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Performance Evaluation Of Different Erbium Doped Fiber

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ABSTRACT

The exact gain shape profile of erbium doped fiber amplifies (EDFA's) are depends on fiber length and pump power. In this paper simulative study of erbium doped fibers in co-directional configuration with 980 nm laser pump is done using GainMaster™ for two different erbium doped fibers. Each EDF under consideration has length of 10m test length. The gain and noise figure (NF) for variable pump powers at 10mw, 30mw and 50mw were obtained. The gain obtained for pump power 50 mw in I-4 and I-6 EDF (30.932 and 33.117 dB) at optimizations.

Keywords - Erbium doped fiber amplifier, Giles Equation,Gain , Noise Figure

I. INTRODUCTION

Erbium doped fiber amplifier (EDFA) play an important role in light wave communication systems. In order to transmit signals over long distance (>100 km), it is necessary to compensate for attenuation losses within the fiber because the cumulative effect of attenuation and dispersion make the signals to become weaker, indistinguishable and to be detected reliably [1]. Before this happens, the strength and shape of the signals must be restored. This can be done by using either a regenerator or an optical amplifier at an appropriate point along the length of the fiber. Electrical repeaters, which require optical-electrical signal conversion, have previously been used to compensate the power losses increasing with distance. The use of such repeaters in optical communication systems have made the systems more complex and increased their installation costs. The optical amplifiers enable the optical signals to be directly amplified optically. The fiber amplifiers can be made using different rare ions, the most interesting element is Erbium, because erbium doped fiber amplifier (EDFA) made by doping the silica fiber with erbium ions can operate in a broadband with in the 1550 nm window at which the attenuation of silica fiber is minimum and therefore its ideal for the optical fiber communication systems operating at this wavelength range.

II. THE CONFIGURATION OF EDFA

The main components of an EDFA (Fig.1) should be at least consisting of:

1. The erbium-doped optical fiber
2. The pump laser
3. The wavelength-selective coupler

The pump light is guided into the erbium-doped fiber by means of a wavelength division multiplexing (WDM), which is used to couple the pump signal into the doped fiber. Additionally, an isolator is generally placed at the output of an amplifier to prevent back reflection which can degrade amplifier performance or cripple the amplifier due to laser oscillation in the amplifier. Typically, the EDFA configuration can be categorized by pumping schemes into particular arrangements. These schemes are:

1. Forward-pumped (co-pumped).
2. Backward-pumped (counter-pumped).
3. Dual-pumped.

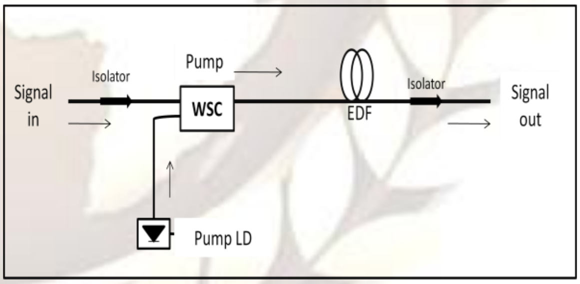

Fig.1 Forward pumped EDFA structure

Efficient EDFA pumping is possible using semiconductor lasers operating near 980-nm and 1480-nm wavelengths. The required pump power can be reduced by silica fibers doped with aluminum and phosphorus or by using fluorophosphates fibers with the availability of visible semiconductor lasers, EDFAs can also be pumped in the wavelength range 0.6- 0.7µm. Most EDFA us 980-nm pump lasers as such lasers are commercially providing more than 100mw of pump power, and it's used where low-noises required. Pumping at 1480nm requires longer fibers and higher powers because it uses the tail of the absorption band, and it's used for higher power amplifiers [2].

Pumping at a suitable wavelength provides gain through population inversion the gain spectrum depends on the pumping schemes as well as on the presence of other dopants, such as germanium and alumina, within the fiber core.

III. SIMULATION MODEL

Giles algorithm calculation was used which provides a full spectral solution and the propagation equation is integrated back and forth along the fiber in an iterative numerical process until the solution converges, or the maximum number of iterations is reached and additional loss mechanism such us pump excited state absorption ESA, and the effects of background loss are only considered during the Giles algorithm calculation [3]. A simpler method of fiber characterization can be done by writing the amplifier equations in terms of Er^{3+} absorption coefficient (α_k), gain coefficient (g_k), and a fiber saturation parameter (ζ). These parameters can be obtained by conventional fiber measurement techniques.

The saturation parameter (ζ) can be defined theoretically as

$$\zeta = \pi . b^2_{eff} . n_t / \tau \quad (1)$$

where b_{eff} is the equivalent radius of the doped region, n_t is local erbium ion density, and τ is metastable life time parameter.

And the absorption and gain coefficients are expressed in terms of distributions of the ions and optical modes.

$$\alpha_k(\lambda_k) = \sigma_a(\lambda_k) \cdot \iint_{00}^{2\pi\infty} i_k(r,\phi) \cdot n_t(r,\phi,z) \cdot rdrd\phi \quad (2)$$

where $i_k(r,\phi)$ is defined as the normalized optical intensity.

$$g_k(\lambda_k) = \sigma_e(\lambda_k) \cdot \iint_{00}^{2\pi\infty} i_k(r,\phi) \cdot n_t(r,\phi,z) \cdot rdrd\phi \quad (3)$$

For a uniform ion distribution the absorption and gain coefficients can be simplified as:

$$(\lambda_k) = \Gamma(\lambda_k) \cdot \overline{n_t} \cdot \sigma_a(\lambda_k) \quad (4)$$

$$g_k(\lambda_k) = \Gamma(\lambda_k) \cdot \overline{n_t} \cdot \sigma_e(\lambda_k) \quad (5)$$

Giles and Desurvire wrote the propagation equation in terms of saturation parameter, with absorption and emission coefficients.

$$\frac{dp_k(z)}{dz} = u_k \cdot P_k(z) \cdot \left(g_k((v_k) + \alpha_k(v_k)) \cdot \frac{\overline{n_2}}{\overline{n_t}} - \alpha_k(v_k) - l_k\right) + u_k \cdot P_{ok} \cdot g_k(v_k) \cdot \frac{\overline{n_2}}{\overline{n_t}} \quad (6)$$

Where each beam propagates in the forward (u_k=1) or backward (u_k= -1) direction and P_{ok} means the spontaneous emission contribution from the local metastable population n2. P_{ok} = m.h.υ_k.$\Delta\upsilon_k$. Where m is normalized number of modes, and Δυ is the noise band width, and l_k is the background loss.

In the same way, the steady-state solution of rate equation may be written as:

$$\frac{\overline{n_2}}{\overline{n_1}}(z) = \frac{\sum_{k=1}^{n} \frac{P_k \cdot \alpha_k v_k}{h_k \cdot v_k \cdot \zeta}}{1 + \sum_{k=1}^{n} \frac{P_k(z) \cdot (\alpha_k(v_k) + g_k(v_k))}{h v_k}} \quad (7)$$

The above two equations (6) and (7) are referenced further as a Giles model. These equations are solved in the homogeneous line broadening case.

IV. GAIN AND NOISE FIGURE

Gain of an erbium-doped fiber with a length of L is the ratio of signal power at the fiber output to the signal power injected at the fiber input as [4]:

$$G = Ps(L) / Ps(0) \quad (8)$$

Amplified Spontaneous Emission (ASE) noise generates during amplification process is added to the signal leading to decrease in signal to noise ratio(SNR) at the amplifier output.SNR reduction ratio from input to output of the amplifier is defined as Noise Figure(NF),which is also used for electronic amplifier:

$$NF = (SNR)in /(SNR)out \quad (9)$$

Noise Figure can also be expressed in terms of gain and spontaneous emission factor (nsp) :

$$NF = 2nsp\ (G-1)/G \approx 2nsp \quad (10)$$

$$nsp = n2/\ n2-n1 \quad (11)$$

n1 and n2 are ionic population in two energy levels .

V. EDFA PARAMETERS

In this paper simulative study of erbium doped fibers in co-directional configuration with 980 nm laser pump is done using GainMaster™ for two different erbium doped fibers manufactured by Fibercore LT.UK [5]. Each EDF under consideration has length of 10m test length. The system was implemented with 980 nm laser pump as it has shown better noise figure (NF) advantage compared to 1480 nm laser pumps. The specifications of each EDF analyzed are given below .

Table 1. EDFA Specifications (IsoGain^{TM} EDF)

Property	IsoGain (I-4)	IsoGain(I-4)
Cut-off wavelength	870-970	870-970
Numerical Aperture	0.22-0.24	0.23-0.25
ModeField Diameter(µm)	3.5 at 980nm 5.9at1550nm	3.5at 980nm 5.9at1550nm
Absorption at 980nm pump in dB/m	3.5-4.5	4.5-5.5
Absorption at 1550nm pump in dB/m	5.0-6.7	7.2-8.4
Background Loss (dB/m)	<10	<10
Polarization dispersion	<0.005	<0.005
Fiber Diameter	125± 1	125± 1

Obtained from Fibercore LTD., UK Specification sheet

VI. RESULT AND DISCUSSIONS

The fig.1 shows the co-directional pumped configuration of the EDF based WDM system. In such a configuration, the portion of the fiber where the signal enters is more inverted compared to the portion where it exits. Hence, more gain /length is obtained in the initial region EDF than the exit, which in turn gives low noise figure. A laser pump of 980nm was employed with varying powers of 10mw,30mw,50 mw. The input signal power is -30dBm at wavelength 1550 nm. The wavelength selective coupler (WSC) has a signal and pumps insertion loss of 0.2dB, pump and signal isolation of 20dB and 30dB respectively, signal and pump return loss of 50dB and 50dB and directivity of 55dB. An isolator is included after the multiple sources to reduce the reverse propagation. It has an isolation of 20dB, insertion loss of 0.3dB, input return loss of 60dB and an output return loss of 55dB.

6.1. Analysis of Co-Directional IsoGain^{TM} (I-4) Configuration

IsoGainTM (I-4) is manufactured by Fibercore Ltd.,UK provides better tolerance to peak absorptions. Hence, they are more suitable for long-distance communications. As seen from the simulation results of fig.2,(Gain vs Fiber length) with 980nm co-directional configuration with pump powers contrasted: 10mw,30mw and 50mw at fiber length 10 m. The maximum gain of 30.932 dB is obtained at 50 mw pump power.

The Noise Figure variation as obtained in fig.3 shows. For higher pump powers, the inversion in the front portion of the fiber more depleted due to backward ASE, resulting in high NF in the beginning of C-band. Table.2 shows the Gain and noise figure for different pump power.

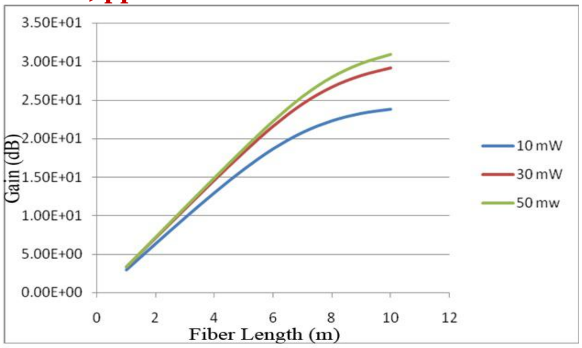

Fig.2 Gain variation for different pump powers

Table 2. Gain and Noise Figure for different pump power

Property	50mW	30mW	10mW
Gain in dB	30.932	29.203	23.793
Noise Figure in dB	3.8	3.84	3.92

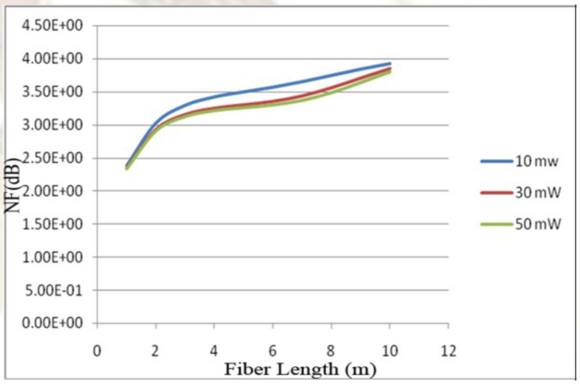

Fig.3 Noise Figure variation for different pump power

6.2. Analysis of Co-Directional IsoGain^{TM} (I-6) Configuration

IsoGain^{TM} (I-6) showed a more normalized gain (Fig.4) in the L-band region compared to IsoGain^{TM} (I-4). At a particular wavelength, the gain is a function of absorption and emission cross-section ratio. The non-uniformity of gain can be reduced by reducing the 980nm pump power. As the pump power reduces, the erbium ion inversion percentage also reduces which in turn reduces the gain tilt of the system. Lesser the gain tilt better is the system for analog communication. Table.3 shows the Gain and Noise Figure for different pump powers.

However, reducing pump power reduces overall gain, which may not be favourable for digital systems where signals must be distinguishable at the receiver end. Fig.5 shows the Noise Figure variation.

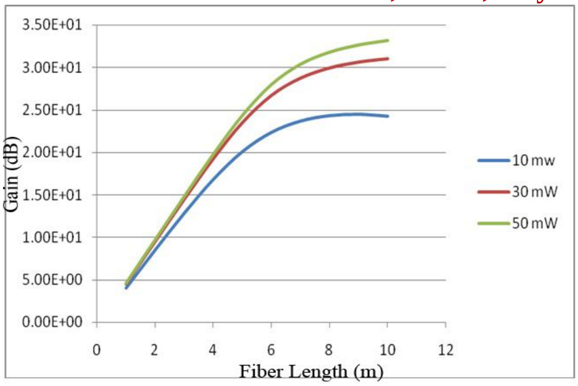

Fig.4 Gain variation for different pump powers

Table 3. Gain and Noise Figure for different pump power

Property	50mW	30mW	10mW
Gain in dB	33.117	31.023	24.297
Noise Figure in dB	4.175	4.172	4.097

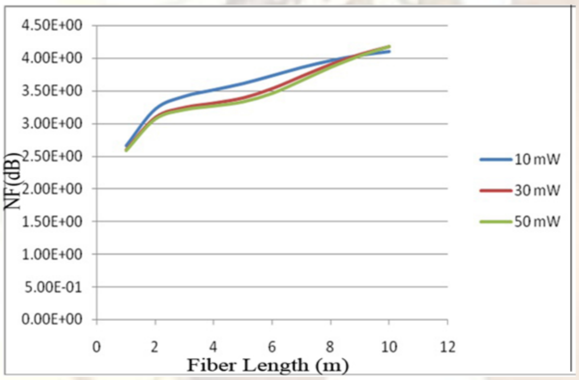

Fig.5 Noise Figure variation for different pump powers

VI. CONCLUSION

The paper successfully examines two different EDF in a co-directional 980nm pumped configuration. The noise figure and gain for each of the fibers were examined in details. The gain and noise figure are strongly depended on the fiber length, pumping power, signal input power. The natural gain and noise figure(NF) for variable pump powers at 10mw,30mw and 50mw were obtained. The gain obtained for pump power 50mw in I-4 and I-6 EDF (30.932 and 33.117 dB) at optimizations. These characteristics of the EDF can be assessed to obtain a desired gain with a different configuration in C and L band. I-6 EDF have good gain and low noise figure. so, I-6 EDF is the better configuration for EDFA in the CATV network applications.

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