# Channel distributions of the transient power overshoot in backward-pumped Raman amplified WDM systems

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The time and amplitude characteristics of the transient power overshoot caused by channels adding up are studied both experimentally and numerically in the backward-pumped Raman amplified wavelength division multiplexing (WDM) system. The results show that the shorter the signal wavelength is, the smaller the last time of the transient power overshoot will be. The maximal power overshoot is small and does not deadly damage the optical component, and the channel distribution of the maximal value of the power overshoot has similar curve in shape with that of the system ON-OFF gain.

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The Raman amplifier (RA) has become a key technology in the high-capacity ultra-long-haul wavelength division multiplexed (WDM) optical transmission system due to its low noise and flexibility in the amplification and band assignment. In the backward-pumped Raman amplifier (BPRA), the transient power response has been observed[1−3] due to the sudden variation of the input signal power. Several methods have been proposed to suppress it[4,5]. Then the transient was studied in the multi-wavelength backward-pumped Raman amplifier (MW-BPRA) in Ref. [6], where the transient effects on the channel powers and the system gain are illustrated. In contrast, this article focuses on the other aspect of the transient, such as the time and amplitude characteristics of the power overshoot.

The results in Ref. [1] showed that in the Raman system with single signal and pump, using the dispersion compensation fiber (DCF) as the gain medium, the power overshoot caused by channel adding up would reach a large value, as shown in Fig. 1. Such large power overshoot would not only degrade the system performance temporally but also damage the optical components. Therefore, it is worthy of being further investigated in the Raman amplified WDM system with the standard single mode fiber (SMF) as the gain medium. In this work, the time and amplitude characteristics of the power overshoot, caused by channels adding up, are firstly studied experimentally in MW-BPRA using SMF as the gain medium, by the way of single signal sweeping. Then these distributions are studied numerically in the MW-BPRA with multiple signal channels. To describe the time and amplitude characteristics of the power overshoot, two parameters, the maximal power overshoot value $P_{max}$ and the lasting time $T_{lasting}$, are defined, as illustrated in Fig. 1. $T_{lasting}$ is time used for the output signal power to drop from the maximal value $P_{max}$ to the minimal value $P_{min}$.

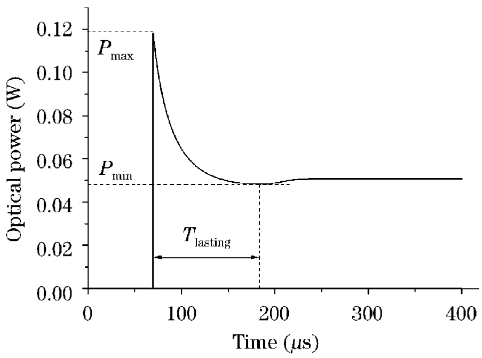


Fig. 1. The power overshoot reported in Ref. [1].

The experimental setup for observing the two characteristics of the power overshoot at different wavelength channels in BPRA WDM system is shown in Fig. 2. The tunable laser (TL) is used as the signal source. The wavelength of the input signal is tuned from 1522 to 1610 nm at the step of 2 nm. The average input power of each signal channel is −3 dBm. An acoustooptic modulator (AOM) is used to chop the input signal and to simulate input signal power fluctuation. Here we concern the system response while the input signal power jumps from zero to 0 dBm. The electrical pulse generator generates a square wave at 160 Hz with an approximate 50% duty cycle. The Raman gain medium is 100-km SMF. The RA is gain flattened designed within the wavelength range from 1520 to 1600 nm. Five Raman pumps (with the wavelengths of 1424.2, 1436.3, 1448.4, 1460, and 1497 nm, and the corresponding powers of 139.6, 133.8, 93.6, 70.4, and 128.8 mW) are backwardly coupled into the fiber at the output end. At the receiving end, for the linear response range of the used photodetector (PD) is below −10 dBm, the output signal is first attenuated by the value of 4.57 dB, and then detected by a PD and monitored by an oscilloscope (OSC).

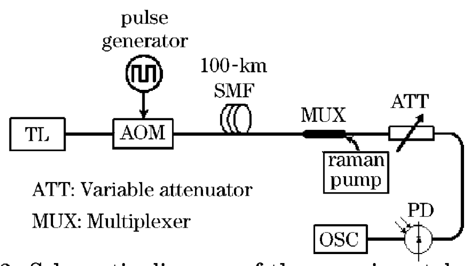


Fig. 2. Schematic diagram of the experimental setup.

Different from the experimental setup, in the simulation, one hundred signal channels are used, which are even distributed from 1511 to 1610 nm with the interval of 1 nm, then the signal-to-signal Raman interaction can be taken into account. Except for such change, the other system parameters, such as the length of SMF, the pump powers, and wavelengths, are the same as those in the experimental setup.

Figure 3 shows the experimental and simulation results of the channel distribution of $T_{\text{lasting}}$. It is found that the lasting time of the power overshoot at different signal channels is not equal to each other. The shorter the wavelength of the signal is, the smaller the lasting time of the power overshoot will be, which results from the difference of the effective length of each pump. The short-wavelength signal is mainly amplified by the short-wavelength pump, which has smaller effective length, so it will cost smaller time to drop from $P_{\max}$ to $P_{\min}$ during the transient. Figure 3 also shows that the experimental results and the simulation results have good consistency. This wavelength-dependent time characteristic of the transient should be considered in the design of the

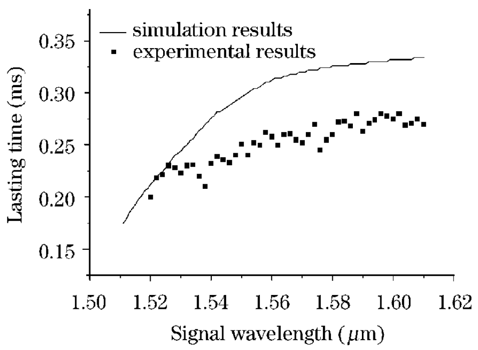


Fig. 3. The channel distribution of the lasting time of the transient power overshoot.

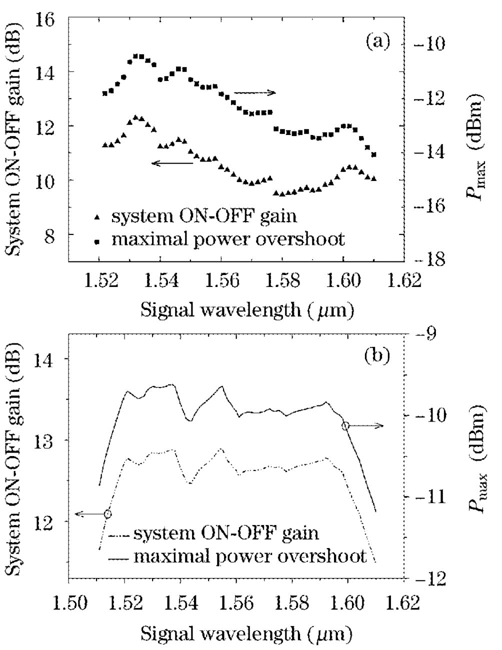


Fig. 4. The channel distributions of the maximal power overshoot value $P_{\max}$ and system ON-OFF gain for multiple pumps. (a): Experimental results; (b): simulation results.

transient control circuits. And it is suggested that the short wavelength be preferred because the lasting time of the power overshoot of short-wavelength channel in the transient is smaller than that of the long-wavelength channel and then the system will be safer.

Figure 4 describes the channel distributions of $P_{\max}$ of the power overshoot and the system ON-OFF gain. The results show that in the Raman system with SMF as the gain medium, the power overshoots in the transient caused by channels adding up are not so large as those observed in Ref. [1], where DCF, which has smaller effective area and larger Raman gain coefficient, is used as the gain medium. So the potential damage to the optical components, caused by the power overshoot in the former systems, is comparatively small. In the experimental results, the power overshoot and the system gain of the shorter wavelength channel are larger than those of the long-wavelength channel for there is only one signal channel in the system. In the simulation, one hundred signal channels are used, and the signal-to-signal Raman interaction makes the distribution curves more flat. The results in Fig. 4(b) are a little larger than the corresponding results in Fig. 4(a) when the linewidth of each pump is not considered in the numerical simulation, then the pump has a higher efficiency. Figure 4 also shows that the channel distributions of $P_{\max}$ and system ON-OFF gain have similar shape, because during both the transient and steady states the Raman gain coefficient of each signal channel keeps unchanged. So while the system ON-OFF gain is flat, big differences among the power overshoots of all channels could be avoided.

In conclusion, the time and amplitude characteristics of the power overshoot in the transient caused by channels adding up are investigated both experimentally and numerically in the MW-BPRA with SMF as the gain medium. The results show that: (1) the shorter the signal wavelength is, the smaller the lasting time of the power overshoot will be. So it is suggested that the short wavelength be preferred to avoid the influence of the power overshoot; (2) The power overshoot in this kind of system is small and would not cause deadly damage to the optical components. And the channel distribution of the maximal values of the power overshoots is similar in shape with that of the system ON-OFF gain. Big differences among the power overshoots of all channels can be avoided, the system ON-OFF gain is flat.

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