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Effect of SNR of Input Signal on the Accuracy of a Ratiometric Wavelength Measurement System

Ginu Rajan

Technological University Dublin, ginu.rajan@tudublin.ie

Qian Wang

Technological University Dublin, qian.wang@tudublin.ie

Gerald Farrell

Technological University Dublin, gerald.farrell@tudublin.ie

See next page for additional authors

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Authors

Ginu Rajan, Qian Wang, Gerald Farrell, Yuliya Semenova, and Pengfei Wang

Effect of SNR of input signal on the accuracy of a ratiometric wavelength measurement system

Ginu Rajan, Qian Wang, Gerald Farrell, Yuliya Semenova and Pengfei Wang
Applied Optoelectronics Centre, School of Electronics and Communication,
Dublin Institute of Technology, Kevin Street, Dublin-8, Ireland
ginu.rajan@student.dit.ie

Abstract:

The impact of a change in SNR of the input signal on the accuracy of a ratiometric wavelength measurement system is studied. The variation of the output ratio of the system due to the change in SNR of the input signal is modeled and the experimental investigation has been carried out, and both indicate that the accuracy is influenced significantly by variations in the SNR of the input signal. The demonstration example shows a wavelength shift of 0.055 nm when the SNR of the input signal varies from 47 dB to 42 dB (the measurable range is from 1500 nm to 1600 nm and the edge filter used has a slope of 0.15 dB/nm).

Keywords:- Ratiometric system, edge filter, SNR

Introduction

Wavelength measurement is involved in many optical systems such as dense wavelength division multiplexing (DWDM), and optical sensing based on fiber Bragg gratings (FBGs) [1,2] where an accurate measurement of wavelength is needed. Among different wavelength measurement schemes, a ratiometric detection scheme [3-6] employing an edge filter has a simple configuration which uses the transition region of the filter's transmission response and converts wavelength measurement to a signal intensity measurement. The different edge filters used are bulk thin film filters [3], biconical fiber filters [4], fiber gratings [5], macro bend singlemode fiber [6] etc. In principle a ratiometric scheme should allow for the measurement of the wavelength of an input signal without a dependency on other parameters of the input signal such as signal power or SNR. In practice, the input signal has a limited signal-to-noise ratio (SNR), and it has been proven in a previous investigation [7] that the SNR limits the slope of the edge filter and measurement range of the system. In this letter the accuracy of a ratiometric system is investigated theoretically and experimentally, taking into account the effect of the SNR of the input signal, which indicates that variations in the SNR have a significant influence on the system's accuracy.

Analysis of the impact of SNR on ratiometric system

The schematic configuration of the ratiometric wavelength measurement system based on a macrobending fiber filter is shown in Fig.1. The input signal is split into two signals. One passes through a reference arm and the other passes through the bending fiber. The macrobending fiber acts as an edge filter as in Ref. [6]. Two photodetectors are placed at the ends of both arms. The system effectively operates as a discriminator, where the ratio of the power levels reaching the photodetectors is wavelength dependent. The wavelength of the input signal can be determined,

assuming a suitable calibration has taken place, using the ratio of the electrical outputs of the two photodetectors [7], which is:

$$R(\lambda_0) = -10 \log_{10} \left[\frac{\int S_{1\lambda_0}(\lambda) I_{\lambda_0}(\lambda) T_f(\lambda) d\lambda}{\int S_{2\lambda_0}(\lambda) I_{\lambda_0}(\lambda) d\lambda} \right] \quad (1)$$

Where $S_1(\lambda)$ and $S_2(\lambda)$ are the transmission responses of the arms of the splitter. $T_f(\lambda)$ is the transmission response of the edge filter and $I_{\lambda_0}(\lambda)$ is the spectrum of the input signal. In practice, the light from a tunable laser or reflected by an FBG element has a limited signal-to-noise ratio. Assuming for convenience a source with a power of 0 dBm at the peak wavelength, then as in Ref. [7], the spectrum of such an input signal can be modelled as:

$$10 \log_{10}[I_{\lambda_0}(\lambda)] = \begin{cases} 10 \log_{10} \left[\exp(-4 \ln 2 \frac{(\lambda - \lambda_0)^2}{\Delta \lambda_0^2}) \right], & |\lambda - \lambda_0| \leq \Omega \\ -S(\lambda) + Rand.Rs, & |\lambda - \lambda_0| > \Omega \end{cases} \quad (2)$$

S is the SNR for the source in dB. To describe the random fluctuations in the noise floor of the optical source, the term $Rand.Rs$ is used, where $Rand$ is a random number (between +1 and -1) and Rs is a parameter in dB which dictates the peak fluctuation in the SNR and is dependent on the nature of the source. Ω is a parameter which is determined by the noise level and can be determined for a source with a given SNR

from the relationship $10 \log_{10} \left[\exp \left(-4 \ln 2 \frac{\Omega^2}{\Delta \lambda_0^2} \right) \right] = -S$.

Using the above equations a system with an edge filter with a discrimination range of 25 dB and a 3 dB coupler which splits the input signal is modelled for different SNR values, for a wavelength range 1500 nm to 1600 nm. The modelled results are shown in Fig. 2 and it can be seen that different SNRs produce a discrimination characteristic which is not the linear ideal. In practice, when the SNR of the input signal changes,

the measured wavelength will be an error where the original calibration curve designed for a different SNR is used. Fig. 3 shows a numerical example of the influence of SNR on output ratio for a fixed wavelength. Assume the wavelength of the input signal is 1520nm and the slope of the edge filter is 0.25dB/nm. When the SNR decreases from 50 dB to 45 dB, the calculated ratio variation is 0.0042dB which would lead to a wavelength error of 0.017 nm. Thus it is seen that for a system SNR changes will have a significant impact on the wavelength accuracy of the system.

For low SNR values another source of error can also be deduced from Fig. 2. For high values of SNR, for example 50 dB, the slope of the characteristic is close to the ideal. However for low values of SNR, below 30 dB, the slope is much lower. For example over the wavelength range 1550 nm to 1600 nm the slope with a 50 dB SNR is 0.25 dB/nm, whereas for an SNR of 30 dB the slope is less than 0.1 dB/nm. The consequence of the reduced slope is decreased measurement accuracy, particularly for low optical input powers, because of electrical noise and the limited resolution of the electrical subsystems that process the photodiode electrical power outputs.

Experimental Investigation

To verify the influence of SNR on the ratiometric system accuracy experimentally, a ratiometric wavelength measurement system based on the macrobending singlemode fiber was built with a slope of approximately 0.15 dB/nm. The test source used was a tunable laser for which the SNR varies from 47 dB to 42 dB when tuning the power from 0 dBm to -5 dBm respectively. The system is calibrated for the discriminator characteristic for an SNR of 47dB. The ratio is measured for a wavelength range of 1500 nm to 1600 nm at 0 dBm and -5 dBm, respectively. The variation in the ratio is presented in Fig. 4. A comparison with the simulated results is also presented which show that both are in good agreement and which clearly emphasises the effect of SNR

on the system. To estimate the wavelength inaccuracy with the changes in the SNR, the variation in ratio and the corresponding wavelength shift for 1520 nm is obtained. The measured ratio variation at different SNR and its comparison with the simulated results are shown in Fig. 5. The measured and simulation results show how the ratio of the system changes with SNR. It is seen that the variation of the ratio is 0.0087 dB when the SNR decreases from 47 dB to 42 dB. Any change in ratio leads to a wavelength measurement error. To illustrate this, the corresponding variation in wavelength measured is shown in Fig. 6 for a step change in SNR. It can be seen that the wavelength error reaches 0.055 nm due to the change of SNR of 5 dB.

Conclusion

The wavelength inaccuracy in a ratiometric measurement system employing an edge filter has been studied theoretically and experimentally. It has been shown that a different SNR for the input signal corresponds to different effective discrimination characteristics. It is been demonstrated that for a wavelength of 1520 nm when the SNR varies from 47 dB to 42 dB the measured wavelength error is 0.055 nm for a system with a slope of 0.15 dB/nm. This suggests that when there is a change in the SNR of the input signal, e.g., where a ratiometric system is switched to a different source, a re-calibration will be required due to the influence of the SNR on the system's accuracy.

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Figure captions:

Figure. 1. Schematic of a fiber bend loss ratiometric wavelength measurement system

Figure. 2. Ratio of an edge filter at different SNR

Figure. 3. Variation in ratio when SNR changes from 50dB to 45dB

Figure. 4. Ratio variation when SNR changes from 47dB to 42dB and its comparison with simulation result

Figure. 5. Comparison of measured and modelled ratio variation

Figure. 6. The measured wavelength shift when SNR changes from 47dB to 42dB

Figure 1

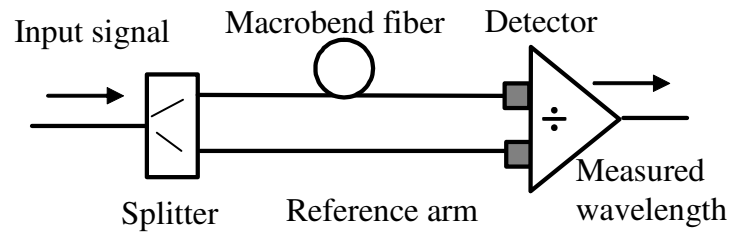


Figure 2

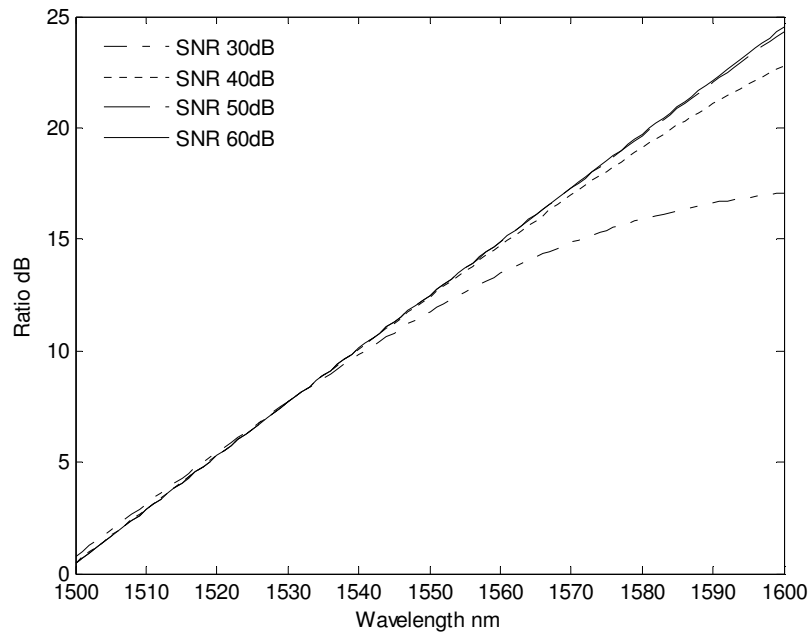


Figure 3

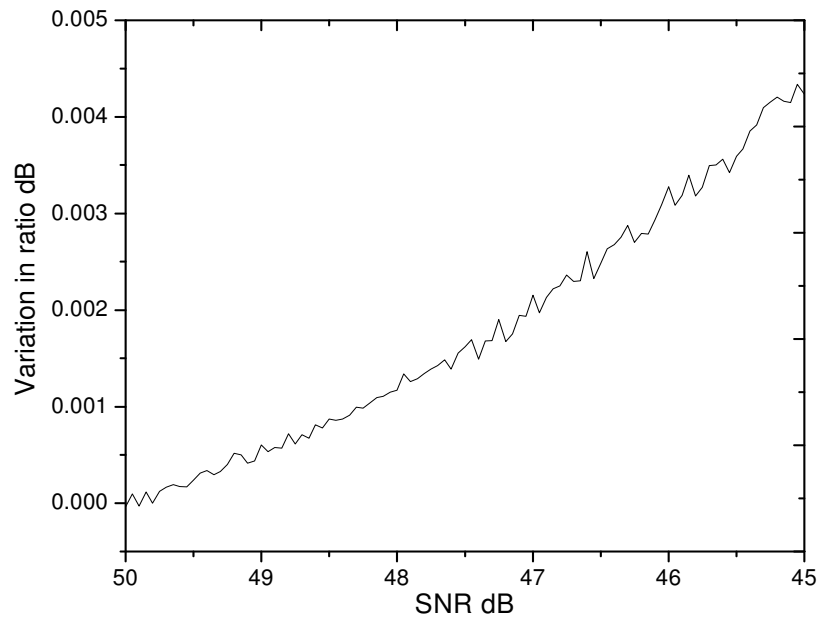


Figure 4

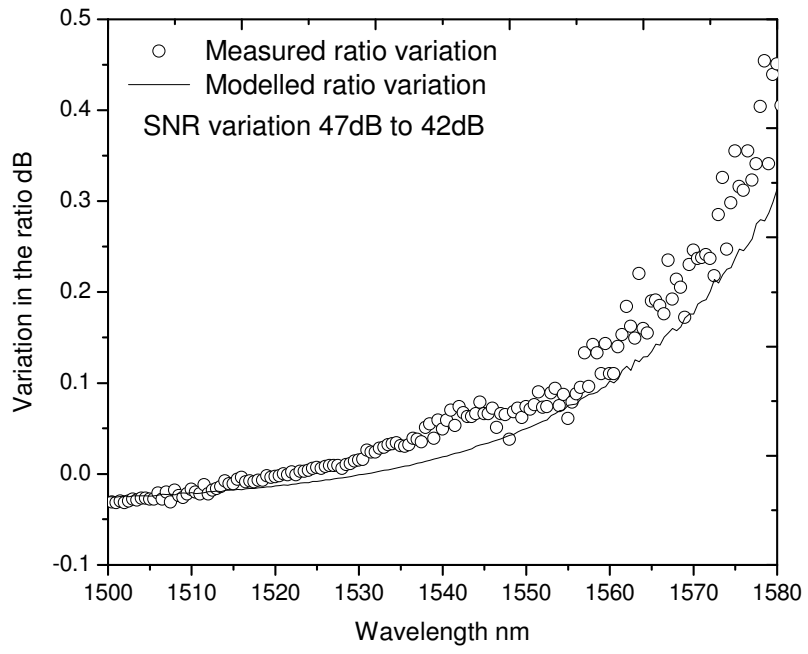


Figure 5

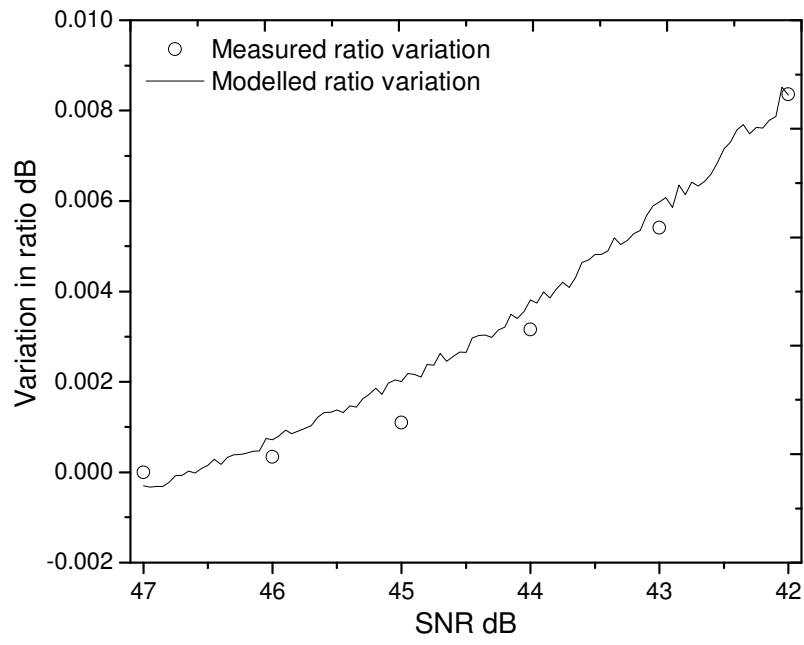


Figure 6

