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128 x 8 split and 60 km Long-reach PON Transmission using 27 dB-gain Hybrid Burst-mode Optical Fiber Amplifier and Commercial Giga-bit PON System

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Abstract: We demonstrate error free transmission of a 128 x 8 split and 60 km long-reach PON system over 12 hours; a loss budget of over 60-dB is achieved by combining a hybrid burst-mode optical fiber amplifier (OFA) and a commercial G-PON system. Our proposed hybrid burst-mode OFA, which consists of a gain-clamped praseodymium-doped fiber amplifier (PDFA) and a fast automatic gain controlled PDFA, successfully achieves over 27-dB gain and over 16.5-dB dynamic range.
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1. Introduction

Passive optical network (PON) systems are being utilized to provide cost-effective optical access network systems [1]. To offer PON-based optical access services more effectively, we have intensively investigated long-reach PON systems using burst-mode optical amplifiers based on a couple of linear-gain control techniques, gain-clamping (GC) [2], fast automatic gain controlling (fast AGC) [3], and fast automatic level controlling (fast ALC) for optical amplifiers [4]. In particular, fast AGC techniques allow the linear gain region of OFA's to be expanded without any gain suppression. GC techniques, on the other hand, are usually accompanied by considerable gain suppression. Accordingly, we expect AGC techniques will realize both higher linear gain and a wider linear gain region (wider dynamic range). Previous reports of our fast AGC praseodymium-doped fiber amplifier (PDFA), however, note a linear gain of only 20-dB.

In this paper, we propose a hybrid burst-mode OFA that consists of a GC-PDFA and an AGC-PDFA; it achieves the 26 dB linear gain specified in ITU-T Recommendation G.984.6. We then demonstrate a long-reach PON transmission experiment and upstream allowable loss budget measurements to confirm its feasibility.

2. Hybrid burst-mode optical fiber amplifier

Figure 1 shows the configuration of a hybrid burst-mode optical fiber amplifier (OFA) that consists of a GC-PDFA block and a fast AGC-PDFA block. The PDFA blocks offer constant gain of around 10 dB and 20 dB, respectively, with optical input powers from -40 dBm to -5 dBm. A 20 nm optical band pass filter (OBPF) is set at the output port of the GC-PDFA. The fast AGC-PDFA employs a feed-forward (FF) controlled pump-LD for quick gain adjustment, several tens of nano-seconds, of the PDFA. The FF-controlled pump-LD quickly adjusts pump power according to the monitored signal power. Thus the hybrid burst-mode OFA can offer constant gain, over 27 dB, with input powers from -40 dBm to -15 dBm (these correspond to input average powers of -37 dBm to -12 dBm).

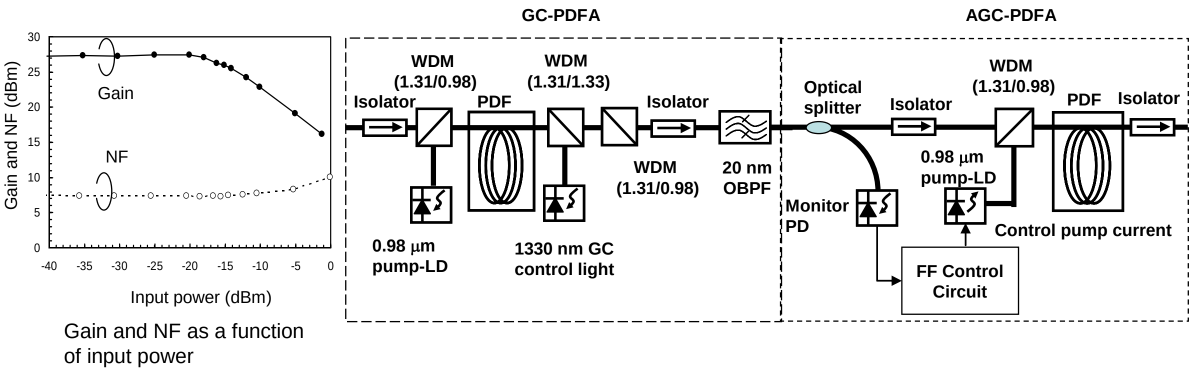

Fig.1 Fundamental configuration of hybrid burst-mode optical fiber amplifier

3. Experimental setup for upstream allowable loss budget measurement of optically amplified PON system

Figure 2 shows the experimental setup used to measure the upstream allowable loss budget of a long-reach PON system that consists of our developed amplifier-based PON repeater and a commercial Giga-bit PON system. The commercial PON system supports 60 km transmission range. The upstream bit rate and the downstream bit rate are 1.24416 Gbit/s and 2.48832 Gbit/s, respectively. The transmitted powers of ONU#1, ONU#2, and the OLT were 5.0 dBm, 5.0 dBm, and 3.0 dBm, respectively. The central wavelengths were 1311.0 nm, 1311.9 nm, and 1492.6 nm, respectively. Overloads were above -8 dBm. The sensitivities (BER = 10^{-10}) of ONU#1 and the OLT were -35.4 dBm and -30.5 dBm, respectively. Forward error correction, RS(255,232), was applied to the upstream signals. The downstream signals were bypassed by WDM couplers to evaluate only upstream signal amplification because the upstream loss greatly exceeds the downstream loss. Upstream signals with different intensities were generated by the VOA's at the output of each ONU. In this experiment, the input power of OUN#2 was set to -15 dBm or -30 dBm. We varied link-loss between ONU#1 and the hybrid burst-mode OFA (Link-loss A), and the link-loss between the hybrid burst-mode OFA and the OLT (Link-loss B), and measured the BER of the signals received from ONU#1 to confirm the upstream allowable loss budget of our long-reach PON system.

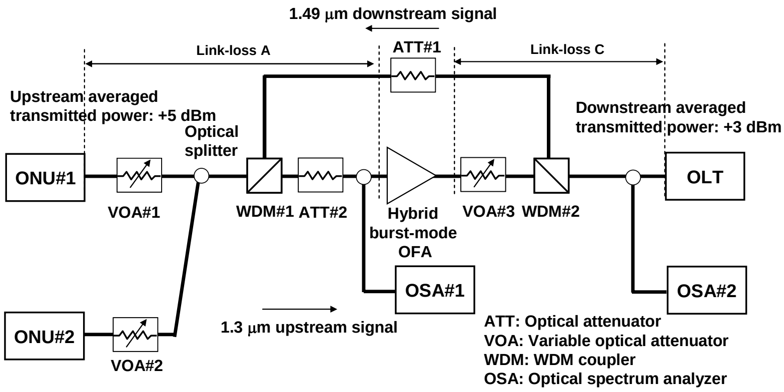

Fig.2 Experimental setup used to measure the upstream allowable link-loss of long-reach PON system

4. Experimental results

Figure 3 shows allowable link-loss B as a function of link-loss A. At the link loss B value of 27.5 dB, we achieved the error free attenuation range around 16.5-dB which means that the hybrid burst-mode OFA achieved over 16.5-dB dynamic range (average optical input power). We achieved the allowable loss budget of over 60 dB for link loss A values from 20 dB to 35 (maximum 66 dB loss budget in the link loss range from 26 dB to 31 dB). For link loss A values from 19 dB to 34 dB, we achieved over 15 dB error free attenuation range of link loss B (maximum 20 dB range got link loss A value of around 25 dB). This indicates that we successfully achieved over 60 dB total loss budget and over 15 dB attenuation range for both links. Amplified spontaneous emission (ASE) induced degradation was relatively small because of the use of FEC, although we employed the OBPF with relatively wide bandwidth of 20 nm.

Finally, we introduce our 128 x 8 split and 60 km long-reach PON transmission experiment using the optical amplifier-based PON repeater; we combined our proposed hybrid burst-mode OFA with a conventional Thulium -doped optical fiber amplifier (TDFA) with 20 dB gain, and a commercial Giga-bit PON system. Figure 4 shows the experimental setup. The SM fiber between the OLT and the PON repeater was 40 km long. Only three ONU's were connected to the optical splitter but the splitting ratios were 128 and 8 to emulate the loss budget of a 1024-ONU system. We assigned 300 Mbit/s upstream and downstream transmission capacities to each ONU. The transmission distances between the PON repeater and the three ONUs were 0km, 10km, and 20 km. The measured average losses of SM fibre for upstream and downstream wavelengths were 0.375 dB/km and 0.225 dB/km, respectively. The 128 way splitter and WDM#1 loss were measured as 23.0 dB and 0.7 dB, so the losses between the repeater and the ONU's were estimated to be 31.2 dB, 27.5 dB, and 23.7 dB in the upstream direction, respectively. In the downstream direction, the corresponding losses were 29.2, 26.0, and 23.7 dB. The measured 8 way splitter loss and WDM#2 loss were 10 dB and 0.7 dB, respectively. The VOA between the repeater and WDM#2 was used to adjust the upstream link-loss between the repeater and the OLT. We set the losses between the OLT and the repeater to 30.0 dB and 19.7 dB for up and downstream direction. With these conditions, we successfully demonstrated over 12 hours of error free transmission in each direction in the long-reach PON system. This error free time corresponds to the BER of better than 10^{-13} for each flow thus confirming the validity of our hybrid burst-mode OFA.

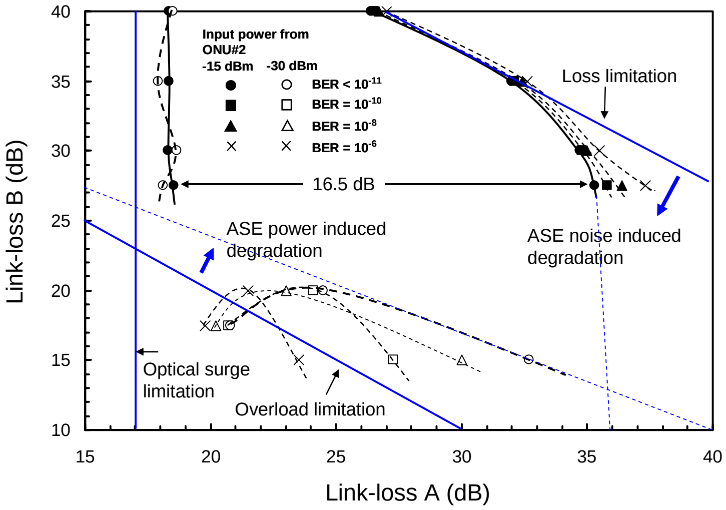

Fig.3 Allowable link-loss B between hybrid burst-mode OFA and OLT as a function of link-loss A between ONU#1 and hybrid burst-mode OFA

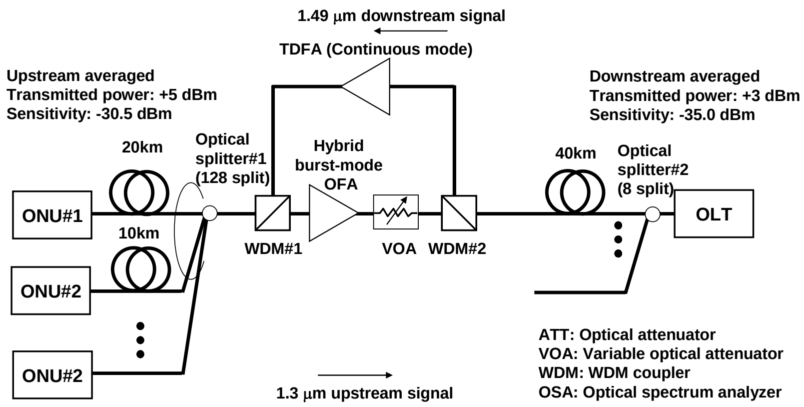

Fig.4 Experimental setup of 128 x 8 split and 60 km long-reach PON transmission

5. Conclusion

We successfully demonstrated error free transmission of a 128 x 8 split and 60 km long-reach PON system for over 12 hours, its loss budget exceeded 60-dB and its attenuation range exceeded 15 dB due to the use of our hybrid burst-mode OFA and a commercial Giga-bit PON system followed by FEC. We also showed that our hybrid burst-mode OFA, which consists of a GC-PDFA and a fast AGC-PDFA, can achieve high gain, over 27-dB, and excellent dynamic range, over 16.5-dB.

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6. References

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