Communications on Applied Electronics (CAE) – ISSN : 2394-4714
Foundation of Computer Science FCS, New York, USA
Volume 3– No.4, November 2015 – www.caeaccess.org

Performance Analysis of Millimeter-Wave Signal Generation using Optical Dual Electrode Mach-Zehnder Modulator

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ABSTRACT

This paper deals with the radio over fiber system which is novel technique for millimeter wave transmission using optical fiber. An analytical expression is found to generate and distribute millimeter wave signals using an optical dual electrode mach-zehnder modulator.It is found that the odd-order electrical harmonics are cancelled and even-order electrical harmonics are generated at the output of a photo-detector. The analytical expression is verified by simulations and simulation results oriented to measure the performance of Radio over fiber system.

Keywords

Dual electrode Mach-Zehndar Modulator (DEMZM), Photo-detector (PD),Optical single side band (OSSB).

1. INTRODUCTION

This approach to generating and distributing a wideband, continuously tunable millimeter-wave signal using an optical dual electrode mach-zehnder modulators and Signal Analyzer is proposed. A millimeter-wave signal tunable from 32 GHz to 50 GHz is obtained by tuning the microwave drive signal from 8 GHz to 12.5 GHz. The generated millimeter-wave signal is stable and high spectral purity[1].

A millimeter-wave signal that has four times the frequency of the microwave drive signal is generated by beating the two second-order optical sidebands at a photo-detector.

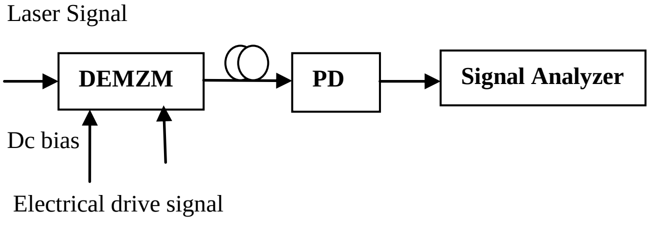

Fig.1 Signal Model of the mm-wave signal generationsystem using DEMZM modulator

The electric field at the output of a dual electrode mach-zehnder modulator, $\mathrm{V_{out1}(t)}$, can be approximately expressed as:

$$\mathrm{V_{out1}(t) = E_L \cos\left[\frac{\phi[V(t)]}{2}\right].\cos(\omega_L t)} \qquad (1)$$

Where $\mathrm{E_L}$and $\omega_\mathrm{L}$are respectively the electric field amplitude and angular frequency of the input Optical carrier, V(t)is the applied electrical drive voltage, ϕ[V(t)] is the optical phase difference caused by V(t) between the two arms of the dual electrode mach-zehnder modulator[2].

The dual electrode mach-zehnder modulator is driven by a sinusoidal electrical signal and biased with a constant DC voltage, ϕ[V(t)] is expressed as:

$$\phi[\mathrm{V(t)}] = \phi_0 + \frac{\pi}{\mathrm{V}\pi}.V_m \cos(\omega_m\, t) \qquad (2)$$

Where ϕ_0 is a constant phase shift determined by the constant DC bias voltage, $V_\pi$is the half-wave voltage at high frequency and $V_m$and $\omega_m$are the amplitude and angular frequency of the electrical drive signal respectively. Substituting Eq. (2) into Eq. (1).

The electric field of the output optical signal can be written as:

$$V_{out1}(t) = E_L \cos\left[\frac{\phi_0}{2} + \frac{\pi}{2V_\pi}.V_m \cos(\omega_m t)\right].\cos(\omega_L t)$$

$$= E_L\left[\cos\frac{\phi_0}{2}\cos(\beta\, cos\, \omega_m\, t) - \sin\frac{\phi_0}{2}\ \sin(\beta\, cos\, \omega_m\, t)\right].cos(\omega_L t)$$
(3)

Where $\beta = \frac{V_m}{V\pi}.\frac{\pi}{2}$is the phase modulation index

The DC bias of the dual electrode mach-zehnder modulator is tuned to have $\phi_0 = 0{,}2\pi{,}4\pi$, Then, all the odd-order optical sidebands associated with the term $\sin(\frac{\phi_0}{2})$ vanish, as indicated in Eq.(4). Only the even-order optical sidebands are kept.

We know that,

$$\cos[\beta \cos(\omega_L\, t)] = \sum_{n=-\infty}^{n=\infty} [(-1^n) J_n(\beta)\cos(\omega_m n t)]$$

$$J_{-n}(\beta) = (-1^n) J_n(\beta)$$

Therefore, Eq. (3) can be further simplified to

$$V_{out1}(t) = [E_L\, k\, J_0(\beta)\cos(\omega_L t) - E_L J_2(\beta)\cos(\omega_L t - 2\omega m\, t - ELJ2\beta\cos\omega Lt + 2\omega m\, t + ELJ4\beta\cos\omega Lt - 4\omega m\, t + ELJ4\beta\cos\omega Lt + 4\omega m\, t$$

(4)

When this optical signal is fed to a photo-detector, a strong frequency-doubled electrical signal and a weaker frequency-quadrupled electrical signal will be generated.

Assume that all odd-order optical sidebands generated by the modulation of the dual electrode mach-zehnder modulator by a sinusoidal signal can be completely suppressed by using an appropriate DC bias voltage[3]. That means that the condition of $\phi_0 = 0{,}2\pi{,}4\pi$,.... is satisfied with a constant DC bias. Assume also that the attenuation α dB.where$k$ is the optical electrical field attenuation factor,which is related to α by α= -20Log $_{10}$ k.

Usually, for a commercially available DEMZM the maximum available phase modulation index, $\beta_{max}$is 2.Eq. (4) shows that the optical signal consists of an attenuated optical carrier and 4 optical side bands[4]. When the optical signal shown in transmits over a single mode fiber, the chromatic dispersion of the fiber will cause an extra phase shift to each optical sideband compared to the optical carrier[5]. By expanding the propagation constant β*(ω)* of the fiber for each optical sideband to a Taylor series around the angular frequency of the optical carrier, i.e.

$$\beta(\omega_L \pm 2n\omega_m) = \beta(\omega_m) + \beta'(\omega_L)(\pm 2n\omega_m) + \frac{1}{2}\beta''(\omega_L)(\pm 2n\omega_m)^2 + \cdots \quad (5)$$

Where $\beta^{'}(\omega_L)$and $\beta^{''}(\omega_L)$is the first- and second-order derivative of the propagation constant β(ω) at the angular frequency ω_0, respectively. The effect of higher-order dispersion is neglected for the single mode fiber at 1550 nm band And $\beta^{''}(\omega_L)$ can be expressed by the chromatic dispersion parameters D as:

$$\beta^{''}(\omega_L) = -\frac{C}{2\pi f_L^{\,2}} D \quad (6)$$

where*c* is the speed of light in free space and $f_L$is the frequency of the optical carrier[6].

The electric field representing the optical signal at the end of the transmission over a single mode fiber of length *L* can be obtained by adding the transmission phase delay, $\beta(\omega_L \pm 2n\omega_m)L$,to the corresponding optical sideband shown in Eq. (4). Electrical harmonics will be generatedby applying this optical signal to a photo-detector[7].

The output voltage of the generated high frequencyelectrical signal is:

$$V_{out}(t) = \Big[\big[E_L\, kJ_0(\beta)\cos(\omega_L t) - E_L J_2(\beta)\cos(\omega_L t - 2\omega_m t) - E_L J_2(\beta)\, cos(\omega_L t + 2n\omega mt) + ELJ4(\beta)\ cos(\omega Lt - 4\omega mt) + ELJ4(\beta)\, cos(\omega Lt + 4\omega mt) \times EL\ k\ J0(\beta)\ cos(\omega Lt) - ELJ2(\beta)\ cos(\omega Lt - 2\omega mt) - ELJ2(\beta)\, cos(\omega Lt + 2n\omega mt) + ELJ4(\beta)\, cos(\omega Lt - 4\omega mt) + ELJ4(\beta)\, cos(\omega Lt + 4\omega mt)$$

$$V_{out}(t) = \big[E_L{}^2k^2J_0{}^2(\beta) + 2\,E_L{}^2J_2{}^2(\beta) + 2E_L{}^2J_4{}^2(\beta) - 4\,EL^2kJ0\beta J2\beta + 4\,EL^2kJ2\beta J4\beta cos2\omega mt + 4EL^2kJ0\beta J4\beta + 2\,EL^2kJ2^2\beta cos4\omega mt + - 4\,EL^2kJ2\beta J4\beta cos6\omega mt + EL^2kJ4^2(\beta)cos(8\omega mt)$$

$$V_{out}(t) = \Big[E_L{}^2k^2J_0{}^2(\beta) + 2\,E_L{}^2J_2{}^2(\beta) + 2E_L{}^2J_4{}^2(\beta) - \Big[4\ E_L{}^2kJ_0(\beta)\,J_2(\beta)\cos\Big[4\pi cDL\left(\frac{f_m}{f_L}\right)^2\Big] + 4\ E_L{}^2kJ_0(\beta)\,J_2(\beta)\cos\Big[12\pi cDL\left(\frac{f_m}{f_L}\right)^2\Big]\Big] cos[2\omega_m t - 2\omega_m\beta^{'}(\omega_L)L] + \Big[\,4\,E_L{}^2kJ_0(\beta)\ J_4(\beta)\cos\Big[16\pi cDL\left(\frac{f_m}{f_L}\right)^2\Big] + 2\ E_L{}^2kJ_2{}^2(\beta)\Big] cos[4\omega_m t - 4\omega_m\beta^{'}(\omega_L)L] - \Big[4\ E_L{}^2kJ_2(\beta)\,J_4(\beta)\cos\Big[12\pi cDL\left(\frac{f_m}{f_L}\right)^2\Big]\Big] cos[6\omega_m t - 6\omega_m\beta^{'}(\omega_L)L] + \big[E_L{}^2kJ_4{}^2(\beta)\big]cos[8\omega_m t - 8\omega_m\beta^{'}(\omega_L)L]\Big] \quad (6)$$

The Power Intensity of Second ,Fourth and Sixth-order electrical harmonics $I_{2,}I_4$ and I_6 given as,

$$I_2 = \Big[\,4\,E_L{}^2k\,J_0(\beta)J_2(\beta)\,cos[4\pi cDL\left(\frac{f_m}{f_L}\right)^2] + 4\,EL^2\,k\,{}_{J2}(\beta)J4(\beta)\,cos[12\pi cDLfmfL^2]$$

$$I_4 = \Big[2\,E_L{}^2kJ_2{}^2(\beta) + 4\,E_L{}^2k\,J_0(\beta)J_4(\beta)\ cos[16\pi cDL(\frac{f_m}{f_L})^2\,]\Big]$$

$$I_6 = \Big[4E_L{}^2k\,J_2(\beta)J_4(\beta)\,cos[12\pi cDL(\frac{f_m}{f_L})^2]\Big]$$

$$C = [\,E_L{}^2k^2J_0{}^2(\beta) + 2\,E_L{}^2J_2{}^2(\beta) + 2E_L{}^2J_4{}^2(\beta) + E_L{}^2kJ_4{}^2(\beta)]$$

Where C is constant.

2. RESULT DISCUSSION

For a distribution system that operates at 1550nm with a transmission distance of 25km over standard single mode fiber with D = 17ps/(nm.km),Frequency of the electrical drive signal (the power intensity I_4 and harmonic suppression of I_4/I_2 versus the modulation depth b (0 ≤ b ≤ 2) are plotted in fig.2.

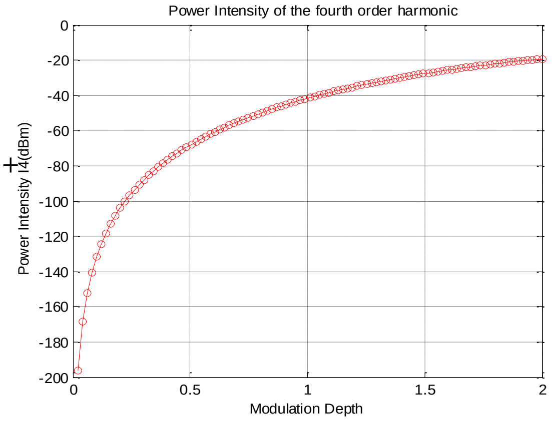

Fig.2(a) Power intensity I_4 of the forth – order harmonic.

Fig.2(a) shows that the power intensity I_4 is monotonically increasing for (0 ≤ b ≤ 2). At modulation depth (b=0.5) the power intensity is approximately -70dBm and At (b=1) the power intensity reach around -39dBm.

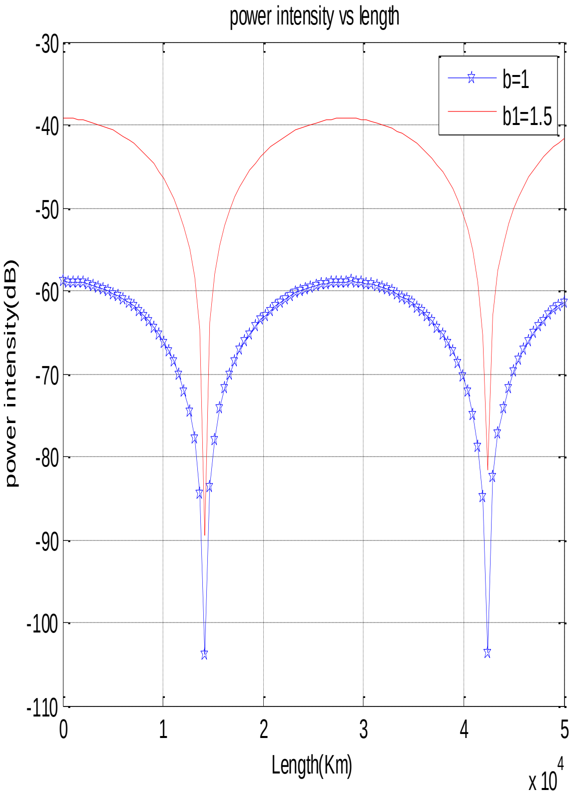

Fig.2(b) Power intensity I$_2$ of the second – order harmonic.

Fig.2(b) shows that Power Intensity of second order harmonics vary with fiber Length for Two different modulation depth. At modulation depth (b=1) the power intensity is approximately -62dB and At (b=1.5) the power intensity is found -39dB. That means say that power intensity will increase for increasing the modulation depth for same fiber length.

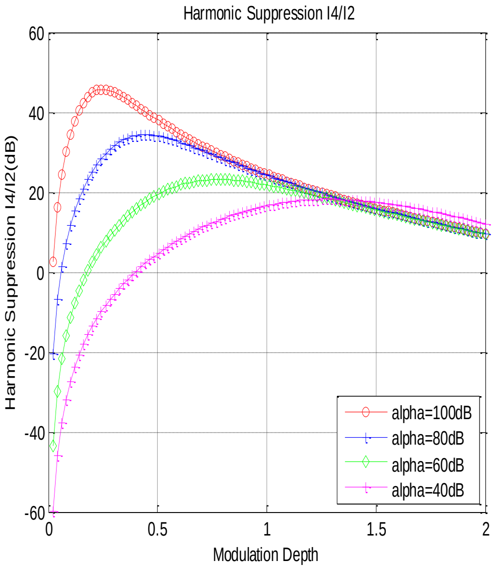

Fig.2(c) Harmonics suppression I$_4$/I$_2$

3. CONCLUSION

This paper including the analysis of a novel microwave-photonics system that could generate and distribute a broadband ,frequency-tunable mm-wave signal using a low frequency DEMZM . The technique was based on the non-linear response of the DEMZM by properly biasing it to suppress the odd-order optical side bands. Analytical analysis on the harmonic suppression with different modulation depths and power intensity with different fiber length and modulation depth was discussed. A system using a DEMZM and optical fiber was built. The result showed that a stable ,high spectral purity mm-wave signal from 32GHz to 50GHz was directly observed on an electrical spectrum analyzer by tuning an electrical drive signal from 8GHz to 12.5GHz. The generated mm-wave signal was distributed over 25 km standard single mode fiber. the integrity of the generated mm-wave signal at the end of the fiber span was maintained after the transmission.

4. REFERENCES

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