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Performance of optical DSB signal based millimeter wave communication system with higher-order dispersion

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Abstract

In this paper, the impact of higher-order dispersion compensation on normalized signal power has been investigated in DSB transmission. We show that if there is dispersion compensation, the normalized power gets increased thereby optimizing the overall system performance. The first- and second-order dispersion compensation has been demonstrated. It is observed that the first- dispersion compensation has the major impact in comparison with second-order dispersion compensation. Further the impact of dispersion compensation on the transmission distance has also been analyzed. It is seen that the transmission distance can be enhanced by 10^3 and 10^6 if dispersion compensation is performed using first- and first- and second-order together, respectively.

Keywords: Noise; Double side band; Dispersion; Higher-order dispersion; Millimeter wave; Optical phase conjugation; Fiber Braggs gratings (FBG); Normalized signal power; Normalized length

1. Introduction

It is of utmost importance to calculate and compensate the dispersion effects because these are the physical limitations for high-speed transmission systems resulted from the transmission properties of optical fiber. With the current trends towards ultrahigh bit rate transmission systems, the effects of second- and higher-order are becoming increasingly significant [1]. The broadband millimeter wave fiber radio access system will meet demand for “wireless first/last hoop” to customers, which can support broadband and portable services. The dispersion effects including higher-order dispersion terms plays a significant role in the dense wavelength division multiplexing (DWDM) channel allocation for mm-wave fiber-radio access systems. There are two DWDM approaches. One is the optical single side band (SSB) modulation, which is

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implemented at the transmitter and other is the optical SSB filtering of the optical signal spectrum, performed at the transmitter or receiver. The optical SSB modulation requires a special class of modulator, a dual-electrode modulator, biased at quadvature under push–pull operation, thereby requiring fine-tuning of the phase of the applied electric field over the signal bandwidth. On the other hand, in the optical SSB filtering at the receiver has been demonstrated for DWDM fiber-radio system [2]. It will also resolve the scarcity of available microwave band radio frequency (RF) resource problem. When the external optical modulator is used for the generation of millimeter wave, then the sub-carrier multiplexed (SCM) double side band (DSB) generated signal suffers from sever dispersion effects that results in the degradation of the signal. This problem had been solved by using many methods [3] like SSB modulation, optical filtering of side band and by using fiber Braggs grating (FBG), optical phase conjugation (OPC) methods. The FBG is key components in optical communication links as filters, gain flatters and dispersion compensators. The effect of random phase and amplitude errors in the FBG was analyzed and a statistical model was proposed [4] and it was found that the random fluctuation gave to enhanced fluctuations of the time delay spectral response, degrading their performance as dispersion compensators. The advantages and limitation of FBG as a dispersion compensator were discussed [5] and a theoretical model was proposed. In the long distance optical communication systems EDFA (erbium doped fiber amplifier) are used as in line optical repeaters. As an alternative approach, OPC are shown to be a good device to compensate the nonlinear effects. A scheme was proposed with the use of OPC [6] and it was found that it is possible to transmit 40 Gb/s signal over 10,000 km. Further it was also shown that capacity limit stems from β_2 effect rather than the imperfect compensation of the OPC system. The use of OPC for compensating nonlinear distortion and SPM (self phase modulation) had been investigated for AM–SCM systems [7] and the results was derived using first-order dispersion compensation. The compensation using midway OPC was described [8] and degradation caused by asymmetric power change had also been analyzed.

In this paper we study the effect of higher-order dispersion terms with FBG and OPC. The modified expression for diode current with the higher-order dispersion terms has been derived and first- and second-order compensation has been discussed using the OPC and FBG. The normalized signal power has been plotted with the normalized fiber length containing higher-order dispersion terms. In Section 2, the analysis has been carried out including higher-order dispersion effects. In Section 3, dispersion compensation using FBG and OPC has been demonstrated. The results have been discussed in Section 4 and finally conclusions are drawn in Section 5.

2. Theory

The optical DSB signal based mm-wave fiber radio system is shown in Fig. 1. The normally generated SCM optical DSB signal has been considered. In this system the OPC or FBG can be inserted in the fiber link for dispersion compensation [3]. The optical carrier from a CW (continues wave) light source is intensity modulated with the mm-wave carrier using an external optical amplitude modulator (EAM), resulting in the optical DSB signal. After the propagation in a nondispersion shifted single mode fiber (SMF), the mm-wave signal is generated by square law detection using the photodiode (PD). It is amplified and then transmitted from antenna.

2.1. Optical double sideband signal transport in single mode fiber

The electrical field of the DSB signal modulated with data imposed mm-wave carrier of ω_m is expressed as

$$E(0,t) = \sqrt{I_0}\mathrm{e}^{\mathrm{j}\{\omega_0 t+\phi(t)\}}\left[1+\frac{m}{2}(1+\mathrm{j}\alpha)\cos\{\omega_{mt}+\varphi(t)\}\right], \tag{1}$$

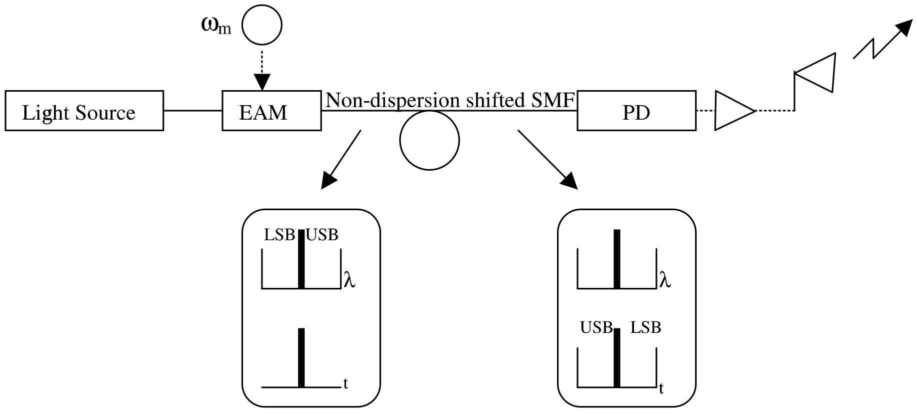

Fig. 1. The block diagram of optical DSB based mm fiber radio system.

where I_0 is the intensity of light, ω_0 is the angular frequency, $\phi(t)$ is the phase of light wave from the source, m is the depth of the modulation, α is the chirp parameter and $\phi(t)$ is the PSK signal. It consists of optical carrier along with upper side band (USB) and lower side band (LSB).

$$E(0,\omega) = \mathrm{FT}[E(0,t)], \tag{2}$$

$$E(0,\omega) = \sqrt{I_0}\Big[\delta(\omega-\omega_0)\mathrm{e}^{\mathrm{j}\phi(t)} + \frac{m}{2}(1+\mathrm{j}\alpha)\big(\delta(\omega-\omega_0-\omega_m)\mathrm{e}^{\mathrm{j}(\phi(t)+\varphi(t))} + \delta(\omega-\omega_0+\omega_m)\mathrm{e}^{\mathrm{j}(\phi(t)-\varphi(t))}\big)\Big], \tag{3}$$

where FT denotes the Fourier transform. During the propagation in the SMF, the LSB lags behind the USB due to fiber dispersion as shown in Fig. 1. The electrical field may be given as

$$\begin{aligned} E(L,t) = {} & \sqrt{I_0}\exp\{\mathrm{j}\{\omega_0 t + \phi(t-\tau) - \beta(\omega_0)L\}\} \\ & + \frac{m}{2}\sqrt{I_0(1+\alpha^2)}\exp\{\mathrm{j}[(\omega_0+\omega_m)t + \phi(t-\tau_+) + \varphi(t-\tau_+) - \beta(\omega_0+\omega_m)L + \tan^{-1}\alpha]\} \\ & + \frac{m}{2}\sqrt{I_0(1+\alpha^2)}\exp\{\mathrm{j}[(\omega_0-\omega_m)t + \phi(t-\tau_-) - \varphi(t-\tau_-) - \beta(\omega_0-\omega_m)L + \tan^{-1}\alpha]\}, \end{aligned} \tag{4}$$

where β is the propagation constant of the fiber mode, L is the length of the transmission fiber, τ_+ and τ_- the delay times of the USB and LSB, respectively.

The propagation constant β in terms of taylor series can be expanded around $\omega = \omega_0$ as mentioned in [9–11] as

$$\beta = \beta_0 + (\omega-\omega_0)\frac{\mathrm{d}\beta}{\mathrm{d}\omega} + \frac{1}{2}(\omega-\omega_0)^2\frac{\mathrm{d}^2\beta}{\mathrm{d}\omega^2} + \frac{1}{6}(\omega-\omega_0)^3\frac{\mathrm{d}^3\beta}{\mathrm{d}\omega^3} + \frac{1}{24}(\omega-\omega_0)^4\frac{\mathrm{d}^4\beta}{\mathrm{d}\omega^4} + \cdots, \tag{5}$$

where $\frac{\mathrm{d}\beta}{\mathrm{d}\omega} = \tau$ is the group delay for unit length

$$\beta_2 = \frac{\mathrm{d}^2\beta}{\mathrm{d}\omega^2} = -\frac{\lambda^2}{2\pi c}\frac{\partial\tau}{\partial\lambda}, \tag{6}$$

is first-order dispersion

$$\beta_3 = \frac{\mathrm{d}^3\beta}{\mathrm{d}\omega^3} = \frac{\lambda^2}{(2\pi c)^2}\left[\lambda^2\frac{\partial^2\tau}{\partial\lambda^2} + 2\lambda\frac{\partial\tau}{\partial\lambda}\right], \tag{7}$$

is second-order dispersion.

$$\beta_4 = \frac{d^4\beta}{d\omega^4} = \frac{\lambda^3}{(2\pi c)^3}\left[\lambda^3\frac{\partial^3\tau}{\partial\lambda^3} + 6\lambda^2\frac{\partial^2\tau}{\partial\lambda^2} + 6\lambda\frac{\partial\tau}{\partial\lambda}\right], \tag{8}$$

is third-order dispersion.

Recalling Eq. (7) and using Eq. (6)

$$\beta_3 = \frac{\lambda^2}{(2\pi c)^2}\left[\lambda^2 D' + 2\lambda D\right] \Rightarrow D' = \beta_3\frac{(2\pi c)^2}{\lambda^4} + \frac{2\beta_2(2\pi c)}{\lambda^3}. \tag{9}$$

Recalling Eq. (8) and using Eq. (9)

$$\beta_4 = -\frac{\lambda^3}{(2\pi c)^3}\left[\lambda^3 D'' + 6\lambda^2 D' + 6\lambda D\right], \tag{10}$$

using Eqs. (9) and (10) we get dispersion D as

$$D = -\frac{(2\pi c)^3}{6\lambda^4}\beta_4 - \frac{(2\pi c)^2}{\lambda^3}\beta_3 - \frac{2(2\pi c)}{\lambda^2}\beta_2 - \frac{\lambda^2 D''}{6}, \tag{11}$$

where

$$D'' = \frac{\partial^3\tau}{\partial\lambda^3} \quad \text{and} \quad D' = \frac{\partial^2\tau}{\partial\lambda^2}. \tag{12}$$

After the square law photo detection of the optical double side band signal. The mm-wave signal generated as

$$\begin{aligned} I_p = {} & mI_0\sqrt{(1+\alpha^2)}\cos\Big[\omega_m(t-\tau) - \phi(t-\tau) + \phi(t-\tau_+) + \varphi(t-\tau_+) - \frac{1}{2}\omega_m^2\frac{d^2\beta}{d\omega^2}L \\ & - \frac{1}{6}\omega_m^3\frac{d^3\beta}{d\omega^3}L - \frac{1}{24}\omega_m^4\frac{d^4\beta}{d\omega^4}L + \tan^{-1}\alpha\Big] \\ & + mI_0\sqrt{(1+\alpha^2)}\cos\Big[\omega_m(t-\tau) + \phi(t-\tau) - \phi(t-\tau_-) + \varphi(t-\tau_-) + \frac{1}{2}\omega_m^2\frac{d^2\beta}{d\omega^2}L \\ & + \frac{1}{6}\omega_m^3\frac{d^3\beta}{d\omega^3}L + \frac{1}{24}\omega_m^4\frac{d^4\beta}{d\omega^4}L - \tan^{-1}\alpha\Big]. \end{aligned} \tag{13}$$

The above expression can be further analyzed by using

$$\cos(A) + \cos(B) = 2\cos\left(\frac{A+B}{2}\right)\cos\left(\frac{A-B}{2}\right). \tag{14}$$

Substituting Eq. (13) in Eq. (14), we get

$$\begin{aligned} I_p = {} & 2mI_0\sqrt{(1+\alpha^2)}\cos\left[\omega_m(t-\tau) + \frac{1}{2}\phi(t-\tau_+) - \frac{1}{2}\phi(t-\tau_-) + \frac{1}{2}\varphi(t-\tau_+) + \frac{1}{2}\varphi(t-\tau_-)\right] \\ & * \cos\Big[\tan^{-1}\alpha - \phi(t-\tau) + \frac{1}{2}\phi(t-\tau_+) + \frac{1}{2}\varphi(t-\tau_+) + \frac{1}{2}\phi(t-\tau_-) - \frac{1}{2}\varphi(t-\tau_-) \\ & - \frac{1}{2}\omega_m^2\frac{d^2\beta}{d\omega^2}L - \frac{1}{6}\omega_m^3\frac{d^3\beta}{d\omega^3}L - \frac{1}{24}\omega_m^4\frac{d^4\beta}{d\omega^4}L\Big], \end{aligned} \tag{15}$$

where * stands for the sign of multiplication. After the propagation in the fiber, each of the spectral component experiences a different phase shift depending on the first- and higher-order dispersion terms.

This phase shift sets a limit to the maximum fiber length at which the RF beat signals after the detection exhibit a phase shift of π and thus interfere each other destructively. So the transmission distance or fiber length is given as from Eq. (15)

$$L = (\pi - \tan^{-1}\alpha)\Big/\left(-\frac{1}{2}\omega_m^2\frac{d^2\beta}{d\omega^2} - \frac{1}{6}\omega_m^3\frac{d^3\beta}{d\omega^3} - \frac{1}{24}\omega_m^4\frac{d^4\beta}{d\omega^4}\right). \tag{16}$$

As apparent from Eq. (16), the maximum fiber length can be extended when the modulator exhibits a large negative chirp value α [3]. The other way to extend the maximum fiber length is by first- and second-order dispersion compensation, i.e., we can extend the fiber length for same values of α if the first-order dispersion term is compensated and the increase in length will be more if the first- and second-order dispersion terms are compensated.

3. Dispersion compensation

As the degradation of the signal due to dispersion effects has more impact on the carrier to noise ratio (CNR). We can compensate the dispersion by using any of the compensation technique but here we will focus on the FBG and OPC as dispersion compensators and derive the modified expression for diode current containing the effect of the higher-order dispersion terms. As the FBG equalizes the group delay of the USB and LSB, τ_+ and τ_- by providing the optical path length differences that matches to the one induced by the dispersion induced group delay difference. It may be inserted anywhere along the fiber link [3]. The output of the photodetector in the presence of higher-order dispersion terms can be expressed as

$$\begin{aligned} I_p = 2mI_0\sqrt{(1+\alpha^2)}\cos\bigg[&\omega_m(t-\tau) + \frac{1}{2}\phi(t-\tau_+-\widehat{\tau}_+) - \frac{1}{2}\phi(t-\tau_--\widehat{\tau}_-) + \frac{1}{2}\varphi(t-\tau_+-\widehat{\tau}_+) \\ &+ \frac{1}{2}\varphi(t-\tau_--\widehat{\tau}_-) - \omega_m\frac{d\beta}{d\omega}L - \omega_m\frac{d\widehat{\beta}}{d\omega}l\bigg] \\ * \cos\bigg[&\tan^{-1}\alpha - \phi(t-\tau_-\widehat{\tau}) + \frac{1}{2}\phi(t-\tau_+-\widehat{\tau}_+) + \frac{1}{2}\varphi(t-\tau_+-\widehat{\tau}_+) + \frac{1}{2}\phi(t-\tau_--\widehat{\tau}_-) \\ &- \frac{1}{2}\varphi(t-\tau_--\widehat{\tau}_-) - \frac{1}{2}\omega_m^2\frac{d^2\beta}{d\omega^2}L - \frac{1}{6}\omega_m^3\frac{d^3\beta}{d\omega^3}L - \frac{1}{24}\omega_m^4\frac{d^4\beta}{d\omega^4}L - \frac{1}{2}\omega_m^2\frac{d^2\widehat{\beta}}{d\omega^2}l \\ &- \frac{1}{6}\omega_m^3\frac{d^3\widehat{\beta}}{d\omega^3}l - \frac{1}{24}\omega_m^4\frac{d^4\widehat{\beta}}{d\omega^4}l\bigg]. \end{aligned} \tag{17}$$

In Eq. (17) the delay times with cap represent those of the FBG. To completely eliminate fading, the constraints imposed on the FBG can be derived from Eq. (17), as

$$\tan^{-1}\alpha - \frac{1}{2}\omega_m^2\left(\frac{d^2\beta}{d\omega^2}L + \frac{d^2\widehat{\beta}}{d\omega^2}l\right) - \frac{1}{6}\omega_m^3\left(\frac{d^3\beta}{d\omega^3}L + \frac{d^3\widehat{\beta}}{d\omega^3}l\right) - \frac{1}{24}\omega_m^4\left(\frac{d^4\beta}{d\omega^4}L + \frac{d^4\widehat{\beta}}{d\omega^4}l\right) = m\pi \quad m = 1,2,3,\ldots \tag{18}$$

Now by using OPC dispersion compensation scheme, which is inserted in the midway of the fiber link. As described in [8] the pulse distortion caused by the dispersion and self phase modulation due to Kerr effect can both be compensated. Here the midway OPC to the fiber radio system has been theoretically analyzed, the optical DSB signal and converts the carrier frequency from $\omega = \omega_0$ to ω_c. The modified output of the photodetector in terms of higher-order dispersion terms is given by

$$\begin{aligned} I_p = 2mI_0\sqrt{(1+\alpha^2)}\cos\Big[&\omega_m(t-\tau) + \frac{1}{2}\phi(t-\tau_{1+}-\tau_{2-}) - \frac{1}{2}\phi(t-\tau_{1-}-\tau_{2+}) + \frac{1}{2}\varphi(t-\tau_{1+}-\tau_{2-}) \\ &+ \frac{1}{2}\varphi(t-\tau_{1-}-\tau_{2+}) - \omega_m\frac{d\beta^1}{d\omega}L_1 - \omega_m\frac{d\beta^2}{d\omega}L_2\Big] \\ *\ \cos\Big[&\tan^{-1}\alpha - \phi(t-\tau_{1-}\tau_2) + \frac{1}{2}\phi(t-\tau_{1+}-\tau_{2-}) + \frac{1}{2}\varphi(t-\tau_{1+}-\tau_{2-}) + \frac{1}{2}\phi(t-\tau_{1-}-\tau_{2+}) \\ &- \frac{1}{2}\varphi(t-\tau_{1-}-\tau_{2+}) - \frac{1}{2}\omega_m^2\frac{d^2\beta^1(\omega_0)}{d\omega^2}L_1 - \frac{1}{6}\omega_m^3\frac{d^3\beta^1(\omega_0)}{d\omega^3}L_1 - \frac{1}{24}\omega_m^4\frac{d^4\beta^1(\omega_0)}{d\omega^4}L_1 \\ &+ \frac{1}{2}\omega_m^2\frac{d^2\beta^2(\omega c)}{d\omega^2}L_2 + \frac{1}{6}\omega_m^3\frac{d^3\beta^2(\omega_c)}{d\omega^3}L_2 + \frac{1}{24}\omega_m^4\frac{d^4\beta^2(\omega_c)}{d\omega^4}L_2\Big]. \end{aligned} \tag{19}$$

In Eq. (19) the delay times with subscripts 1 and 2 respectively represents those of the fibers before and after the OPC. By placing the OPC at appropriate position in the midway of the optical fiber link, the group delay of the LSB and USB can be equalized. To completely eliminate fading, the constraints imposed on the OPC can be derived from Eq. (19) as

$$\begin{aligned} \Big[&\tan^{-1}\alpha - \frac{1}{2}\omega_m^2\left(\frac{d^2\beta^1(\omega_0)}{d\omega^2}L_1 - \frac{d^2\beta^2(\omega c)}{d\omega^2}L_2\right) - \frac{1}{6}\omega_m^3\left(\frac{d^3\beta^1(\omega o)}{d\omega^3}L_1 - \frac{d^3\beta^2(\omega_c)}{d\omega^3}L_2\right) \\ &- \frac{1}{24}\omega_m^4\left(\frac{d^4\beta^1(\omega o)}{d\omega^4}L_1 - \frac{d^4\beta^2(\omega_c)}{d\omega^4}L_2\right)\Big] = m\pi \quad m = 1,2,3\ldots \end{aligned} \tag{20}$$

It is also noteworthy here that in Eq. (20) the fiber optic nonlinear effects such as optical Kerr effect and wave-mixings are ignored in the analysis. Note that as the distance between the CS (central station) and the BS (base station) varies link by link in the practical systems. The fiber length is to be tailored by inserting space fibers with an appropriate length into each link so that overall length satisfies Eqs. (18) and (20).

In practical system design, it is important to evaluate the tolerance to the deviations of the fiber length and dispersion properties. Here in the case of FBG [3], the relation between above deviations and modified normalized signal power $\eta(0 \leqslant \eta \leqslant 1)$ can be derived from Eq. (18) as

$$\begin{aligned} \eta = \cos\Bigg[\frac{\lambda^2\omega_m^2}{4\pi c}\Bigg\{ & l\left(-\frac{(2\pi c)^3}{6\lambda^4}\widehat{\beta}_4 - \frac{(2\pi c)^2}{\lambda^3}\widehat{\beta}_3 - \frac{(2\pi c)}{\lambda^2}\widehat{\beta}_2 - \frac{\lambda^2 D''}{6}\right) \\ &* \cos\left(\frac{\Delta l}{l}\,\frac{\frac{(2\pi c)^3}{6\lambda^4}\Delta\widehat{\beta}_4 + \frac{(2\pi c)^2}{\lambda^3}\Delta\widehat{\beta}_3 + \frac{(2\pi c)}{\lambda^2}\Delta\widehat{\beta}_2}{\frac{(2\pi c)^3}{6\lambda^4}\widehat{\beta}_4 + \frac{(2\pi c)^2}{\lambda^3}\widehat{\beta}_3 + \frac{(2\pi c)}{\lambda^2}\widehat{\beta}_2 + \frac{\lambda^2 D''}{6}}\right) \\ &+ L\left(-\frac{(2\pi c)^3}{6\lambda^4}\beta_4 - \frac{(2\pi c)^2}{\lambda^3}\beta_3 - \frac{(2\pi c)}{\lambda^2}\beta_2 - \frac{\lambda^2 D''}{6}\right) \\ &* \cos\left(\frac{\Delta L}{L} + \frac{\frac{(2\pi c)^3}{6\lambda^4}\Delta\beta_4 + \frac{(2\pi c)^2}{\lambda^3}\Delta\beta_3 + \frac{(2\pi c)}{\lambda^2}\Delta\beta_2}{\frac{(2\pi c)^3}{6\lambda^4}\beta_4 + \frac{(2\pi c)^2}{\lambda^3}\beta_3 + \frac{(2\pi c)}{\lambda^2}\beta_2 + \frac{\lambda^2 D''}{6}}\right)\Bigg\}\Bigg]. \end{aligned} \tag{21}$$

Eq. (21) is modified normalized signal power in the light of the higher-order dispersion terms. Where Δ is the dirac delta function.

4. Results and discussions

Referring to ITU-T recommendations [12], we assume $\lambda = 1548.8$ nm, $\frac{\partial\tau}{\partial\lambda} = 20$ ps/nm km and $D' = \frac{\partial^2\tau}{\partial\lambda^2} = 0.085$ ps/nm^2 km, we obtain following dispersion parameters using Eq. (6), Eq. (7) and Eq. (8), respectively.

$$\beta_2 = \frac{d^2\beta}{d\omega^2} = -25.44\ (\text{ps})^2/\text{km},\ \ \beta_3 = \frac{d^3\beta}{d\omega^3} = 0.179\ (\text{ps})^3/\text{km},$$

$$\beta_4 = \frac{d^4\beta}{d\omega^4} = -0.001277\ (\text{ps})^4/\text{km},\ \ D'' = -0.001\ \text{ps/Km/(nm)}^3.$$

The normalized length deviation is defined as change in fiber length to the original fiber length. In the calculations, the total dispersion of fiber length (ΔL) is assumed to be 600 ps in the frequency span of $2f_m = 120$ GHz. Using first-order dispersion term only, it is clear from the Fig. 2 that as the normalized length deviation ($\Delta L/L$) increases, the normalized signal power (η) decreases. The decrease in this normalized power agrees with the result reported in [3] where only the first-order dispersion term was considered. Now in order to illustrate higher-order dispersion effects, we plot the normalized length deviation ($\Delta L/L$) against normalized signal power (η) for the combined effect of first-order dispersion term (β_2),

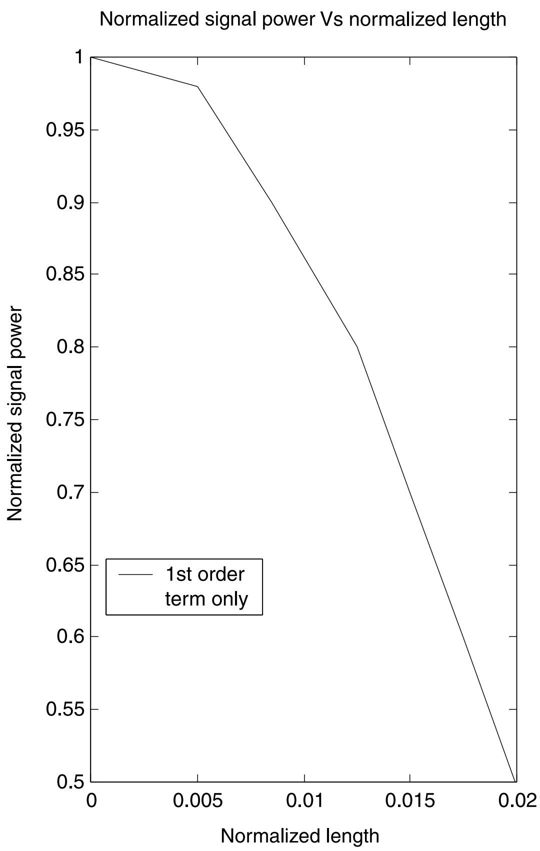

Fig. 2. Normalized signal power is plotted against normalized length deviations with first-order dispersion term only.

second-order dispersion term (β_3) and third-order dispersion term (β_4) by using Eq. (21) and using the values of β_2, β_3 and β_4 we get as shown in Fig. 3. It is apparent from Figs. 2 and 3 that the value of η becomes unity when $\Delta L = 0$ and $\Delta\beta_2 = \Delta\beta_3 = \Delta\beta_4 = 0$, i.e., which satisfy Eq. (21). Not much difference is seen with the combined effects, which illustrates that the second-order dispersion effects are very small, when the first-order dispersion term is present. Now when we compensate the first-order dispersion term, the effect of second- and third-order term is clearly visible. It is seen that the normalized power is increased which reflects the improvement in overall system performance. Further it is seen that if the first- and second-order dispersion terms are compensated, the effect of third-order dispersion terms comes into play that shows very minute deviations in comparison to that of second- and third-order effects together. The increase in the normalized power can be very helpful in optimum system design.

Further by using Eq. (16) and the values of β_2, β_3 and β_4, we get modified values of transmission distance as shown in Table 1. It is seen that the transmission distance can be enhanced by 10^3 and 10^6 if dispersion compensation is performed using first-, first- and second-order dispersion terms, respectively. The transmission distance changes from 2.266 to 2.5541×10^3 km with first-order dispersion compensation reflecting the importance of first-order compensation. Again if we compensate the first- and second-order dispersion terms then this transmission distance can be enhanced to 3.7962×10^6 from 2.266 km. This is considered as tremendous enhancement and will be useful in long haul optical communications systems specially in the transoceanic fiber installations.

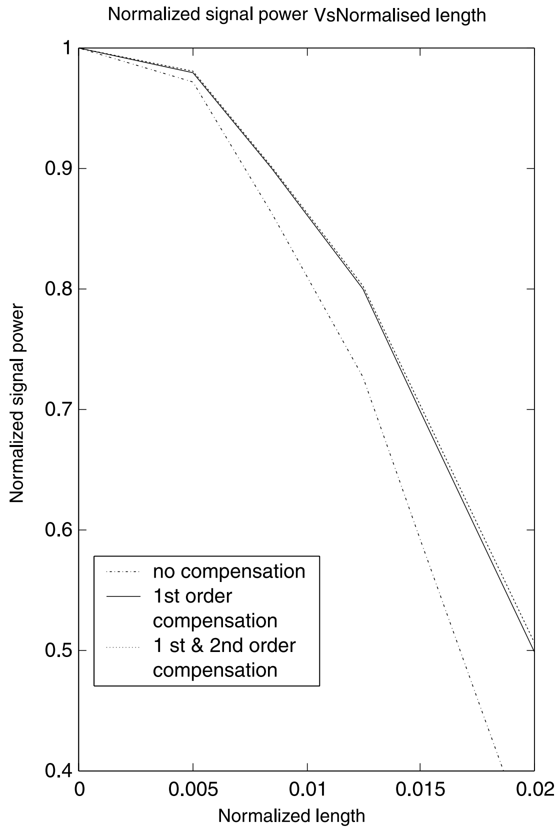

Fig. 3. Normalized signal power is plotted against normalized length deviations. As indicated according to Eq. (21).

Table 1

Dispersion compensation	Transmission distance L (km)
No compensation	2.266
β_2 Compensated	2.5541×10^3
β_2 and β_3 Compensated	3.7962×10^6

The minimum wavelength division multiplexing (WDM) channel interval for optical DSB signals can be realized and it enables the optical SSB filtering technique at the receiver side by using a square response of FBG filter optical frequency interleave between the neighboring channels without any serious signal degradation due to the inter-channel interference. This clearly suggests that higher-order dispersion compensation effect of FBG and OPC has to be taken into account in the DWDM channel allocation for mm-wave fiber radio access systems. Further, the performance can be enhanced by the optical SSB filtering technique by taking advantage of a square and narrowband response FBG filter.

5. Conclusions

The impact of higher-order dispersion compensation on normalized signal power has been investigated in DSB transmission. The modified expression for diode current with the higher-order dispersion terms has been derived. We show that if there is dispersion compensation, the normalized power gets increased thereby optimizing the overall system performance. The first-order, second-order and third-order dispersion compensation has been demonstrated. It is observed that the first-order dispersion compensation has the major impact in comparison with second- and third-order dispersion compensation. Further the impact of dispersion compensation on the transmission distance has also been analyzed. It is seen that the transmission distance can be enhanced by 10^3 and 10^6 if dispersion compensation is performed using first-, first- and second-order dispersion terms together, respectively, this compensation results will enhance the DSB transmission in the mm-wave fiber radio system.

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