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System impact of EDFA gain fluctuation in WDM optical packet networks

R. Gaudino, A. Carena and V. Ferrero

Optical Communications Group - Politecnico di Torino - Italy

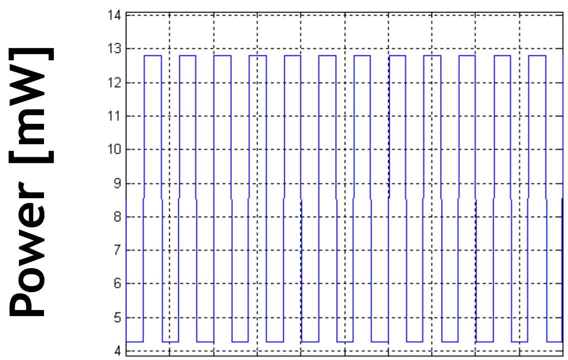
Introduction

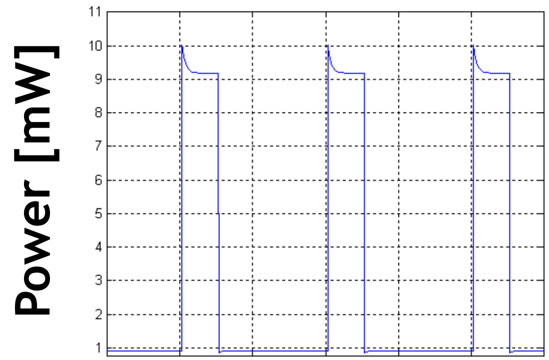
- Today optical networks are all based on continuous data stream transmission (SONET/SDH, Gigabit Ethernet): the optical layer does not handle data packets
- Future true all-optical packet networks will handle data packet at optical level: no power is transmitted on empty slots
- Fast signal power transient at the input of EDFA cause time dependent saturation effects generating significant output power fluctuations

EDFA dynamic behaviour

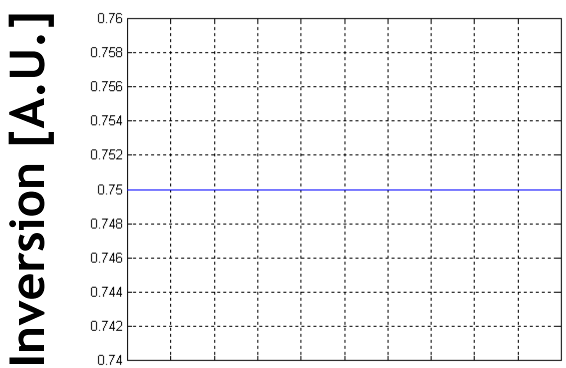
Fast modulation (bit)
2.5 Gbit/s

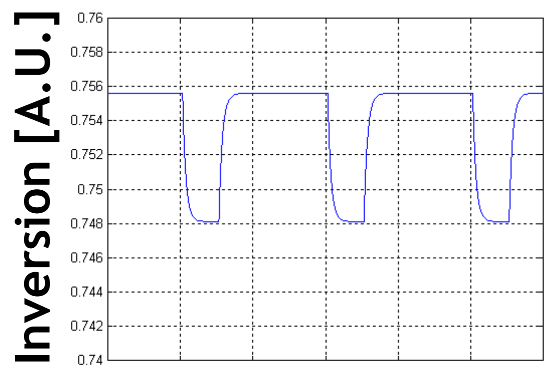
Slow modulation (packet)
1 μs





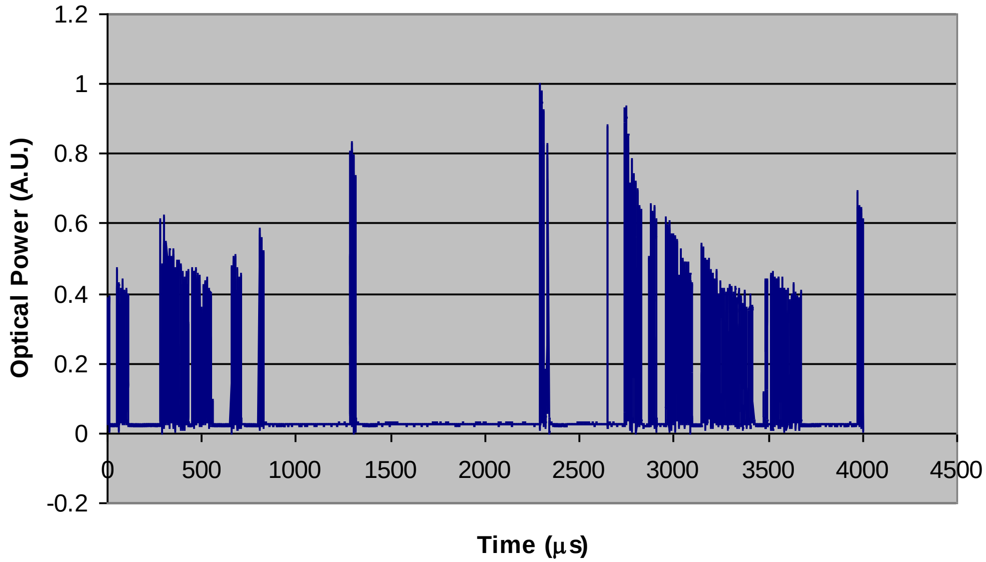
Fast modulation is not "seen" by the population inversion. Indeed, slow modulation is "followed" by the inversion, resulting in gain modulation.

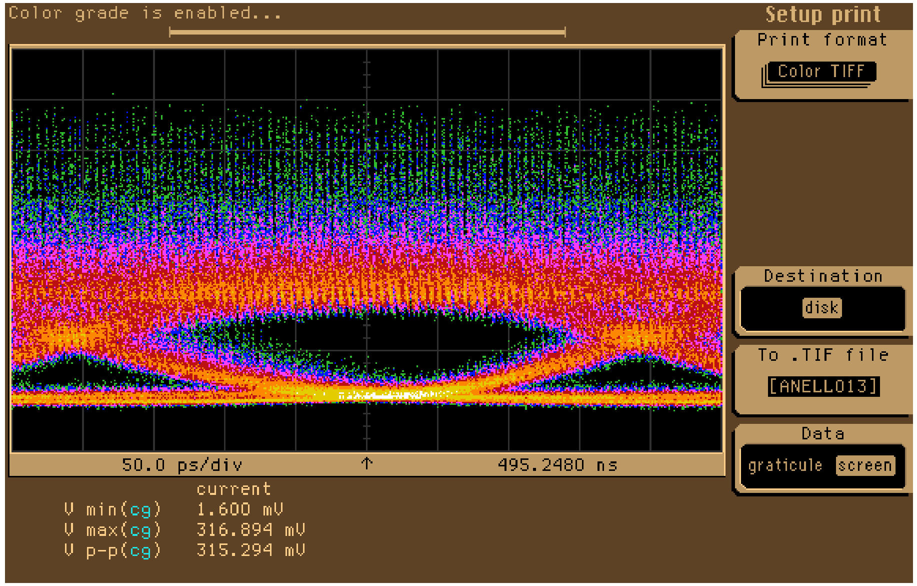




Packetized transmission

Packetized transmission using non controlled EDFAs: dynamic gain variation strongly affect the signal and the system performance.



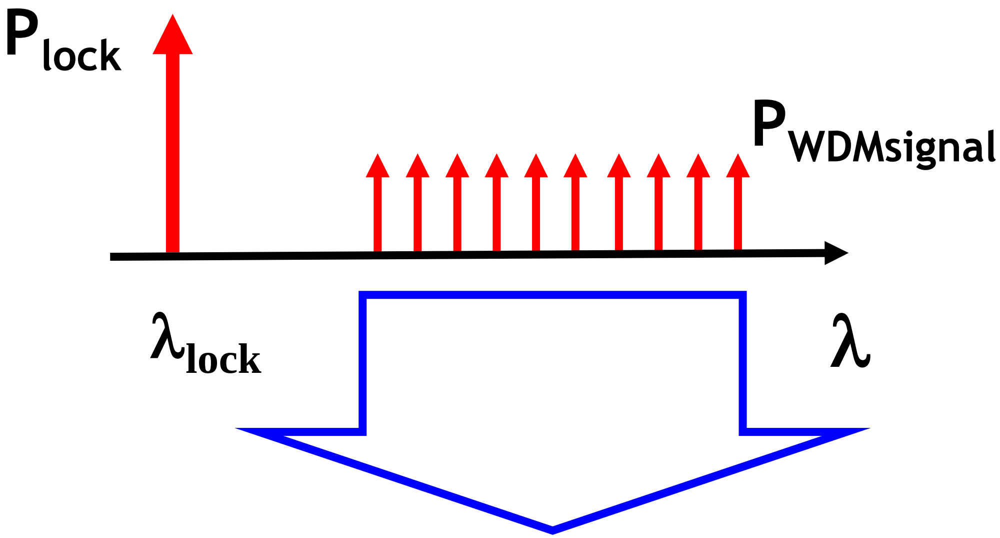


The proposed gain locking technique

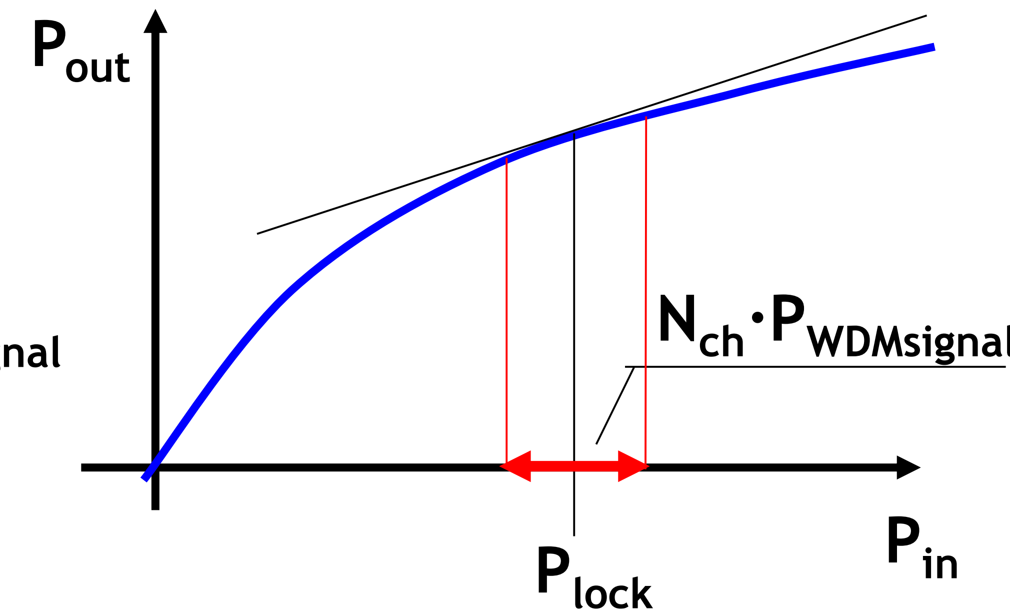
- A strong CW signal is added to the WDM signals carrying packetized traffic: it will be called locking signal
- The locking signal power must be high enough in order to saturate the EDFA
- The aggregate power of all WDM signals must be small with respect to the locking signal power
- WDM signals will experience a small signal gain, without dynamic fluctuations, around the bias point fixed by the locking signal

The proposed gain locking technique

CW locking signal



N_{ch} WDM signals with packetized traffic

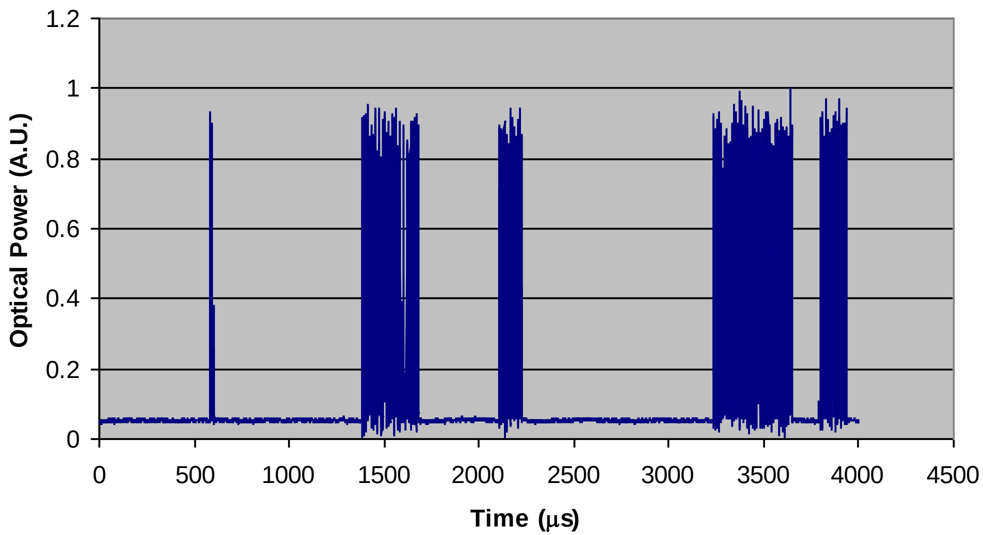


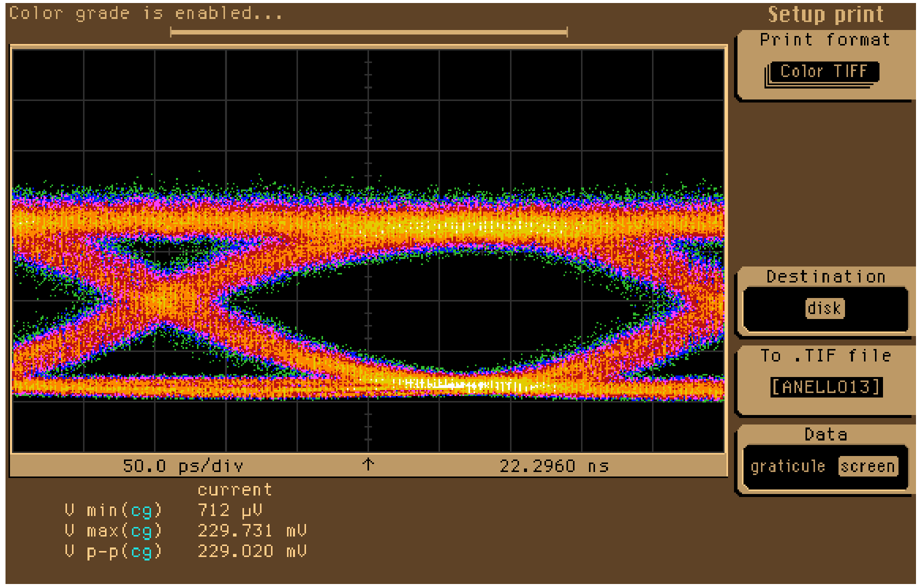
$$\text{if} \quad N_{ch} \cdot P_{WDMsignal} << P_{lock}$$

$$G_{WDMsignal} = \left. \frac{dP_{out}}{dP_{in}} \right|_{P=P_{lock}}$$

Packetized transmission with gain locking

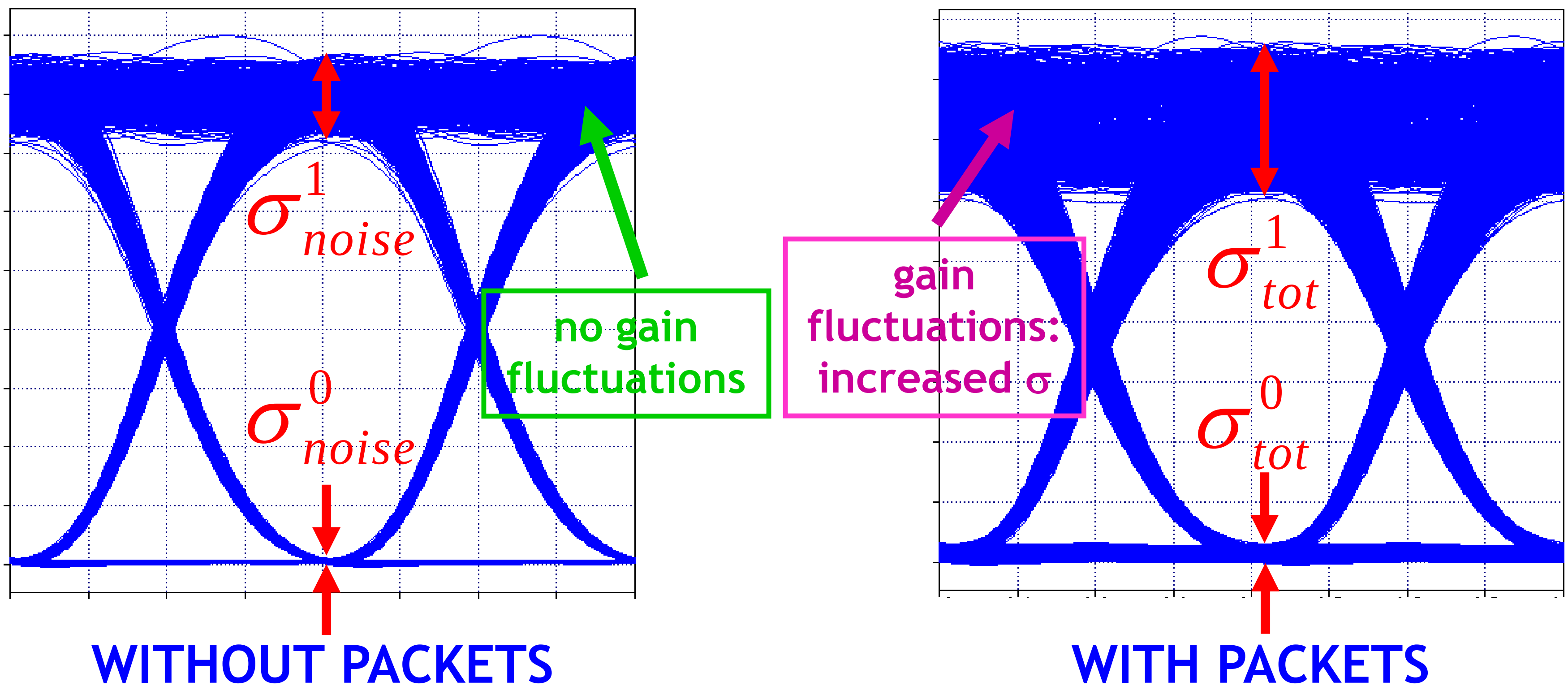
Packetized transmission with gain locked EDFAs. The dynamic gain fluctuation is negligible: system performance is not affected.





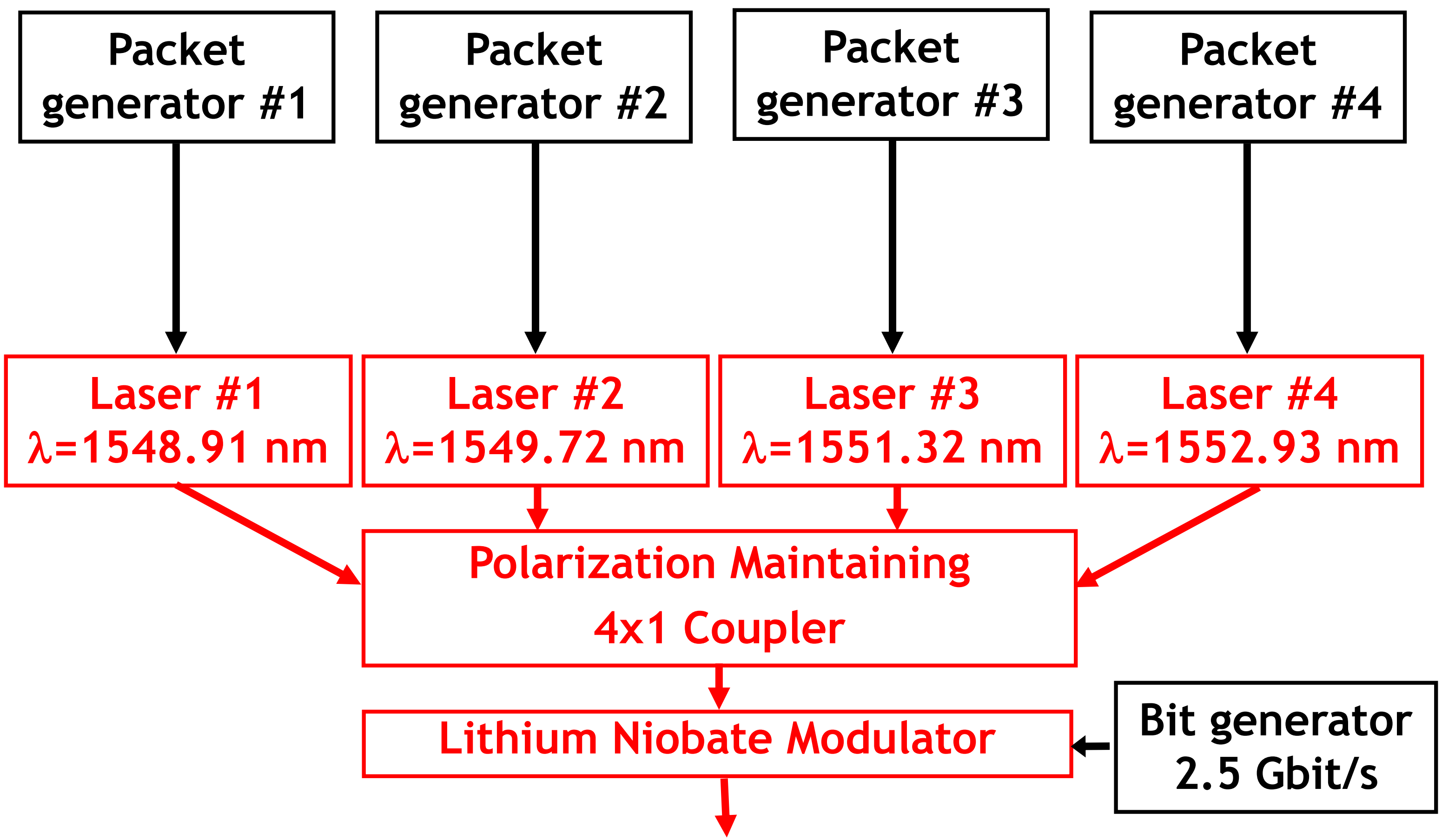
Measuring the impact: a new parameter

$$Q_{\Delta G} = \frac{E}{\sigma_{\Delta G}} = \frac{m_1 - m_0}{(\sigma_{tot}^1 - \sigma_{noise}^1) - (\sigma_{tot}^0 - \sigma_{noise}^0)}$$



Experimental setup

The 4 channel packet transmitter



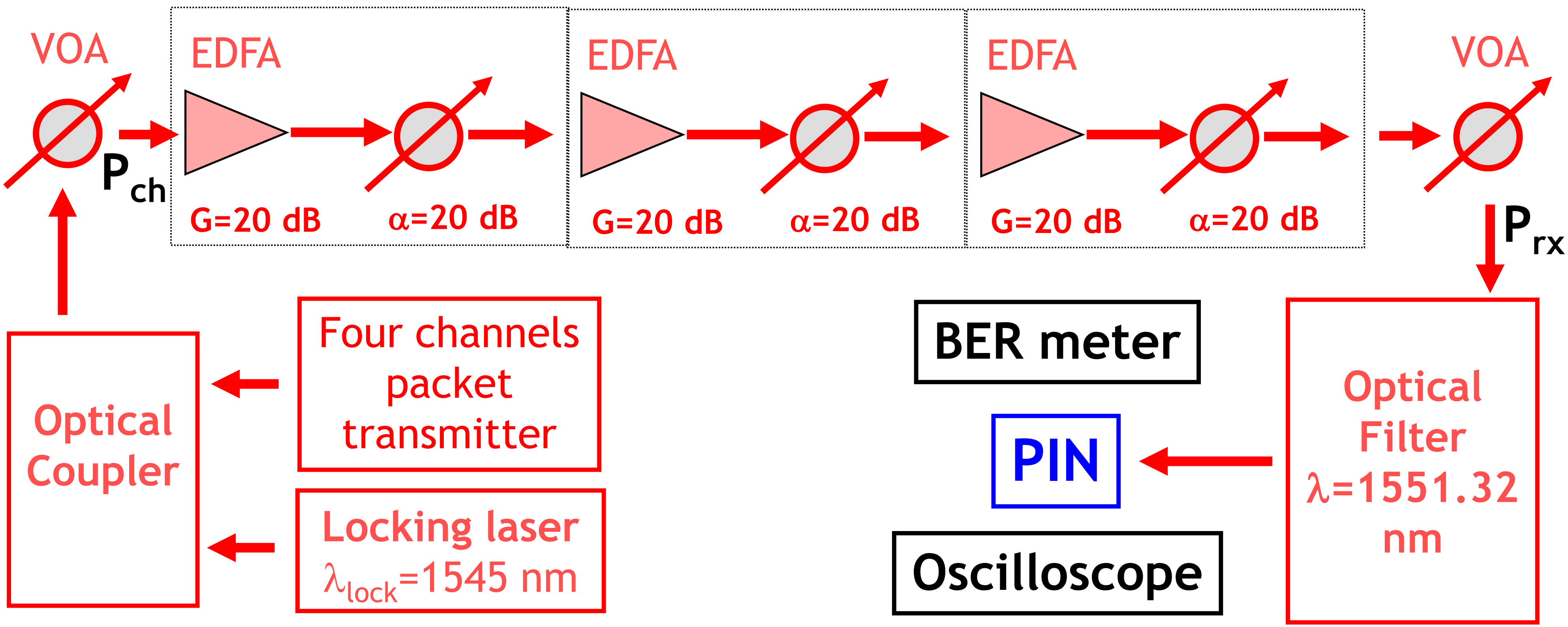
Independent packet generators at 1Mbit/s (slot time 1 μs). Packet arrival process is modeled using geometrically distributed random number generators.

Array of 4 lasers, spaced 200 GHZ (1.6 nm) on the ITU grid, directly modulated by packet generators.

A 2^{20}-1 pseudorandom bit stream is overwritten on packets.

Experimental setup

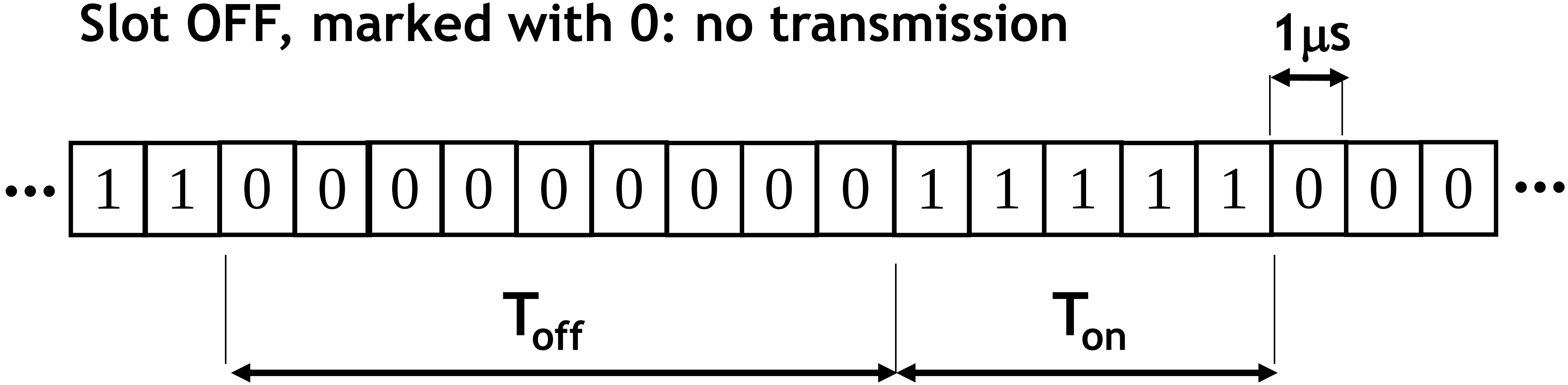
The amplified link with three cascaded EDFA



P_{ch} transmitted power per channel; P_{rx} received power per channel

Traffic description

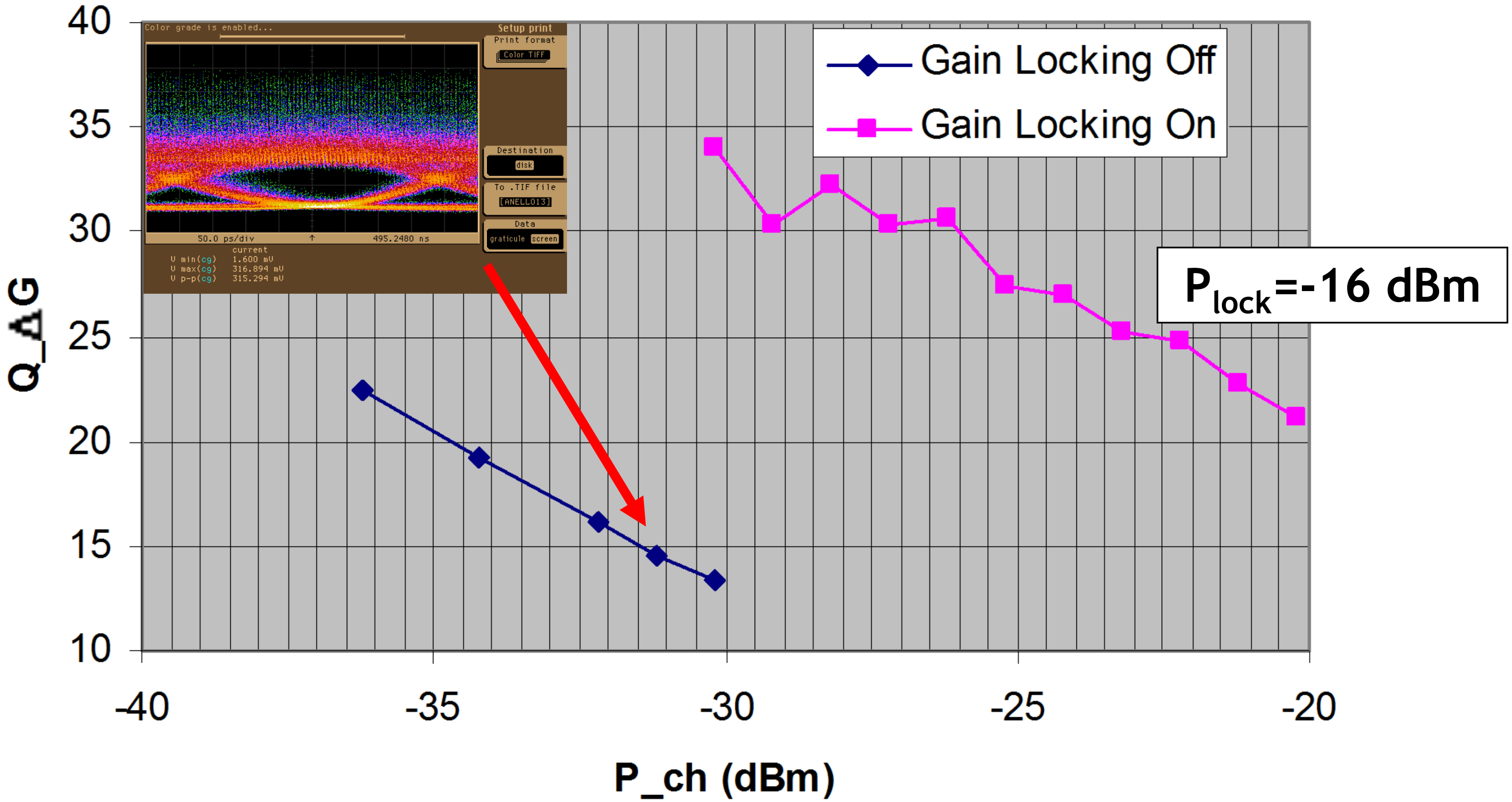
Slot ON, marked with 1: packet transmission
Slot OFF, marked with 0: no transmission



- T_{off} and T_{on} are geometrically distributed random numbers
- T_{on} is the average number of consecutive slot ON
- T_{off} is the average number of consecutive slot OFF
- $T_{on}/(T_{off} + T_{on})$ is the average traffic load
- $T_{off} + T_{on}$ gives an indication of the traffic burstiness

$Q_{\Delta G}$ vs. P_{ch}: gain locking improvement

$T_{on}+T_{off}$ = 400 slots; Load = 50%



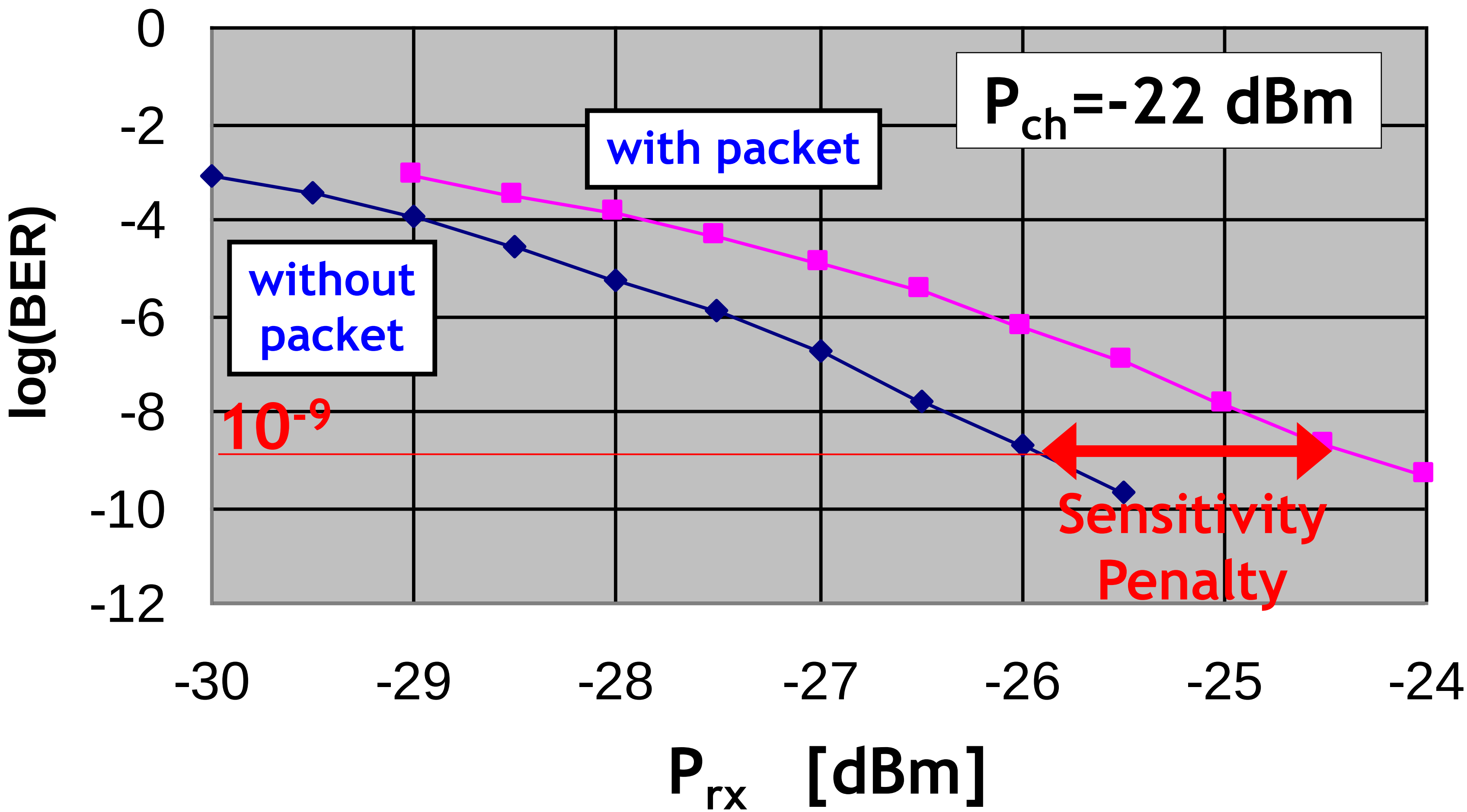
Experiment description

- For each value of P_{ch}, set using the variable optical attenuator (VOA) after the transmitter, a BER vs. P_{rx} curve is obtained sweeping P_{rx} by mean of the VOA after the receiver filter

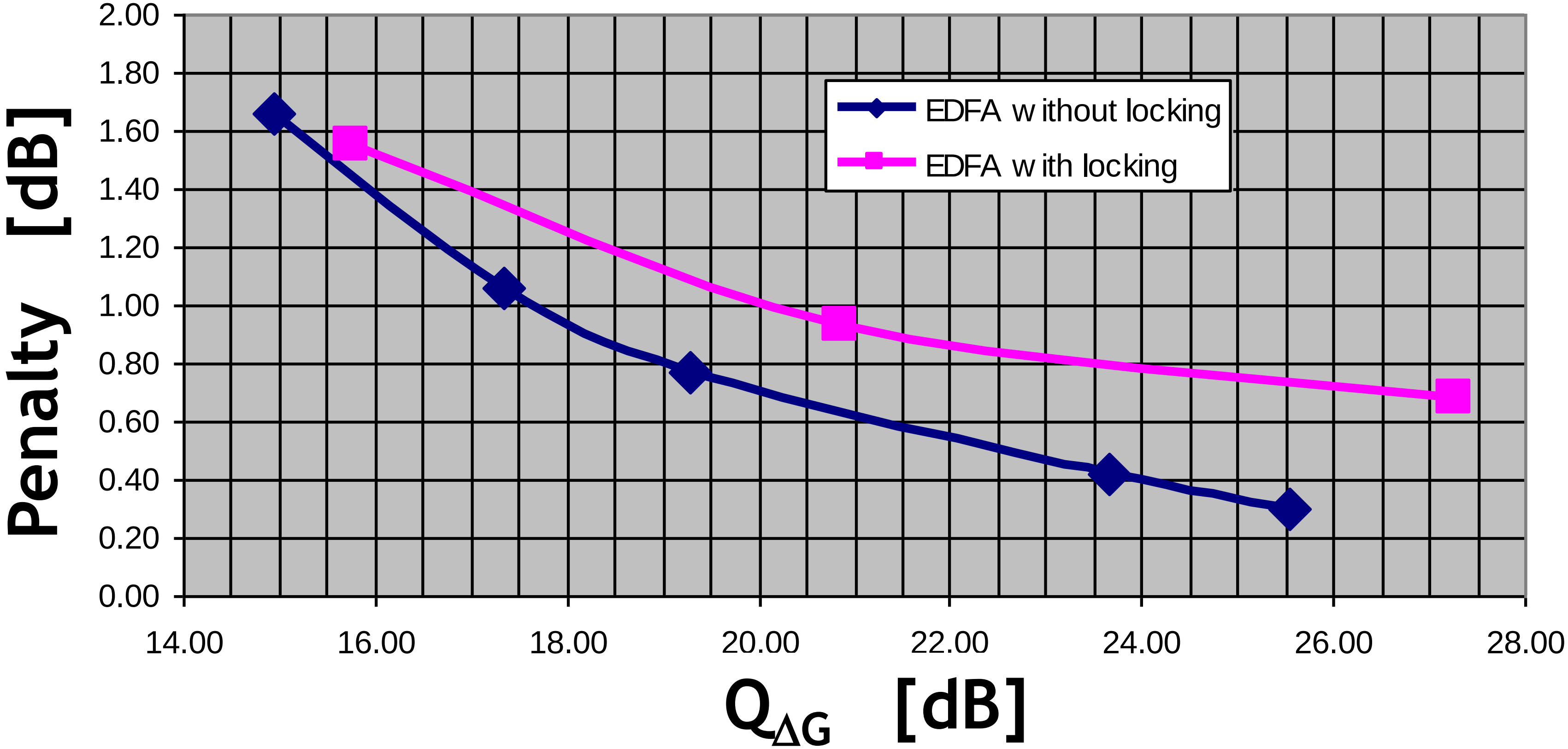
- Measuring BER with packet ON and OFF, we get a sensitivity penalty at a reference bit-error-rate set to 10^{-9}

- At each penalty we relate the newly introduced parameter $Q_{\Delta G}$, in order to obtain the relationship between sensitivity penalty and $Q_{\Delta G\ curve}$

BER measurements

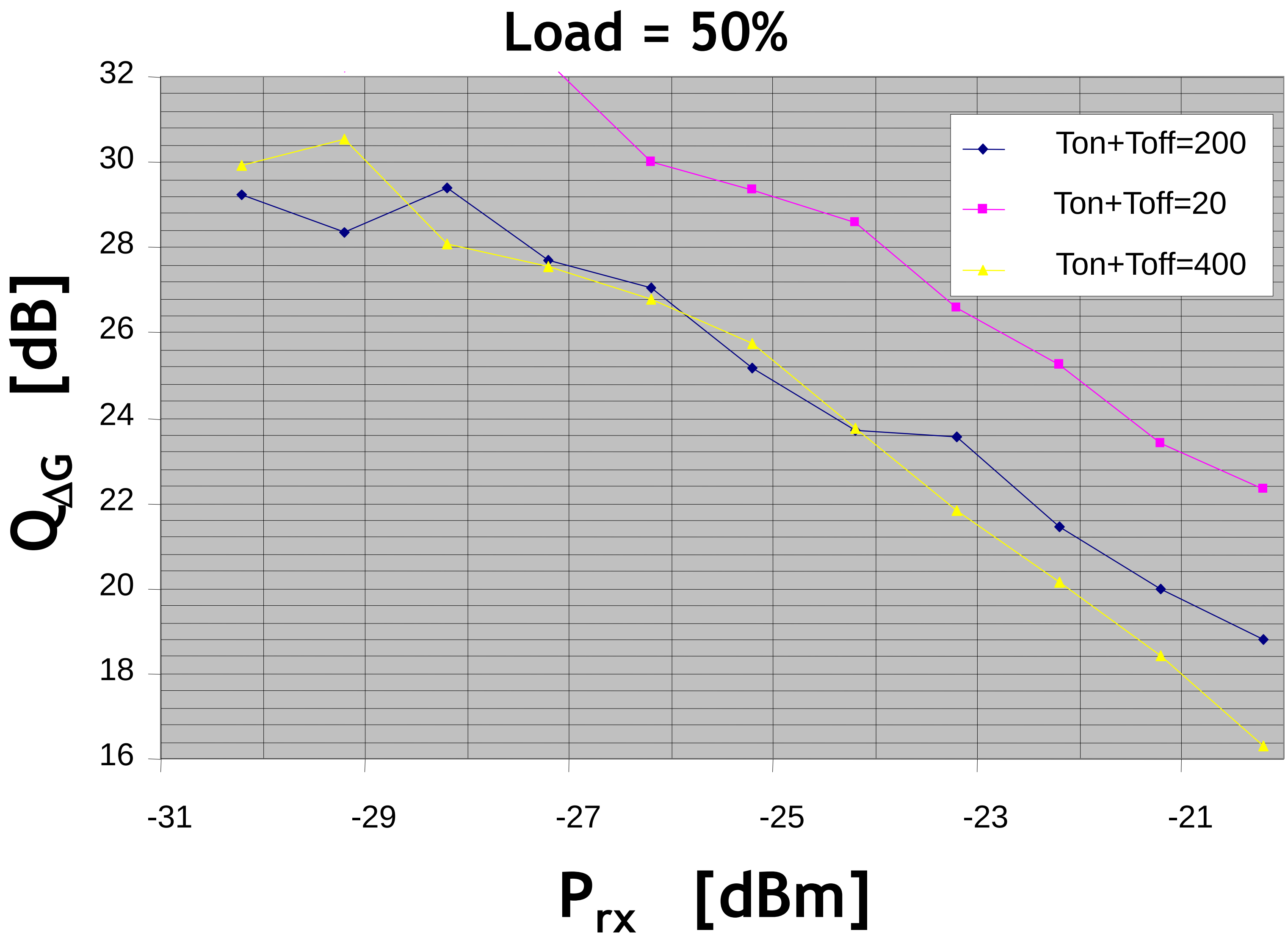


Correlating Penalty and $Q_{\Delta G}$

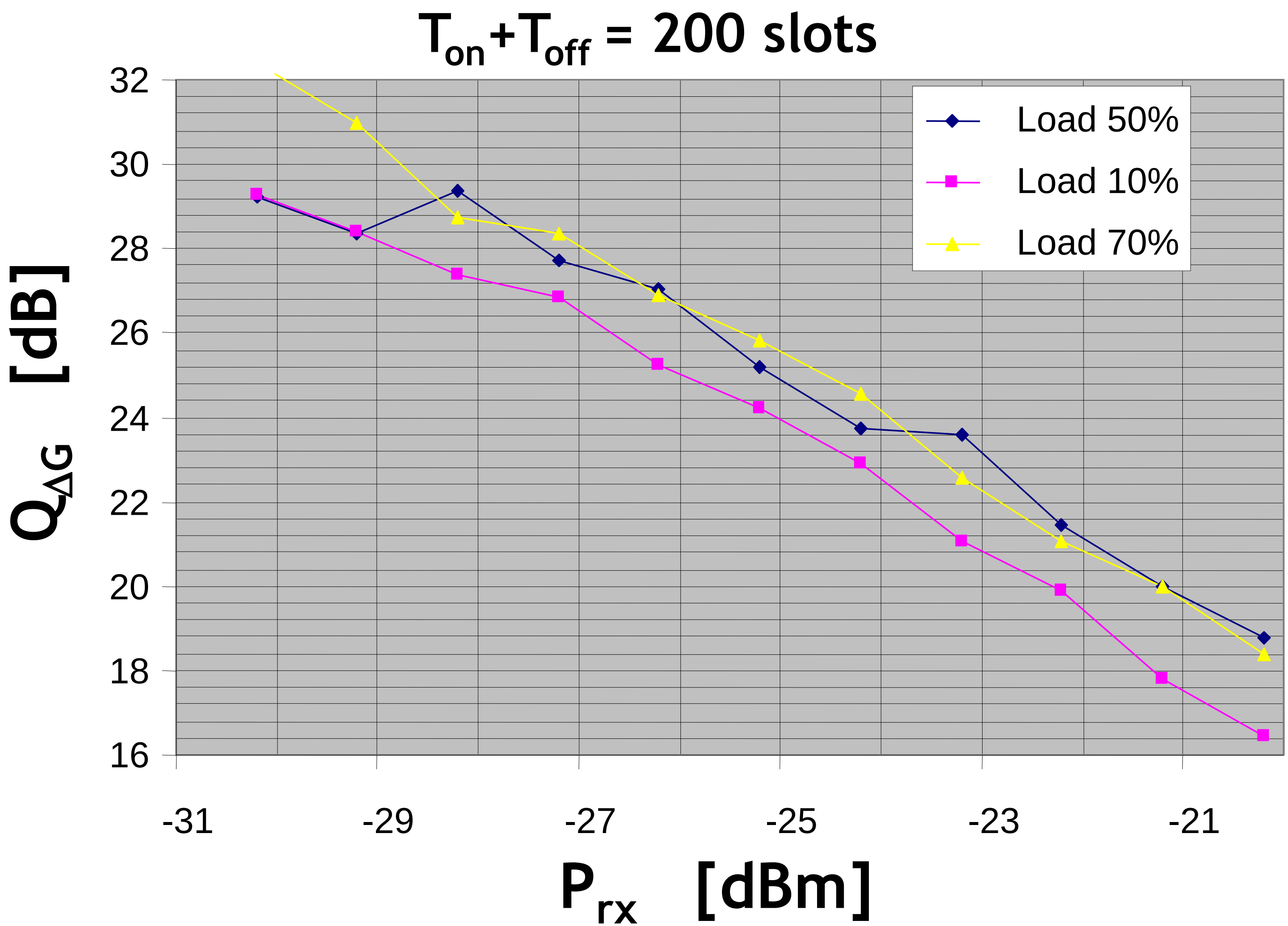


Rule of thumb: $Q_{\Delta G}$ should be greater than 18-20 dB in order to have a sufficiently low system impact.

$Q_{\Delta G}$ traffic dependence: burstiness



$Q_{\Delta G}$ traffic dependence: load



Conclusions

- We experimentally addressed the impact of bursty input optical signals on the gain fluctuation of EDFA amplifiers
- We introduced a new and easily measurable parameter that allow to quantify the effect
- We related this parameter to the system sensitivity penalty

Acknowledgments

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- For any inquiry, feel free to contact: gaudino@polito.it