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Form Approved
OMB No. 0704-0188

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1. REPORT DATE 2007		2. REPORT TYPE		3. DATES COVERED 00-00-2007 to 00-00-2007	
4. TITLE AND SUBTITLE Fiber Optic Towed Arrays				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Research Laboratory, 4555 Overlook Avenue SW, Washington, DC, 20375				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

Fiber Optic Towed Arrays

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Introduction: Towed arrays were one of the first application areas considered for fiber optic acoustic sensors. The concept of having only the low-cost, passive components (fiber optic elements) in the “wet” end of the system, while the lasers and expensive components were located in the tow vessel, addressed the increasing costs of Navy towed arrays. The earliest demonstration of this technology was made in 1983: the fiber interferometric sensor was formed with fiber couplers (to split the light), with the sensing fiber wrapped on a solid plastic mandrel. For this demonstration, the laser and the demodulation electronics were collocated with the fiber interferometer. In 1984, smaller-diameter sensors and interrogation approaches suitable for remote sensor interrogation were developed. The 48-channel All Optical Towed Array (AOTA) demonstration in December 1990 positioned this technology for production of fatline arrays, but the end of the Cold War resulted in cancellation of the program. There were continuing efforts funded by ONR to develop the technology for small-diameter (thinline) fiber optic towed arrays through the 1990s. In the late 1990s there was renewed interest in producing a fiber optic towed array to address the cost and reliability issues of the TB-29 conventional thinline towed array.

TB-33 Towed Array: The current effort to bring the fiber optic towed array to production (designated the TB-33) is a joint effort involving Naval Undersea Warfare Center (NUWC), Chesapeake Sciences Corporation, General Dynamics, and NRL. NRL has played a critical role in developing the hydrophone design for this array and the interrogation/multiplexing approach used in the system. Unlike the AOTA demonstration and the Navy’s fiber optic LightWeight Wide Aperture Array (currently in production), which are coupler-based systems, the TB-33 array uses low-reflectivity fiber Bragg gratings written in the fiber to define the sensors by forming low-reflectivity Fabry-Perot interferometers. The hydrophones are passively multiplexed both in time and in wavelength to allow hundreds of channels to be carried over just four optical fibers. This architecture is ideally suited to the towed array — it minimizes the number of optical components in the array, which is critical to minimizing the diameter of the hydrophone core, and in turn allows a thicker hose wall to be used, thus increasing the durability and reliability of the array.

Performance: During testing, the fiber optic hydrophones both in calibration and under tow have

shown excellent uniformity in responsivity. Figure 8(a) shows the relative responsivity of an array of 24 channels under static ensonification; in the frequency band of interest, the spread is ~ 0.2 dB. Figure 8(b) shows the raw output of an array of 84 hydrophones under tow; the uniformity is excellent.

Until recently, much of the testing of the fiber optic array concept involved arrays with rather low channel counts; the results were then scaled up to arrays with hundreds of elements. During this type of testing, NRL measurements indicated that the system architecture was susceptible to a number of noise terms that would appear identically on multiple channels (known as coherent noise, which results in an apparent target broadside to the array). One noise term was associated with the thermally induced phase noise of the fiber in the compensating interferometer associated with the interrogation system (referred to as a compensator). This was easily addressed by simply increasing the number of compensators from one to eight, thus lowering the coherent component. Another coherent noise term observed was due to strains in the optical signal path between the compensators and the hydrophones, which resulted in a small phase shift (noise term) in each channel. For a full-scale TB-33 array this would give a noise ~ 60 dB above the coherent noise specification.

NRL proposed three basic approaches to solving this noise problem in the array architecture. The first solution was to move the compensators from the tow platform into the array. This move resulted in an ~ 30 dB decrease in signal path coherent noise. The second solution was to develop a signal path strain cancellation system to reduce the apparent strain in the tow cable; this system and its performance are shown in Fig. 9. This also gave an ~ 30 dB reduction in noise. The final technique to improve the signal-to-noise ratio of the array was to increase the responsivity of the hydrophone by 6 dB. To achieve this, the hydrophone had to be made more compliant, and thus would experience greater deformation due to hydrostatic pressure. Several approaches to this new hydrophone were proposed by the design team. The NRL design, incorporating an internal stop to suppress buckling of the hydrophone mandrel up to the survival pressure, was the only design to survive. The results of the pressure tests of several of the designs are shown in Fig. 10. Although 6 dB is a relatively modest improvement, this design reduced not only the coherent noise, but also the incoherent noise contribution. Chesapeake Sciences Corporation has taken this basic design and productionized it for the TB-33 system. The combination of these three approaches lowered the coherent noise term by ~ 70 dB, thus allowing the fiber optic system to meet the coherent noise requirement.

Acknowledgments: This work was sponsored in part by NAVSEA's (PMS-401) TB-33 program. [Sponsored by NAVSEA]

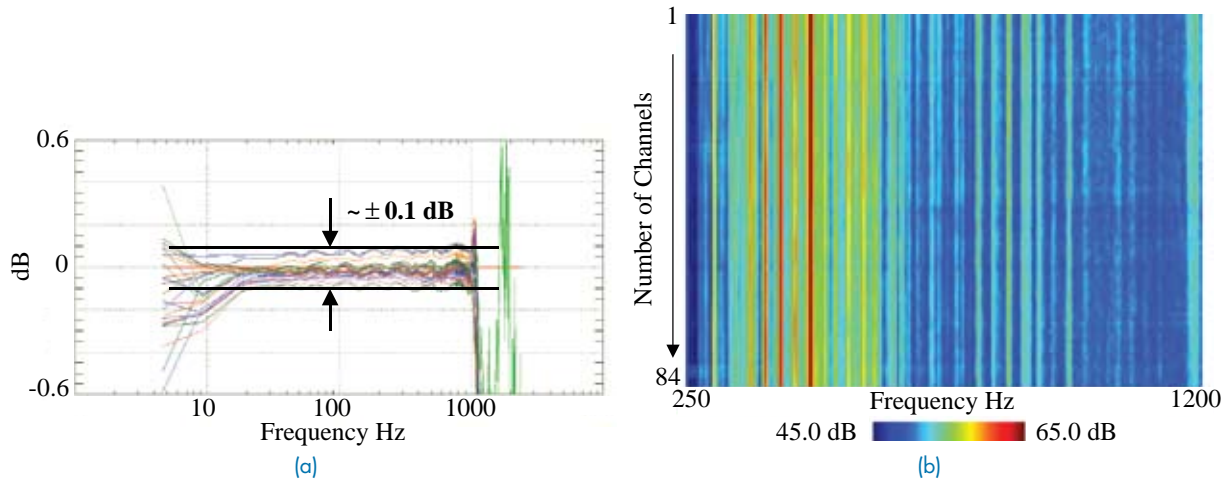


FIGURE 8 Examples of fiber optic hydrophone response uniformity from the Fiber Optic TB-16 (FOTB-16) program (Northrop Grumman, NUWC, NRL). The calibration uniformity of 24 channels is shown in (a) while the spectra for 84 channels under tow are shown in (b).

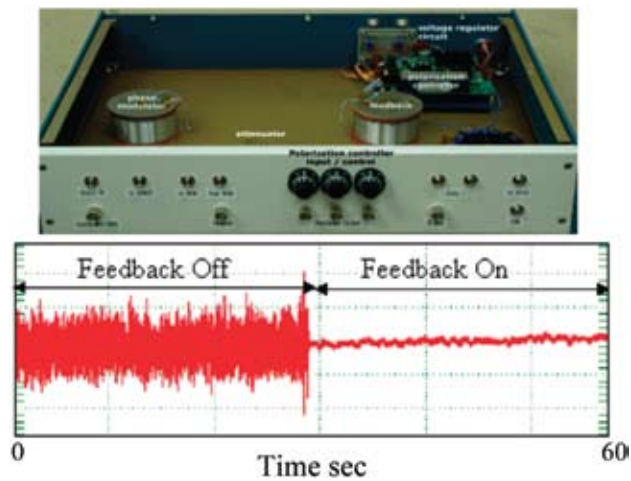


FIGURE 9 Signal path strain cancellation hardware and noise reduction results.



**High Responsivity Fiber
Hydrophones for TB-33**

Initial Baseline, 0dB, **Failed**

NRL Concept, +6 dB, **Fully Successful**

Industry Concept, +5 dB, **Failed**

Industry Concept, +6 dB, **Failed**

Industry Concept, +5 dB, **Failed**

Industry Concept, + 5 dB, **Failed**

FIGURE 10
Fiber optic hydrophone crush results for six design concepts.