Quasi-Constant Signal Power Transmission with Low Signal RIN by DRA with Incoherent-Forward and Coherent-Backward Pumps

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Abstract: We measure characteristics of a transmitted WDM signal in an 80 km-long SMF under bi-directionally pumped DRA with incoherent-forward and coherent-backward pumps. The signal shows OSNR of 50.0 dB and RIN less than -140 dB/Hz. © 2022 The Author(s)

1. Introduction

Bi-directionally pumped distributed Raman amplifications (DRA) in fiber transmission systems reduce signal power variation along a transmission fiber. In case of forward and backward Raman gains are comparable, the signal power variation is minimized, and quasi-constant signal power transmissions are obtained [1-3].

The quasi-constant signal power transmissions allow us to have high optical signal-to-noise ratio (OSNR) in fiber transmission systems. However, forward-pumped Raman amplification that uses narrow band laser diodes (LD) as pump sources degrades signal quality due to relative intensity noise (RIN) transfer from pump sources to signal [4-7]. Hereafter, we refer to the narrow band LDs such as Fabry-Perot laser diodes (FP-LD) with fiber Bragg gratings (FBG) as coherent pumps (cPump). On the other hand, wideband incoherent light sources used as pump sources suppress the RIN transfer in forward pumped DRA [8-10]. Hereafter, we refer to the wideband incoherent light sources as incoherent pumps (iPump). Since input power to a transmission fiber from an iPump was increased more than 250 mW [11], multiplexed iPumps are expected to output high power incoherent light enough for having forward Raman gain equivalent to backward Raman gain.

In this paper, we demonstrate a quasi-constant signal power transmission in an 80 km-long G.652.D single mode fiber (SMF) by bi-directional DRA using iPumps as forward pumps and cPumps as backward pumps. We measure characteristics of the transmitted signal.

2. Incoherent pump light source

An iPump consists of a seed semiconductor optical amplifier (SOA), a booster SOA and two isolators and is packaged in a standard 14-pin butterfly package. The isolators are placed between the seed and the booster SOAs and at output end of the booster SOA. The booster SOA amplifies amplified spontaneous emission from the seed SOA under saturated amplification region. Output power of an iPump achieved 270 mW. Figure 1 shows output spectra of two iPumps having peak wavelengths at 1425 nm and 1466 nm with 3dB bandwidth of 28 nm and 29 nm, respectively. Small downward peaks on the spectra around 1400 nm in Fig.1 are come from OH absorption in air.

Figure 2 shows typical RIN spectra of an iPump and a cPump. The iPump shows low RIN value less than -150 dB/Hz below 1 GHz and saturated maximum value up to -130 dB/Hz around 40 GHz, which is much lower than that of the cPump. The saturated maximum RIN value almost coincides with RIN value of white light with the same bandwidth.

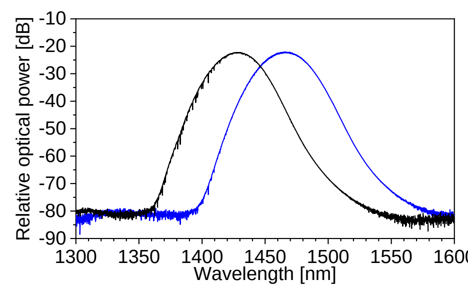

Fig.1 Optical spectra for iPumps with peak wavelength of 1425 nm (black line), and 1466 nm (blue line), respectively.

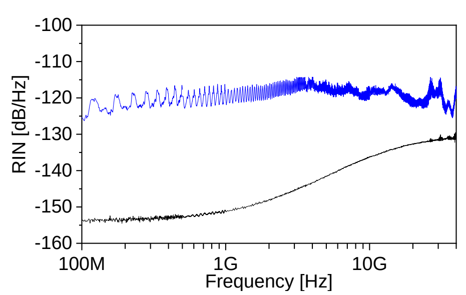

Fig.2 Typical RIN spectra of an iPump (black line) and a cPump (blue line).

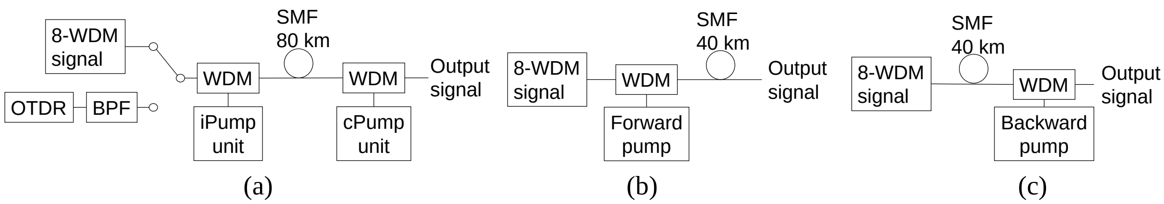

Fig.3 Experimental setups.

3. Quasi-constant signal power transmission

Figure 3(a) shows experimental setup for a quasi-constant signal power transmission. Input signal was an 8-wavelength division multiplexing (WDM) signal in C-band. We used an optical time domain reflectometer (OTDR) followed by a bandpass filter (BPF) when we measured signal power evolution in a transmission fiber. A transmission fiber was an 80-km long G.652.D SMF. We used an iPump unit and a cPump unit as forward and backward pump light sources, respectively, for bi-directionally pumped DRA. The iPump unit consisted of two 1425-nm iPumps and two 1466-nm iPumps. Launched powers from the iPump unit into the transmission fiber were 286 mW and 177 mW for 1425-nm and 1466-nm iPumps, respectively, after passing through polarization beam combiners and WDM couplers. A cPump unit consisted of cPumps with wavelength of 1424 nm, 1435 nm, and 1465 nm that output 71 mW, 127 mW, and 243 mW, respectively. An 8-WDM signal has optical power of 0 dBm/ch resulting in total power of 9 dBm. Figure 4 shows optical spectra measured in the forward direction at the input end of the transmission fiber as shown in Fig. 3(a) and measured in the backward direction at the output end of the fiber. In case of no DRA condition, an additional erbium doped fiber amplifier (EDFA) was used to compensate fiber loss.

Figure 5 shows Raman gain spectra with above pump conditions of bi-directional DRA. A Raman gain spectrum for the bi-directional DRA in 80 km-long SMF measured with configuration shown in Fig. 3(a) shows averaged gain of 0.2 dB and gain flatness of 0.7 dB. Under the same pump condition, we measured Raman gain spectra of forward-pumped DRA using the iPump unit and backward-pumped DRA using the cPump unit in 40 km-long SMF with configurations shown in Fig.3(b) and (c), respectively. The forward-pumped one shows averaged gain of -1.3 dB and gain flatness of 0.3 dB. The backward-pumped one shows averaged gain of 0.6 dB and gain flatness of 0.6 dB. Quasi-constant signal transmission was successfully obtained since Raman gains by forward and backward pumpings are almost the same.

We measured OSNR of 1550.9 nm signal in the 8-WDM signal with resolution bandwidth of 0.1 nm under the bi-directional DRA configuration as shown in Fig.3(a). The measured OSNR was as high as 50.0 dB, which is 10 dB higher than that of 40.1 dB measured under an EDFA amplification condition.

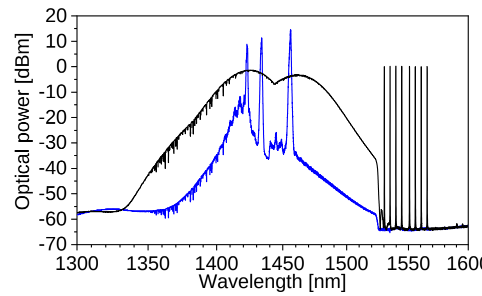

Fig.4 Optical spectra for 8-WDM signal and the iPump unit (black line), and for the cPump unit (blue line).

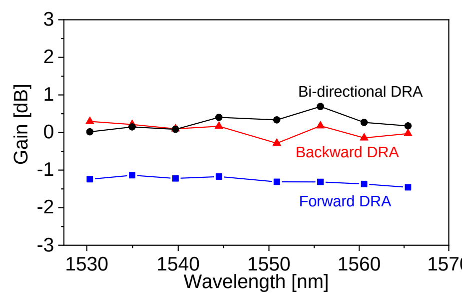

Fig.5 Raman gain spectra for bi-directionally pumped (black, circle), forward pumped (blue, square), and backward pumped (red, triangle) DRAs.

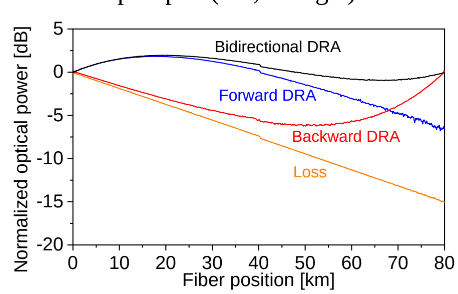

Fig.6 Measured signal power evolutions for bi-directional (black line), forward (blue line), backward (red line) DRA, and no DRA, i.e., only fiber loss (orange line) conditions.

Figure 6 shows signal power evolutions measured with configuration as shown in Fig.3(a) using an OTDR. In the measurement for bi-directional DRA, backward pump power was adjusted from the aforementioned values to have 0 dB signal at 80 km point, since input power from the OTDR was so small that Raman pump depletion was decreased. In the measurement for backward DRA, backward pump power was increased to have 0 dB signal at 80 km point. Power variations on the signal evolutions for bi-directional DRA and for backward DRA were 2.9 dB and 6.4 dB, respectively.

4. RIN of the transmitted signal

We measured RIN of forward-pumped, and bi-directionally pumped transmitted signal to confirm RIN transfer and impact of pump sources.

Figure 7 shows RIN spectra for forward pumped 1550.9 nm signal in the 8-WDM signal pumped by the iPump unit and the cPump unit using the configuration shown in Fig. 3(b). Here, peak at 10.9 GHz is caused by stimulated Brillouin scattering (SBS) of the signal. RIN of the transmitted signal pumped by the iPump unit shows lower RIN value than that pumped by the cPump unit. We confirmed that the RIN transfer pumped by the cPump unit extends to 40 GHz as indicated in Ref. 6 and 7.

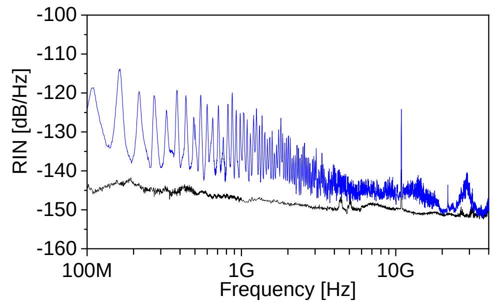

Fig.7 RIN spectra of forward pumped 1550.9 nm signal using the iPump unit (black line) and the cPump unit (blue line).

Figure 8 shows RIN spectra measured with the configuration shown in Fig. 3(a) for bi-directionally pumped 1550.9 nm signal in 8-WDM signal and for no DRA signal where fiber loss was compensated with an EDFA. Here, peak at 10.9 GHz is caused by SBS of the signal. We confirmed that RIN of the bi-directionally pumped signal is lower than that of no DRA, i.e., an EDFA amplified signal.

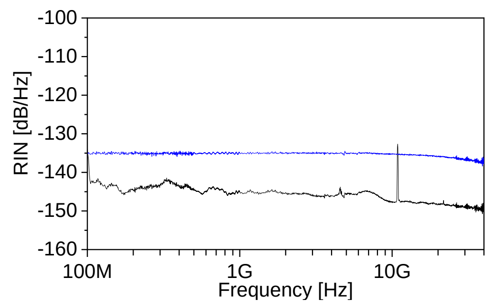

Fig.8 RIN spectra for bi-directionally pumped 1550.9 nm signal (black line), and for no DRA, i.e., an EDFA amplified signal (blue line).

5. Summary

We demonstrated quasi-constant signal power transmission on 80 km-long G.652.D SMF by bi-directional DRA with the iPump unit as forward and the cPump unit as backward pumps. Thanks to increased power of iPumps to 270 mW, output power of the iPump unit achieved to 463 mW sufficient for the quasi-constant signal power transmission. We confirmed that RIN of forward-pumped transmitted signals using the iPump unit is smaller than that using the cPump unit. The bi-directionally pumped transmitted signal shows OSNR as high as 50.0 dB and RIN spectrum lower than that of the EDFA-amplified signal. Quasi-constant signal power transmissions by bi-directional DRA using iPumps as forward pumps would be feasible for installed transmission fibers.

6. Acknowledgements

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