C+L Band Transmission under Bidirectionally Pumped Distributed Raman Amplification Using Semiconductor Incoherent Pumps

Shigehiro Takasaka, Daichi Ogata, Ayato Shirai, Satoru Ichihara, Junji Yoshida, and Norihiro Ohishi
Furukawa Electric Co., Ltd, 6, Yawata-kaigandori, Ichihara, Chiba 290-8555, Japan
shigehiro.takasaka@furukawaelectric.com

Abstract: We demonstrate a 100Gbaud DP-16QAM signal transmission over either 150/200 km SSMF/CSF under bidirectionally pumped Raman amplification using semiconductor incoherent sources as forward pumps. We confirm effectiveness of the incoherent sources for high signal quality. © 2024 The Author(s)

1. Introduction

Bidirectionally pumped distributed Raman amplifications (DRA) increase optical signal to noise ratio (OSNR) of a transmitted signal[1]. However, it was an issue for the bidirectionally pumped DRA that relative intensity noise (RIN) transfer from forward pumps to optical transmitted signals occurs in forward pumped DRA and degrades quality of a transmitted signal where Fabry-Pérot laser diodes using fiber Bragg gratings (hereafter referred to as cPUMPs) which are conventionally employed in backward pumped DRA are applied to forward pumps[2-4]. The RIN issue was solved by application of wideband incoherent optical sources as forward pumps[5-7]. A forward pumped DRA using wideband incoherent optical sources improves optical signal quality[6-10].

Semiconductor wideband incoherent sources (hereafter referred to as iPUMPs) for forward pumped DRA pumps have been developed [11,12]. Output power of the iPUMPs exceeded 200 mW[11]. The iPUMPs having suitable center wavelengths for forward pumped DRA over C+L bands were fabricated[11,12]. RINs of optical signals under forward pumped DRA using the iPUMPs as forward pumps are suppressed enough and are smaller than those of optical signals amplified by erbium doped fiber amplifiers (EDFAs)[11,12].

In this paper, we measure and discuss optical signal quality of transmitted optical signals under bidirectionally pumped DRA over C+L bands using iPUMPs as forward pumps. Following to Ref.12, cPUMPs are used as second-order forward and first-order backward pumps. We employ two kinds of transmission fibers to investigate effect of mode field diameter difference.

2. Experimental setup

Figure 1 shows experimental setup for evaluation of a transmitted DP-16QAM signal interleaved in 46-WDM signal under bidirectionally pumped Raman amplification, backward pumped Raman amplification, and only EDFA amplification. Transmission fiber was either SSMF (Standard Single Mode Fiber) compliant with G.652.D or CSF (Cutoff Shifted Fiber) having effective area of 110 μm^2 compliant with G.654.E with length of either 150 km or 200 km. Mode field diameter of CSF is larger than that of SSMF so that Raman coefficient of CSF is smaller than that of SMF. Attenuation of SSMF and CSF is 0.178 dB/km and 0.162 dB/km at 1550 nm, respectively. We used two kind of pump units for Raman amplification; One was an iPUMP unit comprised of iPUMPs and cPUMPs and another was a cPUMP unit comprised of only cPUMPs. Figure 2 shows optical spectra of outputs of the iPUMP unit and of

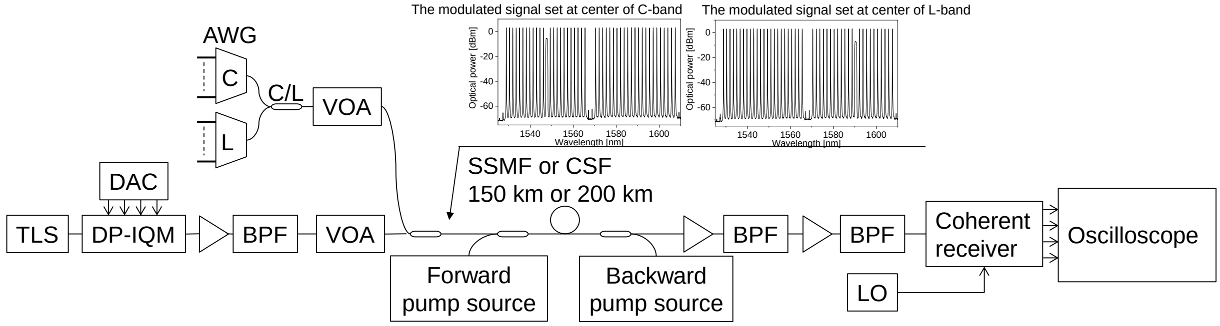


Fig.1 Experimental setup.

the cPUMP unit. Pump setups for the iPUMP unit and for the cPUMP unit are shown in Tab.1 and 2, respectively. Total output power of the iPUMP unit and of the cPUMP unit was 946 mW and 692 mW, respectively.

A 100 Gbaud DP (dual polarization) 16QAM signal was generated by modulating an optical signal from a TLS (Tunable Laser Source) according to electric signals from a DAC (Digital to Analogue Converter) with bandwidth of 67 GHz and sampling frequency of 256 GSa/s using a DP-IQ modulator (IQM) with bandwidth of 53 GHz. The modulated signal was amplified by an EDFA. After an optical bandpass filter (BPF) extract the amplified signal, signal power was adjusted by a variable optical attenuator (VOA). Output wavelength from the TLS was set either at 1547.69 nm as a center of C-band signal or at 1590.41 nm as a center of L-band signal. A 46-WDM (Wavelength Division Multiplexing) signal where wavelength that was the same with wavelength of the DP-16QAM signal was not loaded was generated by multiplexing 46 continuous waves using two arrayed waveguide gratings (AWGs) with 200 GHz spacing. After the WDM signals in C-band and in L-band were coupled with a C/L coupler, signal power was adjusted by a VOA. After the DP-16QAM signal and the 46-WDM signal was coupled by an optical coupler, the coupled signal was launched into the transmission fiber through a WDM coupler to combine the signal and a forward Raman pump.

After an output signal from the transmission fiber passed a WDM coupler that combines a backward Raman pump, the output signal was amplified by an EDFA. A BPF extracted the DP-16QAM signal. The extracted signal was amplified and extracted again by a following EDFA and a BPF and was input into a coherent receiver. An optical signal was input into the receiver as a local oscillator (LO). Output electric signals from the receiver were measured by an oscilloscope with bandwidth of 110 GHz and sampling frequency of 256 GSa/s. The measured signal was demodulated by offline calculations. Then, Q-factor of the transmitted signal was obtained.

Figure 3 shows on-off Raman gain spectra when optical power input into the transmission fiber was 3 dBm/ch measured under two Raman pump conditions; one is i-c combination where the iPUMP unit and the cPUMP unit are used as forward and backward pump source. Another is c-c combination where the two cPUMP units were used as forward and backward pump source. Regarding input power of 3 dBm/ch, under pump condition of the i-c combination, averaged gain was 14.5 dB and 15.1 dB for 150 km and 200 km SSMF transmissions, respectively, and 9.7 dB and 9.8 dB for 150 km and 200 km CSF transmissions, respectively. Under pump condition of the c-c combination, averaged gain was 13.5 dB and 14.0 dB for 150 km and 200 km SSMF transmissions, respectively, and 9.8 dB and 10.0 dB for 150 km and 200 km CSF transmissions, respectively. Smaller on-off gain of CSF reflects larger mode field diameter of CSF.

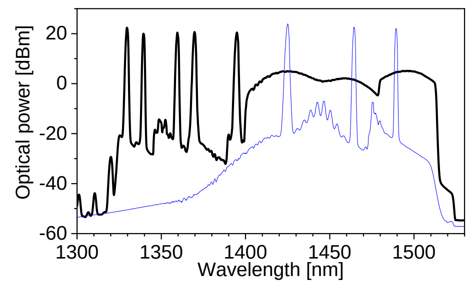


Fig.2 Output spectra of the iPUMP unit using iPUMPs as 1st order and cPUMPs as 2nd order pumps (thick black line), and the cPUMP unit using cPUMPs as 1st order pumps (thin blue line).

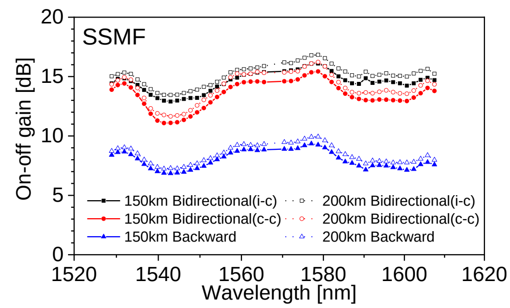
Tab.1 Pump setup for the iPUMP unit

	units	iPUMP		
Wavelength	nm	1425	1461	1495
Power	mW	89	38	75

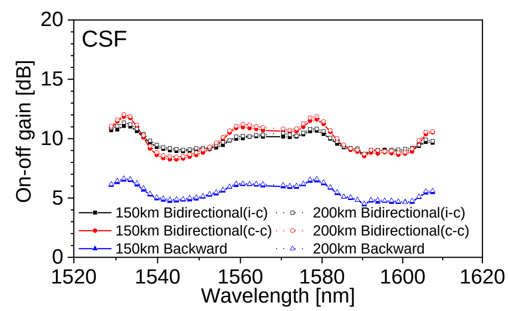
	units	cPUMP				
Wavelength	nm	1328	1338	1358	1368	1393
Power	mW	189	99	140	158	158

Tab.2 Pump setup for the cPUMP unit

	units	cPUMP		
Wavelength	nm	1425	1465	1490
Power	mW	378	191	123



(a)



(b)

Fig.3 On-off Raman gain spectra under input signal power of 3 dBm/ch for SSMF (a) and for CSF (b).

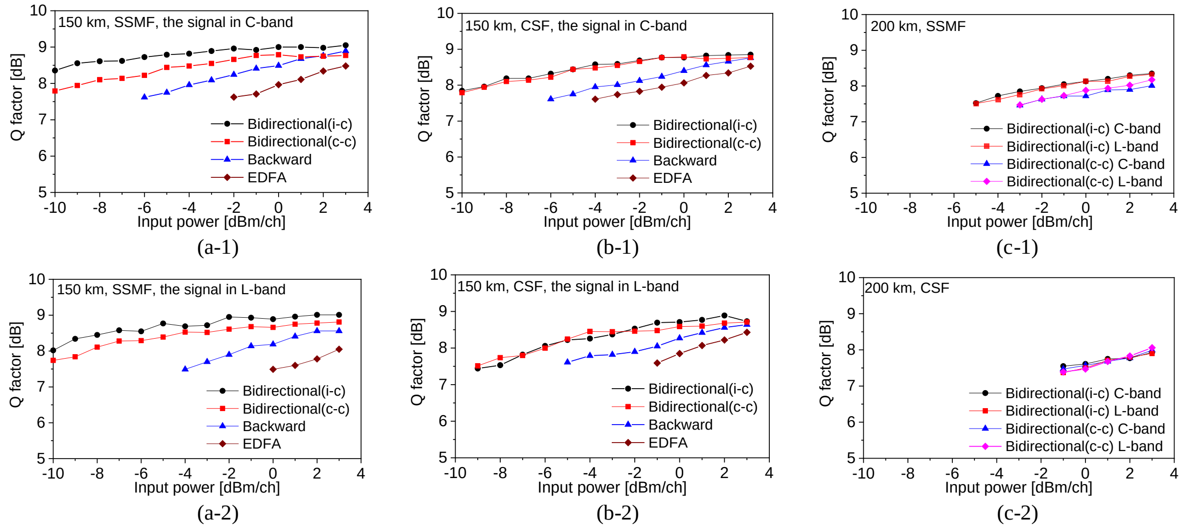


Fig.4 Measured Q-factors for transmissions of 150 km-SSMF with C-band signal (a-1) and with L-band signal (a-2), and of 150 km-CSF with C-band signal (b-1) and with L-band signal (b-2), and of 200 km-SSMF with both C and L band signals (c-1) and 200 km-CSF with both C and L band signals (c-2).

3. Results and discussion

Figure 4 shows measured Q-factors for 150 km-SSMF (Fig.4 (a-1),(a-2)), 150 km-CSF(Fig.4 (b-1),(b-2)), 200 km-SSMF(Fig.4 (c-1)), and 200 km CSF(Fig.4 (c-2)) transmissions. Bidirectionally pumped Raman amplification with the i-c combination shows the highest Q-factors in all measurement conditions. Q-factors for bidirectionally pumped Raman amplification with the c-c combination were slightly worse than those with the i-c combination on the SSMF transmissions as shown in Fig.4(a-1, a-2, c-1) indicating that difference of Q factors are caused by RIN transfer from Raman pump to the measured signal, and were almost the same with those with the i-c combination on the CSF transmission as shown in Fig.4(b-1, b-2, c-2) implying that the RIN transfer effect is small in the case of lower Raman gain. OSNRs of the 200 km transmitted signals over both SSMF and CSF amplified by backward Raman amplification and by only EDFAs were not enough to obtain Q-factors as shown in Fig.4(c-1, c-2) indicating that bidirectionally pumped Raman amplifications for i-c and c-c combinations are effective to transmit the signal longer length. Q-factors of the C-band signal were almost the same with those of the L-band signal in all measurement condition thanks to flat on-off Raman gain over C+L band.

4. Summary

We evaluated quality of the transmitted 100Gbaud DP-16QAM signal interleaved in 46-WDM signals over either 150 km and 200 km SSMF and CSF under C+L band bidirectionally pumped Raman amplification using iPUMPs as 1st order forward pumps. Q-factors in all measurement conditions for bidirectionally pumped Raman amplification with the i-c combination were higher than those for backward pumped Raman and for EDFAs amplifications. Q-factors for bidirectionally pumped Raman amplification with the c-c combination were lower when transmitting on the SSMF and were almost the same when transmitting over CSF under the condition of the same Raman pump powers.

We confirmed that bidirectionally pumped Raman amplifications using the iPUMPs as 1st order forward pumps are effective to obtain high signal quality.

5. Acknowledgements

We appreciate Mr. Haruki Ogoshi for suggestive discussion. These research results were supported in part from the commissioned research (No.04501) by National Institute of Information and Communications Technology (NICT), Japan under “Bandwidth extended optical node technologies to realize Beyond 5G ultrahigh-speed and large-capacity networks”.

References

[1] J.-C. Bouteiller et al., ECOC2002, symposium 3.4 (2002).
[2] C. R. S. Fludger et al., JLT 19(8), pp. 1140-1148 (2001).
[3] C. Martinelli et al., IEEE PTL 17(9), pp. 1836-1838 (2005).
[4] K. Keita et al., J. Opt. Soc. Am. B 23, 2479-2485 (2006).
[5] D. Vakhshoori et al., OFC 2003, PD47 (2003).
[6] M. Morimoto et al., IEEE PTL 29(7), pp. 567-570 (2017).
[7] M. A. Iqbal et al., JLT 36(13), pp. 2611-2618 (2018).
[8] T. Kobayashi et al., OFC2019, Tu3F.6. (2019).
[9] T. Kobayashi et al., IEICE Com. Ex. 8(5), pp. 166-171 (2019).
[10] N. Taengnoi et al., ECOC2022, We4A.1 (2022).
[11] S. Takasaka et al., OFC2023, W2A.11 (2023).
[12] S. Takasaka et al, ECOC2023, P.10 (2023).