



## Efficient multi-source and multi-streamer configuration for dense cross-line sampling

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### Keywords

Acquisition, survey design, cross-line sampling

### Summary

Broadband data allows for high-frequencies to be recovered but due to operational and efficiency reasons the cross-line bin size leaves much of these data aliased. These aliased data, either noise or the desired signal, are filtered during processing and imaging leaving either artefacts in the case of noise or incomplete migration in the case of signal. An efficient method of acquiring dense cross-line bin sizes is proposed which relies on multiple blended sources; variable streamer separations in combination with fan-mode shooting; and real-world spread movements to achieve a randomized midpoint distribution to fully sample the wavefield, within the kinematic constraints of narrow-azimuth spatial sampling.

### Introduction

Broadband acquisition has become mainstream in the industry but the potential is limited by the poor cross-line sampling that current source and streamer separations allow, which leaves high-frequencies aliased in the cross-line direction. These separations are limited for efficiency reasons, that is the ability to acquire the survey in a reasonable time-frame and cost, and operational ones where the streamers are at risk of tangling, especially with long offsets, with small separations. However given the general depth of targets and the earth's attenuation of high-frequencies the general used cross-line sampling of 25m is sufficient, where it fails is for potentially high-frequency shallow targets and for high-frequency noise that is seen as near random at the target due to aliasing.

To overcome the cross-line aliasing an acquisition geometry is proposed which uses multiple sources and variable streamer separations to provide small cross-line bins of 6.25m over the traditional 25m bins. The cost of this is the reduction of the acquisition footprint, for 12 streamers, from 600 to 500m. To achieve this the streamer and source separations are set such that not all bins are nominally covered, instead the system relies on real-world spread movements and fan-mode shooting to complete coverage. For the sources each of the six sub-array elements is equally spaced at 12.5m, and sub-arrays are used in more than one source to provide 5 sources spaced at 12.5m [Dunbar, J Patent US 4868793 A].

An initial test was conducted to acquire 4 lines in the proposed geometry to test the basic issues of the physical

deployment and recording room setup, and the premise that bins would be sufficiently filled in real a world scenario.

### Source Design

In traditional source design two sources are defined by either 2 or 3 sub-array elements spaced 6-8m apart, with the center of each source separated by half the distance of the of streamer separation. This leads to a typical 50m source and 100m streamer separation, with a resulting bin size of 25m in the cross-line direction. The physical limit of this method is 25m source and 50m streamer separations, as below this the risk to equipment is great, the operational cost is at least doubled and the resulting bin size of 12.5m still leaves data aliased.

In the design the sources are set such that each of the 6 sub-array is equally spaced at 12.5m. By reusing sub-arrays more than once 5 sources can be defined where source 1 consists of sub-arrays 1 and 2; source 2 of sub-arrays 2 and 3; and so on, with a firing sequence such that there is enough time for sub-array elements to recharge to full pressure, see Table 1. This gives a surface extent of 62.5m and a mid-point coverage of 5x6.25m cross-line bins.

In order to generate sufficient fold the shotpoint interval is 12.5m and is dithered over 1 second which allows for deblending of the shots. Each source fires every 62.5m, which compares to the general 50m in flip-flop acquisition. The first four to five seconds of data are clean and do not require deblending, thus ensuring the highest quality of data for shallow high-frequency targets or for drilling hazard identification and delineation, though if this was the sole purpose the shotpoint interval could be reduced further to enhance fold, important where there are limited offsets with shallow targets.

Table 1 Source definition and firing sequence, source 1 consists of sub-arrays 1 and 2; source 2 of sub-arrays 2 and 3. Note each sub-array has sufficient time for recharge, ~15seconds

Source Number & Firing Sequence	Sub-Array Number						Delta Time
	1	2	3	4	5	6	
1	1						0
			3	3			5
					5	5	10
		2	2				15
				4	4		20
1	1						25

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### Streamer Design

So far we have seen that that the source configuration will generate midpoints over 31.25m in the cross-line direction, which implies a nominal 62.5m streamer separation. If we were to acquire over this separation the costs of the survey would not be too dissimilar to 50m-streamer separation surveys, and this might well be suitable for a survey focused on very shallow targets and hazards, where the near-group offset is a factor, with large spreads leading to mute holes in the final section. Specialist surveys aside we need to acquire a larger footprint and still maintain sufficient mid-point distribution to fill 6.25m cross-line bins so the survey becomes time and cost efficient. To do this we can consider the following in the streamer configuration:

- Currently it is common to acquire surveys in fan-mode, where the idea is that the streamers separations increase with offset to 125-150% of the front. This is used to reduce far offset infill in general but can be used with a more rigorous approach of Fresnel zone binning [Monk, D 2009]. We can also consider the effect of fan-mode acquisition on the near-offsets and see that this will introduce nominally random mid-point positions spread through multiple bins, more so for 6.25m bins than conventional 25m ones.
- If Fresnel zone binning theory is applied then the acquisition will be along pre-plot lines to ensure full coverage where the Fresnel zone is small. The design must allow for some overlap on the swath boundaries so that holes are not created with feather variations, and
- Near-offset spread is sufficiently wide for efficiency
- Given that the real-world acquisition spread will be feathered and in motion the nominal geometry need not fill every bin.
- Increasing offset requires less cross-line sampling due to reduced frequency content with depth. Noise contamination in the shallow, or multiples thereof in the deeper section will predominantly affect the near offsets. In the farther offsets there will be larger dip discrimination to aid removal.
- Source spread limited to 62.5m, due to the desire to generate 6.25m bins; limitations on the number of sources; and a reasonable sub-array separation.

Taking these points the following streamer configuration below is proposed, where we have smaller separations in the center of the spread, increasing as we go the outer streamers, see Figure 1 below. Other variations are possible and the example below is the one used in the field trial.

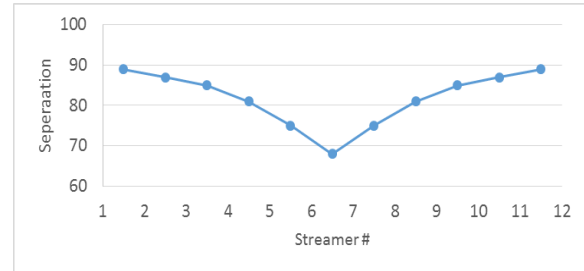


Figure 1 Streamer separations, increasing from center spread outwards.

### Nominal geometry analysis

The following figures show the nominal geometry of the design with a conventional 12x100m acquisition as reference (without fan-mode geometry). In Figure 2 we can see that coverage is variable for the geometry with 36 as compared to 60 fold for the reference. In Figure 3 the effect of the streamer separations and the source design to give us a “hit 5 miss 2” column acquisition. This pattern should be lost with feather and spread movements in the real world.

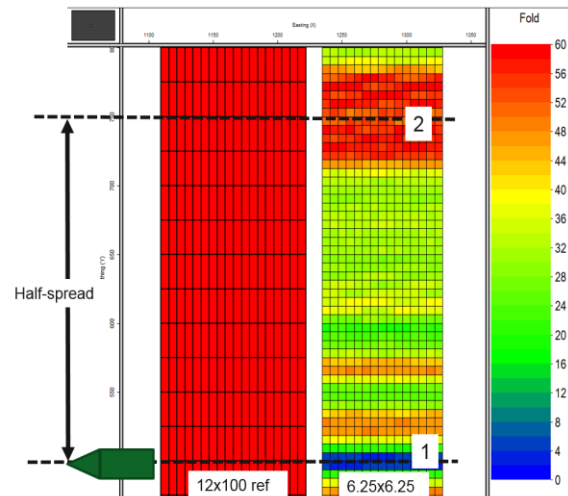


Figure 2 Half-spread (250m) shown with nominal full-fold analysis for conventional 12x100 acquisition on 6.25x25m bins and the proposed geometry with 6.25x6.25m bins. Fold for nominal is 60, and for 6.25m bins 36 average. At “1” zero fold at spread center. At “2”, overfold on spread edge

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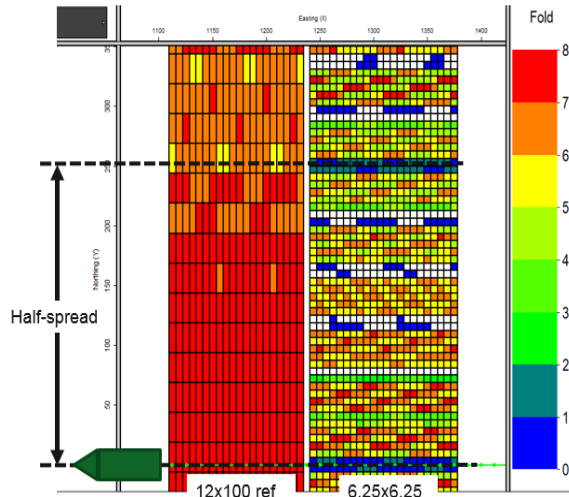


Figure 3 as figure 2 with offset limited 1000m radial. The sparse sampling of the design where we end up with a pattern of acquire 5 miss 2 columns is evident. This is seen clearer in Figure 4

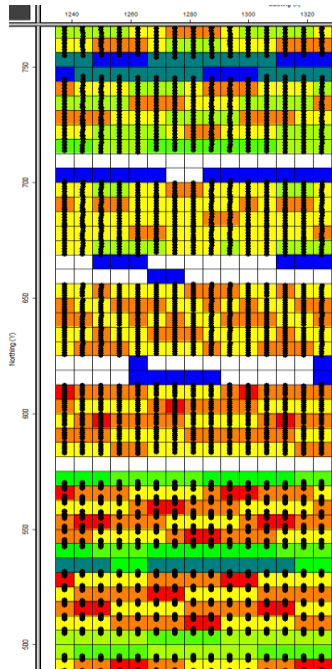


Figure 4 Half-spread shown, as in the preceding figures, with 1000m radial offset limit. Midpoint locations plotted. Here the pattern of hit 5 miss 2 is more clearly seen, with gaps of 10-14m. Spread of the mid-points cross-line due to the fan of the streamers. Also note that the source time dithering is not applied here. In the final survey geometry the midpoint positions will be spread, or randomized in the inline direction due to source time dithering.

### Fold

In the nominal geometry analysis we see that compared to conventional fold of 60 the proposed design is on average 36. Though this seems like a large drop the effect on the ability to reduce random noise is given by root N, thus we end up with S/N ratios of 7.8 and 6 for the 60 and 36 fold respectively, or -2.3dB. The impact is therefore small. However the idea is that noise previously seen as random in the inline will be resolved as coherent when seen with the fine cross-line sampling, which opens up ways to remove it by other methods over the “brute” ones such as anomalous amplitude attenuation, or for that matter the power of stack.

### Processing considerations

An advantage of the geometry is that no special processing or imaging processes are needed.

Deghosting would be achieved by using deep flat streamer design [Fontana, P 2014] which has the advantage of giving low noise pressure data and no issues are foreseen with modeled ghost de-ghosting algorithms.

Simultaneous source deblending is a maturing technology as can be seen in Figure 5, and is not required for targets shallower than 4 seconds.

In the shot domain sampling is down from 50 to 62.5m which would have some impact in shallow water SRME, however it is standard practice now to have deterministic shallow water demultiple solutions. Adaptive subtraction of shallow water multiple models have a slight disadvantage with 62.5 over 50m trace spacing in the common trace domain.

5D regularization is commonly applied now and the even and random mid-point distribution should aid the process as compared to the very asymmetric data, in the sense of inline versus cross-line midpoint distribution, from conventional acquisition.

A disadvantage over multi-component wavefield reconstruction methods [Vassallo et al 2010] is that the ability to remove cross-line noise is limited to after regularization, or at least 3D binning. This is because the multi-component reconstructions methods generate dense cross-line sampling in the shot-domain which would allow 3D coherent noise suppression to be run earlier in the processing sequence, for example seismic interference elimination [Vassallo et al 2012]. Essentially the difference between surface and sub-surface sampling. However an advantage is simpler processing with good quality pressure data over the difficulties of processing low-signal Y-component velocity data with high amounts of noise.

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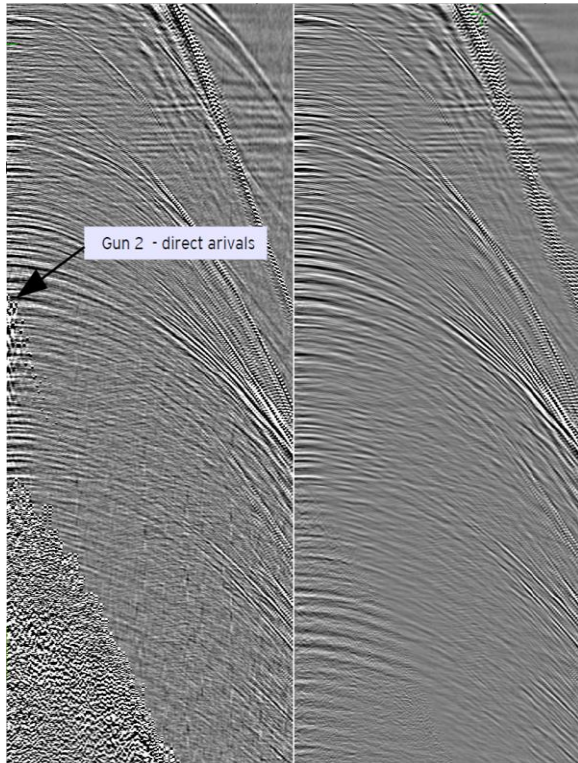


Figure 5 Example of source deblending, NMO'ed CMP gather before and after deblending. Data courtesy Polarcus MC, Capreolus Survey, NWS Australia. Processing by DownUnder GeoSolutions, Perth

### Acquisition field trial

In January 2015 a field trial of the geometry was acquired to demonstrate that the components come together to achieve reasonable midpoint distribution with real-world feathers and that these data can be processed. The test was performed in the Carnarvon basin, NWS, Australia.

Reconfiguration and deployment to the new geometry was achieved easily. One concern was the source separation between sub-arrays 3 and 4 as these are on different paravanes, however the use of a rope held separations steady and no problems were seen.

Four lines were acquired in the same direction and each featured different feathers that will help determine acquisition specifications in the future. See Figure 6.

Sources were every 12.5m on average, dithered over 1 second, to allow for source deblending. See Figure 7

In Figure 8 we can see that the fold distribution for both full fold and near-offsets is smoothed out as compared to the nominal geometry, as desired.

In Figure 9 we highlight three different scenarios where we

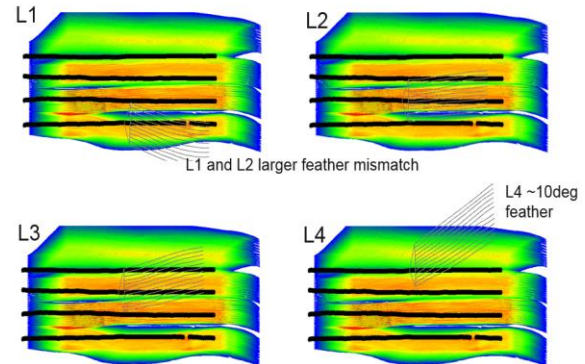


Figure 6 Four lines acquired featured a variety of feather differences: between L1 and L2 large opposite feather mismatch and L4 which had a large 10 degree feather, but in the same direction as L3. Between L1 and L2 would normally require infill based on Fresnel zone binning requirements. Overall fold is shown with the oranges ~40-50 fold and greens 20-30

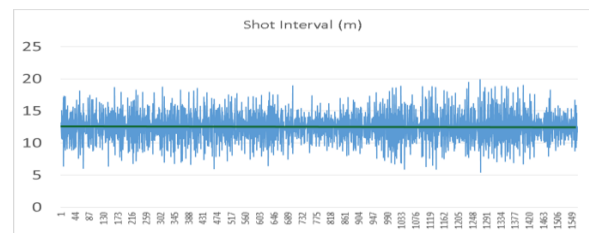


Figure 7 Shot intervals for one line, average of 12.5m shown. 1 second random dither gives shotpoint interval range of 6-19m

have large feather; feather that is close to the fan feather; and lastly the typical case we hope to have in general.

### Conclusions

The idea of the proposed acquisition geometry is to achieve dense cross-line sampling, to aid noise suppression and high fidelity imaging, whilst being time and cost efficient. The design has two main elements –reuse of the sub-array to create multiple sources spaced at 12.5m cross-line; and variable streamer separations which increase from the center of the spread outwards. Streamer separations are such that not all bins are expected to be filled, instead fan-mode shooting in conjunction with real-world spread movements are expected to achieve a random distribution of the mid-points.

Benefits are that standard processing tools developed over the last few years can be used, and are relied upon, such as

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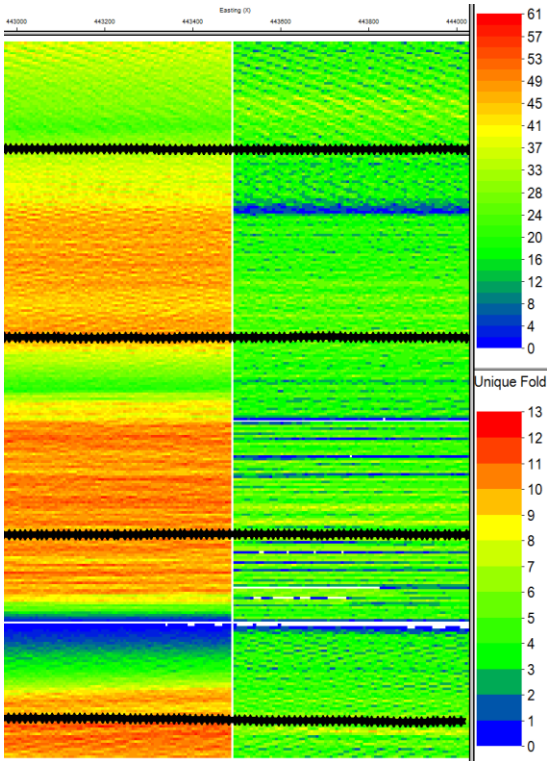


Figure 8 Unique fold of coverage maps (50m offset bins), 4 vessel tracks plotted (black), left full fold, right 0-1000m radial offset limited. In both full and offset limited we can see good distribution in fold with minimal holes and no evidence of the nominal geometry (see Figures 2 and 3). Large hole between sail-lines 1 and 2 (bottom two sail-lines) would normally be in-filled

model-based deghosting, source deblending and 5D regularization. Otherwise no real problems are foreseen to achieve a final image.

The acquisition test showed that the premise works and the geometry is robust to a variety of feather scenarios.

Final processing will be limited by the lack of cross-line aperture for both multiple suppression and migration, however a good shallow section should still be possible, which would demonstrate the validity of the method.

The field test as run here could also show that the future lies in combinations of re-used sub-arrays and source deblending, to the point where sources firing is governed more by air recharge time than regular spatial points.

### References

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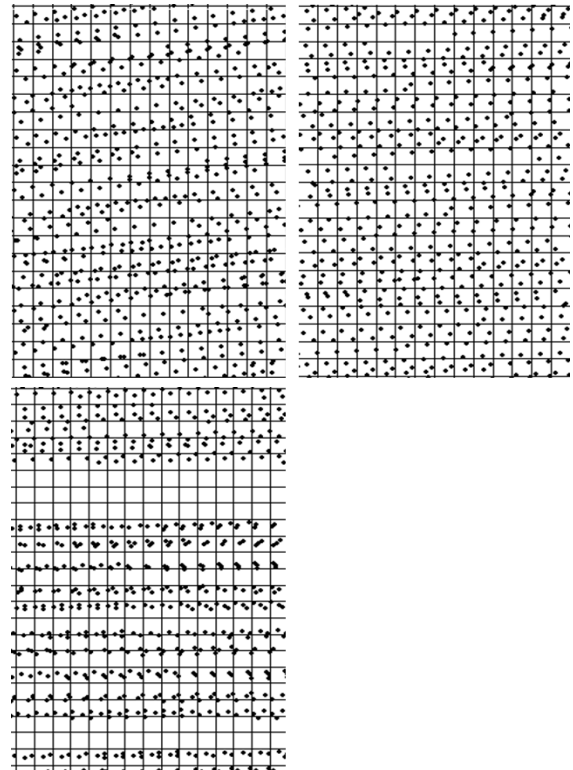


Figure 9 Midpoints plotted for 900-1100m offset range showing variations in pattern. Bin size is 6.25x6.26m. Top left shows midpoints with a high feather and the resulting alignment, due to feather being more dominant than the fan. Top right shows general distribution, as desired. No evidence of the "miss 2" pattern. Bottom left probably worst case scenario where the fan and feather are similar thus causing the midpoints to align rather than spread as desired. Also note one of the larger coverage holes near top, but still only 3 columns, or 18.75m. No cases are seen which would create problems in regularization

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