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Simulative investigation of nonlinear distortion in single- and two-tone RoF systems using direct- and external-modulation techniques

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Abstract

In this paper, we investigated a Radio-over-Fiber (RoF) system consisting of two different system set-ups using direct- and external-laser modulation techniques to study frequency response. Further, second- and third-harmonic generations of single- and two-tone RoF systems have been studied. In this work, we also measured the electric Rf power of two receiving channels and BER at received optical power at different modulating Rf frequencies up to 20 GHz using EDFA or SOA amplifiers. The results have been compared for the electric Rf power of receiving channels obtained using a $\sin^2$ Mach Zehnder modulator and a linear modulator, and an improvement in the received Rf power with linear modulator in comparison with the $\sin^2$ modulator is observed.

Keywords: Radio-over-Fiber; EDFA; SOA

1. Introduction

Radio-over-Fiber (RoF) techniques are attractive for realizing high-performance integrated networks. The growth of mobile and wireless communications fuels increasing demand for multimedia services with a guaranteed quality of service. This requires realization of broadband distribution and access networks. Within this framework, RoF schemes can be applied for realizing seamless wireless networks since they allow for the easy distribution of microwaves and millimeter waves over long distances along optical fibers [1,2]. Several techniques for distributing and generating microwave signals via optical fiber exist. The techniques may be classified into two main categories, namely Intensity Modulation-Direct Detection (IM-DD) and Remote Heterodyne Detection (RHD) techniques [3].

In such systems, it is desirable to achieve better receiver sensitivities, higher dynamic ranges, and lower nonlinear distortions. Techniques to reduce nonlinear distortions have been investigated extensively. A method for reducing nonlinear harmonic distortions (HDs) and inter-modulation distortions (IMDs) is to use the pre-distortion method [4], counteracting the nonlinear effects of the optical modulation characteristics. However, if EAMs are used, it was found that EAM modulation characteristics are dependent not only on wavelength but also on input optical power [5]. Thus, different pre-distortions for different wavelengths and/or different power levels have to be used, making the radio-over-fiber system design very complicated.

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Another technique is to use two wavelengths for each RoF system, in which one wavelength is tunable so that EAM transfer function nonlinearities at the two wavelengths will be matched. Recently, two balanced systems with one wavelength and two fibers and two wavelengths and one fiber were demonstrated to suppress second-order HD (HD2) and second-order inter-modulation distortion (IMD2) and improve dynamic range in an RoF system [6,7]. The balanced system that utilizes one wavelength and two fibers, in which two EAMs have mirrored transfer functions, is very difficult to maintain balance between two fiber transmissions, resulting in less suppression of HD2 and IMD2. Also, a feedback control system is required to maintain balance [6]. Later, this technique was improved by using two wavelengths and one fiber for each RoF system [7], which is referred to as the conventional balanced system in this paper. However, spectral efficiency is considerably reduced because two wavelengths for each RoF system are utilized. Also, the two EAMs must have very similar modulation characteristics at the two wavelengths, which may not be easy to obtain because EAM modulation characteristics depend on wavelength [4].

Alternatively, in order to reduce nonlinear distortions, low optical modulation indexes or depths (the ratio of optical signal sub-carrier to optical carrier) were usually preferred. Unfortunately, in this case the optical carrier is dominant in comparison to the optical signal sub-carrier, which leads to reduced receiver sensitivity. So, higher modulation indexes are preferred, which leads to significant increases of nonlinear distortion.

In this paper, we investigate nonlinear distortions consisting of harmonic distortions and inter-modulation distortions, both of which come from the nonlinear modulation characteristics of the optical modulators of a single- and a two-tone RoF system with different modulation and amplification techniques. We will show by simulation that the EDFA with the external-modulation technique performs better than other techniques discussed in this paper in the reduction of nonlinear distortions.

2. Simulation set-up

In our simulation set-up schematically shown in Fig. 1, a single-tone Rf signal of varying frequency from 1 to 20 GHz is modulated either by using the external-modulation technique over a continuous wave (CW) laser at 1550.5 nm biased at 4 a.u of laser line width

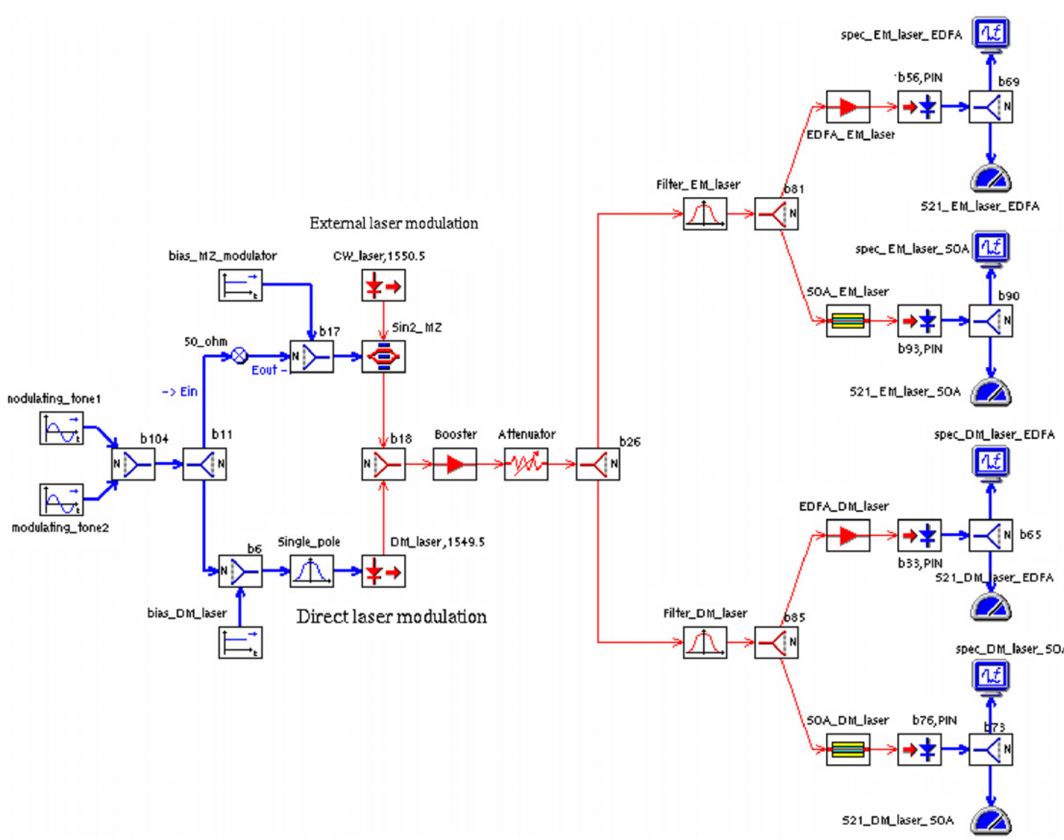

Fig. 1. Simulation set-up to study single- and two-tone RoF systems.

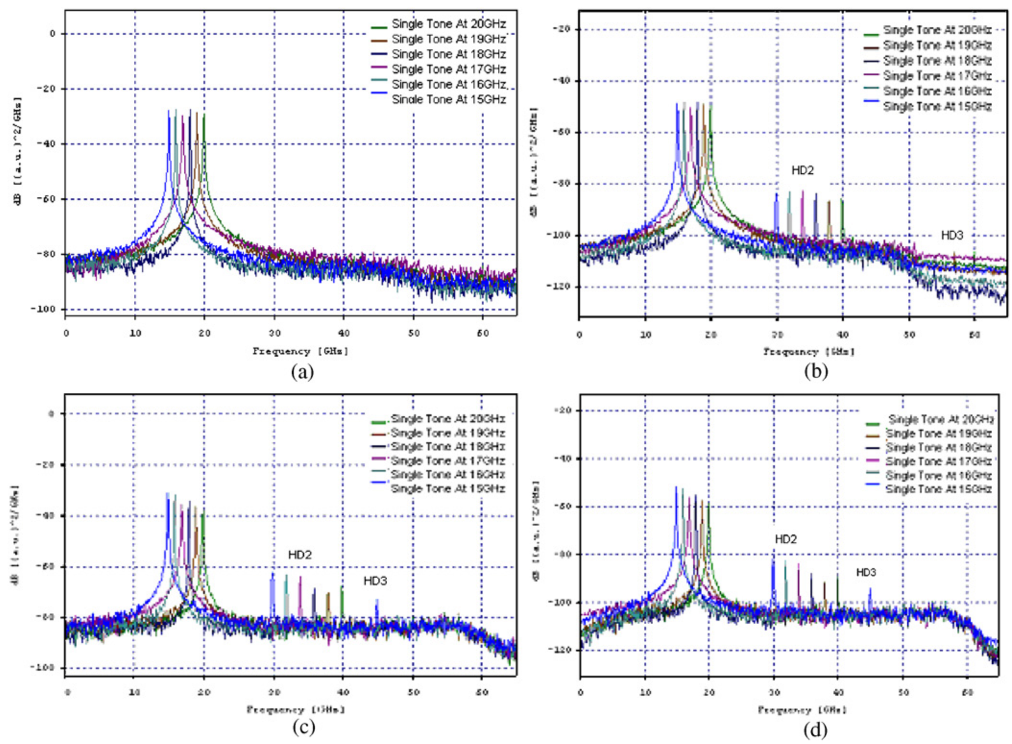

Fig. 2. Electrical power measurement of single-tone RoF system at chirp = 0 with: (a) EDFA with external modulation; (b) SOA with external modulation; (c) EDFA with direct modulation and (d) SOA with direct modulation.

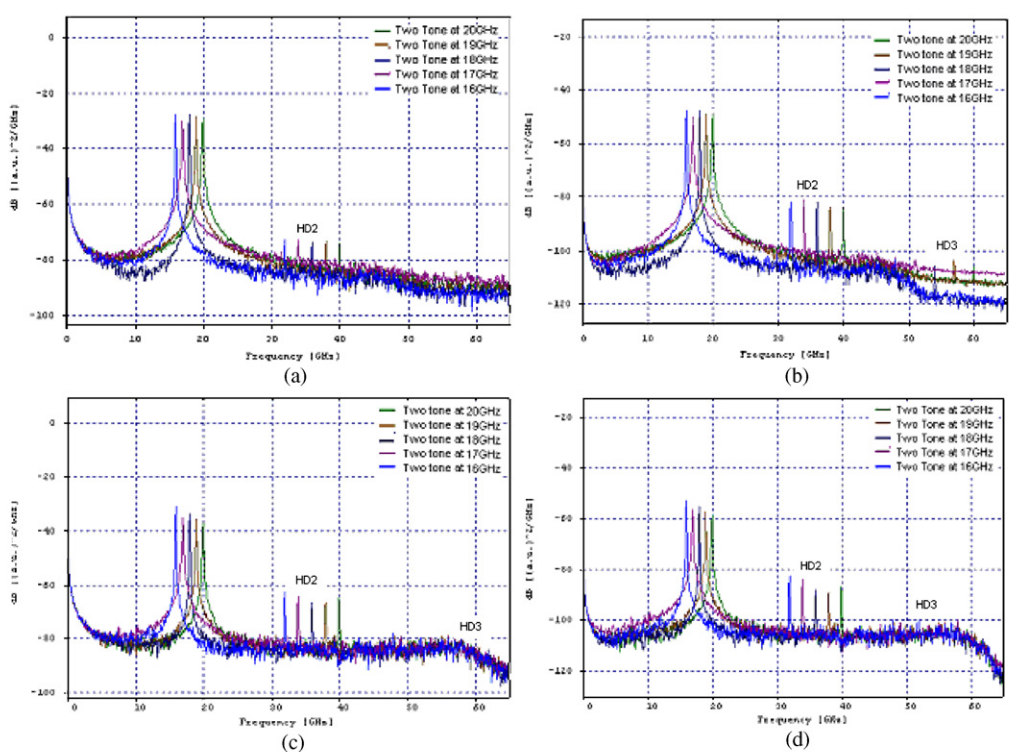

Fig. 3. Electrical power measurement of a two-tone Rof system at chirp = 0 with: (a) EDFA with external modulation; (b) SOA with external modulation; (c) EDFA with direct modulation and (d) SOA with direct modulation.

10 MHz with a CW power of 10 mW or by using direct-modulation technique over a LD at 1549.5 nm of a modulation index of 0.04 biased at 0.07 a.u. The propagation is modeled with an attenuator since RoF systems are usually employed over short distances. At the receiver section, the two channels are splitted,

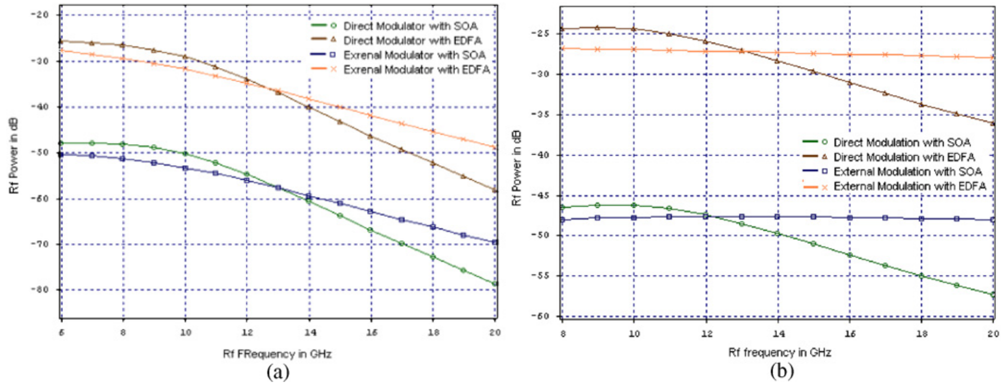

Fig. 4. Received Rf power versus Rf modulating frequency with different modulation and optical amplification of (a) single-tone RoF system and (b) two-tone RoF system.

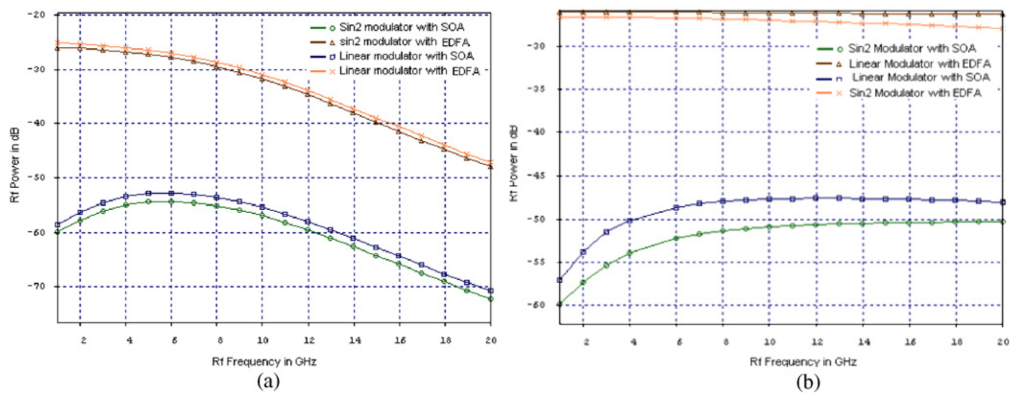

Fig. 5. Received Rf power versus Rf modulating frequency with external modulation of (a) single-tone RoF system and (b) two-tone RoF system.

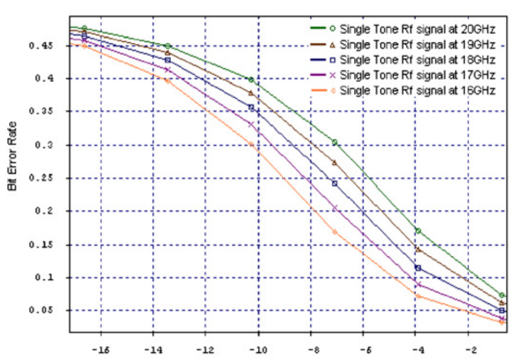

Fig. 6. Simulated BER versus received optical power at different Rf modulating frequencies with $\sin^2$ modulator using EDFA with external modulation.

amplified with either an EDFA or an SOA and detected by connecting Electric Spectrum Analyzer (ESA) and two narrow bandwidth electric power meters. To study the two-tone RoF system, two modulating tones are employed. The frequency of one tone is varied from 1 to 20 GHz through parametric runs, while the other one is fixed at 5 GHz while the rest of the system parameters are kept same.

3. Result and discussion

We first consider our simulation set-up to investigate the frequency response and second- and third-order harmonic distortions (HD2 and HD3) of single- and two-tone RoF systems as shown graphically in Figs. 2 and 3. It is observed that the second- and third-order harmonic distortions are almost suppressed in a single-tone Rof system by using EDFA with external modulation as shown in Fig. 2 with chirp = 0. By comparing Fig. 3(a)–(d), an improvement of 9 dB in HD2 suppression is obtained in a two-tone Rof system by using EDFA with external modulation.

It is also observed that the electric power of single- and two-tone Rf signal is reduced to 24.289 dB at an Rf frequency of 20 GHz using the direct-modulation technique compared to external modulation as shown graphically in Figs. 2 and 3.

Fig. 4 calculates the received Rf power at various Rf frequencies with direct- and external-modulation techniques either with SOA or with EDFA for single- and two-tone RoF systems.

The received Rf power using EDFA with the external-modulation technique is −47.830 dB and is reduced to

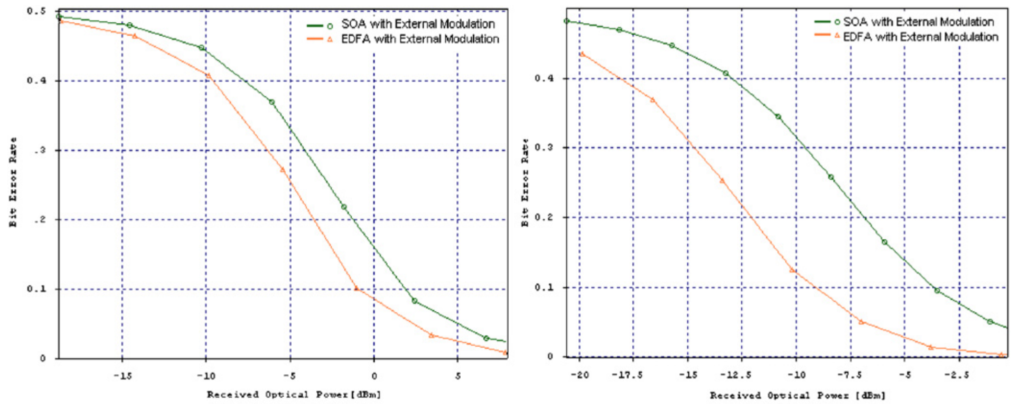

Fig. 7. Simulated BER versus received optical power at an Rf modulating frequency of 20 GHz with $\sin^2$ modulator for (a) single-tone RoF system and (b) two-tone RoF system.

−72.119 dB at 20 GHz using SOA with the external-modulation technique, but the received Rf power using EDFA with the direct-modulation technique is −57.863 dB and is reduced to −78.373 dB at 20 GHz using SOA with the direct-modulation technique for a single-tone RoF system as shown in Fig. 4(a). The same behavior is shown by a two-tone RoF system as shown in Fig. 4(b).

Fig. 5 compares the received Rf power with a $\sin^2$ modulator and a linear modulator at various Rf frequencies using the external-modulation technique with SOA and EDFA for single- and two-tone RoF systems. An improvement in the received Rf power is observed with the linear modulator in comparison with the $\sin^2$ modulator for both the systems as shown graphically in Fig. 5(a) and (b).

Fig. 6 shows that the impact of harmonic distortion increases as Rf modulating frequency increases. For the above discussion, the detailed comparison of HD2 suppression impact is shown in Fig. 7, which shows the comparison of the simulated bit error rate with received optical power in dBm for single- and two-tone RoF systems using either EDFA or SOA at an Rf modulating frequency of 20 GHz. It is seen that EDFA with the external-modulation technique has better HD2 suppression as compared to all other techniques discussed earlier in this paper.

4. Conclusion

In this paper, we investigated the frequency response and the nonlinear distortions consisting of harmonic distortions of back to back a single-tone and a two-tone RoF system using direct- and external-modulation techniques either with EDFA or with SOA. Using our simulations, we have shown that better suppression of HD2, HD3 and IMD2 can be achieved by using EDFA with the external-modulation technique. Further, we also observed an improvement in the received Rf power with a linear modulator in comparison with the $\sin^2$ modulator for both the single- and double-tone systems.

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