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Design and Analysis of a Hybrid Optical Amplifier using EDFA and Raman Amplifier

Deepak Sharma
UIET, MDU Rohtak, Haryana

ABSTRACT

In optical communication network, signals travel through fibers over long distances without significant attenuation. However, when distances become hundreds of kilometers, it becomes necessary to amplify the signal during transit. Optical fiber amplifiers provide in-line amplification of optical signals by effecting stimulated emission of photons by rare earth ions implanted in the core of the optical fiber. In this paper a review of optical amplifier is presented with their operating principle and their shortcomings .In this paper design of hybrid optical amplifier using Raman amplifier and Erbium Doped Fiber Amplifier (EDFA) using flatting technique is proposed and evaluated for various qualitative parameters.

Keywords: EDFA, Stimulated Raman Scattering (SRS), Wavelength Division Multiplexing (WDM), Dispersion Compensated Fibers (DCF), Amplified Spontaneous Emission (ASE), L-Band, C-Band.

INTRODUCTION

In optical fiber communication the signal suffers various losses such as fiber attenuation losses, fiber tap losses, fiber splice losses, etc., and the detection of the original signal at the receiver becomes difficult. In order to transmit signal over a long distance it is necessary to compensate all losses in the fiber either by using optoelectronic repeaters or optical amplifiers [1]. Earlier Optoelectronic repeaters were used to compensate the power losses in which the optical signals are first converted into electric signal, then amplified in electric domain and then finally converted back to optical signals. Such repeaters in optical communication systems have made the systems more complex and expensive for wavelength division multiplexed (WDM) in light wave systems [2, 3].

Optical amplifiers, as their name implies, operate solely in the optical domain with no inter-conversion of photons to electrons [4]. The signal is optically amplified in strength by several orders of magnitude without being limited by any electronic bandwidth. The shift from regenerators to amplifiers thus permits a dramatic increase in capacity of the transmission system. Optical amplifiers play an important role in increasing the capacity of optical communication systems using such amplifiers. Optical amplifiers have been essential elements for high capacity, long-lifespan and multiple connection of optical for communication network applications.

ERBIUM DOPED FIBER AMPLIFIER (EDFA)

Optical fiber amplifiers provide in-line amplification of optical signals by effecting stimulated emission of photons by rare earth ions implanted in the core of the optical fiber. Erbium is the preferred rare earth for this purpose though amplifiers using Praseodymium are also in use. The Erbium-Doped Fiber Amplifier was the first optical amplifier widely used in optical communications systems; it has become a key component in many optical networks because it provides efficient, low-noise amplification of light in the optical fiber low-loss telecommunications window near 1550 nm. EDFAs are used to provide amplification in long distance optical communication with fiber loss less than 0.2 dB/ km by providing amplification in the long wavelength window near 1550 nm. The principle of rare earth doped fiber amplifier is the same as that of lasers excepting that such amplifiers do not require a cavity whereas a cavity is required for laser oscillation as shown in Figure 1 below.

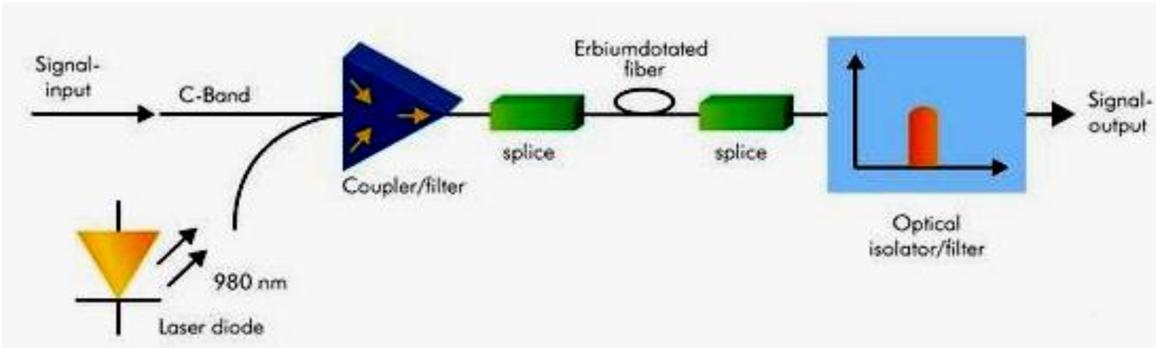


Figure 1: Block diagram of EDFA amplifier

Principle of EDFA:

The rare-earth ions that used in doping of optical fiber are Erbium (Er), Ytterbium (Yb), Thulium (Th), Praseodymium (Pr), and Neodymium (Nd). Each one of these is used at certain wavelength band. Energy levels of Er^{+3} doped system is shown in the figure.

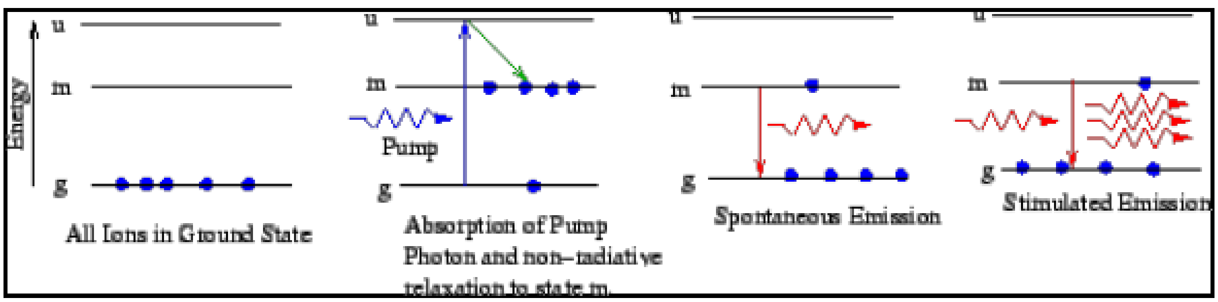


Figure 2: Energy levels and working principle of EDFA

It may be noted that the energy levels form three groups of energy levels marked with their spectroscopic notations. For simplicity, we will model these three groups of energy levels by three sharp levels of energy denoted by ***u, m*** and ***g***, representing the upper, the metastable and the ground states respectively [8, 9].EDFA uses a pump laser (980 or 1480nm) to bring up electrons to a higher energy level, signal amplification is achieved by the emitted photons using stimulated emission.

Amplification Window: EDFA can be used to amplify signal in two bands of wavelengths in the third transmission window. The wavelength range **1525 nm to 1565 nm** is known as the **C-band** or the conventional band and the second band from **1568 nm to 1610 nm** is known as the **L-band** or the long band. The name long band is given because the doped section used for this band is longer. Advantages of EDFA are as follows:

I. It provides in-line amplification of signal without requiring electronics i.e., the signal does not need to be converted to electrical signal before amplification. The amplification is entirely in optical domain.
II. It provides high power transfer efficiency from pump to signal power.
III. The amplification is independent of data rate.
IV. The gain is relatively flat so that they can be cascaded for long distance use. On the debit side, the devices are large, there is gain saturation and there is also presence of amplified spontaneous emission (ASE).

RAMAN AMPLIFIER

Nonlinear effects within optical fiber may also be employed to provide optical amplification. Such amplification can be achieved by using Stimulated Raman Scattering (SRS) [4]. If the intensity of the incident field is below a threshold, spontaneous scattering occurs; this stimulated process can be used for light amplification. If a small signal at Stokes frequency is present along with the pump, the signal gets amplified keeping all the characteristics of the input signal. [4].

They can be operated over a range of telecommunications windows, from below 1300 nm to beyond 1650 nm, often with broader spectra than those of erbium doped fiber amplifier

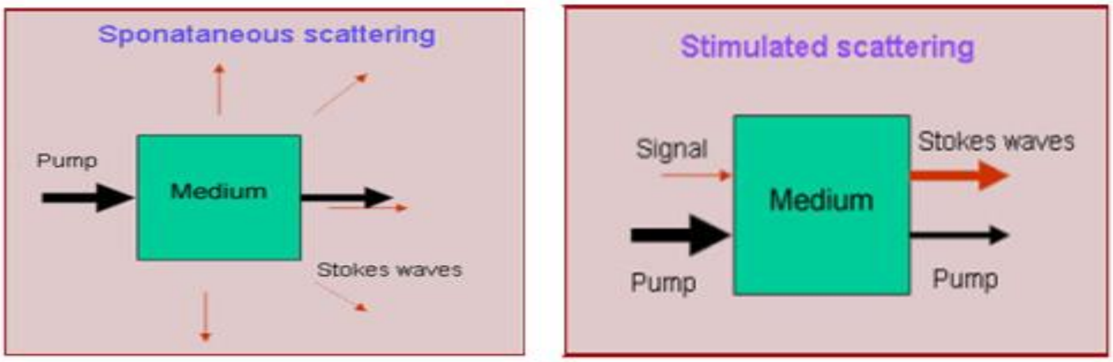


Figure 3: Difference between Spontaneous and Stimulated Scattering

Using Raman amplification the whole transmission bandwidth of the optical fiber can be exploited. (The EDFA) makes use of a very small fraction of the transmission window). In an optical fiber multiple Raman processes can go on simultaneously. That means using multiple pumps, ultra wideband amplifiers can be realized and it is a distributed amplifier as compared to the EDFA or the semiconductor optical amplifier (SOA)[5]

The gain medium can be transmission fiber or dispersion compensating fiber (DCF). DCF-based Raman amplifiers boost the propagating signals and compensate for accumulated chromatic dispersion .Raman amplifiers utilize pumps to impart a transfer of energy from the pumps to the transmission signals through the Raman Effect mechanisms.

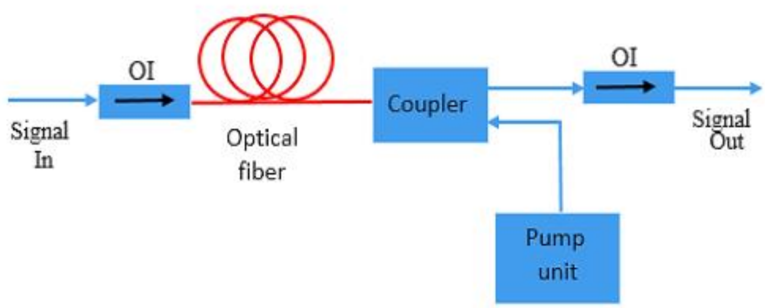


Figure 4: Schematic diagram of Raman Amplifier

The pump signal optical wavelengths in Raman fiber amplifiers are typically 500 cm-1 higher in frequency than the signal to be amplified, and the continuous-wave Raman gains exceeding 20 dB in silica fiber. The basic physical idea behind Raman scattering is an interaction of an incident light wave with intrinsic vibrations of molecules. When a light wave is propagating in the medium, it scatters, creating a phonon through excitation of the molecule vibrations. The maximum length or gain beyond which the Raman amplifiers no longer improve the system performance is determined by the so called double Rayleigh back scattering (DRBS) multi-path interference (MPI) noise.

DESIGN AND SIMULATION OF HYBRID OPTICAL AMPLIFIER

As the gain or the amplification window of an EDFA is quite narrow and although the Raman Amplifier with a single pump gives a bandwidth of about 60nm but the transmission window of an optical fiber is 400nm hence multiple pumping is required in Raman Amplifier. For WDM/ DWDM system the Raman interaction is very complicated. Every wavelength acts as a pump for wavelengths longer than it, and as Stokes wave for a wavelength shorter than it [4]. Hence Due to Raman scattering every channel receives power and every channel loses power. There is systematic flow of power from higher frequency channels to the lower frequency channels. This affects the total performance of the system in the case of a nonlinearity-sensitive transmission system, where due to the limitations on signal amplification caused by nonlinearity, the received optical power penalty plays a great role as it affects the receiver's sensitivity needed for achieving a definite bit error rate (BER).

In this proposed hybrid combinations of EDFA and Raman amplifier have been used to extend the seamless bandwidth to amplifying 32 channels WDM system in L-band region 1560-1600 nm. In general, the combination of more than one optical amplifier in any configuration is called hybrid optical amplifier (HOA). EDFA amplifies the signal but the gain spectrum is not uniform. To reduce the gain variations hybrid combination of EDFA and Raman amplifier is the best choice [5].

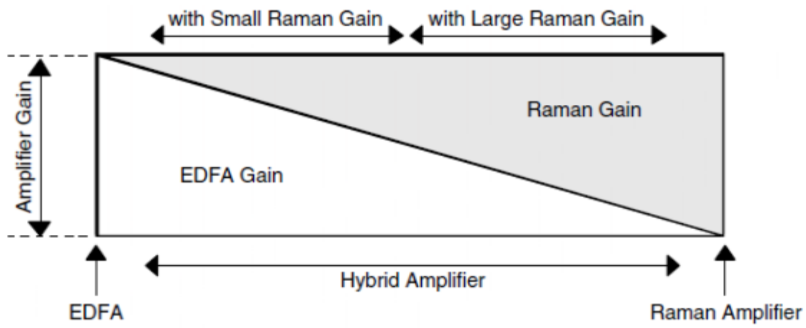


Figure 5: Gain Profile of a Hybrid Amplifier

The specifications of the Raman amplifier and EDFA are given below in the following tables.

Table 1: Parameter specifications of the Raman amplifier and EDFA

EDFA Amplifier		Raman Amplifier	
PARAMETER	**VALUE**	**PARAMETER**	**VALUE**
LENGTH	13.5m	LENGTH	8.05
Core radius	2.2µm	Dispersion	-85ps/nm/km
Doping radius	2.2µm	Dispersion slope	-0.03ps/nm^2/km
Numerical aperture	.24	Attenuation	0.2dB/Km
Concentration	10e^{+24}m^{-3}	Temperature	300k
Pumping power	300mw	Pumping power	300mw
Pumping wavelength	1490nm	Pumping wavelength	1490nm

The two types of amplifiers were pumping in backward at wavelength 1490nm and power 300mw, as shown Figure 6. All the channels are transmitted into the WDM multiplexer with zero insertion loss, here all the light signals are combined and transmitted over the erbium doped fiber of length 13.5m.The erbium doped fiber amplifier is counter pumped at 1480nm.The counter pumping scheme gives more gain than that of co-propagating pumping scheme.

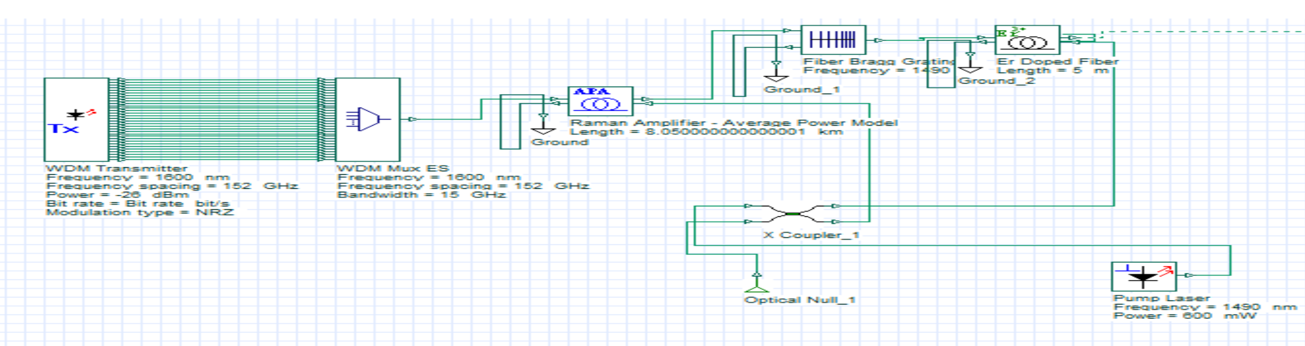


Figure 6: Hybrid amplifier using EDFA and Raman Amplifier for L- band

Here in this hybrid amplifier, Fiber Bragg grating used to eliminating the pump signal of Raman amplifier to enter into EDFA. The dispersion compensating fiber (DCF) acts as the gain medium in Raman amplifier which simultaneously boost the propagating signals and compensate them for accumulated chromatic dispersion during transmission .The simulation values for the dispersion is -85 ps/nm/km and dispersion slope is set at -0.03 ps/nm2/km. the simulation of the hybrid amplifier was carried out using OPTISYSTEM simulator and for further improving gain the flatting technique using Gaussian filter is used between Raman Amplifier and EDFA. As shown in Figure 6.

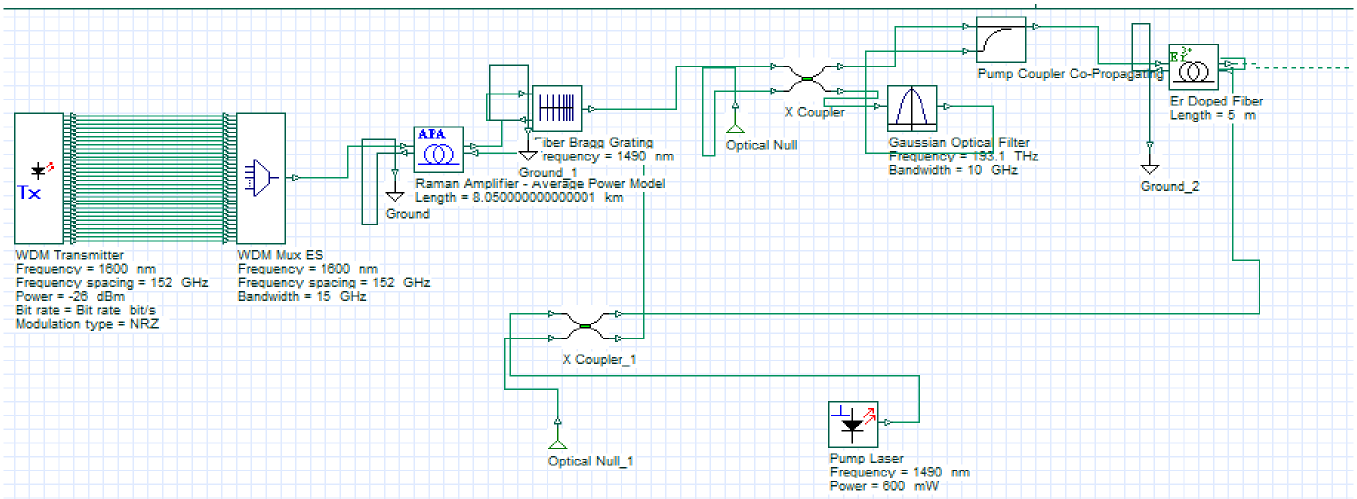


Figure 6: Hybrid amplifier with flatting technique in between the two amplifiers

The purpose of this design is to get optimized gain over different range of frequencies. The signal is divided into two branches by using X-coupler and a Gaussian band pass filter (BPF) is used to flatten a specific region of required frequency band. The second branch connects to the BPF which has center wavelength of 1580 nm with bandwidth 11nm, after the BPF, the coupler used to combine these branches various simulation parameters are given in the table above.

SIMULATION RESULTS AND DISCUSSION

The proposed hybrid design was simulated for an equal pumping power and wavelength for the EDFA and Raman amplifier and the gain variation of EDFA, Raman amplifier, and overall gain as shown in Figure 7. It is found that the gain of HOA is almost flat after the observation. The maximum gain is achieved with the hybrid optical amplifier that means that the combination of EDFA and Raman is responsible to increase the gain.

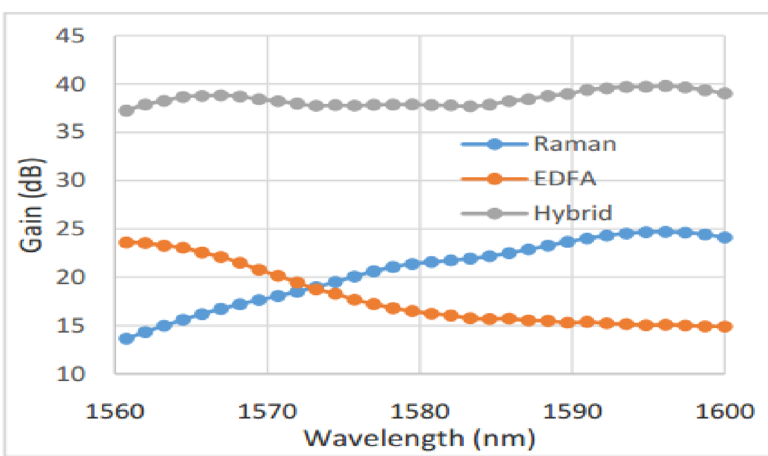
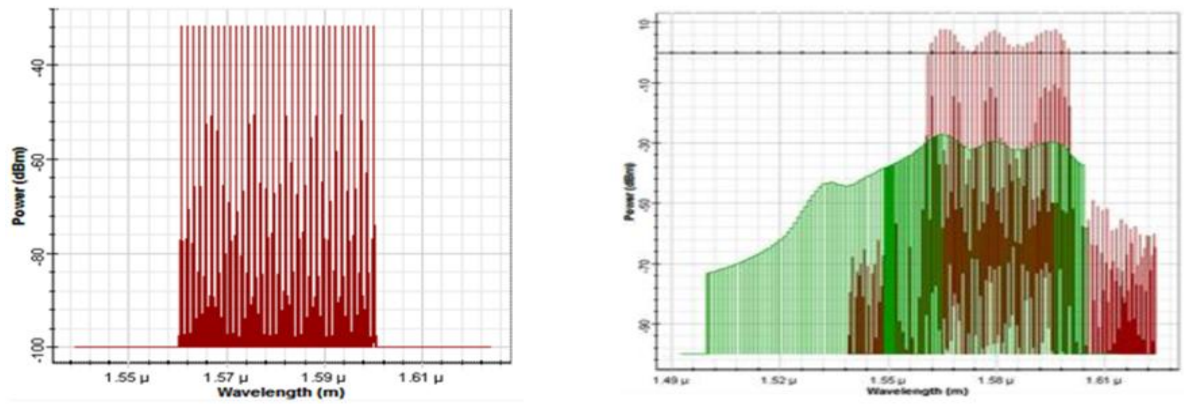


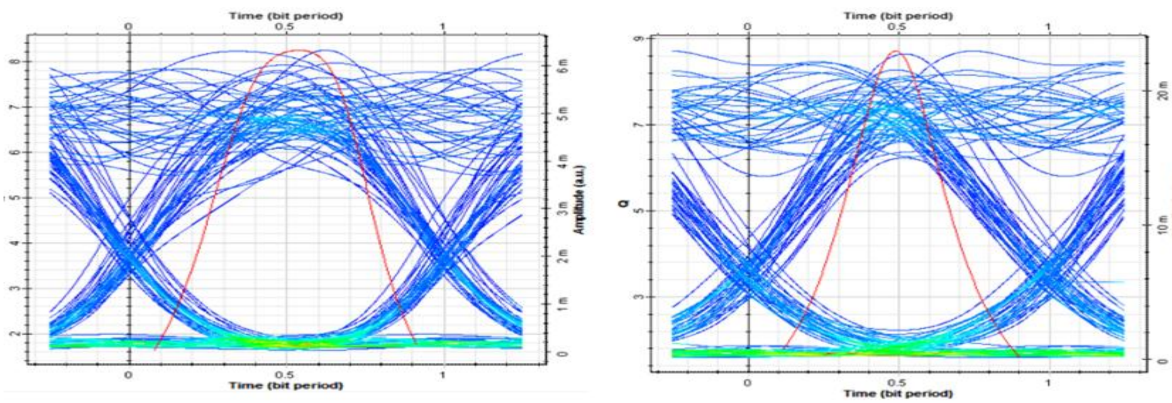
Figure 7: Gain Variation with frequency of Raman amplifier, EDFA and Hybrid

As flatting technique improve the gain and it doesn’t increase the noise of amplifier system as shown in the figure 8. The noise spectrum shown in green color in Figure 8 (b)appear after 1120km from Raman and EDFA optical amplifier.



(a) (b)

Figure 8: Signal power (a) Transmitted signal channel (b) Received signals after 1120km



(a) (b)

Figure 9: Eye diagram after 1120km (a) for the first channel (b) for the eighteenth channel

The above Figure 9 shows the eye diagram after 1120 km for first and eighteenth channel and the corresponding value of BER and Q Factor are given below in Table 2

Table 2: BER and Q Factor values

Parameter	Channel 1	Channel 18
BER	5.98×10^{-17}	1.26×10^{-18}
Q factor	8.24	8.71

CONCLUSIONS

The erbium doped fiber amplifier has very high gain and can be made suitable for optical transmission systems for long haul communications by employing appropriate gain flattening technique. In this work a new design of the hybrid amplifier using Raman amplifier and EDFA is presented. In the hybrid configuration, it is possible to reduce gain variations by optimizing erbium fiber length and using gain flattening technique and provides a high gain .This hybrid optical amplifier design used in the optical communication system for 1120km and provides a good Bit Error Rate. In future the increased number of channels can be transmitted with reduced channel spacing by incorporating different co doping concentration, multiple pumping schemes, with variable pump wavelengths and pump powers to ensure a good performance.

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