Multi-source design and penta source case study from the NWS Australia

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SUMMARY

Marine towed streamer acquisition has been largely restricted to just a few geometries which are determined by the streamer separation and number of sources. Most acquisition uses two sources with 100m streamer separations, or sometimes 75m and 50m for higher resolution surveys. Greater flexibility can be gained by using more than two sources and this leads to a range of design options more commonly associated with land acquisition. The aim here is to allow greater tuning of the acquisition to meet efficiency, quality or time restraints of the survey so that so a better match is obtained between the actual and desired survey.

The use of multiple sources is in part enabled by the commercialisation of interfering shot energy removal which has long been practiced in land seismic, but is much more challenging with marine streamer data due to the lack of azimuthal and offset variation of the source positions relative to the receivers. The ability to remove interfering shot energy means shotpoint intervals can be reduced, enabling multi-source designs by increasing inline fold, which is needed for successful processing of the data in domains such as 2D CMP and common-trace.

With triple sources we show that the options are greatly increased to either improve efficiency or quality and sometimes both, but we can also consider 5 or penta sources with which we obtain very high density data - 6.25m cross-line cells –with acquisition efficiency.

A 400km^2 survey was acquired on behalf of Quadrant Energy using the 5 source method and in addition a smaller 50km^2 using a conventional geometry. Direct comparisons can be made between the geometries and the simple fast-track processing shows the benefits of decreasing the cross-line sampling to fully realise the benefits of broadband data as high-frequencies are fully sampled in the cross-line domain.

Key words: acquisition, multi-source, broadband, resolution

INTRODUCTION

Since the advent of 3D marine towed streamer acquisition the industry has been limited by the dual source designs that give a reasonable balance between efficiency, which is the amount of data that can be acquired in a single pass, and quality, or the cross-line resolution. Dual source designs also allow for an inline fold that is high enough to allow processing of the sub-surface line. Finally dual-source designs allow for sufficient time between shots so that the record length is long enough for most survey requirements.

In the past attempts were made to record triple source data but these suffered during processing with insufficient inline fold for processing affecting the 2D CMP and common-trace domains or shortened record lengths. With the commercialisation of interfering shot energy removal these constraints are reduced as the inline fold and record length become independent of the shotpoint interval. We can then consider a much wider range of streamer and source designs enabling optimisation of the survey geometry in a similar manner to land acquisition where it is more common to tune the receiver and shot effort in relation to quality, efficiency and operational restraints.

With a new advancement of technology we must consider the risk associated with it and in the case of processing interfering shot energy the risk is that the analysis that can be performed on the data in the pre-stack stage, such as AVO or pre-stack inversion, are compromised due to excessive residual noise or attenuated signal. We can note though that the reflection energy interference starts at the time below the water-bottom relative to the shotpoint interval so, for example, with a 12.5m interval the time interval is 5.4 seconds which means that as long as the targets are less than 5.4 seconds below the sea-bed time there is no significant interference and so low-risk. Deeper structural interpretation is at the post-stack stage where the risk is very much lower from residual shot energy or attenuated primary signal.

A 400km^2 survey was conducted on the North West Shelf Australia for Quadrant Energy with a 5 source design and in addition a smaller 50km^2 reference survey with conventional geometry so that comparisons can be made which would cover issues such as cross-line resolution, interfering shot energy removal, source energy, shot density, deep imaging, regularisation. In this paper I show that with simple fast-track processing we see significant improvements between conventional and 5 source data because of the increased cross-line sampling.

MULTI-SOURCE DESIGNS

First we will consider the options that multi-source designs give us over conventional dual source designs and discuss benefits. In Figure 1 we can see in the centre the most typical geometry -2 source with 100m streamer separations. Over the years the number of streamers has increased from four to twelve and beyond as vessels have become larger and more powerful, but otherwise the basic geometry remains the same and gives us 25m cross-line bins. For high resolution or HD3D surveys the streamer separation can be

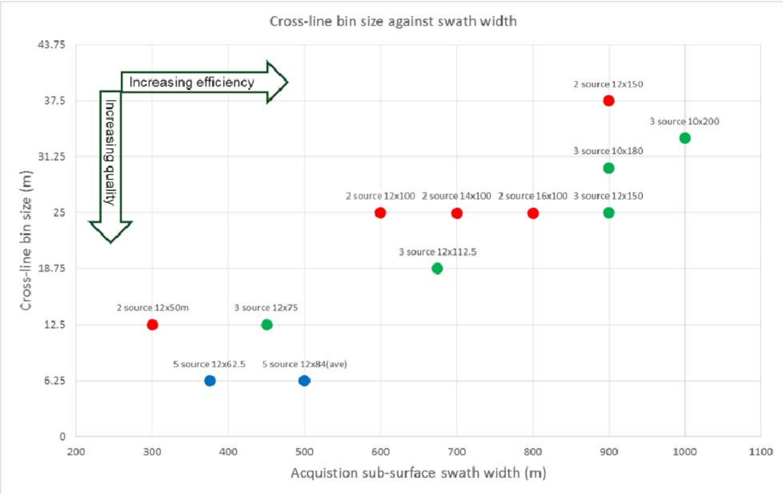


Figure 1: Comparison between sub-surface swath width, which governs acquisition efficiency, and cross-line bin size which governs quality. Various dual source (red), triple source (green) and penta source (blue) designs are plotted showing some of the possibilities of multi-source offers

lowered to 75m or 50m but with half the efficiency or sub-surface swath acquired per pass of the vessel but cross-line bins of 12.5m. HD3D surveys even though desired have not been acquired much due to cost, operational constraints or survey duration in areas with limited weather/environmental windows.

In the following we discuss the efficiency, operational and quality of multi-source over dual source. The issues discussed in the introduction regarding the removal of interfering shot energy should be remembered. For simplicity the efficiency is quoted without considering that wider spreads take longer on line-change and so final time saved or survey efficiency is relative to the line length.

Efficiency

A 50% efficiency gain can be achieved with triple source whilst maintaining the same cross-line bin size as a dual source design. We can look at two examples –conventional 12x100m dual where we acquire 600m per swath and 12x150m triple where we acquire 900m per swath. Secondly we can look at 12x50m dual (HD3D) where we acquire 300m per swath and 12x75m triple where we acquire 450m per swath. Both offer substantial gains and puts HD3D as a viable option when using a triple source.

For extreme efficiency the largest spread width that has been be towed is 10x200m (1km sub-surface swath width) and with dual-source this gives a 50m cross-line bin which is not great for quality, but much better than 2D or unsurveyed acreage. There is also option of interleaving parts of such a survey at a later date once targets have been identified. If we consider 10x200m with triple source we get a rather ugly 33.33m cross-line bin but the spread could be extended slightly to 10x210m to give 35m bins, or reduced to 10x187.5 for 31.25m (a multiple of 6.25m). For a more detailed look at these geometries please refer to Table 1 below.

Quality

For triple source to work we need a smaller shotpoint interval to maintain fold and with a 12.5m shot point interval each individual source fires every 37.5m, which compares to conventional dual source of 50m. This is a 33% increase in fold. Fold however is not the only metric we can consider –we should also look at the shot and trace densities as in land surveys. Along with fold these indicate different quality aspects of the survey geometry, for example: inline fold for the ability to process sub-surface lines; shot density for variety of noise to the signal; and trace density for the unique ray-paths and hence signal-to-noise post-migration.

Another option to enhance quality and efficiency is to consider 12x112.5 with a triple source. Here we not only acquire more data than 12x100m but also reduce the cross-line bin size from 25m to 18.75m.

For the highest quality we can look at the penta source where we achieve 6.25m cross-line bins and this allows for virtually all seismic-frequency data to be captured un-aliased finally realising the full potential of broadband data. The penta source designs can be configured with the nominal streamer separation of 62.5m, suitable for shallow water areas where largest near-group offset is a limiting factor in the spread width, or with the streamer separations increased to achieve up to 500m acquisition swaths. The latter is discussed in the case study below. The physical limit of recharging an air-gun places a time constraint on how often we can fire the source and based on field tests a shotpoint interval of just over 8m is possible. This gives an inline fold of 96 and a shot density of 320/km^2 and when compared to a 12x100m survey nearly 5 times the data volumes and compared to a traditional HD3D we would have 2.5 times the trace density.

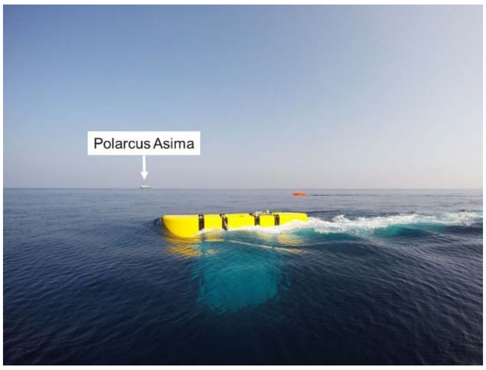


Figure 2 View from "door" or "deflector" for a 10x200m survey. Towing vessel 1km distant illustrating the scale of such acquisition

Operational Considerations

How we shoot a survey and the risks associated with it should be considered in conjunction with the survey aims of efficiency and quality. If we first look at increasing the number of streamers we face increasing in-sea maintenance to keep a functioning spread which is both a time issue but more importantly increases safety exposure with small-boat operations. In areas where barnacles grow on the streamers we may reach a point where the number of deployed streamers can't be cleaned fast enough.

When we acquire a traditional HD3D survey with 50m streamer separations there is an increased risk of streamers getting tangled, especially in areas of volatile currents, and one way to mitigate that is to reduce the streamer length but this may not always be desirable geophysically. By using a triple source design we either reduce the risk further or maintain the desired maximum offset. If survey design shows that wider spreads are acceptable (eg near-group offset, footprint) then we can mitigate risk further by reducing survey duration.

	Streamer #	Source #	Streamer seperation	SP Interval	Xline bin size	Sub-surface Spread	SP per source	Shot density (per km2)	Trace density (per km2)	nominal Fold (8km streamer)	Data volumes rel to 12x100m
Conventional	12	2	100	25	25	600	50	67	512,000	80	1.00
	18	2	100	25	25	900	50	44	512,000	80	1.00
	12	3	150	12.5	25	900	37.5	89	682,667	107	1.33
HD 3D	12	2	50	25	12.5	300	50	133	1,024,000	80	2.00
	12	3	75	12.5	12.5	450	37.5	178	1,365,333	107	2.67
18.75m xline bins	12	2	75	25	18.75	450	50	89	682,667	80	1.33
	12	3	112.5	12.5	18.75	675	37.5	119	910,222	107	1.78
Wide-spread	10	3	187.5	12.5	31.25	937.5	37.5	85	546,133	107	1.07
	10	2	200	25	50	1000	50	40	256,000	80	0.50
	10	3	210	12.5	35	1050	37.5	76	487,619	107	0.95
6.25m bins	12	5	84	9.37	6.25	500	46.85	213	1,632,000	85	3.19
	12	5	62.5	8.3	6.25	375	41.5	321	2,467,470	96	4.82

Table 1 Dual, Triple and Penta source designs. For efficiency we can look at the sub-surface spread and for quality both the xline bin size and the fold/shot density. 8000m streamer used in calculations

PENTA SOURCE CASE STUDY

In November 2015 the 400km^2 Baxter survey was conducted for Quadrant Energy using 5 sources with variable streamer separations. In addition a smaller of 50km^2 reference survey using a conventional 10x100m dual-source geometry was acquired. The idea of the reference survey is to give a direct comparison to the penta source design and will be used to show if shot interference removal, source volume, shot density, regularisation, sparse binning and more are factors in data quality. In this paper will look at the benefits of having a small cross-line sampling of 6.26m versus the 25m of the reference survey using fast-track post-stack migrated data.

Penta Source Design

The basis of 5 source acquisition is that sub-arrays are used in more than one source definition. Figure 4 below shows that each sub-array is separated by 12.5m and that sub-arrays can be used in more than one source, for example sub-array 2 is defined in source 1 and source 2. The cross-line spacing is limited to 12.5m to give us the 6.25m cross-line bin size. We can't widen the spacing as this would give rise to source directivity problems. Making the spacing narrower would result in smaller cross-line bins which would only be useful in very limited circumstances. For the Baxter survey the shotpoint interval was 9.37m, or 46.8m between the same shot and is comparable to 50m to for the conventional dual-source reference survey.

The streamers were configured with a variable separation which allows for a 500m sub-surface swath to be acquired per sail-line. This configuration is sparse in that not all bins are filled, instead we assume the coverage will be randomised by the natural movements of the spread and the fan, and the remainder can be filled by regularisation, see Hager et al (2015) for details. From the Baxter survey an example of the resultant coverage is shown in Figure 3 where we can see the non-regular fold and some empty cells showing that regularisation should be considered part of the design when variable streamer separations are used.

The reference conventional data consisted of 11 lines with a 10x100m 25m flip-flop design which gives a 500m sub-surface swath width that matches the penta source data. The source volume was 3480cuin with 3 sub-arrays and compares to the 2495 2 sub-array source of the penta source.

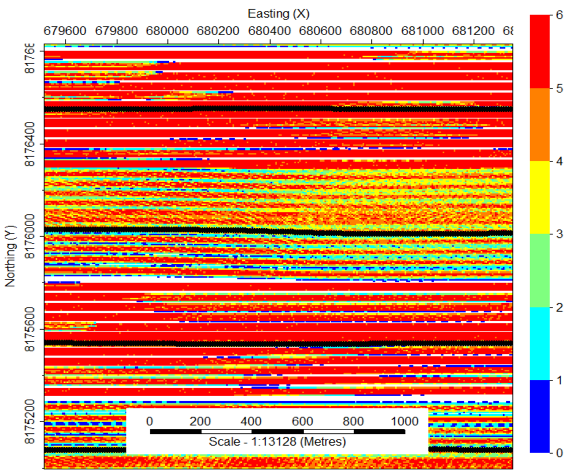


Figure 3 Example fold of coverage from the 5 source survey. Unique fold for offsets 500-1100m. Sail-line vessel position black dots. 6.25x6.25m bins

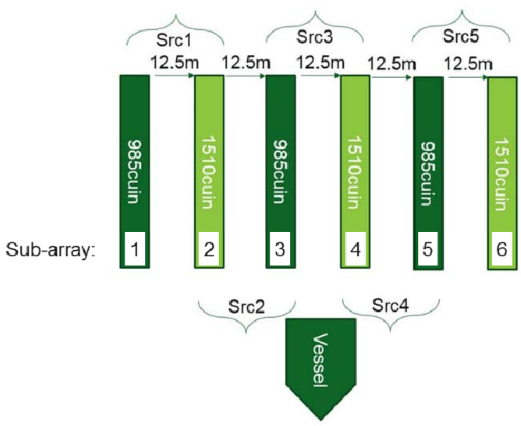


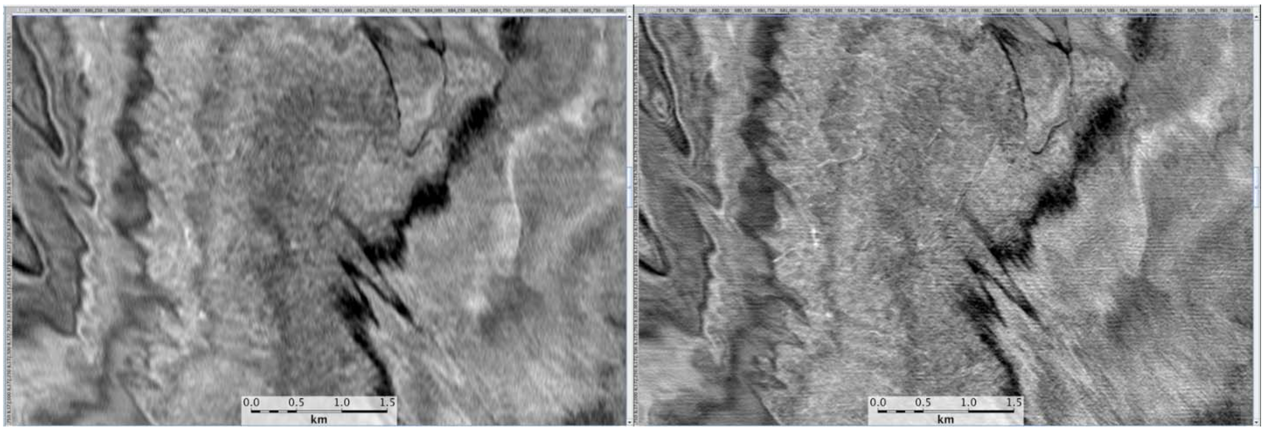
Figure 4 5 source design. Sub-arrays are placed 12.5m apart and each source uses pairs of sub-arrays. Sub-arrays are used in more than one source to allow 5 source definitions from 6 sub-arrays.

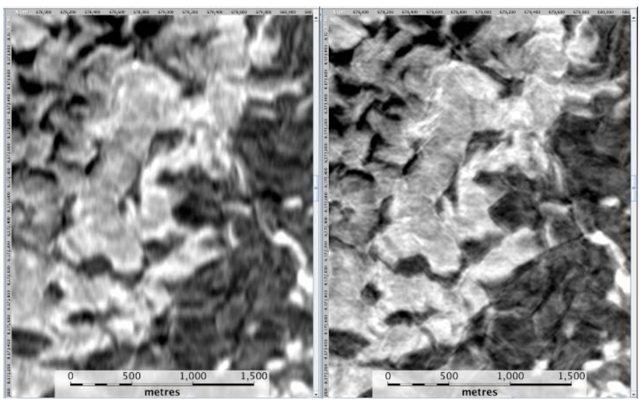
Processing

Both the penta and conventional data were processed in an identical manner with basic de-noise, 2D SRME, de-ghosting, de-signature. The penta source data had the direct arrival energy attenuated through linear near removal, but full shot interference removal was not attempted during this processing and simply muted out which limits the data to 6seconds. Given a 6 second record length the offsets were limited to 6km from the acquired 9km.
The data was stacked with a 2x2km 4th order velocity field and 30 degree angle mute. Duplicate traces were removed giving one trace per offset range. The conventional data was matched to the penta source by applying a single gain scalar and limited to its full fold area (approx. 45km^2). Aperture data for the conventional came from the 5 source data which after stacking was decimated to 25m bins to match the conventional.
Imaging for the penta source was at 6.25x6.25m and 6.25x25m for the conventional.

Results

The displays below show what might be expected by increasing sampling by a factor of 4 in the cross-line direction: improved resolution. We can also see amplitude stripping caused by the fold variations in the penta source but this would be expected without any type of regularisation, or even hole-fill for that matter. An interesting side note is how similar the datasets are other than the cross-line resolution and highlight an underrated feature of de-ghosting in that the wavelets between surveys are very stable





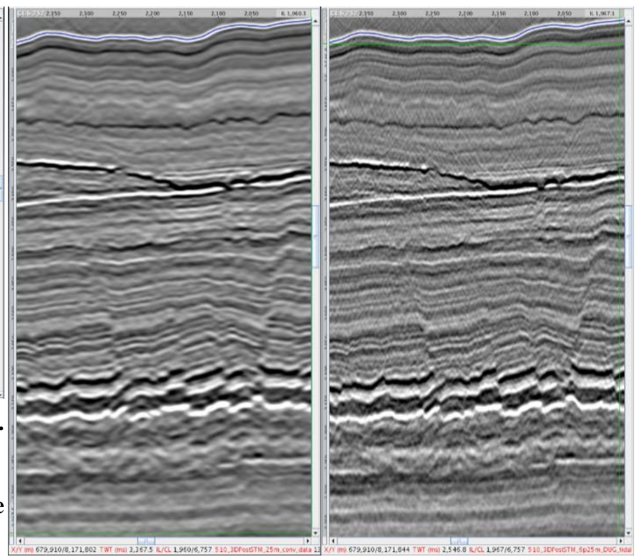


Figure 5Top: timeslice at 2600ms. Left timeslice at 3140ms. Right crossline 6776 (2.7-3.6s, 2.7km wide).
Conventional 25m left and penta source 6.25m right.
Migration artefacts are seen on the 5 source data but are expected due to the lack regularisation.
Images courtesy Quadrant Energy

CONCLUSIONS

We've seen that adding extra sources to designs can improve the efficiency and quality of designs but maybe more importantly we now have a greater range of options so that the survey can be better matched to the desired geophysical and operational outcome. The risk of the multi-source designs is the overlapping source energy and primarily this is when the target time below the water-bottom is greater than 5 seconds. Other factors such as smaller sources may make sub-surface line processing more difficult for deep data and widening the spread may increase the acquisition footprint. We can balance these negatives with positives such as increased fold, higher shot and trace-densities and/or greater efficiency.
Given that we can remove interfering shot energy we can also think of doubling the fold of dual-source designs and this has been shown to be useful in the Capreolus survey NWS Australia where over 22,000km^2 was acquired in this manner.
The penta source design offers a demonstrable way to improve the resolution of seismic and its design simplicity means that specialised processing is not required.

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REFERENCES

Ed Hager, Marc Rocke, and Phil Fontana (2015) Efficient multi-source and multi-streamer configuration for dense cross-line sampling. SEG Technical Program Expanded Abstracts 2015: pp. 100-104. doi: 10.1190/segam2015-5857262.1