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ANN based model of automatically gain controlled EDFA in WDM systems

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Erbium Doped Fiber Amplifier (EDFA) has revolutionized the optical communication system as its ability to amplify the signals and enabling the transmission upto thousands of kilometres. With the advent of WDM technology, along with EDFA realized the effective utilization of bandwidth paving the way for several generations of advancement in the communication network. Several automatic gain control techniques are widely used to compensate the gain fluctuations in a WDM channel, arising due to the power fluctuations at the signal, as a flat gain spectrum across the whole usable bandwidth is preferred because of accumulated imbalance likely to happen in different ways. This launching power discrepancy between different channels give rise to imbalance in received power and signal to noise ratio (SNR) and directly affects the system performance. Firstly, the disparity in received power can be outside of the dynamic range of the receiver and then the SNR degradation would cause the BER to fall below the required minimum due to inadequate gain compensation. Therefore, an effective communication system requires optimized gain stabilization techniques along with all other requirements of quality signal reception. In this paper, we attempt to model a feed forward EDFA with automatic gain control (AGC) using artificial neural networks (ANN). Detailed study is carried out and the system is verified with the experimental results in C-Band, and, very promising results could be achieved. In the characteristics, we are mainly trying to quantify the gain and optical noise figure as a performance measure of the system. The flattened gain calculated as the ratio of maximum to minimum signal power at the receiver is 1.16 dB against the allowable range of 3 dB. The ANN model computes with an accuracy of mean square error (MSE) of 3.9717 x 10^{-5}, justifies an accurate forecast with a low computational time in milliseconds range.

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1. Introduction

Optical Communication system involves transmission of signals over long distances and different mechanisms are necessary to compensate the attenuation and dispersion losses. Dispersion shifted and Dispersion compensated fibres are widely used to overcome this spreading of light, called dispersion [1-2] .Likewise, initially optoelectronic devices and later with the advent of technology, various Optical amplifiers are used to minimize the attenuation effect which made the success of optical communication system. The erbium-doped fiber amplifier (EDFA) is the most deployed optical amplifier as its amplification window coincides with the third transmission window of silica-based optical fiber [3].It uses doped optical fiber as a gain medium to amplify an optical signal. The signal which is to be amplified and a pump laser are multiplexed into the doped fiber, and the signal is amplified through interaction with the doping ions. EDFA has a larger gain bandwidth, which is typically tens of nanometres and this helps to amplify data channels with the highest data rates without introducing any effects of gain narrowing. A single EDFA may be used for simultaneously amplifying many data channels at different wavelengths within the gain region. Before such fiber amplifiers were physically available, there was no practical method for amplifying all channels between long fiber spans of a fiber-optic link. One had to split all data channels, detect and amplify them electronically, optically resubmit and again combine them. The introduction of fiber amplifiers thus brought an enormous reduction in the complexity, along with a corresponding increase in reliability. In WDM systems by multiplexing, a stream of wavelength channels particularly in C and L-band regimes can simultaneously amplify to a desired power level where the amplification of any particular channel is dependent on the signal wavelength, the number of signals present in the system, the input signal powers and its absorption and emission cross-sections[4].The gain-flattened Erbium-Doped Fiber Amplifier (EDFA) is thus a key component in long haul multichannel light wave transmission systems such as the Wavelength Division Multiplexing (WDM)[5].

One difficulty in implementing a WDM system including EDFA’s is that the EDFA gain spectrum is wavelength dependent and gain fluctuation can happen due to the signal power fluctuations. So, In a WDM system, the EDFA does not necessary amplify the wavelength of the channels equally. EDFA in a WDM system are often required to have equalized gain spectra in order to achieve uniform output powers and similar Signal Noise Ratios (SNR)[6]. There are several methods in designing a flat spectral gain EDFA such as by controlling the doped fiber length and the pump power [7,8],proper choosing of optical notch filter’s characteristic[9],by using an acousto-optic tunable filter[10], and by employing an in homogeneously broadened gain medium[11].

So, there is always a need for designing the perfect amplifier with high gain and low noise with minimum cost. Modelling of the amplifier to obtain the desired characteristics will help to improve the amplifier performance on fabrication and deployment based on the intrinsic and extrinsic analysis. Here, the study is purely based on to model an EDFA with AGC, focusing towards the flattened spectrum with very low noise figure. Various studies on the performance improvement have already been done by several researchers and lots of enhancements in EDFA technology is observed in the last few decades [12-15]. Here, we are trying to model the automatic gain controlled EDFA characteristics with the help of neural network.

2. Implementation

We have chosen the network as multi-layer feed forward type with the error back–propagation learning type using the neural network (NN) tool box from MATLAB. To give a background, NN facilitates to estimate the relationship between one or several input variables called descriptors and one or several output variables called dependant variables or responses. An example of multilayer perceptron (MLP) is given in Fig. 1, for a model with n descriptors x1, x2, x3, xn and a single response y. The descriptors are presented to the NN at the input layer and then weighted by the connections w'ij between the input and hidden layer. Hidden layer nodes receive simultaneously weighted signals from input nodes and perform two tasks: a summation of the weighted inputs followed by a projection of this sum on a transfer function fh, to produce an activation. In turn, hidden nodes activations are weighted by the connections w"j between the hidden and output layer and forwarded towards the nodes of the output layer. Similarly to hidden nodes, output nodes perform a summation of incoming weighted signals and project the sum on their specific transfer function f0. In Fig. 1 (a), single response y is modelled and the output layer contains only one node. Although NNs can be considered as non-parametric tools, the models that they yield are defined by sets of adjustable parameters determined by an algorithm, not a priori by the user. Adjustable parameters are the weights w'_{ij}, w''_j and biases θ', θ" that act as offset terms by shifting the transfer functions horizontally.

They are determined with an iterative procedure called training or learning. The adjustable parameters are first ascribed initial random values, then training starts and proceeds in two steps.

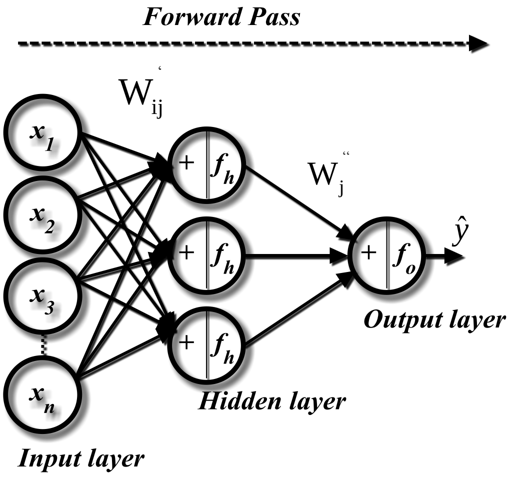

Fig 1(a)

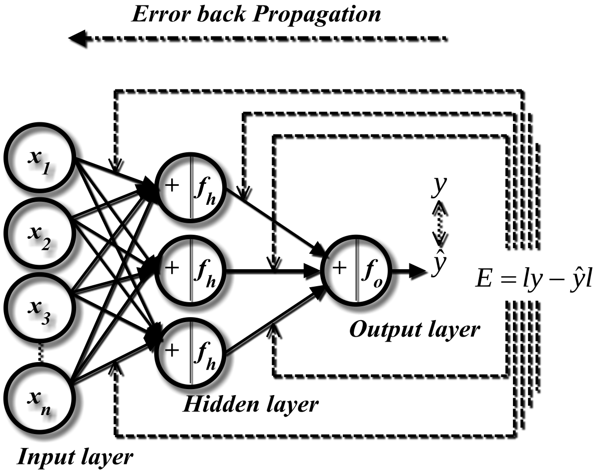

Fig 1(b)

Fig. 1. Feed-Forward NN Training

First, a forward pass [Fig 1(a)] is performed through the NN with a set of training samples with known experimental response y. At the end of the pass, the magnitude of the error between experimental and predicted responses is calculated and used to adjust all weights of the NN, in a back propagation step [Fig 1(b)]. These two steps constitute an iteration or epoch. A new forward pass is then performed with the training samples and the optimised parameters. The whole procedure is repeated until convergence is reached. This means that a pre-specified or acceptably low error level is reached [16]. The WDM signal is amplified with use of EDFA in order to compensate the fiber attenuation loss and to transfer the signal for long distance. As shown in Fig. 2, the EDFA gain is automatically controlled and flattens by ANN. Here, ANN monitors the output gain response and control the EDFA gain by adjusting the Pump Power.

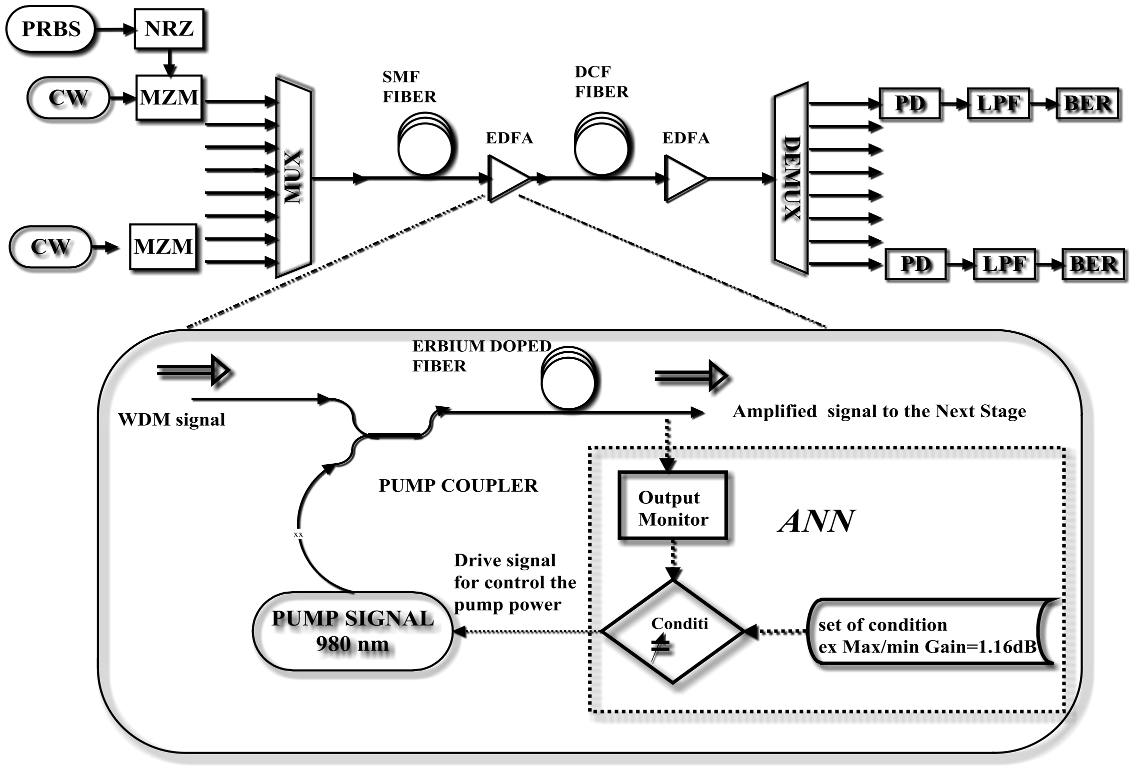

Fig. 2 Proposed WDM communication system with use of ANN controlled EDFA amplification.

Fig. 2 shows the Proposed WDM communication system with use of ANN controlled EDFA amplification. 32*10Gbps NRZ format modulated signals are multiplexed and transferred through single mode fiber. The signals are affected by three factors during the transmission such as attenuation, dispersion and non-linearity. The non-linearity is eliminated by maintaining each channel input power below certain value. Dispersion is nothing but wavelength dependent refractive index and the respective pulse broadening behaviour. This will create Inter symbol Interference (ISI) in the receiver. Attenuation is another impact factor, which will limit the transmitted power in the optical fiber. After a certain distance, the signal couldn't be with the required power level in order to retrieve the original signal. We have to compensate these limitations, what are discussed so far, in order to retrieve the original transmitted signal. As already stated, non-linearity is overcome by maintaining the minimum input power. Attenuation is compensated by introduction of the amplifier in the channel; dispersion is compensated by DCF fiber with negative dispersion next to the single mode fiber. Normally all optical amplifier is preferred compared to O/E/O technique to overcome the problems associated with it. As shown in the Fig. 2, the multiplexed signal is transferred through a single mode fiber over certain distance and then the attenuated signal is amplified by EDFA. The accumulated dispersion of the signal is compensated by DCF, and the attenuation introduced by DCF is compensated by the second EDFA. Finally, attenuation and dispersion compensated signal is recovered at the receiver. As we mentioned, fiber with rare earth doped element such as Erbium, Thallium, Ytterbium used for all optical amplification. Particularly, Erbium doped fiber amplifier is promising one, because it's having the energy band in the currently deployed optical communication C band. Normally, EDFA having unequal gain spectrum over the C band as in figure 3, but it should be flattened in order to preserve the Quality of service for the operated 32 channels.

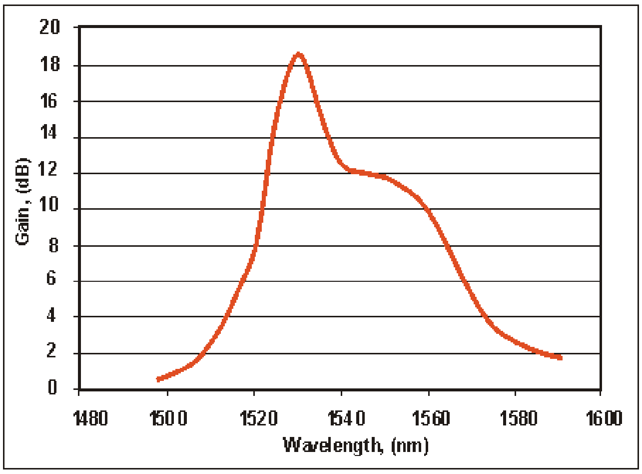

Fig. 3. Normal EDFA Gain Spectrum

It can be achieved by optimizing the fiber parameters, using gain flattening filters and also by controlling the external Pump signal. As shown in figure 2, here, we discuss the gain flattening by controlling the external pump signal with use of an ANN network.

3. Results and discussion

In the present work, we have collected the experimental data and divided them to two interleaved sets. Figure 5 shows the gain performance of the data used for model the network. The experimental set up is such that a flattened spectrum is received by controlling the gain parameters which stabilizes the input frequency variations by adjusting the pump power. The difference between maximum and minimum power received is calculated as ratio of maximum to minimum power, and is less than 1.16 dB, which shows a promising result since any value less than 3 dB can be considered as a flattened gain in optical communication system, based on the sensitivity and dynamic range of the receiver [17]. Dynamic range limits the maximum power which can be fed into the fiber. Along with other nonlinear impairments like cross phase modulation, this also limits the maximum transmission distance, L. If $P_{in\ max}$ is the maximum input power, the transmission distance is L, and P_r is the minimum receiver power; then equation (1) shows the maximum input power that can be sent into the fiber, and equation (2) shows the maximum transmission distance.

$$P_{in\ max}(dB) = \alpha L + P_r\ (dB) \qquad (1)$$

$$L = [P_{in\ max}(dB) - P_r\ (dB)]/\ \alpha \qquad (2)$$

where α is the attenuation constant. So, the suggested model can also be used to predict many desired parameters indirectly [18-19].

A co –propagating pump laser of frequency 980 nm and power 68 mW is used initially for the signal transmission from an NRZ modulated WDM source of 32 channels with frequency spacing of 100 GHz and bandwidth of 30 GHz using EDFA of length 5m. Erbium(Er) metastable life time of the fiber used is 10 ms with a core and Er doping radius of 2.2 µm. To achieve the automatic gain control, a feedback circuit is used to adjust the pump power so that the ratio of Maximum to Minimum power in the system is less than 1.16 dB. The source input power is -17 dbm with an extinction ratio of 10 dB and line width of 10MHz. One data set is fed to the input layer of the network and the second set is used for training the network.

Fig. 4 shows the power output of the data used for training the network for 32 channels of wavelength differ by 100 GHz. Since, the circuit used was gain controlled one; the output power measured at the receiver end would not vary to a great extent. Fig. 5 shows the gain performance for each wavelength and a flattened spectrum is observed. The noise figure response for the trained data also depicted in figure 6. Here, the launching input signal power to the EDFA is maintained at -17dBm, the obtained maximum gain is 20.25dB with gain tilt (ratio max/ min over spectrum) of 1.16 dB.

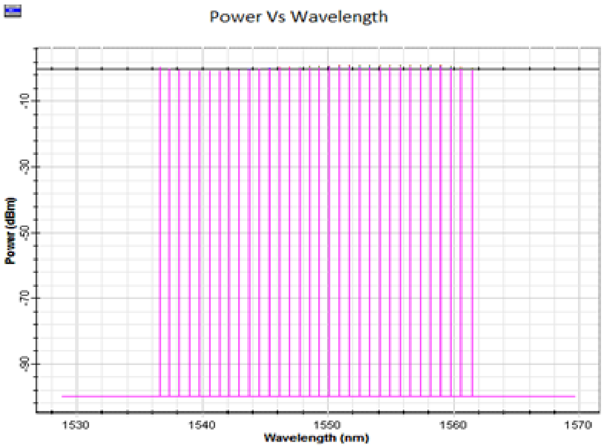

Fig. 4 power data spectrum for ANN Input

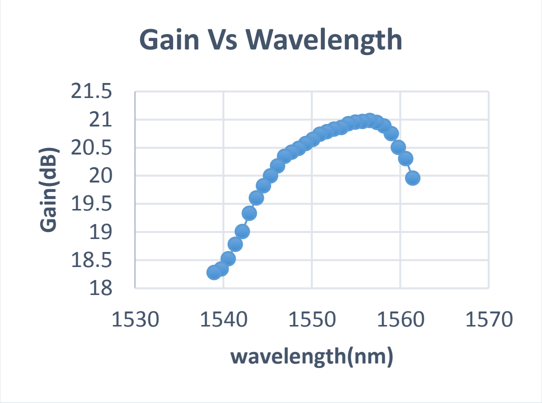

Fig. 5 Gain performance data spectrum for ANN input

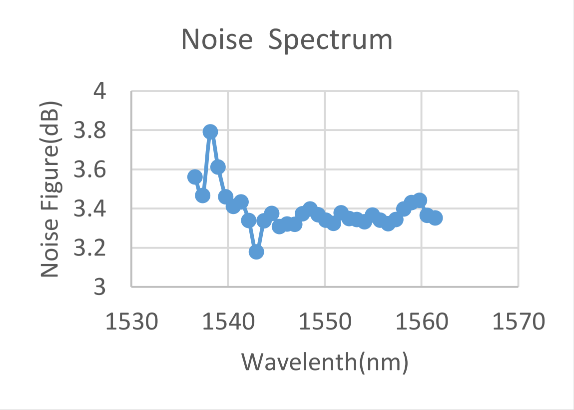

Fig. 6 Noise data spectrum for ANN input

We used 1000 epochs and Levenberg-marquardt (trainlm) training function for the performance of MSE. The network internally used the adaption learning function of LEARNGDM. During the training phase, the overall goal is to assign the most accurate weights to be assigned to the connector lines. Also, during training, the output is computed repeatedly and the result is compared to the preferred output generated by the training data. Any variance is considered as a training error and it is important for this training error to be small as possible so that the forecasted output is reliable. In order to minimize this error, the originally assigned weights are adjusted until the error declines [20]. This weight adjustment is accomplished through the use of algorithm. By adjusting the weights, the error is minimized continuously until a point is reached that represents the least amount of acceptable error. At this point, accurate forecast can be produced. We could achieve the performance of 3.9717 x 10^{-5} mean square error (MSE).

Fig. 7 shows the gain values obtained from experimental results and network simulation. From the figure, it is clear that the modelled EDFA can be used for predicting gain values of similar systems. The performance optimization of constructional parameters were already studied and reported to model the EDFA [21]. In this approach, we have used only the extrinsic values which are directly coupled to the output gain viz. input signal frequency(THz) and power(dBm),Noise figure(dB), input SNR(dB) and input noise(dBm). Gain values are denoted in dB. To estimate the efficiency and performance of the model, the predicted values through simulation against the test data is cross verified experimentally and found in good agreement with the results.

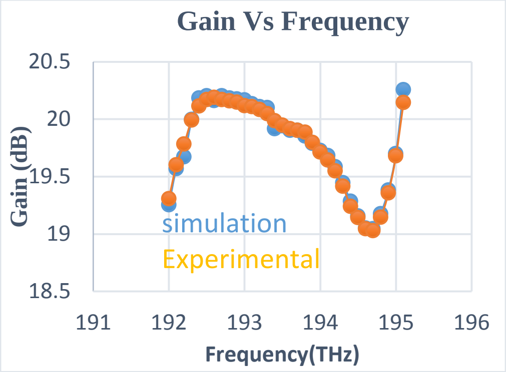

Fig.7 comparison of ANN forecast results with experimental data for EDFA Noise Figure.

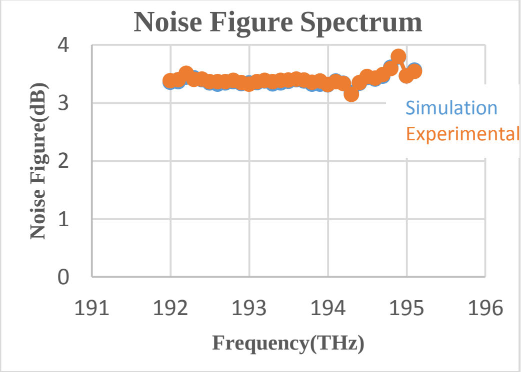

Fig.8 comparison of ANN forecast results with experimental data for EDFA gain performance.

Like gain parameter, optical signal-to-noise ratio is also an important fundamental design tool in the amplifier design. The study of noise in optical systems is adequately complex that it can be characterized with simple engineering formulae. To better understand simply, the optical noise figure, which affects EDFA performance, is a parameter used for quantifying the noise penalty added to a signal due to the insertion of an amplifier. If SNR (0) is the signal to noise ratio before the light enters in an optical amplifier and after amplification it is SNR (Z), [22] then,

$$Optical\ Noise\ Figure,\ NF\ opt = SNR(0)/\ SNR(Z \tag{3}$$

Fig. 8 shows the noise introduced in the system through experimental set up and simulation results. Various studies on noise figure details the affordable value of NF so that the original signal is retrieved. If the noise figure of the amplifier were 1, then the initial signal to noise ratio would be maintained throughout amplification. However, it is shown that, the quantum limit for an optical amplifier [23] is 3dB, therefore the signal to noise ratio after amplification is half (50%) of the original value. For real optical amplifiers, the noise figure can be as high as 6 dB whereby the signal quality is sufficiently deteriorated that the detector's ability to discriminate signal from noise is compromised.

In the current work, we obtained the noise figure in the range of 3.3 to 3.7 dB through the experimental set up and in the range of 3.3 to 3.8 dB through simulation. We have used the same approach as in the case of gain to predict the noise figure of EDFA through modelling.

4. Conclusion

An artificial neural network model of EDFA with AGC is presented. With the prediction values obtained through ANN, for gain and noise figure envisages how NN is a preferred choice for many intelligent networks, for its ability to reproduce the unknown relationships through training the network. The ANN model computes with an accuracy of mean square error (MSE) of 3.9717 x 10-5, justifies an accurate forecast with a low computational time in milliseconds range. It is able to forecast the data patterns which is too complex for the traditional statistical tools. ANN model for AGC based EDFA serves as a promising network model to find out the performance under defined situations. This can be extended to other desirable parameters based on how accurately we train the system with data. The study is carried out to present the modelling and simulation aspects purely and not to increase the performance of the system. To increase the characteristic values, parameters like pump power, EDFA length etc can be varied. But, the circuit is simulated in such a way that flattened spectrum is achieved with automatic gain control. The flattened gain through ANN calculated as 1.21 dB against the experimental value of 1.16 dB.

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