OPTOELECTRONICS AND ADVANCED MATERIALS – RAPID COMMUNICATIONS Vol. 12, No. 1-2, January-February 2018, p. 38 - 42

Estimation and mitigation of four wave mixing in wavelength division multiplexing radio over fiber system using hybrid modules

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In this paper, we have proposed hybrid four wave mixing (FWM) suppression modules to mitigate the effects of FWM in wavelength division multiplexing (WDM) radio over fiber (RoF) network. The two hybrid modules comprise of optical phase conjugator (OPC), fiber Bragg grating (FBG) and dispersion compensating fiber (DCF). These modules improve the execution of the WDM-RoF framework by suppressing the FWM power up to 30dBm. The overall FWM power is estimated and is found to vary as a function of channel input power. The results depict that the FWM power varies from -70dBm to -47.5 dBm in FBG plus OPC module and from -73.6 dBm to -49.8 dBm in DCF plus OPC module. The FBG plus OPC module provides a suppression of FWM power up to 27.3 dBm while the FBG plus OPC module suppresses up to 30 dBm. Thus, DCF plus OPC module has greater efficiency for mitigating FWM effects than the FBG plus OPC module.

(Received October 4, 2016; accepted February 12, 2018)

Keywords: Radio over fiber, Wavelength division multiplexing, Optical phase conjugator, Dispersion compensating fiber and fiber Bragg grating

1. Introduction

The growing number of Internet users and bandwidth-driven applications, such as online gaming, streaming video, telemedicine, video conferencing and others bring various challenges for network operators and force them to migrate toward new architectures. Radio-over-Fiber (RoF) technology is an integration of microwave radio and optical fiber technologies. It is a potential solution for Next Generation Access Networks [1]. RoF is a spectacular incorporation of both wired and wireless technologies offering the benefits of high information rate and increased mobility. The concept of RoF involves transmission of Radio Frequencies (RFs) over an optical fiber link in order to support several wireless applications [2]. The modulation of the broadband microwave information signals on an optical carrier occurs at the central station which are then transported to remote locations via an optical fiber link. At the base stations, the RF signals are transmitted over small areas by using microwave antennas [3]. Normally when light waves are transmitted through RoF, they have slight interactions with each other and do not change while passing through the optical fiber link. However, there are exceptional cases in which the light waves interact with the material transmitting them and generate nonlinear effects [4]. The nonlinear effects occur either because of intensity dependence of the refractive index of medium or because of inelastic-scattering phenomenon.

FWM is one of the nonlinear effects occurring due to the power dependence of refractive index in optical fiber link. FWM occurs in an optical fiber when two or more light waves of variable wavelengths are launched in a WDM system [5,6]. This not only leads to the shifting of the phase of signals coming from the channels but also generation of new cross products. FWM is generated by third order distortion which produces third order harmonics [7]. These generated cross products cause interference with the original wavelengths and results in mixing. For N input wavelengths, the number of mixing products (M) are given by [8]:

$$M = \frac{N^2}{2}(N-1) \qquad (1)$$

Several methods are available to suppress the undesirable effects of FWM. OPC, FBG, DCF and rectangle filter are some of the components that are used in a WDM system to mitigate the FWM effects. Many researchers have already addressed the same problem and made progress to provide a solution. Selvamani et al. [9] mitigated the FWM effects by placing an OPC in the middle of optical fiber link. The FWM was reduced by 0.3–0.8dBm which is insignificant according to current requirements. Kaur et al. [10] analyzed the FWM power suppression in hybrid network topology by using an OPC. The hybrid network topology consisted of bus and ring topologies. Jain et al. [8] analyzed the performance of WDM system using several external modulation schemes and optical filter under the FWM effects. Sharma et al. [11] stated the improved analysis for cross-phase modulation and self-phase modulation induced crosstalk by changing the walk off parameters (input optical power, transmission distance and modulation frequency) with the aim to attain the minimum value of total induced crosstalk.

In previous works, authors have used a single component (FBG, DCF, OPC or rectangle filter) to reduce the FWM effects and were able to achieve the suppression till 20dBm. The authors mainly concentrated on FWM mitigation in systems based on WDM technique.

In this paper an approach of Wavelength Division Multiplexing (WDM) RoF link capacity expansion based on the usage of hybrid four wave mixing (FWM) suppression modules concepts presented. The two hybrid modules of optical phase conjugator (OPC), fiber Bragg grating (FBG) and dispersion compensating fiber (DCF) compared.

After introduction, the paper is sorted out as follows: In section II, the simulation setup of the proposed scheme is discussed. In section III, results are discussed and explained and conclusion is drawn in section IV.

2. Simulation setup

In the proposed WDM-RoF framework, two signals with wavelength of 1551.72 nm and 1552.52 nm (with a spacing of 0.8 nm) are transmitted as shown in Fig. 1. On the transmitter side, a Gaussian pulse generator converts the binary data delivered by pseudo-random bit generator into Return-to-Zero (RZ) super Gaussian electrical pulses and thus, the baseband signal is generated. The information rate for re-enactment of both the downlink and uplink sign is set to 1Gbps. Every single other parameter are appropriately changed in accordance with get a worthy estimation of Q-value. An electrical amplitude modulator having carrier frequency of 1.7GHz is used to convert the baseband signal frequency to the frequency of RF clock. The RF signal is connected to 90° hybrid coupler after SCM carrier generator as shown in Fig. 1(b). Further, the outputs of hybrid coupler are connected to dual port dual drive LiNb Mach-Zehnder modulator (MZM). MZM is used for the transformation of microwave signal into optical signal. MZM has four ports out of which three are used as input port and one as output port. Subsequently, Port 1 of MZM is driven by the amplitude modulator and Port 2 by 1Gbps baseband signal. The optical signal obtained on the output port of MZM further which is transmitted over the optical fiber link. The two signals are combined by a WDM multiplexer and transmitted over a single mode fiber (SMF) of length 15km followed by the hybrid modules. At the receiver side, a WDM demultiplexer is used to demultiplex the received signal and then further distributes to the respective receivers. The received signal is demodulated by passing through a PIN diode and Bessel filter and is investigated by using a bit error rate (BER) analyzer. Other various parameter for simulation tool is shown in Table 1.

Table 1. Various parameter of simulation tool

Parameter Name	Value
Reference wavelength	Transmitter 1: 1551.72nm
	Transmitter 2: 1552.52nm
Channel Spacing	0.8 nm
Launched power	-15 dBm to 15 dBm
Fiber used	SMF
Fiber length	15 Km
Dispersion of fiber	10ps/nm/km
Suppression Modules	OPC, DCF, FBG

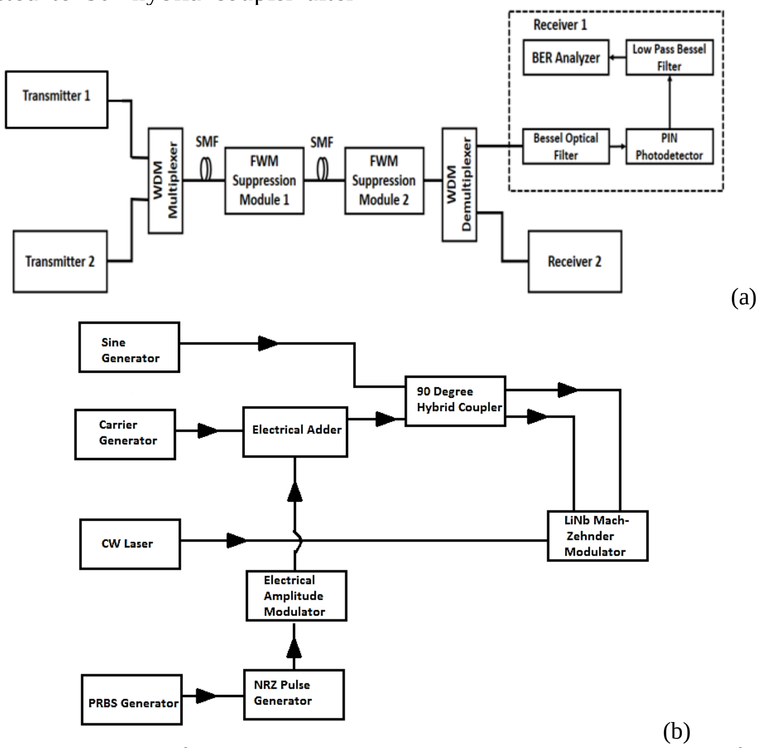


Fig. 1. (a) Block diagram of the proposed WDM-RoF system. (b) Internal structure of transmitter

Fig. 2(a) and (b) depict the two different FWM suppression hybrid modules comprising of OPC, FBG and DCF. The efficiency of OPC is set to 0.1, D_{total} (total compensating dispersion) of FBG is used 40 ps/nm, and dispersion of DCF is -46 ps/nm/km is consider for the system.

The FBG+OPC forms the hybrid module in which FBG is placed after the SMF and is followed by an OPC as shown in Fig. 2(a). The first OPC (OPC1 used in FWM suppression module 1) is placed in the middle of two spans of SMF. OPC1 optically conjugates the phase of optical signal in the middle of transmission link so that the impairments occurring before conjugation (in the first fiber span of SMF) can be cancelled by the impairments occurring after conjugation (in the second span of SMF). The other OPC placed at the output of second SMF span recovers the original signal from the reversed one. It strongly suppresses the FWM signal by introducing the destructive interference between the first and second halves of the fiber optical link.

The other component used is FBG. A FBG has a periodic structure and is built in a small section of optical fiber link to reflect specific wavelengths of light. It is achieved by creating a wavelength-specific dielectric mirror in the fiber core by varying its refractive index periodically. Thus, a FBG can be used as a wavelength-specific reflector allowing all the wavelengths to pass through except the one which satisfies the Bragg law. Bragg's law is expressed as [12]:

$$\Lambda = \frac{\lambda_B}{2n_{eff}} \tag{2}$$

where Λ represents period of grating, λ_B signifies the reflected wavelength and n_{eff} = 1.46 mm represents fiber core's effective group refractive index.

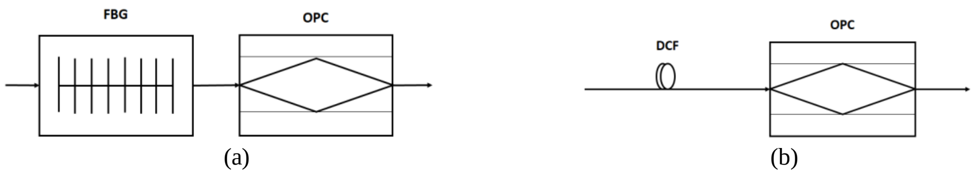


Fig. 2. FWM suppression hybrid modules (a) FBG+OPC hybrid module (b) DCF+OPC hybrid module

Fig. 2(b) shows the hybrid module involving DCF+OPC. The FWM effects are suppressed twice by DCF which is followed by the OPC. OPC1 is placed in the middle of two fiber spans consisting of SMF and DCF. It introduces destructive interference between the two halves of the optical fiber link (each half consisting of SMF and DCF) for reducing the FWM effects. DCF is the other component of the hybrid module. FWM occurs in those non-linear WDM networks where dispersion is negligible. So, we use components which deliberately add dispersion in WDM networks. DCF compensates this deliberately introduced dispersion in optical fiber link which leads to reduction in FWM effects.

3. Results and discussion

Fig. 3(a), (b) and (c) show the optical spectrum of the multiplexed signal. The optical spectrum of signal without any FWM suppression is shown in Fig. 3(a), and we can observed that, the effect of FWM power is more than suppressing module spectrum. Fig. 3(b) and 3(c) depict the optical spectrum of signal after suppressing the FWM effects using FBG+OPC and DCF+OPC hybrid modules respectively. We observe that the FWM power is reduced the FWM power from -47.5 dBm to-56 dBm in FBG+OPC module and compensate all the FWM power in DCF+OPC module. Thus, DCF+OPC module suppresses larger FWM power as compared to the FBG+OPC module.

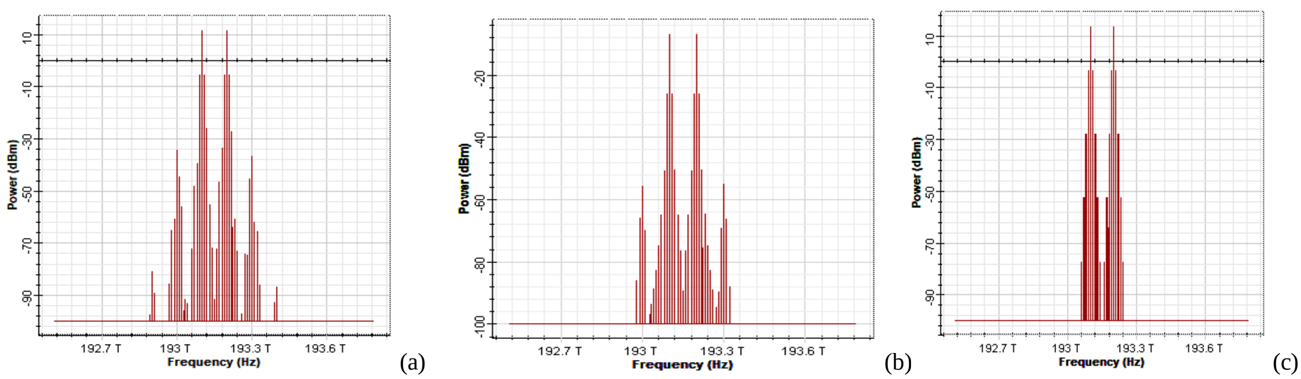


Fig. 3. Optical spectrum of multiplexed signal (a) without any suppression (b) with FWM suppressed by FBG + OPC module (c) with FWM suppressed by DCF+OPC module

Fig. 4 depicts the variation of overall FWM power as a function of channel input power. The FWM power is measured after the second fiber span when different hybrid modules are used. We observe that as the input power is increased from -15 dBm to 15 dBm, the FWM power also increases in both the configurations. This confirms that FWM depends directly on the power level of signal source. The DCF+OPC module results in lower values of FWM power as compared to the FBG+OPC module. For instance, the value of FWM power is -55.2 dBm and -58.3 dBm in case of FBG+OPC and DCF+OPC modules respectively when the input power is fixed at 5dBm.

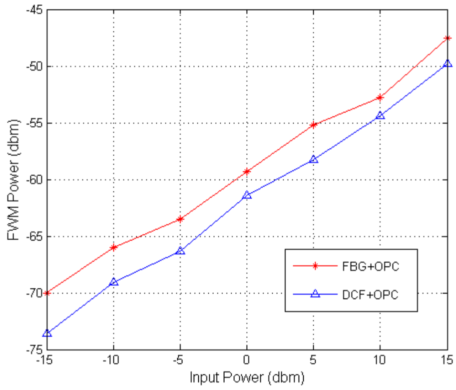


Fig. 4. Variation of overall FWM power from the two hybrid modules as a function of channel input power

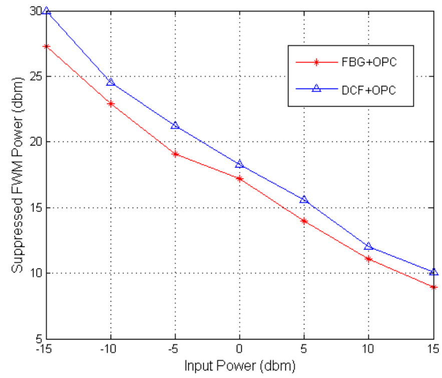
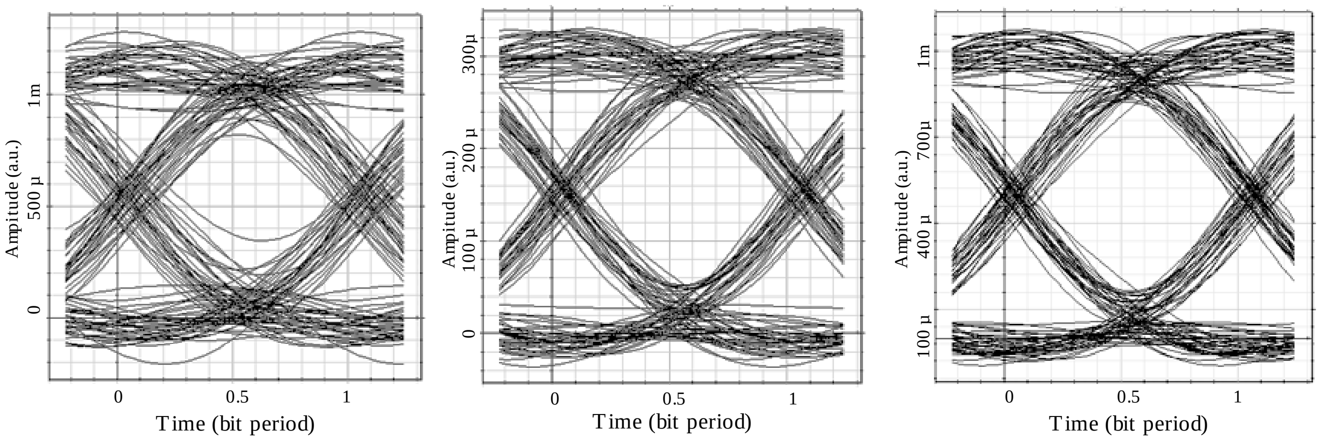


Fig. 5. Variation of suppressed FWM power from the two hybrid modules as a function of channel input power

In order to calculate the FWM power suppressed by the hybrid modules, the signal power is first analyzed after the first SMF (P1) and then after the OPC2 (P2). The final suppression of FWM power is calculated as: (P1 − P2) − 3 dB, where 3 dB refers to attenuation which is a product of SMF length and its losses. Fig. 5 shows the variation of suppressed FWM power with the channel input power for both the configurations. We observe that the FWM power suppressed by the DCF + OPC module is larger as compared to the FBG + OPC module. In our setup, the suppressed FWM power is 22.9 dBm and 24.5 dBm in case of FBG+OPC and DCF+OPC modules respectively when the input power is set to -10 dBm.

Fig. 6(a), (b) and (c) depict the eye diagrams of the received signal. Fig. 6(a) shows the eye diagram of signal when no suppression module is used. Fig. 6(b) and Fig. 6(c) show the eye diagrams when FBG+OPC and DCF+OPC hybrid modules are used respectively. An eye diagram indicates the signal quality during high speed digital signal transmission. The closure of an eye diagram depicts distortion in the signal waveform due to noise and inter-symbol- interference. Thus, an open eye diagram represents minimum signal distortion. The eye opening in Fig. 6(b) and (c) clearly shows that the performance of the system is improved by using the hybrid modules. Further, BER is analyzed for both hybrid suppression module when the proposed setup varying at different input power. From Fig. 7, it is seen that as the input power increased, the BER is increases but the propose system give us acceptable BER for all input power. It is also observed that, the DCF+ OPC give us better system performance as compared to FBG+OPC suppression module.



(a) (b) (c)

Fig. 6. Eye diagrams of received signal (a) without any suppression (b) with FWM suppressed by FBG+OPC module (c) with FWM suppressed by DCF+OPC module

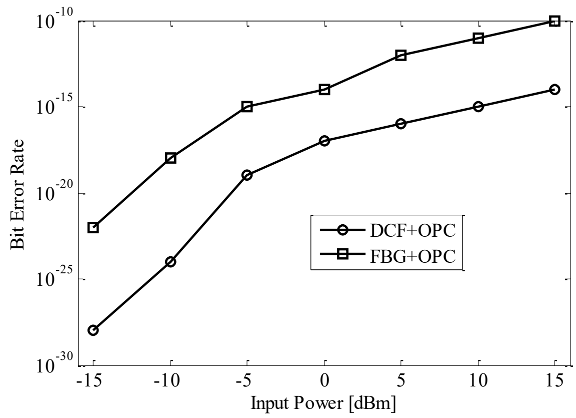


Fig. 7. Bit error rate as function of input power for DCF+OPC and FBG+OPC suppression modules

4. Conclusion

In this paper, the effect of FWM suppression hybrid modules on the execution of WDM-RoF system is investigated. These hybrid modules improve the performance of the system by mitigating the FWM power up to 30dBm. The overall FWM power and the suppressed FWM power are calculated for the two hybrid modules (FBG+OPC and DCF+OPC) and their variation is studied at different channel input power. The results show that the overall FWM power varies from -70dBm to -47.5dBm in case of FBG+OPC module and from -73.6dBm to -49.8dBm in case of DCF+OPC module The FBG+OPC module suppresses the FWM power up to 27.3dBm while the DCF+OPC module suppresses it up to 30dBm. Thus, DCF+OPC module is more efficient in mitigating the undesirable effects of FWM than the FBG+OPC module.

Acknowledgement

This work was supported by a grant from Department of Biotechnology under the Ministry of Science and Technology, Government of India, Grant No. BT/PR10634/PFN/20/825/2013 and also supported by a grant from Rajiv Gandhi national fellowship under University Grants Commission, Grant No. F117.1/201415/RGNF2014 15SCPUN61657/ (SAIII/ Website).

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