Flat-gain characteristics of C+L slit-band hybrid waveguide amplifier for dense wavelength division multiplexed system at reduced channel spacing

SIMRANJIT SINGH*, R. S. KALER[a]
Department of Electronics and Communication Engineering, Punjabi University, Patiala, Punjab, India
[a]*Department of Electronics and Communication Engineering, Thapar University, Patiala, Punjab, India*

In this paper, split-band hybrid waveguide amplifier (HWA) is proposed using parallel configuration of Er-doped waveguide amplifier (EDWA) and Er-Yb co-doped waveguide amplifier (EYDWA) for C+L-band dense wavelength division multiplexed system at 0.2 nm interval. This HWA plays a role to boost the DWDM signals and giving a larger gain while keeping the little power/gain variations over effective gain bandwidth product. With the proposed amplifier, the gain and power variation is reduced from 7.2 to 3.1 dB without using any costly gain clamping techniques. Further, the impact of various parameters of EDWA/ EYDWA has been investigated and performance has been evaluated in the term of optical power.

(Received January 21, 2014; accepted September 11, 2014)

Keywords: Dense wavelength division multiplexed system, Waveguide amplifiers, Hybrid optical amplifier, Gain flatness

1. Introduction

The recently improved performance of the available optical gain of optical waveguide amplifiers has attracted more and more interest in this research area. These integrated devices offer the prospect of combining passive and active components on the same substrate while producing compact and robust devices at lower cost than commercially available fiber-based counterpart. However, the way to implement all-optical network relies on the control of gain variation of amplifiers which is sensitive to total input power variation. Several works have been devoted to stabilize optical amplifier gain by electronic and optical means [1], [2]. However, a solution for extreme operation conditions such as to achieve large gain flatness among integrated dense wavelength division multiplexed (DWDM) channels with waveguide amplifiers at reduced channel spacing (0.2 nm) is still to be solved. In literature, several gain-clamping techniques have been reported, such as the all-optical gain-clamped method [3], or different optical filters including fiber Bragg grating filters, and fiber acousto-optic filters [4], [5].

Ennser et al. [6] demonstrate an all-optical WDM ring network immune to transients based on individual optically gain clamped waveguide amplifiers. It was reported that the gain stabilization strength depends on the extra pump power injected in OGC-EDWA means higher the pump power, the stronger the gain clamping. Yeh et al. [7] experimentally investigated the forward optical feedback technique for OGC-EDWA. Choi et al [8] demonstrated an optical power equalization amplifier with a wide dynamic range with no electronic control. It was reported that the lesser power variation can be achieved by amplify each channel individually using optimized erbium doped fiber amplifier (EDFA) which increases the cost of the system. Also it was suggested that the proposed amplifier will be more promising when it is applied to a planar waveguide device to integrate the components. Unfortunately, all of them significantly increased the complexity and cost of the specific optical components. Also these investigations are limited to number of channels as modern optical system needs large number of channels at reduced channel spacing for efficient utilization of bandwidth.

Recently, we have investigated the various hybrid optical amplifiers (HOAs) for DWDM system at reduced channel spacing and high bit rate [9]. It was observed that the Raman-EDFA (R-E) HOA is the best combination to achieve better results. To take the advantage of R-E, further various techniques have been addressed to achieve better gain flatness without using any other costly components [1]. It was reported that, with an input signal power of 3 mW, a flat gain of >10 dB is obtained from hybrid distributed Raman amplifier and EDFA across the frequency range from 187 to 190.975 THz with a gain variation of less than 4.5 dB without using any gain flattening technique.

In this paper, we proposes the HWA as booster to improved our previous schemes to further increase the gain flatness over C + L band without using any costly gain clamping techniques. With respect to previous works, we have used a split-band HWA consisting parallel EDWA and EYDWA with higher gain to address typical requirements in metropolitan networks.

To the best of our knowledge, this paper reports on the first investigation of HWA giving better results even in the scenario of 130 × 10 Gbps DWDM system at reduced channel spacing (0.2 nm). In addition, this work has also been investigated on the observation of further much lesser gain variation induced by our previous proposed HOA reported in [1]. After this introductory part, the setup and results of the proposed system are described in Section II. Section III summarizes the conclusions.

2. System setup and results

A. Investigations on HWA at reduced channel spacing:

Hybrid amplifier combines several amplifiers with different gain bandwidths to extend the gain bandwidth product of the optical amplifiers. Those amplifiers can be connected either in parallel or in series. In parallel configuration, the DWDM signals input to the amplifiers are first demultiplexed into several wavelength-band groups with a band splitter, then they are amplified by amplifiers that have gains in the corresponding wavelength band, and then they are multiplexed again with a band combiner. The parallel configuration is very simple and applicable to all amplifiers.

In our previous work reported in [1], we have investigated an R-E HOA which was able to increase gain flatness without using any other costly components. Unfortunately, we have considered the conventional optical amplifiers, such as, Raman and EDFA which are costly as compared to integrated amplifiers. In this work, we have extended our previous work to increase the gain bandwidth product and gain flatness using integrated waveguide amplifiers. The DWDM system with split-band HWA consists of a parallel EDWA and EYDWA is shown in Fig. 1. For multiple channel amplification, our aim is to accommodate 130 channels in both C-band (1540–1549.8 nm) and L-band (1565-1578.8 nm) with channel spacing of 0.2 nm, where 50 and 70 channels were allocated to C and L-band, respectively. The unamplified C+L band DWDM channels are amplified by the corresponding waveguide amplifier (C and L-bands are individually amplified by EDWA and EYDWA, respectively) after C/L-band splitter. Each laser emits the light signal with 3 mW of power. The data stream from a 10 Gb/s pattern generator with a NRZ binary sequence is pre-coded and drives a sine squared amplitude modulator. The parameters of waveguide amplifiers are described in Table 1. Both amplifiers are counter-pumped with 980 nm having 300 mW of power. Then NRZ amplified DWDM signals are further amplified by our previous proposed R-E HOA. The various parameters of R-E HOA are described in [1]. Where in first stage of HOA, pumped SMF of 100 km is used as Raman and fixed output power EDFA is considered as a second stage.

Table 1. Parameters of considered waveguide amplifiers.

Parameter	EDWA	EYDWA
Waveguide Length	0.07 m	0.09 m
Er Ion Density	2×10^{26} m^{-3}	2×10^{26} m^{-3}
Er Pump Excess Loss	37.3 dB/m	37.3 dB/m
Yb Ion Density	Nil	1×10^{27} m^{-3}
Yb Pump Excess Loss	Nil	44.95 dB/m

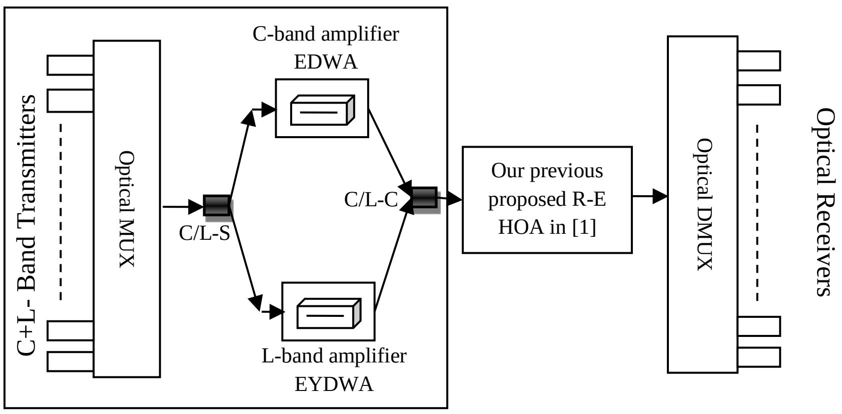

Fig. 1. Configuration of split band HWA for DWDM system; C/L-S: C and L band splitter, C/L-C: C and L band combiner.

Fig. 2 shows the gain spectrum of the 130 × 10 Gbps DWDM system using split-band HWA. For both C and L band, the gain variation with wavelength is not uniform as each waveguide amplifier induces its own nonlinearities, ASE noise and losses due to its planar nature. Two different variable curves refer to gain variation over C and L-band due to dynamic nature of EDWA and EYDWA, respectively. It is found that the gain reached its maximum (> 14.3 dB) over C-band and gradually dropped as the signal wavelength tuned across L-band, it shows good agreement with [10]. The integrated split-band HWA plays a role to boost the DWDM signals and giving a larger gain while keeping the little power/gain variations over effective bandwidth. Higher gain levels in both regions were achieved and no additional power adjustments were required to flatten the gain. A gain variation of 0.9 dB and 0.5 dB with maximum gain of > 14.3 dB and > 14 dB is observed form EDWA and EYDWA, respectively. Till now, reported results are taken without considering transmission distance.

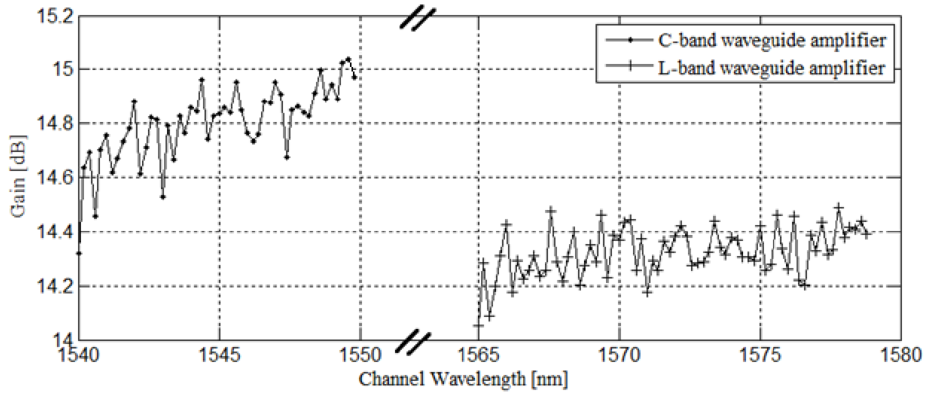

Fig. 2. Gain spectra of proposed HWA over C+L- band DWDM system.

Further we have conducted the same investigation on our previous proposed R-E HOA in [1] to take the advantage of HWA as booster to further increase the gain and gain flatness. From Fig. 3, it can be observed that the gain flatness of 3.1 dB is achieved using proposed HWA is used as booster of R-E HOA instead of other optical amplifiers, with better performance over [1], [11]. Moreover, with other conventional optical amplifiers (such as EDFA, SOA etc. as booster) the R-E HOA induces 7.2 dB of gain variation. From these results it is observed that the gain variation of previously proposed R-E HOA is reduced from 7.2 to 3.1 dB without using any costly gain clamping techniques. Also, the power variation of R-E HOA is reduced from 6.3 to 2.4 dBm using gain stabilized HWA, as shown in Fig. 4.

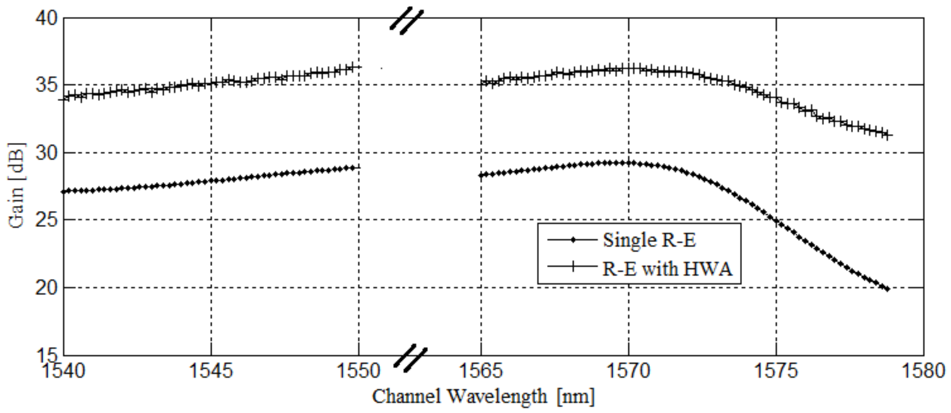

Fig. 3. Gain spectra of R-E HOA proposed in [1] using gain stabilized HWA.

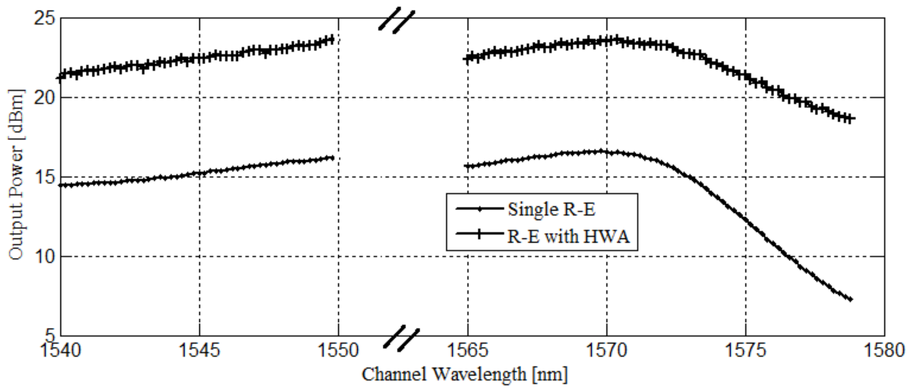

Fig. 4. Output power spectra of R-E HOA proposed in [1] using gain stabilized HWA.

C. Investigation of various parameters of EYDWA/ EDWA on proposed DWDM system

In this section, the effect of EDWA/ EYDWA parameters (such as Pump power, amplifier length and Er/ Yb concentration) has been investigated and evaluated in the term of optical power measured after HWA and HOA. The results have been taken at 1565 nm of wavelength. Fig. 5 presented the variation of output optical power after proposed HWA and HOA with respect to the pump power of used waveguide amplifiers (EDWA/ EYDWA). It can be observed that, as the pump power of EDWA/EYDWA increases the output power level is also increases because more the pump power level then high population inversion takes place. Similarly, Fig. 6 shows the variation of power corresponding to the EDWA/ EYDWA length. As we increased the amplifiers length then the corresponding output power decreases this due to the planar nature of waveguide amplifiers. The variation of power directly affects the gain of the HWA/ HOA.

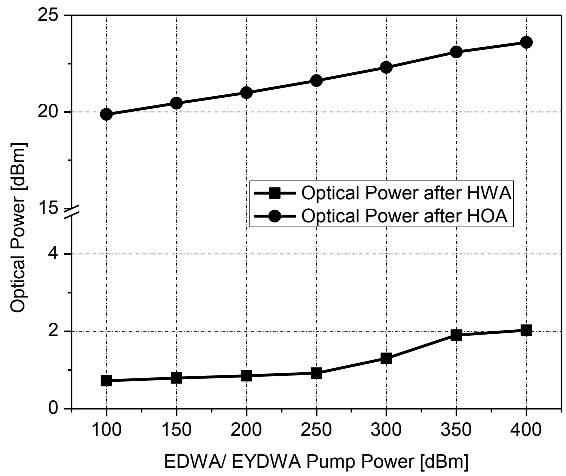

Fig. 5. Waveguide amplifier pump power versus optical power for proposed DWDM system.

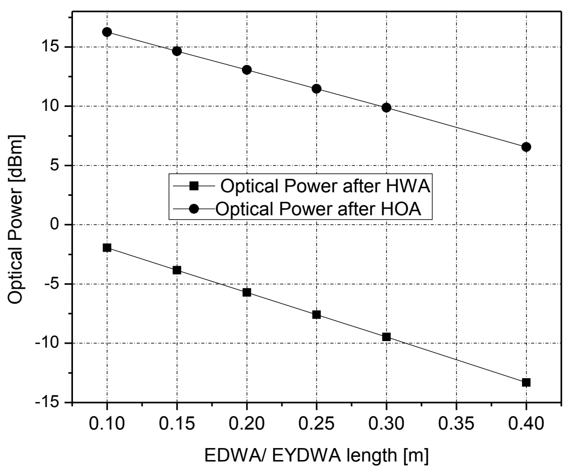

Fig. 6. Waveguide amplifier length versus optical power for proposed DWDM system.

Similarly, we have conducted the same investigation to check the impact of Er and Yb concentration on optical power. It can be observed from Table 2, that the output power increases as we increment the value of concentration because higher the concentration more the conductivity (more the transformation of ions between higher and ground level).

Table 2. Variation of optical power after HWA and HOA with respect to Er and Yb concentration of used waveguide amplifiers.

Er concentration in EDWA/ EYDWA [m^{-3}]	Yb concentration in EYDWA [m^{-3}]	Optical Power after HWA [dBm]	Optical Power after HOA [dBm]
1×10^{26}	4×10^{27}	-3.1	14.54
2×10^{26}	5×10^{27}	2.4	19.14
3×10^{26}	6×10^{27}	6.3	22.98
4×10^{26}	7×10^{27}	11.1	28.5
5×10^{26}	8×10^{27}	15.6	32.3

B. Crosstalk calculation of proposed HWA:

In this section, we represented the crosstalk induced by HWA for different input laser powers. The crosstalk calculations are carried out for system setup as in Fig. 1 with two channels NRZ signal for corresponding amplifiers. To calculate the crosstalk, various methods have been given in the literature. One method of calculating the crosstalk in amplifiers is to use two input signals when only one of them is modulated. The other method is to use two input signals when both are modulated. In this paper, we have used the second method to calculate the crosstalk induced by the HOAs. Then, the crosstalk in this method is the variation of the output power at λ_1 (first channel) caused by the addition of the input signal at λ_2 (second channel). Here, we can calculate the crosstalk as [12- 14]:

$$Crosstalk = \frac{p_{1,out}(p_{2,in} = off) - p_{1,out}(p_{2,in} = on)}{p_{1,out}(p_{2,in} = off)}$$

Where $P_{2,in}$ is input power, $P_{1,out}$ is amplified output power, and index 1 and 2 are two signal wavelengths. Of course, P_1 and P_2 are all modulated signals. As expected, the crosstalk will also increase as the input power increases due to gain saturation as shown in Fig. 7; it shows good agreement with [12]. Both waveguide amplifiers induced lesser crosstalk but the crosstalk is little less in EDWA.

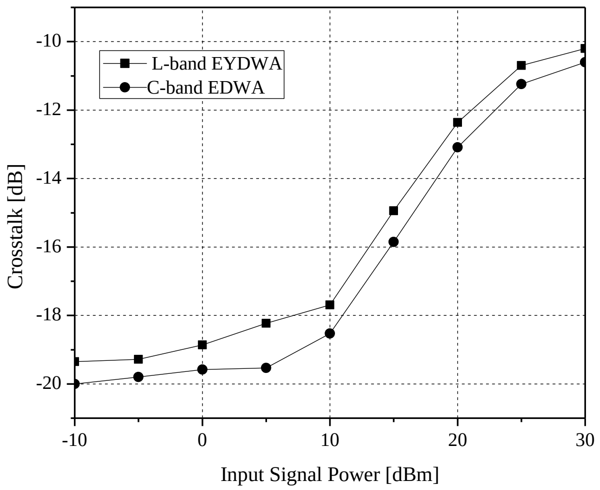

Fig. 7. Crosstalk calculated with different input power.

3. Conclusion

The HWA with flat gain characteristics are proposed using a two parallel stage configuration. This HWA have been investigated as a DWDM system with 0.2 nm channel spacing. With a hybrid EDWA and EYDWA, flat gain of > 14.3 dB is obtained across the effective bandwidth with a gain variation of 1.1 dB without using any gain clamping techniques. With the proposed HWA the gain and power variation due to the R-E HOA is reduced from 7.2 to 3.1 dB and 6.3 to 2.4 dBm, respectively. The proposed HWA is simple gain control configurations based on cheapest standard optical/ waveguide amplifiers which are suitable for the next generation WDM networks.

References

[1] S. Singh, R. S. Kaler, IEEE Photon. Technol. Lett. **25**, 250 (2013).
[2] R. Randhawa, S. Singh, J. S. Sohal, R.S. Kaler, Fiber and Integrated Optics. **28**, 154 (2009).
[3] S. Singh, R. S. Kaler, IEEE Photonics Technology Letters, **26**, 173 (2014).
[4] A. K. Garg, R. S. Kaler, Chines Opt. Lett., **6**, 244 (2008).
[5] K. C. Reichmann, P. P. Iannone, M. Birk, N. J. Frigo, D. Barbier, C. Cassagnettes, T. Garret, A. Verlucco, S. Perrier, J. Philipsen, IEEE Photon. Technol. Lett. **13**, 1130 (2001).
[6] K. Ennser, S. Taccheo, T. Rogowski, J. Shmulovich, Journal of Lightwave Techno. **25**, 1670 (2007).
[7] C. H. Yeh, H. C. Chien, C. C Lee, S. Chi, J. of Optics Communications. **246**, 73 (2005).
[8] B. O. Choi, Optics Communications **267**, 92 (2006).
[9] S. Singh, R. S. Kaler, Int. J. Fiber Integr. Opt. **31**, 208 (2012).
[10] M. A. Ummy, M. F. Arend, L. Leng, N. Madamopoulos, R. Dorsinville, J. of lightwave tech. **27**, 283 (2009).
[11] J. Chen, X. Liu, C. Lu, Y. Wang, Z. Li, J. of Lightw. Technol. **24**, 935 (2006).
[12] M. G. Oberg, N. A. Olsson, IEEE Quantum Electronics. **24**, 52 (1988).
[13] S. Singh, R. S. Kaler, Optical Fiber Technology. **19**, 428 (2013).
[14] S. Singh, R. S. Kaler, Optical Engineering. **53,** 036102 (2014).

*Corresponding author: simrankatron@gmail.com