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Adaptive upstream optical power adjustment depending on required power budget in PON access

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ABSTRACT

According to the present passive optical network (PON) standard, the fiber transmission lengths are from 500 m to 20 km between the optical line terminal (OLT) and different optical network units (ONUs). It will result in difference power losses (ΔP_{loss}) from 4 to 5 dB. Hence, we propose to adjust adaptively the output optical power of the upstream laser diode (LD) depending on the different fiber lengths. With the different fiber transmission lengths, we can properly adjust the bias current and modulation index of upstream LD for energy-saving. We characterize and analyze experimentally the relationship of output optical power and modulation amplitude Vamp under different fiber transmissions in PON access. Moreover, due to the adaptive power control of upstream signal, the optical upstream equalization also can be retrieved with power variation of 1.1 dB in this experiment.

1. Introduction

Recently, the time-division-multiplexed passive optical network (TDM-PON) is one of the promising choices for the next generation fiber to the home (FTTH) system [1]. And the TDM-PON has been thoroughly explored and standardized, and commercial products for the TDM-PON have already existed [2,3]. In practical, the point-to-multipoint connectivity between the optical line termination (OLT) and multiple optical network units (ONUs) is obtained using a passive branching device at the remote node (RN). Typically, the 1310 and 1490 nm wavelengths are used for the upstream and downstream signals in current TDM-PON networks [4,5].

In particular, the broadband PON systems have the higher power consumption than that of metro and core networks, due to the high number of communication components involved [6]. Generally speaking, to reduce the energy consumption in communication systems, nodes are allowed to switch to sleep mode since they are idle, and to wake up when they need to either send or receive data. To reduce the energy consumption in PON system, most of the studies were conducted within both the research community [7] and working groups in standard bodies [8] build upon the idea of allowing PON network devices, specifically the ONUs, to switch to sleep mode for power saving [9].

According to the standard PONs, the fiber transmission length was between 500 m and 20 km. Hence, it would result power loss difference of 4–5 dB between the OLT and each ONU because of the fiber loss. Usually, the output power of Tx in each ONU was fixed at certain power level for upstream data traffic. Hence, the larger power budget can obtain while the shorter fiber length is used between the OLT to ONU. In addition, the auto-gain control (AGC) and clock and data recover (CDR) processes have to be performed in the OLT to different upstream signals sending form different ONUs. And the success of the AGC and CDR processes require that the incoming upstream signals should be in a certain power dynamic range. By using the adaptive power control, the upstream signal powers from different ONUs can be adjusted in the optical domain; hence other power equalization processes [10,11] are not required.

In this work, we propose to adaptively control the upstream optical output power in each ONU by properly adjusting the bias current and modulation amplitude voltage (V_{amp}) depending on the different fiber transmission lengths. Due to 4–5 dB power difference, the shorter fiber length can use smaller upstream power for data traffic and achieve energy saving. We characterize and analyze experimentally the relationship of output optical power and modulation amplitude V_{amp} under different fiber transmissions in PON access. Besides, the maximum received upstream power difference (ΔP_{up}) at the OLT can be measured within 1.1 dB in for power equalization simultaneously by the proposed method.

2. Experiment and discussions

Fig. 1 shows the typical TDM-PON system. The fiber length between the OLT and ONU is from 500 m to 20 km long. As shown in Fig. 1, the 1490 nm downstream signal is broadcasting to each

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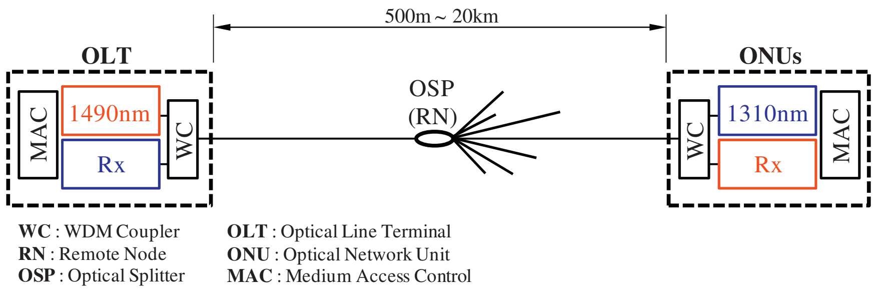

Fig. 1. Standard TDM-PON architecture.

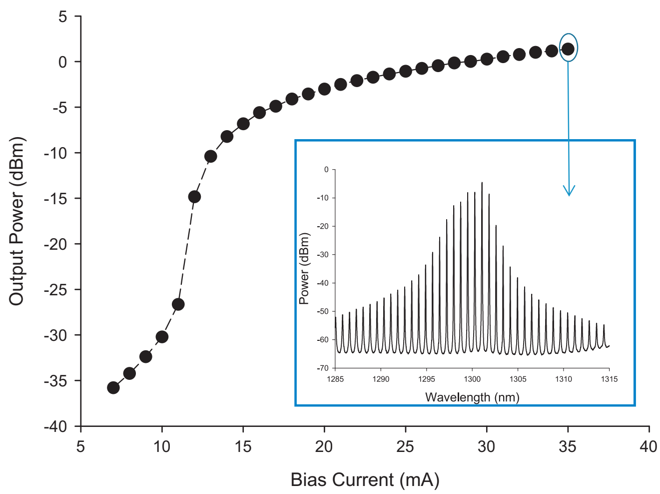

Fig. 2. Output power curve of 1310 nm FP-LD under different bias currents. Insert is the output spectrum of FP-LD at 35 mA.

ONU. And each 1310 nm upstream signal is scheduled for the upstream data traffic via the multi-point control protocol (MPCP) mechanism. Hence, the difference of fiber transmission lengths will result in power loss difference (ΔP_{loss}) of 4–5 dB. According to the ΔP_{loss}, we can adaptively adjust the output power of 1310 nm laser for energy saving. The output power can be adjusted by varying the laser operating bias current and modulation index.

Fig. 2 presents the output power of 1310 nm Fabry–Perot laser diode (FP-LD) versus different bias currents. We observe that the threshold current (Ithres) of FP-LD is around 10 mA. The maximum output power of FP-LD is about 1.4 dBm at the bias current of 35 mA. Usually, the 1.4 dBm upstream power can be used to support 20 km fiber transmission. And, when the bias currents are 18 and 24 mA, respectively, the measured output powers of −3.5 and −1.4 dBm can be obtained. Besides, the inset of Fig. 2 is the output spectrum of 1310 nm multi-mode FP-LD at the bias current of 35 mA.

Here, we select three output powers of 1.4, −1.4 and −3.5 dBm (with 4.9 dB power difference) from upstream FP-LD in this measurement due to the maximum fiber loss difference of 4–5 dB in PON. In the experiment, the FP-LD is directly modulated at 1.25 Gb/s non-return-to-zero (NRZ) format with pseudo-random binary sequence (PRBS) of $2^{31}-1$. Fig. 3(a) presents the upstream receiver (Rx) sensitivities against different modulated amplitude voltages (V_{amp}) using 3 different cases of output powers (output powers are 1.4, −1.4 and −3.5 dBm). The Rx sensitivity was measured at bit error rate (BER) level of 10^{-9}. In each output power case, the Rx sensitivity at B2B is always lower than that after 20 km fiber transmission. This is because the fiber chromatic dispersion degrades the upstream signal in the fiber transmission, producing power penalty and increasing the Rx sensitivity. While the output powers are 1.4, −1.4 and −3.5 dBm, respectively, the Rx sensitivities can be measured at −29.3, −29.4 and −29.3 dBm at B2B status under the V_{amp} of 1.3, 0.9 and 0.5 V, as shown in Fig. 3(a). And the Rx sensitivities of −23.6, −25.6 and −28.3 dBm also can be observed through the fiber transmissions of 20, 10 and 1 km respectively.

The measured V_{amp} of 1.3, 0.9 and 0.5 V has the minimum Rx sensitivities at various output power of FP-LD, as seen in Fig. 3(a). The reason we selected minimum Rx sensitivity is because it requires less Rx optical power to achieve the same BER performance (at BER of 10^{-9}). Hence, this means that the three V_{amp} are the optimal operating points for different upstream output powers at different fiber lengths. Moreover, the related power penalty is also measured under the different V_{amp} as the output power is 1.4, −1.4 and −3.5 dBm, respectively, after transmitting through 20, 10 and 1 km fiber transmission length as illustrated in Fig. 3(b). And the power penalties of 5.3, 3.8 and 1.0 dB can be observed respectively, at the same operating conductions as above. Insets of Fig. 3(b) are the corresponding eye diagrams at the V_{amp} of 1.3, 0.9 and 0.5 V in the fiber transmission of 20, 10 and 1 km, respectively. And these measured eyes are widely opening and clear. As shown in Fig. 3(b), when the V_{amp} is increased gradually, the power penalty decreases.

The total power consumption (P_{total}) of upstream FP-LD with modulation status can be expressed as below

$$P_{total} = P_S + P_D = I_{bias}^2 R + C V_{amp}^2 f \quad (1)$$

where P_S and P_D are the power consumptions of static and dynamic states. Here, the I_{bias} and R (=6 Ω) are the bias current and resistance for the FP-LD respectively. Besides, the C, V_{amp} and f are the capacity (=3 pF), modulation amplitude voltage and signal frequency (=1250 × 70% = 875 MHz), respectively.

Fig. 4 shows the power consumption of P_S and P_D under different bias currents and V_{amp}, respectively. Here, as the bias current and V_{amp} are increased, the obtained P_S and P_D are also increase, as shown in Fig. 4. When the I_{bias} is 18, 24 and 35 mA respectively, the P_S is measured at 1.94, 3.46, 7.35 mW. And its corresponding P_D is also observed at 0.066, 0.213 and 0.444 mW, when the V_{amp} is 0.5, 0.9 and 1.3 V respectively.

Here, to realize the total energy consumption of upstream FL-LD, we set three fiber transmission lengths of 20, 10 and 1 km, respectively, at three output powers of 1.4, −1.4 and −3.5 dBm. Three scenarios are discussed while the corresponding operation conditions are used in PON with 64 ONUs, as shown in Table 1. Scenario I is the extreme case in which all the ONUs are assumed located at 20 km away from the OLT, hence each ONU should be operated in full power. Then we arbitrarily select half the number of ONUs at 20 km away and the other half at 10 km away (scenario II); and the ONUs are distributed in 20, 10 and 1 km away from the OLT (scenario III). In general, each ONU is operated at maximum output power in current PON. As seen in Table 1, the total power consumption per day can be calculated at 42,396.5 W in the scenario (I), when the 64 ONUs are used and switched-on

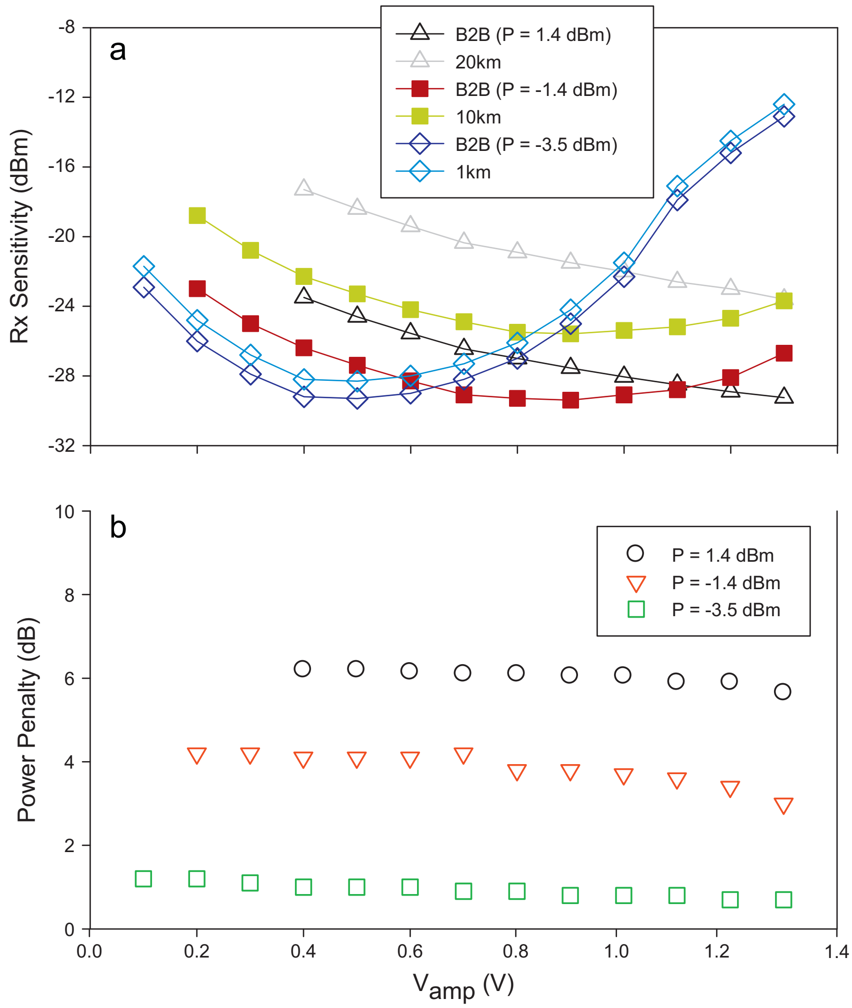

Fig. 3. (a) The upstream received power and (b) measured power penalty under different modulated amplitude voltage (V_{amp}), when the FP-LD is directly modulated at 1.25 Gb/s NRZ-OOK format at BER level of 10^{-9} at B2B and 20, 10 and 1 km fiber transmissions, respectively, when the output power of FL-LD are 1.4, −1.4 and −4 dBm. Insert of (b) is the corresponding eye diagrams at the V_{amp} of 1.3, 0.9 and 0.5 V, respectively.

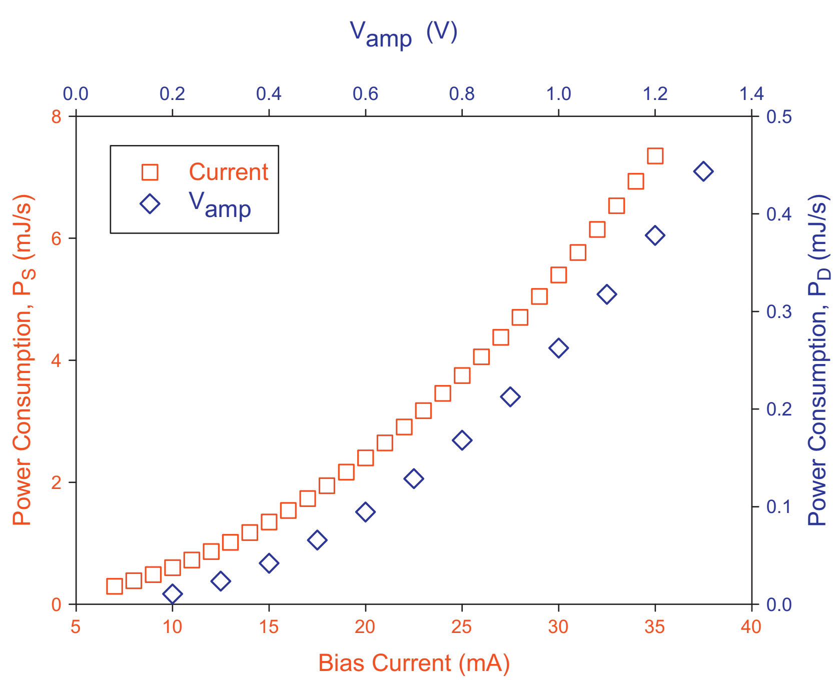

Fig. 4. Power consumption of P_S and P_D under the different bias current and V_{amp}, respectively.

Table 1
Power consumption of upstream signal under different operation conditions at the fiber transmission lengths of 20, 10 and 1 km, respectively.

	ONU number	Fiber distance (km)	Operating condition	Power consumption (mW) per second	Power consumption per day (J)
I	64	20	I_{bias}=35 mA V_{amp}=1.3 V	490.7	42,396.5
II	32	20	I_{bias}=35 mA V_{amp}=1.3 V	245.4	31,181.8
	32	10	I_{bias}=24 mA V_{amp}=0.9 V	115.5	
III	12	20	I_{bias}=35 mA V_{amp}=1.3 V	92.0	19,681.9
	20	10	I_{bias}=24 mA V_{amp}=0.9 V	72.1	
	32	1	I_{bias}=18 mA V_{amp}=0.5 V	63.7	

for a whole day. To achieve energy saving, we can adaptively adjust the upstream output power with properly modulation V_{amp} according to the different fiber transmission lengths. As shown in Table 1, the scenarios (II) and (III) will reduce the energy consumption when the properly bias current and V_{amp} of upstream FP-LD are employed. As a result, we can properly adjust the upstream output power and V_{amp} according to the different fiber transmission lengths for power saving.

Finally, we analyze if there is enough upstream optical power for achieving the PON having a split-ratio of 64. The split ratio of 64 corresponds to 18 dB power loss. The Rx optical powers at OLT are −20.6, −21.4 and −21.7 dBm after transmitting through 20 km (4 dB loss), 10 km (2 dB loss) and 1 km (0.2 dB loss) fiber transmission lengths, respectively, when the output powers of FP-LD are 1.4, −1.4 and −3.5 dBm. According to Fig. 3(a), the Rx sensitivities of −23.6, −25.6 and −28.3 dBm are observed through the fiber transmissions of 20, 10 and 1 km respectively. Therefore, the Rx optical powers are higher than the Rx sensitivities in the 3 cases, showing the feasibility of the proposed PON supporting a split-ratio of 64.

3. Conclusion

We have proposed to adaptively control the output optical power of the upstream Tx in each ONU by properly adjusting the bias current and modulation index (V_{amp}) of upstream FP-LD according to the different fiber transmission lengths. Therefore, when ONUs closer to the OLT (shorter fiber transmission length), the bias current and V_{amp} of FP-LD can be reduced properly for energy saving and enhance the PON performance simultaneously. Thus, when more ONUs are used in PON access, the proposed technique would obtain more energy saving. In addition, due to the adaptively power adjustment of each upstream FP-LD in a properly fiber length, it also can result in 1.1 dB upstream power variation (ΔP_{up}) for upstream power equalization in the PON.

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