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Effects of Frequency Allocations and Polarization Allocations on FDM Lightwave Transmission Systems

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Abstract

Dependence of four-wave mixing (FWM) noises on frequency allocations and polarization allocations is investigated. FWM noises are drastically reduced when light polarizations are perpendicularly crossed at both sides of the zero dispersion frequency.

1. Introduction

Transmission characteristics in frequency-division-multiplexing (FDM) lightwave transmission systems with low-dispersion optical fibers such as dispersion-shifted fibers are limited by four-wave mixing (FWM) [1].

We focus on the fact that characteristics of FWM are closely related to frequency allocations and polarization allocations. From the viewpoint of frequency allocations, unequally-spaced (US) allocations [2], repeated unequally-spaced (RUS) allocations [3], and modified RUSs such as equally-spaced RUS (ERUS) and unequally-spaced RUS (URUS) allocations [4] were demonstrated to overcome the problems in equally-spaced (ES) allocation [5]. It was found that RUS, ERUS, and URUS have lower FWM light intensities with signal frequencies than ES and narrower total bandwidths than US. With regard to polarization allocations, it has been shown that FWM noises are reduced by arranging the polarization states of the channels [6].

In this work, FWM noises for ES, RUS, ERUS, and URUS are calculated using four polarization allocations such as (a) common polarizations, (b) orthogonal polarization states in adjacent channels, (c) orthogonal polarization states in adjacent base units, and (d) orthogonal polarization states in the channels located at both sides of the zero dispersion frequency. In our calculations, a dispersion shifted fiber (DSF) is assumed to have fiber length L of 80 km, a decay rate α of 0.2 dB/km, and a derivative dispersion coefficient $dD_c/d\lambda$ of 0.07 ps/km/nm^2. An oscillation wavelength for a light source is assumed to be 1550 nm. The base unit and the channel spaces are common in all frequency allocations which are studied in this paper, and the used values are the same as those in Refs. 3 and 4. It is revealed that FWM noises are drastically reduced when light polarizations are perpendicularly crossed at both sides of the zero dispersion frequency.

2. Calculated Results

2.1 Averaged FWM Efficiency

Figure 1 shows a relation between an averaged FWM light efficiency and polarization allocations in ES, RUS, ERUS, and URUS when the number of channels is 19. In Fig. 1, (a), (b), (c), and (d) show four polarization allocations where polarization directions are indicated by arrows. Open squares, gray squares, dark gray squares, and black squares correspond to ES, RUS, ERUS, and URUS, respectively.

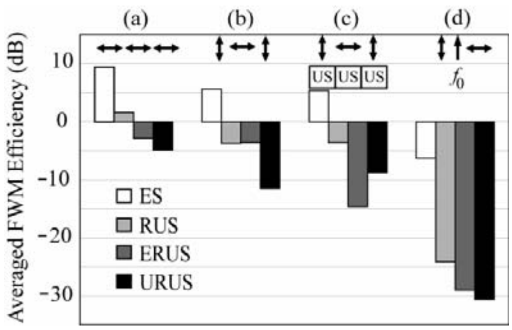

Fig. 1 Averaged FWM Efficiency

In polarization allocation (a), the averaged FWM light efficiencies for ES, RUS, ERUS, and URUS are 9.4 dB, 1.7 dB, −2.9 dB and −4.9 dB, respectively. In polarization allocation (b), the averaged FWM light efficiencies for ES, RUS, ERUS, and URUS are 5.6 dB, −3.7 dB, −3.6 dB and −11.5 dB, respectively. In polarization allocation (c), the averaged FWM light efficiencies for ES, RUS, ERUS, and URUS are 5.4dB, −3.6 dB, −14.6 dB and −8.8 dB, respectively. In polarization allocation (d), the averaged FWM light efficiencies for ES, RUS, ERUS, and URUS are −6.3 dB, −24.1 dB, −29 dB and −30.6 dB, respectively. It is found that FWM noises are lowest in polarization allocation (d). This reason is as follows: When light frequencies f_i and f_j satisfy f_i , $f_j = f_0 \pm \Delta f$ where f_0 is the zero dispersion frequency, FWM noises grow up significantly. Therefore, FWM noises are decreased when polarization states of the channels are perpendicularly crossed at both sides of the zero dispersion frequency f_0.

2.2 Bit Error Rate

Figure 2 shows BERs of Channel 10, which is a midchannel of FDM signals, as a function of received power for ES, RUS, ERUS, and URUS. Here, the Gaussian approximation is used, a modulation speed is 10 Gbit/s, and the number of channels is 19. In Fig. 2, (a) and (d) indicate polarization allocations, and a broken line, a dash-double-dotted line, a dash-dotted line, and a solid line correspond to ES, RUS, ERUS, and URUS, respectively. In polarization allocation (d), BER for URUS overlap BERs for RUS and ERUS.

In polarization allocation (a) for ES, BER of 10^{-9} is not obtained. On the other hand, in polarization allocation (d) for ES, BER of 10^{-9} is obtained. Also, receiver sensitivities to achieve 10^{-9} for ES and that for the others are −20.3 dBm and −20.7 dBm, respectively. As can be seen in Fig. 2, BERs are efficiently reduced by alternating the polarization states of the channels.

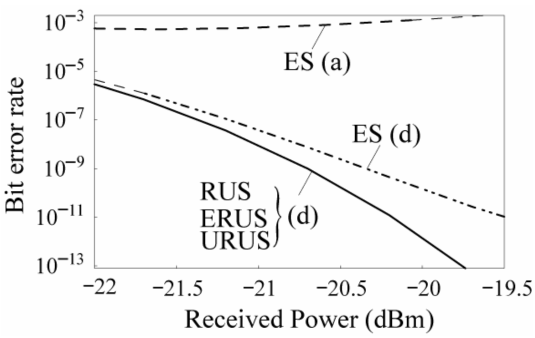

Fig. 2 Bit Error Rate

2.3 Power Penalty

Figure 3 shows power penalties of Channel 10, which is a midchannel of FDM signals, as a function of an input power for ES, RUS, ERUS, and URUS, when the number of channels is 19 in polarization allocation (d). A broken line, a dash-double-dotted line, a dash-dotted line, and a solid line correspond to ES, RUS, ERUS, and URUS, respectively. Power penalty for URUS overlap power penalties for RUS and ERUS.

In polarization allocation (a), power penalties at an input power of 1.3 dBm/ch for RUS, ERUS, and URUS are 0.0988 dB, 0.0209 dB, and 0.0062 dB, respectively. On the other hand, in polarization allocation (d), power penalties at an input power of 1.3 dBm/ch for ES, RUS, ERUS, and URUS are 0.2999 dB, 0.0023 dB, 0.0016 dB, and 0.0015 dB,

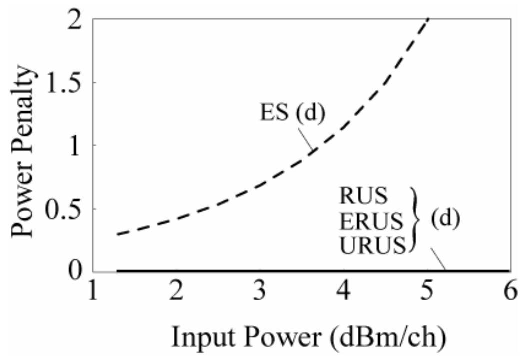

Fig. 3 Power Penalty

respectively. It is found that power penalties are also diminished by alternating the polarization states of the channels.

3. Summary

FWM noises were reduced in ES, ERUS, and URUS with arranging polarization allocations of the channels. Among four polarization allocations, FWM noises were lowest in polarization allocation (d). By comparing polarization allocation (a) and polarization allocation (d), averaged FWM efficiencies were reduced by 15.7 dB, 25.8 dB, 26.1 dB, and 25.7 dB for ES, RUS, ERUS and URUS, respectively.

BERs and power penalties were also reduced with alternating polarization allocations of the channels. In polarization allocation (a), BER of 10^{-9} was not obtained in ES. On the other hand, in polarization allocation (d), BER of 10^{-9} was obtained in ES. Among four polarization allocations, BERs and power penalties in polarization allocation (d) were lowest.

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