Optimization of the Output Wavelength of an Optically Amplified Feedback Circuit for a Multi-wavelength Optical Sensing System

Biswajit Biswas, MD Syful Islam, Kokoro Kitamura and Hiroji Masuda

Graduate School of Natural Science and Engineering, Shimane University

Abstract **We propose a novel optical-power sensing method using an optically amplified feedback circuit and investigate output-wavelength dependence of the performance of the circuit. We experimentally optimize the output-wavelength of the circuit (1553 nm) for a multi-wavelength optical sensing system application, and achieve a significantly large improvement factor of 418 at the optimum wavelength.**

1. Introduction

Highly sensitive optical power sensing is indispensable for realizing advanced photonic systems such as optical communication and optical measurement systems [1-4]. Improving the sensitivity of the power variation is beneficial in the application. Our proposed method called "optically amplified feedback circuit (OAFC) method" that can significantly improve the optical power resolution in photonics applications [4-10]. In this study, we report the output-wavelength dependence of performance of the OAFC method for a multi-wavelength optical sensing application [4].

2. Experimental configuration

The experimental configuration of our proposed OAFC is shown in Fig.1. We used the pump light of erbium doped fiber (EDF) as the input light of this system. The input light can be chosen as the signal light of the EDF, if needed, as in the cases of [5, 6]. The input light (pump light) was emitted from a pump light source (PLS), which was a Fabry-Perot laser diode module. The wavelength of the input light was ~1470 nm. The PLS is driven with a constant current and an optical variable attenuator (VOA) is installed at the rear stage of the PLS to change the input optical power at the EDF input. The input light is branched for monitoring its power by a branch fiber module (BR) and measured by an optical power meter (PM1).

The gain medium of the OAFC is an EDF and the feedback path has a fiber ring configuration. An optical isolator (ISO) is set at each side of the EDF in order to eliminate the counter-clockwise propagating light and the residual reflection. The input light is coupled into the fiber ring circuit using an optical coupler (CP) and the residual pump emitted from the EDF is eliminated by a pump rejection optical filter (PR). An optical bandpass filter (OBPF) is set after the EDF section. A polarization controller (PC) is set after the OBPF. Moreover, another branch fiber module (BR) is set after the PC. An optical attenuator (ATT) is installed after BR in the loop.

We obtain the light branched by the BR in the loop as the output light of the OAFC. The optical power and wavelength of the output light are measured by an optical power meter (PM2) and an optical spectrum analyzer (OSA), respectively, where PM2 and the OSA are set after the BR in the loop. The center wavelength of the OBPF (λ_c) was changed to be 1548, 1553, 1558, 1563 and 1568 nm. The input and output light powers for the OAFC are labeled as P_{in} and P_{out} in dBm units, respectively.

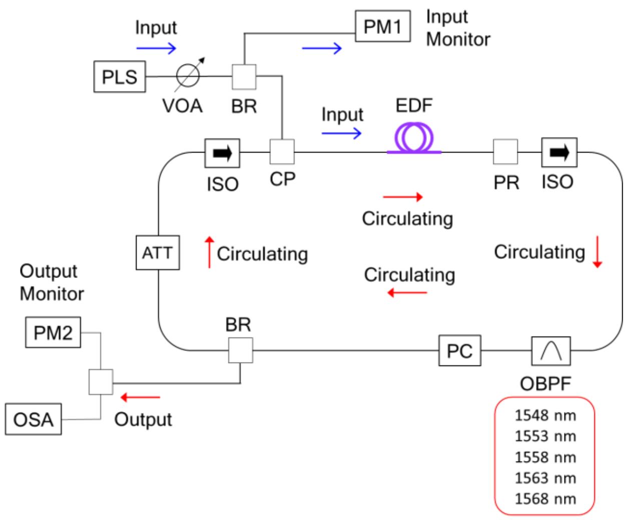

Fig. 1 Experimental configuration

3. Experimental Results

The performance of the OAFC is shown in Fig. 2 where output power P_{out} is plotted as a function of the input power P_{in}. Figure 2 shows the input-output characteristics in dBm in the cases with the OBPF wavelengths of 1548, 1553, 1558, 1563 and 1568 nm. Figure 2 also shows that P_{out} increased nonlinearly with P_{in}. The center wavelength of the output light spectrum measured by the OSA coincided with the center wavelength of the OBPF λ_c.

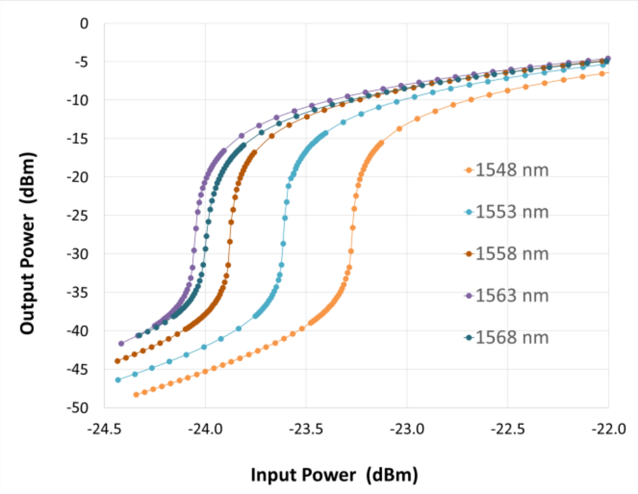

Fig.2 Output power vs. Input power

The slope (S) is shown as a function of P_{in} in Fig. 3. The slope S is defined as the ratio of the variation in P_{out} in dB ($\triangle P_{out}$) to the variation in P_{in} in dB ($\triangle P_{in}$): $S = \triangle P_{out}/\triangle P_{in}$. The slope S indicates the value of the improvement in the optical power resolution thanks to using the OAFC method [4]. Let denote the maximum value of S to be S_{max} for each curve in Fig. 3.

S_{max} is 381 at λ_c = 1548 nm and P_{in} = −23.3 dBm. Moreover, S_{max} is 418 at λ_c = 1553 nm and P_{in} = −23.6 dBm, S_{max} is 382 at λ_c = 1558 nm and P_{in} = −23.8 dBm, S_{max} is 287 at λ_c = 1563 nm and P_{in} = −24.1 dBm, and S_{max} is 277 at λ_c = 1568 nm and P_{in} = −24.0 dBm.

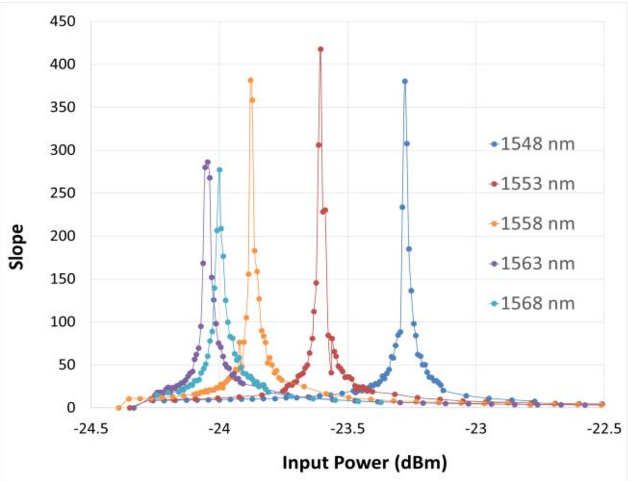

Fig.3 Slope vs. Input power

From Figs. 2 and 3, the nonlinear response in the input vs. output relation in the optical powers is the origin of the improvement in the optical power resolution. It is considered that the nonlinear response is caused by the optical power transfer process from the input- to output-lights and the optical filtering effects of amplified spontaneous emission in the circulating loop.

From the curves of plots shown in Fig. 3, we can more accurately measure and determine the peak values of the slope if we set the input power by a smaller step. Therefore, the measured peak values are approximate values at this time. We will measure the slope by a smaller step and will show the results based on the experiment in another paper in the future.

The stability and reproducibility of the input-output relation of optical powers of the OAFC were evaluated in our earlier study [4]. Some sufficient degree of reproducibility was confirmed in a few minutes of the operation duration of the OAFC in the case of a slope of ~32 in the study. It is considered that sufficient degrees of reproducibility will be achieved if there are no excess noise in the OAFC, whereas the excess noise is considered to be caused by some changes in the environmental conditions such as temperature and vibration. There were no significant time variations of the measured output powers in this experiment. The details of the stability and reproducibility of the OAFC described in this paper will be confirmed and reported in another paper in the future.

Figure 4 shows S_{max} as a function of λ_c. We can clearly see the wavelength dependence of performance of the OAFC. S_{max} are 381, 418, 382, 287, 279 at λ_c of 1548, 1553, 1558, 1563 and 1568 nm, respectively. Therefore, the maximum value of S_{max} is 418 at λ_c of 1553 nm. The reason why the wavelength of 1553 nm gives the largest slope is not clear at this time. We think the reason is an important issue in the future.

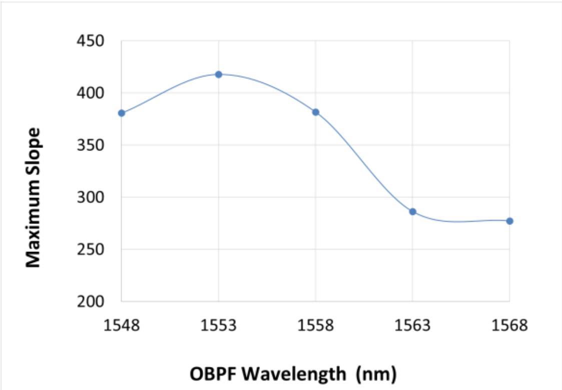

Fig. 4 Maximum slope as a function of OBPF wavelength

We will show some results on the optical spectrum of the output light emitted from the OAFC in another paper in the future. We can further understand the operation and characteristics of the OAFC from the results.

4. Conclusion

We proposed a novel configuration of an optically amplified feedback circuit for multi-wavelength optical sensing applications. By using the configuration, we successfully clarified the output-wavelength dependence of the performance of the circuit. We achieved a maximum slope value S_{max} of 418 at the optimized output-wavelength of 1553 nm, where S_{max} equals to the improvement factor in the optical power resolution for the optical sensing applications.

References

[1] G. P. Agrawal, Fiber-Optic Communication Systems, 4th ed., John Wiley & Sons, Inc. (2002).

[2] B. E. A. Saleh and M. C. Teich, Fundamentals of Photonics, 2nd ed., John Wiley & Sons, Inc. (2007).

[3] https://www.keysight.com.

[4] H. Masuda and K. Kitamura, “Highly sensitive optical sensing scheme using erbium-doped fiber ring circuit,” The 7th Asia-Pacific Optical Sensors Conference (APOS), Wed-6 (2018).

[5] K. Kitamura and H. Masuda, “Nonlinear Characteristics of a Fiber Ring Circuit with a Semiconductor Optical Amplifier for Sensing Applications,” The 23rd OptoElectronics and Communication Conference (OECC), 3C1-3 (2018).

[6] K. Kitamura and H. Masuda, “Optically Amplified Feedback Circuit using a Laser Diode for Optical Power Sensing,” The 23rd MicroOptics Conference (MOC), P.26 (2018).

[7] H. Masuda, K. Kitamura, MD Syful Islam, and Biswajit Biswas, “Optically Amplified Feedback Circuit with High Improvement in Optical Power Resolution,” MC2-5, OECC (2019)

[8] H. Masuda and K. Kitamura, “Optically Amplified Feedback-Circuit Scheme for Optical Measurement Applications with Significantly Improved Optical-Power Resolutions,” IEICE Society Conference (2019)

[9] Biswas Biswajit, MD Syful Islam, K. Kitamura, and H. Masuda, “Output Wavelength Dependence of the Performance of an Optically Amplified Feedback Circuit,” IEICE Society Conference (2019)

[10] MD Syful Islam, Biswas Biswajit, K. Kitamura, and H. Masuda, “Loop Loss Dependence of the Performance of an Optically Amplified Feedback Circuit,” IEICE Society Conference (2019)