Journal of the Optical Society of Korea, Vol. 9, No. 1, March 2005, pp. 13-15

Chromatic Dispersion Tolerance of the SSB-Modulated Signals

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(Received January 12, 2005 : revised February 24, 2005)

It is shown that the SSB modulated signal has smaller chromatic-dispersion induced penalty than the DSB modulated signal only when the accumulated dispersion is large. When the accumulated dispersion is small, the SSB modulated signal has larger dispersion penalty than the DSB modulated signal. Therefore, if one builds a system with very low dispersion penalty, SSB modulation may end up with a larger dispersion penalty.

OCIS codes : 060.4510, 060.4080

I. INTRODUCTION

The single-sideband (SSB) modulation format has received considerable attention in the optical communications community. In SSB modulation, one of the two sidebands is removed to reduce the width of the signal spectrum to half. It has been expected that this reduction of the spectral width leads to two benefits [1]. Firstly, it has been expected to reduce the transmission penalty from the chromatic dispersion of the fiber. Secondly, it has been expected that we can place more WDM channels in a given optical bandwidth of the WDM systems to increase the system capacity.

In this letter, we show that the first advantage, which is related to the dispersion compensation, is limited to the region of a relatively large accumulated dispersion. We have found that when the accumulated dispersion is very small, SSB-modulated signal suffers more from the fiber dispersion. As the accumulated dispersion grows, the penalty on the DSB-modulated signal grows more quickly and becomes larger than the one on the SSB-modulated signal. The cross-over occurs where the eye-opening penalty is about 1 dB. Therefore, depending upon whether the allowed dispersion-related penalty is larger or smaller than 1 dB, SSB modulation can be superior or inferior to DSB modulation in terms of the chromatic-dispersion tolerance.

We start by representing a DSB signal $e_{DSB}(t, z=0)$ using its Fourier spectrum $E(\omega)$.

$$e_{DSB}(t) = \int_{-\infty}^{\infty} d\omega\, e^{-i\omega t} E(\omega) \tag{1}$$

The spectrum of the DSB signal can be divided into the upper sideband $E_U(\omega)$ and the lower side-band $E_L(\omega)$, which are defined as

$$E_U(\omega) = \begin{cases} E(\omega), & \omega > 2 \\ E(\omega)/2, & \omega = 2 \\ 0, & \omega < 2, \end{cases} \tag{2}$$

and

$$E_U(\omega) = \begin{cases} 0, & \omega > 2 \\ E(\omega)/2, & \omega = 2 \\ E(\omega), & \omega < 2\,. \end{cases} \tag{3}$$

When $e_{DSB}(t)$ is a real function, we have $E_L(-\omega) = E_U^*(\omega)$ from the properties of the Fourier transform. From this we can obtain

$$e_{DSB}(t, z=0) = 2\int_0^{\infty} d\omega\, \mathrm{Re}\left[e^{-i\omega t} E_U(\omega)\right], \tag{4}$$

where Re [·] means the real part of the complex argument. The SSB signal associated with the DSB signal of Eq. 1 can be expressed similarly as follows.

$$e_{SSB}(t, z=0) = \int_0^{\infty} d\omega\, e^{-i\omega t} E_U(\omega) \tag{5}$$

From Eqs. (4) and (5), we can observe that the DSB signal differs from the SSB signal by the presence of the Re [·] function in the integrand. We can also observe that a factor of 2 is not present in Eq. (5). This comes from the fact that the SSB signal is constructed by throwing away half of the spectrum of the DSB signal.

When we launch the DSB modulated signal $e_{DSB}(t, z=0)$ into a fiber of length L and dispersion β_2, the signal modified by the chromatic dispersion can be expressed as [2]

$$e_{DSB}(t,L) = 2\int_0^\infty d\omega \,\mathrm{Re}\left[e^{-i\omega t} E_U(\omega)\right] e^{-i\beta_2\omega_2 L/2} \tag{6}$$

where $e^{-i\beta_2(-\omega)^2 L/2} = e^{-i\beta_2\omega^2 L/2}$ was used. The SSB modulated signal after transmission can be expressed similarly as follows.

$$e_{SSB}(t,L) = \int_0^\infty d\omega e^{-i\omega t} E_U(\omega) e^{-i\beta_2\omega^2 L/2} \tag{7}$$

When we receive an SSB-modulated signal, we should use coherent detection, in which the measured electrical signal is just the real part of the received optical field [3]. In this case, the electrical signals measured from DSB- and SSB-signals of Eqs. 6 and 7 are expressed as

$$e_{DSB}(t,L) = 2\int_0^\infty d\omega \,\mathrm{Re}\left[e^{-i\omega t} E_U(\omega)\right] \cos(\beta_2\omega_2 L/2) \tag{8}$$

$$e_{SSB}(t,L) = \int_0^\infty d\omega \,\mathrm{Re}\left[e^{-i\omega t} E_U(\omega) e^{-i\beta_2\omega^2 L/2}\right]. \tag{9}$$

When we compare Eq. (8) with Eq. (9), we can observe that the effect of fiber dispersion appears as a factor of cos ($\beta_2\omega_2 L/2$) for the DSB modulated signal, while for the SSB modulated signal it appears as a factor of $e^{-i\beta_2\omega^2 L/2}$. For a small x, $\cos x \approx 1 - x^2/2$ and $e^{ix} \approx 1 + ix$. Therefore, when the accumulated dispersion $\beta_2 L$ is small, the effect of fiber dispersion on the DSB signal is in the second order of $\beta_2 L$, while the effect on the SSB signal is in the first order of $\beta_2 L$. Therefore, when the accumulated dispersion is very small, the SSB modulated signal suffers more from the fiber dispersion than the DSB modulated signal does.

To verify this, we performed numerical calculations of optical transmission through dispersive fiber. The transmission speed was 10 Gb/s, and the transmitter and receiver bandwidths were 10 GHz and 8 GHz, respectively. Fiber nonlinearities were not included in calculations. As the measure of the signal distortion, we used the eye-opening penalty, which is defined as the ratio of opening in the eye-diagram after the transmission to the one before. Figure 1 shows the EOP as a function of the accumulated dispersion. We can clearly observe that when the accumulated dispersion is smaller than 900 ps/nm the EOP from SSB signal is larger than the one from the DSB signal. One might suspect that this result applies only to the systems

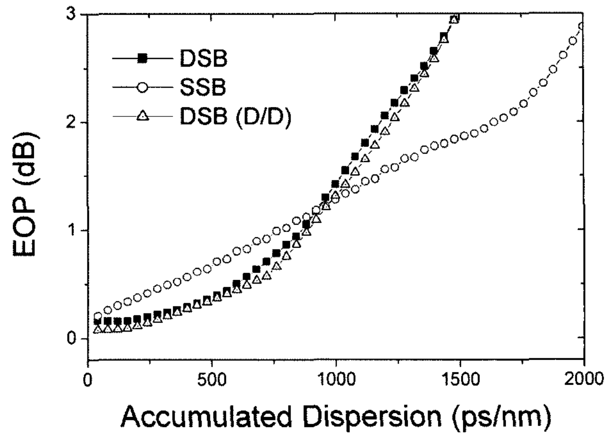

FIG. 1. Eye-opening penalties vs. accumulated dispersion.

using coherent detection. In order to determine whether this suspicion is true, we repeated numerical calculations for the DSB signals using the conventional direct-etection, and the result is also on Fig. 1. The penalty measured by the direct-detection was very close to the one measured by the coherent detection. Therefore, we can conclude that for a small accumulated dispersion, the dispersion penalty of the SSB signal is larger than the DSB signal regardless of the receiver type. (Note that for the SSB modulated signal, direct detection is impossible unless very large penalty is accommodated.) Also, we repeated calculations with several transmitter and receiver filter parameters, and obtained results similar to Fig. 1.

In Fig. 1, at the cross-over points of the EOP-vs-ispersion curves, the EOP is about 1.2 dB. Therefore, if the tolerable dispersion penalty of the system is larger than 1.2 dB, then the SSB modulation format has advantage over the DSB format. However, if the tolerance limit is smaller than 1.2 dB, then SSB modulation format is inferior to DSB modulation format in terms of chromatic dispersion penalty.

In summary, we showed that the SSB modulated signal has smaller chromatic-dispersion induced penalty than the DSB modulated signal only when the accumulated dispersion is large. When the accumulated dispersion is small, SSB modulated signal has larger dispersion penalty than the DSB modulated signal. For 10 Gb/s signals, the cross-over occurs at around 900 ps/nm and EOP of 1.2 dB. Therefore, when one builds a system with very low dispersion penalty, SSB modulation may end up with a larger dispersion penalty.

ACKNOWLEDGEMENT

This work was supported by ETRI, Daejeon, Korea.

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