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Photonic Implementation of 4-QAM/QPSK Electrical Modulation at Millimeter-Wave Frequency

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***Abstract*—We propose a photonic method for generating millimeter-wave 4-QAM/QPSK modulated signals. The method is based on optical phase modulation by multilevel electrical signals and optical carrier-suppression. Simulation results are presented for 2.5 Gsymbol/s 4-QAM and QPSK signals at a 36 GHz carrier. Furthermore, this method can be extended to generate millimeter-wave *m*-PSK signals and can be incorporated into broadband radio-over-fiber systems to support wireless/ wireline converged access network.**

I. INTRODUCTION

The continue demand from end-users for high capacity wireless communication links encourages us to research for techniques to realize high frequency wireless systems carrying high bit rate signals[1]. Conventional signal generation at radio frequencies (RF) requires signal modulation at baseband or intermediate frequency followed by one or more mixing, amplification, and filtering stages for up-conversion to the desired carrier frequency and removal of undesired spectral components. Radio-over-fiber (RoF) system has recently received considerable attention due to its well-know advantages of high bandwidth, low loss, etc. It is foreseen that hybrid optical wireless systems will be used to delivered to the end user both high capacity and flexibility. Therefore, the generation of millimeter-wave (mm-wave) signals for remote signal delivery in wireless and wireline access networks using photonic techniques is highly desired.

Up to date, most efforts in photonic generation of modulated millimeter wave signlas have been focused on the development of broadband all-optical binary phase-shift keying (BPSK) modulation [2–4]. However to enhance the capacity and the spectral efficiency of communications links, it is necessary to be able to implement more complex formats such as quaternary phase-shift keying (QPSK), *m*-PSK and *m*-quadrature amplitude modulation (*m*-QAM) which are commonly employed in wireless communication systems. In this sense, some approaches have been proposed for photonic generation of vector modulation subcarrier [5-7]. Typically, they are based on the vector summation technique, which consists in achieving the desired carrier phase and amplitude by summing two orthogonal components, namely in-phase (I) and quadrature (Q) components.

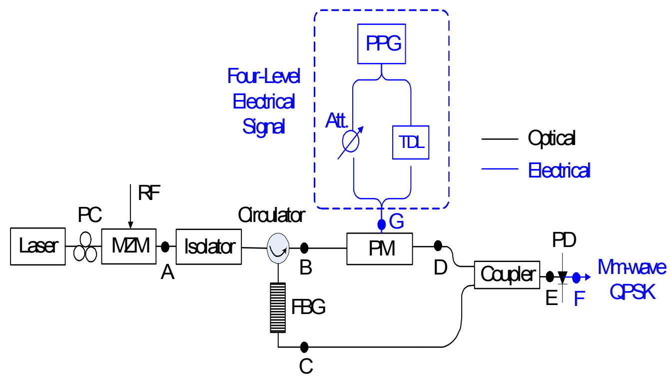


Figure 1 Proposed configuration for photonic generation of millimeter-wave 4-QAM/QPSK. PC: polarization controller, MZM: Mach-Zehnder modulator, PPG: pseudo pattern generator, PM: phase modulator, Att.: tunable attenuator, TDL: tunable delay line, PD: photodetector.

In this paper, we propose a photonic method for implementation of millimeter-wave vector modulation formats based on optical phase modulation by using multilevel electrical and optical carrier-suppression.. In this way, the generated high frequency millimeter-wave has narrow linewidth due to the correlated phase noise of the two optical side band used for its generation[8].Proof-of-concept simulation results for 2.5 Gsymbol/s 4-QAM/QPSK signals at 36 GHz are presented. Furthermore, due to the linearity of optical phase modulators, our proposed method can be extended to implement millimeter-wave *m*-PSK electrical modulation.

II. OPERATION PRINCIPLE

The proposed configuration for photonic generation of millimeter-wave 4-QAM/QPSK signals is shown in Figure 1. The continuous wave (CW) from the output of a laser is intensity modulated using a Mach-Zehnder modulator (MZM) which is driven by a radio frequency (RF) signal at frequency

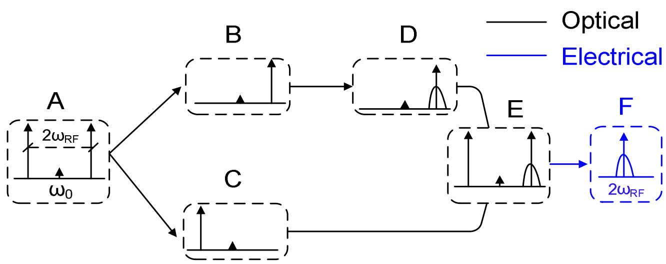


Figure 2 Representation for signal generation at the A-F points shown in Figure 1.

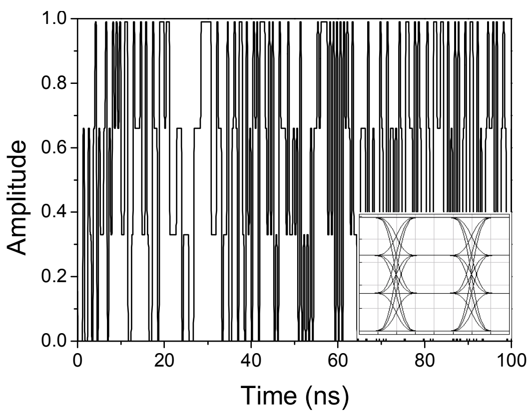


Figure 3 Electrical signals with normalized amplitude-levels of 0, 1/3, 2/3 and 1 at point G of Figure 1, used to generate 4-QAM modulation. Inset: eye-diagram of four-level signal.

ω_{RF}. In order to achieve carrier suppression modulation, the MZM is biased at its minimum transmission point. In the optical domain, we can observe two wavelengths with frequency separation of $2\omega_{RF,}$ as shown in point A of Figures 1 and 2. These two wavelengths are split by a narrow band fiber Bragg grating (FBG). In this case, as shown in points B and C in Figure 1, one wavelength is reflected to the upper optical path and the second is transmitted to the lower optical path. The wavelength in the upper path is phased encoded by a four-level electrical signal by an electro-optic phase modulator (PM). The four-level signal can be achieved by using weighted and summing technology. In this way, we apply two different intensity factors to two pseudo pattern generator (PPG) channels (1 for 1st channel and 2 for 2nd channel) and sum them. At point E of the system, these two optical signals are combined in a 3 dB optical coupler and fed to a high-speed photodetector (PD). QPSK modulated millimeter-wave at frequency of $2\omega_{RF}$ is generated by the resulting frequency beating of the two wavelengths as shown at point F in Figures 1 and 2.

For the reason of simplicity, assuming that the phase deviation between marks and spaces at PM is 2π, the optical field at the input of PD can be given as:

$$E_{in} = \sqrt{P_1}\exp j[(\omega_0 + \omega_{RF})t + \varphi_i \cdot 2\pi] + \sqrt{P_2}\exp j[(\omega_0 - \omega_{RF})t] \quad (1)$$

Here ω_0 is the optical angular frequency of the CW output from laser, φ_i (i=0, 1, 2, 3) are normalized electrical

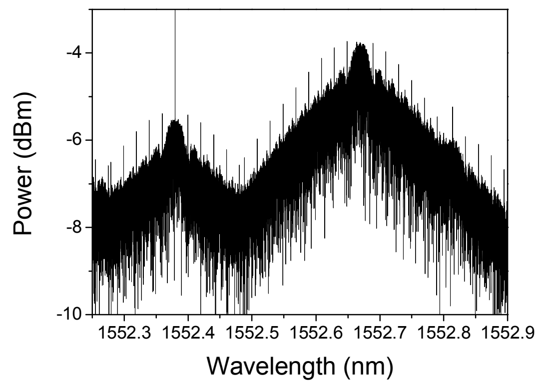


Figure 4 Optical spectrums at the input of PD.

level inputs to PM, respectively. At the output of the PD, the generated electrical signal can be expressed as:

$$E_{out} \propto 2\sqrt{P_1 P_2}\cos[2\omega_{RF} t + \varphi_i \cdot 2\pi] \quad (2)$$

Therefore, when $\varphi_i = 1/8 \cdot 2i$ and $\varphi_i = 1/8 \cdot (2i+1)$ (i=0, 1, 2, 3), 4-QAM and QPSK modulated millimeter-wave is obtained, respectively.

III. Simulation Results and Discussions

In order to test the proposed scheme, a series of computer simulation using VPITransmissionMaker tool are performed. The system simulated follows the configuration shown in Figure 1. An 18 GHz RF modulating frequency and 2.5 Gbps PPG are used. As shown in Figure 3, an electrical signal with normalized amplitude-levels of 0, 1/3, 2/3 and 1 is obtained by controlling the weighting factor and delay time. When the phase deviation is set as $3\pi/2$, the generated millimeter-wave will have phase states of 0, $\pi/2$, π and $3\pi/2$. The inset indicates the corresponding eye diagram. At the input of the PD, the optical spectrums of the combined optical signals coming from the two optical paths are shown in Figure 4. We can observe that the optical signals at longer wavelength are modulated with digital information. In principle, the second optical signals at shorter wavelength should have no modulation. Due to the limited suppression ratio of FBG, the modulation at shorter wavelength is very weak comparing to that of longer wavelength.

To analyze the generated millimeter-wave 4-QAM, the output optical signals are detected in a high-speed PD and the subcarrier signal is synchronously demodulated using a mixer driven by a local oscillator (LO) which has double frequency of that deployed in the transmitter. A lowpass filter with cut-off frequency of 1.8 GHz is used to remove high frequency components. Figure 5 displays the electrical frequency spectrum at the output of the PD. The demodulated signals can be observed using a sampling scope, and the digital constellation and the demodulated Q-component eye diagram are depicted in Figure 6. By adjusting the phase-shift of the LO to demodulate the different quadrature signals, Figures

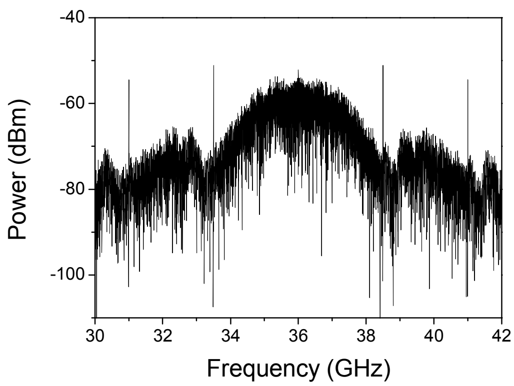
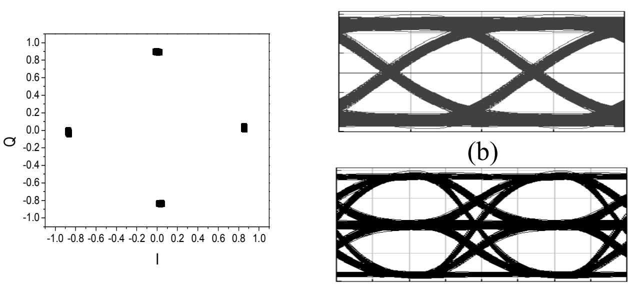


Figure 5 Electrical spectrums at the output of PD.



(a) (c)

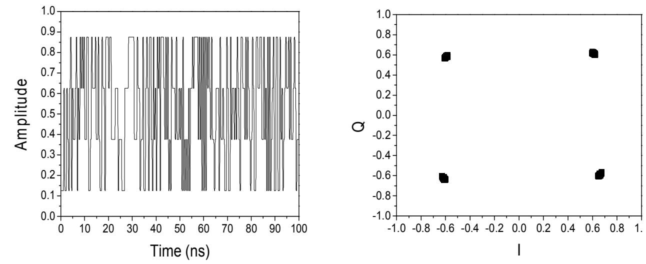
Figure 6 (a) Constellation of demodulated 4-QAM signals. (b) Eye-diagrams for digital signal when phase shift of LO ±45°, Horizontal scale: 200ps/Div, Vertical Scale: 50mv/Div. (c) Eye-diagrams for multilevel signal when phase shift of LO 0° or 90°. Horizontal scale: 100ps/Div, Vertical Scale: 100mv/Div.

6(b) and 6(c) show the demodulated eye diagrams of the digital and multilevel signals, which are obtained with phase shift in the LO of ±45° and 0°/90°, respectively. We can notice that a 2.5Gbps 4-QAM signal at 36 GHz is successfully generated. Furthermore, the phase error caused by imbalance of two optical paths is less than 1° in the simulation. For high-frequency millimeter-wave real system, it is possible to compensate for the imbalance by adjusting the LO phase.

As discussed in section □, if we apply electrical signal with normalized amplitude-levels of 1/8, 3/8, 5/8 and 7/8, and PM phase deviation of 2π, millimeter-wave QPSK with phase states of π/4, 3π/4, 5π/4 and 7π/4 will be generated. The demodulated constellation is shown in Figure 7. In principle, this method can be also used to implement millimeter-wave *m*-PSK when by applying *m*-level electrical signals to the phase modulator provided if the level $\varphi_i = 2\pi/m \cdot i$ (*i*=0, 1, 2 … (m-1)).

IV. CONCLUSIONS

We propose a photonic method implement the generation of millimeter-wave 4-QAM/QPSK electrical modulation



(a) (b)

Figure 7 (a) Electrical signals with normalized amplitude-levels of 1/8, 3/8, 5/8 and 7/8 at point G of Figure 1, used to generate QPSK modulation. (b) Constellation of demodulated millimeter-wave QPSK.

formats. The millimeter-wave is generated by using optical carrier-suppression modulation employing an optical MZI intensity modulator. The 4-QAM/QPSK is imposed by optical phase modulation driven by a four-level electrical signal. We simulated this proposed system showing successful generation for the case of 2.5 Gsymbol/s 4-QAM/ QPSK signals at 36 GHz. This proposed method can also be used to implement generation of millimeter-wave *m*-PSK modulation formats. As this method used conventional photonic components, it has potential applications in broadband RoF systems for wireless/wireline converged access network.

REFERENCES

[1] K. Ohata, K. Maruhashi, J. Matsuda, M. Ito, W. Domon, and S. Yamazaki, "A 500 Mbps 60 GHz-band transceiver for IEEE 1394 wireless home networks," in *30th Eur. Microwave Conf. Proc.*, vol. 1, Oct. 2000, pp. 289–292.

[2] Y. Doi, et al., "Phase shift keying using optical delay modulation for millimeter-wave fiber-optic radio links", J. Lightwave Technol., 2000, 18, pp. 301–307.

[3] A. Loayssa, and D. Benito, "Dispersion-tolerant all-optical subcarrier modulator for broad-band BPSK transmissions", IEEE Photonics Technol. Lett., 2004, 16, (4), pp. 1161–1163.

[4] A. Martinez, et al., "Experimental demonstration of dispersion-tolerant 155Mb/s BPSK data transmission at 40 GHz using an optical coherent harmonic generation technique", IEEE Photonics Technol. Lett., 2003, 15, (5), pp. 772–773.

[5] W. D. Jemison, A. J. Kreuzberger, and E. Funk, "Microwave photonic vector modulator for high-speed wireless digital communications," *IEEE Microw. Wireless Compon. Lett.*, vol. 12, no. 4, pp. 125–127, Apr. 2002.

[6] P. Candelas, J. M. Fuster, J. Martí, and J. C. Roig, "Optically generated electrical-modulation formats in digital-microwave link applications," *J. Lightw. Technol.*, vol. 21, no. 2, Feb. 2003, pp. 496–499.

[7] R.Sambaraju, M.A. Piqueras, V.Polo, J.L. Corral, J. Marti, "Generation of Multi-Gigabit-per-Second MQAM/MPSK-Modulated Millimeter-Wave Carriers Employing Photonic Vector Modulator Techniques", *J. Lightw. Technol.*, vol. 21, no. 2, Feb. 2003, pp. 3350–3357.

[8] X. Yu, X. Zheng, H. Zhang, "Polarization state rotation filter for optical generation of continuously tunable millimeter-wave signal employing an external intensity modulator", *Optical Fiber Technology*, vol. 13, no. 1, 2007, pp. 56-61.