Simulations of Modulator Nonlinear Effects in Radio-over-Fibre Systems

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We propose the use of optical frequency multiplication as a cost-effective method to optically generate wireless radio frequencies (RFs) and deliver them from a central station to remote radio access units. Mach-Zehnder modulators (MZMs) are employed to transport the RF data. We focus on the impact of the nonlinearity of MZMs on the radio-over-fibre system performance for single-carrier and orthogonal frequency division multiplexing (OFDM) formatted data. A larger system penalty is shown in the OFDM RoF system due to a more severe nonlinear cross-talk effect between sub-carriers, compared with the single carrier system.

Introduction

The wireless communication services may provide fixed, mobile, radiolocation or satellite communication services to individuals and business on demand of their spectrum range or geographical area. Various wireless communication standards have been commercially utilized in the market throughout the last decade, such as global system of mobile (GSM) and IEEE 802.11 standard, to provide larger data capacity, better services and low price. However, larger wireless bandwidth and higher radio carrier frequency are strongly demanded when wireless capacity increases. Meanwhile, the use of higher frequency and larger bandwidth per users give rise to a great reduction of the wireless cell size, therefore leading to a significant increasing cost given by the large amounts of equipment in the antenna site. The emerging radio-over-fibre (RoF) technique is becoming very attractive in this scenario because most of the radio processing which was previously in the antenna site is moved to the central station when using RoF, resulting in a simplified and compact radio access unit (RAU) in the access network. This cost-effective method combines the advantages of the very large capacity of fibre and the wireless access flexibility, and brings a potentially low-cost solution to future wireless access networks.

One of the proposed RoF techniques is the so-called optical frequency multiplication (OFM) [1]. Experiments employing this scheme have demonstrated the generation and transmission of microwave carriers up to 40 GHz, carrying 16- and 64-QAM radio signal up to 20 MS/s total symbol rate over multimode fibre [2]. Simultaneous transmission of five 64-QAM signals with a total bit rate of 108 Mbit/s has been shown using OFM scheme [3]. It has also been reported that the OFM method has an advantage in dispersion tolerance [2]. In this paper, we firstly describe the OFM RoF system in the numerical method using computer simulation and evaluate the nonlinear impact of intensity modulator on the RoF systems for two different signal standards.

RoF System modeling using optical frequency multiplication

The method to deliver radio over optical fibre using OFM is to generate many frequency harmonics by harmonically sweeping the phase of a laser light source, and use one of these harmonics as an optical carrier at the frequency of interest to transport radio frequency (RF) signals. The principle of the RoF link test platform employing OFM is shown in Fig. 1. In the down-link of the proposed RoF system, the laser diode is phase modulated by a harmonic sweep signal with frequency f_{sweep}. This electrical sweep signal can be written as $E_{sweep} = \beta \sin(2\pi f_{sweep} t)$, where β is the modulation index and t is the time scale. The phase modulated signal is passed through a Mach-Zehnder interferometer (MZI), whose transfer function is the same as a periodic band-pass filter (BPF) with a parameter free spectral range (FSR). The frequency modulation (FM) to IM conversion of the phase modulated signal is realized by this BPF, so that the strengths of the harmonic components can be detected by a photo-detector and selected by another Gaussian-shaped BPF with a central frequency as same as that of the n-th order harmonic. The phase modulated signal is then modulated by a chirp-free Mach-Zehnder modulator (MZM). The electrical RF data signal is generated according to different formats defined in the wireless standards, such as quadrature amplitude modulation (QAM) or orthogonal frequency division multiplexing (OFDM). The RF data is imposed onto the harmonic and received by the detector. In the present paper, we only investigate the back-to-back transmission and the model for optical fibre is not inserted in the simulation system. For the same consideration, the up-link of the system is simplified in such a way that the electrical-optical-electrical conversion and the fibre are not included in the Fig. 1. In the up-link, the electrical RF signal with high frequency is firstly down-converted into baseband, and then filtered by a Gaussian low-pass filter, with 3-dB bandwidth of ¾ of the signal central frequency f_{MIX}. Then the output signal is directly de-modulated and evaluated by using the transmitted signal in the down-link as reference.

The input data pattern is generated as 10^{th} order pseudo-random binary sequence (PRBS). Due to a computer memory limitation, the sweep signal is set as f_{sweep} = 20 KHz and β = 1. The continuous wave (CW) laser is model as its envelope. The signal after MZI is shown in Fig. 2, where Fig. 2 (b) is the zoomed view of Fig. 2 (a). From Fig. 2 (a) it is seen that the time window of the simulation is set large enough so that there is nearly no overlap between different harmonics. In Fig. 2 (b), it is clearly plotted that the frequency seperation between different harmonic is the same as the sweep frequency

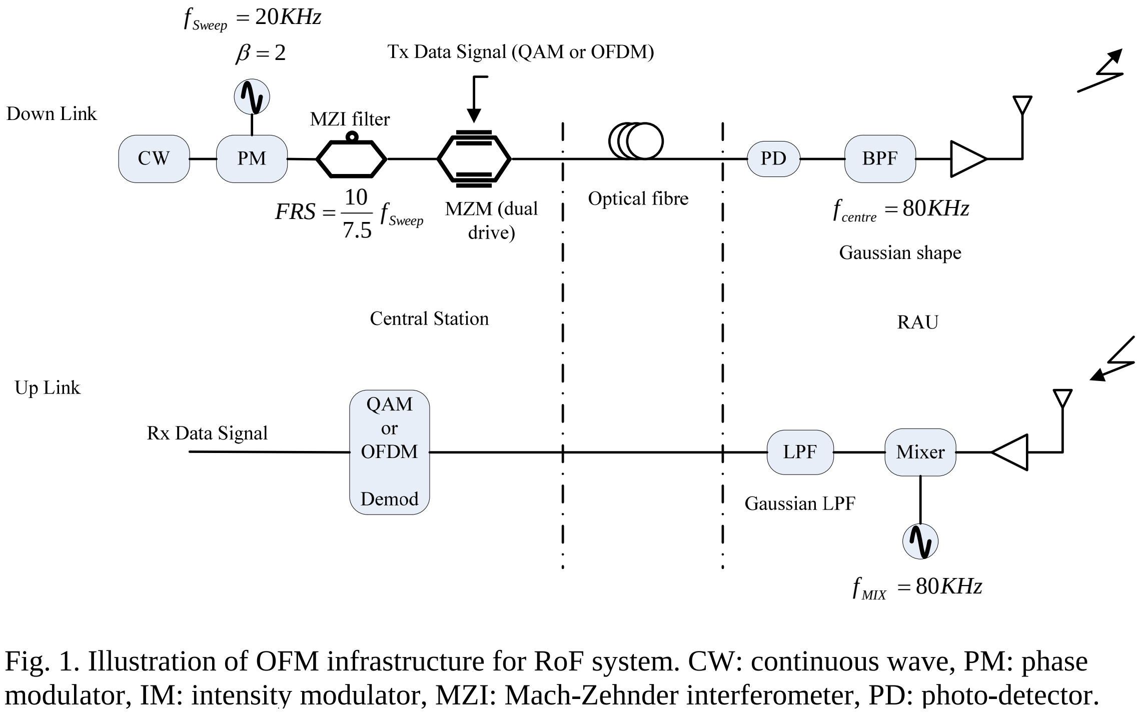
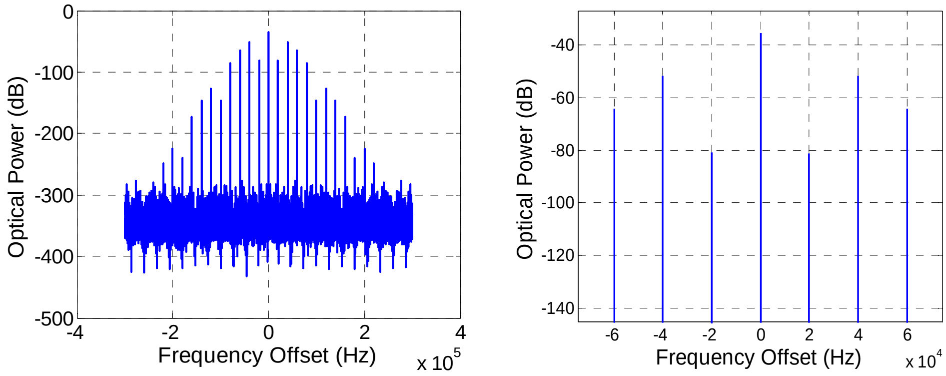


Fig. 1. Illustration of OFM infrastructure for RoF system. CW: continuous wave, PM: phase modulator, IM: intensity modulator, MZI: Mach-Zehnder interferometer, PD: photo-detector.

***f*$_{sweep}$**. In present paper, the phase noise due to the laser linewidth and other system white noise are neglected. We transmit a 16-QAM signal with sub-carrier frequency of 3 KHz using the dual-drive MZM. The power spectrum of the output signal of MZM is presented in Fig. 3. It is seen that the QAM data signal is carried by each harmonics, and the data tip (4.3e4 Hz, -114.4 dBm) labels the frequency of the right sideband QAM signal carried by the 2nd order harmonics, which can be expressed by: $f = n \times f_{sweep} + f_{sc}$, where $n = 2$.



(a) (b)

Fig. 2. Optical power spectrum of the output signal from MZI, frequency is offset from central frequency of the laser diode. (b) is a zoomed view of (a). The sweep frequency ***f*$_{sweep}$** is 20 KHz.

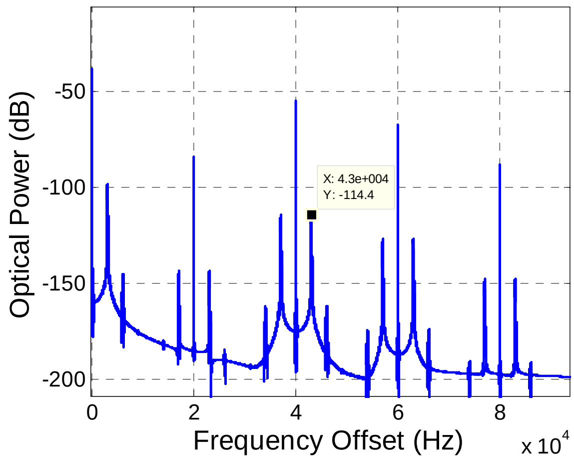


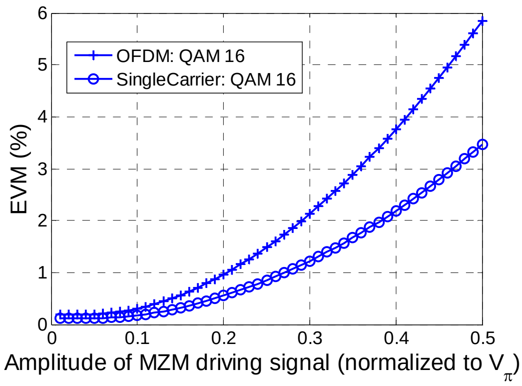
Fig. 3. Optical power spectrum of the output signal from transmitter in an OFM RoF down-link, with sweep frequency and 16-QAM sub-carrier frequency equal to 20 KHz and 3 KHz respectively, and the data tip labels (x, y) = (4.3e4 Hz, -114.4 dBm).

Nonlinear effect of MZM

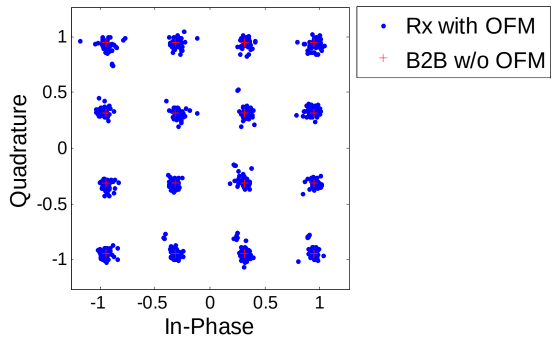
Based on this system model, we investigate the impact of MZM nonlinearity on the RoF system performance. The MZM imposes a nonlinear attenuation to the electrical driving signal, and the relation between output optical power and input electrical signal can be written as:

$$P_{out} = P_{in} \cdot \cos^2\left[\frac{\pi(V_1 - V_2)}{2V_\pi}\right] \qquad \text{(Eq. 1)}$$

where V_1 and V_2 are the upper and lower driving signal in the chirp-free driving mode, and V_π is the π phase switch voltage of the modulator. Therefore, the larger difference of the driving signals imposed on the MZM gives rise to the larger degradation of the system performance, because of the nonlinear relation given by Eq. 1. In Fig. 4 (a), we show the different impact of the MZM nonlinearity on the performance for two different data formats, single carrier 16-QAM and 16-carrier OFDM signal of 16-QAM. The system performance is evaluated by the value of error vector magnitude (EVM). The number of channels of OFDM modulation is 16. It is seen in Fig. 4 (a) that the impact of MZM nonlinearity is larger for the OFDM than the single-carrier signal. More than 1 % difference of EVM value between single-carrier and OFDM signal is observed when the driving amplitude is larger than 0.3 V_π. This is because the cross-talk between the sub-carriers of OFDM signal and the harmonics in OFM system. Fig. 4 (b) shows degradation of the normalized constellation of 16-QAM in the OFDM format, when the driving signal amplitude is 0.5 V_π.



(a)



(b)

Fig. 2. (a) Error vector magnitude (EVM) value as a function of driving signal amplitude, for OFDM and single-carrier 16-QAM signals. (b) Comparison of constellation of transmitted and received OFDM signal when the amplitude of driving signal is 0.5 V_π.

Conclusion

We have shown a numerical study of the RoF system employing the OFM technique. A preliminary home-made simulation tool has been developed. Simulation results have shown that the impact of the MZM nonlinearity on the OFM system performance is larger for the OFDM-format QAM signal, than the single-carrier QAM signal, due to a greater cross-talk between RF sub-carriers and OFM harmonics. Future work will concentrate on the implementation of high frequency and system noise.

Reference

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