Performance of an Advanced Transient Suppressed EDFA in Diverse Dynamic Optical Network Scenarios

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Abstract *We extend the study of an advanced transient-suppressed EDFA to wider timescales and investigate its performance as a function of network reconfiguration-time and required optical-feedback power, demonstrating improved performance compared to a conventional amplifier.*

Introduction

Future dynamic optical networks (DONs) are expected to transmit data in units varying from nanosecond optical packets to continuous streams, on multiple wavelength channels[1,2]. These networks require optical amplification that is insensitive to optical input power fluctuations (IPFs) which may range from zero to the output saturation level at timescales determined by the network scheme in operation. The erbium-doped-fibre-amplifier (EDFA) has become the standard for point-to-point WDM systems but IPFs cause gain transients and signal degradation, particularly when fixed decision-thresholds burst receivers are used[3-10]. Techniques to minimise transients fall into 2 categories. The first is gain clamping (GC) by a non-signal wavelength by either feed-forward (FF) electronic power control[3] or optical feedback (FB) in a resonant cavity[4-6]. In addition to transient suppression, GC provides fixed gain for each signal channel at the cost of reducing the gain of all channels but this maybe minimised by careful design based on network parameters[5]. The second technique uses electronic FB and FF pump control[7] or also with output waveform envelope shaping using a variable optical attenuator (VOA)[8]. Pump control techniques have the disadvantage that gain adjustments to compensate for IPFs affect all channels and, hence, cause power fluctuations in throughput channels where the reconfiguration time/burst length exceeds the control loop bandwidth.

In addition to active compensation, mitigation of gain transients in DONs has been achieved by utilizing fiber with a larger active area of erbium. This transient suppressed (TS)-EDFA has shown strong transient suppression in optical packet switching (OPS) systems[9,10] but requires supplementary control techniques to protect against traffic density variations, link failures and for DONs with lower traffic granularity such as in optical burst switching (OBS). Here, we show that, compared to a conventional (C)-EDFA this TS-EDFA is tolerant to transients over much wider timescales, reducing the requirement and overhead of additional control loops or traffic engineering, and that when used with supplementary control techniques the TS-EDFA requires less optical FB allowing for larger gain in signal channels.

Experimental description

To measure and compare gain transients, a two channel burst transmitter, capable of replicating a range of traffic scenarios experienced by an optical amplifier in a DON was constructed. The first channel, λ_C, was operated continuously at a wavelength of 1543.3nm and the second, λ_B, operated in burst mode at a wavelength of 1548.8. Both channels were modulated with a 2^{31}-1 non-return-to-zero pseudo-random-bit-sequence and variable channel powers were used to cover the expected input power range of an EDFA in a DON and investigate the effect of multiple packets being added and dropped simultaneously. λ_C was maintained at -16dBm for all measurements and λ_B powers of -16dBm, -9dBm and -3dBm, corresponding to 1, 5 and 20 equal power channels, were used. A sampling oscilloscope was used to make direct measurements of gain variations in the received signals as shown in Fig. 1.

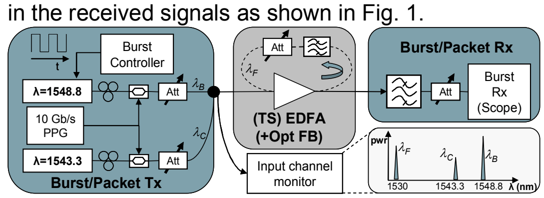

Fig. 1: Experimental set-up for gain transient measurement

For the TS-EDFA, the maximum small signal gain and noise figure was 27dB and 5dB, respectively, at a λ_B input power of -16dBm, and a C-EDFA with similar characteristics was selected. Additional transient control was achieved using an optical FB loop formed using two 3dB couplers, an optical filter to select the lasing wavelength and a VOA to control the feedback cavity loss (FCL). The FB wavelength (λ_F) was set at the EDFA gain peak to maximise the signal channel gain[5] and the minimum FCL was 14dB, set by the insertion loss of the tap/couplers and other loop components. For a real network, the cavity design should be optimised for the specific network[5] and the optimal FCL set by the tap ratios (typically <5%) in ring cavities, or the fiber Bragg grating design for linear resonators[6]. Increasing the FCL reduces the power of λ_F and increases the signal channel gain but limits the range of input powers for which transient suppression is achieved. Hence, the required FCL to suppress transients beyond a specified level maybe used to compare amplifier performance.

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For each amplifier, two sets of measurements were performed with and without optical FB. For each λ_B power, the FCL was set to allow maximum gain in the TS-EDFA whilst maintaining transients below 1dB, as in ref. 5, and the same value used for the C-EDFA. Firstly, to investigate the impact of traffic density changes in an OPS system, the duration of the λ_B guard band between 400ns packets was varied from 400ns to 100ms (Fig.2), equivalent to a 10dB change of average total signal input power. Secondly, the application of the TS-EDFA to longer burst length OBS schemes was investigated by operating λ_B with an equal weight ON/OFF signal (Fig. 3) and varying the switching frequency. This allows measurement of the transients induced by the add/drop of 1, 5 or 20 equal power bursts as a function of the minimum network reconfiguration time, t_R, determined by the minimum burst length and/or the network architecture.

Varying Burst Channel Guard Band

With optical FB employed, gain excursions/transients due to varying guard band between 400ns packets was suppressed below 0.5dB for all λ_B powers for the TS-EDFA. With the same FCL, transients of up to 3dB were observed in the C-EDFA. In this case, to obtain the same transient suppression with the C-EDFA, the FCL had to be reduced by 6dB. Without optical FB for λ_B powers of -3dBm, -9dBm and -16dBm the gain of the received signals varied by 12dB, 7dB and 3dB for the C-EDFA compared to 6dB, 3.5dB and 2dB, respectively, for the TS-EDFA. Fig. 2 shows the worst case for a λ_B power of -3dBm. For this case, an FCL of 20dB, corresponding to a gain compression of 3dB, was used.

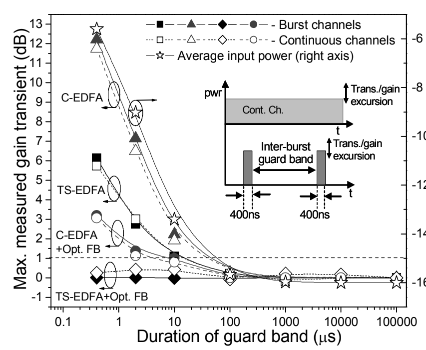

Fig. 2: Gain excursions on λ_B and λ_C as function of the guard band between 400ns packet for λ_B power of -3dBm

Fig. 2 shows how gain excursions caused by traffic density changes closely match the average amplifier input power, plotted on the right axis. In summary, these measurements reveal that the TS-EDFA is able to reduce deleterious effects caused by traffic density changes compared to a C-EDFA. They also show that where optical FB is still required to guarantee adequate transient suppression, the TS-EDFA required up to 6dB less λ_F power, corresponding to an increase of 3dB in signal channel gain.

Varying Reconfiguration Time t_R

When varying the t_R or burst length, similar trends are observed. With optical FB employed, the TS-EDFA was able to suppress transients below 1dB in all cases. Gain excursions of up to 3dB were observed for the C-EDFA in the same conditions which again required a 6dB reduction of the FCL to match the TS-EDFA performance. Without optical FB the magnitude of gain excursions were up to 3 times greater in the C-EDFA compared to TS-EDFA. More importantly, these measurements reveal that the slower response of the TS-EDFA makes it significantly less susceptible to rapid IPFs. Considering a 1dB threshold, the TS-EDFA is able to suppress transients below 1dB for t_R values of up to 100μs in all cases, an order of magnitude greater than the C-EDFA, as shown in Fig. 3 for a λ_B power of -3dBm. This result is important since it determines the bandwidth of any electronic control system or the timescale over which traffic engineering needs to be employed for each amplifier.

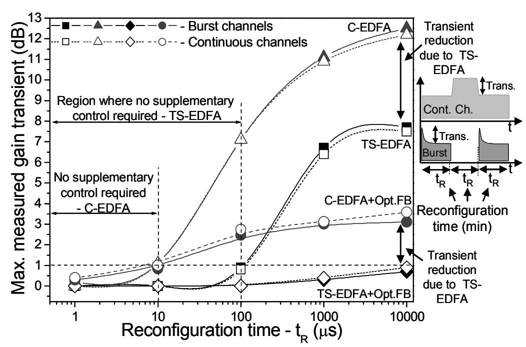

Fig. 3: Gain transients on λ_B and λ_C as a function of min. network reconfiguration time for λ_B power of -3dBm

Conclusions

We show that a TS-EDFA, using larger active area fiber and optimised to mitigate impairments caused by input power fluctuations in dynamic networks, can suppress gain transients for network reconfiguration times up to 100μs, an order of magnitude greater than a convention EDFA. When optically gain clamped, the TS-EDFA required up to 6db less feedback channel power, providing 3dB additional signal gain, for the same transient suppression performance. These results show that use of a TS-EDFA is desirable for a wide range of dynamic optical networking scenarios.

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