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Impact of the all-optical gain-clamping technique on the transience characteristics of cascaded discrete fiber Raman amplifiers

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Abstract

We theoretically analyse the dynamic response of amplifier cascades involving combinations of unclamped and gain-clamped discrete fiber Raman amplifiers (DFRAs) in the worst possible case of power transients. We consider a 64-channel system in which all of the channels except one (i.e. the surviving channel) are modulated to simulate channel add/drop. We vary the number and the position of the gain-clamped DFRAs in the cascade to determine whether a cascade in which only a few amplifiers are gain-clamped (referred to as a mixed cascade) can be as effective as a cascade comprising all gain-clamped amplifiers for controlling the power transients within tolerable limits (for example, 1 dB). We take into account the location of the surviving channel and the operational regime of the amplifiers. Our results show that the location of the gain-clamped DFRAs in a mixed cascade affects the transient characteristics and that it is possible to control the transients within tolerable limits.

Keywords: Gain transients; Fiber Raman amplifiers; Gain control; Multi-wavelength networks

1. Introduction

The Internet has profoundly changed the telecommunications domain and the revolution is still ongoing. The capacity demand continues to increase with the emergence of imaging technologies such as videoconferencing and telemedicine. Present networks may not be capable of responding to the new demand of capacity and among the different solutions being explored, dynamic networks seem to hold a particular attention. These networks, such as the Agile All-Photonic Network (AAPN) [1], exploit both time division multiplexing (TDM) and wavelength division multiplexing (WDM). Fiber Raman amplifiers (FRAs) may be of interest in AAPNs for enabling them to increase the transmission capacity. Indeed, the amplification bandwidth cannot be increased with the use of erbium doped Fiber amplifiers (EDFAs) alone.

The major advantage of FRAs over EDFAs is the possibility to broaden the gain spectra by the use of multi-wavelength pump sources [2]. In 1999, Emori et al. demonstrated the possibility to achieve a 100 nm bandwidth flat-gain fiber Raman amplifier pumped by 12 lasers [3]. Other notable characteristics are the flexibility to provide gain bandwidths not usually available in doped-fiber amplifiers with the provision of suitable pump sources and the fact that the amplification can be achieved in wide variety of fibers.

As with EDFAs, FRAs suffer from power transients when the power of the input signals varies. In 2001, Chen and Wong observed power transients in FRAs which are comparable to those in EDFAs [4]. Subsequent theoretical and experimental studies have been performed to determine the effects of pumping scheme, input signal power, pump power, fiber length, type of fiber, and wavelength of the surviving channel(s) on the dynamic behaviour [5,6]. Pump control and all-optical gain-clamping (AOGC) have also been investigated to control the gain and limit power transients [6–12].

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In terms of analyzing the dynamic response of cascaded FRAs, several studies have been conducted [13–15]. In [13], Zhang et al. analyze the gain transience in single-stage FRAs and in cascaded discrete FRAs (DFRAs). For the latter, they only consider cascades of identical amplifiers, namely a cascade of seven unclamped DFRAs and a cascade of eight gain-clamped DFRAs. They use two WDM channels and consider one operational regime for the amplifier that is saturated (0.2 mW per channel input power). In [14], Bolognini et al. also study cascades of identical DFRAs (either a cascade of 10 unclamped DFRAs and a cascade of 10 gain-clamped DFRAs). As in [13], they also consider one operational regime which corresponds to the small-signal regime (−12 dBm per signal input power) but they increase the number of WDM channels to 16, of which 15 are dropped and added. In [13,14], AOGC is achieved with an optical feedback loop. In [15], Karásek et al. also consider AOGC using an optical feedback loop and they study two configurations of cascades: one cascade of three unclamped DFRAs and one cascade of three DFRAs where only the first DFRA is gain-clamped and where the lasing (feedback) signal is subsequently allowed to propagate through the two other unclamped DFRAs. To induce the gain transience, the cascades are fed by two WDM channels of which one is modulated and they operate the cascades in only one operational regime, i.e. the small-signal regime (−8 dBm per channel input power).

In this paper, we theoretically analyse the dynamic response of nine different cascades of DFRAs. As the studies described in the previous paragraph consider only three cases of cascades – a cascade of all unclamped DFRAs, a cascade of all gain-clamped DFRAs, and a cascade where only the first DFRA is gain-clamped with the propagation of the lasing signal through the other DFRAs of the cascade – we consider cascades of mixed unclamped and gain-clamped DFRAs. The gain-clamping is an efficient technique to mitigate the power transients but it is pump power consuming. So gain-clamping each amplifier of the cascade or gain-clamping the first amplifier and letting the lasing signal *propagate* through the cascade requires a lot of pump power. The results of our study will be used to determine whether or not it is necessary to gain-clamp each DFRA of the cascade to control the transients within tolerable limits. The ability to control the transients using only a few properly placed gain-clamped DFRAs would present the advantage of reducing the total pump power required in the cascade. We also consider a WDM situation where each cascade is fed by 64 WDM channels, of which 63 are modulated to simulate the operations of channel add and drop (see Fig. 1). In order to control the transients, we use AOGC, in which the feedback signal is created using a pair of FBGs to form a standing-wave cavity. Unlike [15], we do not allow the feedback signal to propagate through the cascade. We are especially interested in assessing the impact of mixing unclamped and gain-controlled amplifiers on the transience characteristics, taking into account the location of the gain-clamped amplifiers. In particular, we want to determine whether or not it is possible to maintain the overshoots, undershoots, and steady-state gain variations resulting from channel add/drop at the input of the first amplifier in the cascade within certain predefined tolerance limits using only a few gain-clamped amplifiers. We also monitor the evolution of the rise and fall times in the surviving channel after each amplifier in the cascade.

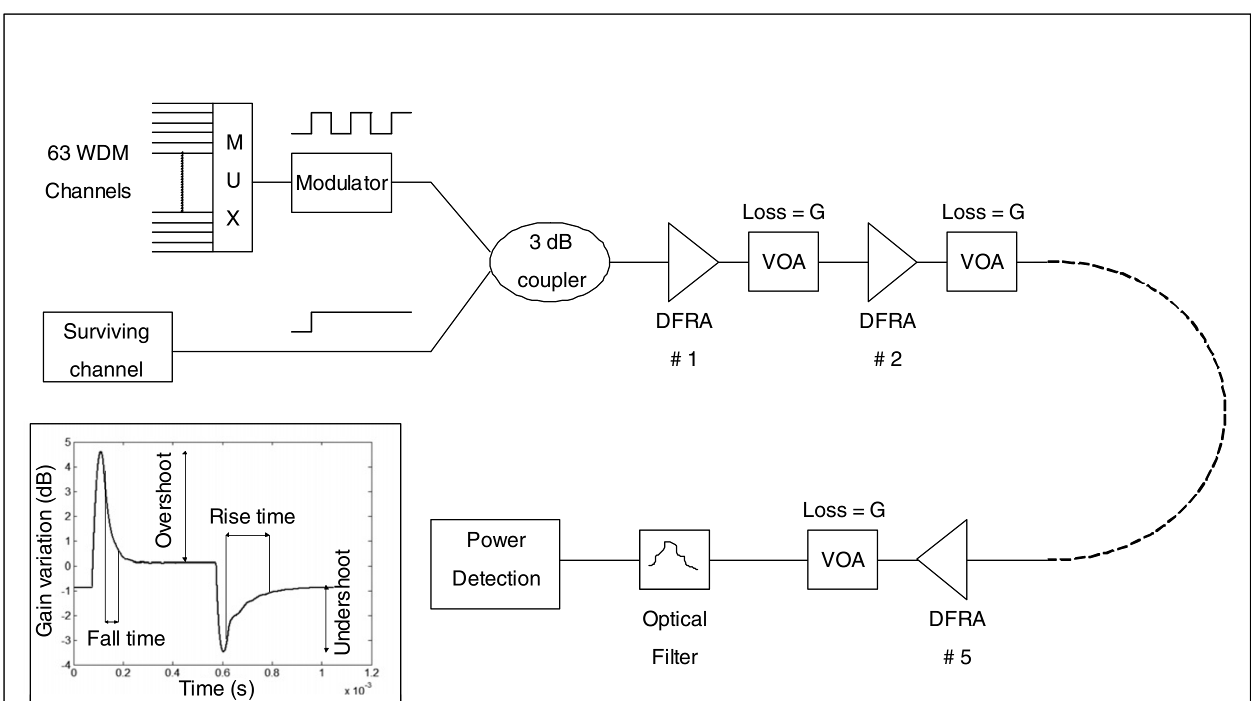

Fig. 1. Set-up of numerically simulated amplifier cascade. Each DFRA can be either unclamped or gain-clamped.