Detection of seismic wave signal using singlemode-multimode-singlemode fiber probe

M. YASIN[1,*], RETNA APSARI[1], KRISTIA NINGSIH[1], Y. G. Y. YHUWANA[1], M. ZULKARNAEN[1],
MITRA DJAMAL[2], IRWAN MEILANO[2], MARIA EVITA[2], NINA SITI AMINAH[2], WAHYU SRIGUTOMO[2],
ARI SETIAWAN[3], HERLAN DARMAWAN[3], IMAM SUYANTO[3], WAHYUDI[3], WIWIT SURYANTO[3],
HERIANSYAH PUTRA[4], IRZAMAN[4], PERDINAN[4], S. W. HARUN[5]
[1]Department of Physics, Faculty of Science and Technology, Airlangga University, Surabaya 60115, Indonesia
[2]Department of Physics, Faculty of Mathematics and Science, Institut Teknologi Bandung, Bandung, Indonesia
[3]Department of Physics, Faculty of Mathematics and Science, Universitas Gadjah Mada, Yogyakarta, Indonesia
[4]Center for Disaster Studies, Institute of Research and Community Empowerment, IPB University, Kampus IPB Baranangsiang, Bogor, Indonesia
[5]Photonic Engineering Laboratory, Department of Electrical Engineering, University of Malaya, Kuala Lumpur, Malaysia

---

A fiber-optic sensor based on singlemode-multimode-singlemode (SMS) fiber structure was proposed and demonstrated for measuring both amplitude and frequency of seismic wave signal. This sensor system consisted of an amplified spontaneous emission (ASE), SMS fiber probe and photodiode detector. A seismic wave generator was used as a seismograph stimulator. The SMS fiber probe was attached onto a loudspeaker to gather an acoustic pressure which was modulated by a seismograph signal from the audio generator. The proposed seismic wave sensor has the capability to measure the seismograph signal operating within a frequency range from 2.0-2.6 Hz with a linearity of more than 98%. This sensor is advantageous due to its simplicity of the design and low fabrication cost while exhibiting good sensitivity and dynamic range. It is also suitable to be applied in real field to detect volcano eruption.

(Received December 1, 2021, accepted June 7, 2022)

Keywords: Fiber optic, SMS fiber structure, Energy efficiency, Seismograph signal

---

1. Introduction

The advanced dense seismic networks to detect microearthquakes have attracted attention in recent years for applications in various fields including volcano seismology and hydraulic fracture monitoring, as they reveal their activities and structure at depth [1-2]. The occurrence of earthquake is traditionally detected by comparing short term averages (STA) with to long-term averages (LTA) of transforming seismogram amplitudes and detection is declared when the ratio exceeds a predefined threshold [3]. Generally, a sudden increase in changing amplitude due to an impulsive earthquake phase arrival is rather straightforward to identify. However, because of the relatively weak signals buried in ambient noise and inadequate seismic networks, the detection of micro-earthquakes has been frequently overlooked [4-6]. Therefore, the improvement of the existing seismology technique to detect earthquake and its location are still required and many new techniques are also developed [ref].

Many optical techniques for detecting small vibration have also been reported in many literatures. One of the most popular techniques is based on the interferometer, where a laser signal beam is directed onto a vibrating target, and back-reflected light is recombined with part of the incident light [7-8]. The performance of this technique is excellent, but it is costly and requires stringent mechanical alignment. Another approach is to exploit the Doppler effects [9], but this method is not accurate enough for the precise measurement of minimal displacement as well as quite expensive.

Recently, a singlemode-multimode-singlemode (SMS) fiber structure has also attracted increasing interest for various sensing applications due to its high sensitivity and low cost [10–12]. For instance, Kumar et al. [10] demonstrated static mechanical micro-bent measurement using a SMS fiber sensor. On the other hand, an effective near-surface seismic monitoring system must use measurements with sufficient resolution to provide early warnings before seismic activities develop and earthquakes occur. Low-cost, low-maintenance dense arrays at kilometer scales and beyond are now possible thanks to fiber-optic distributed acoustic sensing (DAS) techniques. The DAS provides new opportunities for near-surface seismic monitoring.

In this paper, a SMS structure is proposed and demonstrated for the measurement of amplitude and frequency of seismograph signal. The signal was generated by seismograph generator. The proposed sensor is based on intensity modulation technique and uses a SMS fiber structure as a probe. This technique is the improvement of the previous work [13-14].

2. Experimental setup

The schematic diagram of the proposed SMS-based sensor is presented in Fig. 1. Inset of Fig. 1 shows a schematic diagram of the SMS fiber structure consisting of a multimode fiber (MMF) section, which was spliced in between two single mode fibers (SMFs). When the light transfers from the SMF to the MMF, a series of eigenmodes are excited in the MMF. These eigenmodes then experience multimode interference while propagating in the MMF and lastly couple back to the output SMF to generate interference. A fabrication of the SMS fiber structure is carried out by using a commercial fusion splicer. The MMF is a step-index type with a core diameter of 105 µm and a length of about 10 mm. It is connected at both ends to a step-index SMF with a core diameter of 8.2 µm. For a principal operation of seismograph monitoring by using the SMS fiber structure, an artificial seismograph wave is generated by the seismic wave generator to simulate the seismograph signal at different frequency ranging from 2.0 Hz to 2.6 Hz. The signal is amplified and transferred into mechanical vibration by the audio amplifier and the loudspeaker. The optical light source (ASE) with a peak wavelength of 1550 nm is launched onto the SMS fiber probe while the MMF was placed in the center of the loudspeaker. A tape with a diameter of 15 mm was used at both ends of the MMF to fix the sensor probe. The output power from the SMS fiber structure is recorded by the optical voltmeter meter. Meanwhile, the generated seismograph signal is measured and captured by the oscilloscope. When the light transmits from the SMF to MMF and then SMF, due to the multimode interference effect, the interference spectrum is observed at the output. The change of external condition induced by the seismic wave can change the interference intensity distribution in the MMF, which can accordingly be detected by the change of transmission of the light.

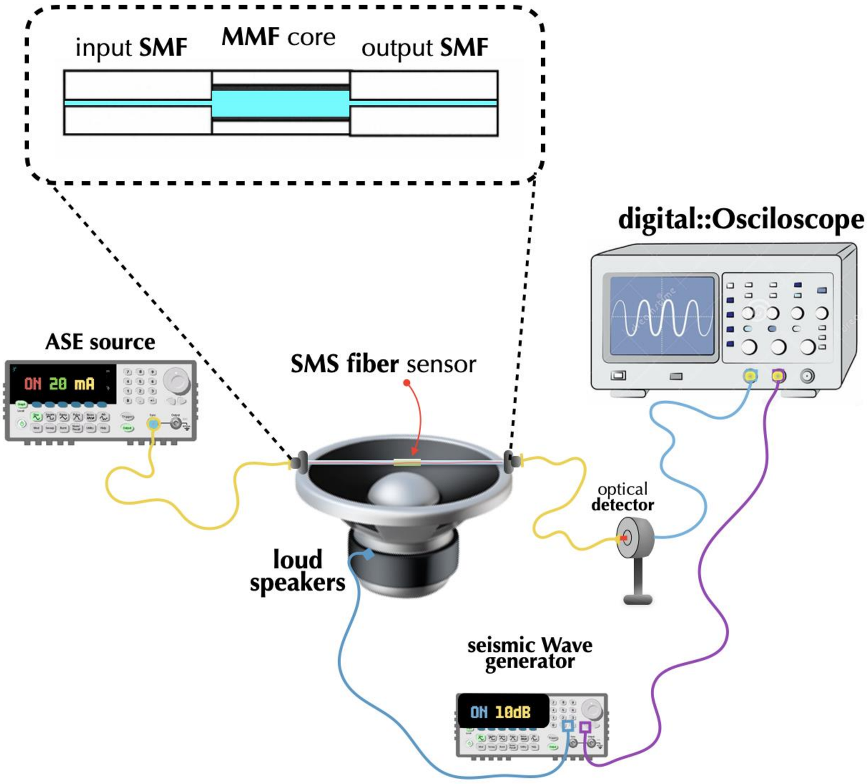

Fig. 1. Experimental setup for monitoring the seismic wave signal using a SMS fiber structure as a sensor probe (color online)

3. Result and discussions

For the seismic wave measurement, at first, the SMS fiber probe is placed in the centre of the speaker when it is set at zero vibration condition. As the driving voltage is given, the vibration is detected by the sensor. It is observed that the proposed sensor can measure seismic wave signal within a frequency range of 2.0-2.6 Hz. Fig. 2 (a), (b), (c) and (d) shows the measured pulse signal at different frequencies of vibration; 2.0, 2.2, 2.4 and 2.6 Hz, respectively. In the experiment, the input signal is detected after seismic wave generator while the output pulse signal that comes out from the receiving fiber is measured using a silicon detector. It is observed that the output signal is weaker but still follows the pattern of input signal. Fig. 3 compares the fast Fourier transform (FFT) of the seismograph signal between the input signal from the wave generator and the signal detected by the photodetector at frequency of 2.0 Hz. As expected, the frequency of the output signal matches the frequency of the seismograph signal very well.

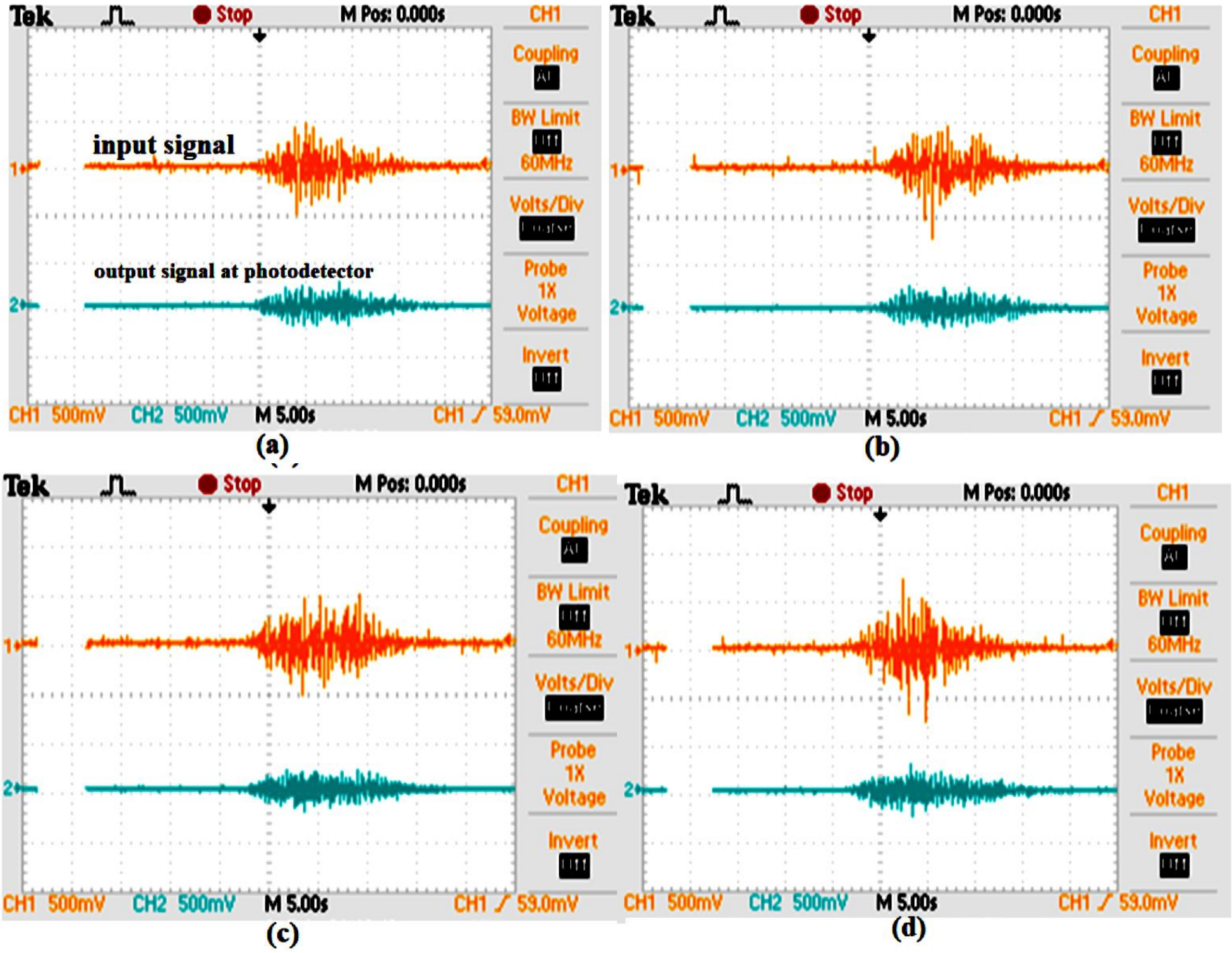

Fig. 2. Comparison of seismic wave signal from the generator and sensor output at different dominant frequencies of (a) 2.0 Hz (b) 2.2 Hz (c) 2.4 Hz and (d) 2.6 Hz (color online)

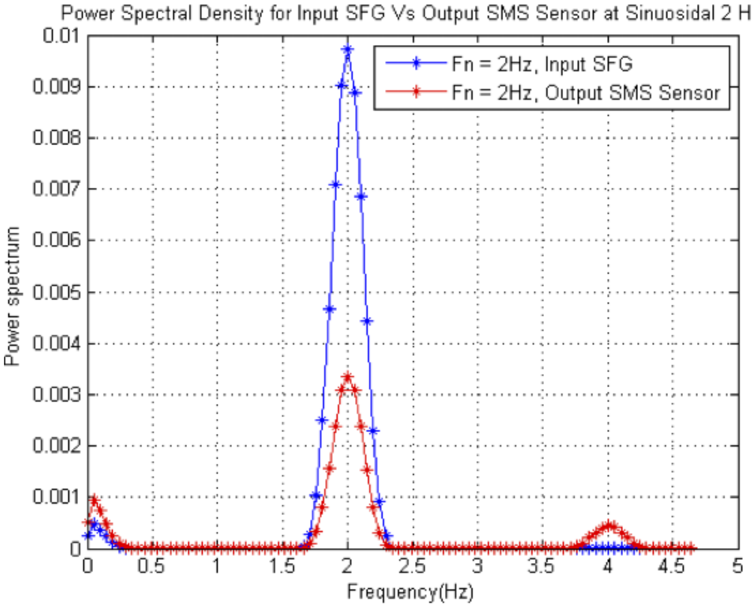

Fig. 3. FFT power spectral density at 2.0 Hz (color online)

Fig. 4 plots the relation between the measured frequency from the output sensor and the input frequency from the seismograph generator. It shows a linear function with a slope of more than 0.99 for seismograph module frequency from 2.0 to 2.6 Hz. Fig. 5 shows the relationship between the measured output amplitude at the photodetector and the input amplitude from the seismograph generator when the frequency was fixed at 2.0 Hz. It is shown in the figure that the variation of seismograph amplitude of the output sensor has a linear function relation with the input amplitude of seismograph. With the increase of acoustic pressure on the SMS probe, the output voltage signal of the photodetector increases accordingly. The slope is obtained with 0.95 linearity. This result indicates that the proposed sensor can accurately estimate the amplitude of the seismograph signal. The simplicity of the design, high degree of sensitivity, dynamic range and the low cost of the fabrication make it suitable for real field applications.

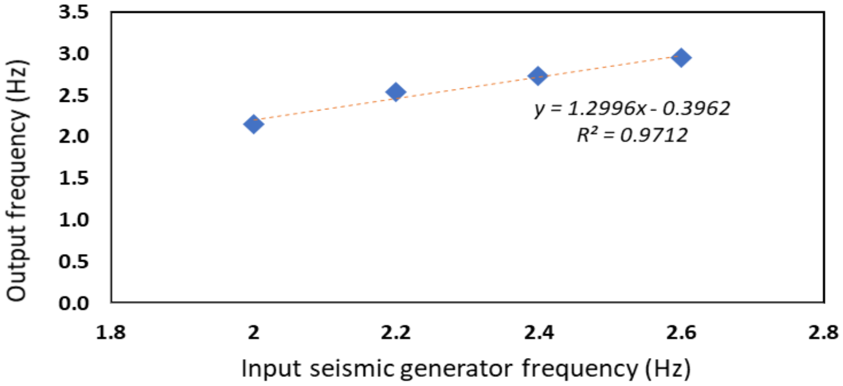

Fig. 4. Output frequency versus input frequency of the sensor (color online)

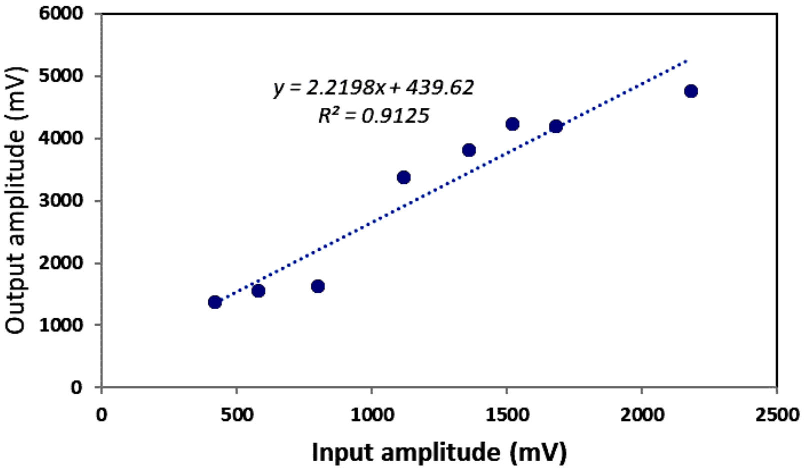

Fig. 5. Peak amplitude versus input amplitude of the seismic wave signal when the sensor operating at 2.0 Hz (color online)

4. Conclusion

An intrinsic SMS fiber structure as sensor probe has been successfully demonstrated to measure the amplitude and frequency of the seismograph signal. The sensor setup consists of SMS fiber structure, ASE of light source and photodiode detector while a seismograph stimulator was used in the testing. The SMS fiber probe was mounted on the loudspeaker to gather an acoustic pressure which was modulated by a seismograph signal from the audio generator. The sensor is capable of measuring seismograph within a frequency range of 2.0 – 2.6 Hz with more than 99% linearity. The sensor could be applied to monitor the vibration signal of a volcano eruption.

Acknowledgments

This work was financially supported by Indonesia Government and Riset Kolaborasi Indonesia (RKI) through Airlangga University – Word Class University - 2020.

References

[1] Hwajung Yoo, Sehyok Park, Linmao Xie, Kwang-Il Kim, Ki-Bok Min, Jonny Rutqvis, Antonio Pio Rinaldi, Geothermics **89**, 101982 (2021).
[2] Philip M. Benson, David Carlo Austria,

Stephan Gehne, Emily Butcher, Claire E. Harnett, Marco Fazio, Pete Rowley, Ricardo Tomas, Geomechanics for Energy and the Environment **24**, 100169 (2020).
[3] R. Allen, Bull. Seismol. Soc. Am. **72**, S225 (1982).
[4] Tsiriandrimanana Rakotondraibe, Andrew A. Nyblad, Michael E. Wysession, Raymond J. Durrheim, Gérard Rambolamanana, Ghassan I. Aleqabi, Patrick J. Shore, Martin J. Pratt, Fenitra Andriampenomanana, Georg Rümpker, Tectonophysics **790**, 228547 (2020).
[5] Kwang-Il Kim, Ki-Bok Min, Kwang-Yeom Kim, Jai Won Choi, Kern-Shin Yoon, Woon Sang Yoon, Byungjoon Yoon, Tae Jong Lee, Yoonho Song, Renewable and Sustainable Energy Reviews **91,** 1182 (2018).
[6] Shaoqian Hu, Huajian Yao, Tectonophysics **744**, 1 (2018).
[7] P. J. Pinzo, D. S. Montero, A. Tapetado, C. Vazquez, IEEE J. Sel. Top. Quantum Electron. **23**, 5600406 (2017).
[8] Zhenan Jia, Xianfeng Zhao, Wei Fan, Hong Gao, Qinpeng Liu, Zhen Yong, Yinggang Liu, Kaiqing Yang., Optical Fiber Technology **61**, 102447 (2021).
[9] K. Yuan, W. D. Zhu, Mechanical Systems and Signal Processing **155**, 107606 (2021).
[10] A. Kumar, R. K. Varshney, R. Kumar, Opt. Commun. **232**, 239 (2004).
[11] A. Sun, Y. Semenova, G. Farrell, Technol. Lett. **53**(2), 442 (2011).
[12] Q. Wu, M. Yang, J. Yuan, H. P. Chan, Y. Ma, Y. Semenova, P. Wang, C. Yu, G. Farrell, Opt. Laser Technol. **63**, 29 (2014).
[13] M. Yasin, Retna Apsari, Kristia Ningsih, Y. G. Y. Yhuwana, M. Zulkarnaen, Mitra Djamal, Irwan Meilano, Maria Evita, Nina Siti Aminah, Wahyu Srigutomo, Ari Setiawan, Herlan Darmawan, Imam Suyanto, Wahyudi, Wiwit Suryanto, Heriansyah Putra, Irzaman, Perdinan, S. W. Harun, Optik **208**, 164554 (2020).
[14] M. Yasin, M. Zulkarnaen, Samian, A. H. Zaidan, Y. G. Y. Yhuwana, H. Trilaksana, S. W. Harun, J. Optoelectron. Adv. M. **21**(9-10), 558 (2019).

---

[*] Corresponding author: yasin@fst.unair.ac.id