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RESEARCH ARTICLE

Design and simulation of 40 GHz–WDM communication system-based optical frequency comb generator

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Abstract In this paper, a 40 GHz wavelength division multiplexing communication system-based optical frequency comb generator (WDM–OFCG) is design and investigated via OptiSystem software. The proposed design produced up to 25 channels with constant channel spacing of 40 GHz and average power of –10.84 dBm. The generated comb is spread over approximately 8 nm, ranging from 1546.17 to 1553.85 nm. In addition, the generated comb is employed as a multiwavelength laser source to carry information with a bit rate of 375 Gbps over a 120 km link distance. This represents an efficient evaluation to the proposed design since the achievable bit rate product repeater distance (BL) is about 45,000 (Gbps.km).

Keywords Wavelength division multiplexing · Optical frequency comb generator · Carrier · Link distance · Fiber optic system

Introduction

The optical frequency comb generator (OFCG) is an essential source for several applications, including optical frequency measurement, optical frequency division multiplexing, microwave photonic signal processing, optical arbitrary waveform generation, and dense wavelength division multiplexing [1–3]. The fundamental concept behind OFCG is to produce a number of optical signals or harmonics to maximize the use of optical bandwidth from a single optical source [4, 5]. The OFCG can be used to reduce the optical sources on the optical line terminal (OLT), providing a wide bandwidth and high transmission data rate [6]. Equal frequency spacing between lines, optical spectrum flatness, tiny linewidth of each comb line, low implementation cost, and a wide spectrum wavelength range are the essential features of the OFCG [7]. Over the past few years, a wide range of strategies have been given, each with its own set of benefits and drawbacks. These approaches were divided into electrical and optical categories. The optical approach is currently the most widely utilized in research since the electrical method's bandwidth was constrained by the electrical components' capabilities, but the optical method allowed for a broader bandwidth [7, 8]. The main drawbacks of the optical method, which uses a mode-locked laser (MLL) to implement OFCG, are stability and the difficulty in tuning the spacing between lines because the carrier frequency depends on the cavity of the laser diode due to environmental factors and requires a complex feedback loop for stable operation [9, 10].

The four-wave mixing effect and stimulated Brillouin scattering, which has a complex structure and necessitates high-power optical amplifiers and optical filters to sort the optical spectrum, are another method based on fiber nonlinearity [11]. The most popular and effective optical modulation approach makes use of one or more modulators with nested, cascaded, or loop structures to optically modulate a limited internal or external seed source to generate a variety of wavelengths or frequency comb lines [6]. This technique stands out for its stability, simplicity in adjusting comb spacing, and versatility [12, 13]. The continuous wave (CW) laser diode can be modulated using a single modulator, resulting in a simple

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system with few comb lines [14]. To enhance the number of comb lines, cascading modulator techniques were presented. The bandwidth of this method is constrained by the optical modulator's insertion losses [15]. In optical communication, various optical devices are integrated with optical fibers. In recent decades, it has been established that optical filters play a critical role in optical communication networks. Optical filters are critical components of optical communication systems [16]. By using wavelength division multiplexing (WDM) and dense-WDM (DWDM) [17–20], the capacity of a single optical fiber may increase such that it can transport several (4, 8, or more) channels at different centers wavelength [21–24]. One can select the desired optical channel using an optical filter [25, 26]. In fact, without using any electronic devices, one can separate the very closely spaced optical channels by utilizing optical filters [27, 28].

In addition, for various target applications, the resulting comb has distinct properties. The frequency comb spacing, comb flatness, and signal-to-noise ratio are regarded as the three most crucial comb performance characteristics in the area of optical communication systems.

In this work, a simple, cost effective, and efficient comb generator is demonstrated and evaluated via WDM optical communication system. Moreover, the generated comb is examined through the system in terms quality factor and BER.

Simulation design

In the proposed OFCG, the input optical power is achieved from a continuous laser source (CW) at wavelength of 1550 nm and input power of 10 dBm. The optical signal is feed to a dual drive Mach–Zehnder modulator (MZM) to generate up to 25 flat channels with channel spacing of 40 GHz. In addition, a sine generator is connect to a fork inorder to split the sine signal into two paths, both signals amplified by two electrical amplifiers and connected to MZM as illustrated in Fig. 1b. The generated comb is connected to a WDM a demultiplexer (De-WDM) to extract each channel alone. Then, each channel modulated via an MZM and combine all modulated channels through a WDM to send via single mode fiber (SMF) as depicted in Fig. 1c. Furthermore, a dispersion compensation fiber (DCF) is used to compensate the chromatic dispersion within attenuation losses of 0.4 dB/km. Two optical amplifiers were used to amplify the optical signal before/after the DCF as illustrated in Fig. 1a. Finally, the receiving signal is evaluated in terms of BER and Q-Factor utilizing the receiver assembly as

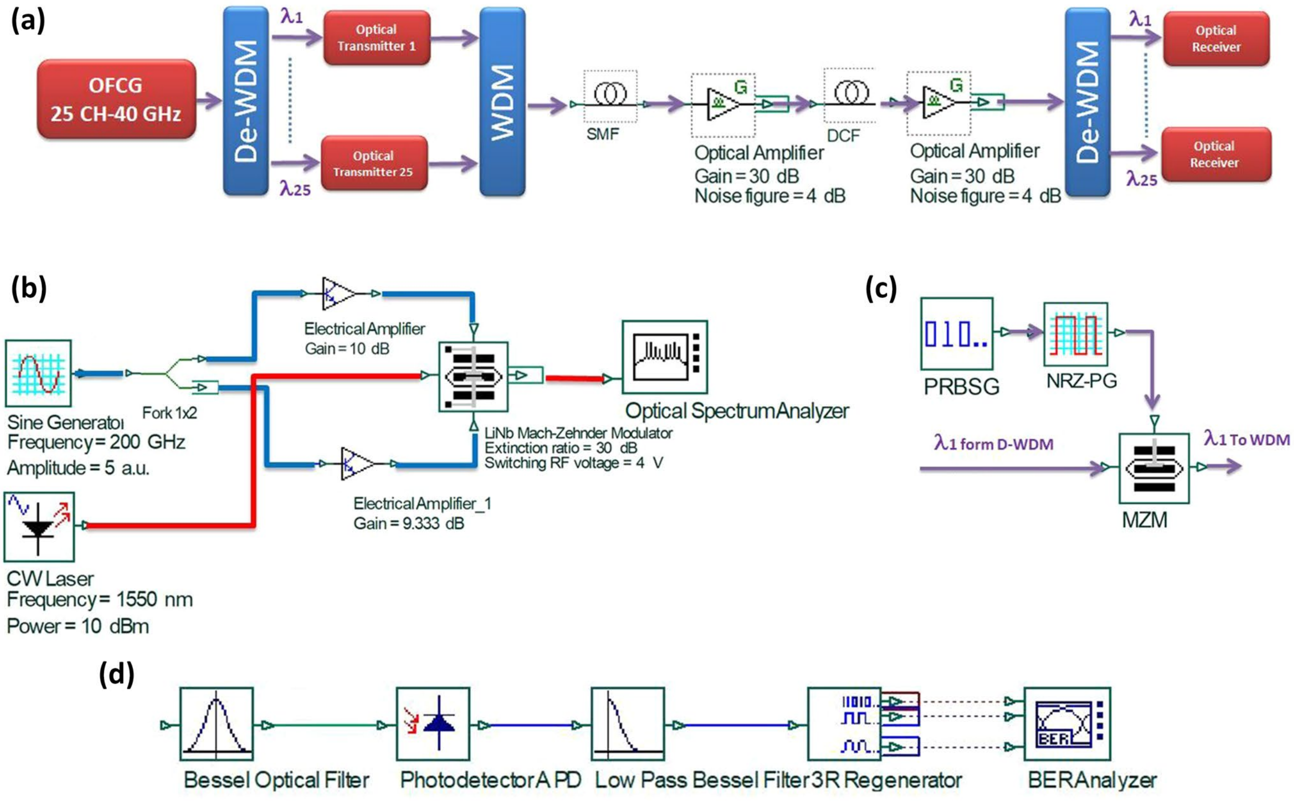

Fig. 1 Illustrate **a** the proposed OFCG–WDM communication system, **b** OFCG system, **c** Optical transmitter, **d** Optical receiver

Table 1 Simulation design parameters

System	Item	Description
Transmitter assembly	CW Laser	Frequency = 1550 nm; power = 10dBm
	Sine Generator	Frequency = 200 GHz; Amplitude = 5a.u
	Electrical Amplifier	Gain = 10 dB
	MZM	Extinction ratio = 30 dB; bias voltage = 4 V
Transmission channel	SMF	Sweeped from 10 to 200 km
	EDFA	Gain of 30 dB and NF of 4 dB
	DCF	Sweeped 1.4 to 30.7 km
Receiver assembly	Photodetector APD	Gain = 3
	Low Pass Bessel Filter	0.75*bit rate
	3R Regenerator	
	BER	

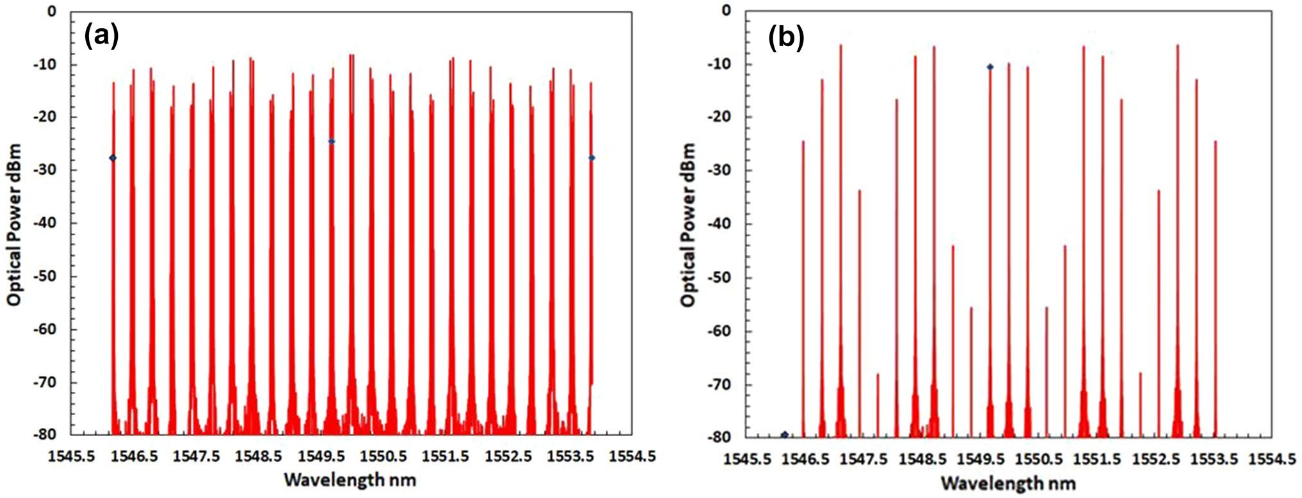

Fig. 2 Shows the generated comb at several switching RF voltage of the MZM **a** 1 V, **b** 10 V

shown as in Fig. 1d. In addition, all the design parameters that adopting in this work are illustrated in Table 1.

Results and discussion

In this part, the design parameters of the proposed comb generator are investigated to achieve the optimum frequency comb performance. The switching RF voltage of the MZM is significantly affect on the 3–dB comb flat, therefore its need to carefully adjust. In addition, the channel spacing is effected by several parameters, namely the input power, the frequency of the sine generator, and the system bit rate. Therefore, these parameters need to optimize carefully to achieve higher number of generated channel with high performance.

In order to investigate the effect of switching RF voltage on the generated comb, this voltage is varied from 1 to 10 V with a step of 1 V; the results of the 1 and 10 V are depicted in Fig. 2a and b, respectively; the results show that the optimum voltage is about 4 V. From the other side, the sine generator frequency is varied from 100 to 300 GHz with a step of 100 GHz as shown as in Fig. 3. In result, the optimum parameters for switching RF voltage and sine generator frequency are about 4 V and 200 GHz, respectively, as illustrate in Fig. 4. The achieved comb is depicted in Fig. 4, up to 25 channels are achieved with constant channel spacing of 40 GHz and average power of –10.84 dBm. The generated comb is spread over approximately 8 nm, ranging from 1546.17 to 1553.85 nm. This comb is qualified to use as a source for WDM communication system. In the next steps, the achieved comb will be evaluated after integrated it in fiber optic communication system.

The WDM–OFCG communication system is used to evaluate the generated comb as depicted in Fig. 1a. In this work, both of the attenuation and dispersion budget were analyzed and improved utilizing the optical amplifier and the DCF, respectively. Therefore, the SMF is swept from

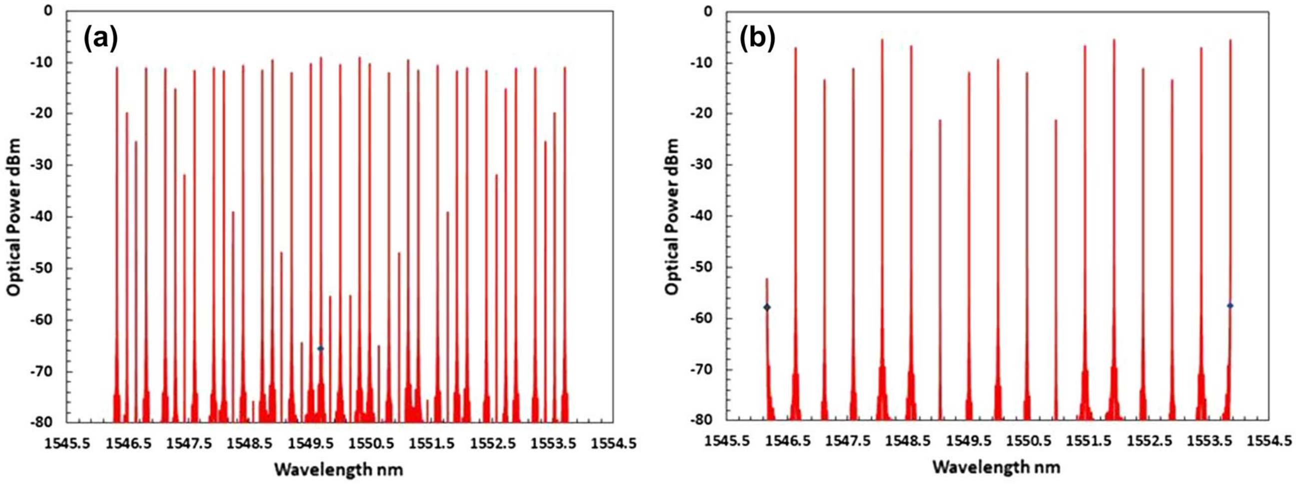

Fig. 3 Shows the generated comb at several frequency of the sine generator **a** 100 GHz, **b** 300 GHz

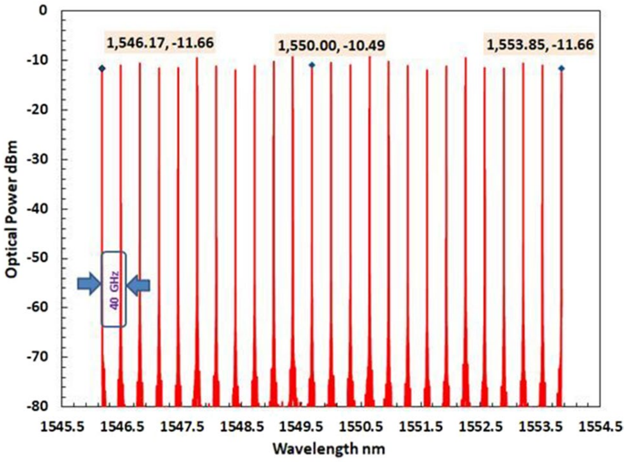

Fig. 4 Generated comb at optimum design parameters of 4 V and 200 GHz for switching RF voltage and sine generator frequency, respectively, up to 25 channels over of 8 nm with 40 GHz channel spacing and −10.84 dBm of average power

10 to 200 km with a steps of 10 km. While the DCF is swept from 1.4 to 30.7 km to compensate the chromatic dispersion of the SMF. Two optical amplifiers were used to compensate the attenuation of the propose system with gain of 30 dB and NF of 4 dB. The performance of the proposed system in terms of Q–Factor and BER is investigated as illustrated in Fig. 5a and b, respectively. According to the results, the performance is degraded as the link distance increases and the maximum achieved distance is about 120 km at a communication condition of 6 and 10E-9 of Q-factor and BER, respectively.

Based on the eye diagram pattern, the quality of the communication system can be assessed. Thus, the eye diagram for the proposed WDM is investigated for λ_1, $\lambda_{13,}$ and λ_{25} at link distance of 120 km as illustrated in Fig. 6.

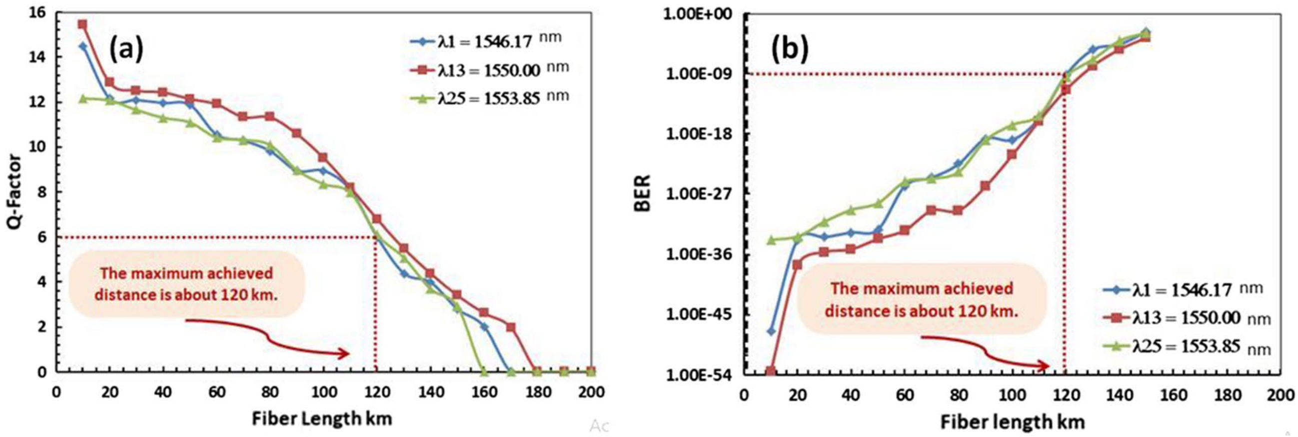

Fig. 5 Shows the effect of fiber length on both of **a** Q–Facto and **b** BER

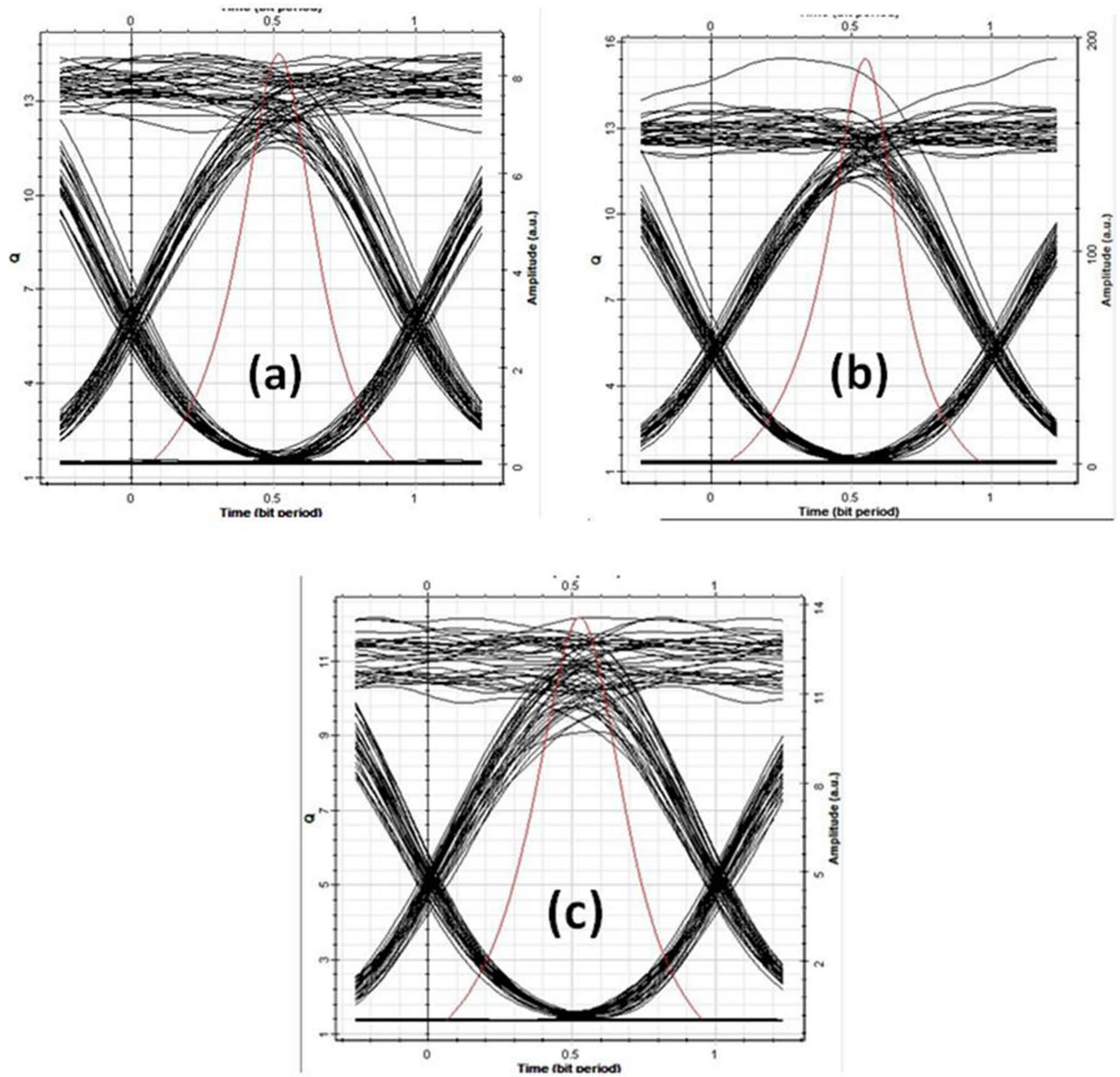

Fig. 6 Eye diagram for several wavelength of **a** λ_1, **b** $\lambda_{13,}$ and **c** λ_{25}

Conclusions

The WDM–OFCG communication system is simulated by OptiSystem software. According to the results, comb performance in the terms of flatness and the number of channel is effect by both of switching RF voltage and sine generator frequency. The proposed design produced up to 25 channels with constant channel spacing of 40 GHz and average power of –10.84 dBm. The generated comb is spread over approximately 8 nm, ranging from 1546.17 to 1553.85 nm. The proposed WDM–OFCG produced a BL about 45,000 Gbps.km.

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