D deghosting then de-multiple using the surface-related multiple elimination (SRME) process as well as weighted least-squares radon demultiple. Finally, the data was prestack time migrated using the same velocity field as used in the 3D survey.

The migrated slanted-streamer 2D line was compared to a neighbouring line from the 3D survey (Figure 3). Note that, because the acquisition of the 2D lines was not intended to steer the source and streamer to replicate exactly previous shot and receiver locations, there are some variations on the locations of the subsurface line. However, the improvements as shown in Figure 3 are very clear. The same processing sequence was applied to both datasets and, hence, we only see the effect of the acquisition and deghosting which has brought a higher signal-to-noise ratio and enhancement of the low frequencies especially in the deeper part of the section.

![Figure 3](image2.png)

*Figure 3* Migrated 2D stack constant depth (left) – Migrated 2D stack slanted-streamer acquisition (right). Data courtesy of WesternGeco and Sonangol E&P.

Case study 2 – Shallower water: Europe
The second case study is from European waters and is located offshore Norway in a shallower water setting. A circular acquisition survey of 757 km² using slanted streamers was acquired in the late 2012 using a spread that consisted of eight towed streamers, 100 m apart, and 8000 m in length. The depth of the streamers varied from 8 m to 24 m on the far offsets. The near offset is 50 m. A large source array of 5085 cu. in was used with dual flip-flop sources at a 25 m pop interval.

The processing on the vessel included an initial noise removal. It was decided to keep the receiver spacing at 6.25 m to effectively attenuate the residual noise later in the sequence, as well as deghost at a finer spatial interval. A similar noise removal technique to that described by Zamboni (2012) was used on these data.

At the time of this writing the onshore processing is ongoing; however, an initial fast-track data set has been produced. The deghosting was executed onshore post shot-to-shot amplitude variation removal and debubble. Following deghosting, zero phasing was performed, and then followed by 3D SRME.

The results viewed on stacks (Figure 4) of the deghosted data set showed an uplift in the low frequencies given by the acquisition technique.

![Figure 4 Stack before deghosting (left) and after deghosting (right). Data courtesy of WesternGeco.](image)

**Conclusions**

In this paper, we discussed a slanted-streamer acquisition technique and the related deghosting aspect. Slanted-streamer acquisitions are a cost-effective approach to broadband seismic acquisition for exploration purposes without the need of any purpose-built cables.

We propose deghosting data very early in the processing sequence, which opens up options within prestack processing and enables inversion QC at key stages of the sequence.

We then compared the effect on deghosting on two different acquisitions performed in Africa and Europe in 2012. At the time of this writing, the final imaging is still ongoing; however, the preliminary results illustrate the benefits of broadband acquisition in these areas and the benefits provided by deghosting upfront in the processing sequence.

**Acknowledgements**

The authors thank WesternGeco and Sonangol E&P for allowing the use of the Angola data and WesternGeco for the Barents Sea data. The authors also thank Andrew Furber, Larissa Oni, Ed Palmer, Njál Flesjå, Pete Watterson.

**References**
