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Reduction of Four Wave Mixing Effect in Hybrid Optical CDMA/WDMA System-A Simulation Study

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Abstract—Increase in the data rate of fiber optic communication system is limited due to the nonlinear effects like Self phase modulation (SPM) Cross phase modulation (CPM),Four wave mixing (FWM),Stimulated Raman Scattering(SRS) and Stimulated Brillion scattering (SBS). Many investigations are carried to mitigate these effects and in multi channel systems, four-wave mixing(FWM) in optical fibers[2]induces channel crosstalk and possibly degrades system performance .A technique to design the channel frequency allocation in order to minimize the crosstalk due to FWM is presented. By using suitable unequal channel spacing it can be found that no four-wave mixing product term is superimposed on any of the transmitted channels. This is obtained at the expense of some expansion of the system bandwidth.

Index Terms—Nonlinear effects, Four Wave Mixing (FWM), Crosstalk, Unequal channel spacing,

I. INTRODUCTION

FWM is a nonlinear process in which three waves of frequencies f_i,f_j,f_k($k\neq i,j$) interact through the third order electric suspectability of the optical fiber to generate a wave of frequency [10]$f_{ijk} = f_i + f_j - f_k$,Thus, three copropagating waves give rise, by FWM, to nine new optical waves [4]. In a WDM system, this happens for every possible choice of three channel waves, therefore, even if the system has only ten channels, hundreds of new components are generated by FWM. In conventional WDM systems ,the channels are typically equally spaced in frequency .This choice substantially worsens the effects of FWM, since all the product terms generated by FWM in the bandwidth of the system fall precisely at the channel frequencies.This paper is subdivided into nine sections,where in Section2 discusses the study of FWM Effect. Section3 discusses the frequency allocation technique to reduce FWM effect. Section4 gives the system design of FBG based FFH-OCDMAsystem.Section5 gives the details of Fiber model. Section6 gives the details of the optical orthogonal codes for FFH-OCDMA systems.Section7 discusses the receiver model. The conclusion of this work is described in Section8.

II. STUDY OF FWM EFFECT

The simulation block diagram of Four wave mixing Effect is shown in the Figure1.

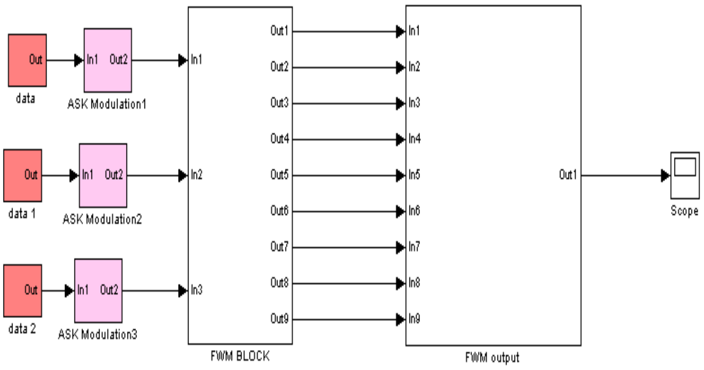

Fig.1 Four wave mixing effect system

2.1 Data Stream Block

The random data generator is realized with Bernoulli Binary random generator block to generate a data stream at a rate is of 40 Gbps. The simulation model is shown in Figure 2.

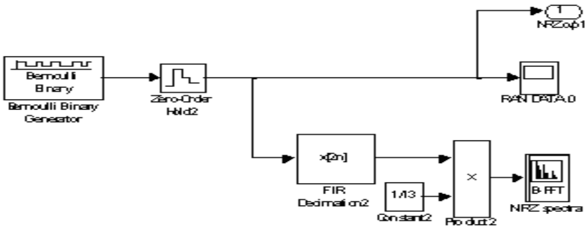

Fig. 2 PRBS generation Simulink platform

2.2 ASK Modulation

The MZIM to generate ASK modulated signal is modeled as shown in Figure 3.

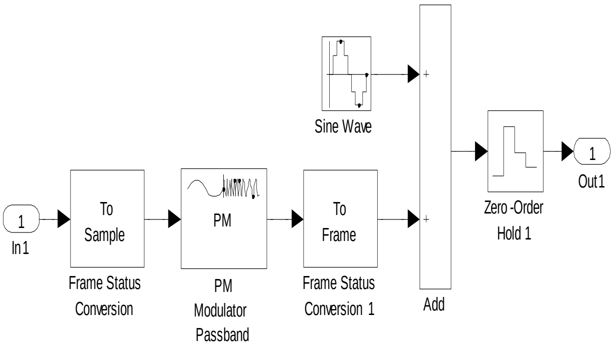

Fig. 3 SIMULINK Block diagram of the external MZIM

The ASK modulated output is viewed with the spectrum scope. The simulation is done in such a way that the output consist of twenty-nine scaled frequencies which lies in the range of 5.5 THz – 8.5 THz and represented as (λ_0 λ_1 λ_2 ……………….. $\lambda_{28)}$. .Each User is assigned a particular frequency using a Bandpass Filter which allows only one particular Frequency assigned to the user and filters remaining frequencies.

2.3 FWM Block

The Four Wave Mixing Block is modeled as shown in Figure 4.

In Four Wave Mixing block, three filtered frequencies are passed through the block generating Nine Frequencies which may be a new frequency or same as input frequency creating crosstalk[5] .

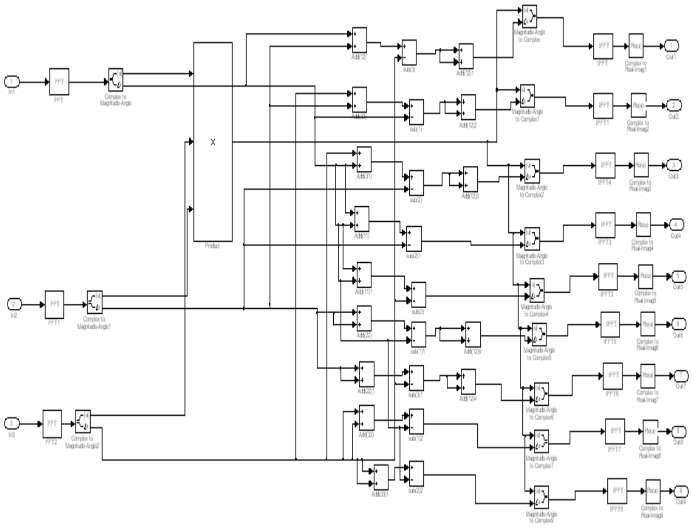

Fig. 4 Simulink Block Diagram of FWM Block

2.4 FWM Output

The FWM output is modeled as shown in Figure 5.The Nine Frequencies generated due to FWM effect are combined and the output is viewed using scope.

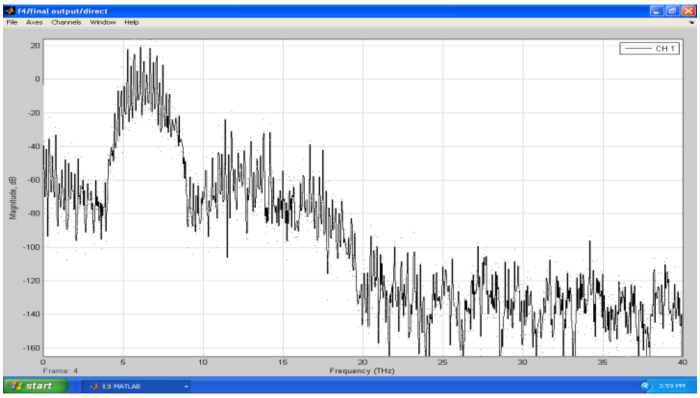

Fig. 5 Spectrum of FWM Effect Output

III. FREQUENCY ALLOCATION TECHNIQUE

The channel allocation design can be reduced to an integer linear programming (ILP) problem, by dividing the available optical bandwidth into equal slots of bandwidth Δ f large enough to avoid appreciable overlap between spectra in adjacent slots. Note that the bandwidth occupied by an FWM wave is only slightly larger than the bandwidth of a channel.Given an reference optical frequency fo, the ith slot is centered around the optical frequency $f_i=f_0+(n_i-1)\,\Delta f$, where n_i is an integer that will be referred to as the slot number of the ith frequency slot. In terms of slot numbers,becomes $n_{ijk}=n_i+n_j-n_k$ ($k\neq i,j$) .If n_{ijk} does not coincide with any of the channel slot numbers forany choice of i, j , k, no FWM wave generated by the signals is created on any of the channel slots.In this paper, ten numbers of DWDM channels are taken and by using the Orthogonal coding technique the frequencies are allocated for the ten channels. The Optical orthogonal code applied in this paper for a 10-channel DWDM system[9] is

C = {1, 6, 16, 22, 30, 39, 50, 57, 69, 82 } with each slot of 25 Ghz wide and T_c=1ns,$\rho=4.0\times10^{-19}s^2$ where

ρ= (distance between the codes)*T_c/(frequency separation)

The Unequal frequency Spacing allocated for the 10channel- DWDM is given by

{f1=191.9,f2=192.025,f3=192.275,f4=192.425,f5=192.625, f6=192.85, f7=193.125, f8=193.3, f9=193.6, f10=193.925}

IV. SYSTEM DESIGN FOR SINGLE USER

In FFH-OCDMA systems the available bandwidth is subdivided into a large number of contiguous frequency slots. The transmitted signal occupies one frequency slot in each chip signaling interval (T_c).Frequency hopping is a method of spreading a relatively low data rate digital signal over a large bandwidth where carrier frequency of transmitted signal is changed at regular intervals. In FFHSS technique the hop period (T_{hop}) is selected to be less than the symbol period (T), so that the same symbol is transmitted on multiple hop ($T_{hop}<T$). The generalized structure for FBG based FFH-OCDMA system with PIN photo diode detection in the optical domain is shown in

Figure. 6.

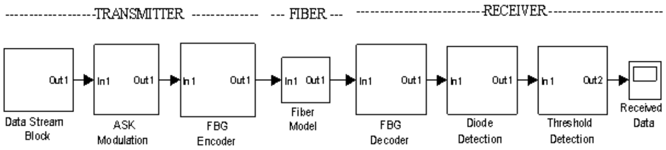

Fig. 6 Block diagram of FBG based FFH-OCDMA system

At the receiver, a FBG decoder produces a peak in the correlation output for the intended user. Data bits are discriminated in the chip duration using a photodiode followed by a threshold process.

5.1 Modeling of fiber Bragg gratings using coupled-mode theory

A fiber Bragg grating is a short length of optical fiber that reflects particular wavelengths of light and transmits all others. This is achieved by periodically spaced zones in the fiber core are altered to have different refractive indexes slightly higher than the core. This structure selectively reflects a very narrow range of wavelengths. A fiber Bragg gratings reflector can therefore be used as an inline optical filter to block certain wavelengths or as a wavelength-specific reflector in a wave length division multiplexing (WDM) system and used to stabilize the output of a laser. The relation between the spectral dependence of a fiber grating and the corresponding grating structure is usually described by the coupled-mode theory. Coupled-mode theory is described in a number of texts; detailed analysis can be found in [8]. Throughout this analysis, we assume that the fiber is lossless and single mode in the wavelength range of interest. In other words, we consider only one forward and one backward propagating mode. A uniform grating has constant coupling coefficient over a limited range $0\leq z\leq L$, where L is the grating length. In this situation, the coupled-mode equations can be solved analytically. The resulting reflection coefficient becomes

$$r_{tot} = \frac{-q\sinh(\gamma L)}{\gamma\cosh(\gamma L) - i\delta\sinh(\gamma L)} \qquad (1)$$

Where the various quantities appearing in the equations are defined as follows:

q is the coupling coefficient,

$$q = 2\Delta n f_B / c \qquad (2)$$

L is the length of the fiber,

$$L = Md \qquad (3)$$

δ is the frequency detuning factor,

$$\delta = \beta - \pi/\Lambda = (f - f_B)2\pi n_{eff}/c, \qquad (4)$$

Where, f_B is the Bragg frequency for which maximum reflection occurs,

$$f_B = c/\lambda_B \text{ and} \qquad (5)$$

γ is the parameter relating the coupling coefficients as follows

$$\gamma^2 = |q|^2 - \delta^2 \qquad (6)$$

The total reflectivity, the ratio of the two intensities, is the square of the magnitude of the reflection coefficient

$$R_{tot} = |r_{tot}|^2 \qquad (7)$$

Equation (1) is derived from the coupled-mode theory, models the fiber Bragg grating as reflection filter. This is implemented in Simulink and incorporated into encoder/decoder part of FBG based OCDMA system. The Simulink block diagram of FBG filter for single downscaled frequency $(6.3THz)$ and the corresponding spectrum scope output is shown in Figure.7 and Figure.8 respectively.

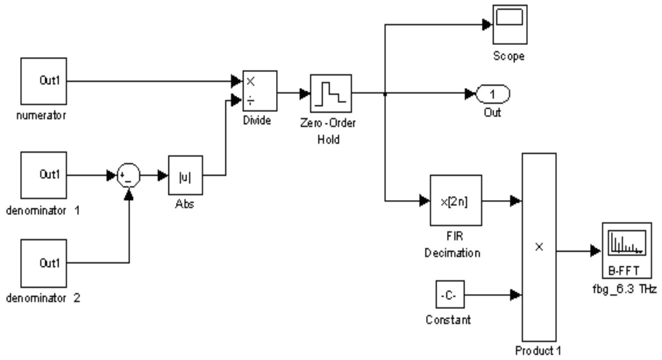

Fig. 7 Simulink block of FBG filter at 6.3 THz

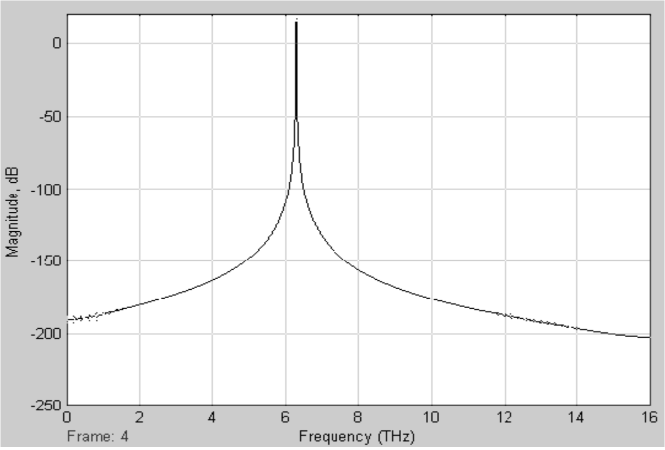

Fig. 8 Spectrum scope output of FBG filter at 6.3 THz

5.2 FBG encoder/decoder

The conventional FFH-CDMA system requires the frequency synthesizer to select a frequency according to the output from the pseudo-random code generator at the transmitter part. At the same time, the synchronization block is required in the receiver to acquire and maintain synchronism between the code generator and the desired received signal. But the proposed encoder/decoder does not require the frequency synthesizer and hence the synchronization loops, particularly simplifying the decoding operation [1,8].

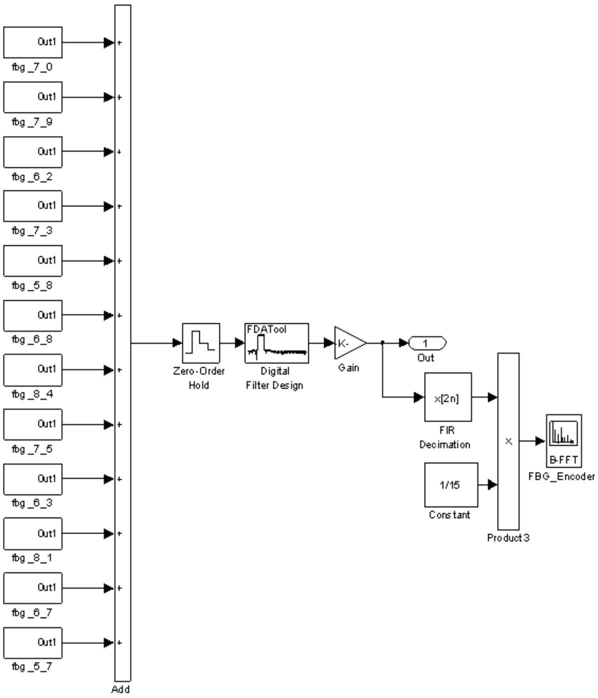

Fig. 9 Simulink block of FBG encoder

The Simulink blocks of FFH-OCDMA encoder/decoder are shown in Figure.9 and Figure.10 respectively. In FBG based FFH-OCDMA systems, each encoder/decoder is a fiber Bragg grating array (FBGA), which consists of N equally spaced gratings tuned to wavelengths corresponding to the Bin family of codes. Chip duration and number of grating will be established by the nominal bit rate of the system. The gratings in the encoder slice an incoming broadband optical pulse spectrally and spread it temporally, i.e. encoding. In the present implementation, each encoder/decoder consists of N=12 gratings correspond to an ordered selection of 12 frequencies. The decoder is modeled similar to the encoder. The filters in the decoders are arranged in the reverse to that of encoder to compensate for varying time delay. The output of the entire section is added to give a decoded output and further given the PIN photo diode.

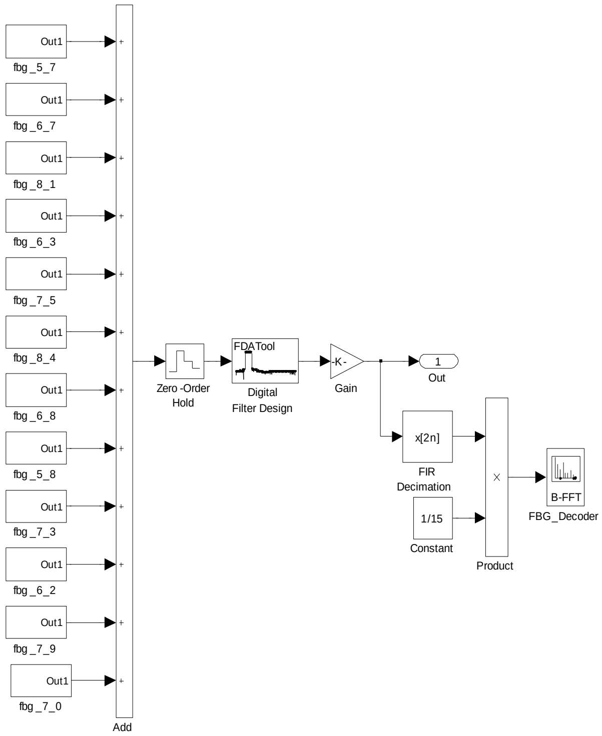

Fig. 10 Simulink block of FBG decoder

The spectrum of encoded and decoded outputs which consists of code sequences (λ_{14}, λ_{23}, λ_6, λ_{17} λ_2, λ_{12}, λ_{28}, λ_{19}, λ_7, λ_{25}, λ_{11}, λ_1) for single user are shown in Figure.11 and Figure.12 respectively.

Tabel I: FREQUNCY ASSIGNMENT FOR THE CODE SEQUENCES OF USER ONE

Code	**Hop pattern**	**Downscaled Frequencies (THz)**
1	14,23,6,17,2,12,28,19,7, 25,11,1	7.0,7..9,6.2,7.3,5.8,6.8,8.4,7.5, 6.3,8.1,6.7,5.7

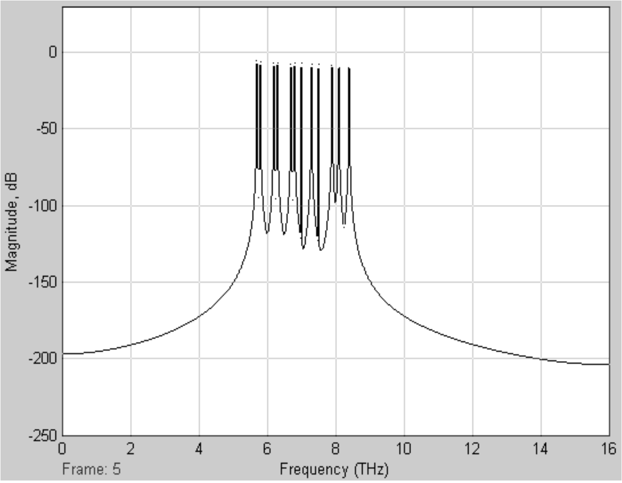

Fig. 11 Encoded output for the downscaled frequencies

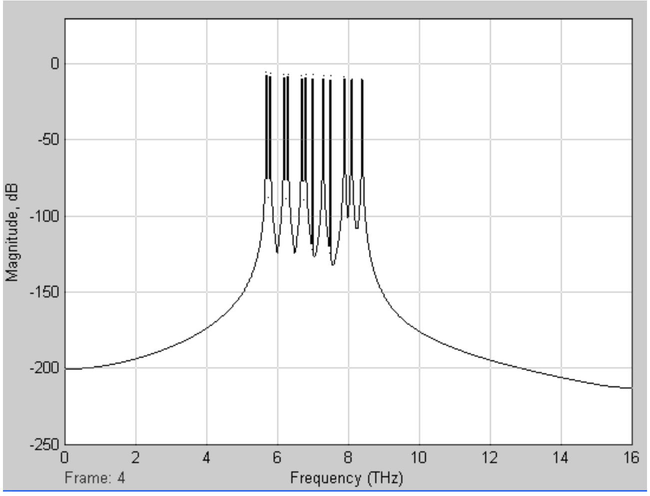

Fig. 12 Decoded output for the downscaled frequencies

V. FIBER MODEL

In this paper, we consider the Single mode fiber model (SMF)[6].Fiber allows digitized light signals to propagate for distances beyond 100 km spans with loss compensated by optical amplification. The fiber is assumed to be a low pass filter.

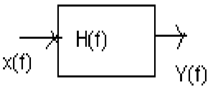

Fig. 13 Block diagram of the fiber model

The transfer function $H(f)$ of SMF can be expressed as,

$$H(f) = e^{-j\pi D\lambda Lf} \qquad (10)$$

By taking the FFT of the input modulated signal in Simulink, then multiplying by $H(f)$ and finally taking the IFFT (inverse FFT), we can accurately represent fiber propagation with any additional chromatic dispersion, thus making the model linear. For the standard SMF fiber model we use $D(\lambda)_{SMF} = +17\,ps/nm.km$ at $1550nm$ wavelength, $L = 1km$ with no optical amplifiers.

VI. OPTICAL ORTHOGONAL CODES FOR FFH-OCDMA SYSTMS

High weight codes such as m-sequence codes, Walsh Hadamard codes are suitable for FFH-OCDMA scheme . In this work sub optimal code sequence is used. The l^{th} chip pulse is modulated with frequency offset f_l about the carrier frequency f_c .

$$f_l = h(l)\frac{B}{q} \qquad (11)$$

where B is the signal bandwidth, $h(l)$ is the placement operator (also called the frequency hop pattern), and q is the number of available frequencies. The placement operator is a sequence of N ordered integers determining the placement of frequencies in the N available time slots. Each user selects a set of N frequencies from a set of q available frequencies $S = (f_1, f_2, \cdots f_q)$ where $N \le q$. They are noted by

$C_1 = (\lambda_{14}, \lambda_{23}, \lambda_6, \lambda_{17}, \lambda_2, \lambda_{12}, \lambda_{28}, \lambda_{19}, \lambda_7, \lambda_{25}, \lambda_{11}, \lambda_1)$,

$C_2 = (\lambda_{15}, \lambda_{24}, \lambda_7, \lambda_{18}, \lambda_3, \lambda_{13}, \lambda_0, \lambda_{20}, \lambda_8, \lambda_{26}, \lambda_{12}, \lambda_2)$ and so on up to eight users.

VII. RECEIVER MODEL

In order to detect the optical signal at the output of the fiber, FBG decoder and PIN photodiode are used in the receiver circuitry. The Simulink model for the receiver is given in the above figure. The value of the responsivity is assumed as 0.5 A/W.

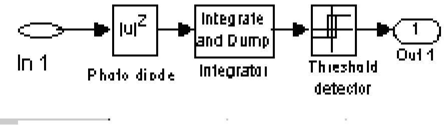

Fig. 14 Simulink model of a receiver

The integrator is used to remove high frequency components. By setting the proper threshold levels, the RZ data is recovered at the output of the detector and converted to NRZ format. The following figure shows the transmitted data and the received data respectively for a single user.

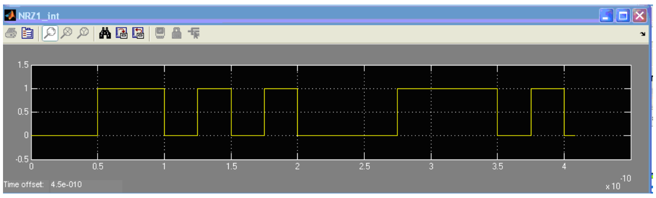

Fig. 15 Transmitted data

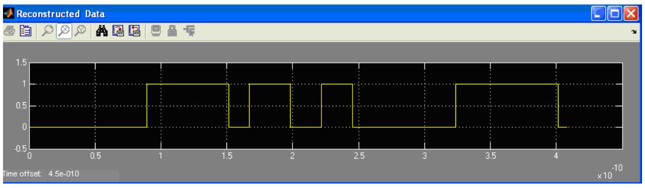

Fig. 16 Received data

VIII. RESULTS

In this project, Fiber Bragg grating based FFHOCDMA is combined with WDM and the performance is analyzed for 10-DWDM channels having unequal channel separations in order to reduce the crosstalk due to FWM effect. The individual users in the DWDM network are having their own optical orthogonal codes and the BER performance is carried out for 10 simultaneous users as shown in Figure.17.

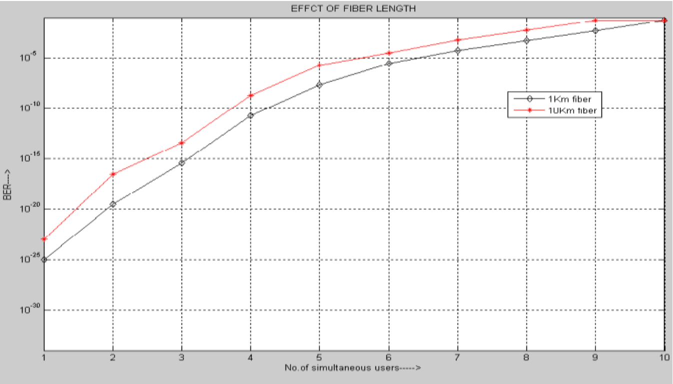

Fig. 17 Performance of FBG/FFH-OCDMA system for 10 DWDM channels with unequal channel separations for 1km and 10km fiber

The BER performance analysis for the FBG based FFH OCDMA system is carried out by determining the Q factor from the eye diagram of the signal at the receiver output.

IX. CONCLUSION

To summarize,in this paper the Fiber Bragg Grating based FFH optical CDMA communication system is modeled and a method to design the channel spacing in a WDM system,capable of minimizing the degradation due to FWM with improved BER performance has been simulated using simulink in Matlab 7.4.

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