Two-tone signal generation using a dual-parallel Mach-Zehnder modulator for third-order harmonics suppression

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Abstract: We propose a novel two-tone signal generation method using a dual-parallel Mach-Zehnder modulator (DP-MZM). One MZM in the DP-MZM is used to generate a basic two-tone signal with high-order harmonics, which cause waveform distortion. The other MZM is used to compensate third-order harmonics, which are the most dominant cause of distortion. The proposed method was investigated by numerical simulation and experiment. In the experimental demonstration, suppression of the third-order harmonics component was improved by 20 dB.

Keywords: two-tone signal, Mach-Zehnder modulator, radio-over-fiber

Classification: Fiber-Optic Transmission for Communications

References


1 Introduction

Broadband wireless communication networks require more capacity to accommodate increasing internet traffic due to the rapid spread of smartphones. Radio-over-Fiber (RoF) is regarded as a promising technology that can meet the bandwidth demand. In the RoF scheme, electronic signals are converted to optical signals and are transmitted along optical fibers instead of coaxial cables. This enables lower system cost and longer transmission distances. One of the key aspects of this scheme is the generation of a two-tone lightwave signal. One method to generate two-tone signals is to use two phase-locked laser sources. However, a drawback with this method is that the phase locking condition is very sensitive to temperature and mechanical vibrations [1]. Another method is double-sideband suppressed carrier (DSB-SC) optical modulation, which can be realized by using a Mach-Zehnder modulator (MZM) and a radio-frequency (RF) sinusoidal signal. However, a drawback with this method is that nonlinearity and an asymmetric splitting ratio in the MZM increase high-order harmonics of the generated two-tone signal, which cause waveform distortion. Some methods for suppressing high-order harmonics have been studied [2, 3, 4, 5, 6]. Some of these employ specially designed MZMs [2, 3], and some use multiple RF generators [4, 5]. One simple method employs MZMs connected in tandem to suppress the third-order harmonics component [6]. In this paper, we propose a novel two-tone signal generation method using a dual-parallel MZM (DP-MZM). Third-order harmonics in the generated signal can be suppressed using a simple optical construction. Furthermore, the system can be achieved by using only one off-the-shelf modulator module and can potentially achieve low excess loss. We demonstrated the effectiveness of the proposed method by numerical simulation and experiment.

2 Principle

2.1 Double-sideband suppressed carrier

A two-tone signal is usually generated by DSB-SC optical modulation. DSB-SC optical modulation is realized by multiplying a carrier and an RF signal, which is expressed as

\[
\cos(2\pi f_c t) \cos(2\pi f_s t) = \cos(2\pi(f_c + f_s)t) + \cos(2\pi(f_c - f_s)t),
\]

where \(f_c\) and \(f_s\) are the carrier frequency and the RF signal frequency, respectively. In Eq. (1), ideal linear multiplication is assumed. The multiplication is achieved by...
using an MZM in which an optical carrier is modulated by an RF signal. However, nonlinearity of the multiplication realized by an MZM increases high-order harmonics in the generated two-tone signal. In particular, third-order harmonics constitute the dominant component in the high-order harmonics.

### 2.2 Proposed method

Fig. 1 schematically shows our proposed two-tone signal generation scheme using a DP-MZM [7, 8]. A two-tone signal is basically generated by MZ1. An input lightwave with frequency $f_c$ is modulated by a radio frequency (RF) signal $f_s$ in MZ1, which is biased at the bottom point. Here, MZ1 is driven by an RF signal with amplitude $V_\pi$, where $V_\pi$ is the half-wave voltage, to achieve maximum optical power. However, the two-tone signal generated by MZ1 includes high-order harmonics caused by the saturation characteristics of the MZM. In particular, the third-order harmonics component seriously distorts the generated sinusoidal waveform. MZ2 is used to suppress the third-order harmonics component. MZ2 is biased at the bottom point and driven by $3f_s$ RF signal, which is generated by a frequency tripler. The condition to cancel the third-order harmonics has to satisfy the relations expressed as

$$J_1\left(\frac{\pi A}{V_\pi}\right) = J_3\left(\frac{\pi}{2}\right),$$  

$$\phi_1 - \phi_2 = 0,$$

where $J_n$, $A$, $\phi_1$, $\phi_2$ are the $n$-th order Bessel function of the first kind, the amplitude of the driving signal on MZ2, the phases of the driving signals on MZ1 and MZ2, respectively. The third-order harmonics are canceled by the output lightwave from MZ2 by adjusting the driving amplitude and the phase of the output lightwave of MZ2. Here, we can use a commercially available DP-MZM module and a frequency tripler. Usually, the RF amplitude needed for the $3f_s$ signal is much smaller than $V_\pi$, because the third-order harmonics component is about 20-dB smaller than the required two-tone signal. Therefore, an expensive DP-MZM and frequency tripler with wideband frequency characteristics are not required in our proposed method.

Fig. 1. Proposed scheme of third-order harmonics suppression in two-tone lightwave signal generation.
3 System setup

Fig. 2 schematically shows the system setup used in our numerical simulation and experiment. A lightwave with a wavelength of 1549.5 nm (193.47 THz) was polarization-controlled (PC) and modulated by DP-MZM. MZ1 was driven by a 10 GHz RF signal. At the same time, MZ2 was driven by a 30 GHz RF signal generated by a frequency tripler. The phase of the 30 GHz signal was controlled using an RF phase shifter (PS). An attenuator (ATT) was used for adjusting the amplitude of the driving RF signals. The driving RF amplitudes for the DP-MZM and bias points were adjusted while observing the output optical spectrum using an optical spectrum analyzer (OSA) (Anritsu, MS9710C, 0.05-nm resolution). The extinction ratio of the MZMs was assumed to be 20 dB in the simulation.

4 Results and discussion

First, we performed a numerical simulation to investigate the ideal performance of our proposed scheme. Figs. 3(a) and (b) show the results of the numerical simulation. Fig. 3(a) is the optical spectrum when only MZ1 was used. Fig. 3(b) is the optical spectrum when MZ1 and MZ2 were both active. In Fig. 3(a), many high-order harmonics components are observed. Third-order harmonics are the dominant components, with a power level of about 20 dB smaller than the required two-tone signal (the first-order components). However, the third-order harmonics were completely canceled by our proposed scheme in the simulation, as shown in Fig. 3(b). Figs. 3(c) and (d) show the results of the experiment. Fig. 3(c) is the optical spectrum when only MZ1 was used. The power level of the third-order harmonics was about 20 dB smaller than the required two-tone signal. However, when MZ1 and MZ2 were both used, the power level of the third-order harmonics was suppressed down to 40 dB smaller than the two-tone signal, successfully achieving a 20 dB improvement of the suppression, as shown in Fig. 3(d).
5 Conclusion

We proposed a novel method for generating a two-tone lightwave signal, in which the third-order harmonic component is suppressed, using a DP-MZM. The performance was investigated by numerical simulation and experiment. The simulation results clearly showed that our method can completely suppress the third-order harmonics component of the generated two-tone signal. In the experiment, we achieved a 20 dB improvement in suppression.