Abstract

We generate multiple optical carriers with ultra-low phase noise, over a useable bandwidth of 160 GHz, from an externally injected gain-switched comb source with exceptional low linewidth below 10 Hz. We show successful transmission of 17 demultiplexed channels using 64-quadrature amplitude modulation signals at 5 Gb/s.
constellation points in a transmission format for optical transmission systems based on optical frequency combs from gain-switched lasers. These results demonstrate the feasibility to create a highly-integrateable optical superchannel source requiring only one ultra-lowlinewidth laser source.

2 Low-phase noise comb generation and demultiplexing

The ultra-low linewidth optical frequency comb, as shown in Fig. 1(b) is generated via gain-switching the slave laser and injection locking using the ultra-low linewidth master laser. The linewidth properties of the master laser are transferred to each line in the comb. The slave laser was gain-switched at 10 GHz, therefore the comb line spacing (or FSR) is 10 GHz. The comb spectrum is shown in Fig. 2(a). The FM-noise spectra of the master laser and the filtered lines from the comb source were measured using delayed-self-heterodyne method [7]. The FM-noise results are shown in Fig. 2(b). The value of the FM-noise of the master laser descends below 10 Hz, and the increase in the FM-noise at higher frequencies is the noise floor of our measurement technique. Likewise the FM-noise of the comb lines approach the same value as the master laser. This is lowest recorded FM-noise for a gain-switched comb. The FM-noise of a fiber laser is also shown for comparison, and the ultra-low linewidth comb outperforms the fiber laser.

The comb is actively demultiplexed by injection-locking the DFB laser in the superchannel transmitter to one of the comb lines. More details about the comb demultiplexor can be found in [8]. The DFB laser in the comb demultiplexor injection-locks to the spectrally-closest comb line; therefore a different comb line can be demultiplexed by appropriately tuning the DFB laser. The spectra of the demultiplexed comb lines using a DFB laser are shown in Fig. 3, note that the exact same comb was used throughout and also that the suppression of the unwanted comb lines exceeds 40 dB.

3 Transmission Results

Now that the comb-referenced superchannel transmitter has been described, we proceed to show results of the 64-QAM
transmission. A schematic of the experimental setup and the offline-DSP is shown in Fig. 4. One line from the ultra-low linewidth optical frequency comb is selected by injection-locking a DFB laser in the superchannel transmitter. Different lines from the low-linewidth comb can be demultiplexed by tuning the DFB laser so that the free running wavelength of the DFB is within the locking range of the required comb line. The light from the DFB laser is modulated using 64-QAM format at 5 Gbaud. The modulated signal is then transmitted over 25 km of standard single mode fiber before detection at the coherent receiver. The main item in the offline-DSP for carrier phase recovery is the decision-directed phase locked loop (DD-PLL) [9]. The BER results are shown for demultiplexing of each comb line (channel number) in Fig. 5(a), the BER for each channel is below the 20% FEC limit and all but two channels below the 7% FEC limit. and therefore each channel could be used as a transmitter in a superchannel source. The total number of comb lines that showed successful transmission is 17, therefore the total spectral span of the superchannel is 160 GHz (10GHz FSR × (17-1)). This result implies that it is possible to create any superchannel i.e. any possible baudrate, any number of channels provided that the selected carriers are within this 160 GHz useable spectral range, with no consideration is needed for spectral guardbands because of the comb-referencing.

To unequivocally show the impact of referencing to the low-linewidth comb, we present the received constellations with and without using the injected comb in Fig. 5(b). Clearly the DFB lasers are not able to transmit the 64-QAM encoded data unless injection-locked to a high-quality, ultra-low phase noise comb line.

4 Conclusion

We have successfully shown the ability to transfer the ultra-low phase noise of a single laser to multiple optical transmitters using optical frequency comb generation and active demultiplexing. The system allowed us to transmit data encoded on 64-QAM format, the highest reported constellation cardinality for a gain-switched laser comb system. The scheme showed successful transmission of all possible channels at 10 GHz granularity over a 160 GHz bandwidth, which would be more than sufficient bandwidth to create 1.6 Tbit/s superchannels. For this submission we chose 10 GHz FSR and this sets the channel granularity, an important property of the gain-switched comb source is that the channel granularity can be easily and continuously tuned by varying the frequency of the gain-switching signal without changing the overall useable bandwidth, thus allowing for broad range of superchannel configurations. Work is underway to integrate (see inset of Fig. 1(a)) the comb and demultiplexor laser system onto a single chip [10] paving the way for flexible and powerful comb-based superchannel transceivers.

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6 References

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