Bandwidth-On-Demand Ultra Dense WDM Access (1.25/2.5 Gb/s × N-ch) Employing Time-Domain Interleaved Wavelength-Swept Transmitter

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Abstract *To realize a flexible WDM signal format, the dynamic control of channel number and data rate is proposed. A total rate of more than 10 Gb/s with ultra-dense spacing (< 10 GHz) is demonstrated experimentally.*

Introduction

WDM is a promising technique that meets a growing demand for increased bandwidth and various types of services in future access networks [1]. With downlinks in particular, it is expected that the growth of high-quality video distribution and on-demand services will drive the need for much higher speeds. In future WDM-based access systems, channel granularity will be an essential factor as regards accommodating many users/services within the limited spectrum bandwidth unoccupied by existing systems. In addition, there will be a need for flexibility to cope with the wide range of user and system requirements. As a solution for future WDM-based access systems, we have already proposed a wavelength-swept light based WDM transmitter [2]. With this method, WDM signals with a dense channel spacing can be realized with only a single wavelength-swept light source. And, by adjusting the wavelength sweep range, we can realize dynamic control of the number of wavelength channels.

In this paper, we propose the concept of the combined use of a wavelength-domain approach (bandwidth-on-demand operation) and a time-domain approach (interleaving for multiplication of data rate) to realize more flexible control of the WDM signal format for wavelength-swept WDM access systems. With this technique, we can dynamically control both the number of channels and the data rate of each channel, depending on user/system demand. We demonstrate 1.25/2.5 Gb/s/ch ultra dense WDM transmission, where the channel spacing is less than 10 GHz, and confirm the feasibility of the proposed technique for a total data rate of more than 10 Gb/s.

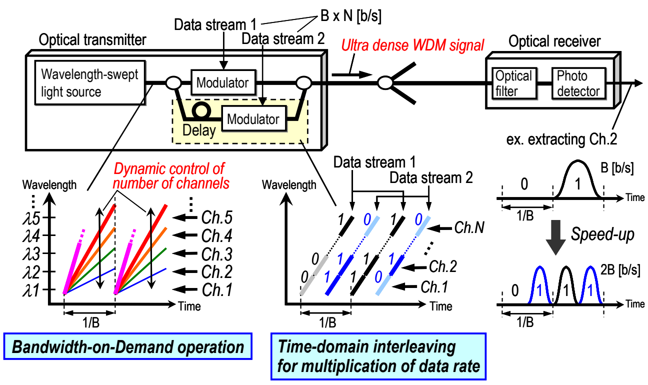

Fig. 1: Concept of two-domain (wavelength and time) approach for flexible control of WDM signal format

Principle

In our wavelength-swept light based scheme, WDM signals are realized by modulating the wavelength-swept light with a data stream, which is obtained by multiplexing all the channel data in the time domain [2]. This method requires only a single light source, and by adjusting the wavelength sweep characteristic we can control the wavelengths of all the channels. Moreover, by utilizing the wavelength sweep feature, we can easily realize flexible control of the WDM signal format, namely the number of wavelength channels and the data rate of each channel as shown Fig. 1.

First, with this scheme, we can control the number of wavelength channels simply by adjusting the wavelength sweep range and the number of channel data to be multiplexed in the time domain and input into the modulator. This means that we can effectively cope with the wide range and rapidly changing demands for bandwidth without installing additional lasers. We have already reported a preliminary demonstration of 1.0 Gb/s/ch WDM transmission employing heterodyne detection, and adjusting the number of channels [2]. Furthermore, since there is sufficient guard time between bits, the data rate of each channel can be multiplied by additionally time-domain interleaving plural data streams [3]. As an example, the interleaving of two data streams is shown in Fig. 2. In this case, the data rate of each channel can be doubled. By combining the two domain approaches, we can manage the wide range of user/system demands with greater flexibility.

Experiments and results

Fig. 2 shows an experimental setup that emulated 1.25 and 2.5 Gb/s/ch (interleaved) WDM transmission. On the transmitter side, 1.25 GHz wavelength-swept light is yielded by the direct frequency modulation of a DFB-LD with a ramp wave modulating signal. A following SOA operated under a gain-saturated condition and suppressed the intensity modulation effect induced by the direct modulation. At an EAM, the wavelength-swept light was modulated with 1.25 Gb/s × N (N: number of channels) PRBS data, which synchronized with the wavelength sweep. Fig. 3 shows the optical waveform at an EAM output for a four-channel case. We can expect each wavelength band to be modulated with the corresponding channel data bit-sequentially as shown in Fig. 3. And, Fig. 4 (a) shows a 1.25 Gb/s eye diagram (without interleaving) of each channel. To demonstrate two-channel to six-channel WDM,

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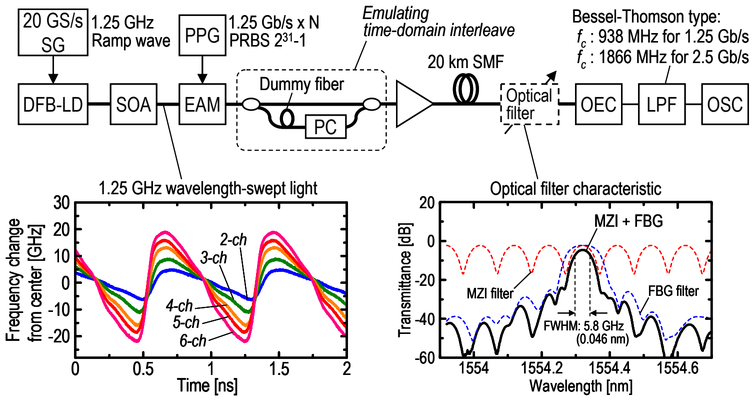

Fig. 2: Experimental setup for 1.25/2.5 Gb/s/ch ultra dense WDM transmission

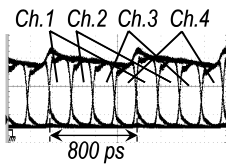

Fig. 3: Optical waveform at EAM output with four channels

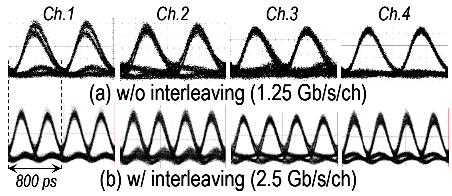

Fig. 4: Eye diagrams for four channels with and without time-domain interleaving

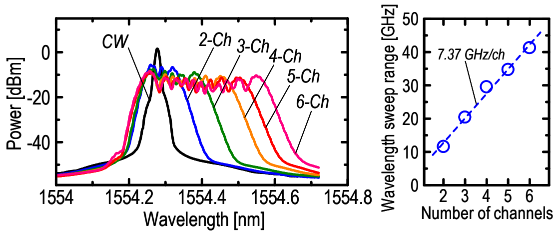

Fig. 5: Optical spectra at EAM output and wavelength sweep range versus number of channels

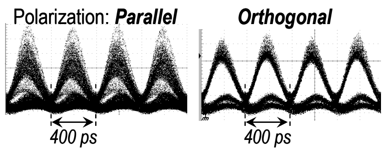

Fig. 6: Eye diagrams of Ch.2 for three-channel case

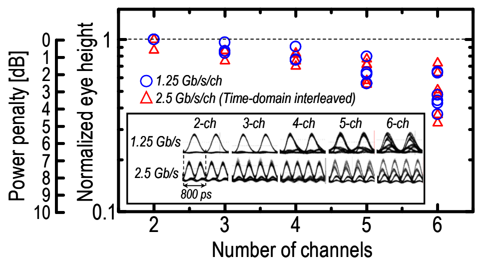

Fig. 7: Normalized eye heights (insets are eye diagrams of worst channel)

we adjusted the wavelength sweep range as shown in the Fig. 2 inset, by changing the current amplitude of the ramp wave modulating signal, and set the total data rate at 2.5 (1.25 × 2) ~7.5 (1.25 × 6) Gb/s. Fig. 5 shows the optical spectra at the EAM output in each case, and the wavelength sweep range versus number of channels. These figures show that we achieved an ultra dense channel spacing of less than 10 GHz. On the receiver side, we used the MZI filter (FSR = 12.5 GHz) and the FBG filter (FWHM = 10.5 GHz) in tandem as a narrow optical filter, as shown in the Fig. 2 inset, to extract a desired channel. In this experiment, the time-domain interleaving of two data streams was emulated using a single modulator as shown by the dotted line in Fig. 2; i.e., the EAM output signal was split into two, and coupled after a time difference (skew) of 400 ps had been added. In one of the two paths, a dummy fiber was used to reduce the correlation between the two data streams. Here, we used a polarization controller (PC) to investigate the impact of the polarization relationship between the two light streams. Fig. 6 shows the eye diagrams of the center channel (Ch. 2) for a three-channel case, when the polarization relationships were "parallel" and "orthogonal", respectively. We can see that whereas in the "parallel" case, the eye opening degraded owing to the crosstalk between the two data streams, an open eye was obtained in the "orthogonal" case. Based on this result, we measured eye diagrams for all cases with an "orthogonal" polarization relationship. As examples, eye diagrams for the four-channel case with interleaving are shown in Fig. 4 (b). Fig. 7 shows all the measured eye heights (ε) normalized by the value of the shorter wavelength channel (Ch. 1) for two channels (2-ch), in all cases, and the insets are eye diagrams of the worst channel, with the most closed eyes, in each case. In these measurements, sufficient optical power (> -10 dBm) was maintained at the OEC input to allow us to separate the impairment induced by receiver noise. We also show the power penalty (= $-10\log_{10}(\varepsilon)$ [dB]) compared with that of Ch. 1 for two channels on the vertical axis. The result shows that almost the same performance was obtained for both 1.25 and 2.5 Gb/s/ch (interleaved). And, even though there was a power penalty of more than 2 dB owing to inter-channel crosstalk for a part of the five- and six-channel cases, the impairment was not very serious in the other cases. These results show that flexible operation in two domains can be realized for a total data rate of more than 10 Gb/s (2.5 Gb/s × 4).

Conclusions

We proposed the concept of the combined use of a wavelength-domain approach (bandwidth-on-demand operation) and a time-domain approach (interleaving) for a wavelength-swept WDM access system. We demonstrated 1.25/2.5 Gb/s/ch ultra dense WDM transmission, where the channel spacing was less than 10 GHz, and the results confirmed that flexible control of both the number of channels and the data rate of each channel can be achieved for a total data rate of more than 10 Gb/s.

References

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