Filter-Less Synthesis of 50-GHz Double-Spaced Flat Optical Comb by In-phase/Quadrature Electro-Optic Modulator for High Bandwidth Transmission

Shun Harada, Tatsuki Ishijima and Takahide Sakamoto
Tokyo Metropolitan University, Japan
23861650@ed.tmu.ac.jp, tsaka@tmu.ac.jp

Abstract: 50-GHz spaced flat optical comb is experimentally generated in the electro-optic modulation process by using an IQM driven with 25 GHz signals. We demonstrate that the double-frequency-spaced comb effectively carries multi-channel 5x28 Gbaud signals.

1. Introduction

Optical comb generators based on electro-optic (EO) modulators are expected to be applied in a wide range of fields such as ultrafast/ultra-broadband optical measurements, ultra-short-pulse light sources, fiber-optic communication and so on. In addition to traditional comb generators based on single- or a few-stage modulators [1][2], these days, serial [3] or parallel extension of the modulator structures allows us high-bandwidth and functional optical frequency comb generation [4][5]. For the application to fiber-optic transmission systems, an optical comb with wider frequency spacing can avoid crosstalk among channels, allowing larger capacity transmission. An optical comb with 50 GHz frequency spacing and flat spectra well fits to wavelength grid of wavelength-division multiplexing (WDM) transmission systems, which can accelerate the rate up to 50 Gbaud per lambda; moreover, 28 Gbaud transmission is easily achieved even without tight spectral shaping on the tributary channels.

However, in traditional optical comb generators, the frequency spacing of the generated combs cannot exceed the bandwidth of the EO modulators and their driving circuits. It is still difficult to directly generate 50 GHz frequency spaced combs by operating the modulators and amplifiers at a high frequency of 50 GHz or higher [6].

To overcome these issues, in this paper, we demonstrate frequency spacing doubling of the optical comb in the modulation process using an in-phase/quadrature optical modulator (IQM). The comb generator can selectively output only even-order frequency components or odd-order ones with keeping flatness when the IQM is driven under specific conditions [5]. We can flexibly switch between the two comb patterns with even or odd-order frequency components. In this method, any optical filters and higher-frequency electric signals are not required for the frequency-spacing doubling, which enables flexible spectral shaping and wavelength tuning of the generated combs.

In this paper, we construct an optical frequency comb generator based on the IQM for generating comb that has double frequency spacing. We experimentally demonstrate generating a flat optical comb with 50 GHz spaced frequency components from 25 GHz electric driving signals. Using the comb source, we demonstrate 28 Gbaud QPSK modulation on the generated comb to show that the comb source is applicable for 28 Gbaud per lambda multi-wavelength transmission.

2. Principles

Fig. 1 shows the principle of the double-frequency-spaced optical comb generation using IQM [4][5]. The IQM is interpreted as a quad-parallel phase modulator, which consist of four phase modulators arranged in parallel. In the modulator structure, a continuous-wave (CW) light is split into four arms and individually phase modulated in the arms and combined again on the output side. The upper and lower sub MZMs nested in the main MZM are driven with inphase sinusoidal signals $a_1(t)= A_1 \sin(2\pi ft+\theta)$, $a_2(t) = A_2 \sin(2\pi;ft+\theta)$, at a common frequency f.

The frequency spacing becomes doubled and the spectral profile becomes flattened when the following conditions are satisfied [4].

$$[\ \theta_{b1}\ ,\ \theta_{b2}\ ,\ \theta_{b3}\ ,\ \theta_{b4}\ ] = \left[\mp\frac{\Delta A}{2}, \mp\frac{\Delta A}{2} \pm \frac{\Delta A}{2}, \pm\frac{\Delta A}{2}\right] \tag{1}$$

where θ_{b1}, θ_{b2}, θ_{b3}, θ_{b4} are phase offsets of the phase modulated lights, and $\Delta A = (A_1 - A_2)/2$. The phase offsets can be translated into the DC biases applied to the IQM.

$$[\ \theta_I\ ,\ \theta_Q\ ,\ \theta_{main}\ ] = \left[0\ , 0, \mp\frac{\Delta A}{2}\right] \tag{2}$$

where single-arm phase shift induced by the DC biases are θ_I, θ_Q, θ_{main} denoted in Fig.1.
Under the condition, the even-order harmonics of the phase-modulated light will be interferometrically vanished when the four phase-modulated lights are superposed at the output of the modulator. In addition, the paring of the phase modulated lights generated from the upper sub-MZM and the lower one enables equivalent spectral power distribution in the frequency domain, spectrally flattening the double frequency spaced combs.
In a similar way, we can erase odd-order of the generated comb if the DC biased are set as

$$[\,\theta_I\,,\,\theta_Q\,,\,\theta_{main}\,] = \left[-\pi\,,-\pi\,,\frac{\pi}{2}\mp\frac{\Delta A}{2}\right] \quad (3)$$

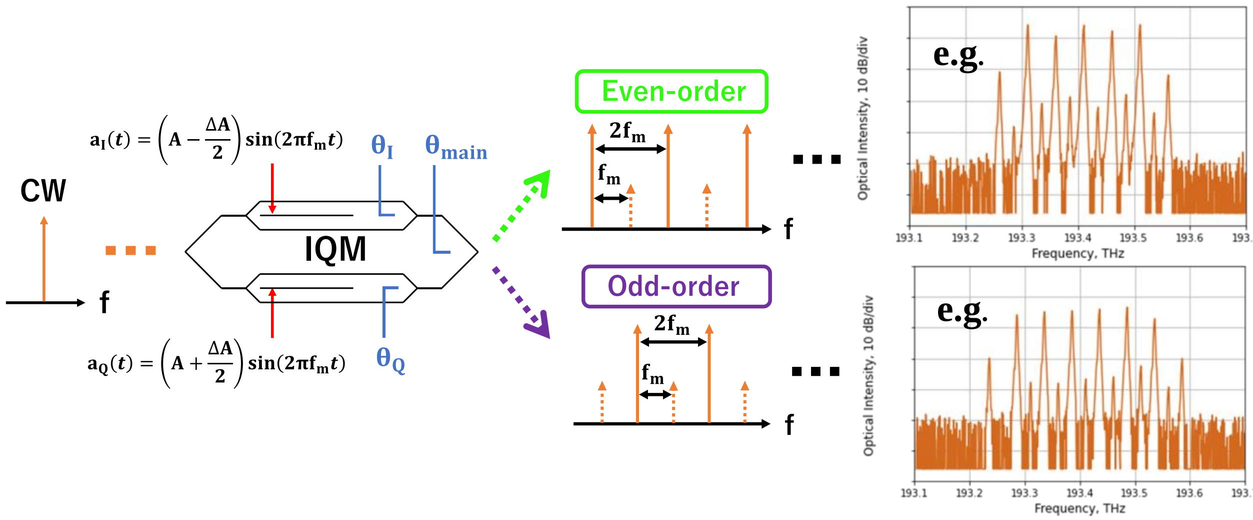


Fig. 1: principle of double-frequency-spaced flat comb generation

3.Experiments

Fig.2 shows the experimental setup for generation of double-frequency-spaced flat optical comb and QPSK modulation on it. 28 Gbaud QPSK signals were generated with a transmitter which consisted of an arbitrary waveform generator (AWG), a CW laser diode (LD), an erbium-doped amplifier (EDFA), and an IQM. The centre wavelength of LD was 1551.78 nm. The IQM was driven with I and Q data streams of 28-Gbaud non-return-to-zero (NRZ) PRBS signals generated from the AWG clocked at 64 GSa/s. The QPSK modulated light was input to the proposed 50-GHz spaced comb generator. The comb generator consisted of another IQM, a two-channel sinusoidal signal generator (2-ch. SG), two frequency doublers, two bandpass filters (BPFs), two driver amplifiers. Two sets of 12.5 GHz sinusoidal signals were generated from the 2-ch. SG; the signals were frequency-doubled; then, the IQM was driven with the two sets of 25-GHz sinusoidal signals (Rf-a, RF-b). RF Power of Rf-a, b was 29.5 dBm, 30.0 dBm respectively. The IQM comprised two push-pull-type sub-MZMs with a half wave voltage (at DC frequency) of 2.2V. The DC biases of the IQM were controlled by three voltage sources. The amplitude and phases of driving signals were controlled with the controller implemented in the 2-ch. SG. On the receiver side, each QPSK channel carried by the comb line signal was sliced with an optical band-pass filter (BPF) with 0.4-nm passband.
The received QPSK signal mixed with a CW local light in an intradyne receiver was coherently detected. By using an offline DSP, we estimated the carrier phase and demodulated the QPSK signals. An adaptive 15-tap FIR equalizer was applied for the equalization.

Figs. 3(a) shows optical spectra of experimentally generated double-spaced combs without QPSK signals applied. Optical comb with a 50GHz frequency spacing and flat spectra was successfully generated, where only the even-order frequency components were selectively generated from the IQM. On the other hand, the odd-order frequency components were successfully suppressed about 20 dB. Figs. 3(b) shows optical spectra of the QPSK-modulated 50-GHz frequency spaced flat comb. Note that 50-GHz frequency spacing was wide enough to discriminate spectral channels one by one, even in the situation where 28 Gbaud QPSK modulation was applied on the generated comb. Figs. 4(c) ~ (g) show the constellations of channels -2 ~ +2. Clear constellations were observed in all channels. The EVMs corresponding to (c) ~ (g) were 16.44 %, 18.77 %, 13.82 %, 16.17 %, 15.11 %, respectively. Fig. 5 shows the EVMs of the received channels measured against OSNRs (at 0.1nm), indicating that no significant distortion was observed in all the channels.

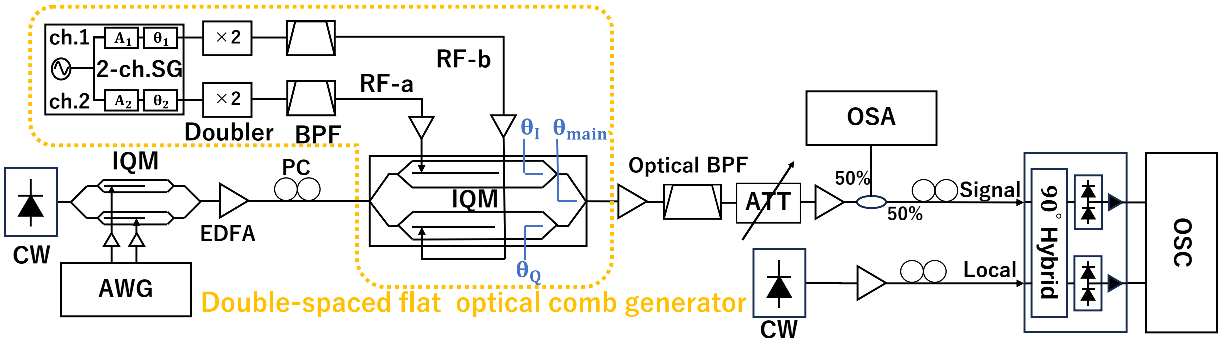
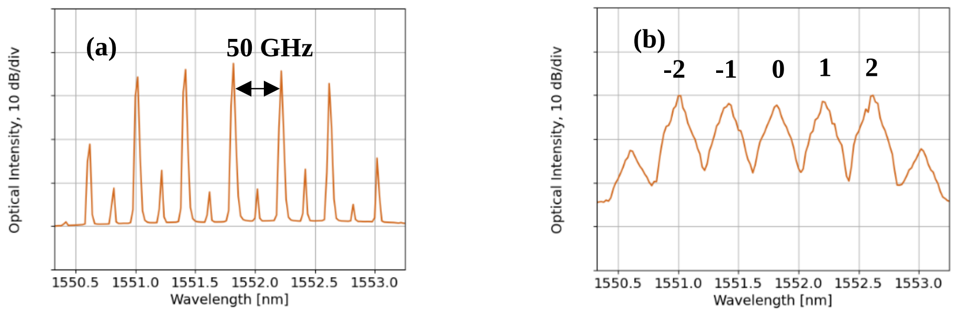
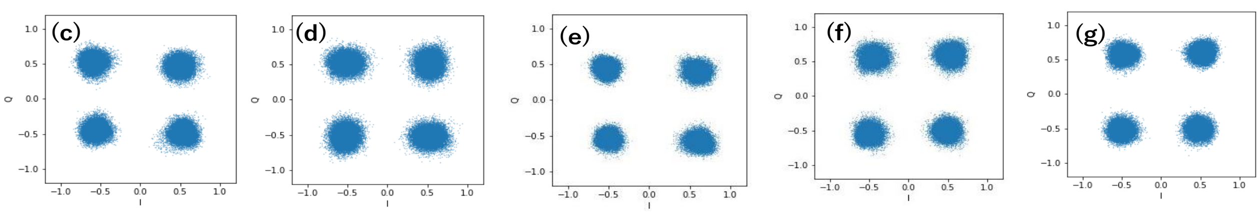


Fig. 2: experimental setup (OSC: real-time oscilloscope for offline processing)



Figs. 3: Measured spectra, (a) 50-GHz spaced flat comb, (b) 50-GHz spaced flat comb with QPSK signals.



Figs. 4: Measured constellations, (c) Channel -2, (d) Channel -1, (e) Channel 0, (f) channel 1, (g) Channel 2

4.Conclusions

50-GHz spaced flat comb was experimentally generated from in-phase/quadrature optical modulator driven at 25 GHz. The 50-GHz frequency spacing was wide enough to carry muti-channel 28-Gbaud data streams.

Acknowledgements

This work was partly supported by CREST, Japan Science and Technology Agency, Grant Number JPMJCR2103, Japan; NEDO Extensive Support for Young Promising Researchers, Japan; JSPS Grant-in-Aid for Scientific Research (A), Grant Number 18H03788, Japan.

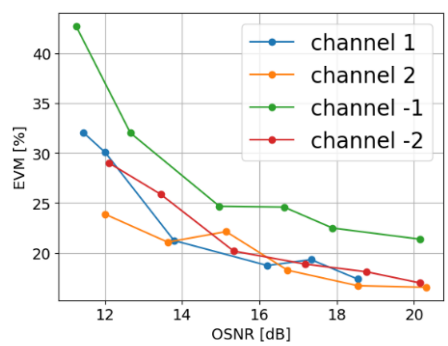


Fig. 5: EVM vs OSNR

References

[1] M. Fujiwara et al, Electron. Lett., 37, 967–968, (2001).

[2] T. Sakamoto et al, Opt. Lett., 32, 1515–1517, (2007)

[3] T. Ishijima and T. Sakamoto, CLEO'22, JTh3A.24 (2022).

[4] T. Sakamoto and A. Chiba, Opt. Lett., 42, 4462– 4465 (2017).

[5] A. Chiba et al, CLEO-PR'17, P1–071 (2017).

[6] T. Hoshi et al, CLEO-PR'07, ThD2-3 (2007).