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Transmission performance of OSSB-RoF system using MZM electro-optical external modulator

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ABSTRACT

Both the EAM and the MZM, the commonly used electro-optical external modulators in RoF systems, have pointed on their transfer function curve at which link performance is optimized. In discussing the difficulty of maintaining the optimum modulator bias point, we prefer MZM because unlike EAM, it has a predictable transfer function shape. In this paper, the simulative investigation is analyzed and discussed to study the impact of extinction ratio with low chirp of single- and dual-electrode Mach–Zehnder (SEMZM and DEMZM) external modulators over RF power degradation introduced in Radio-over-Fiber (RoF) systems due to fiber dispersion, which is one of the limiting factors to RoF link. Our simulative results show that longer transmission distance spanned between a receiver and transmitter with minimum RF power degradation can be achieved by using low extinction ratio and chirp of MZM modulators. Further, it is also observed that a dual-electrode MZM with low extinction ratio and chirp enables the transmission of RF signal not only with minimal dispersion but also with maximal second-order harmonic (HD2) reduction.

1. Introduction

For realization of future high performance integrated networks, broadband distribution and access networks and to meet the increasing demand of multimedia services with a guaranteed quality of service, RoF technology comes out as the most promising technology. RoF technology combines the capacity of optical networks with the flexibility and mobility of wireless networks. Reduction in complexity at the antenna site, reduction in installation cost of access networks, possibility of dynamically allocation of radio carriers to different antenna sites, transparency and scalability are the few advantages of Radio-over-Fiber (RoF) technology. The applications of RoF technology include cellular networks, satellite communication, Multipoint Video Distribution Services (MVDS), Mobile Broadband System (MBS) and Wireless LANs over optical networks [1]. RoF technology involves the use of optical components and techniques to allocate RF signals from the control stations (CS) to the base stations (BS). Thus, RoF makes it possible to centralize the RF signal processing function in one shared location (CS) with use of single mode optical fiber that has a very low signal loss to distribute the RF signals to the BSs [2]. The micro and pico-cellular architectures are installed with low power radio access points (RAPs) to increase the frequency reuse and capacity of a wireless network to provide wireless access. The best way to connect these RAPs to CS unit is RoF technology. Further, RoF technology allows a fiber-fed distributed antenna network to be implemented that provides several advantages such as low RF power remote antenna units, frequency reuse, better coverage, high capacity, high quality signal as well as low fiber attenuation. Further, with RoF technology, the antenna need not be within the control area but can be sited a lot of kilometers away for the purpose of improved satellite visibility or reduction in interference from other terrestrial communication systems.

Several methods have been reported for the generation of modulated RF optical carriers in fiber-wireless systems. However, the simplest technique for the optical generation and distribution of the RF signal modulated with data is an intensity modulation scheme via direct or external modulation of a laser in which the RF signals are either externally or directly modulated onto the optical carrier. But, the frequency chirping due to the direct modulation of a semiconductor laser limits the transmission bandwidth of RoF system. An external modulation technique is an alternative candidate in order to eliminate this problem. Currently, two types of external modulators are commercially available and can be considered for use in high-bit-rate digital or high-performance microwave fiber-optic links. Because of having a predictable transfer function shape,

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we prefer MZM over EAM external modulators in RoF systems. By controlling the amplitude of the drive signals applied to two electrodes of Dual Electrode Mach–Zehnder (DEMZM) modulators, both the chirp and the extinction ratio of the signal can be precisely adjusted to extend transmission distance without dispersion compensation [3,4]. Dual-drive MZ modulators are also important for high spectral efficiency dense wavelength-division-multiplexed (DWDM) systems since the minimum mean-square bandwidth are achieved when the transmitted signal contains no chirp [5]. However, it has been reported through computer simulation that an MZ modulator with a finite dc extinction ratio will always be accompanied by residual chirp [6].

The optical carrier is modulated to generate an optical field with the carrier and two sidebands in conventional intensity modulation. At the optical receiver, each sideband beats with the optical carrier, thereby generating two beat signals which constructively interfere to produce a single component at the RF frequency. However, if the signal is transmitted over fiber, chromatic dispersion causes each spectral component to experience different phase shifts depending on the fiber-link distance, modulation frequency, and the fiber-dispersion parameter. These phase shifts result in relative phase differences between the carrier and each sideband, and produce a phase difference in the two beat signals at the RF frequency, which results in a power degradation of the composite RF signal [7]. When the phase difference is kept equal to π, the complete cancellation of the RF signal occurs. As the RF frequency increases, the effect of dispersion is even more pronounced and the fiber-link distance severely limited [8,9]. Some types of external intensity modulators such as directional-coupler type modulator, loss modulator, Mach–Zehnder interferometer type modulator and total internal reflection type modulator have been studied [10]. Further, the measurement and influence of chirp parameter of MZM externally modulators over dispersion have been analyzed in fiber-wireless systems [11–13]. Smith et al. [14] demonstrated that the achievable link distance could be increased by varying the chirp parameter of the modulator to give large negative chirp using a dual-electrode Mach–Zehnder modulator (MZM) biased at quadrature. Kim and Gnauck [15] has investigated the chirp characteristics of dual-drive MZ modulators exhibiting a finite dc extinction ratio and found that the residual chirp could be minimized simply by driving the MZ modulator in a push–pull mode with unequal-amplitude signals.

In this work, the influence of extinction ratio with low chirp of MZM external modulators over RF power degradation introduced in RoF systems due to chromatic dispersion is reported which is not studied in earlier work. We discussed graphically, in Section 4 depending upon our simulative results obtained from Section 3, which reveals that RoF link can be improved and high quality microwave signal can be obtained by using SEMZM and DEMZM external modulators with low extinction ratio and chirp. The reduction in second order harmonic distortion (HD2) is also reported with low extinction ratio and chirp of MZM external modulators.

2. Theory

A continuous-wave (CW) signal from a laser is externally modulated using non-ideal DEMZM with non-identical loss introduced in each arm, which causes the finite extinction ratio ε_{LIN} of the device. The extinction ratio ε_{LIN} defines as the ratio between the output optical powers corresponding to the maximum transmission value and the one corresponding to the minimum transmission value. The output optical field at DEMZM is represented as

$$\overrightarrow{E_{out}} = 10^{-EL_{dB}/20}\left[\cos\phi_D - \frac{j}{\varepsilon_{LIN}}\sin\phi_D\right]e^{j\phi_s}\cdot e^{j(\alpha \ln P_{out}/2)}\cdot\overrightarrow{E_{in}} \tag{1}$$

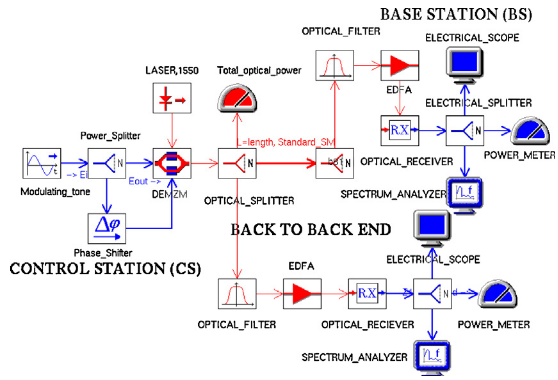


Fig. 1. Simulation setup using OPTSIM 4.6 for OSSB-RoF system.

where α is the chirp parameter; $V_{in} = (V_A - V_B)/2$; V_A, V_B are the input voltages applied to the two arms of DEMZM modulator, $\varepsilon_{dB} = 20\log[\varepsilon_{LIN}]$, $\phi_S = \pi/4[(V_A + V_B)/V_\pi]$, $\phi_D = \pi/2[(V_{in} - V_0)/V_\pi] = \pi/2[(V_A - V_B - V_0)/V_\pi]$ and V_0 is the offset voltage corresponding to the zero phase retardation in the absence of any electric field and is the value of the electrical input corresponding to the maximum transmission state. When the semi-difference between input voltages V_{in} is equal to V_0, the power of the optical signal is attenuated by the excess loss EL_{dB}, introduced by the modulator, so the modulator is said to be in maximum transmission state. Ideally, this value is 0 V, but often modulators become slightly unbalanced in the absence of any applied electric field. Thus, a biasing voltage must be applied to compensate the offset. To switch to the minimum transmission state, a V_π voltage must be added or subtracted to V_0.

To generate an optical SSB modulated signal, the DEMZM needs to be biased at the linear point, $V_A - V_B = V_\pi/2$ with a phase shift between MZM drives of $\phi_A - \phi_B = \pi[V_A/V_\pi] - \pi[V_B/V_\pi] = \pi/2$ that makes $\phi_D = \phi_s = \pi/4$. A significant advantage of the optical generation of high frequency electrical signals is the ease by which they can be distributed using optical fiber, without significant loss, over much greater distance than by using conventional electrical cables or waveguides. However, when this SSB optical modulated signal is transmitted over a single mode fiber (SMF), the chromatic dispersion of the fiber will cause an extra phase shift and introduce RF power degradations in RoF link expressed as [12]

$$P_{rf} \propto \cos\left[\frac{\pi L D \lambda_c^2 f_{rf}^2}{c\{1-(2/\pi)\arctan\alpha\}}\right] \tag{2}$$

where α defines the frequency chirp of an external MZM modulator, D is the dispersion parameter, L is the length of the fiber, λ is the carrier wavelength, f_{rf} is fixed radio frequency.

3. Simulation setup

In our simulation set up schematically shown in Fig. 1, a RF signal of frequency 20 GHz is modulated by using either single- or dual electrode MZM (DEMZM) external modulator over a continuous wave (CW) laser at 1550 nm of laser line width 10 MHz with power of −2 dB. The value of V_π for the single electrode modulator is measured as 13.0 V while the dual-electrode device has V_π = 8.2 V. The optimum operating point was achieved by biasing at quadrature $\gamma = \pi/2$, i.e., which is defined as the mid-point of the normalized spread of the transfer function of MZM and applying an RF signal of 20 GHz with a drive level of 0.45 V_π. The offset voltage V_0 corresponding to the zero phase retardation in the absence of any electric field is 0 V, ideally. But, usually, external modulators become slightly unbalanced in the absence of any applied electric

Table 1
Simulation parameters.

D (ps/nm/km)	17
Fiber loss (dB/km)	0.2
Fiber non-linearity coefficient (1/W/km)	1.267
Core effective area (m^2)	80
Quantum efficiency (PIN)	0.799
Responsivity (PIN) (A/W)	1
MZM offset voltage, V_0 (V)	5

field. Thus, we have applied a biasing voltage of 5 V to compensate the offset in both, i.e., SEMZM and DEMZM modulators.

Both the RF electrodes of the MZM are driven as $V_A - V_B = V_\pi/2$ to bias DE-MZM at the linear point to achieve an optical SSB modulation with a phase shift between MZM drives of $\phi_A - \phi_B = \pi/2$. The modulated optical signal is, then transmitted over different optical links (up to 50 km), which act as a dispersive medium. At the receiver section, the optical channel is detected by pin detector and analyzed the received electrical signal by connecting ESA (Electric Spectrum Analyzer) and electric power meter.

The RF power degradation due to fiber dispersion that can be defined as the difference between the detected RF power at 50 km and the detected RF power at 0 km is investigated under the impact of extinction ratio of external modulator. The parameters of our RoF model designed by using OPTSIM 4.6 are depicted in Table 1.

4. Results and discussion

In this section, the simulative investigation is analyzed and discussed to study the impact of extinction ratio with low chirp of SEMZM and DEMZM over dispersion and optical link spanned between a receiver and transmitter.

Fig. 2 measures the RF power degradation of the applied RF signal as a function of the optical links at different RF frequencies of 18, 20 and 22 GHz at $\alpha = -3$ and it is observed that the power nulls observed at 18 GHz exhibits longer optical link with minimal effect

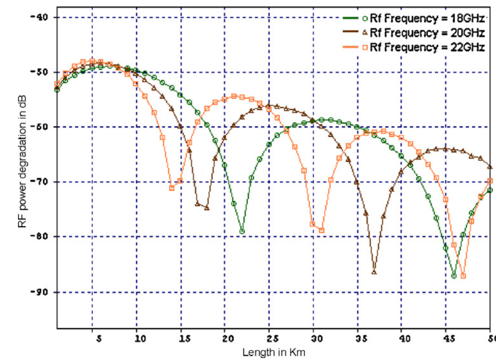
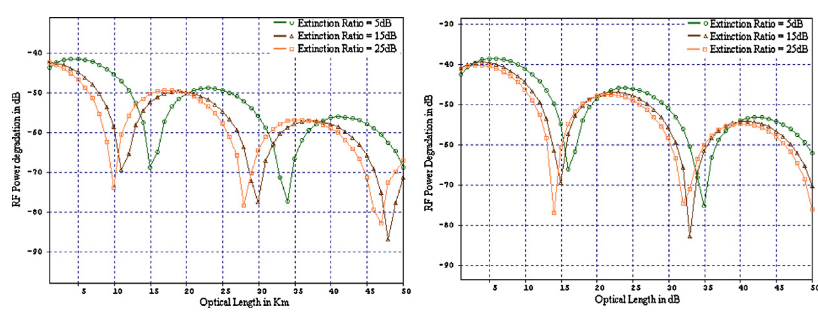


Fig. 2. RF power degradation versus optical distances at different Rf frequencies with $\alpha = -3$ using single-electrode MZM modulator.

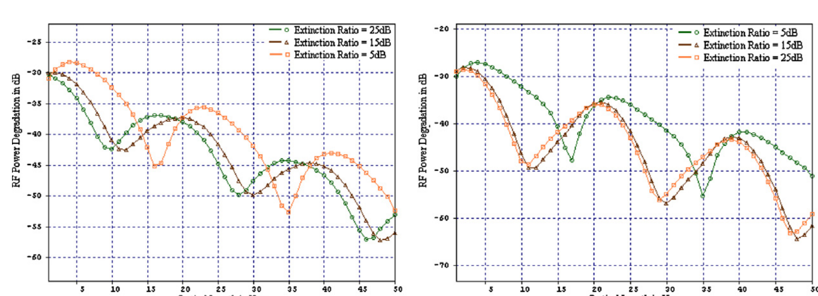
of chromatic dispersion. Hence, RF frequency is also one of the dominating factors in RoF systems that help in reducing the RF power degradations due to fiber dispersion.

The fiber dispersion induced RF power degradation with different extinction ratio and chirp parameters as a function of transmission distance in SSB-RoF link for SEMZM- and DEMZM-modulators is shown in Figs. 3 and 4 respectively. It is found that the impact of chirp and extinction ratio on RF power degradation due to fiber dispersion and transmission distance spanned between transmitter and receiver is evident, for example, a periodic power degradation with first power null is observed at almost 15 km with extinction ratio = 5 dB while at 10 km with extinction ratio = 25 dB at $\alpha = 0$ in case of SEMZM modulator as shown in Fig. 3(a). On decreasing the α to -1, the fiber-link distance increased and minimum reduction is achieved with extinction ratio = 5 dB as depicted in Fig. 3(b). In case of DEMZM, a similar periodic degradation is observed with maximum fiber link distance at $\alpha = -1$ and extinction ratio = 5 dB as shown in Figs. 4(a), (b) and 5. That means the RF power degradation introduced in SSB-RoF link due to fiber



(a) (b)

Fig. 3. RF power degradation versus optical distances at different extinction ratio with (a) $\alpha = 0$, (b) $\alpha = -1$ using single-electrode MZM modulator.



(a) (b)

Fig. 4. RF power degradation versus optical distances at different extinction ratio with (a) $\alpha = 0$, (b) $\alpha = -1$ using dual-electrode MZM modulator.

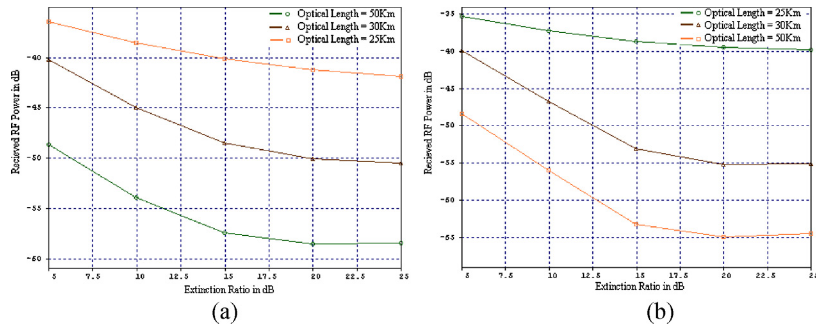


Fig. 5. Received RF power versus extinction ratio of DEMZM modulator at different optical links with chirp (a) $\alpha = 0$, (b) $\alpha = -1$.

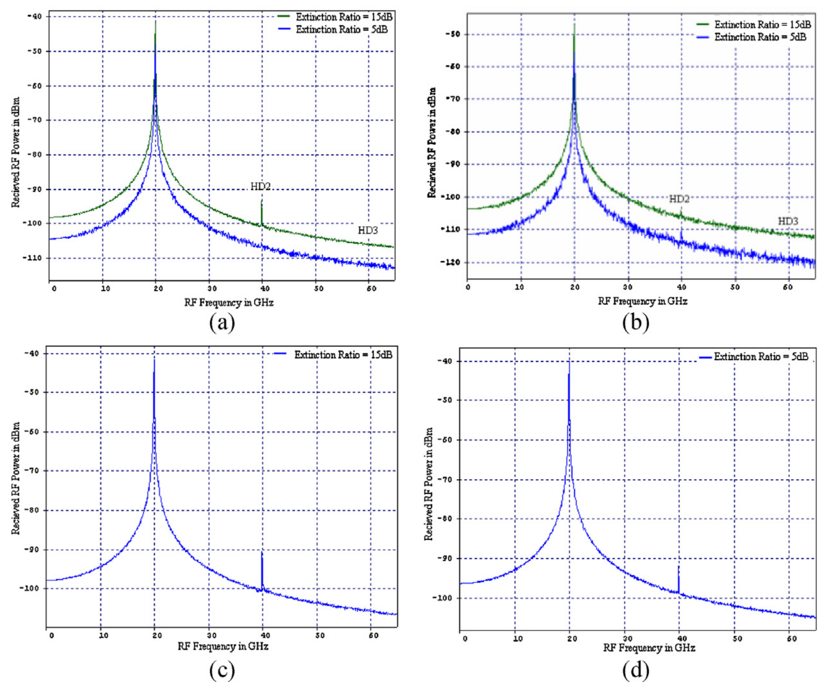


Fig. 6. Received RF power versus RF frequency at optical link of 50 km at different extinction ratio with (a) $\alpha = -3$, (b) $\alpha = 0$ and (c), (d) $\alpha = 3$ using dual-electrode MZM modulator.

dispersion can be limited by using external modulator especially MZM modulators with low chirp and extinction ratio parameters.

Further, the detailed comparison of HD2 suppression under the impact of extinction ratio and chirp parameter of DEMZM external modulator is depicted in Fig. 6. It is observed that a 3 dB suppression of HD2 is achieved with extinction ratio of 5 dB of DEMZM modulator on comparing with modulator of extinction ratio of 15 dB at $\alpha = 3$ as shown in Fig. 6(c) and (d). On reducing the chirp parameter of DEMZM to zero, the suppression of second-order harmonic (HD2) is further reduced as shown in Fig. 6(b) while HD2 is almost vanished on reducing the extinction ratio to 5 dB with chirp parameter, $\alpha = -3$ as depicted in Fig. 6(a).

Hence, better reduction of HD2, which come from the nonlinear modulation characteristics of the optical modulator, can be achieved not only by reducing the chirp parameter but also by reducing the extinction ratio of MZM modulators.

5. Conclusion

In this paper, we have discussed the impact of extinction ratio- and chirp-parameter of a single- and dual-electrode Mach–Zehnder modulator (SEMZM and DEMZM) over chromatic dispersion and RoF link spanned between a receiver and transmitter in RoF Communication systems. It is observed that not only by decreasing the chirp parameter but also the low value of extinction ratio of external modulators helps in improving the achievable link distance with minimum dispersion induced power penalties. Further, the second harmonic distortion (HD2) is almost vanished by using DEMZM with extinction ratio of 5 dB at chirp parameter $\alpha = -3$.

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