

Research on WDM optical fiber transmission system based on fiber Raman amplifier

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Received April 22, 2003

After wavelength division multiplexing (WDM) optical fiber transmission system based on fiber Raman amplifier (FRA) is investigated in detail, the influence of the collocation of dispersion compensation fiber (DCF), the dispersion coefficient, dispersion slope (DS), effective core area, nonlinear index, length of FRA, launch power and the bandwidth of Bessel filter on bit error rate (BER) is deduced. The influence of Rayleigh backscattering noise on optical signal noise ratio (OSNR) is also investigated, which affects the performance of long haul transmission badly. The result indicates that the broadband long haul transmission can be realized through the reasonable design of the fiber. The result is useful to the optimal design of the WDM optical fiber transmission system based on FRA.

OCIS codes: 060.2320, 190.5650, 060.2330, 190.4360, 190.4370, 060.4370, 060.2360.

In the past ten years, with the development of internet and other data transmission services, the information capacity has increased rapidly^[1]. The communication capacity that present optical communication system can offer will be exhausted. How to increase capacity and the span length of optical communication system has become the focus of optical communication research^[2]. As a key device of the upgrade of optical fiber communication system, fiber Raman amplifier (FRA) plays an important role in the optical fiber transmission system^[3]. FRA which adopts distributing amplification not only reduces the system nonlinear impact brought by large launch power but also enhances the optical signal noise ratio (OSNR), so the span length is extended and the system performance is improved^[4]. With the rapid increase of transmission speed and communication capacity of optical fiber communication system, the research and exploitation of FRA is becoming more and more urgent and important^[5]. In this paper the influence of the collocation of dispersion compensation fiber (DCF), the dispersion coefficient, dispersion slope (DS), effective core area, nonlinear index, length of FRA, launch power and the bandwidth of Bessel filter on bit error rate (BER) is deduced. The influence of Rayleigh backscattering noise on OSNR is also investigated in detail, which affects the performance of long haul transmission badly. The result indicates that the broadband long haul transmission can be realized through the reasonable design of the fiber. The result is useful to the optimal design of the WDM optical fiber transmission system based on FRA. In the experiment we use the signals from the 41 channels. Each channel adopts 7 order pseudo random non-return-to-zero codes. The channel speed is 40 Gb/s. The first channel frequency is 191.5 THz. The channel interval is 100 GHz. The signals enter the fiber segments controlled by the ring controller after transiting WDM device. The fiber segments are composed of three segment fibers. From left to right there are respectively DCF₁, FRA and DCF₂. Under the control of the ring controller the signals transmit through six fiber segments. Through

the 3 order Bessel filter the test channel is received. In the experiment the test channel is the last channel. The gained signals are inspected by oscillograph after passing through PIN and the clock recovery. DCF₁ and DCF₂ have the same parameters except for the fiber length. The total length of DCF which compensates not only the dispersion of FRA but also the DS of FRA completely is constant. A coefficient b determines the length of DCF₁ and DCF₂. The length of DCF₁ is the product of b and the total length of DCF. The gain of FRA is flat in the signal spectrum and FRA uses two pump sources pumping backward to reduce noise. Other parameters of the system are given in Table 1. In the experiment all the parameters with relation to optical frequency are the parameters at 193.5 THz. In the following experiment we will investigate the relation between the parameters listed in Table 2 and $-\lg(\text{BER})$ respectively. When we investigate the impact of one parameter on BER, the other parameters keep permanent.

Table 1. Some Parameters of the System

Dispersion Coefficient of DCF	$-90 \times 10^{-6} \text{ s/m}^2$
Effective Core Area of DCF	$50 \mu\text{m}^2$
Nonlinear Index of DCF	$2.6 \times 10^{-20} \text{ m}^2/\text{W}$
Pump Frequency (Power) of FRA	203.5 THz (185 mW)
Pump Frequency (Power) of FRA	210.3 THz (1.5 W)

Table 2. The Parameters Investigated in the Experiment

b	0.2
FRA Dispersion Coefficient	$15 \times 10^{-6} \text{ s/m}^2$
FRA Dispersion Slope	80 s/m^3
FRA Nonlinear Index	$2.6 \times 10^{-20} \text{ m}^2/\text{W}$
FRA Effective Core Area	$80 \mu\text{m}^2$
Bessel Filter Bandwidth	50 GHz
FRA Length	90 km
Launch Power	0 dBm
The Number of FRA	6

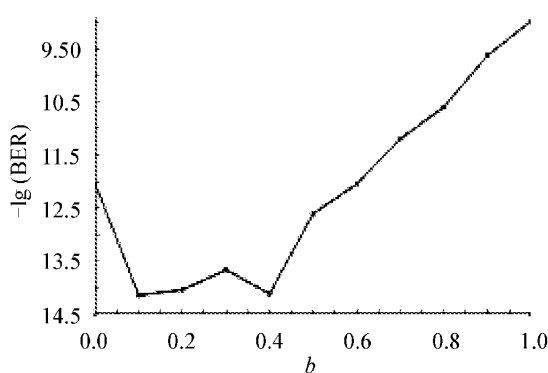


Fig. 1. The relation between $-\lg(\text{BER})$ and b .

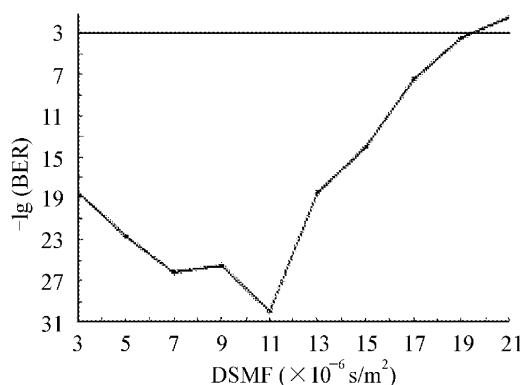


Fig. 2. The relation between $-\lg(\text{BER})$ and DSMF.

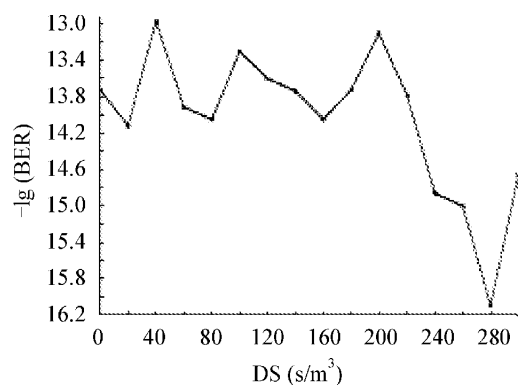


Fig. 3. The relation between $-\lg(\text{BER})$ and DS.

Figure 1 depicts the relation between $-\lg(\text{BER})$ and b . When b changes between 0.1 and 0.4, BER keeps low. When b increases, BER increases rapidly. The phenomena show that when the length of DCF₁ is zero, the signal power is very high through the FRA amplification. The signal suffers the nonlinear impact badly, so the system performance is bad. When the length of DCF₁ is long, BER is also high because OSNR is very low after the signals pass the DCF₁.

The relation between $-\lg(\text{BER})$ and FRA dispersion coefficient (DSMF) is depicted in Fig. 2. From Fig. 2 we can see that when the dispersion coefficient changes between 3×10^{-6} and 15×10^{-6} s/m², BER keeps low. When dispersion coefficient is 11×10^{-6} s/m², BER is minimum. When the dispersion coefficient continues increase, BER becomes high. So when we design the fiber,

the dispersion coefficient should be reduced in the permission range of technics. We can also draw a conclusion that when the dispersion coefficient exceeds a certain value the system performance becomes very bad even if we use DCF to compensate FRA dispersion completely.

Figure 3 describes the relation between $-\lg(\text{BER})$ and FRA DS. We can see that when DS changes between 0 and 220 s/m³, BER does not change notably. When DS changes between 240 and 300 s/m³, BER keeps low. It shows that large DS benefits system performance enhancement.

The relation between $-\lg(\text{BER})$ and FRA nonlinear index (N) is shown in Fig. 4. Because of lesser nonlinear index the stimulated Raman scattering cannot come into being, BER keeps high. When nonlinear index becomes too large, BER also keeps high because other nonlinear effects such as XPM, SPM, FWM become serious. As a whole, biggish nonlinear index keeps BER low.

Figure 5 shows the relation between $-\lg(\text{BER})$ and FRA effective core area. Because of biggish effective core area, the efficiency of stimulated Raman scattering is very low. The signals cannot be amplified enough, so BER is high. When effective core area becomes too small, BER becomes high because other nonlinear effects become serious. When effective core area is $70 \mu\text{m}^2$, BER is minimum.

The relation between $-\lg(\text{BER})$ and launch power (the input optical power of DCF₁) is described in Fig. 6. Too low launch power can directly lead to low received OSNR while too high launch power can lead to high nonlinear impact. They both result in high BER. The influence

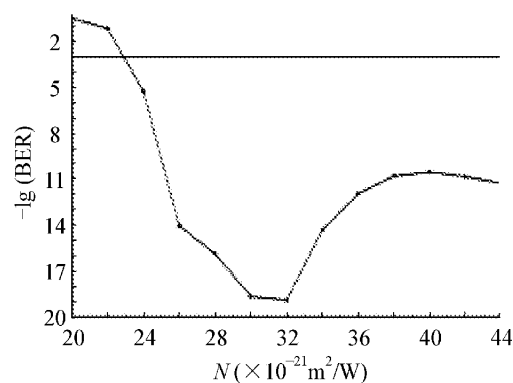


Fig. 4. The relation between $-\lg(\text{BER})$ and N .

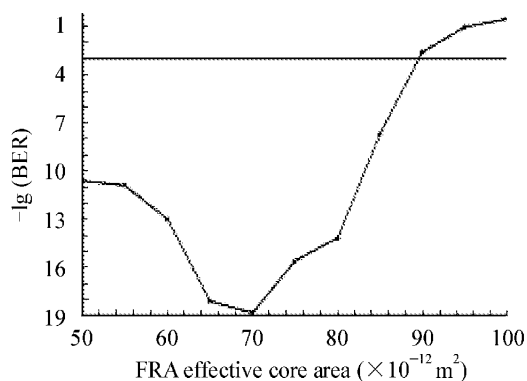


Fig. 5. The relation between $-\lg(\text{BER})$ and FRA effective core area.

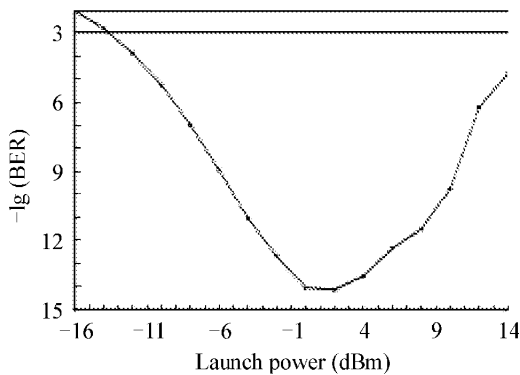


Fig. 6. The relation between $-\lg(\text{BER})$ and launch power.

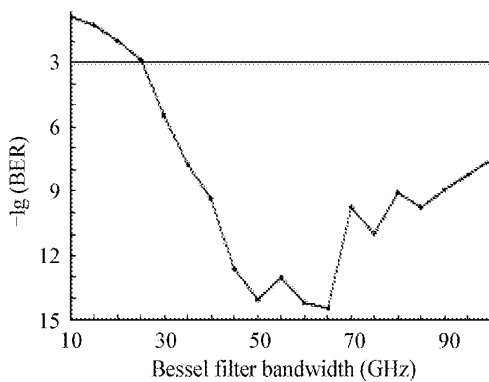


Fig. 7. The relation between $-\lg(\text{BER})$ and Bessel filter bandwidth.

coming from two aspects has a tradeoff. When the launch power is 2 dBm, the whole system performance is best.

Figure 7 shows the relation between $-\lg(\text{BER})$ and Bessel filter bandwidth. Too narrow filter bandwidth can directly affect the received signals quality, while too wide filter bandwidth cannot eliminate noise outside signal spectrum, resulting in high BER. So the choice of filter bandwidth is very important. From the figure we can see that the filter bandwidth has better be designed in the range of 50 – 65 GHz to ensure the good system performance.

Differing from the fiber transmission system based on EDFA, in the fiber transmission system based on FRA the Rayleigh backscattering noise cannot be neglected. It becomes one of the limit factors in the long haul transmission system. Figure 8 shows the OSNR difference (DOSNR) of all channels through FRA under the condition of different FRA lengths. With the increase of length, the OSNR difference becomes large, which shows that the longer FRA is, the more serious the influence of Rayleigh backscattering on system performance is. But this cannot show that when we design system, the FRA length should be as short as possible, because under the condition of constant pump power and frequency the short FRA means the high output signal power and system nonlinear impact (shown in Fig. 9). So when we design system the influence of two aspects should be

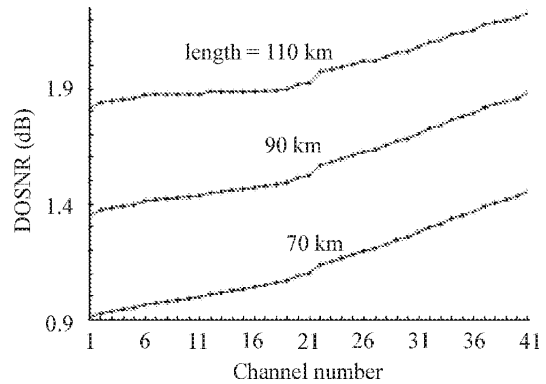


Fig. 8. DOSNR of all channels through FRA under the condition of different lengths.

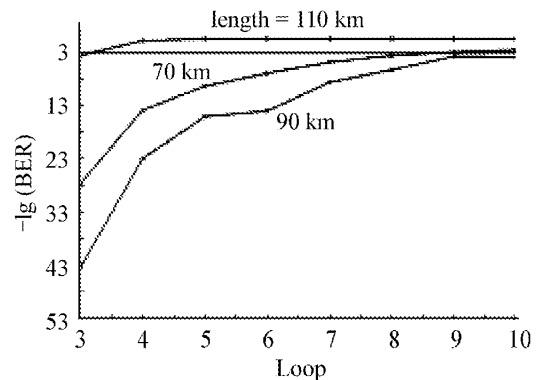


Fig. 9. The relation between $-\lg(\text{BER})$ and loop.

taken into account synchronously. Figure 9 shows the relation between $-\lg(\text{BER})$ and the number of FRA (loop) under the condition of different FRA length. When the FRA length is long, the Rayleigh backscattering noise is large and OSNR is low because of biggish fiber loss. When the FRA length is short, the system nonlinear impact is high because the signals receive much more gain through FRA. So for the constant pump power and frequency there is an optimal FRA length.

This work was supported by the Teaching and Research Award Program for Outstanding Young Teachers in Higher Education Institutions of MOE, P. R. China. F. Xue's e-mail address is xuefei_chenyue@163.com.

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