*pico*DAS Fiber Optic Distributed Acoustic Sensing System

*pico*DAS is a fiber optic distributed acoustic sensing system (DAS), designed for applications where sensitivity is of paramount importance. The following key features make this product a unique tool to produce unmatched acoustic data quality:

- Exceptionally high sensitivity
- Excellent channel-to-channel sensitivity uniformity
- No sensitivity deterioration caused by distance
- Zero cross-sensitivity between neighboring channels

Each of the features above is unique and their combination sets *pico*DAS apart from the other DAS products on the market, making it an ideal choice to fulfill needs that require high acoustic data quality yet exhibit cost sensitivity.

1. WHY IS *pico*DAS UNIQUE?

Distributed acoustic sensing or DAS utilizes silica optical fiber to measure acoustic waves along the fiber's entire length. Traditional DAS works by sending laser pulses from an interrogation instrument into a sensing fiber. A small fraction of the incident laser is backscattered via Rayleigh scattering. By measuring the arrival time of backscatters at the optical receiver in the interrogator, the location where each backscatter was produced can be determined by optical time domain reflectometry (OTDR). Traditional DAS operates based on the detection of the Rayleigh backscatters. However, traditional DAS suffers from a major fundamental limitation, which is

poor acoustic detection sensitivity dictated by the extremely weak backscatters. This problem is caused by two factors.

The first factor is the extremely weak Rayleigh backscatter. For standard singlemode silica fiber, the backscatter strength is -82dB, or 6 parts per billion, for a 1ns laser pulse at 1550nm. The second factor is the fiber loss, which makes the Rayleigh backscatters at the photodetector even weaker as the sensing distance increases. For example, fiber cable in the field typically exhibits 0.5dB/km loss. This means the strength of the signal from 10km becomes one order of magnitude weaker. The weak Rayleigh scattering and fiber loss together make the already rather limited sensitivity further deteriorate with fiber distance from the interrogator. This often causes these systems to fail to generate quantitative acoustic measurements when the distance exceeds 10km. Moreover, these systems have another major limitation resulting from the randomness of the coherent Rayleigh backscatters, which is significant variation in acoustic detection sensitivity from position to position and from time to time.

*pico*DAS completely overcomes these fundamental limitations of traditional DAS by innovations in fiber fabrication, interrogator design and signal processing. This product offers unprecedented sensitivity that does not decline with increasing fiber distance and does not exhibit any cross-sensitivity between neighboring sensing channels. Additionally, *pico*DAS provides high quality quantitative acoustic measurement by its unique phase demodulation scheme.

2. TYPICAL APPLICATIONS

*pico*DAS's unmatched performance significantly advances the state of the art for distributed acoustic sensing and makes it especially attractive for the numerous applications described below, as well as novel applications where sensitivity and sensor consistency are important design factors.

2a. Oil/Gas Downhole Measurements

Acoustic sensing is important in every phase of oil and gas recovery. Some of these measurements include vertical seismic profiling (VSP), fracture monitoring, quasi-static mechanical strain and temperature measurement, micro-seismic event detection and well flow and integrity monitoring. These measurements utilize different frequency domains of DAS signals. They range from high frequencies produced by injection to near-zero frequencies caused by hydrocarbon flow into the well bore in different perf clusters. In all of these measurements, sensitivity and spatial resolution with minimum cross-sensitivity matter immensely. Our DAS has been demonstrated to be able to detect downhole micro-seismic signals. What is even more impressive is that such successful detection is through the well casing which heavily attenuates the already extremely weak acoustic signal.

2b. Pipeline and Perimeter Monitoring

Long pipelines and perimeters of high value assets require real-time monitoring for leak or intrusion detection. Distributed acoustic sensing has been demonstrated to be a rather attractive option and in many cases the only cost effective option. However, an extremely low false alarm rate is essential, which must begin with a DAS system that has features of an exceptionally low and constant noise floor for the entire sensing length. At the same time, many of these applications are also cost sensitive. *pico*DAS satisfies the demanded features and offers a perfect choice for a cost effective yet very high-performance solution.

2c. Flow Measurement

*pico*DAS has been proven to permit fluid flow sensing by measurement of the acoustic waves produced by the flow of fluids in a pipe. The product can be applied to pipes that have different diameters, fluids, flowrates and temperatures. This non-intrusive sensing method offers highly sensitive and accurate real-time measurements simultaneously at multiple locations. The excellent channel-to-channel consistent data quality and sensitivity uniformity of *pico*DAS is especially important for customers who perform their own data modeling and analysis based on the DAS raw data.

2d. Structural Health Monitoring

Many important civil structures such as bridges, dams and tunnels require real-time monitoring of their structural integrity and operating conditions. DAS can provide rich information about the health condition of these structures. A DAS system can be especially useful if it can be engineered to provide a sufficient sensitivity with a broadband response for detection of ultrasonic waves emitted by crack initiations, which have been concluded to be perhaps the only reliable early warning of a structure collapse.

*pico*DAS is a perfect fit for the applications above. Having clean, low-noise data for every moment and every location is also important to significantly reduce the demand for data storage. Therefore, the cost-effective *pico*DAS equipment plus the savings in data storage systems allow operators to achieve their goals with reduced capital investment.

3. SPECIFICATIONS

Model	*pico*DAS
Spatial Resolution	2m or 5m or custom
Maximum Sensing Range	5km plus up to 15km lead fiber
Sampling Rate	15-125kHz
Sensitivity	$< 0.15n\epsilon$ typical, $0.5n\epsilon$ max
Sensitivity Disparity	<20%
Interrogator Dimensions and Weight	27x45x44cm, 17.3kg
Computer Interface	Ethernet
Power	240/110V, 50/60Hz
Power Consumption	82W Max
Operating Temperature	0 to 45°C
Humidity	5-95%
Fiber Connector	FC/APC or E-2000/APC

4. SPECIAL SOFTWARE FEATURES

*pico*DAS is equipped with powerful software that offers real-time 3-D display of acoustic waves at each position of the sensing fiber. The 3-D graph can be freely rotated and adjusted in display scale. Data storage can be synchronized by external trigger or set by a predetermined threshold of the acoustic amplitude. The software provides various digital signal processing and analysis. Additionally, data can be downsampled after filtering to significantly decrease storage demands while avoiding inadvertently aliasing noise into the frequency range of interest. This gives the noise-reducing capabilities of a high sampling frequency combined with the data size of a low sampling frequency.

Various output data formats can be provided per custom request. They may include the Hierarchical Data Format version 5 (HDF5) and the Production Markup Language (PRODML).

5. RELEVENT DATA

*pico*DAS has been tested extensively both in laboratories and in the field. The results have demonstrated the system's superior performance and long-term field use reliability since 2018.

In one example of a performance evaluation, the system is tested by wrapping one channel of fiber on a piezoelectric cylinder that is driven by a function generator with varying sine wave amplitude. Figure 1 shows the *pico*DAS output in units of fiber strain for different driving signal amplitudes. The results show that the output is proportional to the applied voltage with an excellent linearity and signal fidelity. The spurious free dynamic range (SFDR) exceeds 20dB. This harmonic-free acoustic detection is especially important to applications such as downhole vertical seismic profiling (VSP), where an extremely clean signal response is highly desired.

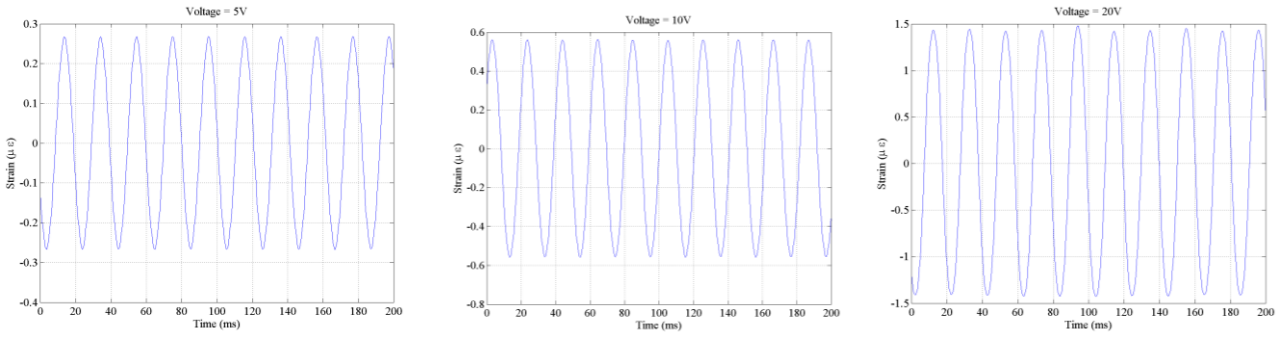

Figure 1. *pico*DAS responses to fiber dynamic strain produced by a piezoelectric cylinder, which show excellent response linearity and signal detection fidelity. More importantly, such response is offered by every section of the entire 5km sensing fiber with the same acoustic detection sensitivity, linearity and fidelity.

Figure 2 shows real measurement data from a 5km sensing fiber that is interrogated by *pico*DAS with 5m spatial resolution. The red color 'carpet'-like plane comprises 360 sensor output lines as part of the 1,000 outputs. All these lines exhibit nearly identical noise floors within ±20% around the mean value ($0.16n\epsilon$). A 4.95m fiber segment at 4.2km position is wrapped on a piezoelectric cylinder, which is driven by a function generator to

produce an impulse stretch to the fiber. The output of this fiber segment is given in the blue trace, which demonstrates high-frequency and high-fidelity response with no cross-sensitivity from the neighboring sensing fibers.

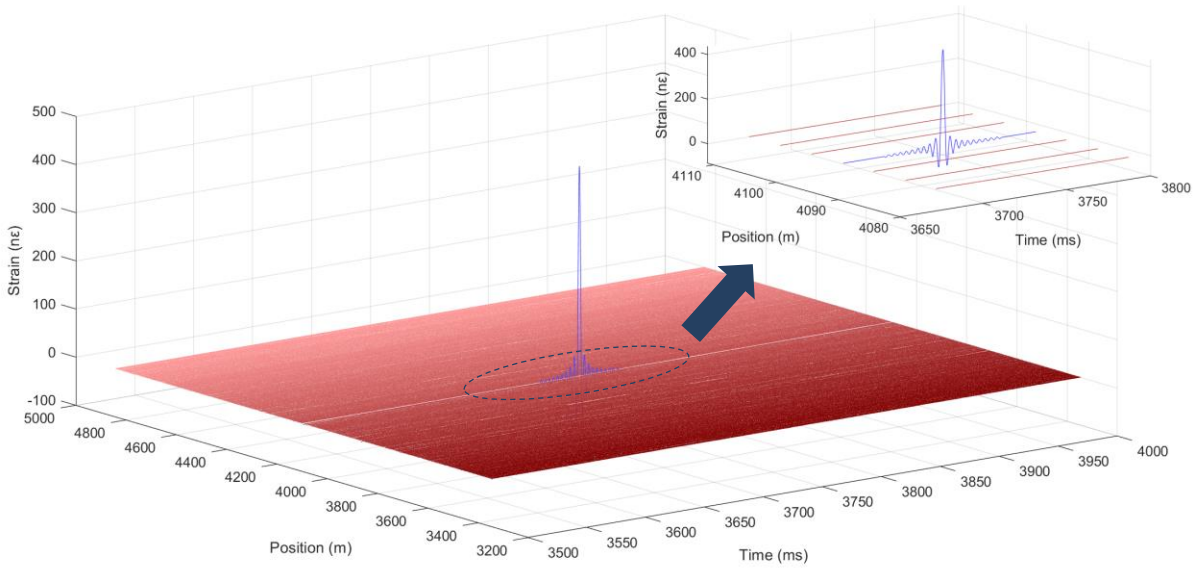

Figure 2. Measurement of channel-to-channel sensitivity uniformity over the entire 5km sensing fiber. Besides clearly demonstrating the system's extremely high sensitivity, the result also exhibits zero cross-sensitivity as shown in the inset between neighboring sensing channels.

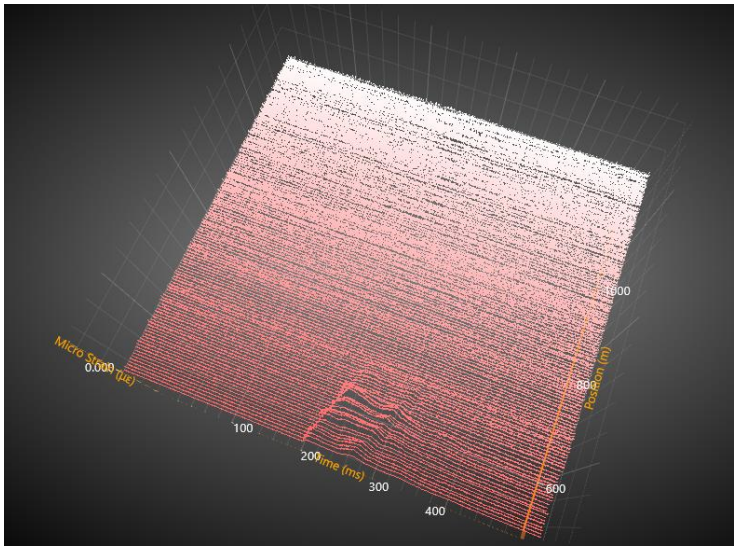

Figure 3. *pico*DAS has been deployed in various wells for micro-seismic event detection. Given its exceptionally high sensitivity, successful detection can be achieved with the fiber cable either in the cement surrounding the well casing or in the borehole. The graph on the left presents one example of a micro-seismic event successfully detected with a high signal quality. This detection was performed with the fiber cable in the bore filled mostly with water. This achievement is special because the weak signal is significantly attenuated by the well casing already. The high-quality data clearly shows *pico*DAS suitability for downhole measurement of acoustic waves including those that cannot be detected by other DAS systems.