Fiber Optic Permanent Seismic System for Increased Hydrocarbon Recovery

Jan Langhammer, Morten Eriksrud and Hilde Nakstad, Optoplan AS, Norway
Carl Berg*, CGGVeritas, Norway

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Abstract

Permanent seismic installations at the sea-floor have emerged as a potential tool for oil companies in their work to actively monitor oil/gas flows and injection processes in order to increase hydrocarbon recovery and optimize production. The advantage of fiber optic over electric sensors is that the fiber optic sensor technology is completely passive at the wet-end, i.e. no short circuits will happen, longer life-time of components, high sensitivity, high dynamic range, less intrinsic noise, no corrosion of sensing components, fewer parts and potentially cheaper complete receiver systems. Large fiber optical ocean-bottom receiver systems for 4D-applications, can now be produced and installed at locations where the oil companies would like to exploit the life-of-field seismic concept. We are advocating optical sensing technology to be an important part of the tool box for the oil companies in their work to implement the instrumented oil field in a cost efficient way.

Introduction

A fiber optic multi-component ocean bottom seismic system, for permanent installations, has been developed and pilot test data from the system have been acquired and subject to analysis. The use of a permanent multi-component OBC system is widely accepted as an alternative to marine surface seismic, or retrievable OBC acquisition techniques, for acquiring 4D data (Barkved, 2004). In connection with time-lapse seismic, repeating shot and receiver positions are important in order to minimize noise in connection with detection of production induced 4D signals. In towed marine surveys both receiver and source positions cannot be repeated completely, but permanent seismic cable installations have eliminated the receiver repeatability problems. The enhanced repeatability from survey to survey achievable with a permanently installed system can aid the operating oil companies in modeling the subsurface and the effect of production, thus maximizing the oil recovery rate from the reservoir. In addition to repeatability, the performance of the receivers over time is also highly important. Compared to repeated streamer seismic, a permanent ocean-bottom seismic installation is expected to be giving on-demand 4D seismic with higher resolution and greater fidelity over the life of the field (Houston, 2003). The repeat surveys will also be less costly compared with traditional methods as it is only necessary to bring in a single vessel each time to supply the seismic source. It can therefore be the preferred alternative if the economics related to its use over the life of the field are superior. This kind of seismic acquisition allows for full freedom in azimuth and offsets, giving a high-fold multi- and wide-azimuth dataset ready for processing and interpretation. In-well fiber optic sensors for measuring flow rates, pressures, temperatures and for VSP applications have previously been developed and tested (Bostick et al., 2003, Keul et al., 2005 and Hornby et al., 2007).The Low power loss and large bandwidth of optical fibers enable extremely high data transmission rate over long lead-in cables and is certainly an advantage when the field is operated from sub-sea installations and the platform may be several kilometers away from the producing wells. Reliability over time is possibly the most important feature in order to keep the total cost over the years of operation as low as possible. Fewer parts and no electronics will lower the probability of failure significantly compared to electronic receiver systems. The fiber optic system does not require any electronics embedded into the receiver stations trenched at the sea floor, which gives the operator of the field a seismic system which will require a minimum of maintenance over the years of operation. All the sophisticated instrumentation is located at the surface, which makes it easy to maintain and upgrade. All these advantages make the fiber optic sensor technology perfectly suited to be utilized in ocean bottom receiver cables in connection with life-of-field seismic projects. In addition, a fiber optic permanent installed seismic system, with high sensitivity, is perfectly suited for detection of micro-seismic events, which may occur as the field is produced (Chambers et al., 2007).

Main principles of fiber optic technology

Each 4C ocean bottom seismic station consists of an optical 3C-accelerometer unit and a fiber optic hydrophone, as shown in Figure 1.

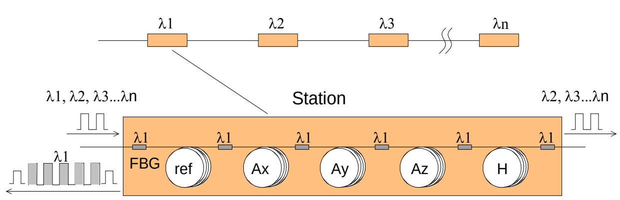

Figure 1: Fiber optic senor configuration. Ax, Ay, Az are x, y and z direction accelerometer coils, H is the hydrophone mandrel and ref is a reference coil. All FBGs (in between each coil and mandrel) in a sensor station are adapted to respond to the same wavelength. Only passive components are used in-sea or in-well for well sensing applications.

No components of the in-sea part of the system require electrical power. The optical fiber between two fiber Bragg gratings (FBG's), is the active sensing element. In sensor systems based on FBG's, different wavelengths of reflected light from the FBGs can be used to multiplex several receiver stations along a single fiber.
The sensors within one station are time multiplexed, and the receiver stations are wavelength multiplexed along one sensor link fiber. Accelerometers (x, y and z) are mounted orthogonal to each other and consist of fiber which is wounded on moving-mass coils. The hydrophone consists of fiber wounded on an air-backed mandrel, while the last coil acts as a reference interferometer for common mode noise reduction.
When subject to an external force, the fiber length in each sensor change as a result of the disturbance in the active sensing element, creating phase changes of the laser light propagating in the fiber. Using optical interferometric techniques, the fiber length changes can be measured with extreme accuracy, and the corresponding phase changes of the light are converted to seismic wavelets at the top-side instrumentation.
An optoelectronic top-side instrumentation, shown in Figure 2, with all the main components, is used to interrogate a large number of sensors and receiver stations.

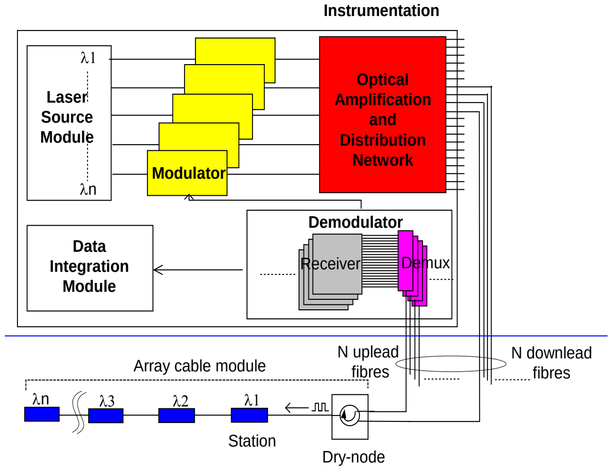

Figure 2: Optoelectronic top-side instrumentation and receiver cable modules consisting of a number of receiver stations and N down-lead fibers to build up the total fiber optic cable network using several modules.

A complete sub-sea receiver spread is built up by several array cable modules through N down-lead fibers forming a total length of sensor cables to cover any part of interest of the producing field (Figure 3). There is also a potential to combine this system intended for permanent reservoir monitoring with the systems previously developed for in-well applications. After the advanced demultiplexing and transformation of phase changes of laser light to standard seismic traces, the data is transferred to a conventional seismic recording system for storage, QC and data management.

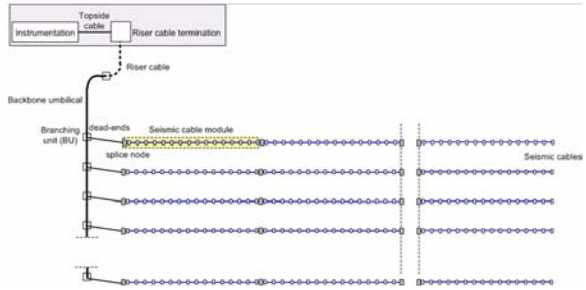

Figure 3: Sub-sea cable network with top-side instrumentation. The network is connected to the platform through fiber optic seabed backbone cables and a riser cable.

Field tests and data examples

During the development phase of the fiber optic receiver cable systems, two small scale field tests were conducted. The first experiment was carried out at 35 m water depth in harbor area of Trondheim, Norway, where two fiber optic cable units were deployed and for comparison a state of the art electrical 4C seabed system was installed in parallel (Thompson et al., 2006). The second experiment was carried out in a fjord in Norway where the water depth was about 270 m (Thompson et al., 2007). The systems to be tested were trenched about 1 m into the sea floor sediments. Repeated tests with few months interval were performed at both locations.
Key issues addressed in the data analysis were visual inspection of raw data plots, vector fidelity, and frequency response, intrinsic system generated noise, signal-to-noise ratio and ground-station coupling. The data from both test locations were of very high quality where both the frequency content and the quality of the data from all stations appear to be uniform. This indicates very good coupling of the trenched receiver stations to the seafloor and high signal-to-noise ratio.
An example of data in the common receiver domain from one of the fjord tests is shown in Figure 4. Note the high quality accelerometer components and hydrophone data and excellent signal-to-noise ratio. The hydrophone data is differentiated in time (dP/dt) in order to be compared with the vertical component accelerometer data.
Good vector fidelity of 3C receivers is important in order to reliably record the vector wave field and accurately process the PS converted wave data to produce reliable images and results to be interpreted in conjunction with the P-wave data. Figure 5 shows traces from a fiber optic receiver station from one of the tests where the position of the shot was at approximately 45-degree azimuth to horizontal receiver components. Note the similarity of first arrival of the two horizontal traces. The corresponding hodograms of the traces are shown in Figure 6. The linear behavior of the hodograms confirms excellent vector fidelity, making the system a perfect choice for reliable measurement of the vector wave-field.
During the summer of 2008, the fiber optic receiver system was tested at two producing fields in the North Sea and the quality of the data from these tests was excellent. The data are presently undergoing analysis and

being processed by the oil companies operating the fields. The pilot installations were successful in terms of installation at different water depths, for its excellent data quality and for fitting the equipment into the field infrastructure at the sea floor. In addition, transmittal of data between the platforms and client base at shore were also tested. An installation of a fiber optic receiver system over a large producing field in the North Sea, covering about 60 sq.km, is scheduled for 2010. This is a breakthrough for the fiber optic sensing technology in connection with life-of-field seismic projects.

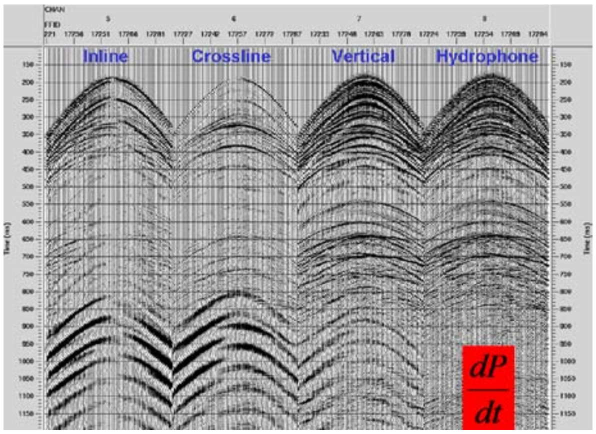

Figure 4: Example of common receiver gathers from the inline, crossline and vertical accelerometers (x, y and z) and the hydrophone from a selected station. The hydrophone is differentiated in time in order to be compared with the vertical accelerometer component.

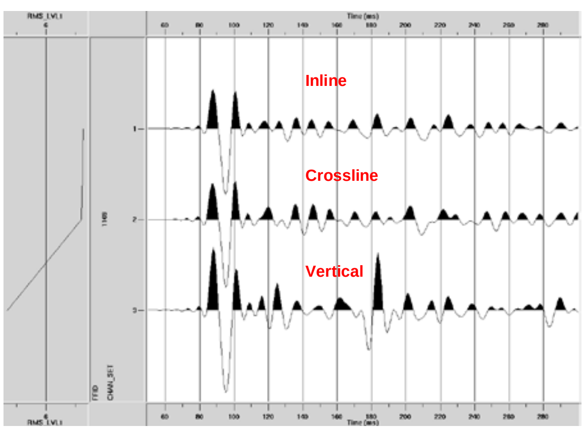

Figure 5: Accelerometer traces from a selected receiver station of a shot which is about 45-degree azimuth relative to the two horizontal components x and y (two upper traces), and the z-component (bottom). Offset-depth ratio is about 0.87. Filter: 3Hz (18dB/oct) – 150Hz (72dB/oct).

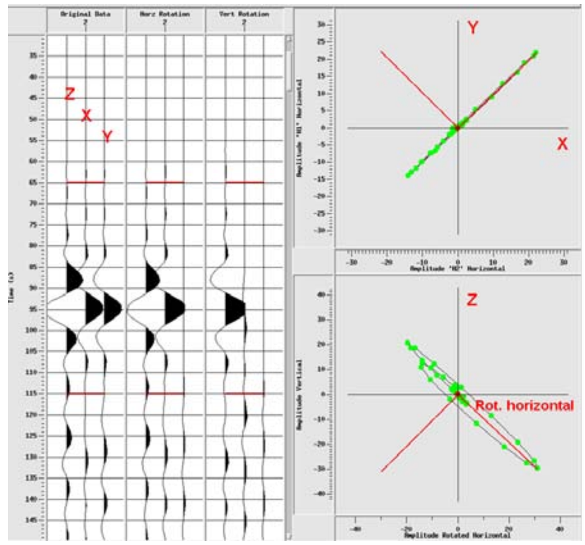

Figure 6: Hodogram of the two horizontal components x and y (upper hodogram), and hodogram of the rotated horizontal components versus the vertical component (z) (lower hodogram). Filter: 3Hz (18dB/oct) – 100Hz (72dB/oct).

Conclusions

Fiber optic multi-component ocean-bottom receiver systems for 4D applications can now be produced and installed successfully at locations where the oil companies would like exploit the life-of-field seismic concept. The analysis of the data from the pilot tests confirms the systems high degree of vector fidelity, high signal-to-noise ratio, very good ground-station coupling, reliability and excellent response in general to wave modes in connection with ocean-bottom seismic. Fiber optic based permanent seismic monitoring systems represent a great opportunity for the field engineers to optimize production and increase the hydrocarbon recovery rate from existing fields. We are advocating optical sensing technology to be an important part of the tool box for the oil companies in their work to implement the instrumented oil field in a cost efficient way. The "optical oil field" should represent the next step in technology in connection with reservoir monitoring in order to increase the hydrocarbon recovery rate.

Acknowledgments

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