Australian Government
Department of Defence
Defence Science and Technology Group

Optimisation of a Fibre Laser Hydrophone for Marine Traffic Monitoring

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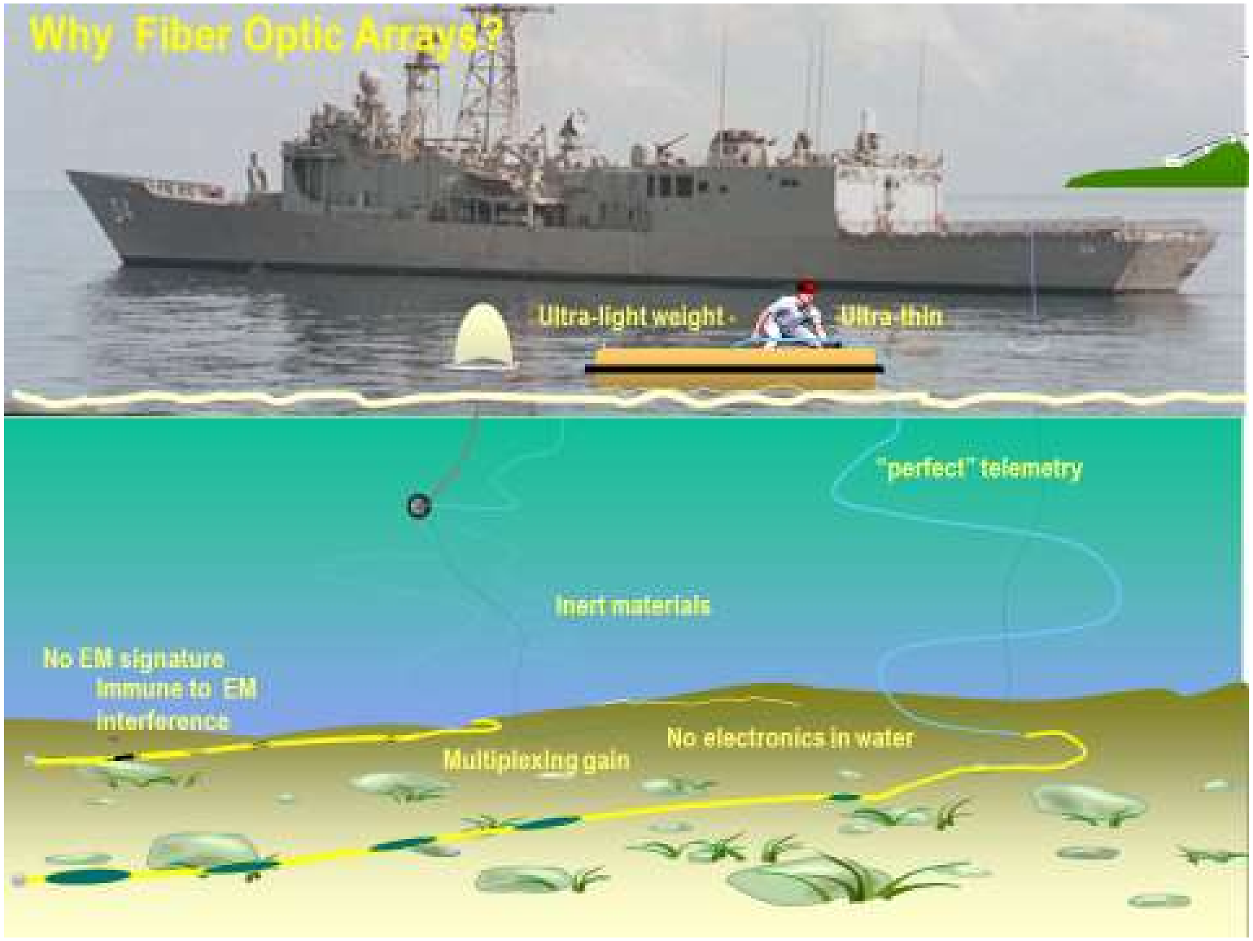
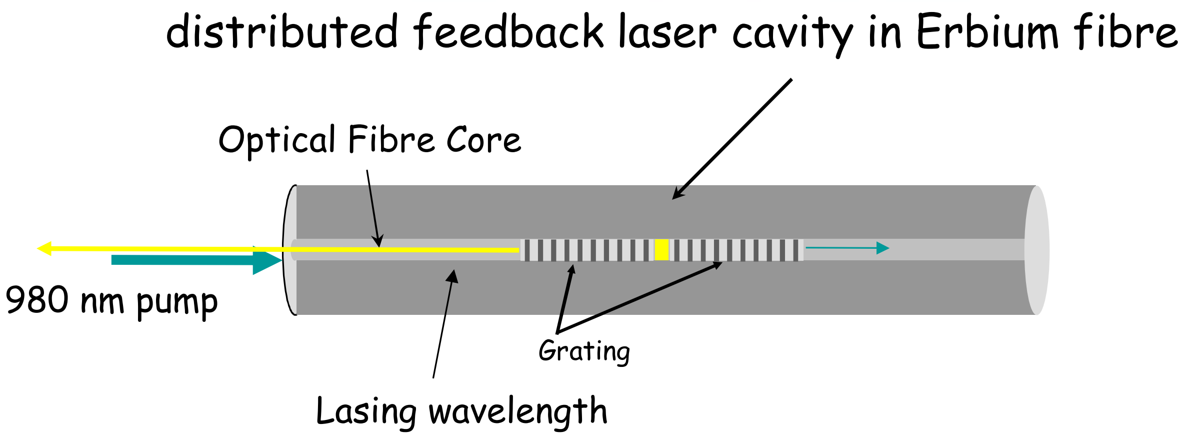
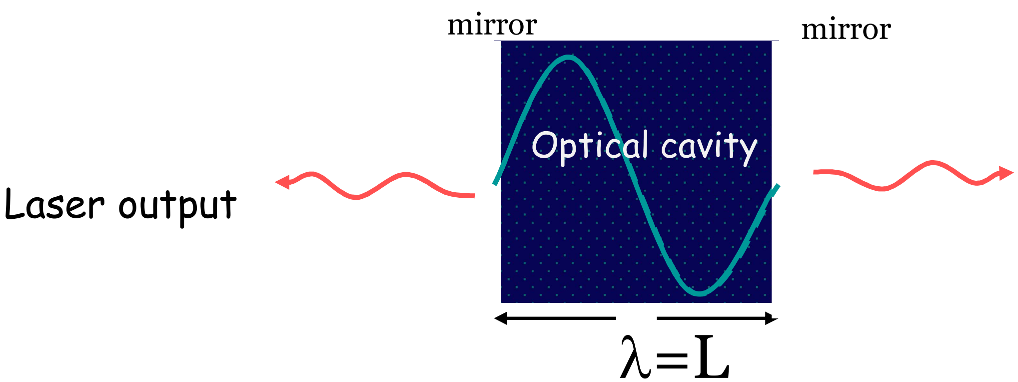
Overview of current design cycle

- FL Hydrophone redesign justification:
  1. Need for deep water deployments
  2. Better longevity
  3. Higher yield during fabrication/ easier assembly procedures
  4. Shorter design cycles
  5. Materials properties


Why Fiber Optic Arrays?
Ultra-light weight -
Ultra-thin
"perfect" telemetry
Inert materials
No EM signature
Immune to EM
interference
No electronics in water
Multiplexing gain

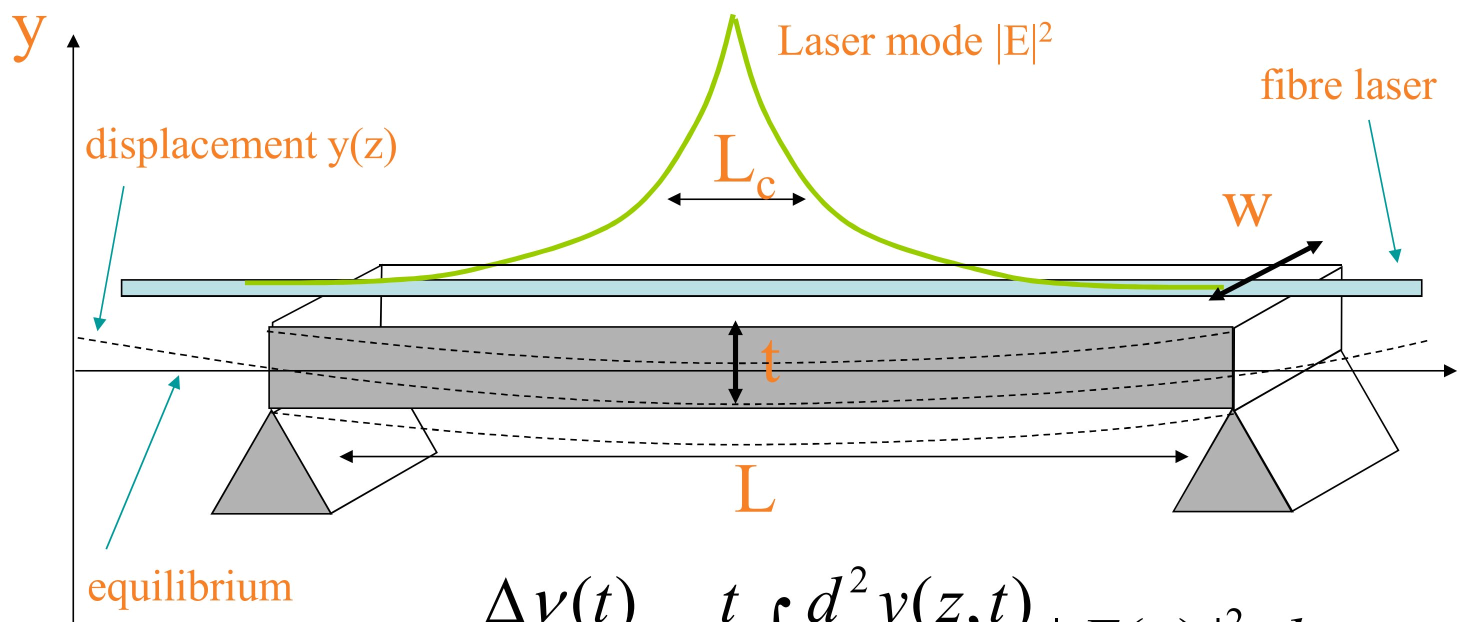


DFB FL is a very sensitive strain sensor



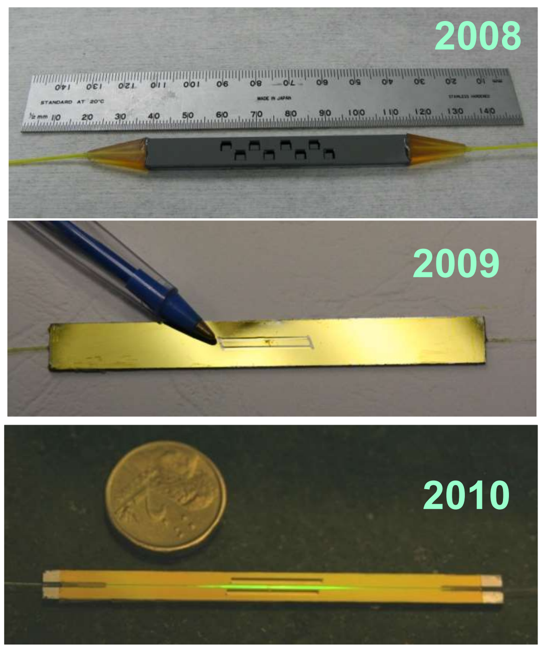
Bender transducer principle

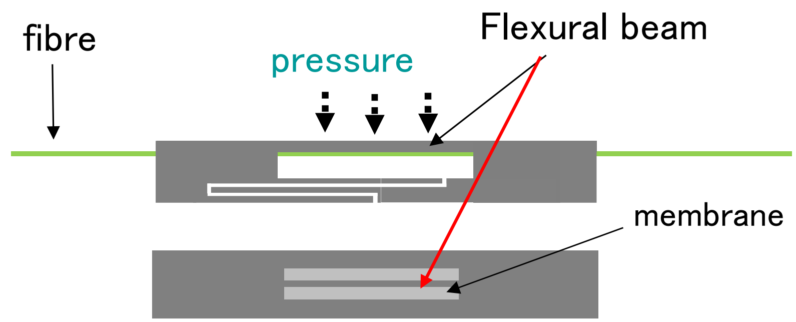
(how to translate pressure into strain?)



$$\frac{\Delta \nu(t)}{\nu} \approx \frac{t}{2} \int \frac{d^2 y(z,t)}{dz^2} \, |E(z)|^2 \, dz$$

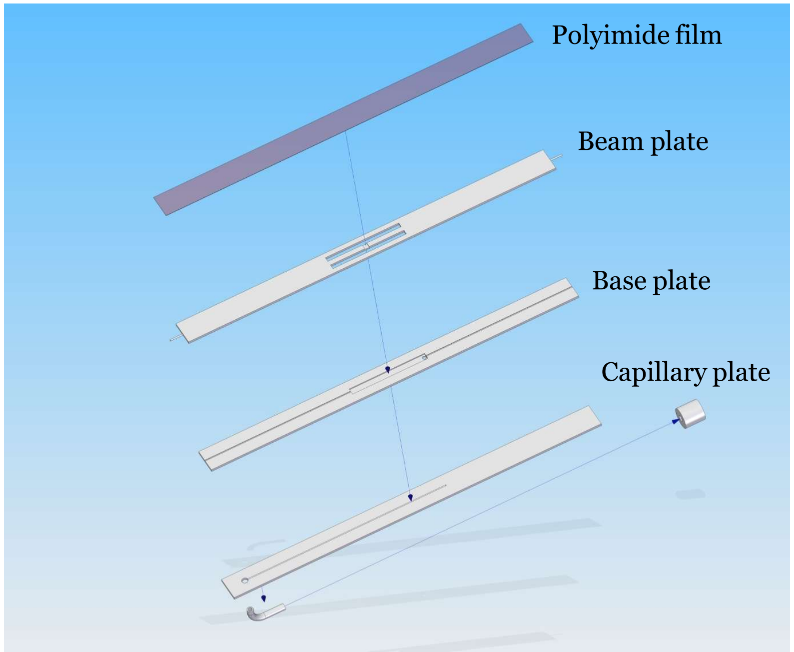
Fibre Laser Hydrophone design overview

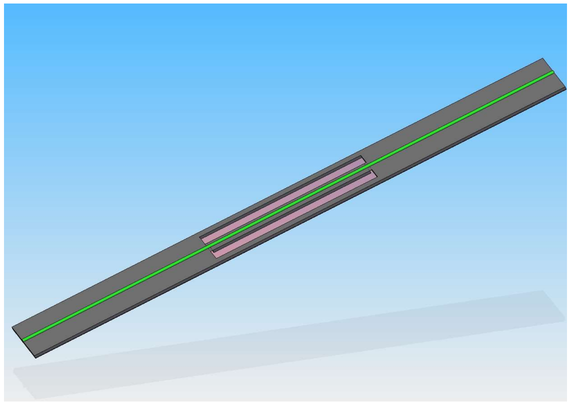


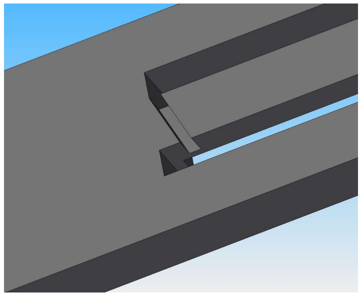


- ✓ High responsivity with flat response over 10kHz band
- ✓ Acoustic noise floor (equivalent) below SS0 (usual lowest ocean noise)
- ✓ Background pressure compensation to 80m demonstrated
- ✓ Point sensors (<2cm)

Hydrophone bender construction



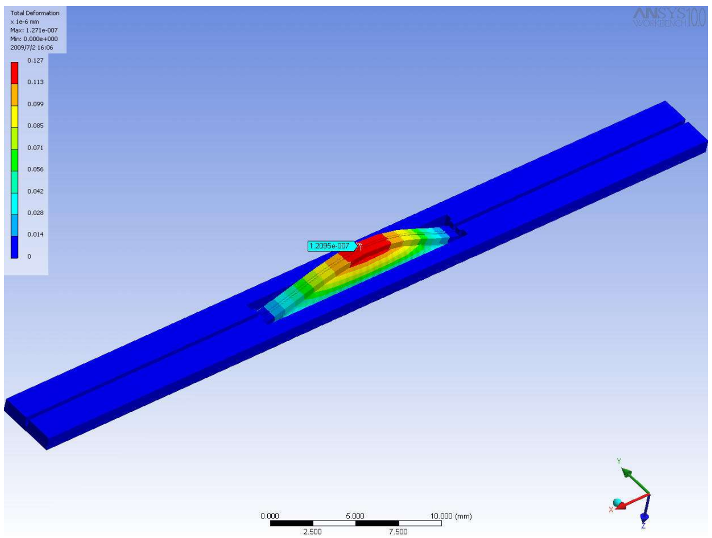




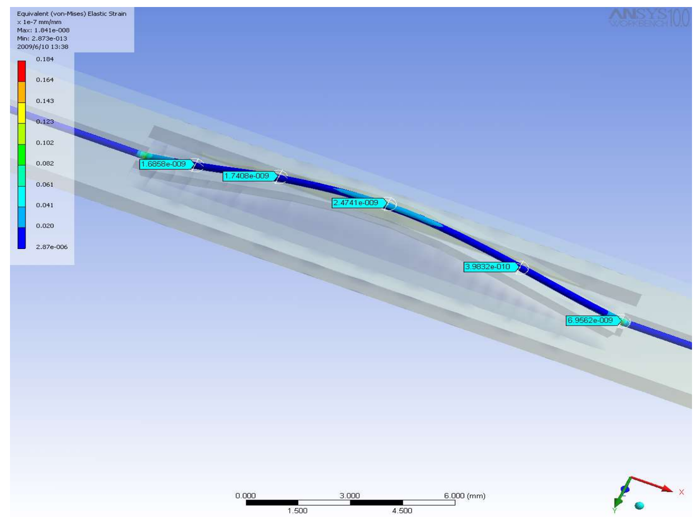
Beam undercut

Mechanical action of the beam

Displacement – 1.2e-7mm Re 1Pa



Strain – 2.47e-9 max Re 1Pa



Beam resonance

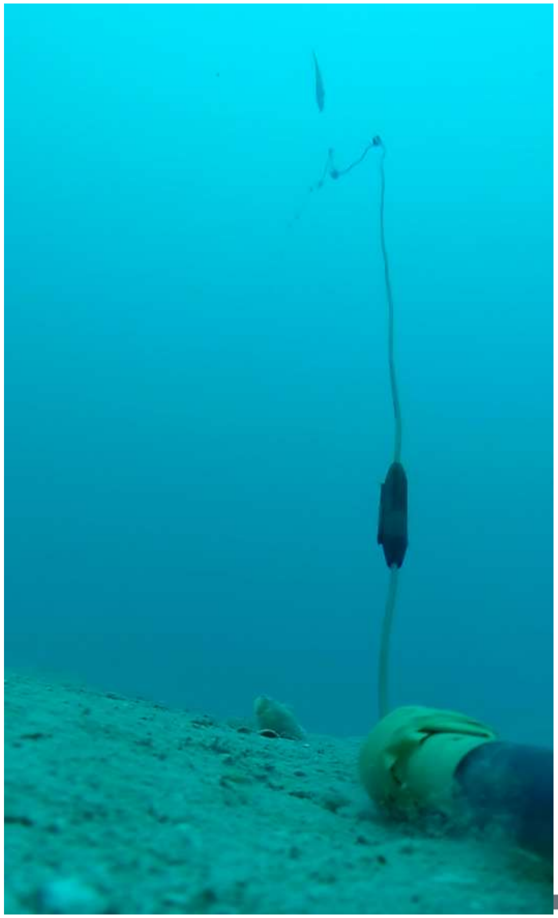
$$f_0 = \frac{t c_b \pi}{2\sqrt{12} L^2}$$

$$c_b = \sqrt{E/\rho_b}$$

E-Young's modulus

ρ_b -beam density

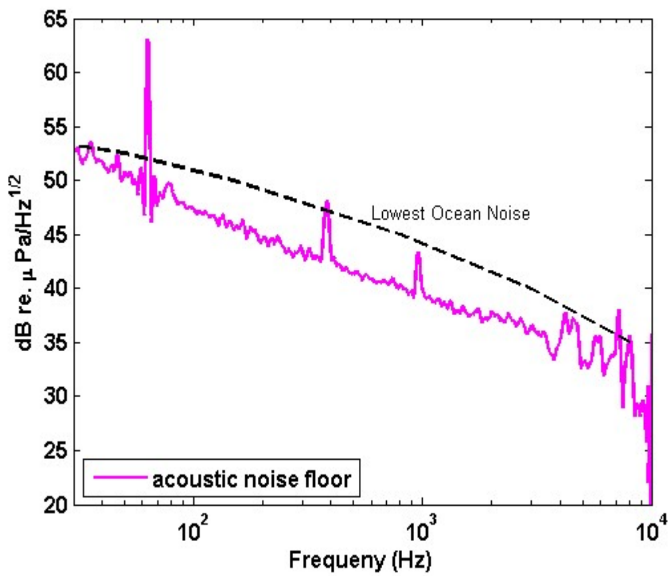
Demonstration of fibre laser hydrophone array in Gulf St Vincent (2013)

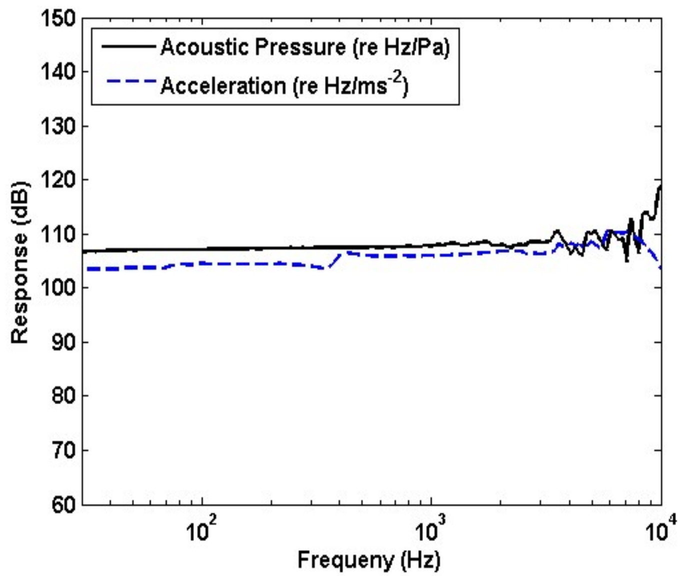


Performance

a. Acoustic sensitivity: 105dB re Hz/Pa
b. Frequency range: 10Hz- 5kHz

FL sensor noise limitations

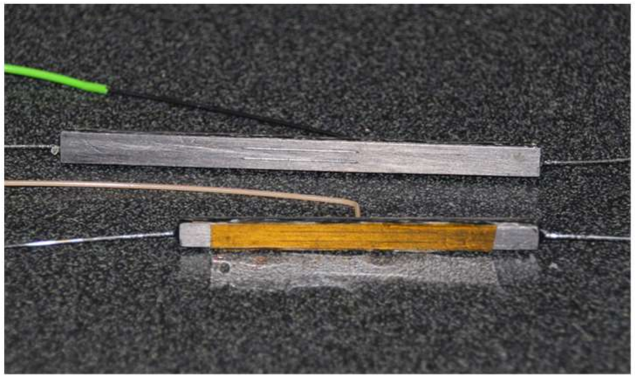




Hydrophone material choice

	Al	Si	Carbon fibre	SiO_2
E	70 GPa	130 GPa	70 GPa	72 GPa
ρ	2.7 g/cm^3	2.33 g/cm^3	1.6 g/cm^3	2.2g/cm^3
C_t	$23*10^{-6}$ 1/K	$2.6*10^{-6}$ 1/K	$2.1*10^{-6}$ 1/K	$6.8*10^{-7}$ 1/K

New Design Carbon fibre FL Hydrophone



Hydrophone Optimisation

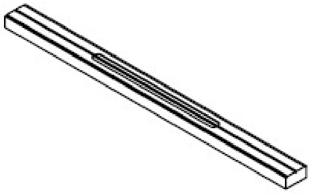
Better expected longevity
Integration into smaller, better protected volume
Higher production yield

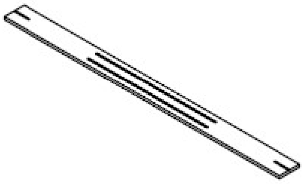
Pressure compensation: →
100m → 500m

Internal volume: →
$15mm^3$ → $3mm^3$

Hydrophone response: →
107dB re Hz/Pa → 120dB re Hz/Pa

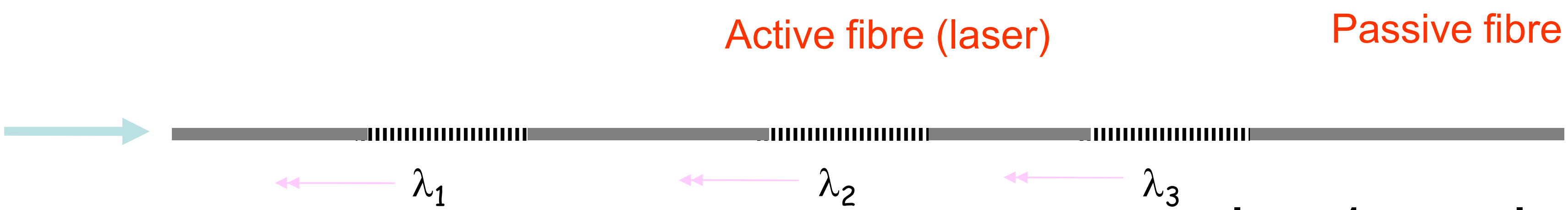
Dimensions: →
75x5x2mm → 55x4x2.5mm

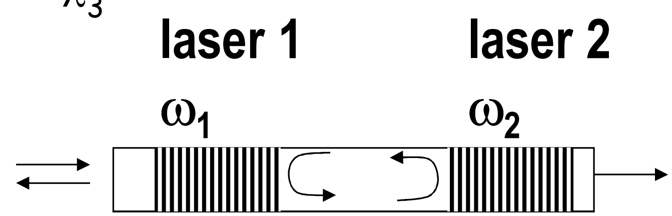




Beam resonance frequency: →
10kHz → 6kHz

Array multiplexing noise



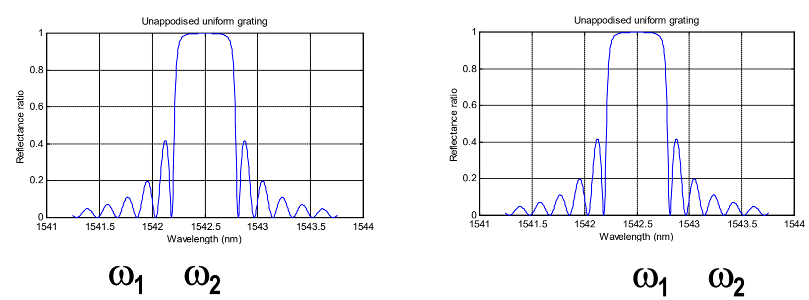


1. Multiplexing noise
1.1 Spectral confinement (sidelobes)
1.2 Laser mode confinement

For weak reflections (R<<1):

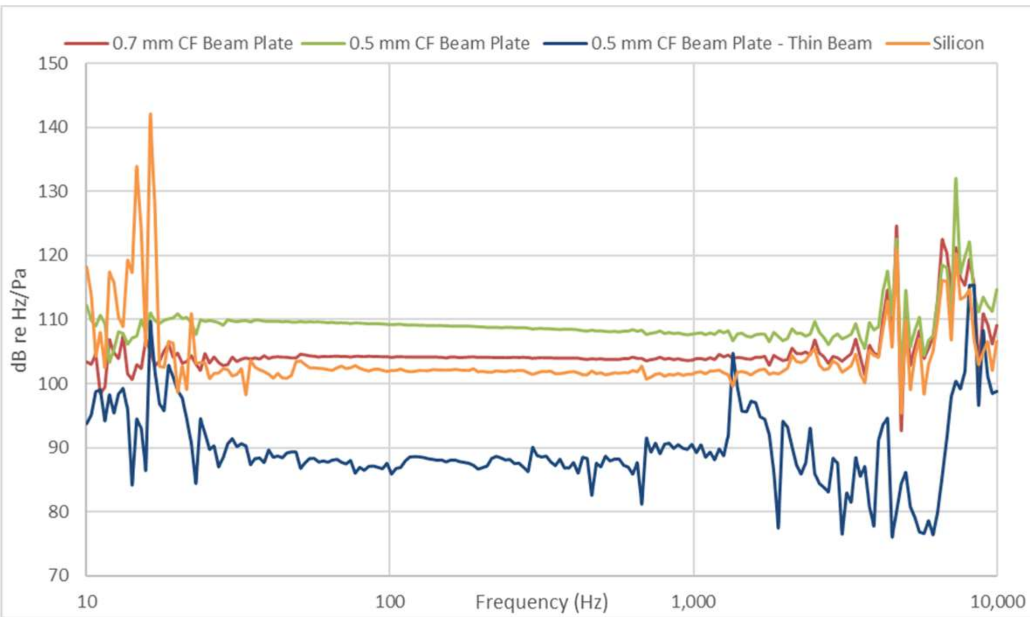
$$\Delta\lambda = 2\lambda_n^2 \kappa |R| \cos(2\pi d / \lambda_n - \phi_R) e^{-\kappa L}$$

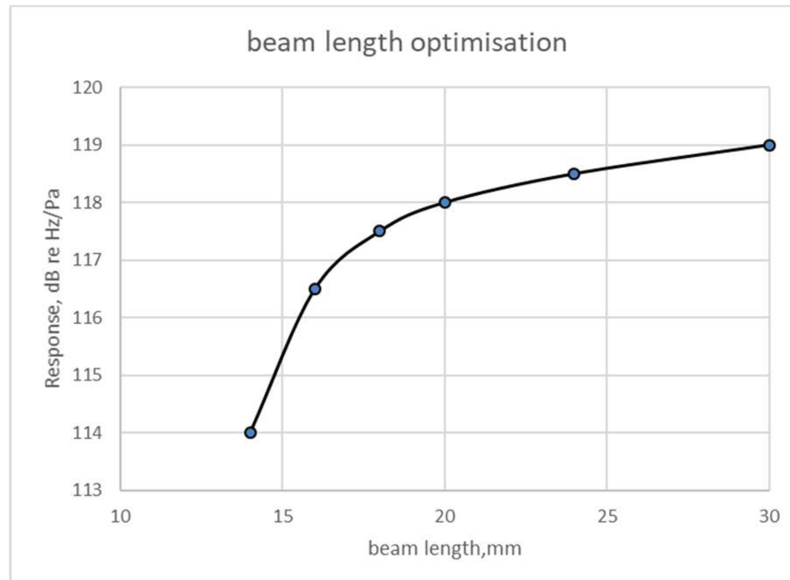
Shift in laser wavelength due to back-reflections from a neighboring sensor



Beam transducer optimization:

Plate Thickness and Beam Length

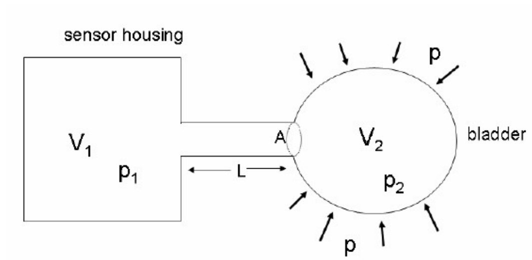


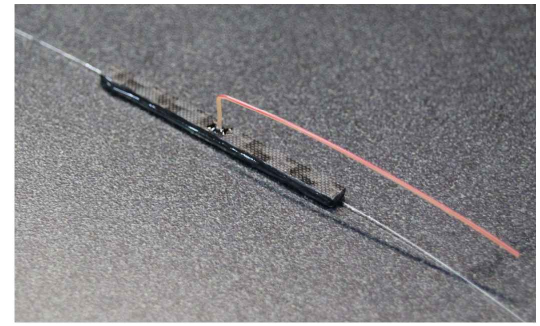


Pressure Compensation & Cut-off Frequency

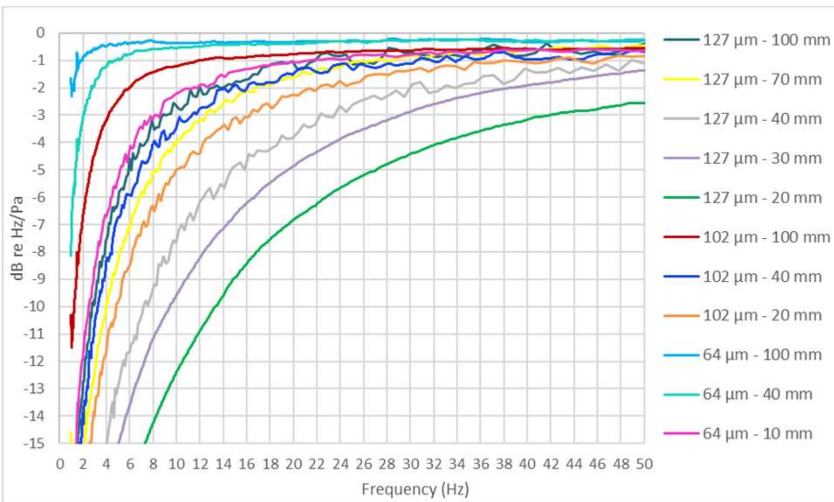
Helmholtz resonator

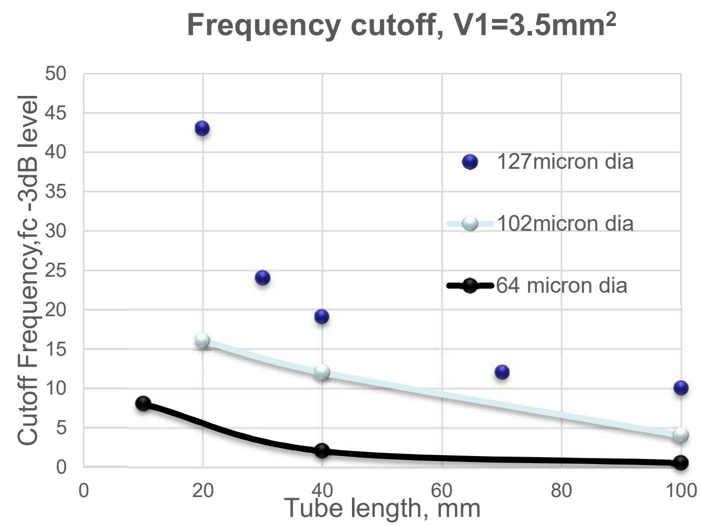
$$f_c \sim (2\pi)^{-1}\sqrt{\frac{s}{m}} \simeq (2\pi)^{-1} c\sqrt{\frac{A}{V_1 L}}$$



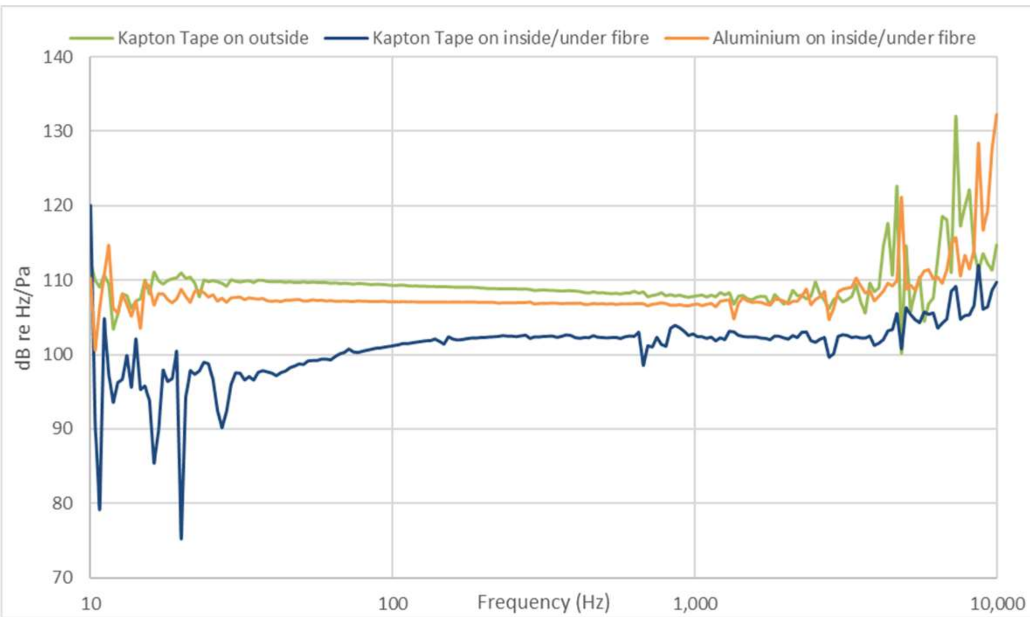


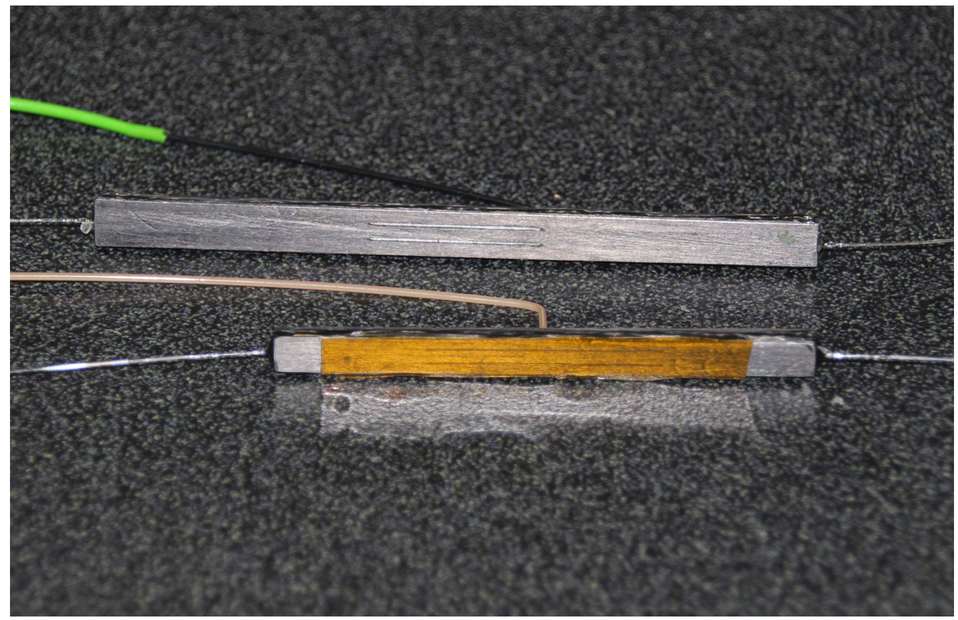
Normalised hydrophone response vs frequency





Internal Volume reduction (replacing the polyimide membrane with Al film)





Conclusions:

- We have designed and demonstrated a Carbon Fibre-based hydrophone optimized for practical acoustic underwater monitoring
- The hydrophone deployment depth has been increased to 500m
- The reduced internal volume (from 13 to 3mm^3) makes it possible to integrate the hydrophone into smaller mechanical enclosure
- The increased hydrophone response (from 107 to 120 db re Hz/Pa) mitigates the array multiplexing noise due to the residual out-of band FL reflections, effectively raising the signal/noise ratio
- The current design and material choice simplifies the sensor fabrication effectively reducing the time of the fabrication cycle and improves the assembly yield
- Fabrication of the updated array using the CF –based hydrophones is currently under way with redesigned mechanical enclosures to protect the sensitive parts from elements
- Further array in-water testing is planned with the desired longevity of the array of 10 years

References

– [1] S. Foster, A. Tikhomirov, and J. van Velzen, "Towards a High Performance Fiber Laser Hydrophone," Journal of Lightwave Technology, vol. 29, no. 9, pp. 1335-1342, 2011/05/01 2011.
– [2] S. Goodman, A. Tikhomirov and S. Foster, "Pressure compensated distributed feedback fibre laser hydrophone", in Proc. SPIE, Perth, Australia, Apr.2008, vol. 7004, Paper 26.
– [3] A. Tikhomirov and S. Foster,"DFB FL Sensor Cross-Coupling Reduction", Journal of Lightwave Technology, vol. 25, no. 2, pp. 533-537, 2 Feb 2007.