A new MultiSensor Solid Streamer

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Summary

Multi-Component recording of seismic data with two components and four components has been in use in shallow water environments for nearly three decades. The use of motion sensors for streamer marine acquisition has a much shorter history. The earliest system introduced by PGS in 2007 used a combination of hydrophones and gimbaled vertical geophones, but in recent years two additional systems have been deployed that also record the horizontal motion of the streamers in the crossline direction. The motivation for the introduction of the vertical sensor was to improve the spectral content of the data, while for the horizontal sensor it is to enable sensor rotation when gimbals are not being utilized. This paper will describe the design considerations and characteristics of one of these systems.

Introduction

The water-to-air interface at the surface of the ocean has a very large acoustic impedance contrast that results in an almost perfect reflection of any upgoing energy arriving at the surface. Since the reflection coefficient is approximately equal to -1 the polarity of the resulting downgoing pressure wave is reversed. This downgoing energy is typically referred to as the "ghost" and results in both constructive and destructive interference of the upgoing and downgoing wavefields. The frequencies over which these effects are observed depend on the sensor type, the sensor depths below the water surface and water velocity. The attenuated frequency ranges are commonly termed "ghost notches" and can severely limit the interpretability of the data. Ghost effects occur at both the source and the receivers.

In 1956, Haggerty (US Patent 2,757,356) patented the use of both pressure and motion sensors to attenuate the effect of the ghosts for the receivers. He also patented the use of deploying sensors at different depths to enable the separation of the upgoing and downgoing wavefields. Unfortunately, marine towed streamers exhibit significant vibration modes (Tenghamn et al, 2009) that create noise on any motion sensors that are deployed within the streamer. In the early days of data acquisition with streamers, these vibrations affected both pressure and motion sensors until the invention of acceleration canceling hydrophones in 1969 by Hancks et al. (US Patent 3,458,857) However, the use of motion sensors within streamers was considered too noisy to be effective until 2007 when PGS introduced a dual-sensor streamer and demonstrated that much of the noise on the motion sensors is in the lower frequencies and that some denoising technique could be used to recover the higher end of the spectrum. If the streamers were towed deeper, both hydrophones and gimbaled geophones were deployed in the streamer, and with careful processing, the hydrophone data could be used for the lower frequencies and the geophone data used to fill in the missing frequencies in the ghost notches.

Considerations for integrating motion sensors into streamers

With the advances in modern electronics in terms of power requirements and size, it is now possible to deploy more sensors within a given volume of streamer. In order to acquire useful information from motion sensors within a streamer the following issues must be understood:

a) noise resulting from transverse wave modes within a streamer under tension
b) type of sensor that is to be used
c) motion sensor orientation with respect to vertical when the cable is rotating during data acquisition

Transverse Wave noise

The strongest noises that will affect motion sensor measurements within a streamer are transverse vibrational modes.

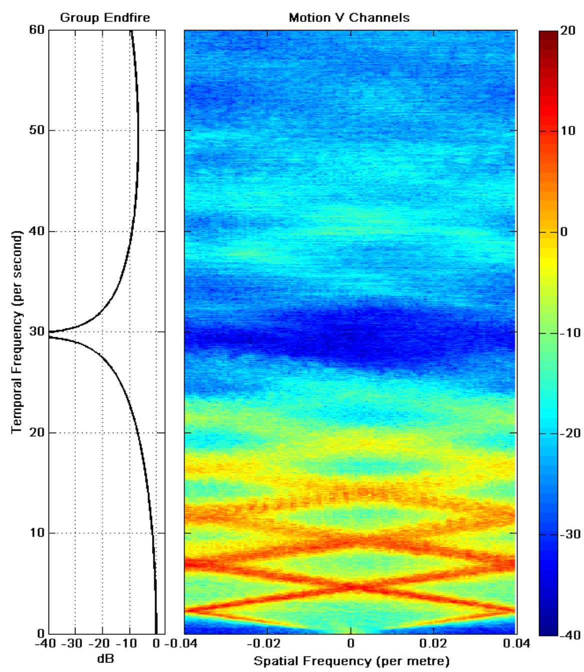

Figure 1: F-K plot of motion data recorded during tow noise test that shows the effective attenuation of the higher frequencies of the transverse noise by the sensor array.

These vibrational modes propagate at very low velocities and have very large amplitudes. As discussed above, motion sensors within the streamers are extremely noisy and so a primary concern is the attenuation of as much of this noise as possible. An extremely important additional consideration is that the required signals for broadband data acquisition must not be compromised and therefore any arrays that are used must be short enough to retain the high frequencies. In order to achieve this it was decided to use short arrays that would attenuate the higher frequency transverse noise without adversely affecting high frequency reflections. The group spacing is 12.5m, consistent with the current hydrophone receiver groups. Figure 1 shows an F-K plot from several noise records that were acquired during some early tests. It can be seen that the strong low frequency noises are clearly not attenuated but the higher frequency noise above 25 Hz is. This enables us to provide good signal content above 25 to 30 Hz.

Type of sensor

Several types of sensor were considered: gimbaled velocity sensors, MEMS accelerometers that can automatically measure and correct for tilt and fixed accelerometers with separate tilt measurement and correction. With regards to gimbaled sensors an immediate consideration was the noise associated with gimbals. Although these can have quite low noise levels when new, after extensive field use the noise level is frequently seen to increase. Also, because they require some form of damping mechanism that is usually a fluid or oil that is within the chamber, temperature variations that will change the viscosity of the fluid become a concern.

In comparison, MEMS sensors generally require more electronics to be managed. The direct consequence is a step change in equipment cost and reduced reliability that would highly compromise the operational efficiency of a seismic vessel.

Another issue was the cable construction. Our production solid cable construction has a radially symmetrical form, with a central strength member at the core. Retaining this configuration was very important for us to be able to manufacture a streamer at a realistic cost. As a result the selected sensors were orthogonally mounted analog accelerometers. separate tilt sensor provides the required information to correct the orientation.

Streamer rotation and sensor orientation

Streamers undergo significant variations in tension during acquisition and these cause rotational or torsional waves to transmit along the length of the streamer. This means that the orientation of motion sensors requires correction to provide true vertical and horizontal measurements. After testing it was determined that the torsional variation within short distances was minimal and that over a receiver group length of 12.5m a single tilt correction would be adequate for that group. In our system this single measurement is made independently at the group center and applied to the recorded measurements. We then get the benefit of being able to accurately design the tilt measurement conditioning adapted to the cable torsional behavior.

Field testing of prototypes of the new streamers

After several years of engineering design and testing, several kilometres of prototype sections were manufactured and a field test was acquired. The water depth in the test area was between 1000 and 1200m and during the tests the weather conditions changed significantly. The vessel deployed 5 streamers which had multisensor capability.

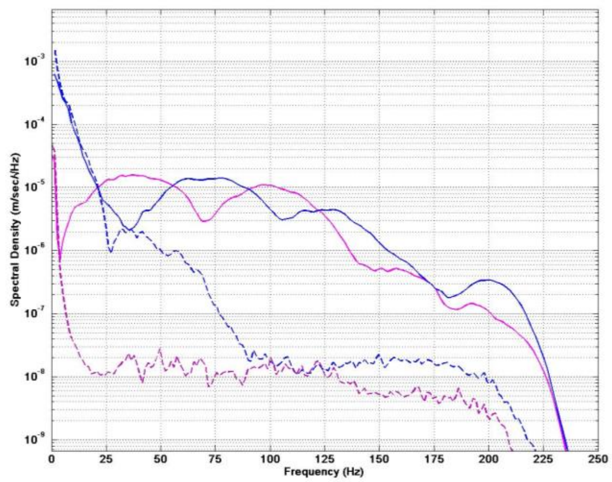

Figure 2:

Relative amplitude spectral displays of 4 recordings: Magenta represents the hydrophone group and Blue the accelerometer group. Solid lines represent the data with a shot (S+N) and dashed lines the group self-noise (N).

In Figure 2 we can observe some spectral amplitude displays of data that were recorded during the tests. Noise records were made before and after the recording of each test line. The plots in Figure 2 show averaged spectral content of both the hydrophone and accelerometer groups, both with and without airgun shots being taken. Therefore these represent the spectra of the signal plus the noise and just the noise. These have been converted to equivalent units of velocity in m/s to permit accurate comparison. It can be seen that the hydrophones have a clear separation of signal and noise at frequencies higher than 2 or 3 Hz, while the accelerometer graphs overlay at the frequencies below 24 Hz, which demonstrates that the noise is the dominating factor at the low frequencies. As a consequence, the hydrophone information only is usually used to reconstruct the low frequency part of the signal in the PZ summation process, as has been described by previous authors (Tenghamn et al., 2009, Caprioli et al., 2012).. However, above 25 to 30 Hz the accelerometer graphs show a clear separation of the signal above the noise. The close proximity of the accelerometer graphs at frequencies between 32 and 37 Hz is caused by the ghost notch of the motion sensors.

Data examples

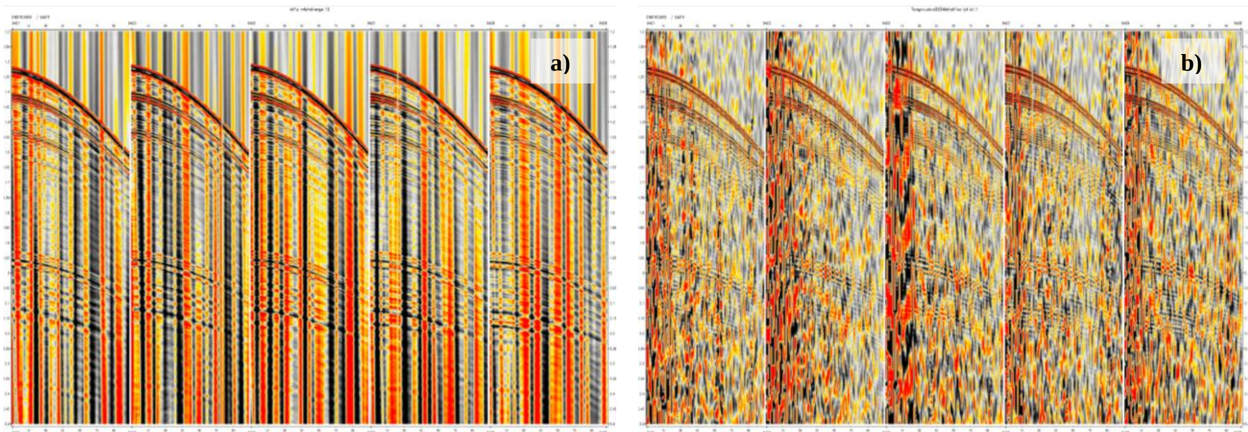

Figure 3: Displays of portions of five raw shot records with no noise attenuation. a)Hydrophones, b)Accelerometers (vertical component)

A number of different tests were acquired, one of which is used in the following data examples. This test was acquired with a flat multisensor streamer deployed at 12m depth. In Figure 3 a) hydrophones and b) vertical accelerometers, we have several shot records displayed with no noise attenuation whatsoever. In these we can clearly see the strong influence of the low frequency noises. For hydrophone data in many cases a simple lowcut filter will attenuate much of this noise. However, for the accelerometer data the noise extends up into the range between 20 and 30 Hz (see Figure 2)

For the accelerometer data it is obvious that more noise attenuation is required. Figure 4 a) and b) show the same data as Figure 3 but after a more elaborated noise attenuation than a simple lowcut filter.

Figure 5 (hydrophones) and Figure 6 (vertical accelerometers) show single fold data along a portion of the line after the noise attenuation. The difference in frequency content between the two different types of sensor is clearly visible, with the accelerometer data showing a much higher frequency content.

Conclusions

Transverse wave modes are the most troublesome for recording motion sensor information within streamers. For the higher frequencies the design of our array provides good attenuation of this noise and good signal preservation above 30Hz. The rotational issues of the streamer are well understood and high quality motion sensor data can be acquired in the higher frequency ranges. The vector fidelity of the inline and

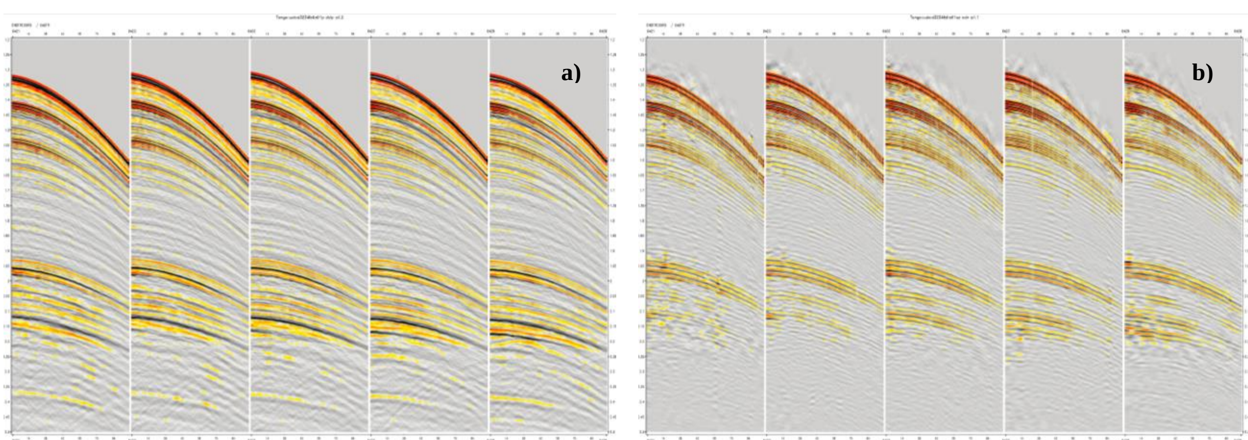

Figure 4: The same field records as shown in Figure 3 with a more elaborated noise attenuation method. a) Hydrophones, b) Accelerometers (vertical component)

crossline data is well preserved and guarantees the accuracy of vertical motion measurement. The combination of acquired vertical motion and pressure sensor data provides broad band seismic signals with a good recovery of frequency ranges normally lost within the ghost notches of a streamer equipped with only hydrophones.

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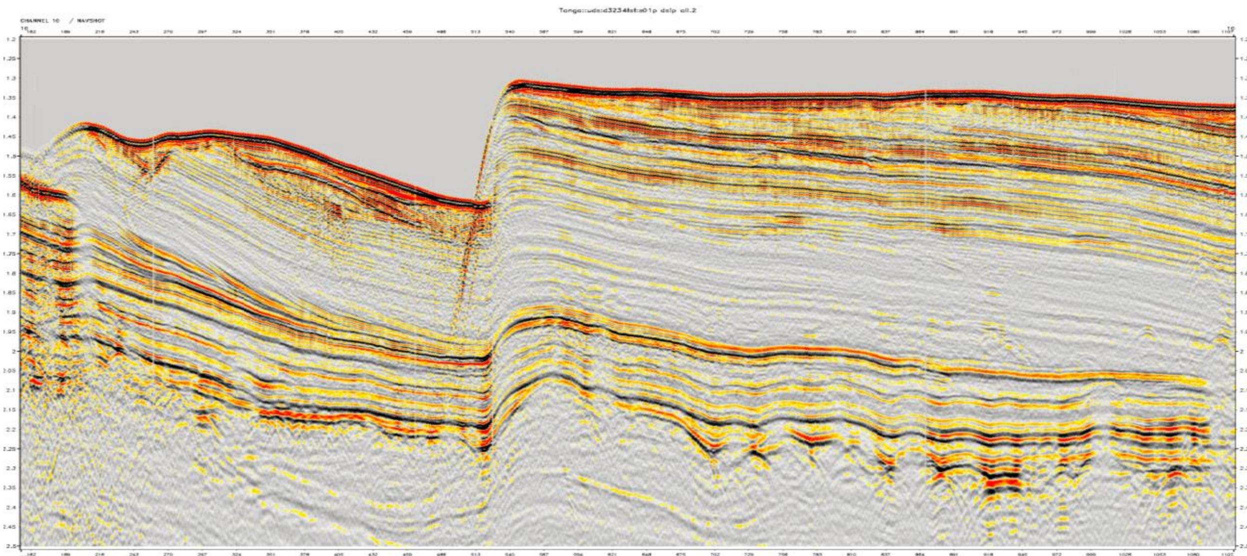

Figure 5: A single fold, short offset gather of the hydrophone data after noise attenuation along a portion of the test line.

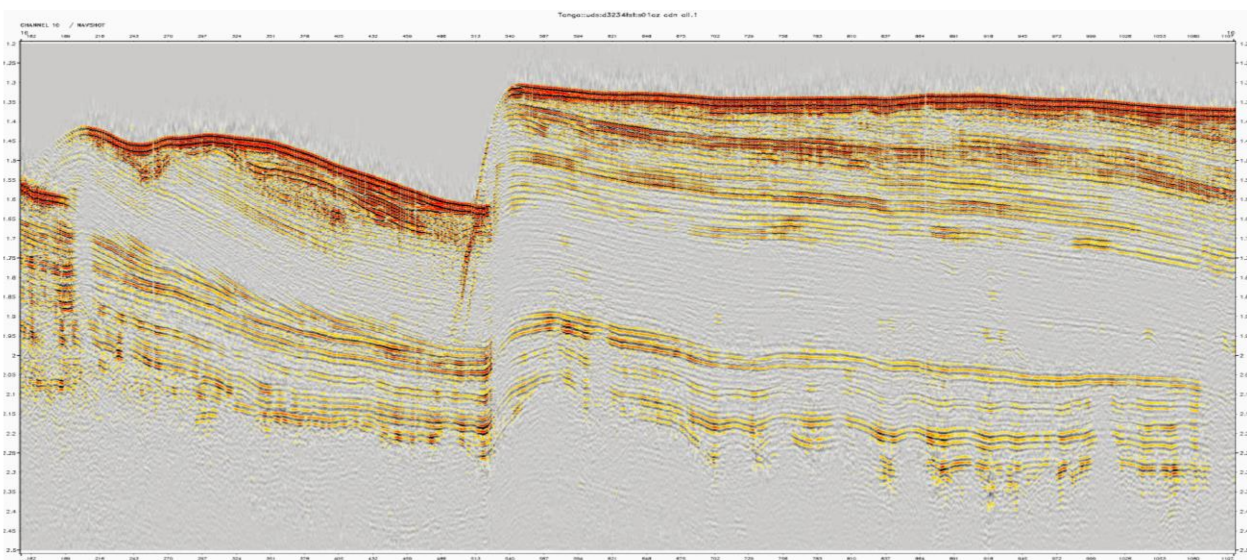

Figure 6: The same portion of the test line as shown in Figure 5 but showing the vertical accelermoneter data after noise attenuation.