Transmission of optical communication signals by distributed parametric amplification

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Abstract: We have demonstrated, for the first time to our knowledge, distributed parametric amplification, i.e. amplification of 10-Gb/s communication signals along a 75-km transmission fiber by using a co-propagating pump with only 66.5 mW of power.
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1. Introduction

Distributed parametric amplification has been investigated in the past as a detrimental effect, as strong carriers can amplify in transmission fibers the ASE generated by EDFAs used to amplify signals between fiber spans. This has been done for one-pump [1], [2] and two-pump [3] parametric amplification. Here we investigate, for the first time to our knowledge, a possibly useful application of distributed parametric amplification (DPA), namely amplification of communication signals along a transmission fiber by using a co-propagating pump.

2. Theory

Compared to distributed Raman amplification (DRA), DPA has the advantage of requiring only about 1/3 the pump power for DRA to obtain the same gain. This is attractive, as the power levels required for DRA have raised safety and reliability concerns. In addition DPA is free from double Rayleigh scattering, which is a concern in DRA.

Because of the large length of transmission spans (generally > 40 km) the pump power P_0 required to make up for fiber loss is relatively modest, of the order of 100 mW. This implies that the gain bandwidth will be fairly small, at best of the order of 10 nm. Hence DPA will not compete with methods providing much larger bandwidths, such as DRA, tellurite EDFAs, etc. On the other hand DPA may be a useful supplement for these other techniques: for example it could be used for transmission near 1300 nm in a system using standard singlemode fiber (SMF) primarily for transmission in the C-band.

Fig. 1 shows theoretical gain spectra for one- and two-pump DPAs using 70 km of DSF, with the following parameters: loss α = 0.2 dB/km, β_4 = -1.0x10^{-55} m^{-1}s^4; zero-dispersion wavelength λ_0 = 1550 nm; dispersion slope D_λ = 0.07 ps/(nm km); nonlinearity coefficient γ = 2 W^{-1} km^{-1}; total input pump power P_0 = 100 mW.
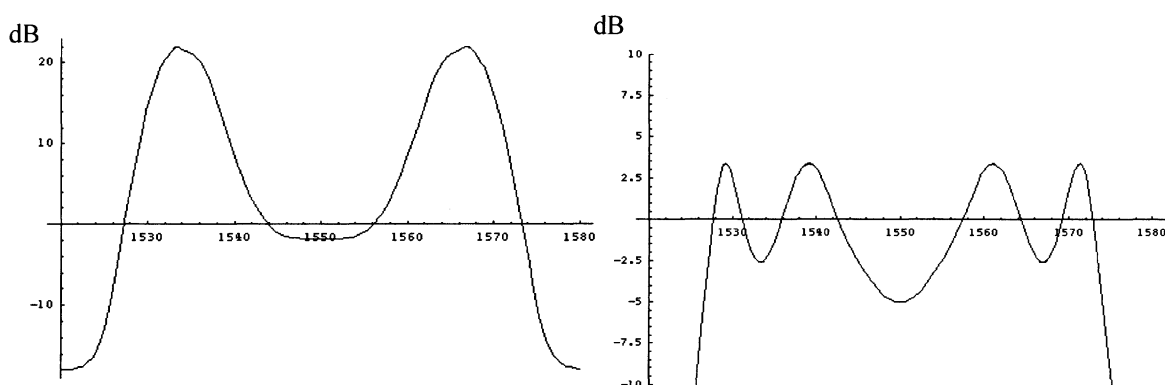

Fig. 1 Theoretical DPA gain spectra. (a) One pump, at $\lambda_1 = \lambda_0$ = 1550 nm;
(b) Two pumps, at λ_1 = 1530.44 nm and λ_2 = 1570 nm.

The gain shapes of Fig. 1 are quite sensitive to the choice of the pump wavelength(s); this is particularly true for Fig. 1(b), for which decreasing λ_1 by 0.01 nm leads to a drop of the center of the spectrum by about 5 dB. This high sensitivity is due to the fact that we have assumed that λ_0 is constant along the fiber. In real fibers, however, λ_0

varies randomly along the fiber length, with a standard deviation σ_0 of the order of 1 nm. Then it is clear that the gain spectrum cannot be affected by changes in λ_1 much smaller than σ_0. This has been verified experimentally in Ref. [3], where it was found that a 2.5 nm change in λ_1 was required in order to obtain a drop in gain of 5 dB. Hence the gain shape in real fibers, while not exactly predictable by the theory for uniform fibers, should be relatively insensitive to pump wavelength(s). λ_0 variations can also help to obtain a flat-topped gain spectrum, as indicated by the results of Ref. [3]. If needed, gain flattening could be implemented by means of a filter at the fiber output. This filter could also remove the residual pump power, and the idler(s). Fig. 1 indicates that a signal gain bandwidth of the order of 10 nm could be available with either type of DPA with suitable gain flattening.

3. Experiment

The experimental set-up is shown in Fig.2. The transmission fiber consists of three 25 km DSF spools with average zero-dispersion wavelengths λ_0 of about 1550 nm. The dispersion slope D_λ is 0.07 ps/(nm^2 km) and $\gamma = 2$ W^{-1} km^{-1}. The fiber attenuation is about 0.207 dB/km, hence 15.53 dB total loss. A tunable laser source, TLS4, set at λ_p =1551.13 nm, serves as the pump source. The CW pump is phase-modulated by two phase modulators in cascade, PM1 and PM2, in order to suppress Stimulated Brillouin Scattering (SBS). Both of them are driven by a 2.5 Gb/s pseudo-random bit sequence (PRBS) [4].
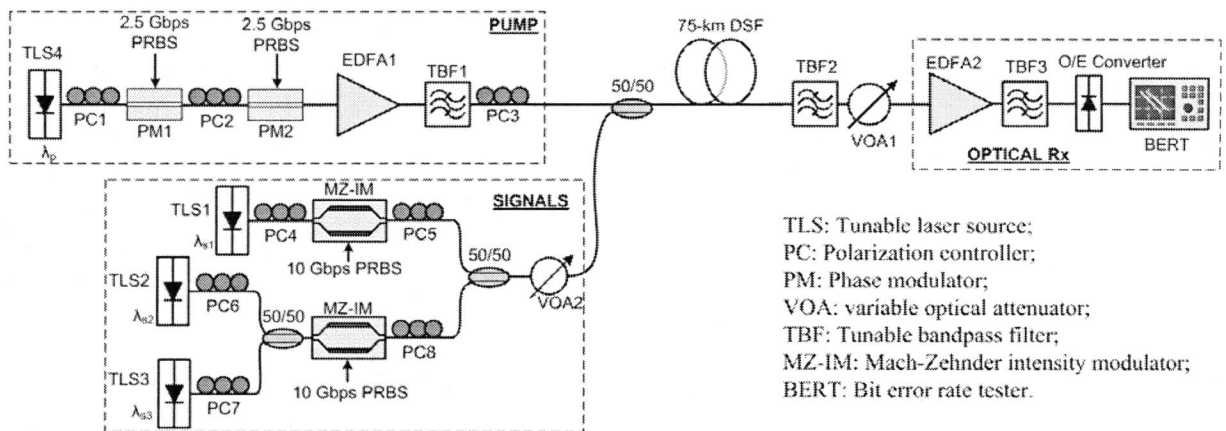

Fig. 2. Distributed OPA experimental set-up.

Polarization controllers PC1 and PC2 align the SOP of the pump with PM1 and PM2, respectively. The pump is then amplified to the desired power level by a C-band EDFA (EDFA1) and filtered by a 1.3 nm tunable bandpass filter (TBF1) to reduce the ASE noise of EDFA1. Three other tunable laser sources, TLS1, TLS2, and TLS3, tuned at 1549.14, 1549.46, and 1549.76 nm, respectively, serve as signal sources. They are modulated by 10 Gb/s NRZ $2^{23} - 1$ PRBS as shown in Fig. 2; they are also used to measure the DPA gain. Maximum OPA gain is achieved by aligning the SOPs of signals and pump by PC3, PC5, and PC8. Signals and pump are then combined by a 3-dB coupler, and enter the DSF. The signals input power into the DSF is maintained below −18 dBm, while the input pump power is 18.23 dBm (66.5 mW). This ensures that the pump is undepleted, and that low signals-related nonlinear effects would be generated (e.g. XGM, FWM). The output spectrum of the DSF is observed with an optical spectrum analyzer (OSA). Tunable bandpass filter TBF2 selects the desired signal wavelength before detection by the O/E converter.

4. Results and Discussion

We first removed TBF1 in order to inject a broad EDFA ASE spectrum into the DPA. The shape of the ASE spectrum at the output of the DPA then provides an indication of the DPA gain spectrum. The experimental data for the amplified ASE spectrum is shown in Fig. 3(a). Its shape shows a 10-dB bandwidth of about 2 nm on each side of the pump, which can be used for amplifying transmission signals. The gain bandwidth is smaller than expected from theory (Fig.1), which may be due to substantial longitudinal variations of λ_0 in this three-segment link.

We then inserted TBF1 to efficiently suppress EDFA ASE, and turned on the signals. The power of channels 1, 2, and 3 at the DSF input was −18.74, -20.71, and -20 dBm, respectively. The corresponding on-off signal gains

were 14.4, 16.9, and 16.5 dB, as shown in Fig. 3(b). The gain is sufficient to compensate the transmission loss of the 75 km DSF (15.52 dB).

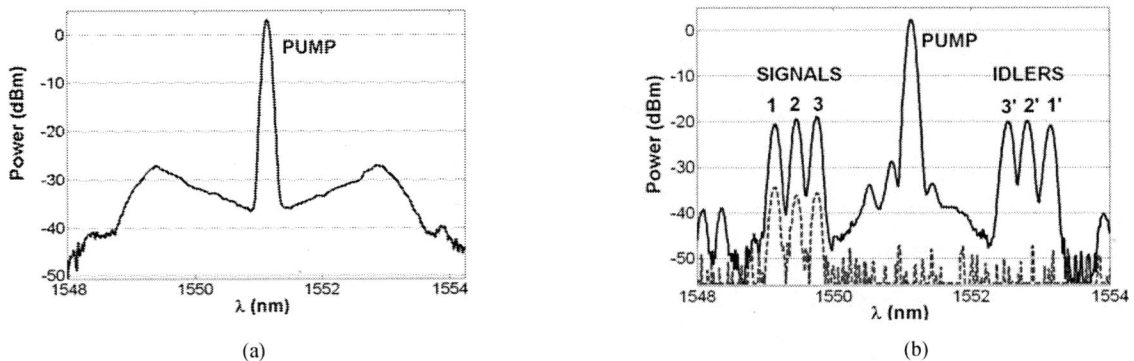(a)   (b)

Fig. 3. (a) ASE output spectrum of distributed OPA with 18.23 dBm input pump power; (b) Spectrum at the output of the 75-km of DSF with the pump ON (solid) and OFF (dashed).

The amplified signal at 1549.14 nm was then selected by TBF2, and detected for three different cases: (i) when just channel 1 was ON, (ii) channels 1 and 3 were ON, (iii) all three channels were ON. The eye patterns were displayed on an oscilloscope. Examples are shown in Fig. 4(a); the clear opening indicates the high quality of the received signal. Bit error rate (BER) was also measured by varying the received power by means of VOA1. BER plots for the three cases discussed above are shown in Fig. 4(b), together with a reference plot for the transmitter and receiver back-to-back (only channel 1 ON, and connected to the receiver bypassing the DSF). It can be seen that the insertion of the DPA leads to a power penalty of the order of 1.2 dB (cases (i), and (ii)), and 2.1 dB (case (iii)).
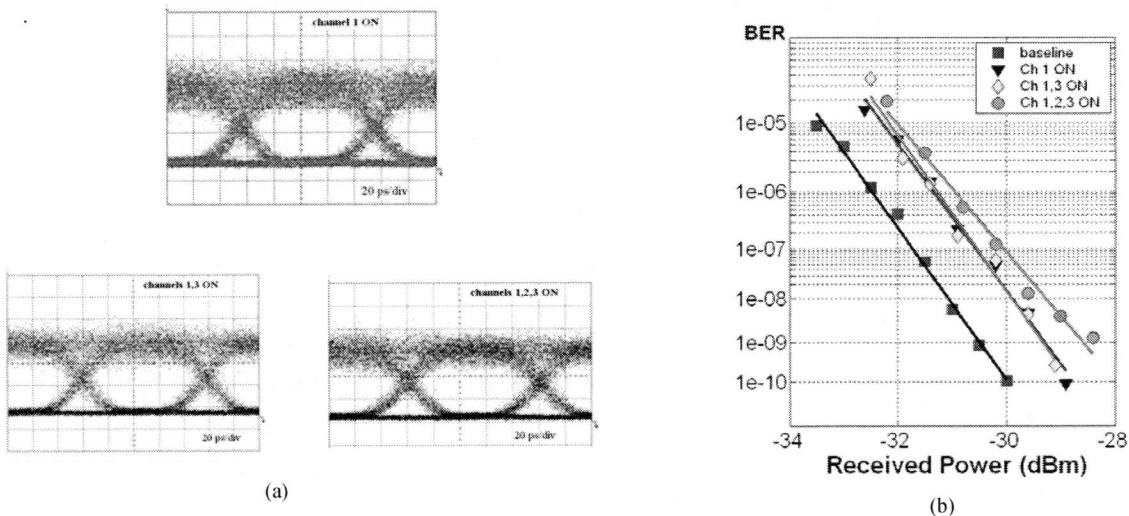

(a)   (b)

Fig. 4. (a) Eye patterns for received signal; (b) BER plots for signal received after the DPA, and for back-to-back configuration.

5. Conclusion

We have demonstrated, for the first time to our knowledge, distributed parametric amplification (DPA), namely amplification of 10-Gb/s communication signals along a 75-km transmission fiber by using a co-propagating pump with only 66.5 mW of pump power. This provides a novel means of signal amplification in communication networks, which may find practical applications for single- or multi-channel systems.

References

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