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Reduction of Four Wave Mixing Nonlinearity Effect in WDM Radio over Fiber Systems

Surbhi Jain and A. Brintha Therese*

School of Electronics Engineering Department, VIT University, Chennai-600127, India; surbhi.jain2013@vit.ac.in, abrintha.therese@vit.ac.in

Abstract

The optical networks are fast, robust and error-free, but there are some nonlinearity hindrances which prevent them from being a perfect medium. The performance of wavelength division multiplexing (WDM) in radio over fiber (RoF) systems is found to be intensely influenced by nonlinearity characteristics within the fiber. In this paper, the performance of WDM network is analyzed using optical filter and various external modulation schemes under FWM nonlinearity effect. Here, the effect of input signal power on FWM is studied. Also, the threshold value of input power for different external modulation technique is calculated and hence duobinary modulation is found to be optimal technique for reducing FWM effect in WDM networks.

Keywords: DPSK, Duobinary, Four Wave Mixing (FWM), Noise Power, QAM, QPSK, Radio over Fiber (RoF), SNR, Wavelength Division Multiplexing (WDM).

1. Introduction

The application of Radio over Fiber (RoF) has become important these days because of its large capacity and low cost in deployment of cellular systems. Radio over fiber (RoF) is a technology in which radio signal modulates light through an optical fiber[1]. When the light signal is transmitted over RoF links, there are little interactions between light waves and the material transferring them which affects the optical signals. Since their strength depends on the square or higher power of light intensity, the effects are commonly called as nonlinear effects[2]. The commonly known effects are stimulated Brillouin scattering (SBS), cross phase modulation (XPM), self-phase modulation (SPM), stimulated Raman scattering (SRS) and four wave mixing (FWM). In the previous paper[3], we designed the architecture of WDM passive optical network at 25 km distance and 2.5 Gbps data rate where we analyzed the effect of Channel Spacing variation, different power level of the source and dispersion variation of the optical fiber. It has been inferred that as the spacing between channels and dispersion parameter of fiber is increased, the FWM effect decreases. Also, as the power level of the signal sources is decreased, the FWM becomes less effective. This paper focuses on the methods of reduction of FWM effect in WDM systems by use of filter and various external modulation techniques.

The paper is organized as follows: section II presents the simulation setup for WDM passive optical network with filter and external modulation schemes. Section III presents the analysis and result of the proposed architecture. Finally, section IV contains the conclusion of the paper.

2. Simulation Setup

Our simulation is performed and analyzed using OptiSystem 13.0 software. In this paper, the architecture is analyzed to reduce the effect of FWM in WDM system which can be done by using:

A) Rectangle Optical Filter
B) External Modulation

2.1 Use of Rectangle Filter

Figure 1 shows the simulation setup in the optisystem software for two channels with data rate of 2.5 GHz and

*Author for correspondence

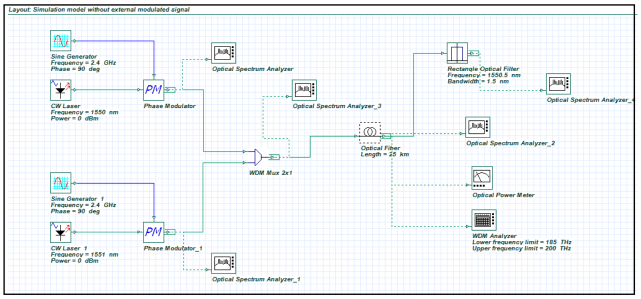


Figure 1. Simulation setup for WDM PON architecture for transmission of two input wavelengths by use of Filter in OptiSystem software.

distance of 25 km for transmission. In this architecture, the two signals are transmitted with different wavelengths as 1550nm and 1551nm. Each transmitter section consists of continuous wave (CW) laser input having 0 dBm power level. After modulation the two signals are then combined using WDM multiplexer and launched through the optical fiber. The rectangle optical filter with appropriate frequency 1550.5nm and bandwidth 1.5nm is used at end of the fiber. The rectangle filter eliminates the unwanted sidebands generated due to the FWM effect.

2.2 Use of External Modulation Technique

This paper deals with the study of reduction of FWM effect by use of various external modulation schemes like Duobinary modulation, Hybrid modulation, QAM modulation, QPSK modulation and DPSK modulation. These schemes are compared on the basis of various parameters like input power level, noise power and SNR.

2.2.1 Duobinary Modulation

Figure 2 shows the simulation setup in optisystem software for two channels transmitted using duobinary modulation. The duobinary pulse generator is used to generate the duobinary sequence, which is then further modulated using mach-zender modulator. Now, the two modulated signals are multiplexed and sent over fiber of length 25 km. The output is analyzed using optical spectrum analyzer and WDM analyzer.

2.2.2 Hybrid Modulation

Figure 3 shows the simulation setup in optisystem software for two channels transmitted using low level hybrid modulation[4]. In this stage, the hybrid modulator portion is the combination of optical PM modulator followed by

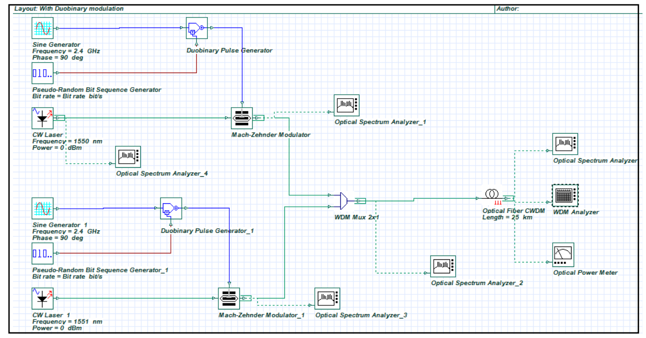


Figure 2. Simulation Setup for WDM PON Architecture for transmission of two input wavelengths by use of Duobinary Modulation in OptiSystem Software

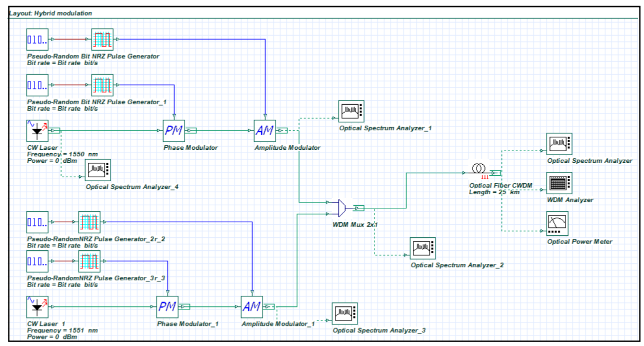


Figure 3. Simulation Setup for WDM PON Architecture for transmission of two input wavelengths by the use of Hybrid Modulation in OptiSystem Software

an optical AM modulator. The optical PM modulator introduces the phase mismatch in each wavelength which is then added constructively or destructively by the AM modulator. The two modulated inputs are then multiplexed and sent over fiber of length 25 km. The output is analyzed using optical spectrum analyzer and WDM analyzer.

2.2.3 QAM Modulation

Figure 4 shows the simulation setup in optisystem software for two channels transmitted using QAM modulation. An electrical QAM modulator is used to generate a QAM sequence which is then further modulated using mach-zender modulator. The two modulated inputs are then multiplexed and sent over fiber of length 25 km. The output is analyzed using optical spectrum analyzer and WDM analyzer.

2.2.4 QPSK Modulation

Figure 5 shows the simulation setup in optisystem software for two channels transmitted using QPSK modulation.

An electrical QPSK modulator is used to generate a QPSK sequence which is then further modulated using mach-zender modulator. The two modulated inputs are then multiplexed and sent over fiber of length 25 km. The output is analyzed using optical spectrum analyzer and WDM analyzer.

2.2.5 DPSK Modulation

Figure 6 shows the simulation setup in optisystem software for two channels transmitted using DPSK modulation.

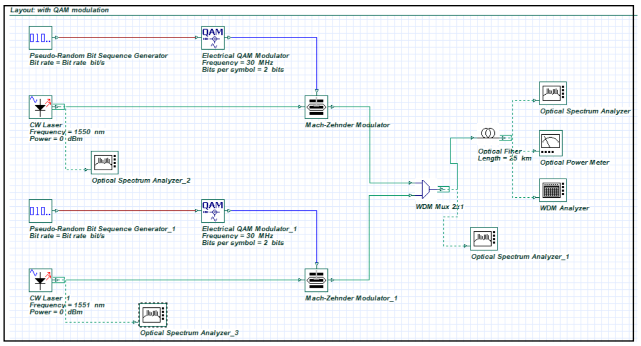


Figure 4. Simulation Setup for WDM PON Architecture for transmission of two input wavelengths by the use of QAM Modulation in OptiSystem Software

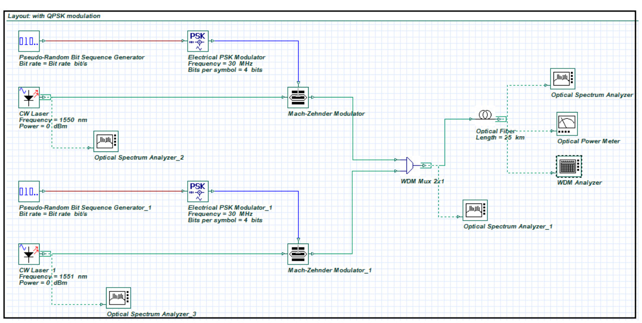


Figure 5. Simulation Setup for WDM PON Architecture for transmission of two input wavelengths by the use of QPSK Modulation in OptiSystem Software

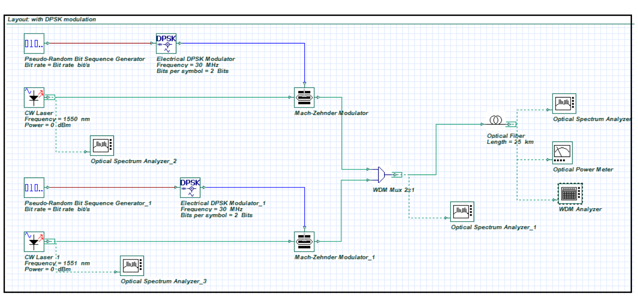


Figure 6. Simulation Setup for WDM PON Architecture for transmission of two input wavelengths by the use of DPSK Modulation in OptiSystem Software

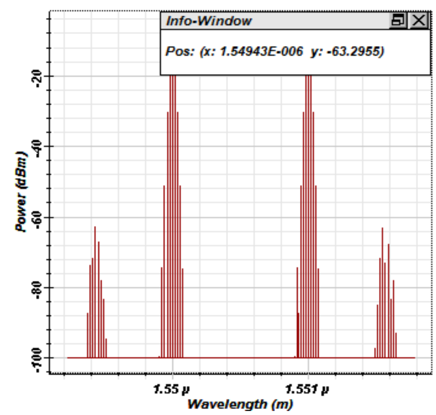
An electrical DPSK modulator is used to generate a DPSK sequence which is then further modulated using mach-zender modulator. The two modulated inputs are then multiplexed and sent over fiber of length 25 km. The output is analyzed using optical spectrum analyzer and WDM analyzer.

3. Results and Analysis

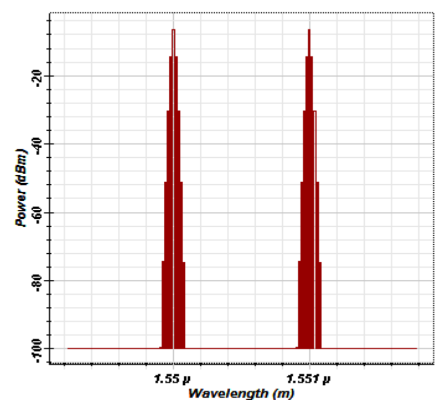
The results obtained from analysis for the two cases has been described below:

3.1 Use of Optical Filter

Figure 7(a) shows the spectrum at the output of optical fiber when two wavelengths are transmitted without external modulation where the power of the each FWM sideband is approximately –63.2 dBm while Figure 7(b) shows the



(a)



(b)

Figure 7. **(a)** Optical spectrum at the output of fiber when two wavelengths are transmitted without any external modulation. **(b)** Optical spectrum at the output of filter when two wavelengths are transmitted without any external modulation

spectrum at the output of optical filter where the unwanted sidebands are suppressed. The use of filter helps to obtain the required original signals without any FWM effect.

3.2 Use of External Modulation Techniques

3.2.1 Duobinary Modulation

When the channel spacing is set at 1nm with Duobinary modulation, the result obtained from the simulation is depicted in Figure 8(a). The interfering wavelengths generated around the original two wavelength system are 1549 nm and 1552 nm thereby the power of the each FWM sideband is approximately –77.9 dBm. Comparing the result with Figure 7(a), it is observed that the power level decreases and hence the FWM effect is less with external modulation. Now, further when we decrease the power level from 25 dBm to –10 dBm, the input power level is compared with noise power and Signal to noise ratio to find the threshold power level above which the FWM effect starts increasing. Table 1 shows the output of WDM analyzer giving the value of the noise power and SNR w.r.t input signal power for Duobinary modulation. Figure 8(b) and 8(c) shows graph between input power level with noise power and SNR respectively. It can be seen that the noise power increases with increase in input signal power. The threshold value of input power is found to be 20 dBm below which the SNR is constant.

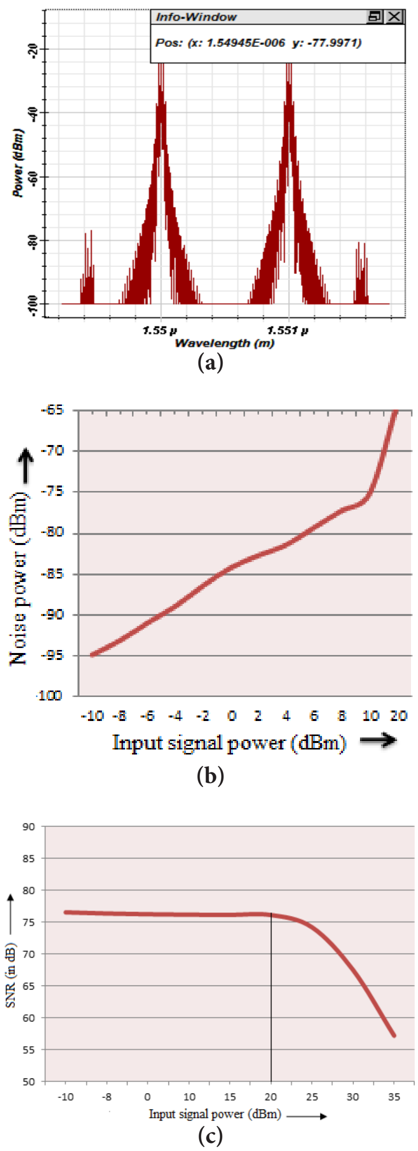


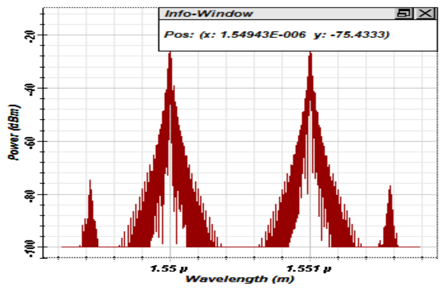
Figure 8. **(a)** Optical spectrum at the output of fiber when two wavelengths are transmitted using Duobinary modulation. **(b)** Graph between Input signal power and noise power for duobinary modulation. **(c)** Graph between Input signal power and SNR for duobinary modulation

3.2.2 Hybrid Modulation

The result obtained from the simulation with hybrid modulation is shown in Figure 9(a). The power of the each FWM sideband is approximately –75.4 dBm. Comparing the result with Figure 8(a), the power level decreases and hence the FWM effect is less with external modulation using hybrid modulation. Table 2 shows the output of WDM analyzer giving the value of the noise power and SNR w.r.t input signal power for hybrid modulation. Figure 9(b) and 9(c) shows graph between input power level with noise power and SNR respectively. It can be seen that the noise power increases with increase in input signal power. The threshold value of input power is found to be 15 dBm below which the SNR is constant.

Table 1. Comparison of parameters for different input power for 1551 nm wavelength for Duobinary modulation

Input Power (in dBm)	Signal Power (in dBm)	Noise Power (in dBm)	SNR (in dB)
25	16.21	–60.11	74.21
20	11.24	–65.31	76.56
10	1.33	–75.19	76.52
0	–8.65	–84.9	76.28
–4	–12.72	–88.92	76.19
–8	–16.74	–93.10	76.36
–10	–18.74	–94.86	76.14



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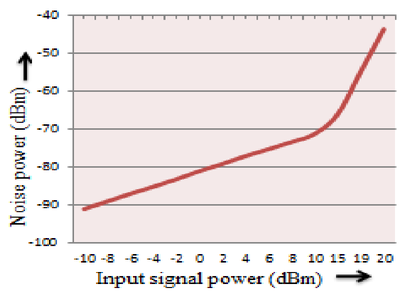

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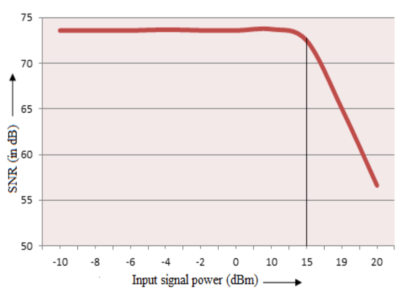


(c)

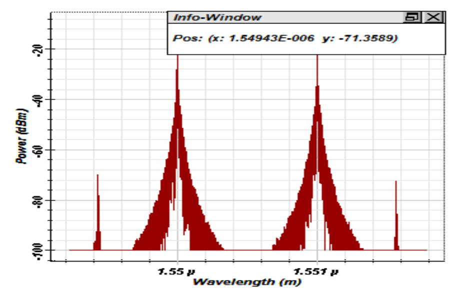
Figure 9. **(a)** Optical spectrum at the output of fiber when two wavelengths are transmitted using Hybrid modulation. **(b)** Graph between Input signal power and noise power for hybrid modulation. **(c)** Graph between Input signal power and SNR for hybrid modulation

Table 2. Comparison of parameters for different input power for 1551 nm wavelength for Hybrid modulation

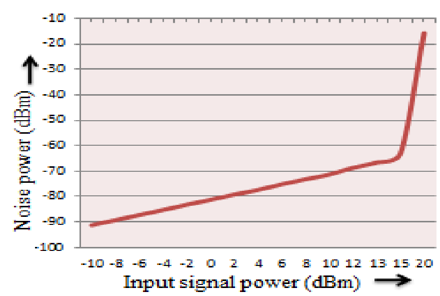
Input Power (in dBm)	Signal Power (in dBm)	Noise Power (in dBm)	SNR (in dB)
20	11.00	–43.60	56.61
19	10.21	–54.78	65.05
15	6.41	–66.07	73.48
10	1.44	–71.27	73.72
0	–8.54	–81.12	73.57
–4	–12.54	–85.22	73.67
–8	–16.54	–89.12	73.57
–10	–18.54	–91.11	73.57

3.2.3 QAM Modulation

The result obtained from the simulation with QAM modulation is shown in Figure 10(a). The power of the each FWM sideband is approximately –71.3 dBm. Comparing the result with Figure 8(a) and 9(a), it is observed that the power level increases. Hence the FWM effect is more with use of external QAM modulation as compared to duobinary and hybrid modulation technique. Table 3 shows the output of WDM analyzer giving the value of the noise power and SNR w.r.t input signal power for QAM modulation. Figure 10(b) and 10(c) shows graph between input power level with noise power and SNR respectively. It can be seen that the noise power increases with increase in



(a)



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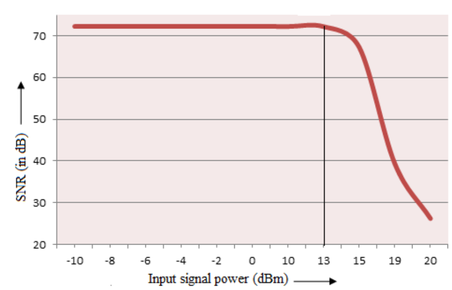


(c)

Figure 10. **(a)** Optical spectrum at the output of fiber when two wavelengths are transmitted using QAM modulation. **(b)** Graph between Input signal power and noise power for QAM modulation. **(c)** Graph between Input signal power and SNR for QAM modulation

Table 3. Comparison of parameters for different input power for 1551 nm wavelength for QAM modulation

Input Power (in dBm)	Signal Power (in dBm)	Noise Power (in dBm)	SNR (in dB)
20	10.56	−15.67	26.23
15	6.45	−63.05	69.52
13	4.39	−66.34	72.30
10	1.96	−71.36	72.33
0	−8.02	−81.30	72.27
−6	−14.02	−87.27	72.24
−10	−18.02	−91.26	72.24

input signal power. The threshold value of input power is found to be 13 dBm below which the SNR is constant.

3.2.4 QPSK Modulation

The result obtained from the simulation with QPSK modulation is shown in Figure 11(a). The power of the each FWM sideband is approximately −70.7 dBm. Comparing the result with Figure 8(a), 9(a) and 10(a), it is observed that the power level increases. Hence, the FWM effect is more with use of external QPSK modulation as compared to duobinary, hybrid and QAM modulation technique. Table 4 shows the output of WDM analyzer giving the value of the noise power and SNR w.r.t input signal power for QPSK modulation. Figure 11(b) and 11(c) shows graph between input power level with noise power and SNR respectively. It can be seen that the noise power increases with increase in input signal power. The threshold value of input power is found to be 13 dBm below which the SNR is constant.

3.2.5 DPSK Modulation

The result obtained from the simulation with DPSK modulation is shown in Figure 12(a). The power of the each FWM sideband is approximately −69.6 dBm. Comparing the result with Figure 8(a), 9(a), 10(a) and 11(a), the power level increases and hence the FWM effect is more with use of external DPSK modulation as compared to duobinary, hybrid, QAM and QPSK modulation technique. Table 5 shows the output of WDM analyzer giving the value of the noise power and SNR w.r.t input signal power for DPSK modulation. Figure 12(b) and 12(c) shows graph between input power level with noise power and SNR respectively.

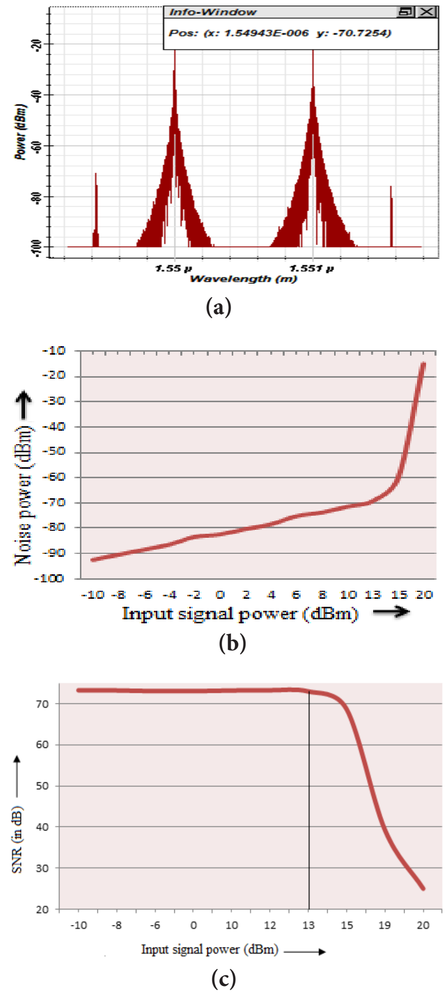
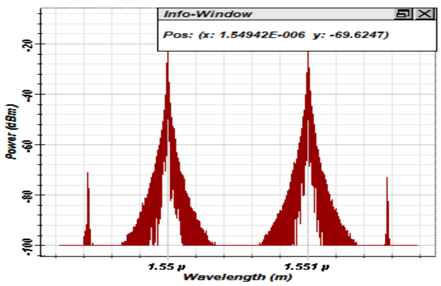


Figure 11. (a) Optical spectrum at the output of fiber when two wavelengths are transmitted using QPSK modulation. **(b)** Graph between Input signal power and noise power for QPSK modulation. **(c)** Graph between Input signal power and SNR for QPSK modulation

Table 4. Comparison of parameters for different input power for 1551 nm wavelength for QPSK modulation

Input Power (in dBm)	Signal Power (in dBm)	Noise Power (in dBm)	SNR (in dB)
20	11.81	−14.95	26.77
15	7.54	−60.35	67.90
13	5.32	−69.24	74.59
10	2.75	−71.45	74.21
0	−7.23	−82.43	75.19
−6	−13.23	−88.45	75.21
−10	−17.33	−92.45	75.22



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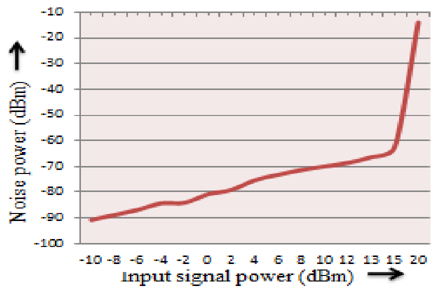

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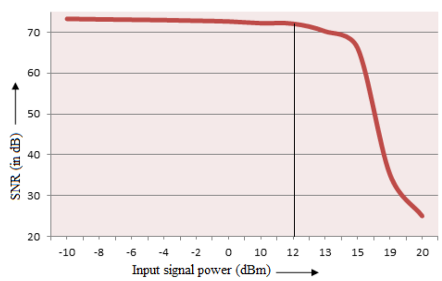

(c)

Figure 12. **(a)** Optical spectrum at the output of fiber when two wavelengths are transmitted using DPSK modulation. **(b)** Graph between Input signal power and noise power for DPSK modulation. **(c)** Graph between Input signal power and SNR for DPSK modulation

Table 5. Comparison of parameters for different input power for 1551 nm wavelength for DPSK modulation

Input Power (in dBm)	Signal Power (in dBm)	Noise Power (in dBm)	SNR (in dB)
20	11.05	–13.97	25.03
15	6.58	–62.30	68.89
13	5.09	–66.35	71.44
12	3.72	–68.59	73.29
10	2.44	–69.99	73.23
0	–7.74	–80.83	73.08
–6	–13.74	–86.83	73.08
–10	–17.74	–90.83	73.28

It can be seen that the noise power increases with increase in input signal power. The threshold value of input power is found to be 12 dBm below which the SNR is constant.

4. Conclusion

In this paper, transmission of signals in WDM over RoF networks is investigated. The degradation due to FWM can be reduced by guaranteeing that there is more channel spacing and dispersion parameter with lesser power level. Here, the performance of WDM network has been analyzed for reduction of FWM nonlinearity effect by the use of filter and various external modulation schemes. The rectangle optical filter with appropriate bandwidth and frequency can be used to eliminate the sidebands produced due to FWM effect and the external modulation technique can reduce the FWM effect. It has been inferred that as the input signal power decreases, the noise power also decreases and hence the FWM effect decreases. Also, the threshold value for different external modulation technique is calculated which concludes that the duobinary modulation is the optimal technique for reducing effect of the FWM in WDM networks with low noise power and high SNR value.

The FWM effect in WDM networks for RoF links are expected to become the key source of degradation of performance in current and future fiber optical communications. Crosstalk is the power transferred from one channel to another which can occur due to the nonlinear effect; especially the FWM effect which produces crosstalk between wavelength channels. The crosstalk strongly depends on the channel separation, optical power and number of sources. Therefore it is important to evaluate how huge is the cross talk in the network. The future work can be done to increase the input power level such that the noise power remains low with a high SNR value.

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