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A Review: Hybrid Optical Amplifiers in Wavelength Division Multiplexed Systems and Their Challenges/Future Scopes

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Abstract*: Hybrid optical amplifiers (HOAs) are remarkably significant for wideband amplification of the data tributaries, as well as are extensively operational in ultra high capacity dense wavelength division multiplexed systems (DWDMs). We review this futuristic technology in the speedily emergent field of optical communication. Moreover, several configurations and arrangements of optical amplifiers are also discussed to comprehend the properties of optical signal boosters. Current study covers the various issues of hybrid optical amplifiers such as the gain flatness, noise figure, large gain bandwidth. Results revealed that the hybrid optical amplifiers exhibits better performance in terms of the gain flatness, less noise figure and supports high data rates. It is noteworthy that HOAs are important candidate in C+L band and also provide good performance without any expensive components for gain flattening.

Keywords*: HOA (Hybrid optical amplifier), GFF (Gain flattening filter), WDM (Wavelength division multiplexing), EDFA (erbium doped fiber amplifier), SOA (Semiconductor optical amplifier).

I. INTRODUCTION

With the increase in high speed internet services, current information shows that triple play and multimedia applications require high-capacity wavelength division multiplexed (WDM) networks. To fulfill the requirements of the current generation, a high speed and large bandwidth medium is needed. The optical fiber is the merely way that provides such a enormous bandwidth and facilitate with good output performance [1]. From 1980s to till now, to serve the rapid growing services reliant on internet, optical fiber is a best alternative. In former days of optical fiber technology, it suffered from the high attenuation or power loss of 1000 dB/km. However, with the advancement in fabrication, provide us a optical fiber with minimum losses of 0.2 dB/km, which is required for multi-terabit system [2]. In order to utilize the available bandwidth of optical fiber, there is technology called dense wavelength division multiplexing, that can pack several channels simultaneously on a single fiber at reduced frequency spacings [3]. In early days, the aforementioned systems were designed using the wavelengths of two different optical widows such as 1550 nm and 1310 nm [4]. As the modifications introduced in WDM technology, in 1990s, researcher were successfully achieved the transmission of more than 5 channels. The frequency spacings was considered 400 GHz in aforementioned systems. To make system cost effective and exhibits spectral efficiency, reduced frequency spacing in WDM was a major area of research. Afterwards, numerous researches has been reported and in 1990s, system supporting 50 channels were demonstrated and technology referred as dense wavelength division multiplexed (DWDM). By the late 1990s, the immense advancement of DWDM systems had been pragmatic with the communication potential of more than 100 parallel channels, tightly packed at 50 GHz [5-6]. Attenuation is not the performance deteriorating factor in optical fibers, pulse broadening and nonlinearities are other major degrading issues [7]. The capacity of the systems can be enhanced by incorporating regenerators in the system, however, employment of this increase the complexity, cost of DWDM. Consequently, development of multichannel systems needs the components that directly boost the input signal without the O-E-O conversions [8].

The optical amplifiers are widely placed in WDM systems as every single channel with diverse wavelengths can be concurrently augmented. There are two widely used configurations of optical amplifiers and categorized as pre, post amplification. An optical amplifier boosts the signal power by inserting it immediately after the transmitter (pre) and by incorporating it immediately before the receiver (post). As the necessity of more number of channels and prolong distance transmission increases, the initiation transmission way out have to be analyzed to accomplish the need of in progress technology. Optical amplifiers have many advantages, but, also suffer from phase noises which curb its use for diverse applications in optical communication systems (OFC). There are also many nonlinear effects such as self phase modulation (SPM), cross phase modulation (XPM), gain saturation, four wave mixing (FWM). Hence, there is a stipulation for optical amplifiers which offer a improved performance in term of nonlinearities tolerance, gain flatness, larger gain bandwidth for dense wavelength division multiplexing systems. In this review article, we have incorporated the diverse concepts and issues of the hybrid optical amplifiers including gain flatness, noise figure etc. Nowadays, the hybrid optical amplifiers are talented and extensively used for current rapid broadband applications to augment the system recital not including costly and complex techniques [9]. HOAs also have some limiting factors that should be considered for betterment of technology. Major issues include fluctuation of gain when channels are added one by one, crosstalk, and nonlinearities. In Raman fiber amplifiers, Rayleigh back scattering, pump noise are also cause degradation. The intend behind the use of the hybrid optical amplifiers is to enhance the gain and widen the gain bandwidth with less fluctuation of gain to different channels, to minimize the degradation due to fiber nonlinearities and to realize a cost effective system without incorporating isolators, GFF (gain flattening filters).

In common, the arrangement of more than one optical amplifier in any arrangement is called a hybrid optical amplifier. In [10], author presented that net gain of the hybrid Raman and erbium doped fiber amplifier (EDFA) is the total of individual gains (in dB) of Raman and EDFA, respectively. Gain of HOA using EDFA-Raman is expressed as

$$G_{Hybrid}=G_{EDFA}+ G_{Raman}$$

Fig. 1 depicts the Gain distribution of R-E configuration of HOA and it is observed that some channels of one optical window are competently amplified by EDFA and the additional are amplified by Raman amplifier. Aforementioned observation revealed that all channels are amplified with HOA and it is also evident that single amplifier exhibit large gain fluctuations.

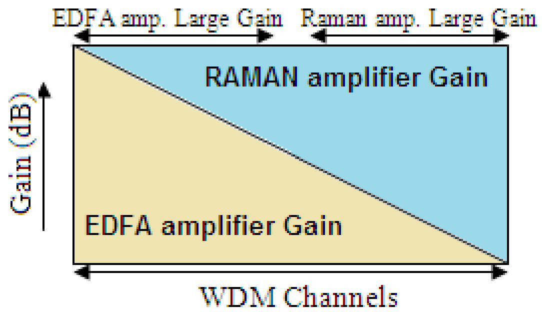

Fig. 1 Gain Distribution of Hybrid Optical Amplifier Using EDFA-RAMAN Amplifiers

II. EVALUATION AND COMPARISON OF OPTICAL AMPLIFIERS

Basic principle of operation for all amplifiers is near about identical, however their incorporation in the system depends upon their characteristic such as operational frequency window, noise figure, nonlinearity impairments and cost. Base on features, amplifiers are described below.

A. Erbium doped fiber amplifier (EDFA):

EDFA is widely used in the application operated in C-band due to maximum gain providing ability of EDFA in this particular band. Also it has gain bandwidth of 10 nm to 40 nm with low noise figures. EDFA comes in dual variants such as single directional and dual directional EDFA. Optical fiber is sensitive to polarization and thus degrade the performance, however EDFA provide 0 dB sensitivity of polarization. Pump of wavelengths 980 nm, 1480 nm are widely used with pump powers typically 10 mW to 50 mW.

B. Semiconductor optical amplifier (SOA):

Advantage of Semiconductor optical amplifier is the capability to operate and provide gain at any optical window. In other words, it does not depend upon the frequencies of signals. Gain bandwidth of SOA is 2- nm to 50 nm and more than EDFA. Two major variants are single and dual directional SOAs. Noise is low in this amplifier and requires injection current for operation irrespective of pumps lasers. SOA is sensitive to the polarization and sensitivity is in few mW. As on chip switches, wavelength converters or logic gates the SOAs are the most excellent alternatives for the reason of their compact size and less power compensation requirement as compared with Raman and EDFA.

C. Fiber Raman amplifier (FRA):

Gain of the fiber Raman amplifier depends upon the pump power and also wavelength of the laser pump. Gin bandwidth of amplifier is from 20 nm to 50 nm as SOA amplifier provides. Raman amplifier has a property to introduce very less noises as compared to EDFA and SOA. Not sensitive to polarization and has two variants as SOA. It requires high power pump sources such as 100 mW to 500 mW.

D. Hybrid optical amplifiers (HOAs):

According to the diverse features of an optical amplifier, described above, the HOA can be suggested for a high-capacity DWDM system where the high gain and gain bandwidth with less variation is required. HOAs are broadly used in the application operated in C-band and L-band due to less fluctuation of gain in both bands. Also it has gain bandwidth of 50 nm to 80 nm with low noise figures. HOAs are also comes in dual variants such as single directional and dual directional. Polarization sensitivity of HOA is not constant and vary according to physical properties used in the system. Pump of wavelengths are same as EDFA and Raman amplifier with pump powers typically from 100 mW to 600 mWx`.

III. ARCHITECTURES OF INDIVIDUAL AND HYBRID OPTICAL AMPLIFIERS

Four types of configurations in hybrid arrangement are demonstrated in [13] and further enhancement is done in [14] to make HOAs cost efficient with the use of one pump. Diverse configurations of optical amplifiers are depicted in figure 2. Fig. 2(a) and 2(b) show the configurations of EDFA amplifier in pre and post amplification respectively. Fig. 2(c) represented using a single EDFA multiple/parallel EDFAs respectively. In addition, for amplifying a large gain bandwidth, Fig. 2(d) and 2(e) show the configurations of hybrid Raman and EDFAs.

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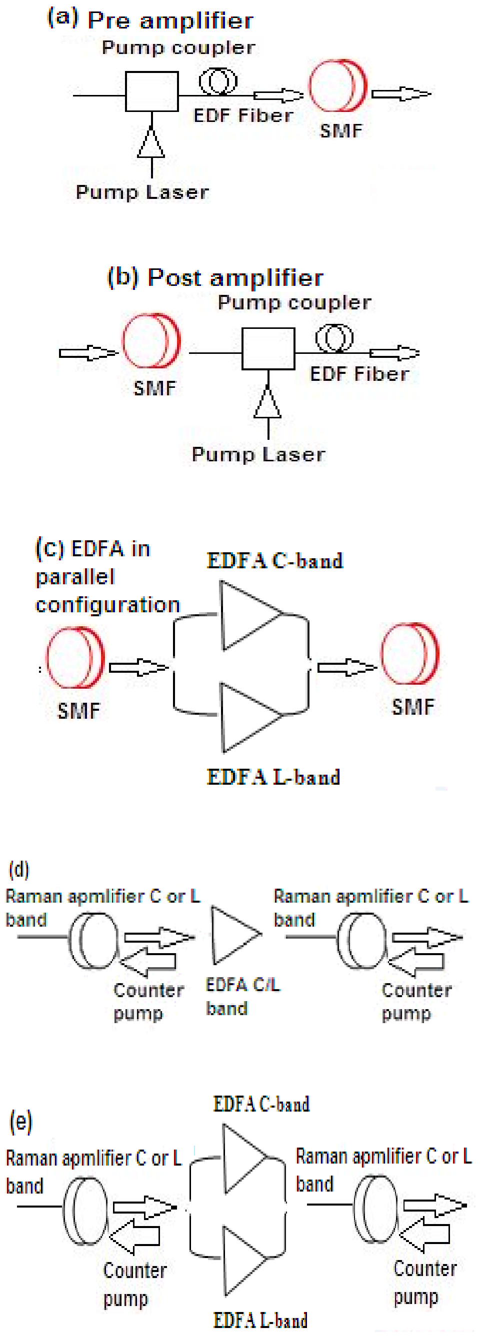

Fig. 2 Basic Configurations of Inline Amplifiers and HOAs (a) EDFA as Pre Amplifier (b) EDFA as Post Amplifier (c) C+L Band EDFAs in Parallel Configuration (d) Cascaded C+L Band Raman-EDFA Amplifier (e) EDFAs in Parallel and Raman in Inline Configuration for HOA

IV. Literature Review And Development Of Hybrid Optical Amplifier

Optical amplifiers are the indispensable elements in highly developed fiber-based networks. They offer the way to neutralize the attenuation or signal degradation caused by the fiber optic, in a row optical components, as well as power splitting up at optical splitters [20]. Therefore, amplifiers ease the high-global capacities, extended communication spans, and multipoint-to-multipoint link necessary for function with increasing information volumes. In their absence, fiber networks would require numerous O-E-O converters for the 3-R regeneration such as electronic repeating, retiming, and reshaping of attenuated and noisy bit streams. The cost would broadcast at considerably less speed, requiring several fibers in each ribbon; additional node buildings, frequently in an luxurious metropolis hub locations; larger tools cabinets, occupying important ground legroom; augmented whole power utilization, by means of its connected ecological impact and, very prominently, higher operating costs to be conceded on to the client [21]Optical amplifier technologies is now as a key to wide data accessibility. Optical boosters give many benefits over the re-generators such as the flexibility to speed up or down the system, can send variable data on multiple channels. This latter features offer to the apprehension of dense wavelength division multiplexed systems, in which multi-terabit speed have been established [22]. With the increase of bandwidth hungry networks, HOAs are the well competent and ubiquitous technology to provide gain for the closely packed channels. The goal is to further improve the gain bandwidth, In order to reduce the losses that induced due to emerged nonlinearities, in addition to avoid GFFs and multi pumps.Numerous studies have been reported to enhance the wide band gain of amplifiers. Methods are including host material for amplifier, GFFs, parallel arrangement of amplifiers, multi-pumps in Raman amplifier and integration of EDFA and FRA. In [23], proposed the hybrid configurations using two EDFA amplifiers incorporating diverse optical pumps of 850 nm and 1480 nm. Gain provided in the configuration was reported more than 35 nm with output power of 17 dB. It was evident that there is significant crosstalk due to the use of same wavelength pumps and compensated by incorporating pumps of diverse wavelength. In [24], demonstrated the wideband hybrid optical amplifier that offer a wide gain from 1549 nm to 1614 nm. To attain the wide gain, several external techniques are employed, i.e., gain equalizers, GFFs, a new pumping scheme, and counter pumped Raman amplification. They achieved 49 nm bandwidth but become us-stable because of high pump powers and low gain compression. They suggested that the use of combination of Raman and EDF exhibits improved signal to noise ratio and BER was also improved. Further, there was successful transmission of 14 channels with 2.5 Gbps at each channels has been done over the fiber stretch of 900 km using HOA. Comparison was established between EDFA and HOA, results revealed that HOA is better than EDFA as reported in [25].

In a Raman amplifier, it is better to use a single pump wavelength instead of multiple pumps because: (1) it is easy to design with minimum cost and (2) the profile of the Raman gain spectrum is independent of channel loading. In [26], built the setup in which EDFAs are used as a booster and as an inline amplifier. The hybrid EDFA and fiber optic parametric amplifier (FOPA) was used as a preamplifier. It was reported that for inline amplification, the FOPAs show better results as good as EDFAs. It was observed that the hybrid EDFA and FOPA deliver improved performance as compared with EDFAs. The performance has been improved in the terms of gain, gain bandwidth, NF, and so on. As compared with back to back values, the proposed hybrid optical preamplifier also improved the system power penalty by 3.2 dB. In [27], studied several gain flattening approaches through numerical simulation. These methods included the hybrid Al-codoped with Al/P-codoped EDFAs, Raman-EDFA HOA, and gain equalizer optical filters. After comparison, it was reported that the gain equalizer filter was the most appropriate method to increase the gain bandwidth product of the EDFAs with a large gain flatness. On the other hand, Raman-EDFA HOA provided the maximum reachable bandwidth without using any high cost or power inefficient optical filters. Nowadays, Raman amplifiers reliant in dispersion compensation fiber (DCF) have generated huge study consideration for their impending applications in prolonged distance communications. It has major two advantages i.e., pump wavelength can change the amplification window. Moreover, the attenuation and pulse broadening issues sorted out along with amplification providing ability. In [28], stated the hybrid Raman and EDFA (FRA-EDFA) in terms of the gain variation and NF measurement. In this work, three types of HOAs are proposed for a multichannel WDM system and it was observed that the multichannel gain spectrum of the HOAs is quite different from the case of a single channel. It was concluded that the hybrid Raman- EDFA configuration using a residual pumping scheme provided the best results in terms of the gain and pump efficiency. But the better BER performance was shown by hybrid amplifier as stated in first and foremost configuration, which is a combination of Raman and EDFA pumped by a residual Raman pump in a co-propagating geometry. In [34], introduced a configuration of the hybrid Raman-EDFA. They also produced some restriction conditions to yield the optimum design. The influence of various Raman amplifier noises [such as amplified spontaneous emission (ASE) and Rayleigh] on the OSNR of the receiver had also been determined in the depth. In this work, various important conclusions have been made such as, with the same span length and with a different large nonlinear weight the value of the Q-factor is larger. On the other hand, the quality degrades if the same nonlinear weight has been chosen with a different span distance. The quality factor degrades with respect to the increment in the span length, which produces the ASE and Rayleigh noise. the quality degrades if the same nonlinear weight has been chosen with a different span distance. The quality factor degrades with respect to the increment in the span length, which produces the ASE and Rayleigh noise.

V. Wavelength Division Multiplexing Incorporating HOAs

The semiconductor optical amplifier and erbium doped fiber amplifier induced as the prominent and attractive technology for SOAs and EDFAs emerged as attractive amplifiers for wavelength division multiplexing due to advantages of wide gain bandwidth along with prolonged distance transmission. Use of EDFA increase the cost of the system, however, use of Raman amplifier is popular and drawn attention for WDM systems and can amplify any wavelength within the bandwidth of the fiber by a simple adjustment of the pump wavelength. However, Gain fluctuation is in individual EDFA and Raman amplifiers. To provide the solution of this problem, the hybrid amplifiers are the most capable and widely used technology. But, there are some issues in HOAs that have to be addressed.

VI. Literature Wide-band Gain And Gain Flatness

To cater the present WDM services, a large bandwidth of gain provided by optical amplifiers is needed. In reported works, several configurations are proposed using various amplifier such as SOA, Raman amplifier and EDFAs, however these arrangements suffered from gain fluctuations. The gain reliant upon the wavelength of the input signal as well as is limited by the width of the radiating energy bands. Consequently, hybrid optical amplifiers are the most excellent alternative and also provide high gain, gain flatness with cost effective methods. In [30], demonstrated a system that has 160 DWDM channel at frequency range of 187 THz to 190.975 THz. The channel spacing is reported of 25 GHz and system analyzed for different input powers (3 mW, 5 mW and 15 mW). From Fig. 3, it is observed that gain variation over the effective bandwidth, i.e., 3.97 THz (33.37 nm), increases with respect to the increment in input power; this is because of the nonlinearities in the fiber. A better performance in terms of the gain flatness (4.5 dB) is achieved with an input power level at 3 mW. The gain flatness can be improved by using various gain flattening techniques (such as filters, DCF, FBG, and so on) but this leads to an expensive system. For a cost effective solution, we have optimized the various parameters of a hybrid EDF-Raman amplifier using a genetic algorithm to attain better gain flatness.

Besides that wide bandwidth gain and gain flatness, there are several issues that need to be addressed such as in saturated amplifiers, transient crosstalk is

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generated between adjacent channels. This is due to the abrupt changes in average power of the optical amplifier due to sudden fiber cuts, add-drop operations, reconfigurability, and so on. Moreover an other effect, in literature, various HOAs are designed, but the distortion in data pulses is still present because of the crosstalk between the transmitted symbols. There are various reasons for the crosstalk: (1) it is induced due to the rapid gain excursion of optical amplifiers. (2) It is induced due to amplifier nonlinearities which change the parameters of the transmitting signal since it depends on the remaining optical signals propagating through the same fiber. Above mentioned effects also needs to be suppressed for future hybrid optical amplifiers.

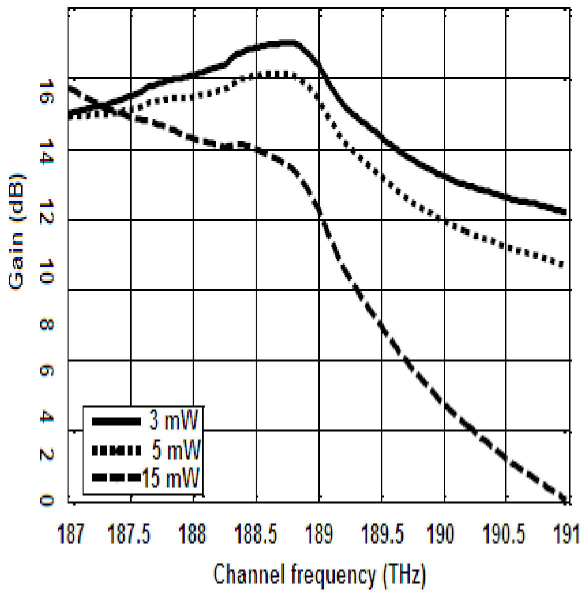

Fig. 3 Performance of HOA at Different Launched Powers [30]

VII. FUTURE SCOPE

Extensive work has been reported so far in the context of Wavelength division multiplexing. However, due to ever-increasing demands of high speed internet, an ultra high capacity WDM system is required. Many research works have been carried out to cater the demands, but either limited in data speed or in capacity. This is an important area of research to design the ultra high capacity WDM system with optical amplifier. Moreover, channel spacing of WDM system plays an important role and has very much impact on system performance. But as the spacing decreases results also degrades due to interference. This is great area of research that how we make system bandwidth efficient (less spacing) without affecting its performance on larger extent and simultaneously amplify wavelength grids using optical amplifiers. Bandwidth efficient WDM system is need of the day. More dense channels spacing allow system to support more channels in more than one frequency band. Consequently, an amplifier is needed that work in two optical windows simultaneously. Most of the work has been reported for C- band wavelengths, however in order to fulfill internet demands we need to use L- band to overcome congestion problems. L-band is not studied widely with optical amplifiers. Numerous works has been reported till date to design a C+L band optical amplifier. However, these amplifiers are proposed with multistage of amplifiers, isolators, Gain flattening filters (GFF) and several other costly and complex modules. To reduce the cost and complexity of the system, we need a single stage amplifier for both C and L band.

Work continues apace on optical amplifiers, driven by the enormous potential benefits of HOAs. Despite the wide range of HOAs that have been used to attain gain variation over a large gain bandwidth with a better performance, no on chip hybrid waveguide amplifier has yet been proposed which can offer a small footprint and low mass production cost. The increased deployment of local area DWDM necessitates the development of cheap planar gain elements. In this field, work continues on the production of planar waveguide devices using silica, fluorides, tellurites, polymers, and chalcogenides. While concentration quenching limits the ultimate gain achievable from doped materials, careful design of wave guide geometries can help to mitigate these effects. Because HOAs have applications in wide area networks as inline amplifiers, the placement of optimum HOAs in different optical network topologies can be studied. The HOAs' placement can also be explored in other broadcast topologies including multilevel topologies. The leading challenges of HOAs in the coming years will continue to be to achieve the lowest power efficiency of the amplifier, to lower the high cost of the pumps, and to solve issues related to the safety and risks of having high-optical powers in the field. The latter could be a major problem of access and fibers to home networks, where optical fibers are located in much more accessible areas (cable masts and interior boxes in houses) and human interaction with the fiber is more likely. Security and monitoring of these systems will be essential for a more widespread use of the HOAs in the coming years.

VIII. CONCLUSION

In this study, we have presented various limitations of optical amplifiers and also stated the configuration used in optical networks. It is concluded that Hybrid optical amplifiers leftover a vigorous and quickly developing technology. The Hybrid optical amplifiers are one of the potential ways to strengthen the broad gain bandwidth product with a minimum gain variationamong the channels. We accentuated on the recent developments and issues in hybrid optical amplifiers such as fluctuation of gain, gain bandwidth, transient effects etc. Suggested ways to quell the limiting factor are also discussed in this paper. Solution of the aforementioned issues will increase the capacity and flexibility of dense wavelength division multiplexed communication system at dense channel spacing. The HOAs are suggested for closely packed channels in WDM system having a large gain bandwidth. There is wide emphasis on the extension of the capabilities of Hybrid optical amplifiers to cater the demands of bandwidth hungry and long haul communication systems.

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