Improved filterless12–tupled optical MM-wave generation and 2.5 Gb/s RoF transmission

K. ESAKKI MUTHU*, A. SIVANANTHA RAJA[a]
Department of ECE, University VOC. College of Engineering, Tuticorin, India
[a]*Department of ECE, Alagappa Chettiar College of Engineering & Technology, Karaikudi, India*

In this paper, we have proposed and demonstrated an improved optical Millimeter Wave (MM-Wave) generation and a 2.5 Gb/s Radio over Fiber transmission using two cascaded Lithium Niobate Mach-Zehnder Modulators (LN-MZM) without any filter. Both the MZMs are biased with symmetrical biasing parameters. By proper adjustment of RF amplitude, phase and biasing parameters in the MZM, twelvefold MM-wave is generated. An unwanted optical sideband suppression ratio (OSSR) higher than 37 dB and Radio frequency spurious sideband suppression ratio (RFSSR) higher than 37dB are achieved without optical filters. Further, a 2.5 Gb/s data transmission performances are also simulated for both dual tone and single tone modulation formats. The dispersion induced power penalty of 5 dB for the dual tone and 0.4 dB for single tone modulation formats are obtained.

(Received June 3, 2016; accepted November 25, 2016)

Keywords: Millimeter Wave, Radio over Fiber, Mach-Zehnder Modulator, RFFSSR, OSSR

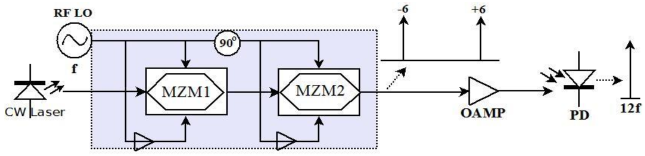
1. Introduction

To support increasing traffic demands and provide multi gigabit services to the wireless customers, a high frequency carrier with sufficient bandwidth is very essential. An obvious choice is the MM-Wave band, which allows 270 GHz bandwidth between 30- 300GHz and thus be the promising candidate for the distribution of future traffic demands. However, a major drawback of the MM-Wave communication is the generation and distribution, since the electrical generation of MM-Waves using conventional methods is costlier and the wireless delivery of MM-Wave is limited within few tens of meters. Hence an optical generation and distribution [1-3] of MM-Waves are preferred. The optical generation is highly stable, tunable and flexible. Several attempts have been made to generate MM-Waves via direct modulation, external modulation and optical heterodyning. However, external modulation based optical frequency multiplication is the most promising technique in terms of higher modulation bandwidth and tunability [4]. A higher frequency multiplication factor is very essential in order to reduce the need of high frequency local oscillator at the central station. In addition to this, filterless MM-Wave generation is another key technique which increases the tunability [5]. P. T. Shih, et al. have demonstrated optical MM-Wave generations via 12 tupling using a MZM and semiconductor optical amplifier [6], and this technique utilized interleavers to select the desired sidebands which increase the cost and limit the tunability. The RFSSR and OSSR of their proposal are low. Y. Chen et al. have demonstrated a full duplex link with 12 tupled MM-wave generation. Here two cascaded MZMs were used to generate fourth order sidebands with carrier and then the frequency multiplication is carried out in the electrical domain after the detector [7]. This scheme used too many components. Z. Zhu, et al. have demonstrated a novel 12-tupling and full duplex RoF transmission with a 0.67 dB dispersion induced power penalty over a 60 km link [8]. H. Chen, et al. have presented a filterless frequency tupling technique using dual parallel MZM with an optical phase shifter [9]. Z. Zhu, et al. have demonstrated a filterless frequency 12-tupling using two cascaded MZMs dual parallel MZMs[10], but the uncontrolled optical sidebands resulted an OSSR of 29 dB and RFSSR of 19 dB.

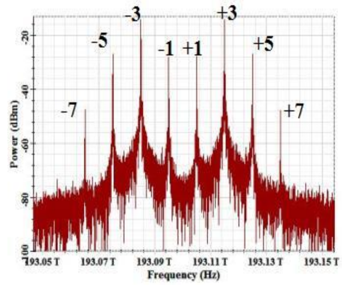
In this paper, we propose an improved optical MM-Wave generation based on frequency 12 tupling without filter and 2.5 GB/s Radio over fiber transmission. This scheme is highly tunable and easy to implement with an RFSSR of 37 dB and OSSR of 37 dB which are higher than the ones previously reported by [10]. Organization of this paper is as follows, section 2 describes the mathematical principle behind the proposed scheme, section 3 demonstrates the transmission performance of the generated MM-Wave and finally, section IV provides the conclusion.

2. Theoretical principle

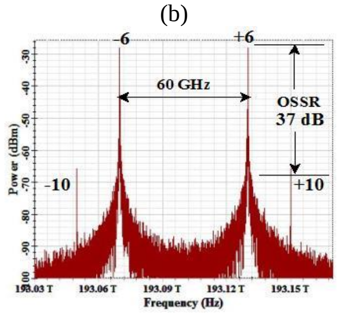
Fig. 1(a) shows the proposed scheme for the MM-Wave generation via frequency 12-tupling. The proposed system consists of a Continuous Wave (CW) laser and two cascaded LN-MZMs with symmetrical biasing conditions. A CW laser field



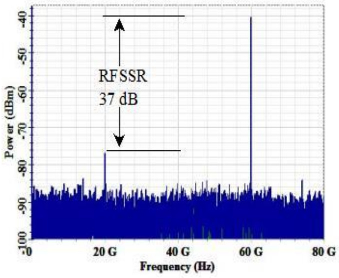
(a)



(b)



(c)



(d)

Fig. 1. a) Block diagram of proposed technique b) Spectrum after MZM1 c) Spectrum after MZM2 and d) Electrical output spectrum

$E_o(t) = E_o cos\omega_o t$ is injected into the MZM1 which is driven by a RF source at one arm and another RF input arm with a negative electrical gain. The output field of the MZM1 can be expressed as,

$$E_{MZM}(t) = \frac{E_o}{2}\cos\omega_o t\left[e^{j\frac{\pi V_{rf2}(t)}{V_\pi}+j\frac{V_{b2}}{V_\pi}} + e^{-j\frac{\pi V_{rf1}(t)}{V_\pi}+j\frac{V_{b1}}{V_\pi}}\right] \quad (1)$$

where V_π is the switching bias voltage, V_{b1} and V_{b2} are the bias voltages of the upper and lower arms $V_{rf1}(t) = V_{rf} sin\omega_m t$, $V_{rf2}(t) = -V_{rf} sin\omega_m t$, , V_{rf1} and V_{rf2} are the RF amplitudes of the Local Oscillators (LO) respectively. By setting $V_{b2}= -V_\pi$ and $V_{b1}= 0$, the equation (1) can be rewritten as,

$$E_{MZM1}(t) = \frac{E_o}{2}\cos\omega_o t\left(e^{jm\sin(\omega_m t)} - e^{-jm\sin(\omega_m t)}\right) \quad (2)$$

where $m=\pi V_{rf}/V_\pi$ is the modulation index. Using the Bessel function of first kind the equation (2) can be written as,

$$E_{MZM1}(t) = 2E_0\cos\omega_o t\sum_{k=0}^{\infty} J_{2k+1}(m)\sin(2k+1)\omega_m t \quad (3)$$

The output of the MZM1 is injected into the MZM2 which is symmetrically biased as MZM1. The MZM2 is driven by $V_{rf1}(t) = V_{rf} sin(\omega_m t + \pi/$ and $V_{rf2}(t) = -V_{rf} sin(\omega_m t + \pi/2)$, hence the output field of the MZM2 can be expressed as,

$$E_{MZM2}(t) = \left(e^{jm\sin\omega_m t+\pi/2} - e^{-jm\sin\omega_m t+\pi/2}\right) \quad (4)$$

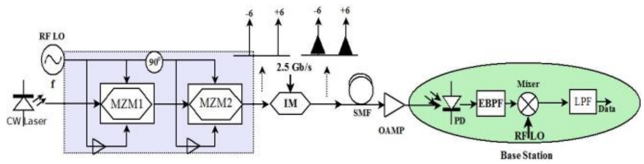
Equation (4) can be simplified using Bessel function as shown,

$$E_{MZM2}(t) = 4\sum_{k=0}^{\infty} J_{2k+1}(m)\sin(2k+1)\omega_m t + \pi/2 \quad (5)$$

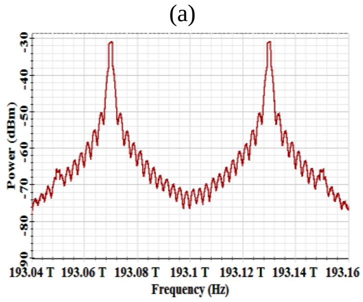
Finally, the output of the cascaded stage can be expressed as,

$$E_o(t) = E_{MZM1}(t) * E_{MZM2}(t) \quad (6)$$

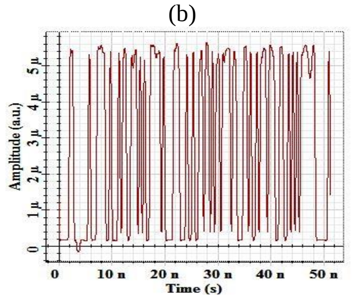
$$E_o(t) = 2E_0\cos\omega_o t\sum_{k=0}^{\infty} J_{2k+1}(m)\sin(2k+1)\omega_m t$$



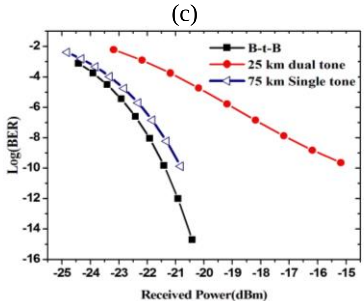
(a)



(b)



(c)



(d)

Fig. 2. a) Simulation experimental setup, b)Data modulated spectrum c) Recovered data d) BER perfromance of both single tone and dual tone modulation

$$*4\sum_{k=0}^{\infty}J_{2k+1}\left(m\right)\sin(2k+1)\omega_m t+\pi/2 \quad (7)$$

Using the trigonometric identity *2sina.sinb=cos(a-b)-cos(a+b*), Equation (7) can be simplified as,

$$E_o\left(t\right)=4E_0\cos\omega_o t\sum_{k=0}^{\infty}J^2{}_{2k+1}\left(m\right)$$
$$*\cos((4k+2)\omega_m t+(2k+1)\pi/2) \quad (8)$$

From the equation, it can be observed that the output of the cascaded stage consists of only the odd sidebands, though when m=3.6295, the first and all the higher order terms above five re neglected due to their low powers. Hence the equation (8) can be rewritten as,

$$E_o\left(t\right)=4E_0\cos\omega_o t\begin{bmatrix}J_3{}^2\left(m\right)\cos 6\omega_m t\\+J_5{}^2\left(m\right)\cos 10\omega_m t\end{bmatrix} \quad (9)$$

Equation 9 contains only sidebands with a frequency six times and 10 times that of the input RF LO frequency. As these sideband beats at a photo detector and the photo current can be expressed as,

$$I_o(t)=\Re\left|E_o(t)\right|^2 \quad (10)$$

By eliminating the DC components, the photo current can be given as,

$$I_o(t)=8E_o{}^2\begin{bmatrix}\mathrm{J}_3{}^4(\mathrm{m})\cos 12\omega_m t\\+\mathrm{J}_5{}^4(\mathrm{m})\cos 20\omega_m t\\+4\mathrm{J}_3{}^2\mathrm{J}_5{}^2(\mathrm{m})\cos 4\omega_m t\\+4\mathrm{J}_3{}^2\mathrm{J}_5{}^2(\mathrm{m})\cos 16\omega_m t\end{bmatrix} \quad (11)$$

From equation (11) one can clearly understand that the electrical spectrum consist of 4^{th}, 12^{th}, 16^{th} and 20^{th} order of sidebands. Among this 12^{th} order sideband shows dominant power than rest with the RFSSR of 37dB.

3. Performance evaluation & results

The simulation experimental setup is shown in Fig. 2(a). A DFB laser source with a center frequency of 193.1 THz and spectral width of 10 MHz is launched into the first MZM. A 5 GHz RF local oscillator with amplitude of 6.93V is connected to one of the RF input arms of the MZM and the other arm is connected with the same RF source with unity negative gain. The half wave voltage of the MZM1 is set to 6V. The output of the MZM1 contains only the odd order harmonics shown in Fig. 1(b). This field is injected into the MZM2 whose biasing parameters are very same as that of MZM1. Another RF LO oscillator with 90 degrees phase shift is connected to the RF input with a negative gain between them. Output of the MZM2 is shown in Fig. 1(c) which contains dominant optical sidebands at 193.07 THz, and 193.13 THz. The frequency difference between the optical sidebands is 60 GHz which is 12 times the input RF LO frequency. In addition to this, another two weak sidebands appear at 193.05 THz and 193.15THz which are considered to be unwanted sidebands. The power difference between the $\pm 6^h$ order and $\pm 10^{th}$order sidebands is higher than 37 dB and it is shown in Fig. 1(d). The transmission performance of the generated optical MM-Wave is evaluated via two different modulations. In first case, a 2.5 Gb/s NRZ data is modulated over $(\omega_c-6\omega_m)$ and $(\omega_c+6\omega_m)$ sidebands using an intensity modulator with 30 dB extinction ratio. In this scheme of transmission no optical filtering is involved. The double sideband modulated signal is shown in Fig. 2(b). In the second case a 1 x 2 demultiplexer is used immediately after the MZM2 to separate the sidebands and one of the sidebands$(\omega_c-6\omega_m)$is modulated with 2.5 Gb/s NRZ data using an intensity modulator with an extinction ratio of 30 dB. he sideband$(\omega_c+6\omega_m)$ is left unmodulated. Then these sidebands are combined using 2x1 multiplexer and transmitted over a single mode fiber with an attenuation coefficient of 0.2 dB/ km and a dispersion coefficient of 16.75 ps/ nm.km. An optical amplifier with 20 dB gain is used to compensate the optical fiber losses in the link. The optical losses will include insertion loss, splitting losses and attenuation. At the receiving base station, a PIN photodetector with 0.7 A/ W responsivity, 10 nA dark current and $100e^{-24}$ W/ Hz thermal power density is employed to detect the signal. After the photodetector a data modulated 60 GHz MM-Wave is recovered, then an electrical band pass filter with a BW of 1.5 times the bitrate is employed to remove unwanted signal. The signal is down converted using an electrical mixer and RF LO. After low pass filtering, the baseband signal is sent to the BER analyzer. The data thus recovered is shown in Fig. 2(c). The BER of both the schemes are evaluated by varying the received optical power. The BER characteristics of both the schemes are compared with the back-to-back BER and it is shown in Fig. 2(d). From the graph, one can clearly understand that the maximum transmission distance of the double sideband modulation is limited to 25 km due to the chromatic dispersion induced bit-walk off effect. Power penalty of 5 dB is achieved for the 10^{-9} BER compared to back-to-back case. This kind of single tone modulation will eliminate the RF power fading and the bit walk-off effect caused by dispersion [11]. However the link distance is extended to 75 km in case of the single sideband data modulation. When comparing the BER of the back-to-back case with this case, it is found that the power penalty is less than 0.4 dB at the BER of 10^{-9}.

4. Conclusion

An optical MM-Wave generation via frequency 12-tupling using two cascaded MZM is proposed and mathematically verified. The quality of the generated MM-Wave is observed via OSSR and RFSSR. Higher the values of OSSR and RFSSR, better the quality. In this work we have reported 37 dB of OSSR and 37 dB of RFSSR.

Also the proposed scheme is tunable over wide range since there are no filters involved in the generation. Transmission performance of the generated and single tone data modulation is found superior than double tone modulation with dispersion induced power penalty less than 0.4dB at the BER of 10^{-9}. The proposed scheme is very simple, easy to implement and cost effective since there are only few components used.

Acknowledgement

The authors thankfully acknowledge the Department of Science and Technology (DST), New Delhi for their Fund for Improvement of S&T Infrastructure in Universities and Higher Educational Institutions – (FIST) grant through the order No.SR/FST/College-061/2011(C) to procure the optiwave suite Simulation tools.

References

[1] G. H. Qi, J. P. Yao, J. Seregelyi, S. Paquet, C. Belise, IEEE Transaction on Microwave Theory and Techniques **53,** 3090 (2005).

[2] J. J.O' Reilly, P. M. Lame, Electronics Letters **30**, 1329(1994).

[3] S. Ray, M. Medard, L. Zheng, IEEE J. Sel. Areas in Communications **29**, 1284 (2011).

[4] J. Ma, C. X. Yu, Z. Zhou, J. J. Yu, Optics Communications **268**, 51 (2006).

[5] J. Yu, Z. Jia, L. Yi, Y. Su, G. K. Chang, T. Wang, IEEE Photonics Technology Letters **18**, 265 (2006).

[6] P. T. Shih, J. Chen, C. T. Lin, W-Jr. Jiang, H. S. Huang, P. C. Peng, S. Chi, Journal of Light Wave Technology **28,** 71(2010).

[7] Y. Chen, A. Wen, L. Shang, Y. Wang, Optics& Laser Technology **434**, 1167 (2011).

[8] Z. Zhu, S. Zhao, Y. Li, X. Chu, X. Wang, IEEE Journal of Quantum Electronics **49**, 919 (2013).

[9] H. Chen, T. Ning, J. Li, L. Pei, C. Chang, J. Yuan, Optics Communications **350**, 128 (2015).

[10] Z. Zhu, S. Zhao, S. Zheng, W. Wang, B. Lin, B Applied Optics **54**, 9432 (2015).

[11] M. Zhou, J. Ma, IEEE/OSA Journal of Optical Communication and Networking **3**, 127 (2011).

*Corresponding author: esaionly@gmail.com