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XPM crosstalk in millimeter wave SCM-WDM for optical ground station

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In this paper, we have presented XPM crosstalk in millimeter wave SCM-WDM for optical ground station using Schrödinger equation. It has been observed that there is exponent increase in XPM crosstalk with the increase in modulation frequencies, transmission lengths and optical powers respectively. A distance of 5 km was achieved with 60 GHz millimeter wave in SCM-WDM for optical ground station.

Keywords: Sub-carrier multiplexing (SCM), Wavelength division multiplexing (WDM), Cross phase modulation (XPM), Millimeter (mm) wave, Optical ground station (OGS)

1 Introduction

The optical ground station (OGS) are combing with air-to-ground terminals to establish an air-to-ground link/ground-to-ground link. The demand for broadband services has driven research on millimeter (mm)-wave frequency band communications for 5G and optical ground station networks due its spectrum availability and the compact size of radio frequency devices. The mm-wave signals suffer from severe distortion due to chromatic dispersion during transmission as well as highly variable atmospheric attenuation dependent largely on absorbtion induced by precipitation. One of the solution to overcome these problems is to use the low-attenuation, electromagnetic interference-free optical fiber. Digital RF over Fiber (DRoF) is a cost-effective, practical and relatively flexible system configuration for long distance transport of millimetric frequency band in Satellite Optical Ground Station. Fiber-to-the-Home (FTTH) has been the main attraction in the telecommunication industry. Direct fiber connection has always been viewed as the long awaited solute on due to the large bandwidth and low maintenance. However, in order for FTTH to remain competitive, a passive optical network is required. SCM is a potential solution for transmission in optical networks[1]. The combination of SCM and WDM is a viable method to further increase the transmission capacity in optical networks[2]. SCM-WDM systems, however suffer from non-linear effects in fiber. These non-linearities cause crosstalk between subscribers on different wavelengths. In a dispersive fiber like single mode fiber (SMF), one of the dominant fiber non-linearities that cause crosstalk is XPM. The phase crosstalk is converted to intensity crosstalk due to GVD. The effects of XPM and GVD in SCM-WDM video transmission systems while considering two WDM channels have been reported in[3-4]. Here XPM crosstalk with higher order dispersion has been discussed under low frequency[5-6]. XPM Crosstalk with V and W band discussed in[7]. New optimization techniques based optical network ground Station is presented in[8-9].

In literature, there is a lack of work dealing with mm wave so in this paper our focus is impact of XPM crosstalk on millimeter Wave-frequency like 40 GHz, 60 GHz and 80 GHz in SCM-WDM for optical ground station.

2 Theoretical analysis

Schrödinger Equation

Consider probe and pump optical signals A_j (t, z) and A_k(t, z) co propagating in the same optical fiber[8]

$$\frac{\partial A_j(t,z)}{\partial z}+\frac{\alpha}{2}A_j(t,z)+\frac{1}{V_j}\frac{\partial A_j(t,z)}{\partial t}+\frac{i\beta_2}{2}\frac{\partial^2 A_j(t,z)}{\partial t^2}=i\gamma_j 2P_k\{t-d_{jk}\}A_j(t,z) \quad \ldots (1)$$

where, α the attenuation coefficient of the fiber and $\gamma = 2\pi n_2 / \lambda A_{eff}$ is the nonlinear coupling coefficient.

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Hence,

$$\frac{\partial A_j(t,z)}{\partial z}=-\frac{\alpha}{2}A_j(t,z)-\frac{1}{V_j}\frac{\partial A_j(t,z)}{\partial t}-\frac{i\beta_2}{2}\frac{\partial^2 A_j(t,z)}{\partial t^2}+2i\gamma_j P_k\{t-d_{jk}\}A_j(t,z) \qquad \ldots (2)$$

In order to simplify the analysis and to be able to focus our attention on the effect of inter-channel crosstalk, translating this propagation equation into the frequency domain using Fourier transformation, we have,

$$\frac{\partial A_j(\omega,z)}{\partial z}=\left[-\left(\frac{\alpha}{2}+\frac{i\omega}{V_j}\right)+\frac{i\omega^2\beta_2}{2}+2i\gamma_j P_k(\omega,0)e^{i\omega z d_{jk}}e^{-\alpha z}\right]A_j(\omega,z) \qquad \ldots (3)$$

Look at the third term on the RHS of equation (3). This term is responsible for the phase noise to intensity noise conversion in the probe signal. In a short fiber section dz, the crosstalk phase modulation in the probe signal, induced by the pump signal can be linearized under the small signal approximation.

$$d\phi_{jk}(\omega,z)=2\gamma_j P_k(\omega,0)e^{(-\alpha+i\omega d_{jk})z}dz \qquad \ldots (4)$$

We can obtain the total intensity noise at the end of the fiber z=L.

$$\Delta A_j(\omega,L)=-2P_j(0)e^{(-\alpha-\frac{i\omega}{V_j})z}\left[\int_0^L 2\gamma_j P_k(\omega,0)e^{(-\alpha+i\omega d_{jk})z}\sin\left[\frac{\omega^2\beta_2(L-z)}{2}\right]\right]dz \qquad \ldots (5)$$

Now, $P_j(L)=P_j(0)e^{-\alpha L}$

$$\Delta A_j(\omega,L)=P_j(L)e^{(\frac{i\omega}{V_j})L}2\gamma_j P_k(\omega,0)\left[\frac{\{e^{\frac{i\omega^2\beta_2 L}{2}}-e^{(-\alpha+i\omega d_{jk})L}\}}{i[(\alpha-i\omega d_{jk})+\frac{i\omega^2\beta_2}{2}]}-\frac{\{e^{\frac{i\omega^2\beta_2 L}{2}}-e^{(-\alpha+i\omega d_{jk})L}\}}{i[(\alpha-i\omega d_{jk})-\frac{i\omega^2\beta_2}{2}]}\right] \qquad \ldots (6)$$

We can find a simple form to describe the relative amplitude fluctuation induced by XPM as

$$\Delta P_j(\omega,L)=\left|\frac{\Delta A_j(\omega,L)}{P_j(L)}\right|^2$$

$$\Delta P_j(\omega,L)=\left|2\gamma_j P_k(\omega,0)\left[\frac{\left\{e^{\frac{i\omega^2\beta_2 L}{2}}-e^{(-\alpha+i\omega d_{jk})L}\right\}}{i\{(\alpha-i\omega d_{jk})+\frac{i\omega^2\beta_2}{2}\}}-\frac{\left\{e^{\frac{i\omega^2\beta_2 L}{2}}-e^{(-\alpha+i\omega d_{jk})L}\right\}}{i\{(\alpha-i\omega d_{jk})-\frac{i\omega^2\beta_2}{2}\}}\right]\right|^2 \qquad \ldots (7)$$

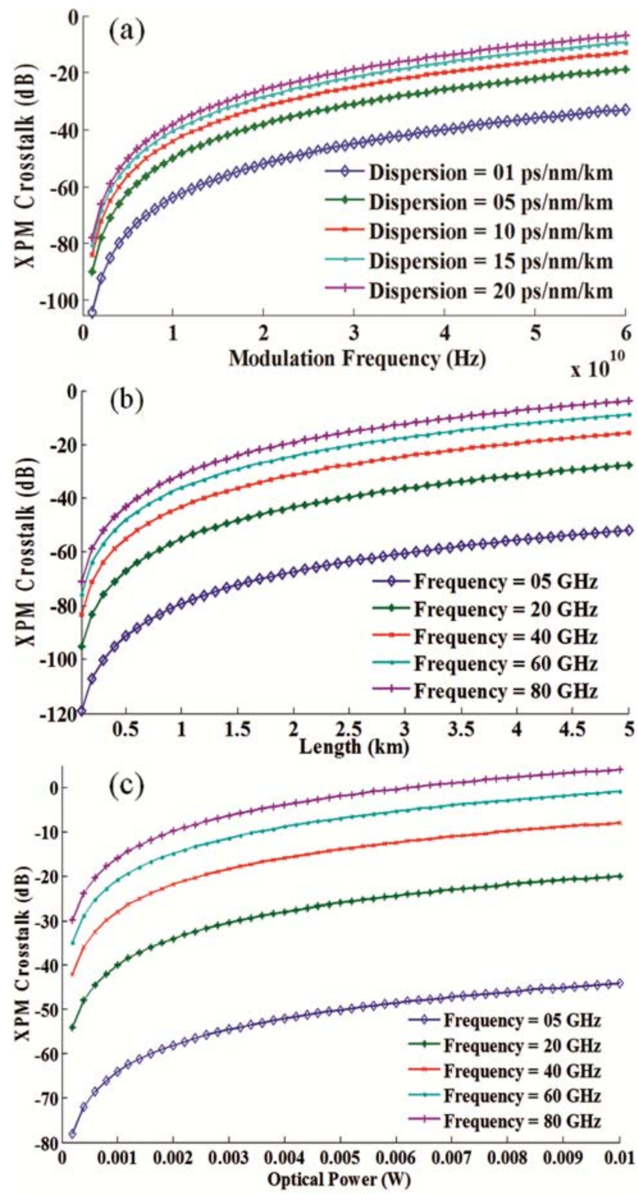

Fig. 1 — (a) The graph between XPM crosstalk versus modulation frequency at varied dispersion parameter, (b) graph between XPM crosstalk versus length at different modulation frequency and (c) graph between XPM crosstalk versus optical power at different modulation frequency.

We define here the following dispersion parameters [9] $\beta_2 = \frac{\lambda^2}{2\pi c} D$ is the second-order dispersion parameter.

3 Results and Discussion

Here the results have been mentioned for XPM crosstalk at various modulation frequencies, transmission lengths and optical powers in the presence of mm wave frequencies. The results have been reported by taking values of the various parameters like: P= 6dBm, $\Delta\lambda$= 0.4nm, L=5 km, α = 0.25dB/km, λ=1550nm, λ_1=1550.4nm and the values of D=16ps/nm/km. and D_1=0.085ps/nm/km.

Fig.1 (a) shows that the XPM crosstalk is (−105 to −37), (−90 to −20), (−85 to −15), (− 80 to −10) and (-78 to -5) dB in the presence of dispersion 1, 5, 10, 15 and 20 ps/nm/km at 0 to 60GHz modulation frequency. As the modulation frequencies increases, XPM crosstalk is increases with the parameter of dispersion.

Fig.1 (b) shows that the XPM crosstalk is (−120 to −70), (−95 to − 30), (−82 to − 18), (−78 to − 10) and (−80 to − 4) dB in the presence of modulation frequency 5, 20, 40, 60 and 80 GHz at 0 to 5km transmission length. As the transmission length increases, XPM crosstalk is increases with the parameter of modulation frequency.

Fig. 1 (c) shows that the XPM crosstalk is (−79 to −45), (−54 to −20), (−42 to −12), (−35 to − 2) and (−30 to 4) dB in the presence of modulation frequency 5, 20, 40, 60 and 80 GHz at 0 to 10mW optical power. As the optical power increases, XPM crosstalk is increases with the parameter of modulation frequency.

4 Conclusion

We have analyzed XPM crosstalk in millimeter wave SCM-WDM for optical ground station using Schrödinger equation. It was observed that the different parameters (dispersion and high modulation frequency) have significant impact on XPM crosstalk. It is therefore concluded that as the higher dispersion and higher modulation frequency parameter increase, XPM crosstalk increases. This result has industrial applications that are useful for mm-wave Next Generation Avionic Networks (NGAN).

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