XArray™: Controlled Soundfield Sampling

To reduce exploration costs E&P companies have sought, and the seismic companies have delivered, major improvements in 3D acquisition productivity. This quest however has been accomplished at the expense of image resolution, most notably in the cross-line direction. This White Paper discusses an approach being posited by Polarcus to eliminate the traditional cost-quality compromise, to provide E&P companies with a full cycle solution that addresses both productivity and quality.

1 Introduction

There is intense commercial pressure on seismic contractors to increase operational productivity to allow shorter turn-around times between project inception and informed drilling decisions. With the lower oil price environment, there is now additional pressure to reduce the cost per square kilometer of 3D seismic data to meet the revised exploration budgets currently evidenced in most E&P companies. The seismic contractors have responded over time by deploying streamer spreads with more and longer streamers and with greater separation between streamers to maximize the sub-surface footprint per vessel sail-line. Where typical seismic spreads 5 years ago were in the order of 10 steamers, 6,000m long, with 100m separations between the streamers, today we are seeing a range of streamer spreads from 16 streamers, 7,000m long, with 100m separations, to 12 streamers, 8,100m long, with 150m separations, and even 10 streamers, 10,000m long, with 200m separations between streamers. In terms of overall survey productivity these large streamer spreads can reduce data acquisition times from between 35% to 50%; no small savings in time and therefore cost for the E&P companies.

However this rush to increase operational productivity has a downside in terms of geophysical data quality. As the streamers get longer, the seismic recording cycle must also increase in order to capture the returning signal from the longer offsets from any one shot. With conventional "flip/flop" dual source recording, the longer record lengths will require more time between shots and therefore a larger in-line spacing between each shot for a given vessel speed. Further, as streamer spacing increases from 100m, to 150m, to 200m, the cross-line CMP sampling will correspondingly degrade from 25m, to 37.5m, to 50m. In short, conventional dual source "flip/flop" acquisition coupled with longer and wider streamer spreads will directly lead to a decrease in overall data density, with a decrease in shots on the surface and a decrease in cross-line sampling in the sub-surface. Each of these factors will have a negative effect on the ability to sample and remove coherent noise, such as surface related multiples, and in providing sufficient spatial sampling to image complex sub-surface geologic structures and interfaces.

E&P companies have had to accept this classic compromise between operational productivity and geophysical quality. Until now. In 2015 Polarcus demonstrated the operationally viability of using three sources, instead of two, to increase cross-line sampling density for any selected streamer separation. Coupled with that infield operational uplift, Polarcus has also demonstrated on a separate project the feasibility of acquiring overlapping 12.5m shot interval data where the shot interference can be removed in processing to produce "clean" shot records of any desired record length. Combining these two initiatives presents an opportunity to take full advantage of the operational productivity of large streamer spreads without compromising the geophysical integrity of the acquired data.

2 Towed Streamer Acquisition – An Overview

In terms of seismic spatial sampling for 3D imaging, the sub-surface imaging grid is a function of the relative spatial geometry between sources and receivers on the surface. In the case of towed streamer acquisition, a sub-surface line is sampled midway between the surface position of each source and each streamer. With that in mind, sets of sub-surface lines are acquired on each pass of a multi-source and multi-streamer survey vessel.

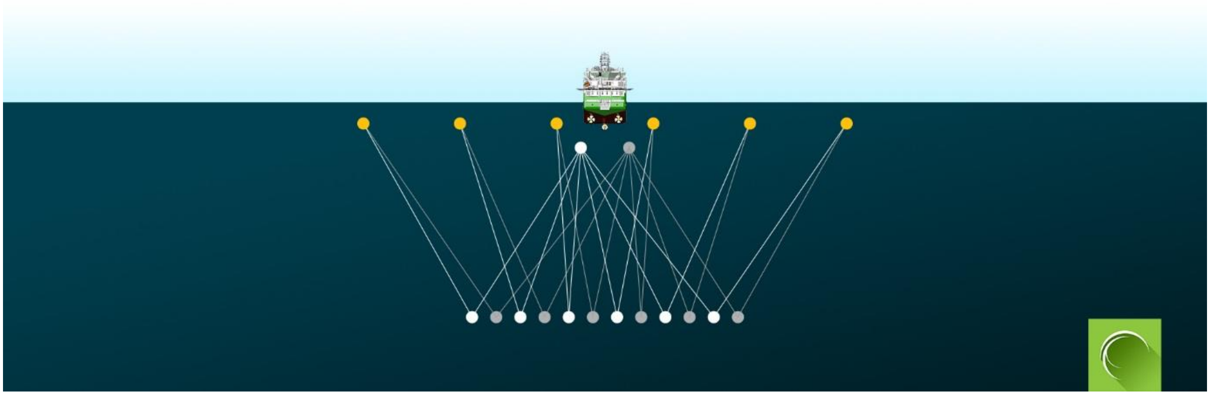

Figure 1: Conventional dual source geometry

From the late '70s to mid-80's almost all seismic survey vessels were designed and rigged to deploy a single streamer. These streamers were relatively short, generally less than 3,000m, and the recording systems were designed to digitize on-board the vessel the analogue data signals transmitted from the hydrophone groups mounted within the streamers. The streamers were basically fluid filled plastic tubes containing hydrophones and wires. That particular architecture was prone to large amplitude low frequency noises generated within the streamer itself and more wide-band random turbulent boundary noise generated along the skin of the streamer as it was towed through the water. To help attenuate these types of noises, hydrophone groups contained many individual elements (16 to 32) to help average out the noise and CMP stacking was used where the number (N) of traces in the stack (fold) produced a square root of N attenuation of random noise. The recording systems of the time also had limited instantaneous dynamic range (12-bit or 72 dB) and fixed, discrete recording cycle times that prevented a shot from going off while the system was still recording data from the previous shot.

With these technology limitations, the first towed streamer 3D surveys started out with single source and single streamer. The next evolutionary step was the use of two sources to double the productivity of the single streamer vessels. The use of two sources meant that the surface shot interval was doubled for any sub-surface line and the CMP fold was, therefore, reduced by a factor of two. The early dual source/single streamer data provided adequate signal-to-noise for the offsets required to meet the early 3D objectives of the E&P companies. The next step was to try and increase the number of sources to further increase the productivity of the single streamer vessels. Consequently several surveys were shot with three or four sources, and single streamers. However it was quickly recognized that going to three or more sources reduced the overall fold, and thus signal-to-noise, to a point where the resulting data quality was no longer meeting the 3D survey objectives. It was this realization that drove the push to add more streamers to the spread. This resulted in a wave of vessel refits in the late 80s and early 90's, and a second wave in the mid-90's of new purpose built multi-streamer seismic vessels that is still going on today.

As these new multi-streamer vessels came into operation the general feeling in the industry was that adequate spatial sampling was being delivered with streamer separations up to 100m or less, so there was no commercial or technical drive to try to increase the number of sources in the system. In parallel, streamer and recording system technology was also advancing, to produce longer and quieter streamers with acquisition systems that allowed continuous recording and much wider instantaneous dynamic range (up to about 120 dB).

With these systems available, in the mid-to-late 90's geophysicists started looking at adding additional sources behind and/or to the side of the streamer spreads to help alleviate illumination issues in areas of complex geology. These ideas started the research into the field of simultaneous shooting of multiple air gun sources in marine towed streamer surveys. Operationally, adding sources by means of separate source vessels presented a few technical challenges, but nothing that could not be overcome with modern navigation and radio telemetry systems. The early multi-vessel wide azimuth surveys in the US Gulf of Mexico are a prime example of adding additional sources for sub-salt illumination purposes. However, those surveys still relied upon sequential firing of each source without contaminating the record of one shot with energy from a succeeding shot. The real challenge was in being able to shoot overlapping, or simultaneous, shots and to post-process the resulting individual shot records that were "contaminated" by the emitted and reflected energy from multiple sources going off at nearly the same time. That challenge remains a major concern within the research departments of many E&P companies and seismic contractors.

Within the last few years the industry has seen a growth in large footprint surveys in areas where quick acquisition turn-around is essential to meet regulatory requirements, whether for environmental reasons or to meet license work commitments. Also, in some areas of the world weather conditions will only allow safe seismic operations during limited periods of the year. This demand from the E&P companies has led to seismic contractors offering more streamers at even larger separations. Over the past decade the trend in number of streamers has progressed from 10, to 12, to 14, to 16 or even more streamers. The trend in streamer separation has in parallel increased from 100m, to 120m, to 150m, to 200m.

The following tables list some of the important efficiency and geophysical quality parameters resulting from this trend for large footprint streamer configurations.

Configurations with 100m Streamer Separations (m)

Number of Streamers	Cross-Line Sampling	Surface Spread	Max Near Offset	Sail Line Interval	Efficiency Factor
8	25	700	400	400	100%
10	25	900	500	500	80%
12	25	1100	600	600	67%
14	25	1300	690	700	57%
16	25	1500	790	800	50%

Table 1: Increasing number of streamers with a constant 100m separation

10 Streamer Configurations with Increasing Separations (m)

Separations	Cross-Line Sampling	Surface Spread	Max Near Offset	Sail Line Interval	Efficiency Factor
100	25	900	500	500	100%
120	30	1100	590	600	83%
150	37.5	1400	730	750	67%
200	50	1900	960	1000	50%

Table 2: Increasing the separation between streamers

Polarcus®

Super Wide Spreads (m)

Number of Streamers	Separations	Cross-Line Sampling	Surface Spread	Max Near Offset	Sail Line Interval	Efficiency Factor
10	200	50	1900	960	1000	100%
12	150	37.5	1650	875	900	111%
14	120	30	1560	825	840	119%
16	100	25	1500	790	800	125%

Table 3: The compromise between efficiency and sampling for large seismic spreads

In table 1 it is clear that going from 8 to 16 streamers doubles the theoretical increase in efficiency. With that, the cross-line sampling is maintained at 25m but the spread width is 1,500m and produces a maximum near offset to the near traces on the outer streamers of close to 800m. This type of wide-spread configuration will present several problems in imaging the sea-floor and shallow seismic section in water depths of <500m, as the reflection angles to the near traces of the outer streamer can approach critical limits where the impinging seismic energy is refracted, not reflected.

In table 2, as with the case of adding more streamers, increasing the separation produces a significant apparent increase in efficiency, a 100% increase going from 100m to 200m separations. However, like the wide spreads in table 1, as streamer separations increase the surface width and maximum near offset to the outer streamers will become problematic when attempting to image shallow reflections in water depths less than about 40% of the spread width. In addition, as the separation between streamers increases, the cross-line sampling interval also increases from 25m for 100m separations, to 50m for 200m separations. Increasing the cross-line sampling interval will lead to lower resolution imaging of steep dipping, low velocity structures in the over-burden.

Table 3 highlights these compromises between operational productivity and geophysical sampling for several large production spreads currently being offered by the seismic companies.

3 Polarcus Multiple Source Acquisition

At Polarcus, we are re-visiting the concept of using multiple sources to increase the cross-line sampling from towed streamer spreads. As discussed earlier, in the early days of towed streamer acquisition attempts were made to use three and four source configurations to increase 3D survey productivity. The results of these attempts were deemed unacceptable in terms of signal-to-noise and inline shot sampling. However the acquisition technologies and processing capabilities available today warranted another look at multi-source configurations. On the source side, modern airgun arrays are more compact and powerful than in former days. Most modern 3D survey vessels have at least six gun strings. On the receiver/recorder side, we have access to true solid streamers that have demonstrated the lowest self-noise performance of any of the other available streamer technologies. Those streamers are coupled with 24-bit electronic systems that provide up to 120 dB of instantaneous dynamic range and a recording system that can be configured to record data continuously, enabling complete flexibility in shot point intervals and record lengths.

Using these tools, we have conducted a number of field trials to test simultaneous shooting, randomized shot intervals, and overlapping shot recordings for two, three, and five source configurations. Through these sea trials we have demonstrated that we can configure the acquisition systems to successfully initiate and record simultaneous and overlapping shots from multiple source configurations. The results of these tests have led to a major client contracting Polarcus to acquire a large survey using three sources, with a spread of 12 streamers, 8,100m long, and with streamer separations of 75m to acquire

12.5m cross-line sampling. This configuration reduced the operational risk of using a closer 50m streamer spacing with dual sources to produce the same cross-line sampling.

From the processing side, Polarcus' data processing partner, DownUnder GeoSolutions ("DUG") has further demonstrated highly successful shot interference removal of overlapping data from 12.5m shot intervals.

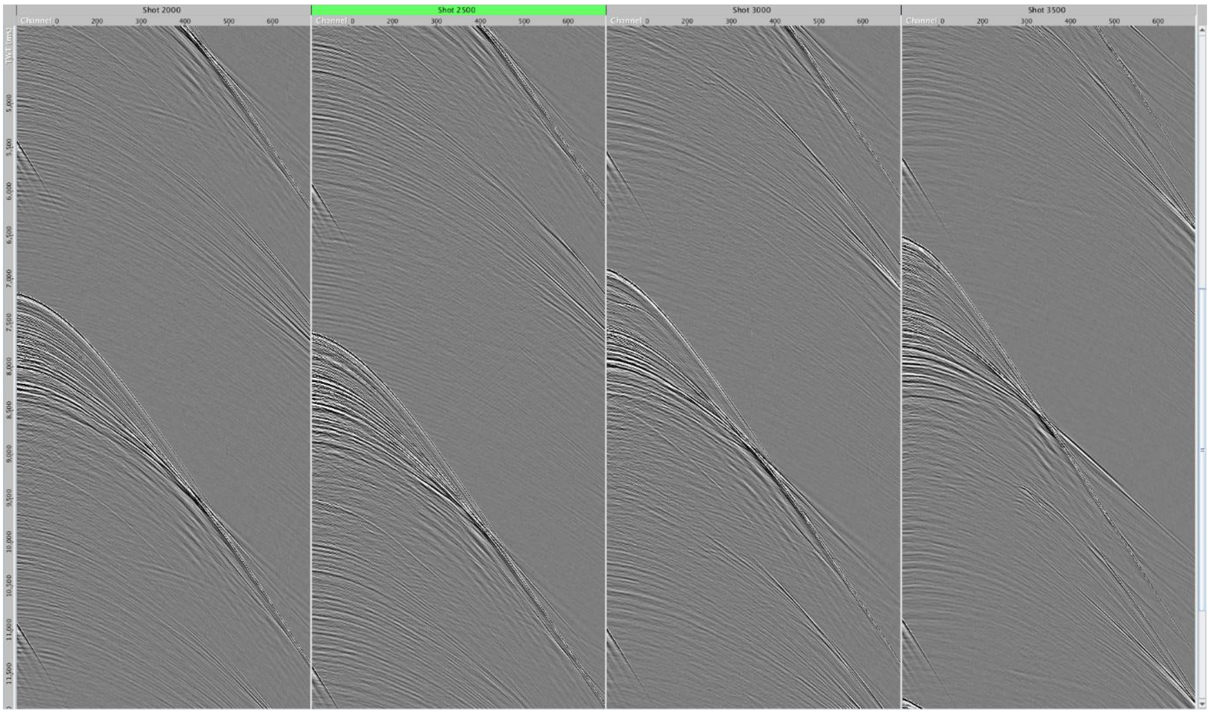

Figure 2: Overlapping seismic interference from 12.5m shot intervals on 12 second shot record

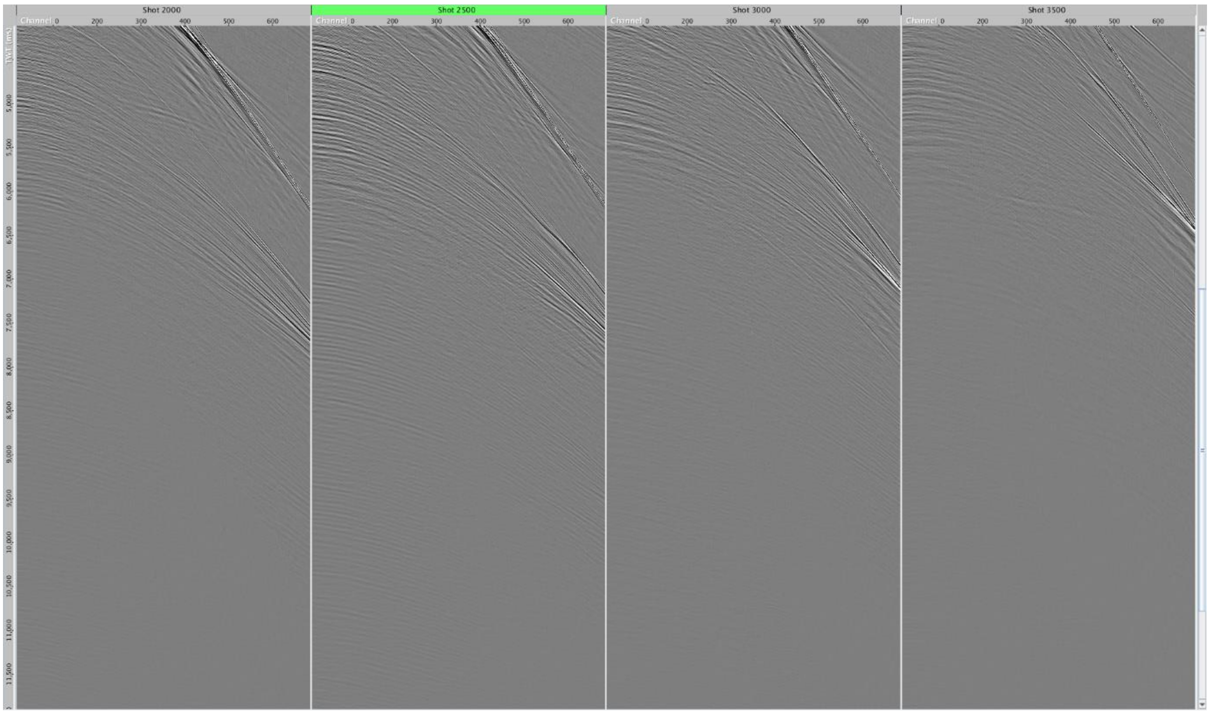

Figure 3: DUG shot interference removal 12 second shot records from 12.5m shot interval

Figures 2 and 3 show the effectiveness of DUG's shot interference removal technique. With this quality of shot interference removal Polarcus and DUG are acquiring and processing approximately 23,000 km^2 of 3D multi-client data in the Roebuck Basin on Australia's North West shelf, leveraging the shot interference removal of 12.5m overlapping shots to produce "clean" 12 second shot records. Compared to conventional acquisition using dual sources to acquire 12 second records, the reduction of the shot interval to 12.5m produces at least a 100% increase in surface shot density.

With the use of Polarcus' triple source acquisition in a full commercial production mode and DUG's successful shot interference removal of overlapping shot data on a large scale fully funded multi-client project, Polarcus is totally confident in offering multiple source acquisition configurations to provide high quality, high density, geophysical sampling, in both the shot and cross-line sampling domains, in combination with large multi-streamer towing configurations to take full advantage of enhanced operational efficiency while providing uncompromised geophysical quality.

The following graph (Figure 4) shows the relationship between cross-line sampling versus streamer separation for dual and triple source configurations.

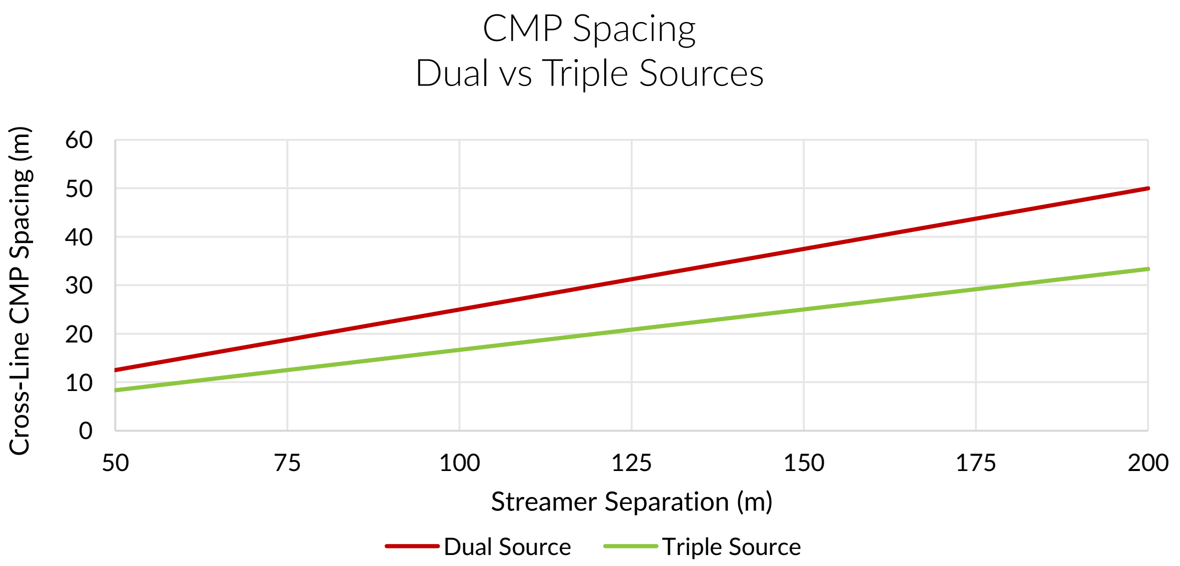

Figure 4: Increased efficiency of triple source vs dual source producing the same cross-line sampling.

From these data it is evident that the increased cross-line sampling from triple versus dual source configurations is significant and further that significance grows as streamer separations increase. For example, as shown on the following plot (Figure 5), the 25m cross-line sampling produced by dual sources and 100m streamer separations can also be achieved with 150m streamer separations and triple sources – a 50% increase in efficiency for 12 streamer spreads. The efficiency benefit for a 12 by 150m streamer spread with triple source spread holds even when compared to an 18 by 100m streamer spread with dual sources.

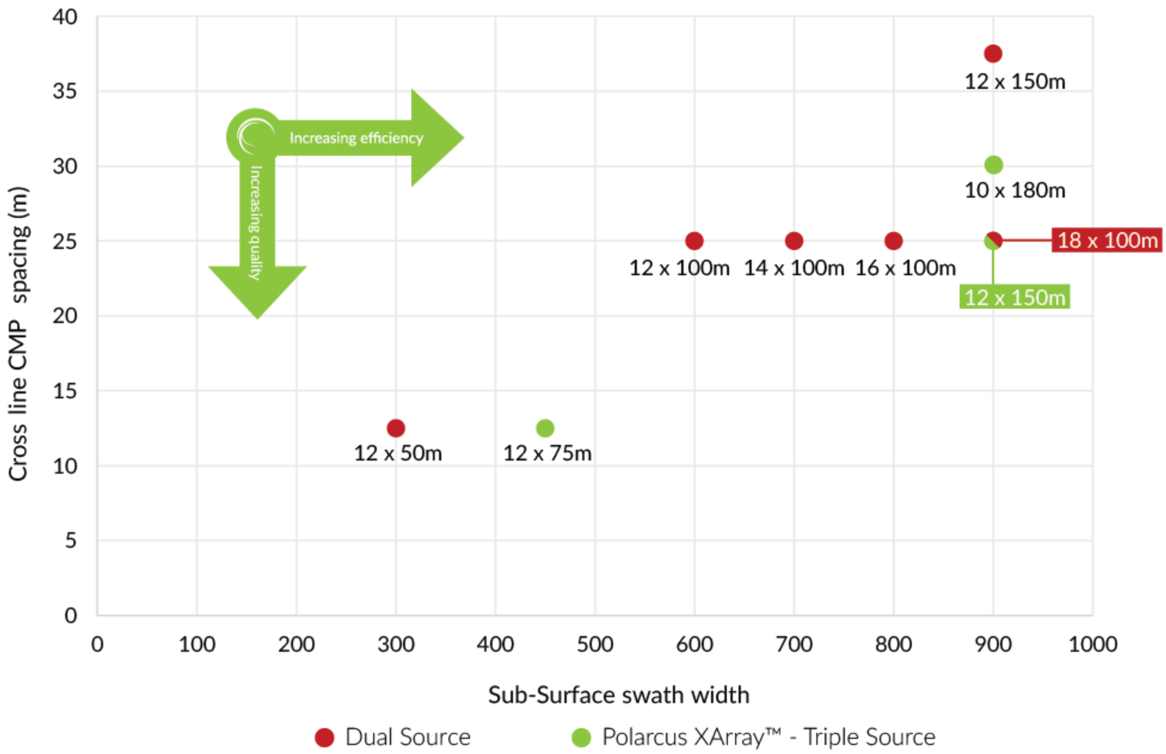

Figure 5: Sub-surface coverage vs cross-line sampling

When the triple source geometry is coupled with shot interference removal of overlapping records from dense in-line shooting, the bin fold can be maintained at near the same levels as dual sources while providing 50% more surface shots and sub-surface source-to-receiver ray paths (see Figure 6).

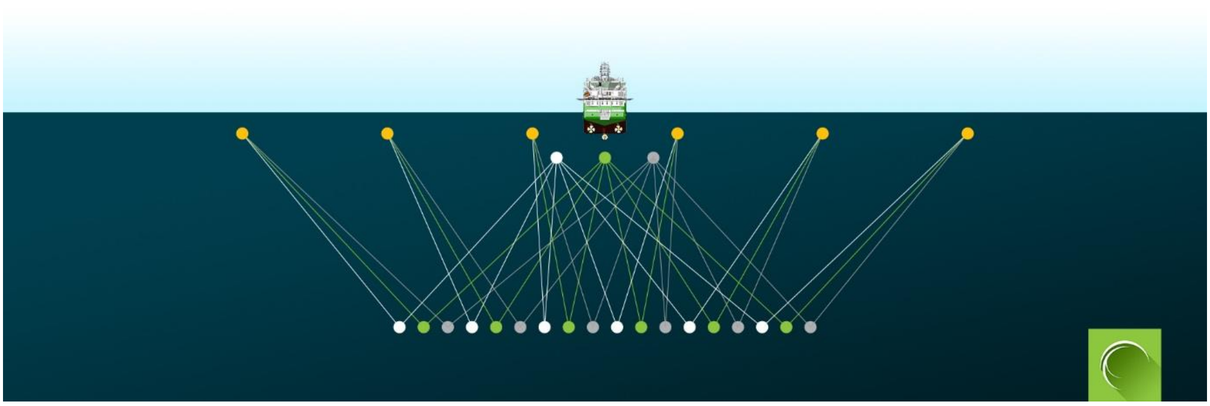

Figure 6: Triple source geometry

We can extend the multi-source overlap shooting concepts to acquire very dense cross-line sampling with conventional streamers. In a recent test we demonstrated 6.25m cross-line sampling using a five (5) source configuration. This type of acquisition is not aimed so much at increased operational productivity but more to specific projects where complex structures in the near surface need to be resolved to allow accurate imaging of the underlying hydrocarbon deposits. The test led to the first commercial survey being acquired in the North West Shelf Australia with a 9.37m shotpoint interval so that inline fold is similar to a conventional 25m flip/flop geometry.

4 Conclusion

The main technology trend in marine towed streamer acquisition over the past three decades has been focused on increasing the number of streamers towed behind a vessel and increasing the spacing between these streamers. As discussed in this White Paper, these large multi-streamer spreads have significantly increased the overall operational productivity of towed streamer surveys. However, using traditional dual-source configurations, as the spreads get larger and wider there is an inevitable loss in geophysical data quality as the cost of increased productivity. By leveraging modern day acquisition technologies of sources and receiver/recording systems and advanced data processing, Polarcus has demonstrated that the use of more than two sources in dense in-line overlapping shot mode can significantly enhance the overall geophysical data quality while maintaining the high productivity of large streamer spreads.