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Performance Analysis of Amplified Spontaneous Emission (ASE) Noise and Cross Phase Modulation (XPM) in Optical System

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Abstract:- In this paper, we studied the limiting factors in design of long-haul fiber optic communication systems and the techniques used to suppress their resulting impairments. These impairments include fiber chromatic dispersion, the Kerr nonlinearity and nonlinear phase noise due to amplified spontaneous emission (ASE). We focus on the impact of transmission impairments in high speed optical networks. Simulation result shows the performance of the optical system based on the Q-factor of system and the power transmission capabilities. Results investigate the Quality-factor (Q-factor) deterioration due to individual effects of cross phase modulation (XPM) and four-wave mixing (FWM) and their collective impact on system Q-factor in presence of ASE noise. The simulation results make it evident that deterioration due to nonlinearities is not the same for different fiber types which suggest the nature of limitations due to different nonlinearities and fiber types.

Index Terms: **Amplified spontaneous emission (ASE), cross phase modulation (XPM), chromatic dispersion (CD), Q-factor.**

I. INTRODUCTION

Optical communication based on Wavelength-Division multiplexing (WDM) [1][7] 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's 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 [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 [1][3][5]. 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.

This paper focuses on the impact of transmission impairments in high speed optical networks. We investigate the Quality-factor (Q-factor) deterioration due to individual effects of cross phase modulation (XPM) and four-wave mixing (FWM) and their collective impact on system Q-factor in presence of ASE noise. The simulation results make it evident that deterioration due to nonlinearities is not the same for different fiber types which suggest the nature of limitations due to different nonlinearities and fiber types.

The rest of the paper is organized as follows: In section II, explain the basic of Wavelength Division Multiplexing (WDM). In Section III, detail of the Amplified Spontaneous Emission (ASE) Noise is given and

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how this affects the performance of optical system. Section IV explains the Cross Phase Modulation effect in optical system. In Section V, shows the simulation results of optical system in the presence of the nonlinearities such as Cross Phase Modulation and Amplified Spontaneous Emission (ASE) Noise. Finally, a conclusion is put forward.

II. WAVELENGTH DIVISION MULTIPLEXING (WDM)

WDM is a technology that transports in parallel several high-speed data channels in a single optical fiber using optical frequency division multiplexing. The huge bandwidth capacity in an optical fiber forms the basis for increasing interest in WDM optical networks [7][8] from both industry and research communities.

Active WDM components [9] include tunable optical filters, tunable sources, and optical amplifiers. Fig. 1 shows the implementation of such components in a typical WDM link. At the transmitting end there are several independently modulated light sources, each emitting signals at a unique wavelength. Here a multiplexer is needed to combine these optical outputs into a continuous spectrum of signals and couple them onto a single fiber. At the receiving end a demultiplexer is required to separate the optical signals into appropriate detection channels for signal processing. At the transmitter the basic design challenge is to have the multiplexer provide a low-loss path from each optical source to the multiplexer output. Since the optical signals that are combined generally do not emit any significant amount of optical power outside of the designated channel spectral width, interchannel cross-talk factors are relatively unimportant at the transmitting end. A different requirement exists for the demultiplexer, since photo detectors are usually sensitive over a broad range of wavelengths, which could include all the WDM channels. To prevent spurious signals from entering a receiving channel, that is, to give good channel isolation of the different wavelengths being used, the demultiplexer must exhibit narrow spectral operation or very stable optical filters with sharp wavelength cut offs must be used.

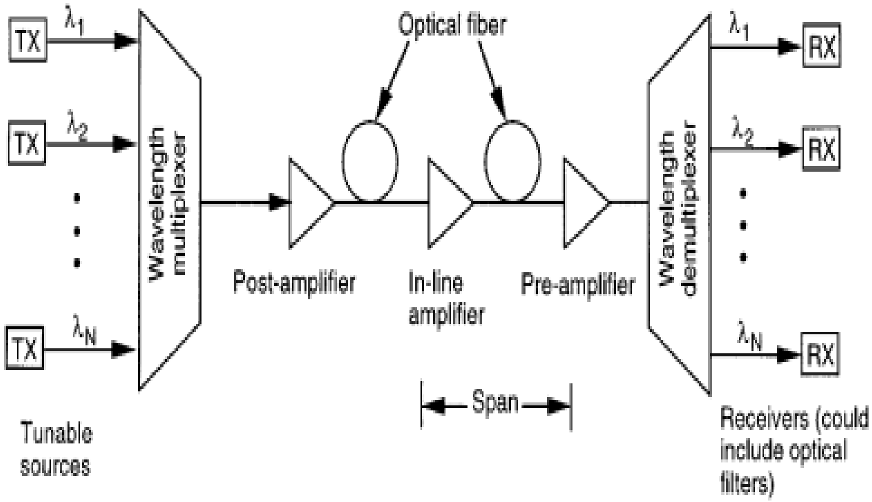

Fig: 1 Wavelength Division Multiplexing (WDM) Networks

III. AMPLIFIED SPONTANEOUS EMISSION (ASE) NOISE

ASE is produced when a laser gain medium is pumped to produce a population inversion [1]. Feedback of the ASE by the laser's optical cavity may produce laser operation if the lasing threshold is reached. Excess ASE is an unwanted effect in lasers, since it limits the maximum gain that can be achieved in the gain medium. ASE creates serious problems in any laser with high gain and/or large size. In this case, a mechanism to absorb or extract the incoherent ASE must be provided, otherwise the excitation of the gain medium will be depleted by the incoherent ASE rather than by the desired coherent laser radiation. Optical amplifiers play an important role in the design of long haul optical communication networks. EDFA is the commonly used optical amplifier in a long-haul WDM network. It has the capability of amplifying multiple wavelengths simultaneously. The amplifier can either be placed at position 'a' (as booster amplifier), or at position 'b' and 'c' (as in-line amplifier), or at position'd' (as pre-amplifier) as shown in Fig. 2.

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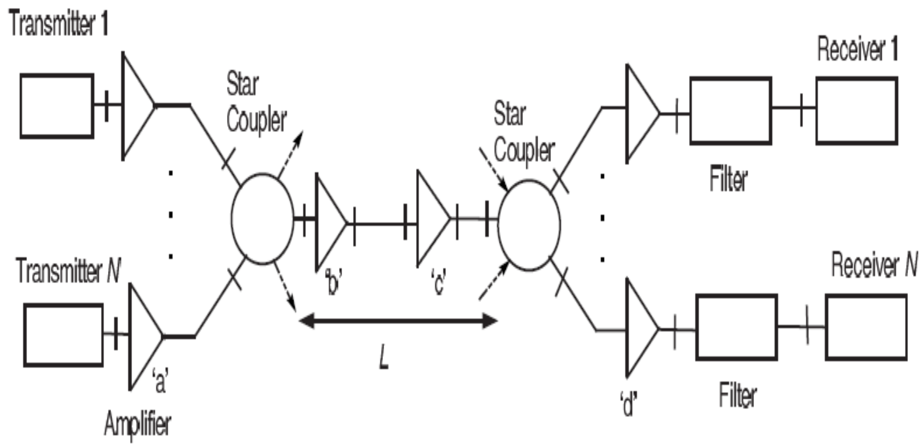

Fig.2 Amplified Spontaneous Emission (ASE) Noise in WDM Network

IV. CROSS PHASE MODULATION (XPM)

XPM originates from the intensity dependence of the refractive index, which results in intensity dependent phase-shift as signal propagates through the fiber. When there is more than one optical signal propagating through the fiber as in multichannel WDM, the non-linear phase shift of a signal not only depends upon its own power but also on the power of other signals . For example, if there are four signals, the non-linear phase shift of the first signal is given by

$$\phi_1 = \gamma L_{eff} (P_1 + 2P_2 + 2P_3 + 2P_4) \quad (1)$$

where P_i i =1 to 4 are the powers of the four signals and L_{eff} the effective length of the fiber. The first term in above equation is due to SPM while other terms are due to XPM [8] that represents the phase-modulation (PM) process. In presence of group velocity dispersion (GVD), this PM is converted into IM (intensity modulation), which degrades the quality of the signal [10]. The XPM-induced phase shift can occur only when two pulses overlap in time due to which the intensity-dependent phase shift and consequent chirping is enhanced, leading to asymmetric spectral broadening and distortion of the pulse shape.
Cross-phase modulation can be relevant under different circumstances:

1. It leads to an interaction of laser pulses in a medium, which allows e.g. the measurement of the optical intensity of one pulse by monitoring a phase change of the other one (without absorbing any photons of the first beam). This is basis of a scheme for *quantum nondemolition* (QND) *measurements*.
2. The effect can also be used for synchronizing two mode-locked lasers using the same gain medium, in which the pulses overlap and experience cross-phase modulation.
3. In optical fiber communications, cross-phase modulation in fibers can lead to problems with channel cross-talk.
4. Cross-phase modulation is also sometimes mentioned as a mechanism for channel translation (wavelength conversion), but in this context the term typically refers to a kind of cross-phase modulation which is not based on the Kerr effect, but rather on changes in the refractive index via the carrier density in a semiconductor optical amplifier.

V. RESULTS AND DISCUSSION

This section deals with the Q-factor and Transmitted Power Analysis with 4 channel optical communication System. Simulations are performed using MATLAB 2012a. Fig. 3 shows the Q-factor analysis with time in dB for FWM-XPM nonlinear effect for 4-channel optical communication System. Fig.4 shows the Q-factor analysis with time in dB for SRS-FWM nonlinear effect for 4-channel optical communication System. Fig.5 shows the Q-factor analysis with time in dB for SRS-XPM nonlinear effect for 4-channel optical communication System. Fig. 6 shows the Q-factor analysis with time in dB for SRS-XPM-FWM-ASE nonlinear effect for 4-channel optical communication System. Fig. 7 shows the Q-factor analysis with time in dB for different combination of nonlinear effect for 4-channel optical communication System. Fig.8 shows the Q-factor analysis with changing transmitted power for FWM-XPM nonlinear effect for 4-channel optical communication System. Fig.9 shows the Q-factor analysis with changing transmitted power for SRS-FWM nonlinear effect for 4-channel optical communication System. Fig. 10 shows the Q-factor analysis with changing transmitted power for SRS-XPM nonlinear effect for 4-channel optical communication System. Fig. 11 shows the Q-factor analysis with changing transmitted power for SRS-XPM-FWM-ASE nonlinear effect for 4-channel optical communication System. Fig. 12 shows the Q-factor analysis with changing transmitted power for different combination of nonlinear effect for 4-channel optical communication System.

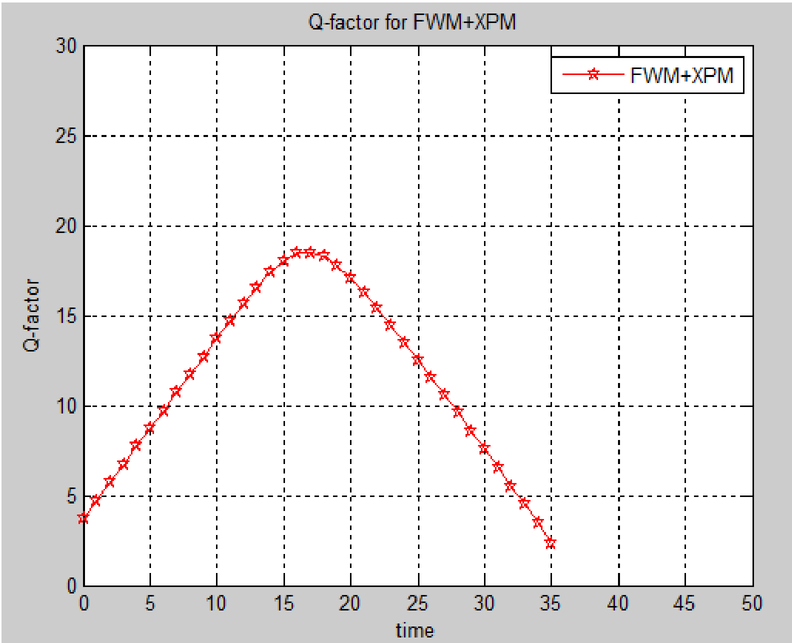

Fig. 3 Q-factor analysis FWM-XPM nonlinear effect for 4-channel optical communication System

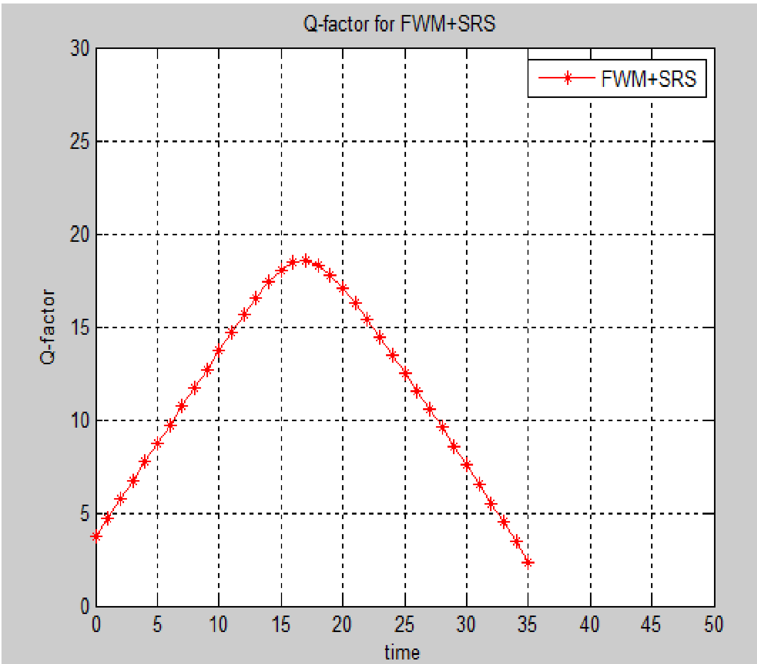

Fig. 4 Q-factor analysis FWM-SRS nonlinear effect for 4-channel optical communication System

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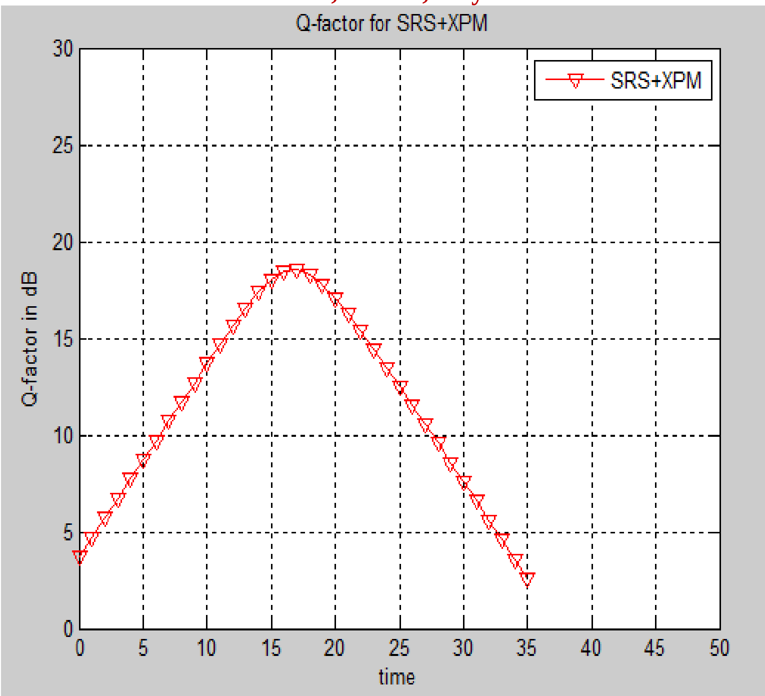

Fig. 5 Q-factor analysis SRS-XPM nonlinear effect for 4-channel optical communication System

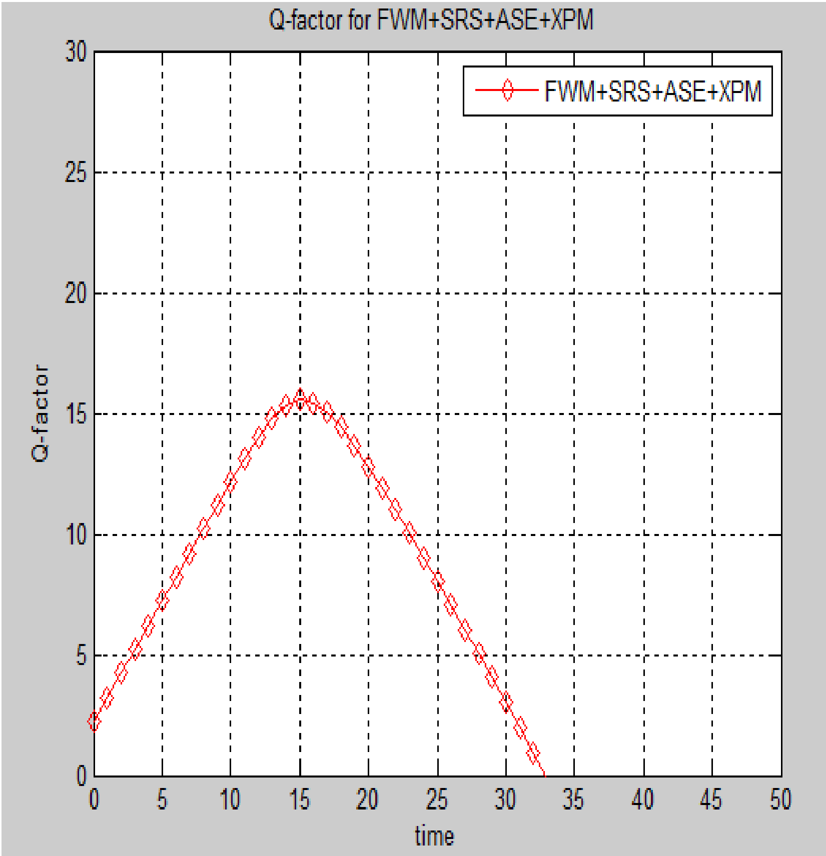

Fig. 6 Q-factor analysis FWM-SRS-ASE-XPM nonlinear effect for 4-channel optical communication System

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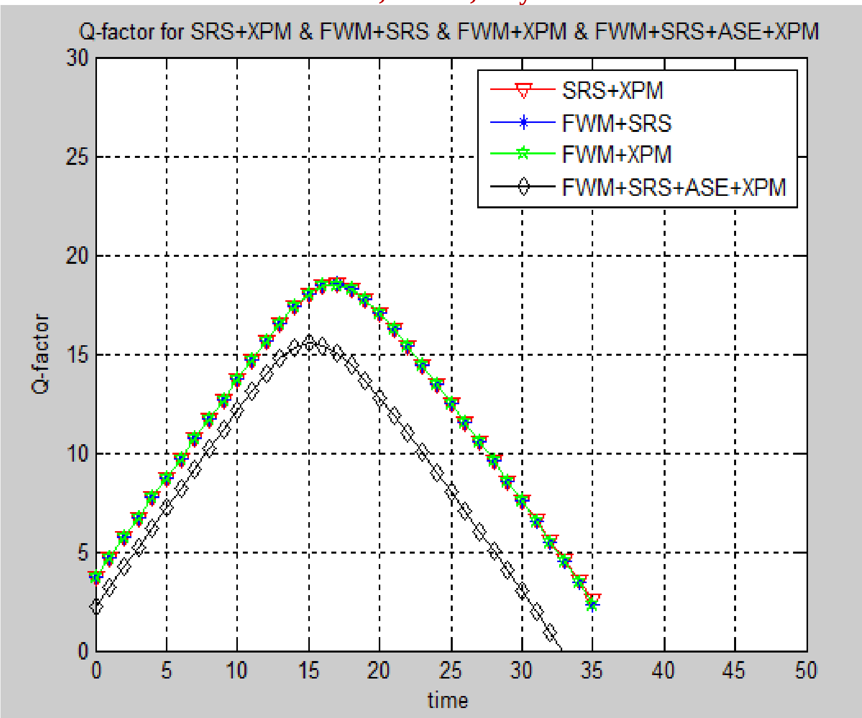

Fig. 7 Combined Q-factor analysis for different nonlinear and linear effect for 4-channel optical communication System

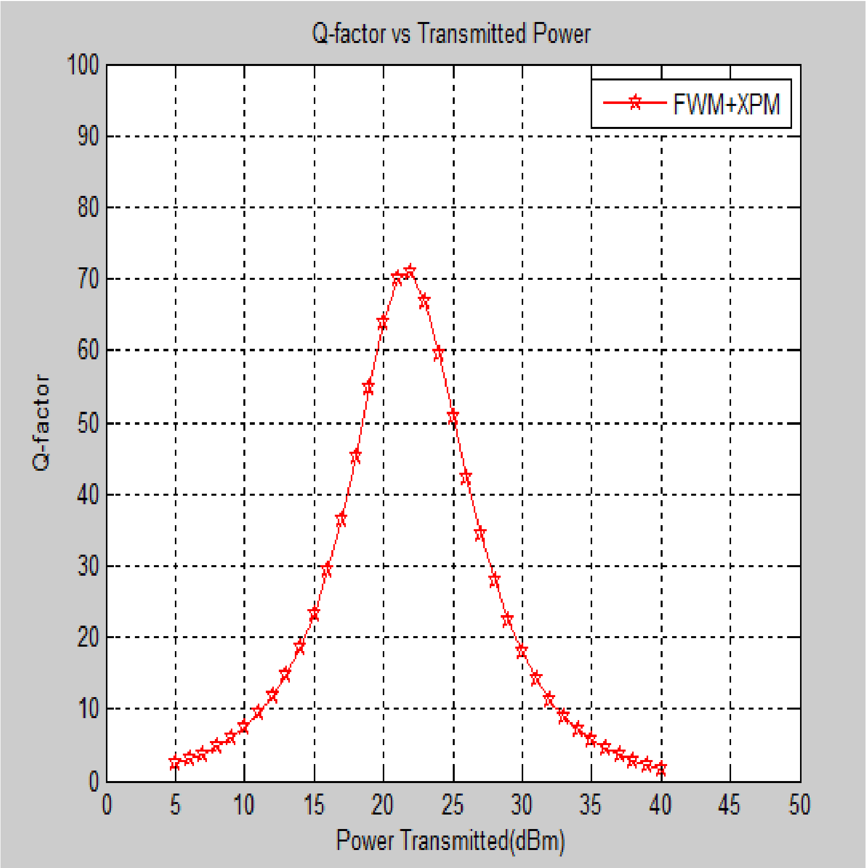

Fig. 8 Transmitted Power Analysis FWM-XPM nonlinear effect for 4-channel optical communication System

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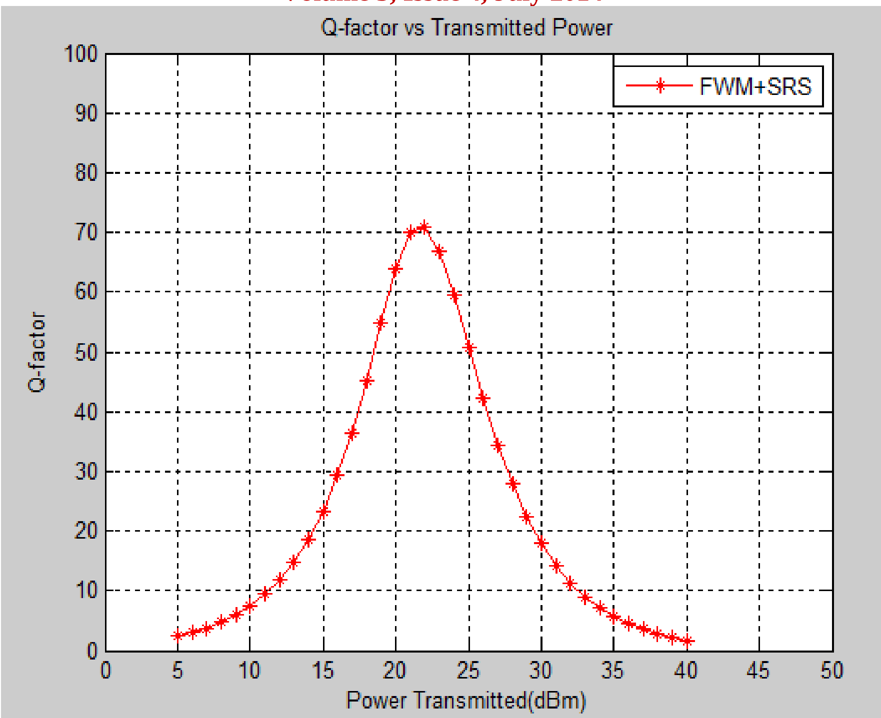

Fig. 9 Transmitted Power Analysis FWM-SRS nonlinear effect for 4-channel optical communication System

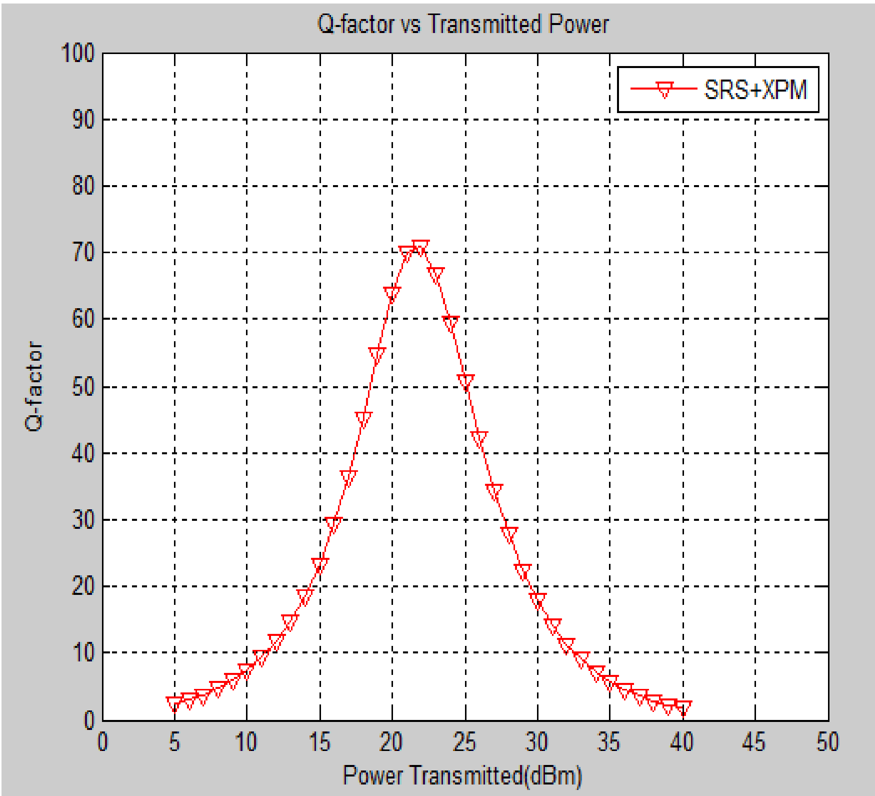

Fig. 10 Transmitted Power Analysis SRS-XPM nonlinear effect for 4-channel optical communication System

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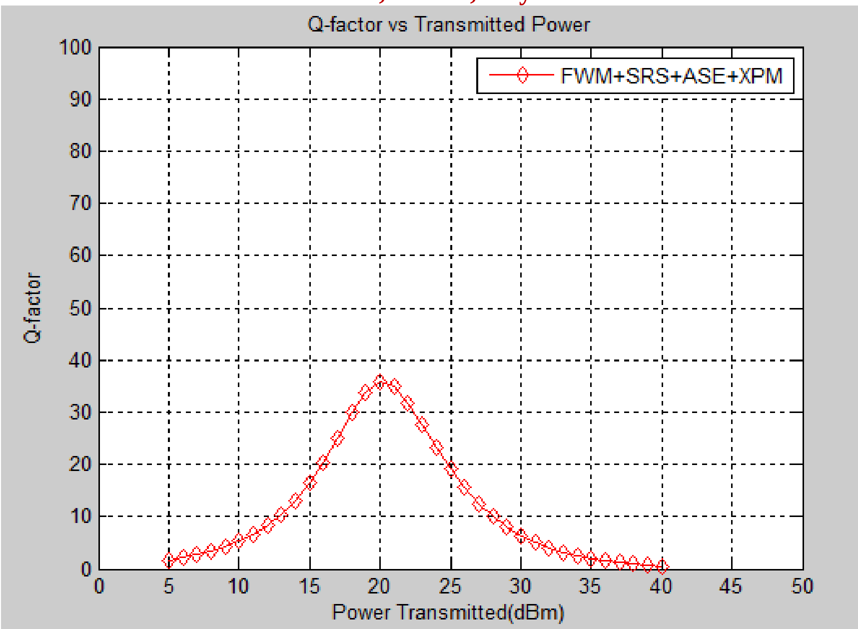

Fig. 11 Transmitted Power Analysis FWM-SRS-ASE-XPM nonlinear and linear effect for 4-channel optical communication System

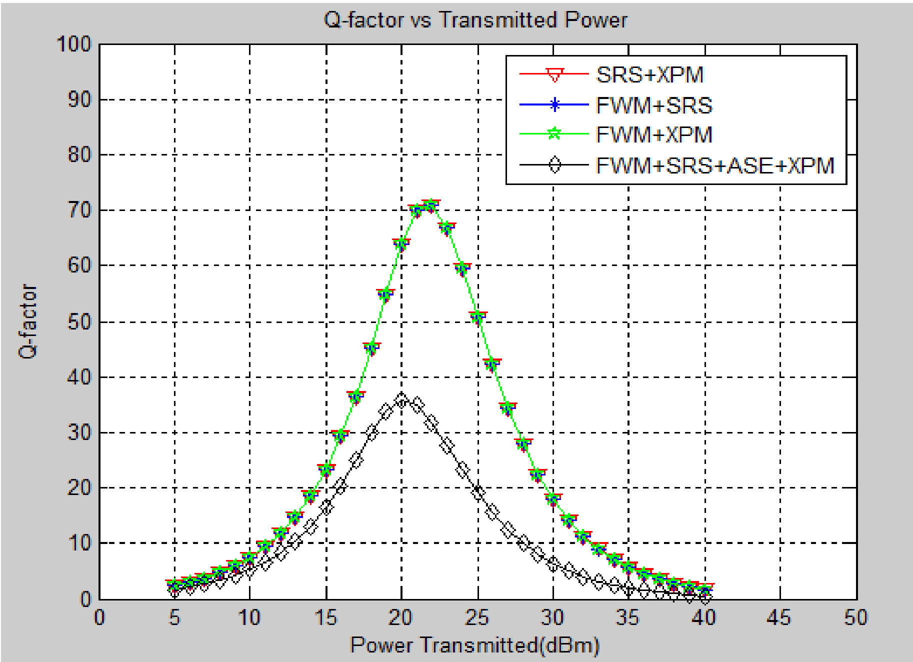

Fig. 12 Combined Transmitted Power Analysis for different nonlinear and linear effect for 4-channel optical communication System

VI. CONCLUSIONS

In this paper, we studied the limiting factors in design of long-haul fiber optic communication systems and the techniques used to suppress their resulting impairments. It is also clearly seen that, as in the case of FWM, an increase in the input power after a certain level leads to rapid increase in XPM penalty leading to decrease in Q-factor values. With the increase in number of channels, power loss in the splitter increases as a result of which higher transmitted power is required to obtain a given value of Q. With the increase in the number of channels, the number of FWM components generated and XPM effect increase leading to degraded network performance.

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