# Analysis of 16 x 10 Gb/s System with Hybrid Amplifier and FBG at Different Raman Pump Powers and Length

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## ABSTRACT
Dispersion has been a main limiting factor in optical communication transmission system. An optical communication system consisting of 16 channels, each operating at 10 Gbps based on EDFA-RAMAN hybrid amplifier and fiber Bragg grating is presented in this paper with single mode fiber as main channel of transmission. The use of FBG along with hybrid amplifier as dispersion compensator shows improved transmission performance in DWDM system. This paper simulates the optical communication system to investigate the effect of Raman pump power and RFA length on Q factor at different transmission distances and also measured other performance parameters such as BER, OSNR and eye diagram.

## Keywords
DWDM, RAMAN-EDFA, OSNR, RFA, BER, WDM, Q Factor

## 1. INTRODUCTION
Wavelength division multiplexing (WDM) is basically frequency division multiplexing in the optical frequency domain, where on a single optical fiber there are multiple communication channels at different wavelengths. A WDM system uses a multiplexer at the transmitter side to join the signals together and a demultiplexer at the receiver side to split them apart. By using WDM and optical amplifiers, they can accommodate several generations of technology development in their optical infrastructure [1]. DWDM is dense wavelength division multiplexing. DWDM technology uses multiple wavelengths to transmit information over a single fiber. Dense WDM is basically WDM utilizing closely spaced channels. Today the demand of network capacity increases. So to increase the information carrying capacity of the network the DWDM system is the most useful technique [2]. In DWDM system due to the attenuation and dispersion, there is degradation in transmission signal with the increase in distance. Dispersion is the main performance limiting factor in optical fiber communication that greatly hampers its performance. Due to dispersion, optical pulse broadens as it travels along the fiber. The dispersion is proportional to the length of the fiber. To remove loss limitations and to amplify the signal, the optical amplifiers are used which directly amplify the transmitter's optical signal without conversion to electric form. The optical amplifiers are mainly used for WDM light wave systems as all channels can be amplified simultaneously [3].

Erbium-doped fiber amplifiers (EDFAs), which have been widely used in the actual optical transmission systems are mainly used in 1.5–1.6 μm band amplification. EDFAs are of low noise, compact size, highly efficient with high gain and capable of amplifying multichannel signals on different wavelengths at one time and hence are quite economical for WDM transmissions. But its working under deeper saturation or having steeper saturation characteristic would result in less BER impairment [4]. But, fiber Raman amplifiers (FRA) in long distance transmission line can not only enlarge the characteristics of the elimination of noise accumulation but also can expand the bandwidth of the gain. Raman amplifiers improve the noise figure and reduce the nonlinear penalty of fiber systems, allowing for longer amplifier spans, higher bit rates and closer channel spacing [5]. A Raman amplifier used to enhance the OSNR and extend the repeaterless transmission distance with low receiver penalty. This technique however requires very high pump power and the low gain compression of Raman amplifiers can induce unstable system performance. Therefore, if Raman amplifier cascaded with erbium doped fiber amplifier called hybrid amplifier (HA), the SNR, Q factor and output power can be improved and bit error rate decreases. In order to improve the performance of amplifiers, hybrid optical amplifier is becoming a hot research topic. Usually, the gain of EDFA is not flat [6]. But Masuda and Kawai achieve the widest seamless 3.0-, 1.3-, and 1.0-dB bandwidths of 80, 76, and 69 nm with a novel discrete hybrid amplifier [7]. Due to the nonlinear nature of the propagation, the system performance depends upon power levels and good power level is achieved by hybrid optical amplifier as compared to alone EDFA.

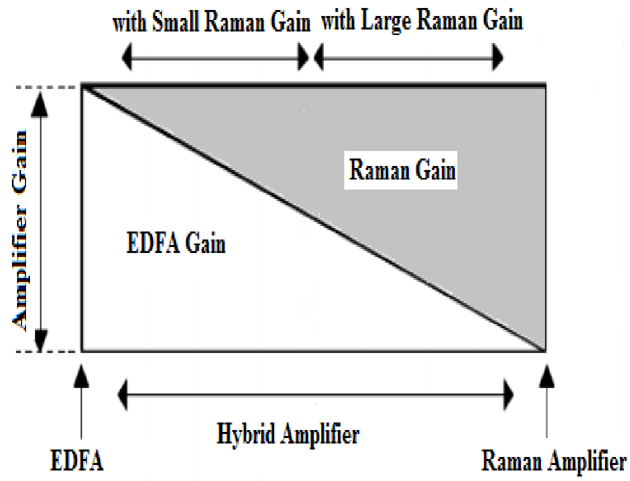


**Figure 1.Gain profile of hybrid amplifier**

Another component used in this paper for dispersion compensation is FBG. FBG is dynamic dispersion compensator which is a type of distributed Bragg reflector that reflects a particular wavelength of light and transmits all others. The FBG device is able to compensate chromatic dispersion at multiple variation of the wavelength. Therefore, it is the favoured solution for chromatic dispersion compensation. A Fiber Bragg Grating is either used as an inline optical filter to block definite wavelength or as a wavelength precise reflector. There is a periodic variation of refractive index in Bragg grating within the propagating medium. The fiber Bragg grating is made segmented with each segment having different refractive index. The chirped FBG is based on the principle of diffraction gratings or Fresnel reflection. Fresnel reflection is, where light travelling between media having different refractive indices may reflect or refract at the edge. This chirped FBG enables the grating to reflect various wavelengths at different points along its grating length. Therefore it sets off different delays for all the different frequencies or wavelengths. These reflected light signals combine to one large reflection at a particular wavelength in which the grating period is approximately half the input lights wavelength. This is Bragg condition and the wavelength at which reflection occurs is called Bragg wavelength. The Bragg wavelength is given by:

$\lambda_B = 2\tilde{n}\Lambda$

The shorter wavelength which travels faster will arrive at the FBG and get reflected further up the FBG where its Bragg condition is met. Hence, a longer delay is introduced for the shorter wavelength. The longer wavelength which travels slower will come across a shorter delay for decreasing grating period. The longer wavelengths are transmitted through to the very last part of gratings and shorter wavelengths are reflected by the initial part of grating. Due to this longer wavelength have to travel a longer distance, so they are delayed, allowing the shorter wavelength to reflect back soon for increasing grating period.

H.S. Chung et al. 2004 [8], successfully demonstrated a long-haul transmission of 16 x10 Gbit/s over single-mode fiber of 1040 km using combined Raman and linear optical amplifiers(RALOAs) as inline amplifiers.

The results offered the feasibility of the RALOAs as inline amplifiers for long distances although the Q-factors were lower than those in the transmission based on the EDFAs.

Chen Yong et al. 2005 [9], applied cascaded chirp fiber Bragg gratings (CFBGs) to compensate the dispersion of 8x10 Gb/s WDM system. The ASE of the EDFA was reduced and the OSNR of transmitted signal increased. The experimental result showed that after 2015 km transmission, the uniformity of the dispersion compensating for each channel was perfect and the CFBGs decrease the transmitted signal's OSNR distortion enormously. The system was economized because of the EDFA-CFBG design.

E. J. Gualda et al. 2004 [10], presented a scheme to enhance the performance of an ultrahigh capacity (100 Gb/s) long haul transmission system that makes use of chirped fibre Bragg gratings (FBG) for dispersion slope compensation. It was shown that the FBG effectively compensate the dispersion slope while at the same time provided appropriate in-line filtering.

Unlike the previous work [8] with the hybrid amplifiers based on LOAs, we used EDFA-RAMAN and FBG together to evaluate the performance of DWDM system taking into account the dispersion inoccuring along the transmission link.

## 2. SIMULATION SETUP

In this model, sixteen channels are transmitted at 10 Gb/s speed with 100 GHz channel spacing. Each input signal is modulated in NRZ format and pre-amplified by a booster. The amplified signals are send to the channel where these signals are transmitted over DS anomalous fiber of different transmission distance. Non linearities are not taken into account and the effect on all the sixteen channels is observed.

Optisystem is a pioneering optical communication system simulation package that designs, tests and optimizes virtually any type of optical link in the physical layer of a broad spectrum of optical networks from analog video broadcasting systems to intercontinental backbones. It is a system level simulator based on the realistic modelling of fiber-optic communication systems. It possesses a powerful new simulation environment and a truly hierarchical definition of components and systems. Its capabilities can be extended easily with the addition of user components, and can be seamlessly interfaced to a wide range of tools.

A transmitter compound component (T) is built up using sixteen transmitters. In transmitter compound each transmitter section consists of the data source, electrical driver, laser source and external Mach–Zehnder modulator. The data source is generating signal of 10 Gb/s with pseudo random sequence. The electrical driver converts the logical input signal into an electrical signal. The CW laser sources generate the 16 laser beams at 191.5–193.2 THz with 100 GHz channel spacing. These beams have random laser phase and ideal laser noise bandwidth. The signals from data source and laser are fed to the external Mach–Zehnder modulator ($sin^2$_M for all configurations), where the input signals from data source are modulated through a carrier. The amplitude modulator is a sine square with an excess loss of 3 dB.

The simulation setup of transmission link using hybrid amplifier (EDFA-RAMAN) and FBG at different transmission distances is shown in Figure 2. EDFA-RAMAN combination of amplifiers is providing better results than RAMAN-EDFA. The output optical signal of the modulator is fed to the channel where a booster is used to boost up the signal. This optical signal is transmitted and measured over different distances for 50, 100, 150, 220 and 300 km at 16.75 ps/nm/km dispersion. The reference wavelength and attenuation for this model is choosed to be 1550 nm and 0.2dB/km respectively.

The optical power meters and optical spectrum analyzers are used to measure the power and spectrum at different levels. The modulated signal is converted into original signal with the help of PIN photodiode and filters. A compound receiver is used to detect all sixteen signals and convert these into electrical form. The setup is repeated for measuring the signal strength at different Raman pump powers and RFA length for various transmission distances. Different results like eye diagram, Q-factor and BER are measured. Optical signal to noise ratio(OSNR) is also calculated for all transmission lengths.

OSNR for each transmission distance is calculated as below:

OSNR (dB) = 0.5Q (Q+1.414)

The fixed output power EDFA is used for amplification with output power as 10 dBm and gain shape is kept flat. The various parameters for RAMAN are: Operating temperature is 300 K and pump wavelength is 1440 nm. The input power is kept constant for all distances and is taken as -10dBm. This value of power is providing optimum Q factor and OSNR.

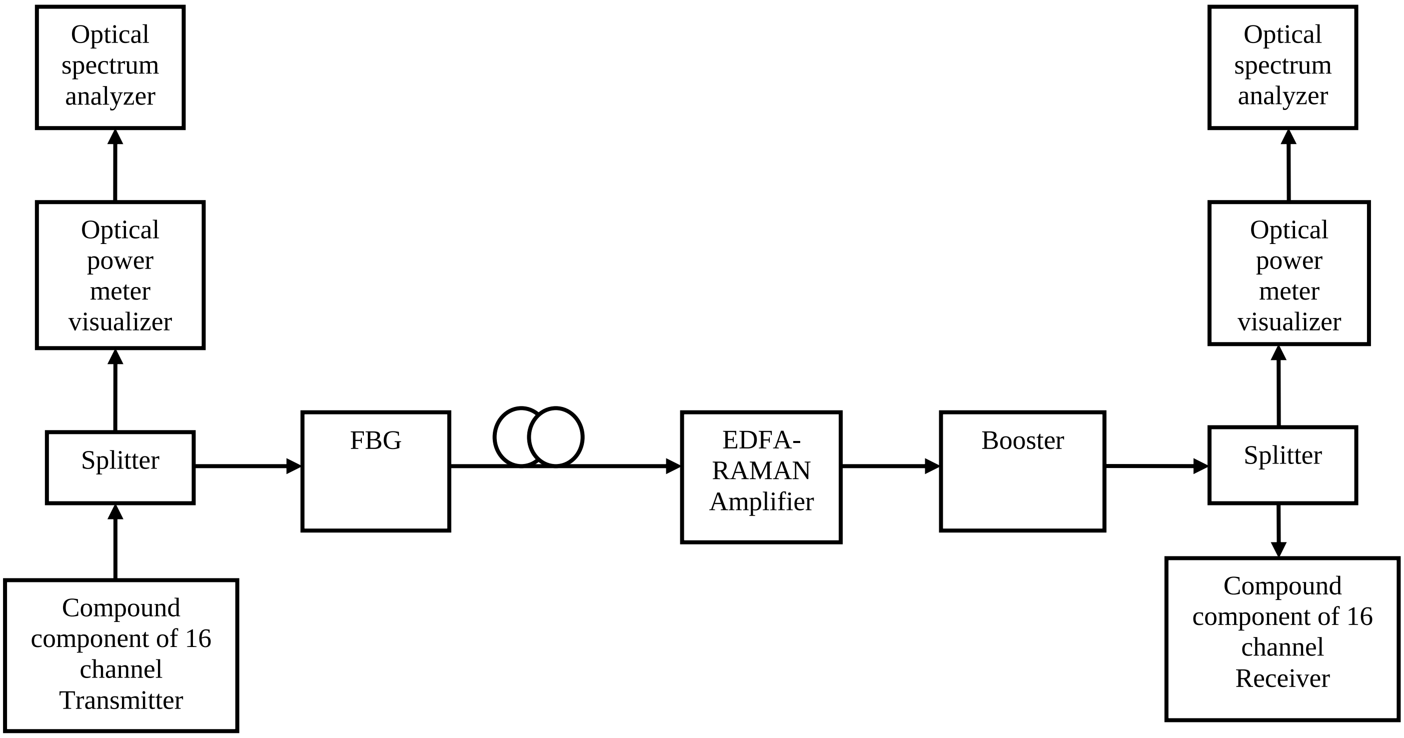


**Figure 2.Block diagram for simulation setup**

## 3. RESULTS AND DISCUSSION

The simulation and optimization of the design is done by Optisystem 7 simulation software. The BER, Q factor and eye diagrams are observed for different parameters of components at different lengths of fiber. All the varied values of RFA, EDFA and FBG dispersion are grouped in following Tables. The related graphs are also plotted.

**Table 1: The EDFA gain, RFA length and pump power for different fiber lengths are tabulated as under:**

| Fiber Length (Km) | EDFA Gain (dB) | RFA Length (Km) | RFA Pump Power (mW) | Dispersi o-n of FBG |
|---|---|---|---|---|
| 50 | 20 | 35 | 50 | -900 |
| 100 | 20 | 31 | 100 | -1800 |
| 150 | 20 | 10 | 700 | -2700 |
| 220 | 30 | 10 | 990 | -3800 |
| 300 | 40 | 10 | 1100 | -5500 |

**Table 2: The various outputs of designed model for parameters tabulated in table 1 are summarised as:**

| Fiber Length (Km) | Q Factor | BER | OSNR (dB) |
|---|---|---|---|
| 50 | 113.58 | 0 | 6530.50 |
| 100 | 75.14 | 0 | 2876.13 |
| 150 | 54.24 | 0 | 1509.33 |
| 220 | 18.10 | 1.28e-073 | 176.60 |
| 300 | 6 | 8.14e-010 | 22.24 |

It is seen that with increase in distance the Q factor goes on decreasing for the same simulation design. The BER is zero for 50, 100, 150 Km but got the above values for 220 and 300 Km. The non linear effects are not taken into account as input power is kept constant for all distances i.e. -10 dBm. At this same value of power the Q factor decreases because of increase in fiber losses along its length. Further increase or decrease in EDFA gain, Raman length and Raman power degrade the performance. The values tabulated in Table 1 and Table 2 are giving highest Q factor at that particular fiber length. Following are the eye diagrams for simulated model.

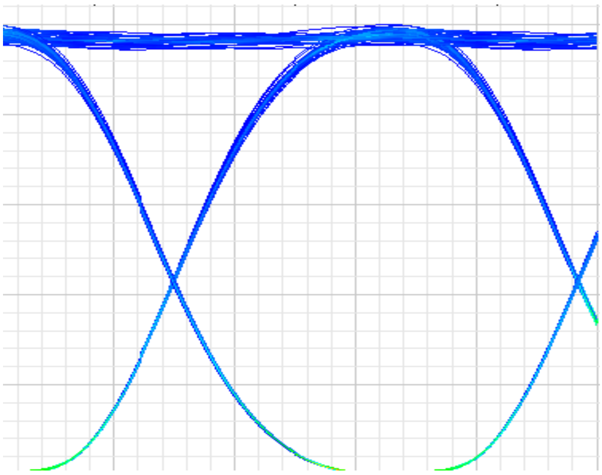

**Figure 3.Eye diagram for 50 km fiber length**

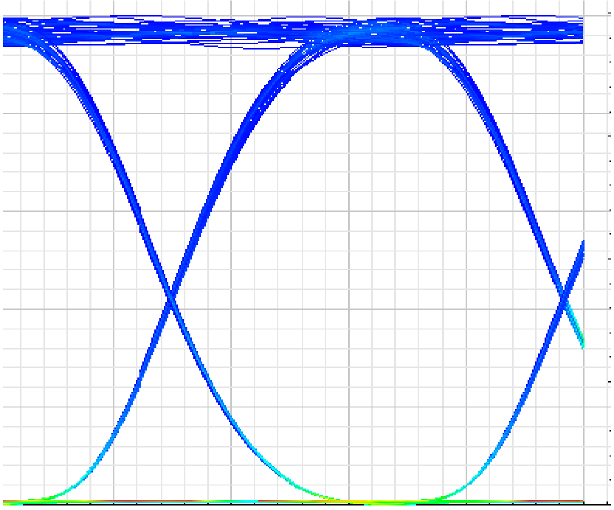

**Figure 4.Eye diagram for 100 km fiber length**

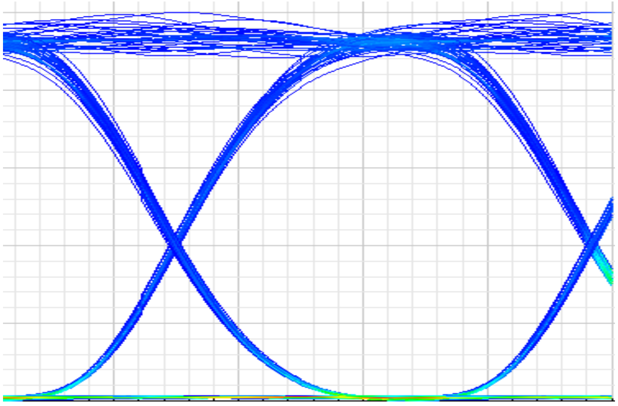

**Figure 5.Eye diagram for 150 km fiber length**

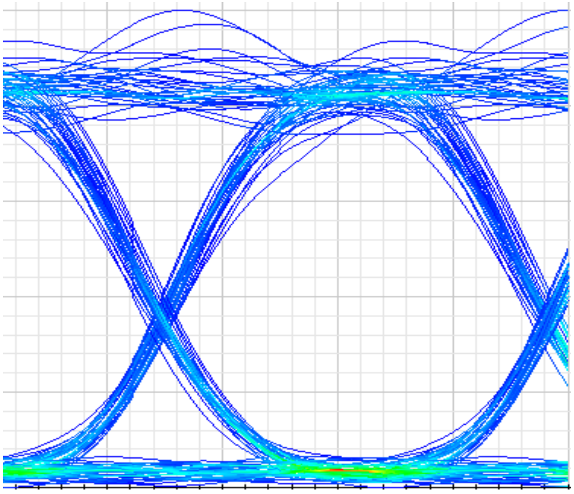

**Figure 6.Eye diagram for 220 km fiber length**

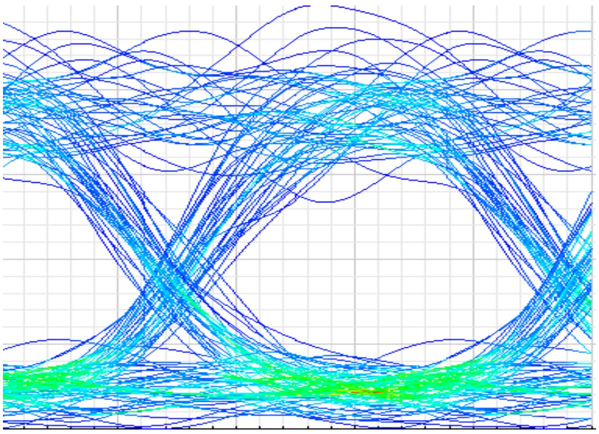

**Figure 7.Eye diagram for 300 km fiber length**

From the above eye diagrams it is seen that the eye opening is more precise for smaller fiber lengths. With the increase in distance ISI is induced due to which different channels are received at different times resulting into timing jitter and also OSNR decreases with increase in distance. Now the variation of Q factor with Raman pump power and Raman length is shown in Figure 7 and 8 respectively.

The Raman pump power actually decides the gain of Raman amplifier which will further flatten the EDFA gain. From figure 7 it is observed that maximum Q factor is obtained at some specific value of pump power for that particular fiber length.

Figure 8 shows that there is one particular Raman length for which optimum results are obtained. The advantage of using distributed Raman optical fiber is that the whole fiber can be transformed into amplifier by using a suitable pump power. There is not any need of inserting a separate spool of length segment for amplification as loss is associated with insertion of each new component into the link.

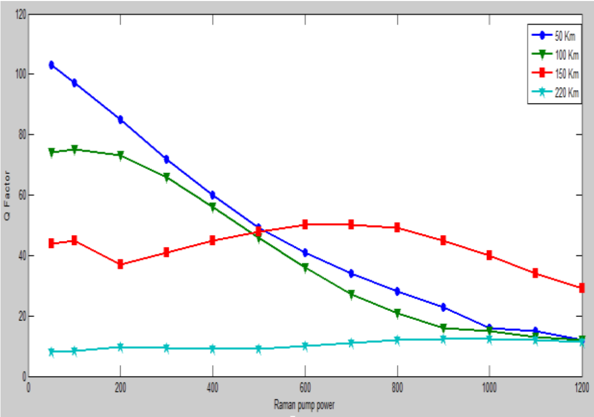


**Figure 8.Q Factor versus Raman pump power**

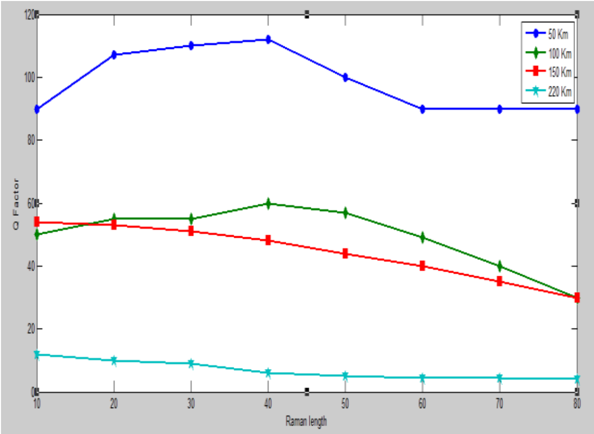


**Figure 9.Q Factor versus RFA Length**

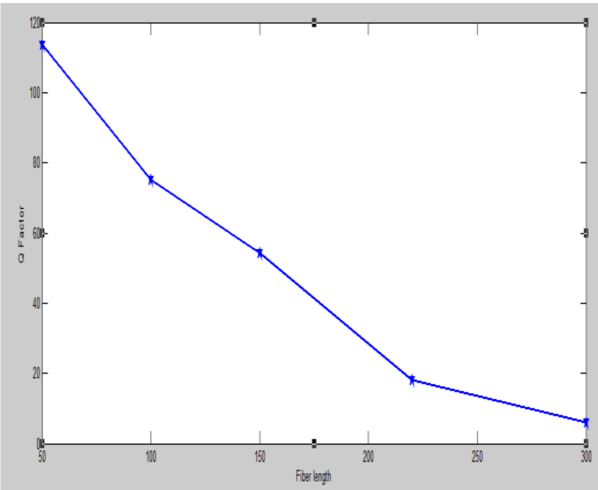


**Figure 10.Transmission length versus Q Factor**

Now figure 9 describes overall performance of designed model. It shows graph between Q factor obtained at different segments of optical fiber length.

Very clearly it is seen that Q factor decreases with increase in transmission distance because of losses inoccuring within the fiber. To compensate for these losses appropriate number of inline amplifiers with suitable noise figure, gain and attenuation are to be inserted within transmitter and receiver.

## 4. CONCLUSION

We have analyzed the 16 channel DWDM system at 10 Gbps with hybrid amplifiers and FBG at different transmission distances. FBG along with hybrid amplifier gives much better results than hybrid amplifier alone. The parameters of EDFA-RAMAN and FBG are adjusted at 50, 100, 150, 220 and 300 Km fiber length individually to obtain maximum possible Q factor at that particular length. We observed that with increase in transmission distance the Q-factor decreases and BER increases even though we have adjusted the parameters to their optimum value. Just one value of RFA pump power (in mW) and RFA length (in Km) is not sufficient for entire transmission link. For each link distance there are different values of link component parameters which will provide the best results.

## 5. REFERENCES

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