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A Novel High Sensitive Optical Fiber Microphone Based on a Singlemode-Multimode-Singlemode Structure

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Abstract: In this paper, a novel multimode interference based optical fiber microphone by employing singlemode-multimode-singlemode (SMS) structure is presented. The acoustic vibration is measured by detecting the transmission loss of the SMS structure that attached to a thick aluminum membrane. Experiments are carried on to test the performance of SMS structured fiber microphone and the experimental results show that the SMS fiber sensor can effectively detect the acoustic signal within the audio range of 20 KHz. It also exhibits a high sensitivity and human voice can also be picked up effectively within the distance of 2 m.

Key word: optical fiber sensor, Singlemode-Multimode-Singlemode, optical fiber microphone, multimode interference

Sound field and sound level measurement is a frequent measurement requirement in a number of areas. A fiber optic microphone (FOM) is a promising sensing technology for sound field and sound level measurement because of its distinctive advantages of immunity to electromagnetic interference compared with electronic microphone. This means that the FOM can work in some difficult measurement environments such as inside magnetic resonance medical imaging equipment and in other industrial applications subject to high electromagnetic fields. A number of different optical fiber microphone schemes have been reported, employing a fiber Bragg grating[1, 2], reflective membrane[3], fiber DFB laser[4], and an interferometer[5-7]. However by comparison to a conventional microphone, the cost of available

FOMs is not competitive since the sensing schemes often require expensive sensor components and complex demodulation systems to achieve a high sensitivity to the weak acoustic pressure.

Singlemode-Multimode-Singlemode (SMS) fiber structures have been studied for different applications such as a refractometer [8] or edge filter[9, 10]. In this paper, a novel high sensitive multimode interference based optical fiber microphone is investigated. In contrast to previous approaches to an FOM, a simple Singlemode-Multimode-Singlemode fiber structure is employed to detect acoustic vibration and the modulated signal is the intensity change of transmission light, which means a simple and low cost sensor and demodulation scheme.

The scheme employs the Multimode Interference (MMI) occurring in Singlemode-Multimode-Singlemode (SMS) fiber structure as a means to sense the vibrations induced in membrane by sound as shown in fig.1. When light propagate through the multimode fiber (MMF) section from singlemode fiber (SMF), higher order eigenmodes are also excited because of the mismatch between the fundamental modes of singlemode and multimode fiber. As a result MMI occurs between different modes in MMF and then coupled into output SMF.

The sensing mechanism of SMS fiber microphone is as shown in fig.2. Acoustic pressure exerted on the membrane causes vibration of membrane, which result in the bending of SMS fiber structure. Since the propagated modes in MMF are sensitive to the bending of multimode fiber, the power coupled to the output SMF is will be very sensitive to the change of interference between different modes at the end of MMF. So the transmission loss of propagation light in SMS structure can be modulated by the acoustic pressure induced vibration of membrane. Consequently the intensity fluctuation of transmission light can be detected at the end of output SMF to acquire the corresponding acoustic vibration.

The experimental SMS fiber sensor is fabricated by splicing a step-index multimode fiber between two standard singlemode fibers. Two standard SMFs (SMF28) are used as input and output fiber. A multimode fiber AFS105/125Y is chosen with a refractive index of 1.4446 for the core and 1.4271 for the cladding. The core radius is 52.5 μm. A circular aluminum foil with a thickness of 3 μm and diameter 3.5 cm is chosen as the elastic vibration membrane and fixed on a mount as means to transfer acoustic vibration to the SMS fiber. Although a larger diameter membrane can enhance the sensitivity of membrane to low frequency acoustic wave, it will limit the frequency response range of membrane.

The length of MMF in the experiment is also around 3.5 cm which is attached to the membrane along the diameter axis of membrane. According to previous research reports[11], the length of MMF will also affect the transmission power and spectrum of propagation light, which means that a higher sensitivity may be achievable by proper optimizing of MMF length. According to our experimental results, however, when the length of MMF exceeds the diameter of the membrane, the transmission loss of the MMF is adversely affected by outside interference such as small vibration or movement because free end of MMF is unstable in free space, which degrades the stability of SMS fiber sensor. In the scheme used here, the length of MMF is no longer than the diameter of the membrane mount.

The Experimental setup for sound measurement is illustrated in fig.3.

In the experiment, an ASE source with an output power of 3 mw and a wavelength range of 1525-1565 nm is used as the sensing source. Demodulation system consists of a photo detector, a PCI card and a commercialized Virtual instrument signal analyzing software. The photo detector used in the experiment is InGaAs based detector with an output of 0.01V/μW. A PCI card is used to collect the detected signal from photo detector with a sampling frequency of 44.1 KHz and sampling accuracy of 16 bits. Finally a computer based virtual instrument is employed to analyze the signal which functions as a frequency spectrum analyzer based on FFT frequency domain analysis. An electronic microphone with a sensitivity of 1.17 mv/Pa@1KHz is employed to calibrate the measurement result of SMS fiber microphone which exhibits a flat frequency response within its measurement range. The acoustic signal is generated through a waveform generator and a lower speaker.

The experiment is carried on to test the performance of SMS fiber microphone within the audio range from 300Hz to 20 KHz. The output signal of SMS fiber microphone is observed firstly through an electronic oscilloscope and then virtual instrument software. Fig.4 shows the representative acoustic signal detected by SMS fiber microphone at 1 KHz as both time domain and frequency spectrum. As a comparison, the output of electronic microphone at 1 KHz is also observed at same time through oscilloscope.

It can be seen clearly from Fig.4-a that both electronic microphone and SMS fiber microphone can detect the sound signal at 1 KHz but SMS fiber microphone exhibits a better signal-noise-ratio. It can also be seen that phase lag occurs between the output of the two microphones which may be caused by the circuit components.

The frequency response of SMS fiber microphone at different frequency is also measured. The sound frequency shifts from 300 Hz to 1 kHz in 100 Hz steps and from 1 kHz to 20 kHz in 1 kHz steps. Although a lower frequency from 20Hz to 200Hz is also detectable, it is seriously affected by environmental noise arise from computer and other instrument. Therefore an anechoic chamber is necessary if better experimental results are expected.
The experimental frequency response of electronic microphone and SMS fiber microphone is shown in fig.5.

It is clear in fig5-A that SMS exhibit a high peak when acoustic signal is 900 Hz which is caused by the natural frequency of aluminum membrane. It is confirmed by another experiment when a foil with a diameter 2.5 cm is used as vibration membrane while the length of the MMF is not changed, which shows a similar frequency response but its natural frequency is up to 1.6 KHz. When the sound frequency is higher than 1 KHz, calibration microphone and SMS fiber microphone show a similar frequency response and four peaks occur sequentially at 2 KHz, 4 KHz, 8 KHz and 10 KHz which may caused by the uneven frequency response of the lower speaker.

In additional, it is obvious in fig.5 that the sensitivity of SMS fiber microphone is higher than that of calibration microphone, and SMS fiber microphone also exhibits a large frequency response range. When sound frequency is higher than 15 KHz, no signal can be detected by the calibration microphone while the detectable frequency range of SMS fiber microphone can reach as high as 20 KHz. It can also be seen that the output of SMS fiber microphone is only 0.2 mV at 20 KHz since no amplifier is employed to amplify the weak electronic signal. So it is possible to achieve a better result at high frequency by employing electronic amplification technique. During the experiment, human voice within 2 meter range can also be detected sensitively by SMS fiber microphone since the frequency of human voice is predominately below 6 KHz.

In summary, a novel optical fiber microphone based on Singlemode-Multimode-Singlemode (SMS) Structure is presented. The experimental results show that SMS fiber microphone exhibits a good sensitivity, large frequency response and high signal-noise-ratio comparing with the calibration microphone that can easily detect human voice within 2 m range. In additional, it also has the advantage of low cost, simple sensor fabrication and demodulation system which means a promising application in practice.

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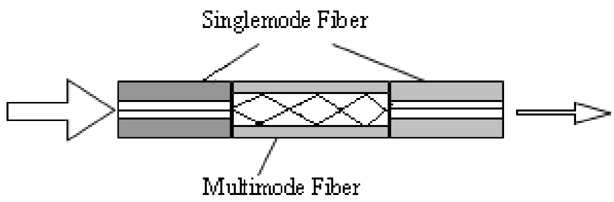

Fig.1 Diagram of SMS fiber microphone

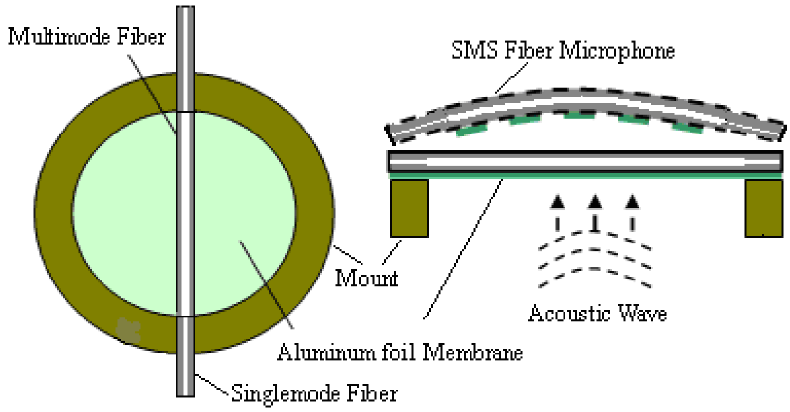

Fig.2. Sensing illustration of SMS fiber microphone

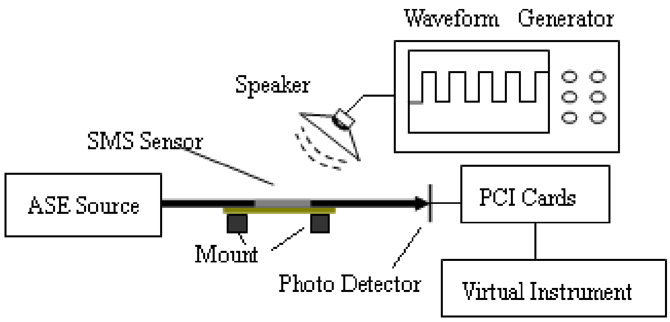

Fig.3. Experimental setup of SMS fiber microphone system

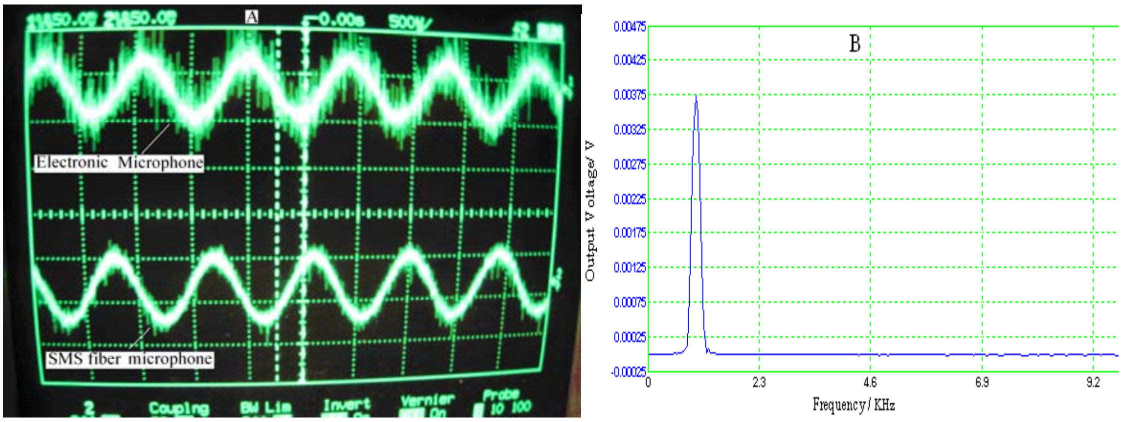

Fig.4. Detected acoustic signal of SMS fiber microphone at 1 KHz (a-time domain and b-frequency domain)

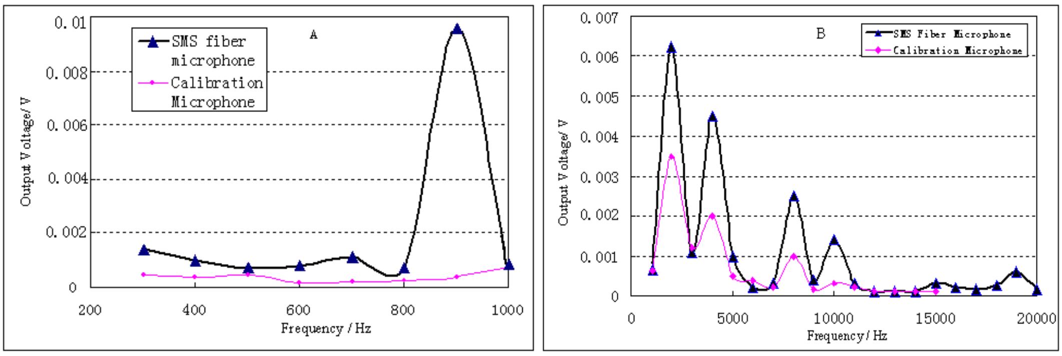

Fig.5 Frequency response comparison of SMS fiber sensor to calibration microphone at low frequency (A-below 1 KHz) and high frequency (B-1 KHz to 20 KHz)