

# Precision-Engineered DAS Hydrophone Arrays for Littoral and Offshore Surveillance

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**Abstract** — Distributed Acoustic Sensing (DAS) is an innovative technology that utilizes fiber optic cables to detect and measure acoustic signals over vast distances. DAS can employ standard optical fibers or engineered special fibers as sensors. When an acoustic wave interacts with the fiber, it causes minute changes (backscattering) in the light traveling through the fiber. These changes can be measured and analyzed. Coiled Fiber Optic Hydrophones (CFH) have been developed. This improves sensitivity and spatial resolution. A noise floor at sea-state zero has been demonstrated in an earlier project by the Swedish Defense Materiel Administration (FMV) in collaboration with Akitemos Solutions AB, Subvision AB, and Silixa LLC. The Coiled Fiber Optic Hydrophones offers significant advantages in manufacturing long hydrophone array for rapid underwater deployment with a broad frequency response from mHz to several kHz. Key advancements discussed include development and manufacturing of long arrays, omnidirectional sensitivity, and use of advanced processing techniques during recent sea trials.

## 1 Introduction

Acoustic sensing plays a critical role in maritime security, infrastructure monitoring, environmental research, and underwater resource exploration. However, traditional hydrophones, designed as point sensors, face significant limitations in scalability and adaptability to complex subsea environments. Distributed Acoustic Sensing (DAS) combined with Coiled Fiber Optic Hydrophones addresses these challenges by detecting and analyzing acoustic signals with remarkable precision and flexibility. By measuring minute changes in Rayleigh or enhanced scattering induced by acoustic waves, DAS systems can pinpoint sound sources over long distances, providing real-time, high-resolution monitoring.

Since its inception, DAS technology has advanced significantly, transitioning from telecommunications and infrastructure monitoring to demanding subsea and terrestrial applications. By introducing the Coiled Fiber Optic Hydrophone, the technology enter a new area of applications where the advantage over standard hydrophones becomes obvious.

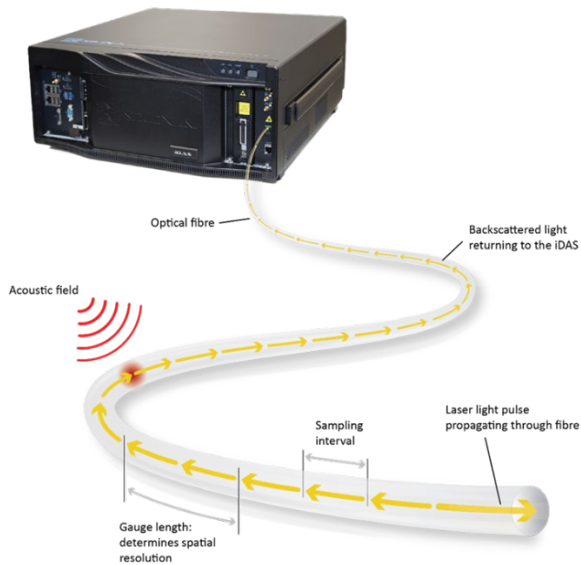


**Fig. 1.** The picture shows a high sensitivity Coiled Fiber Optic Hydrophone. The short size of the hydrophones makes them omnidirectional. The active part is about 5 cm long.

The efforts described in this paper were led by the Swedish Defence Materiel Administration (FMV), in collaboration with Subvision AB, Akitemos Solutions AB, and Silixa LLC. Subvision's innovations in Coiled Fiber

Optical Hydrophone (CFH) arrays, Akitemos Solutions AB's engineering expertise, and Silixa's advancements in DAS systems and signal processing have been instrumental in creating robust and adaptable solutions for diverse monitoring applications.

Figure 2 illustrates DAS's operational principles, featuring acoustic signal detection along a fiber optic cable with CFH arrays. The system's ability to detect various underwater threats, including submarines, divers, autonomous underwater vehicles (AUVs), demonstrates its versatility in real-world applications.



**Fig. 2.** DAS sensing system, including CFHs, demonstrating acoustic detection along a fiber optic cable.

This paper examines technical advancements and methodologies integral to CFH with DAS implementation, including system design, field setup, and acoustic testing. Emphasis is placed on demonstrating the system's omnidirectional sensitivity, ability to detect both seismic and acoustic signals, and its validation through beamforming techniques during sea trials. By focusing on these technical aspects, the paper highlights the systems transformative potential for reshaping acoustic monitoring across defence, environmental, and industrial sectors.

## 2 Technical approach

### 2.1. System design and configuration

Distributed fibre optic sensing, where the fibre is permanently installed, offers many advantages for subsurface monitoring. The DAS utilises Rayleigh backscatter light and allows acoustic data to be acquired along a continuous length of fibre, providing a high-definition acoustic measurement along the entire length of fibre [2].

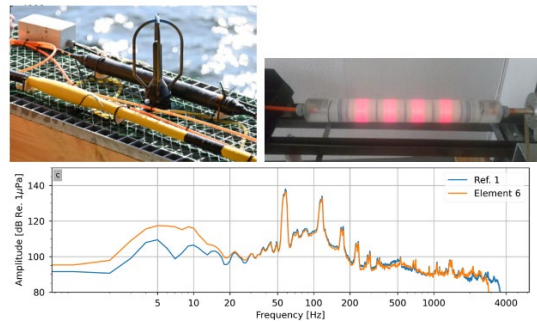
In this work we have used Silixa's Carina Interrogator combined with precision-engineered fiber (Constellation™ fiber).

Coiled fibers enhance localized acoustic detection by amplifying pressure-induced strain sensitivity, a key feature for high-resolution analysis in focused areas.

Subvision's CFHs utilize robust coiled mandrel designs, amplifying strain sensitivity while ensuring durability under field conditions. This provided a baseline to evaluate acoustic signal propagation and detection capabilities under diverse operational scenarios.

The first trials were done to verify the performance of the CFH compared to standard hydrophones. The trial took place at one of FMV's test sites in Sweden. The arrangement included straight and coiled single mode fibers, Constellation fibers, and traditional piezoelectric Reson 4032 hydrophones, allowing direct comparison of their respective sensitivities, noise thresholds, and spatial resolutions.

Acoustic sources were strategically placed at varied distances and angles to simulate realistic underwater acoustic environments.



**Fig. 3.** Frequency sensitivity comparison between CFHs and a reference hydrophone. Frequency responses showing near-equivalent sensitivity across 200-2000 Hz. A filter on the Reson hydrophone crate lower amplitude below 20 Hz.

Having proved the small-scale sensor performance, the next phase in the project was to prove the ability to build long Coiled Fiber Optic Hydrophone arrays in an efficient way.



**Fig. 4.** The picture shows the first small array with four hydrophones built in a semi-automated way.

A production facility was set up to produce arrays from a few meters to several kilometers. The distance between the hydrophones can be selected arbitrary. To be able to keep high quality, the production has to be semi-automated.

Two arrays have been produced with 24 hydrophones each and with a total length of 26 m each, and 1 meter spacing between elements.

## 2.2. Field trial testing

Acoustic testing was performed to assess the sensing system's ability to detect, localize, and analyze sound waves under diverse conditions. Targets were surface vessels, Autonomous surface vessels (ASV) and AUVs.

The system deployed consisted of 1000 m fiber lead-in cable, first array of 24 hydrophones (26 m), 280 m cable to the second array of 24 hydrophones (26 m). Total fiber length was about 2 km plus a return fiber of 1335 m (creating redundancy). Depth was about 40 m.

Due to the small vessel we had to make a special Carousell to deploy the system.



**Fig. 5.** Carousell to deploy more than 3000 m of fiber optic cable including 48 fiber optic hydrophone elements.

The complete system was deployed in about 30 minutes, and the system was ready to go. The captured acoustic data enabled advanced signal processing, such as beamforming, to analyze the system's localization capabilities. Both straight cables and CFHs were deployed in the tests, with the coiled configurations amplifying pressure and strain sensitivity for detecting subtle acoustic variations. Source amplitudes were measured to determine the transfer function of the array and assess its frequency and amplitude response.

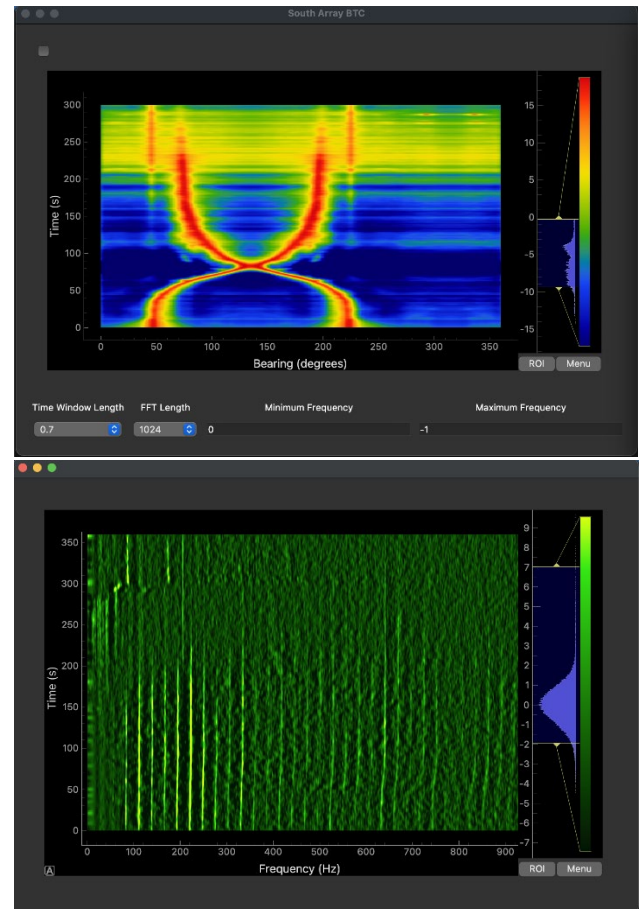
## 3 Results and discussion

The field data emphasizes the omnidirectional response which consistently detects acoustic signals with uniform sensitivity regardless of the source's angle of incidence.

The uniformity of the system's response is critical for applications in dynamic environments where sound sources, such as vessels or marine life, are unpredictable in orientation or movement.

The system's omnidirectional performance is essential for applications in maritime monitoring, where sound sources can originate from any direction, ensuring effective large-area coverage without complex directional adjustments. This capability increases operational efficiency and minimizes the risk of missed detections in real-world scenarios.

The scalability of the DAS system further enhances its versatility. The system achieves exceptional spatial resolution and extensive coverage with potential configurations allowing for about 600 sensors per 10 km of fiber using a 10-meter gauge length. This scalability positions the CFH hydrophone array as a robust solution for subsea defense and environmental monitoring. At the same time, its omnidirectional sensitivity ensures its functional equivalence to traditional hydrophones in dynamic and unpredictable environments.



**Fig. 6.** BTR - plot (bearing vs time) generated from one of the arrays, and LOFAR diagram (from one hydrophone channel) showing a passage of a surface vessel.

Achieving such parity in performance represents a significant milestone for DAS technology, validating its potential as a viable alternative or complement to traditional hydrophone arrays in critical subsea applications. The DAS - Coiled Fiber Optic hydrophone system superior noise floor ensures reliable performance in low-noise environments, such as 'Sea State 0,' where traditional hydrophones may struggle to detect subtle acoustic variations. Furthermore, the DAS-CFH robustness and adaptability across diverse acoustic scenarios—coupled with its capacity to integrate thousands of sensing elements within linear fiber arrays—enable scalable, long-range monitoring. This approach reduces logistical and maintenance challenges compared to traditional hydrophone systems while expanding operational capabilities.

The sea trials showcased the DAS-CFH system's ability to leverage advanced signal processing techniques, such as beamforming, for precise localization of acoustic sources over substantial distances. Beamforming takes advantage of the hydrophone array's coherence, as demonstrated in figure 6, to improve directional resolution and reduce spatial noise, which is vital for applications in maritime surveillance and environmental monitoring [1]. The system detected various targets including surface vessels and AUV's.

Although the linear geometry of the array introduces phase ambiguity, this geometry achieves commendable results. Future exploration of non-linear array designs, such as circular or triangular configurations, could further enhance directional resolution and address these ambiguities. The results also suggest that advanced processing techniques, including 3D beamforming and localization, could unlock additional insights in more complex array configurations.

Beamforming's ability to suppress noise and isolate sound sources underscores its critical role in high-resolution monitoring within dynamic and noisy environments. These capabilities ensure robust performance in applications such as underwater navigation, seismic surveys, and maritime security.

## 4 Future work

A comprehensive long-term sea trial is discussed to evaluate the performance, reliability, and scalability of DAS technology in real-world conditions. This deployment will integrate advanced CFHs, over long distances, and an intuitive graphical user interface (GUI). The GUI will streamline operations with features such as real-time beamforming visualization, automated anomaly detection, and customizable monitoring parameters, significantly reducing operational complexity. The trial

would also test system robustness across varying sea states, focusing on acoustic sensitivity, hydrophone durability, and long-term operational stability. The main applications for this type of systems would be harbor protection and protection of sensitive infrastructure.

## 5 Conclusions

This study underscores the significant technical advancements and capabilities of CFH combined with DAS technology for acoustic monitoring in diverse and challenging environments. By integrating CFHs with advanced signal processing techniques like beamforming,

Field trials validated DAS's capability to precisely localize sound sources, effectively suppress spatial noise, and maintain high sensitivity across a broad frequency range. The linear array configuration exhibited robust performance in capturing acoustic signals, with minor limitations that could be addressed through non-linear geometries to optimize directional resolution. Additionally, the scalability of DAS, which supports thousands of sensors along a single fiber, enables cost-effective and robust long-range monitoring while minimizing logistical complexity, firmly positioning it as a transformative solution for contemporary acoustic sensing challenges.

The arrays are designed to be placed on the seafloor. In the future other configurations are possible. This would include towed arrays and possible also vertical arrays.

DAS arrays with Coiled Fiber Optic Hydrophones, present unique advantages over traditional hydrophone systems: (1) No requirement for distributed power systems, improving reliability and reducing complexity; (2) Long-range capabilities, enabling coverage of large areas with fewer deployment challenges; (3) A high number of sensing elements, simplified system architecture, and improved robustness; These benefits make DAS combined with Coiled Fiber Optic Hydrophones an adaptable and efficient solution for diverse underwater monitoring needs.

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## Author/speaker biographies

Rune Tenghamn, engineering adviser at Akitemos Solutions AB, brings extensive expertise in advanced acoustic sensing technologies. Based in, Sweden, he leads Akitemos Solutions AB in developing innovative solutions for maritime security and environmental monitoring. Rune specializes in integrating cutting-edge systems, fostering collaboration, and advancing research to address complex challenges in underwater sensing and monitoring.

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Dr. Bryce Davis has over 20 years of experience in defence technology, with current focus on fibre optic sensing solutions like DAS for subsea monitoring. He manages projects, collaborates with government agencies and defence contractors, and drives innovation in sensing technologies to enhance security and monitoring within the defence sector.

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