Optical Dispersion Compensation in 10Gb/s Transponders

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Abstract: We present a standard butterfly packaged ODC capable of introducing any dispersion value within +/-1700ps/nm with less than 1dB insertion loss. The ODC is integrated in a 10Gb/s tunable transponder reaching 145km with 2dB penalty.

OCIS Codes: (260.2030) Dispersion; (230.1150) All-optical devices

1. 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 [1], fiber bragg gratings [2] and ring resonators or other PLC structures [3]. Extending the reach of a transponder 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 dispersion compensation technologies listed above have resulted in a packaged device that can be integrated in a standard 10Gb/s transponder, either due to the high insertion loss or the large form factor.

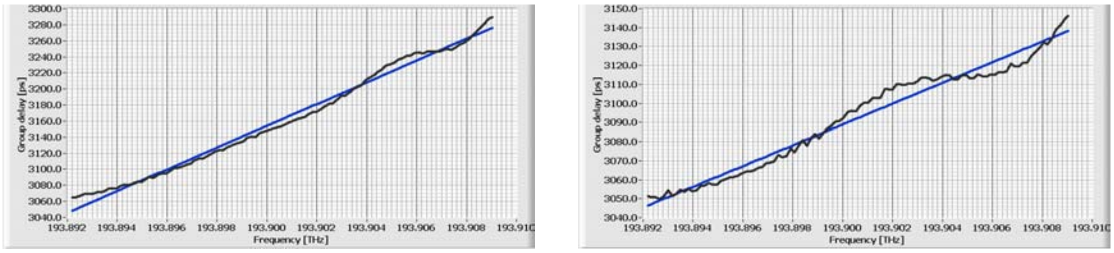
Currently, there are three major alternatives for mitigating the effects of chromatic dispersion in a transponder. One solution constitutes of a different encoding scheme known as Duobinary in which a three-level electric field signal is generated [4]. The receiver on the other end is kept unchanged since the three-level signal translates into a two-level intensity signal. Duobinary encoding can be implemented with a standard Mach-Zehnder modulator at the expense of using $2V\pi$ driving amplitude signal. The resultant bandwidth reduction of Duobinary encoded signals mitigates the chromatic dispersion effects and up to +/-3500ps/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 at long-haul distances.

Another technique to cope with chromatic dispersion is through electronic dispersion compensation (EDC) [5]. EDC is typically based on FFE (Feed Forward Equalizer), DFE (Decision Feedback Equalizer) or MLSE (Minimum Least Squares Error) architectures. It is a low-cost solution that increases the dispersion tolerance up to+/-2000ps/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 nonlinear effects, its performance deteriorates as the bit rate increases and thereof is typically limited to 11.1Gb/s. This may be considered as a major limitation for system designers that use advanced FEC (Forward Error Correction) schemes operating at low OSNR (Optical Signal to Noise Ratio) values for either SONET (Synchronous Optical Network), GbE (Gigabit Ethernet) or FC (Fiber Channel) applications. Such FEC schemes operate at bit rates ranging from 10.7Gb/s to 12.5Gb/s.

Being a optical phenomenon, chromatic dispersion, which is regarded as linear filtering in the electric field domain, can be best compensated for optically, i.e., via an ODC. Nevertheless, ODCs have been considered as bulky, costly, dissipates high power, and often did not provide the necessary required tunability. Until today, there is no available ODC that can fit into a standard 300-pin MSA transponder. This paper presents the first 300-pin MSA transponder with integrated tunable ODC (Optical Dispersion Compensator) that reaches +/-2500ps/nm dispersion tolerance with less than 2dB OSNR penalty.

2. Transpnder with integrated tunable ODC

The proposed ODC is based on free-space optics etalons architecture and is packaged in a standard butterfly package (20.83X12.7X9.25mm). Being an optical compensator with over 18GHz of operating bandwidth, it is bit-rate agnostic. As it is based on free-space optical elements, the insertion loss mainly arises from misalignments and fiber coupling and is less than 1dB. The latter property is of great importance for an ODC that is integrated in a transponder, since it determines the penalty in the transponder's sensitivity. Fig. 1 shows the measured group delay across the operating bandwidth of the ODC for -700ps/nm and -1700ps/nm. The measured GDR (group delay ripple) is smaller than 25psec (peak to peak).



(a) (b)

Fig. 1. Actual (measured) and ideal group delay curves for (a) –700ps/nm and (b) –1700ps/nm

The etalons are thermally tuned and the temperature settings determine amount of dispersion that is introduced. This results in a typical dispersion setting time of 5sec with less than 1W of power dissipation.
Packaged in a 10Gb/s transponder results in the following eye diagrams that show the quality of the optical signal (11.35Gb/s, PRBS-23, 1550nm) after passing through an SMF of 45km, 85km and 120km. It is easily seen that the signal that do not passes through an ODC gradually deteriorates, while the signal that passes through the ODC remains intact.

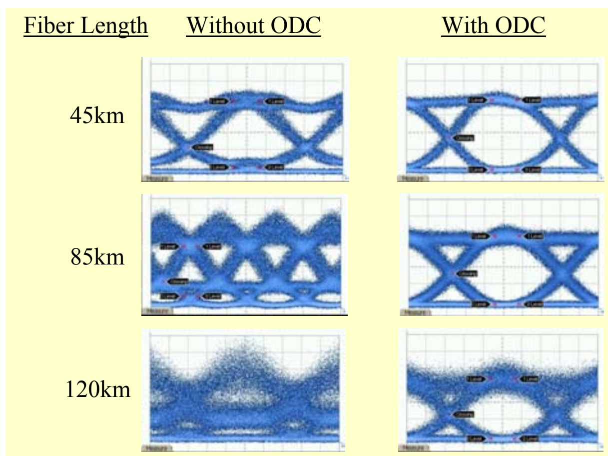


Fig. 2. Eye diagrams with and without ODC at 11.35Gb/s and 1550nm

The following experiment shows the obtained BER values for various fiber lengths for transponders with and without an ODC. In both cases, the transponder at the transmit side is the same as in the receive side. It includes an X-cut $LiNbO_3$ modulator calibrated to provide extinction ratio of 12dB, transmitting PRBS-23 data bits at 11.352Gb/s, and a PIN photodiode. The signal is attenuated and then coupled with noise such that the launch power into the fiber is –2.5dBm at 1550nm and the OSNR is equal to 13dB@0.1nm. The resultant optical signal travels through SMF-28 with adjustable length and an EDFA is used to amplify the optical signal coming out of the fiber. An optical filter extracts the optical signal and a second attenuator is used to calibrate the received optical signal to –14dBm. The results (shown in Fig. 3) clearly show how the BER rapidly increases for fiber lengths greater then 65km while when the integrated ODC is used, only mild OSNR penalty is shown for fiber length of 120km.

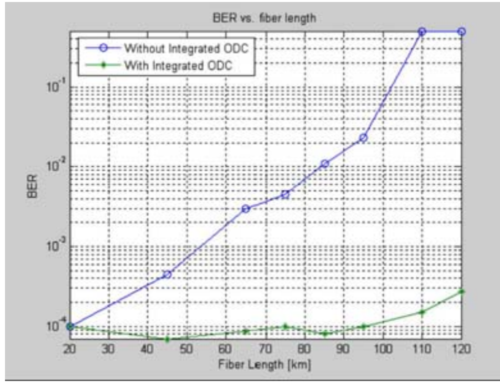


Fig. 3: Measured BER with and without integrated ODC

3. Comparison with EDC

As the ODC is practically bit-rate transparent, it was compared with EDC for various bit-rates. The BER was measured after 80km of SMF-28 for a PRBS-23 sequence at 1550nm and 12.5dB OSNR for three cases: without dispersion compensation, with EDC and with ODC. Back to back measurements under the same conditions without any compensating element are also carried out for comparison. Table 2 summarizes the obtained results. There is some degradation in BER in back to back (without any dispersion compensating element) that is due to the receiver circuitry and the PIN photodiode and is therefore shown when EDC or ODC are used. Nonetheless, the data shows an increasing OSNR penalty over the ODC.

BER / Bit Rate [Gb/s]	Back to Back	80km with ODC	80km with EDC	80km without compensation
9.9	4.3E-05	1.5E-4	4.7E-4	3.0E-3
10.7	1.1E-04	3.6E-4	2.9E-3	9.9E-3
11.1	1.8E-04	5.8E-4	3.9E-3	1.6E-2
11.3	2.2E-04	7.1E-4	6.2E-3	2.0E-2
11.45	2.4E-04	7.7E-4	7.6E-3	2.5E-2

Table 1: BER measurements at back to back and after 80km of fiber with and without EDC and ODC

4. Conclusions

This paper presents experimental results of a standard butterfly packaged ODC. The ODC was integrated in a 300-pin MSA, 10Gb/s tunable transponder and was shown to provide +/-2500ps/nm dispersion tolerance. The performance of the transponder with integrated ODC is compared with that of an integrated EDC. It is shown that under the effect of chromatic dispersion, the ODC is advantageous over the EDC, especially at high bit rates and large dispersion values.

5. References

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