Multichannel tunable dispersion compensation using all-pass multicavity etalons

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Abstract: We propose and demonstrate a novel approach to multi-channel tunable dispersion compensation based on multicavity etalons that can compensate all channels throughout the C or L band with either 50GHz or 100GHz channel spacings for 10Gb/s applications. We demonstrate very low group delay ripple as well as large tuning range and low losses, and indicate that dispersion slope compensation can be achieved, as well as scaling the bandwidth for 40Gb/s applications.

OCIS codes: (060.2340) Fiber optics components; (060.4510) Optical communications

1. Introduction

Tunable dispersion compensation is regarded as a key enabling technology for 40Gb/s optical transmission systems. Furthermore, with the increase in transmission distances as well as the introduction of wavelength dependent routing, even 10Gb/s systems are beginning to require this functionality. Numerous approaches have been demonstrated including fiber Bragg gratings[(1)], Virtual Phased Arrays[(2)] , integrated optical filters[(3,4)] and others. The first two approaches have experienced the widest success to date, and are currently reaching the product stage. However, challenges to improving device performance remain, such as providing multi-channel compensation (in the case of the FBG device which is single channel), reducing Group Delay Ripple (GDR), reducing insertion loss (in the case of the VIPA), increasing bandwidth (limited by waveguide bending radii in the all-pass ring filter case, for example), and reducing size and complexity (as in the case of lattice filters that typically require many tuning elements for a single device).

In this paper we propose and demonstrate a novel approach to achieving tunable dispersion compensation using a combination of two different all-pass multicavity etalons. We demonstrate devices based on lens coupling using etalons with either 50GHz or 100GHz free spectral ranges (FSR), intended for 10Gb/s systems, and show that they can be used to simultaneously compensate all channels throughout the C-band. In addition, we indicate how a dispersion slope (across the C-band) can be designed into the device. These features, together with the fact that we demonstrate very low GDR, raise the possibility of being able to replace some or all of any dispersion compensating fiber (DCF) in a system with this lower loss, lower cost, smaller sized, and nonlinearity free alternative, with the added advantage of tunability. Finally, we indicate that scaling the bandwidth to >75GHz for 40Gb/s systems is readily achievable.

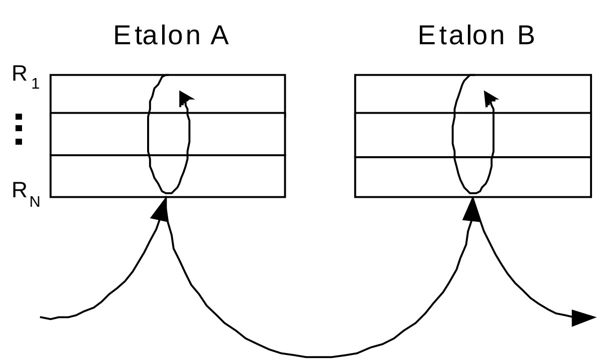

Figure 1. Schematic of multicavity etalon tunable dispersion compensator

2. Principle of Operation

Figure 1 shows the basic principle of operation. Two types of multicavity etalon are designed such that they have a linearly varying dispersion over a particular bandwidth. Etalon "A" is designed to have a negative dispersion slope while etalon "B" has a positive slope. The magnitude of the slopes are designed to be either equal to each other or in a simple ratio so that when the appropriate ratio of reflections is combined, there is a region where the dispersion is constant. The value of the dispersion is determined by the relative spectral shift between the two etalons, which we control thermally. The substrate thicknesses determine the overall device FSR and the end coating reflectivity (R_1) is designed to be close to 100% to yield the all-pass transfer function while the other coating reflectivities vary down to a few percent or less. Optical coupling is done using grin lenses, where we obtain a typical loss per pass of 0.5dB.

The scaling rules for this device are generic to etalon filters and are discussed at length elsewhere[(5)]. Briefly, the device bandwidth scales linearly with FSR, whilst the dispersion tuning range scales as $(FSR)^{-2}$. Also, the tuning range scales linearly with the number of reflections, as does the loss (with an offset due to other components such as circulators).

3. Results and Discussion

Figure 2 shows the resulting group delay and group delay ripple (GDR) for a 100GHz FSR device over one channel at 194THz for dispersion settings near the maximum (+500 ps/nm), zero, and minimum (-500ps/nm) of the tuning range. The GDR is obtained by subtracting a linear fit of the GD over a bandwidth of 30GHz. Figure 3 shows the resulting GDR as a function of dispersion setting for three channels over the C-band (192, 194, 196THz) , while the device specifications are summarized in Table 1 (the specifications in Table 1 are valid over the stated dispersion tuning range, and all channels from 192 to 196 THz).

This device employed one A and two B etalons, and used a mirror/circulator in a double pass configuration. The insertion loss varied from 4.7 to 5.3 dB depending on wavelength and dispersion, and included about 1.5dB for the circulator. From Figures 2 and 3, we see that although this device is specified as having GDR < +/- 3.0ps over the full dispersion tuning and wavelength ranges, for all operating conditions except at the lower limit of the tuning range near 192THz the GDR is closer to +/- 2 ps. This is extremely low – much less than what is typically achieved for fiber Bragg gratings for example – and raises the possibility of cascading this device through the system (in-line applications), in addition to providing dispersion compensation at the terminal end.

We also constructed devices with a 50GHz FSR (one A and one B etalon, double passed) and the resulting specifications are listed in Table 1. Note that the 25 GHz bandwidth here represents a larger fraction of the FSR than that achieved for the 100GHz device, which is why the tuning range is not four times greater.

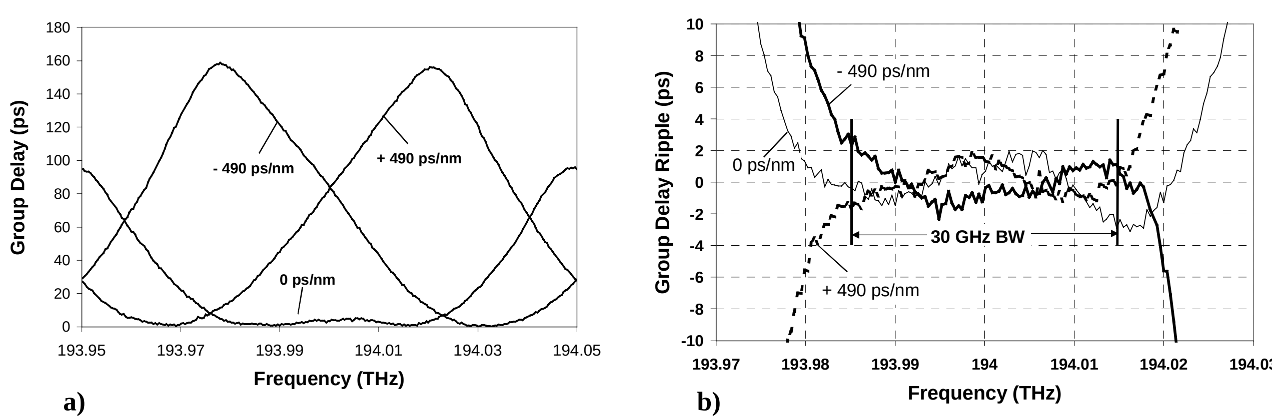

Figure 2. Group delay (a) and group delay ripple (GDR) (b) of 100GHz FSR device for different dispersion settings for the channel centered at 194THz. GDR is obtained by subtracting a linear fit of GD across the operating bandwidth.

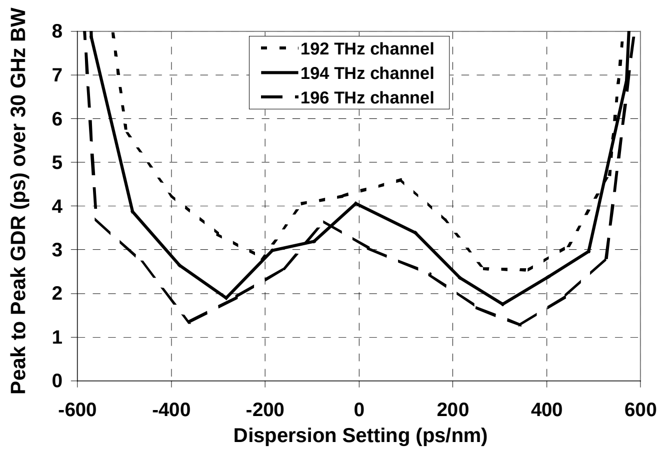

Figure 3. Group delay ripple (GDR) of 100GHz FSR device as a function of dispersion setting for 3 different channels. Note that GDR here is peak to peak and not +/-.

Table 1. Specifications of 50GHz and 100GHz devices

FSR	BW	Range	GDR	Loss
50GHz	25GHz	+/- 800 ps / nm	+/- 4.0 ps	4.4dB
100GHz	30GHz	+/- 500 ps / nm	+/- 3.0 ps	5.3dB

Although in theory, being all-pass filters, our devices have a flat amplitude response (100% reflectivity) over the entire C (or L) band, in practice variations in the etalon reflectivity and coupling efficiency over the FSR produce a small insertion loss ripple (ILR). The ILR for our devices varied from 0.1 to 0.4 dB depending on wavelength and dispersion setting. Optimizing the device design can reduce this further.

Scaling the FSR to 200GHz in order to achieve bandwidths greater than 75GHz, required for 40GB/s systems, is relatively straightforward, in contrast with waveguide ring resonator filters, for example. However, the same scaling rules apply (tuning range ~ $(FSR)^{-2}$), and so in order to achieve the required tuning ranges on the order of +/- 200 to +/- 300 ps/nm more reflections would be needed. By employing more sophisticated etalon designs, however, as well as optimizing the optical coupling, we anticipate losses for a 40Gb/s device in the range of 4 to 5 dB.

Finally, by intentionally mis-matching the FSRs of the two etalons, one can introduce a linear variation of the relative wavelength offset between the two etalons across the band, which will in turn introduce a linear variation in channel dispersion across the band. The resulting dispersion slope (fixed during fabrication) in combination with normal tuning, enables the dispersion to dispersion slope ratio to be adjusted to match any fiber type.

4. Conclusions

We have proposed and demonstrated a novel approach to multi-channel tunable dispersion compensation using all-pass multi-cavity etalon filters for 10Gb/s applications.

5. References

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