Study of Optical Transmission Performance in IP-over-WDM Networks Based on FSK/ASK Combined Modulation Format

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The transmission performance of optical labeling based on a combined frequency shift keying/amplitude shift keying (FSK/ASK) format is studied by numerical simulation. The simulation demonstrates that the bit-error ratio (BER) characteristic of an ASK signal is limited by the extinction ratio, received optical power, and dispersion, simultaneously. However, an FSK signal is mainly limited by the extinction ratio (ER) and received optical power when the peak spectrum, which is used to detect the FSK signal, is relatively narrow.

Keywords: Frequency shifted keying, amplitude shifted keying, wavelength division multiplexing, labeled optical packet/burst switching.

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I. Introduction

Packet-based data traffic is growing rapidly and has overtaken circuit-switching traffic in today's telecommunication networks. However, the commercially available networks are still based on a circuit-switching technique, whose traffic capacity is natively limited. Carrying Internet protocol (IP) packets directly over wavelength division multiplexing (WDM) channels (IP-over-WDM) avoiding synchronous digital hierarchy (SDH) or asynchronous transfer mode (ATM) intermediate layers is considered a promising solution. A labeled optical packet/burst switched (LOBS) network, composed of edge and core routers, is very suitable to such a role due to its fast, flexible, and reliable forwarding of IP bursts/packets across WDM transport networks. In a LOBS network, ingress edge routers encapsulate the IP packets from access networks with a label according to their destination, quality of service (QoS), etc, and then forward them. Core routers perform routing and forwarding operations based on the information from the label assembled by the ingress edge router.

Several techniques for labeling of the optical signals have been proposed, such as a bit serial label [1], optical sub-carrier multiplexed label [2], and optical code division multiplexing [3], [4]. A more efficient, compact, and simple scheme, a combined frequency shift keying/amplitude shift keying (FSK/ASK) was proposed recently [5]-[9]. In this technique, the high speed payload is transmitted using intensity modulation, while the label data is conveyed on the same optical carrier by FSK modulation.

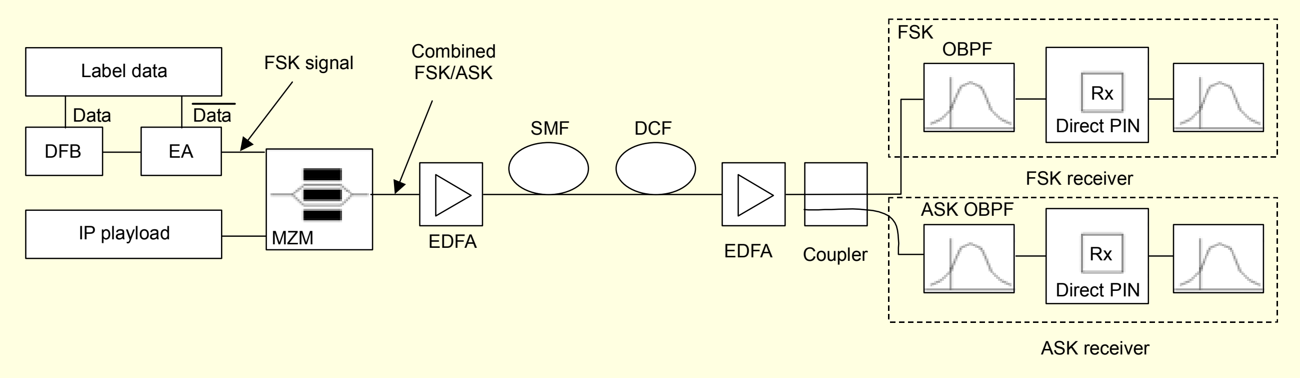

Fig. 1. FSK/ASK combined modulation scheme. MZM: M-Z modulator, EDFA: erbium doped fiber amplifier, SMF: single mode fiber, DCF: dispersion compensation fiber, OBPF: optical bandpass filter.

In this paper, we study the transmission performance of combined FSK/ASK modulation, where the extinction ratio (ER) of the ASK payload, optical power in the receiver end, and the accumulated dispersion of the transmission link are discussed. All of the works are based on the simulation results of VPI simulation software (VPI Transmission Maker).

II. FSK/ASK Combined Modulation Scheme

The FSK/ASK combined modulation scheme is illustrated in Fig.1. The distributed feedback (DFB) laser is driven with a bias current above the threshold and a relatively small modulation current, which results in both intensity and frequency modulation of the output light, as depicted in Figs. 2(a) and 2(b), respectively. The frequency modulation realizes FSK modulation, and the FSK signal can be directly detected after bandpass filtering in the receiver end. The FSK signal in the transmitter end is used as an optical carrier through M-Z and conveys the payload, which is an intensity modulation procedure, so called ASK. Its demodulation can be performed

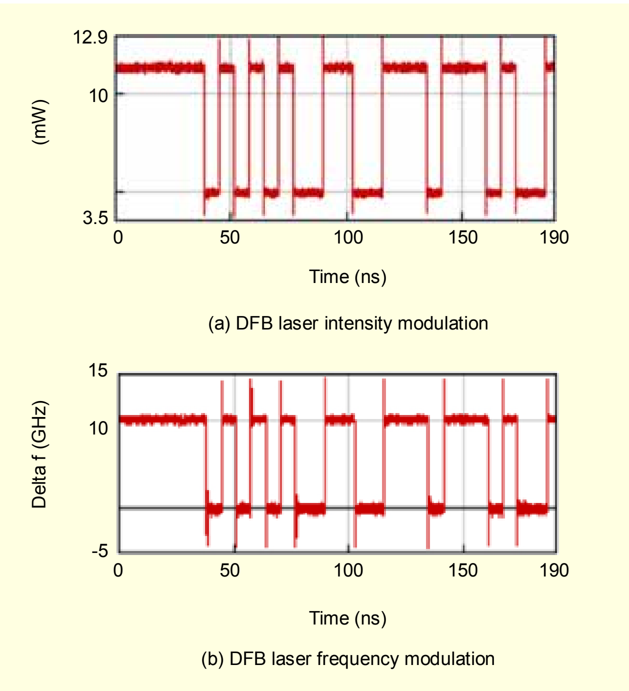

Fig. 2. (a) DFB laser output power versus time and (b) DFB laser frequency modulation versus time.

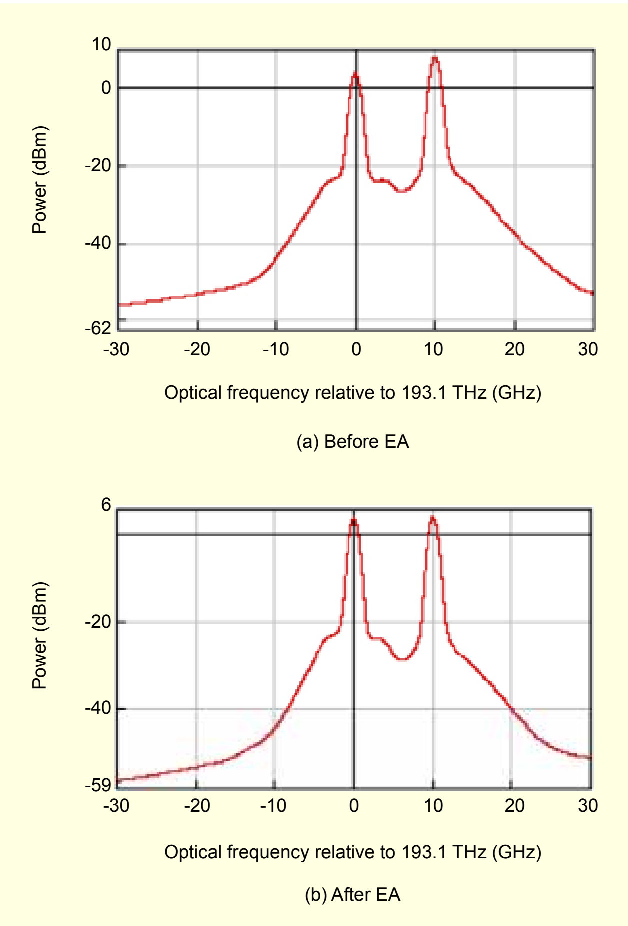

Fig. 3. DFB laser output spectrum (a) without EA and (b) with EA.

via direct detection. Thus, the combined FSK/ASK format is produced and is marked in Fig. 1.

In LOBS, the label is modulated in FSK and the high-speed IP packets/payload is modulated in ASK format. In Fig. 2(a) , it can be seen that the FSK labeled optical power fluctuates according to electronic label data due to intensity modulation, which results in an asymmetric output spectrum shown in Fig. 3(a). This asymmetric spectrum has a detrimental effect on the ASK payload. To overcome this problem, an integrated DFB laser-EA modulator [8] and a single grating-assisted coupler sampled reflector laser source [9] can be used. The DFB laser and EA modulator can also be used discretely to substitute for an integrated DFB laser-EA modulator, as is the case in our simulation. Figure 3(b) shows the output spectrum with obvious improvement when an EA modulator is used.

III. Transmission Performance

A complete FSK/ASK combined modulation and transmission scheme is depicted in Fig. 1. A 2^{23}-1 pseudo random bit sequence (PRBS) pattern for a 10 Gb/s payload and a 2^{7}-1 PRBS pattern for a 155 Mb/s label signal are assumed. The frequency detuning of the FSK signal is 10 GHz. Two peak-power spectra are located at 1553.599 nm (193.1 THz) and 1553.519 nm (193.11THz), as shown in Fig. 3. Therefore, the center wavelength of the ASK signal is located at 1553.559 nm (193.105 THz) which is also the center wavelength of the receiver filter for ASK signal detection. The bandwidth is 40 GHz for the ASK receiver filter. We utilize 1553.519 nm as the center wavelength of the FSK receiver filter and its bandwidth is 14 GHz. A 50 km single mode fiber (SMF) and 10 km dispersion compensation fiber (DCF) are used as a transmission link. The attenuation coefficients of the SMF and DCF are 0.2 dB/km and 0.3 dB/km, respectively. The dispersion coefficient and dispersion slope for the SMF are 16 ps/nm/km and 0.08 ps/nm^2/km, respectively, and -80 ps/nm/km and -0.28 ps/nm^2/km for the DCF, respectively. Two ideal erbium doped fiber amplifiers (EDFAs) are used; the first, with a 5 dB noise figure, is mainly used to boost the optical signal injected to the fiber, and the second, with a 4 dB noise filter, is mainly used to improve the noise characteristic of the received optical signal. Although the degree of intensity modulation for the FSK signal can be reduced through the measures mentioned before, a residual 0.5 dB intensity modulation is still assumed to emulate a worst case. The transmission performance is affected by many factors [6]. Of great importance are the payload ER in the transmitter end, optical power in the receiver end, and the transmission link dispersion compensation amplitude. A detailed analysis is as follows.

1. Extinction Ratio

Figure 4 shows the relation between bit error ratio (BER) and payload ER in the transmitter end for both FSK label and ASK payload, where 20 MHz and 100 MHz of laser linewidth is used and the optical power in the receiver end is basically kept constant (about 2 dBm). It is very clear that a large ER is preferable to achieve a better BER for the ASK payload, while a reduced ER is necessary to achieve a proper detection for the FSK signal. Sufficient optical power should be kept even for consecutive data "zeros" from the ASK in order to detect the FSK label. A compromise of ER that can make the BER below 10^{-9} for the ASK payload and 10^{-12} for the FSK label, simultaneously, must be determined. The ER is between about 3 dB and 11 dB for 2 dBm of total optical power in the receiver. The influence of laser linewidth on the BER is not very obvious in Fig. 4 due to the full dispersion compensation of the transmission link.

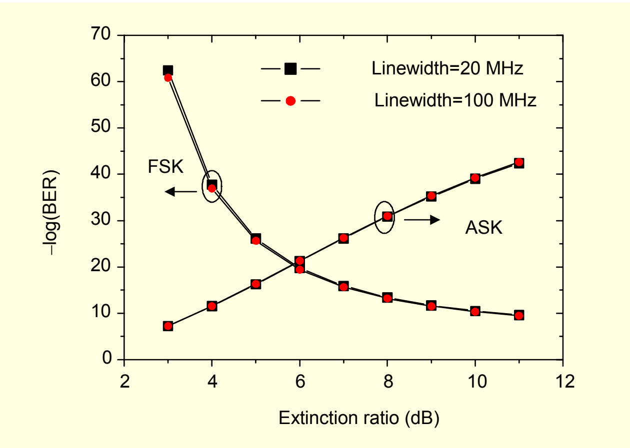

Fig. 4. BER versus ER for 20 MHz and 100 MHz of laser linewidth.

2. Received Optical Power

For a fixed ER, the transmission characteristic of the FSK label and ASK payload varies according to the received optical power, which is shown in Fig. 5 in the case of 7 dB of ER and 50 MHz of laser linewidth. It should be noted that for a constant total received optical power before the coupler in Fig.1, the BER for the FSK label and ASK payload can be optimized by adjusting the coupler split ratio.

More often, the receiver sensitivity, defined as the received optical power for a BER of 10^{-9} and 10^{-12} for payload and label [6], respectively, is adopted to describe the transmission characteristic of FSK and ASK. Figure 6 depicts the FSK and ASK receiver sensitivity as a function of ER, where 20 MHz, 50 MHz, and 100 MHz of laser linewidth are adopted. The simulation results are basically the same as in [5] and [6]. About 8 dB of ER seems proper to guarantee the same sensitivity for FSK and ASK. But it should be noted that this is

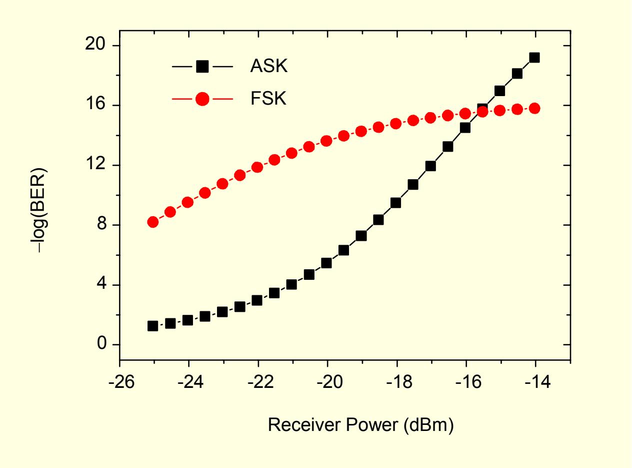

Fig. 5. The relation between BER and received optical power for 7 dB of ER and 50 MHz of laser linewidth.

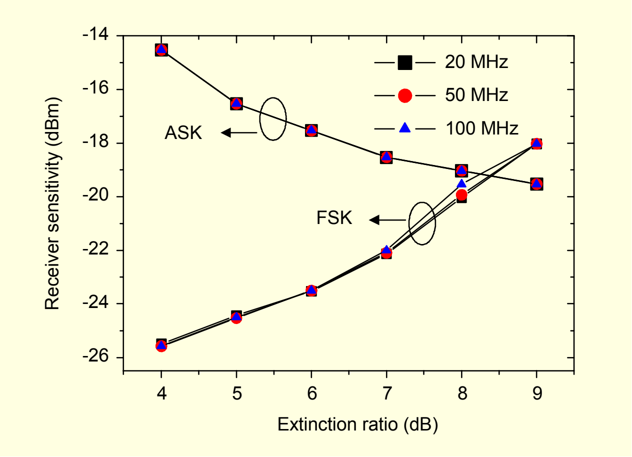

Fig. 6. The receiver sensitivity versus extinction ratio for 20 MHz, 50 MHz, and 100 MHz of laser linewidth.

based on a 50:50 coupler. The relationship between sensitivity and ER varies according to the coupler coefficient.

3. Dispersion Limitation

The ASK signal is affected more severely by the dispersion of the transmission link than the FSK signal due to its broad spectrum as shown in Fig. 3. Figures 7(a) and 7(b) depict the eye diagram opening of FSK and ASK signals, respectively. Here, the payload ER is assumed to be 7 dB. The SMF length is 30 km without dispersion compensation. Other conditions are maintained as before. It is obvious that the eye diagram opening will be inferior for the ASK signal when compared with the FSK signal. In this case, the BER is 9.27×10^{-8} and 6.05×10^{-16} for ASK and FSK, respectively.

Figure 8 shows the BER as a function of the dispersion coefficient for 7 dB of ER. The lengths of the SMF and DCF are still 50 km and 10 km, respectively, and post-compensation is adopted due to its advantage [5]. It can be seen that the best BER characteristic for ASK is achieved when the dispersion coefficient is around -80 ps/nm/km. In fact, the 10 km DCF with such a dispersion coefficient compensates the dispersion accumulated in the 50 km SMF exactly. Both over- or less-dispersion compensation for the dispersion coefficient deviating from -80 ps/nm/km will result in deterioration of the BER for an ASK payload.

For the FSK signal, the influence of dispersion on the BER decreases greatly, which can be seen in Fig. 8. This can be explained from the FSK power spectrum in Fig. 3. Although the FSK signal has two peak spectra with a total bandwidth of more than 10 GHz, only one of them is used in the receiver to detect the FSK label. The 3 dB bandwidth for either peak spectrum is below 1.2 GHz. As is well known, the dispersion limitation effect decreases as the spectrum gets narrower.

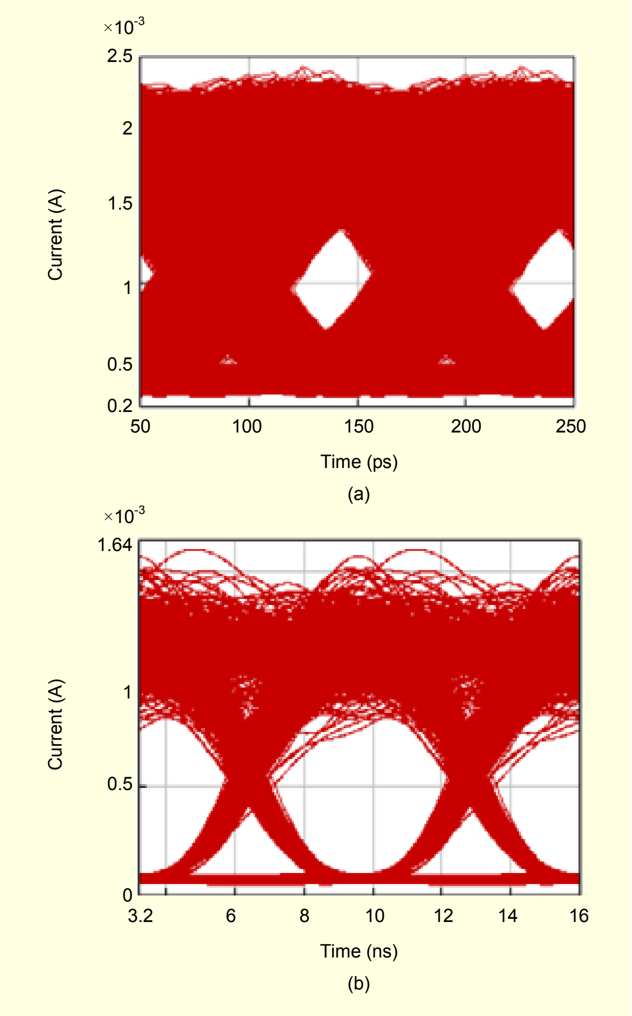

Fig. 7. (a) Eye diagram of ASK payload and (b) FSK label for 20 km SMF without dispersion.

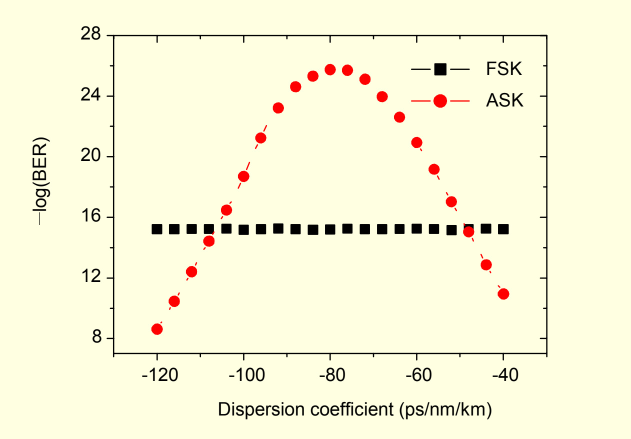

Fig. 8. BER versus dispersion coefficient.

Therefore, the FSK signal suffers less from dispersion.

IV. Conclusions

The combined FSK/ASK modulation format is a promising technique which can be used to carry an IP packet's label/payload, respectively, and its transmission performance is numerically simulated. The simulation demonstrates that the FSK label and ASK payload have different ER requirements. A large ER is helpful to improve the BER of an ASK payload, while the case is reversed for an FSK label. The sensitivity of an FSK label and ASK payload receiver varies with the ER. For a fixed ER, the BER is also a function of the received optical power, and an optimized coupler split ratio exists. Dispersion of the transmission link deteriorates the ASK performance severely. The BER of the ASK signal is as high as 9.27×10^{-8} through 30 km of SMF without dispersion compensation. However, it can be improved to 10^{-12} for a 50 km SMF with a 10 km DCF transmission.

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