Experimental Demonstration of 480 Gbit/s Coherent Transmission Using a Fast Tuneable Laser

Marcos Troncoso-Costas\textsuperscript{1,2}, Gaurav Jain\textsuperscript{3}, Yiming Li\textsuperscript{4}, Mohammed Patel\textsuperscript{4}, Lakshmi Narayanan Venkatasubramani\textsuperscript{1}, Sean O’Dull\textsuperscript{1}, Frank Smyth\textsuperscript{3}, Andrew Ellis\textsuperscript{4}, Francisco Diaz-Otero\textsuperscript{2}, Colm Browning\textsuperscript{1,5} and Liam Barry\textsuperscript{1}

\textsuperscript{1} School of Electronic Engineering, Dublin City University, Glasnevin, Dublin 9, Ireland, marcos.troncosocostas2@mail.dcu.ie
\textsuperscript{2} atlanTTic Research Center, University of Vigo, El Telecommunication, Vigo, Spain
\textsuperscript{3} Pilot Photonics Ltd, Invent Centre, Dublin City University, Glasnevin, Dublin 9, Ireland
\textsuperscript{4} MbryoniX Ltd., Unit 13 Fiontarlann Teo, Westside Enterprise Park, Galway, H91 XK22, Ireland

Abstract We show the characterization of a nanosecond switching time, widely tuneable, low linewidth laser and use it to demonstrate 480 Gbit/s 16QAM transmission over 25 km of single mode fibre for a range of wavelengths covering 19 nm in the C band. ©2023 The Author(s)

Introduction
The widespread use of online services such as cloud computing, storage services and online streaming is imposing a continuous increase in the data rate requirements of optical networks. This upscaling of capacity has resulted in the transition of coherent technology from long-haul communications to ever-shorter distances. Additionally, grid flexibility and channel reconfigurability has gained importance over the last number of years [1]. In this situation, coherent technology is required to continue to deliver capacity growth in a cost effective manner while also ensuring a high degree of reconfigurability in optical metro, access and inter/intra data centre networks (through the potential introduction of optical switching technologies [2]). The key enabling technology for fast reconfigurable coherent systems are fully integrated coherent transceivers capable of high-speed optical switching [3], [4].

For an optical coherent network that employs wavelength switching, low linewidth lasers providing ultrafast switching speeds in the order of nanoseconds, are required. Low power consumption and small footprint enabled by photonic integration are also key features that must be fulfilled. Previous demonstrations of widely tuneable lasers in the C-band have shown relatively large switching times [5], [6], due to the need for thermal/mechanical switching [7], [8], or optical 1/f frequency noise too high to support advanced modulation formats [9]. These factors could impose additional limitations on the optical transmission system. More recent work has shown nanosecond switching time and demonstrated the performance of the laser for a 100 Gbit/s back-to-back transmission [10], [11].

In this paper, we present the characterization of a widely tuneable, low linewidth, fast switching laser suitable for next-generation coherent optical access and data centre networks [12]. We then demonstrate its performance in terms of the pre-forward error correction (FEC) bit error ratio (BER) over a 19 nm wide range of wavelengths after a 25 km optical link using 480 Gbit/s dual-polarization 16-ary quadrature amplitude modulation (16QAM). This is, to the best of our knowledge, the fastest transmission rate demonstrated to date with a nanosecond tuneable laser. We find consistent performance over the whole range of wavelengths studied in this work, demonstrating the potential of the device presented for enabling optical switching of coherent signals in future networks.

Device characterization
The laser structure consisted of an InGaAsP multi-quantum well gain section coupled with two tunable ring resonators and an electro-optic phase modulator, as shown in [13]. A total wavelength coverage of 35 nm was observed with a side mode suppression ratio (SMSR) of more than 50 dB. The device was initially characterized for three different operating points corresponding to emission wavelengths of 1540 nm, 1550 nm and 1560 nm. The relative intensity noise (RIN) was measured using the setup detailed in [14]. Values of -151 dB/Hz were obtained for 1540 nm and 1550 nm, and -147 dB/Hz for 1560 nm (Fig. 1 (a)). In all cases, the measurement was thermal and shot noise limited, meaning that the actual RIN value might be lower than the figures presented here. A frequency noise measurement was performed using a delayed self-heterodyne technique explained in [15]. The frequency noise results are presented in Fig. 1 (b). The curves are scaled...
such that the intrinsic Lorentzian linewidth can be read directly from the flat portions of the curves. For this laser, the linewidth is in the order of hundreds of kHz for the three selected wavelengths. It must be noted that the device did not have an integrated optical isolator, and recent versions of the device with an integrated isolator show linewidth values approaching the 100 kHz value over the whole operating range. Moreover, there is no evidence of deleterious 1/f frequency noise present above 1 MHz as was the case previously for fast switching tuneable lasers based on electronic current tuning [9].

Experimental setup
In order to demonstrate the performance of the device, a 60 GBAud dual polarization 16QAM transmission experiment was performed, resulting in a gross transmission rate of 480 Gbit/s. The experimental setup used in this work is shown in Fig. 2.

Four pseudorandom 4-level signals $2^{16}$ symbols long were generated offline, predistorted to compensate for the bandwidth limitation and the relative delays between tributaries introduced by the RF circuit of the transmitter, and uploaded into an arbitrary waveform generator (AWG) Keysight M8194A operating at 120 GSa/s. The signals from the AWG were sent into a dual polarization IQ modulator (IQM) with a 6 dB analog bandwidth of 40 GHz, where they modulated the four tributaries (IX, QX, IY, QY) of the light from the laser. The wavelengths studied were 1544.1 nm, 1551 nm, 1556.6 nm and 1563 nm.

After the IQM, the signal was sent to an erbium doped fibre amplifier (EDFA) for power boosting. The total launch power over both polarizations was set to the powers of 3 dBm, 8 dBm and 12 dBm, and the signal was transmitted over 25 km of large effective area fibre (LEAF) with a chromatic dispersion parameter of 4 ps/nm/km, attenuation coefficient of 0.19 dB/km and a nonlinear coefficient of around 0.7 1/W/km. At the receiver, an external cavity laser was used as a local oscillator (LO) and a dual polarization coherent receiver containing four balanced photodiodes (Finisar BPDV3120R) with a 3 dB bandwidth of 70 GHz converted the optical signal into electrical signals. Four real time oscilloscopes (RTO) with a 3 dB bandwidth of 70 GHz operating at 200 GSa/s were used for capturing the electrical currents into digital signals for offline processing.

The digital signal processing (DSP) applied to the digital signals consisted of receiver skew compensation, resampling to two samples per symbol, signal normalization, IQ imbalance compensation, chromatic dispersion

---

**Fig. 1:** (a) RIN estimation for 1540 nm, 1550 nm and 1560 nm. (b) FM noise estimation for 1540 nm, 1550 nm and 1560 nm. (c) Switching demonstration for a wavelength tuning over 3.5 nm obtained by sending the optical output of the laser through a tuneable optical filter centered at 1550 nm.

**Fig. 2:** Experimental setup. Inset (a) shows the overlapping spectra of several tuning points covering a 10 nm range in the C band.
compensation, frequency offset compensation [16], matched filtering, and adaptive 31 taps decision-directed multiple input multiple output (MIMO) equalizer. The MIMO equalizer included feed forward equalization combined with carrier phase recovery for polarization demultiplexing and compensation of residual distortions. The tap weights were updated using a least means squares algorithm. The BER of the equalized signals was obtained for each of the wavelengths by averaging over both polarizations and multiple captured sequences.

Results
The BER results obtained in these experiments can be seen in Fig. 3. For reference, the figure shows as dashed lines the BER limit for error-free performance of a 7% overhead hard-decision (HD) FEC coded signal and a typical BER limit for a 15% overhead soft-decision (SD) FEC coded signal. BER values well below the SD limit can be seen for launch powers of 8 dBm and 12 dBm over the whole wavelength range. The 3 dBm results are limited by a low signal to noise ratio (SNR) and the obtained BER values are above the SD threshold. Consistent results were found over the whole wavelength range, with just small performance variations among wavelengths.

Inset figures in Fig. 3 show various constellations under different wavelength and launch power conditions. Clear constellations can be seen for launch powers of 8 dBm and above, while the one for 3 dBm launch power shows a wide spreading of the constellation points due to the degradation in SNR. From these constellation diagrams, it is clear that the laser has a low enough phase noise to support 16QAM, and potentially higher order formats.

Conclusions
We have presented the basic device characterisation and system performance of a fast switching wavelength tuneable laser. RIN and frequency noise characterization over a range of wavelengths covering part of the C band present RIN values in the order of -150 dB/Hz and linewidths in the order of 100 kHz. We then presented the performance of the device in a high-speed communication system operating at 480 Gbit/s 16QAM over a distance of 25 km, demonstrating the feasibility of using this laser for optical access, metro and data-centre networks.

The nanosecond switching time, combined with the excellent performance in terms of RIN and linewidth enable this device to support high transmission rates through coherent transmission, in addition to the deployment of fast reconfigurable optical networks based solely on optical switching. The introduction of optical switching into photonic networks can avoid electronic detection and re-transmission of payload data at each node within the network resulting in lower transient times (latency) and power consumption, while maintaining a small footprint.

Acknowledgements
This work was supported by Science Foundation Ireland (SFI) through research grants 18/EPSRC/3591, 13/RC/2077-P2, 12/RC/2276-P2 and by EPSRC-SFI: Energy Efficient M Communication using Combs (EEMC) under reference number EP/S016171/1.

Pilot Photonics would like to thank SMART Photonics for the collaboration around the tuneable laser development. YL thanks the Director of AiPT for funding.
References


