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OPTICAL MULTI-CARRIER GENERATION USING CASCADED THREE STAGE MODULATORS

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ABSTRACT

High-capacity optical communication networks can be efficiently implemented using an optical multi-carrier generator *(OMCG*). A serial combination of three intensity modulators, such as the amplitude modulator *(AM*), single drive Mach-Zehnder modulator (*SP-MZM*), and AM, is suggested for the synthesis of the largest number of tones with a high tone to noise ratio (*TNR*) and the lowest amplitude difference (*AD*). The presented OMCG designs employ a single RF source; no additional fibre Bragg gratings or specialized techniques are used. The presented system is investigated for different radio frequencies (*RF*) and input powers in terms of AD and TNR respectively. Results revealed that 25 GHz RF frequency and 40 dB extinction ratio are optimal for the proposed system. Total 65 tones with a maximum bandwidth of 640 GHz, 0.96 dB AD, and the greatest TNR of 48.58 dB are offered by proposed system.

Keywords: OMCG, TNR, AD, MZM, AM

INTRODUCTION

Researchers have emphasized technological development in data transmission networks throughout history. More precisely, the growth of bandwidth-hungry applications is accelerating, which inspires researchers to design ultra-high capacity wireless and wired architectures [[Kaur, A., Kaur, B., Singh, K, 2017]. High capacity, low cost, and enhanced performance are the main factors that system designers are concentrating on when commercializing wireless/wired systems [Vikram, B. S., Prakash, R., Nagarjun, K. P., Singh, A., Selvaraja, S. K., and Supradeepa, V. R 2020]. The greater cost is a common problem in high-capacity multi-wavelength systems, also known as wavelength division multiplexing (WDM), because a lot of laser sources are needed. WDM is prominent technique in wired and wireless optical communication systems. The best way to overcome the WDM system's limitations of high cost is through optical Multi-carrier generation (OMCG). Moreover, a good contender for high-speed optical data transmission systems is the optically flat OMCG with high TNR [Jiang, W., Zhao, S., Li, X., Tan, Q 2017]. Different techniques are reported for the generation of OMCG such as supercontinuum generation, cascaded modulators, self-feedback oscillation, recirculating frequency shifter (RFS) loop, etc. Each OMCG generation technique has limitations such as time skews in supercontinuum generation, self-feedback oscillator needs high-powered RF signals through amplification.

High complexity for suppressing the noise emerged in RFS loop due to round trip is a severe limitation along with high cost. However, high TNR, multiple carriers are the two advantages of RFS loop configuration. Amplitude spontaneous emission (ASE) emerges in the single sideband carrier and this cause constraint in the performance and therefore employment of optical finite impulse response (FIR) filters suffers from very high cost [Jiang, W., Zhao, S., Li, X., Tan, Q 2017]. The cascading of several intensity modulators in various configurations, such as the use of single drive (SD)/dual drive (DD) MZM with phase modulators, is another popular OMCG technology. A hybrid interferometer modulator has been used to examine the DD-MZM configuration for OMCG, but it has certain drawbacks, including fewer comb lines, a high AD, a high RF power amplifier, and expensive components [Li, J., Ma, H., Li, Z., Zhang, X.: 2017].

In the literature, there are many research articles reported in the field of OMCG using different techniques. In [S. Chaudhary, D. Thakur, A. Sharma 2017], an OMCG system was presented by integrating serial AMs and generated 11 output carriers having the 2 dB differences in amplitude. Further, in order to generate the more number of carriers, polarization sensitive modulator was employed for the 32 combs having 2.1 dB differences in the comb lines [7]. Difference between the multiple carriers in the OMCG is the predominant performance limiting factor and for improving the AD (1 dB), 7 combs enabled direct detection based MZM was presented [8]. A combination of phase modulator and intensity modulator was demonstrated in [9] for the generation of 38 carriers.

Table 1: Literature review of existing OMCG generation modules

Author [year] [ref.]	**OMCG technique**	**Total comb lines**	**AD (dB)**	TNR (dB)
Yu, J. et al. [2013] [10]	DML+PM	16	3	20
Li, X. et al. [2015] [11]	EML +PM	25	5	20
Jiang, W. et al. [2017] [Jiang, W., Zhao, S., Li, X., Tan, Q 2017]	RFS loop	60	4	36
Ullah et al. [2018] [12]	AM+MZM+ MZM	61	1	44
Sharma, et al. [2022] [13]	IM+PM	24	1.1	-

From the literature review, it is discerned that in all aforementioned OMCG generation techniques, difference in the amplitude of carriers tend to increase with the increase in the number of comb lines. Therefore, least difference in the amplitude of comb lines is needed to get better performance. TABLE I shows the existing OMCG generation techniques and their carrier, TNR as well as AD.

In this research article, a serial combination of three intensity modulators, such as the AM+SP-MZM+AM, is presented for the generation of largest number of tones with a high TNR and the lowest AD. The rest of the research article is drafted as: Section II describes system setup of proposed OMCG technique. Section III lists the results of the investigated OMCG technique. Section IV shows the conclusion and future scopes.

System setup of proposed OMCG technique

For the completion of presented OMCG system, a prominently used simulation software named as Optisystem is considered. The presented work has two types of modulators such as SD-MZM and AM. The cascaded system has AM on the first position, SD-MZM on second and AM on last positions.

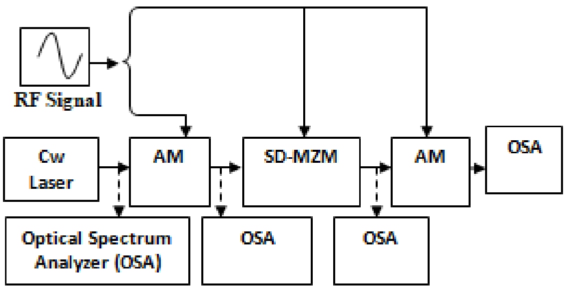


Fig. 1: Block diagram of proposed OMCG configuration

Table 2: OMCG system parameters and their values

Parameter	Values
RF frequency	25 GHz
Time window	1.28e-008 s
sampling rate	6.4e+11 Hz
Frequency	192.15 THz
SD-MZM Extinction ratio	40 dB
AM modulation index	0.955
PM phase shift	90^0

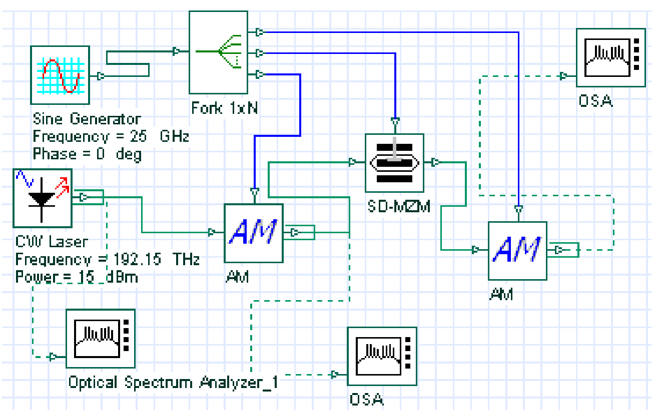
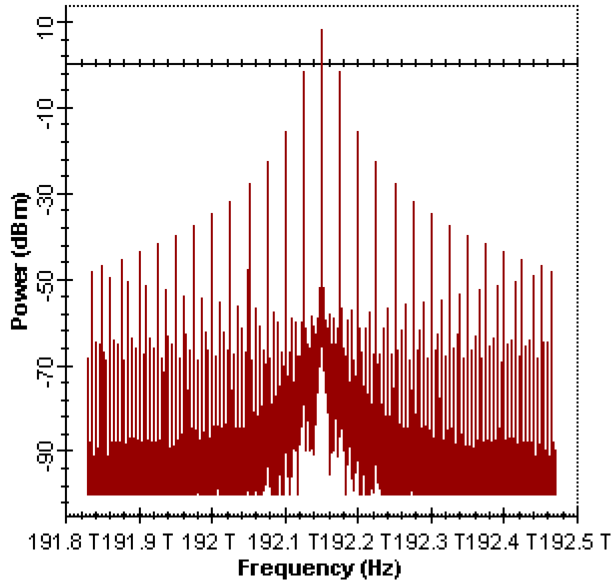


Fig. 2: Simulation diagram of AM+SD-MZM+AM configuration

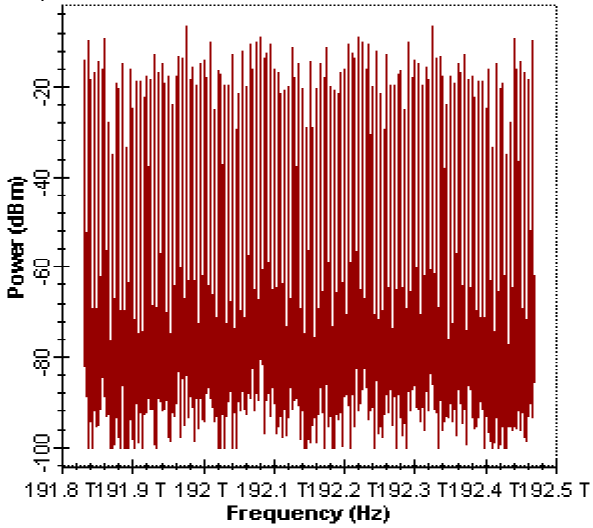
Each of the modulator has driven of radio frequency generation such as 25 GHz, amplitude 5 a.u. and bias 3 a.u. A single laser is employed for all the three modulators having input frequency 192.15 THz, laser linewidth 0.1 MHz, noise 3 dB, and input power 15 dBm. Fig. 1 depicts the block diagram of presented OMCG configuration. Simulation setup of proposed work is depicted in Fig. 2. TABLE II represents the system and modulator parameter values. A 15 dB power enabled laser signal is fed to the first stage i.e. AM and Multi-carrier output is obtained. However, the generated carriers are having high AD and therefore, a SD-MZM is employed at second stage to lowering the AD between the comb lines. Moreover, by integrating SD-MZM in the configuration, more number of comb lines are obtained. These comb lines are stable but carrier generation is still low and therefore, a third stage is introduced using AM. Here, at third stage, AM energies the power deficit carrier sidebands and introduce more number of comb lines. The optical spectrum analyzers are coupled to the system at each modulator stage as well as after CW laser.

RESULTS AND DISCUSSIONS

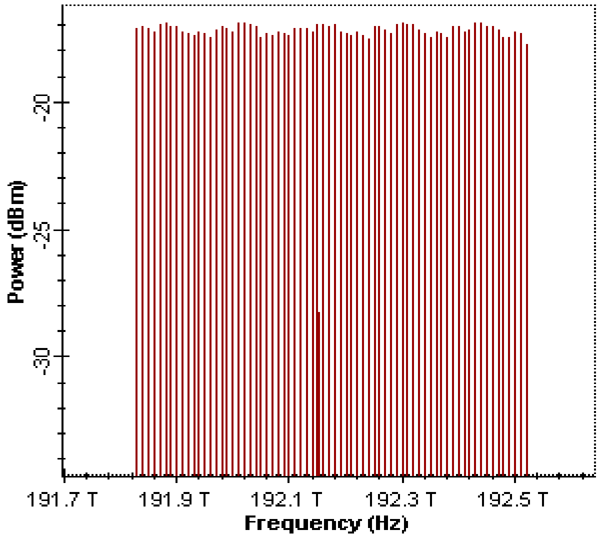
In this section, a detailed investigation of cascaded AM+SD-MZM+AM system is presented at different input parameters.



(a)



(b)



(c)

Fig. 3: Optical carriers recorded after (a) first stage (*AM*) (b) second stage (*SD_MZM*) (c) third stage (*AM*)

First and foremost, the optical carrier spectrums are observed after first stage in Fig. 3 (a), followed by second stage in (b) and lastly third stage output shown in (c). It is discerned that output carrier spectrum is unstable after the first stage and AD of carriers tend to decrease when SD-MZM is incorporated in the system. The large number of carriers are observed after the second stge. However, even after the second stage, high AD is observed. Therefore, a third stage is introduced to lower the AD and results revealed that there is significant improvement in the proposed system.

Further, effects of input RF signals are considered on the AD of the proposed work. Input RF signal is varied from 1 GHz to 30 GHz and graphical representation is depicted in Fig. 4. RF effects on the AD are considered after each stage. Results revealed that minimum AD for all the three stages is observed at 25 GHz input RF signal. Lowest AD is seen after the last stages followed by second stage and first stage.

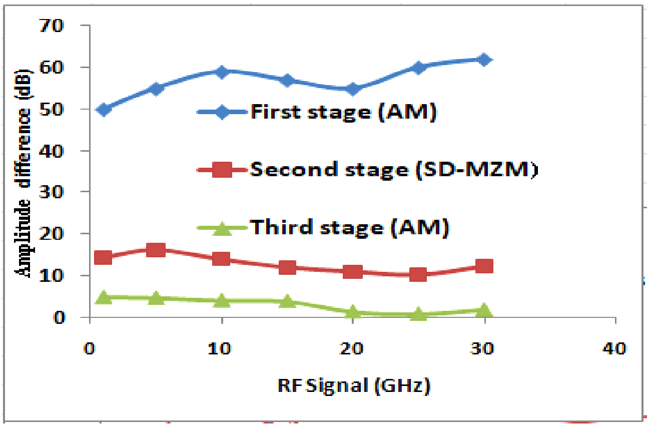


Fig. 4: Effects of RF proposed system

Extinction ratio of MZM plays an important role is deciding the performance of the system and in Fig. 5, extinction ratio of the second stage SD-MZM is varied from 5 dB to 55 dB and results are noted in terms of TNR. With the increase in the input extinction ratio of the SD-MZM, output TNR also increases. However, high extinction ratio is more prone to the external noises. Highest TNR is observed at 40 dB input extinction ratio and if we go further, extinction ratio little bit deteriorate.

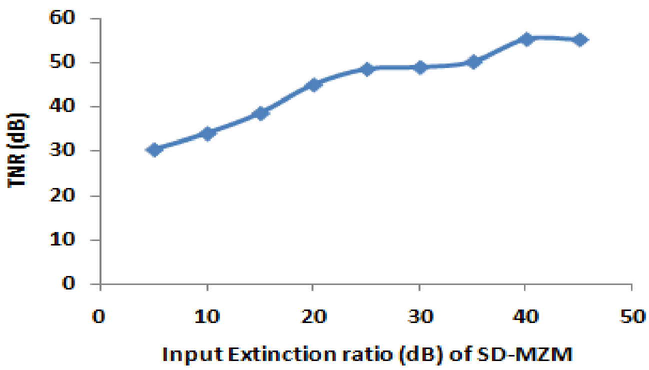


Fig. 5: Effects of SD-MZM's extinction ratio on proposed OMCG configuration

Table 3: Comparison of proposed work and different reported studies

Author [year] [ref.]	OMCG technique	Total comb	AD (dB)	TNR (dB)

		lines		
Ullah, R. et al. [2016] [14]	DML+PM	4	1.5	20
Li, J. et al. [2017] [Li, J., Ma, H., Li, Z., Zhang, X.: 2017]	RFS Loop	80	11	16
Ullah et al. [2018] [12]	AM+MZM+MZM	61	1	44
Das, B et al. [2020] [15]	parallel 4-MZMs	54	0.5	
Yan, J. et al. [2021] [16]	PM-optoelectronic oscillator	17	7.7	-
Proposed work	AM+SP-MZM+AM	65	0.96	48.58

TABLE III shows the comparison of different existing research articles with the proposed OMCG system in terms of generated frequencies, AD and TNR. It is discerned that proposed system is better than reported systems in terms of carrier generation, AD and TNR.

CONCLUSION

In this research article,a serial combination of three intensity modulators, such as the AM+SP-MZM+AM, is presented for the generation of largest number of tones with a high TNR and the lowest AD. Optical carriers are studied after first, second and third stage and results revealed that stable comb lines with lowest AD is obtained after last stage (AM). Further, effects of RF signal are studied on each modulator stage and 25 GHz found out to be optimal with lowest AD. Further, MZM extinction ratio effects are explored and it is evident that with the increase in the input extinction ratio of the SD-MZM, output TNR also increases. However, high extinction ratio is more prone to the external noises. Highest TNR is observed at 40 dB input extinction ratio and if we go further, extinction ratio little bit deteriorates. The presented OMCG designs employ a single RF source; no additional fibre Bragg gratings or specialized techniques are used. Total 65 tones with a maximum bandwidth of 640 GHz, 0.96 dB AD, and the greatest TNR of 48.58 dB are offered by proposed system. In near future, dual drive MZM can be studied in the proposed system.

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