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Numerical Study of APSK Format for Long-Haul Transmission and Its Performance Improvement by Zero-nulling Method

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Abstract
Transmission performance of APSK format was studied theoretically. The extinction ratio of the ASK caused a trade-off of the performance. Improvement by adopting zero-nulling method was proposed and its effectiveness was confirmed by the simulation.

Introduction
Advanced modulation formats are attracting many attentions because they can enable improved transmission performance [1] and improved spectral efficiency [2]. Amplitude and phase shift keying (APSK) format is one example of such technology, and it has been investigated theoretically and experimentally [3],[4]. Even though, there are not enough studies focusing on a long-haul applicability of the APSK format.
In this paper, a theoretical study to clarify the long-haul transmission performance of the APSK format was conducted. The transmission performance of the APSK format was examined as a function of the extinction ratio of the amplitude shift keying (ASK), and the trade-off between the ASK performance and the phase shift keying (PSK) performance was clarified. Then, in order to overcome this trade-off, zero-nulling method was proposed, and its effectiveness was confirmed through the numerical simulation.

Simulation model
This study utilized a following simulation model to evaluate the transmission performance of the APSK signal. Figure 1 shows a schematic diagram of the simulation model. This model is impersonating the undersea system like transmission line [5]. The numerical simulator solved the nonlinear Schrödinger equation using the split-step Fourier method [6].
At the transmitter, there were 16 modulated signals ranged from 1545.5nm to 1554.5nm with 0.6nm channel separation. The modulation bit-rate and the pattern were 10Gbit/s and 2^9-1, respectively. There were 256 bits delay between the pattern for the ASK and that for the PSK. The ASK signal had return to zero (RZ) raised-cosine waveform. There was no wavelength selective function in the multiplexer. At the input of the transmission line, the pattern of all transmitters was synchronized to be the same.

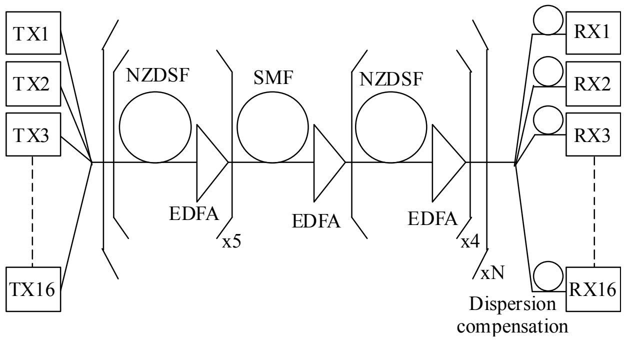

Figure 1 A schematic configuration of the simulation

For the optical fiber transmission line, a combination of the non zero dispersion shifted fiber (NZDSF) and the conventional 1.3μm zero dispersion single mode fiber (SMF) was used. The chromatic dispersion, the dispersion slope, the loss and the effective area of the NZDSF were -2ps/km/nm, 0.08ps/km/nm^2, 0.21 dB/km and 50μm^2, respectively, and those of the SMF were +18ps/m/nm, 0.06ps/km/nm^2, 0.18dB/km and 75μm^2, respectively. The nonlinear refractive index of both fibers was 2.6 x 10^{-20}. The repeater span length was 50km. Undersea system like dispersion management [5] was adopted, and ten fiber spans composed one block. The first to the fifth and the seventh to the tenth spans were the NZDSF, and the sixth span was the SMF. The output power of the repeater was +9dBm, and the noise figure was 4.5dB. The wavelength dependent gain of the repeater was ignored. The cumulative chromatic dispersion for each channel was fully compensated at the receiving end in order to clean up the linear waveform distortion due to the chromatic dispersion.
The optical demultiplexer had the Gaussian shape with the bandwidth of 0.2nm. The ASK signal is directly detected by the optical receiver. The electrical bandwidth of the receiver was 7.5GHz, and the electrical filter shape was assumed to be the third order Bessel filter. The PSK signal is detected by the delayed demodulation scheme and the balanced photo detector.
The performance of the received signal was evaluated

by the Q-factor [7]. For the ASK signal, the photo current of the receiver was directly converted to the Q-factor. For the PSK signal, differential optical phase was used to calculate the Q-factor following the method of reference [8].

Results and discussions

Figure 2 shows the transmission performance of the ASK and the PSK as a function of the transmission distance and the extinction ratio of the ASK. As seen in the figure, the transmission performance degraded as the transmission distance extended. In addition, the transmission performance of the ASK signal became better when the extinction ratio increased. In the mean time, the transmission performance of the PSK signal became better when the extinction ratio decreased. The results showed a clear trade-off between the ASK performance and the PSK performance. The reason of the PSK performance degradation could be attributed to the degradation of the phase information in the space signal of the ASK format. As the space of the ASK format suffers the effect of the optical amplifier noise more severely, the information of the PSK format on this part was damaged, and the overall performance of the PSK signal was degraded. When the performances of the ASK signal and the PSK signal were compromised, the optimum extinction ratio for over 2000km transmission should be around 5 to 6dB.

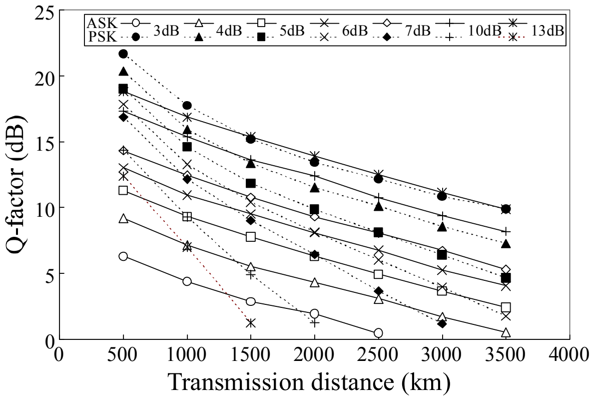

Figure 2 Transmission performance of the APSK signal

Then, a method to improve the performance was considered. As the reason of the degradation of the PSK signal could be attributed to the information on the space of the ASK signal, the performance of the PSK signal should be improved if the PSK information on the space of the ASK signal is to be ignored. Figure 3 shows a proposed method schematically. The PSK information is carried only by the mark signal of the ASK, and the information is nulled while the ASK signal is zero.

The effectiveness of this "zero-nulling" method was confirmed through the simulation. Figure 4 shows the results. The extinction ratio of the ASK was 13dB. As seen in the figure, the ASK performance was almost identical though the PSK performance of the zero-nulling method was greatly improved. Therefore, the zero-nulling method was proved to be quite effective to improve the long-distance transmission performance of the APSK format.

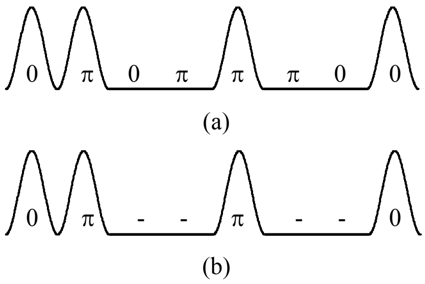

Figure 3 A schematic to explain zero-nulling method
(a) Original APSK, (b) Zero-nulling APSK

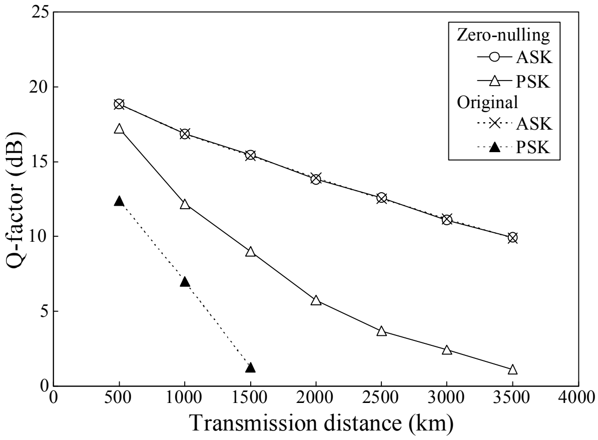

Figure 4 Transmission performance of APSK signal with zero-nulling method

Conclusions

The transmission performance of the APSK signal was investigated theoretically. There was a trade-off of the performance between the ASK and the PSK due to the extinction ratio of the ASK. In order to overcome this tradeoff, the zero-nulling method was proposed, and its effectiveness was confirmed through the numerical simulation.

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