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Acoustic Noise Measurements Utilizing High Performance Fiber Optic Hydrophones in the Arctic

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Optical Technique Branch
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13. ABSTRACT *(Maximum 200 words)*

In April 1990 two fiber optic hydrophones were used to measure the ambient acoustic noise under shore-fast ice at the mouth of Independence Fjord in the vicinity of Kap Eiler Rasmussen, Greenland. The hydrophones were fiber Mach Zehnder interferometers operating at 1.3 μm, one device was powered with a semiconductor diode laser source, the other with a diode pumped Nd:YAG laser source. The electro-optic system (lasers, detectors, and electronics) was located in a shelter on the ice, the hydrophones were interrogated over 2 km of fiber optic cable. Measurements of the ambient noise were made over a 9 day period and contained data ranging from substantially below sea state zero to high noise levels due to the presence of machinery.

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ACOUSTIC NOISE MEASUREMENTS UTILIZING HIGH PERFORMANCE FIBER OPTIC HYDROPHONES IN THE ARCTIC

Introduction

Since the successful demonstrations of fiber optic sensors in the Navy's All Optical Towed Array (AOTA) program[1], there has been interest in using fiber optic sensor technology for a number of other acoustic applications. One particular area of interest is in high performance, low noise fiber hydrophones with threshold detections of around 10 dB re $\mu Pa/\sqrt{Hz}$. In 1989 we demonstrated a prototype high performance fiber optic sensor using a semiconductor diode laser source operating at 0.83 μm, with an optical scale factor of -128 dB re rad/μPa. This sensor was operated with a simple, free running homodyne demodulation system to achieve a threshold detection of 7 dB re $\mu Pa/\sqrt{Hz}$ at 1 kHz in the laboratory environment[2].

In this paper we report the results of ambient noise measurements made with two fiber optic hydrophone systems under shore-fast ice in the vicinity of Kap Eiler Rasmussen in April 1990. One of the systems used a semiconductor diode laser source, this used a path balanced sensor, similar to the device described above. The other system used a long coherence length Nd:YAG source which allowed the use of a reference fiber substantially shorter than the sensing fiber. The hydrophone systems used in these measurements operated at 1.3 μm, employed passive demodulation and was packaged to survive in the arctic environment.

Experimental System

The experimental fiber optic sensor system consisted of three parts: the fiber optic hydrophone, the cable and the electro-optic system.

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Fiber Hydrophone

The high performance fiber optic hydrophones used in this work were configured as Mach-Zehnder interferometers. A schematic diagram of a Mach-Zehnder fiber optic interferometric sensor is shown in Figure 1. A laser launches coherent light into an optical fiber, the light is then split by a 50/50 coupler into two arms of an interferometer. One arm contains the sensing coil and the other arm contains the reference coil. The light is then recombined at a second coupler and the output is detected and demodulated. The parameter measured by the interferometer is the change in length of the sensing arm relative to the (constant) length of the reference arm due to a signal applied to the sensing arm. One way to increase the sensitivity of these devices is to increase the length of fiber in the sensing arm of the interferometer since the sensitivity is directly proportional to the active length of fiber.

A diagram of the sensor construction is shown in Figure 2. The hydrophone design consists of concentrically arranged cylinders. The inner cylinder is aluminum and is wrapped with the reference fiber. The sensing portion of the hydrophone consists of a compliant mandrel. The the sensing coil was wound on this mandrel, which was then mounted outside the inner aluminum cylinder. The arms of the interferometer were then balanced to the desired optical path difference. The couplers and splices were then placed into the center of the sensor and the interior was potted with a hard curable epoxy. The reference fiber (wrapped on the aluminum cylinder) was also potted in the hard curable epoxy. The finished dimensions of the hydrophone were ~20 cm long by 2.5 cm diameter. A protective cage was placed on the outside of the hydrophone, bringing the diameter to 3.2 cm.

The primary hydrophone was designed for operation with a long coherence length Nd:YAG source[3]. The sensor had a fiber path difference of 80 m. This hydrophone is referred to as H1. Its responsivity was measured to be -131 dB re rad/μPa in the frequency range 3 to 2000 Hz between 0-20^{o}C and 0-200 psi[4]. The hydrophone was designed to operate at pressures up to ~1000 psi.

The second hydrophone tested, H2, was designed to operate with a semiconductor diode laser source[2]. It was constructed with a 4 cm fiber path difference. This sensor had a sensitivity of -137 dB re rad/μPa[4] due to a shorter length of sensing fiber. The path differences of the two sensors were chosen to facilitate the frequency modulation phase generated carrier (FM-PGC) demodulation approach used to interrogate these sensors[5]. The construction of this sensor was similar to H1. Each hydrophone was mounted in a cage which was then placed inside a butyl rubber boot filled with castor oil[6].

Representative data of the acoustic response of the two hydrophones used in the Arctic (a total of six fiber optic hydrophones were built and taken to the Arctic, i. e. there were four back-up hydrophones none of which were required) is shown in Figures 3 and 4. Figure 3 shows the acoustic sensitivity as a function of frequency at 50 and 200 psi for H1 at a temperature of 6^{o}C. Figure 4 shows the acoustic sensitivity as a function of frequency at 6^{o}C and 22^{o}C for H2 at a pressure of 200 psi. In these figures, the measured values of $\Delta V/\Delta P$ from the Crane calibration have been converted to $\Delta\phi/\Delta P$ by removal of the demodulator constant. The high frequency response of this design of hydrophone was also measured (at USRD, Orlando), this measurement of a prototype Arctic sensor is shown in Figure 5.

Cable

The cable was a commercially available product containing six dispersion shifted optical fibers. The fibers were coated with a 1.0 mm gel-filled nylon tube. The cable was lightweight, contained Kevlar reinforcement and remained flexible to temperatures ~ -40°C. The total cable length was 2 km, 1 km being deployed to the hole in the ice, the remaining km was left on the reel. A schematic of the arrangement is shown in Figure 6. Each hydrophone was attached to three fibers in the cable (i. e. using three of the four available input/output fibers of each interferometer). The hydrophones were separated vertically by two meters and were lowered through a four inch hole in the 7 m thick ice to a depth of 100 m. The location of the hydrophones was chosen to minimize as much as possible the amount of camp noise present. The camp itself was located on a frozen lead; the hydrophones were deployed on the far side of the pressure ridge surrounding the camp through multi-year ice. A schematic map of the camp and the position of the hydrophones is shown in Figure 7.

Figure 8a shows two of the authors holding the hydrophone assembly immediately prior to deployment. Figure 8b shows a close up of the head of the 4 inch PVC pipe which lined the hole down through which the hydrophones were deployed. Figure 8c shows the hole and the reel containing the 2 km of cable and Figure 8d shows the arrangement used to deploy the cable. Figure 8e shows the remaining 1 km of cable on the reel beside the tent containing the electro-optic system after the deployment of the cable.

Electro-optic system

A schematic diagram of the electro-optic system incorporating the long coherence length diode pumped Nd:YAG non-planar ring laser is shown in Figure 9. This source had an output power level of 3 mW of which 2 mW was launched via a lens system and an optical isolator into an optical fiber. Balanced photodetectors were used at both the sensor and reference interferometer outputs to provide rejection of intensity noise[7]. As indicated earlier the remote interrogation approach used to demodulate the sensors required a large phase carrier (2.6 rad amplitude) to be generated by frequency modulating the laser(s), the frequency of the carrier was 20 kHz. The frequency modulation of the Nd:YAG laser was obtained by applying a voltage to the pzt element on which the Nd:YAG crystal was mounted. For the semiconductor diode laser, direct current modulation was used. The demodulators were the standard NRL differentiate cross multiply demodulator[5].

The sensor interrogation/demodulation approach which was used was the standard NRL differentiate cross-multiply approach employing a phase generated carrier. The basic approach in this passive homodyne technique is to generate two signals that are shifted in optical phase by 90°. This is accomplished by modulating the interferometer's phase by a high frequency sinusoidal modulation (in this case 20 kHz). The output of the interferometer has the following form

$$i = \varepsilon I_0 \alpha \cos\Delta\phi = \varepsilon I_0 \alpha \cos (\phi_d + \phi_s \sin\omega t + \phi_c \cos\omega_c t) \qquad (1)$$

where ε is the responsivity of the detector, I_o the optical intensity, α the interferometric mixing efficiency, $\Delta\phi$ the phase of the interferometer comprising , ϕ_c (the carrier), ϕ_s (the acoustic signal), ϕ_d (low frequency phase excursions), ω_c and ω being the carrier and signal frequencies respectively. This equation can be expanded in terms of Bessel functions. It is clear from these expansions that when $\phi_d=0$, only even multiples of ω_c are present in the output signal, whereas for $\phi_d= \pi/2$, only odd multiples of ω_c are present. Furthermore, it is seen that $\phi_s \sin \omega t$ appears as sidebands to the ω_c carrier terms. When $\phi_d = 0$, even (odd) multiples of ω are present in the output centered about the even (odd) multiples of ω_c. When $\phi_d = \pi/2$, even (odd) multiples of ω are present about the odd (even) multiples of ω_c.

The sidebands contain the signal of interest and are either present about the even or the odd multiples of ω_c. The signal is obtained by mixing the total output signal with the proper multiple of ω_c and low pass filtering to remove terms above the highest frequency of interest. The amplitude of the carrier components for 0, ω_c, and $2\omega_c$ after mixing and filtering are shown below

$$
\begin{array}{lll}
0 & \varepsilon I_0 \alpha \; J_0(\phi_c) \; \cos(\phi_d + \phi_s \sin\omega t) & \\
\omega_c & \varepsilon I_0 \alpha \; J_1(\phi_c) \, D \sin(\phi_d + \phi_s \sin\omega t) & (2) \\
2\,\omega_c & \varepsilon I_0 \alpha \; J_2(\phi_c) \, E \cos(\phi_d + \phi_s \sin\omega t) &
\end{array}
$$

where D and E and the amplitude for the mixing signals ω_c, and 2 ω_c. Obviously by adjusting the amplitude of tho phase carrier ϕ_c, any pair of quadrature components (i.e. 0 and ω_c, ω_c and $2\omega_c$) can be made equal (assuming D=E). This output is of the form required for passive homodyne demodulation.

In the demodulator used here the fundamental and first harmonic of the carrier are used to generate the quadrature components. This was achieved electronically by mixing (with multipliers) the output from the interferometer with ω_c and $2\omega_c$, and then filtering the output with a simple two pole filter. The amplitude varies as a function of sine (or cosine) ϕ_d. As can be seen from equation (2) these outputs are dependent on the intensity and the mixing efficiency in the interferometer, to remove this dependence the initial output of the interferometer is passed through an automatic gain control stage (AGC) such that the voltage outputs are now of the form

$$V_1 = X_1 \sin(\phi_d + \phi_s \sin\omega t) = X_1 \sin\Phi \qquad (3)$$

$$V_2 = X_2 \cos(\phi_d + \phi_s \sin\omega t) = X_2 \cos\Phi.$$

The two signals are then differentiated and cross multiplied such that

$$\Delta V = V_1 (dV_2/dt) - V_2 (dV_1/dt) = X_1 X_2 \, d(\Phi)/dt \qquad (4)$$

which within the dynamic range of the demodulators allows $d\Phi/dt$ to be measured independent of the value and variation of Φ. It should be noted that X_1 and X_2 are approximately equal. This output is then processed by a band limited integrator to provide an output proportional to ϕ_s (in the frequency band of interest). The functional blocks of the demodulator and the output transfer function for acoustic signals are shown schematically in Figure 10. It should be noted that at this final output stage the very low frequency (<10 Hz) phase information has been lost.

The demodulator constant was approximately flat in the 50 Hz to 2 kHz band. As a check of the correct operation of the hydrophone system the amplitude of the phase generated carrier was regularly monitored during acoustic data collection. To further check the electro-optic system a small, in band, frequency modulation was applied periodically to the laser(s) to provide a calibration tone of known phase shift. This tone also served to provide a reference tone for the demodulated data which was recorded with an analog tape recorder, this data was analyzed at NRL after the test (see results and discussion).

Because of the path imbalance in sensor H1 (60 m), the phase noise due to frequency fluctuations of the laser dominated the self noise of the hydrophone[8]. At 1 kHz the minimum detectable phase shift ϕ_{min} was -100 dB re rad/√Hz, resulting in a threshold detection of 31 dB re μPa. To improve the performance of this system standard noise reduction techniques were used to suppress the laser induced phase noise. The threshold detection improved to ~14 dB re μPa/√Hz at 1 kHz using these techniques. The optical noise floor of the Nd:YAG system is shown in Figure 11 with and without the laser noise suppression.

The experimental setup for the semiconductor diode laser source was similar to that for the Nd:YAG source. The semiconductor laser had a noise level of -94 dB re rad/√Hz at 1 kHz. This combined with the lower sensitivity of H2 made the threshold detection level for this sensor 43 dB re μPa/√Hz. With the laser noise reduction in operation, the optical noise floor was lowered by approximately 13 dB, which resulted in a noise floor of ~30 dB re μPa at 1 kHz. The optical noise floor of the semiconductor diode laser system is shown in Figure 12 with and without the laser noise suppression.

Results and Discussion

The ice camp where these measurements were taken was a support base for other more remote camps. At times there was a fair amount of machinery noise present due to aircraft, snowmobiles and runway clearing equipment. A plot of a typical ambient noise level taken while a piece of snow removal equipment was in operation is shown in Figure 13. As the acoustic noise level was approximately 60 dB greater than the self noise of the less sensitive hydrophone (H2), this signal served as a check of the operation of the two independent hydrophone systems. The two hydrophones agreed to within ±1 dB, sea state zero is also shown in Figure 13 for reference. At the time some of our data was being recorded another experiment was using a 3 kHz pinger in the water, this was located approximately 1.0 km from the hydrophones. A typical output (H1) is shown in Figures 14a and 14b, the output of both hydrophones is shown in Figure 14c, in each case the output level is arbitrary.

Most of the acoustic data recorded was of the level shown in Figure 15. This data was taken with the Nd:YAG laser system using laser noise reduction. At these acoustic noise levels the semiconductor laser system showed some excess noise at 2 kHz, due to the optical system noise. Again sea state zero is shown for comparison. By listening to recordings of the data shown in Figure 15, it was clear that much of the noise was due to sudden ice cracking. By adjusting the analyzer threshold level, these large transients could be ignored to get the data shown in Figure 16.

Figure 17 shows the quietest acoustic level recorded at the ice camp with the fiber optic hydrophones. This data was taken from H1 using laser noise reduction. This data was acquired at 1 a.m. when there was little activity in the camp and the air was calm. Once again sea state zero is shown for reference. Between ~200 Hz and 1 kHz the acoustic noise level was 26 dB below sea state zero. Below 200 Hz the acoustic noise level increases with a well defined peak at 110 Hz. This peak is substantially broadened owing to the 3.75 Hz data collection bandwidth (used for all data collection unless otherwise stated). Figure 18 shows the electro-optic system noise floor recorded during the same data run (and bandwidth) as the acoustic data of Figure 17. The lower curve is the electronic noise floor of the demodulator; the middle curve is the output of an acoustically insensitive reference interferometer with similar optical properties to H1, and the upper curve is sea state zero. Above 350 Hz the noise floor is dominated by the electronics of the demodulator. At 350 Hz and 1 kHz the self noise of the hydrophone system corresponded to 37 dB and 32 dB below sea state zero respectively. Below 350 Hz there are a number of tonals which are probably due to acousto-mechanical pickup of the reference interferometer used to make this measurement. Clearly better isolation of this portion of the electro-optic system is required. Ideally with the suppression of the laser induced phase noise and the elimination of this acousto-mechanical pick-up, the performance of the system should be limited solely by the demodulator noise floor.

The data of Figures 17 and 18 were analyzed with a Hewlett-Packard 3562A spectrum analyzer, the spectral content of the data being recorded on disk. After this quiet data was analyzed real time data was recorded the next day, which, although not as quiet, allowed more detailed spectral analysis back at NRL. An example of this data is shown in Figure 19. Here a 1 Hz bandwidth was used, and the low frequency tonals are more clearly resolved, again sea state zero is also shown. With this data an acoustic level of 20 dB below sea state zero were recorded at 160 Hz. During the latter part of our stay at the ice camp, the weather turned windy and ambient acoustic noise never returned to those of shown in Figures 17 and 19.

Conclusions

The viability of using fiber optic hydrophones in the Arctic environment has been demonstrated. The lowest noise fiber hydrophone system employed a diode pumped Nd:YAG laser source and in the 200 Hz to 2000 Hz band measured acoustic levels ~26 dB below sea state zero with a self noise floor of better than 30 dB below sea state zero. At lower frequencies the self noise of the system was contaminated by acousto-mechanical pickup from the electro-optic system.

Acknowledgement

The authors would like to acknowledge the support of the Space and Naval Warfare Systems Command, Code PMW 181-4 which sponsored this work.

References

[1] R. Elswick, M. J. Berliner, K. P Rainey, A. Dandridge, A. B. Tveten, A. M. Yurek, J. S. Diggs, W. Williams and S. Berlin, "All-Optical Towed Array (AOTA) December 1988 Sea Trial Report (U)", Confidential NUSC TM893003, April, 1989.

[2] A. B. Tveten, A. M. Yurek and A. Dandridge, "High Performance Fiber Optic Hydrophone (U)", accepted for publication in J. Underwater Acoustics (April 1990).

[3] A. M. Yurek, A. B. Tveten, J. E. Colliander and A. Dandridge, "Acoustic Calibration of Fiber Optic Hydrophones for Planar Array and Sonobuoy Applications (U)", Confidential NRL Memorandum Report, in process.

[4] NWSC, Crane,IN., Test Report #7053-2894, March 1990.

[5] A. Dandridge, A. B. Tveten, and T. G. Giallorenzi, "Homodyne Demodulation Scheme for Fiber Optic Sensors using Phase Generated Carrier," IEEE J. Quantum Electron., **QE-18**, 1647 (1982).

[6] The booting of the hydrophones (six in total were built) was done at NWSC, Crane, ID.

[7] A. Dandridge and A. B. Tveten, "Noise Reduction in Fiber Optic Interferometer Systems," Appl. Optics, **20**, 2337 (1981).

[8] K. J. Williams, A. Dandridge, A. D. Kersey, J. F. Weller, A. M. Yurek, and A. B. Tveten, "Interferometric measurement of low frequency phase noise characteristics of diode pumped Nd:YAG ring laser," Electron. Lett. **25**, 774 (1989).

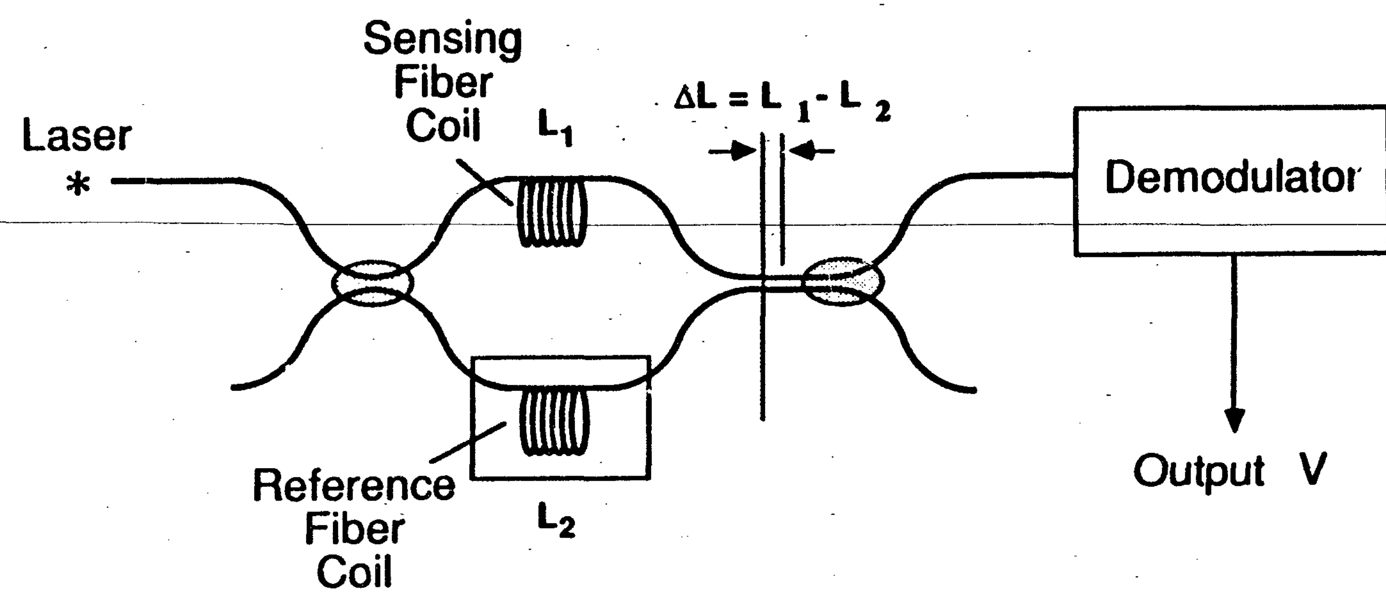


Fig. 1 — Schematic diagram of a Mach-Zehnder fiber optic interferometric sensor

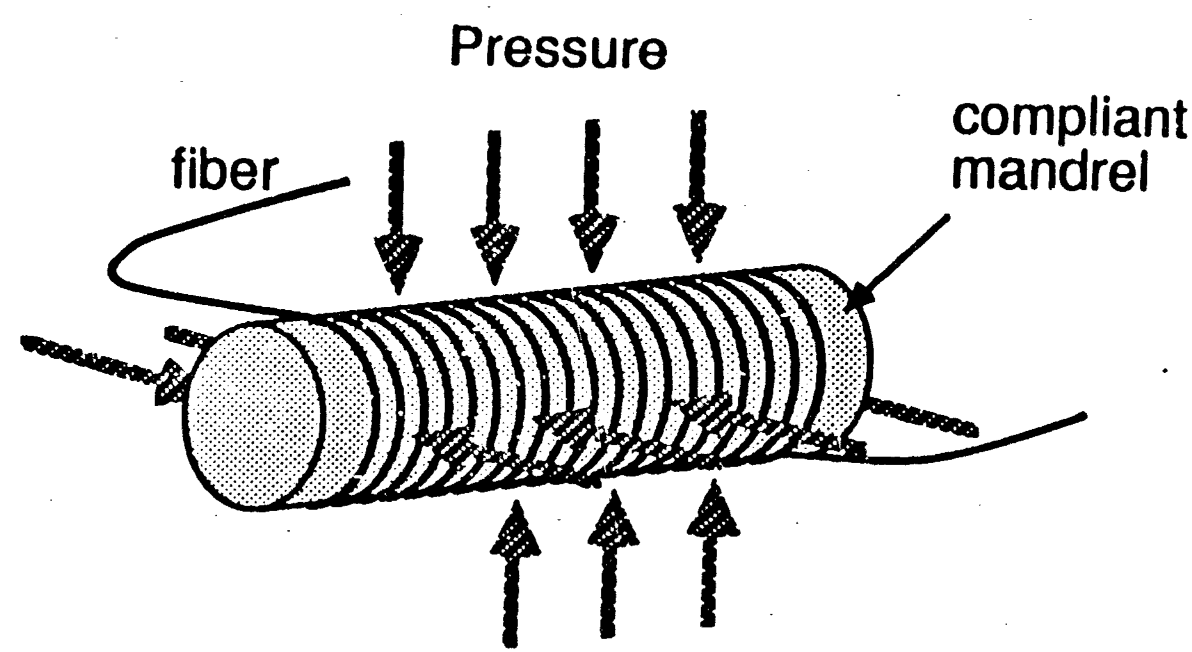


Fig. 2 — Compliant mandrel sensor approach

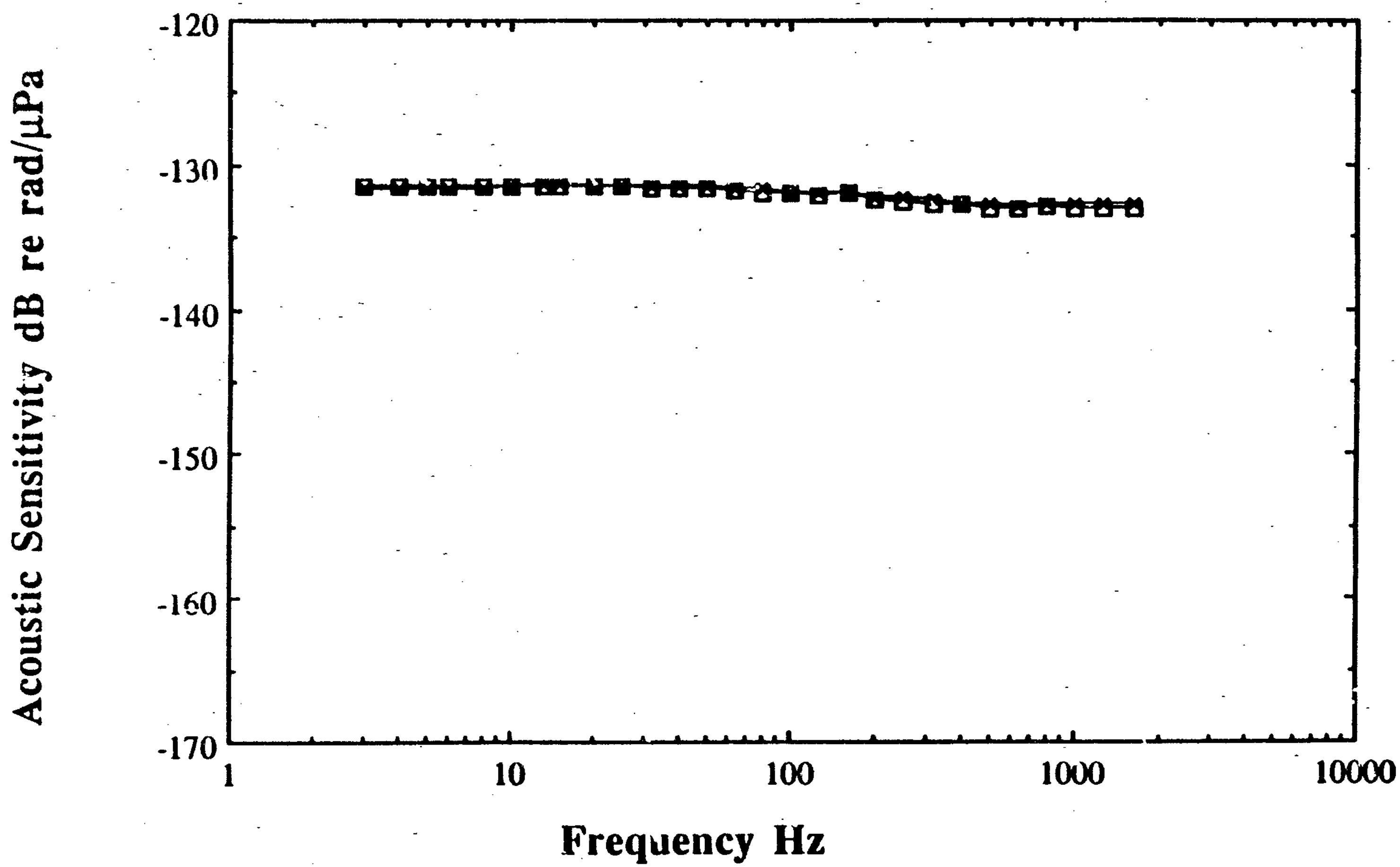


Fig. 3 — Acoustic sensitivity as a function of frequency at 50 and 200 psi for fiber hydrophone H1 at 6°C

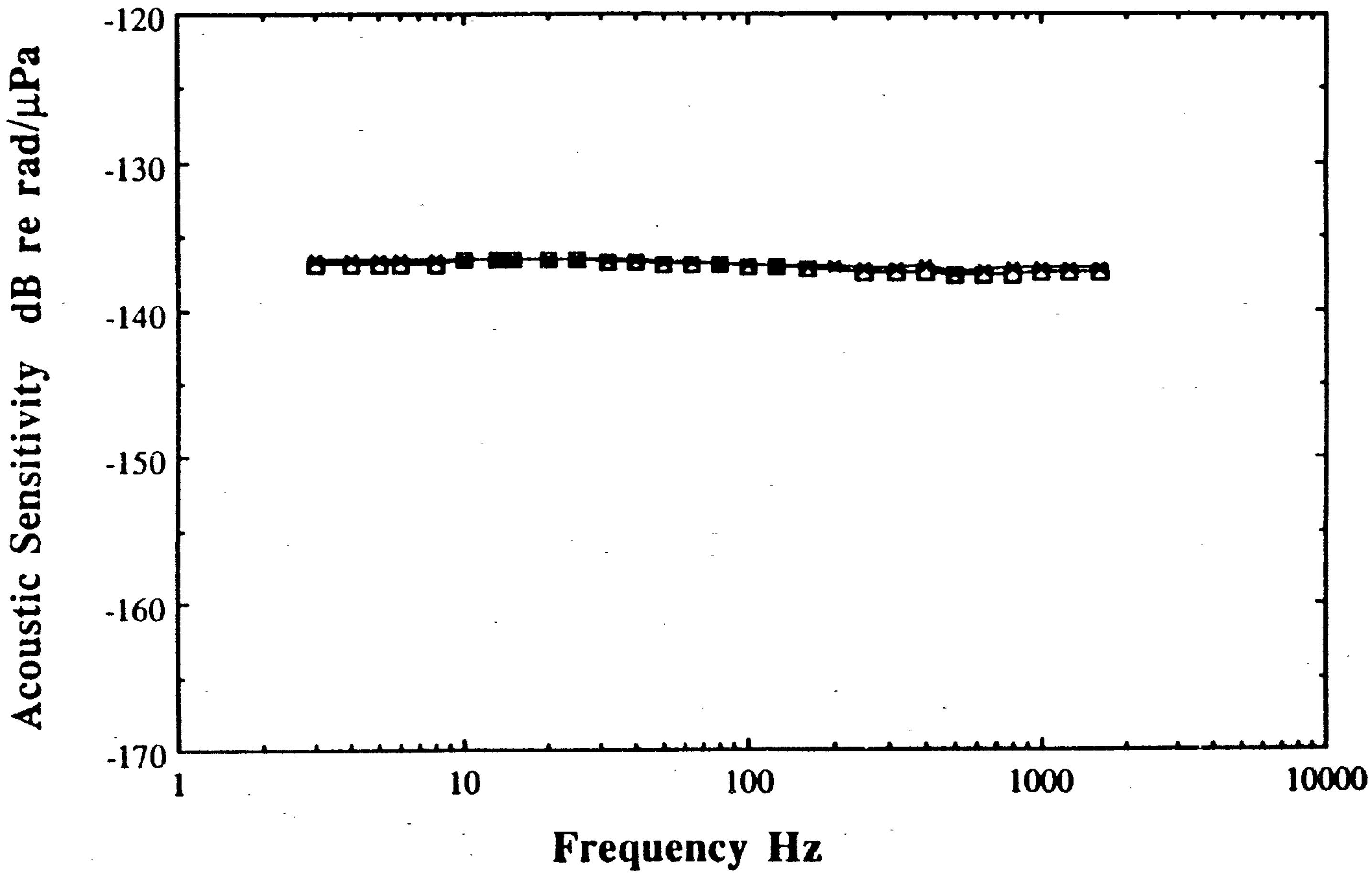


Fig. 4 — Acoustic sensitivity as a function of frequency at 6°C and 22°C for fiber hydrophone H2 at 200 psi

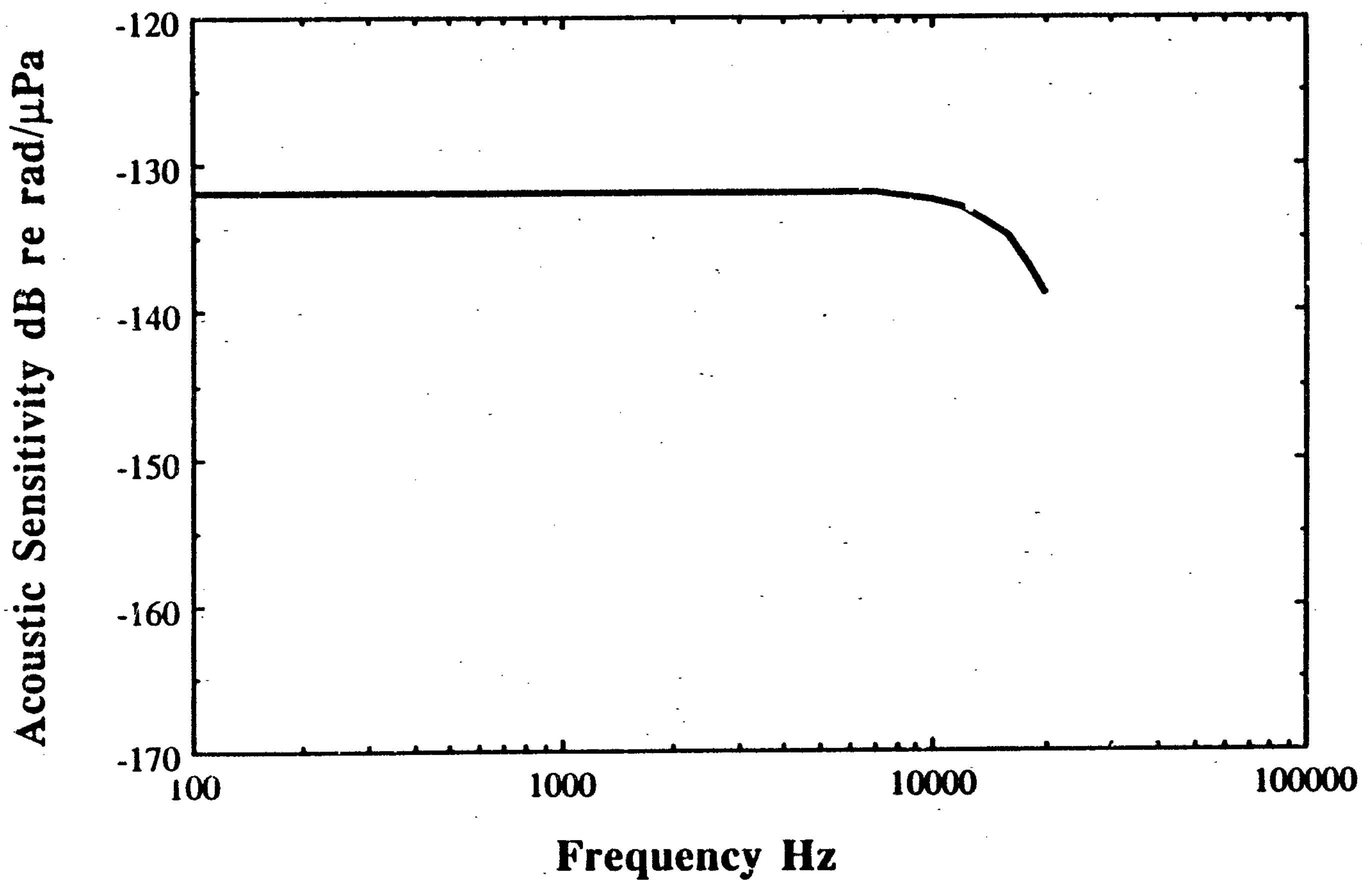


Fig. 5 — High frequency response of Arctic hydrophone design

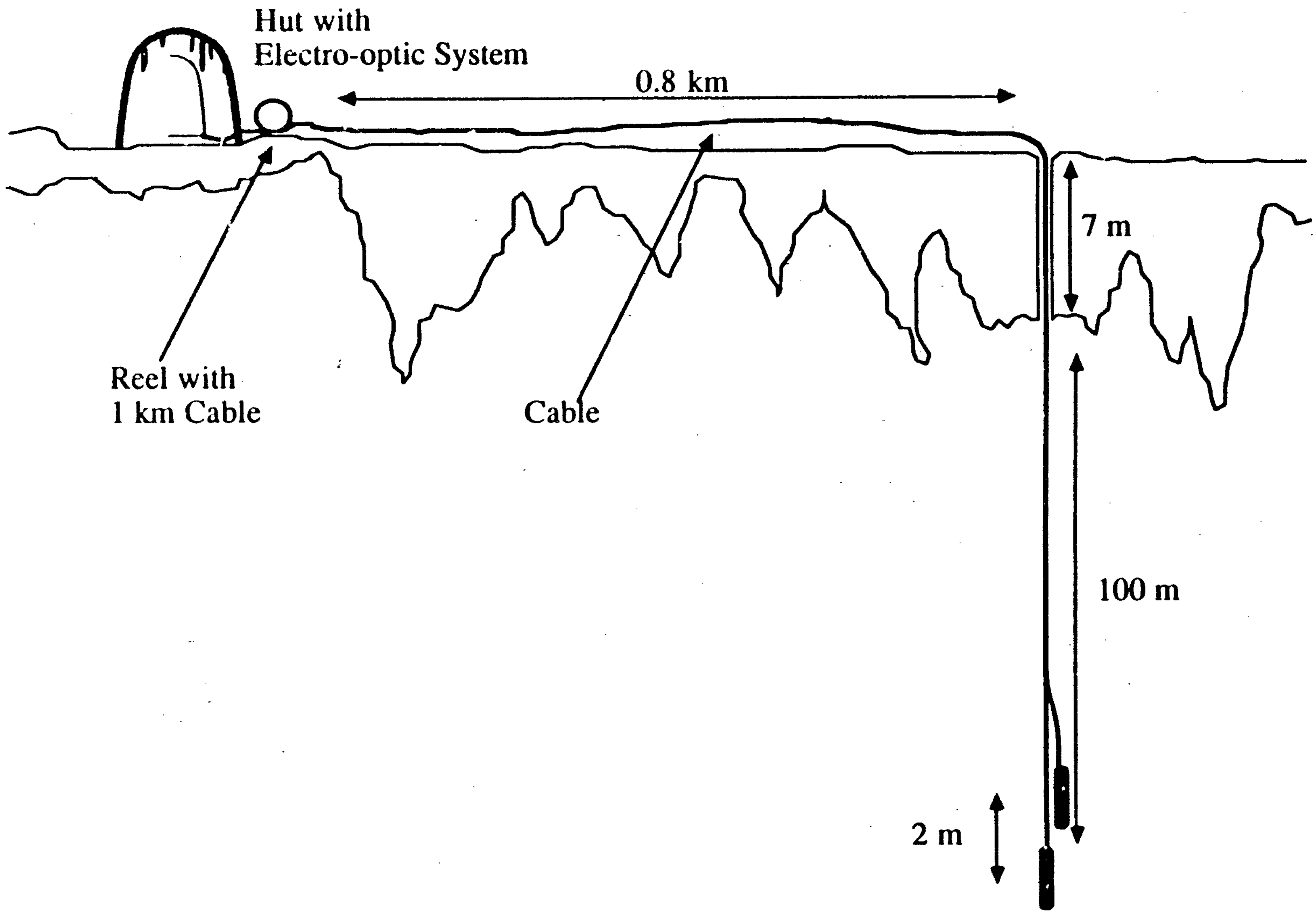


Fig. 6 — Schematic diagram of hydrophone deployment

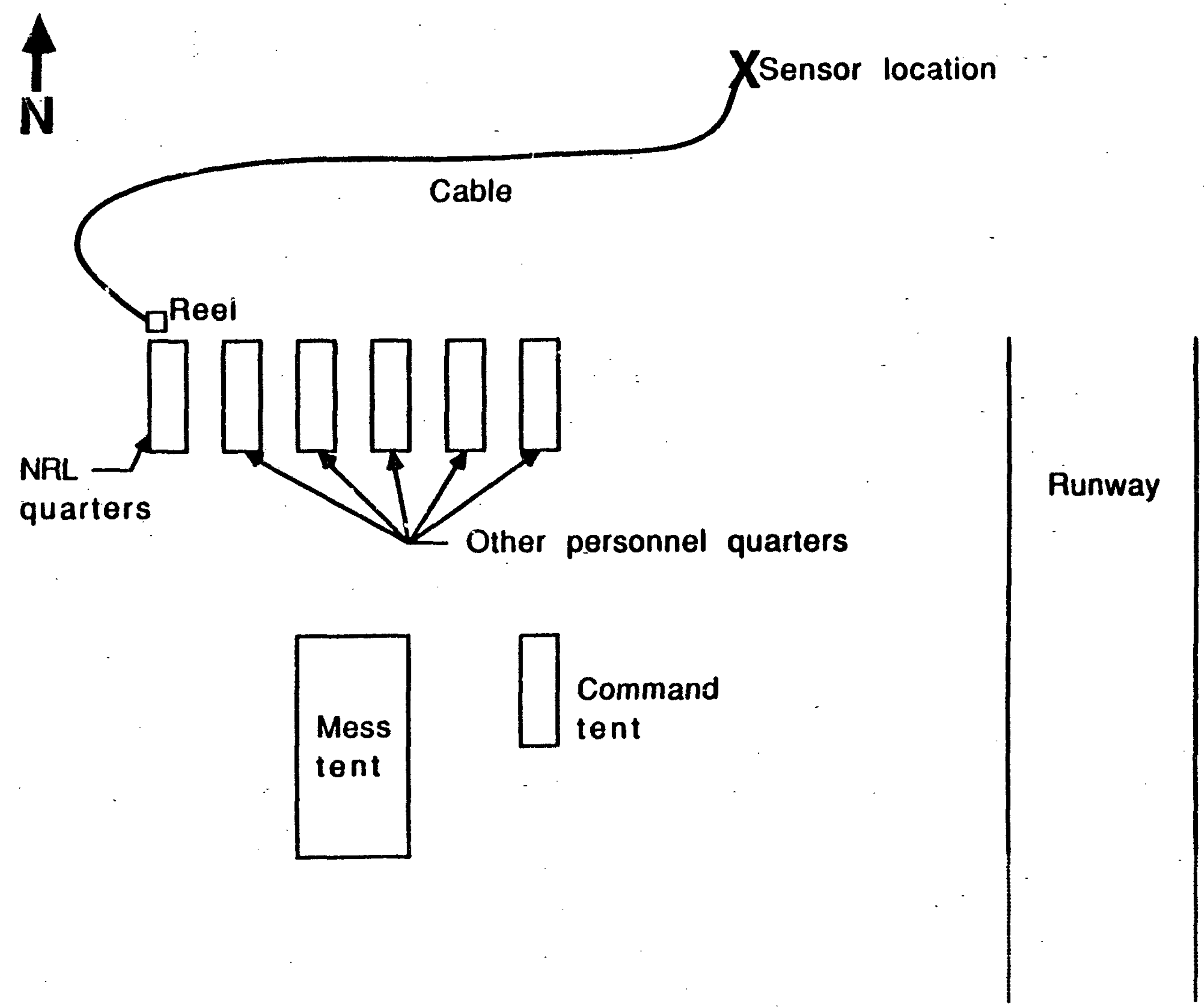
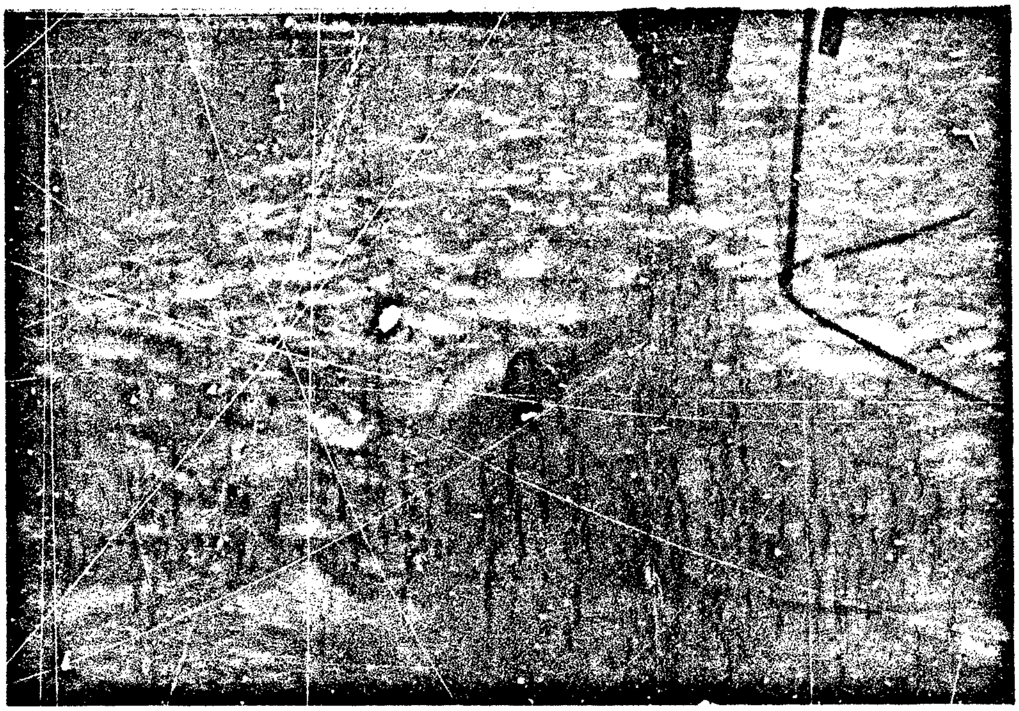


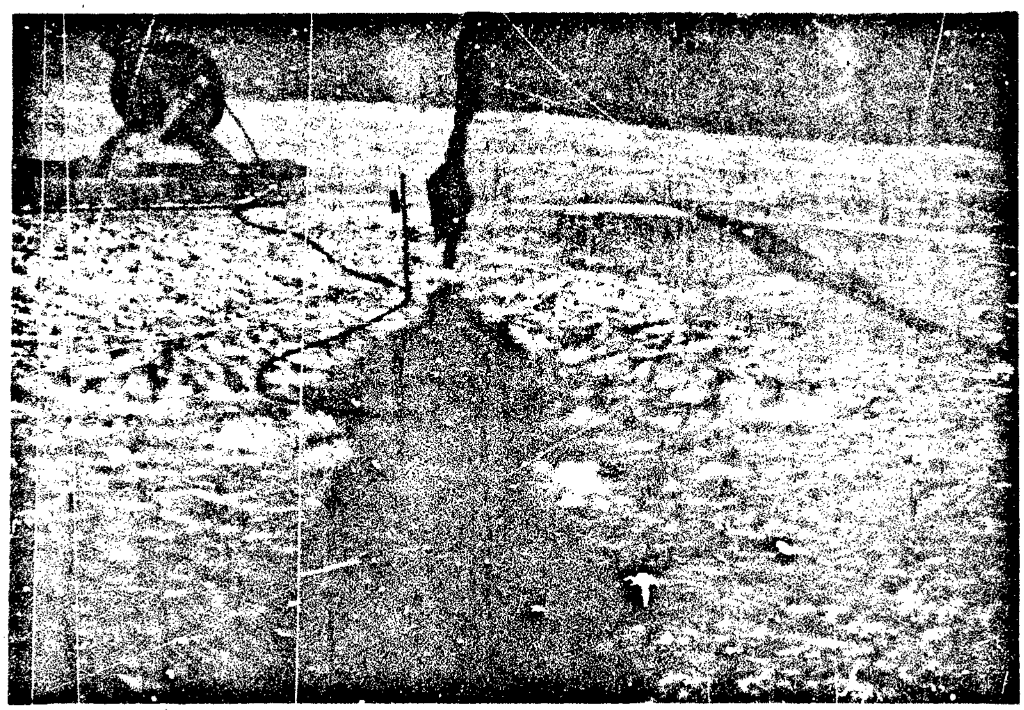
Fig. 7 — Schematic map of the hydrophone placement with respect to the ice camp

(a)

Fig. 8 — Photographs of a.) Hydrophone assembly immediately prior to deployment, b.) Top of pvc pipe showing the cable strain relief, c.) Hole in ice and reel containing 2 km of cable, d.) Arrangement used to deploy the cable, e.) Remaining 1 km of cable on reel beside tent



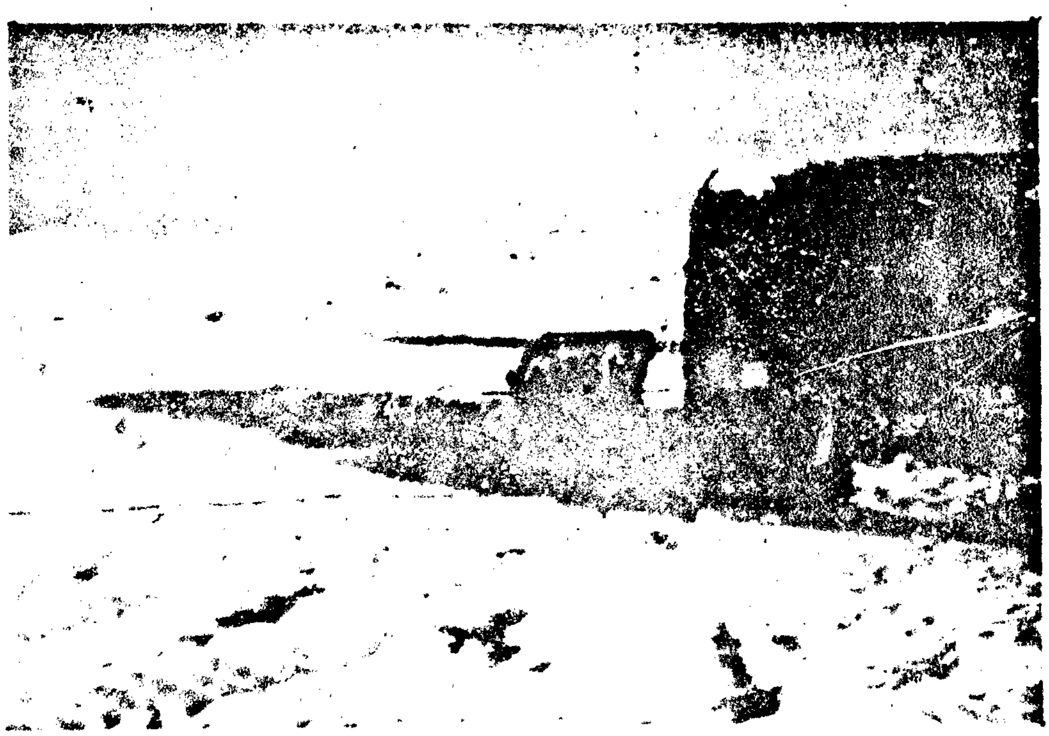
(b)



(c)

Fig. 8 — (Continued) Photographs of a.) Hydrophone assembly immediately prior to deployment, b.) Top of pvc pipe showing the cable strain relief, c.) Hole in ice and reel containing 2 km of cable, d.) Arrangement used to deploy the cable, e.) Remaining 1 km of cable on reel beside tent

(d)



(e)

Fig. 8 (Continued) Photographs of a.) Hydrophone assembly immediately prior to deployment. b.) Top of pvc pipe showing the cable strain relief. c.) Hole in ice and reel containing 2 km of cable. d.) Ar[illegible]ngement used to deploy the cable. e.) Remaining 1 km of cable on reel beside tent.

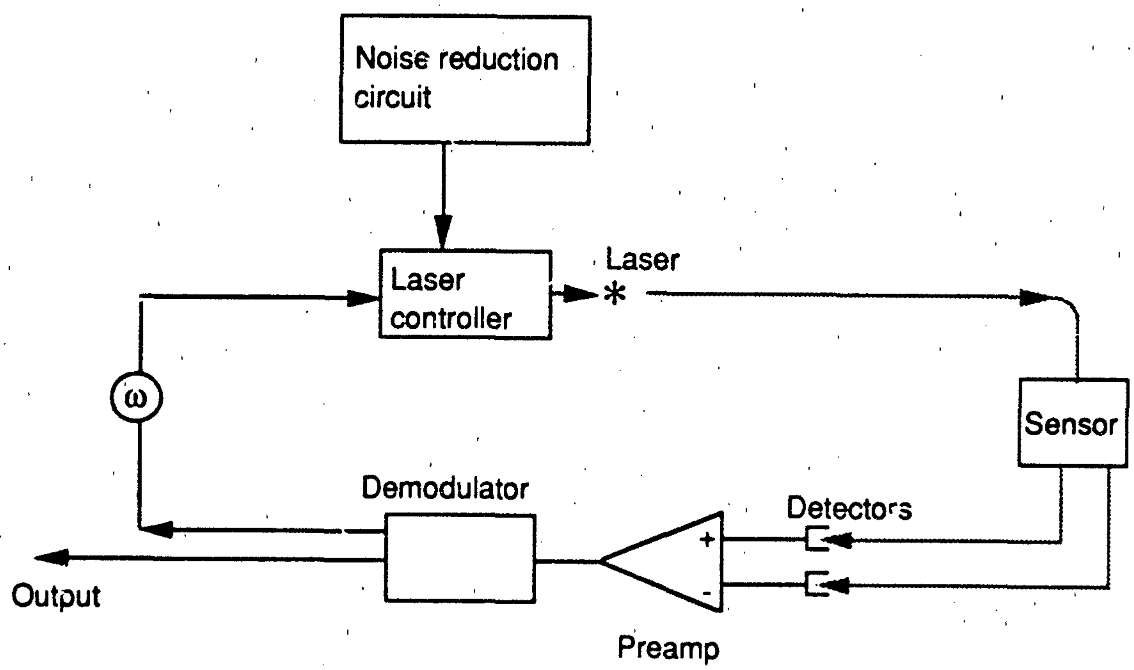


Fig. 9 — Basic Electro-optic system used to interrogate fiber hydrophones H1 and H2

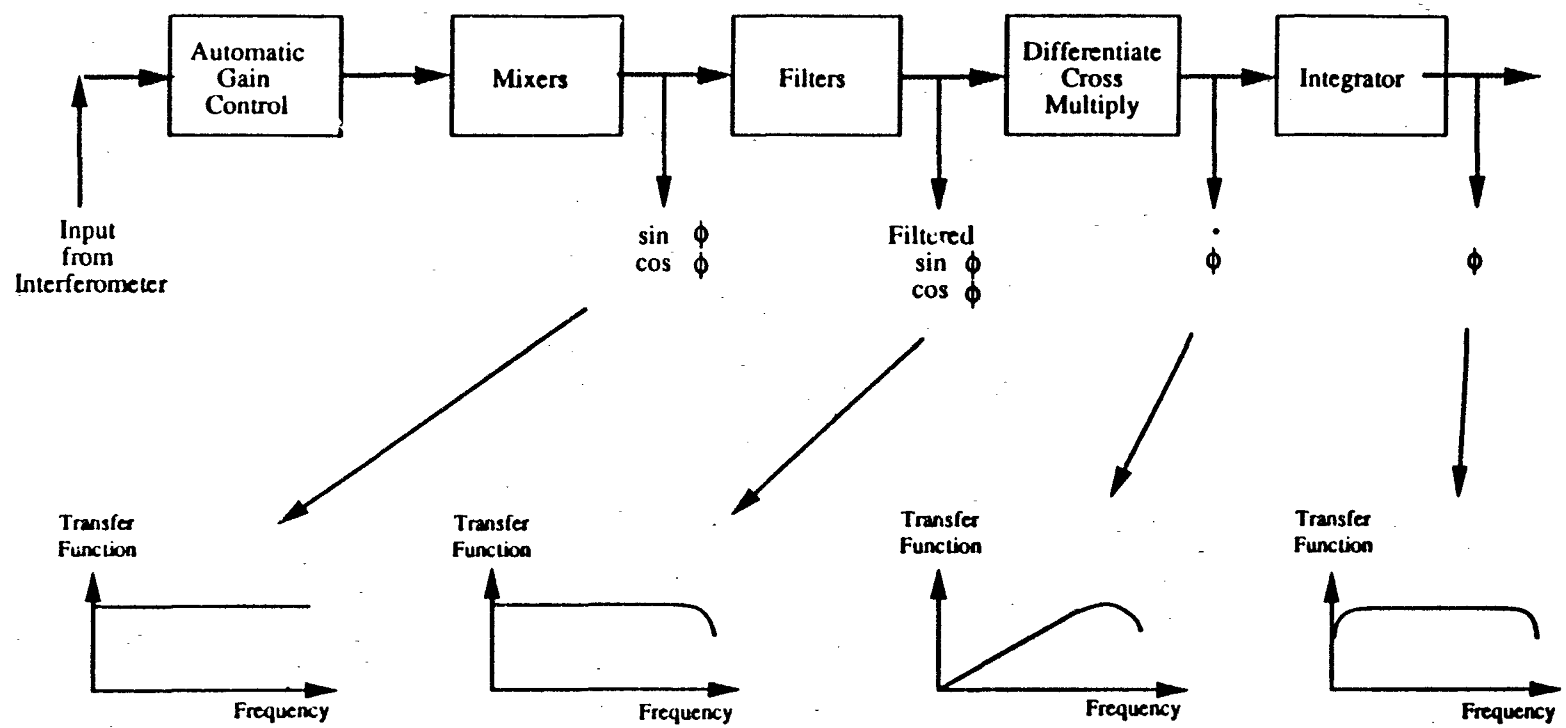


Fig. 10 — Functional blocks and the output transfer function of the demodulator

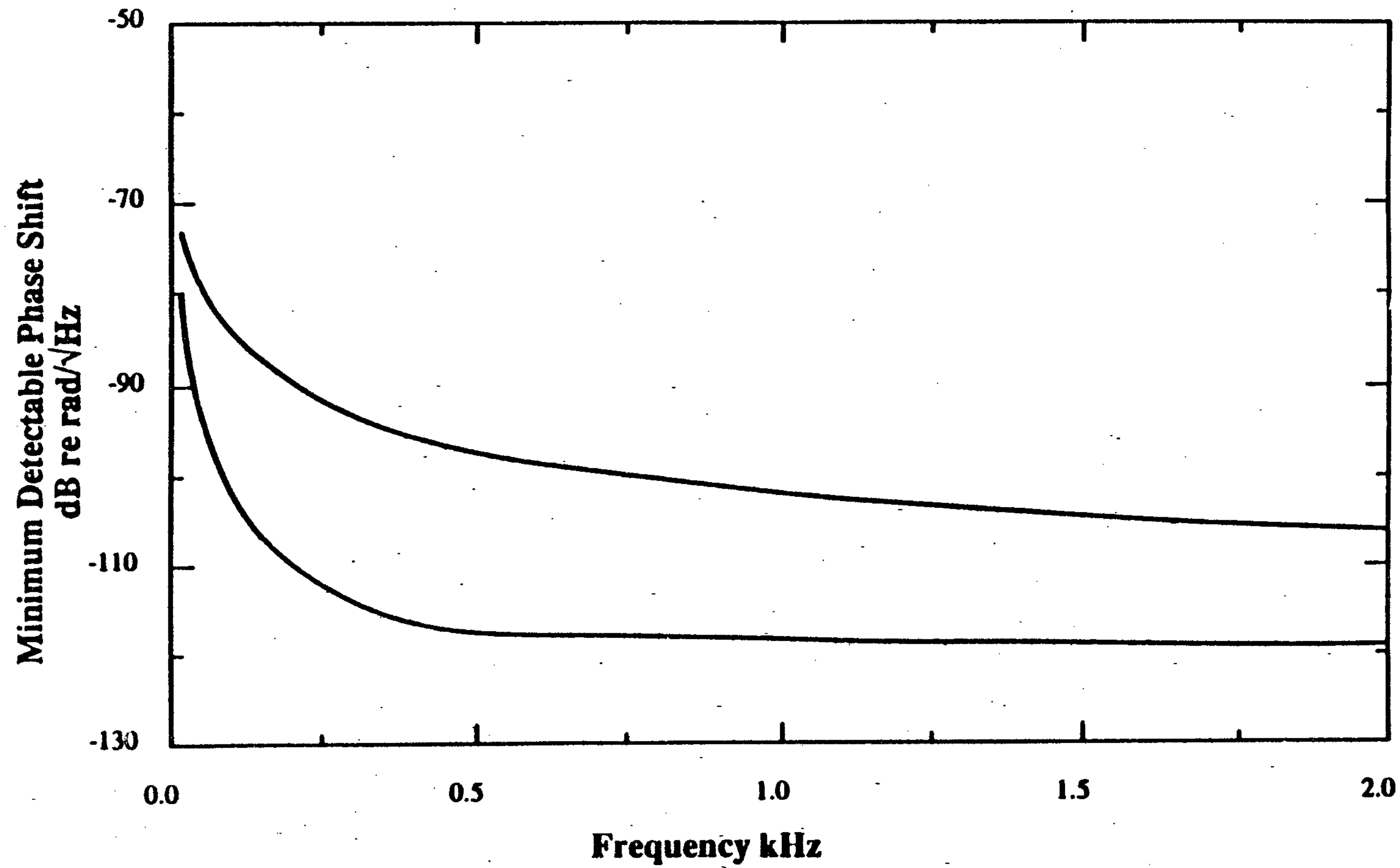


Fig. 11 — Optical noise floor of the Nd:YAG system with and without laser noise suppression

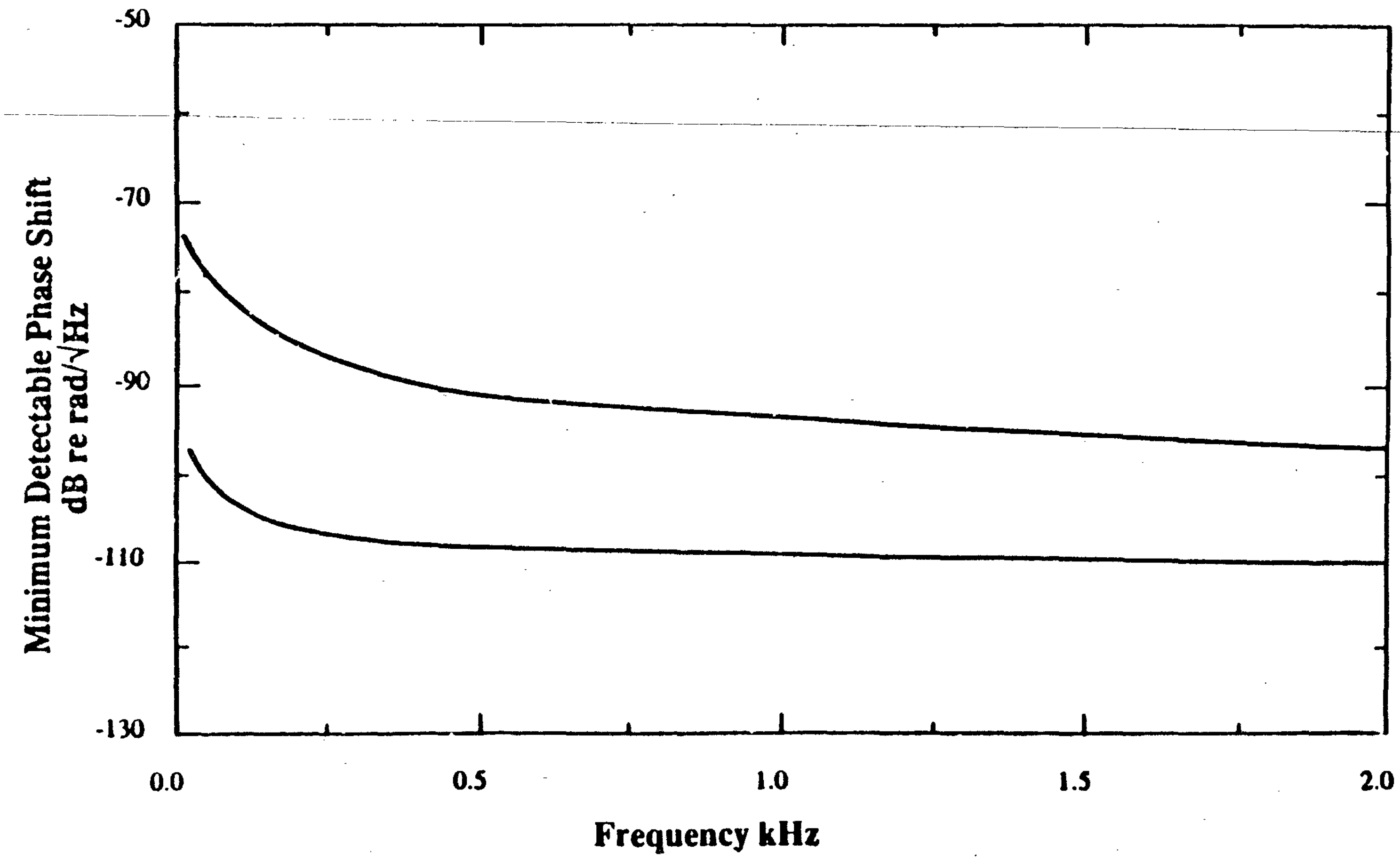


Fig. 12 — Optical noise floor of the semiconductor diode laser system with and without laser noise suppression

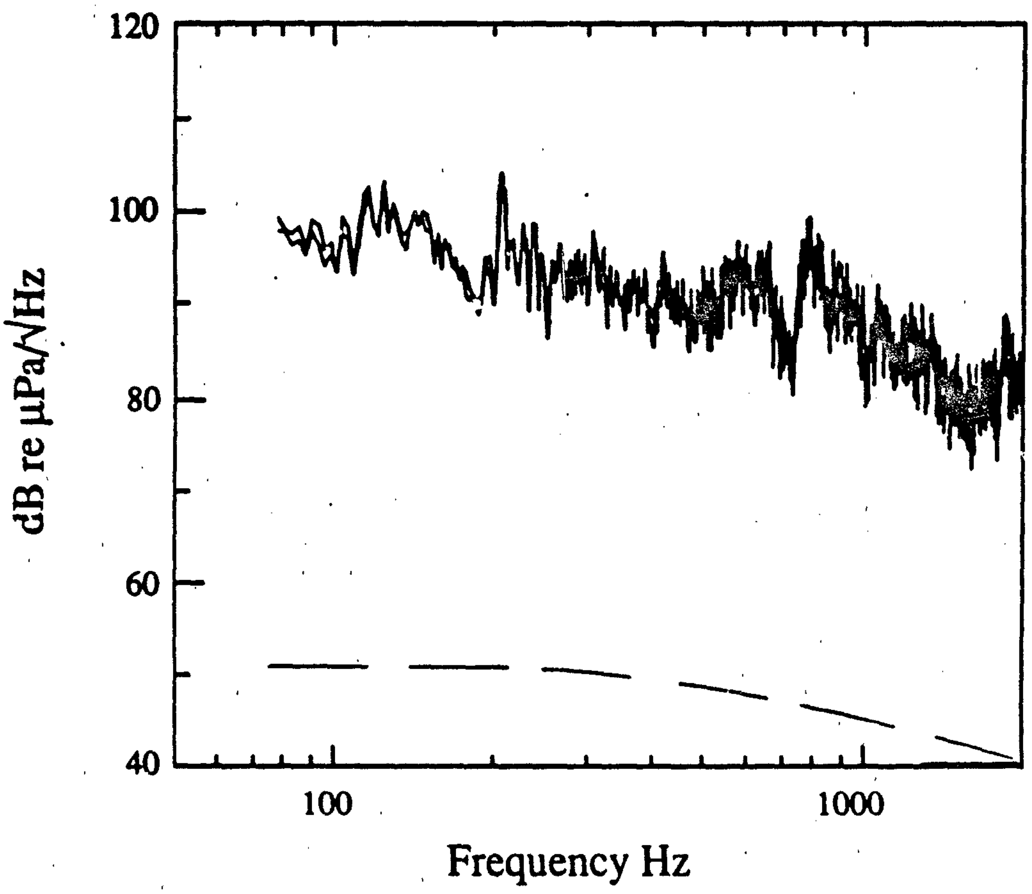


Fig. 13 — High acoustic noise levels (due to operation of snow removal equipment) recorded by fiber hydrophones H1 and H2 (solid line). Sea state zero shown for comparison (dashed line).

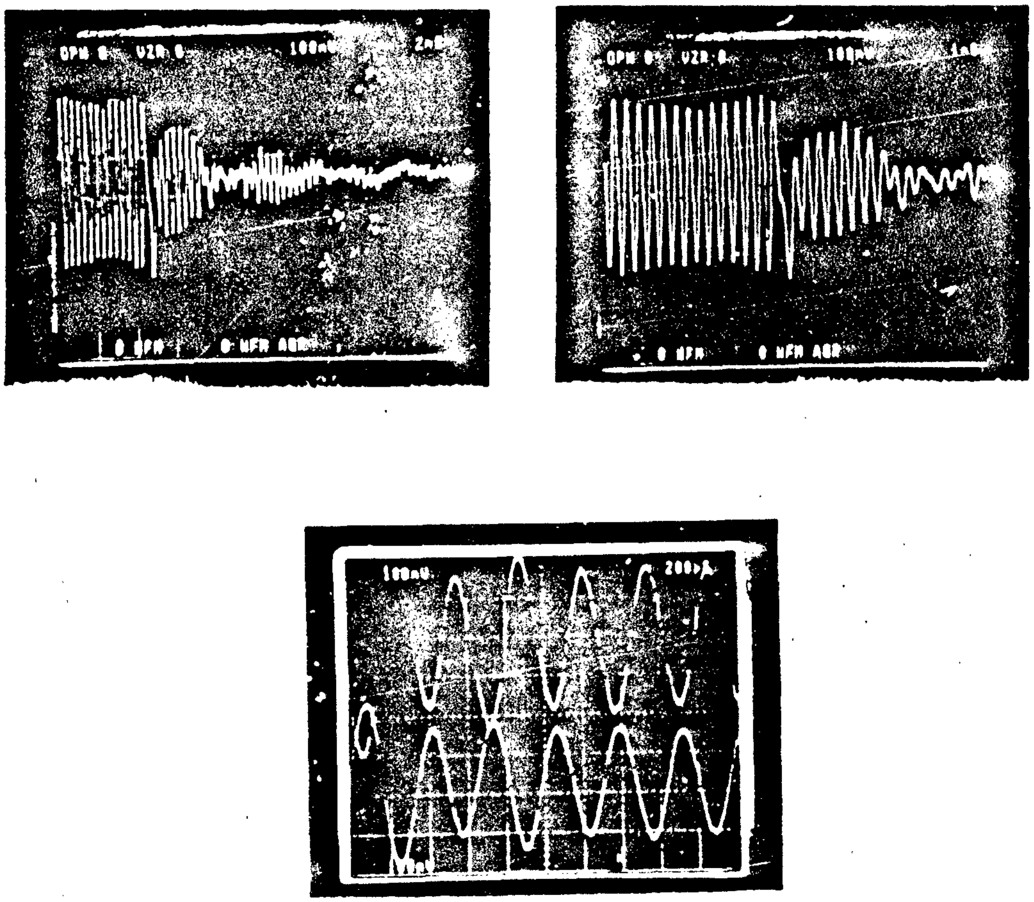


Fig. 14 — a.) Pinger signal on H1, 2 μsec per division b.) Pinger signal on H1, 1 μsec per division, c.) Pinger signal of both H1 and H2, 200 μsec per division

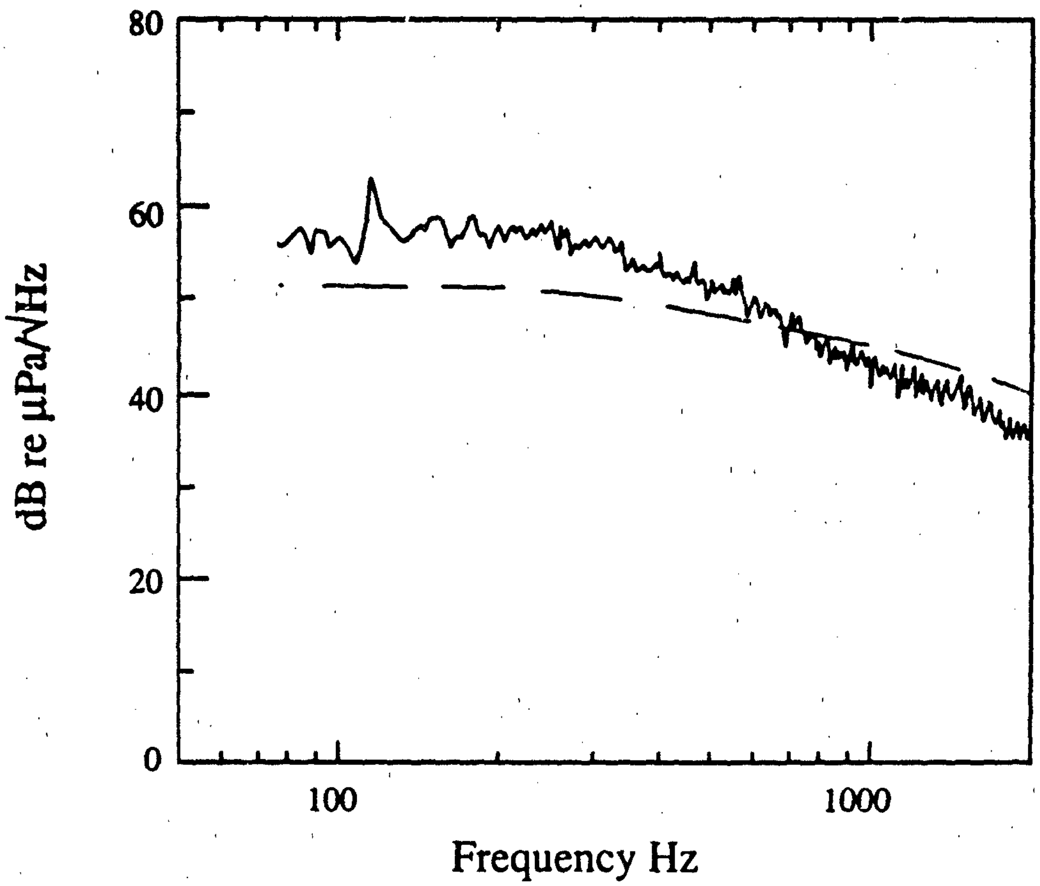


Fig. 15 — Typical ambient acoustic levels, recorded by H1 (solid line). Sea state zero shown for comparison (dashed line).

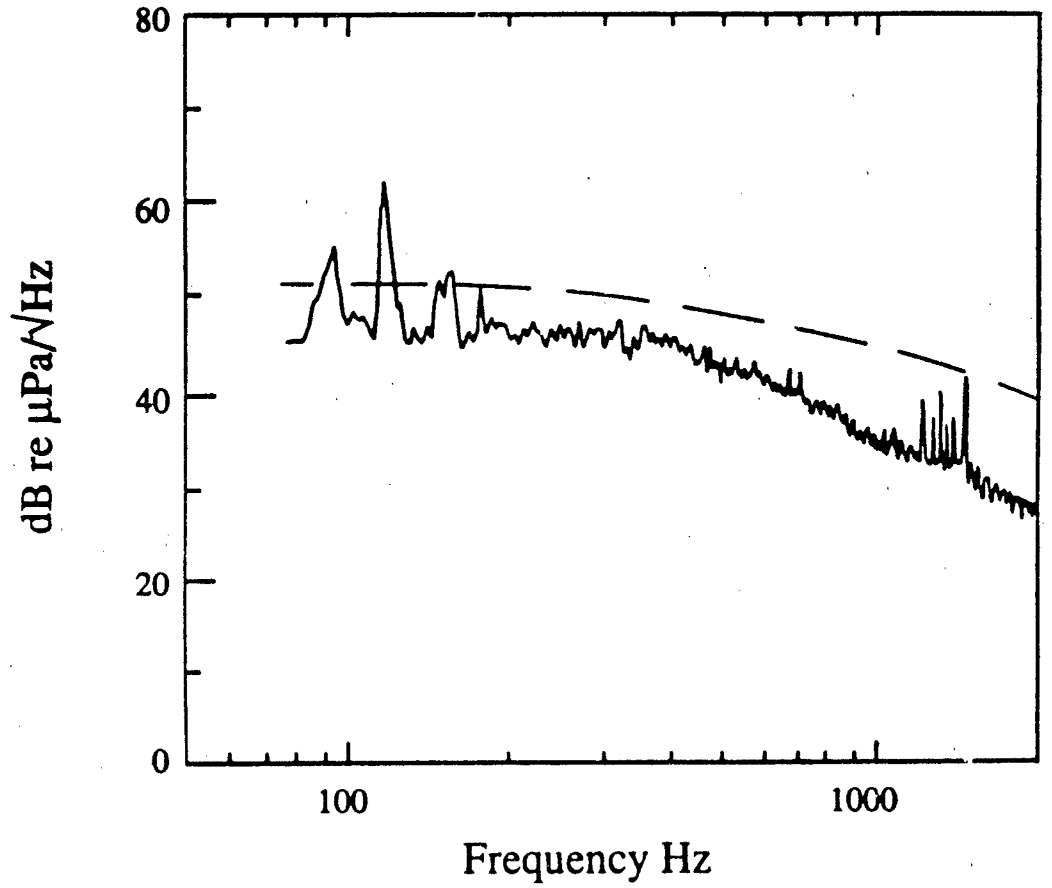


Fig. 16 — "Transient free" acoustic noise level recorded by H1

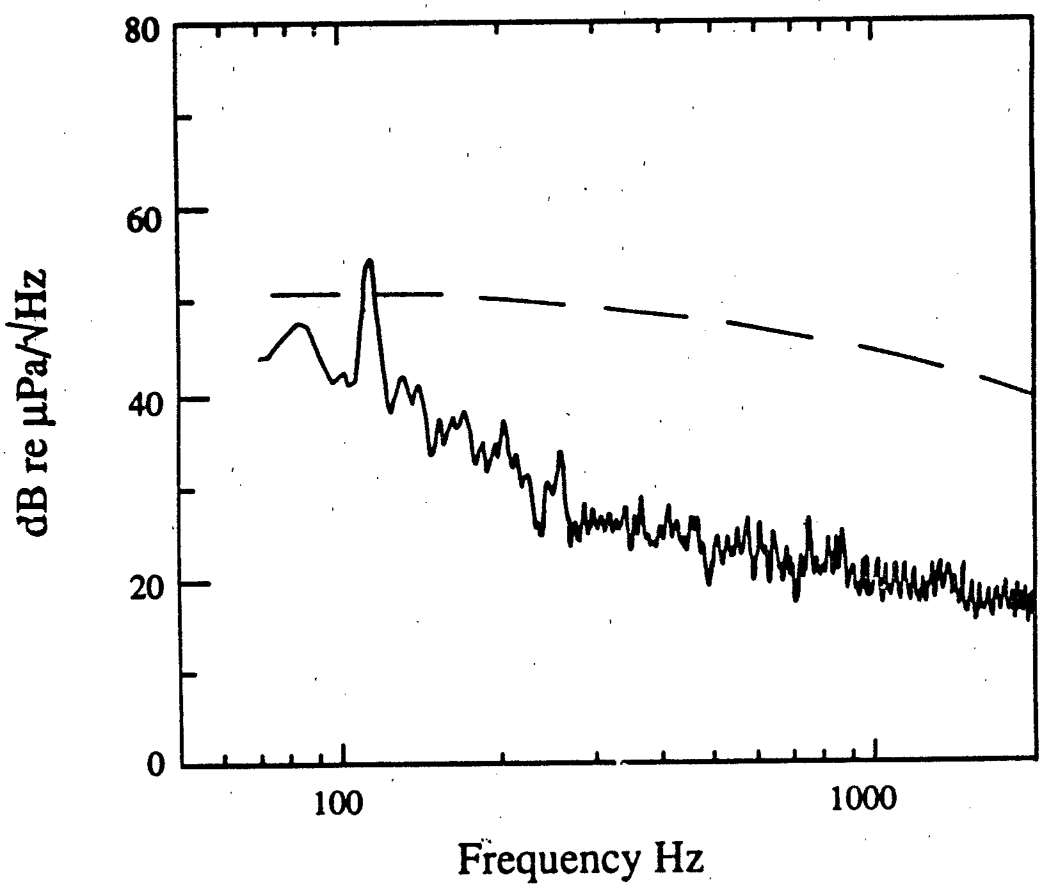


Fig. 17 — Quietest acoustic data recorded (by spectrum analyzer) during the 9 day period, hydrophone H1 (solid line). Sea state zero shown for comparison (dashed line).

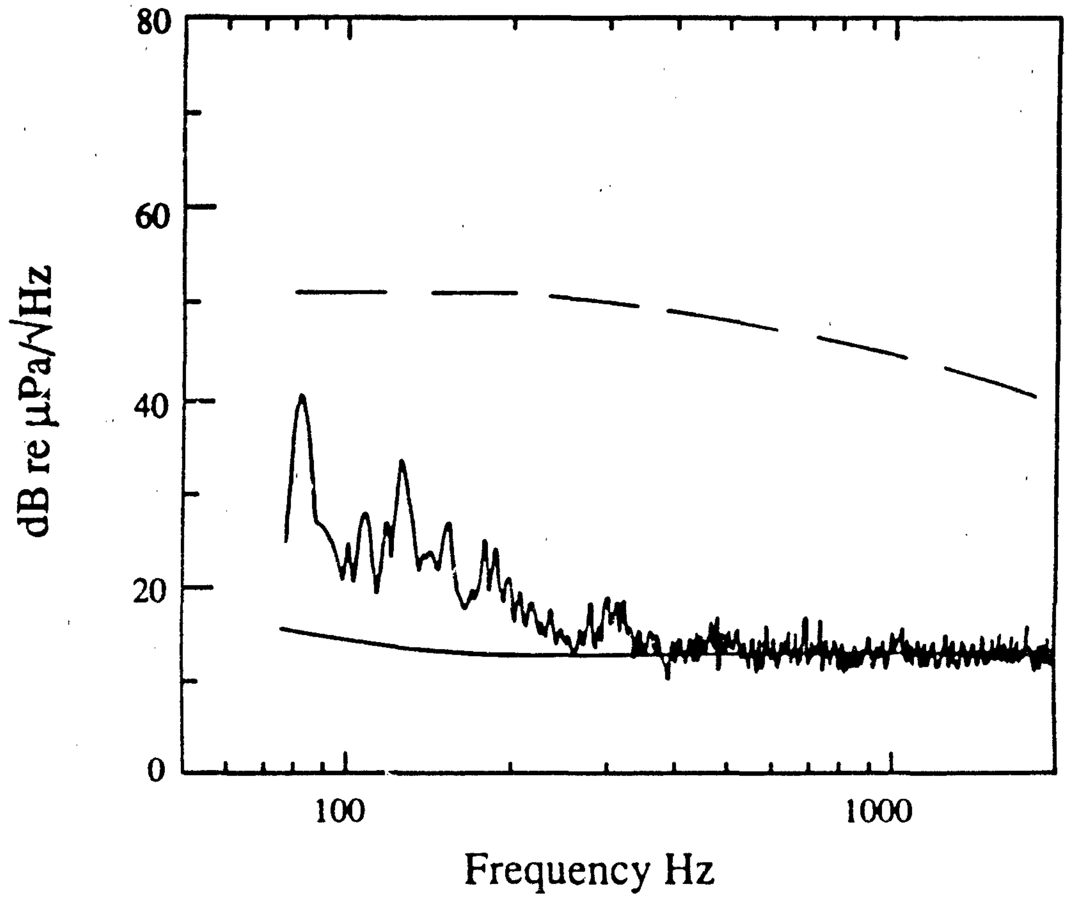


Fig. 18 — Noise floor of the electro-optic system used to interrogate hydrophone H1. electronic demodulator noise floor also shown (lower curve). Sea state zero shown for comparison (dashed line).

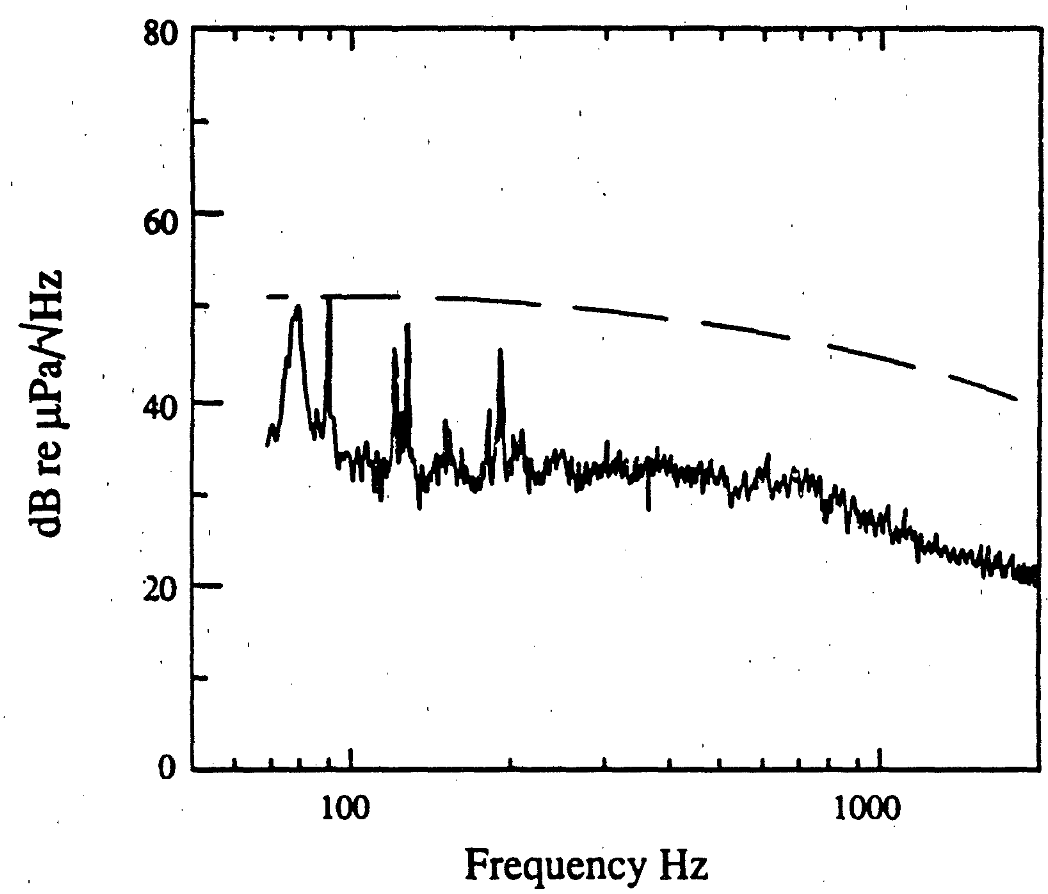


Fig. 19 — Relatively quiet acoustic data recorded by hydrophone H1 on an analog tape recorder and analyzed with a 1 Hz bandwidth at NRL. Sea state zero shown for comparison (dashed line).

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