Optical Frequency Comb Generation Utilizing Mach-Zehnder Modulator and Multi-Laser Sources

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Abstract *We investigate a wideband optical frequency comb generator based on multi-laser sources and a single-stage Mach-Zehnder modulator. The generated comb lines were successfully increased as compared with a single laser.*

Introduction

Optical frequency comb generators (OFCG) can offer many attractive applications such as optical communications [1], radio over fiber [1], coherence optical orthogonal frequency-division multiplexing (CO-OFDM) [2], metrology [3] and physics research. The major advantage of the optical frequency comb is the high stability, low noise, low jitter and the fixed frequency spacing which makes it very useful for all these applications. The most popular way of generating a frequency comb is with a mode-locked laser (MLL) [4]. Unfortunately, this conventional approach has a weak stability because of the long-length cavity. This approach is influenced by the environmental conditions and the fixed frequency spacing which depends on the cavity length. Other techniques based on semi-conductor lasers and highly non-linear optical fibers have also been reported [5]. They use photonic crystal fibers for generating new frequencies by four-wave mixing (FWM) and Kerr nonlinearity, using a high optical power to induce non-linear effects in the fibers.

Recently, optical modulation has been used to realize OFCG signals that overcome some of the limitations mentioned above, providing stable and precise optical frequencies with tunable spacing. Optical comb sources based on modulators are good candidates for flexible and stable sources because of their operating principle which works without a cavity. A Mach-Zehnder modulator (MZM) approach has been used and demonstrated [6]. The comb spacing and the bandwidth can be varied by the frequency and the power of an RF signal. The only disadvantage of this technique is mainly due to the limited number of generated comb lines. To broaden the spectrum of these comb signals, non-linear optical fibers are typically used [8]. However, this technique requires a high optical power source which generates noise and produces instability in the comb signal. Recently, other techniques have been proposed and demonstrated using an MZM with an optical feedback loop [7].

In this paper, we propose a new technique to increase the generated comb lines by using multi-laser sources injected simultaneously into an MZM. We also provide a simple equation to correctly define the wavelength of each laser source needed to duplicate the comb signal without a gap. The preliminary results show the multiplicative growth of the generated comb lines as a function of the number of launched laser sources.

Flat optical frequency comb generation

This section describes the principle of a flattened OFCG based on a single stage MZM. A conventional dual-drive-type MZM fabricated on a $LiNbO_3$ crystal is commonly used to produce multiple sidebands on both sides of the center wavelength by use of optical modulation. As shown in Fig. 1, the MZM is driven by two sinusoidal RF signals with a slight difference in their amplitude. An electrical sinusoidal waveform is used to modulate the launched CW laser source in both arms of the MZM. Subsequently, the optical signals, obtained from the two arms, are recombined to generate relatively flat comb lines. The spectral spacing and the bandwidth are governed respectively by the RF frequency and the RF power. Flat comb signals are obtained when the condition given by equation below is satisfied [7].

$$\Delta A \pm \Delta\theta = \pi/2 \quad (1)$$

In this equation ΔA is the amplitude difference between the RF signals and $\Delta\theta$ is the optical phase difference between the two arms of the MZM.

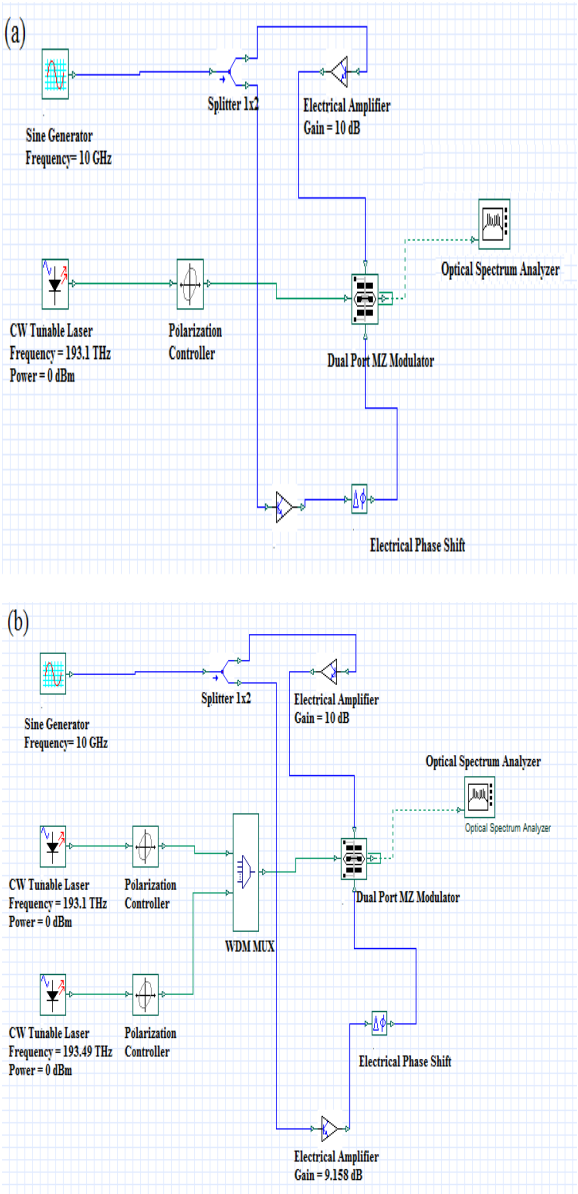


Fig. 1: Simulation diagram of OFCG with single and multi-laser sources

MZ-FCG with single and multi-laser sources

In this section, we describe the basic configuration of the MZ-FCG and our proposed system depicted in Fig.1. The design and the simulation results are obtained using Optisystem which is a commercial software package introduced by Optiwave. The first configuration presented in Fig. 1(a) consists of a CW laser and an MZM driven by an RF sinusoidal signal of 10 GHz. In Fig. 2(a), 32 modes were clearly observed with a good flatness, and a spectral spacing of 10 GHz.

The concept of MZ-FCG, depicted in Fig. 1(b) is the duplication of the generated comb lines that are achieved by a single laser source. Our idea is to generate comb lines from multi-laser sources in the operating wavelength of MZM. For this purpose, multi-laser sources and a WDM multiplexer system is added to the basic configuration. In this case, it is necessary to define correctly the center frequency and the phase of each source to duplicate the comb lines with a good flatness and without gap. We define the center frequency of two successive laser sources by Equation (2) bellow.

$$f_{Cf}(k) = f_{Cf}(k-1) + 2\,n\,\Delta f \qquad (2)$$

In this equation $f_{Cf}(k)$ and $f_{Cf}(k-1)$ are the center frequencies of two successive laser sources, k is the number of input sources, n is the tooth number and Δf is the comb tooth spacing.

Fig. 1(b) shows the design of our system with two laser sources. In our simulation, the frequency of the first laser source is $f_{Cf}(1) = 193.1$ THz and according to the Eq. (2), the center frequency of the second laser source is $f_{Cf}(2) = 193.49$ THz. The simulation result for a single source is presented in Fig. 2(a), it is clear that from this figure that 32 comb lines are generated with a good flatness. Fig. 2(b) shows the result of MZ-FCG based on two multiplexed sources, by using this configuration, we see that the number of comb lines are duplicated. The interference between the different comb teeth which have the same frequency is governed by the phase of the first and second laser sources. In our simulation, we fix the phase of the first laser source and we adjust the phase of the second laser to obtain a constructive interference that results in a good flatness of the power spectrum.

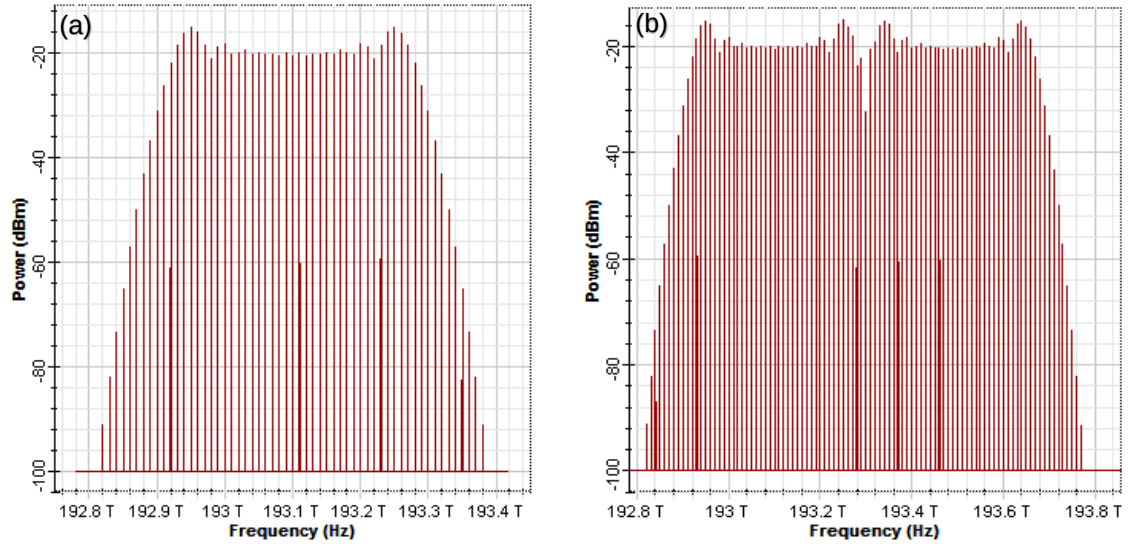


Fig. 2: Optical spectra of generated comb signal; (a) with one laser source and (b) with two laser sources

Conclusion

A new technique for generating a wideband optical frequency comb based on multi-laser sources and a single MZM has been proposed and simulated. As more and more laser sources are launched simultaneously using a WDM multiplexing system, more OFCG signal bandwidth achieved accordingly.

Disclaimer

Certain commercial equipment, instruments, or materials are identified in this paper in order to specify the experimental procedure adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the materials or equipment identified are necessarily the best available for the purpose.

References

[1] C. Chen, C. Zhang, W. Zhang, W. Jin, K. Qiu. "Scalable and reconfigurable generation of flat optical comb for WDM-based next-generation broadband optical access networks". Opt. Commun. 321 (2014) 16–22.

[2] Wu and X. Zhang. "Impact of nonlinear distortion in radio over fiber systems with single-sideband andtandem single-sideband subcarrier modulations". J. Lightwave Technol. 24, 2076-2090 (2006).

[3] T. R. Schibli, K. Minoshima, F.-L. Hong, H. Inaba, A. Onae, H. Matsumoto, I. Hartl, and M. E. Fermann, "Frequency metrology with a turnkey all-fiber system". Opt. Lett. 29(21), 2467–2469 (2004).

[4] D. J. Jones, S. A. Diddams, J. K. Ranka, A. Stentz, R. S. Windeler, J. L. Hall, and S. T. Cundiff. "Carrier-envelope phase control of femtosecond mode-locked lasers and direct optical frequency synthesis". Science 288(5466), 635–639.

[5] I. Morohashi, T. Sakamoto, N. Sekine, T. Kawanishi and I. Hosako. "Broadband optical comb generation using a MZM-based flat comb generator and a dispersion-shifted fiber for high accurate terahertz wave generation". Engineers Australia. 978-1-922107-21-3.2014.

[6] T. Sakamoto, T. Kawanishi, and M. Izutsu. "Asymptotic formalism for ultraflat optical frequency comb generation using a Mach–Zehnder modulator". Optical Society of America. 0146-9592/07/111515-3. 2007.

[7] I. Morohashi, T. Sakamoto, H. Sotobayashi, T. Kawanishi, and I. Hosako, "Broadband optical comb generation using Mach-Zehnder-modulator-based flat comb generator with feedback loop". IEEE. 978-1-4244-8535-2/10. 2010.