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Chirped and chirped free optical OFDM MMW generation with direct detection to overcome fiber chromatic dispersion and MZM non linearity

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This paper addresses the generation of optical OFDM millimeter wave (MMW) signal to compensate the fiber chromatic dispersion and the Mach Zehnder Modulator (MZM) non linear distortion. Two optical OFDM signals generated by chirped and chirped free MZM are transmitted over a fiber. We compared the system performance by varying QAM modulation formats over a single mode fiber optic links extending up to 75kms. Our results show that, the chirped based OFDM signal transmission proves to be more robust against the chromatic dispersion of the fiber. Accordingly studies were carried out to reduce the impact of the non linearity of the MZM on system performance by appropriately selecting the drive power of the OFDM signal. Considering an Error Vector Magnitude (EVM) threshold of -14.5 dB as specified by the ECMA-368 standard, the optical receiver sensitivity of chirped based MMW signal generation is 2.6dB more as compared to chirped free operation.

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1. Introduction

The increase in demand for the bandwidth from the next generation broadband optical access networks requires the data rate in terms of Giga bit/sec [1]. Next generation optical networks have been the subject of extensive research to meet the demand of high bandwidth applications [2]. Fiber to the Home (FTTH) and Radio over Fiber (RoF) technology providing high capacity and bandwidth along with user mobility takes advantage of extremely low loss of standard single mode fiber (SMF) to transmit data [3]. The generation and processing of the higher order layers of OSI model and signal processing of the RF signal takes place at the central office which makes the receiver units simpler and lighter [4]. However, with the increase in data rate, the chromatic dispersion and the polarization mode dispersion increases [5]. Considering these limitations with respect to high data rate, OFDM, a type of modulation and multiplexing scheme providing high spectral efficiency and tolerance to chromatic dispersion is been widely considered as a modulation technique in RoF communication [6]. Optical communication systems based on OFDM are more immune to chromatic dispersion and the polarization mode dispersion [5].

The MZM is widely used for the generation of optical MMW. Every MZM exhibits a finite amount of residual chirp due to its uneven device geometry [7]. This chirp of the device depends upon the extinction ratio and the unbalanced ratio of the drive signal of the MZM. The MZM with zero chirp (balanced one) also called as chirped free MZM generating Double Sideband Full Carrier (DSBFC) is less immune to the chromatic dispersion, limiting the transmission distance. DSBFC signal undergoes a periodic degradation of the signal when it travels through the fiber. If the chirp parameter of the MZM is varied and made negative, the overall chromatic dispersion effect decreases and the signal transmission range increases [8]. Besides, the power transfer characteristics of MZM is non linear. The performance of the system degrades with the increase in applied bias and RF drive signal levels beyond the linear region of operation of MZM [9]. Thus, the proper selection of the RF drive power becomes very crucial to maintain the operation of MZM in its linear region.

This paper presents the theoretical and simulative study of optical OFDM generation and up conversion using chirped and chirped free MZM. The OFDM supports high data rate applications and MZM with negative chirp reduces the effect of the chromatic dispersion. To prove this, we employ different QAM modulation formats by varying fiber span. The OFDM signal power is applied appropriately so as to maintain MZM in its linear region. Later, the received optical power is varied in order to obtain the minimum value of EVM as prescribed by ECMA-368 standard [10] and to calculate the receiver sensitivity of chirped and chirped free OFDM signal generated by the MZM. Optisystem 13.0.3 is used to perform simulations.

2. Generation of optical orthogonal frequency division multiplexing (OFDM) signal

Fig.1, shows the simulation setup for the optical OFDM generation, transmission and demodulation. The serial data symbols are applied to a serial to parallel converter to convert it into parallel data blocks. The symbols are mapped by using different QAM modulation schemes. These symbols are used as inputs to IFFT, which converts the signal from frequency to the time domain. The IFFT output after cyclic prefix addition is then applied to parallel-to-serial converter for transmission.

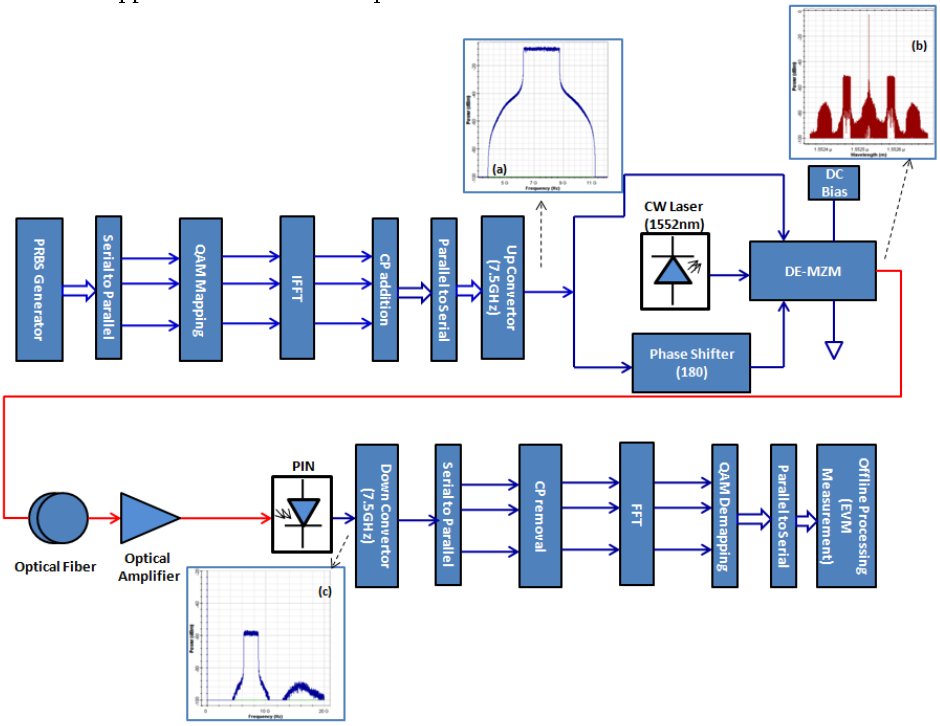

Fig.1. Optical OFDM MMW Generation with Direct Detection. (a) OFDM spectrum after up conversion. (b) Optical OFDM DSBFC spectrum. (c) Photodetected RF spectrum

In time domain, OFDM signal can be represented as,

$$s(t) = \sum_{n=0}^{N-1} \frac{e^{[j2\pi(f_c+n\Delta f)t]}}{\sqrt{T}} s(n), \quad (1)$$

where, N is the number of data carrying OFDM subcarriers, f_c is the carrier frequency of the n_{th} subcarrier, Δf is the subcarrier frequency spacing, $s(n)$ is the input data stream and T is the total symbol duration.

The OFDM signal is then up converted to 7.5GHz by a quadrature modulator. The Fig. 1(a) shows the RF spectrum of an upconverted OFDM signal. The up converted OFDM and its 180^0 phase shifted signal then acts as an RF input to the two electrodes of MZM. A continuous wave laser of -2dBm with line width of 10MHz, act as an optical input to the MZM. The switching voltage V_π = 4V, and the DC biased, V_{dc}=2V. The Fig. 1(b) shows the optical spectrum of the DSBFC OFDM MMW signal.

The output optical power of MZM is given by [11],

$$P_o(t) = P_i(t)\left\{cos^2\left(\frac{\pi}{2}\left[\varepsilon + \alpha Re\left(s(t)e^{j\omega_{RF}t} - s(t)e^{j(\omega_{RF}t+\varphi)}\right)\right]\right)\right\}, \quad (2)$$

where, $P_i(t)$ is the input optical power, ε is the normalized bias, α is the modulation index, ω_{RF} is the angular frequency of the RF signal used for upconversion of the OFDM signal with phase angle φ. The cos^2 term makes the MZM non linear and the optical OFDM signal power depends on the value of the normalized bias and modulation index.

The chirp parameter υ in dual electrode MZM is varied by varying the amplitude of the RF OFDM drive signal applied at the two electrodes of MZM. The relationship between the chirp parameter υ and the relative RF OFDM drive signals υ_1, υ_2 to the two electrodes is given by [8]

$$\upsilon = \frac{\upsilon_1+\upsilon_2}{\upsilon_1-\upsilon_2}. \quad (3)$$

The optical signal transmission takes place through a fiber with dispersion parameter of 16.75 ps/nm/km and 0.2 db/km attenuation loss up to 75kms. An optical amplifier overcomes the attenuation loss. The received signal is detected by a PIN photodiode with responsivity of 0.6 A/W. Fig. 1(c) shows the detected RF spectrum of OFDM signal.

The RF received power is given by [8]

$$P_{frf} \propto \cos\left\{\frac{\pi L D \lambda_c^2 f_{rf}{}^2}{c\left[1-\frac{2}{\pi}\arctan v\right]}\right\}, \quad (4)$$

where D is the dispersion parameter, L is the length of the fiber, λ_c is the carrier wavelength, f_{rf} is the radio frequency, v is the chirp parameter , c is the speed of light. The RF signal is amplified by an electrical amplifier. The RF signal is again downconverted by using a quadrature demodulator. At the OFDM demodulator, the FFT block transforms the signal back to frequency domain. The signal is again decoded and converted back to serial form. Table 1, shows the parameters used for simulation.

Table 1. Simulation parameters

Parameter	Value
Subcarrier modulation format	4, 16,64 QAM
OFDM bandwidth	2.5GHz
Number of data-carrying subcarriers	512
OFDM subcarrier frequency spacing	4.882 MHz
Cyclic prefix length	25%
Chirp of the MZM	-3
Data Rate	5GBPS
Information duration	204.83 nsec
Cyclic prefix duration	40.005 nsec
OFDM symbol duration	244.835 nsec
Upconversion frequency	7.5GHz

3. Chirped and chirped free OFDM signal transmission over different fiber length and QAM modulation formats

The performance of the chirped and chirp free OFDM signal optically up converted by MZM is evaluated for 4, 16, 64 QAM modulation formats. The analysis computed is based on the EVM performance of the optical OFDM system. The EVM is the difference between the measured signal value and the ideal reference value. The EVM is obtained by subtracting the n^{th} received symbol s_n from its ideal reference value z_n given by [11],

$$EVM = \sqrt{\frac{\frac{1}{N}\sum_{n=1}^{N}|z_n - s_n|}{\frac{1}{N}\sum_{n=1}^{N}|z_n|^2}}, \quad (5)$$

where, N is the total number of the OFDM symbols transmitted. The received signal after photo detection is demodulated by the OFDM demodulator. Fig.2 shows the EVM performance of the chirped and chirp free optical OFDM signal. It is evident from the figure that, the received constellation for the chirp OFDM signal is much more confined as compared to the chirp free OFDM signal. As the transmission distance increases, the signal degradation of chirp free OFDM is higher than its counterpart, leading to spreading of the constellation. The distortion of the constellation increases with the higher order modulation formats.

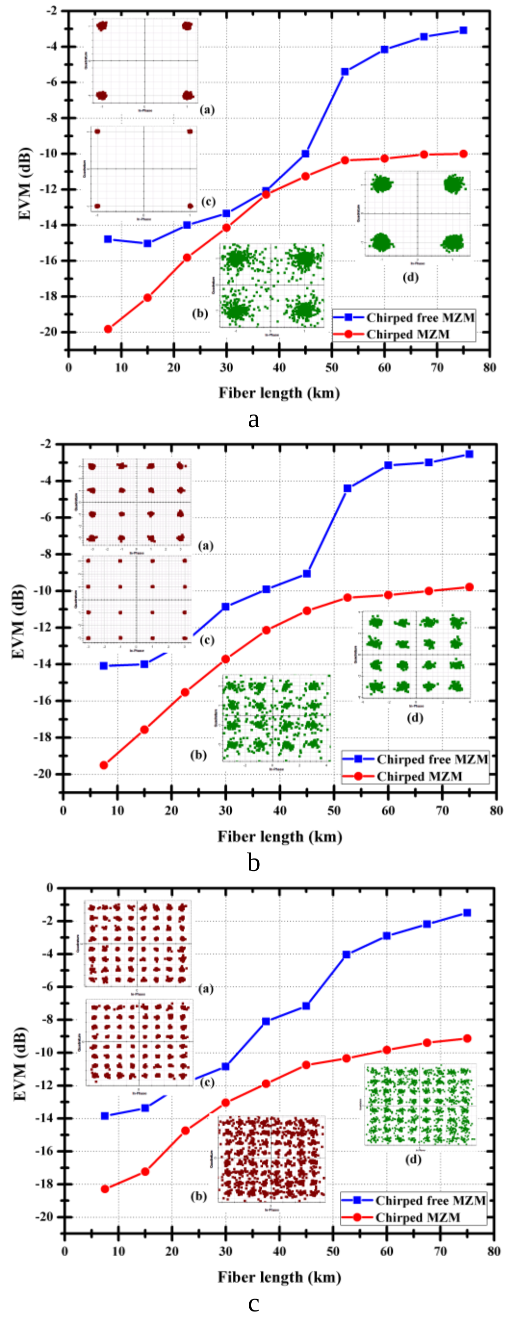

Fig. 2. EVM performance analysis for different fiber lengths for(i) 4QAM, (ii) 16QAM, (iii) 64QAM. Iinset (a,c for chirp free and chirped OFDM respectively) Constellation at distance 7.5kms (b,d for chirp free and chirped OFDM respectively) Constellation at distance 75km

The chirp free OFDM signal faces a periodic degradation as it travels along the fiber. The degradation is observed at 16, 30 and 45kms, where there is an increase in EVM leading to poor system performance. On the contrary, due to negative chirp as indicated by equation

(4), the chirped OFDM signal undergoes a small periodic degradation and the received RF power is high. Thus, a small variation in EVM is observed as the signal travels from 7.5 to 75kms. For 4, 16, 64 QAM, the EVM is -10, -9.78, -9.13dB and -3, -2.54, -1.49 dB for the chirp OFDM and chirp free OFDM respectively over the distance of 75kms.

4. The impact of MZM non linearity

Expanding (2) and obtaining the MZM power transfer function, we get

$$\frac{P_o(t)}{P_i(t)} = \frac{1}{2}\left\{1 + sin\left(\frac{\pi}{2} - \varepsilon\pi + \alpha\pi Re\left(s(t)e^{(j\omega_{RF}t+\varphi)} - s(t)e^{j(\omega_{RF}t)}\right)\right)\right\}. \qquad (6)$$

It is inferred from (6) that, the OFDM signal drive power is proportional to the modulation index (α). As the amplitude of OFDM signal is increased to increase the OFDM signal drive power, the α increases.

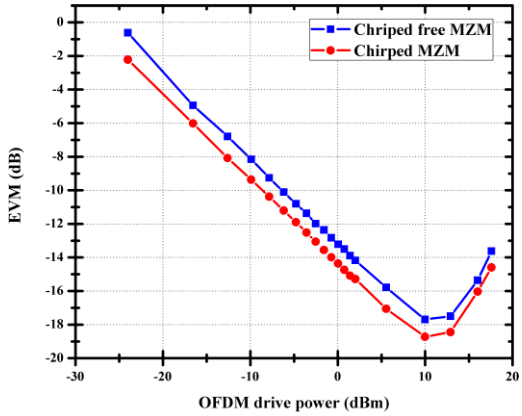

Fig. 3. EVM performance to analyze MZM non linearity

The optical OFDM DSBFC signal has all the fundamental components in both sidebands. The power degradation caused by fiber dispersion will affect both the fundamental and third-order intermodulation (IMD3) components. The degradation of the system performance is determined by the power level of the fundamental component and IMD3 terms which depends on the value of α.

The power of the fundamental component proportional to α is given by [9]

$$P_f = 2\left(10^{-\frac{\alpha_{att}L}{10}} L_{att}{}^2 A^2 R J_0{}^3(\pi MI) J_1(\pi MI)\cos\theta_{f1}\right)^2 \qquad (7)$$

Where, α_{att} is the fiber attenuation, L_{att} is attenuation of MZM, A is the amplitude of the optical signal generated by the laser, R is the responsitivity of photodiode, $\alpha = \frac{v_1}{V_\pi}$ is the ratio of modulating voltage to the switching voltage, $J_k(.)$ is the Bessel function of the first kind of order k and $\theta_f = \frac{\pi L D \lambda^2 f^2}{c}$.

The power of the IMD3 component is given by,

$$P_{IMD} = \frac{1}{128}\left\{\left(10^{-\frac{\alpha_{att}L}{10}} L_{att}{}^2 A^2 R(\pi MI)^3\right)^2 * C_d\right\} \qquad (8)$$

Where,

$$C_d \approx 16cos^6\left(\frac{\pi L D\lambda^2 f^2}{c}\right) \qquad (9)$$

Where, f is the frequency of the fundamental component.

It is noted from the equations (6-9), for lower values of α, the IMD3 power is negligible as compared to the fundamental component.

To analyze the influence of MZM non linearity, the SMF length is fixed at 20kms. The RF variable attenuators are used to vary the amplitude of the OFDM signal so as to vary its signal drive power from -24dBm to 17dBm. The rest of the simulation parameters remain unchanged. Fig.3 shows, EVM performance against varying OFDM signal drive power. As we increase the OFDM signal drive power, the overall SNR increases, decreasing the EVM and improving the system performance. The EVM keeps on decreasing till the OFDM drive power reaches a threshold value of 9.9dBm. Also with the increment in the OFDM signal drive power, α increases, causing a rise in the power of IMD3 components. Beyond the optimum threshold value of 9.9dBm, the power of the IMD3 terms is higher than the fundamental, resulting into non linear distortion and degrading the EVM performance. Thus, there is a system performance tradeoff with respect to increasing the OFDM signal drive power, i.e. increasing SNR and non linear distortion IMD3 terms of MZM.

The fundamental and IMD3 components experience different degradations due to fiber chromatic dispersion. This is due to the dependency of the former on $\cos^2\theta_{f1}$ and the latter on $cos^6\theta_{f1}$, while θ_{f1} depends upon the dispersion parameter D. As indicated by Equation (4), the effect of fiber chromatic dispersion on chirped OFDM signal is low as compared to the chirp free OFDM signal, resulting into low IMD3 power. Hence, as shown in fig.3, the EVM performance of chirped OFDM is better than chirp free OFDM signal transmission.

5. Impact of received optical power

As the signal travels along the fiber, the relative phase shift is introduced and orthogonality between the subcarriers is lost due to RF carrier phase noise and fiber chromatic dispersion. This effect will lead to intercarrier interference (ICI) [11].

Considering, the other noise sources such as photodetector noise, shot noise, amplified spontaneous emission noise (ASE), relative intensity noise (RIN), total EVM of the system is given by [12],

$$EVM^2 = EVM_0{}^2 + \frac{1}{SNR}, \quad (10)$$

where, EVM_0 is the result of phase distortion due to fiber chromatic dispersion.

The impact of chromatic dispersion on the chirp free OFDM signal is high, losing the orthogonality among the subcarriers and thus resulting in high EVM_0. For the chirped OFDM signal transmission, the chromatic dispersion effect is low, maintaining the orthogonality among the subcarriers and thus resulting in low EVM_0. With the increase in received optical power, the other sources of noise are overcome and SNR increases.

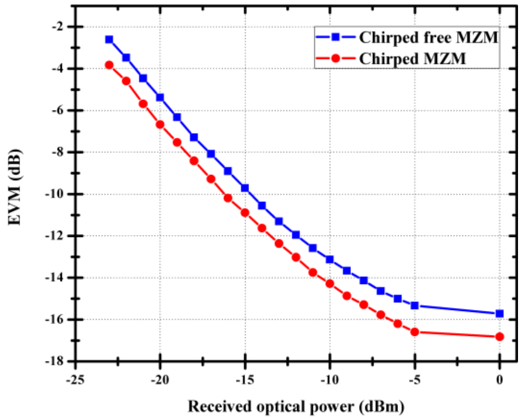

Fig. 4. EVM performance to analyze receiver sensitivity

For the simulation purpose, the received optical power at the photodetector is varied by optical attenuator from -24dBm to 0dBm. Fig. 4 shows the EVM variation with respect to the received optical power. Incrementing the received optical power, improves the received SNR and reduces the EVM, which is in excellent agreement with the above explanation. Thus, the overall EVM performance improves for the chirped OFDM signal with increasing received optical power

As the frequency of signal transmission is within the range of Ultra Wideband (3.1 to 10.6 GHz), the EVM threshold of -14.5dB prescribed by ECMA – 368 standard is considered to measure the optical receiver sensitivity for both OFDM signal transmission. The optical receiver sensitivity for the chirped and chirped free OFDM signal is -9.6dBm and -7dBm respectively. Thus, the chirped OFDM signal transmission increases the receiver sensitivity by 2.6dB as compared to chirp free OFDM signal transmission.

6. Conclusion

We compared and analyzed the chirped and chirp free OFDM signal generation techniques by MZM. The comparison of both the techniques was based on different higher order modulation formats and with increasing distance to prove that the chirped OFDM signal is more immune to the fiber chromatic dispersion against the chirp free OFDM signal. The impact of MZM non linear distortion based on OFDM signal drive power is estimated. An optimum drive power is measured such that the MZM non linearity due to IMD3 components is low. By selecting an optimum drive power level of the chirped OFDM signal, the signal can be transmitted to a longer distance before fading. The chirped OFDM signal transmission improves the receiver sensitivity by 2.6dB as compared to chirp free OFDM signal transmission.

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References

[1] A. Chowdhury, Hung-Chang Chien, Yu-Ting Hsueh, Gee-Kung Chang, Journal of Lightwave Technology **27**(12), 1920 (2009).
[2] Gee-Kung Chang, A. Chowdhury, Zhensheng Jia, Hung-Chang Chien, Ming-Fang Huang, Jianjun Yu, G. Ellinas, Journal of Optical Communications and Networking, IEEE/OSA **1**(4), C35 (2009).
[3] J. Beas, G. Castanon, I. Aldaya, A. Aragon-Zavala, G. Campuzano, Communications Surveys & Tutorials, IEEE **15**(4), 1593 (2013).
[4] Ming-Fang Huang, Jianjun Yu, Zhensheng Jia, Gee Kung Chang, Journal of Lightwave Technology **26(**15), 2653 (2008).
[5] D. J. F. Barros, J. M., Kahn, Journal of Lightwave Technology **28(**12), 1811 (2010).
[6] B. Schmidt, A. J. Lowery, J. Armstrong, Journal of Lightwave Technology **26(**1), 196 (2008).
[7] S. Walklin, J. Conradi, IEEE Photonics Technology Letters **9**(10), 1400 (1997).
[8] G. H. Smith, D. Novak, Z. Ahmed, IEEE Transactions on Microwave Theory and Techniques **45(**8), 1410 (1997).
[9] Tae-Sik Cho, Kiseon Kim, Journal of Lightwave Technology **24**(5), 2052 (2006).
[10] European Computer Manufacturers' Association, "High rate ultra wideband PHY and MAC standard," Ecma International Std. ECMA-368, Dec. 2008.
[11] Oluyemi Omololu Omomukuyo, "Orthogonal Frequency Division Multiplexing for Optical Access Networks", Ph.D thesis, University College London, April 2013.
[12] M. N. Sakib, B. Hraimel, Xiupu Zhang, M. Mohamed, Wei Jiang, Ke Wu, Dongya Shen, Journal of Lightwave Technology **27(**18), 4112 (2009).

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