Semiconductor Optical Amplifier Placement in CDMA All-Optical Star Network

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Abstract

In this paper, analysis of CDMA network with Optical Amplifiers has been done. As the optical amplifier provides gain as well as has nonlinear characterstics, gain is expected due to signal amplification as well as operation of SOAs as limiter due to gain saturation. In this paper results have been computed for with different SOA placements in a typical star topology employing CDMA. The results show that in a star topology network employing CDMA, placement of SOAs before CDMA decoder does provide benefit due to gain as well as because of clipping due to nonlinear gain saturation. It is also seen that preamplifier scheme works better than postamplifier scheme.

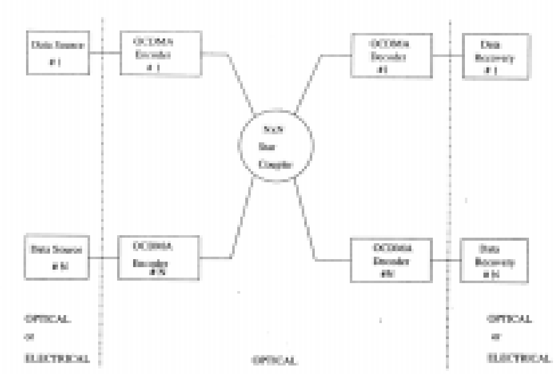

Figure 1: Star topology for CDMA network

1 Introduction

All-optical networks have been of immense interest to the persons involved in communication networking. Optical fiber has become the choice for the medium of transmission in most of the point-to-point links. This is evident by the fact that most of the trunk line and inter-exchange carrier lines use optical fiber. But such point-to-point links are having limitation when a multiaccess environment is considered. In that case a switch need to be present at central location and all the users are connected to this switch using point-to-point links. Since fiber has tremendous bandwidth (around 40 THz) [1], one should be able to support a large number of users in a passive optical broadcast network without any switch. Only requirement is a method to access and utilize the available bandwidth. Simplest of the broadcast optical network is star toplogy (Fig.1).

Passive optical broadcast networks suffer from split loss problem. In these, a transmitted optical signal is split and directed to every user. The receiver depending on the address in the packets either drops or uses the packets. The splitting of optical power reduces the amount of optical power recieved. Since receivers need to receive a minimum amount of power (receiver sensitivity), the amount of split and hence the number of users that can be supported are limited. In order to alleviate the network from this problem, use of optical amplifier has been studied in past [2, 3]. Further to utilize the large available bandwidth in the fiber, all-optical networks use TDMA, WDMA or CDMA techniques. Among these the impact of using OAs in WDMA systems has been extensively studied. But the impact of using OAs in CDMA is relatively unexplored.

Salehi and Brackett [4] have given that the use of hard limiter before CDMA decoders improves the performance. OA is also a nonlinear device due to gain saturation. Consequently, it will be interesting to explore the impact of OA and its non linear characterstics on the CDMA receiver performance. In this paper we have given a methodology to investigate this. In next section, we have described

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basic CDMA network structure. CDMA decoder and receiver for all-optical CDMA network are also discussed. The concept and model of OA is also given. Section 3 gives cases of optical amplifier and their placement options which are considered alongwith the computational model. Section 4 gives computed results for a typical network. Thereafter the conclusions are drawn Section 5.

2 CDMA network

CDMA networks use code division to separate the signals from all users. Since in optical domain, it is not possible to have signals with negative value (intensity is a non-negative entity), the code cannot have zero crosscorrelation. Consequently, the optical CDMA systems use psuedo-orthogonal codes known as optical orthogonal codes (OOC).

2.1 Optical Orthogonal Codes

In general an OOC family derived from {0,1} sequences is characterized by parameters $(M, F, K, \lambda_a, \lambda_c)$ [4, 5]. Each code family consist of M distinct codewords $C = \{C_i\}$ of length F and code weight K. The code weight K is equal to number of *ones* in the code words. The λ_a and λ_c are out of phase autocorrelation and crosscorrelation values respectively. The above implies that autocorrelation for a code family will obey the following equation

$$\sum_{n=1}^{F} C_{jn} C_{j(n+m)} \begin{cases} = K & for\ C_{jn} \in C,\ m = 0 \\ \leq \lambda_a & for\ C_{jn} \in C,\ 1 \leq m \leq (F-1). \end{cases} \quad (1)$$

Similarly, the crosscorrelation will follow the following equation

$$\sum_{n=1}^{F} C_{in} C_{j(n+m)} \leq \lambda_c \quad for\ C_i \neq C_j \in C,\ 1 \leq m \leq (F-1). \quad (2)$$

The CDMA codes are generated by encoders. A passive CDMA encoder splits a short optical pulse and passes them through different delay lines before merging them together. In this manner a bit is converted to a code sequence. The encoding can also be done by directly modulating the optical source by code sequence. This is termed as active encoding. For decoding, the code sequence is split into multiple copies and passed through different delay lines in such a way that one pulse from each of the split path adds when the delayed signals are combined. This acts as correlator [6]

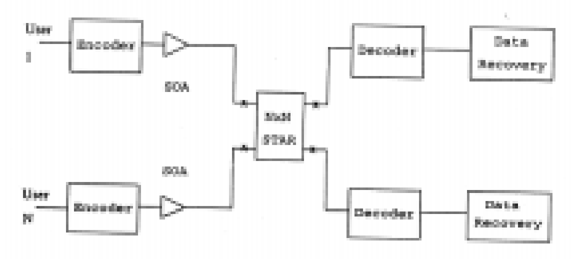

Figure 2: Postamplifier scheme

2.2 Optical Amplifier

An optical amplifier works on principal of stimulated emission. They are mainly of two kinds, semiconductor optical amplifier (SOA) and doped fiber amplifiers (DFA). In this study, SOAs have been considered. The SOA is basically modelled by equations for amplifier gain saturation and amplified spontaneous emission (ASE) noise power spectral density (psd). The gain of SOA is given by

$$G = G_0 \exp\left(-(G-1)\frac{P_{in}}{P_{sat}}\right), \quad (3)$$

and ASE noise psd by

$$S_{sp} = n_{sp}(G-1)h\nu \qquad Watts/Hz. \quad (4)$$

In these equations, G_0 is unsaturated gain, P_{sat}, the saturation power level, n_{sp}, the spontaneous emmission factor, h, the Plank's constant, and ν, the optical frequency.

3 SOA placement options in CDMA star

The SOAs can be placed at three positions as shown in Fig. 2, 3 and 4. Using the models of ASE beat noises, thermal noise and shot noise of receiver and the methodology as given in [7], the computations have been done for the sample network and results are analysed.

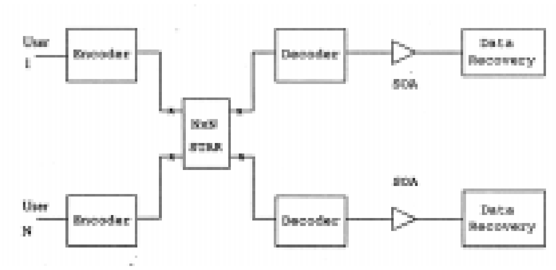

Figure 3: Preamplifier after decoder (preamplifier-1)

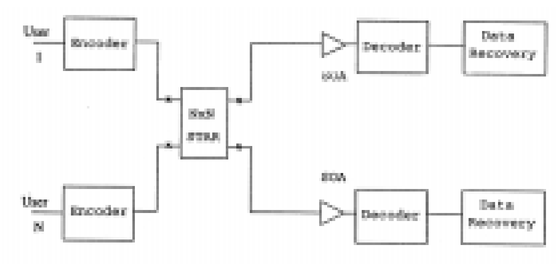

Figure 4: Preamplifier before decoder (preamplifier-2)

4 Example and Results

An example network with the typical parameters is considered. The results have been computed for this network using the models described above. The typical values of the parameters are given in Table 1. Figure 5 shows the results for postamplifier. Curve A is for without SOA. Curve B corresponds to saturated SOA and curve C corresponds to unsaturated SOA. The two set corresponds to active encoding and passive encoding cases. The set having better performance corresponds to start with active encoding.

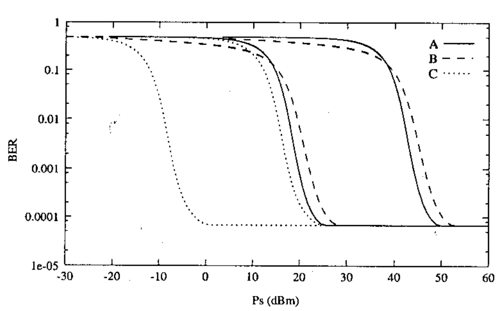

Figure 5: BER vs. P_s for postamplifier case. A- without amplifier, B- saturated SOA, C- unsaturated SOA

Amplifier Gain	G_0	30 dB
Amplifier Saturation Power level	P_{sat}	6 dBm
Spontaneous emission factor	n_{sp}	2.0
Amplifier Coupling Loss	L_A	3 dB
Optical Bandwidth	B_o	10 GHz
Operating Wavelength	λ	1550 nm
Quantum efficiency of photodetector	η	0.75
Receiver temperature	T	300^o K
Receiver electrical bandwidth	B_e	10 GHz
Load Resistance	R_L	100 Ω
Splice loss	L_{sp}	0.5 dB
Insertion loss of 2×2 coupler	L_i	0.5 dB
Fiber length between user and star coupler	L	1 km
Fiber attenuation coefficient	α	0.2 dB/km

Table 1: Typical Parameters for various components in CDMA star network

Since the peak output of CDMA decoder reduces due to effect of gain saturation in preamplifier-1 case, two new threshold values are used. The threshold-1 given by

$$I_{th}(1) = R_o \frac{KP_r G\left(KP_r\right)}{2} \tag{5}$$

causes degradation after certain value of P_s (Fig. 6, curve B). The threshold-2 (Fig. 6, curve C) given by

$$I_{th}(2) = R_o \frac{KP_r}{2} G\left(\frac{KP_r}{2}\right) \tag{6}$$

gives preformance as good as unsaturated preamplifier-1 case (Curve D, Fig. 6). In the above P_r is power received for a pulse at the input of SOA from a single source and P_s is the power transmitted. Curve A in Fig. 6 is for CDMA star without any SOA. Fig. 7 shows the gain saturated preamplifier-1 performance for two different P_{sat} values. Curve A and B corresponds to threshold-1 with $P_{sat} = 6$ and 10 dBm respectively. Curve C and D are for threshold-2 with $P_{sat} = 6$ and 10 dBm respectively. It shows that use of threshold-2 gives more improvement for lower values of P_{sat}.

Fig. 8 gives the results for preamplifier-2 case. Curve A is for unsaturated case. Curve B and C are for gain saturation with uniform and non-uniform multiple access intereference (MAI) respectively. The figure shows that gain saturation

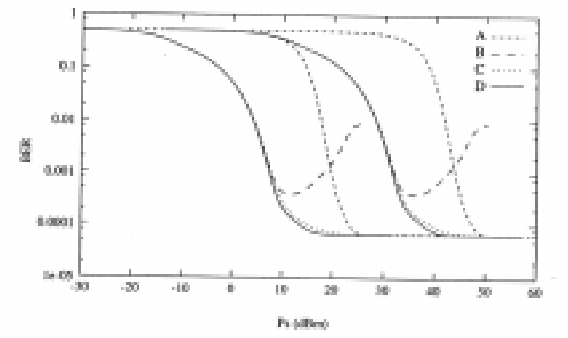

Figure 6: A) CDMA star without SOAs; preamplifier-1: B and C) gain saturation with threshold-1 and threshold-2, D) without gain saturation

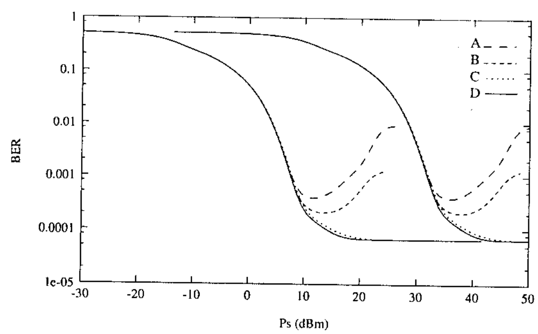

Figure 7: BER v/s P_s for gain saturated Preamplifier-1; A, C for $P_{sat} = 6$ dBm and B, D for 10 dBm for threshold-1 and threshold-2 resp.

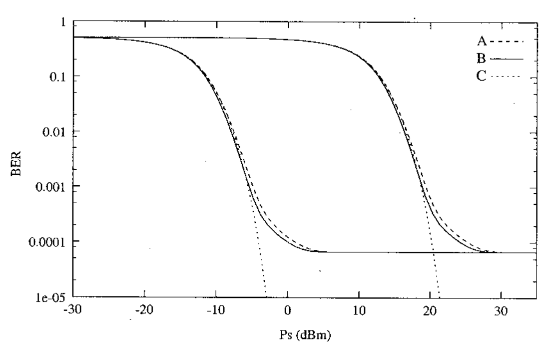

Figure 8: BER v/s P_s for preamplifier-2 with gain saturation

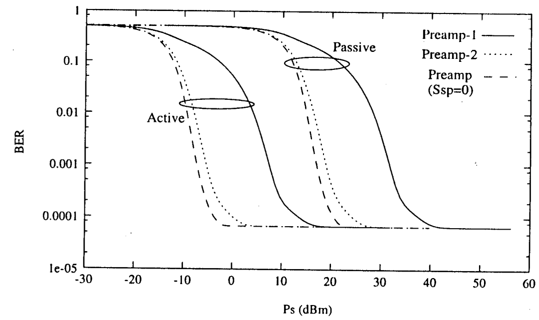

Figure 9: BER v/s P_S for preamplifier-1, preamplifier-2 and preamplifier-1 with zero ASE noise. No gain saturation is considered.

improves the performance slightly. The actual peformance will be in between two extremes given by curve B and C.

The results in Fig. 9 show that preamplifier-1 (amplifier placed after the CDMA decoder) performs poorly as compared to preamplfier-2 (amplifier placed before the CDMA decoder). In computing this, the gain saturation has not been considered. The preamplifier-2 performance is almost as good as that of preamplifier-1 without ASE noise. This implies preamplifier-2 configuration has very small degrading effect of ASE noise. One can also deduce from Fig. 6 and Fig. 8 that gain saturation will affect negligibly in the preamplifier-2 case.

5 Conclusions

This work investigated into the use of SOAs in optical CDMA broadcast star topology network. Three possible placement positions were mentioned. It is concluded from results that preamplifier-2 is best configuration when SOAs are used. It is also observed that SOA provides advantage due to gain as well as nonlinear gain saturation charactestics in the placement position. While in other configurations, gain saturation degrades the performance.

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