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Pulse-carving technique for suppressing transient state in external wideband FSK modulation

Takahide Sakamoto[a)], **Tetsuya Kawanishi, and Masayuki Izutsu**
National Institute of Information and Communications Technology
4–2–1 Nukui-kitamachi, Koganei-shi, Tokyo 184–8795, Japan
a) *tsaka@nict.go.jp*

Abstract: A novel pulse-carving technique for an externally-modulated wideband frequency-shift-keying (FSK) format is proposed. Synchronous intensity modulation on the FSK signal suppresses undesired transient components generated during the bit transition time. Numerical analysis for the pulse-carving technique employing a Mach-Zehnder modulator driven by a sinusoidal signal indicates that the suppression of the components is typically more than 20 dB.

Keywords: pulse carving, optical frequency-shift keying, external modulation

Classification: Photonics devices, circuits, and systems

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1 Introduction

External modulation technologies play important roles in high-speed and long-haul optical fiber communication systems [1]. Recent progress in optical modulation formats, such as differential phase-shift-keying, is also sustained by the external modulation technologies [2]. However, external frequency-shift keying (FSK) modulation had been difficult to perform for a long time, before a high-speed $LiNbO_3$ FSK modulator was successfully developed [3].

This FSK modulation scheme, however, has the drawback that the modulated signal suffers from a transient optical beat at the transition of a modulation data sequence. To overcome this problem, in this paper, we propose

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pulse carving the FSK signal, a new technique to suppress the transient signal. The effectiveness of this technique is examined using numerical analysis.

2 Principles

The basic concept of FSK modulation with the pulse-carving technique is shown in Fig. 1. Schematic (a) depicts the structure of a transmitter made of an FSK modulator and a Mach-Zehnder modulator. The principle operation of the FSK modulator, surrounded by a dotted box in the figure, is explained as follows. In the modulator, two Mach-Zehnder modulators (MZ-a and MZ-b) are embedded in each arm of a main modulator (MZ-c). MZ-a and MZ-b are biased at the null point and driven by sinusoidal signals (RF-a and RF-b). The signals have the same frequency, f_0, but the phase difference between them is $\pi/2$. When the optical phase difference between MZ-c arms is $-\pi/2$ or $\pi/2$, the upper-sideband (USB) or lower-sideband (LSB) component at f_0, respectively, is constructively generated, while the other sideband components are destructively suppressed. If a non-return-to-zero (NRZ) baseband signal (DATA) at a bit rate of B [bit/s] is fed to the MZ-c electrode, USB or LSB is generated according to the DATA bit sequence. Thus, external FSK modulation is achieved when the mark and space levels induce phase differences of $\pi/2$ and $-\pi/2$, respectively.

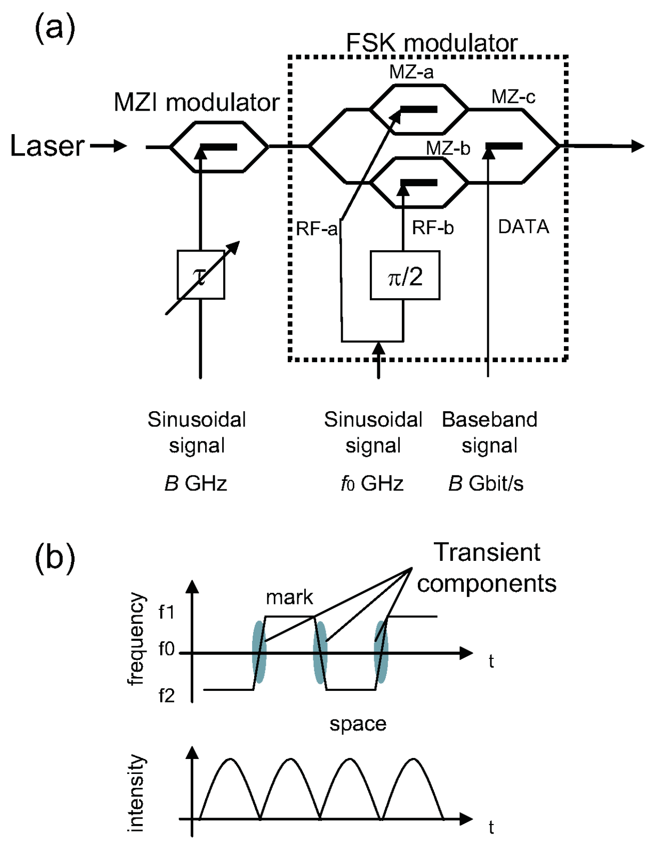

Fig. 1. Concept of FSK modulation with a "pulse-carving" technology. (a) Basic structure; (b) suppression of transient components.

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In the operation of such an external FSK modulation, however, the optical intensity of the modulated signal oscillates during the transition between the USB and LSB signals. This is because both sideband components are emitted from the modulator during the transient state.

To overcome this problem, we propose a novel technique for suppressing the transient components: pulse carving using a Mach-Zehnder modulator. FSK modulated light is intensity modulated to decrease the optical intensity to zero during the transition, as shown in Fig. 1 (b). This optical intensity control is achieved by using another intensity modulator driven by a sinusoidal RF signal synchronous to the baseband data.

3 Numerical analysis

3.1 Conditions for the simulation

A numerical simulation model for pulse carving on an external modulated signal in FSK format is shown in Fig. 2. An FSK modulator is connected to a Mach-Zehnder intensity modulator (IM) in tandem. The frequency of the sinusoidal signal fed to the RF-a and RF-b electrodes is 10 times the bit rate of the baseband signal ($f_0 = 10\,B$). The baseband signal is in NRZ format whose transient time ($T_{\rm tr}$) is set to any value. $T_{\rm tr}$ is defined, here, as the sum of the rise and fall times of the NRZ waveform. The IM modulator is biased at the $\pi/4$ point and driven with a sinusoidal signal at f_0 for the pulse carving. The RF delay (τ) between this signal and the baseband data is variable in this simulation.

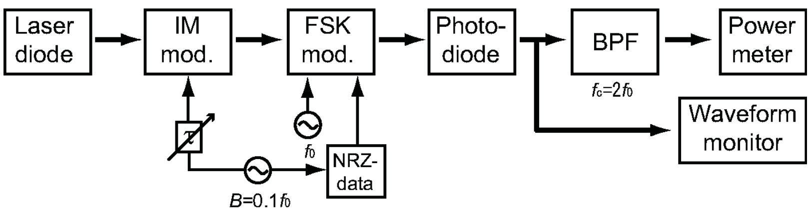

Fig. 2. Simulation model.

3.2 Results

Fig. 3 (a) shows suppression ratio of the transient components calculated as a function of the timing delay between the baseband data and the pulse-carving signal. The suppression ratio is defined as $\kappa = \log(\mathrm{P}_{\rm tr,RZ}/\mathrm{P}_{\rm tr,NRZ})$, where $\mathrm{P}_{\rm tr,RZ}$ and $\mathrm{P}_{\rm tr,NRZ}$ are RF intensities around the frequency of $2f_0$ in the FSK signal, which are evaluated when the pulse carving is applied or not, respectively. Squares, circles and triangles have different values of the transient times: $T_{\rm tr} = 0.1\,B^{-1}$, $0.2\,B^{-1}$, and $0.4\,B^{-1}$, respectively. These results indicate that the suppression ratio is dependent on the RF delay τ. The maximum suppression is obtained when $\tau = nB^{-1}$, which corresponds to the case, in which optical intensity becomes zero at the transient state. Although the suppression ratio (κ) becomes worse for the longer transient

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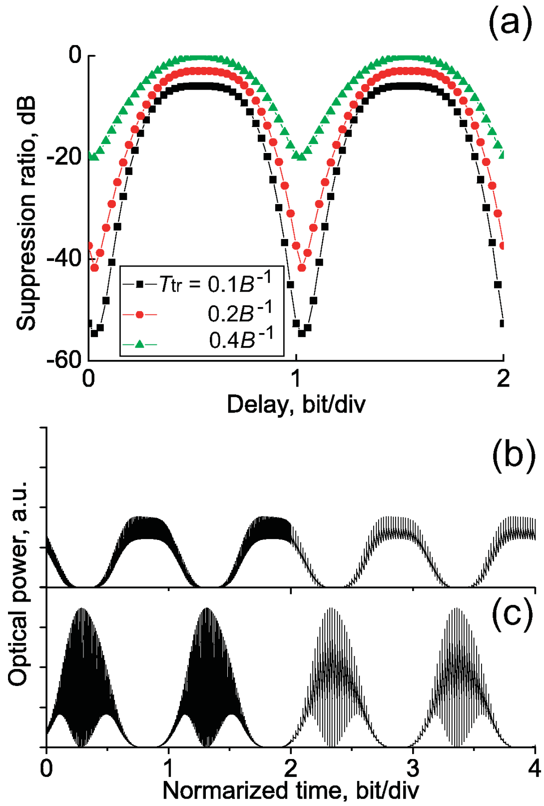

Fig. 3. (a) Suppression ratio of the transient components as a function of timing delay of pulse carving signal. Optical waveforms. (b) Timing delay between pulse carving signal and baseband data is in the optimum condition, $\tau = nB^{-1}$, and (c) in the worst case, $\tau = (n + 1/2)B^{-1}$.

time (T_{tr}), the κ keeps more than 20 dB even if $T_{tr} = 0.4\,B^{-1}$. This graph also shows that timing delay tolerance of κ, for keeping 20-dB suppression, is more than $0.25\,B^{-1}$, if $T_{tr} < 0.2B^{-1}$.

Optical waveforms at the output of the modulator are shown in Fig. 3 (b) (c). Waveform (b) indicates the case at $\tau = nB^{-1}$, where the transient components are successfully suppressed. On the other hand, these components are emphasized in the worst case at $\tau = (n+1/2)B^{-1}$, as shown in Fig. 3 (c).

3.3 Discussions

Because the transient components are attributed to the optical beat between the USB and LSB signals, the FSK-modulated signal has the frequency components around $2f_0$; thus, an electrical low-pass filter installed on the receiver side easily eliminates such high-frequency components. Note that the role of the pulse carving is to suppress the transient optical beat before the FSK-modulated signal is introduced into fiber transmission lines. Without this technique, the transient signal generates out-of-band components due to nonlinear effects in the fibers that induce four-wave mixing between the adjacent bits of the FSK signal; accordingly, it is possible that the signals in neighboring WDM channels are degraded.

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4 Conclusions

In this paper, we have proposed the pulse-carving technique for externally modulated wideband FSK signal. By setting the optical intensity to zero when its frequency shifts to the other state, between the USB and LSB, the transient components can be highly suppressed. Numerical simulation indicated that the suppression ratio is more than 20 dB even if transient time exceeds 0.4 times the bit duration.

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