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Bias Optimization of Mach-Zehnder Modulator Considering RF Gain on OFDM Radio-Over-Fiber System

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Abstract**—**Most of the recent wireless LANs, broadband access networks, and digital broadcasting use Orthogonal Frequency Division Multiplexing techniques. In addition, the increasing demand of Data and Internet makes fiber optics an important technology, as fiber optics has many characteristics that make it the best solution for transferring huge frames of Data from a point to another. Radio over fiber is the place where high quality RF is converted to optical signals over single mode fiber. Optimum values for the bias level and the switching voltage for Mach-Zehnder modulator are important for the performance of radio over fiber links. In this paper, we propose a method to optimize the two parameters simultaneously; the bias and the switching voltage point of the external modulator of a radio over fiber system considering RF gain. Simulation results show the optimum gain value under these two parameters.

Keywords**—**OFDM, Mach Zehnder Bias Voltage, switching voltage, radio-over-fiber, RF gain.

I. Introduction

WIRELESS communication systems experience a big challenge to find the suitable channel that can offer the very high bandwidth and offer high data rate. On the other hand, fiber could be the suitable solution for a numerous data and high bit rate. The configuration of the Radio over Fiber (RoF) link with Orthogonal Frequency Division Multiplexing (OFDM) could be the suitable solution for this challenge in which the optical signal is modulated by radio frequency. This technique enables transmission of microwave and millimeter-wave signals for long distances with low losses [1]. The data in OFDM signals are transmitted in a large number of orthogonal subcarriers, each subcarrier occupies a small bandwidth, and hence, it will not be affected by the channel fading [9]. The role of the RoF technology in next generation of mobile communication system was introduced and demonstrated in [10], [11]. The RoF link has a very high bandwidth because of the characteristics and the huge capacity of the fiber. However, the nonlinearity of the most important component in the RoF link, the Mach-Zehnder Modulator (MZM) [12], [13], will affect the gain of the RoF link which also has an effect on the noise figure and the spurious free dynamic range (SFDR). As the result, the bandwidth of the link will be decreased. Therefore, decreasing the nonlinearity of OFDM and MZM will improve the total gain of the link. This improvement can be done by optimizing the parameters of the MZM such as the bias voltage V_{bias} and the half wave voltage (switching voltage) V_{π}. In this paper, we present a simple way to optimize the bias voltage of the MZM in presence of OFDM.

Section II introduces the related works to this topic, while Section III explains and describes the setup of the system, the way to simplify the total gain formula to maximize the radio frequency gain. Section IV shows some of the numerical results. The last section concludes this work and suggests future research directions on the subject.

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II. Related Work

Many authors have studied the gain of the RoF link and they try to optimize different parameters of the MZM. Authors [2] studied the OFDM through Coherent optical orthogonal frequency division multiplexing and combat dispersion in optical media. It is shown that optical-signal-to-noise ratio penalty at 10 Gbit/s is maintained below 2 dB for 3000 km transmission of standard-single mode fiber without dispersion compensation. In [3], the authors study the effect of the nonlinearity of an MZM on optical OFDM signal distortion. The optical OFDM signal output from the MZM is expressed as a Taylor series including third-order and fifth-order nonlinear distortion terms, by which they can easily establish a mathematical model of the optical OFDM signals in different formats and rates. According to their model, they can get the Error Vector Magnitude (EVM) at the optimized point. The author in [4] had studied the nonlinear distortion of the OFDM signals that are transmitted over fiber optic links. This distortion is related to the high link density and the high peak-to-average power ratio (PAPR) of the OFDM signals. This will cause a distortion in the signal orthogonality, which will lead to an inter-channel interference. Therefore, the author has developed a statistical mathematical model for different optical modulators including the MZM. In that model, the optical OFDM signal output from an optical modulator was expressed as a power series, then the performance of the modulators was computed and compared based on that model. The improvement of the gain by improving the noise figure of the link by find expressions for noise figure and a dynamic range as a function of the modulator bias angle was discussed in [5]. In [6], the authors studied the broadband wireless access systems that employ OFDM schemes and suffer from nonlinear distortion of the RoF channel due to nonlinearity

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inherent in Electrical to Optical (E/O) conversion. In their research they suggest a new RoF transmission scheme employing Envelop Pulse-Width Modulation (EPWM) transmitter to efficiently suppress the impact of RoF channel nonlinearity on OFDM signals. They apply this idea in a typical RoF channel that uses a MZM as its E/O.

As we can notice from these literatures, OFDM did not do any optimization of the MZM parameters. In this work, we will optimize two parameters of MZM to get a high RF gain of RoF link.

III. System Model

The RoF system is shown in Fig. 1. It consists of an OFDM source, a Distribution Feedback Laser (DFB) provides a continuous light wave, while the MZM main function is to modulate the optical signal with the RF signal, i.e. convert the RF signal to optical signal.

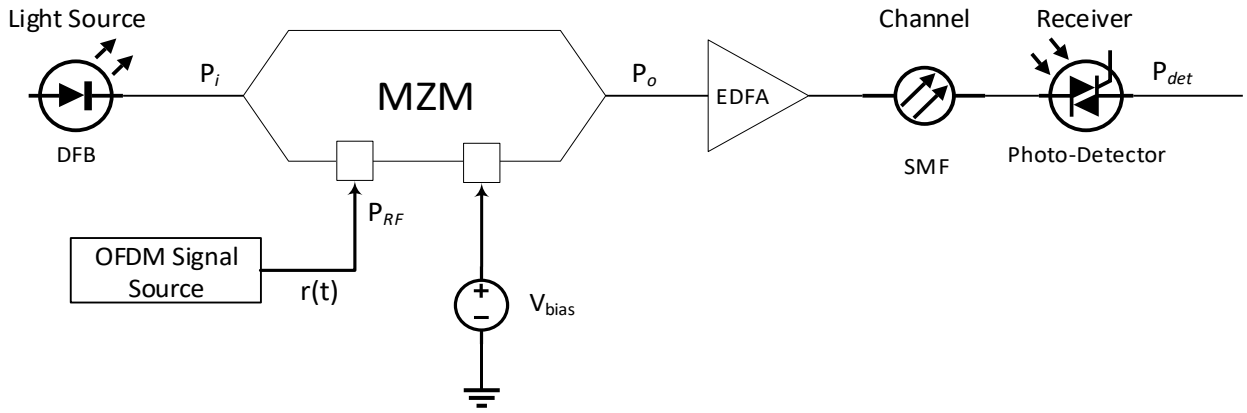


Fig. 1 Schematic diagram of the RoF system

Fig. 2 shows the schematic diagram of the working principle of the MZM, where the coherent light generated from the laser is split in two optical paths. Each path contains an electro-optic material with reversed polarity electrodes. An external field is applied across the electrodes. The light fields of both optical paths are combined again and interfere depending on their respective phase shifts that is induced as a result of the applied external field across the electrodes. Hence, the phase difference between the two waves is converted to an amplitude modulation.

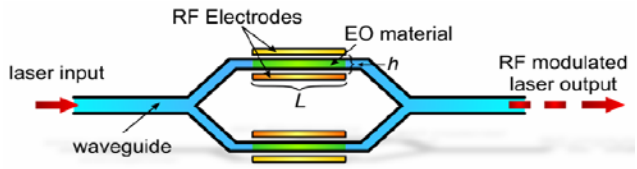


Fig. 2 MZM principle of work [14]

The Erbium Doped Fiber Amplifier (EDFA) is used to amplify the optical signal. The photo detector converts the output signal from optical to electrical signal. It is worth mentioning that we use in this model a single mode fiber (SMF) as a channel.

The radio frequency gain for the link shown in Fig. 1 is given by [7]:

$$G_{RF} = \frac{P_{det}}{P_{RF}} \tag{1}$$

where G_{RF} is the total gain of the RoF link, P_{RF} is the input power of the RF signal $r(t)$ at the MZM, P_{det} is the RF output power of the link, i.e., the power at the detector output.

From [1], the mean optical output power of the MZM modulator P_o is given by:

$$P_o = \frac{P_i}{2}\left[1 - \sin\left(\frac{\pi}{V_\pi} r(t)\right)\right] \tag{2}$$

where P_i is the unmodulated input optical power of the MZM modulator, V_π is the half wave voltage, and $r(t)$ is the modulating RF (OFDM) signal.

For simplicity, assume that the RF signal $r(t)$ is a single tone signal as:

$$r(t) = m(t)\cos(2\pi f_c + \phi(t)) \tag{3}$$

where $m(t)$ is the message signal. Accordingly, P_o will be expressed as:

$$P_o = \frac{P_i}{2}\left[1 - \sin\left(\frac{\pi}{V_\pi} m(t)\cos(2\pi f_c + \phi(t))\right)\right] \tag{4}$$

The power at the output of the detector photo diode P_{det} is given by [3] as:

$$P_{det} = \frac{P_i}{2}\left[1 + \cos\left(\frac{\pi(V_{bias} + |r(t)|)}{V_\pi}\right)\right] \tag{5}$$

where V_{bias} is the DC bias voltage.

From (1)-(5):

$$G_{RF} = C\left[G_{EDFA}\sin\left(\frac{\pi V_{bias}}{V_\pi}\right)\right]^2 \tag{6}$$

Here, C is a constant. The gain of the EDFA is given by [8]

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as:

$$G_{EDFA} = \frac{G_o}{1+(G_o P_o / P_{o,max})^{\alpha}} \quad (7)$$

where G_o is the small signal gain of the EDFA, $P_{o,max}$ is the maximum output power of the EDFA at the saturation state, α is an imperial parameter that is close to 1.

By some simplifications of the total gain in Eq. (6), we get the final formula of the total gain

$$G_{RF} = \left(\frac{\pi P_i T \eta_{det} R |r(t)| \sin(\pi V_{bias}/V_\pi)}{4V_\pi}\right)^2 G_{EDFA} \quad (8)$$

where η_{det} is the detector responsively [A/W]. T is the optical transmission that includes coupling loss between components, MZM insertion loss, and propagation loss, while R is the load resistance.

After defining $\Theta = \frac{\pi V_{bias}}{V_\pi}$ and $K = \left(\frac{\pi P_i T \eta_{det} R |r(t)|}{4V_\pi}\right)^2 G_{EDFA}$, the final formula of the gain will be simplified as:

$$G_{RF} = K \sin^2(\Theta) \quad (9)$$

IV. Numerical Results

Table I contains the values that are used for the simulation parameters.

TABLE I
SIMULATION PARAMETERS

Load resistance R	50Ω
The detector responsively η_{det}	0.8 W/A
Optical loss T	4 dB
DFB Laser source power P_i	-2 dBm
The Eribum Doped fiber amplifier gain G_{EDFA}	45 dBm
Half wave voltage V_π	3.35 V
$\|r(t)\|$	2 V

By analyzing these final equations (8) and (9), it is clear that the total gain of RoF link depends on the bias voltage V_{bias}. Thus, optimizing this parameter to get the maximum value of the gain is our purpose. Many simple optimization techniques can be used here such as Newton's Rahpson method or gradient method to get the analytical values of the bias voltage and the switching voltage.

The effect of the bias voltage on the total gain of the link is very clear as [3] shows. Fig. 3 shows the three-dimension view of the relation between bias voltage and the half wave voltage and the gain function. By analyzing the total gain and apply gradient optimization method for the bias voltage and the gain, we get the optimization point (1.7V, 0.32) which gives the highest gain, where this gain is equivalent to -11.4 dBm. Fig. 4 shows the relation of the bias voltage with the gain. As a conclusion, the MZM modulator should be biased at these points to have maximum RoF link gain.

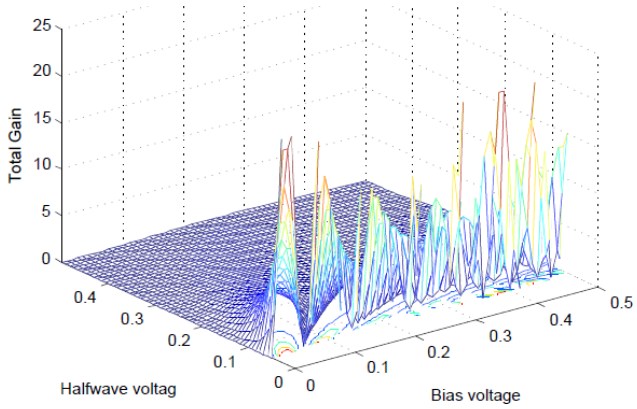


Fig. 3 3-D view of the gain vs. V_{bias} and V_π

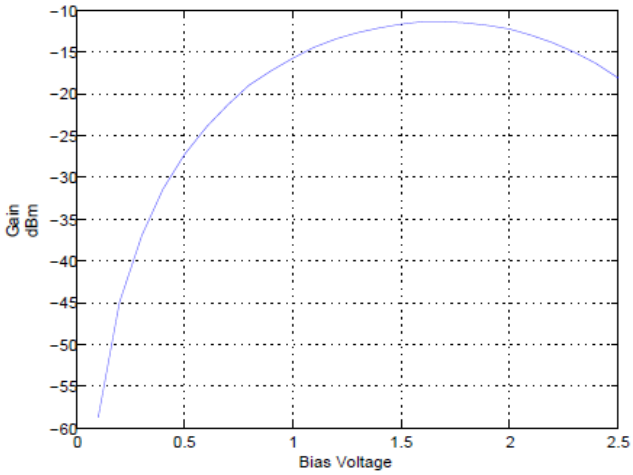


Fig. 4 The bias voltage vs gain

V. Conclusion

In this work, we derive a formula of the gain of the RoF link. We maximize the gain by optimizing the bias voltage parameter and the switching voltage. Numerical value for this parameter for a given constrains was found, the numerical analysis agreed with the theoretical model.

Future work should be done to verify the noise figure and the superior free dynamic range in addition to calculate the figure of merit depending on optimization of the two parameters.

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