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Analysis of Nonlinearities in Fiber while supporting 5G

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Abstract - *The upcoming generation of wireless 5G technology assures to provide gigabit-class cellular browsing speeds, with reduced latency. Fiber plays a vital role in backhauling of fifth generation. There are many non-linearities in the optical transmission. One of the serious effect is the FWM (four wave mixing), which introduces an unwanted signal into the base band signal. Though there are non-linearities while transmission in optics, it is highly preferred because of its ability to support latency tolerance. In this paper three modulation techniques are used viz, Direct Modulation(DM), Mach Zehnder Modulation(MZM) and Optical Phase Modulation(OPM) for supporting the analysis. The FWM is evaluated over various distances ranging from 10 km to 50 km. Finally, the signals are amplified using Erbium doped Fiber Amplifier(EDFA) and Semiconductor Optical Amplifier(SOA).*

Key Words: **5G, SCM-WDM, FWM, DM, MZM, OPM, EDFA, SOA.**

1. INTRODUCTION

5G wireless communication can be expected completely by 2020. So for an excellent communication the backhauling has to be strong enough to support. Here optical fiber can be used for seamlessly using the band width and also for satisfying the essentials. Many techniques are used to deduce the non-linearity that occur in fiber due to the varying input power, channel spacing, frequencies, distance while transmitting. When optical intensity inside the fiber increases, the refractive index of fiber is modified. The wave propagation characteristics become the function of optical power. Inside a SMF, optical power of few tens of mW drive the medium into nonlinearity.

1.1 SCM-WDM

When fiber becomes nonlinear, pulse propagation is modified and also new frequencies are generated. These newly generated frequencies give rise to various nonlinear distortions, one of them being FWM. To reduce the efficiency of FWM, the chosen system is SCM-WDM system. In SCM, firstly the base band signal is modulated over the radio frequency carrier in GHz range and eventually modulated over the optical carrier. Since Subcarrier multiplexing has competency to multiplex the signals and to place different optical carriers together closely, they are used in this system. SCM along with WDM makes use of most of the available fiber bandwidth. Thus the SCM-WDM system provides higher bandwidth for efficient communication system (Single Mode Fiber(SMF) is used with the length of 50 km). So by using the SCM-WDM system for radio over fiber, the efficiency for the utilization of bandwidth can be expected to be higher than that of the simple WDM system. Other than utilization of maximum bandwidth it also intensifies transmission capacity, flexibility, and reduces the crosstalk in the fiber.

1.2 Modulation Technique

In order to transmit multiple signals simultaneously over a single channel, modulation techniques are used. Various modulation techniques are in practice. In the proposed method three important techniques are used. In direct modulation, output power of the system directly depends on input driven current. In Mach-Zehender modulation technique, the laser output is split into two signals and is allowed to pass through the two wave guide interferometer arm, then the voltage is made to pass through one fiber, there occurs the phase difference when recombined with converted amplitude modulation. Optical phase modulator is used to control the optical phase of the light wave.

Since this system is designed for transmitting the signals with high data rate, there occurs losses and in order to overcome the losses the optical amplifiers (amplifiers that are used to amplify the optical signals) are used at the receiving side. Here the preamplifiers like EDFA and SOA are cast-off. EDFA used in this analysis has the amplifying bandwidth at the range of 1542 nm to1558nm.

2. THEORY

The major non linearity that occurs in an optical fiber communication system in Four Wave Mixing. FWM occurs when three or more frequencies that passes through the fiber mix together to form a fourth frequency. This newly formed frequency may either lie in the out-band frequency range or in the in-band frequency range. If the new frequency lie in the out-band it may be easily filtered out, but when it falls in the in-band then it will be difficult to remove those frequencies. Thus crosstalk is induced among channels.

The Taylor series based optical energy transmission can be written as:

$$\beta = \beta_0 + (\omega - \omega_0)\frac{d\beta}{d\omega} + \frac{1}{2}(\omega - \omega_0)^2\frac{d^2\beta}{d\omega^2} + \frac{1}{6}(\omega - \omega_0)^3\frac{d^3\beta}{d\omega^3} + \ \dots \dots$$

where β is propagation constant

$\frac{d\beta}{d\omega}$ = τ is the propagation delay per optical length.

Power of the FWM crosstalk is given by:

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

Where η = FWM efficiency

L = transmission distance

γ = nonlinear coefficient

P_x, P_y, P_z = input channels power

FWM efficiency is given by,

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

Where,

$$\Delta\beta' = \Delta\beta - \gamma_i(P_x + P_y - P_z)\left[\frac{(1-\exp(-\alpha L_{ef})}{\alpha L_{ef}}\right]$$

i is an integer,

$L_{ef} = \frac{1-\exp(-\alpha L)}{\alpha} \approx \frac{1}{\alpha}$, is the effective length of the fiber.

3. SIMULATION SETUP

Nonlinear Distortions occur in the output signal while transmitting optical signals through Optical Fiber. This is due to the interaction of the optical channels and the signals having different wavelengths. These fiber nonlinearities further leads to nonlinear distortions in the transmitted signal. In this paper, a simulative study which deals with the transmission of SCM-WDM based signal through different modulation techniques is done. Here, Direct Modulation (DM) and External Modulation techniques like Mach-Zehnder Modulation (MZM) and Optical Phase Modulation are used. This simulation is carried out in the optical simulator OPTSIM. The Transmitter part is shown in the Fig.1

The three RF carriers of frequencies 19 GHz, 20 GHz and 21GHz are electrically modulated, combined and then modulated at wavelengths of 1549 nm, 1550 nm and 1551 nm using three different optical modulators namely, Direct Modulated laser, Mach-Zehnder Modulator and Optical Phase Modulator. After double modulation the SCM-WDM modulated signal is amplified and is transmitted through the Optical Fiber over a distance of 50 km.

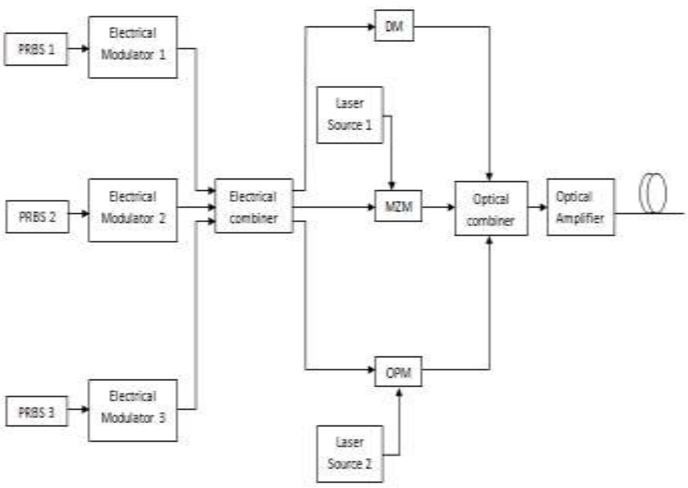


Fig.1:Block Diagram of SCM-WDM Transmitter section

The signals received are filtered out using 3 optical filters of respective wavelengths and the amplification is done by two types of amplifiers viz., SOA and EDFA, which are connected in parallel to compare their performances. Then the amplified signal is detected and the output is analyzed using Electrical Spectrum Analyzer.

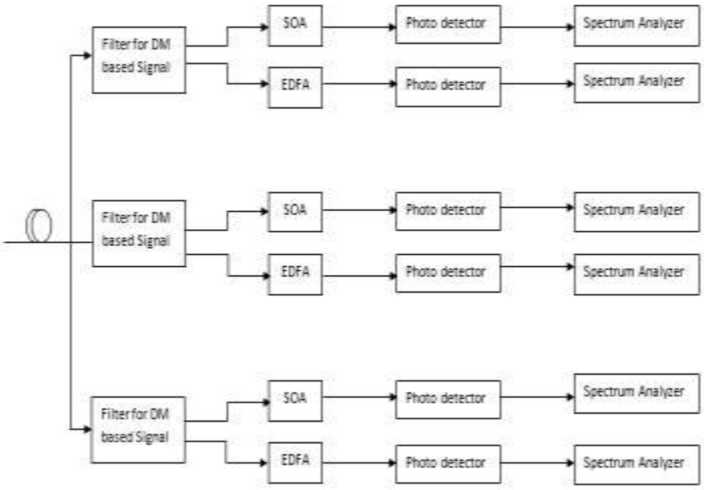


Fig.2: Block Diagram of SCM-WDM Receiver section

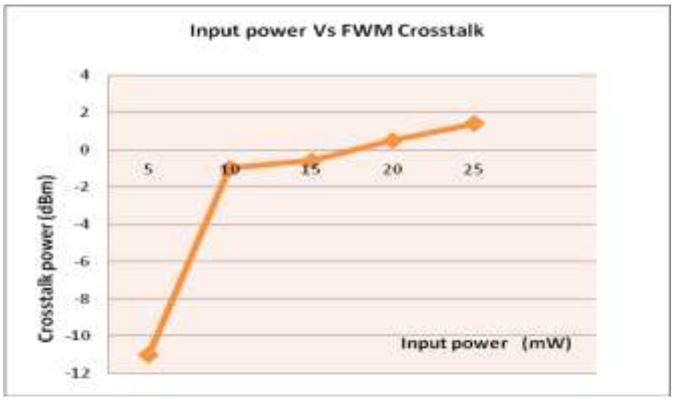
The parameters that are used for this simulation are tabulated.

Table -1: Parameter values

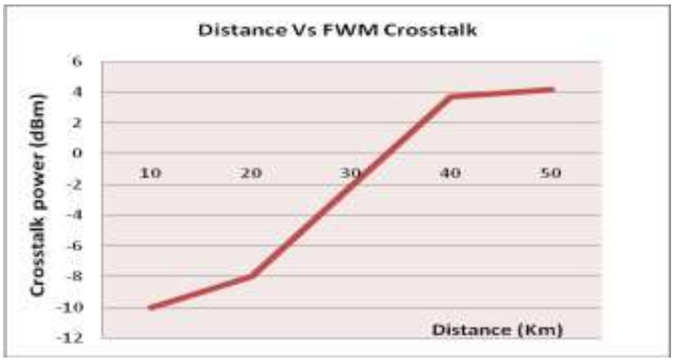
Parameters	Values
Data rate	20 Gbps
RF Carrier Frequencies	19 GHz, 20 GHz, 21 GHz
Modulating Wavelengths	1549 nm, 1550 nm, 1551 nm
Dispersion in Fiber (D)	16 ps /nm-km
Dispersion curvature (D2)	2.377E-4
Dispersion curvature (D3)	7.064E-6
Raman Pump Wavelength	1546 nm
Brillouin gain(g)	5.5E-11
Nonlinearity Coefficient	0.00095/km/W
Attenuation Constant(α)	0.22 dB/km

4. RESULTS AND DISCUSSION

In this section, the experimental results obtained are analyzed. The FWM Crosstalk due to various fiber nonlinearities were analyzed for different channel input power and fiber distances using OPTSIM.



(a)



(b)

Chart -1: (a) FWM Crosstalk Vs Input power
(b) FWM Crosstalk Vs Distance

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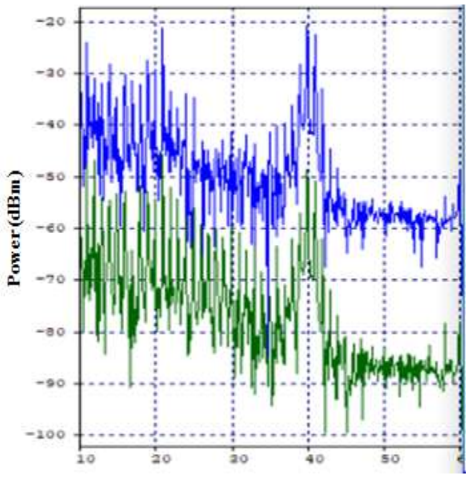
Chart -1 :(a) shows the crosstalk induced due to FWM against channel input power. The input power has been varied from 5 to 25 mW while keeping distance fixed at 30 km. It is found that crosstalk increases as the input power is increased. The crosstalk due to FWM at input power of 25 mW is almost 2 dBm. The behavior of nonlinear crosstalk against distance has been shown in Chart -1 :(b). Here also, the crosstalk induced due to FWM rises with the increasing distance. Further, the FWM induced crosstalk rises sharply from -10 to 4 dBm when distance is swept from 10 to 50 km. Further, the performance of this RoF system has been evaluated through electrical spectrum by simulating the developed block diagram shown in Figs. 1 and 2. The radio frequencies 19, 20 and 21 GHz are combined and modulated through three different modulators on different wavelengths as shown in Figs. 1 and 2. The OPM and MZM have excess loss of 0 dB, extinction ratio of 15 dB and -3dB bandwidth is 40 GHz. The gain of optical amplifier at the transmitter is 16 dB.

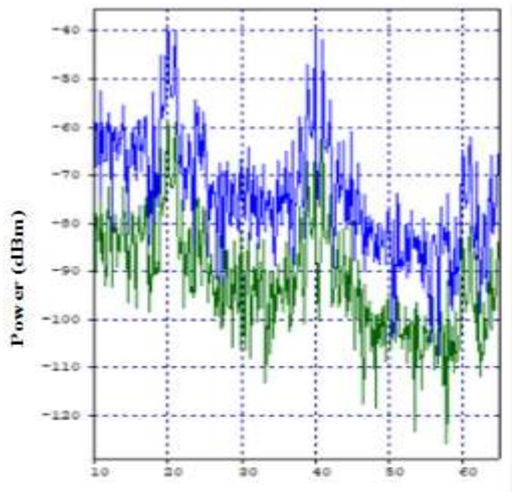
The optical filter wavelengths are 1549 nm, 1550 nm and 1551 nm for DM, MZM and OPM respectively. The responsivity of PIN photodiode is 0.9 A/W.



Frequency (GHz)

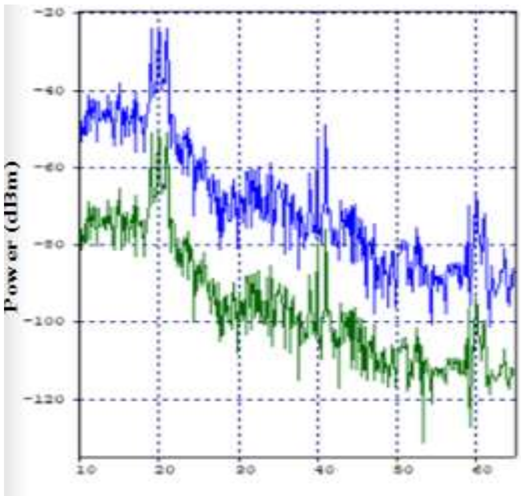
(a)

Fig.4. shows the electrical spectrum received at the photodiodes through various modulators. From the spectrum it is inferred that besides the peaks of 19 GHz, 20 GHz and 21 GHz signal, other unwanted peaks are present in the form of Harmonics and inter modulation (IM) terms. These terms are due to FWM effect.



Frequency (GHz)

(b)



Frequency (GHz)

(c)

Fig.4: Received electrical spectrum through (a) DM (b) MZM (c) OPM

Table -2: Intermodulation Terms and Harmonics

DM	MZM	OPM
$2f_1, 2f_2, 2f_3, 3f_1, 3f_2, 3f_3, 3f_3 - 2f_1, 3f_3 - 2f_2$	$2f_1, 2f_2, 2f_3, 3f_1, 3f_2, 3f_3, 3f_3 - 2f_1, 3f_3 - 2f_2, f_3 + f_2 - f_1$	$2f_1, 2f_2, 2f_3$

Table -2. Shows the IM terms that occur in various modulation techniques. From the table it is inferred that number of IM terms in OPM modulation technique is negligible when compared to other modulation techniques. This improved performance of OPM is because it does not require any biasing for its operation.

5. CONCLUSIONS

In this paper we have presented a study of the nonlinear effects induced in SCM-WDM based fiber communication system which is obviously the backbone for the next generation 5G communication networks. FWM, one of the serious nonlinear effects is briefly explained and evaluated against transmission distance and channel input power. It is found that FWM crosstalk increases as the input power is increased. The crosstalk due to FWM at input power of 25 mW is almost 2 dBm. Further, the FWM induced crosstalk rises sharply from -10 to 4 dBm when distance is swept from 10 to 50 km.

The peak value of crosstalk in DM modulated electrical spectrum is -20 dB and that of MZM modulated electrical spectrum is -40 dB, but the peak value of crosstalk in OPM is -45 dB. From this, it can be concluded that OPM is the best modulation technique to minimize the crosstalk occurring in the received signal.

Further the performance of Optical Phase Modulator can be improved by using EDFA amplifier.

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