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Quality Factor Evaluation of Stimulated Raman Scattering (SRS) and Four-Wave Mixing (FWM) in Passive Optical Networks

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Abstract: - In this paper, we presents the quality factor evaluation of stimulated Raman scattering (SRS) and four wave mixing (FWM) in optical networks. The nonlinearity effect of stimulated Raman scattering (SRS) and four wave mixing (FWM) with 16-channel optical system. Two parameters are used to evaluate the performance of the optical passive networks. These parameters include transmitting power and quality factors. Simulation result shows are performed based on Q-factor of the optical system and based on transmitting power of the optical system. Simulation results indicate that the quality factor of the optical system goes on decreasing with the addition of nonlinearities of optical system. Results also reveals that the quality factor of the optical system increase for a limited value of transmitting power but after a particular level this goes on decreasing.

Keywords: **Stimulated Raman scattering (SRS), four wave mixing (FWM), Q-factor, passive optical Networks.**

I. INTRODUCTION

Optical communication based on Wavelength-Division multiplexing (WDM) [1]-[9] has become the key technology to enable the very high capacity networks required by our communication thirsty society. WDM systems dominate long-haul and ultra-long-haul networks due to performance and cost advantages. To quench the rapidly increasing capacity requirement for further progress of information technology, WDM networks with narrower channel spacing are being used [4]. As a result, the dominant nonlinearities become more and more pronounced which puts a challenge to system design engineers. Also, the desired increase in launched power in order to expand the WDM network is limited by these nonlinearities. Among the nonlinearities known to limit the throughput of WDM system, four-wave mixing (FWM), cross-phase modulation (XPM) and stimulated Raman scattering (SRS) are the dominant effects [1] [5].
SRS is significant when there are a number of signals on different wavelengths and it induces power transfer from the shorter wavelength channels to longer wavelength channels leading to power penalty in the shorter wavelength channels [1][5]. FWM acts as crosstalk between channels as it results in the mixing of two signals at different frequencies, which leads to the generation of "sum and difference" frequencies [10]-[15]. XPM leads to phase change of one channel according to power of the other channels and the presence of group velocity dispersion (GVD) transforms this phase-modulation (PM) into intensity-modulation (IM) [1][5]. This PM-IM conversion results in XPM acting like crosstalk between channels leading to deterioration of the signal quality. In long haul WDM systems, Erbium-Doped fiber amplifiers (EDFAs) are used to compensate for signal attenuation, thus allowing high data rate transmission over a long distance. The high optical power level available from EDFAs though, leaves the system performance more vulnerable to various nonlinear effects [3]. Also, ASE noise of all the amplifiers accumulates at the receiver and results in degradation of system performance. In this paper, we presents the quality factor evaluation of stimulated Raman scattering (SRS) and four wave mixing (FWM) in optical networks. The nonlinearity effect of stimulated Raman scattering (SRS) and four wave mixing (FWM) with 16-channel optical system. Two parameters are used to evaluate the performance of the optical passive networks. These parameters include transmitting power and quality factors. Simulation result shows are performed based on Q-factor of the optical system and based on transmitting power of the optical system. The rest of the paper is organized as follows: In section II, explain the basic four wave mixing (FWM) in optical networks.. In Section III, detail of the stimulated Raman scattering (SRS) is given and how this affects the performance of optical system. In Section V, shows the simulation results of optical system in the presence of the nonlinearities such as four waves mixing (FWM) and stimulated Raman scattering (SRS). Finally, a conclusion is made.

II. FOUR-WAVE MIXING (FWM)

Four-wave mixing [2] is an intermodulation phenomenon in non-linear optics, whereby interactions between two wavelengths produce two extra wavelengths in the signal. It is similar to the third-order intercept point in electrical systems. Four-wave mixing is a nonlinear effect arising from a third-order optical nonlinearity, as is described with a $X(3)$ coefficient. It can occur if at least two different frequency components propagate together in a nonlinear medium such as an optical fiber. Assuming just two input frequency components $f1$ and $f2$ (with $f2 > f1$), a refractive index modulation at the difference frequency occurs, which creates two additional frequency

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components. In effect, two new frequency components are generated: $f3 = f1 - (f2 - f1) = 2f1 - f2$ and $f4 = f2 + (f2 - f1) = 2f2 - f1$. Furthermore, a pre-existing wave the frequency $f3$ or $f4$ can be amplified.

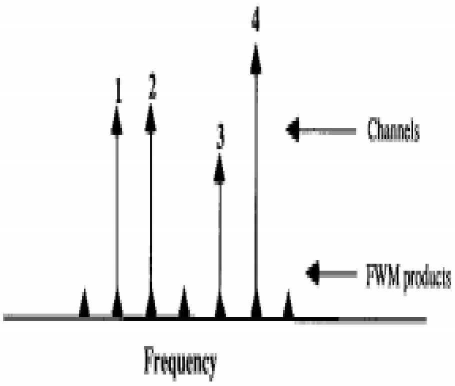

Fig. 1 Effect of four wave mixing

The simplest picture of the four-wave mixing process in fibers can be illustrated by the transmission and cross-phase modulation of four equally spaced channels shown in Fig. 1 Channels 1 and 2 interfere, producing an index of refraction which oscillates at the difference frequency. This modulation in refractive index modulates channel 4, producing sidebands at channels 3 and 5. This is only the simplest combination of frequencies. Four-wave mixing allows any combination of three frequencies beating together to produce a fourth. If the fourth frequency lies within a communication band, that channel can be rendered unusable. This channel interference can affect either closely spaced channels, as one encounters with coherent communications, or the rather widely separated channels of a WDM system. Efficient four-wave mixing requires phase matching of the interacting waves throughout the interaction length widely separated channels will therefore be phase matched only in a region of low-fiber dispersion.

III. STIMULATED RAMAN SCATTERING (SRS)

SRS is due to interaction of incident light wave with vibrational modes of silica molecule i.e., if two or more optical signals at different wavelengths are injected into a fiber, SRS causes energy from lower wavelength channels to be transferred to the higher wavelength channels [1][2]. This in turn reduces the signal-to-noise ratio of the lower wavelength channels and introduces crosstalk on higher wavelength channels which can lower the information carrying capacity of the system. The threshold power in case of SRS can be estimated as

$$P_{th} \approx 16 A_{eff} / g_R L_{eff} \quad (1)$$

where g_R is the Raman gain and L_{eff} the effective length of the fiber. If the fiber is sufficiently long, then $L_{eff} \cong 1/\alpha$. In that case

$$P_{th} \approx 16 A_{eff} \alpha / g_R \quad (2)$$

The value of g_R is 1 x 10^{-13} m/W for silica at λ =1550 nm. The value of α as 0.2 dB/km and A_{eff} as 55 2 μm, results in P_{th} equal to 570 mW. Hence, the effect of SRS is insignificant in case of single channel. In WDM systems, where there are number of signals on different wavelengths, the effect of SRS is significant and it results in transfer of energy from signal at shorter wavelength to signal at longer wavelength. In case of N equally spaced channels with frequency separation between adjacent channels Δf Hz, assuming scrambled polarization and Raman gain g_R to be linear, the power loss due to SRS by the shortest wavelength (i.e., first) channel is given by

$$D = \sum_{i=2}^{N} (m_i) \frac{P_i \gamma_i L_{eff}}{2 A_{eff}} \quad (3)$$

where m_i is the modulation of i^{th} channel, P_i the power injected in i^{th} channel in watts and γ_i the Raman gain coefficient coupling the i^{th} channel and first channel. Assuming the Raman gain profile to be triangular, γ_i is given by

$$\gamma_i = \begin{cases} \frac{(i-1)\Delta f}{1.5x10^{13}} \gamma_p & \text{for } i\Delta f < 1.5x10^{13} Hz \\ 0 & \text{otherwise} \end{cases} \quad (4)$$

Where γ_p is the peak Raman gain coefficient. Since m_i are independent random variables, power depletion D converges to a Gaussian random variable. Equally spaced channels with intensity-modulated/direct-detection (IM/DD) system have been assumed for analysis. It is observed that the presence of SRS along with FWM further degrades the network performance. This is due to the fact that the power received at the receiver due to SRS is lower than the power received at the receiver when SRS is not present.

IV. SIMULATION RESULTS

In this section, we present the Q-factor and Transmitted Power Analysis with 16 channel optical communication System. Simulations are performed using MATLAB 2012a. Fig.2 shows the Q-factor analysis with time in dB for FWM-XPM nonlinear effect for 16-channel optical communication System. Fig.3 shows the Q-factor analysis with time in dB for SRS-FWM nonlinear effect for 16-channel optical communication System. Fig.4 shows the Q-factor analysis with time in dB for SRS-XPM nonlinear effect for 16-channel optical

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communication System. Fig.5 shows the Q-factor analysis with time in dB for SRS-XPM-FWM-ASE nonlinear effect for 16-channel optical communication System. Fig.6 shows the Q-factor analysis with time in dB for different combination of nonlinear effect for 16-channel optical communication System.

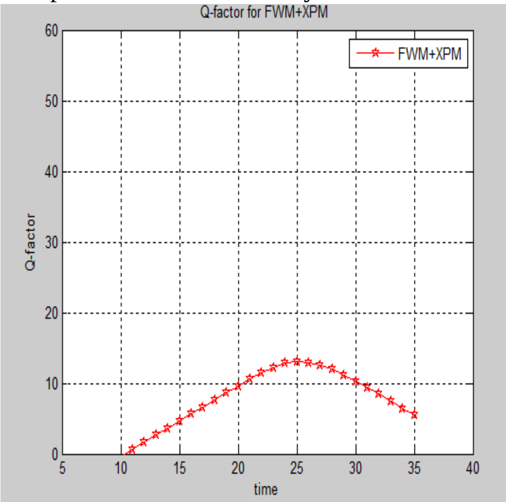

Fig. 2 Q-factor analysis FWM-XPM nonlinear effect for 16-channel optical communication System

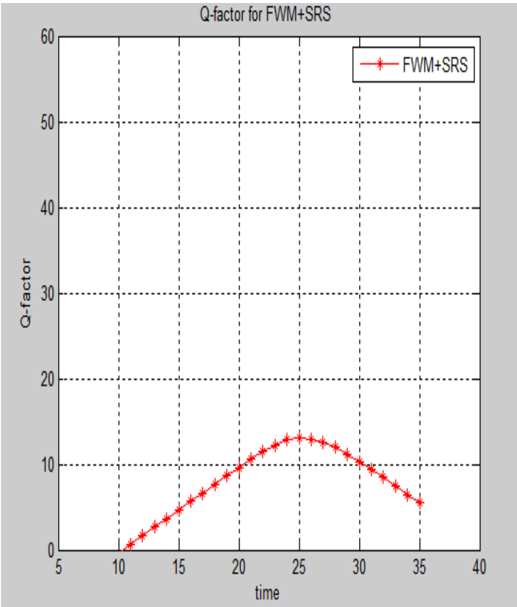

Fig. 3 Q-factor analysis FWM-SRS nonlinear effect for 16-channel optical communication System

Fig.7 shows the Q-factor analysis with changing transmitted power for FWM-XPM nonlinear effect for 16-channel optical communication System. Fig.8 shows the Q-factor analysis with changing transmitted power for SRS-FWM nonlinear effect for 16-channel optical communication System. Fig.9 shows the Q-factor analysis with changing transmitted power for SRS-XPM nonlinear effect for 16-channel optical communication System. Fig.10 shows the Q-factor analysis with changing transmitted power for SRS-XPM-FWM-ASE nonlinear effect for 16-channel optical communication System. Fig.11 shows the Q-factor analysis with changing transmitted power for different combination of nonlinear effect for 16-channel optical communication System.

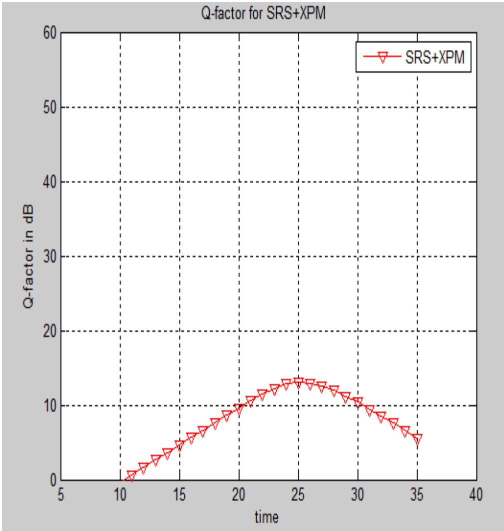

Fig. 4 Q-factor analysis SRS-XPM nonlinear effect for 16-channel optical communication System

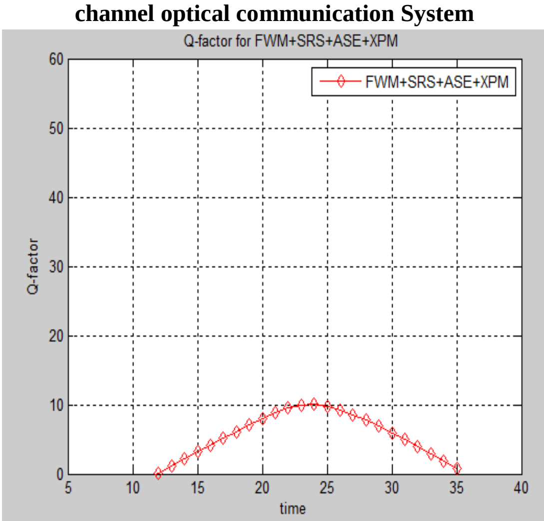

Fig. 5 Q-factor analysis FWM-SRS-ASE-XPM nonlinear effect for 16-channel optical communication System

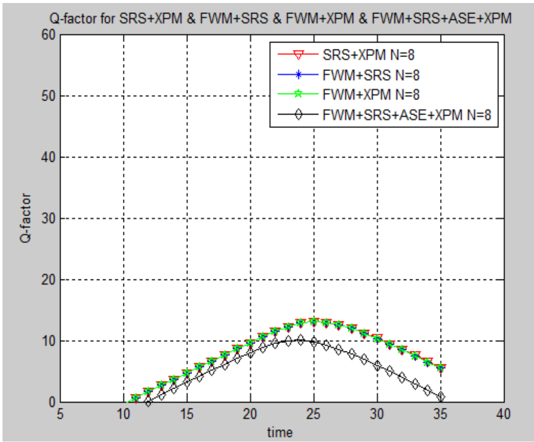

Fig. 6 Combined Q-factor analysis for different nonlinear and linear effect for 16-channel optical communication System

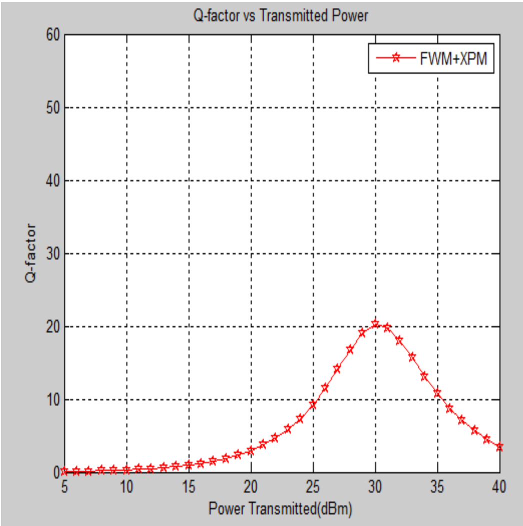

Fig. 7 Transmitted Power Analysis FWM-XPM nonlinear effect for 16-channel optical communication System

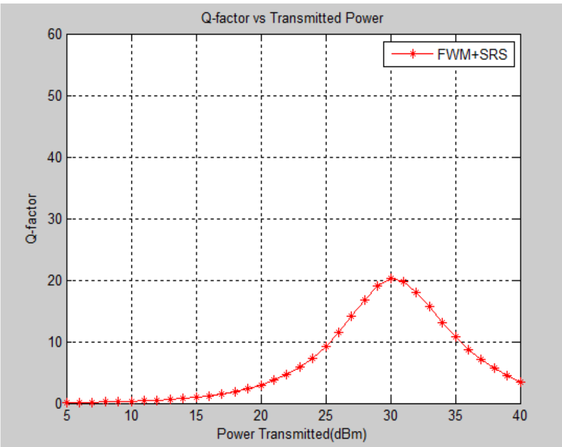

Fig. 8 Transmitted Power Analysis FWM-SRS nonlinear effect for 16-channel optical communication System

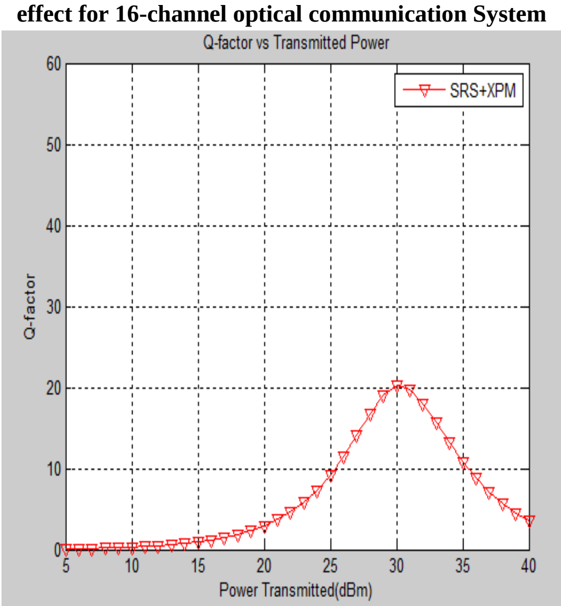

Fig. 9 Transmitted Power Analysis SRS-XPM nonlinear effect for 16-channel optical communication System

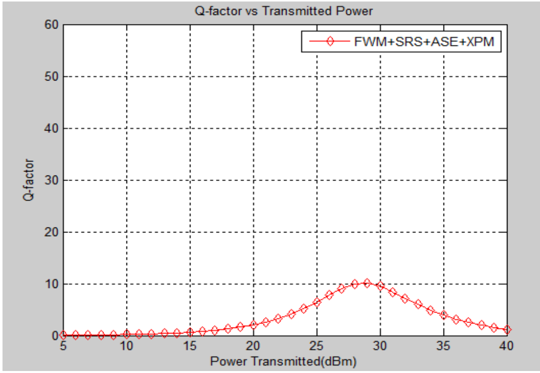

Fig. 10 Transmitted Power Analysis FWM-SRS-ASE-XPM nonlinear and linear effect for 16-channel optical communication System

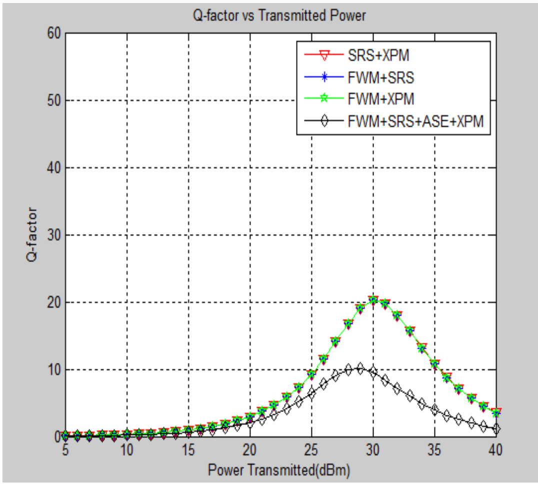

Fig. 11 Combined Transmitted Power Analysis for different nonlinear and linear effect for 16-channel optical communication System

V. CONCLUSIONS

In this paper, we presents the quality factor evaluation of stimulated Raman scattering (SRS) and four wave mixing (FWM) in optical networks. The nonlinearity effect of stimulated Raman scattering (SRS) and four wave mixing (FWM) with 16-channel optical system. Two parameters are used to evaluate the performance of the optical passive networks. These parameters include transmitting power and quality factors. Simulation result shows are performed based on Q-factor of the optical system and based on transmitting power of the optical system. Results also reveals that the quality factor of the optical system increase for a limited value of transmitting power but after a particular level this goes on decreasing.

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