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A Novel Wavelength-Matching Scheme for Wavelength Routers Without Any Reference Sources

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ABSTRACT

In this paper, we propose and demonstrate a novel and effective wavelength-matching scheme for wavelength grating routers (WGR) to match their transmission peaks to the wavelength assignment of the data channels without any reference sources. The unused portion of the amplified spontaneous emission (ASE) power of the Erbium doped fiber amplifiers (EDFA) is utilized as the monitoring light source and fiber Bragg gratings of a particular center reflection wavelength is used as the wavelength reference. The scheme supports in-service monitoring and will not degrade the performance of the data channels. It is also insensitive to dynamic ASE power variations arising from channel add-drop. We have experimentally demonstrated the proposed wavelength-matching scheme for WGR and analysed the scheme numerically for design optimization.

Keywords: optical networks, wavelength grating routers, wavelength stabilization, fiber Bragg gratings

1. INTRODUCTION

Wavelength grating router (WGR) is one of the most critical network elements in all-optical transport networks performing the functions of channel routing, add-drop, and demultiplexing. To achieve optimal operation of the WGR, it becomes essential that the transmission peaks of the WGR should always match with the wavelength assignment of the data channels. However, depending on the material that the WGR is fabricated from, the spectral response can greatly be influenced by the ambient temperature fluctuations or device ageing, causing wavelength mismatch between the data wavelengths and the WGRs. This not only leads to substantial attenuation of the transmitting signals, but also introduces severe crosstalk to the neighbouring channels, thus greatly impairing the performance of the entire system. A wavelength-matching scheme must be implemented to ensure optimal network operation.

Wavelength matching by tuning the source wavelength[1] is inapplicable in wavelength routing networks while dithering of the reference signal[2] induces system penalty and requires complicated circuitry. The scheme proposed in [3] is feasible but it requires an additional stable laser source and uses up two dedicated WGR output ports for monitoring. In this letter, we propose and demonstrate a novel and effective wavelength-matching scheme for WGRs. The scheme makes use of a temperature-compensated fibre Bragg grating (TC-FBG) and the amplified spontaneous emission (ASE) from the Erbium-doped fibre amplifier (EDFA) as the monitoring source. This scheme is also insensitive to dynamic ASE power variations arising from channel add-drop.

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2. PROPOSED SCHEME

Fig. 1 shows the proposed wavelength-matching scheme for an NxN WGR, which can be formed by an NxN arrayed waveguide gratings (AWG)[4]. Although a static WGR is shown in the diagram, the principle of operation can also be applied to a dynamic WGR in which the demultiplexed channels have to pass through banks of $k\times k$ switches, k being the number of wavelength channels in each input fibre. There is an EDFA placed at each input port so as to compensate and equalize the power among various channels[5] caused by the near-far effect of the add-drop nodes. We assume that the free spectral range (FSR) of the WGR is less than the usable bandwidth of the EDFA's ASE spectrum and the unused portion of the ASE can be used as the monitoring source. As a result, at each output port, in addition to the transmitted wavelength channels, there are multiple filtered ASE peaks, each originates from different input EDFAs in accordance to the characteristics of AWG.

For our wavelength-matching scheme, only two adjacent filtered ASE peaks at one of the WGR's output are needed. A temperature compensated fibre Bragg grating (TC-FBG) with its center wavelength matched at the midpoint (crossover wavelength) between the two adjacent filtered ASE peaks is placed at one output port (inset of Fig. 1). TC-FBG is adopted since it has a very small temperature-induced shift in center wavelength ($\sim 10^{-5}$ nm/°C)[6], about several orders of magnitude better than that of the usual SiO_2-based WGR device (~0.015 nm/°C), although a high performance AWG with a temperature-dependent wavelength drift of 5.9×10^{-4} nm/°C was reported recently[7]. The TC-FBG reflects the filtered ASE power at that crossover wavelength back to the two corresponding input ports. The two reflected signals are then tapped off by circulators, filtered by Fabry-Perot (FP) filters and detected by photo-diodes as shown.

In order to compensate the dynamic variations in input ASE power, the two reflected signals are normalized with their respective input ASE power. The difference of the normalized signals is monitored carefully. Any change in the difference signal will trigger a servo-control circuitry, which controls the current source of a thermo-electric cooler attached to the WGR. The sign and the magnitude of the difference signal will lead to heating or cooling of the WGR until a predefined level in difference signal is reached. In this way, automatic wavelength matching is achieved. Such scheme also supports in-service monitoring and will not degrade the performance of the data channels.

3. EXPERIMENTS AND RESULTS

In our experiment, a 16 x 16 AWG with a channel spacing of 100 GHz, a 3-dB full-width of 0.4 nm, and a temperature coefficient of 0.012 nm/°C is used to simulate the WGR. Two optical amplifiers with similar gain outputs are placed in front of input port #11 and input port #12 of the WGR. Modulated data at λ=1546.2 nm is also fed into input port #11. An FBG with a center reflection wavelength of λ_{FBG}=1559.525 nm and a 3-dB full-width of 1 nm is placed at the WGR's output port #12 where the two adjacent filtered ASE peaks considered are located at λ_1=1559.144 nm and λ_2=1559.906 nm (Fig. 2 inset) when the WGR's temperature is set at 11.5°C. By activating the control-servo circuitry, the peak transmission of the WGR gradually shifts from the initial wavelength, corresponding to the initial temperature of 21.8°C, to our desired wavelength assignment corresponding to 11.5°C within four minutes. Over the many hours of testing, the difference signal remains constant within ±0.01 dB, which corresponds to < ±0.001 nm in wavelength deviation (Fig. 2). Bit error rate measurements are also performed using 1-Gb/s 2^{10}-1 PRBS NRZ data with the circuitry on, and no performance degradation is observed (Fig. 3). The effect of dynamic variations in EDFAs' ASE power on the stability of the difference signal is also analysed numerically. The input power of one EDFA is varied by over 10 dB while the other is kept constant for three mismatch conditions (ΔT=0°C (matched), -5°C, -10°C). The results are shown in Fig. 4, revealing that our scheme, which has dynamic power compensation, is insensitive to any dynamic power variation in EDFA's ASE.

4. SUMMARY

We have proposed and demonstrated a simple and effective wavelength-matching scheme for WGR in all-optical transport networks. No dedicated laser source for reference is required. The scheme supports in-service monitoring and will not degrade the performance of the data channels.

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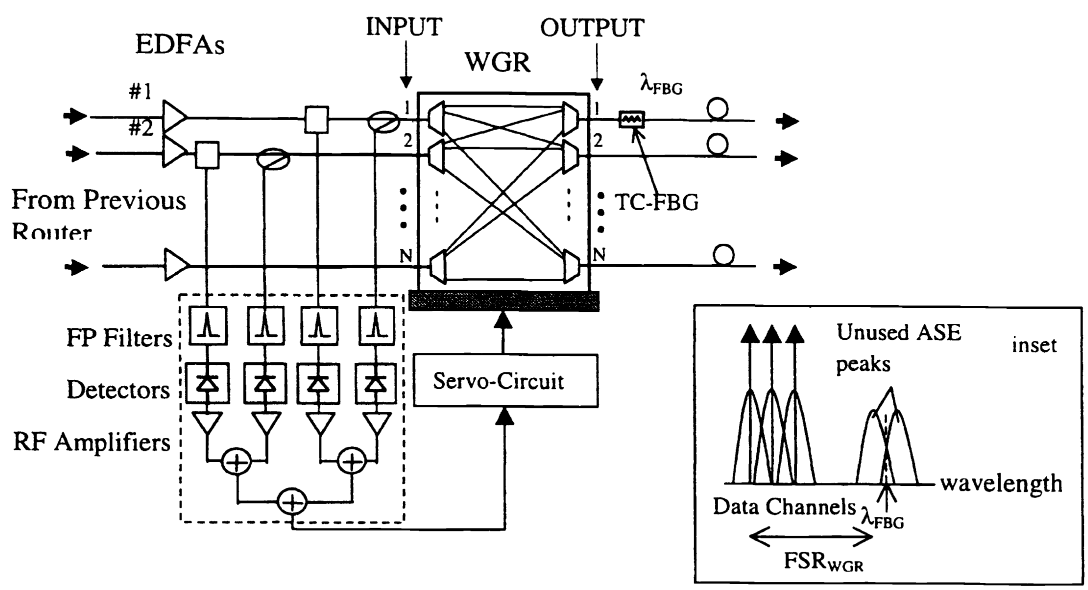

Figure 1: Proposed Wavelength-Matching Scheme for WGR

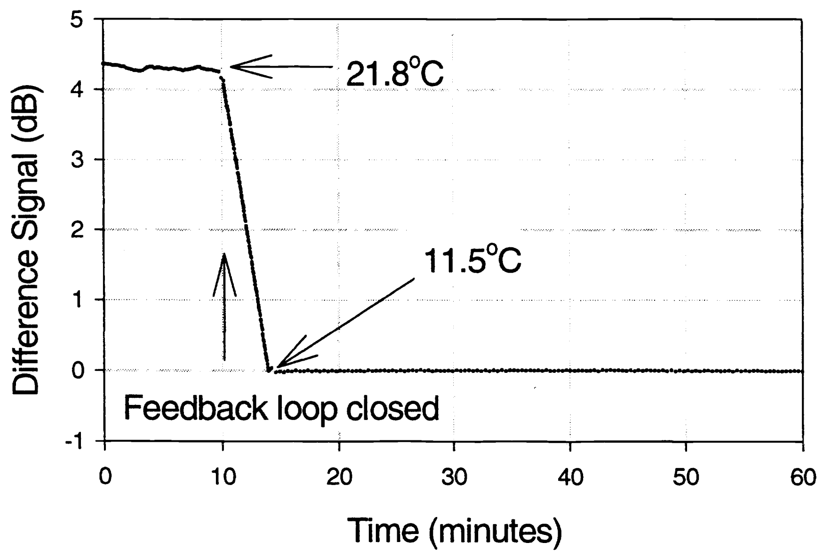

Figure 2: Experimental results: difference signal before and after the feedback loop is closed.

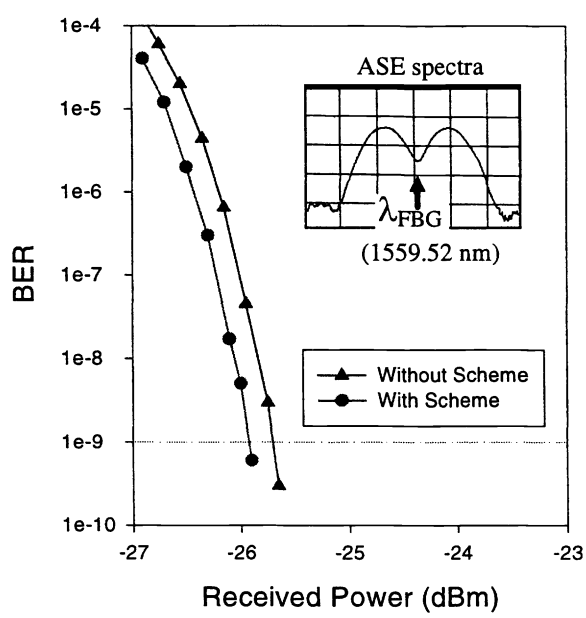

Figure 3: Experimental results: BER performance of a 1-Gb/s 2^{10}-1 PRBS NRZ data stream with and without the proposed scheme. Inset shows the two transmitted ASE spectra (one FSR away from the data wavelengths) before the FBG on WGR's output port #12. The FBG is centered at the mid-point between the peak wavelengths of these two spectra.

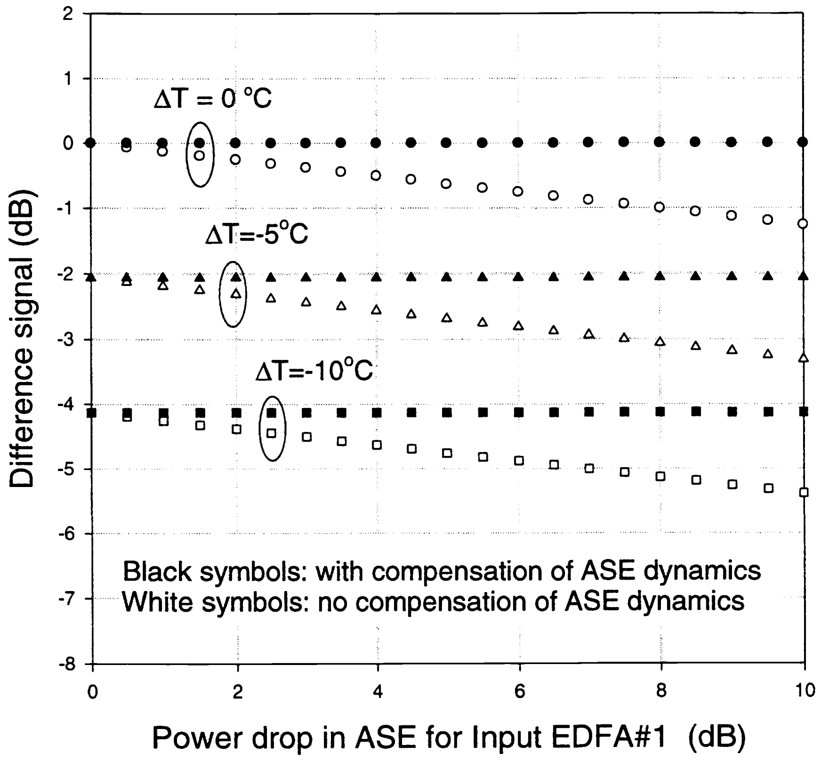

Figure 4: Numerical Result. Difference signal vs. attenuation of input ASE power of one input EDFA (input ASE power of the other EDFA is kept constant) for temperature shifts of $\Delta T=0^{\circ}C$, $-5^{\circ}C$ and $-10^{\circ}C$, with or without compensation for ASE dynamics.