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ULTRA FLAT OPTICAL FREQUENCY COMB GENERATION TAKING INTO ACCOUNT DYNAMICS OF CASCADED MODULATION FOR ENHANCING 5G AND BEYOND

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Abstract. The versatility of optical frequency combs in test and measurement has grown. Spectroscopy, metrology, precision distance measuring, sensing, optical and microwave waveform synthesis, signal processing, and communications are examples. Bandwidth optimization is crucial. Our unique and simple method for C-band millimeter-wave double-sideband vector signal creation was tested. This approach cascades one single-drive and one push-pull Mach-Zehnder modulator. After driving the first one with a 2, 4, 8, 16, 32, 64 GHz RF pulse, an optical frequency comb with six flat carriers was formed. The outputs were evaluated after each of the five stages following careful tuning to meet optical system harmonics. Multiple frequencies can be sent in one channel, making this architecture adaptable and scalable. For the suggested approach, experimental results match theoretical and simulation assessments.

Keywords: optical frequency comb, C-band millimeter-wave double-sideband components, Mach-Zehnder modulator, vector signal, 5G.

1. Introduction

An optical frequency comb (OFC) technology reinvented optical communications through its many applications, DWDM and OFDM, which split data into several subcarriers, are highlighted as key applications. These subcarriers are generated and manipulated by OFCs, ensuring fast and reliable transmission. In time-division multiplexing and ultrafast spectroscopy, the method generates brief laser pulses for accurate temporal synchronization. Additionally, OFC is used in optical arbitrary waveform generation (OAWG) to synthesize complicated waveforms with great precision for signal processing, waveform shaping, and advanced modulation technology [1]–[4]. DWDM, OFDM, short pulse generation, and OAWG all use OFC technology, which is versatile and essential to optical communications.

Cascading intensity and phase modulators with an RF source generate low-duty-cycled periodic optical signals for OFC synthesis[5]–[7]. We use signal-driven intensity modulator (IM) and phase modulator to create an ultra-flat OFC generator, unlike earlier microwave frequency-driven techniques. The new method, developed by Oleg G. Morozov [8]–[11]. Using of electro-optic modulators have to provide a simpler, more stable, and easily tuning OFC for a cost-effective solution that supports a wide range of optical communications and other applications.

2. Operating Principle and System Design

The optical transmission channel must be optimized for high-performance data transfer in optical communications, which is continually changing. A tuned ultra-flat OFC generator is used to achieve this. A cascaded intensity and phase modulators and a single-drive Mach-Zehnder modulator (MZM) are used in this cutting-edge technology. By using this cutting-edge technology, the single-drive MZM is crucial for precise optical frequency comb control and tuning. The ideal parabolic waveform is difficult to acquire, but the sinusoidal waveform can be used as a substitute for the ideal parabolic waveform. The beginning OFC scheme is shown in figure 1 [12].

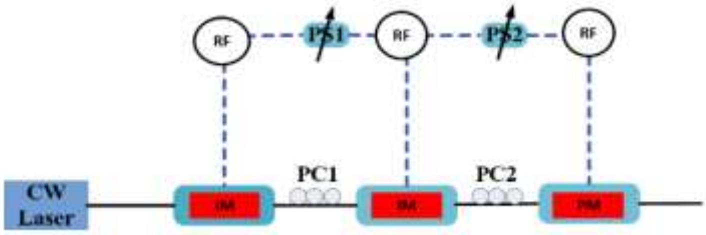


Fig.1. Beginning OFC block-scheme [12]:
intensity (IM) and phase (PM) modulators; microwave phase shifter, PS; polarization controller, PC

The utilization of IM that is driven by a sinusoid that has an amplitude is a rather straightforward method for the generation of flat-topped pulses $V = V_\pi / 2$ of the modulator and a DC bias corresponding to a phase shift of $\phi_{dc} = -\pi / 2$. Once the IM has been applied, the envelope of the output field can be determined by the relation [12]. Pure quadratic temporal phase waveforms lead to pure quadratic spectra at large phase modulation limits. Unlike pulse shaper-based methods, a sufficient length of ordinary single-mode fiber (SMF) may compress a linear chirp pulse to the bandwidth limit with high quality. Fiber dispersion slope affected bandwidths little [13]. Figure 2 shows three possible system stages.

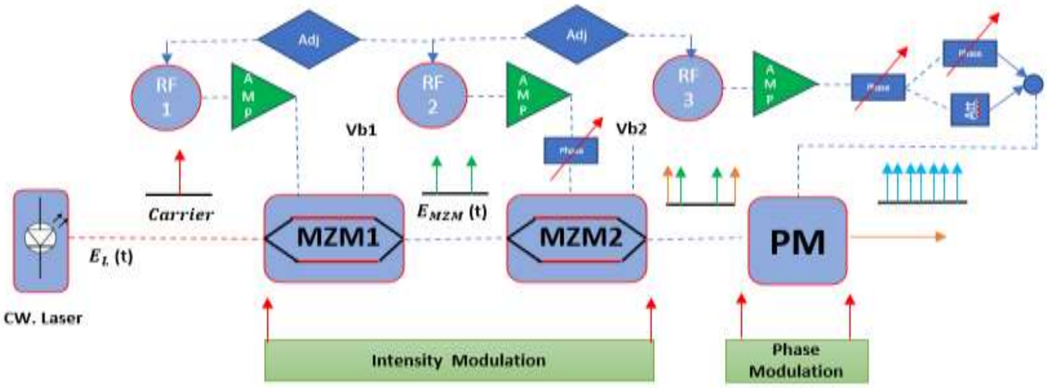


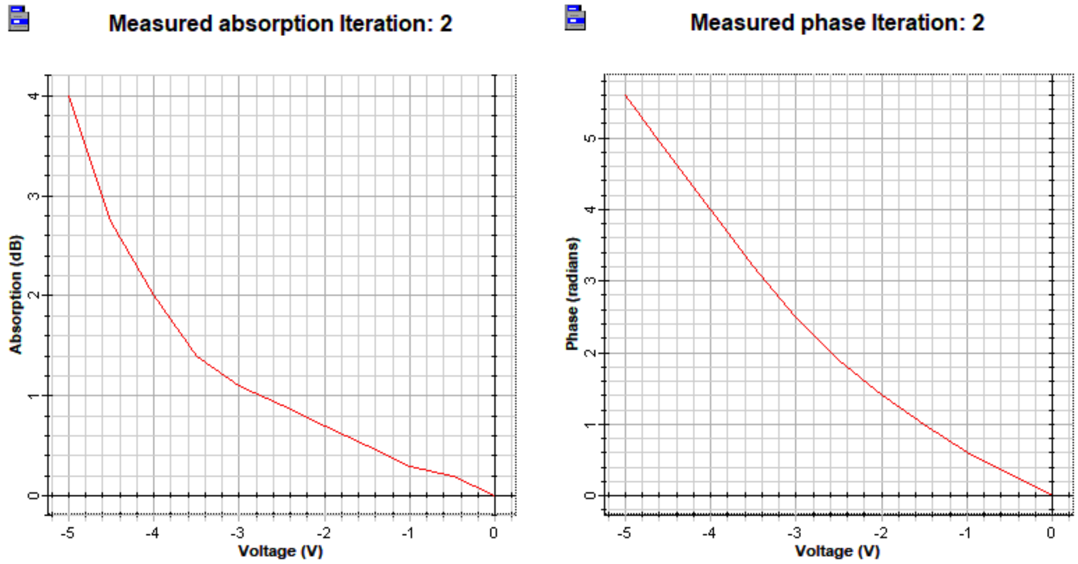
Fig. 2. Three cascades system: MZM_1, MZM_2 and PM

Two cascade intensity modulators MZM_1 and MZM_2 are biased at V_{b1} and V_{b2} when the microwave frequency RF_1, RF_2 is represented as (1) and (2) [14].

$$V_1(t) = V_1 \sin(\omega_1 t), \tag{1}$$

$$V_2(t) = V_2 \sin(\omega_2 t). \tag{2}$$

For MZM_1 and MZM_2, the input radio frequency signals have amplitudes V_1 and V_2 with frequencies ω_1 and ω_2. We can follow voltage curve shown in figure 3 *a*,*b* we got at universal set up which is shown in figure 4.



a) *b)*

Fig. 3. MZM_1 voltage to absorption curve (*a*), MZM_2 phase (radiation) to voltage curve (*b*)

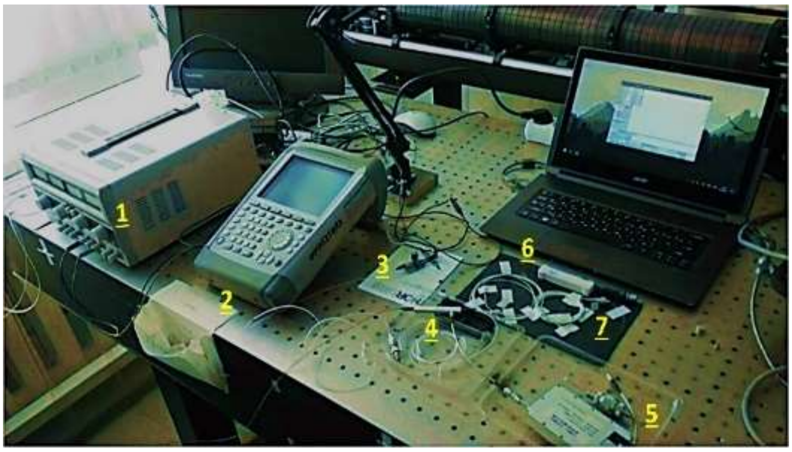


Fig. 4. Universal setup for microwave photonics experiment:
1 – DC power supply, 2 – spectrum analyzer , 3 – narrow-band laser , 4 – PM, 5 – microwave signal generator, 6 – MZM modulator, 7 – photodetector [15]

MZM1, MZM2 and PM were used to form three cascades OFC with 40-line optical spectrum output, power near −12 dBm and a frequency comb spacing – 16.516 GHz shown in Figure 5. It is 45º phase difference between each line. The MZM's optical field can be calculated mathematically as:

$$E_{\text{MZM}}(t) = \alpha E_0 \exp(-j\omega_0 t)\cos\left(\frac{\varphi_{\text{DC}}}{2} + \frac{m_{\text{MZM}}}{2}\cos(\omega_{\text{RF}} t)\right) = \\ = \alpha E_0 \exp(-j\omega_0 t)\left[\sum_{n=-\infty}^{\infty} \cos\left(\frac{\varphi_{\text{DC}}}{2} + \frac{n}{2}\pi\right) J_n\left(\frac{m_{\text{MZM}}}{2}\right)\exp(jn\omega_{\text{RF}} t)\right]. \quad (3)$$

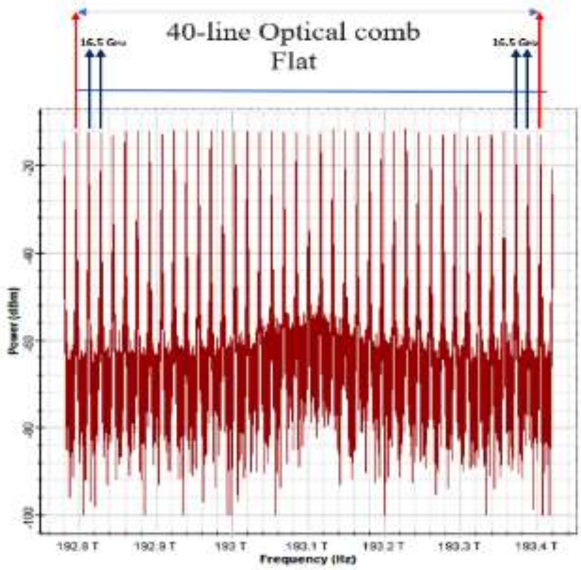


Fig. 5. Output spectrum of MZM1, MZM2 and PM form three cascades OFC

3. Conclusion

This work found that modulating the RF and DC signal intensity applied to five channels with three cascades MZMs and PM can build an affordable broadband flat OFC. The Il'in-Morozov's approach shows its suitability for several stages and microwave frequencies. Its efficiency has been established in optical communications at different frequencies because the inter-pulse distance can be regulated without interference and the power level matches optical system requirements. We then added two levels of intensity modulation to support microwave frequencies to establish its efficiency through analysis and simulation with a minor power difference. Since pulses are constant distance apart and do not interact, the results are excellent. The system also responded well to microwave frequency selection. We constructed a wide, flat optical frequency comb with a short duty cycle. Generation of pulses at transition time increases line spacing compared to typical frequency comb generators since the RF signal is quasi-periodic. The line is built with an external laser and radio frequency source. It's suitable for 5G and beyond due to its configurable spacing and frequency.

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ГЕНЕРАЦИЯ СВЕРХПЛОСКОЙ ОПТИЧЕСКОЙ ЧАСТОТНОЙ ГРЕБЕНКИ С УЧЕТОМ ДИНАМИКИ КАСКАДНОЙ МОДУЛЯЦИИ ДЛЯ УЛУЧШЕНИЯ ХАРАКТЕРИСТИК СИСТЕМ 5G И ВЫШЕ

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Аннотация. Универсальность оптических частотных гребенок в тестировании и измерениях возросла. Примерами могут служить спектроскопия, метрология, прецизионные измерения расстояний, сенсорика, синтез оптических и микроволновых сигналов, обработка сигналов и связь. Оптимизация полосы пропускания имеет решающее значение. Был протестирован наш уникальный и простой метод создания векторного сигнала миллиметрового диапазона C с двухполосной модуляцией. При таком подходе используется одноприводный и двухтактный модуляторы интенсивности Маха-Цендера с подключенным далее фазовым модулятором. После запуска первого модулятора интенсивности радиочастотным импульсом частотой 2,4,8,16,32,64 ГГц была сформирована оптическая частотная гребенка с шестью несущими. Выходные данные оценивались после каждого из пяти этапов ее формирования и после тщательной настройки в соответствии с определенными гармониками оптической системы. В одном канале можно передавать несколько частот, что делает эту архитектуру адаптируемой и масштабируемой. Для предлагаемого подхода экспериментальные результаты соответствуют теоретическим и модельным оценкам.

Ключевые слова: оптическая частотная гребенка, двухполосные компоненты миллиметрового диапазона C, модулятор Маха-Цендера, векторный сигнал, 5G.

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