Optik 124 (2013) 4001–4004

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Simulation analysis of crosstalk among channels with fiber Raman amplifiers at 10 Gb/s

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ARTICLE INFO

Article history:
Received 23 July 2012
Accepted 1 December 2012

Keywords:
FRA
WDM
SRS
SIR

ABSTRACT

We have investigated the effects of crosstalk in fiber Raman amplifiers (FRAs) by propagating signals through the Raman fiber. We have observed that quality factor reduces for lesser channel spacing. We have able to propagate the signals in two channels with spacing of 20 GHz and quality factor above 25 dB was obtained. The effect of signal input power and injected pump power on crosstalk and signal interference ratio (SIR) has analyzed. It is observed that the signal gain and the injected pump power should be limited to the value well below the threshold of Raman amplification to ensure small crosstalk and high SIR. The effect of Raman fiber length on crosstalk is also studied and it is observed that for high values of Raman fiber length, SIR reduces considerably.

1. Introduction

Wavelength division multiplexing (WDM) has enabled an explosive increase in the capacity of optical transmission systems with announced commercial systems reaching capacities beyond 1 Tb/s. The amplifiers based on Raman scattering enable the capacity of WDM systems to be increased [1]. The WDM is a technique in which number of optical signals from many different light sources having properly spaced peak emission wavelength are transmitted simultaneously over the same fiber. Thus, the use of multiple channels over the same fiber provides unprecedented transmission capacity. One of the main advantages of this technology is that a huge increase in available bandwidth can be obtained without deploying additional optical fiber [2]. Because of their broad band, Raman amplifiers are used to amplify several channels simultaneously in a WDM light wave system. The Raman amplifier offers much wider essential gain bandwidth [3]. The performance of a WDM system is strongly affected by an important parameter, called as crosstalk occurring between different channels. Crosstalk is defined as the interference in a communication channel caused by activity in other communications channels. The cause of crosstalk is some form of coupling mechanism between the disturbed channel and the disturbing channel. Coupling between channels is caused by the physical proximity and relative orientation of the transmission media.

In this paper, we have investigated the crosstalk between two channels with Raman amplification by calculating quality factor and Signal interference ratio (SIR) for different values of signal input power and injected pump power. The impact of Raman fiber length on SIR has also been demonstrated.

2. Related work

In optical fiber transmission systems using WDM, the stimulated Raman scattering (SRS) interaction between channels could result in significant nonlinear crosstalk. The crosstalk between individual wavelength channels caused by SRS is a disturbing out of phase transfer of information between the wavelength channels which decreases strongly as the modulation frequency of the light increases [4–8]. The cross talk is strongly dependent on the input powers and on the signal gain. Further, it is also sensitive to the relative wavelength of the input signal. Measurements have shown that the cross talk is strongly affected by the wavelength mismatch between the signals. With careful wavelength turning and at a certain power level, zero crosstalk can be obtained between two digitally intensity modulated signals [9]. It has been concluded that the crosstalk due to SRS depends upon wavelength channel spacing, polarization states, fiber dispersion and subcarrier frequency [10]. There is obvious crosstalk in multichannel Raman amplification, even if it works in linear amplification area and it can be denoted by SIR. So the signal power must be limited and the pump power must be under the saturation for higher SIR of the system. To

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http://dx.doi.org/10.1016/j.ijleo.2013.03.001

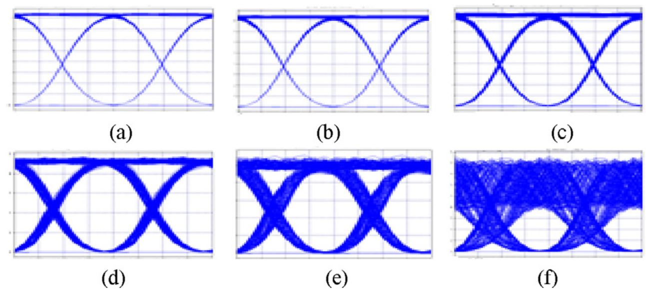

Fig. 1. Eye diagrams for different channel spacing (a) 124.8 GHz, (b) 62.48 GHz, (c) 37.45 GHz, (d) 25 GHz, (e) 20 GHz and (f) 12.58 GHz.

obtain higher SIR, the input signal power must be high but crosstalk limits the value of input signal power. So, the input signal power in multichannel Raman amplification should be smaller [11]. Also, the higher-order dispersion severely degrades the performance of optical communication systems and to ensure small crosstalk and high SIR, the signal gain and the injected pump power should be limited to the value well below the threshold of Raman amplification [12–14].

3. Effect of signal input power and pump power on SIR

A silica fiber Raman amplifier pumped at a wavelength of 1451.2 nm with pump power 1200 mW was designed. Data source at 10 Gb/s was used. This data source was applied to a driver with NRZ format. The bandwidth for simulation was from 192.94 Thz to 193.88 Thz and wavelength limits were from 1546.25 to 1553.75 nm. The bit rate was kept at 10 Gb/s for a 0 dBm input signal source for studying the impact of crosstalk in FRAs, two channels were simultaneously propagated through the same Raman fiber. Simulation was carried out by keeping channel 1 at wavelength 1550 nm and then varying the wavelength of channel 2, thereby varying the spacing between two channels. Fig. 1 shows the eye diagrams obtained by varying the channel spacing between two channels from the value of 124.8 GHz to 12.5 GHz.

The eye diagrams clearly indicate that the output gets distorted with the reduced channel spacing and it was worst for spacing of 12.5 GHz. So optimized spacing between channels comes out to be 20 GHz corresponding to wavelength difference of 0.16 nm between two channels.

The optimum spacing of 20 GHz between two channels obtained from the previous work was utilized to study the effect of signal input power and injected pump power on crosstalk. The channel 1 was kept at wavelength of 1550 nm and channel 2 at 1550.16 nm. Simulation was carried out by varying the input power from −20 dBm to 20 dBm for different values of pump power without using any booster before Raman fiber. The Raman fiber length was kept at 10 km.

The Crosstalk can be calculated as [7]

$$\text{Crosstalk} = \frac{P_{2\,out}(P_{1\,in} = on) - P_{2\,out}(P_{1\,in} = off)}{P_{2\,out}(P_{1\,in} = off)}$$

where $P_{2\,out}(P_{1\,in} = on)$ is output power of channel 2 when channel 1 is on and $P_{2\,out}(P_{1\,in} = off)$ is output power of channel 2 when channel 1 is off

The SIR can be calculated as [10]

$$\text{SIR} = 10\log_{10}\frac{S(L)}{|I|}$$

where $S(L)$ is output power as a function of Raman fiber length L and $|I|$ is crosstalk induced between channels.

Table 1 shows the value of SIR for different values of pump power (0–25 dBm) and signal input power (−20–20 dBm). Results clearly indicate that SIR decreases with increase in input signal power. For pump power of 0 dBm, the SIR at input power of −20 dBm was 53 dB, whereas it reduces to the value of 12.86 dB for signal input power of 20 dBm. Further, as we increase the pump power, there is net decrease in SIR. For input signal of −20 dBm, the SIR at pump power of 0 dBm was 53 dB and it reduces to the value of 48.92 dB at pump power of 25 dBm for the same input power.

Table 1
Variation of SIR for different value of signal input power at different pump powers.

Signal input power (dBm)	Pump power (0 dBm) SIR (dB)	Pump power (15 dBm) SIR (dB)	Pump power (25 dBm) SIR (dB)
−20	53	52.48	48.92
−15	48	47.49	43.97
−10	43	42.48	38.95
−5	38	37.47	33.98
0	33	32.5	28.94
5	29	27.8	24.14
10	23	22.47	19.1
15	17.9	17.45	14
20	12.86	12.51	8.91

Fig. 2 shows SIR versus the input signal power for different pump powers.

It is clear from the above figure that SIR decreases sharply with signal input power and also with increase in pump power, SIR reduces.

4. Threshold value of pump power for high SIR

The work was further extended for calculating the threshold value of pump power to have high SIR. For this, both channels with spacing 20 GHz were propagated in a Raman fiber length of 100 km without using any booster. The input signal source was kept at 0 dBm and pump power was varied from 0 to 45 dBm.

Fig. 3 shows SIR and quality factor for different values of injected pump power.

Results indicate that quality factor shows very little variation up to the pump power of 35 dBm but beyond this value, there is significant decrease in this factor. At pump power of 40 dBm, quality factor falls to a value of 19.71 showing deterioration of the signal. Further, SIR value also decreases with increase in pump power. SIR decreases by small amount up to the value of 25 dBm of pump power but after that it falls sharply, thus indicating the threshold of pump power at 25 dBm for SIR of more than 30 dB.

Fig. 4 shows the eye diagrams obtained from this work. We can have a very clear idea about the variation of quality factor and SIR with pump power from these eye diagrams

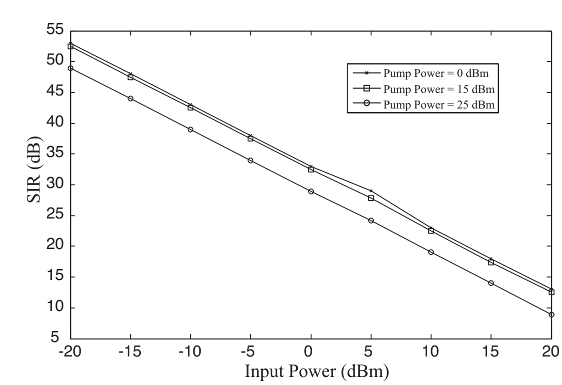

Fig. 2. Variation of SIR for different values of input and pump power.