Remote light source for silicon photonic transceivers in mobile fronthaul applications

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The design and experimental characterisation of a depolarised light source for feeding a remote transceiver based on silicon photonics are presented. Since the transceiver only works in TE mode, the source is designed to deliver, over up to 10 km standard single-mode fibre links, a continuous-wave light with almost constant power along this polarisation direction, whatever be the random polarisation rotation because of the fibre link. The depolarised light source is realised by combining the output of two independent distributed feedback lasers, having orthogonal polarisation and controlled frequency difference. The transmission performance and stability of the remote light source are successfully tested.

Introduction: Silicon photonic integrated transceivers are very promising owing to their low cost, low power consumption and low footprint. Among other applications, there is great interest in this technology regarding next-generation radio base stations for mobile fronthaul communication, in which high-speed common public radio interface signals are transmitted between centralised radio equipment controllers (RECs) and remote radio equipment (RE), distributed over cell sites, through optical links of up to 10 km in length.

In typical applications of commercial silicon photonic transceivers, the light source (usually a continuous-waves [CW] distributed feedback (DFB) laser) is uncooled and integrated with optical modulators on the silicon photonic chip [1, 2] and typically driven with high current to share a single optical source for multiple parallel modulators. For the above reasons, the operating conditions of the integrated laser in commercial silicon photonic transceivers are guaranteed in the temperature range of 0–70°C for reliable operation. Although this is widely acceptable in thermally controlled environments, e.g. in data centres, it is not feasible in mobile fronthaul applications; in this case the maximum temperature the circuitry can reach is up to 90–100°C, since the REs include RF power amplifiers and are normally placed at the top of poles or cell towers subjected to harsh environments.

In this case, the use of silicon photonic transceivers requires that a remote light feeder source should be located remotely, i.e. in the thermally controlled REC cabinets. However, the laser relocation far from the optical modulators has a key relevant consequence, since the optical modulators realised in silicon photonics that must be fed with the external light source are single polarisation devices (SPDs) normally designed to work only in single-TE mode. If a standard single-mode fibre (SMF) is used to connect the RE and the REC units, the state of polarisation (SOP) of the light arriving at the remote transceiver is unpredictable due to changes caused by environmental disturbances on the fibre. Using a common CW laser source, this could lead to large power fading at the modulator output. Therefore, in the work reported in this Letter we experimentally investigated a depolarised light source that is able to deliver a stable input power to the single polarisation modulator, regardless of the SOP variations occurring in the feeder fibre.

Proposed light source: The light source is realised by combining two optical beams generated by two DFB lasers having orthogonal states of polarisation and different frequencies, by means of a polarisation beam coupler (PBC), as shown in Fig. 1.

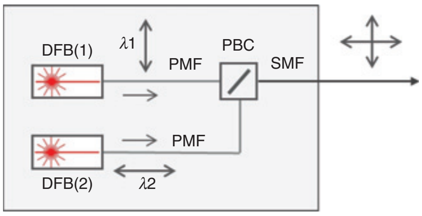

Fig. 1 *Remote depolarised light source scheme*

When the combined beams travel along a SMF spool, both their SOPs will change randomly; to maintain the orthogonal relationship between the two beams, the condition that gives the stability of the power at the modulator, the fibre length should not exceed a maximum value because of the fibre polarisation mode dispersion effects, and the frequency shift between the two lasers has to be limited because of the frequency-dependent characteristic of the fibre [3, 4]. The frequency shift between the two lasers must be limited also to avoid a transmission penalty at the receiver caused by the chromatic dispersion in the drop optical fibre transporting the modulated signal from the modulator to the receiver. If the orthogonal relationship between the two optical beams at the far end is maintained, when the light enters in the silicon photonics modulator, which works as a linear polariser, the sum of the two power values selected by the silicon modulator has a constant optical power, regardless of the SOP changes occurring upon propagation. However, the instantaneous intensity changes as a sine wave of frequency $\Delta\nu$. Therefore, it must be noted that if $\Delta\nu$ is comparable or even lower than the electrical bandwidth of the receiver, the resulting photo-detected signal has unacceptable intensity variations. On the other hand, if the frequency shift $\Delta\nu$ is high, the beating noise is averaged out by the electrical filters in the receiver and can be neglected.

A similar approach for a depolarised source is presented in [5] but in that paper the distance between the remote light source and the optical modulator was of few hundred metres and the modulating signals was a 300 MHz sinusoid. For this reason, the analysis was focused on the investigation of the beat note and mixing terms that have detrimental effects on the signal-to-noise ratio. In our work, the maximum source to modulator distance was increased to 10 km and the transmitted signal was intensity modulated at 10 Gbit/s. Our analysis was then focused on the impacts of the beating noise and the chromatic and polarisation mode dispersion effects.

Depolarised light source analysis and validation: The stability of the light source was tested using the setup shown in Fig. 2. Thermal cycles were applied to the fibre spool, in order to stimulate the state of polarisation variations of the CW light along the SMF. The polariser was used to select a wanted linear SOP after propagation in the fibre (to simulate the single polarisation input of the silicon photonic transceiver) and a polarimeter measured the power variation at the polariser output.

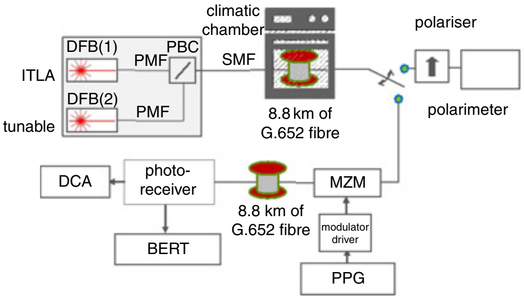

Fig. 2 *Setup for remote light source stability test and transmission performance test*

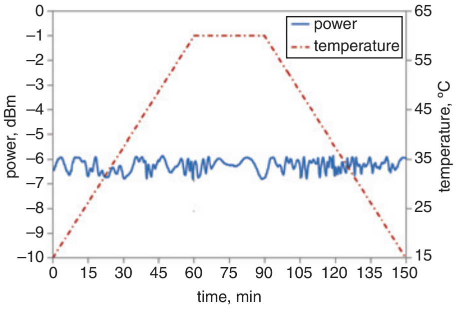

Fig. 3 *Power fluctuation of depolarised light source during thermal cycle*

Fig. 3 shows the measured power fluctuation at the polariser output during the thermal cycle 15°C–60°C–15°C. It was <1 dB and was mainly caused by a small power inbalance between the two used DFB lasers. Experimental evaluation of transmission performances was carried out with the setup shown in Fig. 2. Two DBR tunable lasers were used as polarised light sources: DBR(1) was an integrable tunable laser assembly (ITLA) with 50 GHz resolution, whereas DBR (2) was a tunable laser with 100 MHz resolution. DBR(2) was finely tuned in order to accurately investigate the transmission performance dependence on the frequency shift of the two sources. The two CW beams were combined by a PBC and then sent over a 8.8 km-long spool of G.652 SMF, representing the light feeding link of the RE, received from the REC cabinet. At the end of the SMF spool a polarisation-dependent Mach-Zehnder modulator was used for intensity modulation of the power received from the depolarised light source after the selection of the wanted polarisation, with a 2^{31}–1 pseudo-random binary sequence at 9.953 Gbit/s.

A commercial modulator driver, with a 12.5 GHz bandwidth, was placed between the pulse pattern generator (PPG) and the modulator to generate the driving electrical signal level. The modulated optical signal was transmitted over further 8.8 km of G652 SMF (drop fibre, representing the upstream link from the RE to the REC) and then directly detected by the photo-receiver. A variable optical attenuator was placed in front of the photo-receiver (a pin-photodiode with 7.86 GHz electrical bandwidth) to adjust the optical power level. Finally, the electrical signal was sent to the bit error rate tester to analyse the performance by using a digital communication analyser.

System performance was evaluated for several DBR(1) and DBR(2) frequency detuning. Bit error rate (BER) curves in back-to-back condition and after 8.8 km G.652 fibre propagation are shown in Figs. 4 and 5 respectively.

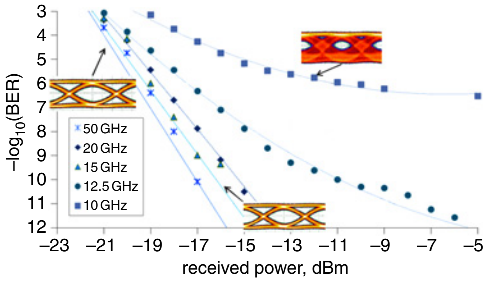

Fig. 4 *BER curves and eye diagrams in back-to-back condition*

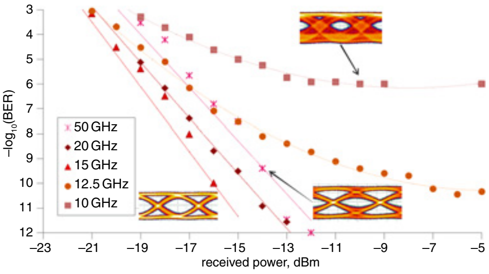

Fig. 5 *BER curves and eye diagrams after transmission in 8.8 km of G652 fibre*

Relevant eye diagrams are also shown in Figs. 4 and 5. In the back-to-back condition, reducing the optical carrier frequency distance below 15 GHz (i.e. 12.5, 10 GHz frequency spacing), the BER performance showed sensible degradation due to the optical carriers beat frequency falling within the electrical bandwidth of the photo-receiver; this degradation is also confirmed by the related eye diagrams. On the other hand, after transmission by increasing the frequency detuning up to 50 GHz, the eye diagrams confirmed that the chromatic dispersion effect becomes predominant on system performance.

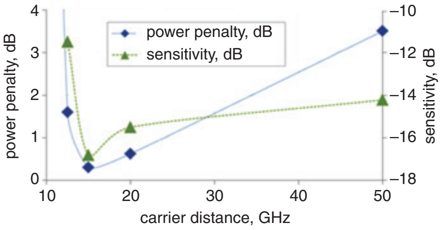

Fig. 6 *Power penalty and sensitivity measured at BER = 10^{-9} against DFB's frequency shift (carrier distance)*

Fig. 6 shows the measured power penalty and the receiver sensitivity at BER = 10^{-9} by varying the lasers frequency detuning. The Figure shows that a 15 GHz frequency shift is the best trade-off between beating noise and chromatic dispersion-limited performance. We note that with the proposed solution, the power penalty with a carrier frequency shift ranging from 12.5 to 40 GHz remained well below 3 dB.

Conclusion: A depolarised light source for the remote feeding of single polarisation devices has been described, tested and validated for application in mobile fronthaul communications, where silicon photonic transceivers are placed inside remote REs (operating in a harsh environment and requiring the feeding of light by a central office located source). The light source has shown good stability against the state of polarisation variations over the 8.8 km SMF link. Furthermore, the easy and fast implementation of the solution and the possibility to feed more than one remote transceiver with a single light source ensures a cost saving and simplification of the overall system architecture.

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One or more of the Figures in this Letter are available in colour online.

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References

1 De Dobbelaere, P., *et al.*: 'Packaging of silicon photonics systems'. Proc. OFC, San Francisco, CA, USA, March 2014
2 Masini, G., *et al.*: 'CMOS photonics for optical engines and interconnects'. Proc. OFC, Los Angeles, CA, USA, March 2012
3 Gordon, J.P., and Kogelnik, H.: 'PMD fundamentals: polarization mode dispersion in optical fibers'. Proc. of the National Academy of Sciences 97.9, 2000, pp. 4541–4550
4 Curti, F., Daino, B., De Marchis, G., and Matera, F.: 'Statistical treatment of the evolution of the principal states of polarization in single-mode fibers', *J. Lightwave Technol.*, 1990, **8**, (S), pp. 1162–1166
5 Burns, W.K., Moeller, R.P., Bulmer, C.H., and Greenblatt, A.S.: 'Depolarized source for fiber-optic applications', *Opt. Lett.*, 1991, **16**, (6), pp. 381–383