VOL. 9, NO. 8, AUGUST 2014 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

ANALYSIS OF FOUR WAVE MIXING IN WDM OPTICAL FIBER SYSTEMS USING LABVIEW

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ABSTRACT

This paper introduces the non linear optical effect known as four wave mixing (FWM). In wavelength division multiplexing (WDM) systems four wave mixing can strongly affect the transmission performance on an optical link. As a result it is important to investigate the impact of FWM on the design and performance of WDM optical communication systems. The main objective of this paper is to analyze the FWM power and efficiency for different channel spacing of transmitted signals, dispersion and core effective area of fiber by designing and simulating a model in LabVIEW. In this paper, we have simulated the FWM design for three waves. The results obtained show that the FWM power and efficiency decreases with the increase of the channel spacing of transmitted signals, dispersion and core effective area of fiber.

Keywords: four-wave mixing (FWM), optical communication, wavelength-division multiplexing (WDM), LabVIEW, nonlinear effects, core effective area of fiber, channel spacing, dispersion.

1. INTRODUCTION

Four wave mixing (FWM) is one of the major limiting factors in wavelength division multiplexing (WDM) optical fiber communication systems that use low dispersion fibers or narrow channel spacing. As a result, estimating FWM efficiency and power is becoming very important for both the design and evaluation of dense wavelength division multiplexed (DWDM) systems [1, 2]. When a high-power optical signal is launched into a fiber, linearity of the optical response is lost. FWM is due to changes in the refractive index with optical power called Optical Kerr Effect. If two or more channels interact with each other through four-wave mixing, optical power will be generated with new frequencies at the cost of a reduction of power in the original channels. This power loss makes it more difficult to correctly detect the digital data in these channels at the far end of the fiber, making errors more likely [1]. Four-wave mixing in WDM systems can be minimized by ensuring that phase matching does not occur.

For any three co-propagating optical signals with frequencies f_i, f_j, f_k the new frequencies f_{ijk} generated by FWM are represented by $f_{ijk} = f_i + f_j - f_k$ for i,j,k. Considering all the possible permutations, N co-propagating optical signals will give rise to M new optical signals as $M = N^2(N-1)/2$. Therefore in FWM effect, three co-propagating waves produce nine new optical sideband waves at different frequencies. When this new frequency falls in the transmission window of the original frequencies, it causes severe cross talk between the channels propagating through an optical fiber. Moreover, the degradation becomes very severe for large number of WDM channels with small channel spacing [1, 3].

The formula, which has been widely used to evaluate the FWM induced crosstalk in WDM systems [2-6], can be written as

$$P_{ijk}(L) = \frac{\eta}{9} D^2 \gamma^2 P_i P_j P_k \exp(-\alpha L) \left\{ \frac{[1-\exp(-\alpha L)]^2}{\alpha^2} \right\} \qquad (1)$$

where P_i, P_j, P_k are the input powers for the signals at frequencies f_i, f_j, f_k, respectively, L is the fiber length, α is the fiber attenuation coefficient, and the degeneracy factor D equals to three or six for degenerate and nondegenerate FWM, respectively. The nonlinear coefficient γ is given by [2]

$$\gamma = \frac{2\pi n_2}{\lambda A_{eff}} \qquad (2)$$

where A_{eff} is the core effective area of fiber, λ is the vacuum wavelength, and n_2 is the fiber nonlinear refractive index, which is related to the nonlinear susceptibility χ_{1111} by [2].

$$n_2 = \frac{48\pi^2}{cn^2} \chi_{1111} \qquad (3)$$

where n is the refractive index of the fiber core and c is the vacuum speed of light. Also, η is the FWM efficiency [1, 2, 3], which can be expressed as

$$\eta = \frac{\alpha^2}{\alpha^2 + \Delta k^2} \left\{ 1 + \frac{4\exp(-\alpha L)\sin^2\left(\frac{\Delta k L}{2}\right)}{[1-\exp(-\alpha L)]^2} \right\} \qquad (4)$$

In this expression, Δk is the phase-matching factor, which depends on the fiber dispersion and the channel spacing [1, 2] and can be expressed as

$$\Delta k = \frac{2\pi\lambda_k^2}{c} \Delta f_{ik} \Delta f_{jk} \left[D_c + \frac{\lambda_k^2}{2c} (\Delta f_{ik} + \Delta f_{jk}) \frac{dD_c(\lambda_k)}{d\lambda} \right] \qquad (5)$$

where $\Delta f_{mn} = |f_m - f_n|$, (m,n = i,j,k) is the channel spacing, D_c is the fiber chromatic dispersion, $dD_c/d\lambda$ is the dispersion slope, and λ_k is the wavelength corresponding to the wave at frequency f_k.

In this paper, by using above equations we have designed a model in LabVIEW to study and analyze the effect of varying channel spacing of transmitted signals, dispersion and core effective area of fiber on the FWM power and efficiency of the WDM optical communication systems. The block diagram is provided to illustrate the design method by using LabVIEW software. The front panel of the simulation system is also presented which acts as a user interface. Finally the graphs are shown and the results are discussed.

2. SIMULATION DESIGN

According to the equations provided, the model for simulating the FWM effect on the WDM optical fiber system by using LabVIEW software is provided. Firstly, the system accepts the data input from users, which include the refractive index n, the nonlinear susceptibility χ_{1111}, the wavelength λ_k, the dispersion slope $dD_c/d\lambda$, the fiber attenuation coefficient α, the fiber length L, the vacuum wavelength λ, the degeneracy factor D, the input powers P_i, P_j and P_k, the channel spacing, the core effective area A_{eff} and the chromatic dispersion D_c. Then the power and efficiency is calculated by using above equations. The results are fed to the graphic control to show the graphs. The block diagram of the system is shown in Figure-1.

In the front panel, all the plots can be seen on a single XY graph indicator. An axis switch control box is designed to select the desired X and Y axis parameter, where X axis parameters include effective area, dispersion and channel spacing, and Y axis parameters include power and efficiency. Non linear refractive index is also shown as an output parameter. Figure-2 shows the front panel of the system.

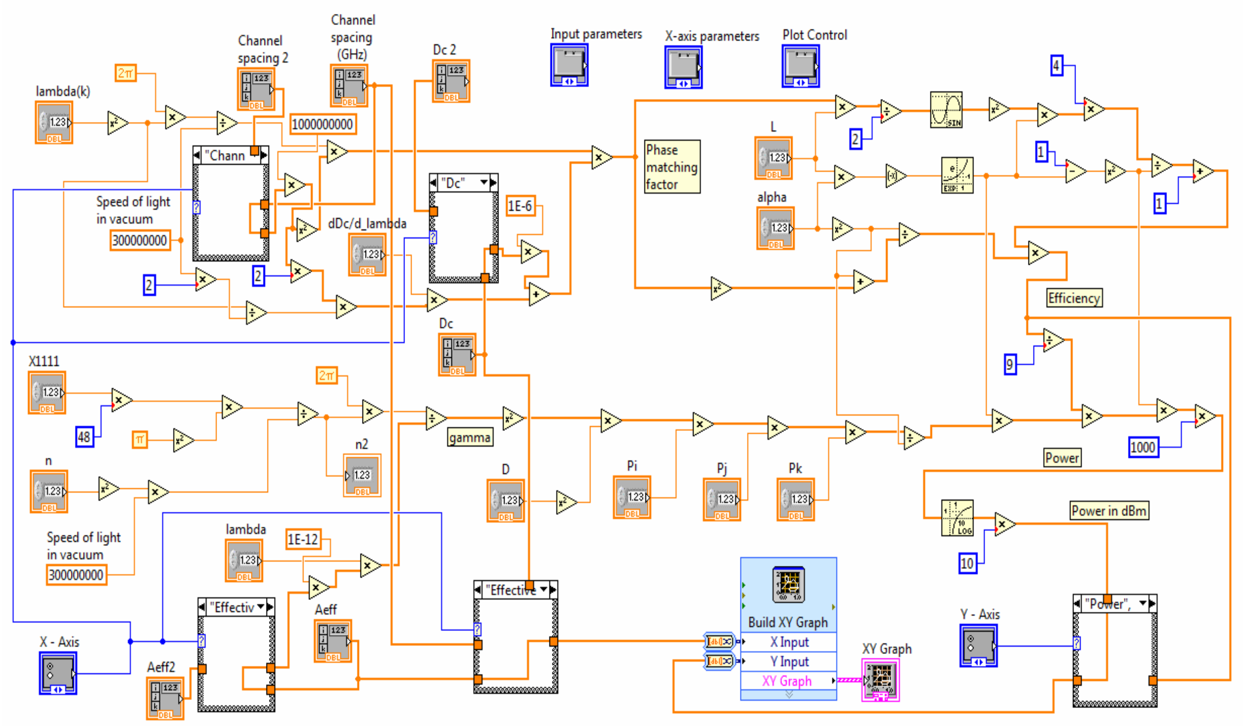
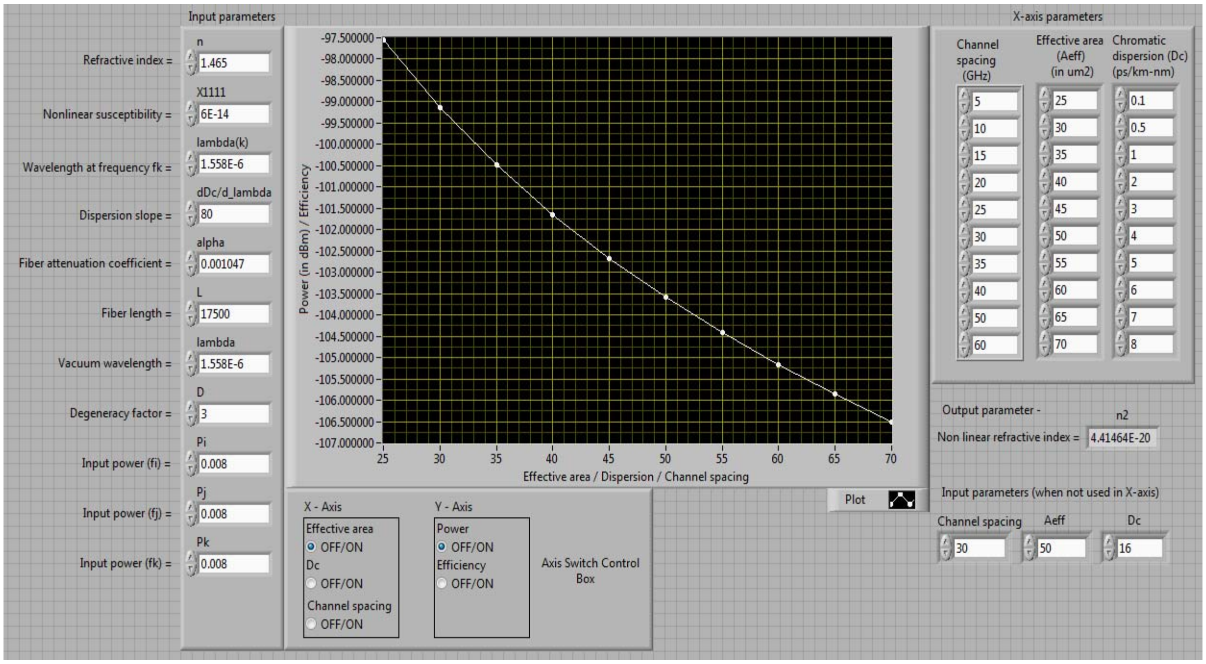


Figure-1. Block diagram of the system design based on LabVIEW.



Input parameters

Refractive index = n 1.465
Nonlinear susceptibility = X1111 6E-14
Wavelength at frequency fk = lambda(k) 1.558E-6
Dispersion slope = dDc/d_lambda 80
Fiber attenuation coefficient = alpha 0.001047
Fiber length = L 17500
Vacuum wavelength = lambda 1.558E-6
Degeneracy factor = D 3
Input power (fi) = Pi 0.008
Input power (fj) = Pj 0.008
Input power (fk) = Pk 0.008

X - Axis
Effective area
● OFF/ON
Dc
○ OFF/ON
Channel spacing
○ OFF/ON

Y - Axis
Power
● OFF/ON
Efficiency
○ OFF/ON

Axis Switch Control Box

X-axis parameters

Channel spacing (GHz)	Effective area (Aeff) (in um2)	Chromatic dispersion (Dc) (ps/km-nm)
5	25	0.1
10	30	0.5
15	35	1
20	40	2
25	45	3
30	50	4
35	55	5
40	60	6
50	65	7
60	70	8

Output parameter -
Non linear refractive index = n2 4.41464E-20

Input parameters (when not used in X-axis)
Channel spacing 30
Aeff 50
Dc 16

Figure-2. Front panel of the simulation system.

3. RESULTS AND DISCUSSIONS

The plots of output FWM power versus core effective area, dispersion and channel spacing are shown in Figure-3, Figure-4 and Figure-5, respectively. And the plots of efficiency versus dispersion and channel spacing are shown in Figure-6 and Figure-7, respectively. The simulation result shows that the FWM power and efficiency decreases as we increase the core effective area, chromatic dispersion and frequency spacing between the channels. The value of the parameters used in the simulation is given in Table-1.

Table-1. Parameters used in simulation.

n	1.465
X1111	6×10^{-14} m^3/J
λ	1.558×10^{-6} m
$dD_c/d\lambda$	0.08 ps/km-nm^2
α	0.2 dB/km
L	17.5 km
Dc	16 ps/km-nm
Δf_{mn}	30 GHz
P_i, P_j, P_k	8 mW
D	3
A_{eff}	50 um^2

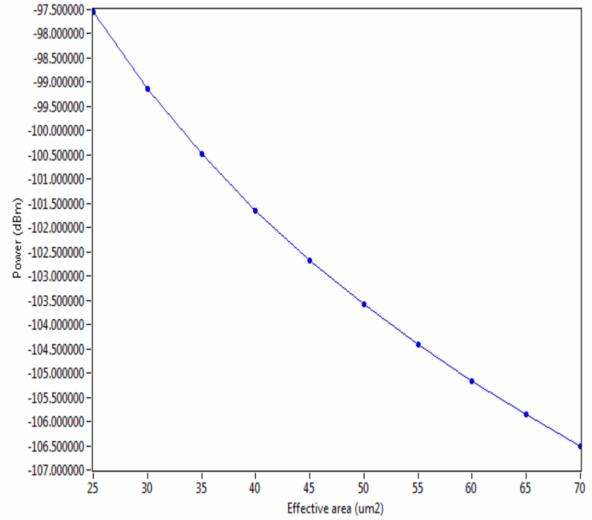


Figure-3. FWM power versus core effective area.

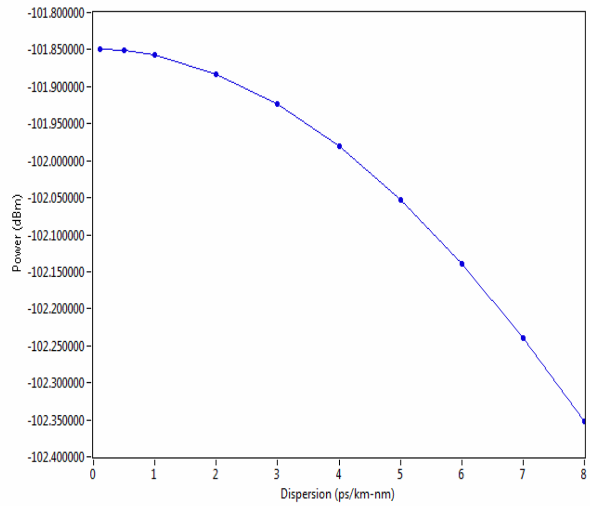


Figure-4. FWM power versus chromatic dispersion.

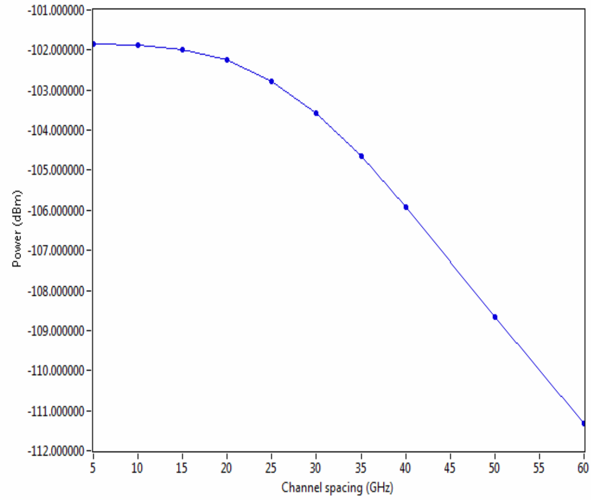


Figure-5. FWM power versus channel spacing.

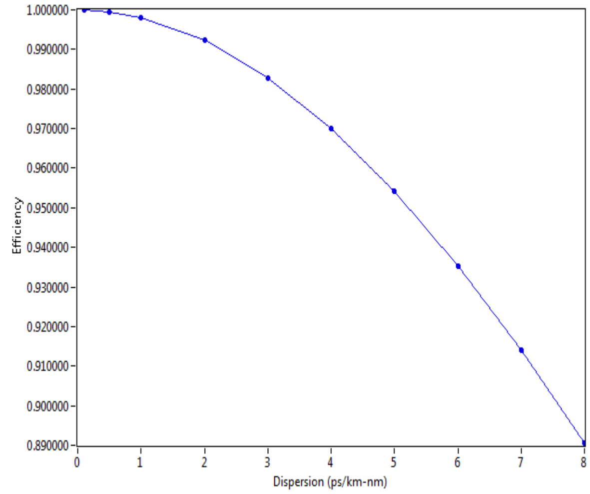


Figure-6. FWM efficiency versus chromatic dispersion.

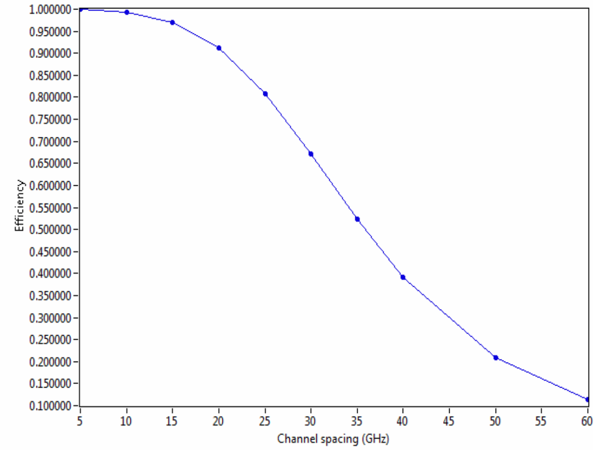


Figure-7. FWM efficiency versus channel spacing.

4. CONCLUSIONS

In this paper, a LabVIEW model is developed and presented for the analysis of FWM effect on the WDM optical communication systems by using equations of the FWM power and efficiency. From the simulation, it is concluded that FWM power and efficiency reduces as the channel spacing of transmitted signals, core effective area and dispersion of fiber is increased.

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