NUMEREICAL ANALYSIS OF FOUR WAVE MIXING AND EXTRACTION OF DISPERSION PARAMETERS OF THE FIBRE

S.Sugumaran[1], Sabyasachi Goswami[2], Saurabh Palsania[3], Arun Raj[4], P.Arulmozhivarman[5]
School of electronics engineering, Vellore institute of technology,
Vellore 632014, Tamil Nadu, India
[1]ssugumaran@vit.ac.in
[2]sabbs1990@gmail.com
[3]saurabh.palsania@gmail.com
[4]rajarun40@gmail.com
[5]parulmozhivarman@vit.ac.in

***Abstract*- Four wave mixing generally occurs when two or more different wavelengths from two or more sources are launched into the fibre, resulting in a new wavelength known as idler (different from the given wavelengths). Here in this paper the efficiency of the generation of idler and the power of idler will be numerically simulated for two wave fibre transmissions. From this simulation, a curve will be obtained between power of idler and wavelength separation between signal and pump source, which will be used to propose a power independent method for extraction of dispersion parameters of a fibre.**

Keywords: Four wave mixing (FWM), Efficiency, Power of Idler, and Dispersion Parameters

I. INTRODUCTION

The field of nonlinear optics was ushered in with the development of the first laser by Maimenin 1960. Although nonlinear optical effects had been known as early as the nineteenth century (The Pockels and Kerr effects), but remained unexplored until the classic experiment by Franken and co-workers in which second-harmonic generation was demonstrated in quartz with the use of a ruby laser. The field of nonlinear optics has elaborated at a tremendous rate since its inception in 1961 and has proven to be a nearly inexhaustible source of new phenomena and optical techniques. ([1],[2],[3])

The paper generally explores the concept of calculation of the efficiency of the generated wave and hence calculates its power. The concept is mathematically based on various equations relating the phase mismatch factors, power, and the efficiency of the generated wave. The concept of three electromagnetic fields interacting to produce a fourth field is central to the description of all four-wave mixing processes. The experiment is performed using a highly non-linear fibre. The experiment classifies itself as a technique to calculate the dispersion parameters. The first input field causes an oscillating polarization in the dielectric which re-radiates with some phase shift determined by the damping of the individual dipoles; this is just traditional Rayleigh scattering described by linear optics. The application of a second field will also drive the polarization of the dielectric, and the interference of the two waves will cause harmonics in the polarization at the sum and difference frequencies. Now, application of a third field will also drive the polarization, and this will beat with both the other input fields as well as the sum and difference frequencies. This beating with the sum and difference frequencies is what gives rise to the fourth field in four-wave mixing [4]. Four-wave mixing (FWM) is an example of optical Kerr effect, and occurs when light of two or more different wavelengths is launched together into a fibre. Generally FWM occurs when light of three different wavelengths is launched into a fibre, generating a new wave (known as the idler), the wavelength of which does not coincide with any of the others.FWM is a kind of optical parametric oscillation.[5]

The explosive growth in long-haul telecommunications achieved in recent years has been largely attributable to DWDM technology and the role played by EDFAs, but the nonlinear effects of signals amplified by EDFAs have resulted in the degradation of system performance. Attention has recently been focused on dispersion managed systems as a means of suppressing FWM. Reverse-dispersion fibre (RDF) is used in combination with conventional single-mode fibre (SMF). At 1550 nm, RDF has a chromatic dispersion of the same magnitudes SMF but of opposite sign (normal dispersion), and the dispersion slope is reversed. Thus it can compensate for both dispersion and dispersion slope simultaneously. The results of high-capacity WDM experiments using dispersion-managed systems consisting of SMF and RDF have been reported .A number of methods have been developed for measuring the nonlinear coefficient g, including the use of self-phase modulation, cross-phase modulation and four wave mixing. ([6],[7]) Conventional methods which extract dispersion parameters of an optical fibre using four wave mixing rely on the measurement of optical power in the generated wavelengths, and hence are prone to measurement errors. A power-independent method will be discussed to extract the dispersion curve of a fibre using four wave mixing (FWM). The analytical equations that have been traditionally used to estimate the phase mis matchin FWM are modified to cater to low-dispersion fibres, and are verified.

II. THEORY

FWM is a nonlinear process in which two frequencies (wavelengths) propagating through a medium mix with each other through third order susceptibility of the medium and generate a third frequency. Originally Hill et al investigated FWM process both theoretically and experimentally [13], But later their work was modified by Shibata et al. [12] to include the dependence of the phase-matching.

The efficiency of FWM process is now given by

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

Where α is attenuation constant, Δβ is phase matching condition and η is the efficiency of the FWM process. This phase mismatch condition is further given by

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

where dDc /dλ is slope of dispersion.

Now this efficiency is related to the power of idler. The power of idler after length 'L' of fibre is given by

$$P(L) = \frac{\eta}{9}D^2\gamma^2P_1^2P_2\exp\left(-\alpha L\right)\left(\left|\frac{1-\exp\left(-\alpha L\right)}{\alpha}\right|^2\right) \tag{3}$$

Here γ is the nonlinear parameter, P_1 and P_2 are the powers at frequencies f_1 and f_2 respectively, D is the degeneracy factor. Since the FWM considered here almost degenerate the value of D is chosen to be 3.

The nonlinear factor γ is calculated as [14]

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

Where A_{eff} is the effective fibre core area, λ is the vacuum wavelength, n_2 and is the fibre nonlinear refractive index,

Eq. (1), (2) and (3) show the dependence of power of idler on efficiency and hence wavelength separation between pump and signal fields. This dependence will be used to plot a graph between power of idler and wavelength separation.

Now there is another way to find Δβ. This is given by [15]

$$\Delta\beta_s = ((\omega_1-\omega_2)^2\times aD_c)+\left((\omega_1-\omega_2)^3\times(a\left[\left(a\frac{dD_c}{d\lambda}\right)-\left(\left(\frac{2}{\omega_0}D_c\right)\right]\right)\right)+(\frac{7}{12}(\omega_1-\omega_2)^4\times(a\left[(a^2\frac{d^2D_c}{d\lambda^2}\right)-\left(a\left(\frac{6}{\omega_0}\right)\frac{dD_c}{d\lambda}\right)-\left(\left(\frac{6}{\omega_0^2}\right)D_c\right)] \tag{4}$$

Where the dispersion and its higher order derivatives are estimated at wavelength (λ_0), corresponding to ω_0.

This equation will be used in determining the dispersion parameters.

III. NUMERCAL SIMULATION AND DISCUSSION

A. *Efficiency vs. phase mismatch factor and wavelength separation*

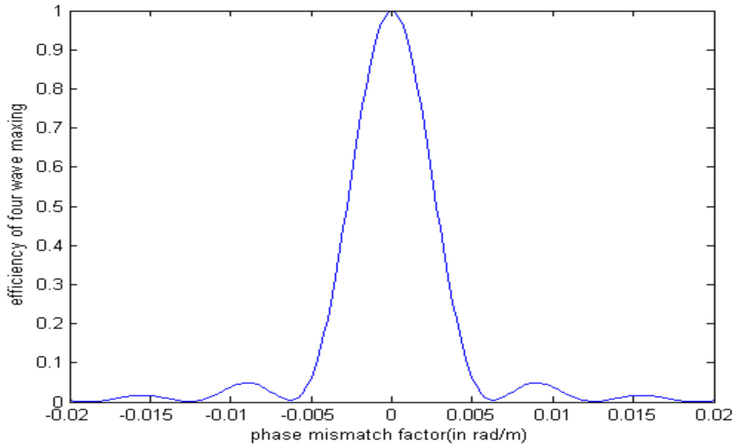


Fig. 1 Variation of Efficiency as function of phase mismatch factor

Figure (1) shows that how the efficiency of the four wave mixing varies in a fibre with phase mismatch factor. Efficiency of process becomes minimum when phase mismatch factor becomes integral multiple of $2\pi/L$.

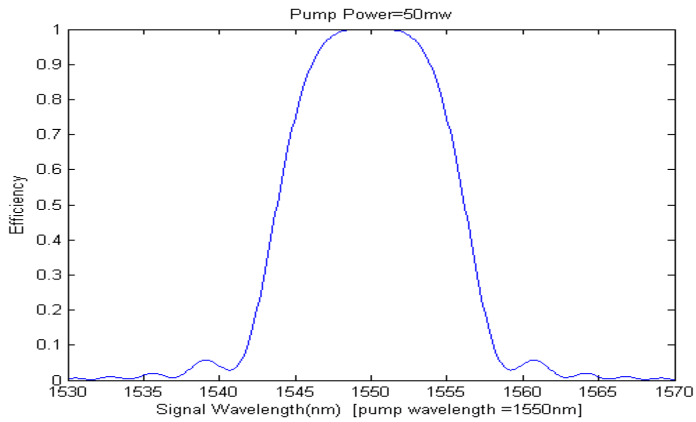


Fig. 2 Variation of efficiency of FWM process as function of wavelength separation

Figure (2) shows the variation in efficiency with respect to signal wavelength when pump wavelength is fixed to 1550 nm.

B. *Power of idler vs. wavelength separation*

The pump wavelength is fixed to 1550 nm and the signal wavelength is varied between 1530 nm to 1570 nm**.**

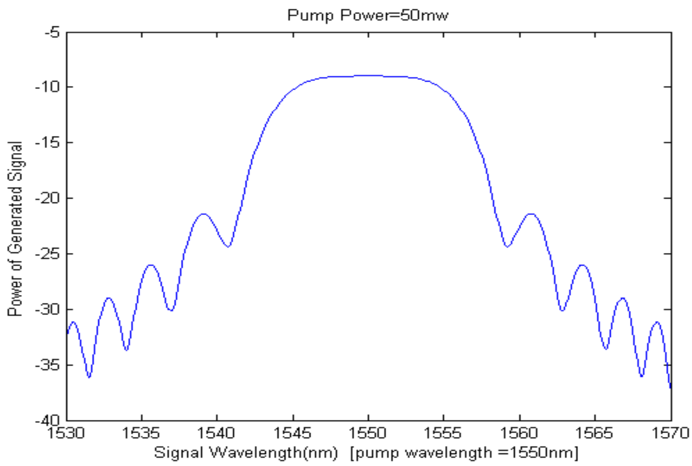


Fig. 3 Variation in power of generated frequency vs. wavelength separation between input power sources

From figure (2) and (3) it is clearly evident that the power of idler becomes minimum when the efficiency of the FWM process becomes minimum. Efficiency becomes minimum when phase mismatch factor becomes integral multiple of $2\pi/L$. So by calculating the phase mismatch factor the dispersion parameters can be calculated using Eq (4). For this phase mismatch factors have to be calculated at as many minima of figure (3) as there are unknowns in Eq. (4).

IV. EXPERIMENTAL SETUP AND METHODOLOGY

The idler power curve that has been plotted previously theoretically can be obtained experimentally by following arrangement. Two lasers, laser1 and laser2 are used at different wavelengths. Laser 2 is fixed at 1550 nm, whereas laser1 is varied from 1530nm to 1570nm. The graph is plotted for the obtained power corresponding to the wavelength difference. A highly nonlinear fibre is used in the setup of length 50km. The wavelength of laser1 is varied on the scale of 1nm and the corresponding power is recorded. These data are analysed for obtaining the wavelength separation corresponding to the minima of the idler power, which is further used to extract the dispersion parameters. Figure 4 shows the experimental setup to obtain the power of the idler.

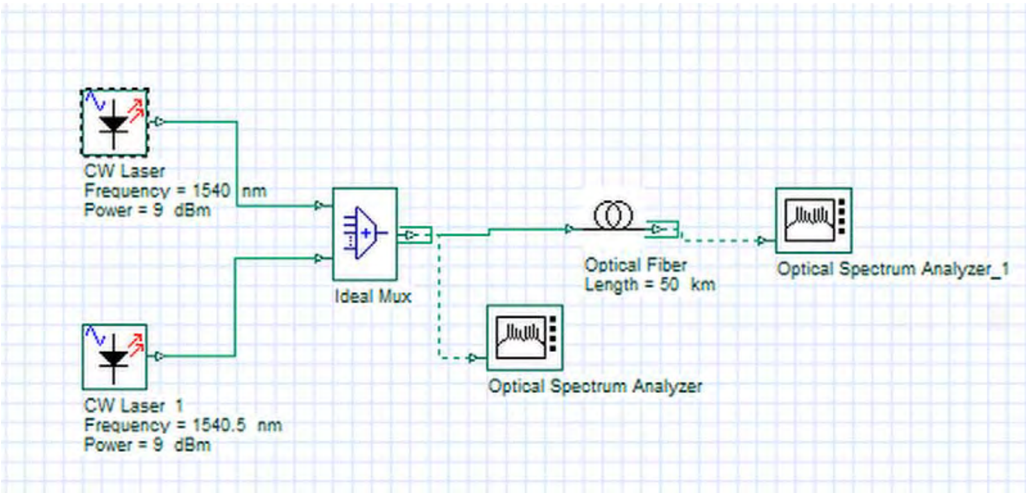
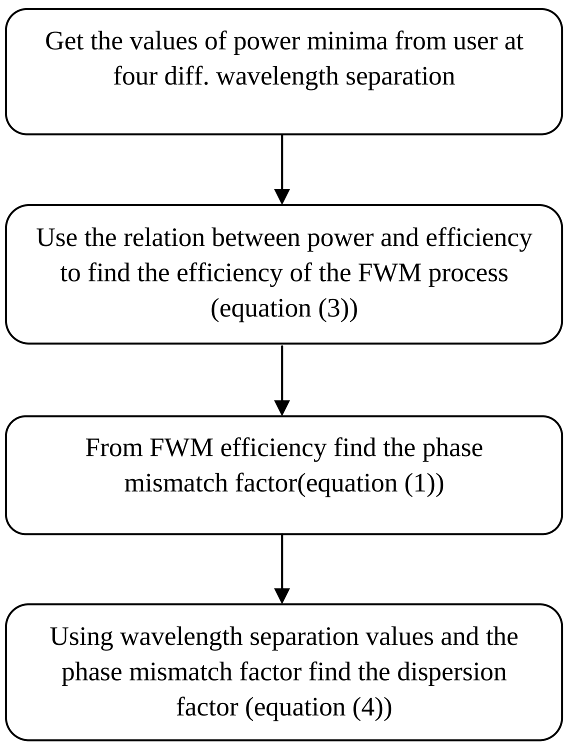


Fig. 4Experimental arrangement for finding out the power of idler as a function of wavelength separation

Once the idler power graph is obtained for the fibre the following algorithm can be used to find the dispersion parameters.

A. *Algorithm to find the dispersion curve*



V. CONCLUSIONS

For communication and nonlinear optical applications, estimation of dispersion parameters of a fibre is extremely critical. A method to obtain the dispersion curve of a fibre utilizing four wave mixing has been proposed and demonstrated. A matlab code has been written demonstrating the various relations between the phase mismatch factors and efficiency and power of idler and wavelength separation. The FWM efficiency is then related to the power of the generated frequency, i.e. the idler. Modification is provided in the analytical expression for phase mismatch factor of FWM that is traditionally used. The demonstrated method can be used for all fibres for which FWM efficiency is experimentally measurable. The method relies on the measurement of power generated in the idler wavelength, as a function of wavelength separation between the two pump wavelengths. The wavelength separation for which the idler power is minimal is measured experimentally. This information is used to extract the corresponding phase mismatch, and hence the dispersion parameters of the fibre.

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