A Wavelength-Matching Scheme for WDM Systems

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Abstract: We propose a simple and low-cost wavelength-matching scheme for multi-wavelength optical links and networks using grating demultiplexers. We demonstrated that the wavelength can be matched and maintained within 0.006 nm with the reference wavelength, and thus among all other demultiplexers in the links and networks.

Summary: Low-loss waveguide demultiplexers [1-7] can be used to select wavelength channels in multi-wavelength optical links and networks. The spectral response of these demultiplexers can be influenced by local temperature fluctuations, and more importantly, by device-to-device variations from fabrication. Depending on the material in which the grating demultiplexers are fabricated, the temperature dependence of wavelength (dλ/dT≈0.1 nm/°C for semiconductor based gratings and ~0.015 nm/°C for SiO₂ based gratings) can be corrected by active temperature control. However, the device-to-device variations can be as large as ~1 nm [8] even within each wafer run. Tighter control in fabrication will reduce the device-to-device variations but total elimination of this effect is unlikely. Implementing these devices without correction schemes can cause wavelength mismatches between individual demultiplexers which ultimately degrade the system performances and limit the number of wavelength channels in the links and networks. Several wavelength-reference schemes [9,10] have previously been proposed, but these often require dithering of the reference signal and complicated locking circuitry. Here, we propose a simple, low-cost and yet effective technique to match the wavelengths of all the demultiplexers in the entire links and networks.

The proposed scheme requires a reference laser wavelength available to the demultiplexers in the links and networks. The wavelength of this reference laser λ_{ref} must be very stable and accurate (e.g. a standard etalon or a HeNe laser) and can be located at one of the nodes (for links) or in the central office (for networks). We further require two of the wavelength channels in the demultiplexers to be dedicated for wavelength matching purposes. The passbands of these reference wavelength channels are identical to that of the signal channels and nominally designed to bracket the reference wavelength such that equal optical power of the reference laser P_{ref} will be collected by each channel, i.e., the reference wavelength is at the mid-point between the peak filtered wavelengths of the channels. The separation between these reference wavelength channels Δλ_{ref} can be much narrower than the separation between the signal channels Δλ, and will be discussed in details in the next section.

Figure 1(a) shows the schematic diagram of the wavelength matching and locking scheme. For an optical link or network with N channel wavelengths, we have N+1 total wavelengths in the device, λ₁, ..., λ_N and λ_{ref}, injected into the input
arm of the demultiplexer. There are \(N+2\) outputs from the demultiplexer, \(N\) outputs being for the signal channels and the two adjacent arms for the stabilization function. These two reference outputs are fed into photodetectors followed by two amplifiers. In order to achieve operation that does not depend on the amount of power at the reference wavelength, logarithmic amplifiers are used. At the same time the logarithmic amplifiers provide an enhancement in dynamic range and sensitivity. The signals from the amplifiers are then subtracted from one another and the difference is fed into a servo-control circuitry which controls the current source of a thermo-electric cooler attached to the waveguide demultiplexer (variations in manufacturing are assumed to be adjusted within the range of operation of the thermo-electric coolers). The sign and the magnitude of the difference signal will lead to heating or cooling of the demultiplexer until a zero in difference signal is reached (Fig.1(b) and Fig.1(c)). As one and every other demultiplexer is matched with the reference wavelength which is fixed across the link and network, the entire \(N\) signal channels will be matched with all other demultiplexers. Thus, the entire optical links and networks will be wavelength matched.

To demonstrate the wavelength-matching scheme, we used a setup similar to that illustrated in Fig.1(a). In the experiment, we used a four-channel fiber-pigtailed etched grating demultiplexer operated in the 1.55 \(\mu\text{m}\) communication window. Briefly, the spectrograph (grating) is based on a planar waveguide \(\text{SiO}_2/\text{Si}\) grating with average pitch of 11 \(\mu\text{m}\) [1]. A 5 \(\mu\text{m}\) thick core layer is sandwiched between a 12 \(\mu\text{m}\) bottom layer of cladding on top of Si substrate (525 \(\mu\text{m}\)) and a 8 \(\mu\text{m}\) top cladding layer. The grating operates in the first order and the input/output channel guides have a maximum radius of curvature of 20 mm. The channel-to-channel separation is 20 nm with a 3-dB bandwidth of 10 nm. The grating exhibits a fiber-to-fiber loss of \(-7\text{dB}\) at the peak transmission wavelengths of the signal channel and a \(-20\text{dB}\) at \(\lambda_{\text{ref}}\) (see inset in Fig.2). The grating also exhibits a stress-induced birefringence such that the \(TE\) and \(TM\) modes of identical wavelength are shifted by 0.9 nm at the output. Thus, the polarization of the reference laser is required to be maintained and monitored throughout the experiment.

To determine the wavelength dependency on temperature, we monitored the peak transmission wavelength of the third output port (peak wavelength at \(-1.543\ \mu\text{m}\)) of the grating demultiplexer while heating and cooling it with the thermo-electric cooler. In Figure 2, which shows the dependence of the peak wavelength with temperature, a weak quadratic behavior of the peak transmission wavelength with temperature is seen. Over the temperature range (from 0\(^\circ\text{C}\) to 50\(^\circ\text{C}\)) of investigation, the wavelength shift is found empirically to be \(d\lambda/dT = 0.016\ \text{nm}/\text{oC}\) and \(d^2\lambda/dT^2 = -2.084 \times 10^{-4}\ \text{nm}/\text{oC}^2\), corresponding to a \(1.5 \times 10^{-5}\ \text{oC}\) change in the refractive index.

We used a tunable laser source (SANTEC TSL300) emitting at 1.535 \(\mu\text{m}\) as the reference laser source. The difference in outputs from photodetectors/amplifiers was formed by an ultra-low offset voltage operational amplifier before feeding into a servo circuit (ILX LDT 5910B) which controlled the temperature of the thermo-electric cooler attached to the bottom of the grating (about 500 \(\mu\text{m}\) in thickness). The setup has a dynamic range of 20 dB only restricted by the equipment we used in the experiment. A thermistor on the top of the grating registered the grating temperature. The demultiplexer was embedded in a thermally isolated box. Figure 3 shows the difference signal as a function of time. When the feedback loop was opened, the difference signal from the operational amplifier drifts between -1.3 to -1.1 dB from the zero level. Shortly after the feedback loop is closed, the difference signal quickly decreased to 0 dB in about 2 minutes. The difference signal remained locked near the 0 dB point throughout the entire time of the experiment (>24 hours).
difference signal fluctuated within ±0.025 dB, corresponding to ±0.006 nm in wavelength. We have demonstrated a simple, low-cost wavelength-matching scheme for multi-wavelength optical links and networks using grating demultiplexers. The proposed scheme has the advantage of being independent of variations in the optical power of the reference wavelength and of variations in attenuation of the grating demultiplexers. We further show that the wavelength can be matched within ±0.006 nm with the reference wavelength and thus with all other demultiplexers in the system. The grating device was fabricated at LETI in the frame of the EEC program RACE 1008.

References


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Fig. 1 Illustration of the proposed wavelength-matching scheme (a). (b) and (c) show the locked and unlocked states.

Fig. 2 Temperature dependence of wavelength of the grating demultiplexer. Inset shows the spectral response of the grating.

Fig. 3 The measured difference signal from two adjacent channels as a function of time. After the feedback loop is closed, the difference signal reduces to 0.025 dB.