

Performance Optimization based Spectrum Analysis on OFRA and EDFA Devices

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Abstract

As the key devices, erbium doped fiber amplifier (EDFA) and optical Raman fiber amplifier (OFRA) have been widely applied in the fields of optical communication, sensing and measurement. However, the performance optimization is always one of the hot topics in the study of optical fiber amplifiers, because its output characteristics are hardly dependent to the key designing parameters. In this paper, in order to cope with such problem, we adopt the novel analysis based spectrum to study the output performance of EDFA and OFRA systems, respectively. Through simulating the operation of the two amplifying system, their output characteristics are first demonstrated with the various parameters. And according to the numerical results obtained, the key designing parameters of EDFA and OFRA systems are determinate, and the performance of amplifying systems are improved and optimized obviously in terms of output power, signal noise ratio, and the level of gain flatness.

Keywords: fiber Raman amplifier, erbium doped fiber amplifier, performance optimization, spectrum analysis, simulation.

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1. Introduction

Undoubtedly, as one of the most key devices in the high speed optical communication system, the performance of optical amplifier is significant with respect of cost, energy consumption, the quality of signals, etc. The study on optical amplifier is always an open issue and concerned by many researches [1]. At present, the erbium doped fiber amplifier (EDFA) is still one of the most widely-used optical amplifiers. But, considering its only 20 nm flat gain bandwidth, and the tremendous increase of data services in the optical transmission networks, EDFA system maybe not meet the future application of optical networks. Therefore, the study on optical amplifiers with high gain power and wide gain bandwidth has been paid much attention by many researchers [1-6]. Among these studies, due to a wide gain bandwidth about 100 nm, optical fiber Raman amplifiers, in short OFRA, has been regarded as one of the main potential amplifier devices, although its gain power is not high comparatively. Hence, that combines the advantages of the EDFA and OFRA to amplify light signals in C band and L band has become one of the hot topics in the field of optical communication and measurement [1-3].

Note that, because of the complex working principle, the output performance of both EDFA and OFRA systems are hardly affected by some designing parameters, e.g. pumping wavelength, pumping power, and doped fiber length [3]. To optimize the output performance, many researchers have devoted to analyze the output characteristics of EDFA, OFRA, or the combined systems by the numerical calculation based on the rate equations, but, with strongly complicated and limited analyzing processes [4-6]. On the other hand, taking the high cost of the optical devices and analyzer into account, it is a hard work to conduct the spectrum analysis of OFRA system though adopting the traditional experiments. In order to overcome such problems, the simulation ways have been used in the performance analysis of the optical devices by some researches, which are with the advantages of low complexity, fast speed, flexible configuration and vision. Ref [7] uses the SPICE2 software to analyze light transmission system. Ref [8] simulates the features of the 1550nm fiber laser through FEM. And in our previous work, the output performance including the superfluorescent source, laser diode, and fiber laser (with the center wavelength at 1550nm) by simulation are achieved to analyze and optimize [9-11]. In this paper, through using the Optisystem software, we develop the analysis

based simulation on EDFA and OFRA system, respectively. And according to the output spectrum and gain natures, our work will focus on discussing the parameters effects, and take the optimization of the output performance of EDFA and OFRA system.

2. Simulation and Analysis on the OFRA System

Generally speaking, there are three typical pumping configurations of OFRA, which are forward pumping, backward pumping and bidirectional pumping. Due to the length limitation, in this paper, we will pay much attention to the analysis on the high efficient OFRA system with backward pumping [3].

In Optisystem, the simulation model of the OFRA system with backward pumping is shown in Figure 1, which consists of signal generator, one pumping source, one APA Raman Amplifier, and some optical spectrum analyzers. Especially, in the signal generator part, a CW (continuous wavelength) laser array with the wavelength from 1515 nm to 1590 nm is selected, whose input power are same at -3dBm. And through the LiNb Mach-Zehnder modulator, bit sequence generator and pulse generator with 10G bits/s, six light signals with the 15nm inter-wavelength are sent into the ARA Raman Amplifier with the NRZ (Not Return Zero) code format. Other key parameters are pumping wavelength is 1420nm, pumping power is 24 dBm, the length of SMF (single mode fiber) is 25 km, the working temperature is 300 K, the polarized factor is 2, the background loss and gain efficiency is constant and set by the optisystem 10.0 software. We then study the output characteristics of the OFRA system by various pumping wavelength and pumping power.

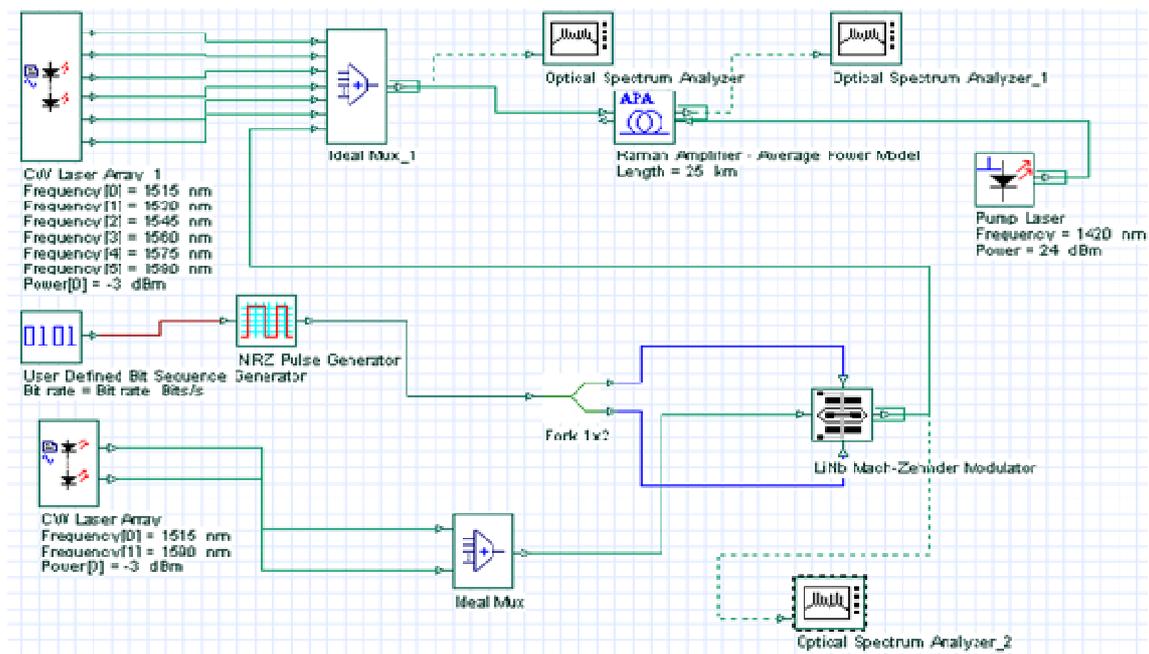


Figure 1. The simulation model of OFRA with backward pumping

2.1 Various Pumping Wavelength

In our work, to study the effects of the pumping wavelength on the output of an OFRA system, we first set the pumping power is at 24 dBm, and four different pumping wavelengths (denoted by W_{pump}) are selected, which are 1420 nm, 1450 nm, 1480 nm, 1500 nm, respectively. Then, adopting the model as seen in Figure 1, some numerical results of the output gain spectrum of the OFRA system were obtained. From Figure 2(a), the maximum and minimum values of the signal lights (red lines) gain are 2 dB and -9 dB respectively. That means the gain flatness of the output spectrum is not ideal, because the gain difference (GD) reaches

11 dB. Again, according to the numerical results in other three pictures, we find the GD value is decreased with the increase of the pumping wavelength from 1450 nm to 1500 nm. For instance, in Figure 2(b), when $W_{pump} = 1450$ nm, the GD value is over 7 dB. And when $W_{pump} = 1480$ nm and 1500 nm (shown in Figure 2(c) and Figure 2(d)), both the GD values are about 3.6 dB. Further, through comparing the amplified spontaneous emission (ASE) noises (green part) in four pictures, the output performance of the OFRA system at $W_{pump} = 1500$ nm is optimal and the signal noise ratio (SNR) reaches 74.8 dB.

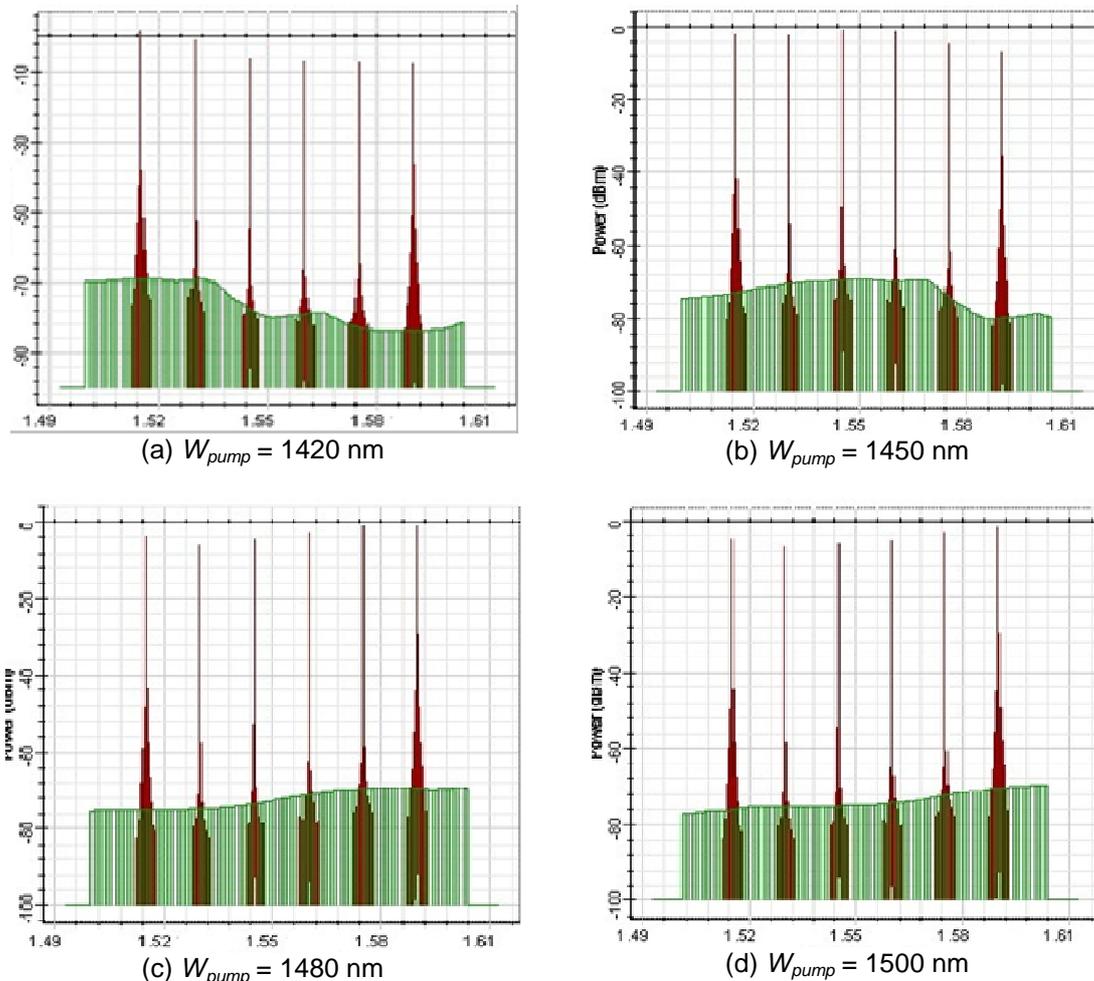


Figure 2. Gain spectrum of the OFRA system with various pumping wavelengths

2.2 Various Pumping Power

According to the analytical results above, we set the pumping wavelength is at 1500 nm, and study the effects of the various pumping power (denoted by P_{pump}) on the output performance of the OFRA system. In Figure 3(a), it is obvious that the output powers of light signals are low and less than 0 dBm. That means the pumping power at 14 dBm is not enough high for the Raman amplifying process, although its GD value is only 2 dB.

Comparatively, when the pumping power is over 24 dBm, the gain values of these six light signals are all near or over 0 dBm. However, we also find an interesting phenomenon that, although a higher gain is obtained, the higher pumping power introduce much extra noise and unideal gain flatness. For instance, as seen in Figure 3(c), when $P_{pump} = 27$ dBm, the values of average gain and GD of the six light signals are -2 dBm and 9 dB (e.g. the maximum and minimum gain values are -4 dB at 1530 nm and 5 dBm at 1590 nm) respectively. At the same time, the ASE noise increases -70 dBm, which means the input power to generate the extra

noise partially, not for the light signals. In other words, this pumping power is overlarge for the OFRA system. The similar results are obtained again in Figure 3(d), the values of average gain and GD are 3 dBm and 17 dB respectively, and the SNR value is decreased obviously and only 59 dB. So, when the fiber length is 25 km, and the pumping wavelength is 1500 nm, the output performance of the OFRA system is optimal at $P_{pump} = 24$ dBm.

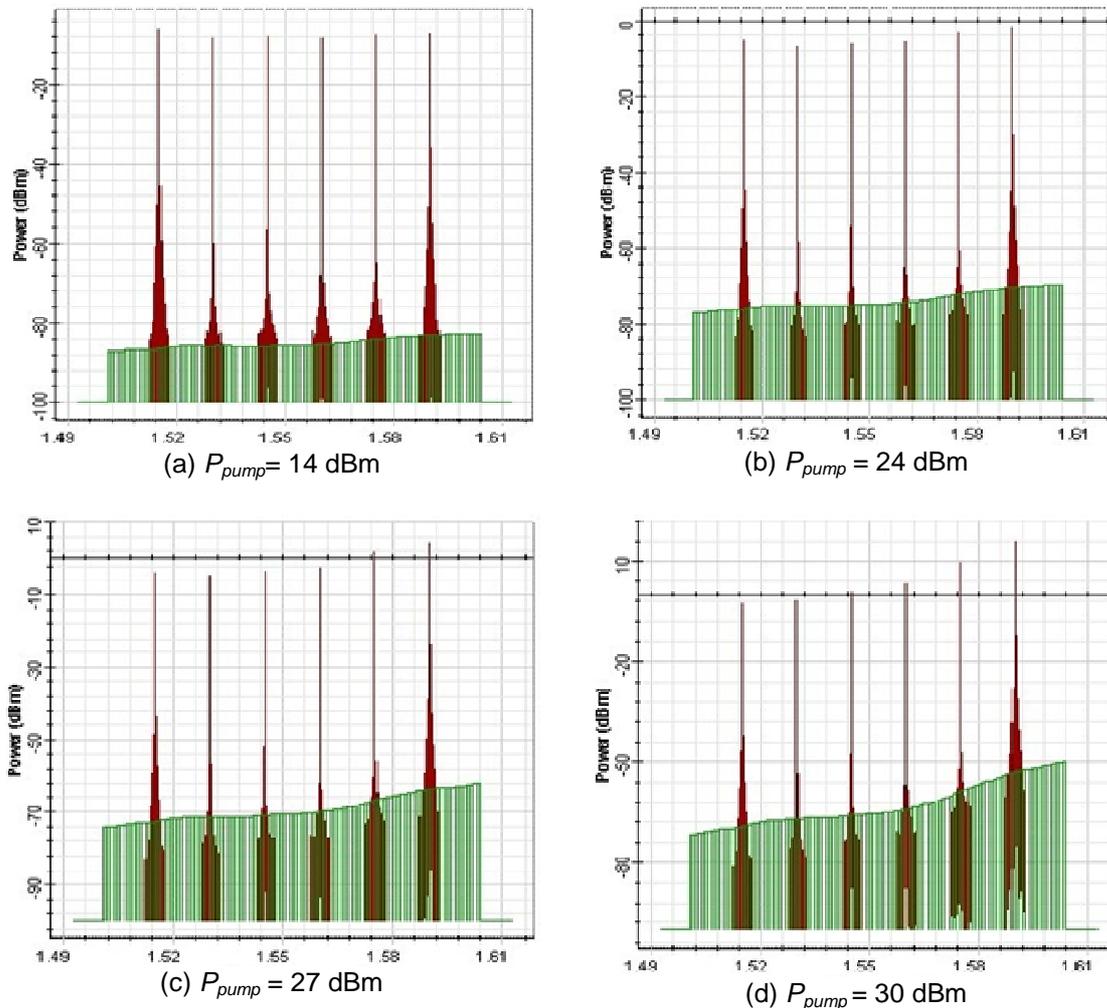


Figure 3. Gain spectrum of the OFRA system with various pumping power

3. Simulation and Analysis on the EDFA System

In this section, in order to match with the OFRA system, we conduct the performance analysis of an EDFA system based output gain spectrum. As shown in Figure 4, the typical EDFA system with forward pumping consists of five parts at least, i. e. the continuous wavelength (CW) laser array, the pumping source, WDM device, erbium doped fiber (EDF) and optical spectrum analyzer (OSA).

In particular, the CW laser array is used to model the three optical signals from 1540 nm to 1560 nm, with the same power -20 dBm. And a laser diode with the center wavelength at 980 nm is chosen as the pumping source, whose output power is 100 mW. Here, we assume the WDM device is ideal and without any extra loss. Two OSA devices are applied into our model to monitoring the output optical signals and ASE noise. Furthermore, for the EDF, its initial parameters are designed as that the length is 5m, the NA value is 0.24, and erbium ion density is $1 \times 10^{25} \text{m}^{-3}$, respectively. According to Ref [4-7], not only the pumping power, but the length and density of EDF have the obvious effect to the output features of the EDFA system.

Nevertheless, owing to the density of erbium ion is constant in Optisystem, we then model the output performance of the EDFA system as in Figure 4 with various EDF lengths and pumping power

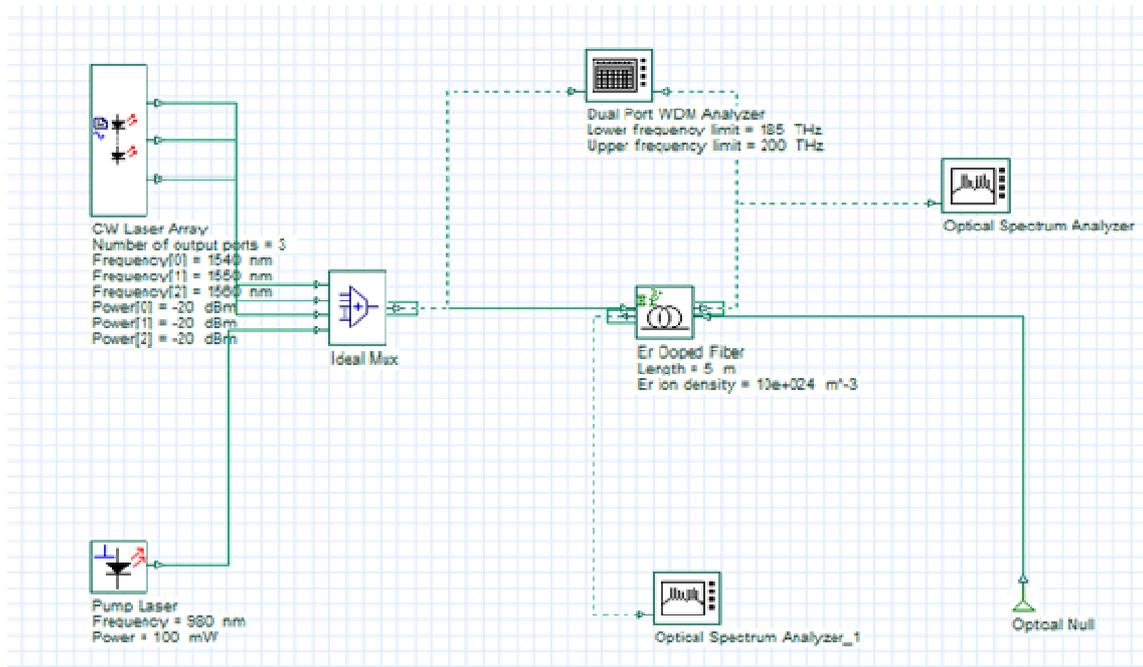


Figure 4. The simulation model of EDFA system with forward pumping

3.1. Various Length of EDF

Here, the density of erbium ion is constant at $1 \times 10^{25} \text{m}^{-3}$, and the pumping power (denoted by P_{pump}) is set as 100 mW. We then study the effects of output performance of the EDFA system by the various length of EDF. The initial value of the length of EDF (denoted by L_{Er}) is designed as 5 m, and the output spectrum features of the EDFA system are first shown in Figure 5(a) by simulation.

In Figure 5(a), we see the power of the optical signals reaches about 10 dBm. In other words, there is a 30 dB gain obtained. Also, we find an ideal flatness among the three signals (red parts), which the difference between the maximum and minimum output power is less than 1 dBm. On the other hand, the power of ASE noise (green part) is near to -45 dBm within the range from 1540 nm to 1560 nm.

Comparatively, when the length of EDF is 10 m, there is a different picture for the signals and ASE noise. As shown in Figure 5(b), the signal at 1560 nm obtains the maximum gain, whose output power reaches over 12 dBm. But, for the signal at 1540 nm, its output power after amplifying is only about 4 dBm. So, the gain difference is 8dB, much larger (4 times) than the case of $L_{Er} = 5$ m. Correspondingly, the ASE noise spectrum is hardly fluctuated at the band between 1540 nm and 1560 nm, though the average power of noise is still in the level of -45 dBm. The similar numerical results are shown in Figure 5(c) when the length of EDF is 15 m. In Figure 5(c), we see the gain difference is further enlarged, and its value maybe reach 16 dB. Especially, for the signal at 1540 nm, there is a negative gain (about -4 dBm) occurred. That means the amplifying function of the EDFA system has been lost at the band of 1540 nm. And according to the spectrum of ASE noise, we also find the center of gain has changed into 1560 nm in that case. Therefore, by comparing the numerical results obtained in Figure 5, the optimal output performance in terms of gain and flatness is achieved when $L_{Er} = 5$ m.

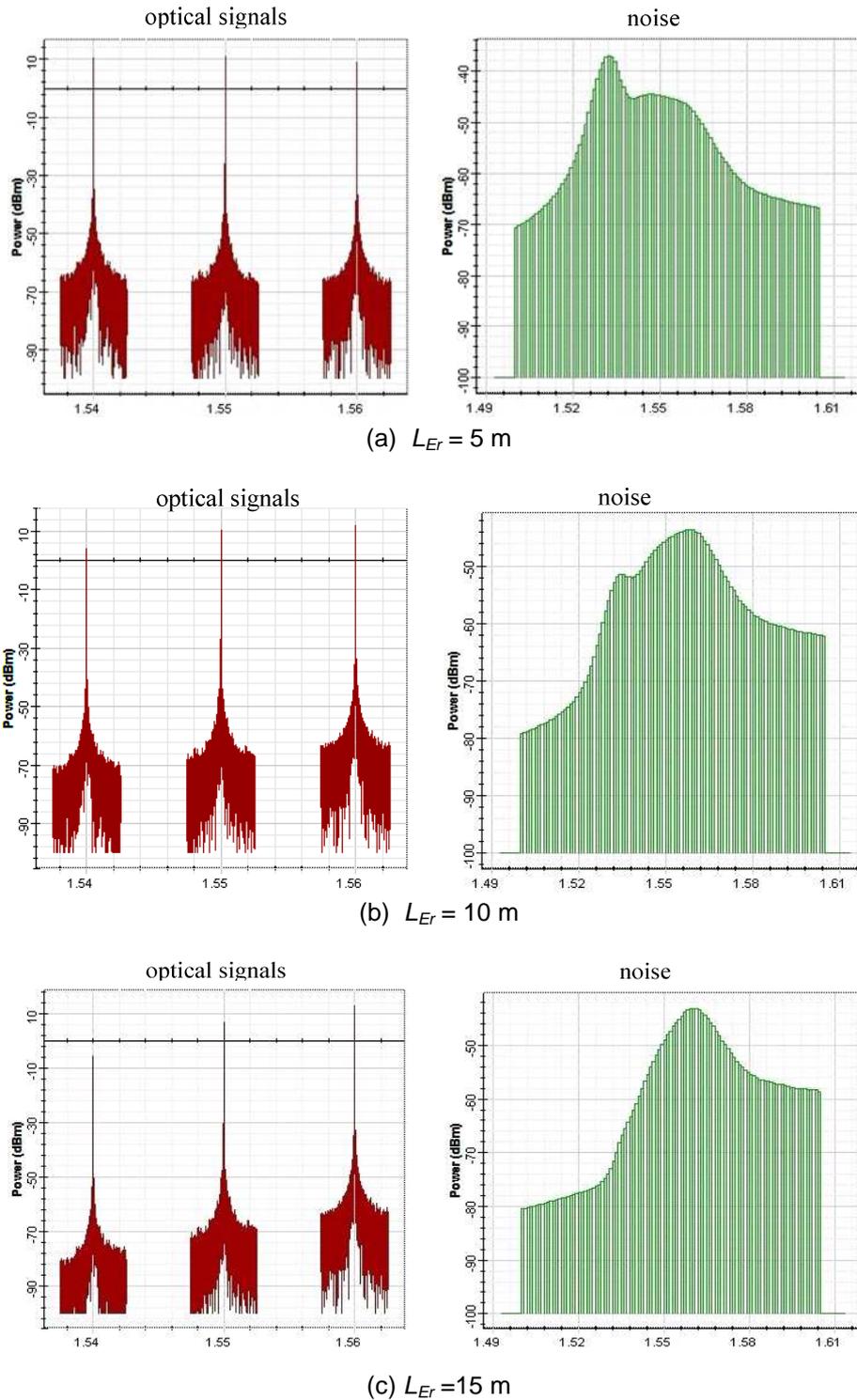


Figure 5. Gain and noise spectrum of EDFA system with various L_{Er}

3.2. Various Pumping Power

We then analyze the output characteristics of the EDFA system with the various pumping power. Similar to last section, we keep the density of erbium ion at $1 \times 10^{25} \text{m}^{-3}$. Again, based on the results above, we set $L_{Er} = 5$ m, and the initial pumping power $P_{pump} = 100$ mW.

The simulation results are shown in Figure 6. Particularly, the black lines in the left of all three pictures are the output of pumping source with the wavelength at 980 nm.

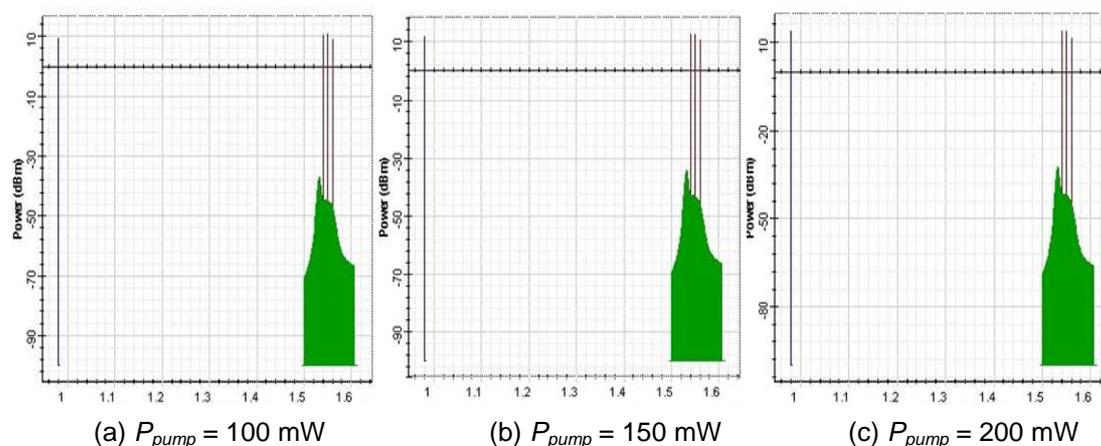


Figure 6. Output spectrum of EDFA system with various P_{pump}

In Figure 6(a), we see the signal powers are about 10 dBm, and the average amplitude of the ASE noise is -45 dBm when $P_{pump} = 100$ mW. Comparatively, when $P_{pump} = 150$ mW, the signal powers are raised about 2 dBm, but the ASE noise is still -45 dBm. So, the value of SNR of the EDFA system increases 2 dB. But, with the continuous raising for P_{pump} , e. g. $P_{pump} = 200$ mW (see Figure 6(c)), the SNR of the EDFA system is not further improved due to the larger ASE noise. That indicates that the optimal output performance will be obtained when the pumping power is 150 mW.

4. Conclusion

In this paper, by adopting the Optisystem software, we develop the performance analysis of the EDFA and OFRA system based on the output spectrum characteristics. According to the gain spectrum obtained, we focus on studying the gain, flatness and noise characteristics of the two optical amplifying system. Finally, by quantifying the values of gain difference and SNR, the designing parameters in terms of pumping wavelength, pumping power and doped fiber length are determinate. So, with such matching parameters, the output performance of the optical amplifying system is enhanced and optimized obviously. And our next work is to take the analysis on the combined system with EDFA and OFRA by numerical simulation.

Acknowledgements

This work is supported by Heilongjiang Province Natural Science Foundation (No. 201009), China Post Doctor Foundations (No. 2012M520779), College of Heilongjiang Province, Key lab of Electronic Engineering Outstanding Young Foundation (DZZD201003), and Heilongjiang Province Educational department Science and Technology Project (No. 11511382).

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