# A simple 1x2 plastic optical fiber coupler based vibration sensor

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## ABSTRACT

A simple noncontact fiber optic vibration sensor is designed using multimode fiber optic coupler. The sensor works on principle of reflection intensity modulation. A single fiber port of the coupler is used as sensing head. A linear change in light intensity during its displacement from the reflecting surface within 1 mm of linear region shows a high sensitivity of 2.45 mV/µm which is used for the vibration measurement. Experimental results show that the sensor has the capability of measuring vibrations of frequencies up to 1300 Hz with ~1µm resolution of vibration amplitude over a range of 0-1mm. In comparison with dual-fiber and bifurcated-bundle fiber, this sensor eliminates the dark region and front slope which facilitates the easy alignment. The high degrees of sensitivity, economical along with advantages of fiber optic sensors are attractive attributes of the designed sensor that lend support to real time monitoring and embedded applications.

**Keywords:** Vibration sensor, Plastic fiber Coupler, displacement, LED, Photo-detector, Fast Fourier.

## 1. INTRODUCTION

Fiber optic sensors are playing vital role in sensing various physical parameters namely displacement, vibration, pressure, etc.. The advantages are being high sensitivity, immune to EMI and low cost of maintenance [1]. Basically there are two types of fiber optic sensors, one is based on phase modulation and the other is based on intensity modulation. Even though vibration sensors based on phase modulation provide very high performance, exhibit low stability and impose stringent mechanical requirements because of the critical alignment [2]. Consequently, they are having limitations in practice. Whereas the intensity modulation sensors having advantage of simple in design, easy alignment and economical [3].

In this paper, a simple geometrical intensity modulated vibration sensor was designed using a 1x2 fused plastic optical fiber fused coupler. This sensor works on the principle of reflective intensity modulation. In this design, a single fiber is used as a sensing probe to deliver the incident light as well as to collect the reflected light from the vibrating object. The easy alignment of proposed sensor is advantageous over the dual-fiber and bifurcated-bundle fiber vibration sensors by eliminating the dark region and disappear the front slope (positive slope) [4, 5]. So, the sensor consist only single slope that is back slope (negative slope) due to its geometry.

## 2. THEORY

The basic principle for the vibration measurement is intensity modulation due to the displacement of the reflecting surface glued to the vibrating target from the sensing fiber probe. The light guiding mechanism through the coupler is shown in fig. 1. A light source of power $P_a$ is coupled to the node 2 of the coupler and directed to the node 1. The light incident on the reflector via node 1 is reflected back into the same fiber (node1) and it is a function of the gap '$x$' between the sensing fiber probe (node 1) and the reflector. The power of light received by the photo-detector via node 3 is denoted by $P_d$ and is given by [6]

$$P_d = \frac{P}{2}\left(\frac{(2a)^2}{\left(2x\tan(\theta)\right)^2}\right)P_a \qquad (1)$$

Where $P_d = 1.15cr(1-cr)(10^{-0.1L} - 10^{-0.1D})^2$ is a constant, $a$ is radius of the fiber core, $\theta = \sin^{-1} NA$ is divergence angle of the fiber, $cr$ is coupling ratio of the coupler, $L$ is excess loss and $D$ is directivity of the coupler. The power

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received by the photo-detector is directly proportional to the square of the fiber diameter and inversely proportional to the square of the distance between sensing fiber probe and the reflector (Equation (1)).

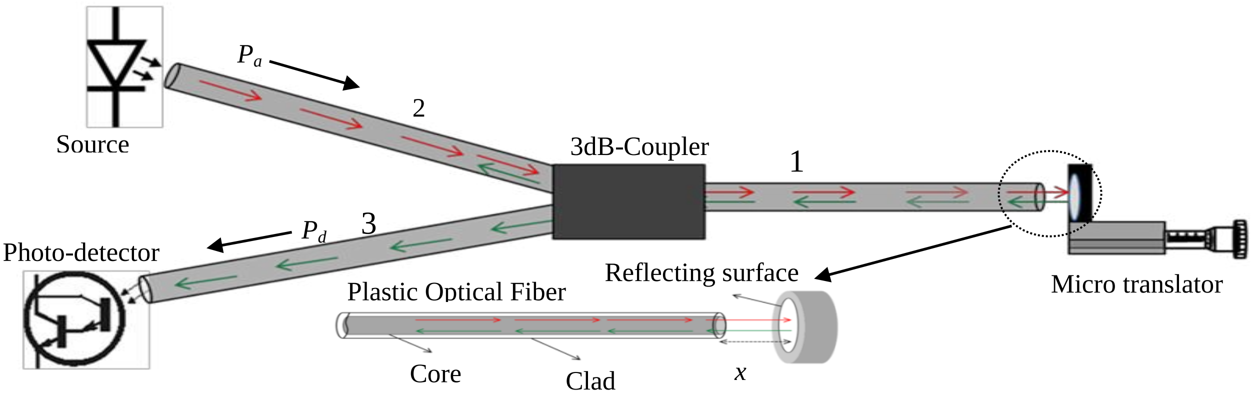


Fig. 1 Schematic of the sensor working principle.

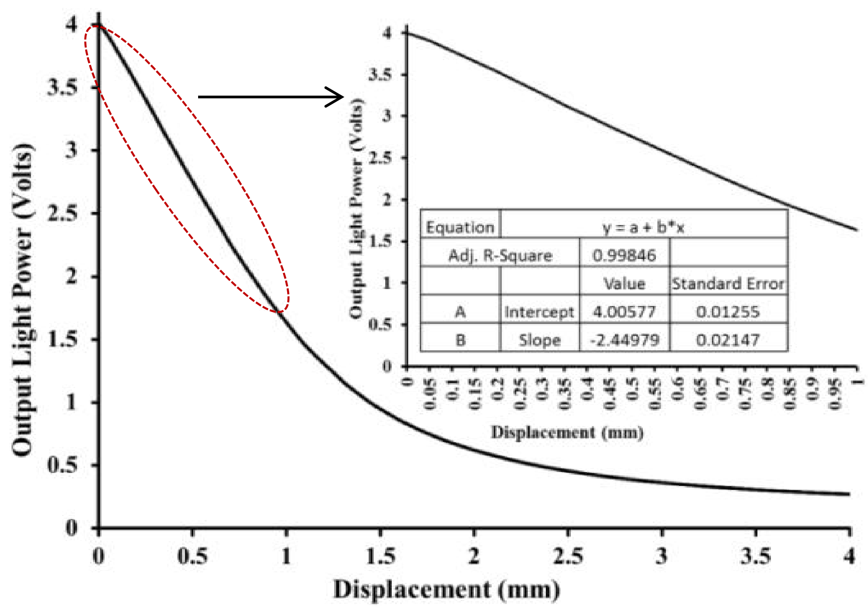


Fig. 2. Displacement characteristic curve of the Sensor.

## 3. EXPERIMENT

Fig. 1 shows the method to calibrate the amplitude of vibration of the sensor. A small reflector is glued to the surface of a rectangular block fixed to the micro translation stage perpendicular to the sensing head of the fiber coupler (IF-562, i-fiberoptics). The LED (IFE-96, i-fiberoptics) of wavelength 650 nm is coupled to the node 2 and the light is incident on the reflector through the node 1. The reflected light from the reflector is coupled back to the same fiber (node 1) and is incident on the photo-detector (IFD-93, i-fiberoptics) through the node 3. A digital multimeter (Protek 608) is used to measure the output light power in terms of the voltage with respect to the spacing between the reflector and the sensing head (node1) in steps of 10 µm over a span of 4000 µm and the characteristic curve is plotted as shown in fig. 2. It has a linear region of 0-1000 µm shown in sub-plot of fig. 2 with the slope of 2.45 mV/µm and is used to measure the amplitude of vibrations.

Fig. 3 shows the schematic experimental setup of the fiber optic vibration sensor. The whole setup is mounted on a vibration free table (Newport). A synthesized function generator (HM8130) and a commercial speaker with calibrated reflector attached at the centre of it are used to test the response of the sensor. The speaker is adjusted to place within the linear region of the displacement characteristic curve from the sensing head. The light is allowed to be incident on the reflector via node 1 and the modulated reflected light due to the vibration of the speaker is received by the same fiber. The light power received by the photo-detector is converted into its equivalent voltage signal by a simple receiving circuit. It is recorded and monitored by the storage oscilloscope (SM1060). The Fast Fourier Transform (FFT) technique is used to convert the time domain signal into frequency domain to analyse the vibrations in terms of frequency of the object and amplitude of vibration. The experiment is repeated for different frequencies and amplitudes (driving voltages) of vibrations.

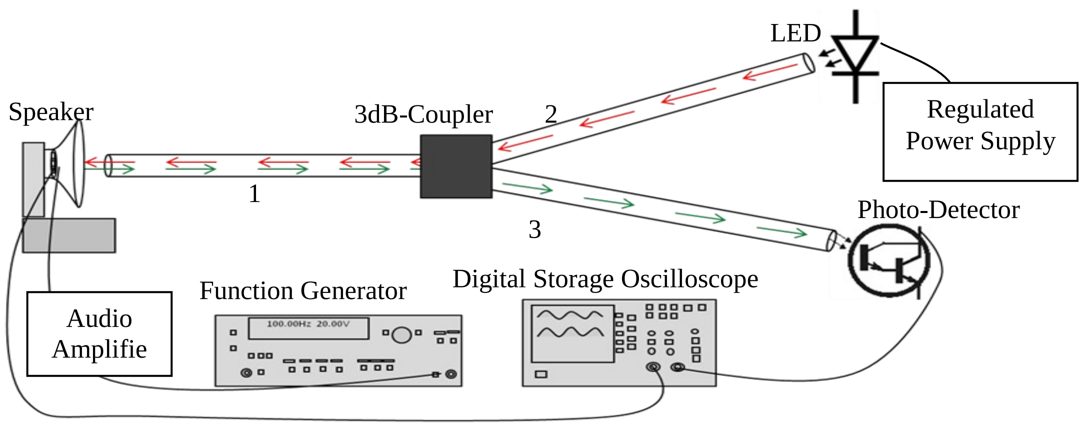


Fig. 3. Schematic diagram of the experimental Setup.

## 4. RESULTS AND DISCUSSION

The sinusoidal wave is applied to the speaker (CH1) and the response of the sensor (CH2) is recorded by the oscilloscope as shown in fig. 4. The FFT of both the signals gives the frequencies of the applied signal and the output signal of the sensor. It is evident from fig. 4 that there is a perfect matching in frequency between input and output signals. At constant vibration i.e. at constant driving voltage, the frequency range applied to the speaker is 0-1400Hz and measured the frequency of the vibrating speaker form the sensor output. The obtained results show the perfect matching between the frequencies applied to the speaker and measured by the sensor up to 1300 Hz. The amplitude response of the sensor between the driving voltage to the speaker and FFT peak voltage of the sensor output at different frequencies are plotted in fig. 5. From the slope of the displacement characteristic curve the sensitivity of the sensor is found to be 2.45 mV/µm. Experimentally the minimum amplitude resolvable by the sensor is 2 mV, which in turn gives a resolution of nearly 1 µm. The experiment is repeated for testing the reliability of the system and response of the sensor is found to be consistent.

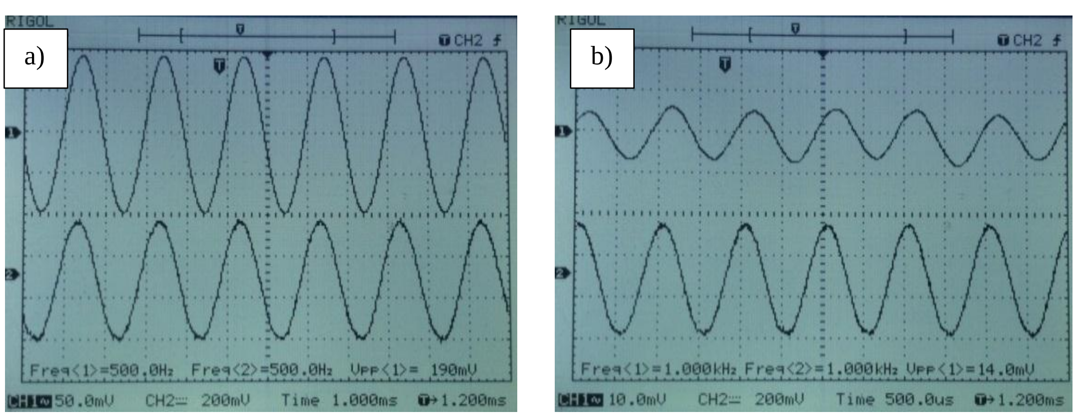


Fig. 4. Experimental Results of the sensor at a)500 Hz and b)1k Hz.

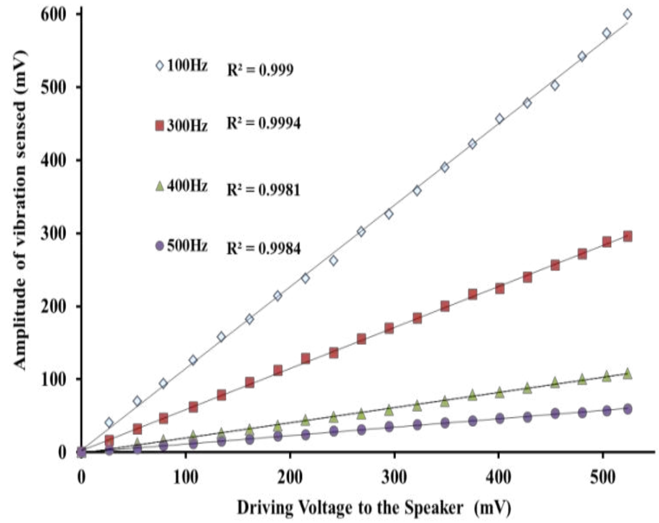


Fig. 5. Amplitude response of the sensor at different frequencies.

## 5. CONCLUSIONS

A simple intensity modulated noncontact vibration sensor has been reported using fiber optic fused 1x2-coupler. A single fiber is used as sensing head and consist only single slope with high sensitivity of 2.45 mV/µm about 1 mm linear region facilitating the easy alignment and accurate measurement. The sensor is capable of sensing the frequency range 0-1300 Hz with amplitude resolution of 1 µm. The simple design, light weight, immune to EMI, non-contact measurement, portability and of low-cost features of this sensor may find applications in engineering and industrial embedded systems.

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