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Design and Performance analysis of Dynamic EDFA

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Abstract: - Design of a real time multichannel dynamic Erbium Doped Fiber Amplifier (EDFA) Simulink model having flat gain and gain clamping ability on a MATLAB platform. The EDFA simulator design is based on one-dimensional nonlinear differential equation. The differential equation describes the time dependent population density. MATLAB function blocks are used to show gain flattening multiplexed channels at different wavelengths. To replicate the noise performance of EDFA that add noise dynamically at signal wavelength novel forward amplified spontaneous emission (ASE) noise blocks are designed. The performance characteristics of an EDFA has been studied in both C- band and L- band. Noise figure for different signal wavelengths are calculated based on the designed ASE generator. The novel design can be realized successfully as a test bed in the study of EDFA gain dynamics over the entire third optical communication bandwidth (1525 to 1690 nm) in signal amplification.

Keywords: - *EDFA- Erbium Doped Fiber Amplifier Simulator, ASE- Amplified Spontaneous Emission, WDM- Wavelength Division Multiplexing, Pp -Pump power.*

I. INTRODUCTION

Of all the existing methods of loss compensation mechanisms in fiber optic communication systems, optical amplification, especially using erbium doped fiber amplifiers (EDFAs), based on silica fibers is dominating the third optical communication window. Several models have been developed to predict performance characteristics of such photonic amplification devices under steady state [1]. Erbium doped fiber amplifier (EDFA) is an imperative element in DWDM networks. This all-optical amplifier enables simultaneous amplification of multiple wavelengths in regard of electronic regeneration, direct optical amplification using erbium-doped fiber amplifiers offers many advantages for long haul repeated transmission. The static models are used to explain the EDFA characteristics for long haul systems where a steady data stream is managed.

In such cases, the propagation of pump and wavelength division multiplexing (WDM) signals is represented by steady state coupled equations[1] But static model is not useful in situations such as non-periodic input power change due to channel add/drop, net- work reconfiguration, fiber cuts, or packetized traffic such as internet data lead to dynamic change in the EDFA gain versus wavelength profile[8] Standard EDFA models, which are typically static, are not well suited to investigating gain modulation, which is a dynamic effect. So we must use dynamic models. EDFAs with high output powers for a multiple channel optical network are strongly saturated and the resulting effective time constant is reduced to the order of tens of microseconds, which is thousands of times shorter than its lifetime[9]. This time dependent problem is especially important in optical networks where the optical channels are constantly reconfigured. During multichannel amplifications dynamic modeling can predict EDFA gain more accurately. Due to the development towards reconfigurable, mesh optical networks, EDFAs used in optical communication networks need to be studied in a dynamic context. It is useful to understand and explain transient and dynamic phenomena, and was previously observed in simulation and experiment on EDFAs. Models have been developed to predict performance characteristics of EDFAs under dynamic state [10].

Based on the conclusion that the real time simulation technique can provide good time synchronization between the simulator and its physical counterpart, EDFAs can play a better role in fast evolving areas of communication system development. A real time dynamic multichannel EDFA simulator based on the Bononi and Rusch approach for the mathematical modeling of a dynamic EDFA has been designed on a MATLAB platform and performance characteristics of an EDFA were analyzed by simulation.

II. EDFA

The invention of the EDFA was one of the major events in the history of optical communications. The active medium in an optical fiber amplifier consist of 10-30 m length of optical fiber, that has been lightly doped (1000 ppm) with a rare earth elements such as Er3+ (Erbium); Thulium; Yr3+ (ytterbium);Praseodymium. The host fiber material can be standard silica. The operating region of these devices depends on the host material and the doping elements.

The operation of EDFA is limited to 1530 nm- 1560 nm and we operate in 1550 nm therefore EDFA is most commonly used optical amplifier.

Some salient features of EDFA are:

1. Transparent to bit rates and transmission formats.
2. Simultaneous amplification of wide spectrum of channel wavelengths.
3. Gain insensitive to polarization as active dipoles are randomly oriented in the glass matrix.
4. Gain stability to temperature range of 100°c due to homogeneous line broadening.
5. Immune to interference between light channels due to a relatively long upper level life time (10 ms).
6. Noise figure as low as 3 dB.

The amplification mechanism is the key for developing EDFA simulation models. Amplifier properties such as the operating wavelength and the gain bandwidth are determined by the dopents rather than by silica fiber, or host medium. The optical amplification gain is supplied by the excited erbium ions when the amplifier is pumped to achieve population inversion. The gain spectrum depends on the pumping scheme as well as on the presence of other dopents, such as Germania and alumina, within the fiber core. Erbium-doped fiber is usually pumped by semiconductor lasers at 980 nm or 1480 nm. A three- level model can be used for 980 nm pumps, while a two level model usually suffices for 1480-nm pumps. Complete inversion can be achieved with 980-nm pumping but not with 1480-nm pumping. The quantum efficiency is higher with 1480-nm pumps. The spontaneous lifetime of the metastable energy level (4I13/2) is about 10 ms, which is much slower than the signal bit rates of practical interest. As a result of slow dynamics, intersymobol distortion and interchannel crosstalk are negligible it is key advantage of EDFAs.

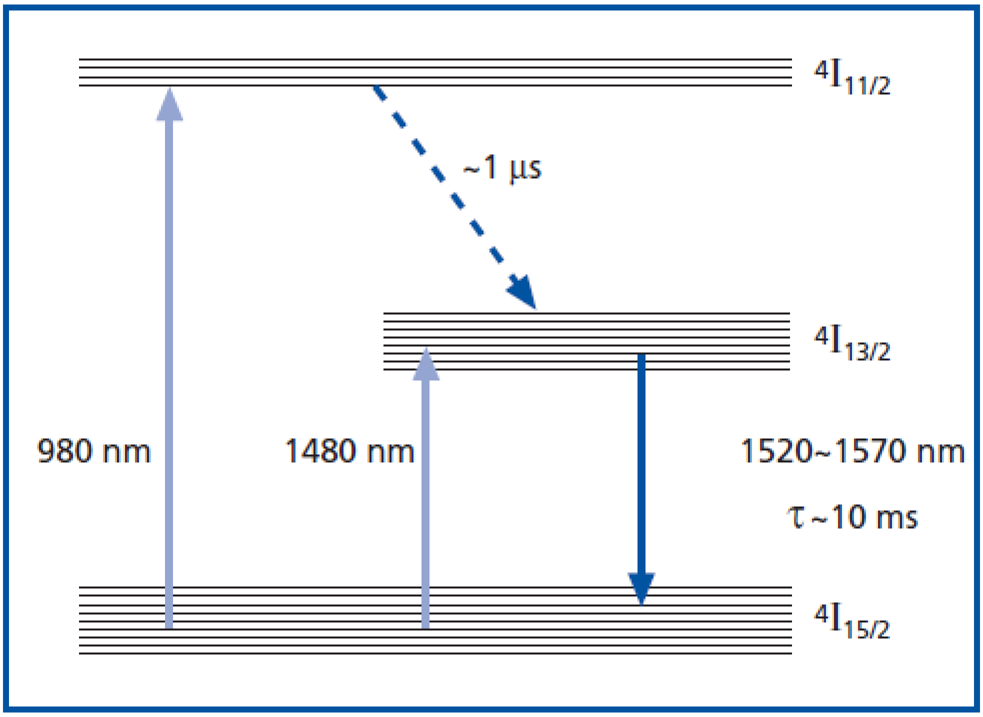


Fig.1 Erbium ion energy level diagram and corresponding spontaneous lifetime.

To study which modulation format is effective in real time system. A novel real time dynamic EDFA simulator for multichannel amplification in WDM optical network is being proposed. The design is based on Bononi & Rusch approach for modeling of multichannel EDFA in its dynamic state.

The simulator which is proposed to be designed for the study of multichannel amplification has advantage over the previously designed simulator in terms of:

1. flat gain in both C-band and L-band
2. less Computation time
3. High sensitivity to signal and pump power variation
4. The designed simulator will provide protection against the power imbalance at the input of photo detector at receiver side provided by gain clamping.
5. Dynamic modeling will give accurate EDFA gain during multichannel amplification.

BLOCK DIAGRAM

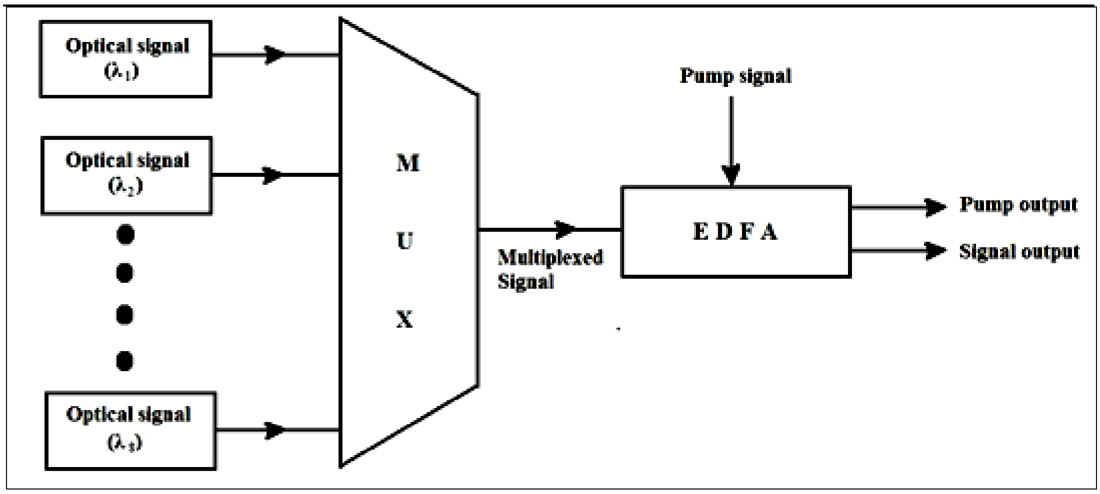


Fig. 2 :Block diagram representation of the WDM system using EDFA as a power amplifier

By using MATLAB simulink simulation tool for study of EDFA dynamics. Because the simulator provides toolboxes & blocksets adequately for setting up any complicated system configuration under test.

Real time dynamic EDFA simulator has been designed using MATLAB Simulink tools and few specific block sets such as :

Digital signal processing block set

Simulink sink

Simulink source,

Simulink communication block set and

Simulink user function block set.

A Real time EDFA simulator based on equation (1) consists of following segments with each Segment having different sub-sections as described below:

$$\frac{\partial N_2}{\partial t} = \sum_{\lambda_0}^{\lambda_n} P_s(0,t)(1-\exp[G_S]) + P_p(0,t)(1-\exp[G_P]) - (N_2/\tau) - \gamma_p P_p - \sum_{\lambda_0}^{\lambda_n} \gamma_s P_s \quad \ldots\ldots(1)$$

Where, Ps, Pp- Signal and Pump Power respectively

N2-Population Density of erbium ion in its excited states

Bs & Cs-Multiple signal wavelengths

τ-Rate of Spontaneous Emission

A rigorous EDFA model must include the spectral dependence of emission and absorption, a variation of the pump and signal powers with fiber length, the transverse form of the signal and pump modes as well as a dopant profile. Constant blocks involved in this segment, to falicitate direct

Observation of Gs by the simulator’s display by following the below equations

$$Gp = \left[\frac{\Gamma p(\sigma_{1-3} + \sigma_{3-1})}{A}\right] N_2 - \Gamma p \sigma_{1-3} \rho L \ \ldots.(2)$$

$$Gs = \left[\frac{\Gamma s(\sigma_{1-2} + \sigma_{2-1})}{A}\right] N_2 - \Gamma s \sigma_{1-2} \rho L \ \ldots.(3)$$

Where N2 is the ion population in metastable state

P-Erbium ion density

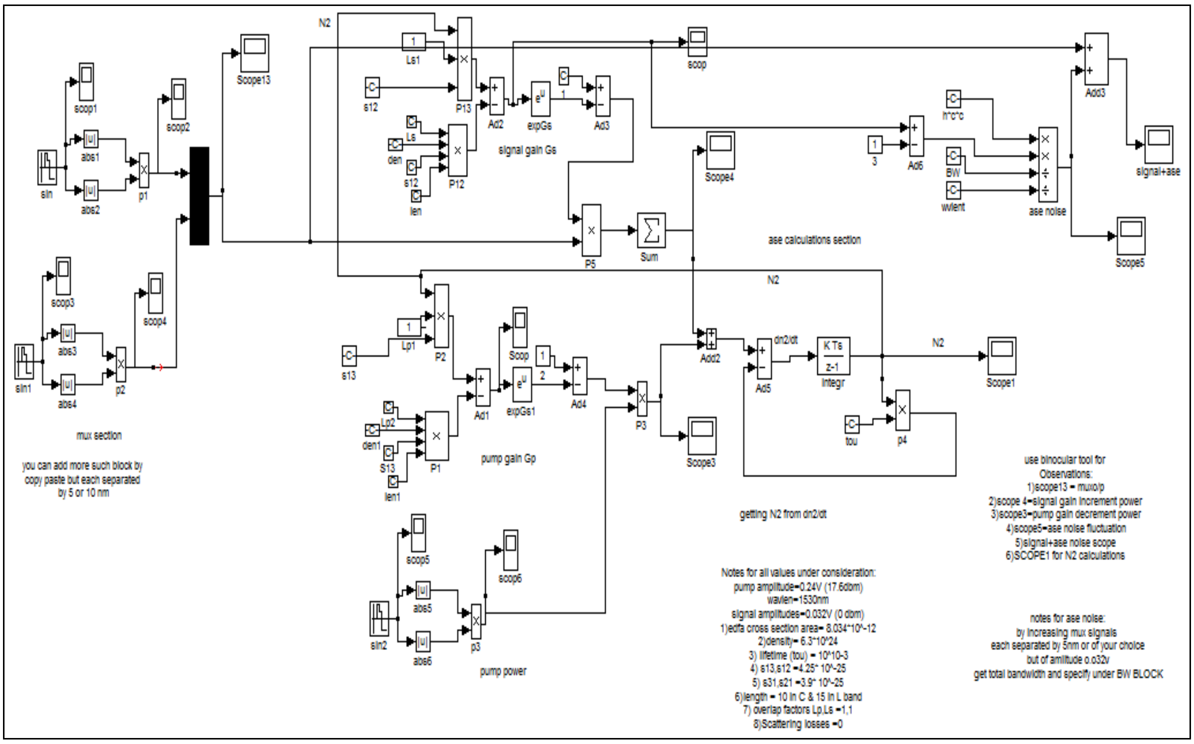
L-Fiber length

Γs and Γp overlap factors for the signal and pump respectively.

σ1-2 and σ2-1 are the absorption and emission factors

σ1-3 and σ3-1 correspond to pump wavelength

1. IMPLEMENTATION OF PROPOSED SYSTEM:



mux section

you can add more such block by
copy paste but each separated
by 5 or 10 nm

getting N2 from dn2/dt

Notes for all values under consideration:
pump amplitude=0.24V (17.6dbm)
wavlen=1530nm
signal amplitudes=0.032V (0 dbm)
1)edfa cross section area= 8.034*10^-12
2)density= 6.3*10^24
3) lifetime (tou) = 10^10-3
4) s13,s12 =4.25* 10^-25
5) s31,s21 =3.9* 10^-25
6)length = 10 in C & 15 in L band
7) overlap factors Lp,Ls =1,1
8)Scattering losses =0

use binocular tool for
Observations:
1)scope13 = muxo/p
2)scope 4=signal gain increment power
3)scope3=pump gain decrement power
4)scope5=ase noise fluctuation
5)signal+ase noise scope
6)SCOPE1 for N2 calculations

notes for ase noise:
by increasing mux signals
each separated by 5nm or of your choice
but of amlitude o.o32v
get total bandwidth and specify under BW BLOCK

Fig. 3:Real time Dynamic EDFA Simulator Model

III. RESULT & CONCLUSION

PUMP SEGMENT:

It is used in forward pumping configuration of an EDFA. Output of this segment may provide forward pumping power at 980/1480nm. In the design of present segment, sinusoidal signal source at 980/1480 nm has been employed as a pump laser source. Pair of the absolute blocks in combination with the block Product (0) is showing here the intensity of the pump signal i.e. equivalent to the square of amplitude of the sinusoidal source. Pumping signal may provide the required biasing to activate an EDFA in its amplification process by the population inversion of erbium ions in erbium doped fiber.

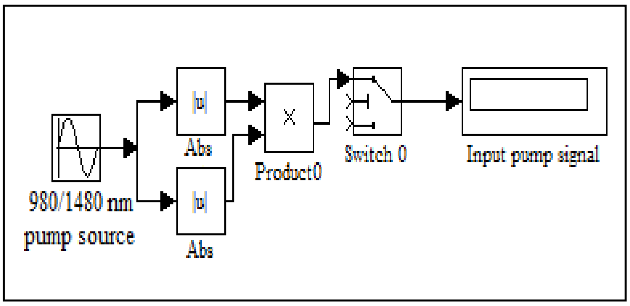


Fig 3.1 Pump Segment

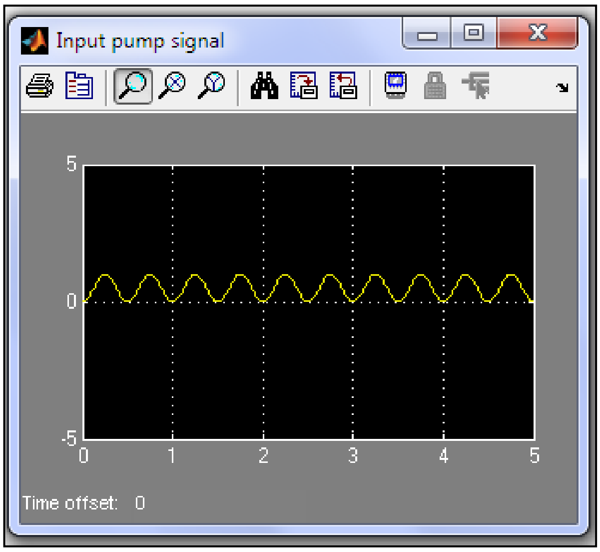


Fig 3.1.1 Output of Pump Segment

Multiplexed Signal Power in C- or L- band:

Part of the simulator, shown in Fig.2 is used in multiplexed signal power generation configuration. Output of this segment may provide multiplexed form of optical signal power of those optical signals, used in the input channels (both in C- and L- band) of present WDM network for their power amplification. Switches; facilitate add/drop channel operation to generate the channel reconfiguration situation in a WDM optical network. Signal input displayer; displays the multiplexed signal powers at their individual wavelengths.

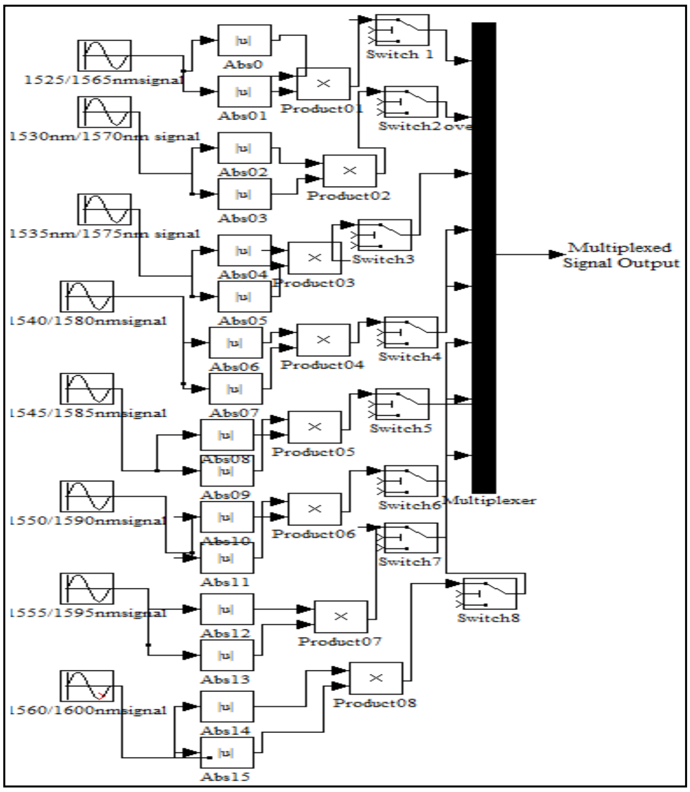


Fig.3.2 Multiplexed signal power in C-L band

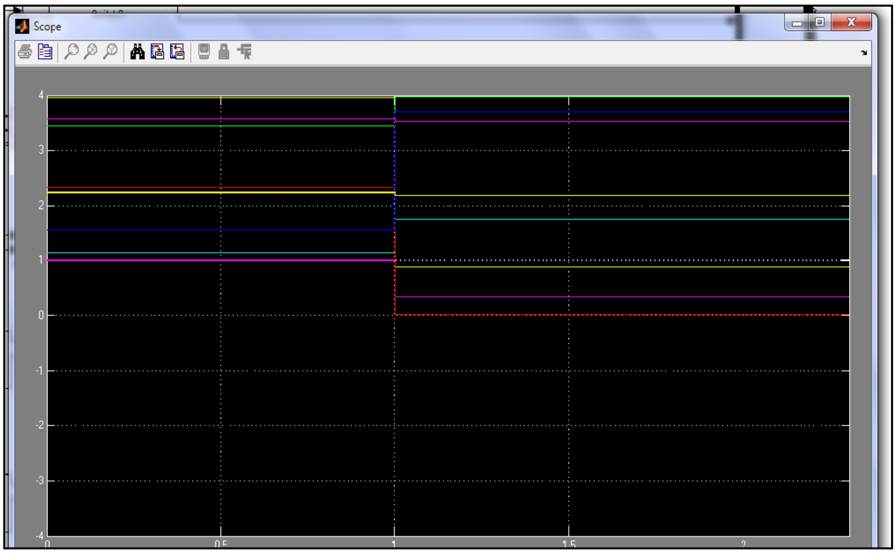


Fig.3.2.1 Multiplexed form of optical signal power in C-L band

Gain Segment:
Generates signal gain parameter responsible for optical power amplification by an EDFA in C-L band.

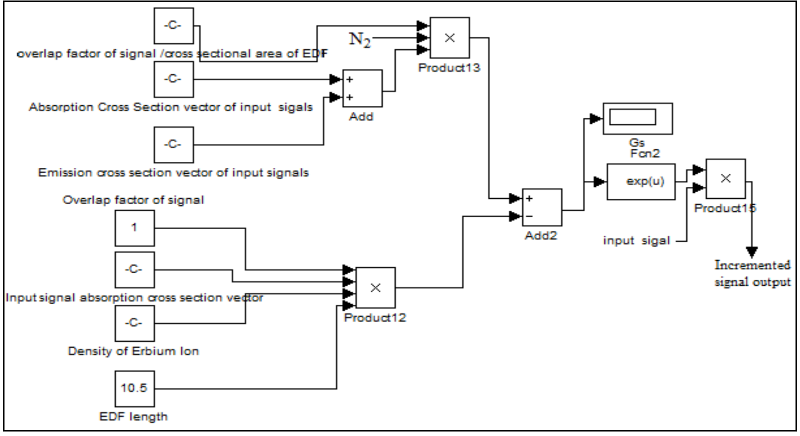


Fig. 3.3: Part of the simulator showing signal gain segment and incremented signal output

Attenuation Segment:
Generates pump power attenuation parameter that is responsible for pump power absorption in population inversion of EDFA. Attenuation segment designed to reduce power imbalance at photo detector or receiver, input to improve sensitivity of designed simulator pump and signal power variation.

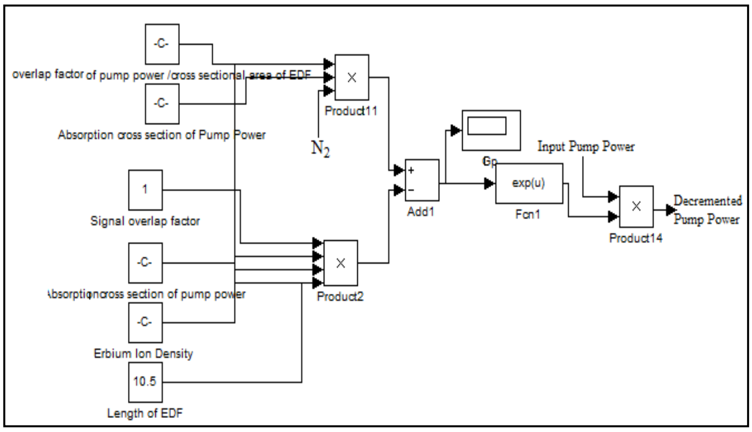


Fig. 3.4: Part of the simulator showing pump power attenuation segment and decremented pump power output

Gain Clamping Segment:

Gain clamping segment accounts for gain clamping by controlling number of photons in metastable state whose rate of change is responsible for signal amplification. It monitors signal power of EDFA and adjust pump power so that output always remains at the same level. Almost uniform flat gain over a wide range of input signal power variation is achieved by employing the present simulator in its signal amplification.

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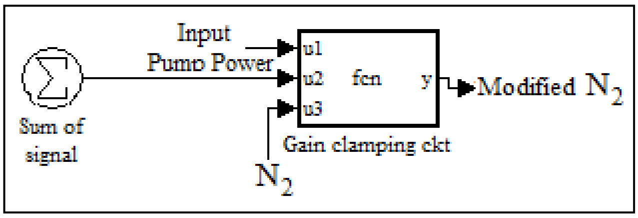

Fig. 3.5: Part of the simulator showing gain clamping segment

Amplified Spontaneous Emission (ASE) Noise Power generating segment:

Part of the simulator shown in fig. accounts for generating the amplified spontaneous emissionn (ASE) noise power by applying the simulators multiplexed gain at a wavelength and its corrosponding spontaneous emission factor in the mathematical relation for ASE noise power,

$$P_{ASE} = h\vartheta n_{sp}[G(\vartheta) - 1]\Delta\vartheta_{opt}$$

Developed within the MATLAB embedded function block shown in figure output signal power, including ASE noise power, may be taken in the present simulator from the output of the block Add6. The simulaor shown in fig. has embedded function block fcn, with four inputs (u1,u2,u3,u4) and a single output (y). Here u1 corrosponds to the desired signal wavelength for

Which ASE noise power has to be observed and is shown by the wavelength block; defines the incremental signal power of the concerned signal wavelengh taken from the EDFA simulators demultiplexer output for the multiplexed signal amplification in EDFA.

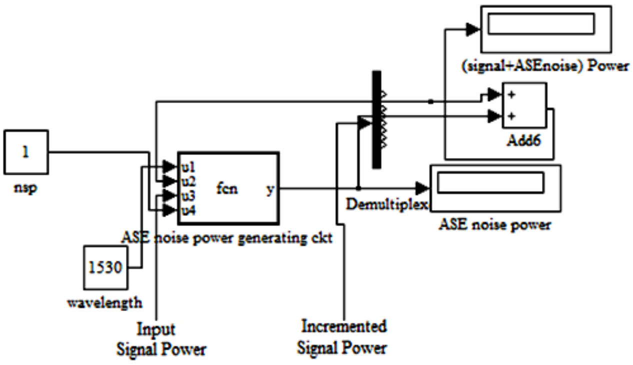

Fig. 3.6: Part of the simulator showing ASE noise power generating segment

All the output displayers have been put into their block names and output values can be read by running the simulator.

a) EDFA gain displayer: It shows signal gain parameter Gs of the signal power evolution in ascending order of signal wavelength.

b) Signal output displayer: It shows the exponential increment of signal power along the EDFA in ascending order of signal wavelength.

c) EDFA pump attenuation displayer: It shows pump absorption parameter Gp of the pump power evolution.

Spectral variation of multiplexed signal gain parameter (Gs) in C- band with gain clamping and without gain clamping at 17.6 dBm pump power:

Comparison in (Gs) value for both the cases: with gain clamping and without gain clamping has been predicted. To observe the variation in gain with input signal power for a single channel at 1530 nm in C- band

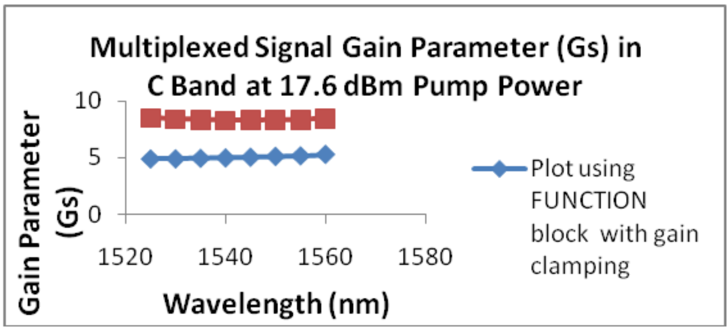

Fig. 4: Spectral variation of multiplexed signal gain parameter (Gs) in C- band with gain clamping and without gain clamping at 17.6 dBm pump power

The dynamic gain at 1530 nm to adding a signal at 1552 nm and dropping of a signal at 1550 nm is shown in figure gains in both the cases are measured when they have stabilized. The gain excursion will be much higher at the instant a particular channel is dropped. It can be observed that approximately in 1s transient gain of the simulator stabilized to a value that corresponds to gain enhancement of about 2.6 dB. It can also be observed that when channel at 1550 nm is dropped rise in gain difference is around 0.026 dB where as by channel addition at 1552 nm fall in gain is around 0.017 dB. In the present chapter EDFA dynamic gain at different observations has been considered under stabilized condition.

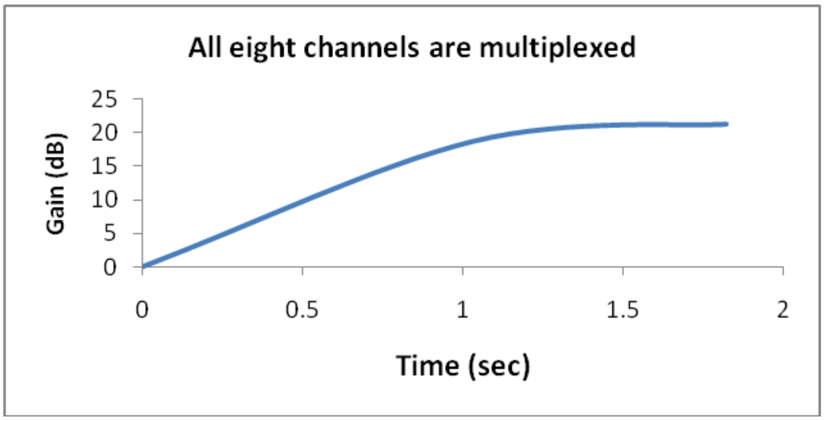

Fig. 5 (a): Time response of dynamic gain at 1530 nm in C- band

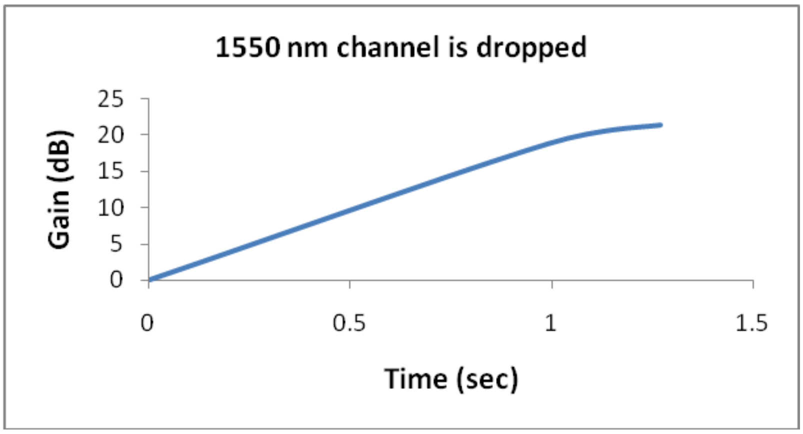

Fig. 5 (b): Time response of dynamic gain at 1530 nm when 1550 nm channel is dropped from its original multiplexed form of eight channels in C- band

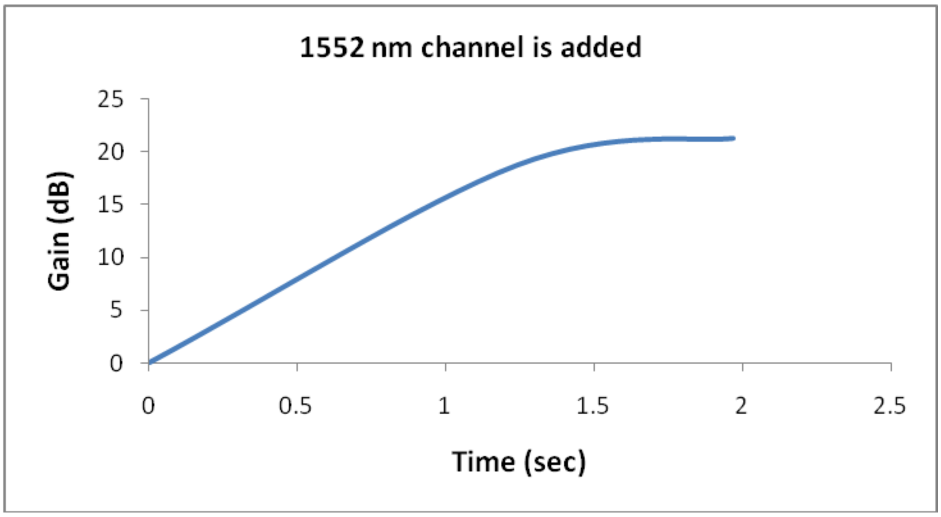

Fig. 5 (c): Time response of dynamic gain at 1530 nm when 1552 nm channel is added to its original multiplexed form of eight channels in C- band

simulator has been implemented to investigate as well as quantify the gain excursion of an EDFA due to cross gain saturation during its multichannel amplification, over the C- and L-band spectral regions. Gain excursions properties shown by theEDFA simulator is categorized into two static gain excursion and dynamic gain excursion. The static gain excursion is the difference in gain when individual channels (or wavelengths) are amplified and gain when all the multiplexed channels (or wavelengths) are simultaneously amplified. The dynamic gain excursion is difference in gain for eight multiplexed channels when one of the channels are dropped from their original multiplexed form or a new channel is added to the original multiplexed form of eight channels. Comparing the static and dynamic gain excursions, from predicted results it can be concluded that dynamic gain excursions are less than static gain excursions at all wavelengths. From predicted results it can also be concluded that dynamic gain excursion during channel drop is more than that of gain excursion due to channel add.

IV. DYNAMICAL MODEL

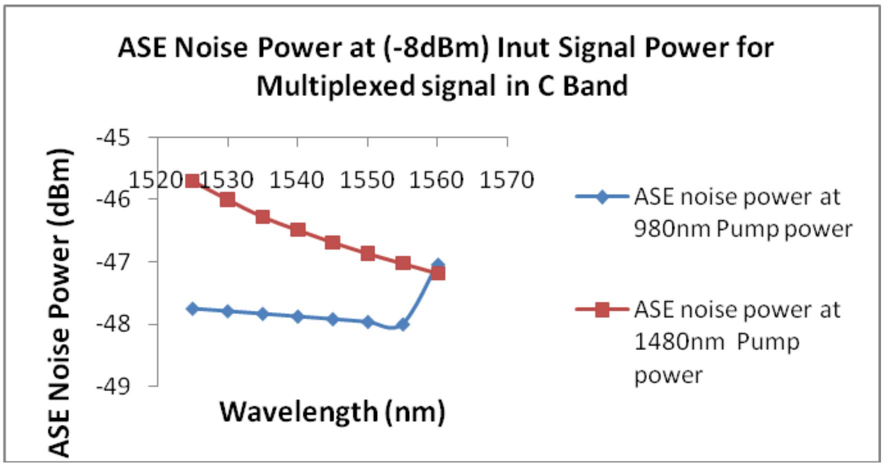

Fig. 6 (a): Spectral variation of ASE noise power (dBm) for multiplexed signals in C- band

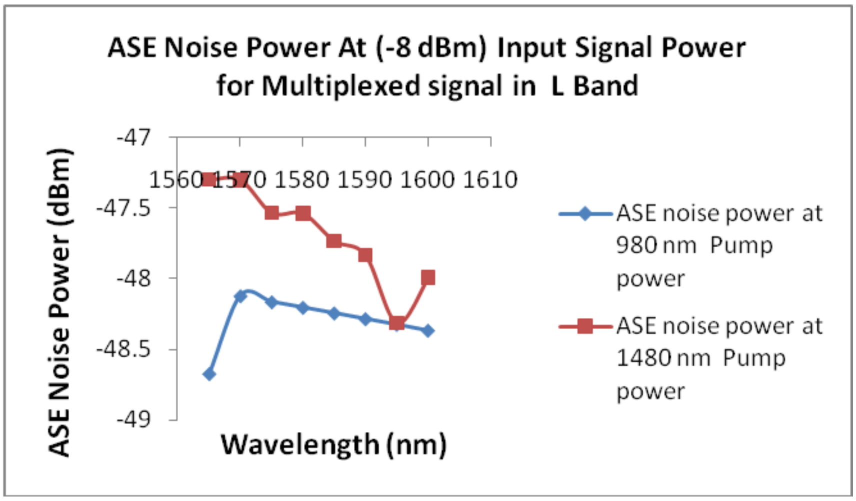

Fig. 6(b) : Spectral Variation of ASE Noise Power (dBm) for multiplexed signal in L- band

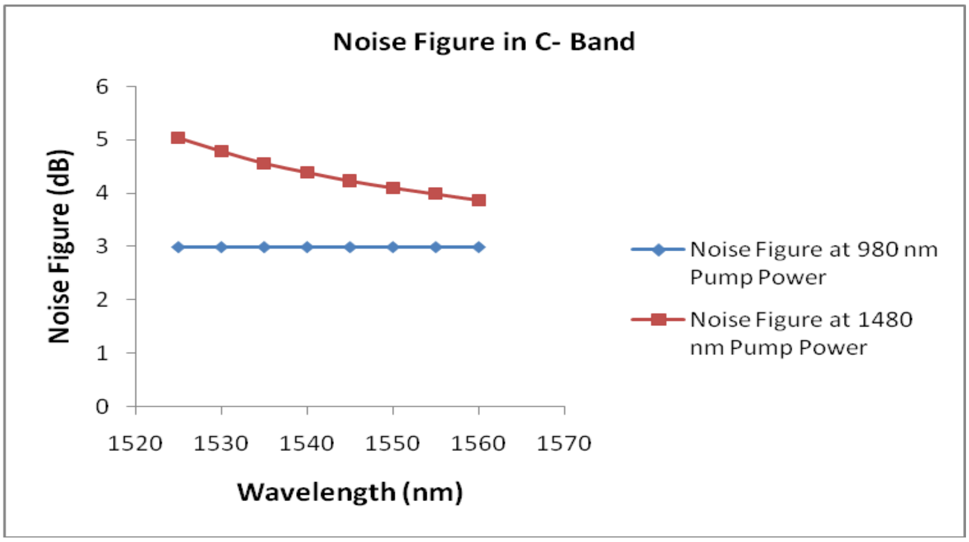

Fig. 6 (c): Spectral variation of Noise Figure in C- band both at 980nm and 1480nm

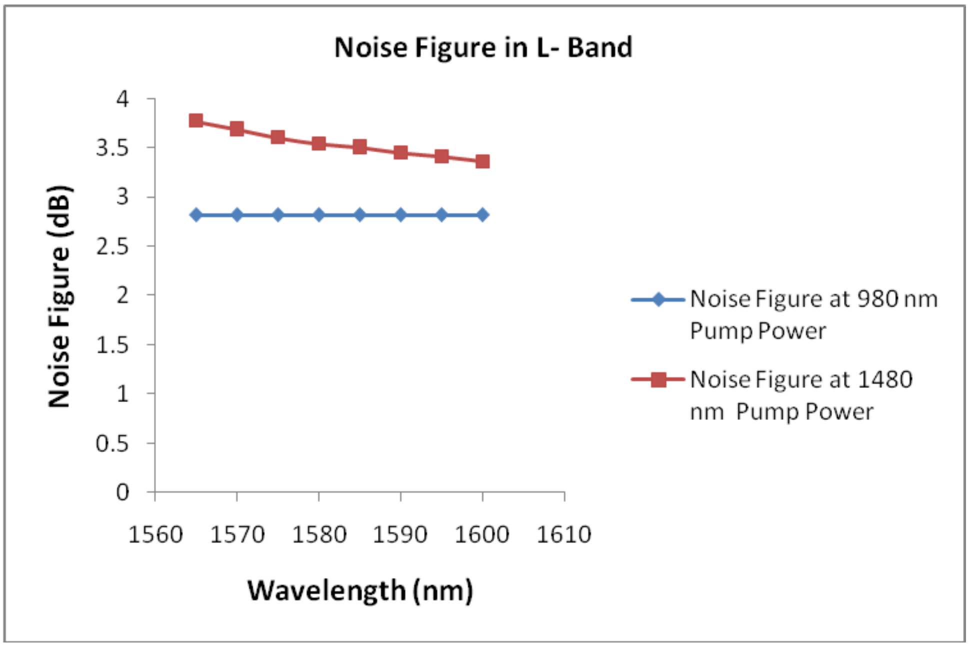

Fig. 6 (d): Spectral variation of Noise Figure in L- band both at 980nm and 1480nm

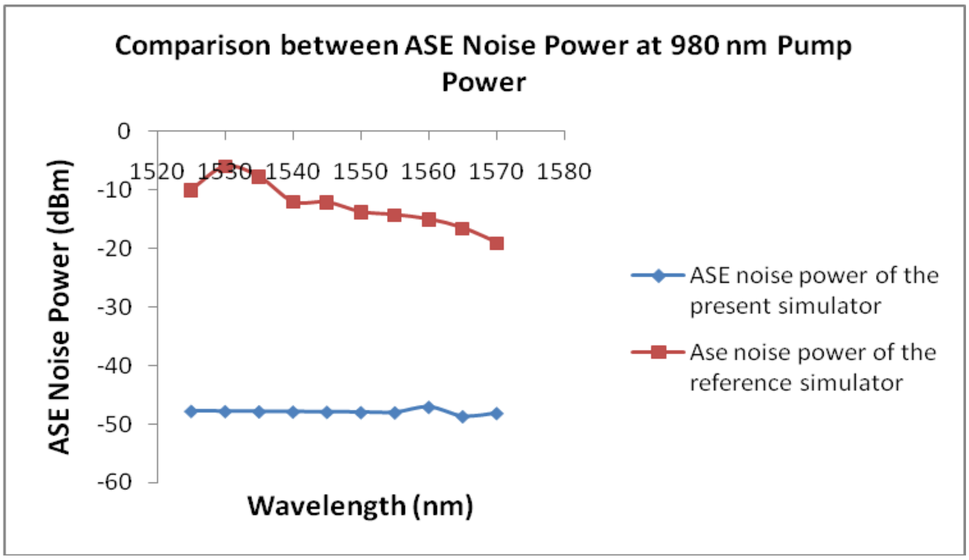

Fig. 6(e): Comparison between spectral variation of ASE noise power predicted by present ASE simulator and predicted by Reference Simulator [Fernando et al., 2004].

V. CONCLUSION

A real time dynamic EDFA simulator for multichannel amplification in WDM optical networks has been proposed. The simulator's design is based on the Banoni and Rusch approach for the mathematical modeling of a multichannel EDFA in its dynamic state. For the analysis of multichannel amplification , the present simulator has a definite advantage over the previously designed real time simulator in terms of flat gain with low ASE noise power in both C and L bands, computation time , high sensitivity to signal and pump power variation and protection against power imbalance at the input of photo detector, or receiver, provided by gain clamping.

VI. ACKNOWLEDGEMENT

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