Analysis of Factors Affecting FWM Inter-Channel Crosstalk Based on VPI

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Abstract. To study the effect factors of inter-channel crosstalk caused by FWM in optical fiber communication and improve communication system performance, we build a simulation system on VPI, observe the changes of optical spectrum of the output, signal power diagrams and the eye diagrams of receiving channels, analyze the effects on FWM produced by different fiber parameters, channel spacing and optical signal power. The results show that the crosstalk between four wave mixing channels will be more serious with the increase of optical signal power, however, increasing the optical fiber’s dispersion coefficient and the effective area of the core can suppress FWM effectively, at the same time, increasing the frequency channel spacing can also reduce the FWM.

1. Introduction

With the rapid increase in the number of network users and the emergence of various business needs such as voice, data, and video, in order to meet the growing demand for transmission services, optical networks have gradually evolved to all-optical networks with transparent transmission characteristics based on dense wavelength division multiplexing [1]. The nonlinear effects of transmission fiber mainly include self-phase modulation (SPM), cross-phase modulation (XPM), four-wave mixing (FWM), stimulated Raman scattering (SRS) and stimulated Brillouin scattering (SBS), etc. [2]. These non-linear effects cause crosstalk and power cost between the channels of the optical transmission system, which in turn causes the degradation of the user's signal quality, limiting the transmission capacity and maximum transmission distance of the optical fiber communication system.

Four-Wave Mixing (FWM) is a kind of coupling effect between light waves generated by the action of the third-order polarization real part of the optical fiber medium, it refers to the phenomenon that a new frequency is generated when optical signals of two or more frequencies are transmitted simultaneously [3,4]. In addition to generating new frequencies, FWM will also cause the deterioration of the optical signal-to-noise ratio. Part of the channel power will be converted to a new optical field through FWM, and some of the new frequency signals generated may be superimposed on the original user signals. It causes cross-band crosstalk, resulting in user signal quality degradation [5]. FWM is a serious non-linear effect that affects the performance of optical transmission systems, which reduces the system performance to some extent [6,7]. Therefore, studying the influencing factors of FWM crosstalk in optical fiber transmission can provide a reference basis for enhancing reliable transmission in optical
fiber communication, and provide ideas and methods for formulating safety protection measures in optical communication.

At present, most researchers have analyzed the generation of FWM and its related characteristics from a theoretical level, but there are few intuitive analysis of the influencing factors of FWM inter-band crosstalk through simulation experiments. This article uses the VPI (VPI transmission Maker) experimental simulation platform to design and build an FWM simulation system. By observing the optical fiber output end spectral change, channel eye diagram change and FWM newly generated channel power change, analyzing the influence of optical signal power, channel frequency interval, fiber dispersion coefficient and fiber core effective area on FWM inter-channel crosstalk, in order to provide a reference for how to effectively suppress the FWM effect and select the appropriate fiber to improve the system performance.

2. FWM simulation system based on VPI

2.1 Construction of the simulation system FWM

The simulation system includes modules such as TxExtModLaser, WDM_MUX, FiberNLS, SignalAnalyzer, Powermeter, and NumericalAnalyzer2D, as shown in Figure 1; the analog external modulation laser module TxExtModLaser is composed of LaserCW, PRBS, Coder_NRZ, RiseTimeAdjust, and ModulatorMZ, as shown in Figure 2.

![Figure 1. FWM effect between analog channels](image1)

![Figure 2. Simulated externally modulated laser module](image2)

2.2 System parameter setting

Signal emitting module: Set the rate of four optical transmitters to 10Gb / s. According to the ITU-T standard, the transmission frequencies $f_1$, $f_2$, $f_3$, and $f_4$ are 193.05, 193.1, 193.15, 193.2THz, and the frequency interval is 50GHz. The signal transmission power is 1mW. After multiplexing the signal, it enters the same fiber for transmission.

Signal transmission module: The optical fiber uses the single-mode optical fiber module Nonlinear Dispersion Optical Fiber (NLS) in VPI. NLS takes into account the nonlinear effects of optical fibers such as SPM, XPM, FWM, and SRS, as well as GVD and attenuation. In the simulation, the fiber loop cycle number is set to 50 times, the light length is 1km, the effective area of the fiber core is $55 \times 10^{-12}$ m², the fiber attenuation coefficient is 0.2dB / km, the dispersion coefficient is 0.2ps / nm / km, the fiber...
The nonlinear refractive index coefficient is $3.2 \times 10^{-20} \text{ m}^2 / \text{W}$, so that the optical signal will be output to the external signal analysis module after every 1km of transmission.

Signal receiving module: Set the receiving end demultiplexer to $1 \times 8$ output, 8 output channels are separated by 50GHz, and the middle 4 channels correspond to 4 optical transmitter frequencies.

3. Analysis of influencing factors of FWM inter-band crosstalk

3.1 Influence of optical signal power on FWM

Increase the optical signal transmission power from 1mW to 10mW, and keep the rest of the parameters at their default values. The experimental results are shown in Figure 3. The analysis result shows that the increase of the optical signal power will cause the FWM inter-band crosstalk to become more serious. Figure 3 (a) shows that at the output end of the fiber, multiple new frequency components excited by the FWM will be superimposed on the original signal optical frequency, resulting in serious energy loss in the optical channel. It can be seen from Fig. 3 (b) that the increase in the power and speed of the newly generated interference signal power of the FWM at the same time becomes larger, resulting in a rapid decrease in the received optical signal power and serious loss. Observing Fig. 3 (c), it is found that the quality of the eye diagrams of the four receiving channels is significantly degraded, indicating that the new frequency components generated as noise fall within the passband of the optical channel filter, increasing crosstalk between channels.

3.2 Influence of fiber parameters on FWM

Dispersion coefficient. Increase the dispersion coefficient of the optical fiber from 0.2ps / nm / km to 16ps / nm / km, and keep the rest of the parameter values unchanged. The experimental results are shown in Figure 4. The analysis results show that increasing the dispersion coefficient suppresses the FWM crosstalk significantly, the energy of the four user channels on the fiber output end is concentrated. As can be seen from Figure 4 (b), the newly generated signal power of the FWM gradually decreases with the increase of the transmission distance, and there is no significant increase in the initial time. At the
same time, observing Figure 4 (c) found that the eye pattern "eye" of the received signal is enlarged and clear, and the quality of the eye pattern has been greatly improved.

Effective area. The effective area of the optical fiber refers to the average area of the optical fiber used to transmit optical power. The effective area of the fiber core is increased from $55 \times 10^{-12} \text{m}^2$ to $100 \times 10^{-12} \text{m}^2$, and the remaining parameters remain unchanged. The large effective area of the core can also weaken the FWM to a certain extent, so that the system has a greater transmission capacity, carries a larger optical power signal, and reduces the bit error rate.

3.3 Influence of channel spacing on FWM
Increase the frequency interval of the channel from 50GHz to 100GHz, and keep the remaining parameter values unchanged. The experimental results are shown in Figure 5. The analysis results show that after increasing the channel interval, the energy of the new frequency component generated by the FWM at the fiber output is significantly reduced; the power increase of the interference signal becomes smaller; the eye diagram of the received signal becomes clear, and the quality of the eye diagram has been improved very well. However, it should be considered that increasing the channel interval will reduce the communication capacity. If a more in-depth analysis of this influencing factor is required, the experimental verification and analysis of the channel equal interval suppression method, partial equal interval suppression method, and unequal interval suppression method are also required [5,8,9].
4. Conclusion
This paper designs and builds an inter-channel FWM simulation system through the VPI experimental platform, analyzes the factors that cause FWM crosstalk. Experimental results show that in optical communication systems, the increase in optical signal power will cause more serious cross-band crosstalk generated by FWM, choosing the appropriate fiber, such as increasing the fiber's dispersion coefficient and effective core area, can effectively suppress FWM crosstalk. In addition, increasing the channel frequency interval can also reduce the FWM crosstalk effect to a certain extent, so that the system performance is improved.

Acknowledgments
This work was supported by the National Science Foundation Project of P. R. China (No.61402529); the Natural Science Basic Research Plan in Shanxi Province of China (No.2020JM-361); the Young and Middle-aged Scientific Research Backbone Projects of Engineering University of PAP (No.KYGG201905); the Basic Research Foundation Project of Engineering University of PAP (No.WJY201920).

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