Suppression of FWM Effects by using Cost Effective Combined DCF and FBG Module

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Abstract

Objectives: The main aim of this research paper is suppression of Four Wave Mixing effect using cost effective combined dispersion compensation fiber and fiber brag grating module. Methods/Statistical Analysis: Four-Wave Mixing (FWM) nonlinearity is observed in this work along with its suppression technique. At high powers, maximum FWM power can be seen and at low power very less nonlinearity. Several FWM degradation schemes proposed so far but they limited in terms of performance and are very expensive such as phase conjugator. Findings: In current work a cost effective FBG in uniform chirping and tanhapodization is used to suppress FWM. Also comparison has been done with single tanhapodized FBG, conventional FBG and combined DCF and FBG module. Application/Improvement: It is realized that, in coming future, use of Broadband amplifier like HOA can be used for the further analysis of this system for C+L band to effect of amplification and dispersion. And work can be further extended to no. of users increased and data rate.

Keywords: Dispersion Compensation Fiber (DCF), Fiber Brag Grating (FBG), Four-Wave Mixing (FWM)

1. Introduction

Optical fiber communication is very popular now days due to fast processing and wide bandwidth. In real scenario, optical fiber communication is limited in terms of distance achievement due to nonlinear effects. Many researchers have come up with different improvements in this area. FWM takes place when light of two or more diverse wavelengths is launched in the fiber, thus generating a new wave. It is a parametric procedure in which unlike frequencies interact and by frequency mixing produce new spectral components. FWM in the frequency domain, packing in the two pumping waves, the light that was there prior to launching wave called the probe light or signal light Figure 1. The idler frequency \( f_{\text{idler}} \) may be determined by:

\[
f_{\text{idler}} = f_{\text{p}_1} + f_{\text{p}_2} - f_{\text{probe}} \quad \text{(1)}
\]

Where \( f_{\text{p}_1} \) and \( f_{\text{p}_2} \) are pumping light frequencies, and \( f_{\text{probe}} \) is probe light frequency. This state is called the frequency phase-matching condition. When frequencies of two pumping waves are same” Degenerated Four-Wave Mixing” (DFWM) term is used and the equation for DFWM is written as:

\[
f_{\text{idler}} = 2f_{\text{p}} - f_{\text{probe}} \quad \text{(2)}
\]

Where \( f_{\text{p}} \) is degenerated pumping wave frequency. FWM is avoided during the transmission of Dense Wavelength-Division Multiplexed (DWDM) signals; it provides an efficient technological base in certain applications. Furthermore, FWM presents the fundamental technology for measuring the nonlinearity and chromatic dispersion of optical fibers.

FWM is the leading degradation effects in WDM systems with narrow channel spacing and less chromatic dispersion in the fiber. If channel are uniformly spaced, the new waves are produced by FWM will fall at channel frequencies and rise the crosstalk between channels. In the case of full in-line dispersion compensation, i.e., 100% dispersion compensation per span, the crosstalk becomes maximum in FWM since the FWM products add coherently in each span. In current work a
cost effective FBG in uniform chirping and tanh apodization is used to suppress FWM. Also comparison has been done with single tanh apodized FBG, conventional FBG and DCF and FBG module.

![Figure 1](image1.png)

**Figure 1.** (a) 2-channel pump wave, (b) 1-channel pump wave.

### 2. System Setup

Several techniques have been used in past to suppress the effect of FWM crosstalk and enhance the signal output. FWM signals are removed by increase channel, decreasing per channel input, by unequal channel spacing. FWM is inversely proportional to dispersion of transmission fiber. Based on grating period FBG have four types: Uniform gratings – have fixed grating interval; Chirped gratings - this gratings are done non-uniformly; Tilted gratings - done tilted but in uniform manner; Superstructure - this gratings are uniformly grouped. By approximation the development grating process is flexible. According to fiber specification the chirp characteristics is readily chosen. To tolerate high optical power without any loss due to non-linear effect is prominent characteristics that separate the DCF and FBG from DCF. At low optical power the DCF show non-linearity effect, but at high power DCF and FBG won’t introduce such effect in optical network.

In this work, 16 optical transmitters are used from 193.1 THz frequency and operated at different input powers to see effect on FWM. This setup works on 160 Gbps each channel at 10 Gbps. Channel spacing among frequencies is choose 50 GHz which is very dense and bandwidth efficient. A ideal multiplexer is placed after transmitter to multiplex all channels and fed to optical fiber of length 50 Km. After travelling through optical fiber FWM sidebands appeared and maximum at high power due to change of refractive index. To compensate the effects of FWM, a DCF (5 Km) and FBG is placed after SMF. It is seen that FWM power degraded after this module and then demultiplexed by using demultiplexer. Same effects are studied after using alone FBG and conventional FBG Figure 2. A receiver and BER analyzer incorporated after Demux for each channel.

![Figure 2](image2.png)

**Figure 2.** Simulation setup of FWM compression using DCF and FBG module.

### 3. Results

Apodized FBGs give better system performance than the conventional FBGs. Figure 3 shows the comparison of apodized FBG and conventional FBG in terms of FWM effect. Figure shows that apodized FBG is better. So in our final system we have used apodised FBG. Hence in our final system we have used linearly chirped uniformly apodised FBG. Figure 4 shows the output power spectra’s at -15 dBm power for system compensated with DCF and uniformly apodised linear FBG, system compensated with DCF and system compensated with uniformly apodised linear FBG.

By comparing DCF and FBG method the cost of optical system and non-linear effect is increased, the two methods we can see that using DCF technique shown in Figure 5. But cost of system decreasing due to FBG and it has low insertion loss. The apodized grating play a very
important role to suppress side lobe and maintaining the reflectivity and narrow bandwidth.

DCF and FBG is the best approach to compensate the system non-linarites and dispersion. System can be optimized by using the combination of the two dispersion compensation techniques by choosing optimal length, power, chirping profile, grating period etc.

**Figure 3.** Comparison of apodized FBG and conventional FBG.

**Figure 4.** (a) Power spectra for DCF, (b) Power spectra for FBG, (c) Power spectra for DCF and FBG.

Comparison between all dispersion compensation technique based on eye diagram Figure 6. Eye diagrams give result on first channel, as we have seen in different eye diagram dispersion compensation have good effect. The edge of diagram is symmetrical, neat and as eye's open very good, quality of signal is high. This indicates DCF greatly compensate chromatic dispersion in different
channel. The time delay in the received bits is negligible in the eye diagram and signal distortion tolerable due to BER. In optical systems, performance of optical signal to noise ratio could not measure accurately, especially in WDM system. To measure the performance of optical system quality factor is very important indicator by which BER is characterized.

4. Conclusion
Four-Wave Mixing nonlinearity is observed in this work along with its suppression technique. At high powers, maximum FWM power can be seen and at low power very less nonlinearity. Several FWM degradation schemes proposed so far but they limited in terms of performance and
are very expensive such as phase conjugator. In current work a cost effective FBG in uniform chirping and tan-
hapodization is used to suppress FWM. Also comparison has been done with single tanhapodized FBG, conven-
tional FBG and DCF and FBG module. It is concluded that apodized FBG is better than conventional FBG and
DCF and FBG module is better than former techniques in terms of FWM power degradation.

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