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Abstract. This paper gives a thorough look at how an intrinsic fiber optic acoustic sensor with a step index SMS structure works, what factors should be considered when designing it, how the experiments should be done, and how well it works. The sensor is specifically designed to accurately monitor both the amplitude and frequency of sound signals. The device consists of an optical light source, a fiber optic structure (Singlemode-Multimode-Singlemode) with a multimode 45 mm length, an audio generator, an output acoustical signal, an oscilloscope, and an optical power meter. The SMS sensor can measure acoustical amplitude ranging from -21.48 to -24.24 dBm. Within the frequency range of 30 to 70 Hz The relative error of the measurement is 2.24%. Inherent optical fiber sensors have several advantages, including their lightweight nature, immunity to electromagnetic interference, and absence of power in the sensing component.

Keyword: Singlemode-Multimode-Singlemode, multimode interference, acousto-optical, intrinsic fiber sensor, multimode step index

INTRODUCTION

The investigation of low-frequency acoustic wave detection has garnered increasing interest in contemporary society and has a wide range of applications in a variety of fields, including science, engineering, medicine, and more. The amplitudes and frequencies utilized in biomedical engineering research exhibit significant variability, contingent upon the specific application and study objectives[1]. The field of biomedical engineering encompasses a diverse array of disciplines, including but not limited to biomedical signal processing, medical devices, and biomechanics[2–4]. Hence, there can be significant variations in the amplitude and frequency values employed across different studies.

The amplitude of medical equipment, such as an infusion pump, pacemaker, or blood pressure monitoring device, exhibits significant variation depending on the specific device and its intended use. The operation frequency of medical devices exhibits variability. As an illustration, a pacemaker is typically designed to function at a lower frequency[5], but an infusion pump is typically designed to operate at a higher frequency[6].

The field of study known as biomedical signal processing focuses on the analysis and manipulation of signals derived from biological systems. The amplitude of a signal exhibits a wide range, spanning from microvolts to milliamps, contingent upon the specific signal type, such as electrocardiography (ECG), electromyography (EMG), or electroencephalography (EEG), seismocardiography (SCG), phonocardiography (PCG) signals. The frequency range exhibits variation across different applications. For instance, in the case of ECG, the primary frequency falls within the range of approximately 0.05–100 Hz[7]. Conversely, in EEG, the primary frequency spans from 0.5 to 100 Hz, contingent upon the specific signal component under examination.

Fiber optic sensors have been applied in various ways in the biomedical field to improve diagnosis, patient monitoring, and medical treatment development[8–10]. Fiber optic sensors have found diverse applications within the biomedical domain, contributing to advancements in diagnostic techniques, patient monitoring, and the creation of medicinal treatments. Sensors using fiber optics possess a multitude of advantageous characteristics, rendering them highly valuable within the realm of medicinal applications. Sensors based on fiber optics offer several notable advantages in the given situation. Optical fibers ensure a small footprint and cabling size, as well as a lightweight structure, with each sensing element having a thickness of less than 250 mm. Minimizing invasiveness and alteration of tissues is a key requirement for biomedical applications, which necessitate the small dimension[11]. Most FOSs offer sensing structures with typically high precision, a linear calibration function, and rapid response. Moreover, fibers adhere to the ISO 10993 standard for medical devices[12]. Multiple sensors can be fabricated on a single fiber for multi-sensing architectures enabled by fiber optic sensors. This enables the transformation of each fiber into a sophisticated sensing instrument capable of measuring multiple parameters with fine spatial resolution.

This study presents a proposed fiber optic sensor that is characterized by its simplicity, durability, affordability, and high efficiency. The sensor is designed specifically for measuring the amplitude and frequency of sound signals. The sensor under consideration utilizes the fundamental principle of a fiber-optic acoustic sensor for phonocardiography.

METHODOLOGY

Figure 1 illustrates the schematic depiction of the experimental configuration utilized for the fiber optic acoustic sensor, which enables the quantification of both the amplitude and frequency of acoustic signals derived from the produced sound. Acoustic testing was performed on the SMS optical fiber sensor that was designed. The schematic representation of the optical fiber sensor construction proposed for SMS (Singlemode-Multimode-Singlemode) operation. The FAL 25 audio frequency generator, manufactured by Pudak Scientific, is utilized for the purpose of generating an electric signal of a specific frequency. The device exhibits a frequency spectrum spanning from 0.1 Hz to 10 kHz, while operating on an input voltage of 110/220 AC V, incorporating fuse safety. The calibration process involves the utilization of an oscilloscope. The Audio Generator is linked in parallel to both the oscilloscope and the speaker. The speaker transforms the electrical signal generated by the audio generator into an acoustic signal, resulting in the production of sound.

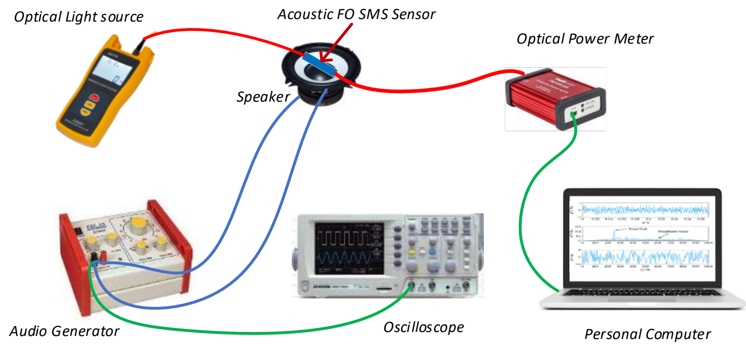

Figure 1. Schematic experimental set-up of fiber optic acoustic sensor for the measurement of amplitude and frequency from audio generator

When acoustic waves move through fibers, we can call acousto-optic effect[13], they cause pressure along the guide and change the way the material conducts electricity through a process called photoelasticity. The application of strain induces modifications in the impermeability tensor, resulting in corresponding variations in the effective refractive index n_{eff}, describe as equation 1)[13].

$$\Delta\left(\frac{1}{n_{eff}^2}\right)_i = \sum_{j=1}^{6} p_{ij}\varepsilon_j, \qquad i = 1, 2, 3, \ldots, 6 \qquad 1)$$

The components of the elasto-optic tensor, denoted as p_{ij}, are related to the j-th component of the strain field, represented as ε_j. The modulation of the features of the guided light in the structure can be achieved by altering the frequency and amplitude of the propagating acoustic wave.

Figure 2. is a structural representation of an SMS fiber configuration, which comprises two identical singlemode fibers (SMF) that are axially spliced at both ends of a multimode fiber (MMF). Changes in the refractive index value occur due to strains in the multimode structure due to external air pressure in the form of acoustic waves. This change in refractive index causes a change in the mmi pattern, which causes a change in the intensity value of the laser source received by the detector.

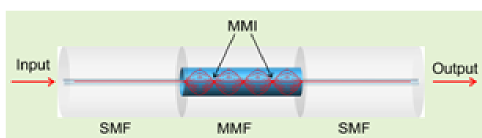

Figure 2. Schematic of SMS fiber structure

RESULT AND DISCUSSION

Figure 3 is the result of the oscilloscope reading of the sound signal output from the audio generator. The reading of the results by the oscilloscope is in the range of 30 to 70 Hz, based on multiples of 10 Hz. The average relative error is 0.20%; based on the relative error, it can be said that the output of the audio generator is close to the actual output frequency.

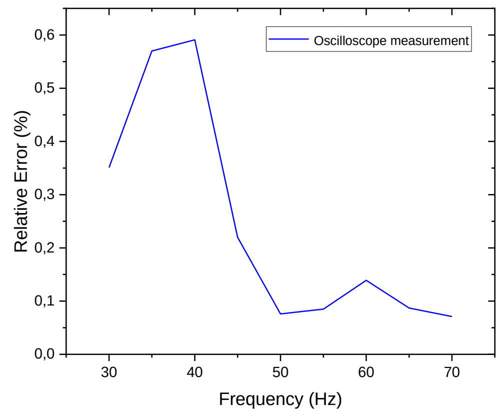

Figure 3. Output frequency read on the oscilloscope of the audio generator.

The SMS fiber-optic acoustic sensor is positioned above a speaker by suspending it from its central point. The central location refers to the step-index multimode fiber construction known as SMS. The acousto-optic phenomenon exerts an influence on the alteration of the refractive index magnitude within the SMS fiber optic configuration. The raw data of acoustic signal measurements at the output of the speaker's output signal within the amplitude range of -21.48 to -24.24 dBm can be seen in Figure 4. The gathering of raw data was conducted for a duration of 14 seconds per measurement. The purpose of this action was to get periodic data and prevent potential external disturbances originating from the immediate environment. The amplitude gain is measured in dBm units, representing the relative power reduction in light intensity caused by acousto-optic phenomena. The speaker output puts air pressure on the index-step multimode fiber optic structure, which changes the pattern of light interference inside the multimode structure.

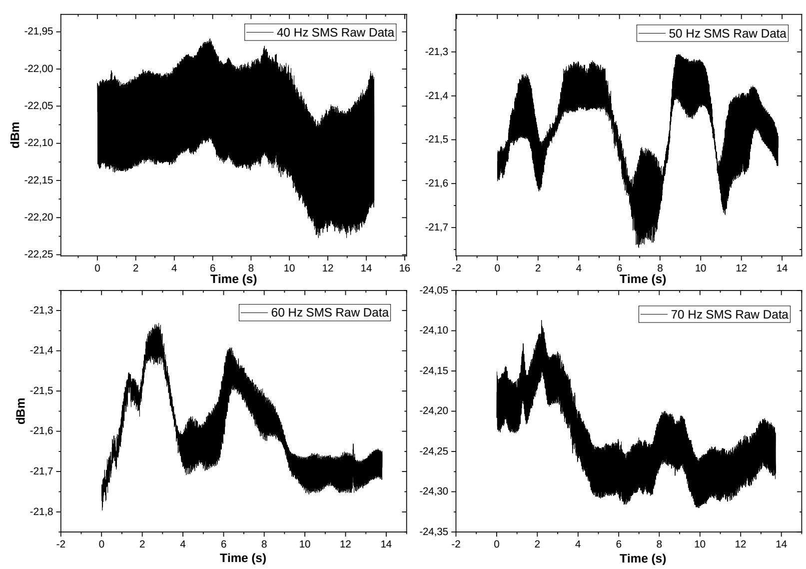

Fig. 4. Raw data on 40–70 Hz measurements from acoustic sensors of SMS Structure.

The recorded raw data from the SMS fiber optic sensor is then subjected to signal processing in the frequency domain using a fast Fourier transform (FFT) algorithm[14]. The FFT is performed at a frequency used for sampling of 356 Hz, enabling the determination of both amplitude and frequency values. The FFT spectra for acoustics at frequencies of 40, 50, 60, and 70 Hz are depicted in Figure 5. The Fast Fourier Transform (FFT) spectral response demonstrates the ability to accurately distinguish and quantify the amplitude and frequency components of the acoustic sensor's output. In addition, the spectrum exhibits higher harmonics. The relationship between sound amplitude and driving voltage exhibits greater variability at lower sound frequencies in comparison to higher sound frequencies.

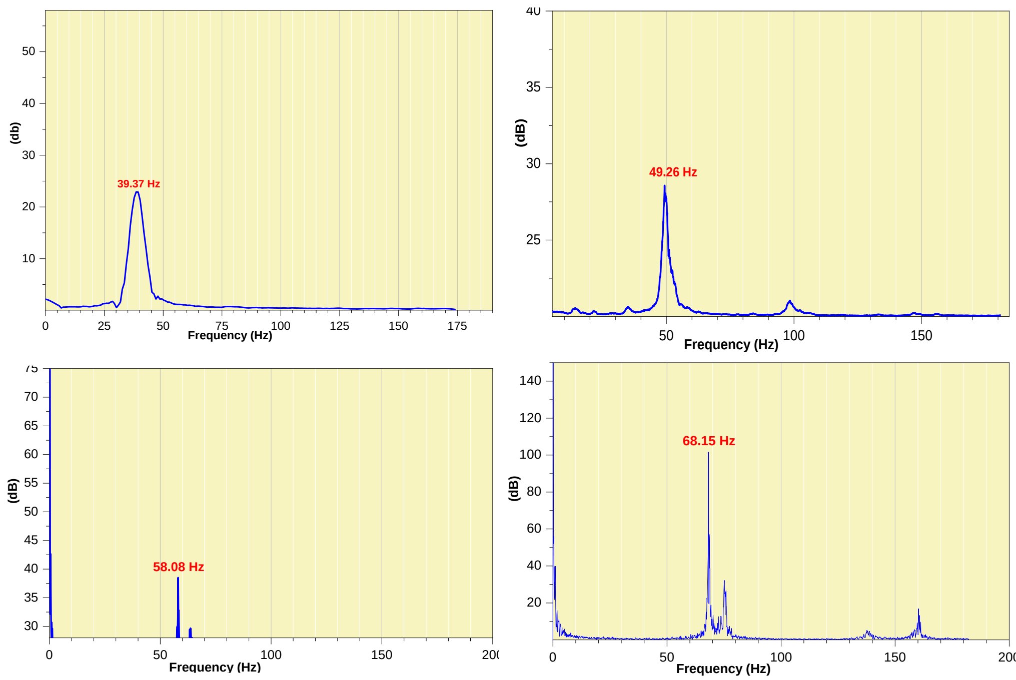

Figure 5. FFT spectrum displays at frequencies of 40–70 Hz and its amplitude value.

The measurement of sound waves generally requires energy that produces successive changes in the pressure of the air or particles in the medium through which they propagate. But in the use of this SMS fiber optic structure applied to the four measurements of the output frequency of the audio generator, the average relative error is 2.24%. The relative error of more than 1% is caused by several things. The first is the positioning of the SMS acoustic sensor, which is right at the end of both sides of the speaker, which can cause vibration distribution at both ends of the singlemode fiber structure, which causes interference between the sound waves received by multimode and the vibrations at both ends of the singlemode structure. Second, the potential sources of inaccuracy in sensor functioning may arise from fluctuations in the light source, the presence of stray light, and the occurrence of environmental noise.

CONCLUSION

An intrinsic fiber optic SMS structure has been proposed for the measurement of the amplitude and frequency of sound waves. The fiber optic sensor exhibits several advantageous characteristics, including simplicity, long-term stability, low power consumption, wide dynamic and frequency ranges, linearity, noise reduction, ruggedness, and a lightweight reflective surface mounted on the speaker. As a result, it presents a promising alternative to existing methods commonly used for measuring the amplitude and frequency of low frequency sound. The test results showed that the fiber optic SMS structure with multimode step index can be used as an acoustic sensor to pick up sounds between 30 and 70 Hz with a 2.24 percent error rate. More low-frequency acoustic waves need to be detected so that the ability of the SMS structure sensor to detect sound waves in a certain frequency range can be determined. The application of this experiment can be used as the initial stage of the application of fiber optic sensors in the biomedical field, especially phonocardiography using fiber optic sensors with low frequency. More low-frequency acoustic waves need to be detected so that the ability of the SMS structure sensor to detect sound waves in a certain frequency range can be determined.

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