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# COMPARATIVE STUDY OF FWM IN WDM OPTICAL SYSTEMS USING OPTSIM AND ANFIS

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**Abstract** Four-Wave-Mixing (FWM) is one of the major degrading factors in Wavelength Division Multiplexing (WDM) optical fiber communication systems and networks along with other fiber non-linearties. As a result it is important to investigate the impact of FWM on the design and performance of WDM optical communication systems. This paper simulates that the FWM power reduced by increasing channel spacing of transmitted signals, dispersion and core effective area of fiber. Further, we propose a fuzzy based approach to calculate the FWM power by varying the channel spacing, dispersion, and core effective area of fiber. The Fuzzy logic helps in dealing with uncertain and complex systems difficult to model mathematically.

**Key Words,** Four wave mixing, WDM, Dispersion and ANFIS.

## 1. Introduction

WDM is widely used for optical communication system and networks in order utilize the maximum bandwidth available for transmission. The fiber non-linearity results severe degradations on the performance of optical Communication systems. The non-linearity in optical fibers falls into two categories [1]: Inelastic Stimulated Scattering and Kerr Effect.

Stimulated scattering (Raman and Brillouin) is responsible for intensity dependent gain or loss. It is generated due to stimulated processes, while Kerr effect happens due to the refractive index in the transmission fiber changes with the intensity of the transmitted signal, the signal suffers phase modulation. The nonlinear refractive index is responsible for intensity dependent phase shift of the optical signal. One major difference between scattering effects and the Kerr effect is that stimulated scattering have threshold power levels at which the nonlinear effects manifest themselves while the Kerr effect doesn’t have such a threshold. Self-phase modulation (SPM), Cross-phase modulation (XPM) and Four wave mixing (FWM) are generated due to optical Kerr effect.

However, Four-wave mixing is the major degrading factor in wavelength Division multiplexed (WDM) optical communication systems [2]. Four-wave mixing is one of a broad class of harmonic mixing or harmonic generation process, in which, three or more waves combine to generate waves at a different frequency that is the

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sum (or difference) of the signals that are mixed and generate a fourth EM wave because of the third order fiber's nonlinear susceptibility.

FWM is a weak effect, but it accumulates, if the signals in the optical channels remain in phase with each other over long transmission distances. Pulses transmitted over different optical channels, at different wavelengths, stay in the same relative positions along the length of the fiber because the signals experience near-zero dispersion. This further magnifies at zero dispersion wavelength. FWM gives birth to new waves of the frequency:

$$\omega_{ijk} = \omega_i + \omega_j - \omega_k$$

For a WDM system with *N* channels, the number of four-wave mixing products, *M*, will given as:

$$M = \frac{1}{2}\left(N^3 - N^2\right)$$

where N is the number of channels transmitted.

Therefore 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.

FWM induced cross talk in WDM systems [3-4] which is given as

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

and the FWM efficiency is expressed as

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

Where D is fiber chromatic dispersion, $\alpha$ is Attenuation factor, $\gamma$ = Non-linear coefficient, $n_2 =$ Fiber non-linear refractive index, and $P_i$, $P_j$, $P_k$ are Input channel powers.

## 2. Fuzzy inference system (FIS):

Fuzzy logic technique contains a potential to give a simplified control for various engineering and non-engineering applications. The rule-based character of fuzzy models allows for a model interpretation in a way that is similar to the one humans use to describe reality. Conventional methods for statistical validation based on numerical data can be complemented by the human expertise that often involves heuristic knowledge and intuition. Despite a number of successful applications, fuzzy modeling is still new in the area of WDM optical communication system.

A fuzzy logic controller (FLC) consists of fuzzifier, inference engine, fuzzy rule base, and de-fuzzifier. Fuzzy logic techniques have been applied to nonlinear, time varying, or non-stationary systems. A fuzzy logic system has the advantage of lower development costs, superior features and better end product performance [5-6].

The FLC membership functions are defined over the range of input and output variable values and linguistically describes the variables in universe of discourse (UOD). Selection of the number of membership functions and their initial values is based on process knowledge and intuition. The output from each rule can be treated as a fuzzy singleton. The FLC control action is the combination of the output of each rule using the weighted average defuzzification method and can be viewed as the center of gravity of the fuzzy set of output singletons. In this paper UOD of the various input and output variables are: Input Variables are Channel spacing and dispersion and Output Variable is FWM Power and is trained using ANFIS.

To explain the procedure of the ANFIS simply, we consider two inputs x and y and one output *f* in the fuzzy inference system. Hence, the rule base will contain two fuzzy “if-then” rules as follows[7]:

Rule 1: if x is $A_1$ and y is $B_1$ then $f = p_1x + q_1 y + r_1$.

Rule 2: if x is $A_2$ and y is $B_2$ then $f = p_2x + q_2 y + r_2$.

## 3. System Description:

A model of WDM optical communication system for different frequencies is simulated using Optsim to illustrate the FWM effect as shown in fig.1. Here, three continuous-wave (CW) semiconductor laser, externally modulated by10 Gb/s NRZ-raised cosine each having different central frequencies. The output of modulator from three channels is fed to optical combiner and amplified by the optical amplifier. At the input side optical splitter is used to connect the output of optical amplifier to optical fiber and to spectrum analyzer to measure the input spectrum. The length of fiber for simulation is taken as 200 km having two spans of 100 kms each. The dispersion is compensated by using ideal fiber Bragg gratings. The receiver consists of optical amplifier and optical splitter. In order to illustrate the effect of dispersion and effective area of fiber on FWM, the optical signal is detected by four power meters tuned at four frequencies (three input and one FWM). The central frequencies of lasers are equally spaced and are at 193.025, 193.075 and 193.125 THz. Results have been reported at dispersion varied from 0 to 6ps/nm/km for different channel spacing 0.05, 0.04 and 0.03 THz and fiber loss 0.2 dB/km, nonlinear refractive index of fiber $2.5 \times 10^{-20}$ and effective core area of fiber is $67.43 \times 10^{-12}$ $m^2$. Further the results have been obtained at dispersion 4 ps/nm/km and the effective area of optical fiber is varied as 25,30,35,40,45,50,55,60,65,70 μm for different channel spacing 0.05, 0.04 and 0.03 THz. The results obtained after simulation using optsim are compared with the results obtained by using Adaptive Neuro Fuzzy Inference System (ANFIS). Comparative study has been done for with and without subclustering based ANFIS.

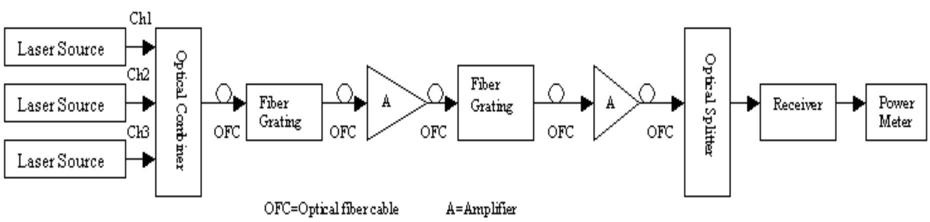


Figure 1 Simulation Model.

## 4. Result and discussion

The output FWM power versus core effective area and dispersion values at various channel spacing are shown in Figure 2 and 3 respectively, which shows that due to increase in core effective area and dispersion, the impairment due to four wave mixing decreases. The simulation result shows that the FWM effects decreases as the dispersion and effective area of fiber is increased. It has been observed that there is decrease in FWM due to increase in dispersion, channel spacing and core effective area in both cases with and without subclustering ANFIS.

This interdependency with the numerical values has also been shown in figure 2 and 3. It has observed from the graph that due to increase in core effective area and dispersion, the impairment due to four-wave-mixing decreases. The simulation result shows that the FWM effects decreases as the dispersion and effective area of fiber is increased. Further

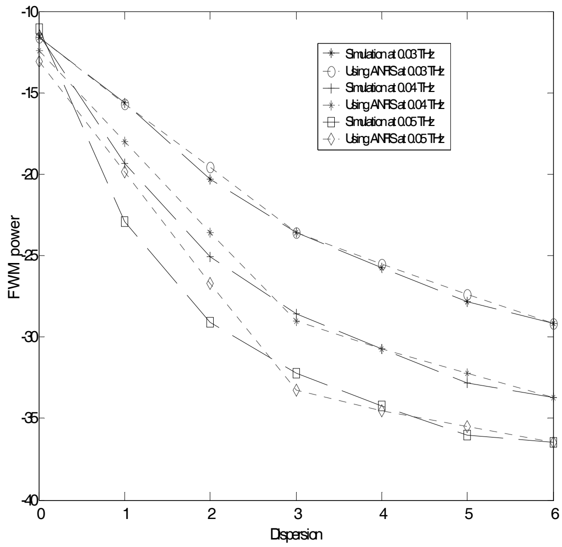


Figure 2(a) Comparison of Simulation and Fuzzy result without sub clustering at various dispersion

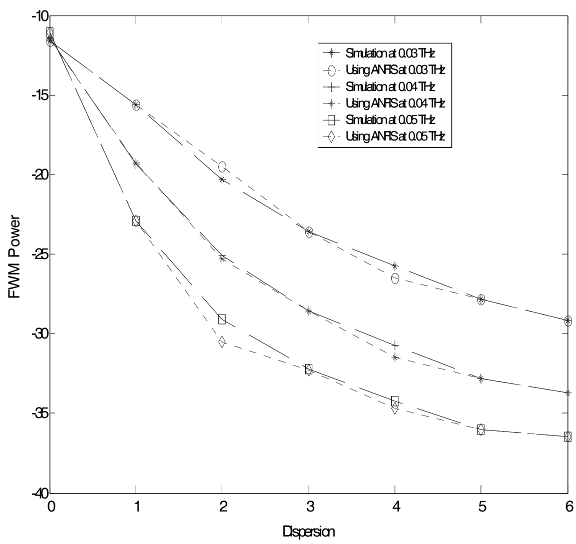


Figure 2(b) Comparison of Simulation and Fuzzy result using sub clustering at various dispersion

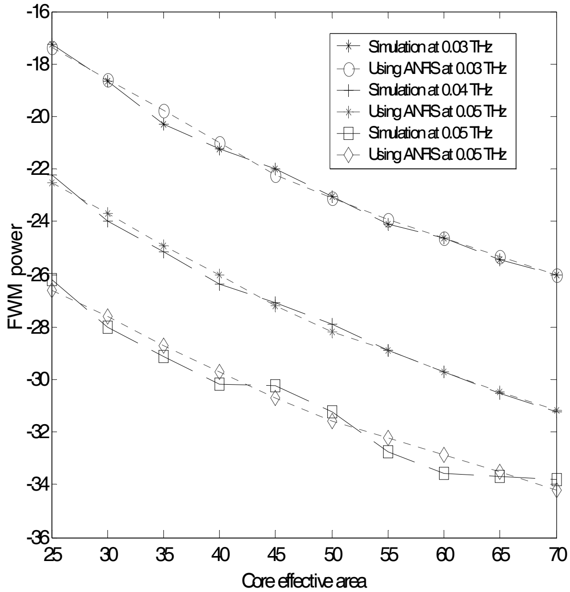


Figure 3(a) Comparison of Simulation and Fuzzy result without sub clustering at various core effective area

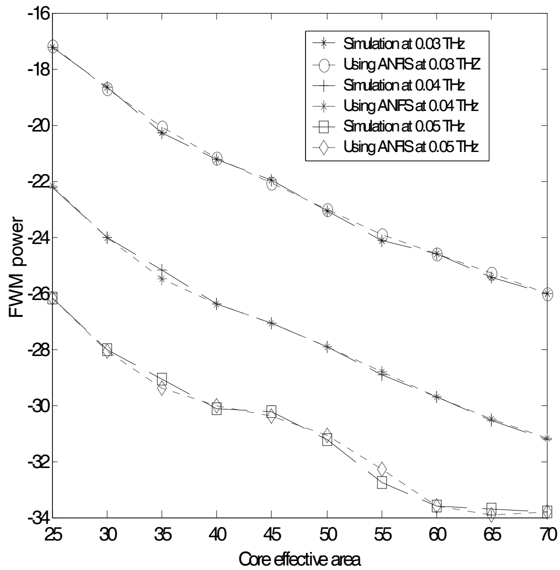


Figure 3(b) Comparison of Simulation and Fuzzy result with sub clustering at various core effective area

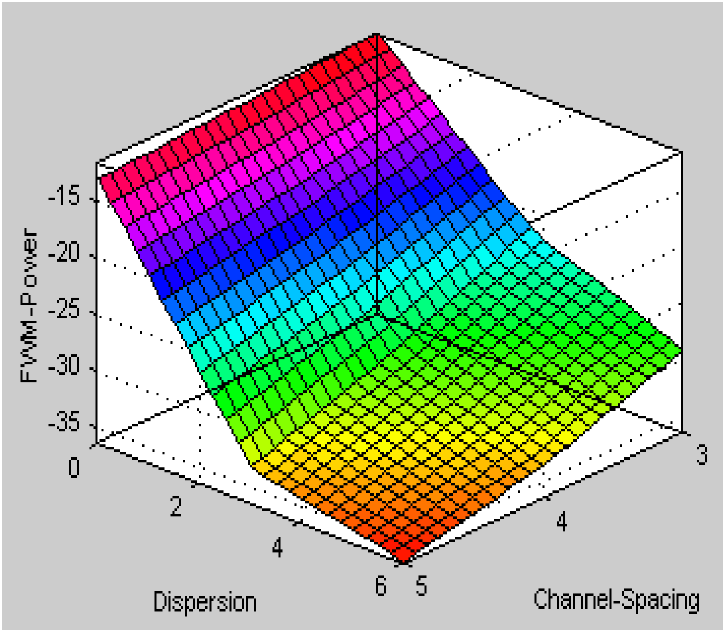


Figure 4(a) Control Surface of fuzzy inference system without subclustering for dispersion

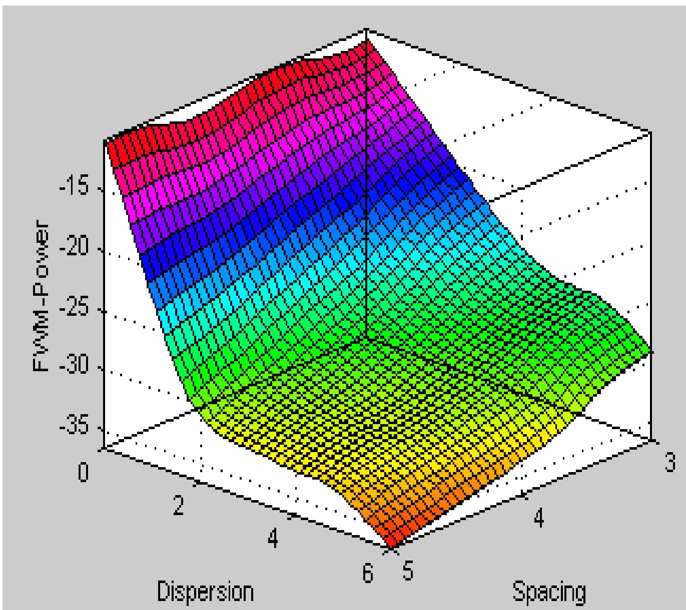


Figure 4(b) Control Surface of fuzzy inference system using sub clustering for dispersion

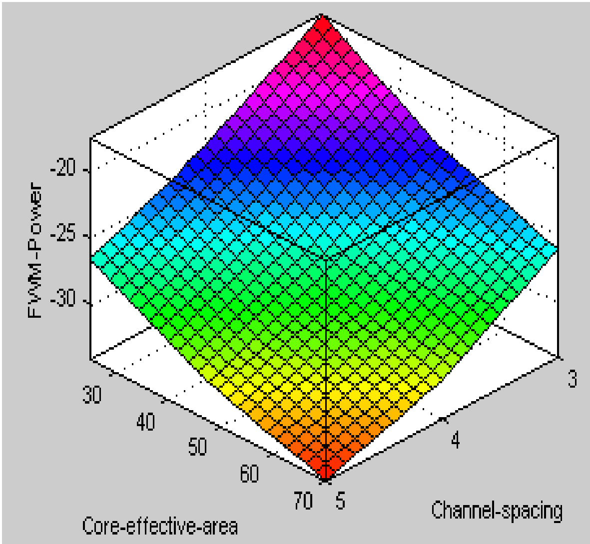


Figure 5(a) Control Surface of fuzzy inference system without subclustering for core effective area

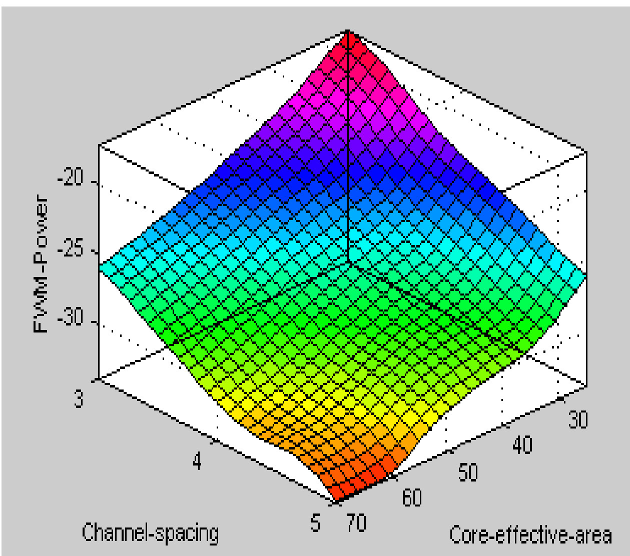


Figure 5(b) Control Surface of fuzzy inference system using sub clustering for core effective area it is observed that the FWM effect decreases more in 0.05 THz spaced channel compared to 0.03 THz and 0.04 THz. The control surface shown in figure 4 and 5 is giving the interdependency of input variables and output variable.

## 5. Conclusions

This paper simulates and gives the comparative study using ANFIS that the FWM reduced by increasing channel spacing of transmitted signals, core effective area and dispersion of fiber. The simulation results shows that the FWM effects decreases as the dispersion of fiber and core effective area of fiber is increased and the FWM effect decreases more in 0.05 THz spaced channel compared to 0.03THz and 0.04 THz.

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