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Combating SRS and FWM in an Optical Fiber through Unequal Spacing and Dispersion

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Abstract— ***In DWDM system, the major non-linearities such as SRS and FWM occurs simultaneously in Long-Haul Communication. As the optical signal propagate through the fiber undergoes power fluctuations and crosstalk between the channels in DWDM system. Due to this major problem, the performance of DWDM system get degrades. In this paper, the effect of SRS and FWM affecting the original Dense Wavelength Division Multiplexed (DWDM) signal power simultaneously is studied and its effect on unequal channel spacing and dispersion is analyzed in fiber optic link. The unequal channel spacing and dispersion are common methods to mitigate the effect of both SRS and FWM in the transmission fiber of DWDM system. This paper also dealt how the combined effect of SRS and FWM makes the signal strength weaken in Long-Haul Communication. The Power Tilt value is compared with unequal channel spacing and unequal channel with dispersion co-efficient.***

Keywords— DWDM, SRS, FWM, Power Tilt, Unequal channel spacing, Equal channel spacing, Dispersion.

I. INTRODUCTION

In DWDM system, the number of channels is closely spaced by combining and transmitting multiple signals simultaneously at different wavelength on the same fiber. The optical signal propagate through the transmission fiber undergoes less signal strength due to SRS and FWM effect occur simultaneously in DWDM systems. Due to this problem, the power variation occurs between the channels and produce interchannel crosstalk while transmitting long distance.

In DWDM system, SRS causes power to be transferred from lower wavelength channels to the higher wavelength channels. SRS between channels in DWDM system is harmful and degrade the performance of the system. Similarly, in DWDM system FWM occurs due to non linear refractive index of the fiber. FWM is a fiber optic characteristic that affects DWDM system where multiple optical wavelengths are spaced at equal intervals (or) channel spacing. These effects are analyzed simultaneously by unequal channel spacing and Dispersion to reduce the degradation of DWDM system performance.

The effect of SRS and FWM are overcome by two common methods such as,

1. Unequal channel Spacing and
2. Presence of Dispersion reduces the SRS penalty by reducing the chance of overlapping between the channels and reduces the inter-channel crosstalk which limits the FWM effect.

The effect of SRS in DWDM is analyzed in [1] by the parameter like error bit ratio, input optical power, number of channel and spacing between channels. The effect of FWM in DWDM system is analysed in [2] by presence chromatic dispersion in both equal and unequal channel spacing to reduce the interchannel crosstalk between the channels and estimation is done by bit-error rate, Q-factor and eye-diagram.

The goal of this paper is to mitigate the effect of SRS and FWM simultaneously by unequal channel spacing and Dispersion in fiber optic DWDM system by using OPTSIM software. This paper deals with an effect of unequal channel and dispersion by varying the dispersion co-efficient of fiber and also based on power tilt obtained from fiber output spectrum. The unequal channel spacing and dispersion are best way to mitigate the effect of SRS and FWM in fiber optic DWDM system.

II. EQUAL CHANNEL SPACING IN DWDM

In DWDM systems, the multiple channels are closely spaced with equal interval (or) with equal channel spacing and signals are transmitted in the same fiber. Due to transmission of signal in equal channel spacing, the signal strength get degrades due to sudden change in power levels between the channels and leads to inter-channel crosstalk. This problem produces SRS and FWM effect in the transmission fiber. Due to equal channel spacing, SRS can couple different channels in a DWDM system and give arise to crosstalk. The interference of FWM in DWDM systems causes an interchannel crosstalk. Hence, both SRS and FWM effects depend on the optical power level, channel spacing, number of channels, etc. The diagrammatic representation of equal channel spacing is shown in Figure 1.

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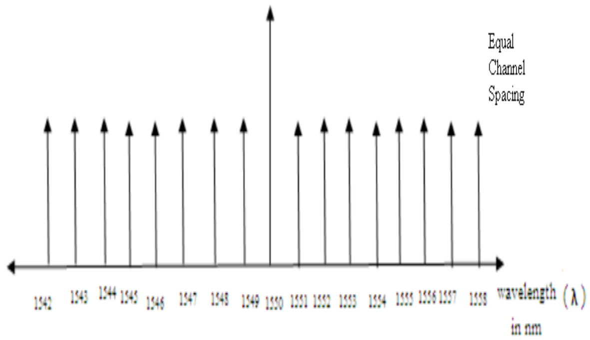

Fig.1. Diagrammatic Representation of Equal Channel Spacing

The equal channel spacing effect is determined from the variation of power level between the first channel and last channel after transmitted through the transmission fiber. The variation of power level is calculated by Power Tilt (Δ) obtained from fiber output spectrum.

III. UNEQUAL CHANNEL SPACING IN DWDM

The unequal channel is one method to overcome the effect of SRS and FWM simultaneously in DWDM system. The effect of unequal channel spacing decreases the power variation between the channels which leads to reduce the power fluctuation and increase the signal strength between the closely spaced channels. The diagrammatic representation of unequal channel spacing is shown in Figure 2.

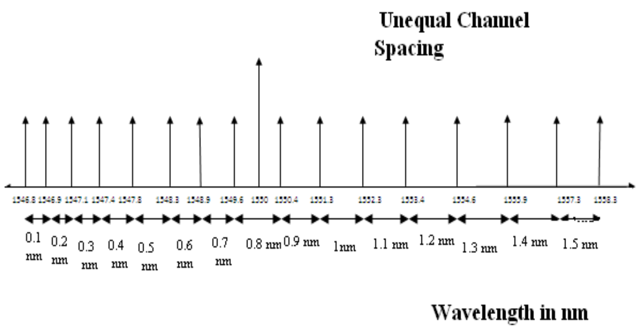

Fig.2. Diagrammatic Representation of Equal Channel Spacing

In this paper, the unequal channel spacing method is used to analyses the effect of SRS and FWM in DWDM system and how it reduces the power tilt (Δ) after the signal is transmitted through the fiber. In this method in-band FWM effect and SRS effect is clearly identified. Here, the unequal channel spacing is done by increasing the channel spacing between the channels. The channel spacing is not common between them and get increasing from one channel to other. The Power Tilt (Δ) is reduced gradually in unequal channel spacing by ascending order. The effect of unequal channel spacing is analyzed for 32- channel and 64 channel DWDM system.

IV. DISPERSION EFFECT

Dispersion is the process in which the Phase velocity of a wave depends on its frequency, or alternatively when the group velocity depends on the frequency. Dispersion is sometimes called chromatic dispersion to emphasize its wavelength-dependent nature, or group-velocity dispersion (GVD) to emphasize the role of the group velocity. Dispersion is added as the modulated beam of light, consisting of a number of closely spaced wavelengths to overcome the major problem of SRS and FWM simultaneously in DWDM system.

Due to presence of Dispersion, the SRS penalty gets reduced and hence reducing chances of overlapping between pulses propagating at different wavelengths. Also, the dispersion leads to reduction of inter-channel crosstalk which limits the FWM problem.

V. EXPERIMENTAL SET-UP

The experimental set-up is shown in Figure 3. It consists of optical transmitters, optical combiner, optical fiber and optical spectrum analyser. The optical transmitters consist of CW Lorentzian optical sources. The optical sources are increased based on number of channels in the system. The optical transmitter has N-number of input optical sources with unequal channel spacing.

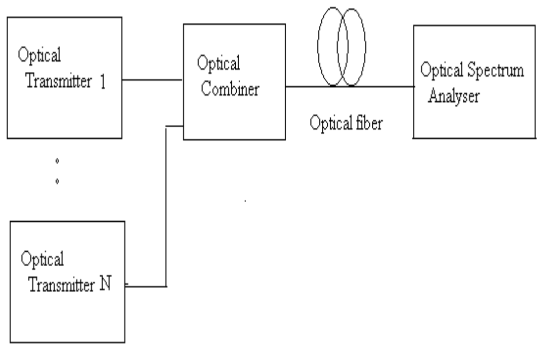

Fig.3. Experimental Set-up

The optical combiner combines all the input sources to join together from the transmitter. It transmits the combined signal from the input source to the optical fiber. The optical fiber consists of non- zero values for Raman crosstalk, fiber PMD, fiber birefringence and fiber non-linearity coefficient. The result is viewed in the optical spectrum analyser.

Here the transmission fiber has length L km with attenuation of α dB/ km. The Raman crosstalk in the fiber has non zero values to analyze the effect of SRS in the DWDM system. The fiber dispersion is set to non-zero values to observe the FWM in the DWDM system.

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VI. RESULTS AND DISCUSSION

A. Equal Channel Spacing in DWDM

For equal channel spacing, the 32 and 64-channel DWDM layout is simulated by OPTSIM to analyse the simultaneous effect of SRS and FWM. In this layout, the non-linear effects such as Raman Crosstalk in fiber properties is set to 'ON' state and remaining non-linear properties is changed to 'OFF' state. In 32-channel layout, the effect of equal channel spacing is analysed for 0.1 nm with the center wavelength of 1550 nm. The combiner output spectrum 32-equal channel spacing is shown in the figure 4.

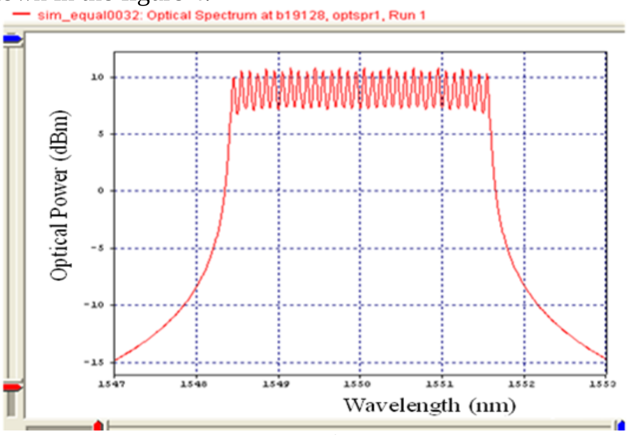

Fig.4. Combiner output Spectrum for 32- Equal Channel DWDM

The combiner output spectrum for 32-equal channel DWDM has equal power distribution between the channels. Then, the output is passed through the fiber with various non-linear properties. In this DWDM layout, the Power Tilt (Δ) obtained from fiber output is 10.51 dBm. The fiber output undergoes deviation in power level between first channel and last channel due SRS effect and some distortion between the channels leads to FWM effect. The fiber output spectrum for 32-equal channel spacing is shown in the figure 5.

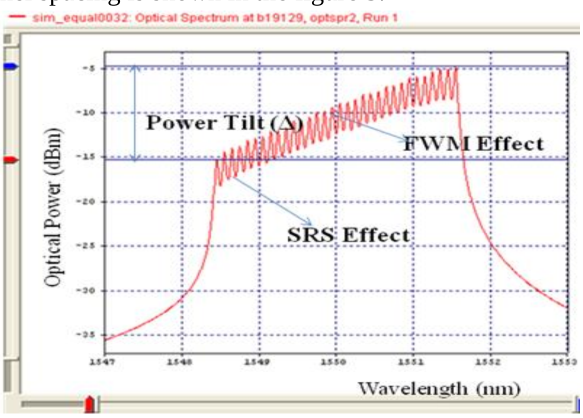

Fig.5. Fiber Output Spectrum for 32- Equal channel DWDM

In this spectrum, the Simultaneous effect is clearly viewed for 0.1nm equal channel spacing. Hence, in fiber output the optical power is transferred from lower signal wavelength to higher signal wavelength. The Power Tilt (Δ) obtained for 32 and 64 equal channel spacing for DWDM system is tabulated in Table I.

TABLE I
POWER TILT FOR EQUAL CHANNEL SPACING DWDM LAYOUT

Number of Channels	**Center Wavelength (nm)**	**Power Tilt (Δ) in dBm obtained after fiber with Equal Spacing of Δλ= 0.1 nm**
32	**1550**	**10.51**
64	**1550**	**20.35**

B. Unequal Channel Spacing in DWDM

For unequal channel spacing, the 32 and 64 –channel DWDM layout is simulated by OPTSIM with unequal channel spacing of 0.1nm, 0.2 nm and so on in ascending order with center wavelength of 1550 nm. The 32-channel DWDM layout with unequal channel spacing is simulated by OPTSIM. The spectrum of combiner output for 32-channel unequal spacing DWDM layout is shown in figure 6.

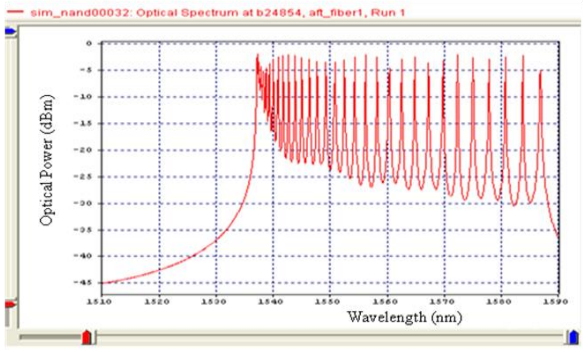

Fig.6. Spectrum of Combiner Output for 32-Unequal Channel DWDM

The spectrum for fiber output is shown in figure 7. In fiber output spectrum, nonlinear effects SRS and FWM are reduced due to less variation in power level between first channel and last channel. The Power Tilt (Δ) from the fiber output is 3.20 dBm.

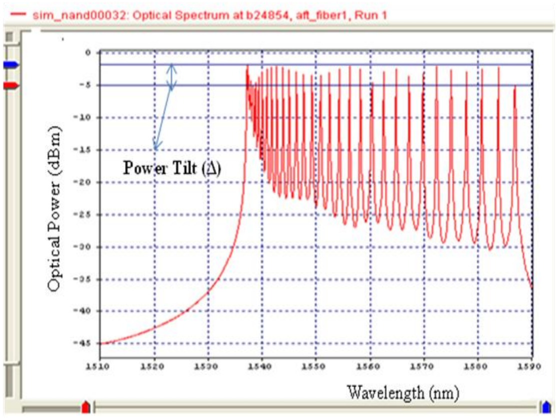

Fig.7. Fiber Output Spectrum for 32-Unequal Channel DWDM Layout

The Power Tilt (Δ) obtained for 32- channel and 64-channel with unequal spacing DWDM system is tabulated in Table II.

TABLE II
POWER TILT FOR UNEQUAL CHANNEL DWDM

Number of Channels	Center Wavelength (nm)	Power Tilt(Δ) in dBm obtained after fiber with the incremental channel Spacing of 0.1 nm
32	1550	3.20
64	1550	4.06

The Power Tilt (Δ) obtained from fiber output spectrum of equal and unequal channel spacing is tabulated in Table III .

TABLE III
POWER TILT FOR EQUAL AND UNEQUAL CHANNEL DWDM

Number of Channels	Power Tilt (Δ) in dBm obtained after fiber with Equal Spacing of Δλ= 0.1 nm	Power Tilt(Δ) in dBm obtained after fiber with the incremental channel Spacing of 0.1 nm
32	10.51	3.20
64	20.35	4.06

This Table III shows that there is variation of power level in between the channels after transmitting through the fiber for equal and unequal channel spacing. The value of Power Tilt is less for unequal channel spacing compared with the equal channel spacing. The comparison plot for equal and unequal channel spacing is shown in Figure 8.

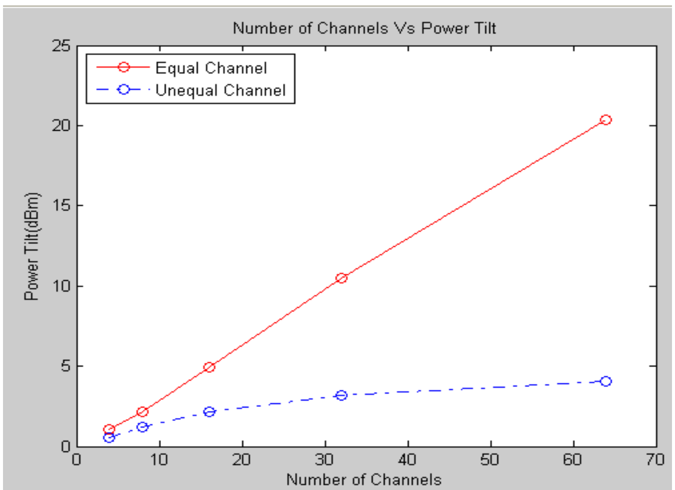

Fig.8. Comparison Plot for Equal and Unequal Channel DWDM

C. Unequal Channel Spacing With Dispersion

The effect of unequal channel spacing with dispersion co-efficient is simulated for 32 and 64-channel DWDM by OPTSIM. This is done by varying the dispersion co-efficient of fiber from D = 2 ps/nm/km to D = 30 ps/nm/km with 0.1 nm of unequal channel spacing with center wavelength of 1550 nm. The combiner output spectrum for 32-unequal channel with Dispersion co-efficient is shown in Figure 9.

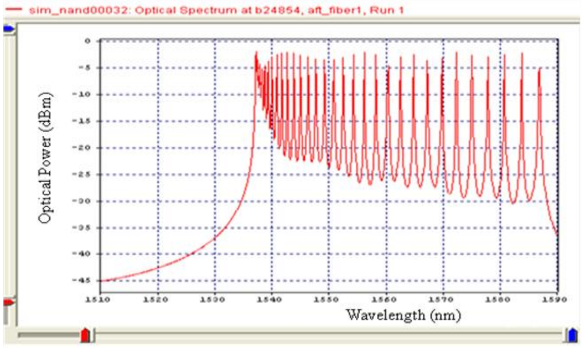

Fig.9. Combiner output for 32- unequal channel with Dispersion DWDM

The fiber output spectrum for unequal channel spacing with dispersion co-efficient is shown in figure 10. The Power Tilt (Δ) obtain from fiber output spectrum is 2.08 dBm.

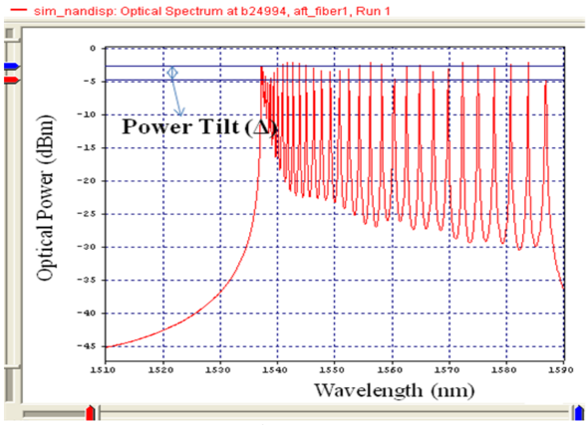

Fig.10. Fiber Output Spectrum for 32-Unequal channel with Dispersion DWDM

The Power Tilt (Δ) obtained from fiber output spectrum of 32-unequal channel with dispersion layout is compared to the power tilt obtained from only unequal channel spacing. The Power Tilt obtained for 32 and 64-unequal channel with dispersion is tabulated in Table IV.

TABLE IV POWER TILT FOR UNEQUAL CHANNEL DISPERSION DWDM

Number of Channels	Center Wavelength (nm)	Power Tilt (Δ) in dBm after the fiber with incremental Channel Spacing of 0.1 nm with Dispersion Co-efficient
32	1550	2.08
64	1550	2.9

The Power Tilt value obtained from equal, unequal and unequal channel spacing with dispersion DWDM layout is tabulated in Table V.

TABLE V

POWER TILT COMPARISON FOR EQUAL, UNEQUAL AND UNEQUAL CHANNEL WITH DISPERSION DWDM LAYOUT

Number of Channels	**Power Tilt (Δ) in dBm obtained after fiber with Equal Spacing of Δλ=0.1nm**	**Power Tilt(Δ) in dBm obtained after fiber with the incremental channel Spacing of 0.1 nm**	**Power Tilt (Δ) in dBm after the fiber with incremental Channel Spacing of 0.1 nm with Dispersion Co-efficient**
32	**10.51**	**3.20**	**2.08**
64	**20.35**	**4.06**	**2.9**

The table V shows that the Power Tilt obtained from combined effect of Unequal channel spacing and dispersion is less compared to other. This shows that the effect of unequal channel spacing and dispersion provides the best way to mitigate the simultaneous effect of SRS and FWM in fiber optic DWDM systems. The comparison plot for equal, unequal and unequal channel spacing with dispersion is shown in Figure 11.

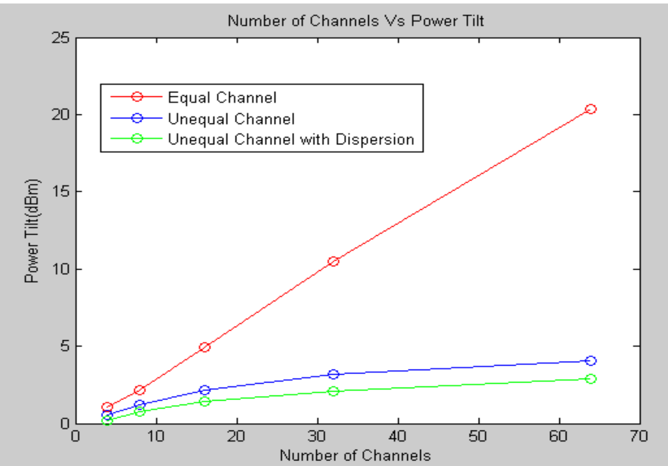

Fig.11. Comparison Plot for Equal, Unequal and Unequal Channel with Dispersion DWDM Layout

VI. CONCLUSIONS

The effect of unequal channel spacing and dispersion on SRS and FWM are simultaneously analysed for DWDM systems by OPTSIM layout. The variation of Power Tilt is compared for 32 and 64-channel DWDM system for equal, unequal and unequal channel spacing with dispersion. As unequal channel spacing and dispersion are common method to mitigate the effect of SRS and FWM simultaneously, Dispersion process makes the signal to undergo some power overshoot at the initial stage of signal transmission through the fiber. So, the future work is implemented by overcome this power shoot and transmit the signal with large number of channels in fiber optic DWDM systems.

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