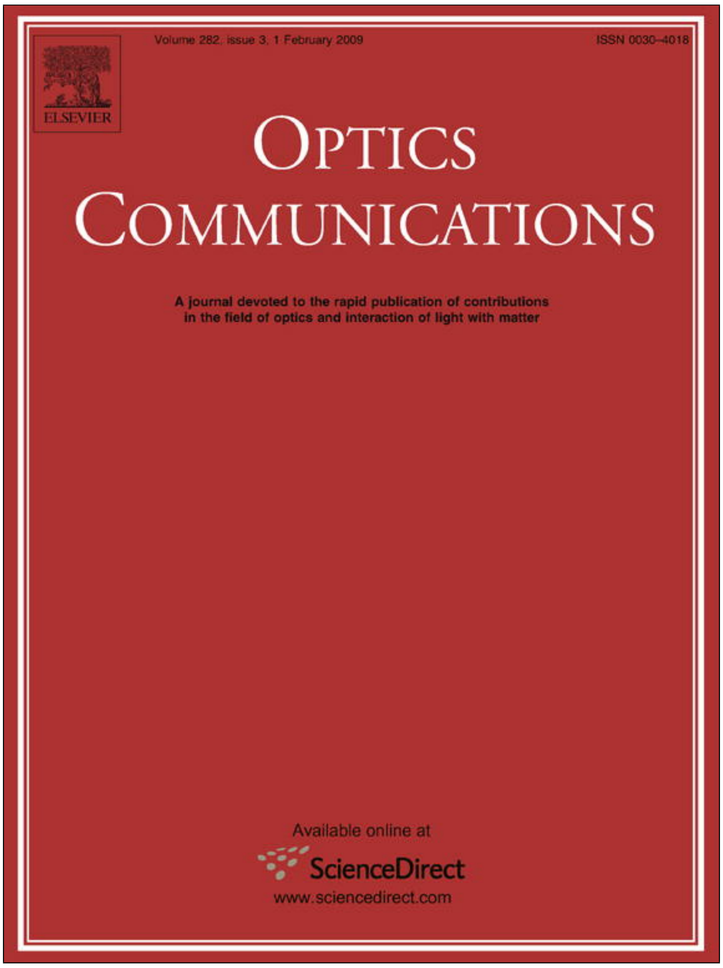
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Investigation on modified FWM suppression methods in DWDM optical communication system

Amarpal Singh [a,*], Ajay K. Sharma [b], T.S. Kamal [c]

[a] Department of Electronics and Communication Engineering, Beant College of Engineering and Technology, Gurdaspur, Punjab, India
[b] National Institute of Technology, Jalandhar, Punjab, India
[c] Doaba Institute of Engineering and Technology, Ropar, Punjab, India

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ABSTRACT

The focus of this paper is to investigate the methods for Four Wave Mixing (FWM) suppression. Modified techniques equal and unequal-channel spacing with polarization, equal channel spacing with alternate channel delay, optical coupling and varied laser power have been proposed to reduce the impact of FWM on Dense Wave Length Division Multiplexing (DWDM) optical communication system. Further the comparison of reduction of FWM for existing and proposed techniques has been discussed by varying the dispersion of fiber from 0 to 16 ps/nm/km. It has been observed that the suggested techniques are simpler to design optical communication system and superior to the existing methods.

1. Introduction

The dispersion and fiber nonlinearities are the parameter which restricts the transmission distance and bandwidth of optical communication systems. The nonlinear effects tend to manifest themselves when optical power is very high and become important in WDM/DWDM systems. The fiber nonlinearities fall into two categories. One the stimulating scattering (Raman and Brillouin) are responsible for intensity dependent gain or loss and generated due to stimulated process. The second types of nonlinearities are Self Phase Modulation (SPM), Cross Phase Modulation (XPM) and Four Wave Mixing (FWM).

The FWM is one of the major and significant degrading factors in WDM and DWDM optical communication systems [1,2]. There have been many reports on methods for solving these problems including the use of nonzero dispersion fibers, dispersion management and unequal-channel spacing techniques [3–5]. However, these techniques require dispersion compensation or a complex system design. For example to design a transmitter of unequal-channel spacing is more complex as compared to equal channel spacing transmitter. Therefore, a novel fiber for suppressing FWM has been needed to increase the transmission capacity and simplify the system design. The FWM efficiency depends strongly on the phase matching condition, which is closely related to the chromatic dispersion for each signal in an optical fiber [6–9]. The various methods for suppressing FWM have been reported in the literature [10–14]. Moreover from the previous literature it is concluded that the FWM is increased at low dispersion (zero dispersion), small and equal channel spacing as compared to unequal-channel spacing.

This paper, proposed new methods for the suppression of FWM and compared the results with existing methods like: equal channel spacing and unequal-channel spacing at various dispersion values 0–16 ps/nm/km.

2. System description

Fig. 1 illustrates system setup for eight-channel DWDM transmission link. The optical fiber length is taken as 200 km having two spans of 100 km. Here, eight-channel system as per ITU grid has been launched over DS fiber. The optical transmitter consists of continuous wave (CW) semiconductor laser with externally modulated by 10 Gb/s NRZ-raised cosine each having different central frequencies. The NRZ rectangular pulse format is transmitted with pseudorandom sequence length of $2^9 - 1$. The eight channel are combined (multiplexed) and amplified with optical amplifier with maximum small signal gain of 35 dB. The fiber loss is taken to be 0.2 dB/km and core effective area of fiber is 67.43×10^{-12} m^2.

The dispersion is compensated by using ideal fiber Bragg grating. In order to observe the impact of suppression method the fiber dispersion value is varied form 0 to 16 ps/nm/km through parametric runs. At receiver the optical power meter is used to measure

* Corresponding author.
E-mail address: s_amarpal@yahoo.com (A. Singh).

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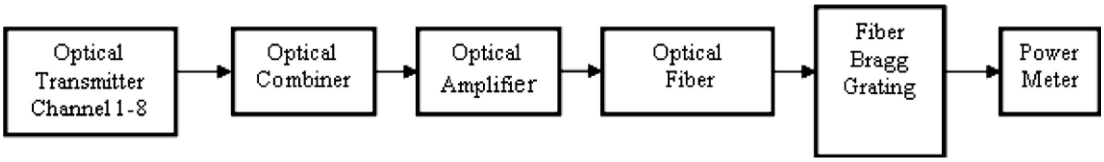

Fig. 1. System setup.

FWM power. The changes in transmitter to discuss the various FWM suppression methods are given below.

2.1. Case-I: equal channel spacing

In the case of equal channel spacing the central frequencies of laser are taken as 193.025, 193.035, 193.045, 193.055, 193.065, 193.075, 193.085 and 193.095 Thz having channel spacing of 0.01 Thz.

2.2. Case-II: unequal-channel spacing

In the case of unequal-channel spacing the central frequencies of laser are taken as 193.025, 193.04, 193.045, 193.055, 193.07, 193.08, 193.085 and 193.095 Thz.

2.3. Case-III: polarization

In the case of polarization method the polarization for alternate channel is rotated 180° around the *s*2 axis of pioncare sphere.

2.4. Case-IV: equal channel spacing with alternate variable laser power

In this case alternate variable laser power is taken for eight-channel WDM systems. The laser power of alternate channel has been kept at the value of 10 and −5 dBm. For channels 1, 3, 5 and 7 laser power is −10 dBm while for channels 2, 4, 6 and 8 it is −5 dBm.

2.5. Case-V: equal channel spacing with optical coupler

In the case of optical coupler the four optical couplers are used to couple the input channels and fed to optical combiner. The first channel combined with fifth, second with sixth, third with seventh, and fourth with eighth. Output port represents the power ratio, on a percentage basis, between each of the inputs and the corresponding cross output, (P_{out2}/P_{in1} or P_{out1}/P_{in2}). The out put ratio is taken as 50.

2.6. Case-VI: equal channel spacing with channel delay

In the case of channel delay the alternate channel has been delayed by 10 ps. The channels 2, 4, 6 and 8 are delayed by a factor of 10 ps using deterministic differential group delay. The principal state of polarization (PSP) applies a deterministic delay between the optical signal components with respect to the PSP. The input optical signal is split into two branches and sent to polarizer POL1 and POL2. These polarizers are complementary, and can set the POL1 polarization in the Stokes space representation, POL2 is automatically set to the orthogonal polarization.

3. Results and discussion

In order to compare the proposed FWM suppression method here all the cases have been compared with well known methods like: equal channel spacing and unequal-channel spacing. Fig. 2 shows the graph for FWM power versus dispersion for equal channel spacing, unequal-channel spacing and equal spacing with alternate delay. The FWM power is less in equal channel spacing with alternate delay and lies in the range from −13.5 to −19.5 dBm as compared to equal channel spacing, −10.5 to −18.7 dBm and unequal-channel spacing, −12 to −18.7 dBm for dispersion values 0 and 16 ps/nm/km, respectively. It is observed that the new proposed method gives better result at zero dispersion and at higher dispersion values. Moreover the results show the decrease in FWM power exponentially with the increase in dispersion.

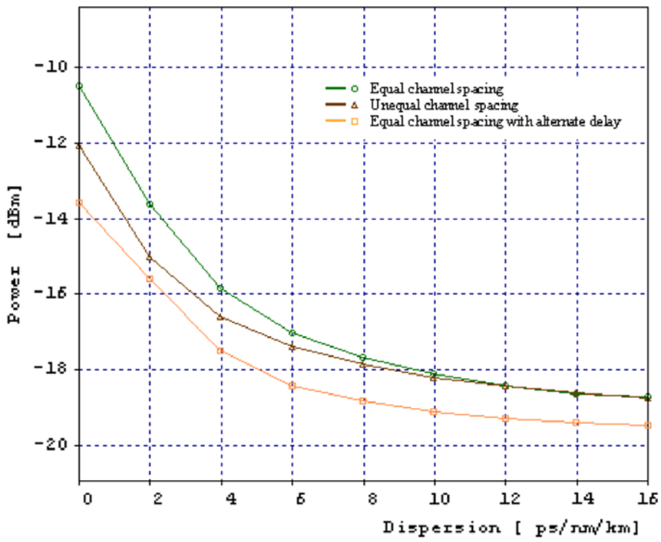

Fig. 2. FWM power versus dispersion (comparison of equal channel spacing and unequal-channel spacing FWM suppression methods with equal channel spacing with alternate delay).

Fig. 3 also show the similar trends as Fig. 2 only difference is that we have taken equal channel spacing with orthogonal polarization. The FWM power lies in the range from −15.2 to −19.7 dBm at a dispersion from 0 to 16 ps/nm/km. It is investigated that the FWM power small as compared to old technique at zero and higher dispersion values.

Fig. 4 shows equal channel spacing with optical coupling the results show that FWM power decreases exponentially and varies in the range from −12.8 to −18.7 dBm at a dispersion from 0 to 16 ps/nm/km. In this case the FWM power is −12.8 dBm as compared to −10.5 and −12 dBm for equal and unequal-channel spacing, respectively at zero dispersion. However, as dispersion increases varies from 11 to 16 ps/nm/km the FWM power approximately gives the same results in all three cases.

Fig. 5 shows the comparison between FWM powers for equal channel spacing, unequal-channel spacing and unequal spacing with orthogonal polarization. In this figure it clearly shows that the new proposed unequal-channel spacing with orthogonal polarization FWM suppression method gives very good results and the FWM power lies in the range from −17 to −19.7 dBm as compared to equal channel spacing from −10.5 to −18.7 dBm and unequal-channel spacing from −12 to −18.7 dBm for dispersion values of 0 and 16 ps/nm/km, respectively.

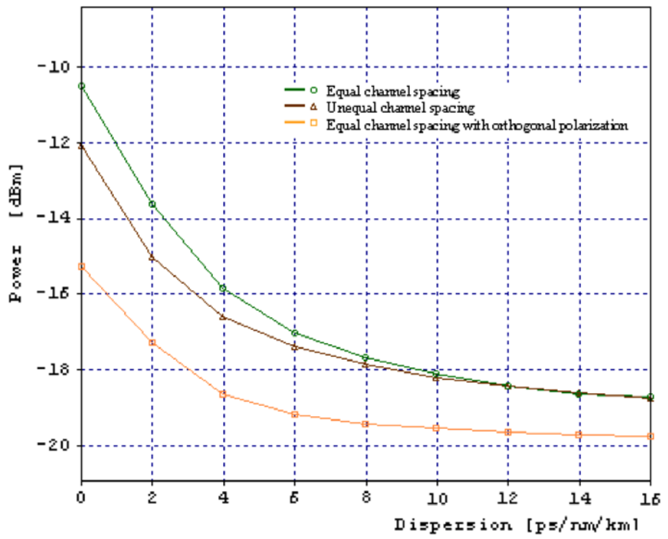

Fig. 3. FWM power versus dispersion (comparison of equal channel spacing and unequal-channel spacing FWM suppression methods with equal channel spacing with orthogonal polarization).

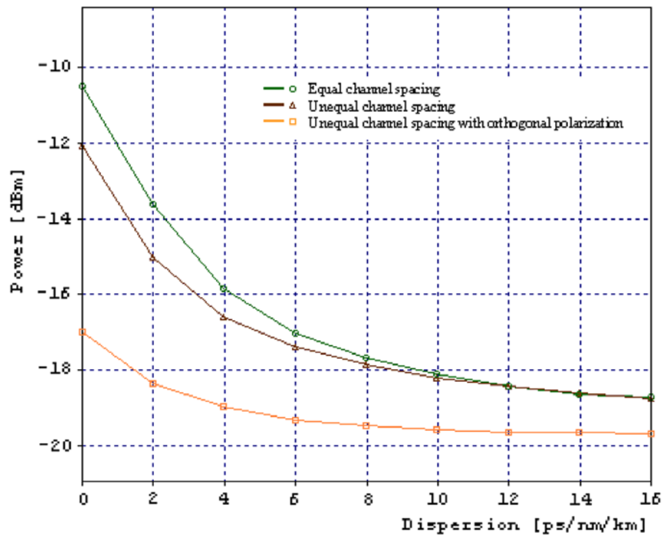

Fig. 5. FWM power versus dispersion (comparison of equal channel spacing and unequal-channel spacing FWM suppression methods with unequal-channel spacing with orthogonal polarization).

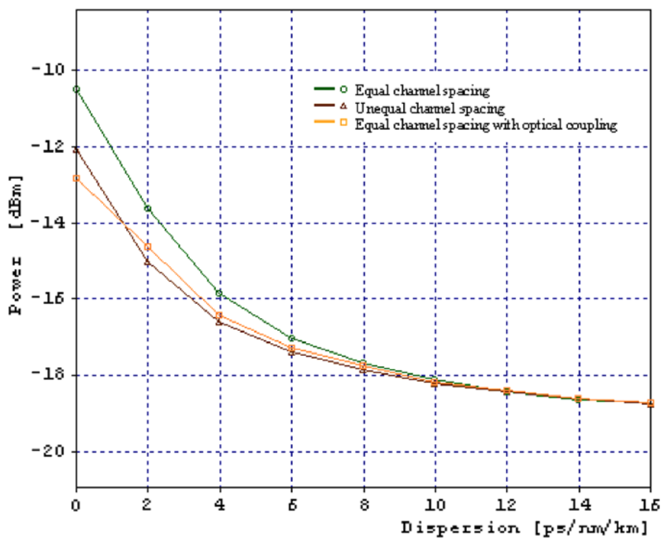

Fig. 4. FWM power versus dispersion (comparison of equal channel spacing and unequal-channel spacing FWM suppression methods with equal channel spacing with optical coupling).

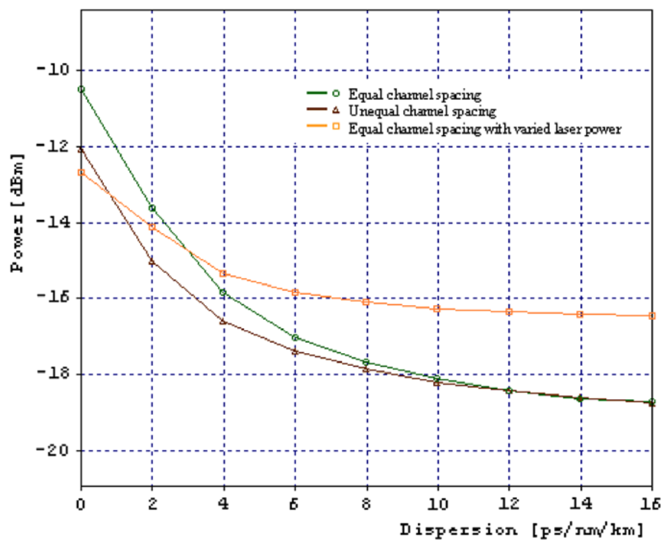

Fig. 6. FWM power versus dispersion (comparison of equal channel spacing and unequal-channel spacing FWM suppression methods with equal channel spacing with varied laser power).

Fig. 6 shows the graphs between FWM powers for equal channel spacing, unequal-channel spacing and equal channel spacing with varied laser power versus dispersions. The results show that output power for equal channel spacing with varied laser power varies in the range from −12.7 to −16.5 dBm for dispersion varying from 0 to 16 ps/nm/km.

The results indicate there is a significant reduction of FWM power in comparison with conventional methods, if the hybrid and new methods are used for FWM suppression. It is observed that the FWM power is −10.5, −12, −12.7, −12.8, −13.5, −15.2 and −17 dBm in case of equal-, unequal-channel spacing, equal channel spacing with varied laser power, optical coupling,

Table 1
FWM power for various suppression techniques.

FWM suppression technique	At $D = 0$	At $D = 2$	At $D = 4$	At $D = 6$	At $D = 8$	At $D = 10$	At $D = 12$	At $D = 14$	At $D = 16$
Equal channel spacing (ECS)	−10.5	−13.6	−15.8	−17	−17.6	−18.1	−18.4	−18.6	−18.7
Unequal-channel spacing (UCS)	−12	−15	−16.5	−17.4	−17.9	−18.2	−18.4	−18.6	−18.7
ECS with alternate polarization	−15.2	−17.3	−18.6	−19.2	−19.4	−19.5	−19.6	−19.7	−19.7
UCS with alternate polarization	−17	−18.3	−18.9	−19.3	−19.45	−19.55	−19.6	−19.6	−19.7
ECS with alternate delay	−13.5	−15.6	−17.5	−18.4	−18.8	−19.1	−19.2	−19.3	−19.5
ECS with alternate coupling	−12.8	−14.6	−16.3	−17.3	−17.7	−18.1	−18.3	−18.6	−18.7
ECS with alternate power	−12.7	−14.1	−15.3	−15.8	−16.1	-16.2	−16.3	−16.4	−16.5

alternate delay, orthogonal polarization and unequal-channel spacing with orthogonal polarization, respectively at zero dispersion value. The FWM power for various suppression methods has been tabulated in Table 1. From table it is investigated that the new proposed method gives the better results when dispersion is fully compensated which can save the bandwidth of system so more number of channels can be transmitted.

It is also observed that the proposed methods are superior to commonly used methods at zero dispersion and FWM power reduces more as the dispersion is increased.

4. Conclusions

The proposed methods for FWM suppression like equal channel spacing with varied laser power, optical coupling, alternate delay, orthogonal polarization and unequal-channel spacing with orthogonal polarization has been found best to the existing methods like equal- and unequal-channel spacing. Moreover the existing FWM suppression method like unequal-channel spacing requires a complex system design. So the proposed methods are superior to commonly used methods when the dispersion is fully compensated (zero dispersion). Further it is observed that the FWM power reduces more as the dispersion is increased.

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