Fiber Four-Wave Mixing in Multi-Channel Coherent Systems

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Abstract

The crosstalk degradation due to four-wave mixing (FWM) in fiber is studied in a 155Mb/s, 16 channel coherent system with the signal powers amplified by an erbium-doped fiber amplifier. When a total power of +8.4dBm (0.46mW/channel) is launched into the fiber, the crosstalk degradation is 0.4dB. A theoretical study indicates the FWM dependence on fiber chromatic dispersion, the total number of channels, and the signal power levels and polarization states.

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1. Introduction

In optical frequency-division-multiplexed systems, the nonlinear interaction between signal channels may set the ultimate limit on the allowable channel spacing, total number of channels and the maximum power per channel [1]. Four-wave mixing (FWM) crosstalk in semiconductor amplifiers has been shown to cause a sensitivity degradation when the channel spacing is a few hundred MHz[2]. In contrast, when fiber amplifiers are used, nonlinear interactions have been considered negligible because of the long fluorescence time constant[3]. However, we have recently found that for a fiber amplifier with a saturation power in the range of 5 to 10mW, the transmission fiber following the amplifier can cause FWM crosstalk[4]. Fiber FWM may also be observed without an amplifier if a wavelength selective coupler is used to combine the laser outputs without any splitting loss.

In our experiment, the power from 16 transmitter lasers was amplified using an erbium-doped fiber amplifier and transmitted through a dispersion shifted fiber. We studied the receiver sensitivity degradation and its dependence on signal frequency under the cases where the interacting channels were modulated and unmodulated. Further theoretical studies have shown that the total number of FWM signal contributions rises dramatically with increasing channel number, but may be reduced by using a transmission fiber with large chromatic dispersion.

2. Experiment

The experimental arrangement is shown in Figure 1. The outputs of 16 DFB lasers at 1.54um were combined using a 16x16 star coupler and amplified with an alumino-silicate erbium-doped fiber amplifier. Laser 7 was modulated with a 155Mb/s pseudorandom data stream in the alternate mark inversion (AMI) signal format. The other fifteen lasers were modulated with independent FSK-AMI data streams derived from digital video coders. The channel spacing was set at 10GHz, and the wavelengths of the 16 lasers fell within the flat gain region of the amplifier. The amplified laser output power of +8.4dBm (0.46mW/channel) was launched into a 12km span of dispersion-shifted fiber whose chromatic dispersion at the laser wavelength was -0.3ps/nm-km. The output of the fiber was transmitted to a polarization diversity heterodyne receiver where the BER degradation of laser 7 was studied. No attempt was made to control the polarization states of the transmitted signals.

3. Results

Figure 2 shows the BER as a function the detected power of laser 7, both with transmission fiber (triangles and circles) and without the fiber (squares). The system performance without the fiber was limited by the receiver thermal noise which was significantly greater than the amplifier spontaneous emission noise. The BER was measured by varying attenuator 1 which changed the power of laser 7 only, without effecting the other 15 lasers. At the detected power of -42dBm, the power of laser 7 was 8dB below the average power of the other lasers. A sensitivity degradation of 3.0dB was measured when only laser 7 was modulated. When all 16 lasers were modulated, the sensitivity penalty was 1.8dB.

The spectral extent of FWM noise was also studied by tuning laser 7. When laser 7 alone was modulated, the FWM interference was pronounced only at the frequency corresponding to 10GHz spacing; penalty-free transmission was attained when laser 7 was tuned a few GHz away from its allocated channel frequency. When all the lasers were modulated, the BER degradations were less severe but were apparent over a larger frequency range; penalty from FWM crosstalk and/or adjacent channel interference was always observed as laser 7 frequency was tuned between the frequencies of lasers 6 and 8.

In our experiment, the receiver sensitivity measurements were made on a signal laser which was 8dB below the average signal power. When laser 7 power is equal to the average power of the other 15 modulated lasers, the expected power penalty is 0.4dB. Because the signal polarization states were random in our experiment, greater penalties can occur if the polarizations become randomly aligned. Figure 3 shows the signal power per channel which produces 0.4dB penalty for different number of channels; it indicates that a power per channel as small as 0.2mW can cause degradations when the total number of channels is 32. The data point for the 16 channels with random polarization corresponds to our experimental result. The dependence of FWM crosstalk on fiber length and chromatic dispersion is shown in Figure 4 for conditions corresponding to our experiment. When a fiber with large chromatic dispersion is used, phase-mismatch between widely spaced channels is large, reducing the FWM efficiency [5]. Also, at large fiber lengths, the transmission loss increases, reducing the FWM power.

In multichannel systems, a large signal power per channel can be expected with the use of high saturation power fiber amplifiers, wavelength selective couplers, or high output power lasers. Our multichannel experiment demonstrates that the FWM interaction in fiber can cause significant sensitivity penalty depending on the number of channels, signal power levels, and chromatic dispersion in fiber. The FWM interference may be reduced by limiting the power per channel into the fiber or by using a fiber with significant chromatic dispersion.

4. Conclusions

The sensitivity degradation due to FWM in fiber was studied in a 155Mb/s, 16 channel coherent system with the signal powers amplified by an erbium-doped fiber amplifier. When a total power of +8.4dBm (0.46mW/channel) was launched into the fiber, a sensitivity penalty of 0.4dB was found with all 16 lasers modulated. Theoretical calculations indicate that the effect is severe when the fiber dispersion is small, the total number of channel is large or when the signal power levels are high.

5. Acknowledgements

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References

1. R.G.Waarts and R.-P.Braun, "System limitations due to four-wave mixing in single-mode optical fibres", Electron. Lett., vol.22, pp873-875, 1986.
2. B.S.Glance, G.Eisenstein, P.J.Fitzgerald, K.J.Pollock, and G.Raybon, "Crosstalk degradation caused by optical amplification in a multichannel FSK heterodyne system," J. of Lightwave Tech., vol.7, pp759-765, 1989.
3. R.I.Laming, L.Reekie, P.R.Morkel, and D.N.Payne, "Multichannel crosstalk and pump noise characterisation of Er^{+3}-doped fibre amplifier pumped at 980nm", Electron.Lett., vol 25, pp455-456, 1989.
4. M.W.Maeda, W.B.Sessa, W.I.Way, A.Yi-Yan, R.Welter, L.Curtis, and R.I.Laming, "Fiber four-wave mixing induced by optical amplification in a 16 channel coherent system", ECOC"89, Gothenburg, Sweden, postdeadline paper.
5. N.Shibata, K.Iwashita, and Y.Azuma, "Receiver sensitivity degradation due to four-wave mixing in a 2 Gbit/s CPFSK heterodyne transmission system", IOOC '89 Technical Digest, Kobe, Japan, paper 18C1-3.

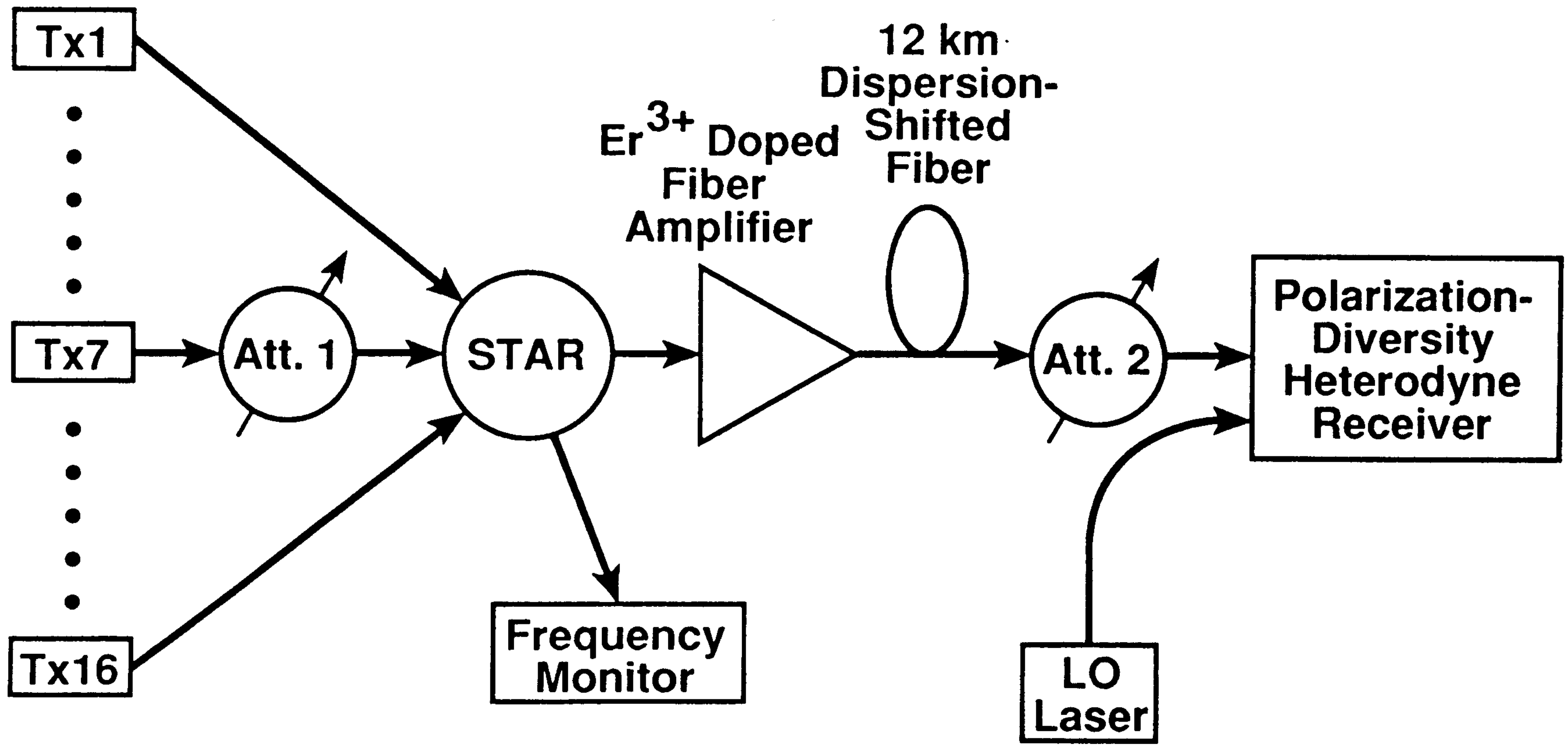
Figure Captions

Figure 1. Experimental arrangement

Figure 2. BER vs. received power.

Figure 3. Power required to produce 0.4dB FWM crosstalk penalty at 10GHz channel spacing with 0.3ps/nm-km chromatic dispersion and 12km fiber length.

Figure 4. FWM strength at laser 7 for 16 channels with 10GHz channel spacing. Our experimental result is indicated with a filled circle.



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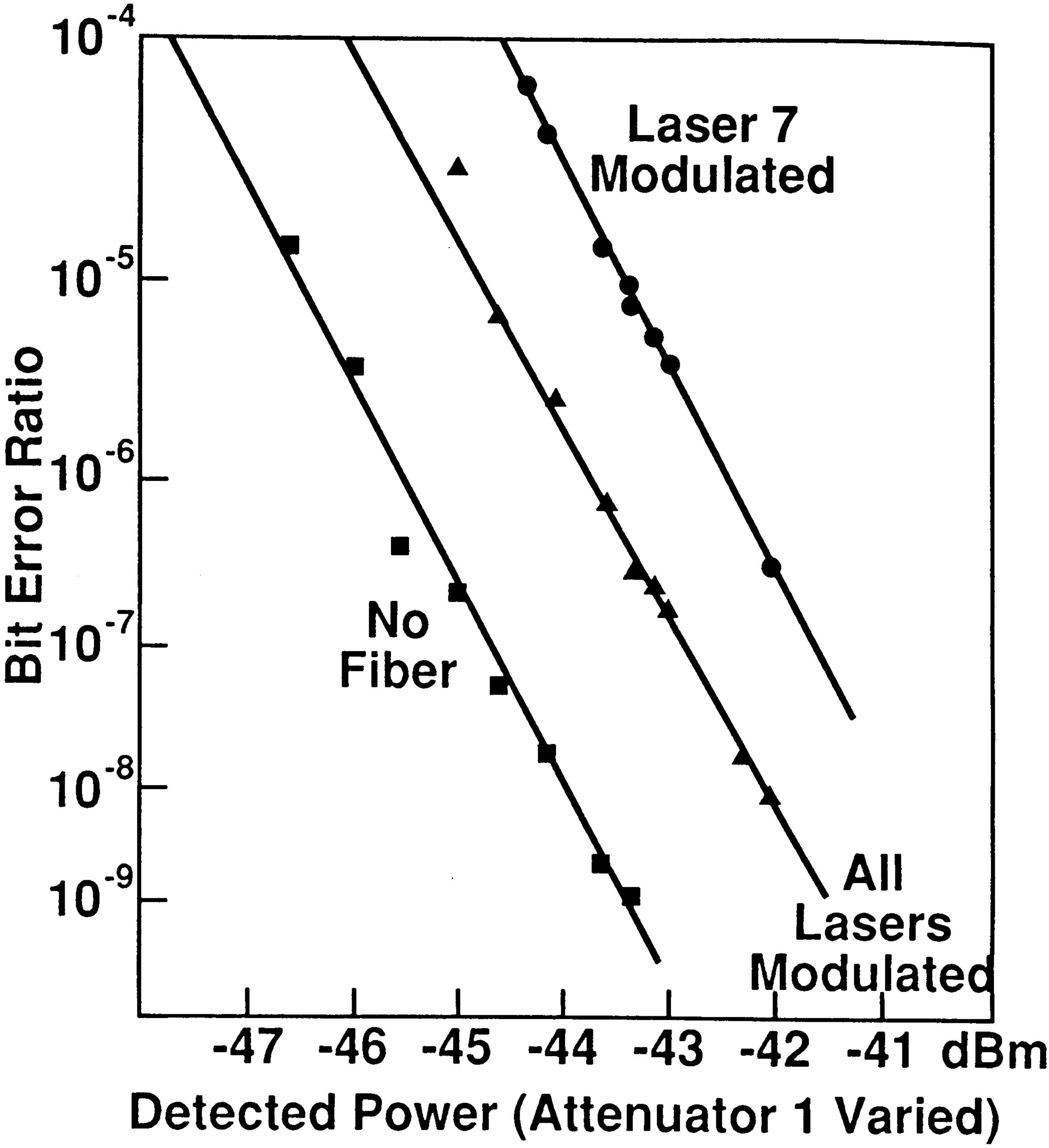

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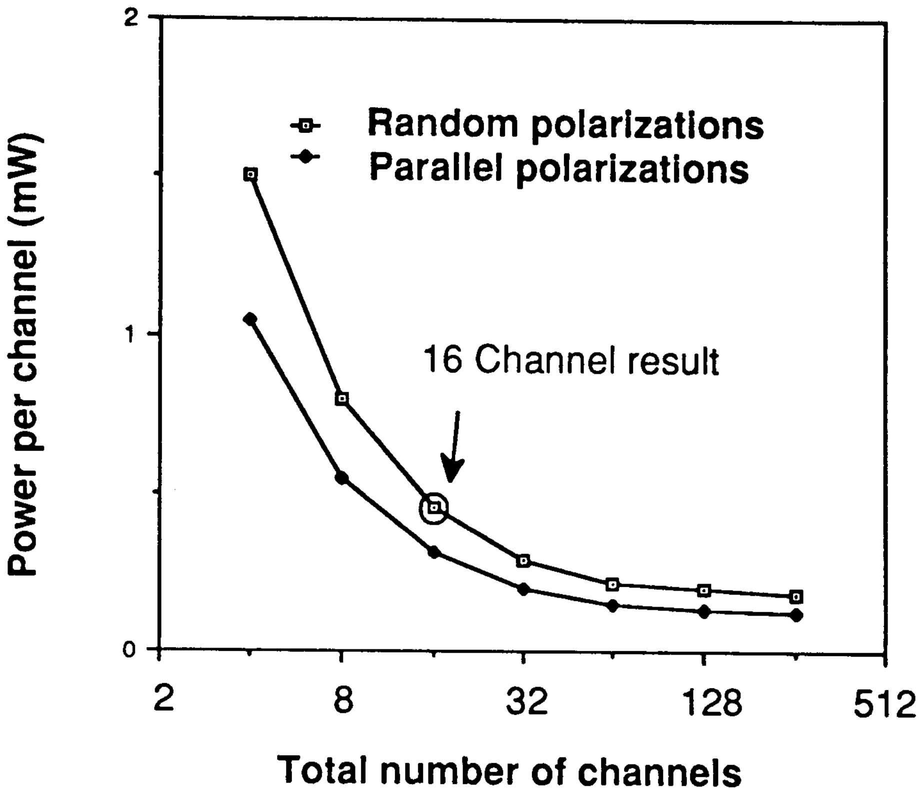
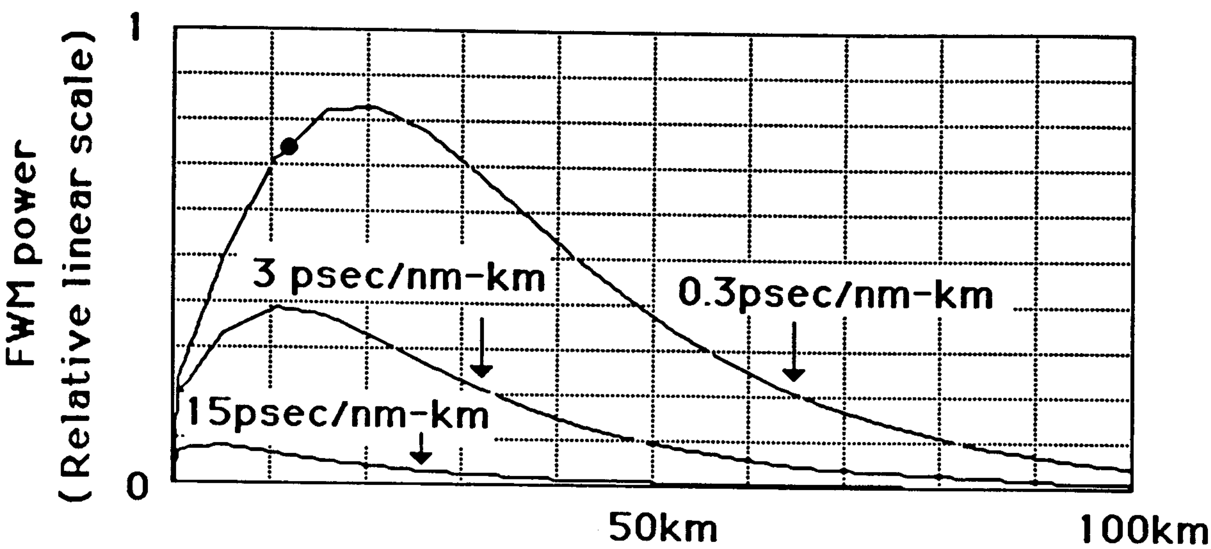


Random polarizations
Parallel polarizations
16 Channel result
Power per channel (mW)
Total number of channels
2
1
0
2
8
32
128
512



FWM power
(Relative linear scale)
1
0
3 psec/nm-km
0.3psec/nm-km
15psec/nm-km
50km
100km