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NEURAL NETWORK BASED DESIGN AND CONTROL OF ACOUSTO-OPTIC FILTER FIBRE-AMPLIFIER MODULE

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ABSTRACT

An Artificial Neural Network (ANN)-controlled acousto-optic-filter fibre-amplifier module is proposed to improve the conventional computer-interfaced computationally heavy algorithm-based techniques.

Keywords: *Neural Network, Erbium doped fiber amplifier, gain flattening, optical filter*

I. INTRODUCTION

Conventional computer-interfaced, computationally heavy algorithm-based techniques for real-time control of the spectra flattening amplifiers often rely on experimental tuning of the acoustic frequencies. Before the deployment of such a module, a more optimal Q-point design of the module parameters such as the RF signal frequencies and powers, and EDFA pump power and length, can be achieved by using artificial neural network (NN) models of the acousto-optic filter and erbium-doped fibre amplifier. More essential for the real-time control of such a module to undo gain fluctuations across the channel spectrum is the adjustment speed of the acoustic frequencies and powers about their pre-set Q-point values. The control speed using computer-interfaced techniques based on emprical control constants for the acoustic-filter and lengthy two-point valued coupled differential equations for the two-stage EDFA structure comes short of what is required for modern optical networks. By using NN model for the module, the adjustment can be achieved at chip speeds of the custom-designed NN electronics without solving any equations and using computers other than monitoring purposes.

In this work, a control scheme using two NN's in a feedback loop is proposed where the first NN (NN1) calculates at chip processing speeds the required filter transmission response by using the measured channel powers at the module input, and the second NN (NN2) calculates the necessary acousto-optic signal frequencies and/or amplitudes to realise this filter response in real time. Our computer simulations of the overall module show that the two NN's are sufficiently trained to give generalization errors of 0.0091, and the rms channel ripple at the module output are reduced by 2-3 dB with respect to the case where no filter is used. The error bottle neck is due to NN2 since NN1 gives excellent approximations to the two-stage EDFA dynamics.

Kim et al. [1] showed that acousto-optic filter can be used for gain flattening by manual tuning of the RF sources, without any dynamic control. Yun et al. [2] later achieved the dynamic control of an acousto-optic filter

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amplifier module by using computer interfacing, albeit with 30 second-long iterations. They however did not explain their control method nor the nature of the algorithms used.

2. MODULE STRUCTURE AND WORKING PRINCIPLE

We consider the module structure consisting of two EDFAs with an acousto-optic filter in between. The transmission response of the filter is pre-designed and continously adjusted so that the output of the second EDFA (EDFA2) is spectrally flat. The channel powers at EDFA2 output and EDFA1 input are assumed to be monitored electronically, and are used by the control circuitry to tune the acoustic signal parameters.

The control circuitry generates the signals to adjust the filter after solving two computationally complex problems: 1) finding which channel power profile should be available at the EDFA2 input to give a flat output at the desired gain level and thus determining the required filter transmission response, and 2) finding which acoustic frequencies and/or amplitudes should be used to realise this filter response. The control circuitry uses two NN blocks in cascade, the first of which (NN1) is predesigned to solve the 1st problem and the second (NN2) to solve the 2nd by using the output of NN1, avoiding the lengthy computations of the EDFA rate equations and filter coupled-mode equations.

NN1 is trained based on the atom and photon rate equations of the two-stage erbium-doped fibre amplifier structure [3]. NN2 is trained based on the coupled mode theory calculations of the acousto-optic filter to determine the filter transmission response [4-5]. Two-layered neural networks are designed with one hidden and one output layers. The training is done to find the best NN structure by changing the number of neurons in the hidden layer. Different learning and training techniques in the literature are utilized [6].

The Q-point design of the module is accomplished by first determining the EDFA and filter parameters necessary to achieve a desired gain and uniformity of a given channel profile, respectively, assuming a flat profile at the module input. The second EDFA is fed by a saturating signal at a non-channel frequency. The initial number and value of the RF frequencies are taken from experimental information and then better values are computed by the full-scale theory.

3. SIMULATION AND RESULTS

The forward pump powers at 980nm for both EDFAs are 100 mW. The EDFA1 and EDFA2 gain-optimized lengths are computed to be 4.9m ve 6.3m, respectively, to give an output power of 0 dBm/channel. The input profile is assumed to have 8 channels each with –11.4dBm power.

Figure 1 shows three filter response curves computed based on: A) the full-scale theory, B) and C) the parameters generated by NN1 and NN2, respectively. NN1 performs so accurately that if it were possible to implement the filter based on its ouput, the filter would fit almost exactly to A which is the required profile for flat output. The profile C generated by NN2 has a root mean-squared error of 1.1 dB with respect to A. Since NN2 computes the acoustic signal parameters to physically implement the filter, its performance limits the overall accuracy.

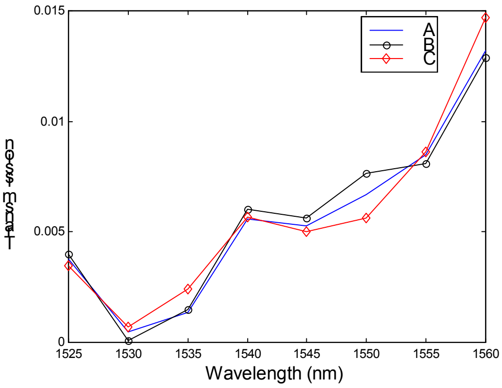

Figure 1 The filter transmission response curves

Figure 2 shows the output profile when the filter is: A) not used at all, B) implemented according to NN2 output.

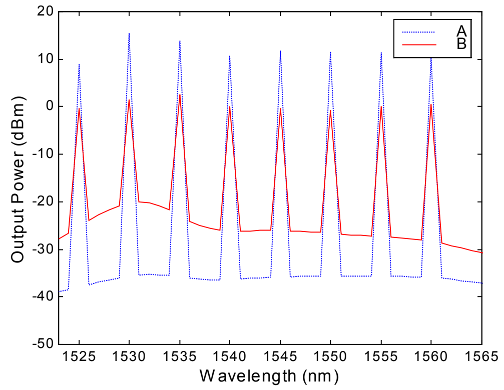

Figure 2. Output profile with and without the filter

As a measure of channel uniformity we define the root mean-squared ripple as $D = \sqrt{\ [\sum(x_k - x_{avg})^2\ ]\ /N}$ where N is the number of channels, x_k is the power of the kth channel, and x_{avg} is the average power. In Figure 2, D is 0.3 dB and 0.7 dB with and without filter, respectively.

Figure 3 shows the output ripple (D_{out}) versus the input ripple (D_{in}) for many different profiles where filter: A) is not used at all, B) were to be implemented based on NN1 output, and C) is implemented based on NN2 output. Using the filter improves the ripple by 2-3 dB with respect to the case when no filter is used.

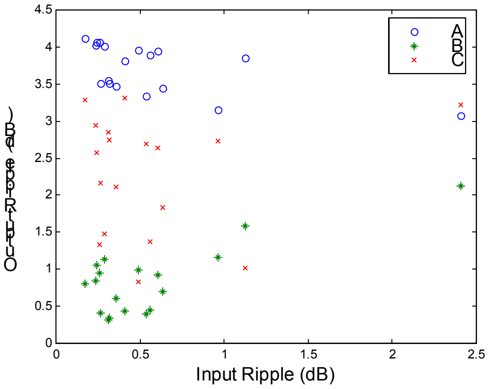

Figure 3. Comparison of ripple with and without filter

4. CONCLUSION

We proposed using two neural network (NN) models for fast control of the acousto-optic filter in an fibre amplifier module. One of the NN (NN1) modelled the two-stage EDFA dynamics so that the real time computation of the required filter profile would be much faster than it would be if full EDFA rate equations were to be solved. The second NN (NN2) modelled the filter transmission response so that the reverse problem of finding the necessary acoustic signal parameters could be done in real time that is otherwise impossible by coupled mode theory. NN1 was trained so efficiently that it generated the required filter response almost exactly. This by itself was a remarkable step in real time control of the module. The NN2 performed quite satisfactorily but not equally well to generate the acoustic signal parameters. Even a minor deviation from the required filter profile resulted in ripples at the output. If NN2 can be trained more accurately and EDFA dynamics can be made less sensitive to the exact shape of the filter response, then this method would prove very efficient and important.

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