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DWDM Link with Multiple Backward Pumped Raman Amplification

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ABSTRACT:
Faced with the challenge of dramatically increasing capacity while constraining costs, carriers have two options either to install new fiber or increase the effective bandwidth of existing fiber. The technology of dense wavelength-division multiplexing (DWDM) has recently resulted in a considerable increase in the transmission capacity of fiber-optic communication systems up to several terabits per second. The further improvement of the transmission capacity of such systems can be achieved through the expansion of the spectral range of WDM transmission toward the short-wavelength region. Therefore in this report we have proposed and investigated the new trends and progress of fiber Raman amplification for dense wavelength division multiplexing photonic communication networks. Forty individual channels carrying PRBS data are transmitted over a 50 km length of ITU-T G.652 single mode dispersive fiber. The design objective is to utilize distributed Raman amplification to compensate for the link attenuation thereby effectively increasing the inter-EDFA span in a longer-haul link.

KEYWORDS: *PRBS, Digital Crossconnect System (DCS), phonons, Dense wavelength division multiplexing (DWDM), stimulated raman scattering (SRS), raman amplification, pump evolution, EDFA*

I. INTRODUCTION

It is needless to mention that the 21st century activities will be drastically hindered without the advent of modern communication system [1]. Off all, the most advanced communication system has been culminated in the form of Internet, allowing all computers on the planet and in the orbit to be connected to each other simultaneously. While telecommunication remains as a major medium and has its own demand for higher bandwidth, the demand for even higher bandwidth is sky rocketed by exponential growth of the Internet traffic. The cumulative demand for bandwidth poses a serious limitation for the existing carrier technologies. High demand coupled with high usage rates, a deregulated telecommunications environment, and high availability requirements is rapidly depleting the capacities of fibers.Faced with the challenge of dramatically increasing capacity while constraining costs, carriers have two options: Install new fiber or increase the effective bandwidth of existing fiber. Laying new fiber is the traditional means used by carriers to expand their networks. Deploying new fiber, however, is a costly proposition. It is estimated at about dollar 70,000 per mile, most of which is the cost of permits and construction rather than the fiber itself. Laying new fiber may make sense only when it is desirable to expand the embedded base. Increasing the effective capacity of existing fiber can be accomplished in two ways [1], increase the bit rate of existing systems or increase the number of wavelengths on a fiber.

In section II, a detailed explanation of Dense Wavelength Division Multiplexing (DWDM) technology is mentioned. Section III describes the basic concept of Raman amplification, comparision of Raman amplifiers with Erbium Doped Fiber Amplifiers (EDFA) and the use of Raman Amplification in DWDM system. In section IV, the design and simulation results of a 40 channel DWDM link with backward pumped Raman amplification is mentioned. The paper ends with section V, which includes the summary and the future scope of Raman amplification in DWDM systems.

II. DENSE WAVELENGTH DIVISION MULTIPLEXING (DWDM)

In fiber-optic communications, wavelength-division multiplexing (WDM) is a technology which multiplexes multiple optical carrier signals on a single optical fiber by using different wavelengths (Lambdas) of laser light to carry different signals as shown in figure 1. DWDM is the clear winner in the backbone. It was first deployed on long-haul routes in a time of fiber scarcity. Then the equipment savings made it the solution of choice for new long-haul routes, even when ample fiber was available [3]. While DWDM can relieve fiber exhaust in the metropolitan area, its value in this market extends beyond this single advantage. Alternatives for capacity enhancement exist, such as pulling new cable and SONET overlays, but DWDM can do more. What delivers additional value in the metropolitan market is DWDMs fast and flexible provisioning of protocol and bit rate-transparent, data-centric, protected services, along with the ability to offer new and higher-speed services at less cost. The need to provision services of varying types in a rapid and efficient manner in response to the changing demands of customers is a distinguishing characteristic of the metropolitan networks. With SONET, which is the foundation of the vast majority of existing MANs, service provisioning is a lengthy and complex process. Network planning and analysis, ADM provisioning, Digital Crossconnect System (DCS) reconfiguration, path and circuit verification, and service creation can take several weeks. By contrast, with DWDM equipment in place provisioning new service can be as simple as turning on another light wave in an existing fiber pair.

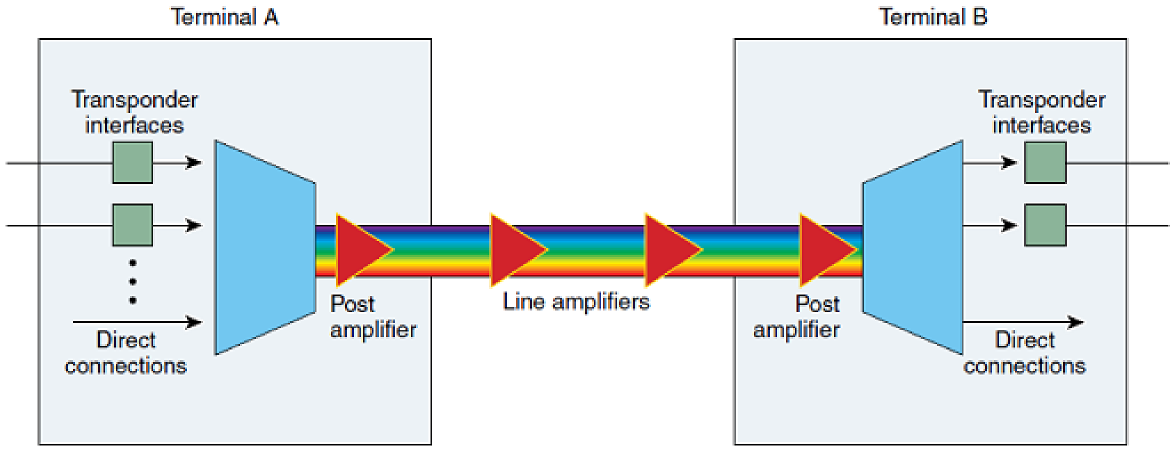

Fig. 1: WDM Technology [2]

Potential providers of DWDM-based services in metropolitan areas, where abundant fiber plant already exists or is being built, include incumbent local exchange carriers (ILECs), competitive local exchange carriers (CLECs), inter-exchange carriers (IXCs), Internet service providers (ISPs), cable companies, private network operators, and utility companies. Such carriers can often offer new services for less cost than older ones. Much of the cost savings is due to reducing unnecessary layers of equipment, which also lowers operational costs and simplifies the network architecture. Carriers can create revenue today by providing protocol transparent, high-speed LAN and SAN services to large organizations, as well as a mixture of lower-speed services (Token Ring, FDDI, Ethernet) to smaller organizations. In implementing an optical network, they are ensuring that they can play in the competitive field of the future.

III. RAMAN AMPLIFICATION IN DWDM SYSTEM

Raman amplification is based on stimulated Raman scattering (SRS) a non-linear effect in fiber optical transmission that results in signal amplification if optical pump waves with the correct wavelength and power are launched into the fiber [4]. One of the most recent and interesting developments includes the constructive usage of the so-called Raman effect in optical amplifiers [8]. A Raman amplifier uses intrinsic properties of silica fibers to obtain signal amplification. This means that transmission fibers can be used as a medium for amplification, and hence that the intrinsic attenuation of data signals transmitted over the fiber can be combated within the fiber. An amplifier working on the basis of this principle is commonly known as a distributed Raman amplifier (DRA). The physical property behind DRAs is called SRS. This occurs when a sufficiently large pump is co-launched at a lower wavelength than the signal to be amplified. The Raman gain depends strongly on the pump power and the frequency offset between pump and signal. Amplification occurs when the pump photon gives up its energy to create a new photon at the signal wavelength plus some residual energy, which is absorbed as phonons (vibrational energy) as shown in figure 2.

As there is a wide range of vibrational states above the ground state, a broad range of possible transitions, are providing gain. This is shown by figure 2. Generally, Raman gain increases almost linearly with wavelength offset between signal and pump peaking at about 100 nm and then dropping rapidly with increased offset. Figure 3 shows a typically measured Raman gain curve [9]. The position of the gain bandwidth within the wavelength domain can be adjusted simply by tuning the pump wavelength. Thus, Raman amplification potentially can be achieved in every region of the transmission window of the optical transmission fiber. It only depends on the availability of powerful pump sources at the required wavelengths. The disadvantage of Raman amplification is the need for high pump powers to provide a reasonable gain. This opens a new range of possible applications. It is possible, for instance, to partially compensate fiber attenuation using the Raman effect and, thus, to increase the EDFA locations. This saves coasts as less EDFAs are needed on the link, and the number of sites to be maintained is reduced [8], [11].

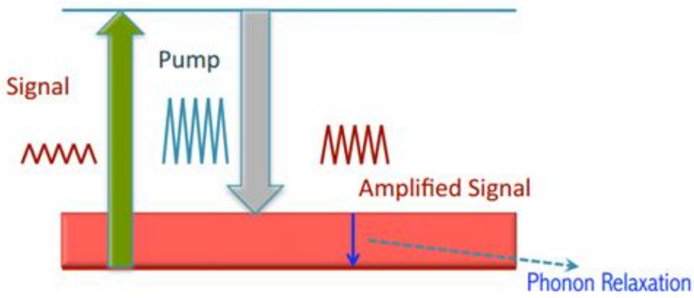

Fig. 2: System Configuration [8]

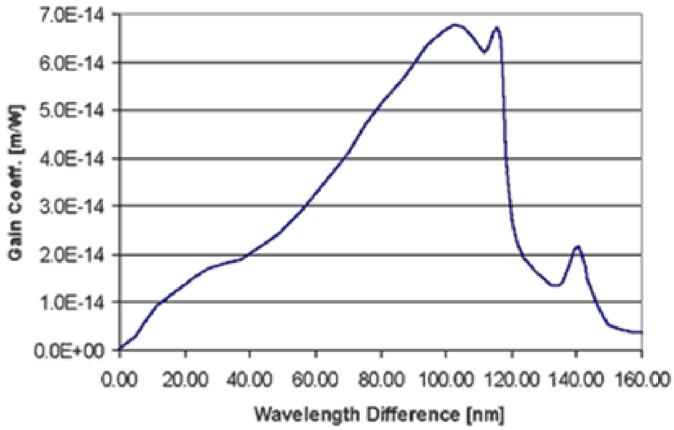

Fig. 3: Typical Raman gain curve versus wavelength offset [9]

Raman amplifiers offer several advantages compared to EDFAs, including the following:

- Low noise build-up.
- Simple design, as direct signal amplification is achieved in the optical fiber, and no special transmission medium is needed.
- Flexible assignment of signal frequencies.
- Broad gain bandwidth.

However, despite the many advantages of Raman amplification, there can be some degradation effects. For example, not only the specially launched pump waves but also some of the WDM channels may provide power to amplify the other channels. This would result in power exchange between WDM channels and thus cross-talk leading to signal degradation. These negative effects occur in unidirectional and bidirectional WDM transmission. So for accurate analysis of advanced WDM systems, it is crucial to model all Raman interactions. Additionally, degrading effects like spontaneous Raman scattering and backward Rayleigh scattering have to be considered. Raman amplifiers are topologically simpler to design than doped-fiber amplifiers, as the existing transmission fiber can be used as a medium if properly pumped. However, the selection of pump powers and wavelengths, as well as the number and separation of pumps, strongly determines the wavelength behaviour of Raman gain and noise.

When building distributed Raman amplifiers, designers face the question of using forward or backward pumping (or even both) with respect to signal propagation. The backward pumping scheme is most commonly used as it offers several advantages. Pump noise strongly affects the WDM signals to be amplified if forward pumping is applied, as the Raman process is nearly instantaneous [5], [6]. When the Raman pump wave has slight random power fluctuations in time, which is almost always the case, individual bits might be amplified differentially, which leads to amplitude fluctuations or jitters. If backward pumping is applied the amplitude fluctuations will be averaged out [7].

4. 40 Gbps DWDM Link with Backward Pumped Raman Amplification

This example simulates a realistic scenario of a 40Gbps DWDM link with inter-channel spacing of 50 GHz. Forty individual channels carrying PRBS data are transmitted over a 50 km length of ITU-T G.652 single mode dispersive fiber. The design objective is to utilize distributed Raman amplification to compensate for the link attenuation thereby effectively increasing the inter-EDFA span in a longer-haul link. Figure 4 below shows a snap-shot of the layout. The multi-line capability of OptSims CW laser model makes it very convenient to generate the source-grid for simulating WDM channels.

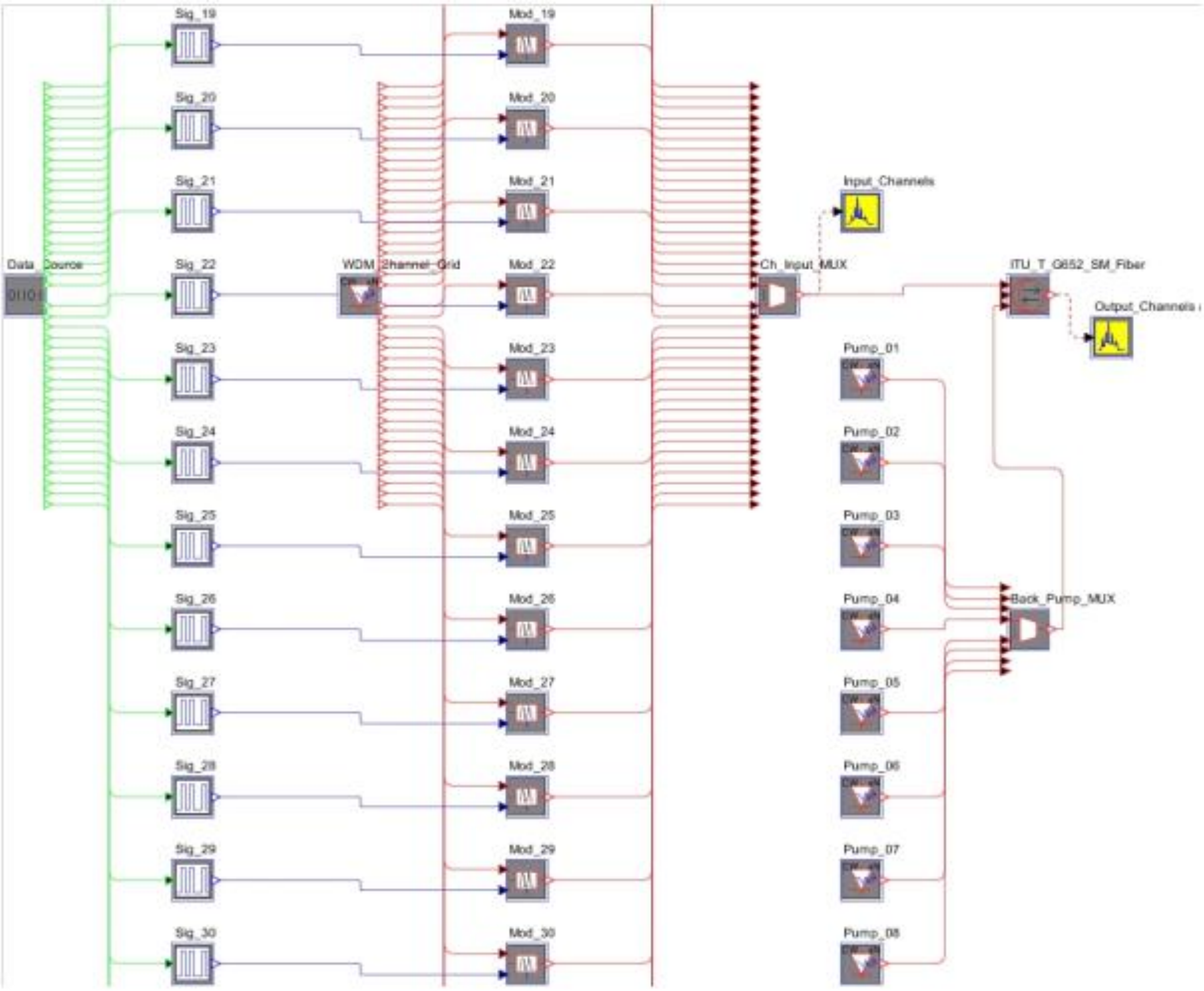

Fig. 4: Sectional snap-shot of a 40-channel DWDM link layout

4.1 Spectrum of Channels

Since backward pumping helps in averaging out power ripples at the receiver end, we choose a backward pumping scheme that employs eight CW pump signals with carefully chosen nominal wavelengths and power values. Figure 5 and figure 6 depicts spectra of input and output channels in presence of backward pumping respectively.

4.2 Backward Pump Characteristics

Raman amplification is a wide-band phenomenon having a highly irregular gain profile over wavelength. The highest Raman gain is observed for a frequency differential range (range of difference between pump signal and data signal nominal frequencies) of 8 to 12 THz. Outside this range, the gain profile exhibits a sharp decline. Therefore, if the number of pumps, their wavelengths, and the power values are chosen carefully, we can achieve the desired gain shape for the input DWDM channels. Figure 7 shows a graph of the backward output spectral density. It is observed that the pump is given at a wavelength of 1330 nm. Power of 0.44 W is launched in the backward channel at 1330 nm as shown in figure 8. It can also be observed that the noise power in the channel is very low. The backward gain ranges from -20 dB to -50 dB in the range of 1300 to 1400 nm as shown in figure 9. Outside this range the backward gain is as low as -66 dB. Figure 10 depicts the backward effective noise figure. Effective noise figure of approximately 40 dB is obtained at 1330 nm. The signal to noise ratio obtained is 180 dB as shown in figure 11.

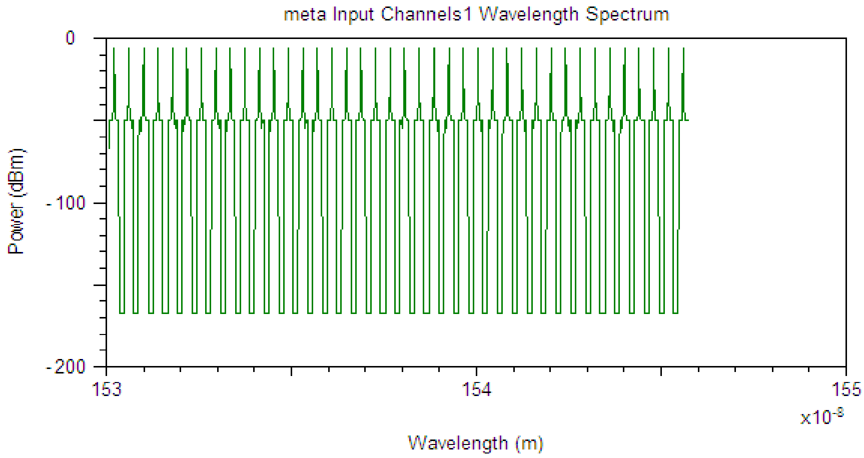

Fig. 5: 40 channel input wavelength spectrum

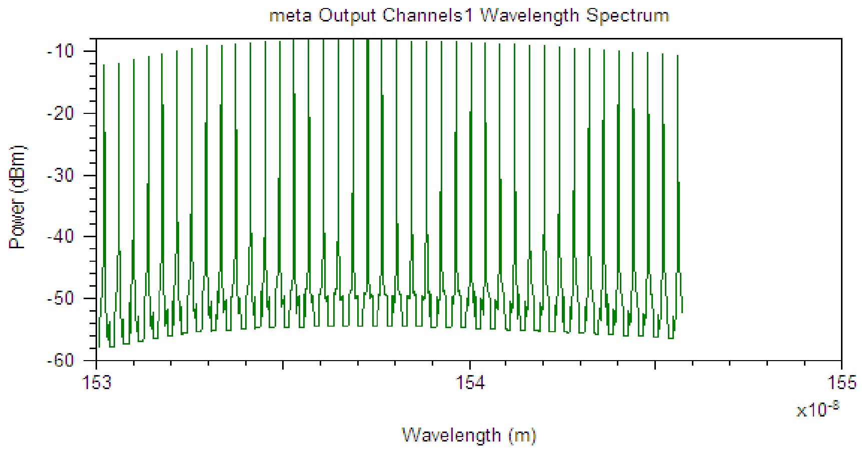

Fig. 6: Output with backward pumping

4.3 Characteristic of Output Signal

The output signal is observed at 1550 nm. As shown in figure 12, forward gain of 6.2 dB is obtained at 1550 nm. It can be seen in figure 13 that power of 1 mW is launched into the fiber at 1550 nm and a final power of 5 mW is obtained at 1550 nm. The forward effective noise figure is shown in figure 14. Effective noise figure of -3.35 dB is obtained at 1550 nm. Figure 15 shows that signal to noise ratio at 1550 nm is 40 dB.

4.4 Pump Evolution

The output spectrum above takes in to account the pump signal and the signal-signal interactions. Besides, the pumps interact with each other, too. Shorter wavelength pumps provide power to longer wavelength pumps. As a result, we can expect rise in longer wavelength pump powers and corresponding depletion of shorter wavelength pumps at the launch end of the fiber. The pump evolution and signal power evolution are shown in figure 16 and figure 17 respectively.

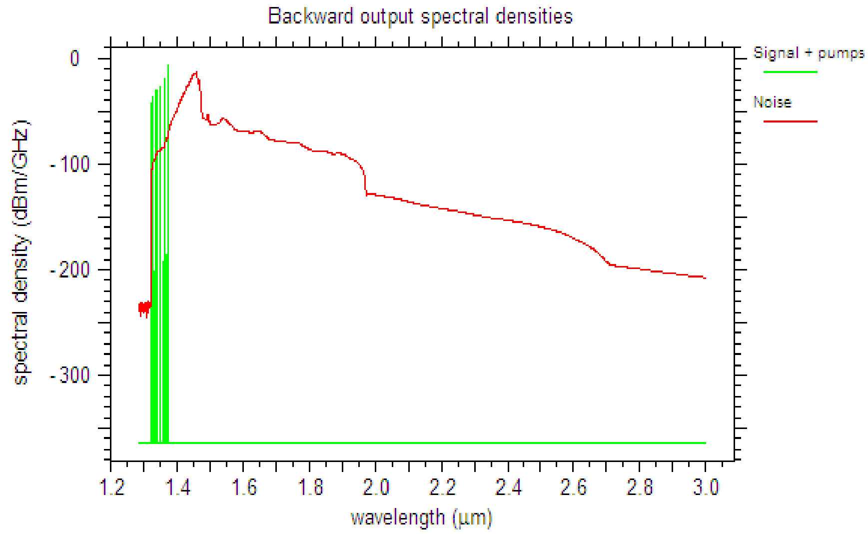

Fig. 7: Backward output spectral density

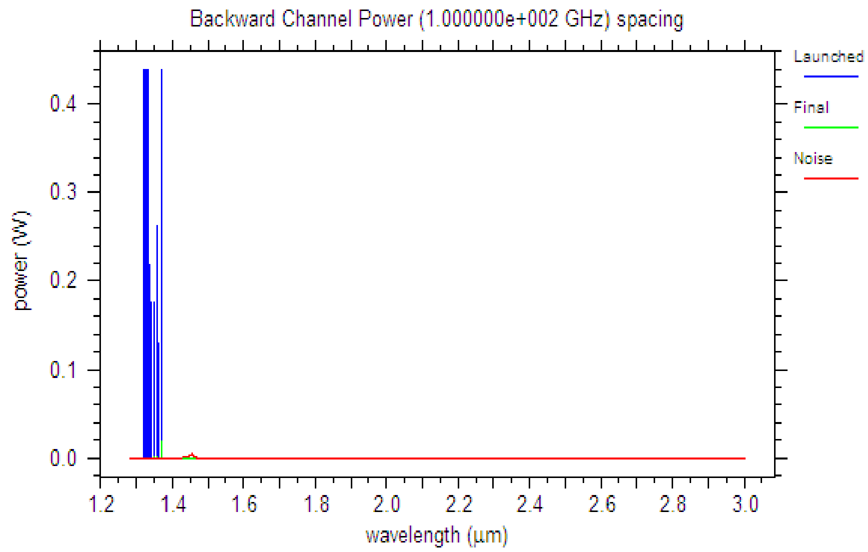

Fig. 8: Backward channel power

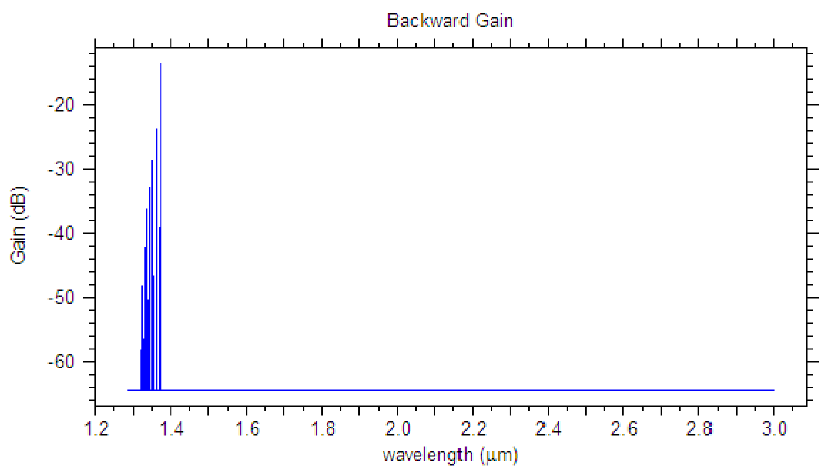

Fig. 9: Backward gain

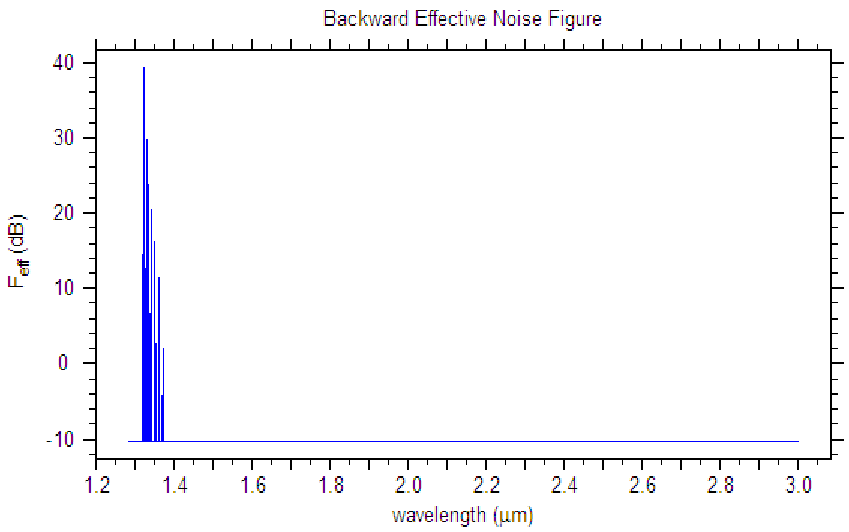

Fig. 10: Backward Effective Noise Figure

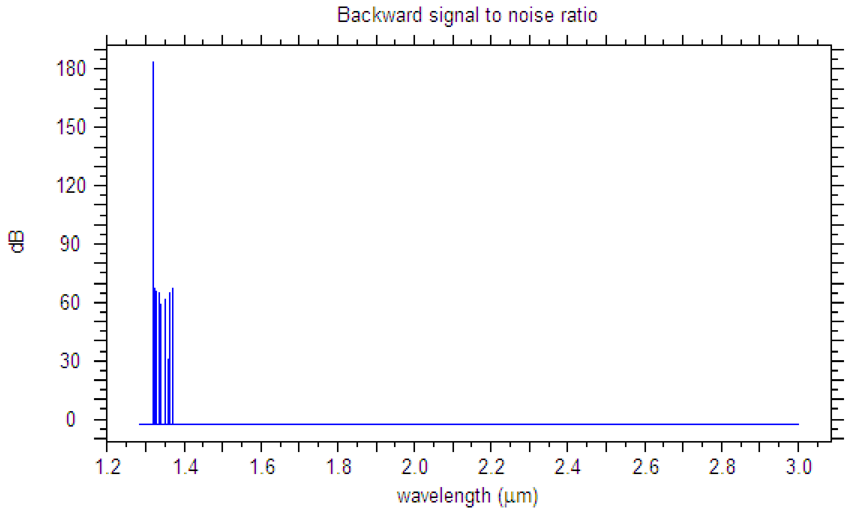

Fig. 11: Backward Signal to Noise Ratio

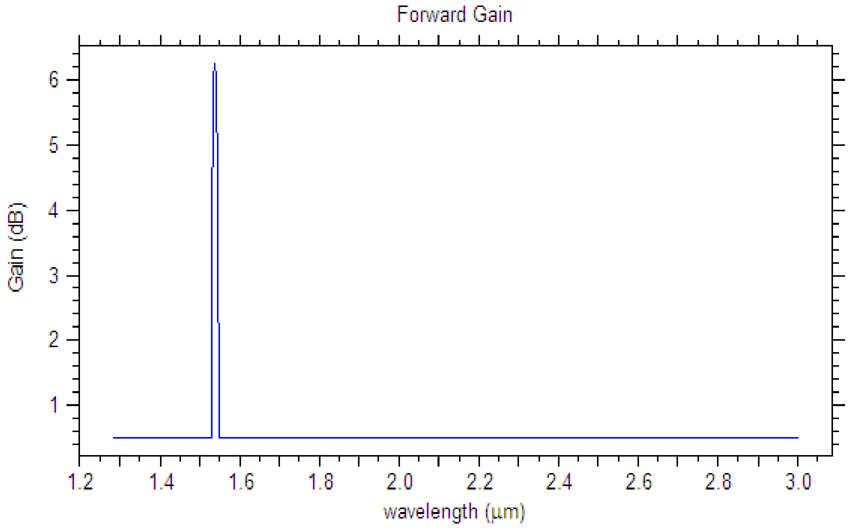

Fig. 12: Forward Gain

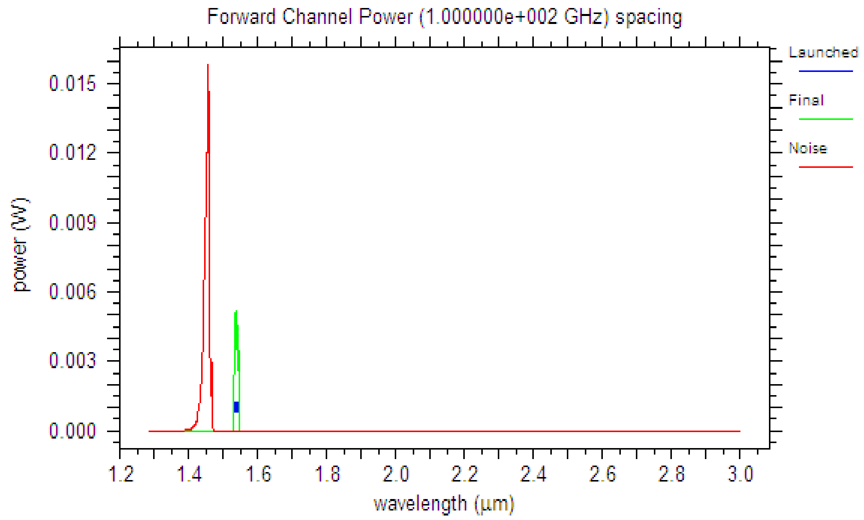

Fig. 13: Forward Channel Power

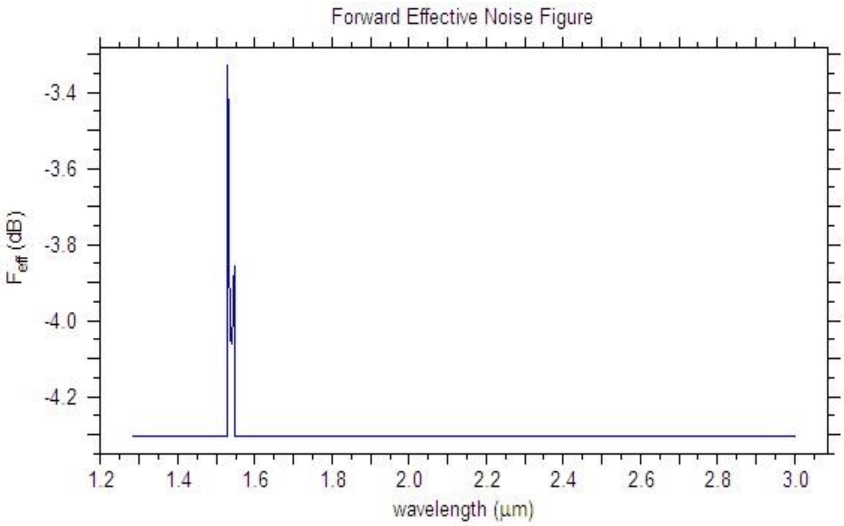

Fig. 14: Forward Effective Noise Figure

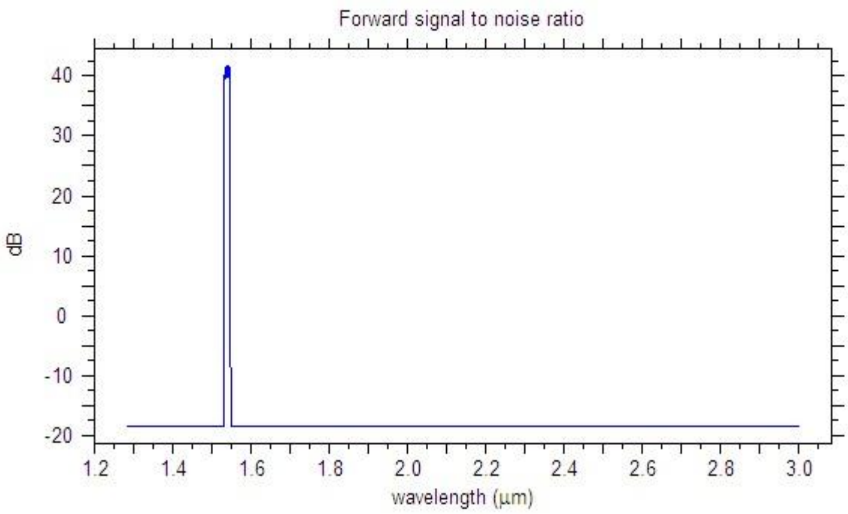

Fig. 15: Forward Signal to Noise Ratio

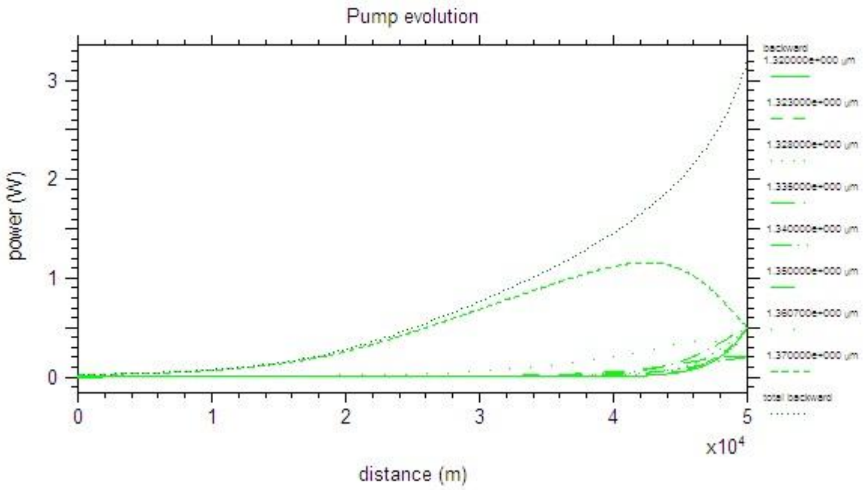

Fig. 16: Pump Evolution

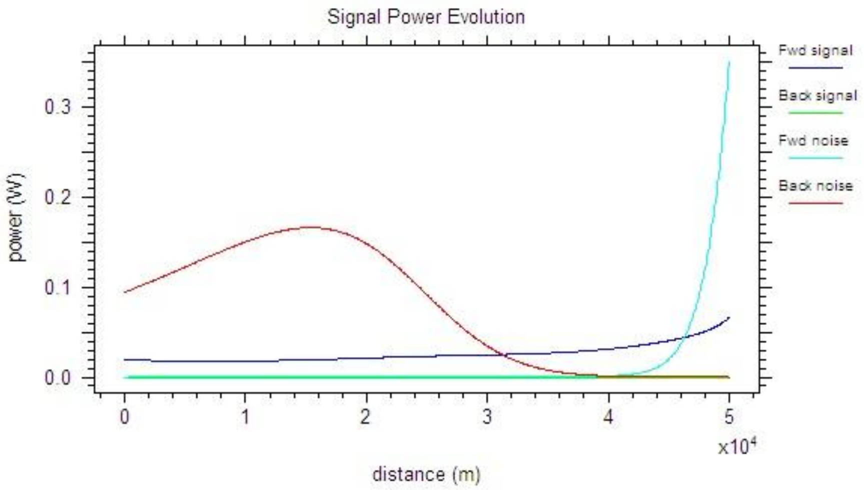

Fig. 17: Signal Power Evolution

IV. CONCLUSIONS

The advantages of fiber Raman amplifiers over the optical amplifiers include the possibility to operate in any wavelength region and superior noise performance of distributed amplification, as well as permits, with the appropriate choice of pump wavelengths and powers, flattening of the gain profile over the whole bandwidth. This report describes the simulation of a realistic scenario of a 40Gbps DWDM link with interchannel spacing of 50 GHz. Forty individual channels carrying PRBS data are transmitted over a 50 km length of ITU-T G.652 single mode dispersive fiber. The multi-line capability of OptSims CW laser model makes it very convenient to generate the source-grid for simulating WDM channels. Since backward pumping helps in averaging out power ripples at the receiver end, we chose a backward pumping scheme that employs eight CW pump signals with carefully chosen nominal wavelengths and power values. Power of 0.44 W is launched into the backward channel at 1330 nm. Noise figure of 40 dB is obtained at this wavelength. The output signal observed at 1550 nm has a gain of 6.2 dB and noise figure of -3.35 dB. Thus distributed Raman amplification is used to compensate for the link attenuation thereby effectively increasing the inter- EDFA san in a longer haul link.

V. ACKNOWLEDGEMENT

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