O+E+S+C Ultra Broadband Hybrid Optical Fiber Amplifier

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***Abstract*—In this work, a hybrid optical amplifier for O+E+S+C band amplification using Praseodymium doped fiber amplifier (PDFA), Thulium doped fiber amplifier (TDFA) and Erbium doped fiber amplifier (EDFA) is presented by optimizing amplifier's physical and geometric parameters. A signal gain (G)$>$ 17.11 dB and noise figure (NF)$<$ 3.23 dB with a maximum gain of 48.09 dB at 1310 nm have been observed for the wavelength region of 1265 nm to 1550 nm. The impact of nonlinear ion-ion interaction mechanism (IM) effect on signal gain is also observed and minimized by optimizing amplifier's geometric and physical parameters.**

***Index Terms*—Multi-band transmission, Rare-Earth Doped Fiber Amplifiers, Ion-Ion Interaction Mechanism.**

I. Introduction

Over the past five years, there has been a substantial surge in the demand for high-speed internet, driven by advancements in the Internet of Things/Everything (IoT/E) [1]. Enhancing capacity by utilizing the unused optical bands within the low-attenuation optical window of standard single mode fiber presents a cost-effective solution to meet the future data traffic demand [2]. Apparently, the effectiveness of this approach relies on the availability of a suitable amplification strategy. The beneficial attributes of rare-earth doped fiber amplifiers (RE-DFAs), including higher signal gain, lesser noise figure, convenient optical coupling and minimized inter-channel crosstalks establish them as a preferred option over fiber Raman amplifiers, semiconductor optical amplifiers and Bismuth doped fiber amplifiers [3].

However, to the best of the authors' knowledge, no hybrid optical amplifiers using RE-DFAs have been developed thus far for multiband transmission covering O+E+S+C band amplification. To establish multiband communication, Hazarika et al. [4] developed a hybrid optical amplifier for E+S+C+L band amplification with G$<$15 dB and NF$<$ 7.5 dB for the first time. However, for O-band and E-band signals higher gain of around 20 dB is specifically required as optical fiber exhibits higher loss within these bands. Rapp et al. [5] provided a detailed discussion on the advantages of using RE-DFAs for multiband transmission. Therefore, this work necessitates a multiband hybrid optical amplifier has been proposed using RE-DFAs including PDFA, EDFA, and TDFA for O+E+S+C band amplification.

TABLE I
Optimized Parameters

PDFA:PDFA, TDFA:TDFA, TDFA:EDFA		
Parameters	**Unit**	**Optimized Values**
Pumping Schemes	-	Bi : Bi, Bi : Bi, Bi : Bi
Length	m	27:27, 100:100, 10:5
Pr^{3+}, Tm^{3+},	m^{-3}	(3:3)$\times 10^{24}$, $(5:5)\times 10^{25}$
Er^{3+} Density		(14:11)$\times 10^{24}$
Doping Radius	μm	1:1, 1:1, 2:1.8
Numerical Aperture	-	0.38:0.38, 0.3 : 0.5, 0.8 : 0.24
Input Power	dBm	-30

II. Simulation Model

Schematically, Fig. 1 illustrates the proposed hybrid optical amplifier design, attained through numerical simulations performed using the sophisticated OptiSystem®. This configuration includes PDFA, TDFA and EDFA for amplification across the O-band, E-band, and S+C-band respectively. Amplification in the O-band is achieved by connecting two PDFAs in parallel, while for E-band amplification, two TDFAs have been connected in parallel. Additionally for S+C-band amplification, a series combination of EDFA and TDFA has been utilized. The multiband amplifier is constructed by connecting these three O band, E band and S+C band amplifier in parallel configuration. Parametric optimization has been performed with objective function to maximize the gain bandwidth within the O+E+S+C band window. It accommodates 22 WDM channels spaced 15 nm apart across the wavelength range of 1250 nm to 1580 nm. The optimized values for the amplifier parameters are presented in Table I.

III. Results and Discussions

This section discusses the findings derived from the simulation outcomes of the proposed O+E+S+C band amplifier module for the wavelength range of 1265 nm to 1550 nm. Figure 2 shows the gain characteristics of the proposed amplifier for various input power using the optimized value of PDFA, TDFA, and EDFA mentioned in Table I. It is observed that the amplifier achieves optimal gain performance for the input power -40 dBm. However, considering the uniformity of the gain characteristics, a -30 dBm signal power is considered as an optimum input. Figure 3 shows the variation in G and NF of the hybrid amplifier module across different signal wavelength.

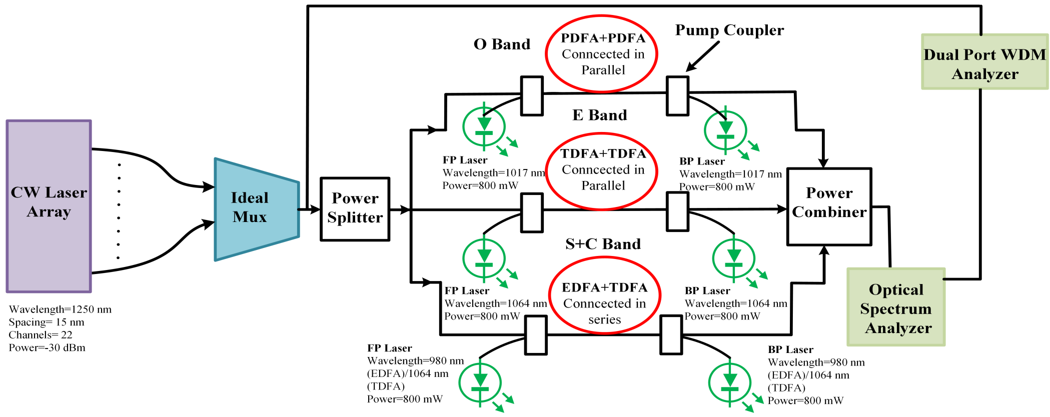

Fig. 1. Simulation setup of the proposed O+E+S+C band hybrid optical fiber amplifier module in OptiSystem®

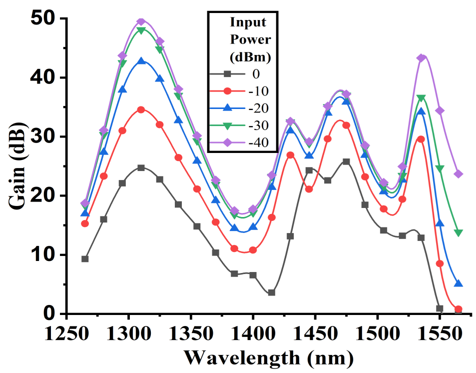

Fig. 2. Variation in signal gain with wavelength as a function of input power

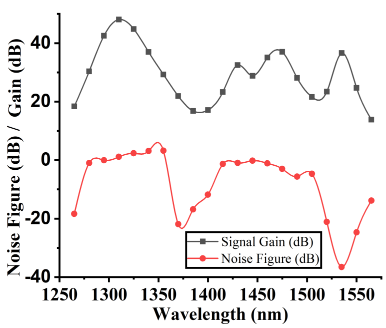

Fig. 3. Optimized plot of signal and noise figure for different wavelengths

It is observed that the amplifier attains a G> 17.11 dB and NF< 3.23 dB with a maximum gain of 48.09 dB at 1310 nm for the wavelength region 1265 nm to 1550 corresponding to a gain bandwidth of 285 nm. Additionally, Fig. 4 depicts the impact of IM effects on the amplifier performance, revealing minimal gain deterioration in the O band and S+C band, while negligible increments and decrements in gain are observed in the E band as a function of signal wavelengths. Specifically, with the inclusion of IM effect, in the E band and S+C band, gain deterioration of 1.9% and 5.37% is observed at wavelengths 1310 nm and 1385 nm, respectively, whereas in the E band, a gain increment of 0.5% is observed at 1385 nm.

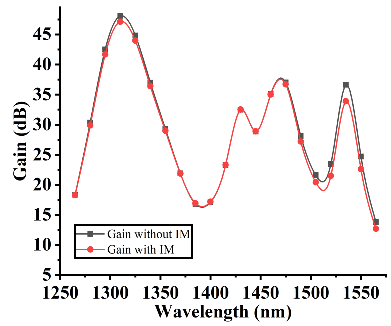

Fig. 4. Impact of IM effect on signal gain

IV. Conclusions

An O+E+S+C hybrid optical amplifier is presented in this work. Parametric optimization including the amplifiers' lengths, ion densities, doping radius of ions, numerical apertures, and input power are performed to achieve precise multiband amplification. Signal gain of >17.11 dB and noise figure of < 3.23 dB with a maximum gain of 48.09 dB at 1310 nm are obtained for 1265 nm to 1550 nm wavelength. The impact of IM effect on the signal gain is also analyzed and minimized through parametric optimization.

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