InP-based Comb-locked Optical Super Channel Transmitter

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Abstract: We demonstrate a comb-based transmitter with a potential to be integrated on a single InP photonic chip. Nyquist-shaped polarization-multiplexed 16QAM/64QAM signals are generated and transmitted over 300-km of SMF-28.

OCIS codes: (060.2330) Fiber optics communications; (130.6622) Subsystem integration and techniques; (140.3520) Lasers, injection-locked; (140.3600) Lasers, tunable

1. Introduction

Driven by the need to reduce the size and power consumption, optical transmission systems are increasingly exploiting integrated transmitter technologies over conventional lithium niobate ($LiNbO_3$) technology for transmitter subassembly [1]. In the last few years, various material platforms and transmitter structures have been proposed for coherent (amplitude and phase) modulation, including InP [2-3], GaAs [4], silicon [5], plasmonic [6], silicon organic hybrid [7], and injection-locked direct laser modulation [8]. Among these technologies, monolithically integrated transmitters in InP platform have shown outstanding maturity and reliability and are expected to be predominant in near future optical transmission systems [2-3, 9].

An interesting option for future transmitter technology is the ability to mutually frequency-lock optical carriers, which can be achieved by employing frequency comb technology [10-11]. It has been shown that dense wavelength division multiplexing (DWDM) transmission systems with mutually frequency-locked optical carriers can potentially offer several advantages as compared to conventional laser-bank based DWDM systems, including higher spectral efficiency, bandwidth flexibility [12], and efficient compensation of fiber nonlinearity [11]. These performance aspects are highly significant for future high capacity, flexible grid optical networks. An integrated transmitter with frequency-locked optical carriers could provide an attractive approach in this context.

In this paper, we review the progress of our proposed integrated comb-based transmitter [13-14]. The key building blocks, i.e. the comb generator, tone demultiplexer and IQ modulators, were all demonstrated using discrete devices and PICs based on the InP platform, promising a potential to be fully integrated. The tone demultiplexing was realized by optical injection lock (OIL) a telecom-grade digital super-mode distributed Bragg reflector (DS-DBR) tunable laser, which allows for flexible wavelength selection and potentially reduced laser phase noise. Dual-polarization Nyquist-shaped 16/64 QAM signals were generated and transmitted over 300-km SMF-28 [14].

2. Transmitter Configuration

Fig. 1a shows the schematics of our proposed comb-locked super channel transmitter. The transmitter has three function blocks: comb generator, tone demultiplexer, and IQ modulators. The comb generator comprises a tunable laser integrated with a dual-electrode Mach-Zehnder modulator (MZM) Broadband flat comb can be generated by driving individual arm using RF signals with appropriate power and phase difference [13]. In the tone demultiplexer, a multimode interferometer (MMI) splits and injects the comb to a set of tunable lasers. The wavelength of each laser is tuned to the wavelength of the selected comb tone so that the laser is injection-locked, giving an output which is frequency-locked to the selected tone (with comb spacings as small as 6.25 GHz). This process is relatively insensitive to the comb tone(s) power(s), thus strongly relaxing the requirements on the power per tone and the power uniformity. It also allows for a significant reduction in the linewidth of the locked laser(s) because of the inherently large OIL locking bandwidth [15]. Finally, the frequency-locked tunable lasers are launched into the respective InP IQ modulators for coherent modulation before combined by a multiplexer to form the super channel signals.

3. Experimental setup

The key building blocks for our transmitter are based on commercially available InP-based devices. We first experimentally studied the comb generation using a compact device that contains a telecom C-band tunable laser emitting 13 dBm and a push-pull modulator with a V_{π} of 2.7 V and a bandwidth of 10 GHz (shown as the comb generator in Fig.1) [13]. The modulator was driven by 10-GHz RF signals with a power difference of 1 dB. DC bias voltages and relative phase difference $\Delta\phi$ are optimized for generating a flat comb. The system experiment that focuses on tone demultiplexing and signal generation/transmission is shown in Fig.2. Although the transmission experiment was conducted using a 25-GHz comb based on Fabry-Perot modulators [16], it does not affect the conclusion we draw in this paper, which focuses on the demonstration of the key building blocks. The generated comb tones had an identical linewidth of about 4 kHz and a total output power of 11 dBm. Their power was attenuated before injection into the DS-DBR laser (Oclaro TL5000 iTLA packaged without any isolator) via an optical circulator. The optical circulator could be avoided by OIL via the rear laser facet as demonstrated in [17]. The modulator used was a dual-polarization InP IQ modulator with a V_π of ~1.5V. The modulator was driven by an arbitrary waveform generator (AWG, Tektronix AWG7122C) that operated at 10-bit 12 GSa/s, generating 10-GBaud Nyquist-16QAM signals, yielding 1.2 samples per symbol. The transmission link comprised of four 75-km spans of SMF-28 with the link loss compensated by three 16-dB gain in-line amplifiers (EDFAs). ASE noise was filtered with a 30-GHz tunable optical band pass filter.

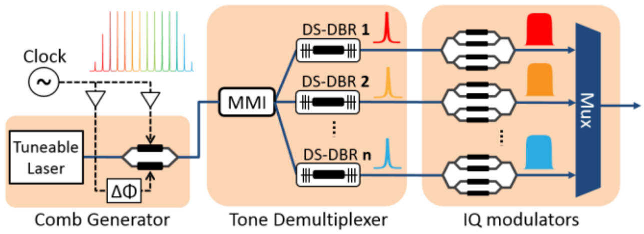


Fig. 1 Schematic of our proposed comb-locked super channel transmitter.

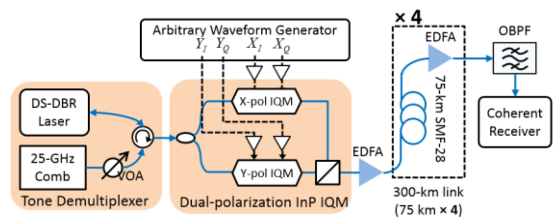


Fig.2 System experimental setup.

3. Experimental results

a) InP compact comb source

The comb generation using InP MZM involves a mixture of amplitude and phase modulation at each modulator electrode. In the experiment, we kept increasing the RF power for obtaining more comb tones up to the 26/27 dBm level. Beyond this point no additional tones were generated and higher attenuation was observed. This is due to shift of the bandgap absorption wavelength when applying voltage on semiconductor material. For a given RF power, we could obtain an essentially flat comb spectrum as shown in Fig. 3 (bottom curve). By optimizing the DC bias voltages and the phase $\Delta\phi$. It was possible to get more comb tones by allowing a dip in the middle of the spectrum, Fig. 3, middle and upper curve. We also see that a wider comb with a more pronounced dip is generated with lower conversion efficiency. Using an off-the-shelf device, 29 tones (corresponds to 280 GHz span) with less than 3 dB power ripple were obtained.

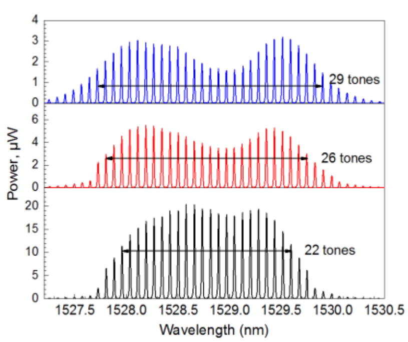


Fig. 3. Comb response when both RF signals were 26/27 dBm for completely flat (22 tones) comb and comb with increased dip in the middle (26 and 29 tones).

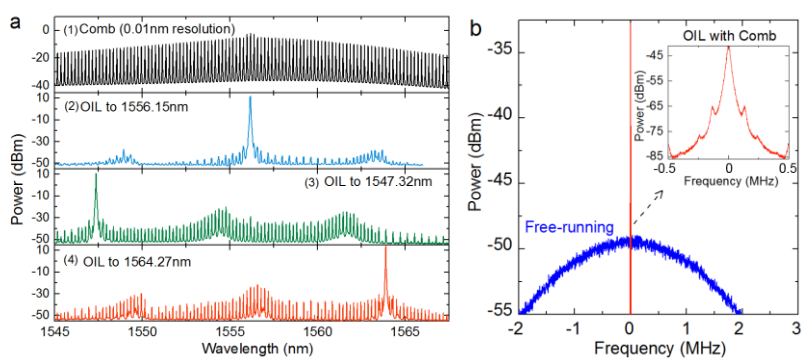


Fig. 4. (a) Optical spectra of the optical frequency comb and DS-DBR laser OIL-locked to three comb tones. (b) Measurement of the laser linewidth using the self-heterodyne method. blue: free-running, red: OIL with comb. The inset shows the result for the laser with OIL.

(b) OIL-based tone extraction

The optical spectrum (10 pm resolution) of the Fabry-Perot modulator based frequency comb (that we used to replace the compact comb due to device availability) is shown in subplot (1) in Fig. 4a. The center tone at 1556.15 nm had a power of -2 dBm and an OSNR (0.1 nm resolution) of 24 dB. The power and the OSNR of the comb tones decreased to -14 dBm and 15 dB at the 1547.32 nm, and -13 dBm and 16 dB at 1564.27 nm, respectively. The subplots (2)-(4) in Fig. 4a show the optical spectra of the comb and OIL-laser at a central wavelength of 1556.15 nm, and at short/long wavelengths of 1547.32 nm, and 1564.27 nm, representing a tuning range of 17 nm. Residual comb tones (>30 dB below the signal level) can be seen in the OIL laser spectrum – these are due to reflection from the front facet. It is believed this could be strongly suppressed if rear-facet OIL was employed [17]. The suppression ratios (‘side-mode-suppression-ratio’, SMSR) of the unwanted tones after OIL were between 30 and 48 dB (for OIL at 1547 and 1654 nm, the strongest comb tones were at wavelengths close to the center of the comb at 1556 nm). The linewidth of the free-running DS-DBR laser was measured to be ~2.5 MHz and this was significantly reduced to 4 kHz (similar to the narrow linewidth of the seed laser) with OIL (shown in Fig. 4b). The single comb tone power injected into the DS-DBR was -28 dBm, resulting in a (measured) locking range of ~700 MHz.

(c) Signal generation and transmission

Fig. 5 shows the BER measurement results for the DP-Nyquist-16QAM. The closed markers show the measured results at back-to-back for 1556.15 (Fig. 5a), 1564.27 (Fig. 5b), and 1547.32 nm (Fig. 5c). The corresponding open markers show the results after transmission over 300-km of SMF-28. The launch power was optimized for the smallest BER (-4 dBm), at which an OSNR of 31 dB was obtained after transmission. At a BER of 3.8×10^{-3}, the required OSNR after the transmission was 23.6, 24.5, and 25.5 dB for 1556.15 nm, 1547.32 nm, and 1564.27 nm respectively. The difference can be attributed to the EDFA gain profile. A preliminary result of DP-Nyquist-64QAM signals is shown in Fig. 6.

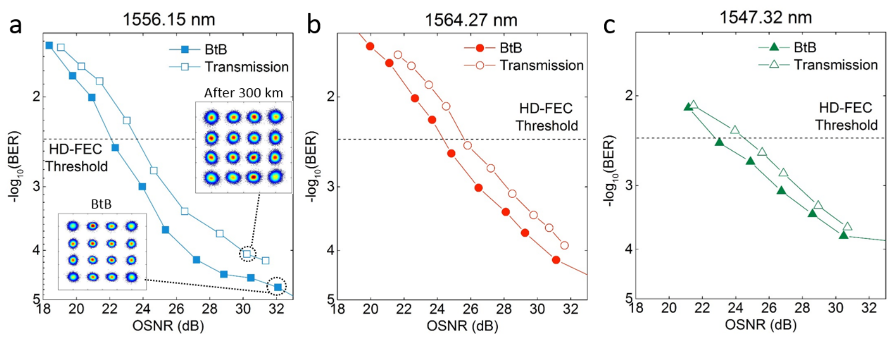
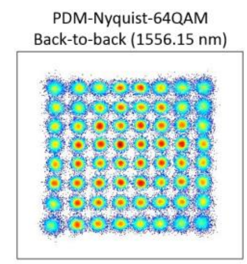


Fig. 5 Measured BER of the single-channel PDM-Nyquist-16QAM for three wavelengths for back-to-back (solid marker) and after transmission (open marker). (a) 1556.15 nm; (b) 1564.27 nm; (c) 1547.32 nm.



	BER
Back-to-back	9.0×10^{-3}
After 300 km	7.5×10^{-2}

Fig. 6 Constellation diagrams and BER for the generated DP-Nyquist-64QAM signal

4. Conclusion

The concept and key building blocks of a super-channel transmitter based on integrated comb and optical injection locking are demonstrated using InP devices. Sub-HD-FEC BER was achieved for PDM-Nyquist-16QAM signal transmission over 300-km of SMF-28. In the future, we plan on locking more lasers simultaneously to several comb tones; generating flexible DWDM and super-channel sources; and investigating the injection locking of DS-DBR lasers from the rear, in order to improve side-mode suppression and to eliminate the need for an optical circulator, thereby facilitating eventual monolithic integration using the InP platform.

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