A 32 element TDM optical hydrophone array

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Introduction

This paper describes the design and development of an optical hydrophone array for a seabed application. Optical hydrophones have been under development in a number of countries [1] as alternatives to piezoelectric based sensors, and the technology has now reached the stage where arrays with significant numbers of sensors can be constructed and deployed in realistic (and frequently hostile) environments. The array described in this paper is being constructed under a collaboration between the Defence Evaluation and Research Agency in the UK and TNO/TPD in the Netherlands (The TNO/TPD work is being funded by the Royal Dutch Navy). The system is modular in form and comprises up to 32 hydrophone elements in a time division multiplexed (TDM) reflectometric architecture. The array has been designed to act as a testbed for different hydrophone technologies and to explore their use in an at-sea trial.

System architecture

The array is designed to be used in conjunction with an optoelectronic interrogation unit developed under a previous project. The array is intended to be deployed from a surface vessel onto the seabed and interrogated through a 5km fibre datalink. The array is designed for operation in depths of up to 200m, and will initially be deployed for periods of up to 2 weeks. The array will require no electrical power and will contain only passive optical components.

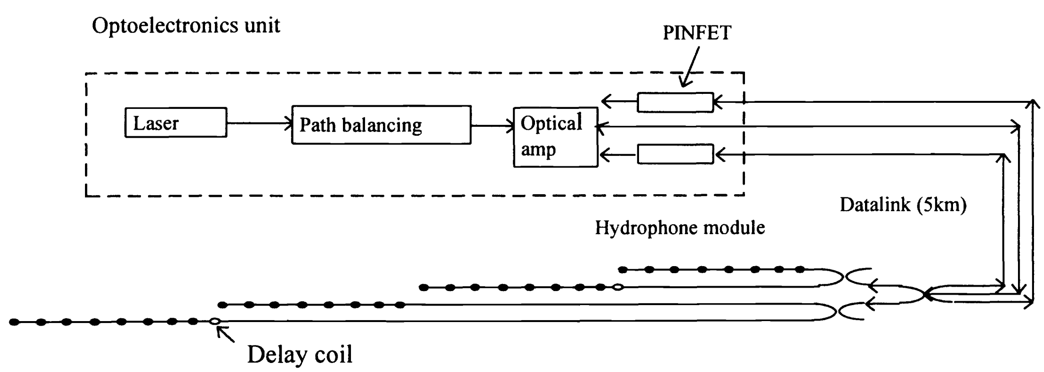

Fig. 1: Array architecture

The array architecture is shown in fig 1. The array consists of up to 4 modules of 8 hydrophones each, arranged in a tree configuration. The system is based on the TDM reflectometric architecture originally developed by Plessey [2]. The hydrophones in each module are time multiplexed on a single line, and are separated by semi-reflective elements which are constructed by silvering one port of a fibre x-coupler. Although the 4 branches are effectively parallel, they are physically arranged to form a single continuous line of 32 hydrophones. The total length of fibre between reflective elements is 100m. The array is interrogated through a single output and 2 return fibres.

Hydrophone design

The array contains hydrophones of 2 designs, one module using a TNO/TPD design while the remaining modules use a DERA designed hydrophone. These hydrophones use different design approaches but have been designed to be integrated into the common optical architecture. One of the purposes of the programme is to compare the performance of the different hydrophones.

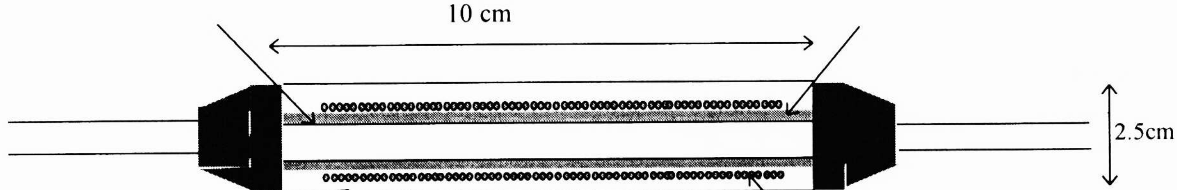

Figure 2: Hydrophone design

The DERA hydrophone design is shown in fig. 2. The hydrophone is an air backed mandrel design, containing 100m of fibre with an overall diameter of 2.5 cm and a length of 10 cm. The fibre coil is encapsulated in a layer of epoxy resin. The hydrophone responsivity has been measured to be -8 dB re 1 rad/Pa, and is flat up to frequencies well in excess of 1 kHz. Although air-backed, the mandrel is comparatively stiff and so the pressure tolerance of this hydrophone is intrinsically quite high.

The TNO/TPD hydrophone is based on a flexural disc design, which is highly compliant and gives a very high gauge sensitivity. This means that a responsivity of -7 dB re 1 rad/Pa can be achieved with a sensor length of just 4m. To achieve compatibility with the overall array architecture, the sensor also contains a 96m delay coil which is shielded from the acoustic signal within the centre of the hydrophone. The high compliance of the disc means that it is inherently prone to collapse under pressure, so the sensor incorporates a pressure compensation mechanism which allows it to operate down to the required 200m depth. The hydrophone has a diameter of 5cm.

Array design

The array is designed to be lightweight, small diameter and easily repairable. Simplicity of manufacture was also a significant requirement. Construction of a system which meets these requirements, while at the same time being able to survive the often hostile environments and handling encountered during deployment and recovery, is a significant challenge. The basic array structure is shown in fig.3. Individual hydrophone elements are joined together using a rigid metal enclosure which contains the reflective x-coupler and associated fusion splices, together with sufficient spare fibre to enable additional splices to be made in the case of hydrophone replacement. This enclosure is 15cm in length and 3.5 cm in diameter. The fibre between spice enclosures and hydrophones is protected in a loose tube cable which contains a Vectran strength member, and has an external diameter of 8mm. Fibres for other array modules are contained within a separate fibre cable which is attached to the array. The 5km datalink attached to the array has a diameter of 8mm and contains 6 fibres, although only 3 are actually used. The array and datalink are normally stored on a 1.5m diameter drum.

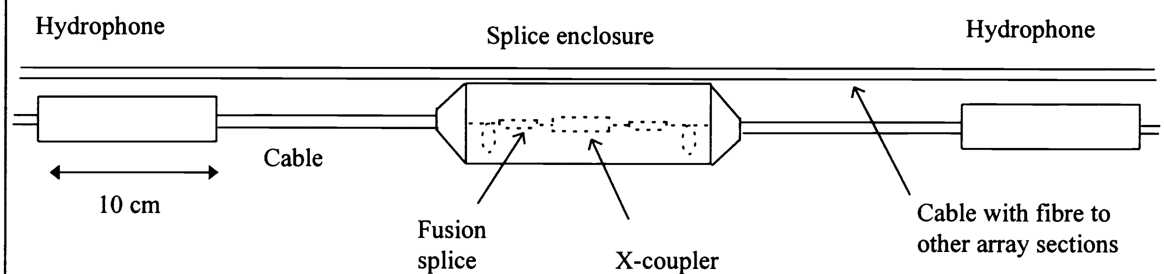

Figure 3: Array structure

Optoelectronic interrogation system

The interrogation system has been previously developed by Thomson Marconi Sonar under DERA funding. The optics and electronics are contained in a compact and rugged unit. The optical circuit is shown in fig. 4, and comprises a fibre laser, followed by a path balancing interferometer and an erbium doped fibre amplifier. A frequency difference is imposed on the light travelling through the two interferometer arms using two acousto-optic modulators. The output of the interferometer consists of 2 pulses, separated by a delay equal to twice the transit time of light through a hydrophone, and with a frequency difference equal to the heterodyne frequency. These pulses are then routed to the array through the single input fibre.

Optical signals returning to the array pass through the two return fibres and are routed onto 2 photodiodes. The signals are then demultiplexed and demodulated using 32 parallel analogue demodulators.

The optoelectronic system has been tested with a previous 32 element array constructed by Thomson Marconi Sonar. The system noise floor obtained with the original system is shown in fig. 5. The noise floor achieved is approximately equivalent to Deep Sea State Zero (moderately rough ocean conditions). The responsivity of the hydrophones in the new array is 4 dB higher than those in the original system, which will lead to a corresponding reduction in the noise floor in fig. 5. The noise floor achieved is higher than theoretically predicted, and further improvements to the electronics and to the acoustic isolation of the reference coil in the interferometer is expected to reduce this level.

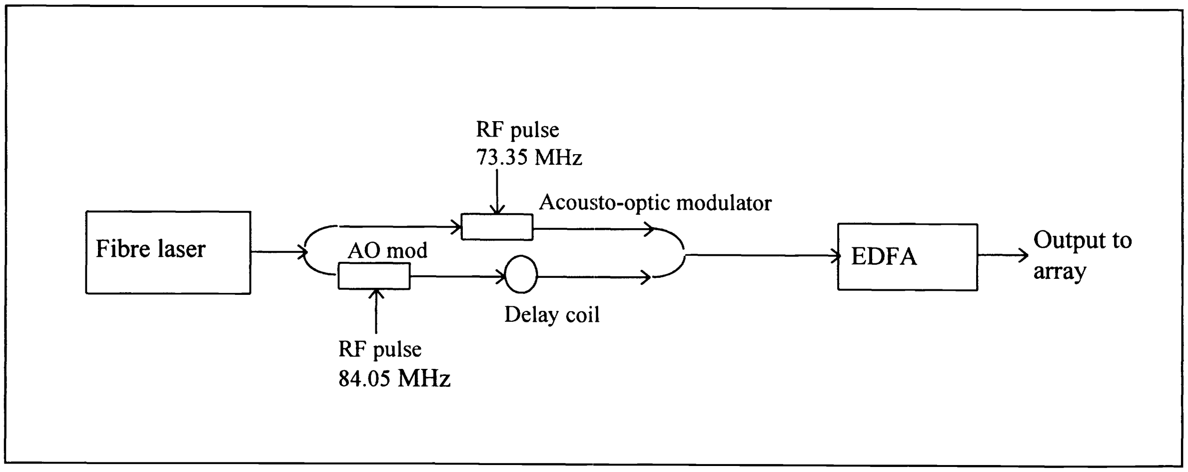

Figure 4: System optical architecture

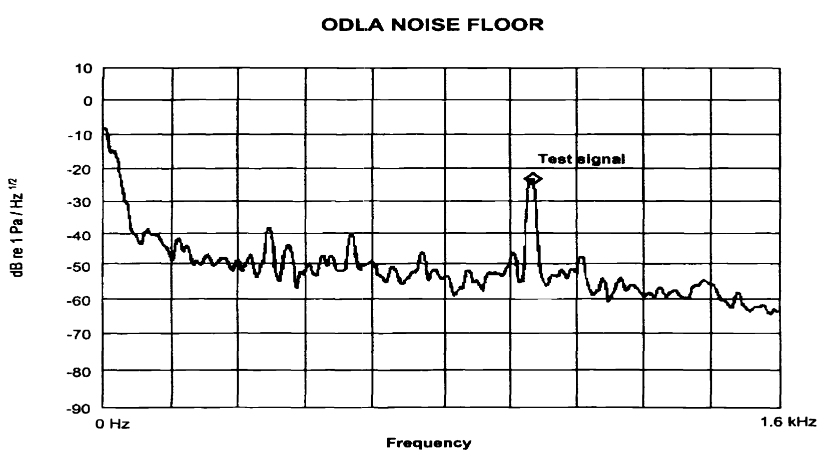

Figure 5: Optoelectronic system noise floor

Experimental programme

The array is being assembled during the first part of 1998 and will be tested during a sea trial in May 98. During this trial, which will be jointly conducted by DERA and TNO/TPD, the array will be deployed onto the seabed and interrogated from the deployment vessel. The performance of the array will be fully characterised in terms of noise floor, system dynamic range and beamforming performance, and the results from the different array hydrophones will be compared. Results from the trial will be presented at the workshop.

References

1. A. Dandridge, "Development of Fibre Optic Sensor Systems, 10th Optical Fibre Sensors Conference, Glasgow 1994

2. M. Henning et al, "Optical Fibre Hydrophones with Downlead Insensitivity", 1st Optical Fibre Sensors Conference, London 1983