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SIMULATION OF OPTICAL FIBER COMMUNICATIONS SYSTEMS USING EDFA

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Abstract. EDFA's technical parameters and the influence of fiber cable attenuation, of fiber cable dispersion are evaluated to meet optical transmission systems' requirements. The type and the number of EDFA are optimized. The maximal length of the communications line is also calculated.

Index terms: EDFA; optical fiber transmission systems' power budget; fiber cable attenuation and dispersion; bit error rate (BER).

I. Introduction

With the development of low loss fibers as the communications medium, efficient compact laser as the light sources, fast photodiodes as the detectors, fiber optics became an alternative technology to electrical systems in telecommunications field. Moreover, the new lightwave generation, with vastly improved capacity and cost, based on the recent development of erbium-doped fiber amplifiers (EDFA) has revolutionized the field of long haul transmission. Typical long distance links installed today contain an optical power amplifier at the transmitter, a series of in-line amplifiers along the transmission line and a preamplifier at the receiver. The EDFA repeaters along the line have replaced expensive and unreliable electronic regenerators, which have commonly equipped in traditional long haul links before. Thus, the evaluations of EDFA's type, of EDFA's number play an important role for designing optical transmission systems.

In this paper, packaged simulations are proposed to optimize the EDFA's type, the number of cascaded amplifiers, and to evaluate the maximal transmission distance. As the matter of fact, in long haul links, the influence of attenuation and dispersion might take place during the operation. Therefore, to predict the type of EDFA, the number of amplifiers in the chain, one should take the attenuation, the dispersion and technical parameters of EDFA [2,3] into account. And to design optical links, the power budget method [1] has been under consideration.

One of the possible methods to overcome the effects of attenuation, of dispersion is to add the penalty power P_{Pen} to the power budget. This solution ensures to remain BER unchanged. In optical transmission systems using EDFA, BER is usually measured in terms of the Q factor [2]. In turn, the Q factor can be calculated through signal to noise ratio SNR, input signal power P_{in}, inversion parameter n_{sp}, etc. In other words, to

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verify the type of EDFA as well as the number of amplifiers and the input signal power, a system of sophisticated equations should be solved.

II. Basic equations

The analysis presented in this paper is applied to an optical transmission system using a single mode fiber cable and EDFA modeled as an effective two-level atomic system. Before deeply going to the simulations, we overlook the power budget method [1]. The optical link loss budget is given by

$$P_T = P_S - P_R = (\alpha_f + \alpha_j)D + \alpha_{cr} + D_L + System - margin, \tag{1}$$

where P_T is total optical power loss (no repeater); P_S is optical power emerging from the end of a fiber flylead attached to the light source; P_R is receiver sensitivity; α_f is fibre attenuation; α_j is splice loss; α_{cr} is connector loss; D is transmission length; D_L is loss penalty; *System-margin* is concerned components aging due to temperature fluctuation.

When optical pulses propagate along the optical fiber, it is observed that each pulse broadens and overlaps with its neighbors, eventually becoming indistinguishable at the receiver. The effect is known as intersymbol interference (ISI). An increasing number of errors may be encountered as the ISI becomes more pronounced, leading to reduction of BER at the receiver [1]. The error rate is also a function of the signal attenuation. Thus, to remain BER unchanged, one should take the dispersion, the attenuation into account, i.e. power compensation known as the loss penalty D_L should be added to the *System - margin*. D_L can be calculated in terms of the root-mean-square spectral width σ and the bit rate B_T [1]:

$$D_L(dB) = (2\sqrt{2}\sigma B_T)^4. \tag{2}$$

We now turn our attention to some EDFA's parameters. Generally speaking, quality of optical transmission systems can be evaluated through BER. In term of the Q factor [3], BER can be well approximated by

$$BER = \frac{1}{\sqrt{2\pi}} \frac{\exp(-Q^2/2)}{Q}. \tag{3}$$

Assume that the signal for a bit "0", $I_S(0) = 0$ and that the noise on the raise "1", $N_{tot}(1)$, is the same as that on the raise "0", $N_{tot}(0)$, i.e. $N_{tot}(1) = N_{tot}(0) = N_{tot}$. The Q factor is then given by

$$Q = \frac{I_S(1)}{2\sqrt{N_{tot}}}. \tag{4}$$

Squaring both sides of Eq. 4, we obtain:

$$Q^2 = \frac{I_S^2(1)}{4N_{tot}}4. \tag{5}$$

When signal-spontaneous noise overwhelms, in preamplifiers and power amplifiers, the Q factor can be presented otherwise [2]:

$$Q = \sqrt{\frac{P_{in}}{h\nu 2B_e n_{sp}}}, \tag{6}$$

where P_{in} is the signal power input to EDFA; h is Planck constant; ν is optical frequency in Hz; B_e is electronic bandwidth; n_{sp} is inversion parameter.-

A common way to characterize the performance of optical amplifiers is through their noise figure NF or their signal to noise ration $SNR.NF$ can be defined as the ration of the SNR at the input to that at the output of the amplifier:

$$NF = \frac{(SNR)_{in}}{(SNR)_{out}}. \tag{7}$$

In terms of the amplified spontaneous emission power P_{ASE}, NF can be written as [3]

$$NF = \frac{P_{ASE}}{h\nu B_o G} + \frac{1}{G}, \tag{8}$$

where B_o is optical bandwidth (equal to bandpass of the optical spectrum) and G is the gain of amplifiers at the signal frequency ν. The gain of an amplifier is expressed as the ratio between the input signal level and the output signal level, typically presented in dB.

$$G(dB) = 10\log_{10}\left(\frac{P_{signal-out}}{P_{signal-in}}\right). \tag{9}$$

When taking the effect of P_{ASE} into account, G can generally be written as

$$G = 10\log_{10}\frac{(P_{signal-out} + P_{ASE}) - P_{ASE}}{P_{signal-in}}. \tag{10}$$

The noise power P_{ASE} at the signal wavelength is calculated from the expressions for spontaneous emission noise n_{sp} [2,3]:

$$P_{ASE} = 2n_{sp}(G-1)h\nu B_o. \tag{11}$$

Sometimes, it is rather favorable to pay attention to SNR than to study NF. In preamplifiers and power amplifiers, SNR can be presented as [2]

$$SNR = \frac{GP_{in}}{4h\nu v_{sp}B_e(G-1)}. \tag{12}$$

In long haul links, it is common to use in-line amplifiers, i.e. a chain of cascaded amplifiers. Consider a system of N amplifiers where SNR_i denotes the SNR after amplifier i. Assume that each amplifier provides a gain G to exactly compensate the loss L between amplifiers and that all amplifiers have the same gain. The overall noise figure of the system is given by:

$$NF_{sys} = \frac{SNR_0}{SNR_N} = \frac{SNR_0}{SNR_1}\frac{SNR_1}{SNR_2}\cdot\frac{SNR_{N-1}}{SNR_N}, \tag{13}$$

where SNR_0 is the SNR at the input of the chain. Thus, the SNR ratios in equation 13 are the noise figures of each amplifier divided to L. In logarithmic units (i.e. in dB), system noise figure is:

$$NF_{sys} = GNF_1 + GNF_2 + \cdot + GNF_N = NGNF. \tag{14}$$

In equation 14, we have assumed all the amplifiers have an equal noise figure and $G = L$. Suppose the signal output power at the end of the chain is equal to the signal input power at the beginning of the chain. It means that the ASE power generated is small in comparison with the signal power and that each amplifier generates an equal amount of ASE as the other amplifiers do. The SNR at the output of the amplifier chain can be then written as

$$SNR = \frac{P_{in}}{4Nn_{sp}h\nu B_e(G-1)}, \tag{15}$$

where P_{in} is power launched to the chain and N is the number of amplifiers in the chain.

From all the above equations, we can easily sort out the suitable type of EDFA, the appropriate number of amplifiers in the chain. Moreover, we can optimize some EDFA's parameters and predict the maximal transmission distance.

III. Simulations and results

To give facilities for designing optical transmission systems, simulation packages have been proposed, based on main $EDFA$ parameters (G, NF, P_{in}, P_{ASE}, etc.) and line parameters (optical power, receiver sensitivity, wavelength, attenuation, dispersion, transmission length, bit rate, BER, *System - margin*, etc.). The packages are written in Visual Basic and executed on Window platform [5].

Many questions have been raised when carrying out optical link's design. We regularly meet the questions like what type of EDFA should be used or how many EDFAs should be installed, ... To optimize the design, one might take the flow chart illustrated in Fig. 1.

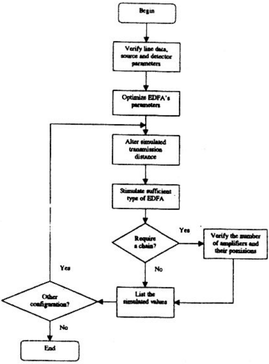


Figure 1. The process of simulations

As can see in Fig. 1, the steps for layout of the systems include:

- Optimize the EDFAs in consideration of line, of source and of detector's parameters. The simulations have shown that optimal gain is around 10 dB [5].

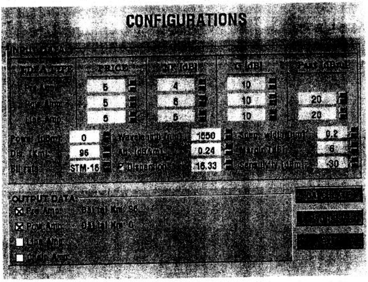
- Predict the type of EDFAs being used. Depended on transmitted distance, on price of different EDFAs,... the simulations will sort out what type of EDFA should be installed.

- In the case of using an amplifier chain, verify the number of EDFAs and the required power at the beginning of the chain [5].

As an example, Fig. 2 shows the simulated configuration. By altering input parameter's values, many configurations have been set up (table 1).

Depending on the transmission distance, the simulations show the optimal configuration, that is what type of EDFA should be used and where to place them. For the first case in table 1, the required transmission length is 96 km. Then, a pre-amplifier should be placed at 96's km and a power amplifier placed at 0's km. No need using any chain of amplifier.

In comparison with field systems shown in table 2 (reference to the recent north - southern Vietnam 2.5 Gbit/s system [4]). One can see that in the real systems, where all spans are fixed, both pre-amplifier and power amplifier have been used except the case denoted by ** (used only one power amplifier). We now turn our attention to the simulated systems (table 1). The corresponding configurations denoted by * have covered the little longer distances than that in the real systems. And if only one amplifier (pre-amplifier or power amplifier) has been used instead, the covered distances are shorter than the corresponding spans. Turn back to the case denoted by double star-mark, the corresponding stimulated distance is also longer than the practical span. Briefly, in any cases, the simulated values are greater than the practical ones. And if a certain span requires two amplifiers, but only one amplifier is used instead, the practical span could not be covered. These meet the demands for designing a certain transmission system: the estimated values should be little greater than the needed values and the difference might be used as the *System - margin*.



CONFIGURATIONS

EDFA TYPE	PRICE	NF [dB]	G [dB]	Psat [dBm]
Pre Amp	5	4	10	
Pow Amp	5	6	10	20
Line Amp	5	6	10	20

Power [dBm] 0
Dis. [Km] 96
Bit rate STM-16
Wavelength [nm] 1550
Att. [dB/Km] 0.24
Dispersion 16.33
Spec. width [nm] 0.2
Margin [dB] 6
Sensitivity [dBm] -30

OUTPUT DATA
☒ Pre Amp Dist [Km]: 96
☒ Pow Amp Dist [Km]: 0
☐ Line Amp
☐ [illegible]

Figure 2. The simulated configuration as an example

Table 1. Calculated values from simulation packages

Length (km)	Att. (dB/km)	Dis. (ps/nm/km)	Configurations						
			Pre-amplifier		Pow.amplifier		Chain		
			Pos. (at km)	Max length (km)	Pos. (at km)	Max length (km)	Beginning position (km)	Step (km)	Number
96*	0.24	16.33	96	81.0	0	68.08	X	X	X
144*	0.25	16.22	144	80.6	0	64.70	X	X	X
97*	0.25	16.16	97	80.9	0	67.69	X	X	X
97*	0.25	16.35	97	79.6	0	66.55	X	X	X
109*	0.24	16.27	109	80.7	0	67.65	X	X	X
140*	0.25	16.12	140	80.1	0	66.74	X	X	X
114*	0.25	16.46	114	79.1	0	66.07	X	X	X
67*	0.25	16.20	X	80.3	0	67.13	X	X	X
125*	0.24	16.46	125	80.1	0	67.30	X	X	X
106*	0.25	16.68	106	78.8	0	66.11	X	X	X
94*	0.23	16.69	94	80.2	0	67.84	X	X	X
117*	0.26	19.49	117	78.7	0	65.67	X	X	X
150	0.25	16.50	150	79.4	X	66.37	37.3	37.3	2
200	0.25	16.50	X	79.4	0	66.37	97.6	37.3	4
250	0.25	16.50	250	79.4	X	66.37	37.3	37.3	5
300	0.25	16.50	300	79.4	0	66.37	97.6	37.3	5
400	0.20	16.00	400	86.1	0	73.49	112	44.4	6
500	0.20	16.00	500	86.1	X	73.49	44.4	44.4	10

Table 2. Practical values from the recent north-southern 2.5 Gbit/s system

Terminals	Attenuation (dB/km)	Dispersion (ps/nm/km)	Practical length (km)
Hanoi-Namdinh	0.238	16.33	96
Thanhhoa-Vinh	0.246	16.22	144
Hatinh-Ron	0.245	16.16	97
Donghoi-Dongha	0.251	16.35	97
Hue-Danang	0.243	16.27	109
Danang-Quangngai	0.254	16.12	140
Quynhon-Tuyhoa	0.253	16.46	114
Quynhon-Ankhe	0.249	16.20	67**
Tuyhoa-Nhatrang	0.242	16.46	125
Nhatrang-Phanrang	0.248	16.68	106
Nuimot-Phanthiet	0.232	16.69	94
Phanthiet-Xuanloc	0.256	16.49	117

VI. Conclusion

From the technical point of view, simulation packages of optical transmission systems using EDFA have been proposed. The optimal type and the minimal number of amplifiers have been derived. The maximal transmission lengths and the required input signal power are also evaluated. These may facilitate the choice of suitable components for designing optical links, reduce the system cost. In comparison with field systems, one can see that the simulation values are in agreement with the real ones as far as the used equations hold.

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