Analysis of Stimulated Raman Scattering for Various Power Levels and Spacings of Individual Channels in Dwdm System

M. Ganesh Babu

Abstract — **The Non-linear optical phenomena greatly enhanced our knowledge about interaction of light with matter and created a dramatic change in optics technology. Stimulated Raman scattering effect is one of the major Non-linear effects in the Dense wavelength division multiplexed (DWDM) fiber optics communication systems. The effect of SRS causes power to be transferred from lower wavelength channels to higher wavelength channels. This unwanted Power tilt will reduce the optical signal to noise ratio (OSNR) which in turn increases the Bit Error Rate (BER). SRS effect could be reduced by setting optimum power in the fiber. It is observed that by setting unequal channel spacing in the fiber, the unwanted Power tilt is getting reduced. SRS has very little impact on system performance for a single channel system. The different DWDM system for various power levels and channel spacings of individual channels is stimulated in the sample mode of OPTSIM software for getting the effects of SRS like Power tilt in the optical spectrum, after the fiber. Power Tilt in the DWDM spectrum for various power levels has been measured.**

Keywords—**Optical Fiber Communication, Power Tilt, Fiber Nonlinearity, DWDM, SRS, BER and OSNR**

I. INTRODUCTION

Fiber optic communications have provided us with high-speed communications with enormous bandwidth potential. Although fibers can support very high data rates, the associated electronic processing hardware will typically not be able to cope up with such high speeds [1]. Light has an information-carrying capacity 10,000 times greater than the highest radio frequencies. Additional advantages of fiber over copper include the ability to carry signals over long distances, low error rates, immunity to electrical interference, security, and light weight.

Early WDM begun in the late 1980s using the two widely spaced wavelengths in the 1310 nm and 1550 nm (or 850 nm and 1310 nm) regions, sometimes called wideband WDM. The early 1990s saw a second generation of WDM, sometimes called narrowband WDM, in which two to eight channels were used. These channels were now spaced at an interval of about 400 GHz in the 1550-nm window [2].

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By the mid-1990s, Dense WDM (DWDM) systems were emerging with 16 to 40 channels and spacing from 100 to 200 GHz. By the late 1990s, DWDM systems had evolved to the point where they were capable of 64 to 160 parallel channels, densely packed at 50 or even less than 25 GHz intervals. In an Optical communication system, the term nonlinearity refers to the dependence of the system parameters on power of the optical beam being launched into the fiber cable. Several experiments in the past have shown that the deployment of high-bit-rate multiwavelength systems together with optical amplifiers creates major non linear effects such as Stimulated Raman Scattering (SRS), Stimulated Brillouin Scattering, and Four Wave Mixing (FWM) [1,9].

The system design engineers should not deploy high bit-rate multiwavelength systems without considering the nonlinear effects and their impact on these systems. The advantages and disadvantages of the above mentioned nonlinear effects are to be seen in order to decide whether they affect the performance of these systems in a positive way or a negative way. The nonlinear effects depend on the transmission length of the optical fiber. The longer the optical fiber and more optical power are available over its length, the more the light interacts with the fiber material and the greater the nonlinear effects. On the other hand, if the power decreases while the light travels along the optical fiber, the effects of nonlinearity diminish [10].

II. DWDM SYSTEMS

WDM is nothing but N independent optically formatted information streams each transmitted at a different wavelength are combined with optical multiplexer and send over the same fiber. The wavelength in WDM must be properly spaced to avoid inter channel interference. Dense wavelength division multiplexing (DWDM) is a technology that puts data from different sources together on an optical fiber, with each signal carried at the same time on its own separate light wavelength. Using DWDM, up to 80 (and theoretically more) separate wavelengths or channels of data can be multiplexed into a light stream transmitted on a single optical fiber. Each channel carries a time division multiplexed (TDM) signal. In a system with each channel carrying 2.5 Gbps (billion bits per second), up to 200 billion bits can be delivered a second by the optical fiber. DWDM is also sometimes called Wave division multiplexing (WDM). DWDM technology utilizes a composite optical signal carrying multiple information streams each transmitted on a distinct optical wavelength. Although Wavelength Division Multiplexing has been a known technology for several years, its early application was restricted to providing two widely separated "wideband" wavelengths, or to manufacturing components that separated up to four channels.

DWDM has been proven to be one of the most capable technologies for communication systems. Although usually applied to optical networks (ONs), Wavelength Division Multiplexing (WDM), in general, is used to increase the capacity of existing networks by transmitting many channels simultaneously on a single fiber optic line.

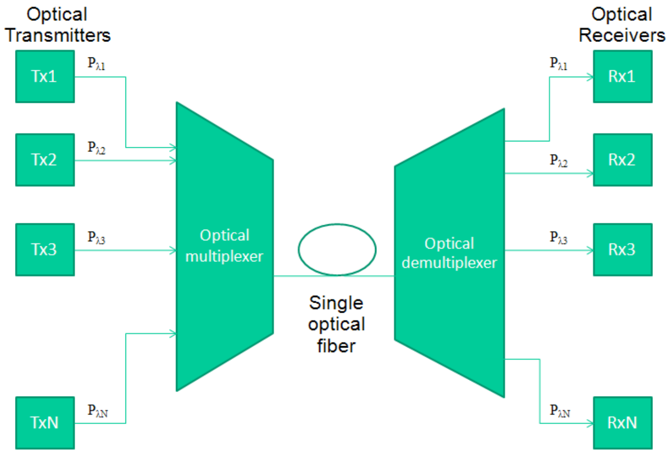

Figure 1. Dense Wavelength Division Multiplexing

In a simple DWDM system (Fig.1), each laser must emit light at a different wavelength, with all the lasers lights multiplexed together and sent into a single optical fiber. After being transmitted through a high bandwidth optical fiber, the combined optical signals must be demultiplexed at the receiving end by distributing the total optical power to each output port and then requiring that each receiver selectively recover only one wavelength by using a tunable optical filter. DWDM transmits multiple signals simultaneously at different wavelengths. This allows a single fiber to operate as if it were multiple fibers, referred to as "virtual fiber". Dense wavelength division multiplexing permits rapid network deployment and significant network cost reduction. In the few short years of deployment, DWDM performance has been improved dramatically.

III. FIBER NONLINEARITIES

Fiber nonlinearities become a problem when several channels coexist in the same fiber. Nonlinearity effects arose, when optical fiber data-rates, transmission lengths, number of wavelengths, and optical power levels are increased [8].

- Stimulated Brillouin Scattering (SBS)
- Stimulated Raman Scattering (SRS)
- Four-Wave Mixing (FWM)

A. Stimulated Brillouin Scattering

Stimulated Brillouin Scattering occurs when an optical signal power reaches a level sufficient to generate tiny acoustic vibrations in the glass. This can occur at powers as low as a few mill watts in single-mode fiber. Acoustic waves change the density of a material, and thus alter its refractive index. The resulting refractive-index fluctuations can scatter light, which is called Brillouin scattering [1, 2].

B. Stimulated Raman Scattering

It is the inelastic scattering of a photon. When light is scattered from an atom or molecule, most photons are elastically scattered **(**Rayleigh scattering**)**, such that the scattered photons have the same energy **(**frequency**)** and wavelength as the incident photons. However, a small fraction of the scattered light (approximately 1 in 10 million photons) is scattered by an excitation, with the scattered photons having a frequency different from, and usually lower than, the frequency of the incident photons [10]. In a gas, Raman scattering can occur with a change in vibrational, rotational or electronic energy of a molecule. Chemists are concerned primarily with the vibrational Raman Effect [7].

If two or more signals at different wavelengths are injected into a fiber, SRS causes power to be transferred from the lower-wavelength channels to the higher-wavelength channels. SRS effect is shown in the Figure 2.

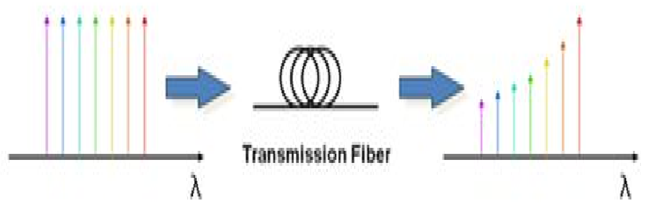

Figure 2. Stimulated Raman Scattering

SRS causes a short signal wavelength to behave as a "pump" for longer wavelengths, either other signal channels or spontaneously scattered Raman-shifted light. The shorter wavelengths is attenuated by this process, which amplifies longer wavelengths. SRS takes place in the transmission fiber. By using suitable Raman Pumps it is possible to implement a Distributed Raman Amplifier into the transmission fiber .

C. Four Wave Mixing

Four-wave mixing is an intermodulation phenomenon in optical systems, whereby interactions between 3 wavelengths produce a 4th wavelength in the signal. It is similar to the third-order intercept point in electrical systems. Four-wave mixing can be compared to the intermodulation distortion in standard electrical systems. FWM is the generation of new optical waves (at frequencies which are the mixing products of the originator signals.

Four-Wave Mixing (FWM) is also present if only three components interact. In this case the term

$$f_0 = f_1 + f_1 - f_2$$

couples three components, thus generating so-called degenerate four-wave mixing, showing identical properties as in case of four interacting waves. FWM is a fiber-optic characteristic that affects wavelength-division multiplexing (WDM) systems, where multiple optical wavelengths are spaced at equal intervals or channel spacing. The effects of FWM are pronounced with decreased channel spacing of wavelengths and at high signal power levels. High chromatic dispersion decreases FWM effects, as the signals lose coherence [7]**.** The interference FWM causes in WDM systems is known as interchannel crosstalk**.** FWM can be mitigated by using uneven channel spacing or fiber that increases dispersion.

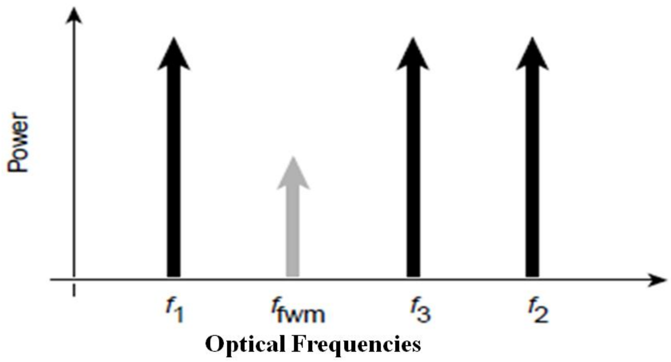

Figure 3. Four Wave Mixing

Effect of FWM is even more severe in the systems with inline optical amplification, as due the increase in effective length of the fiber, over which nonlinear interaction takes place, increases. When the different channels in the DWDM system are closely spaced, the probability of overlapping of FWM products on the input frequencies also increases. In a system with equally spaced channels, most of the original frequencies are getting overlapped by the interfering products. Also, when there is high input power per channel, the output FWM power is also high.

IV. ANALYSIS OF SRS IN DWDM SYSTEM DESCRIPTION

A model of optical communication link is stimulated using OPTSIM software. OPTSIM supports two simulation engines. They are Block mode simulation engine and Sample mode simulation engine. In Block mode simulation engine, signal data is represented as one block of data and is passed between block to block. In sample mode simulation engine, signal data is represented as single sample that is passed between block to block. In DWDM systems, Stimulated Raman Scattering (SRS) in Optical communication is the main parameter that has to be analyzed. When high intensity Optical input power is encountered is single mode fiber, the SRS effect will occur. Due to this SRS effect, the minimum power that could be sent through the fiber is reduced. By decreasing the value of input power and by giving Unequal channel spacing the SRS effect is decreased. In DWDM systems, due to SRS the Number of wavelength channels is increased as 4, 8, 16, 32, ..N. If the input power level is decreased, the Power Tilt (difference between the lower wavelength channel powers to the higher wavelength channel power in dBm) is also decreased. The simulation model for the analysis of SRS using Four channels and Thirty two channels is shown below.

D.Analysis of SRS Using 4- Channel

Fig 4 shows the Layout for 4-channel WDM system in Sample Mode. Consider 4 wavelength channels and all are having an equal power of 10mW (10dB) and Equal channel spacing and this is given to the Multiplexer.

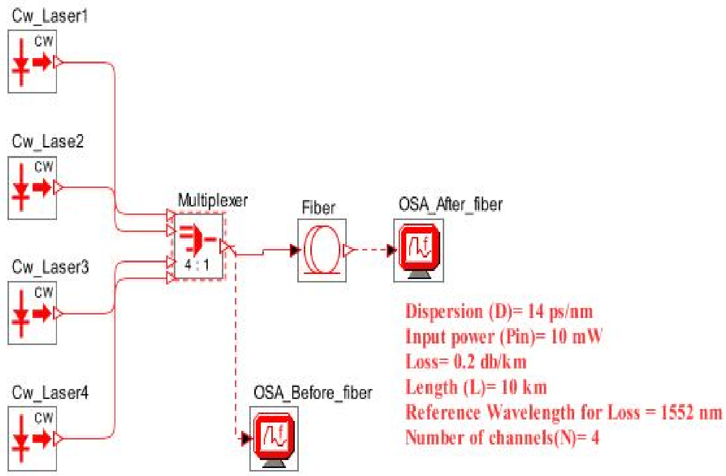

Figure 4. Layout for 4-channel WDM (with P_{IN}=10mW)

The output spectrum of the Multiplexer is shown in Figure 5. Then the Multiplexer output is given into the optical fiber. The properties of Optical Fiber (Raman Crosstalk "ON" condition is changed) and the output optical spectrum after the fiber is shown in Figure 6. Here power tilt (Δ) value is 2.39 dB.

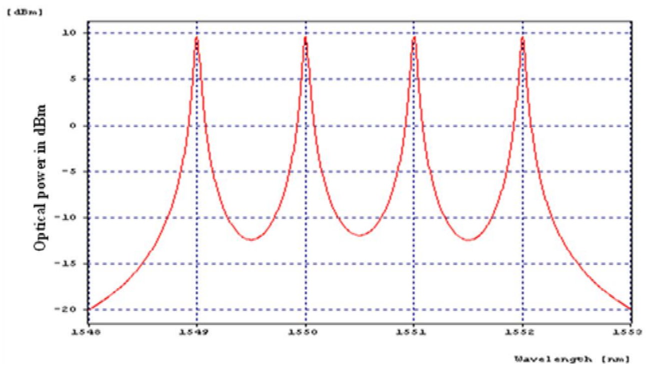

Figure 5. Optical Spectrum before the Fiber

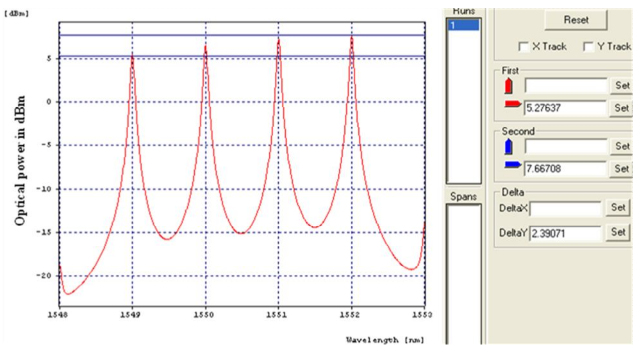

Figure 6. Optical Spectrum after the Fiber

Now consider 4 wavelength channels and all are having an equal power of 10mW (10dB) and Unequal Random order channel spacing and this is given to the Multiplexer. The output spectrum of the Multiplexer is shown in Figure 7. Then the Multiplexer output is given into the optical fiber. The properties of Optical Fiber (Raman Crosstalk "ON" condition is changed) and the output optical spectrum after the fiber is shown in Figure 8. Here power tilt (Δ) value is

2.17 dB. Now Power Tilt is reduced compare to Equal channel spacing.

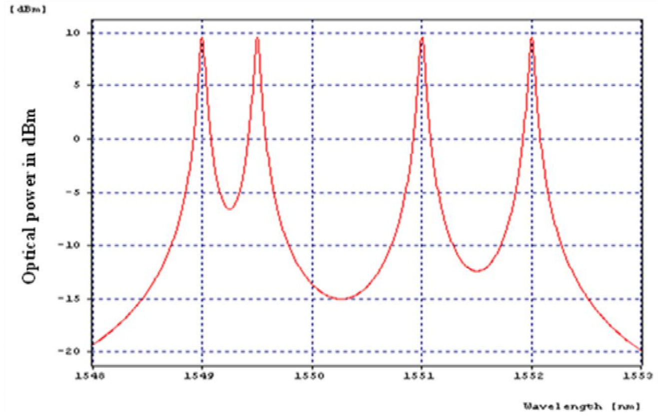

Figure 7. Optical Spectrum before the Fiber

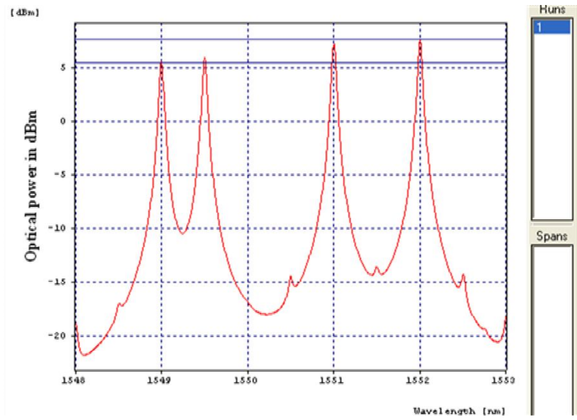

Figure 8. Optical Spectrum after the Fiber

E. Analysis of SRS Using 32-Channel

Fig 9 shows the Layout for 32-channel DWDM system in Sample Mode. Now consider 32 wavelength channels and all are having an equal power of 10 mW (10dBm) and Equal channel spacing and this is given to the multiplexer. The output spectrum of the multiplexer is shown in Figure 10. Then the multiplexer output is given into the optical fiber. The properties of optical fiber (Raman crosstalk "ON" condition is changed) and the output optical spectrum after the fiber is shown in Figure 11. Here power tilt (Δ) value is 46.03 dB.

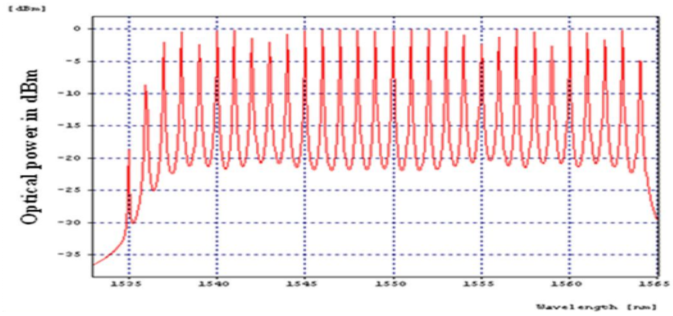

Figure 10. Optical Spectrum before the Fiber

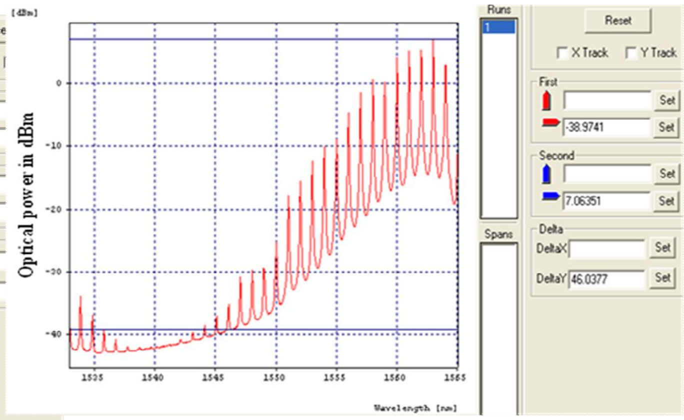

Figure 11. Optical Spectrum after the Fiber

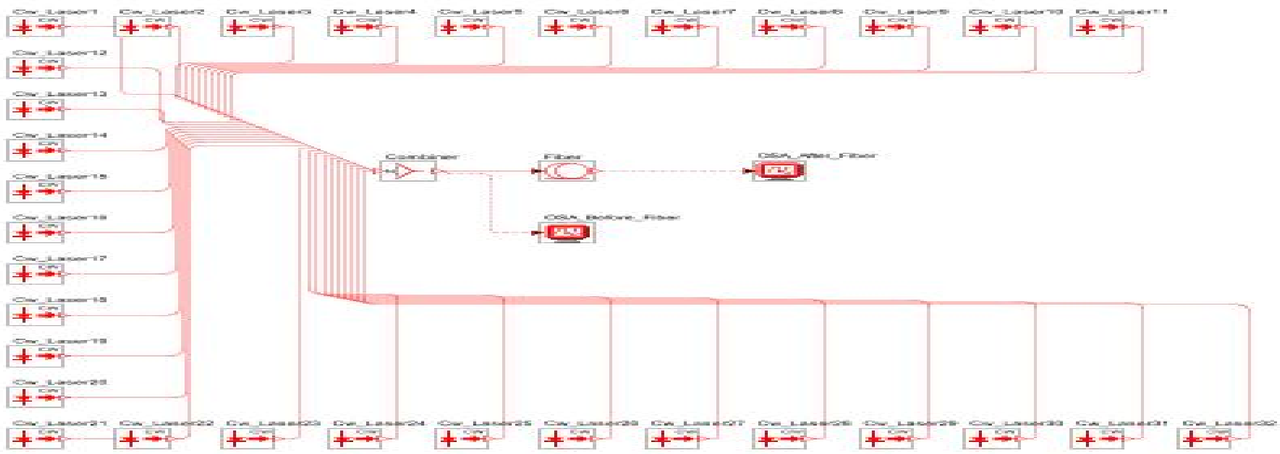

Figure 9.Layout for 32-channel DWDM (with P_{IN} = 10 mW)

Now consider 32 wavelength channels and all are having an equal power of 10 mW (10dBm) and Unequal Random order channel spacing and this is given to the multiplexer. The output spectrum of the multiplexer is shown in Figure 12. Then the multiplexer output is given into the optical fiber. The properties of optical fiber (Raman crosstalk "ON" condition is changed) and the output optical spectrum after the fiber is shown in Figure 13. Here power tilt (Δ) value is

45.68 dB. Now Power Tilt is reduced compare to Equal channel spacing.

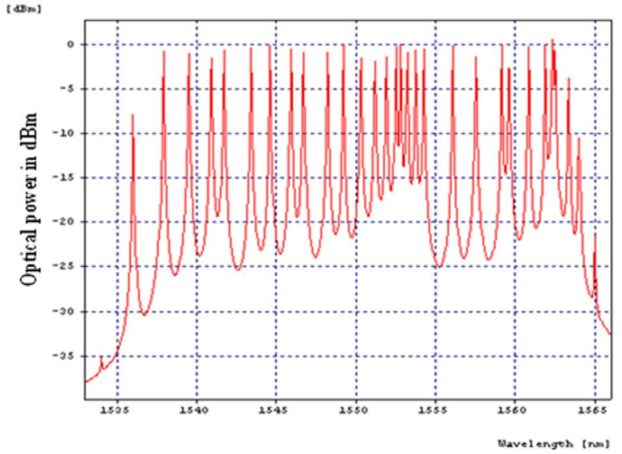

Figure 12. Optical Spectrum before the Fiber

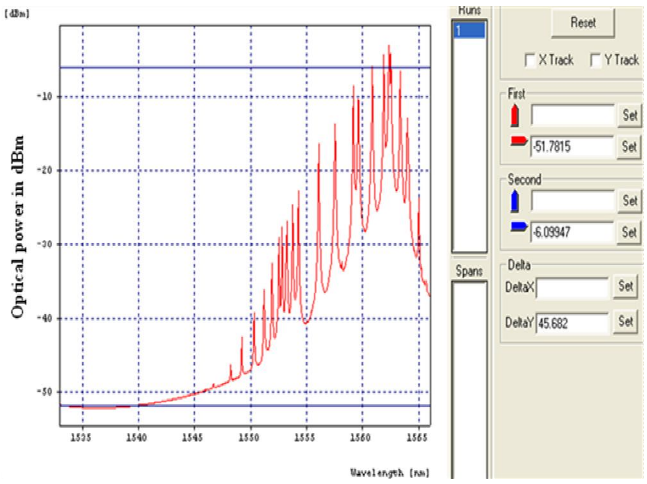

Figure 13. Optical Spectrum after the Fiber

V. NUMERICAL RESULTS

TABLE 1
Optical Power Tilt Vs Input Power

Input Power (mW)	Number of Channels (N)	Power Tilt (Δ) in dBm for Equal spacing	Power Tilt (Δ) in dBm for Unequal spacing		
			Random order	Ascending order	Descending order
1 mW	4	2.24	2.09	2.02	2.32
	8	9.35	9.26	9.24	9.37
	16	35.16	34.7	34.5	38.39
	32	46.03	45.68	44.85	48.25
	64	53.16	51.6	50.67	53.59
10 mW	4	2.32	2.14	2.09	2.47
	8	9.42	9.38	9.26	9.85
	16	37.16	36.18	36.11	36.36
	32	47.57	46.92	46.03	48.40
	64	54.08	52.78	51.03	54.98
20 mW	4	2.39	2.17	2.14	2.90
	8	9.61	9.55	9.43	9.96
	16	37.47	36.7	36.47	37.15
	32	48.69	48.04	47.87	49.01
	64	53.98	53.7	52.89	55.02

A.Matlab Results

Figure 14 and Figure 15 shows the SRS effect for different input optical power and for different channel spacing. In this graph, it is observed that the increase in optical input power leads to unwanted optical power tilt.

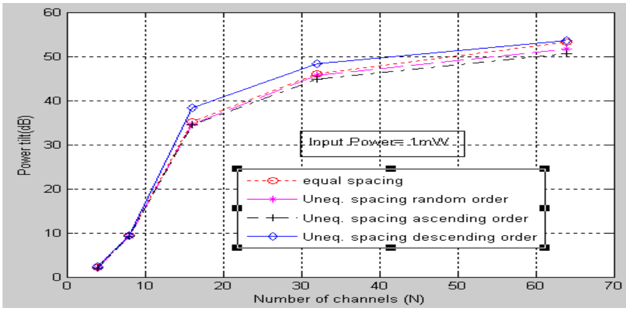

Figure 14. No. of Channels (N) Vs Power Tilt (dB) for P_{IN} = 1 mW

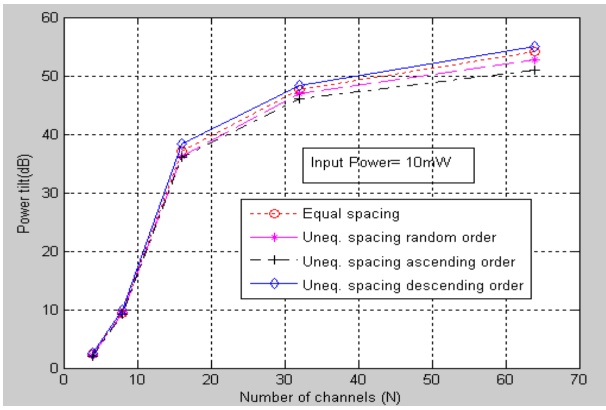

Figure 15. No. of Channels (N) Vs Power Tilt (dB) for P_{IN} = 10 mW

VI. RESULTS AND DISCUSSIONS

From the Figure 4 to 13 and Table 1, it is observed that the Optical Power tilt was decreased with the decrease in input optical power. When the maximum repeaterless transmission distance is increased in DWDM systems, then the required optical power level is increased (which will increase the unwanted power tilt). So the optical power level has to be decreased so that optical power tilt should not be increased. It is found that unequal channel spacing between channels can reduce the unwanted power tilt value. When the input optical power in the individual channel is increased, then unwanted power tilt is also getting increased. So unwanted power tilt is reduced by giving minimum input power, however by reducing the input optical power corresponding OSNR is getting reduced. So input optical power should not be too low and too high. 32-Channel DWDM system for various power levels of individual channels is simulated in the sample mode of OPTSIM software for getting the effect of SRS like Power Tilt in the optical spectrum. For an ideal system, Power tilt should be zero. In order to reduce the Power tilt value, minimum Input power and unequal channel spacings is to be given for the individual channels.

VII. CONCLUSION

Stimulated Raman Scattering is one of the Fiber Nonlinearity effects and these effects are feared by telecom system designers because they can affect system performance. There are many ways by which these SRS can be reduced. When the Input power is decreased, it is observed that the unwanted optical power tilt is also reduced. However by reducing the input power, number of channels in a DWDM system is reduced. Hence Optimum power level settings in the fiber have to be set for DWDM. By Unequal channel spacing the Unwanted Power Tilt is reduced. The analysis of SRS is done by setting various power levels and channel spacing of individual channels in DWDM system. Power Tilt has been observed for three different cases of Unequal channel spacing like Ascending order, Random order and Descending order.

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