

# HIGH BITRATE OPERATION OF A NOVEL OPTICAL PHASE CONJUGATOR USING INLINE FIBRE DFB LASERS

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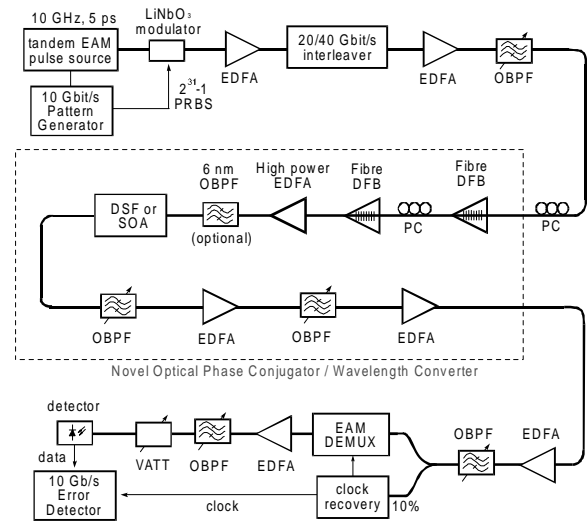
*Abstract: We report the first demonstration of high bitrate, polarisation insensitive optical phase conjugation and wavelength conversion using orthogonally polarised fibre distributed feedback lasers as four-wave mixing pumps in both dispersion shifted fibre and semiconductor optical amplifier.*

Dispersion shifted fibre (DSF) and semiconductor optical amplifier (SOA) are two of the most promising media for optical phase conjugation and wavelength conversion using FWM [1,2]. These are key functions in future high bitrate transmission systems for dispersion compensation using MSSSI [3,4] and switching in WDM networks. Key issues in FWM are the efficiency and polarisation independence. The efficiency has been increased by using both novel fibres [5] and SOAs [6]. Polarisation independent FWM has been demonstrated in both SOA [7] and in DSF [8], using two orthogonally polarised pumps. With this technique, 40 Gbit/s 102 km MSSSI transmission has been demonstrated [9]. However this configuration results in high complexity and component count.

In this paper, we report the use of a novel optical phase conjugator configuration [10] in 20/40Gbit/s system experiments. The conjugator uses inline fibre distributed feedback (DFB) lasers as pumps and polarisation independent operation is achieved by aligning the polarisations orthogonally. This simple configuration eliminates the need for the additional amplifiers and couplers required by the conventional dual-pumped setup [10]. Here, we apply this novel device to FWM in both a highly nonlinear DSF (HNL-DSF) [5] and a long SOA [6] to achieve wideband and high conversion efficiency.

Fig. 1 shows the experimental setup. The signal source is a 10GHz, transform limited 5 ps pulse train generated using a tandem electroabsorption modulator (EAM) configuration [9]. It is externally modulated using a lithium niobate (LiNbO<sub>3</sub>) modulator driven by a 10 Gbit/s, 2<sup>31</sup>-1 pseudo-random bit sequence (PRBS) and interleaved by a 10 to 20/40 Gbit/s interleaver. The interleaver is made from PM fibre and all channels are co-polarised, and delayed with respect to each other by ~10 ns to decorrelate the data patterns. We launch the 20/40Gbit/s signal directly into two inline cascaded, single polarisation Er<sup>3+</sup>:Yb<sup>3+</sup> fibre DFB lasers which serve as the FWM pumps at 1551.5 nm and 1552.8 nm. Each of the fibre DFB lasers is optically isolated for stability and pumped by separate 110 mW, 980 nm diodes to give flexibility in power balance of the pumps. The 1.3 nm wavelength detuning of the pumps is near the minimum required for high bitrate operation [8] as in the SOA case, polarisation

dependence increases with this detuning [9]. A 23 dBm high power optical amplifier is used to boost the signal and pumps before they are launched into the nonlinear mixing media, which is either 440m of HNL-DSF or a 2 mm long SOA at high injection current 550mA.

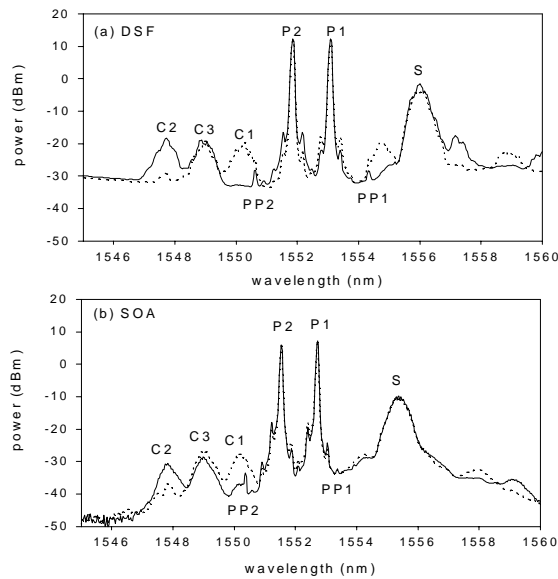


**Figure 1: Experimental setup**

The phase conjugate signal generated by FWM is subsequently filtered and amplified by two 1.3 nm polarisation insensitive optical bandpass filters (OBPFs) and two erbium-doped fibre amplifiers (EDFAs). At the receiver end, 10% of the conjugated signal is coupled out for clock recovery. The derived electrical clock drives the EAM (DEMUX) and the 10 Gbit/s demultiplexed channel is fed to a receiver and error detector.

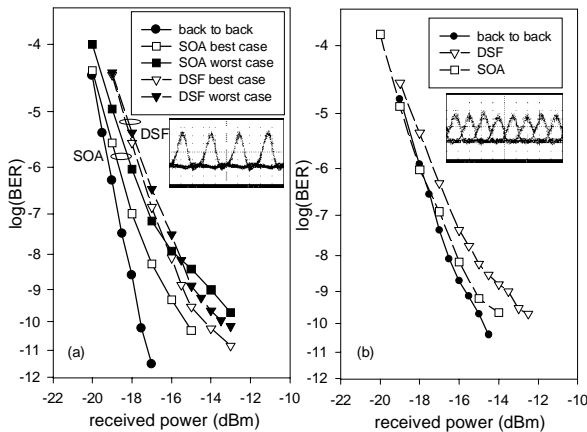
Fig. 2(a) and (b) show the output spectra of the DSF- and SOA-based conjugators respectively. In the SOA case, the signal wavelength is tuned closer to the pumps for higher conversion efficiency and a 6nm OBPF is inserted to filter the out-of-band ASE. The state of polarisations (SOPs) of the two fibre DFB lasers are aligned using a polarisation controller (PC) inserted between them. Orthogonal SOPs could be achieved by monitoring the output spectrum of the conjugator and minimise the pump1-pump2 FWM components, PP1 and PP2 (Fig. 2), to 40 dB below the

pumps. Spectrally, it can be seen that any changes in signal SOP do not change the conjugate (C3) level significantly, hence polarisation independent operation is demonstrated.



**Figure 2: Optical spectra of (a) DSF- and (b) SOA-based conjugators (solid lines and dotted lines represent two extreme signal polarisation cases)**

The BER results of 20 Gbit/s optical phase conjugation are shown in Fig.3(a). Polarisation sensitivity as low as 0.5 dB in power penalty is achieved in the DSF-based conjugator. In an SOA, polarisation induced power penalty is measured to be 1.5 dB due to extra polarisation dependence in the 6nm OBPF. We have error free results at a received power of  $> -10$  dBm despite signal polarisation fluctuations.

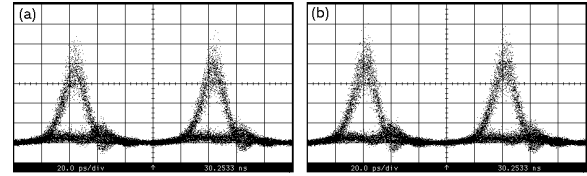


**Figure 3: Bit error rate performance: (a) 20 Gbit/s, polarisation independent and (b) 40 Gbit/s**

Fig 3(b) shows 40 Gbit/s operation with a single fibre DFB laser pump (polarisation sensitive). However, in the polarisation insensitive configuration, we have encountered error floor at around  $10^{-8}$ - $10^{-9}$  error rate. This is due to the ASE-noise at the conjugate wavelength affecting conjugate signal-to-noise ratio. Despite the error floor, we have carried out MSSI transmission over 204 km of standard fibre at 40 Gbit/s. The received demultiplexed signal shows good eyes with low polarisation dependency

in the SOA-based conjugator (Fig.4) and similar performance is obtained DSF.

In order to improve the error performance, one could increase the power of the DFB pumps thus eliminating the need for the amplifier prior to the nonlinear media. This could be done by using a dual-pumped fibre DFB for example.



**Figure 4: Eye diagrams of 204 km MSSI transmission: (a) minimum and (b) maximum received signal**

In summary, we have demonstrated high bitrate optical phase conjugation and wavelength conversion with a novel fibre DFB laser pumped configuration. This configuration has shown good performance both with SOA and DSF at 20 Gbit/s. With the use of a HNL-DSF or a long SOA, practical polarisation insensitive, wideband phase conjugators are realisable, suitable for future WDM and MSSI applications.

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