

# Optical Single Channel Dispersion Compensation Devices and their Application

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**Abstract** We present a standard butterfly packaged tunable optical dispersion compensator capable of introducing different dispersion values and having less than 2dB insertion loss. Experimental results demonstrate the chromatic dispersion compensation capabilities for different scenarios.

## Introduction

Chromatic dispersion (CD) is considered as a limiting factor in 10Gb/s networks. Therefore, CD compensation techniques are being explored intensively, involving different technologies ranging from Gires-Tournois etalons<sup>1</sup>, fiber bragg gratings<sup>2</sup> and ring resonators or other planar lightwave circuit (PLC) structures<sup>3</sup>. Extending the dispersion tolerance of transceivers and transponders is an attractive capability. It allows for a fairly smooth upgrade of 2.5Gb/s to 10Gb/s networks. It potentially saves an EDFA (Erbium Doped Fiber Amplifier) when high-loss, bulky DCMs (Dispersion Compensating Module) are removed. Finally, with greater dispersion tolerance, the dispersion map of a network is simplified and residual chromatic dispersion is easily compensated for. Unfortunately, none of the optical dispersion compensation technologies listed above have resulted in a device that can be integrated in a standard 10Gb/s transponder or transceiver, either due to the high insertion loss or the large form factor. Currently, there are three major alternatives for mitigating the effects of chromatic dispersion in a transponder. One solution constitutes of a different encoding scheme known as Duobinary in which a three-level electric field signal is generated<sup>4</sup>. The resultant bandwidth reduction of Duobinary encoded signals mitigates the chromatic dispersion effects and up to  $\pm 3500$ ps/nm dispersion tolerance was previously reported. Nonetheless, this encoding scheme exhibit some back-to-back penalty and it eventually shows the same performance as NRZ for long haul, multi-span links.

Another technique to cope with chromatic dispersion is through electronic dispersion compensation (EDC)<sup>5</sup>. EDC is typically based on FFE (Feed Forward Equalizer), DFE (Decision Feedback Equalizer) or MLSE (Maximum Likelihood Sequence Estimator) architectures. It increases the dispersion tolerance up to  $\pm 2000$ ps/nm at 9.95Gb/s and can mitigate some PMD (Polarization Mode Dispersion) effects as well. Nonetheless, it may not perform well at the presence of non-linear effects or noise. Its performance deteriorates as the bit rate increases and MLSE based EDCs dissipate high power.

Being an optical phenomenon, CD, which is regarded as linear filtering in the optical domain, can be best compensated for optically, i.e., via a tunable optical dispersion compensator (TODC). Thus far, TODCs have been considered as bulky, costly, dissipate high power, and often did not provide the necessary required tunability. In what follows we will introduce a small form factor, low loss TODC and discuss its potential applications.

## ODC characteristics and applications

The proposed ODC is based on free-space etalons architecture and is packaged in a standard butterfly package. It is based on a cascaded Gires-Tournois (GT) architecture, where all etalons have the same free spectral range (FSR). This results in a flexible design, which permits one to decide on different parameters that match the application at hand. As an example, the reflection coefficients of the etalons determine the trade-off between the amount of dispersion that can be corrected and the operating bandwidth of the device for a permissible group delay ripple (GDR) value. E.g., this architecture can provide  $-1360$ ps/nm (for compensating 80km of SMF) with 20GHz of operating bandwidth and less than 10psec GDR (peak to peak) as shown next.

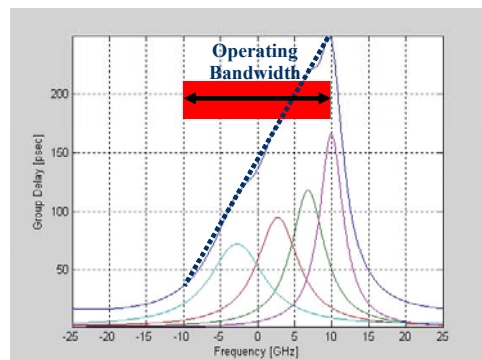


Figure 1: Compensation of 80km of SMF with TODC

Thermal tuning of the refractive index of each etalon allows one to have a tunable device that covers both positive and negative dispersion values.

Since the TODC is based on free-space optical elements, the losses mainly arise from assembly

misalignments and fiber coupling. For a set of four GT etalons, the insertion loss is typically 1.5dB.

The cascaded GT architecture results in a periodic group delay (GD) response whose period is equal to the FSR, which matches the channel spacing in the network (50GHz in the above example). This allows one to consider both multi-channel and single channel applications. This paper addresses the latter type of applications where it is assumed that the incoming channel number is not necessarily known.

The most attractive set of single channel applications for a small form factor, low loss TODC, seems to be its integration in the receiver section of standard transponders and transceivers. No matter what the transmission line code is (e.g, NRZ, RZ or Duobinary), the TODC imitates a conventional fiber with prescribed CD as long as its operating bandwidth accommodates the bandwidth of the signal along with possible wavelength drifts.

Having low insertion loss in this set of applications is of great importance, since it determines the sensitivity penalty of the receiver.

The amount of dispersion that should be corrected for can be found by extracting the clock signal power or by means of other feedback signals (e.g., forward error correction feedback).

### Experimental verification

The following scenario includes a TODC with four GT etalons in cascade, where different settings of temperatures (or etalons' resonating frequencies) are chosen to exhibit different dispersion settings and different operating bandwidths.

A 300-pin MSA tunable transponder modulates 10.7Gb/s, NRZ, PRBS-23 data sequence with Z-cut LiNbO<sub>3</sub> modulator at channel #75 in the C-band. It emits light with 0dBm launch power into 100km of SMF. A first EDFA amplifies the light to +10dBm and take it through additional 110km of SMF. A first attenuator and a second EDFA set the OSNR (Optical Signal to Noise Ratio) to a desired value. Optical filter is then used to filter out the ASE (Amplified Spontaneous Emission) noise and another attenuator is used to set the input optical power at the receiver of a transponder with integrated TODC.

In this experiment, the second attenuator sets the input power to -20dBm. The OSNR was changed while the BER was measured at optimized receiver decision threshold for two cases:

- (1) Back-to-back with a TODC setting of 0ps/nm.
- (2) After 210km of SMF representing over 3600ps/nm chromatic dispersion. The TODC was set to -2500ps/nm with 15GHz operating bandwidth.

The following figures show the BER curves for the two cases as well as the eye-pattern for the 2<sup>nd</sup> case, which was captured for 25dB OSNR value with BER<10<sup>-12</sup>.

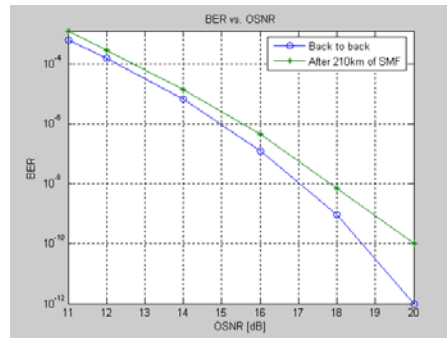


Figure 2: BER vs. OSNR curves

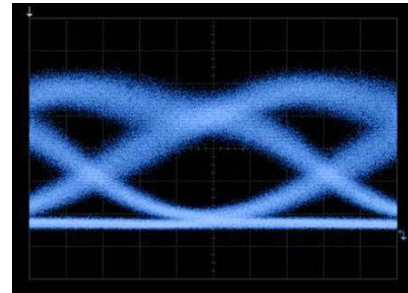


Figure 3: Eye pattern after TODC

### Conclusions

Small form factor, low loss TODC was demonstrated. The TODC is based on free-space, cascaded GT etalons architecture. Since it serves as a linear all-pass filter in the optical domain, it can be used in various scenarios having different modulators (e.g., LiNbO<sub>3</sub> and EML) and different modulation formats. It can be followed by EDC as well to further extend the dispersion tolerance. Additional research is required to exploit the potential of TODC with complementary technologies in single channel applications.

### References

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