Modeling of Wide-Band Optical Signal Amplification in an EDFA Network Using a Tunable Tap

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Abstract—Optical amplification in the C and L band region with wave division multiplexing can provide over 160 channels. The paper provides simulation studies of such a wideband erbium doped fiber amplifier which utilizes a tunable tap at the TLS source end. This isolates and provides two parallel channels for simultaneous amplification in both C and L band. Such a configuration has shown to provide a gain well over 20dB from 1525-1615nm bandwidth with an average noise figure of 10dB (approx.). Gain saturation effects beyond -20dBm/channel signal level and, gain spectra at different pump powers and amplifier lengths have also been studied.

Long haul optical communications today depend on fiber amplifiers such as erbium doped fiber amplifiers operating in the wide band region consisting of a conventional band (C-band, 1525-1565nm) and a long-wavelength band (L-band, 1565-1620nm) [1]. In the 1990s a breakthrough in the L-band communication came when the first measurement of the L-band gain in erbium doped fiber (EDF) was reported by Massicott et al. [2]. It is easier to achieve gain flatness compared to the C-band [3]-[4]. However, the L-band EDFA systems have shown a lower average gain compared to the C-band. This has compelled further research in increasing the L band gain and power conversion efficiency (PCE) values. The C-band seed signal injection [5]-[6] and re-reflection of backward amplified spontaneous emission (ASE) using circulator with fiber reflectors or fiber Bragg gratings [7]-[9] are some of the ways to increase the L band gain.

Increasing optical capacity beyond the C band and expanding it to the L band have led researchers to develop different configurations [10]-[12] and fabricating EDFs with a different host material [13]. In this paper, two parallel stages of EDF from a single tunable laser source (TLS) were drawn using a tunable optical tap with variable tap percentage. A part of the signal power is amplified with an EDF in a bi-directional manner for better noise figure characteristics. And the tapped signal is pumped co-directionally to provide high gain in the L-band regime. The wavelength dependent gain at the outputs can be reduced with the inclusion of gain flattening filters (GFF). For a specific design application; it can be optimized for uniform or full loading for a specific channel. The gain can also show temperature variance [14]-[15] and variance due to spectral hole burning (SHB) [16].

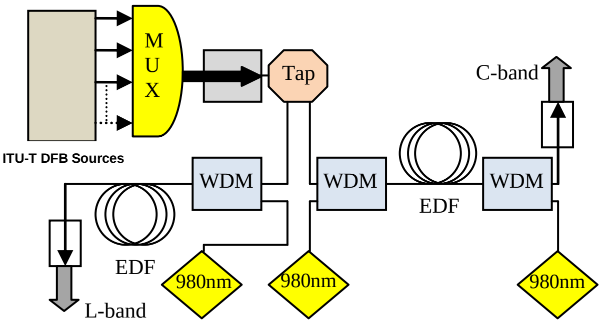

Fig. 1. Schematic of an optical tap based parallel stage EDFA for amplification in an optical wideband.

Figure 1 shows the schematic diagram of the proposed EDFA configuration for simultaneous amplification in the C and L band. An ITU-T source operates with 200GHz channel spacing (operating in accordance with WDM specifications). It has an input isolator which restricts the feedback of an ASE signal in the backward direction; hence preventing the reduction of population inversion. It has an isolation of 20dB, insertion loss of 0.3dB and input and output return loss of 60dB and 55dB. The tap placed at the input end provides two parallel pathways. It has a variable tap percentage, with a constant insertion loss of 0.2dB and input and output return losses of 60dB and 55dB, respectively. The first path, as seen from the figure 1 (for the C band), operates in a bi-directional mode having two 980nm laser pumps. The EDF used for amplification is a single mode polarization maintaining bowtie fiber, which has boron doped stress elements to avoid polarization by inducing birefringence. The specification of the EDF used is given in Table 1. The isolator at the output end restricts the output reflections from re-entering the system.

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TABLE I. SPECIFICATIONS OF THE AMPLIFIERS USED

Parameters	**Erbium Doped Fiber -I** **DHB 1500**[a]
Fiber Diameter	125±1µm
Cut-off Wavelength	860-960nm
Attenuation at 1200nm	≤ 20dB/km
Saturation Parameter	7.3605 x 10^{15}/ms
Parameters	**Erbium Doped Fiber-II** **I-25**[a]
Fiber Diameter	125±1µm
Cut-off Wavelength	870-970nm
Absorption at 980nm	23-27dB/km
Saturation Parameter	1.605 x 10^{16}/ms

a) A product of Fibercore, UK

The other parallel network has a co-directionally pumped EDF with a 980nm laser pump. The specification of the EDF is given in Table 1. The wider shoulder of the gain and absorption spectrum ensures high concentration of Al in the EDF core. The system has been optimized for a 10m EDF length at 120mW pump power at 25°C. The input signal power has been kept constant at -30.0dBm/channel. As seen from Fig. 2, the system provides a high gain (over 20dB) from 1525-1615nm range; however the noise figure decreases gradually. The overall gain tilt over this 90nm high gain region was found to be 16dB.

Figures 3-4 show the gain and noise figure variance respectively, with a different EDF length. The pump power and input signal level were kept constant during the study at 120mW and -30dBm/channel at room temperature, while the fiber length of both EDFs were varied at 5m, 15m and 25m, to obtain different gain and noise spectra.

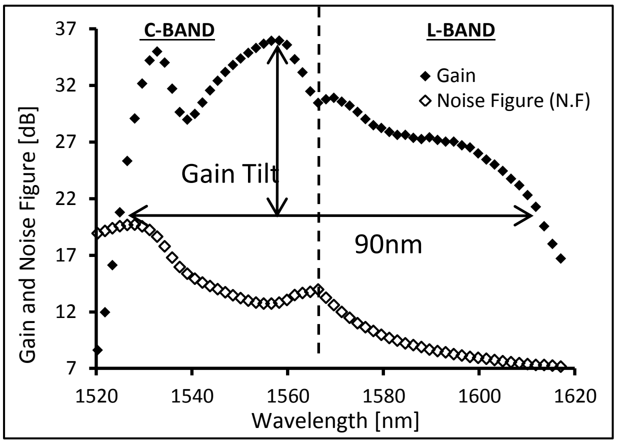

Fig. 2. Gain and noise figure spectrum of EDFA system.

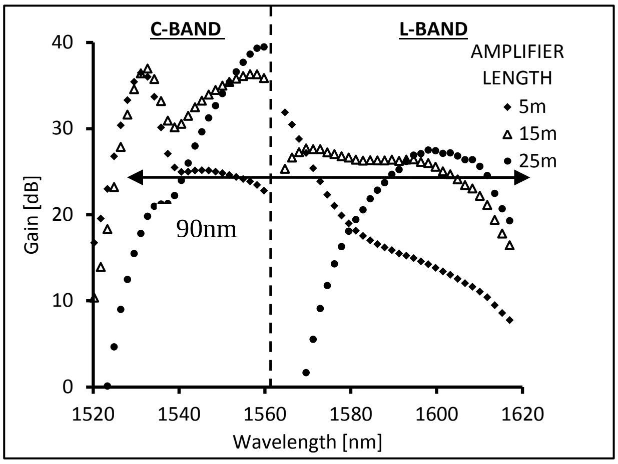

Fig. 3. Gain spectrum of the EDFA obtained for different amplifier lengths at constant signal and pump powers (-30dBm/channel and 120mW) at room temperature.

As seen in Fig. 3, for a 5m amplifier the length gain varies abruptly in the C-band region with gain maxima and minima being at 36.5dB at 1530nm and 26.8dB at 1525nm, respectively, within a 90nm bandwidth. Such high gains can be well flattened using fiber Bragg gratings (FBG) or long period fiber gratings (LPFG) [17, 18]. However, in the L band region the EDFA shows monotonically decreasing gain reaching as low as 7.5dB. Hence at lower amplifier lengths the EDFA has shown an encouraging gain in the C band region while in the L band region its gain minima fall way beyond the accepted value for signal detection at higher wavelengths. Also, for a 25m amplifier length, the C band gain remains well above 20dB, while in the L band region the gain shows a parabolic fall and ceases to exist above 20dB.

Proper optimization of the amplifier length at 15m provided high but non-uniform C band gain spectra and more equalized gain in the L band. The inclusion of a gain equalization filter can provide a more flattened gain in the overall optical wideband. Longer EDFs operating in a co-directional mode with constant pump power may result in complete inversion at the input end of the signal while the other end undergoes partial or no inversion. As a result, the gain falls off while ASE accumulates (spontaneous emission dominates over simulated emission).

Similar studies on the noise figure characteristics (Fig. 4) show a lower noise figure at lower amplifier lengths. This is because of restricted amplified spontaneous emission (ASE) noise accumulation in shorter EDFs. The challenge is to minimize the noise figure in the C band region without effecting the L-band N.F adversely.

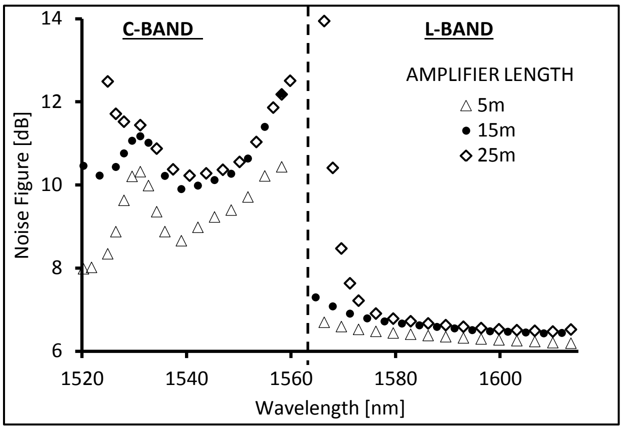

Fig. 4. Noise Figure spectrum of the EDFA for different amplifier lengths at constant signal and pump powers (-30dBm/channel and 120mW) at room temperature.

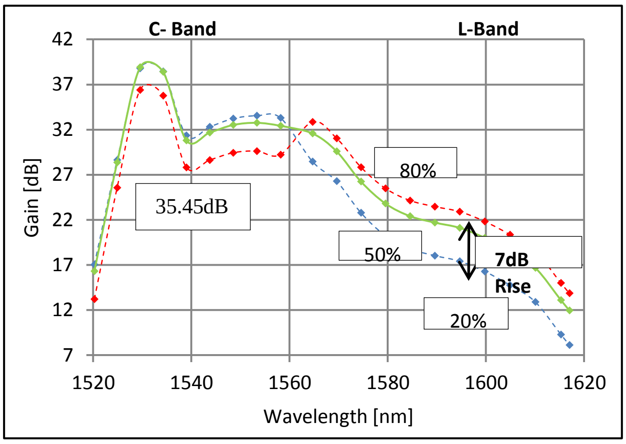

Fig. 5. Gain spectra at different tap percentages at 25^{0}C with 120mW and -30dBm/channel pump and input signal level.

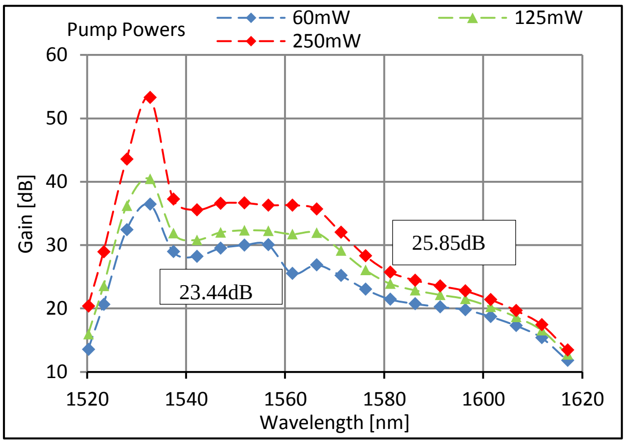

Fig. 6. Gain and Noise figure variation with input signal power at two different wavelengths: 1550nm (C band) and 1610nm (L band).

Figure 5 shows the gain characteristics study of the amplifier operating at different tap percentages of the tunable tap at 25°C. As observed in Fig. 5, increasing the tap percentage raised the signal power in the C-band path compared to its L band counterpart, resulting in the fall of gain in the C band while a rise in the L band gain. On the contrary, lower taping ratios, minimizes the gain in the L band and increases it in the C band. An average rise of 7dB was obtained on a raised percentage from 20% to 80%. As the input signal power increases, the output signal power tends to saturate at constant pump power and considerable amplifier length. In such a situation the inversion is reduced and gain compression occurs.

Figure 6 presents the gain characteristics of the system at different input signal and pump power levels. Constant pump power provides a constant gain until the EDF experiences saturation and no further erbium ion inversion occurs; as a result, spontaneous emission overtakes depleted stimulated emission. At this condition, increasing the pump power can provide a small signal gain and a rise in the inversion level. The fall in the gain becomes prominent beyond -20dBm/channel signal power. However, the noise figure, as expected, remains unaffected.

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