Which point-receiver?
From geophones to GPS-driven 3C MEMS-based accelerometers

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Introduction

With the capability of recording systems to handle an increasing number of channels, the industry is now able to acquire single-sensor/point-receiver data. The benefits provided by such receiver configuration are both operational (productivity, etc.) and geophysical (better signal and noise preservation, etc.). After reviewing different types of single sensors (Figure 1) we focus on the comparison between geophones and the vertical component of MEMS-based accelerometers. Integration of the sensor with the digitizer is not the final step. We must now consider the benefits of GPS chips for synchronizing or positioning/orienting point-receivers.

Different point-receivers

The most basic single sensor is a geophone or a triphone connected to digitizers (Figure 1). By grouping the mechanical sensor and the A/D converter together in a single package we dispense with the cable and connectors (e.g. FDU1 and FDU3). This improves weight, compactness and reliability (less leakage). At the same time all perturbations (pick-up noise, cross-talk) related to the analog transmission are minimized. Because the output of such a package is digits the sensor as a whole is called digital. In essence all digital sensors are single sensors that must be recorded independently.

The sensing part of a digital sensor may be a velocimeter or an accelerometer depending on whether its response in the seismic bandwidth is proportional to the ground velocity or to its acceleration. A geophone is typically a velocimeter, the output voltage of which is proportional to the ground velocity above a specific resonant frequency. However, around its resonant frequency the geophone acts as an accelerometer. This capability has been used to develop the Geophone ACcelerometer (GAC).

The main advantage of accelerometers based on Micro-Electro-Mechanical-Systems (MEMS acting as a capacitor) is that their low tolerance specifications are stable with temperature and aging. Their amplitude and phase responses are flat over a wide frequency range (may be from 0 to 800 Hz). Thus, low as well as high frequencies are recorded without any attenuation or phase variation. Being able to sense Direct Current at 0Hz, a MEMS-based accelerometer can detect the gravity vector used as a reference for sensor calibration and automated tilt corrections. Like geophones, MEMS-based accelerometers are available in 1C (e.g. DSU1) or 3C versions (e.g. DSU3 and VectorSeis) as well as with different housings for use in various environments (e.g. transition zone).

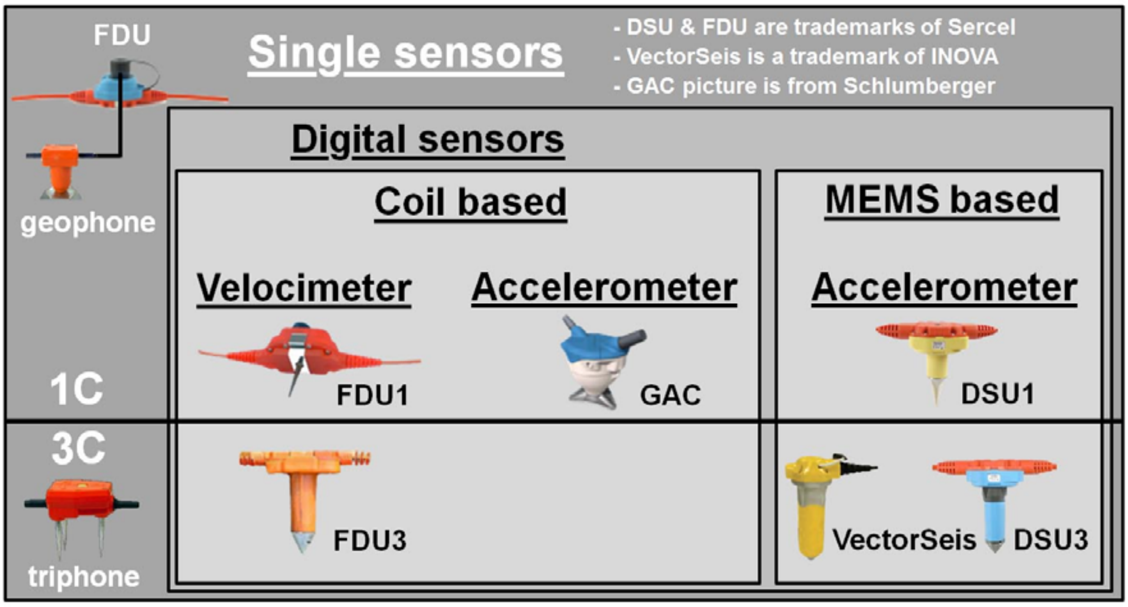

Figure 1: Classification of single sensors as provided by different seismic equipment manufacturers of cable systems

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Comparison of (bunched) geophones with the vertical component of MEMS accelerometers

When moving to point-receiver acquisition two questions often arise:

- should I move to a single geophone or may I keep my string of geophones and bunch them?
- should I replace my geophones with digital accelerometers?

Apart from the fact that strings of geophones are heavy and will require more manpower and vehicles, there are many advantages of using a small amount of bunched phones instead of a single one. Sensitivity is improved as well as coupling and reliability is better. Choosing between the geophone and the digital accelerometer may be trickier. If we take as a reference the 1C MEMS-based accelerometer (DSU1), its weight (0.375 kg) is about half that of a digitizer connected to an external geophone. For a high-channel count crew, this can make a significant difference to operational efficiency. While the DSU1 specifications are fixed, the geophone specifications (resonant frequency, coil resistance, sensitivity and damping) still vary within a range depending on temperature and aging. Even if the resulting impact is not obvious on raw records, it may have a detrimental effect on amplitude preservation. On the other hand, the instrument noise from a geophone connected to a digitizer is lower than that of a DSU1 from low frequencies to about 50Hz. However, the noise from DSU1 (-128dB with respect to ($1m/s^2$)/sqrt.Hz from 10 to 200Hz) is more often than not below the level of the ambient noise. Another issue relates to the difference in sensitivity between MEMS accelerometers and geophones. In the acceleration domain, the sensitivity of the DSU1 after conversion of the digits is fixed ($0.452V/(m/s^2)$). In the velocity domain, it significantly increases (+6dB /octave) towards the high frequencies (28.4V/(m/s) at 10Hz; 284V/(m/s) at 100Hz). Together with a lower instrument noise above 50Hz, this confirms the advantages of the MEMS accelerometer for recording high frequencies.

GPS-driven single sensors

Cableless systems have been the first to integrate GPS chips for synchronization purpose. Some of the autonomous nodes act as point receivers made up of geophone or MEMS-based digital sensors. However, none of them are able to position with the accuracy required by seismic acquisition. Such a capability has been recently proposed by integrating GPS in a 3C MEMS-based accelerometer (DSUGPS). This specific chip is connected via the telemetry cable and the central unit to a reference base station to achieve DGPS accuracy ($\pm$1m). Such a GPS-driven sensor that is also automatically tilt corrected can be placed in many positions, in many areas without any adjustment that may be detrimental to the coupling. The only constraint is that the antennas need to have access to some open sky to see the satellites. Thus, deployment is quicker (stakeless). In difficult conditions (e.g. under canopy), positioning becomes more reliable thanks to the possibility to perform long-time statistics while acquisition is running. A second GPS chip is placed in this type of sensor to be able to define its orientation with a total accuracy of $\pm$3° using phase comparison between the two antennas. When the required accuracy is achieved, this information is automatically reported to the central unit and GPS is switched off.

Conclusion

Many point-receivers are being made available to the industry as a result of the introduction of digital sensors and cableless systems over the last ten years. Accelerometers result from the integration of a sensor with a digitizer. The resulting package is often inserted within a segment of telemetry cable to improve compactness (e.g. the 428XL Link). Some of them are supplemented with GPS chips. If we consider cableless systems, we may even state that an autonomous recorder takes part in the integration.

From a geophysical point of view, single sensor/point-receiver acquisition offers broadband isotropic recording. From an operational point of view, this methodology answers productivity requirements to be as efficient on the receiver side as we can be on the source side with high productivity vibroseis. Laying longer lines within spreads of higher aspect ratio needs to record more channels placed in a wider variety of environments. This also requires the use of lightweight and more integrated digital sensors.