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# 25-Gb/s optical NRZ transmission over 40 km of single-mode fiber at 1550 nm without dispersion compensation

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ABSTRACT

We present a method for transmitting 25-Gb/s optical nonreturn-to-zero signals at a wavelength of 1550 nm over a 40-km single-mode fiber without any dispersion compensation methods. We propose optimized self-phase modulation by varying parameters of the fiber launching power and the extinction ratio of optical non-return to zero signals to overcome severe signal distortions by the chromatic dispersion effect. Using the optimization of the self-phase modulation effect, we were able to transmit 25-Gb/s optical nonreturn-to-zero signals over a 40-km single-mode fiber, which can be applicable to passive optical networks with a single wavelength channel and a high split ratio. We demonstrated that the self-phase modulation effect can be controlled by the extinction ratio and the fiber launching power.



## 1. Introduction

Due to the increasing demand of internet data traffic, high-speed optical communication systems have been deployed in metropolitan areas and access networks. Nowadays, high-speed optical communication systems based on 25-Gb/s optical signals are standardized and are being rapidly developed. 100GBASE-LR4 and 100GBASE-ER4, which are included in the 100-Gb Ethernet (100 GbE), are based on wavelength division multiplexing of four-channel 25-Gb/s optical signals over optical single-mode fibers (SMFs) at a wavelength of 1310 nm. Due to the chromatic dispersion effect in SMFs, the wavelength for 100 GbE using SMFs is limited to 1310 nm. At this wavelength, the chromatic dispersion effect can be avoided.

The transmission of 25-Gb/s optical signals over SMFs at a wavelength of 1550 nm suffers from severe signal distortion by the group velocity dispersion (GVD) effect. The chromatic dispersion effect in optic fibers results in a degradation of a high-speed optical signal as it travels down the length of the fiber and limits the transmission distance and the data rate of optical communication systems. Therefore, many methods for dispersion compensation have been devised to overcome the intrinsic chromatic dispersion effect and increase the transmission distance or the data rate. One method is to use dispersion-tolerant optical transmitters such as the optical duobinary transmitter. Many methods have been proposed to implement dispersion-tolerant optical duobinary transmitters by using additional electrical or optical components [1–4]. 100 GbE systems based on a 4 × 25-Gb/s WDM duobinary transmission at a wavelength of 1550 nm were proposed [5]. In that system, duobinary optical transmitters using additional electrical components were used. In duobinary optical transmitters, a precoder composed of an XOR gate and a 1-bit delay is required because the transmitted bit sequence of optical signals differs from that of the data we wish to send. Another method is to use the chirp effect in an optical nonreturn-to-zero (NRZ) transmitter because the negative chirp effect can compensate for the pulse distortion due to the effect of chromatic dispersion in the anomalous wavelength region of SMFs [6]. The negative chirp effect can be implemented by the self-phase modulation (SPM) effect, another nonlinear fiber effect, in the anomalous wavelength region of SMFs. The SPM effect can compensate for the chromatic dispersion effect by controlling the fiber launching power into SMFs [7]. As the fiber launching power increases, the system performance of the optical communication systems can be improved by the increase in the signal-to-noise ratio and the compensation for the chromatic dispersion by the SPM effect. However, fiber launching powers larger than a threshold of the SPM effect make the signal distortion more severe and degrade the overall system performance despite the increase in the signal-to-noise ratio. The SPM effect on optical pulse propagation in nonlinear optical fiber has been investigated in optical transmission systems [8–10]. In this paper, we investigate the effect of the extinction ratio of the optical NRZ signals on the SPM effect in 25-Gb/s transmission system.

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Here, we propose a simple method for improving the chromatic dispersion tolerance of a conventional 25-Gb/s optical NRZ transmitter at a wavelength of 1550 nm. The method adjusts the fiber launching power into the SMF and the extinction ratio of the optical NRZ signals. We verified theoretically that the SPM effect can be affected by both the fiber launching power and the extinction ratio. Additionally, we numerically showed that 25-Gb/s optical NRZ signals at a wavelength of 1550 nm can be transmitted over 40 km of SMF without any dispersion compensation methods. This system configuration can be applicable to passive optical networks (PONs) with a single wavelength channel and a high split ratio. The increased fiber launching power can make an impact on the SPM effect and the split ratio in PON systems.

## 2. Self-phase modulation effect with respect to the extinction ratio

The SPM effect is a phenomenon that leads to spectral broadening of optical pulses by the intensity dependence of the refractive index in nonlinear media. It is well known that the SPM effect causes a nonlinear phase shift with respect to the amplitude of optical signals and generates the frequency chirp. The instantaneous optical frequency chirp generated by the SPM can be expressed as [7]

$$\delta\omega(T) = -\frac{1-\exp(\alpha z)}{\alpha}\gamma\frac{\partial}{\partial T}(|A(z=0,T)|^2), \tag{1}$$

where $A$ is the amplitude of the slowly varying envelope function, $\alpha$ is the absorption coefficient, and $\gamma$ $(= n_2\omega_0/cA_{eff})$ is the nonlinearity coefficient ($n_2$ is the nonlinear coefficient, $A_{eff}$ is the effective core area, and $\omega_0$ is the central frequency). The amount of the optical frequency chirp is determined by the nonlinearity coefficient of the fibers and the time variation of the optical power of $A(z = 0, T)$.

At the output of the optical transmitter, the extinction ratio $\varepsilon$ is defined by the optical powers at the zero and one levels as

$$\varepsilon = \frac{|A(z=0,\textit{one-level})|^2}{|A(z=0,\textit{zero-level})|^2}. \tag{2}$$

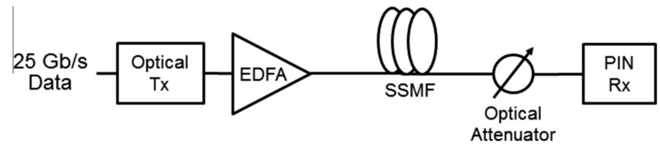


**Fig. 1.** Configuration of the 25-Gb/s optical transmission system.

The average optical power $P_0$ for optical NRZ signals can be expressed as

$$P_0 = \frac{|A(z=0,\textit{one-level})|^2 + |A(z=0,\textit{zero-level})|^2}{2}. \tag{3}$$

Therefore, from Eq. (1), the approximate optical frequency chirp for transition from zero-level to one-level of the optical signals can be expressed using the extinction ratio and the average optical power as

$$\delta\omega_{\textit{from zero-level to one-level}} = -\frac{1-\exp(\alpha z)}{\alpha}\gamma\frac{2P_0}{\Delta t}\left(\frac{\varepsilon-1}{\varepsilon+1}\right), \tag{4}$$

where $\Delta t$ is the transition time from the zero-level to the one-level. The instantaneous optical frequency chirp generated by the SPM effect is affected by both the average optical power $P_0$ and the extinction ratio of the optical transmitter $\varepsilon$. This instantaneous optical frequency chirp plays an important role in compensating for the optical pulse distortion due to the chromatic dispersion in the anomalous dispersion region. This means that the extinction ratio and fiber launching power should be considered in the SPM effect.

## 3. Transmission performance with respect to extinction ratio and fiber launching power

For the numerical simulation of the transmission performance of 25-Gb/s NRZ optical signals over SMF, the method shown in Fig. 1 was used. To control the SPM effect for the compensation for signal distortion due to the chromatic dispersion effect, we adjusted the extinction ratio of the output of the 25-Gb/s optical

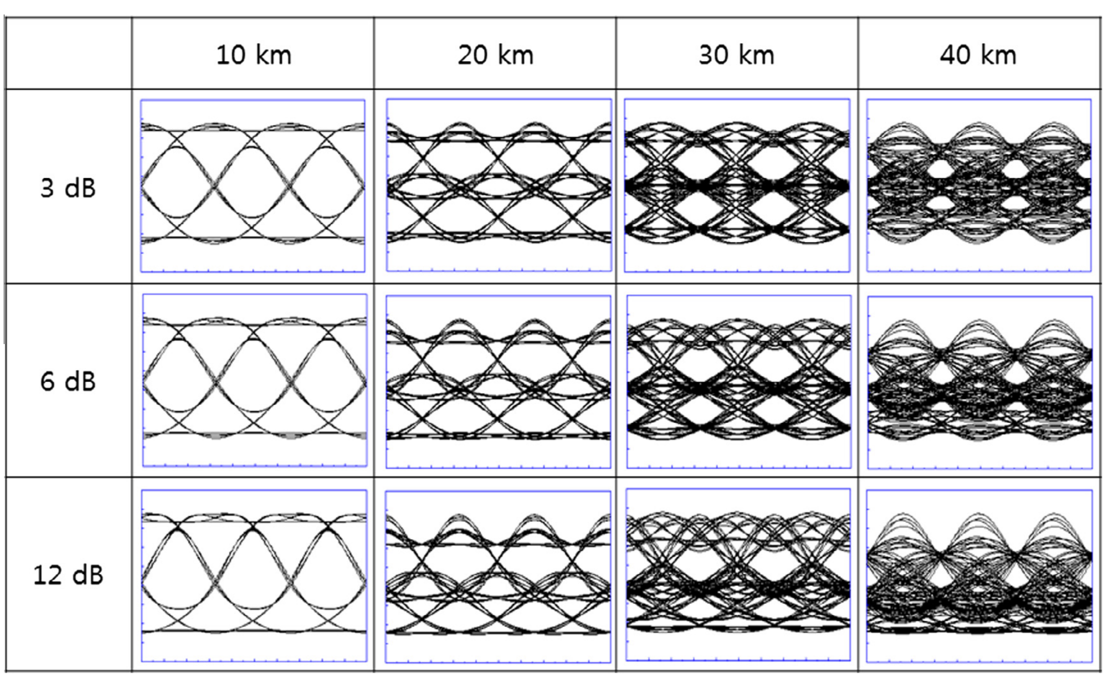


**Fig. 2.** Calculated eye diagrams considering the chromatic dispersion effect only for various extinction ratios of transmitter and fiber length.