Tunable polarization maintaining fiber Bragg grating based OSNR monitor

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A B S T R A C T

A simple optical performance monitoring scheme based on a tunable polarization maintaining fiber Bragg grating is proposed. The proposed technique measures the in-band optical signal-to-noise-ratio through orthogonal polarization detection. The scheme is successfully demonstrated for NRZ-OOK signals at 10 Gb/s with an input dynamic range of around 20 dB. The results show that the performance of the scheme is not sensitive to the effects of chromatic dispersion.

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1. Introduction

Optical signal-to-noise-ratio (OSNR) monitoring is mandatory for performance monitoring of wavelength-division-multiplexing (WDM) networks. OSNR measurement is not only needed for signal quality monitoring at the end of transmission, but also along the transmission for performance optimization through a dynamic tuning device, for example incorporating a dynamic gain equalizer [1]. OSNR degradation can take place owing to signal power fluctuations, variations in optical-amplifier-noise characteristics or changes in light path of a dynamically routed optical network. OSNR monitoring has been carried out using interpolation technique by measuring amplified spontaneous emission (ASE) noise in between WDM signal channels. However, this method is no longer accurate for systems with dense WDM channel spacing and WDM networks with reconfigurable optical add/drop multiplexers (ROADM) [1]. Different configurations to monitor in-band OSNR have been reported in the literature [2–4]. In particular, polarization-nulling has been shown to be a simple and effective scheme for in-band OSNR monitoring. However, when the scheme is used with a tunable filter for monitoring in-band OSNR of multiple WDM channels, a polarization controller (PC) has to be tuned continuously to switch the input signal to the OSNR monitoring unit between two orthogonal polarization states. Recently we reported the preliminary results of our OSNR monitor based on a polarization maintaining fiber Bragg grating (PM-FBG) [5]. Following our initial findings, in this paper we report detailed experimental measurements of our proposed all-optical chromatic dispersion (CD) insensitive OSNR monitor based on orthogonal polarization detection using a tunable PM-FBG. Since the orthogonal reflection peaks of the PM-FBG are prone to wavelength variation due to environmental perturbations, a long term wavelength stability test is performed to see the practicality of our scheme. We also show the feasibility through OSNR experimental measurement for NRZ-OOK signal at 10 Gb/s bit rate in the presence of CD. The experimental results reveal that the scheme has inherent immunity to CD.

The proposed scheme is based on measuring the power of two orthogonal polarization channels. Signal power together with half of the in-band noise is detected when the state of polarization of the input signal is aligned with one of the polarization axis of the PM-FBG. The orthogonal reflection peaks of the PM-FBG are tuned to the signal wavelength. Thus with this technique, we can monitor the true value of OSNR by measuring both the signal and ASE power right at signal's wavelength without the need to tune the polarization of the incoming signal. This scheme can be used for monitoring in-band OSNR of multiple WDM channels.

2. Experiment and results

Fig. 1 shows the schematic of the experimental setup used to demonstrate the in-band OSNR monitoring. The inset of Fig. 1 shows a cross-section of PM-FBG with a bow-tie structure. The OSNR monitoring module consists of an optical fiber circulator, a PM-FBG, a polarization beam splitter (PBS), a PC and power meters at the two output ports of PBS. The PM-FBG was fabricated using a phase-mask and a frequency doubled Argon laser on PM fiber. The

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two reflection peaks correspond to the slow and fast axis’s of the PM fiber. The polarization controller (PC) is used to control the polarization state of the incident light into the PM-FBG. The power meters connected at the outputs of the polarization beam splitter (PBS) detect the power levels of the two polarizations. Initially, the reflection peak of the PM-FBG which corresponds to the slow axis is tuned to be aligned with the spectrum of one channel of the WDM system. By rotating the PC to detect the maximum power, the signal power plus half of the ASE power is detected. Subsequently, by tuning the reflection peak corresponding to the fast axis of the PM-FBG, half of the in-band ASE power will be detected at the other port of the PBS. Hence, the in-band OSNR of the incoming signal is obtained. Through continuous tuning of the PM-FBG, in-band OSNR of multiple WDM channels can be detected. The proposed scheme is experimentally demonstrated for a 10-Gb/s non-return-to-zero on–off-keying (NRZ-OOK) system. A CW light source at 1563.36 nm is externally modulated by a LiNbO3 intensity modulator with \((2^{23} - 1)\) pseudo random bit sequence (PRBS). The modulated signal is then fed into a variable optical attenuator (VOA). The VOA is used to control the power injected into the erbium doped fiber amplifier (EDFA) to vary the optical signal-to-noise-ratio. Monitored OSNR values are compared with the measurement results obtained by using an optical spectrum analyzer (OSA) with a resolution of 0.01 nm. A 50:50 coupler is used to tap 50% of signal and ASE noise into the optical spectrum analyzer (OSA) for base-lining the OSNR. The remaining 50% of the noise degraded signal is launched into the proposed OSNR monitoring module. Fig. 2 shows the reflection spectra of the PM-FBG obtained before and after stretching the grating. The solid grey line indicates the reflection spectrum before stretching whereas the solid black line depicts the spectrum after stretching the PM-FBG. The PM-FBG acted as a filter in our experimental set-up and we assumed the shape filter to be Gaussian. The PM-FBG has a reflectivity of over 90% and a spectral separation of \(\sim 0.5\) nm between the two orthogonal polarization reflection peaks. The bow-tie type PM fiber used for fabricating the FBG has a beat length of around 2.7 mm at 1550 nm. The monitoring wavelength is fixed at 1563.36 nm. The PM-FBG mounted on a translation stage is placed inside a covered compartment to prevent it from environmental perturbations which may shift the reflection spectra of PM-FBG. The input signal is wavelength tuned and polarization aligned (by tuning the polarization controller) to one of the polarization peaks of the PM-FBG to detect the signal power along with half of the in-band ASE noise power. Next the adjacent reflection peak of the PM-FBG is wavelength tuned to the monitoring signal to detect only half of ASE noise power at the other output port of the PBS. The wavelength tuning is performed by stretching the PM-FBG mounted on a translation stage. Monitoring errors would be increased if the stretching of the PM-FBG is not done carefully. Faster tuning is possible by use of a piezoelectric transducer (PZT) controller. Fig. 3 compares various levels of the monitored OSNRs by our scheme with the conventional OSNR measurements using an OSA. The OSNRs agreed well with the reference OSNRs. Fig. 3 also depicts the difference between the OSNRs measured by the proposed scheme and the values obtained by using an OSA. The monitoring errors are within \(\pm 1\) dB while varying OSNR from about 10 dB to 26 dB. It is important to mention here that the monitoring accuracy of the proposed scheme depends on the wavelength
stability of reflection peaks of the PM-FBG. For this reason we monitored the wavelength variation of two reflection peaks of the PM-FBG over a period of 1 h. The wavelength variation before and after stretching of PM-FBG was within 0.03 nm during this period as shown in Fig. 4. This small wavelength variation does not affect the performance of the OSNR monitor since the 3-dB bandwidth of each reflection peak of the PM-FBG is around 0.2 nm. Better control of this small wavelength variation is still possible by packaging the whole experimental setup in a vibration free compartment. In general, the annealed gratings are very stable and therefore over a reasonably long period calibration is not needed. However, a periodic calibration will ensure that the system always functions correctly. This can simply be done by a piezo voltage against central wavelength calibration.

In some of the OSNR monitoring schemes, chromatic dispersion (CD) may affect the accuracy of the measurement; therefore we also investigated the effect of CD on the performance of our proposed technique. For this purpose, we designed a CD emulator made up of single mode fibers of different lengths. The OSNR errors for the 10 Gb/s NRZ-OOK data signal were measured when the signal OSNR was kept at 20 dB, while varying the CD from 0 to 2120 ps/nm. Fig. 5 depicts the results of this measurement. The results confirm that the scheme is not very sensitive to the CD and the errors are within ±1 dB. The same setup can be used to realize even a simpler implementation comparing with the one suggested in [3] to reduce the effect of PMD. For such a system, the wavelength separation between the reflection peaks of the PM-FBG needs to be narrower. This can easily be realized by fabricating longer grating with lower index modulation. With this set up, initially centre portion of the signal spectrum plus half of the ASE noise will be detected at one output port of the PBS, while half of the ASE plus small portion of the signal at the short wavelength side of the signal spectrum will be detected at the other port of the PBS. When the PM-FBG is tuned, half of the ASE plus a small portion of the signal at the centre of the signal spectrum will be detected by one output of the PBS while signal at longer wavelength portion of the signal spectrum plus half of the ASE noise will be detected at the other output port. Since signal spectrum in general is symmetrical, this scheme should effectively allow OSNR measurement in the presence of PMD. Comparing with the scheme in [3], PC needs not be tuned after the filter is tuned to different portions of the signal spectrum. This makes the system implementation very simple.

3. Conclusion

We have experimentally demonstrated a simple configuration for OSNR monitoring based on orthogonal polarization detection using PM-FBG. The proposed scheme is simple, insensitive to CD, scalable to higher bit rate systems and does not require any high speed electronics. The scheme can measure OSNR with an input dynamic range of around 20 dB. The scheme is also potentially insensitive to PMD.

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