Comparison of Downstream Transmitters for High Loss Budget of Long-Reach 10G-PON

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Abstract: A comparison among different transmitters was made by evaluating the sensitivities under various launch powers and reaches. Experimental results indicate that directly-modulated laser based transmitters provide higher loss budget for long reach 10G-PON.
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1. Introduction

For the long-term goal of passive optical network (PON) systems, integration of metro and access networks is becoming a new trend because the CAPEX and OPEX of service providers will be reduced if large number of central offices (COs) is reduced or consolidated [1]. However, the consolidation of COs requires a growth in the reach and split ratio of PONs, which calls for a high loss budget. For a truly passive network, no repeater is allowed in the fiber plant, so the launch power of the transmitter and sensitivity of the receiver determine the link loss budget. The upstream receiver sensitivity can be significantly improved by coherent detection or hybrid Raman/Erbium-doped fiber amplifier, and in most of cases the link loss budget is limited by the downstream direction. Symmetric 10G-PON with loss budget up to 53 dB (considering the FEC limit BER of 3.8×10^{-3}) has been achieved by using coherent digital receiver in optical network unit (ONU) [2]. However, for practical application, direct detection is preferred considering the ONU cost. Loss budget of 51 dB was achieved by using semiconductor optical amplifier (SOA) as preamplifier in ONU [3], which will still increase the ONU cost. Increasing the downstream launching power is another solution to improve the downstream loss budget, however high power induced signal distortion due to nonlinear effects in fiber such as stimulated Brillouin scattering (SBS) and self-phase modulation (SPM) limits the maximal launching power. In most of previous long reach 10G-PON demonstrations, external modulation using Mach-Zehnder modulator (MZM) or electro-absorption-modulated laser (EML) were adopted, which have been considered with superior performance compared with direct modulation laser (DML).

In this paper, we evaluated the link loss budget in long reach 10G-PON of several commonly used transmitters including MZM, EML and DML. By measuring their sensitivities under different launch powers and reaches, we show that DML based transmitters have higher tolerance to fiber dispersion and nonlinearity, which is particularly suitable for long reach PONs. 50-dB loss budget can be achieved for 165-km reach 10G-PON by using DML and APD as transmitter and receiver. Direct modulation and direct detection simplify the network structure and cut down the cost, providing a cost-effective candidate for practical applications.

2. Experimental setup and results

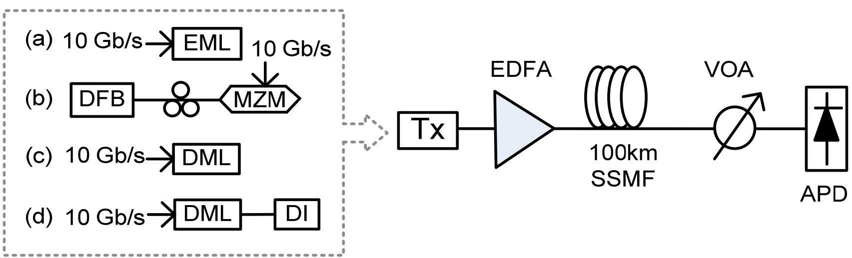

Fig.1 Experimental setup

The comparison of different downstream transmitters was carried out under 100-km standard single mode fiber (SSMF) transmission case. Fig.1 depicts the experimental setup. All the transmitters operating at 1542 nm are driven by 10-Gb/s PRBS data with a word length of 2^{31}-1. An erbium-doped fiber amplifier (EDFA) with an output power up to 23 dBm was used to boost the signal power before being launched into the 100-km fiber. A variable optical attenuator (VOA) was used to imitate the optical splitter and for sensitivity measurement. Four 10-Gb/s transmitters using EML, MZM, DML and DML followed by a delay interferometer (DI) to imitate chirp-managed laser (CML) were used for comparison. For high launch power scenario, an important nonlinear impairment is SBS. From the optical spectral point of view, both EML and MZM based NRZ-OOK format has a strong carrier component that can easily reach the SBS threshold and cause signal distortion. Inversely, the optical spectra of both DML and CML are carrier-less, which make these transmitters especially suited for

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high-launch power applications. DPSK and duobinary formats generated by MZM are also carrier-less, but they are not in the scope of comparison due to higher cost. Besides, SPM is another significant factor that impairs signal when the pulse peak power is high. Signal with a low extinction ratio (ER) has superiority in this respect because the "1" level has a relatively lower power than in high ER case. Finally, fiber dispersion caused signal impairment is also inevitable for long reach transmission.

Fig. 2 gives the experimental results in terms of sensitivity as a function of launching power, which confirms the previous prediction. Note that sensitivity in this paper refers to the power received by the APD with bit error rate (BER) of 3.8×10^{-3}. From the results we can see that for EML, the sensitivity falls down rapidly when the launch power exceeds 14 dBm, resulting in a highest loss budget of 45 dB as marked in Fig. 2(a). Fig. 2(b) show the results for MZM transmitter at two different ER cases. When the signal has an ER of 11 dB, the results are similar with the EML case. As we adjusted the Vpp of the driven signal and decreased the ER to 4 dB, the sensitivity degradation slope becomes much gentle due to the reduction of pulse peak power. As a result, the best loss budgets are 47 dB and 47.5 dB in the 11-dB and 4-dB ER cases respectively. However, for DML and CML, the situation is different as shown in Fig. 3(c) and (d). Generally speaking, DML is unsuitable for high data rate, long distance fiber transmission due to the strong frequency chirp. The chirp broadens the optical spectrum and distorts signal during fiber transmission due to the chromatic dispersion. However, when the fiber is long enough, the fiber dispersion will firstly distort the signal and then convert the frequency modulation into intensity modulation, which is known as dispersion supported transmission (DST) technique [4]. Also, the low ER (2~3 dB) of the signal makes it more robust to SPM effect, which is quite suitable for high launch power application. The measured results of DML under various launch powers are shown in Fig. 3(c). We can see that due to the interaction between SPM and dispersion, the sensitivity was improved with the increase of launch power until the launch power exceeds 21 dBm, providing a highest loss budget of 51 dB. Except for DST, spectral reshaping filter is more widely used to improve the transmission performance of DML, which is also known as CML [5]. By narrowing down the optical spectrum as well as increasing the ER, higher dispersion tolerance is obtained, which allows for long distance transmission. We used a DI as a notch filter instead of a bandpass filter commonly used in CML to realize the spectral filtering. Similar with DML, the carrier-less spectra show higher tolerance to SBS. But as the ER is enhanced to ~10 dB, the SPM effect is stronger. The sensitivity decreases at a lower launching power of 20 dBm as shown in Fig. 2(d). Note that for all the transmitters, when the launching power exceeds 22 dBm, the signals are so severely impaired that we cannot get a BER lower than 3.8×10^{-3}.

Table.1 summarizes the results. It can be concluded that for large-split, long-reach PONs, DML and CML show better performances than other transmitters. In the following section, an investigation on DML and CML was performed to evaluate their performances under various transmission distances for further evaluating their application values in practical situations.

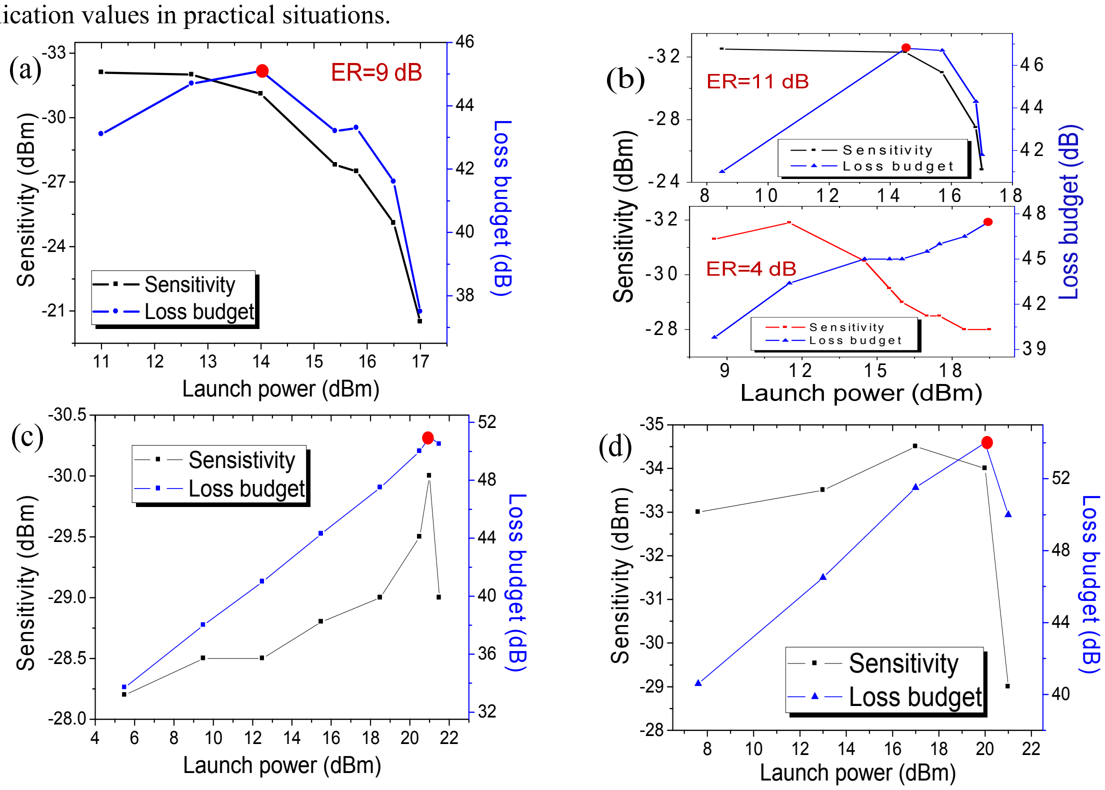

Fig.2 Sensitivity of downstream signal at BER of 1e-3 as a function of launch power using (a) EML (b) OOK modulation using MZM (c) DML and (d) CML as transmitters

Table.1 Summary of transmitter performances

Transmitter	Maximal Launching power (dBm)	Sensitivity (dBm)	Loss budget (dB)	Split ratio	Margin (dB)
EML	14	-31	45	256	1
MZM(ER=11dB)	16	-31	47	512	0
MZM(ER=4 dB)	19.5	-28	47.5	512	0.5
DML	21	-30	51	1024	1
DML+DI	20	-34	54	2048	1

3. Transmission evaluation of DML and CML under different reaches

The transmission performances of DML and CML were further investigated by measuring the receiver sensitivities after various fiber transmission distances as shown in Fig.3. Note that the sensitivities were measured at launching power of 21 dBm and 20 dBm for DML and CML respectively. The eye diagrams are exhibited in the insets of Fig. 3. For non-reshaping case, the eye diagram was firstly distorted during fiber transmission and then became clear again after propagating 75 km. A clear eye opening was obtained even after 165-km SMF transmission, which was in coincidence with the DST theory. By using DI for spectral reshaping, the sensitivities can be further improved by 19 dB, 12 dB, 7 dB, 4 dB and 2 dB in 25 km, 50 km, 75 km, 100 km and 165 km cases respectively. The improvement caused by spectral filtering is obvious when the fiber length is less than 100 km. But the sensitivity differences decrease as the transmission distance exceeds 100 km, meaning that DML can well support long distance transmission even without spectral filtering. At 165-km reach, the loss budget of 50 dB is only 1 dB less than that of the CML based link. And for short distance cases, although the sensitivity is low, the split ratio can also be as high as 1:1024 because of the lower transmission loss of the shorter fiber link. Tab. 2 provides the loss budget evaluation in different transmission distance cases using DML as the downstream transmitter. Taking the transmission performance, the device stability and cost factor into account, DML can be a good option for 10G-PON application, especially in long-reach scenario.

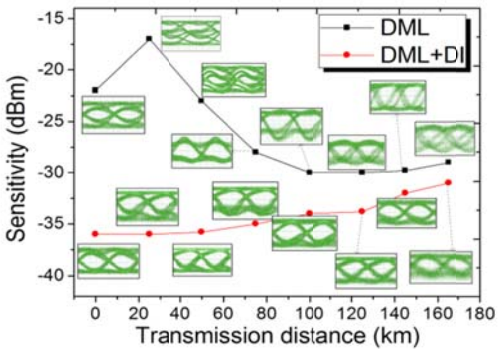

Fig.3 Sensitivities and eye diagrams of DML and CML under various transmission distances

Tab.2 DML loss budget evaluation for different reaches and split ratio

Reach (km)	Loss budget (dB)	Fiber loss (dB)	Split ratio	Margin (dB)
25	38	5	1024	3
50	44	10	1024	4
75	49	15	1024	4
100	51	20	1024	1
125	51	25	256	2
145	50.8	29	128	0.8
165	50	33	32	2

4. Conclusion

The receiver sensitivities of different transmitters were measured under high launching power and long distance transmission conditions. Experimental results demonstrate that DML features a high tolerance to fiber nonlinearities such as SBS and SPM. Moreover, the DST technique makes the long distance transmission possible without any dispersion compensation. 50-dB loss budget can be achieved for reach between 100 km and 165 km which proves DML to be a cost-effective option as downstream transmitter for long-reach, large-split 10G-PON applications.

5. References

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