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A Study on Fiber Optic Hydrophone with Double Interferometers for Optical Path Length Compensation

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Abstract

We report on the development of a fiber optic hydrophone consists of a sensing Michelson interferometer and a compensating Mach-Zehnder interferometer for optical path length compensation. The double interferometer configuration has the following advantages: the hydrophone can be made more small; a laser source with a relatively short coherence length can be used; and the compensating interferometer can be located near the signal processing electronics, far away from the sensing interferometer and noise introduced by reference arm can be greatly reduced. The performance of the hydrophone is evaluated experimentally by immersing the sensing interferometer in a water tank to detect underwater acoustic signals generated by an acoustic wave projector. Experimental results show that over the frequency range of 1 to 4 kHz, the hydrophone has an almost flat response with an average normalized sensitivity of -302 dB re 1/μPa.

Keywords: *Fiber optic hydrophone, Double interferometor, Optical path length compensation, Michelson interferometer, Underwater acoustic sound*

I. Introduction

Fiber optic hydrophones have been demonstrated to have better performance than conventional hydrophones and continuing researches have been actively pursued[1-4]. Moreover, since the successful demonstrations of fiber optic hydrophone array in sea trials, there has been interest in using fiber optic hydrophone array for underwater surveillance system[5,6].

To have the excellent performance in surveillance system, many technologies such as hydrophone design, array system design, signal detection and processing techniques, optical and mechanical reliability, simulation techniques and experiences in ocean environment are needed[7-10]. In general, a fiber optic hydrophone is based on Mach-Zehnder or Michelson interferometer configurations[2,3]. Figure 1 shows schematic configurations of mandrel type hydrophones using interferometers.

In these configurations, noise from outside to reference arm must be isolated. But reducing noise is not easy for array system. So, nowadays the unbalanced interferometer configurations are used to reduce the noise introduced by the reference arm[11].

In this paper, we report on the development of a fiber optic hydrophone with double interferometers for optical path balancing.

We developed a fiber optic hydrophone consists of a sensing Michelson interferometer and a compensating

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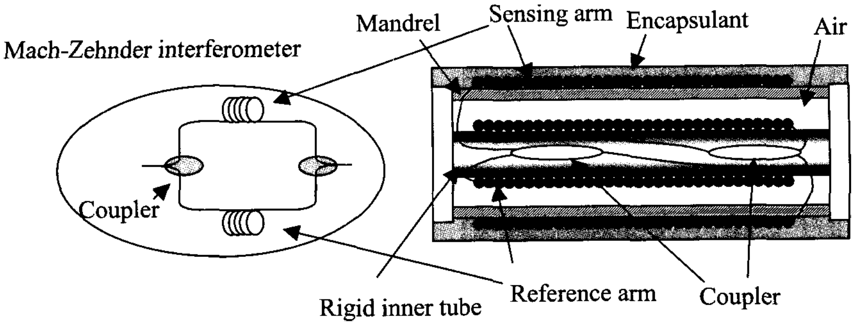
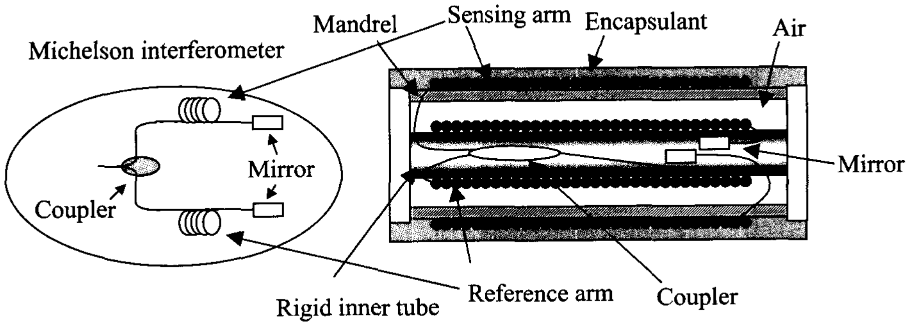


(a) Mach-zehnder interferometer configuration



(b) Michelson interferometer configuration

Figure 1. Typical mandrel type hydrophone.

Mach-Zehnder interferometer for optical path length compensation. The double interferometer configuration has the following advantages: the hydrophone can be made more small; a laser source with a relatively short coherence length can be used; and the compensating interferometer can be located near the signal processing electronics, far away from the sensing interferometer and noise introduced by reference arm can be greatly reduced.

II. System Design

The configuration of the fiber optic hydrophone consists of two interferometers to facilitate optical path length compensation. As shown schematically in Figure 2, the compensating Mach-Zehnder interferometer is located between the two directional couplers C_1 and C_2, whereas the sensing Michelson interferometer is between C_3. The sensing interferometer consists of a sensing arm and a reference arm and acts as a sensing head. It does not contain any active element and is therefore completely passive. On the other hand, the compensating interferometer contains a phase modulator (PM) in the short arm and a long fiber coil in the other arm. The optical path lengths of these two arms are made to be nearly the same as those of the short reference arm and the long sensing arm of the sensing interferometer, respectively.

As illustrated in Figure 2, the light wave generated by the Nd: YAG laser is changed pulse signal with frequency ω_0 by A.O.M. (Acousto-Optic Modulator) and the light wave is split by directional coupler C_1 into two components which are fed to the two fiber arms of the compensating interferometer. The component that passes through the short arm is phase modulated by PM to a new frequency ω_1. The other component that goes through the long fiber coil maintains its original frequency ω_0. As a consequence, the two optical waves with slightly different frequencies ω_0 and ω_1 do not interfere when they are combined at coupler C_2. After this, the combined light wave travels through Coupler C_3 and the down-lead fiber to the sensing

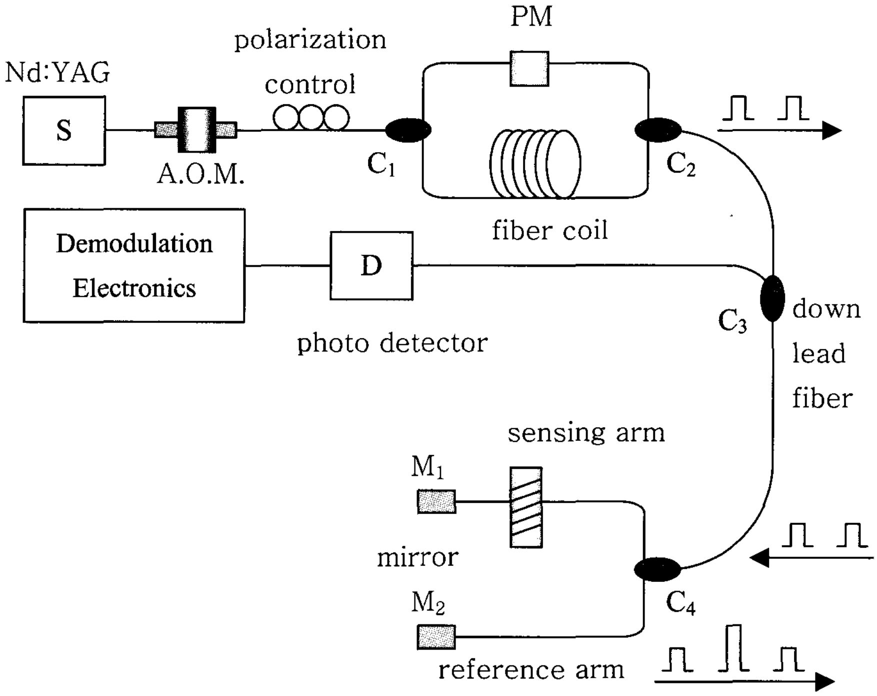


Figure 2. Configuration of fiber optic hydrophone employing the optical path length compensation scheme.

interferometer immersed in water. At coupler C_4, the light waves are split again and fed into the sensing and reference arms of the sensing interferometer. Finally, at coupler C_4, the two arriving optical waves reflected by each mirror M_1 and M_2, each having two frequency component ω_0 and ω_1, are combined. Because the optical path length difference of the sensing interferometer equals that of the compensating interferometer, only the component with frequency ω_1 from the sensing arm and the component with frequency ω_0 from the reference arm are temporally coherent to each other and produce an interference signal. All other pairs of components are incoherent and therefore will not mix to produce an interference signal.

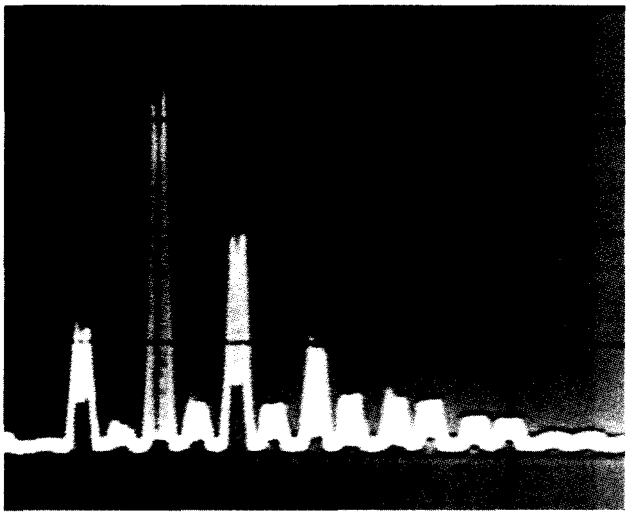


Figure 3. Optical pulse train of 12 channel fiber optic hydrophone array.

Observe that in the sensing interferometer in Figure 2, the reference arm is very short. This will greatly reduce the noise that could be introduced by a long reference arm as used in a conventional configuration shown in Figure 1. Moreover, due to the fiber's low loss and the negligible dispersion over the frequency range of ω_0 to ω_1, the length of the down-lead fiber can be suitably increased without affecting the performance of the sensor.

So, this configuration can be applied to multi channel fiber optic hydrophone array. Figure 3 shows the output optical pulse train of 12 channel fiber optic hydrophone array with double interferometer configuration, which is constructed by Agency for Defense Development[12]. We applied the same hydrophone design, and compensation interferometer which we report in this paper.

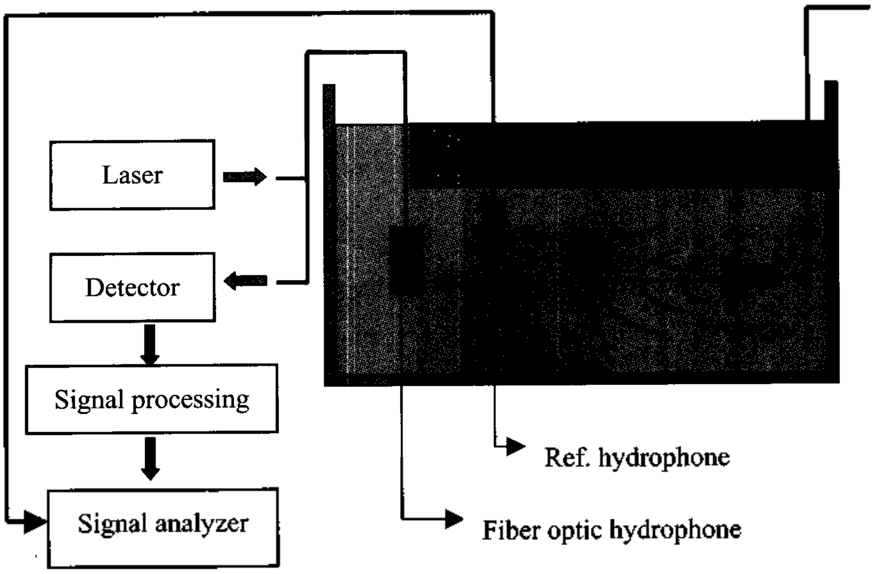


Figure 4. Test arrangement for the fiber optic hydrophone.

III. Performance Evaluation

In order to evaluate the performance of the prototype fiber optic hydrophone, the sensing head is lowered down into a water tank shown in Figure 4. Other key equipments are employed including an acoustic wave projector and a reference piezoelectric hydrophone. The acoustic projector is a general purpose transducer (1500 Hz GRP flextensional transducer) that is specified to generate acoustic waves over the frequency range of 1 to 4 kHz. In addition to the acoustic projector, a standard piezoelectric hydrophone (H-23) is placed next to the sensing head to act as the reference hydrophone for comparison with the performance of prototype fiber optic hydrophone. The experimental measurements are carried out in a 18 m long, 10 m wide and 10 m deep water tank. The water tank is filled up with clear water and its inner wall is distorted to restrain standing waves.

The prototype fiber optic hydrophone and the reference piezoelectric hydrophone are placed about 5 m below the surface of the water tank and 1.5 m away from the acoustic projector.

It is found that the prototype hydrophone works properly and can sense underwater acoustic signals.

To evaluate the performance of the fiber optic hydrophone, we observed that the fiber optic hydrophone is able to reproduce the acoustic sinusoidal signal. In Figure 5, the detected acoustic signal from the fiber optic hydrophone is displayed in the upper trace with the applied signal in the lower trace. And Figure 6 is frequency spectrum of the Figure 5 and the output amplitude is 3.6 dBVrms at 2 kHz.

As shown in Figure 5 and Figure 6, the output signal from the fiber optic hydrophone is very stable. So, we performed sensitivity measurement with test arrangement of Figure 4 and the result is shown in Figure 7. The mean sensitivity up to 4 kHz is -130 dB re rad/Pa. Assuming a linear relation between the sensing fiber length and the

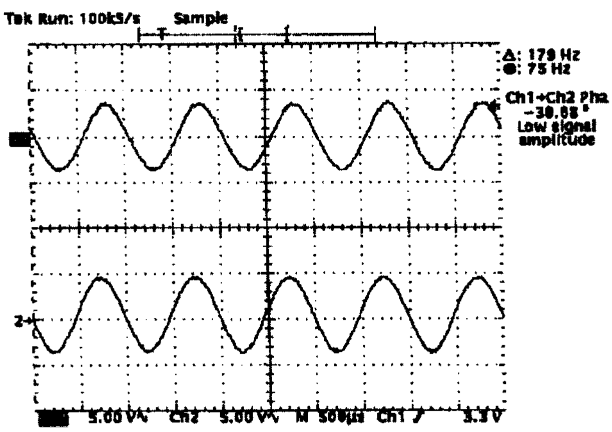


Figure 5. Detected acoustic signal in time domain (upper trace) and applied signal(lower trace) at 2kHz.

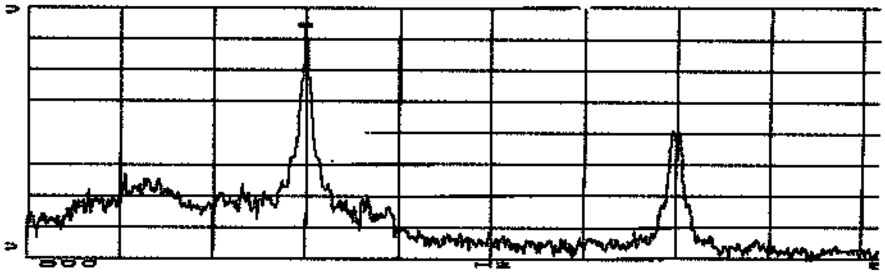


Figure 6. Sound detection in frequency domain (vertical axis: -80 to 10 under 10dBVrms/Div., horizontal axis: 0.5 to 5.5 under 0.5kHz/div.).

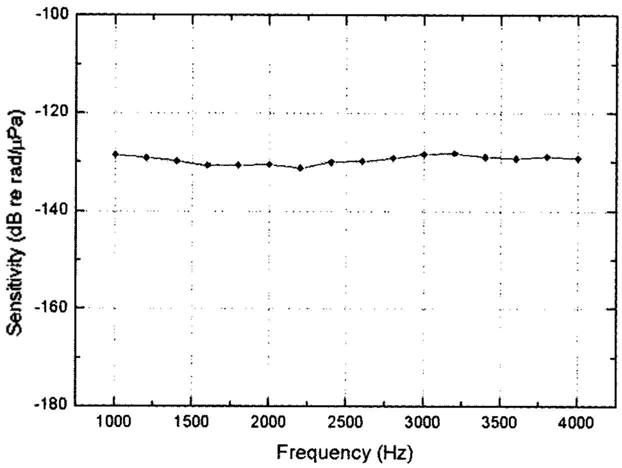


Figure 7. Sensitivity characteristic of fiber optic hydrophone.

sensitivity, a better indication of the sensor performance will be given by normalized sensitivity in which the length of sensing fiber and wavelength are eliminated. The normalized sensitivity is -302 dB re $1/\mu$Pa. This shows excellent responsive performance compared with that of other fiber optic hydrophones which produced by NRL and DERA[3-5]. Our prototype fiber optic hydrophone was made by MC-Nylon hollow mandrel with the sensing fiber length of 29 m.

IV. Conclusion

A high sensitive fiber optic hydrophone with double interferometers for optical path length compensation has been designed, constructed and tested. The experimental results show the normalized sensitivity of -302 dB re $1/\mu$ Pa, which is adequate for the practical acoustic sensing functions. Moreover this configuration can be enlarged to fiber optic hydrophone array having multi channels.

Future study will be extended to the practical multi channel fiber optic hydrophone array system having reliability over 20 years in ocean environment.

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[Profile]

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