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TUE4 Fiber four-wave mixing in multichannel coherent systems

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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 maximum power per channel.[1] The four-wave mixing (FWM) crosstalk in semiconductor amplifiers has been shown to cause a sensitivity degradation when the channel spacing is a few hundred megahertz.[2] In contrast, when fiber amplifiers are used, nonlinear interactions have been considered negligible because of the long fluorescence time constant.[3] However, we recently found that for a fiber amplifier with a saturation power in the 5–10-mW range, 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 with no splitting loss.

In our experiment, the power from sixteen 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 in the cases where the interacting channels were modulated and unmodulated. Further theoretical studies have shown that the total number of FWM signal contributions rise dramatically with increasing channel number but may be reduced by using a transmission fiber with large chromatic dispersion.

The experimental arrangement is shown in Fig. 1. The outputs of sixteen DFB lasers at 1.54 μm were combined using a 16 × 16 star coupler and amplified with an aluminosilicate erbium doped fiber amplifier. Laser 7 was modulated with a 155-Mbit/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 10 GHz, and the wavelengths of the sixteen lasers fell within the flat gain region of the amplifier. The amplified laser output power of +8.4 dBm (0.46 mW/channel) was launched into a 12-km span of dispersion shifted fiber whose chromatic dispersion at the laser wavelength was −0.3 ps/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.

Figure 2 shows the BER as a function of 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 affecting the other fifteen lasers. At the detected power of −42 dBm, the power of laser 7 was 8 dB below the average power of the other lasers. A sensitivity degradation of 3.0 dB was measured when only laser 7 was modulated. When all sixteen lasers were modulated, the sensitivity penalty was 1.8 dB.

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 10-GHz spacing; penalty free transmission was attained when laser 7 was tuned a few gigahertz 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; the 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 8 dB below the average signal power. When laser 7 power is equal to the average power of the other fifteen modulated lasers, the expected power penalty is 0.4 dB. Because the signal polarization states were random in our experiment, greater penalties can occur if the polarizations become randomly aligned. The signal power per channel had a 0.4-dB penalty for a different number of channels; with power per channel as small as 0.2 mW causing degradations when the total number of channels is thirty-two. The dependence of FWM crosstalk on fiber length and chromatic dispersion is shown in Fig. 3 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 a 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.

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

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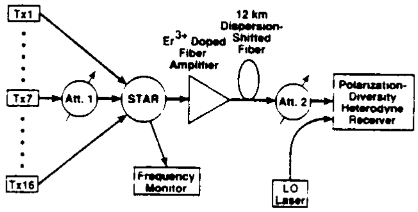
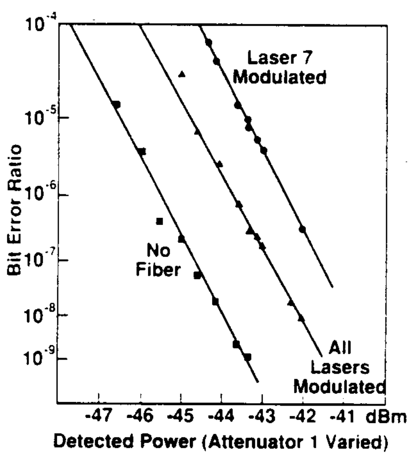
2. B. S. Glance, G. Eisenstein, P. J. Fitzgerald, K. J. Pollock, and G. Raybon, "Crosstalk Degradation Caused by Optical Amplification in a Multichannel FSK Heterodyne System," IEEE/OSA J. Lightwave Technol. LT-7, 759–765 (1989).
3. R. I. Laming, L. Reekie, P. R. Morkel, and D. N. Payne, "Multichannel Crosstalk and Pump Noise Characterisation of Er^{+3}-Doped Fibre Amplifier Pumped at 980 nm," Electron. Lett. **25**, 455–456 (1989).
4. M. W. Maeda *et al.*, "Fiber Four-Wave Mixing Induced by Optical Amplification in a 16 Channel Coherent System," in *Technical Digest, Fifteenth European Conference on Optical Communication*, Gothenburg (1989).
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," in *Technical Digest, International Conference on Integrated Optics and Optical Fiber Communication*, Kobe, Japan (1989), paper 18C1-3.

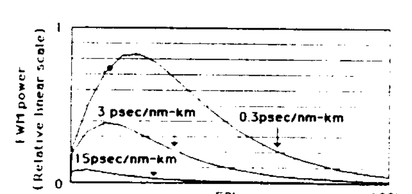
NOTES



TUE4 Fig. 1. Experimental arrangement.



TUE4 Fig. 2. BER vs received power.



TUE4 Fig. 3. FWM strength at laser 7 for sixteen channels with 10-GHz channel spacing. Our experimental result is indicated with a solid circle.