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Effects of Frequency Allocations and Zero Dispersion Frequencies on FDM Lightwave Transmission Systems

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Abstract

FWM noises decrease with an increase in a separation between signal frequencies and the zero dispersion frequency, and it is found that FWM noises in ERUS and URUS are much lower than those in ES.

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].

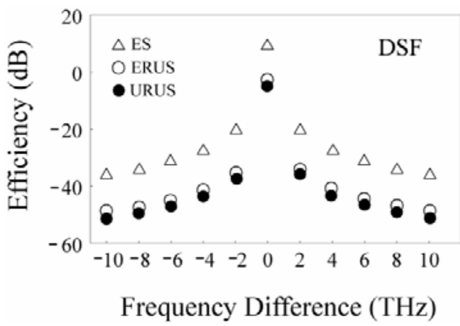
We focus on the fact that characteristics of FWM are closely related to frequency allocations and a zero dispersion frequency. From the viewpoint of frequency allocations, unequally-spaced (US) allocations [2], repeated unequally-spaced (RUS) allocations [3], and modified RUSs such as equally-spaced 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 the zero dispersion frequency, it has been shown that FWM noises decrease with an increase in a separation between the signal frequencies and the zero dispersion frequency in ES [6].

In this work, FWM noises are calculated by changing a separation between the middle frequency of a total bandwidth f_M and the zero dispersion frequency f_0 in ES, ERUS, and URUS, and the calculated results are compared with each other. In our calculations, a dispersion shifted fiber (DSF) and a non-zero dispersion shifted fiber (NZDSF) are assumed to have fiber length L of 80 km and a decay rate α of 0.2 dB/km. Moreover, DSF and NZDSF are assumed to have a derivative dispersion coefficient $dD_c/d\lambda$ of 0.07 ps/km/nm^2 and 0.05 ps/km/nm^2, respectively. 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 work, and the used values are the same as those in Refs. 3 and 4. It is revealed that FWM noises are reduced with an increase in $|f_M - f_0|$, and FWM noises in ERUS and URUS are lower than FWM noises in ES.

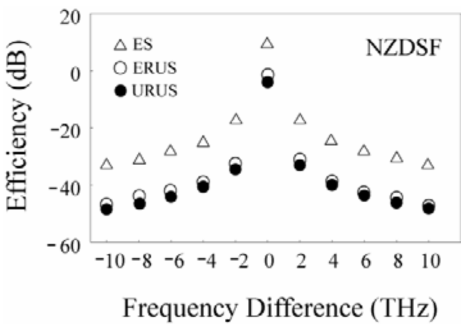
2. Calculated Results

2.1 Averaged FWM Efficiency

Figure 1 shows a relation between an averaged FWM light efficiency and a difference in light frequencies $f_M - f_0$ when the number of channels is 19 with DSF and NZDSF. Figures 1 (a) and (b) correspond to DSF and NZDSF, respectively. Open triangles, open circles, and closed circles correspond to ES, ERUS, and URUS, respectively. Here, f_M is a middle frequency of a total bandwidth, and f_0 is the zero dispersion frequency.



(a)



(b)

Fig. 1 Averaged FWM efficiency

In DSF, when $f_M - f_0 = 0$ THz, the averaged FWM light efficiencies for ES, ERUS, and URUS are 9 dB, −3 dB, and −5 dB, respectively. FWM efficiencies decrease with an increase in $f_M - f_0$. When $f_M - f_0 = 10$ THz, the averaged FWM light efficiencies for ES, ERUS, and URUS are −36 dB,

−50 dB, and −51 dB, respectively. These results show that FWM efficiencies decrease by 45 dB, 47 dB, and 46 dB for ES, RUS, and URUS, respectively, with an increase in $f_M - f_0$ from 0 to 10 THz. In NZDSF, when $f_M - f_0$ = 0 THz, the averaged FWM light efficiencies for ES, ERUS, and URUS are 9 dB, −2 dB, and −4 dB, respectively. When $f_M - f_0$ = 10 THz, the averaged FWM light efficiencies for ES, ERUS, and URUS are −33 dB, −47 dB, and −48 dB, respectively. These results indicate that FWM efficiencies decrease by 42 dB, 45 dB, and 44 dB for ES, ERUS and URUS, respectively, with an increase in $f_M - f_0$ from 0 to 10 THz. In DSF and NZDSF, for $f_M - f_0$ = 10 THz, FWM efficiencies in ERUS and URUS are lower than FWM efficiencies in ES by at least 15 dB. This result suggests that ERUS and URUS are superior to ES in reducing FWM noises.

2.2 Bit Error Rate

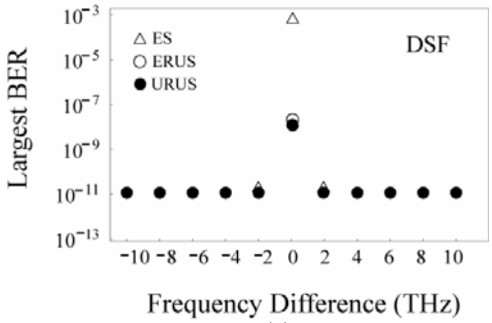
In Fig. 2, the largest BERs among FDM channels are plotted as a function of a difference in light frequencies f_M - f_0 for ES, ERUS, and URUS with DSF and NZDSF when the number of channels is 19 and a modulation speed of 10 Gbit/s. Figures 2 (a) and (b) correspond to DSF and NZDSF, respectively. Open triangles, open circles, and closed circles correspond to ES, ERUS, and URUS, respectively. Without FWM noises, receiver sensitivity to achieve a BER of 10^{-9} is −20.7 dBm. In Fig. 2, BERs are calculated at receiver sensitivity of −20.7 dBm + 0.5 dBm = −20.2 dBm.

In DSF, when $f_M - f_0$ = 0 THz, the largest BERs among 19 channels in ES, ERUS, and URUS are 5.8×10^{-4}, 2.1×10^{-8}, and 1.2×10^{-8}, respectively. In NZDSF, the largest BERs among 19 channels in ES, ERUS, and URUS are 1.6×10^{-5}, 1.0×10^{-9}, and 5.7×10^{-10}, respectively. FWM noises in NZDSF are much lower than FWM noises in DSF. When $f_M - f_0$ = 10 THz, the largest BER among 19 channels in ES, ERUS, and URUS with DSF and NZDSF is 1.2×10^{-11}. Because these differences in BERs are extremely small, BERs for ES, ERUS, and URUS with DSF and NZDSF seem to overlap with an increase in $|f_M - f_0|$ from 4 to 10 THz. As can be seen from Fig. 2, BERs decrease with an increase in $|f_M - f_0|$.

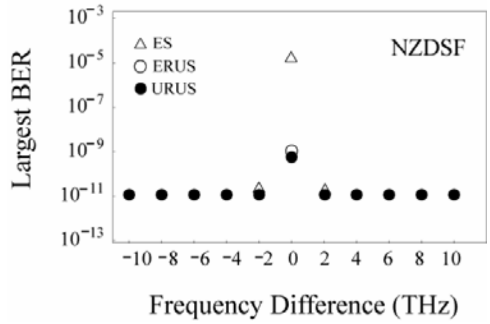
3. Summary

FWM noises were reduced in ES, ERUS, and URUS with an increase in a separation between the middle frequency of a total bandwidth f_M and the zero dispersion frequency f_0 in DSF and NZDSF.

In DSF, FWM efficiencies were reduced by 45 dB, 47 dB, and 46 dB for ES, RUS, and URUS, respectively, with an increase in $f_M - f_0$ from 0 to 10 THz.



(a)



(b)

Fig. 2 Bit Error Rate

In NZDSF, FWM efficiencies were reduced by 42 dB, 45 dB, and 44 dB for ES, ERUS and URUS, respectively. When $f_M - f_0$ = 10THz, FWM efficiencies in ERUS and URUS with DSF and NZDSF were lower than FWM noise in ES by at least 15 dB. These results unveiled that FWM noises in ERUS and URUS became much lower than FWM noises in ES with an increase in $|f_M - f_0|$. BERs also decreased with an increase in $|f_M - f_0|$. In DSF and NZDSF, when $f_M - f_0$ = 0 THz, BER of 10^{-9} was not obtained in ES. On the other hand, when $f_M - f_0$ = 10 THz, BER of 10^{-9} was obtained in ES. By comparing FWM noises in DSF and NZDSF, FWM noises in NZDSF were much lower than FWM noises in DSF.

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