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Heuristic Approximation of Transient Gain Dynamics due to Network Reconfiguration

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Abstract
Transient gain dynamics due to changes in WDM channel count have been investigated. Based on extensive numeric simulations a worst-case approximation for the maximal power overshoot in electronic feedback gain controlled EDFA chains is developed.

1 Introduction

In reconfigurable wavelength-division-multiplexed (WDM) transparent optical transmission systems the addition and dropping of channels - without countermeasures - leads to transient events with power over- and undershoots with respect to the steady-state. In future dynamic transparent automatically switched optical networks switches can initiate adds and drops with rise and fall times in the order of milliseconds and total power changes of more than 10 dB. Beyond that faults such as fiber cuts or component failures may lead to a sudden loss of all express channels. In both cases the remaining traffic should be maintained error-free. In the past several control strategies have been proposed to stabilize the EDFA gain at a given operating point so that the output powers of the surviving channels remain constant. In this paper we assume an electronic pump-power adjustment based on a proportional-integral (PI) controller [1]. The reason for choosing a simple PI controller without D-part lies in the fact that it is very insensitive to power fluctuations induced by noise. In extensive numerical simulations we analyzed the transient behavior of EDFAs under different operating conditions and channel load changes. Based on these results a heuristic formula is derived to approximate the maximal power fluctuation during the transient event. Such an approximation formula is of great importance for the system designer to assess the system response due to dynamic reconfiguration without the need for time-consuming simulations.

2 Simulation methodology

An 80 channel WDM system with 50 GHz channel spacing, which is equivalent to a channel load covering the entire C-band (Fig. 1), has been examined. At $t = 0.25$ ms the channel load is changed. In our simulations we investigated different channel loading conditions. The falltime has been chosen to be either 160 µs or 1 ms, which are realistic values for component failures or switching events in reconfigurable optical cross connects, respectively.

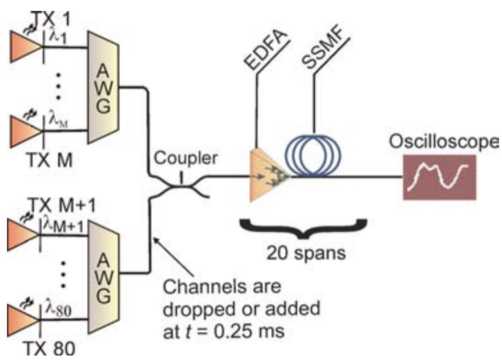

Fig. 1: System setup. A total number of 80 channels has been launched with 50 GHz channel spacing. The power transients due to a change in channel loading after up to 20 spans are analyzed.

In our simulations we used the average inversion level model introduced in [2]. The signal channels are represented by their time-averaged power levels. Amplified spontaneous emission (ASE) noise is included by the spontaneous emission factor n_{sp} in the rate equation, which gives an approximate solution for the ASE influence in EDFAs under dynamic conditions [3]. To facilitate the simulations we assumed the gain spectrum in the relevant wavelength range to be flat – corresponding to ideal gain flattening filters. The electronic control circuit works as follows. The control deviation *e* is calculated from the difference between the total input power $P_{in,tot}$ multiplied by the desired gain *G* and the total output power $P_{out,tot}$. Both powers are obtained from a 5% tap coupler inserted before and after the EDFA. In our simulations we modeled the transmission fiber as a lumped loss element. We deliberately neglected the tilt induced by stimulated Raman scattering (SRS), which has been investigated in e.g. [4]. Furthermore, the effect of spectral hole burning (SHB) has not been considered. In all simulations the same controller parameters have been selected ($k_C = 60$, $\tau_I = 4.5$ ms), which have been determined by extensive simulations. In the following only the results for the dropping of channels are depicted because usually adding channels can be controlled, whereas dropping may be uncontrolled in the case of failures.

3 Heuristic approximation

In the following figures the maximal overshoot calculated for the different setups with activated gain control is depicted. The first graph shows the results for a falltime of 160 µs, the second graph for a falltime of 1 ms.

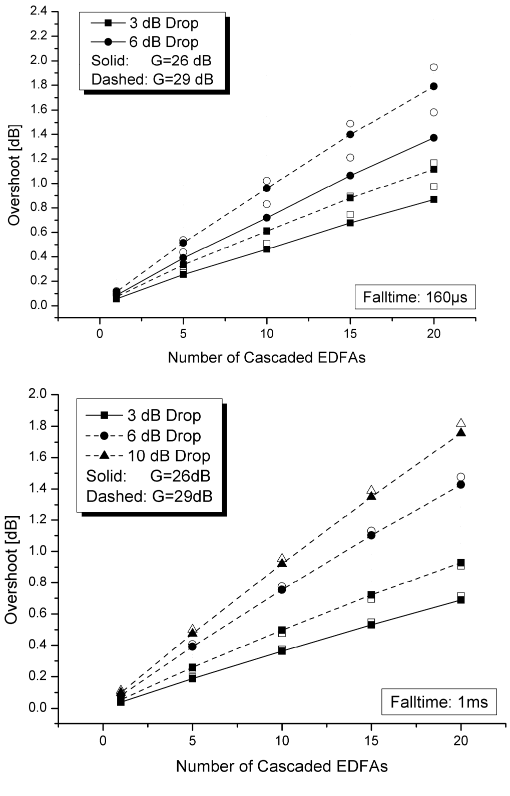

Fig. 2. Maximal power overshoot for different channel dropping ratios, gains and fall times. Hollow symbols depict values obtained from (1).

It can be seen that the maximal power overshoot increases almost linearly (in dB scale) with the number of cascaded EDFAs.

$$Overshoot_{dB} = \left(C - 0.01 \cdot \Delta G\right) \cdot \left(\Delta ch - 0.9\right) \cdot N^{0.93} \qquad (1)$$

Based on these findings a heuristic formula (1) has been developed, which gives a worst-case approximation for an arbitrary number *N* of cascaded EDFAs, a gain difference ΔG (in dB) with respect to the reference gain of 26 dB and different power dropping ratios Δch. The simulated overshoot showed very low dependence on the EDFA output power, and (1) yields a good approximation for saturated amplifiers with gain control. As can bee seen from Fig. 2 the heuristic equation is in good agreement with the simulated values in all cases. In (1) variable *C* has a value of -0.11 for a falltime of 1 ms and -0.15 for a falltime of 160 µs. As an example for a 6 dB power drop, a gain value of 29 dB and a falltime of 1 ms the parameters are $\Delta ch = 0.25$, $\Delta G = 3$ and $C = -0.11$ and eq. (1) yields an overshoot of 1.47 dB.

4 Conclusion

We have presented a study of power transients in transparent optical networks stemming from reconfiguration and changes in WDM channel count. The investigated electrical PI feedback loop can effectively stabilize the EDFA gain level. However, remaining power over- and undershoots will accumulate along the transmission line. The developed heuristic formula allows a fast approximation of the remaining power fluctuations based on basic parameters such as gain, number of cascaded EDFAs and number of switched channels. The approximation formula shows good agreement with the results from numerical simulations and enables the system designer to estimate the expected transient behavior.

References

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