Comparison of an Unconventional All-Optical Chromatic Dispersion Compensation Techniques in Nothing in Line Scenarios with Emphasis to Tuneability

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ABSTRACT In this contribution we compare experimental results based on application of different all-optical chromatic dispersion (CD) compensation techniques including tuneable ones. As fixed CD compensators, we used both channelized and broadband fibre Bragg gratings (FBG). Results obtained by application of thermally tuneable channelized FBGs and Gires-Tournois etalons (GTE) are also compared. In our experimental setup eight 10 Gigabit Ethernet (10 GE) channels were transmitted over 225 km of standard single mode fibre (SSMF) with no inline amplification. Signals were combined in multiplexer, amplified in a standard C-band erbium-doped fibre amplifier (EDFA) and launched in the SSMF fibre. At the receiver side, signals were first amplified in a low noise EDFA, CD was compensated by one of the elements and de-multiplexed. Partial CD pre-compensation was also tested.

Keywords: optical fibre communications, chromatic dispersion compensation, wavelength-division-multiplexing

1. INTRODUCTION

Long distance transmission at rates of 10 Gb/s and higher over standard single mode fibres (SSMF, G.652 according to ITU specification) is of great interest because of the large base of such fibres already installed in the ground. The low loss of these fibres, together with the availability of erbium-doped fibre amplifiers (EDFA's), makes the 1550nm window an attractive wavelength range of operation. However, the chromatic dispersion of SSMF is relatively large (≈ 17 ps/nm/km) within this window, severely limiting transmission distances unless compensating techniques are employed. These exists quite large number ranging from electrical pre- or post-processing to all-optical ones. Unfortunately electrical processing is per wavelength based therefore unsuitable for WDM and suffers from power hungriness. Typical and simple solution is to periodically place a lumped optical element that produces negative dispersion.

Two most common fixed-value negative-dispersion elements are dispersion compensating fibre (DCF) [1] and chirped fibre Bragg grating (CFBG) [2]. Negative dispersion of DCF is typically five to six times as large as the SSMF so that about 13 km spool of DCF is required to compensate for 80 km of SSMF. The insertion loss of the DCF is roughly twice to three times that of SSMF. Although DCF is broadband, dispersion slope of SSMF and DCF is not exactly balanced so that in wavelength division multiplexed systems only one channel can be compensated exactly.

A chirped fibre Bragg grating is a grating written near the fibre core in which the refractive index periodicity varies along the length of the grating. With a proper design, faster propagating spectral signal components are reflected later in the grating and incur a longer delay, whereas slower propagating components are reflected earlier. As a result, compressed and dispersion compensated optical pulses are reflected from the CFBG and can be subtracted with an optical circulator.

Tuneable compensators are necessary for several reasons:

1) Channels at the extremes of the transmission bands in DWDM systems are over or under-compensated when fixed CD compensation is applied at the central channel

2) In reconfigurable networks the network path and the accumulated CD can change due to rerouting or optical add/drop multiplexing

3) Much finer compensation of accumulated CD will be necessary when upgrading from 10 Gb/s to 40 Gb/s as the tolerable threshold for accumulated dispersion is 16 times smaller than that at 10 Gb/s. This means that typical 40 Gb/s transceivers will tolerate only ≈ 100 ps/nm of residual CD which is equivalent of 5.8 km of SSMF. This estimation agrees roughly with the CD tolerance range of 80 ps/nm of the first commercially available 40 Gb/s transceivers from OPNEXT or Finisar.

There are several possibilities how to achieve tuneable CD compensation, including: differential thermal tuning of nonlinearly chirped FBG [3, 4], thermal tuning of free space or FBG coupled-cavities Gires-Tournois etalons (GTE's) [5, 6] and virtually-imaged phase-array (PA's) [7, 8].

Properties of the most frequently used CD compensators (insertion loss IL and maximum polarization dispersion PMDmax) are summarized in table 1. Full CD compensation of 100km of SSMF (≈+1680 ps/nm) is assumed for the comparison. Tuneable commercially available compensators are compared in table 2.

Fixed devices	IL [dB]	PMD max [ps]
DCF 16.2 km	8.9	0.3
broadband FBG	3.5	
channelized FBG	2.9	0.3
GTE	9	0.7

Tab 1: Comparison of fixed compensators compensating CD of 100km SSMF

Tuneable devices	IL [dB]	PMD max [ps]	Tuning range [ps/nm]	Tuning step [ps/nm]	Tuning speed [s]
channelized FBG	6	2	1500	10	10
GTE	2		3400	100	10
PA	8	2	1800	10	0.01

Tab 2: Comparison of tuneable devices

2. EXPERIMETAL SETUP

In research and educational network (REN) environment typically based on leased fibres where aggregation function of network has not so important role, nothing-in-line (NIL) approach is frequently used. In this scenario transmission is done through point-to-point links with no inline equipment reducing both capital and operational expenses.

Our experimental laboratory setup shown in Fig 1 follows NIL approach using no inline equipment and deploying mainly CD post-compensation scenario. Partial CD pre-compensation depicted as dotted line CD compensator has also been tested. Signals from eight 10 GE DWDM XFP transceivers were combined in multiplexer (MUX), amplified in a high-power C-band EDFA and launched into the test link. At the receiver side signals were first amplified in a low noise preamplifier EDFA, CD was compensated according one of the further described scenarios and finally de-multiplexed.

Wavelengths of the transmitted channels (Tx_1-Tx_8) were 1550.12 - 1556.55 nm (wavelength 1553.33 was skipped), which corresponds to channels #34 - #26 according to ITU 100GHz grid (channel #30 was skipped). According to vendor specifications nominal transmitter's output power is in the range -1 to +3 dBm, minimal sensitivity of the receivers is -24 dBm and CD tolerance from 0 to +1600 ps/nm. Bit-error rate tests were done by Packet Blazer 10GigE FTB-5810G module operated in channel #33. The test link consisted of 225km of SSMF on spools with granularity 50 and 25 km. Chromatic dispersion of the link was ≈+3780 ps/nm.

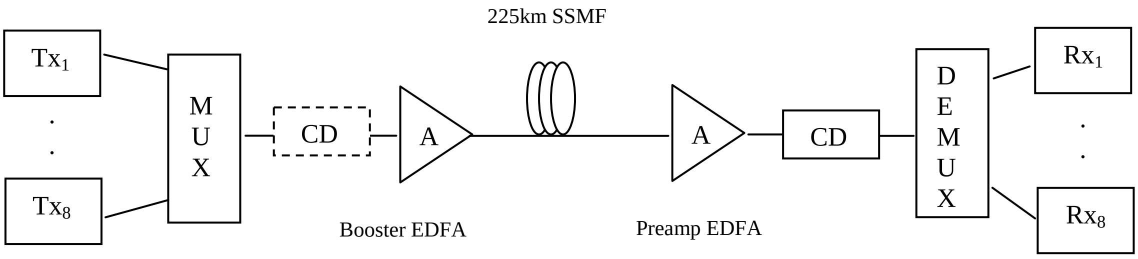


Fig 1: Schematic diagram of the experimental setup.

3. EXPERIMENTAL RESULTS

At first we investigated the transmission tolerance to signal input power launched into the link for post-compensation scenario with fixed value of compensated CD for different compensating devices. CD compensators available were: broadband FBGs, channelized FBGs, channelized tuneable FBGs (TFBGs), tuneable GTEs (TGTEs). Compensated CD value was set to ≈-3400 ps/nm. It was not possible to utilize DCF in the setup shown in Fig. 1 due to extremely high IL. Additional EDFA will be necessary. Figure 2 shows transmission tolerance to launched input power. It follows from the experiments that the setup with TGTEs performs better at lower input powers and broadband FBGs can easily handle relatively high signal powers. Obviously both fixed and channelized FBGs perform nearly identically; performance of tuneable ones is a little worse due to higher IL.

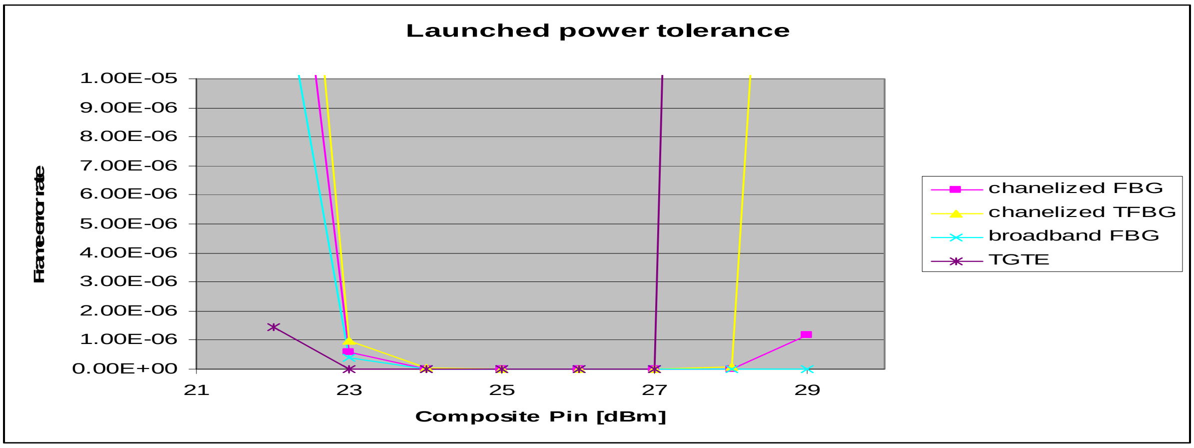


Fig 2: Transmission tolerance to launched input power.

Next we optimized the value of CD for maximum range of input signal power and error-free transmission using tuneable compensators. Both devices (TFGBs and TGTEs) showed the best tolerance at CD compensation of -3200 ps/nm. To achieve error-free transmission TFBGs were able to tolerate Pin in the range of 5dB, TGTEs in the range of 4dB as depicted in Fig 3a and 3b.

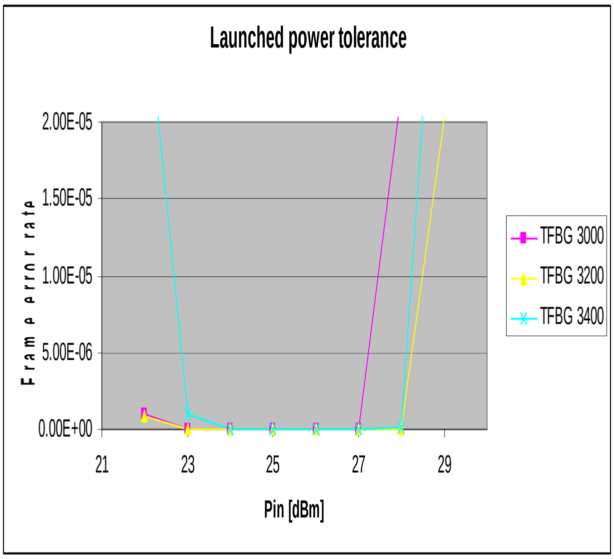


Fig 3a: Transmission tolerance to launched power – CD compensated by TFBGs.

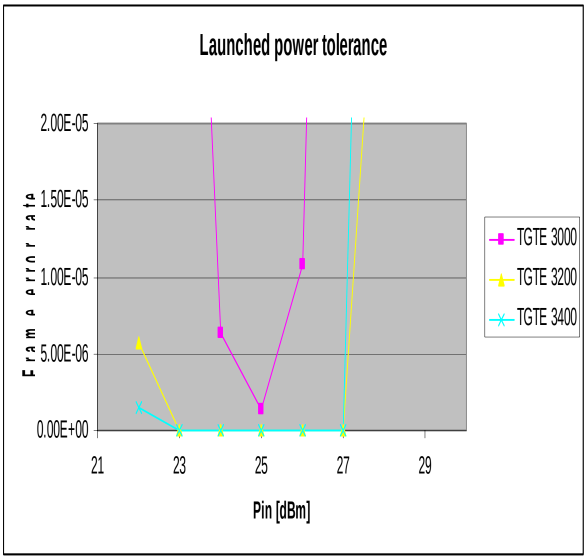


Fig 3b: Transmission tolerance to launched power – CD compensated by TGTEs

Finally comparison of different partial CD pre-compensation schemes has been addressed. Value of pre-compensated CD was changed in steps: 0, -343, -670 and -1090 ps/nm. With no CD pre-compensation TFBGs exhibited error-free operation range of 500 ps/nm and TGTEs showed the range of 300 ps/nm, only as depicted in Fig 4a. Eye diagrams recorded at the receiver corresponding to CD compensation of -3400 and -2800 ps/nm are shown in Fig 5a and 5b.

Addition of a small CD pre-compensation of -343 ps/nm lowered error-free operation threshold by - 300 ps/nm for TFBGs and 400 ps/nm for TGTEs. The addition also significantly extended error-free operation range to 1000 ps/nm for TFBGs and 700 ps/nm for TGTEs as depicted in Fig 4b. Eye diagram responding to this scenario is depicted in Fig 6a. When CD pre-compensation value was increased to -670 ps/nm error-free operation thresholds remained the same as in the -343 ps/nm case, but error-free operation range lowered a little to 900 ps/nm for TFBGs and 700 ps/nm for TGTEs. Eye diagram responding to this scenario is shown in Fig 6b. Next increase of CD pre-compensation to -1090 ps/nm brought significant deterioration of signal and resulted in loss of link at the receiver.

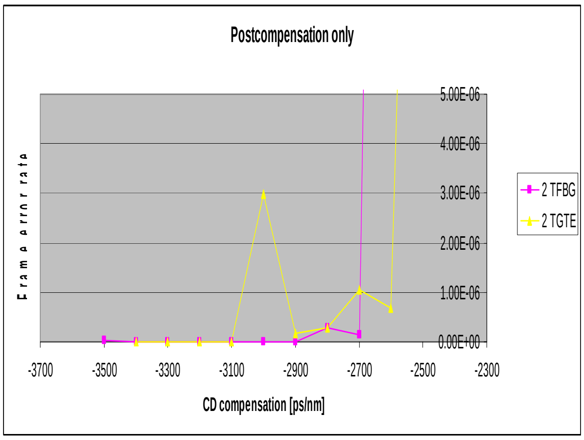


Fig 4a: *Compensation tolerance – post compensation scenario only*

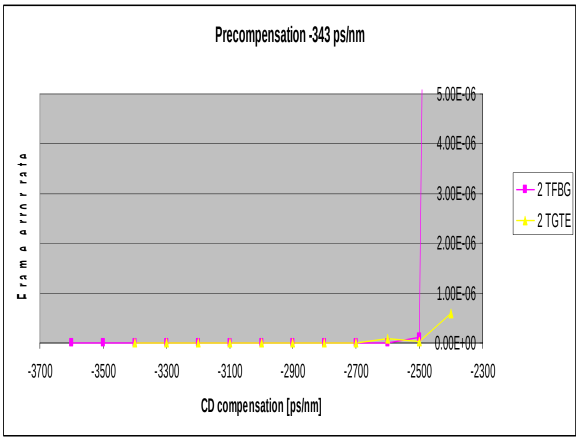
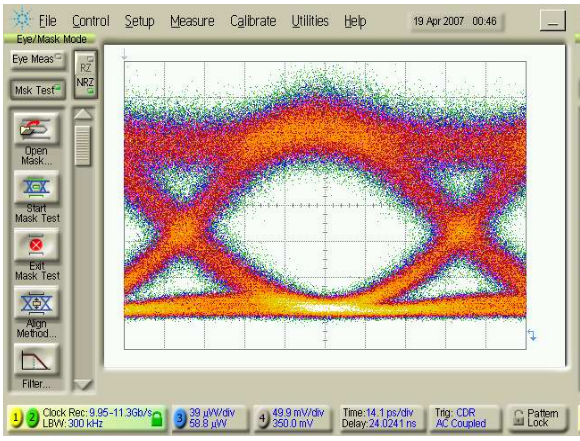
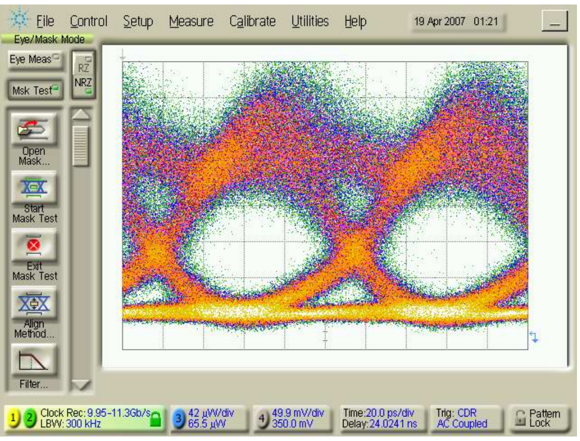


Fig 4b: Compensation tolerance – pre compensation of -343 ps/nm



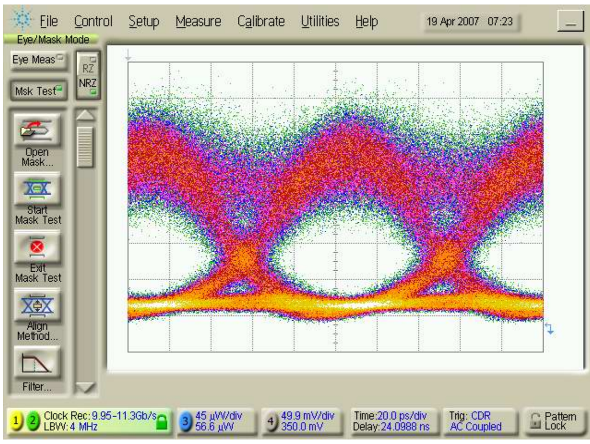
Clock Rec: 9.95-11.3Gb/s LBW: 300 kHz
39 µW/div 58.8 µW
49.9 mV/div 350.0 mV
Time:14.1 ps/div Delay:24.0241 ns
Trig: CDR AC Coupled



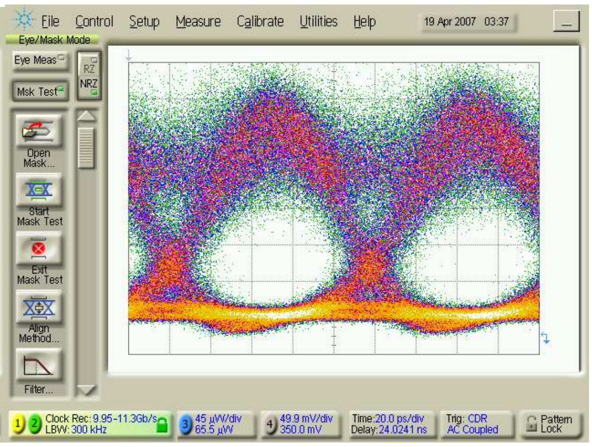
Clock Rec: 9.95-11.3Gb/s LBW: 300 kHz
42 µW/div 65.5 µW
49.9 mV/div 350.0 mV
Time:20.0 ps/div Delay:24.0241 ns
Trig: CDR AC Coupled

Fig 5a: Eye diagram with no CD pre-compensation and post-compensation of -3400 ps/nm

Fig 5b: Eye diagram with no CD pre-compensation and post-compensation of -2800 ps/nm



Clock Rec: 9.95-11.3Gb/s LBW: 4 MHz
45 µW/div 56.6 µW
49.9 mV/div 350.0 mV
Time:20.0 ps/div Delay:24.0988 ns
Trig: CDR AC Coupled



Clock Rec: 9.95-11.3Gb/s LBW: 300 kHz
45 µW/div 65.5 µW
49.9 mV/div 350.0 mV
Time:20.0 ps/div Delay:24.0241 ns
Trig: CDR AC Coupled

Fig 6a: Eye diagram with CD pre-compensation of -343 ps/nm and post-compensation of -2800 ps/nm

Fig 7b: Eye diagram with CD pre-compensation of -670 ps/nm and post-compensation of -2800 ps/nm

4. CONCLUSIONS

We experimentally compared commercially available all-optical CD compensating devices in NIL scenarios. Tests were performed by transmitting 8x10GE channels over 225km of SSMF. Amplification was performed only at transmitter and receiver side by standard C-band EDFAs. Rate of bad frames has been measured by Packet Blazer 10GigE FTB-5810G module operating in the least-favourite channel #33. When the value of compensated CD was fixed at ≈ -3400 ps/nm tolerances to launched power were examined for different compensating techniques. We can summarize that for error-free transmission the GTEs allow for launching of lower signal powers in contrast to broadband CFBGs that tolerate higher launch powers. Experimental setups based on partial CD pre-compensation proved that small CD (≈-340 ps/nm) pre-compensation can dramatically increase transmission CD tolerance range (2 times), we believe due to suppression of self-phase modulation in the link. On other hand higher CD pre-compensation prevented error-free transmission completely.

In the future we would like to experimentally verify applicability of virtually-imaged phase-array CD compensators. Furthermore we would like to use optical network analyzer for precise determination of the set values by tuneable CD compensators or to determine residual CD from the signal waveform at the receiver by a suitable technique, e.g. asynchronous signal sampling.

The results of the performed experiments will be utilized in various projects related to the operational and experimental optical network CESNET2 and CzechLight.

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