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Multi-channel Spectrum Analyzer for High Capacity Optical Transport Networks

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A simple multi-channel spectrum analyzer using an InGaAs array sensor and a diffraction grating is proposed and developed for high-capacity optical transport networks. With the developed multi-channel spectrum analyzer, we could measure signal power, wavelength, and optical signal-to-noise ratio of each channel for multi-channel optical signals with 100 GHz and 50 GHz channel spacing, simultaneously. We could measure each channel power and wavelength with a deviation of less than 0.2 dB and 0.063 nm, respectively. We have obtained optical signal-to-noise ratio with a deviation of less than 1.0 dB compared with conventional optical spectrum analyzer in the wide input power range between -42 dBm and -27 dBm per channel.

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I. INTRODUCTION

As optical transport networks become more transparent, optical performance monitoring is more important as a means to monitor signal properties and to manage network faults due to optical impairments [1]. In the optical transport networks employing optical cross-connect systems and optical add-drop multiplexing systems, multi-channel signals are added or dropped frequently in the optical transmission layer. The optical performance of multi-channel signals can be different from each other, which makes it difficult to perform fault analysis. This is because the individual channel undergoes different optical loss, gain and noise accumulation until arriving at its final destination [2]. Therefore, such optical transport networks require optical performance monitoring of multi-channel signals at every node to confirm the quality of service. Recently, several optical performance monitoring schemes using a diffraction grating and an acousto-optic tunable filter have been proposed [3,4]. However, their configurations are not suitable for high capacity optical transport networks because of the limitation in the optical resolution and long sweeping time.

In this paper, we proposed and developed the improved multi-channel spectrum analyzer to ensure effective maintenance of high capacity optical transport networks. Since the developed multi-channel spectrum analyzer can minimize the effect caused by an aberration and maintain the same F-number in the optical path, it has a high optical resolution and a wide dynamic range. With the developed multi-channel spectrum analyzer, we could measure signal power, wavelength, and optical signal-to-noise ratio (OSNR) of each channel, simultaneously.

II. CONFIGURATION AND PRINCIPAL

Fig. 1 shows the configuration of the developed multi-channel spectrum analyzer. It is composed of a lens, a diffraction grating, a quarter wave plate for polarization compensation, plane mirrors and an InGaAs array sensor. The InGaAs array sensor has 512 elements with 25×250 nm^2 pixel size. The diffraction grating is a ruled type and has grooves of 600 lines/mm. The effect of an aberration can be minimi-

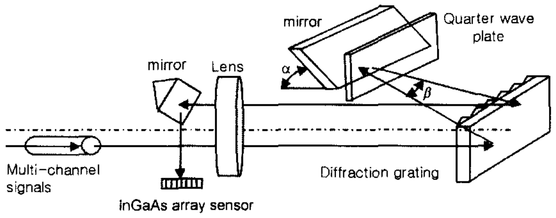


FIG. 1. Proposed configuration of multi-channel spectrum analyzer.

zed to obtain a high resolving power and a wide dynamic range, since the plane mirror is tilted by an angle α with regard to the incident beam. The relation between the titled degree α of the plane mirror and the degree β of beam reflected by the plane mirror is expressed as $\alpha = 2\beta$. As the titled degree α of the plane mirror is adjusted, the angle β of beam reflected by the plane mirror can be controlled. The incident beam from the lens is diffracted by the lower part of the diffraction grating. On the contrary, the incident beam from the quarter wave plate is diffracted by the upper part of the diffraction grating. Therefore, since the developed multi-channel spectrum analyzer has no additional devices such as a beam splitter and an additional lens to focus the output beam from the diffraction grating on the InGaAs array sensor, the aberration can be minimized. We used a double pass configuration to reduce the size of the multi-channel spectrum analyzer. In this case, the grating equation and angular dispersion are expressed as follows

$$a(\sin\theta_i + \sin\theta_d) = \lambda \tag{1}$$

$$D = \frac{2m}{a\cos\theta}\ (\theta_i = \theta_d = \theta) \tag{2}$$

where a is the groove spacing, θ_i is the incidence angle of the grating, θ_d is the diffraction angle of the grating, λ is the wavelength of the input signal, and m is the diffraction order. To reduce the dependence of the diffraction grating's insertion loss on the state of polarization of the input signal, we used a quarter wave plate [5]. After the light beam goes through the quarter wave plate, the vertical component is rotated to become the horizontal component, and the horizontal component is rotated to become the vertical component. Thus, for any input polarization, the final optical output from the diffraction grating is given as a function of the product of the s-wave diffraction and p-wave diffraction efficiencies. The output beam from the grating is then focused on each single pixel on the InGaAs array sensor. If an array sensor is used in the focal plane of the lens to measure the spectrum of multi-channel optical signals, it is convenient to describe the spread of wavelengths on the array sensor in terms of a linear dispersion $dx/d\lambda$, where x is a size of array sensor. Since $dx = fd\theta$, the linear dispersion is given by

$$\frac{dx}{d\lambda} = f\frac{d\theta}{d\lambda} = fD \tag{3}$$

Inserting the Eq. (2) into Eq. (3),

$$\frac{dx}{f} = d\theta = \frac{2md\lambda}{a\cos\theta} \tag{4}$$

To measure spectrum of multi-channel optical signals with 50 GHz channel spacing, the diameter of the Airy disk must not exceed 30 μm. The Airy disk in terms of a focal length is given by

$$A_d = 2.44\lambda\frac{f}{d} \tag{5}$$

where d is a diameter of the diffraction grating. The focal length is 98 mm for the case of Airy disk A_d = 30 μm and the diffraction grating size d = 12 mm (50 × 12 mm^2). The incidence angle and the diffraction angle can be calculated from Eqs. (1) and (4). The angles of incidence and diffraction are 74 degrees and -2 degrees, respectively.

III. EXPERIMENT AND RESULTS

Fig. 2 shows the experimental setup for evaluating the multi-channel spectrum analyzer. Each pixel of the InGaAs array sensor covered approximately 0.06 nm, providing a total detection bandwidth of about 32 nm. Multi-channel optical signals were used with channel spacing of 50 GHz in the range of 1531.89 nm (channel 1) to 1561.82 nm (channel 73). Multi-channel optical signals of C-band_1 have 100 GHz channel spacing and offset from multi-channel optical signals of C-band_2 by 50 GHz. Each channel signal was modulated with 10 Gb/s by external intensity modulator. To simulate OSNR degradation in channel 18 with a center wavelength of 1545.32 nm, the level of the attenuator attached to the laser diode 18 (LD #18) was adjusted, and the input power to the erbium doped fiber amplifier (EDFA) was changed. We measured the spectrum of multi-channel optical signals with 50 and 100 GHz channel spacing, respectively. As a reference, the spectrum was also measured by a commercial optical spectrum analyzer with a resolution of 0.1 nm. Fig. 3 shows the exterior view of the developed multi-channel spectrum analyzer. The dimensions are 178×110×46 mm^3 including control electronics. Figs. 4(a) and (b) show the experimental results of multi-channel optical signals with 100 GHz and 50 GHz channel spacing by using the developed multi-channel spectrum analyzer, respectively. We could measure the spectrum in the OSNR range of about 25 dB and 20 dB for multi-channel optical signals with 100 GHz and 50 GHz channel spacing,

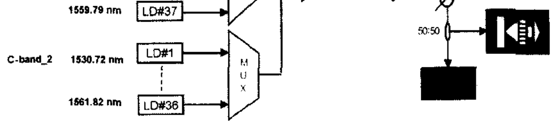


FIG. 2. Experimental setup for multi-channel spectrum analyzer.

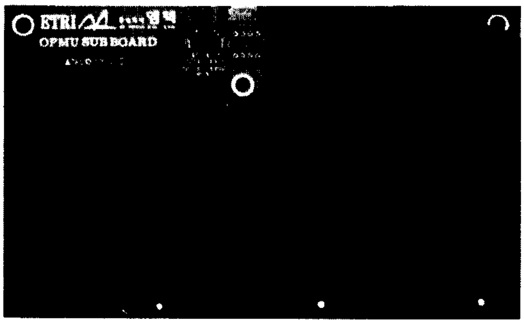
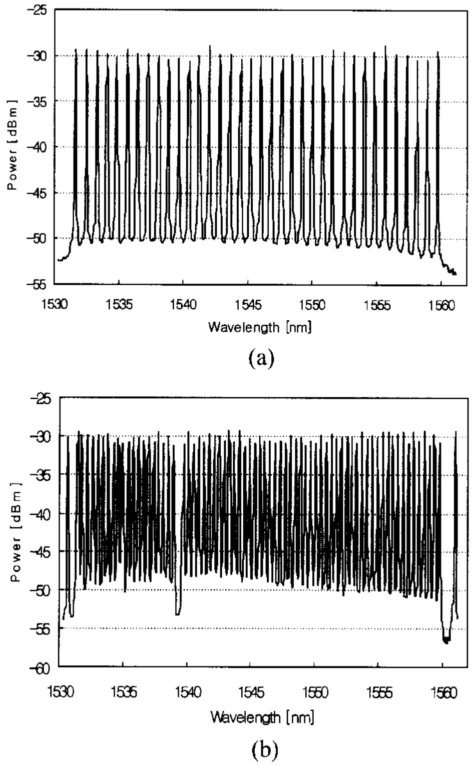


FIG. 3. Exterior view of developed multi-channel spectrum analyzer.



(a)

(b)

FIG. 4. Measured spectrum of multi-channel optical signals (a) with 100GHz channel spacing and (b) 50 GHz channel spacing by multi-channel spectrum analyzer.

respectively. Fig. 5 shows the difference between measured optical spectrum by using the developed multi-channel spectrum analyzer and the conventional optical spectrum analyzer at an optical resolution of 0.1 nm. It was found that the spectrum measured by the developed multi-channel spectrum analyzer agreed well with the spectrum measured by the conventional optical spectrum analyzer in the OSNR range of about 20 dB. With a proper calibration of the wavelength and power levels over the measurement range, the deviation of wavelength was less than 0.063 nm and the power level was accurate to 0.2 dB, including polarization dependence. Fig. 6 shows the measured result of OSNR by using the multi-channel spectrum analyzer and the conventional optical spectrum analyzer. We have obtained OSNR with a deviation of less than 1.0 dB compared with conventional optical spectrum analyzer in the wide input power range between -42 dBm and -27 dBm per channel.

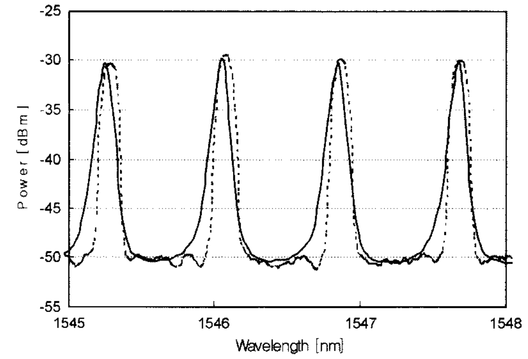


FIG. 5. Difference between measured spectrum by developed multi-channel spectrum analyzer (solid line) and conventional optical spectrum analyzer (dotted line) at 0.1 nm resolution.

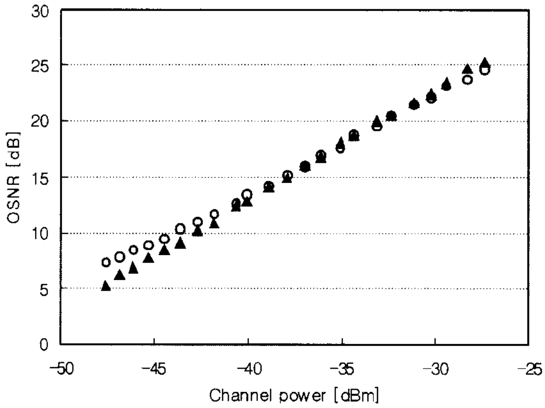


FIG. 6. Difference between measured OSNR by developed multi-channel spectrum analyzer (circle) and conventional optical spectrum analyzer (triangle) at 0.1 nm resolution.

IV. CONCLUSION

We proposed and developed a simple multi-channel spectrum analyzer for high-capacity optical transport networks. We could measure signal power, wavelength, and optical signal-to-noise ratio of each channel for multi-channel optical signals with 100 GHz and 50 GHz channel spacing, simultaneously. Since the developed multi-channel spectrum analyzer has a compact size, high optical resolution, and no moving part, it can be used for high-capacity optical transport networks to provide flexibility and to manage networks faults.

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