# An Optical PSK-RF-signal Transmitter based on ASK-to-PSK Conversion and Self-heterodyning

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**Abstract:** An optical transmitter for generating phase-shift-keying (PSK) radio-frequency (RF)-signal is experimentally demonstrated, where a high-frequency RF-carrier is obtained by self-heterodyning and the PSK-modulation is achieved by the amplitude-shift-keying-to-PSK conversion in an integrated dual-parallel Mach-Zehnder modulator.

OCIS codes: (060.2330) Fiber optics communications; (060.4510) optical communications

## 1. Introduction

Optical transmitter for RF-signal generation and distribution is an important component for the emerging radio-over-fibber (RoF) systems. The transmitter is required to modulate the data, such as PSK signal, to the generated RF carrier. Different schemes have been developed in [1-3] to directly modulate the phase of a RF-signal in the optical domain, where an expensive high-frequency oscillator is indispensable. A PSK-modulated-subcarrier modulator was constructed in [4] utilizing a dual-drive Mach-Zehnder modulator (MZM). In that system, the frequency requirement on the oscillator is relaxed as the carrier-frequency doubling technique is used, but the modulating data rate is limited since the data is loaded to the MZM through the direct current (DC) ports. In [5], a special heterodyne subcarrier source (HSS) was employed to generate two coherent continuous-wave (CW) lights, which were first separated and then recombined together to mix at the photodetector (PD) after one CW light was phase modulated. However, for such a heterodyning technique, separate transmissions of the two light waves through different paths could make the phase of the generated signal unstable.

A novel transmitter is proposed in this paper to optically generate a phase-stable PSK-modulated RF-signal. In this system, four coherent tones are generated by an integrated dual-parallel MZM (DPMZM) combined with a MZM, where two central tones are PSK-modulated by converting the amplitude-shift-keying (ASK) signal to the PSK format in the DPMZM. Then, the PSK-modulated RF-signal at a high frequency can be achieved by mixing a PSK modulated signal with a CW tone at a PD. Thus, no high-frequency oscillator is needed in the transmitter. Also, the novel PSK-modulation scheme achieved by the integrated DPMZM guarantees the phase-stability of the PSK-modulated RF-signal.

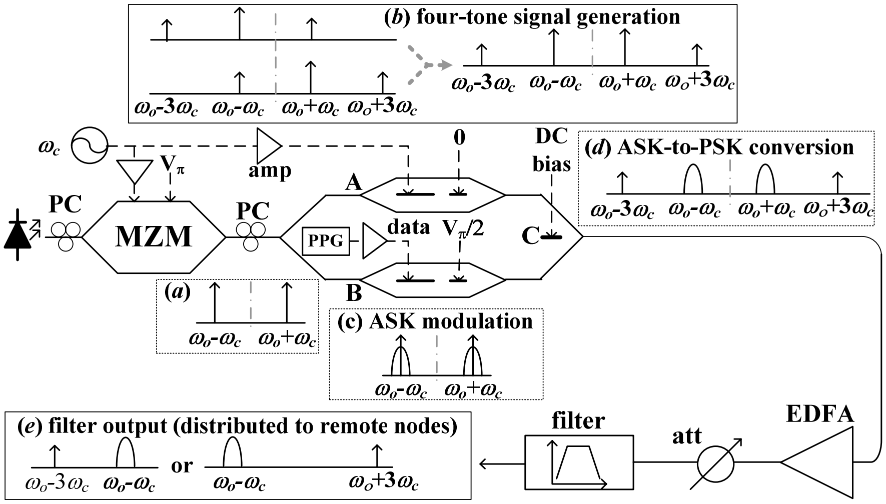

**Fig. 1.** Schematic setup for the generation of PSK modulated RF signals.

## 2. Principle and Experimental Setup

As illustrated in Fig. 1, our transmitter mainly contains an MZM, a DPMZM, and the optical filters. The MZM is driven by a modulating signal:

$$(1+\varepsilon)V_\pi + \alpha V_\pi \cos(\omega_c t),$$

where ε and α are the bias and drive amplitude normalized to $V_\pi$. The output of the MZM is determined by the Bessel function below [6]:

$$\begin{aligned}E_{out}(t)=&\frac{1}{2}J_0\left(\alpha\frac{\pi}{2}\right)\cos\left[(1+\varepsilon)\frac{\pi}{2}\right]\cos(\omega_o t)\\&+\sum_{k=1}^{\infty}\left\{(-1)^k J_{2k-1}\left(\alpha\frac{\pi}{2}\right)\sin\left[(1+\varepsilon)\frac{\pi}{2}\right]\cos[\omega_o t\pm(2k-1)\omega_c t]\right.\\&\left.+(-1)^k J_{2k}\left(\alpha\frac{\pi}{2}\right)\cos\left[(1+\varepsilon)\frac{\pi}{2}\right]\cos(\omega_o t\pm 2k\omega_c t)\right\}\end{aligned}\tag{1}$$

where $\omega_o$ is the frequency of the optical carrier, $J_x(\cdot)$ is the coefficients of the Bessel function, and $k$ = 1, 2, 3, …. Based on this formula, we bias the MZM at $V_\pi$, i.e., $\varepsilon = 0$, to obtain two strong frequency components at $\omega_o \pm \omega_c$ as plotted in Fig. 1(*a*) and known as optical carrier suppressed (OCS) modulation [7]. The OCS signal enters the DPMZM, and its power is separated equally into two parts, which are then modulated by the sub-MZM A and sub-MZM B, respectively. The sub-MZM A is biased at 0, i.e. $\varepsilon = -1$, and also driven by the clock signal $\omega_c$. According to Eq. (1), for the tone at $\omega_o - \omega_c$, all its odd harmonics are suppressed, while its component at $\omega_o - \omega_c$ and two strong even harmonics at $\omega_o + \omega_c$ and $\omega_o - 3\omega_c$ can be obtained by choosing the value of α. Similar process occurs for the tone at $\omega_o + \omega_c$. As a result, in Fig. 1(*b*), the combination of the generated tones yields four lines at $\omega_o \pm \omega_c$ and $\omega_o \pm 3\omega_c$. On the other hand, in the sub-MZM B, by setting the bias around $V_\pi/2$, each tone of the OCS signal is modulated to be an ASK signal in Fig. 1(*c*).

At the DPMZM output, we control the bias C such that the signals from the two arms interfere destructively. In this operation, the central tones of the ASK signals are suppressed by the frequency components at $\omega_o \pm \omega_c$ generated by the sub-MZM A. In the time domain, this is essentially equivalent to subtracting a CW signal from the optical ASK signal, as illustrated in Fig. 2. Suppose that the CW signal has a half amplitude but the same frequency and phase with that of the ASK signal, the “0” bit minus the CW light generates a bit having a same amplitude but an inverse phase compared to the CW light. On the other hand, the subtraction of the CW from the “1” bit results in a reduction of the amplitude by half, without inducing any phase inversion. Consequently, an optical ASK signal changes to a PSK signal. Hence, after the DPMZM, one can obtain two PSK signals at $\omega_o \pm \omega_c$ and two CW signals at $\omega_o \pm 3\omega_c$. However, in practice, it is hard to control the ratio of the amplitudes of the CW and the ASK signals to 1 : 2, which may lead to in a residual modulation on the resulting PSK.

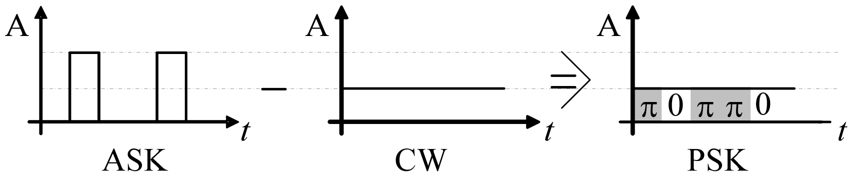

**Fig. 2.** Relationship between ASK and PSK formats.

By using the optical filters at the DPMZM output, one can select a PSK signal and a CW light and distribute them to the remote nodes, as depicted in Fig. 1(e). When an optical PSK signal mixes with a coherent CW signal at the PD in the remote node, a PSK modulated RF-signal is produced, and the frequency of the carrier is determined by the spacing between the PSK signal and the CW signal [5]. The PSK signal at $\omega_o - \omega_c$ mixing with the CW signal at $\omega_o + 3\omega_c$ in the PD leads to a PSK modulated carrier at a frequency of $4\omega_c$. If the PSK signal at $\omega_o - \omega_c$ and the CW at $\omega_o - 3\omega_c$ are sent to the PD, a PSK modulated carrier with a frequency of $2\omega_c$ can be obtained.

## 3. Experiment

In this experiment, the frequency of the clock signal is 10 GHz, and the data generated by the pulse pattern generator (PPG) is a 1.25-Gb/s pseudo-random binary sequence (PRBS) with a word length of $2^7 - 1$. The employed 10-GHz SDMZM (JDSU OC-192) and DPMZM (COVEGA Mach-10$^{TM}$ 060) are commercial components. An EDFA is included in the setup to compensate the insertion losses induced by the modulators. Herein, the fiber Bragg gratings (FBGs) with a bandwidth of ~14 GHz are used as the optical fibers.

The OCS signal generated by the MZM is given in Fig. 3(*a*). The suppression ratio of other harmonics is more than 17 dB. The OCS signal is then fed into the DPMZM. At the sub-MZM A, we observe a four-tone signal as shown in Fig. 3(*b*). The tones are spaced by 20 GHz and the two central tones are ~10 dB higher than that on both sides. Fig. 3(c) depicts that the sub-MZM B modulates the OCS signal with the ASK data. At the DPMZM output, the optical signals from both arms interfere destructively, yielding the spectrum in Fig. 3(*d*). Two central tones are the PSK signals while the tones on both sides are the CW signals. To verify this, we filter out the left and right PSK signals, respectively, in Fig. 3(*e*) and (*i*). The corresponding eye diagrams and waveforms in Fig. 3(*f*), (*g*), (*j*) and (*k*) prove that both signals are the 1.25-Gb/s PSK signals with the residual amplitude modulations. The demodulated PSK signals are displayed in Fig. 3(*h*) and (*l*), where the wide eye-opening confirms the successful demodulation and a good signal quality. Fig. 3(*m*) shows the PSK and CW signals on the right in Fig. 3(d), which are selected by the FBG. When they are mixed at the PD, a 20-GHz signal with a 1.25-Gb/s PSK modulation is generated in Fig. 3(*n*). Fig. 3(*o*) depicts the phase shift between "0" and "1" bits, and the eye diagram of the obtained electrical signal in Fig. 3(*p*) further confirms that the shifted phase between "0" and "1" bits is about π. It is straightforward to envision that a 40-GHz millimeter-wave signal with a 1.25-Gb/s PSK modulation can be obtained if the right PSK signal beats with the left CW signal.

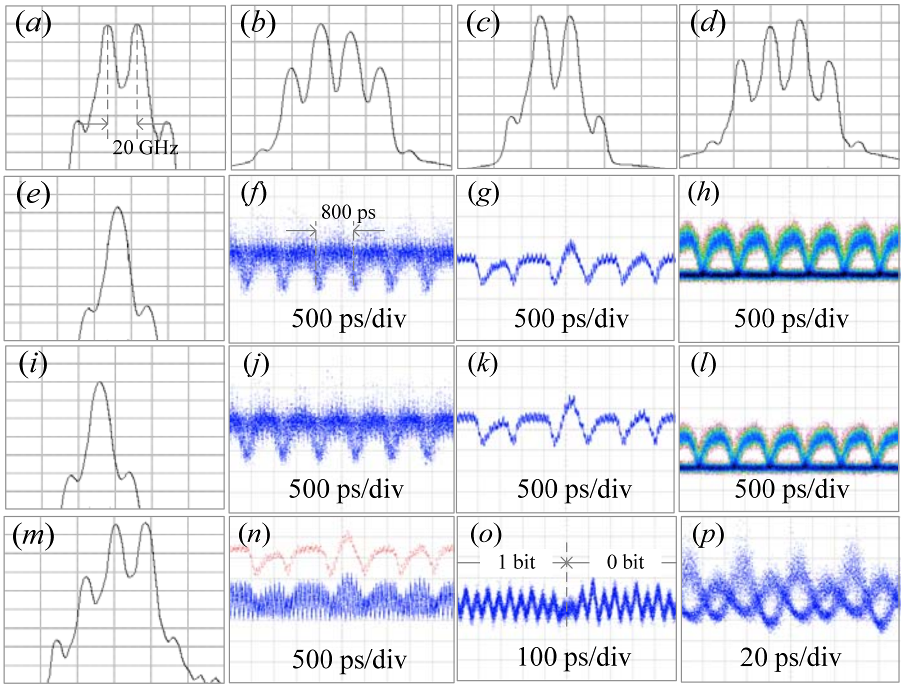

**Fig. 3** Experimental results: optical spectra (*x* axis: 0.2 nm/div, *y* axis: 5 dB /div) and waveforms.

## 4. Conclusion

This paper proposes a transmitter to optically generate the PSK modulated RF-signal at a high frequency by using an MZM and a DPMZM. The feasibility is verified by an experiment, which demonstrates the generation of a 20-GHz microwave carrier conveying 1.25-Gbit/s PSK signal.

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