Influence of realistic optical filter characteristics on the performance of multiwavelength optical networks

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Introduction – Optical multiplexers/demultiplexers (MUX/DMUXs) are key components in multiwavelength networks. MUX/DMUXs are composed by elementary optical filters. When the size of the network increases, a signal may pass through a large number of such filters cascaded together. The bandwidth of their equivalent transfer function is much narrower than the bandwidth of each individual filter. Bandwidth reduction, combined with laser misalignments due to temperature, aging and manufacturing, causes signal distortion. In the past, computer simulation was used to evaluate the performance degradation related to this effect [1]–[4]. For mathematical convenience, these papers were based on simplifying assumptions about the filter shape and the filter parameters, i.e. they assumed identical filter shapes described by Butterworth or Bessel functions.

In practice, these assumptions are inaccurate. As shown in the following, the transfer functions of commercially available optical filters are generally asymmetric and exhibit passband ripple, so they can not be described by the above analytic set of functions. In addition, filter shape and parameters, e.g. central frequency and 3-dB bandwidth, vary randomly from their nominal values between channels of the same device or between different devices.

This paper presents a realistic simulation study of the filter-induced distortion based on measurements of the transfer function of commercial multi-layer interference (MI) filters. Results show that transmission through 100 MUX/DMUXes, of the order of national scale networks, is possible. However, requirements on the passband flatness, passband ripple and other filter parameters are important to achieve such performance.

Results and Discussion – MI MUX/DMUXs are suitable for use in transparent optical networks due to their low insertion loss, excellent frequency stability to temperature variations and reasonably good passband flatness [5]. The transfer functions of eight commercially available MI MUX/DMUXs with 9 channels spaced 200 GHz apart are measured. Fig. 1 shows the transmittance of one MUX. The transfer function shape is slightly different for each channel. The middle channels generally exhibit higher ripple and steeper side slopes than the outer channels.

Histograms for the 3-dB bandwidths and central frequency offsets from the channel nominal frequency are presented in Fig. 2 and 3 respectively. Fig. 2 shows that the mean 3-dB bandwidth is 166 GHz, with a standard deviation of 16 GHz. Fig. 3 shows that central frequency offsets from the channel nominal frequency are concentrated around zero in a range [-22 GHz,+20 GHz], with standard deviation about 6.5 GHz, which is very small compared to the mean 3-dB filter bandwidth. In this case, the impact of misalignment on the bandwidth reduction can be neglected. However, in general, filters with central frequency offsets far apart from the channel nominal frequency can greatly reduce the bandwidth and must be rejected.

Based on the assumption that the transfer functions of different channels within a device are independent, it is possible to define the generalized geometric mean as the M-th root of the product of all M transfer functions shifted around the same frequency. Obviously, the generalized geometric mean is a random quantity, which, for large M, can be considered as a typical value of the transfer function of an individual optical filter. Fig. 4 shows powers of the generalized geometric mean for different number of MI filters. The passband ripple in the filter transfer functions under study is rather systematic so the mean overall transfer function is asymmetric. For 100 optical filters, the passband ripple extends to an aggregate loss range of about 20 dB. If the passband ripple varies rapidly within the signal band, it will dramatically affect the system performance.

The transfer functions of Fig. 4 are used to calculate the intersymbol interference (ISI) due to laser misalignment when the signal passes through a cascade of filters. The bit rate is chosen to be 10 Gb/s; a third order Butterworth lowpass filter with cutoff frequency 6.5 GHz is used at the receiver; perfect ASK modulation is assumed, and fiber dispersion and non-linearities are neglected.

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Fig. 5 (a) and (b) show the output eye-diagrams after a chain of 100 MI filters for laser misalignments ±30 GHz from the filter center frequency. The maximum eye-opening in the absence of optical filters is set equal to unity. Due to the combined effects of bandwidth reduction and laser misalignment, the signal is attenuated and distorted. Due to the asymmetry of the transfer function, the sign of the misalignment results in different values of attenuation (defined as excess loss) and distortion.

As shown in [6] the excess loss can be partially compensated by the gain provided by the optical amplifiers in the chain. However, signal distortion will cause a penalty in the network performance. For laser misalignments up to ±25 GHz, the signal can be transmitted through the entire chain of 100 filters with distortion induced eye-closure below 0.3 dB, which is arbitrarily chosen in the bibliography [1]-[4] as the maximum allowable distortion level. This estimation is exclusively based on the signal distortion and does not take into account the Amplified Spontaneous Emission (ASE) noise accumulation along the optical path and the receiver noises. For a more accurate approach, error probability would have to be used as a criterion for the evaluation of the system performance.

In conclusion, it is possible to cascade 100 realistic optical filters, which is considered a typical value for a national-scale network. In the conference, the authors will present guidelines for the filter selection and the allowable laser/filter misalignments to achieve such performance.

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References

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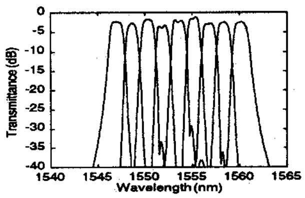

Figure 1: MUX transmittance.

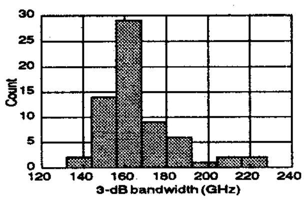

Figure 2: Historgram of 3-dB bandwidths.

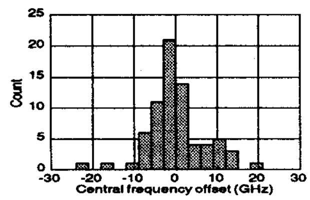

Figure 3: Historgram of central frequency offsets.

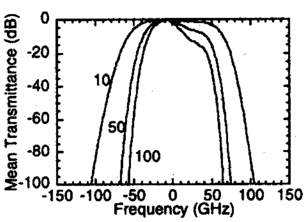

Figure 4: Mean transfer function of a cascade of 10, 50 and 100 optical filters.

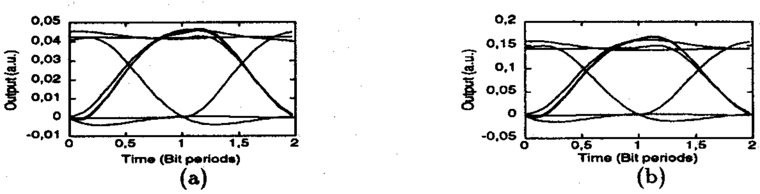

Figure 5: Eye-diagrams after transmission through 100 optical filters for different laser misalignments (a) +30 GHz (excess loss=13.5 dB, distortion=0.65 dB); (b) -30 GHz (excess loss=8 dB, distortion=0.7 dB).