Optical Fiber Technology 38 (2017) 108–112

Contents lists available at ScienceDirect

Optical Fiber Technology

journal homepage: www.elsevier.com/locate/yofte

Regular Articles

Simultaneous transmission of wired and wireless signals based on double sideband carrier suppression

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ARTICLE INFO

Keywords:
Hybrid transmission
Dual-output mach-zehnder modulator
Double sideband carrier suppression
Optical fiber communication

ABSTRACT

In this paper, we proposed and experimentally demonstrated simultaneous transmission of wired and wireless signals based on double sideband optical carrier suppression. By properly adjusting the bias point of the dual-output mach-zehnder modulator (MZM), a central carrier in one output port and a pair of first-order sidebands in another output port are generated. The pair of first-order sidebands are fed into a second MZM to generate second-order order sidebands. A wired signal is embedded on the central carrier while a wireless signal is embedded on the second-order sidebands. Unlike other schemes, we did not use optical filter to separate the carrier from the optical sidebands. The measured bit error rate (BER) and eye-diagrams after a 25 km single-mode-fiber (SMF) transmission proved that the proposed scheme is successful for both wired and wireless signals transmission. Moreover, the power penalty at the BER of 10^{-9} is 0.3 and 0.7 dB for wired and wireless signals, respectively.

1. Introduction

The increase number of high capacity smart devices as well as broadband multi-media services available to the consumer demand high-speed wireless communications. As the frequency spectrum below 10 GHz is saturated, it is difficult to maintain an adequate bandwidth provision for the growing customer demand. Optical fiber communication systems transmit information at higher bandwidth and longer distances than wire cables [1–3]. Radio-over-fiber (RoF) techniques have become attractive solutions in realizing future broadband wireless networks [4–7]. RoF systems have been proposed for many applications such as wireless access networks, sensors networks, and radars. The transmission rate of a data can be increased significantly using higher frequency carriers such as microwave and millimeter wave signals. Generation of millimeter and microwave signals in the optical domain is cost effective and not complex as in the electrical domain. Moreover, distribution of microwave or mm-wave signal in the electrical domain is not practical due to the high attenuated signal loss transmitted through electrical distribution lines, such as coaxial cable. Hence, generation and distribution of microwave or millimeter wave signals in an optical domain greatly simplifies the equipment requirement and distribute a signal through an optical fiber from a central station to a remote base station with a low signal loss.

Microwave or millimeter-wave signal generation techniques in the optical domain can be categorized into three main groups: optical phase locking between two laser diodes, direct beating of a dual-wavelength laser at a photodetector, and external modulation [8–12]. Among these three signal generation techniques, high-spectrum-purity and low phase-noise microwave or mm-wave can be achieved using the external modulation technique. External modulation schemes proposed in [13–15] simultaneously generate and transmit wired and wireless signals based on RoF systems. These schemes require optical filters in order to separate the optical carrier from the second-order sidebands. However, optical filters are affected by temperature and may not be accurate enough to select the center frequency of the laser source. A bidirectional RoF scheme proposed in [16] uses MZM to simultaneously generate baseband, microwave and millimeter wave signals. Besides the optical filter requirement, the modulated data in millimeter wave, microwave and baseband are identical. Millimeter wave generation schemes proposed in [17–20] use cascaded single-electrode Mach-Zehnder modulators (SEMZM) without optical filter based on double-sideband suppressed-carrier modulation. These schemes are cost effective and advantageous to maximize receiver sensitivity and spectral efficiency with low power penalty. However, the schemes designed for only wireless access services; i.e., these schemes don't provide wired and wireless access services simultaneously.

This paper proposes and experimentally demonstrates simultaneous transmission of wired and wireless signals using dual-output MZM without implementing optical filter. Properly biasing the dual-output MZM to a null point generates a carrier and two first-order sidebands

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http://dx.doi.org/10.1016/j.yofte.2017.09.006
Received 6 July 2017; Received in revised form 1 September 2017; Accepted 5 September 2017

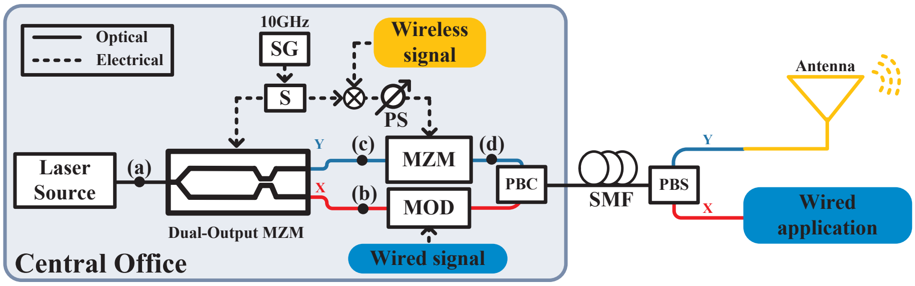

Fig. 1. Schematic diagram of the proposed simultaneous wired and wireless signal transmission system.

with suppressed carrier. The first-order sidebands are fed into the second MZM to generate second-order order sidebands. Reflective semiconductor optical amplifier (RSOA) modulates the wired data on the central carrier while a wireless data is modulated on the second-order sidebands. Then, the optical signal is combined by polarization beam combiner (PCB) and transmitted through a 25 km single mode fiber (SMF).

2. Operation principle

Fig. 1 shows the schematic diagram of the proposed simultaneous wired and RoF transmission system. A light wave emitted from the laser source at the frequency of ω_0 is fed into the dual-output MZM which has two output ports: x-port and y-port. An RF signal with ω_c frequency generated from the signal oscillator (SG) is split into two branches by the power splitter (S). One branch of the RF signal is applied to the dual-output MZM. The bias point of the dual-output MZM depends on the output ports. Biasing the dual-output MZM at the null point of the transfer function for the y-port corresponds to biasing the dual-output MZM at the peak point of the transfer function for the x-port. Therefore, the peak point biasing provides a carrier with center ω_0 as shown in Fig. 2 (b) while the null point biasing provides two first-order sidebands located at $\omega_0-\omega_c$ and $\omega_0+\omega_c$, Fig. 2 (c). The first-order optical sidebands are modulated in the next MZM by the second branch of the RF signal with the phase shift of $\pi/2$; the phase shift is introduced using the phase shifter (PS). The second MZM is biased at the null point to generate a pair of second-order sidebands. Each first-order sideband will generate two new sidebands at the output of the second MZM; i.e., the sideband located at $\omega_0-\omega_c$ generates sidebands at $\omega_0-2\omega_c$ and ω_0 while the one located at $\omega_0+\omega_c$ generates sidebands located at $\omega_0+2\omega_c$ and ω_0. Since the two sidebands located at ω_0 are equal in magnitude and π radians out of phase, they will cancel each other. Hence, only two second-order sidebands separated by four times the frequency of the input RF signal are obtained at the output of the second MZM, Fig. 2(d). The two second-order optical sidebands are 16 dB larger than the other optical sidebands, as shown in Fig. 2(d).

The detail principle of the optical carrier and the second-order sidebands generation is presented as follows. The electric field at the input of the upper and lower arms of the dual-output MZM, $E_{in}(t)$, can be expressed as:

$$E_{in}(t) = \frac{1}{\sqrt{2}}E_0\cos(w_0 t), \tag{1}$$

where E_0 is the electric field amplitude. The optical signal at the upper-arm output, $E_{upper-arm}(t)$, can expressed as:

$$E_{upper-arm}(t) = \frac{1}{\sqrt{2}}E_0\cos(w_0\ t + \Delta\varphi(t)). \tag{2}$$

The phase difference, $\Delta\varphi(t)$, induced by the applied voltage is given by the equation:

$$\Delta\varphi(t) = b + m\cos(w_c\ t + \phi_1), \tag{3}$$

where $b=\frac{\pi V_{bias}}{2V_\pi}$, $m=\frac{\pi V_m}{2V_\pi}$, w_c is the angular frequency and ϕ_1 is the phase of the driving RF signal. For the y-port, the dual-output MZM is biased

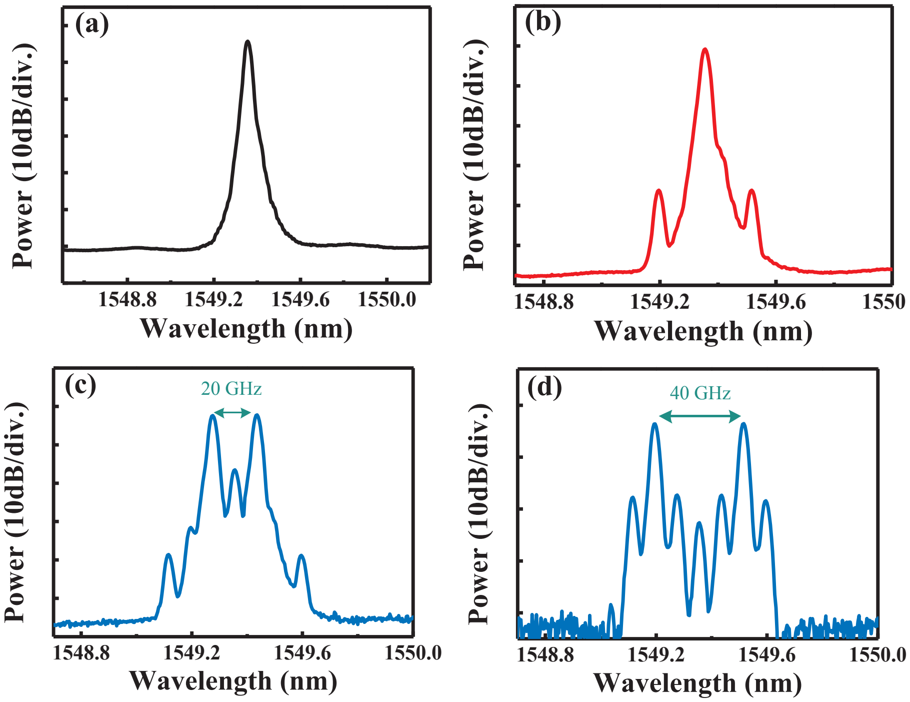

Fig. 2. Optical spectrum at (a) the laser source output (b) the x-port of the dual-output MZM. (c) the y-port of the dual-output MZM. (d) the output of the second MZM.