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Performance improvement of DPSK signal transmission by a phase-preserving amplitude limiter

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Abstract

We show that a phase-preserving amplitude limiter using saturation of FWM in a fiber improves DPSK signal transmission through the reduction of nonlinear phase noise. Influence of imperfections of the limiter is also studied

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1. Introduction

Phase-shift keying (PSK) modulation has advantages including higher receiver sensitivity than on-off keying modulation and suitability for multi-level signaling such as QPSK or DQPSK [1] . The phase noise imposed on the signal generally determines the transmission performance of PSK signals. In long distance systems where higher signal power is required, nonlinear phase noise, which is caused by the translation of amplitude noise to phase noise through nonlinearity of transmission fiber, is especially harmful [2] .

Some means for reduction of the nonlinear phase noise have been proposed [3,4] . In this paper, we study the effect of an optical limiter using saturation of four-wave-mixing (FWM) in a nonlinear fiber [5,6] . The limiter suppresses the amplitude noise which is responsible for the nonlinear phase noise. It is theoretically and experimentally shown that the phase noise at the receiver is reduced by inserting the limiter into a transmission line, leading to improvement of DPSK transmission performance.

2. Theoretical calculation of phase noise

We consider an amplified transmission system consisting of M spans. Amplified spontaneous emission (ASE) from the inline amplifiers is the dominant source of the phase noise. The quadrature component of the ASE relative to the signal makes direct phase fluctuation whose variance accumulates proportionally to the number of amplification stages. The in-phase component, on the other hand, makes amplitude fluctuation, which is translated to nonlinear phase noise through fiber nonlinearity. The nonlinear phase noise becomes large when transmission distance and/or the signal power are large.

An ideal limiter eliminates amplitude fluctuation perfectly without giving additional phase noise. Actual limiters, however, have several imperfections. Firstly, in the case of the limiter using fiber nonlinearity, signals having different input powers suffer different phase shift due to SPM in fiber although the signal power is equalized at the output of the limiter. The induced phase shift $\delta\varphi$ is proportional to the power fluctuation of the input signal δP to be suppressed by the limiter. The proportionality coefficient k is defined by the relation $\delta\varphi=k\delta P/P_{sat}$, where P_{sat} is the saturation input power. Secondly, actual limiters cannot eliminate amplitude fluctuations perfectly. This can be quantified by a residual power fluctuation ratio r, where the input signal power with fluctuation $P_{sat}+\delta P$ yields the output signal power $P_{out}(1+r\delta P/P_{sat})$. Considering these imperfections, the variance of phase noise when limiters are inserted every span is given by

$$\langle\delta\varphi^2\rangle = \left\{1 + 4\left(k + P_{sig}\gamma L_{eff} r\right)^2\left[\left(1 - r^M\right)/\left(1 - r\right)\right]^2\right\}\frac{N_s B}{2P_{sig}}$$
$$+ \left\{M + 4\left(k + P_{sig}\gamma L_{eff} r\right)^2\sum_{i=1}^{M}\left[\left(1 - r^{M-i+1}\right)/\left(1 - r\right)\right]^2\right\}\frac{N_r B}{2G_r P_{sig}}$$
$$+ \left\{M + 4\left(k + P_{sig}\gamma L_{eff} r\right)^2\sum_{i=1}^{M-1}\left[\left(1 - r^{M-i}\right)/\left(1 - r\right)\right]^2\right\}\frac{N_a B}{2P_{sig}},$$

where N_s, B, P_{sig}, γ, L_{eff}, G_r, and N_a is the power spectrum density of the source noise, noise bandwidth, peak power launched into the transmission fiber, nonlinear coefficient and effective length of the transmission fiber, gain of an amplifier in the optical limiter, and spectrum density of ASE from each inline amplifier, respectively. N_s is related to the source OSNR (noise bandwidth of 0.1nm) as $N_s=sP_{sig}/(12.5\mathrm{GHz}\cdot\mathrm{OSNR})$, where s is the duty ratio of the signal (the averaged signal power is given by $P_{ave}=sP_{sig}$) while N_a is given by $h\nu n_{sp}(G-1)$, where $h\nu$, n_{sp}, and G are the photon energy, spontaneous emission factor, and gain of inline amplifier, respectively.

Fig.1 is the phase noise versus average signal power P_{sig} when an imperfect limiter ($k\neq0$ and $r\neq0$) is inserted every span. k and P_{sat} are assumed to be 0.8rad and 50mW, respectively. r=0 corresponds to perfect amplitude limitation while no amplitude limitation exists for r=1. Fig.1 shows that the phase noise is gradually reduced when r is small. However, when r is larger than ~0.4, the phase noise is larger than that without limiters.

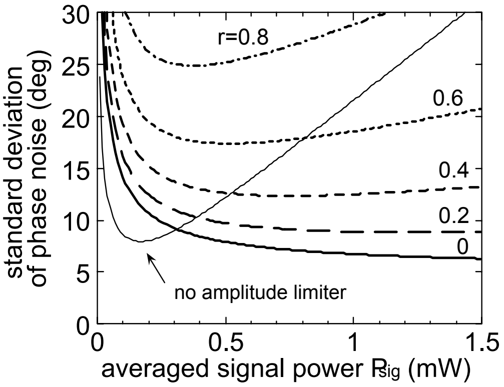

Fig.1. Standard deviation of phase noise at the receiver versus signal power. Amplitude limiters with imperfect noise suppression are inserted every amplifier span. Thin solid curve is the phase noise without using amplitude limiters. γ and α of transmission fiber, source OSNR, and noise figure of amplifiers are 3.5/W/km, 0.3dB/km, 24.5dB, 6dB, respectively. Span length and number of spans are 40km and 5.

3. Experiment

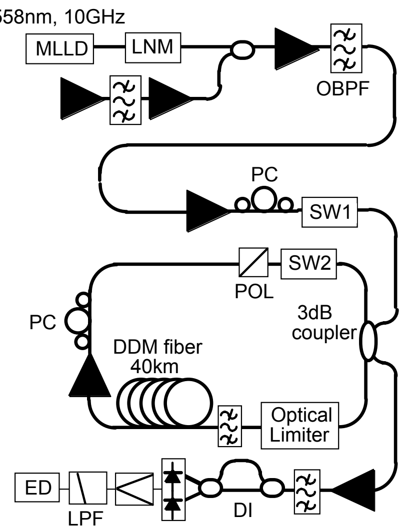

Fig.2. Setup of 10Gbit/s short-pulse DPSK transmission. An amplitude limiter based on saturation of FWM is inserted in the recirculating loop.

Fig.2 shows the setup of a DPSK transmission experiment. 10GHz pulses are generated by a mode-locked laser diode (MLLD) whose width is 6.8ps after optical bandpass filter (OBPF). The transmission fiber (40km) is a densely dispersion-managed fiber originally designed for 80Gbps short-pulse transmission. In this experiment, an amplitude limiter using saturation of four-wave mixing (FWM) in a highly nonlinear fiber (HNLF) is inserted in the recirculating loop. The limiter simply consists of an EDFA with gain G_r, a polarization controller, continuous-wave pump source, HNLF and an OBPF.

Fig3 shows bit-error rate measured after transmission of 200km (five spans) when the limiter is inserted inside the recirculating loop. OSNR of the input signal is 25.7dB. Fig. 3 shows that the BER is decreased in a wide range of signal power when the limiter is activated with the pump power for the FWM turned on. The behavior qualitatively corresponds to the calculated phase noise versus signal power as shown in Fig.3.

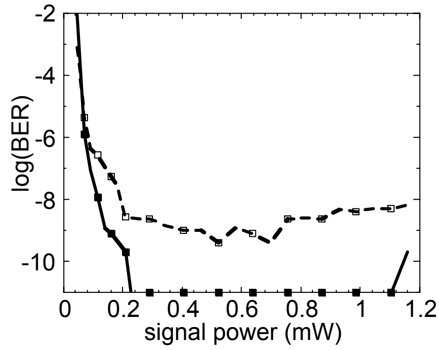

Fig.3. BER versus averaged signal power launched to the transmission fiber. Solid and dashed curves correspond to the cases where pump power in the limiter is on and off, respectively.

4. Conclusion

In this paper, we show both theoretically and experimentally that an amplitude limiter using saturation of FWM in a fiber is effective in improving DPSK signal transmission performance.

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