Pilot Photonics Comb Source as a Cost Efficient Transmitter in a Multi-carrier Wavelength Division Multiplexed System

The extensive increase in bandwidth usage shows no sign of abating and is pushing service providers to deploy long haul, metro and access networks with increased capacity. With this continued push for higher capacities, carriers are resorting to upgrade the WDM systems by deploying higher wave counts or higher capacities per wavelength. One of the factors that has been attracting a lot of attention, with the move to higher line rates, is the information spectral density achieved at the transmitter. A promising approach entails the use of multi-carrier spectrally efficient transmission techniques with the sub-channel spacing equal to the symbol rate of each sub-channel. This can be achieved by electrically generated orthogonal frequency division multiplexing (OFDM), all optically generated OFDM, the combination of both electrical and optical OFDM or CoWDM [1-3]. A key component for optical multicarrier systems is the optical wavelength comb source (OWCS), which generates the coherent optical carriers. The cost and simplicity of these sources are important factors that would determine the applicability of this technology especially in the price sensitive metro and access networks. Most of the earlier reports on all optical implemented OFDM/CoWDM have used single or cascaded Mach Zehnder modulators (MZM) to generate the phase correlated optical comb. Here, we evaluate the performance of a simple and cost efficient comb source based on a gain switched discrete mode laser.

The spectrum of the PP-OWCS, is illustrated in Fig. 1 (a), and shows efficient sideband generation in the lasing mode, with eight clearly resolved 10.664GHz sidebands generated within 3dB of the spectral envelope peak. Power equalization and outer sideband rejection can be achieved by passing the comb signal through an optical filter with both tunable bandwidth and wavelength. This results in the unwanted outer sidebands being suppressed to about 13dB below the 7 chosen subcarriers and also yields a comb flatness within a 2dB margin as shown in Fig. 1 (b).

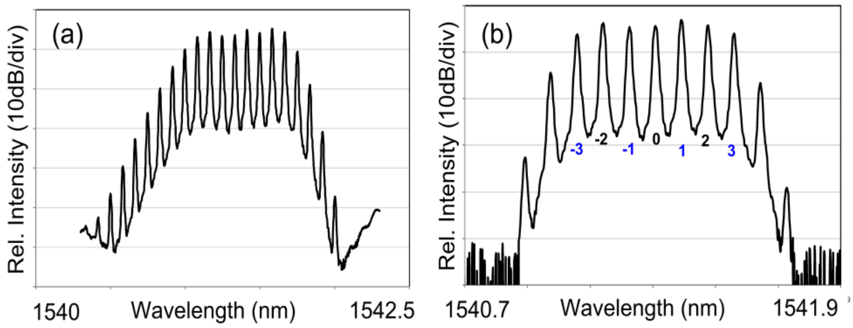

Figure 1 : Optical spectra (a) output comb from PP-OWCS (b) 7 filtered lines from PP-OWCS

CoWDM System using the PP-OWCS

The experimental configuration used for the CoWDM system is shown in Fig. 2 with the CoWDM transmitter consisting of the PP-OWCS (as illustrated in Fig. 1) whose output is optically amplified in order to maintain an adequate optical signal to noise ratio (OSNR).

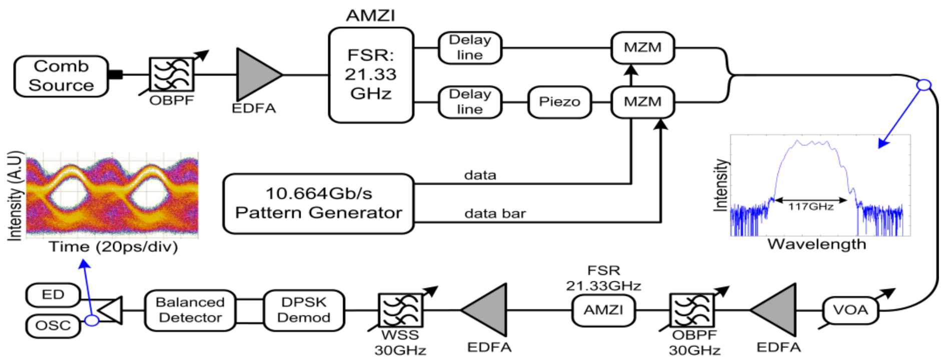

Figure 2 : Experimental configuration of the CoWDM system employing a gain switched DM laser transmitter

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In a practical system, each CoWDM line card would consist of a PP-OWCS, an AWG to filter out the required channels, an array of modulators to independently encode the data on to each of the channels and another AWG to combine them together [7]. However, in this experiment the comb was passed through a dis-interleaver based on asymmetric Mach Zehnder interferometers (AMZI), with a free spectral range (FSR) of 21.33GHz, to separate it into even and odd channels. The subcarriers are numbered to reflect the odd (-3, -1, 1 and 3) and even (-2, 0 and 2) channels. Both, the odd and even channels were passed through a second stage dis-interleaver to improve the extinction ratio to about 40dB. The two sets of channels were then passed through polarization controllers, optical delay lines (ODL) and piezo electric fibre stretchers. The ODLs were used to match the path length of the 2 arms of the interferometer while the piezo electric fibre stretcher was used to adjust the phase of the adjacent subcarriers to be orthogonal thereby minimizing the residual crosstalk. The four odd and three even subcarriers were independently modulated by 10.664Gb/s NRZ electrical data and delayed data-bar streams with a pseudo random bit sequence (PRBS) length of 2^{31}-1 by using two separate Mach Zehnder modulators (MZMs). Both modulators were biased at the null and driven with a 2Vπ data signal, to ensure that optimum phase modulation was imposed on each of the subcarriers. The data and data-bar streams were de-correlated by introducing a 26 bit delay (using different RF electrical cable lengths and RF phase shifters). The two arms were then passively multiplexed with the aid of a polarization maintaining coupler.

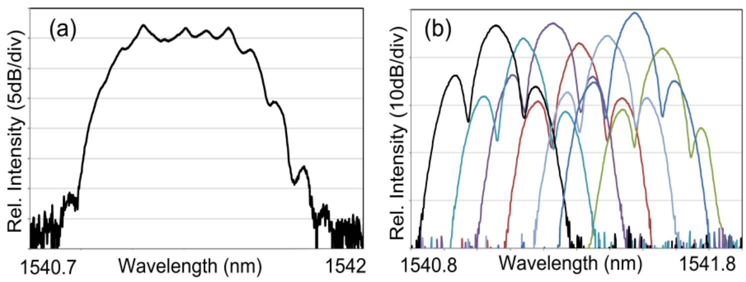

Figure 3 : Optical spectra of (a) 74.648Gb/s CoWDM signal at the Tx and (b) 7 individual filtered DPSK sub-channels each at 10.664Gb/s at the Rx.

The resulting 74.648Gb/s (7×10.664) DPSK CoWDM signal with a 3dB and null to null spectral bandwidth of 75GHz and 117GHz, and is illustrated in Fig. 3. As expected, the signal is characterized by the almost rectangular spectrum due to the strongly overlapping modulation sidebands of the independent data channels. At the receiver side, a variable optical attenuator (VOA) was used to vary the input power falling on a pre-amplified receiver. This receiver consisted of a high gain erbium doped fibre amplifier (EDFA) acting as a pre-amplifier, a 0.3nm tunable optical bandpass filter (OBPF), an AMZI with an FSR of 21.33GHz, a second booster EDFA in automatic power control mode, a wavelength selective switch (WSS), a 10.664GHz DPSK demodulator, and a balanced detector used in conjunction with a limiting amplifier. The 0.3nm OBPF is used to remove the out of band ASE noise and also served as a coarse channel selection filter. The 21.33GHz AMZI was used as a dis-interleaver to separate the 74.648Gb/s CoWDM signal into the odd and even channels, each of which was in turn launched into the second booster EDFA. This signal is then passed through the WSS, which acted as a fine tuning channel filter (bandwidth of 30GHz). Fig. 3 (b) shows the received optical spectrum of the 7 individual filtered DPSK sub-channels each at 10.664Gb/s.

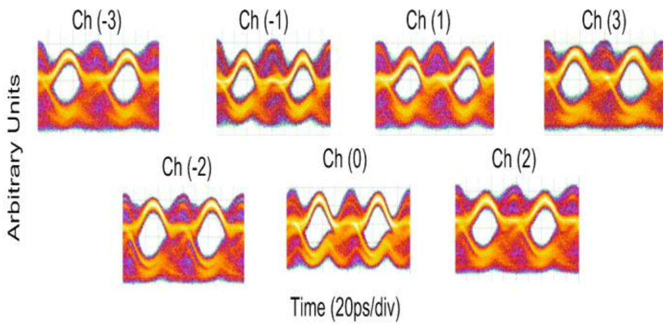

Figure 4: Eye diagrams of the 7 demodulated odd and even subcarriers.

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Finally, the 1 bit delay AMZI was used to demodulate the 10.664Gb/s DPSK signals. The demodulated signal was then detected and amplified using the balanced detector and a limiting differential amplifier respectively, before being fed into an error detector and a high speed oscilloscope. The demodulated eye diagrams for the odd (-3, -1, 1 and 3) and even (-2, 0 and 2) subcarriers of the received 74.648Gb/s DPSK CoWDM signal measured when the limiting amplifier is operated in the linear regime are shown in Fig. 4. It can clearly be seen that the eye at the centre of the bit slot is wide open while the transitions are noisy due to the residual crosstalk.

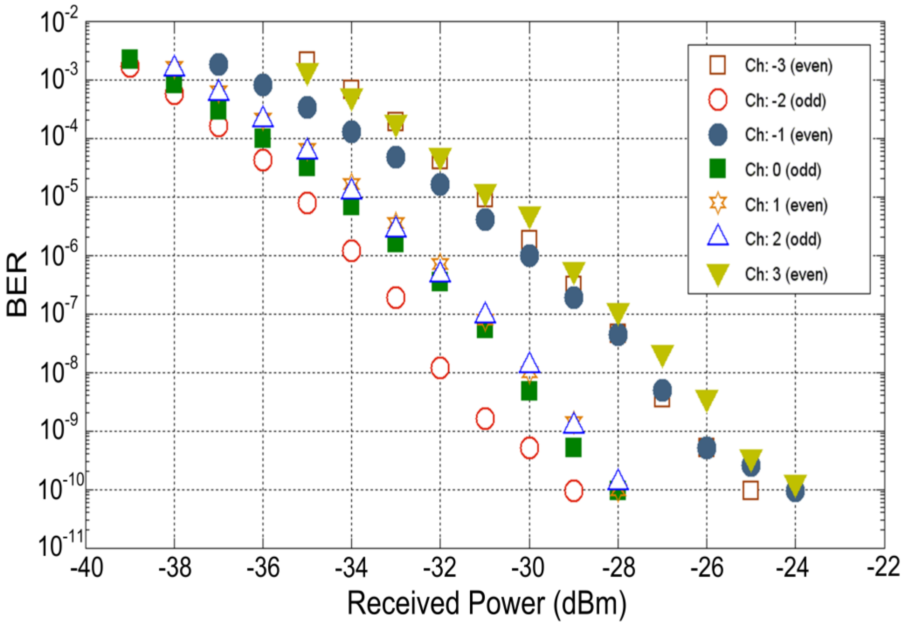

Figure 5 : Measured BER against received optical power for the 74.648Gb/s CoWDM system when the phase was optimized.

Quantitative system performance analysis was carried out by measuring the bit error rate (BER) as a function of the received optical power when the subcarrier phases were optimized [8] and is shown in Fig. 5. As in Fig. 5, the receiver sensitivities at a BER of 10^{-9} for the odd and even CoWDM subcarriers (–3, -2, -1, 0, 1, 2, 3) are -27, -31, -27, -30, -29, -29 and -26dBm respectively. The worst performance is exhibited by the extreme odd channels (-3 and 3) and the best performance is displayed by the even channels (-2 and 0). The power penalty between these channels could be mainly attributed to the power asymmetry of the OFCS and the interference from the non-ideally suppressed unwanted coherent sidebands. Both these effects could be improved by optimizing the comb flatness at the transmitter and using an ideal matched filter at the receiver.

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