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Simulative investigation on the impact of laser-spectral width in single-tone radio-over-fiber transmission system using optical single side-band technique

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ABSTRACT

In this paper, we analyzed the impact of laser-spectral width incorporating dual-electrode Mach–Zehnder modulator (DEMZM) in single-tone radio-over-fiber (RoF) transmission system by simulation setup. It is shown that an improvement in the measurement of received radio frequency (RF) power is achieved by reducing the laser line width from 100 MHz to 100 kHz, which further improves the BER rate and optical link by transmitting the information with low power. The results are calculated for 20 and 50 km optical single sideband (OSSB)–RoF transmission system by varying the chirp from 0 to −3 as it requires less bandwidth than optical dual sideband (ODSB)–RoF system and is tolerable for power degradation due to a chromatic fiber-dispersion, through a standard single-mode fiber (SSMF) carried by a continuous wave (CW) laser at 1550 nm of laser-spectral width varying from 100 MHz to 100 kHz with CW power of 10 mW that modulates a single RF channel of 20 GHz. Further, deployment of such lasers with OSSB scheme helps the telecom industry to reduce the designing cost of RoF communication systems.

1. Introduction

Radio-over-fiber (RoF) techniques are attractive for realizing high performance integrated networks since an optical fiber provides low loss and large bandwidth and a radio signal enables the mobility and easy access and to meet the increasing demands of subscribers for voice, data, and multimedia services that require the access network to support high data rates at any time and in any place inexpensively. However, the performance of RoF systems depends on the method used to generate the optically modulated radio frequency (RF) signal, power degradation due to fiber chromatic dispersion, nonlinearity due to an optical power level, and phase noises from a laser and an RF oscillator [1–14].

There are two techniques to generate the optically modulated RF signal: direct and external modulation. The direct modulation scheme is simple but suffers from a laser-frequency chirp effect, and this chirp effect results in severe degradation of the system performance. However, this can be eliminated by using the external-modulation scheme instead of the direct modulation scheme [2]. Although the external-modulation scheme is employed, the conventional optical double sideband (ODSB) signal can degrade the received RF signal power due to fiber chromatic dispersion drastically. For overcoming the power degradation, an optical single sideband (OSSB) signal, generated by using a phase shifter and a dual-electrode (DE) Mach–Zehnder modulator (MZM), is employed [2].

In addition to these two effects, the nonlinearity of an optical fiber can give a large penalty on the long-haul transmission and multi channel system using a high-power signal. For the high-power transmission, the nonlinear effect should be managed by utilizing a modulation format [3], and by controlling the launched power level [4]. The nonlinear effect, however, can be negligible in short and low optical power (<0 dBm), especially for a single channel transmission.

Unlike these parameters, phase noise is one of the practical and decisive factors in high-quality services that require high signal-to-noise ratio (SNR) [6]. This phenomenon is serious to RoF systems because the purpose of RoF systems is to provide a service of high data rate and high quality, which require a large SNR. Thus, the system performance can be more sensitive to the phase noise in these services. The influence of the phase noise on optical communication systems has been investigated [5–10]. Kitayama et al. analyzed the system performance for an ODSB signal including laser phase noise and suggested how to compensate the differential delay by using a dispersion-compensating fiber (DCF). He focused on how to compensate fiber

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chromatic dispersion for the ODSB signal experimentally and analytically rather than analyze the effect of the phase noise on the performance in detail.

Barry and Lee [6] and Salz [7] analyzed the performance of coherent optical systems with laser phase noise by utilizing a Wiener process, since coherent detection provides better sensitivity than that of direct detection, while direct detection has a simple structure. Gallion and Debarge [8] and Tkach [9] used an autocorrelation function and a PSD function for evaluating the effect of the laser line width and fiber chromatic dispersion on the system performance.

Gallion [10] analyzed the power spectral density (PSD) function of a photocurrent incorporating the laser phase noise in detail. Gliese applied the result in [8] to the evaluation of a carrier-to-noise ratio (CNR) penalty and an rms phase noise at the receiver due to the laser line width and fiber chromatic dispersion in a remote heterodyne detection (RHD) system. For the tolerance to fiber chromatic dispersion, dual correlated lasers were employed to generate an OSSB signal. In [10], the CNR penalty due to the laser line width is negligible in a narrow laser line width and small differential delay (<100 ps) while the CNR penalty is quite large in a broad laser line width and large differential delay. Vishal Sharma [13] analyzed the impact of spectral width of laser over intensity noise introduced inside the fiber incorporating higher order dispersion parameters and showed that intensity noise can be reduced by reducing the laser line width to kHz range in long-haul communication systems.

In this work, we have studied by simulation that effect of laser-spectral width in a single-tone OSSB–RoF transmission system incorporating DEMZM modulator and investigated that the received RF power can be increased by reducing the laser spectral width from 100 MHz to 100 kHz. The model of OSSB-RoF system is analyzed theoretically in Section 2, incorporating DEMZM modulator. Finally, a discussion and conclusion drawn, from results obtained, are presented in Section 3 and Section 4, respectively.

2. Theory

Generally, RoF systems transmit an optically modulated radio frequency signal from a central office (CO) to a base station (BS) via an optical fiber. An OSSB signal is generated by using a DEMZM and a 90° phase shifter. This RF signal is optically modulated by the LD with a DEMZM. The optically modulated signal is transmitted to BS where the received RF signal is recovered by using a photo detector (PD) and a BPF arrives at a user terminal (UT) through a wireless channel. The optical signals from the laser and the RF oscillator are represented mathematically as

$$x_{LD}(t) = A \cdot \exp j(\omega_{LD}(t) + \phi_{LD}(t)) \tag{1}$$

$$x_{RF}(t) = V_{RF} \cdot \cos(\omega_{RF}(t) + \phi_{RF}(t)) \tag{2}$$

where 'A' and V_{RF} are amplitudes of signals from the LD and the RF oscillator, respectively, ω_{LD} and ω_{RF} are angular frequencies of the signals from the LD and the RF oscillator, $\phi_{LD}(t)$ and ϕ_{RF} are phase-noise processes and $\phi_{LD}(t)$ is characterized by a Wiener process [6] as

$$\phi_{LD}(t) = \int_0^t \phi'_{LD}(\tau) d\tau \tag{3}$$

The time derivative $\phi'_{LD}(t)$ is not flat at low frequencies due to $1/f$ noise [5]. The white phase noise, however, is the principal cause for line broadening and is associated with quantum fluctuations [6]. Thus, $\phi'_{LD}(t)$ can be modeled as a zero-mean white Gaussian process with a PSD [5]

$$S_{\phi'_{LD}}(\omega) = 2\pi\Delta\nu_{LD} \tag{4}$$

where $\Delta\nu_{LD}$ defines a laser line width.

After optically modulating $x_{RF}(t)$ by $x_{LD}(t)$ with a DEMZM and by controlling the phase shifter, the OSSB signal is generated by setting θ (phase shift) and γ (normalized dc value of LD) to 90° and 0.5, respectively, and this OSSB signal at the output of DEMZM is represented as

$$E_{OSSB}(0,t) = A.L_{MZM}\left[J_0(\alpha\pi).\exp j\left(\omega_{LD}(t) + \phi_{LD}(t) + \frac{\pi}{4}\right) - \sqrt{2}J_1(\alpha\pi).\exp j(\omega_{LD}(t) + \phi_{LD}(t) + \omega_{RF}(t) + \phi_{RF}(t)\right] \tag{5}$$

where $\alpha = V_{RF}/\sqrt{2}V_\pi$ is the normalized ac value, V_π is the switching voltage of the DEMZM, L_{MZM} is the insertion loss of the DE MZM, and θ is the phase shift by the phase shifter. Generally, $V_\pi \gg V_{RF}$, thus, the high-order components of the Bessel function are neglected. After transmitting the OSSB at the output of DEMZM through standard single-mode fiber (SSMF) of L_{fiber} Km is represented as

$$E_{OSSB}(L,t) = A \cdot L_{MZM} \cdot L_{Loss} \cdot 10^{-(\alpha_{fiber} \cdot L_{fiber})/20} \cdot J_0(\alpha\pi)\left[\exp j\left(\omega_{LD}(t) + \phi_{LD}(t-\tau_0) - \phi_1 + \frac{\pi}{4}\right) - \frac{\sqrt{2}J_1(\alpha\pi)}{J_0(\alpha\pi)} \cdot \exp j(\omega_{LD}(t) + \phi_{LD}(t-\tau_+) + \omega_{RF}(t) + \phi_{RF}(t-\tau_+) - \phi_2\right] \tag{6}$$

where L_{loss} denotes an additional loss in the optical link, α_{fiber} is the SSMF loss, L_{fiber} is the transmission distance of the SSMF, and τ_0 and τ_+ define group delays for a center angular frequency of $\omega_{LD}(t)$ and an upper sideband frequency of $\omega_{LD}(t)+\omega_{RF}(t)$, ϕ_1 and ϕ_2 are phase-shift parameters for specific frequencies due to the fiber chromatic dispersion. By using a square-law model, the photocurrent $i(t)$ can be obtained from (6) as follows:

$$i(t) = R|E_{OSSB}(L,t)|^2 = RA_1^2[B + 2\alpha_1 \cos(\omega_{RF}(t) + \phi_{LD}(t-\tau_+) - \phi_{LD}(t-\tau_0) + \phi_{RF}(t-\tau_+) - \phi_2 + \phi_1)] \tag{7}$$

where

$$A_1 = A \cdot L_{MZM} \cdot L_{loss} \cdot 10^{-(\alpha_{fiber} \cdot L_{fiber})/20} \cdot J_0(\alpha\pi)$$

$$\alpha_1 = \frac{\sqrt{2}J_1(\alpha\pi)}{J_0(\alpha\pi)},\ B = 1+\alpha_1^2,\ R = \text{responsivity of PD}$$

From [7], the autocorrelation function $R_{AF}(\tau)$ is obtained as

$$R_{AF}(\tau) = \langle i(t) \cdot i(t+\tau) \rangle \tag{8}$$

$$\frac{R_{AF}(\tau)}{R^2 \cdot A_1^4} = B^2 \cdot \begin{bmatrix} 2 \cdot \alpha_1^2 \cdot \cos(\omega_{RF}\tau)\exp(-2\gamma_1|\tau|), & |\tau| \le \tau_1 \\ 2 \cdot \alpha_1^2 \cdot \cos(\omega_{RF}\tau)\exp(-2\gamma_{LD}\tau_1 - \gamma_{RF}|\tau|), & |\tau| > \tau_1 \end{bmatrix} \tag{9}$$

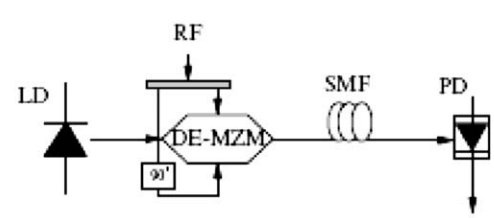

Fig. 1. Single-tone OSSB–RoF transmission system. RF, radio frequency signal of 20 GHz; LD, laser diode; DE-MZM, dual-electrode Mach–Zehnder modulator; SMF, single mode fiber; PD, photo-diode.

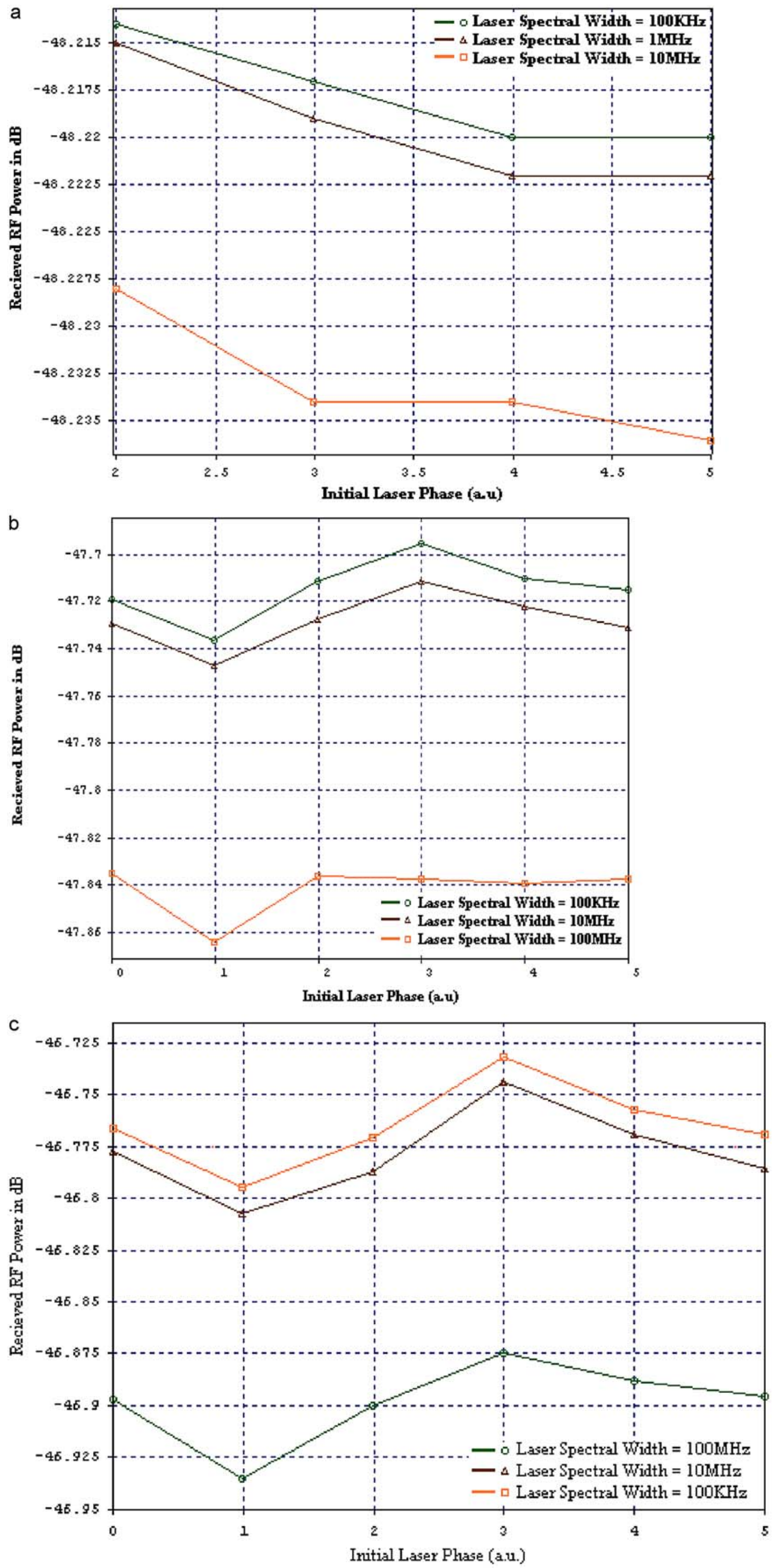

Fig. 2. Received RF power versus initial laser phase at different laser spectral widths with (a) Chirp = 0, (b) Chirp = −1 and (c) Chirp = −3 at optical length of 20 km.

where γ_{LD}, γ_{RF} = normalized dc value of LD and RF, respectively, and total line width, γ_t is given as

$$2\gamma_t = 2\gamma_{LD} + 2\gamma_{RF} = 2\pi\Delta\nu_{LD} + \pi\Delta\nu_{RF}$$

where $\Delta\nu_{LD}$, $\Delta\nu_{RF}$ = line widths for laser and RF oscillators, respectively.

The PSD function of the photocurrent, $S(f)$ can be written as

$$S(f) = F\langle R_{AF}(\tau)\rangle$$

$$\frac{S(f)}{R^2A_1^4} = B_2 \cdot \delta(f) + G(f - f_{RF}) + G(f + f_{RF}) \quad (10)$$

where $G(f-f_{RF}) = S_1+S_2+S_3$ and

$$S_1 = \frac{2\gamma_{RF}\alpha_1^2\exp(-2\gamma_t\tau_1)\cos[2\pi(f - f_{RF})\tau_1]}{\gamma_{RF}^2 + [2\pi(f - f_{RF})]^2} = \text{dc component}$$

$$S_2 = \frac{4\alpha_1^2\exp(-2\gamma_t\tau_1)}{(2\gamma_t)^2 + [2\pi(f - f_{RF})]^2} \cdot \{\gamma_t \cdot \exp(2\gamma_t\tau_1 - \gamma_t \cdot \cos[2\pi(f - f_{RF})]\tau_1)\}$$

$$S_3 = -\frac{4\pi \cdot \gamma_{LD}(\gamma_{LD} + \gamma_{RF}) \cdot (f - f_{RF})}{(\gamma_{RF})^2 + [2\pi(f - f_{RF})]^2} \cdot \{\sin[2\pi(f - f_{RF})]\tau_1)\}$$

The second and third terms i.e. S_1 and S_2 of (10) defines the broadening effects due to the fiber chromatic dispersion and the line widths of the laser and the RF oscillator. By using (10), the received RF carrier power, P_{rcvd} is approximately represented as follows:

$$P_{rcvd} = \int_{f_{RF}-B_{RF}/2}^{f_{RF}+B_{RF}/2} S(f) = \frac{4R^2\alpha_1^2A_1^4}{\pi} \cdot \tan^{-1}\left[\frac{\pi B_{RF}}{\gamma_t}\right], \quad 2\gamma_t\tau_1 \ll 1 \text{ and } \gamma_t \ll \gamma_{RF} \quad (11)$$

From Eq. (11), it is clear that P_{rcvd} is a function of the differential delay, $\tau_1 = (D \cdot L_{fiber} \cdot \lambda^2 \cdot f_{RF}^2)/c$ due to the fiber chromatic dispersion and the line widths of the laser and RF oscillator.

3. Simulation setup

In our setup schematically shown in Fig. 1, a RF signal of 20 GHz is modulated at central office by using dual-electrode MZM external modulator over a continuous wave (CW) laser at

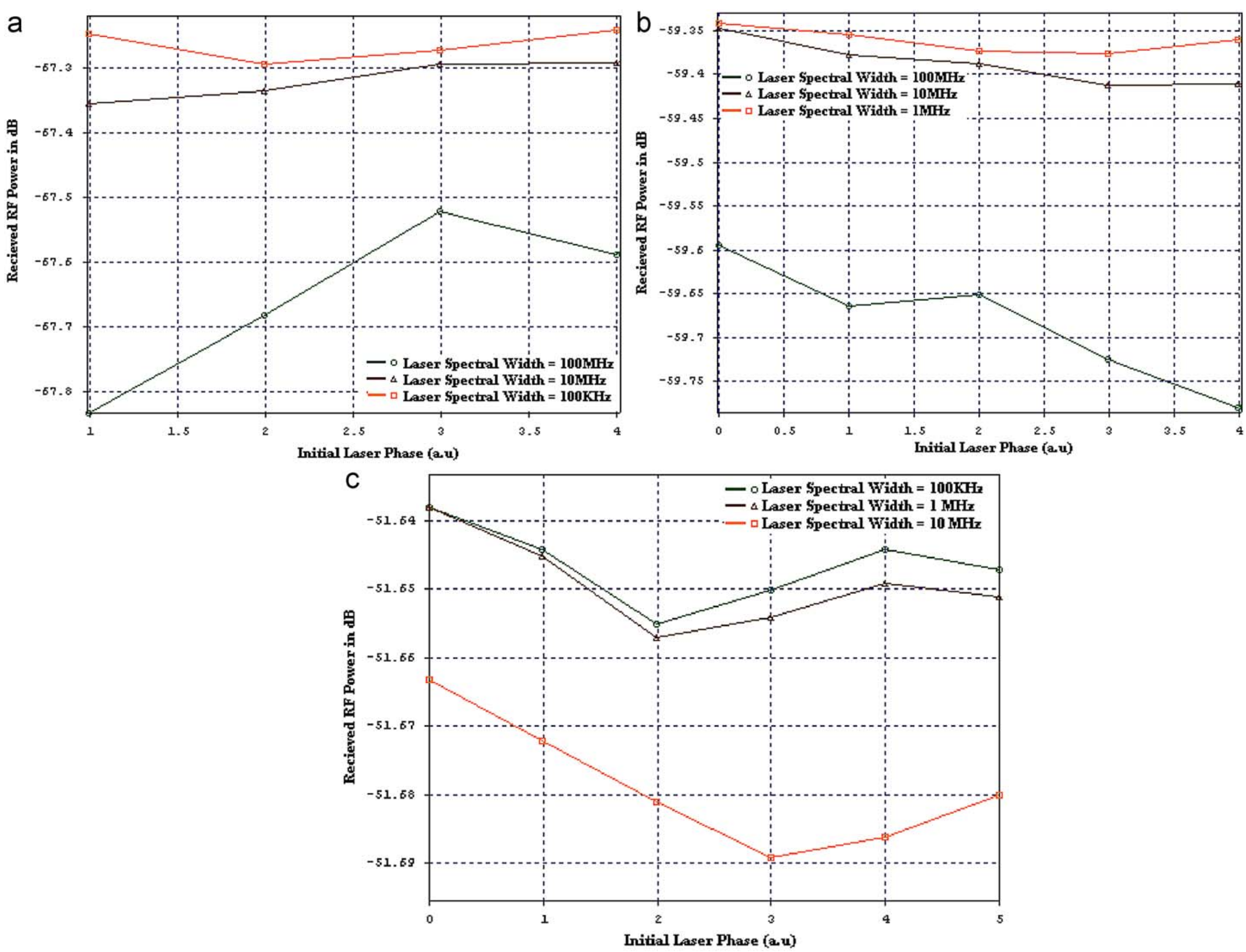

Fig. 3. Received RF power versus initial laser phase at different laser spectral width with (a) Chirp = 0, (b) Chirp = −1 and (c) Chirp = −3 at optical length of 50 km.

1550 nm of laser-spectral width varying from 100 MHz to 100 kHz with power of 10 mW and with different initial laser phases varying from 0–2π. This RF signal applied directly to the one of the DEMZM modulator and the same RF signal with phase shift of 90° is applied to the second arm of the modulator to generate an optical single sideband RF signal as it requires less bandwidth than DSSB–RoF system and is tolerable for power degradation due to a chromatic fiber-dispersion, through a standard single-mode fiber. The offset voltage corresponding to the zero-phase retardation in absence of any electric field on both arms of DEMZM modulator is set at 5 V and V_π voltage is fixed at 8.2 V to minimize the generation of harmonics. The results are calculated for 20 and 50 km OSSB–RoF transmission system by varying the chirp from 0 to -3. At base receiving station (BS), the optical channel is detected by a pin detector and analyzed the received electric signal by connecting electric spectrum analyzer (ESA) and electric power meter.

4. Result and discussions

The impact of laser line width, $\Delta\nu_{\mathrm{LD}}$ is described in Figs. 2 and 3 and results are calculated with RF oscillator line width of 1 Hz for OSSB–RoF transmission system with laser line width varying from 100 MHz to 100 kHz as a function of initial laser phase through SSMF fiber of different optical links (20–50 km) and first-order dispersion of 17 ps/nm km. It is observed that an improvement in the measurements of received RF power is achieved as we reduce the laser-spectral width from 10 MHz to 100 kHz. On comparing Fig. 2(a–c), it is also investigated that on varying the chirp parameter to the large negative values, the received RF power increases. Therefore, power degradation introduced in OSSB–RoF system due to differential delay caused by chromatic dispersion and phase noise can be reduced by reducing the laser line width from 10 MHz to 100 kHz and by making the chirp parameter of DEMZM modulator negatively large.

The same simulation process is analyzed for optical link of 50 km and it is observed that same behavior in the increment of the received RF power is achieved on reducing the laser-spectral width and by making the chirp negatively large as shown in Fig. 3.

5. Conclusion

From our simulative results obtained in Section 3 for 20–50 km OSSB–RoF transmission system through a standard single-mode fiber (SSMF) carried by 1550 nm laser, we have concluded that better RF power can be received by reducing the laser-spectral width and by reducing the chirp parameter of DEMZM external modulator from 0 to -3. Our results are calculated for 20 and 50 km OSSB–RoF transmission system as it requires less bandwidth than DSSB–RoF system and is tolerable for power degradation due to a chromatic fiber-dispersion, through a standard single-mode fiber carried. By reducing the laser-spectral width, we can also reduce the impact of chromatic fiber-dispersion [13]. Hence, by deploying lasers like VSCEL having small spectral width in OSSB–RoF transmission system, we can reduce designing-cost of the central office (CO) comprises of transmitting section and information can be transmitted to a longer distance with minimum number of intermediate optical and RF amplifiers.

References

[1] Smith GH, Novak D. Overcoming chromatic-dispersion effects in fiber-wireless systems incorporating external modulators. IEEE Trans Microwave Theory Tech 1997;45(8):1410–15 (August).

[2] Leibrich J. CF-RZ-DPSK for suppression of XPM on dispersion managed long-haul optical WDM transmission on standard single-mode fiber. IEEE Photon Technol Lett 2002;14(2):155–7 (February).

[3] Wen YJ. Power level optimization of 40 Gb/s DWDM systems with hybrid Raman/EDFA amplification. In: Proc. Conf. Optical Internet/Australian Conf. Optical Fibre Technology (COIN/ACOFT). Melbourne: Australia; Jul. 2003, pp. 309–312.

[4] Kitayama K-I. Ultimate performance of optical DSB signal-based millimeter-wave fiber-radio system: Effect of laser phase noise. J Lightwave Technol 1999;17(10):1774–81 (October).

[5] Barry JR, Lee EA. Performance of coherent optical receivers. Proc Inst Elect Eng 1990;78(8):1369–94 (August).

[6] Salz J. Modulation and detection for coherent ligh twave communications. IEEE Commun Mag 1986;COMM-24(6):38–49 (June).

[7] Gallion PB, Debarge G. Quantum phase noise and field correlation in single frequency semiconductor laser systems. IEEE J Quantum Electron 1984;QE-6(4):343–9 (April).

[8] Tkach RW. Phase noise and line width in an InGaAsP DFB laser. J Lightwave Technol 1986;LT-4(11):1711–16 (November).

[9] Gliese UChromatic dispersion in fiber-optic microwave and millimeter-wave links. IEEE Trans Microwave Theory Tech 1996;44(10):1716–24 (October).

[10] Cho T-S. Modified BER estimation of optical link considering the nonlinear effect of the fiber. Korean Inst Commun Sci (KICS) 2001;23(2):1707–10 (August).

[11] Iqbal M, Kim K. Performance of QAM systems with respect to phase noise spectral shape. In: Proceedings of the Canadian conference on electrical and computer engineering (CCECE) 2000, Halifax, NS, Canada: 2000. pp. 14–16.

[12] Iqbal M, Lee J, Kim K. Performance comparison of digital modulation schemes with respect to phase noise spectral shape. In: Proceedings of the electrical and computer engineering, Canadian Conf. vol. 2. Halifax, NS, Canada: March 2000. pp. 856–860.

[13] Sharma Vishal, Singh Amarpal, Sharma Ajay K. Analysis and simulation of the effect of spectral width over intensity noise under the impact of higher-order dispersion parameters in the optical communication systems. Opt Commun 2008;281:3495–500 (25 February).

[14] Tae-Sik Cho, Changho Yun, Jong-In Song, Kiseon Kim. Analysis of CNR penalty of Radio-Over-Fiber systems including the effects of phase noise from laser and RF oscillator. Journal of Lightwave Technology 2005;23(12).