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2 dB Reduction of Transmission Penalty by Self-Phase Modulation in a 5 Gbit/s FM/AM Conversion System Experiment

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Abstract: The transmission penalty of a standard non-dispersion shifted fiber is experimentally demonstrated to be reduced by Self-Phase Modulation due to the optical Kerr effect. A 2 dB reduction of transmission penalty is achieved in a 5 Gbit/s FM/AM conversion system experiment over 205 km of fiber.

Introduction: The group velocity dispersion penalty of an optical communication system depends to some extent on the frequency chirp of the transmitted signal. One way to diminish the dispersion penalty in linear systems is by introducing a suitable chirp in the transmitted signal in order to obtain less dispersive pulse distortion [1]-[4].

In systems with high-power transmitters, the interaction between Self-Phase Modulation (SPM) due to the optical Kerr effect and the group velocity dispersion has to be taken into account. In order to demonstrate the effect of this interaction, we report observation of transmission penalty dependence of Self-Phase Modulation in a 205 km system experiment. The system employs a 5 Gbit/s frequency modulation (FM) to amplitude modulation (AM) conversion transmitter. A 2 dB reduction of transmission penalty with this modulation scheme is experimentally achieved by increasing the transmitter output power from +7 dBm to +14 dBm.

Experimental Set-up: The experimental set-up is shown schematically in Fig. 1. A three-electrode $\lambda/4$ -shifted DFB laser with a 10 GHz FM-response bandwidth is used as transmitter [5]. The laser is operated at a wavelength of 1548 nm and the linewidth is 2 MHz. The laser is modulated directly from the word generator with a 5 Gbit/s Pseudo Random Binary Sequence of length 2^7-1 . The Continuous Phase-Frequency Shift Keying (CP-FSK) signal of the

transmitter laser is converted into an AM signal by the Mach-Zehnder interferometer (MZI). The differential delay of the MZI is $\tau = 42$ ps. An Erbium Doped Fiber (EDF) booster amplifier with a saturated output power of +15 dBm is used in the transmitter. The level of the transmitter output power is adjusted by an optical attenuator.

The receiver is an optically preamplified pin-detector receiver. The two stage EDF preamplifier is pumped at 980 nm. The fiber-to-fiber gain (including input and output connector insertion loss) is 34 dB and the corresponding noise figure is 4 dB. An optical Fabry-Perot filter with a 3 dB bandwidth of 20 GHz ensures that the noise in the receiver is dominated by signal-spontaneous emission beat noise. The filter is locked to the signal by an Automatic Frequency Control (AFC). The periodic frequency response of the Fabry-Perot filter is eliminated by a broadband optical bandpass filter with a bandwidth of 2.5 nm. A fourth-order Bessel filter with 3 dB cut-off frequency of 4 GHz is used as post-detection filter. The Bit Error Rate (BER) is measured with the error counter which is synchronized by a clock signal recovered by the receiver.

205 km of standard non-dispersion shifted optical fiber is inserted in between the transmitter and the receiver. This fiber length is chosen as a compromise between the available dynamic range of input power and the amount

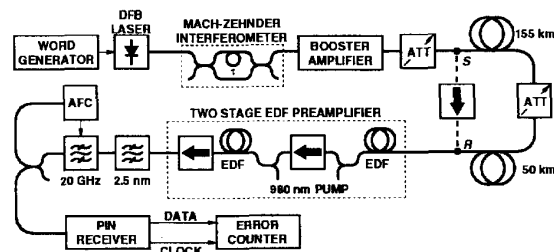


Figure 1. Experimental set-up.

of dispersion penalty. The average dispersion of the fiber is 17 ps/nm/km and the loss is 0.21 dB/km. The transmission fiber is separated in two sections of 155 km and 50 km, respectively. In between the two sections is a second optical attenuator applied in order to vary the level of the received power which is referred to the input connector of the optical preamplifier.

Experimental Results: Baseline measurement of the bit error rate is performed with an optical isolator inserted in between point 'S' and 'R' as indicated in Fig. 1. The frequency modulation index, β , is optimized in order to obtain the best receiver sensitivity. At a modulation index of $\beta = 2.4$, the extinction ratio at the output of the MZI is approximately 13 dB and the receiver sensitivity is -40.3 dBm @ BER = 10^{-9} .

Transmission experiments are performed with the isolator replaced by the 205 km of fiber. BER measurements are performed at different levels of fiber input power varying from +14 dBm to +7 dBm. The FM index is optimized to $\beta = 1.6$ at +14 dBm of fiber input power in order to achieve the best receiver sensitivity. The system performance is affected in two counteracting ways by reduction of the modulation index: a) the frequency chirp of the transmitted signal is reduced proportionally to the reduction of β and b) the extinction ratio is reduced to approximately 10 dB. Consequently, the optimum modulation index is a trade-off between transmission penalty due to frequency chirp and extinction ratio penalty. For transmission over 205 km at +14 dBm of input power, the receiver sensitivity is -38.7 dBm @ BER = 10^{-9} for $\beta = 1.6$. The sensitivity corresponds to a transmission penalty of 1.6 dB with reference to the baseline sensitivity.

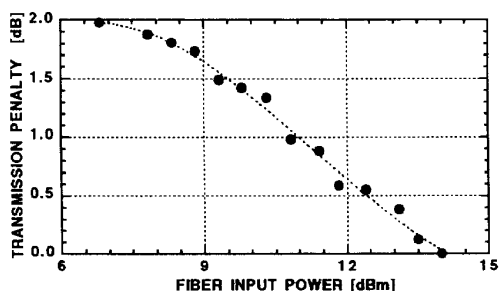


Figure 2. Transmission penalty (@ BER = 10^{-9}) after 205 km relative to +14 dBm of input power.

The transmission penalty relative to the receiver sensitivity obtained at +14 dBm (@ BER= 10^{-9}) is shown as a function of fiber input power in Fig. 2. The slope decreases towards low input power which indicates that the linear dispersion regime is encountered for decreasing input power. Reduction of the fiber input power to +7 dBm results in an additional penalty of 2.0 dB. The input power in the experiment can not be reduced below +7 dBm due to fiber losses. The slope also decreases towards high input power which suggests the existence of a minimum transmission penalty limit. However, the saturation output power of the booster amplifier available for this experiment was too low to verify the existence of such a limit.

Conclusion: A 2 dB reduction of transmission penalty of 205 km of standard non-dispersion shifted fiber has been achieved in a 5 Gbit/s optical communication system experiment. This reduction has been obtained by non-linear Self-Phase Modulation induced by increasing the input power from +7 dBm to +14 dBm.

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