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Visualizing what lies beneath: A new era for fiber optics

A new engineered fiber optic and sensing system provides exceptional data quality on permanent and intervention cables. The improved sensitivity lowers operational costs by reducing the source effort and increasing the frequency of the measurements.

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To enhance recovery and decrease development risks, many producers are considering regular, repeated acquisition of seismic data. In the offshore sector, ocean bottom node (OBN) or permanent reservoir monitoring (PRM) systems are seeing increasing popularity as a result. These seismic data improve the image of hydrocarbon-bearing layers beneath the earth's surface and provide information on the migration of fluids and gas over time, due to production activities. However, critical, accurate in-well seismic data from the most valuable assets are rarely acquired as a result of the operational expense and risks of deploying conventional sensors.

Distributed acoustic sensor (DAS) enables the realization of new applications, where the fiber optic cable can be deployed readily as a dense, wide-aperture acoustic phase-array in novel configurations. The small-diameter, rugged fiber optic sensing cable can be installed permanently along the wellbore, which offers many practical benefits for acquiring seismic data on demand and continuous passive seismic, as well as production monitoring. This allows an operator to perform vertical seismic profile (VSP) acquisition without intervention or placement of geophones in the wellbore. Silixa has been at the forefront of distributed sensing since 2007 and has demonstrated some of the key benefits of DAS for conventional and unconventional reservoir monitoring applications.

Fig. 1. The principle operation of intelligent Distributed Acoustic Sensor.

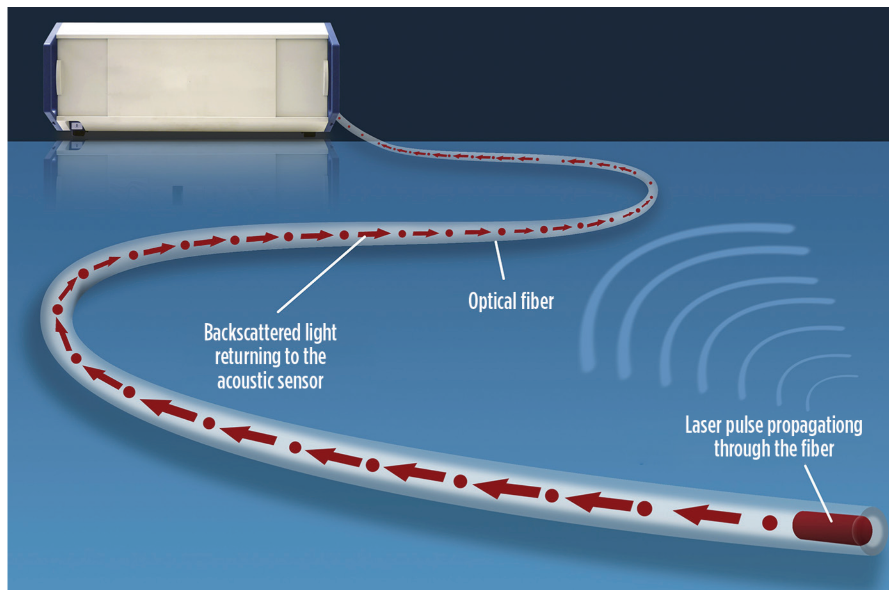
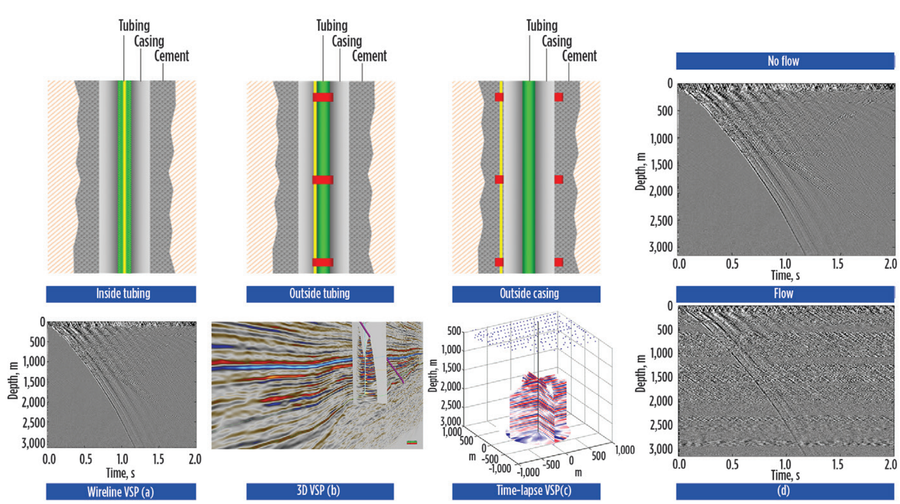


Fig. 2. Examples of sensing cable deployment for seismic data acquisitions and different well conditions.



DISTRIBUTED ACOUSTIC SENSOR

An intelligent Distributed Acoustic Sensor (iDAS) works by launching a laser pulse into the optical fiber. A small portion of the incident light is then scattered back toward the optoelectronic interrogator unit, Fig. 1. The returning, resultant scattered light is affected by tiny strain events along the optical fiber, which are modulated by the acoustic wavefield. By recording the returning

Fig. 3. iDAS seismic data were gathered with high (left: 18 shots 1,900 in.^{3}) and low (right: 276 shots, 160 in.^{3}) source effort array.

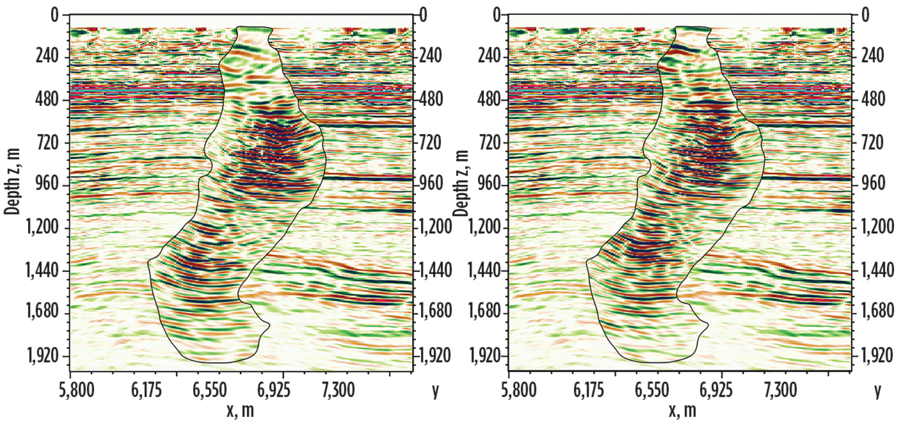
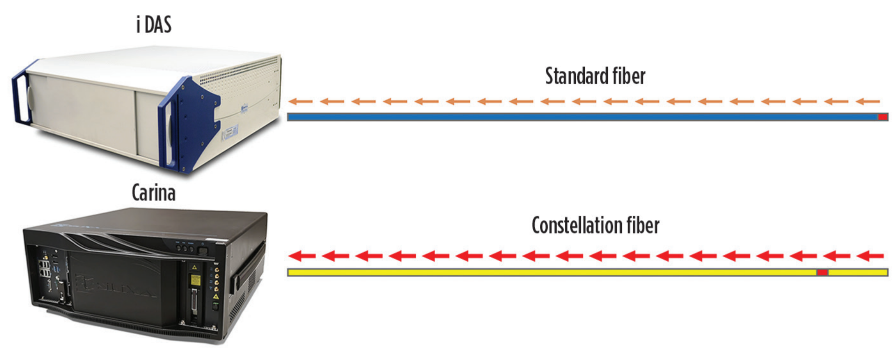


Fig. 4. A DAS system, with standard fiber, and the Carina system equipped with engineered Constellation fiber, with bright scatter centers.



signal against time, the acoustic field along the entire length of fiber can be recorded simultaneously.

The novel optoelectronics architecture of iDAS allows a phase-coherent digital recording of acoustic fields at every location along both, using standard single-mode and multi-mode optical fibers with a frequency range from millihertz to hundreds of kilohertz over a wide dynamic range, and with a fine spatial resolution down to 1 m (Parker). The versatile capability of iDAS offers many advantages for downhole sensing applications, including seismic imaging, production monitoring and well integrity.

Sensing cable deployment. The fiber optic cable can be deployed readily as a dense, wide-aperture acoustic phase-array in various configurations. The small-diameter, rugged fiber optic sensing cable can be deployed, using intervention techniques, or it can be permanently installed along the wellbore, Fig. 2.

Using an intervention method, a continuous length of fiber optic sensing cable is deployed inside the wellbore. The flowing well conditions may be adjusted while recording the data simultaneously across the entire wellbore. The fiber can be used to listen to the flow noise across the perforated zones, and the acoustic energy and the spectra response may be used to characterize the flowing conditions. In addition, using a phase array processing technique, we can determine the speed of sound in up-going and down-going directions. The fluid properties may be determined from the average speed of sound, and the fluid velocity may be determined from the doppler shift experienced between up-going and down-going sound waves (Naldrett).

The wireline also can be used for vertical seismic profiling (VSP) data acquisition. When a small amount of well deviation exists, the frictional coupling between the cable and the wall of the wellbore provides enough coupling to transfer the vibrational energy to strain changes along the length of the fiber.

Permanent installation offers many practical benefits for continuous production monitoring, passive seismic and for seismic acquisition on-demand. In this case, the fiber optic cable may be strapped to the production tubing or clamped and cemented behind casing. Accurate depth correlation can be achieved by combining the distributed temperature data and by mapping the clamps' position to the wellbore trajectory.

Distributed acoustic sensing can provide higher-resolution 3D VSP images near the wellbore than ocean bottom seismic, enabling better placement of infill wells, sidetracks or new perforations. Since the fiber is permanently installed, low-cost, regular, repeat seismic acquisition is possible, and time-lapse VSP seismic images can reveal changes within the reservoir.

iDAS enables the collection of seismic data with a wide range of source types. There is compatibility with guns of different volumes, where post-stack migration has been performed, using data gathered from a single well, using both high- and low-source effort array, Fig. 3. In the image on the left, post-migration output is shown, following a survey performed with 18 shots from a 1,900-in.^{2} array. This is compared with the post-migration output shown on the right, which has been compiled using data obtained through 276 shots from a 160-in.^{2} array.

Improved sensitivity of the fiber optic data acquisition system offers many advantages, in terms of the operational costs, such as reduced source efforts, and increased frequency of measurements. Shooting from smaller sources and fewer shots significantly lowers the source costs, as smaller vessels, such as supply boats with containerized sources, can be used for short-duration surveys.

CARINA SENSING SYSTEM

In 2015, Silixa introduced the advanced Carina acoustic sensing system, that delivers high data quality. A transformative improvement in the measurement sensitivity has been achieved by utilizing the next generation of Constellation fibers, combined with a new, low-noise interrogator optoelectronic unit. The fibers are engineered with bright scatter centers along its length, to capture and reflect more light back to the interrogator without introducing significant loss to the forward propagating laser pulses, Fig. 4.

The high sensitivity and wide dynamic range of the engineered fiber with its broadband and wide-aperture response can provide unprecedented data quality, for both the permanently installed and intervention cables, for fracture monitoring and completion diagnostics.

A VSP survey was carried out by lowering a geophone array and collecting data at 11 positions along the wellbore, Fig. 5. The fiber optic cable was installed and cemented behind casing, and data were acquired simultaneously along the entire wellbore.

The signal-to-noise ratio performance (SNR) of the Carina Sensing System is 100x (20dB) higher, compared to DAS with standard fiber. Its performance is also comparable to that of geophones, along the entire length of the fiber. The higher sampling resolution and full wellbore coverage provide a far more cost-effective operational method for acquiring higher-definition seismic data, especially when combined with permanent sources (Correa).

The performance of Carina below 1Hz and down to sub-millihertz far exceeds the performance of geophones. It provides a new way of monitoring minute, slow strain changes in reservoirs induced by hydraulic treatment, pressure drawdown and subsidence.

CROSSWELL MONITORING

The utilization of distributed fiber optic measurements has been increasing over the past few years. By installing a permanent fiber cable on the outside of a casing string, measurements along the entire wellbore can be collected (Webster). However, the requirements for the cable orientation and directional perforation add additional complexity and costs for installing the fiber and, therefore, limits the number of wells that can be instrumented with fiber and monitored simultaneously.

An example of an unconventional multiple-well monitoring program is shown in Fig. 6. Two of the wells were instrumented with permanent, engineered Constellation fiber cable cemented behind casing. However, it was recognized that acquiring addition data between the wells can be valuable in understanding fracture growth within the reservoir. For this reason, an additional, wireline-based service was introduced. The Carina XwellXpress monitoring service functions by pumping down a Constellation wireline cable in an offset well that provides another measurement axis for monitoring and optimizing hydraulic fracturing operations in real time. The introduction of the wireline has added flexibility in designing the monitoring program while eliminating drilling risks and reducing the overall cost of permanent installations.

We can record both microseismic events and the build-up of low-frequency cross-well strain, Fig. 7. A growth in poroelastic pressure is observed prior to the initiation of the events that are characteristic of frac hits. In addition, by combining the data recorded from all three fiber cable axes, we can improve co-location of microseismic events and build the strain tensor profile. These new data allow completion engineers to map the depth, azimuth and speed of the fractures, and feed that information back into the fracture models to validate and optimize the designs for the next operation.

SUBSEA APPLICATION

There is also a growing interest in the use of DAS for subsea wells. One solution, which is under consideration, is the marinization of the DAS interrogator unit for direct installation near the wellhead, to avoid the long tie-back fiber attenuation. The Carina Sensing System, with the engineered Constellation fiber, can offer a practical solution to this challenge. The initial laboratory and field trials indicate that the brighter scatter signal along the fiber can compensate for the long tie-back fiber losses (up to 20 km) and the high connector losses (few dBs). Remote optical pump

Fig. 5. A comparison of geophones, with the Carina system utilizing an engineered Constellation sensing fiber (Source: CO2CRC Ltd).

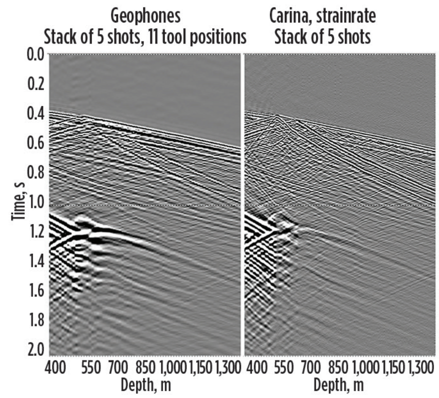


Fig. 6. Multiple fiber cable was deployed to monitor hydraulic fracturing treatment across the reservoir with two fiber optic cables that were installed permanently behind the casing. Carina XwellXpress wireline cable pumped down in well-2 and then moved to well-3.

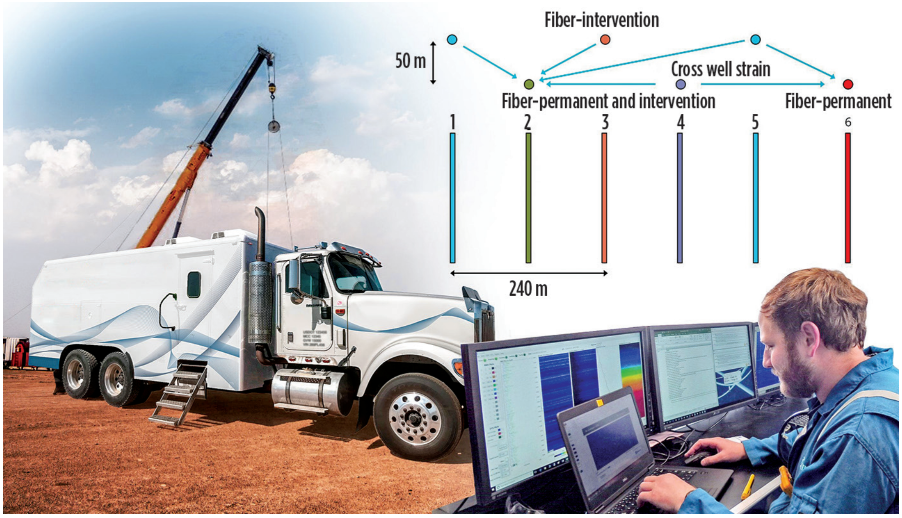
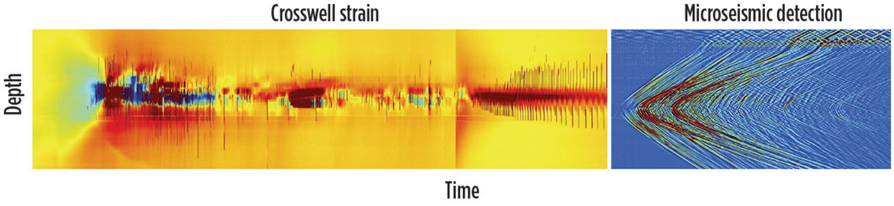


Fig. 7. Low-frequency cross-well strain data (l) and simultaneous detection of microseismic events (r) on the wireline intervention cable.



amplification (ROPA) can further extend the range and performance of the sensing system to an over-50-km range. This provides a new possibility of acquiring high-resolution seismic images in deepwater installations.

SUMMARY

The intelligent distributed acoustic sensor (iDAS) enables the realization of new applications, where the fiber optic cable can be readily deployed as a dense, wide-aperture acoustic phase-array in novel configurations to monitor along the entire wellbore.

The next-generation Carina Sensing System, utilizing the new engineered fiber, offers 100x improvement in sensitivity, compared to standard fiber, and provides unprecedent data quality on both permeant and intervention cables. The improved sensitivity of Carina offers many advantages in terms of the operational costs, such as reducing the source efforts, and increasing the frequency of measurements.

The performance of Carina below 1Hz and down to sub-millihertz far exceeds the performance of geophones. It provides a new way of monitoring minute, slow strain changes in reservoirs, induced by hydraulic treatment, pressure drawdown and subsidence.

The Carina wireline deployment provides additional flexibility in designing a hydraulic fracturing monitoring program while eliminating drilling risks and reducing the overall cost of permanently installed fibers. Data acquired through wireline can be combined with data collected on permanently installed fibers. to provide a wide-volume coverage for fracture monitoring and completion diagnostics.

The sensing system also can offer a practical solution for extending the measurements range in long tie-back subsea wells. The high-quality distributed fiber optic data, combined with machine learning techniques, can be used to generate images of what lies beneath the earth's surface. WO

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