Chromatic Dispersion Monitoring using RF Spectrum Analysis

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Abstract: This paper describes a chromatic dispersion monitoring technique based on RF spectrum analysis using optical modulation, and assesses its suitability for use in multi-channel dynamically reconfigurable transparent optical networks.

1. Introduction.

Future networks will evolve from static to dynamically reconfigurable architectures providing bandwidth on demand. These networks will require advanced optical performance monitoring (OPM) techniques to allow for real time control of compensation devices [1]. Currently available OPM techniques include optical spectrum analysis [2] and polarisation nulling [3]. Some advanced techniques include RF spectrum analysis [4,5], histogram sampling methods [6] and electrical equaliser coefficient comparison [7]. These advanced OPM techniques allow for the measurement of the degradation effects without knowing the path history of the data.

This paper describes a chromatic dispersion monitoring technique based on RF spectrum analysis using optical modulation, and assesses its suitability for use in multi-channel dynamically reconfigurable transparent optical networks.

2. Principal of RF spectrum analysis for dispersion monitoring.

Performance monitoring techniques based on RF spectrum analysis are very attractive compared to various other techniques due to their potential fast response time (sub-ms); thus their applicability to dynamically reconfigurable networks. These techniques are applicable to the most widely used optical modulation formats (NRZ, RZ and CSRZ) [8], and would be suitable for bit rates beyond 40 Gbit/s.

When transmitting a dual side-band (DSB) signal over a fibre, the frequency dependent dispersion creates a phase shift between both sidebands, thereby causing a RF power fading at the receiver. This fading effect is a function of the tone frequency and the accumulated dispersion. This signal is a periodic function of the accumulated CD [5]. For this reason, the measurement range is defined and restricted by the first monotonic segment of the curve. The measurement range is given by [1]:

$$\mathrm{GVD}_{\max} = \frac{c}{2\lambda^2 f_0^2} \qquad (1)$$

Where GVD_{max} is the maximum monitoring range; λ the wavelength; f_o the tone frequency and c the speed of light. This expression is bit rate independent. It has been shown [9] that when using a tone frequency of 8 GHz, a measurement range of 1000 ps/nm was obtained for a 10 Gbit/s NRZ system with a negligible power penalty (<0.5 dB). However, this measurement is also dependent on PMD. To suppress PMD effect, the use of a single sideband (SSB) setup has been proposed.

In a SSB configuration, the accumulated CD induces a time delay between both sidebands [10].This method has been applied to NRZ and RZ modulation format at 40 Gbit/s bit rates. Both NRZ and RZ formats have 2 optical side-bands that carry the same data. A tunable filter is used to sequentially extract the upper then lower sidebands. This method involves measuring the phase difference between each sideband and the recovered clock signal. The cumulated phase difference is proportional to the relative group delay caused by the CD:

$$\Delta\varphi = 2\pi \frac{\lambda^2}{c} f_0^2 DL \qquad (2)$$

This method presents the advantage of having a linear transfer function (phase measurement vs. GVD) and its measurement range is also given by equation 2. The monitoring range is increased by decreasing the modulation frequency, with a corresponding reduction in the resolution. In addition, this method is independent of first-order PMD. This is the case as the phase difference between the carrier and the sideband components for both polarizations remain equal with DGD. However, higher order mode PMD will have some effect on the measurement due to their wavelength dependence.

3. Comparison between RF spectrum analysis using electrical and optical modulation.

Previous work [10] has demonstrated an implementation of this concept for CD monitoring based on electrical mixing and measurements of the RF spectrum.

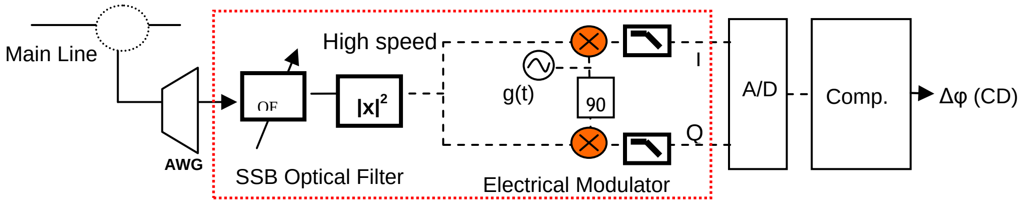

Figure 1 : Chromatic dispersion monitoring system based on electrical mixing.

This implementation, shown in *Figure 1*, uses a tunable band-pass optical filter used to suppress firstly the upper, then the lower side-band. An RF I-Q mixer is used after square law detection, to obtain the phase of each side-band. The chromatic dispersion is then determined from the phase difference between the two sidebands.

This method presents various advantages: It has a fast response time (sub ms); the SSB measurement is inherently independent of first order PMD; the monitor does not require clock recovery or transmitter modification, thus can be used inline in a node or between two nodes. However, its main limitation resides in its single-channel operation. This is indeed the case as each high speed component must be duplicated per monitored channel (see *Figure 1*), which makes this method less cost effective in WDM systems.

We propose a method based on RF spectrum analysis using optical modulators. This new method maintains all advantages obtained in the method previously described using electrical modulation, in addition to having a multi-channel operation. This is possible with the simultaneous down-conversion of all channels using two intensity optical modulators.

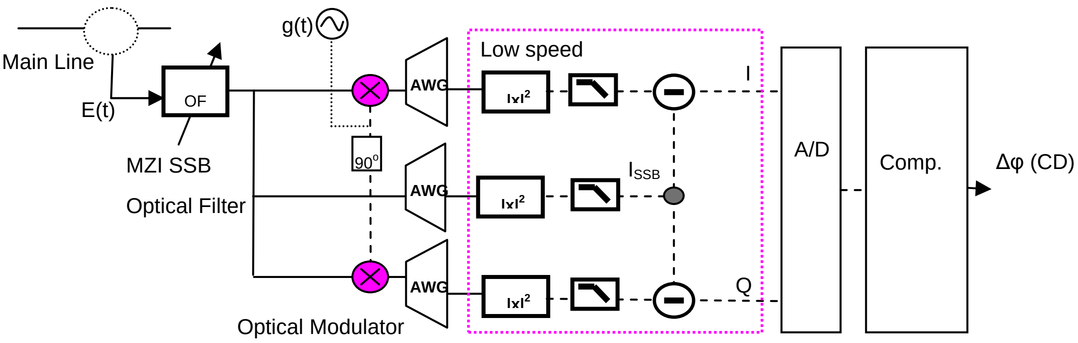

Figure 2: Chromatic dispersion monitoring system based on electro-optical mixing.

The use of an optical intensity modulator for down-conversion gives rise to an additional DC component that is proportional to the average power in the optical signal. Thus, an additional path is used to measure the average power so that this can be subtracted from the quadrature measurements. This path also allows for individual channel power monitoring. In a WDM system, only the low speed components, shown within the shaded area of *Figure 2*, must be duplicated per monitored channel, which makes this method cost effective for multi-channel operation.

4. Simulation results.

4.1. Monitoring range. The setup described has been analysed for a multi-channel non-return-to-zero (NRZ) 40Gbit/s system where only linear degradation effects have been considered. The phase difference, proportional to the measured dispersion, is a periodic function of the accumulated dispersion. For this reason, the unambiguous measurement range is restricted to a monotonic segment of the curve corresponding to a phase shift of 2π between the optical sidebands. The resulting range is given by equation (2) and depends on the frequency of the signal component that is monitored. The following figure shows the monitoring range for 2 modulation frequencies: 20Ghz and 10GHz.

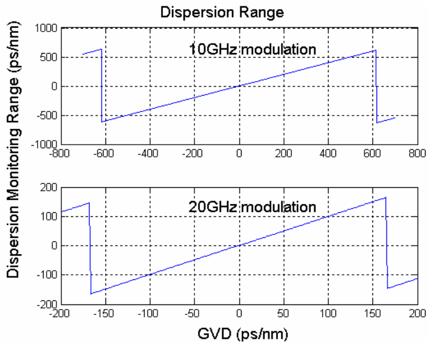

Figure 3: Chromatic dispersion monitoring range for 10GHz and 20GHz modulation frequencies

(A single channel band-pass filter has been used for this simulation).

For a 40Gbit/s signal, if the 20GHz clock tone is monitored, the range obtained is +/-156ps/nm; whereas for the 10GHz tone, it is increased to +/-624ps/nm. This range can be further increased by monitoring lower frequency sub-harmonics of the bit-rate; however, there is a fundamental trade off between the achievable range and the sensitivity. As this range increases, the sensitivity, equal to the slope (range/2π), increases. Thus, the range can be improved at the cost of sensitivity reduction. The dispersion monitoring range provided by the 20GHz tone is suitable for 40Gbit/s systems, thus a 20GHz modulation frequency is used for the experimental work.

4.2 Optical Filter effect. In a single channel monitoring, better measurement accuracy can be achieved when the band-pass filter bandwidth is close to the modulation frequency (20GHz bandwidth for a 20GHz modulation) [10]. In order to achieve multi-channel monitoring in this configuration, it is necessary to use a periodic filter such as a Mach-Zehnder interferometer (MZI) with a free spectral range (FSR) equal to the channel spacing (e.g. 200GHz). It is used as a notch filter to suppress one side-band component allowing interference between the second side band component and the carrier. This type of filter can easily be tuned to either SSB frequency component by changing the phase on one arm of the MZI. We compare the dispersion error when using a single channel band-pass filter and a multi-channel notch filter. We observe that the measurement error varies with the optical filter. When using a multi-channel MZI filter, an error of 6ps/nm is produced over the total dispersion measurement range (150ps/nm) when the 20GHz tone is monitored. This is due to the unwanted interference between any two frequencies within the optical signal whose spacing is equal to 20GHz within the broad pass-band of the MZI filter. This is in contrast to the very small error (below 1ps/nm) produced when using a narrow band-pass filter (bandwidth=20GHz). We note however that in both cases, the measurement error remains less than 5%.

4.3 OSNR effect. The system sensitivity to OSNR is shown in *Figure 4*. When varying the OSNR from 40dB to 22dB, the RMS error, averaged over the entire measurement range, is less than 35ps/nm for the 20GHz tone. This shows the system robustness to OSNR degradation.

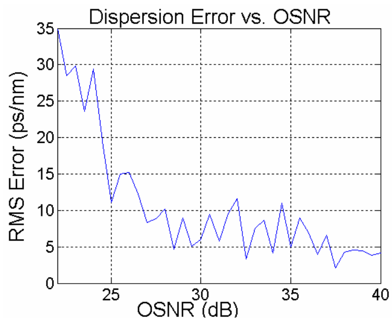

Figure 4: OSNR effect on the dispersion measurement

(A MZI filter with 200GHz FSR has been used for this simulation).

5. Preliminary Experimental Results.

The initial implementation has been done for a single-channel non-return-to-zero (NRZ) 40Gbit/s. The dispersion is added to the system using various lengths of SMF fibre whose loss is compensated for using a variable optical attenuator. The optical filter is manually tuned to each side-band. Two Mach-Zehnder modulators (MZM) have been used for the optical down-conversion. We note that these modulators are polarization sensitive and require manual polarisation alignment making them unsuitable for operation in a real system. In a realistic system, polarisation independent electro-absorption modulators will be used. This system has been used to evaluate the dispersion of a number of fibre spans whose residual dispersion varied from 0-200ps/nm. Initial measurements obtained an accuracy of 60ps/nm. However it is envisaged that this will be dramatically improved with an automated setup that reduces the drifts encountered with slow manual measurements.

7. Summary.

A novel technique for the simultaneous multi-channel monitoring of chromatic dispersion is proposed. The performance of this technique is experimentally assessed for a single-channel 40Gbit/s NRZ system. When using a modulation frequency of 20GHz, a range of +/-156ps/nm is achieved with measurement accuracy of 60ps/nm.

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