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# Effect of Non Linear Impairments on Different Optical Fibers

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***Abstract: In this paper the analysis of stimulated raman scattering induced crosstalk has been discussed. The expression for SRS induced crosstalk have been observed at different fiber types such as single mode fiber, dispersion compensation fiber, non zero dispersion shifted fiber and non zero dispersion fiber with the variation of modulation frequency, transmission length and the input power. It has been observed that as an increase in the modulation frequency the crosstalk decreases.***
***Keywords: SRS, DCF, NZDF, NZDSF, modulation frequency, transmission length***.

## I. INTRODUCTION

A communication system transmits information from one place to another, whether separated by a few kilometers or by transoceanic distances. Information is often carried by an electromagnetic carrier wave whose frequency can vary from a few megahertz to several hundred terahertz[1]. Virtually there are only two windows used for broadband communications. First window is between 100 KHz to 300 GHz and second window from 30 THz to 300 THz. As per now the demand for bandwidth is increasing enormously so the second window is used which is optical and has a capacity of 100 Tb/s and beyond. The initial development of optical fiber was for long haul or submarine transmission but now everywhere optical fibers are used[2]. Year after year there was development in the optical fibers and each new generation bring a fundamental change which helps to improve the system performance further. Optical networks are divided into optical active network (OAN) and optical passive network (OPN). 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 solution 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 OPNs [4]. The combination of SCM and WDM is a viable method to further increase the transmission capacity in OPNs [5]. 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, the dominant fiber nonlinearity that causes crosstalk is cross-phase modulation (XPM). Fiber nonlinearities such as stimulated raman scattering (SRS) and cross phase modulation (XPM) may generate significant amounts of nonlinear crosstalk between adjacent SCM channels because they are very closely spaced [6,7]. SRS and SBS transfer energy from pump pulse to generate stoke pulses which co-propagates along with the pump signal in the same or opposite direction if the peak power of the incident waves is more than the threshold level, and these two pulses interact with each other through the raman gain and XPM[10]. The SRS effect is more dominant for the frequencies which are adjoining to the transmitted ones[11,12]. Crosstalk mainly due to SRS, SBS and XPM occurs due to nonlinearities of the fiber. The crosstalk levels obtained to date [13,14] indicated that crosstalk in SCM-WDM systems can easily reach intolerable levels even with two wavelengths.

### A. *SRS induced crosstalk*

In this analysis two optical waves with different modulation index, amplitude and phase have been considered. The optical power at the input of the fiber is assumed to be fixed[13].
An approach used to determine crosstalk level is to solve following coupled equation governing phase modulation under the slowly envelop are given by [10]

$$\frac{\partial S_1}{\partial z} + 1/V_{g_1}\frac{\partial S_1}{\partial t} = (gS_2-\alpha)\, S_1 \qquad (1)$$
$$\frac{\partial S_2}{\partial z} + 1/V_{g_2}\frac{\partial S_2}{\partial t} = (gS_1-\alpha)\, S_2 \qquad (2)$$

Where $V_{g_1}$ is the group velocity for the transmitted signal at $\lambda_1$, $V_{g_2}$ *is* the group velocity for the transmitted signal at $\lambda_2$. α is the fiber loss coefficient , g is the standard coefficient divided by the fiber effective area ($g=g_R/A_{eff}$)

$$S_1(z,t) = S_1(0,\tau_1)\, e^{-\alpha z} \qquad (3)$$

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We first solve for $S_1$ in equation (1) by neglecting g. we then substitute $S_1$ into (2) to solve for $S_2$ to obtain

$$=S_o e^{-\alpha z}\left[1- g\, S_o\left[\frac{1-e^{-\alpha z}}{\alpha}\right] - g\, m S_o \frac{\sqrt{1+e^{-2\alpha z}-2e^{-\alpha z}\cos(\omega d_{12} z)}}{\sqrt{\alpha^2+(\omega d_{12})^2}}\cos(\omega\tau_2 + \Theta_{SRS})\right] \quad (4)$$

where $\Theta_{SRS} = tan^{-1}\left(\frac{-\omega d_{12}}{-\alpha}\right) + tan^{-1}\frac{e^{-\alpha z}\sin(\omega d_{12} z)}{e^{-\alpha z}\cos(\omega d_{12} z)-1}$,

Hence, $g = \frac{g_R}{A_{eff}}$

In equation (4), the first term corresponds to the carrier power after fiber loss. The second term corresponds to the interaction between the optical carriers, this result in optical dc power gain or loss. The third term is the crosstalk as the result of modulation depletion through SRS interaction between pump channel optical carrier and signal channel subcarrier. The crosstalk suffered by the subcarrier in the probe channel due to SRS is (5)

$$\text{Crosstalk, (SRS) [10]} = \left| g S_o \frac{\sqrt{1+e^{-2\alpha z}-2e^{-\alpha z}\cos(\omega d_{12} z)}}{A_{eff}\sqrt{\alpha^2+(\omega d_{12})^2}}\right|^2 \quad (5)$$

*B. XPM induced crosstalk*

The XPM induced crosstalk due to 3OD is given by

$$= -S_2(0,\tau_2)\, e^{-\alpha z}\beta_3 \frac{\partial \emptyset}{\partial \tau_2}\frac{\partial^2 \emptyset}{\partial \tau_2^2}$$

$\beta_3$=third order dispersion parameter

$$= \frac{\partial^3 \beta}{\partial \omega^3} = \frac{1}{(2\pi c)^2}\left[\lambda^2 D_1 + 2\lambda D\right]$$

Crosstalk(XPM) 3OD

$$= -\frac{2m\beta_3\gamma^2 S_C \omega^3}{(\alpha - j\omega d_{12})^3}\{(3+2\alpha l+4e^{-\alpha l}\cos(\omega d_{12} l) - e^{-2\alpha l}\cos(2\omega d_{12} l) + j4e^{-\alpha l}\sin(\omega d_{12} l) - e^{-2\alpha l}\sin(2\omega d_{12} l) - 2\omega d_{12} l\ )\}$$

## II. RESULT ANALYSIS

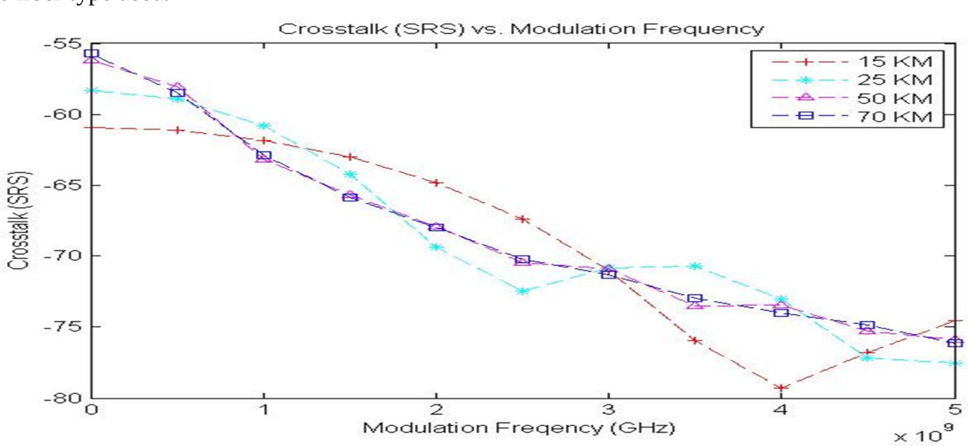
Here, the results have been mentioned for SRS induced crosstalk using different fiber parameters variation in modulation frequency in range of 0 – 5 GHz, optical power and transmission length.

Table 2 Parametric characteristics of different fiber types [11]

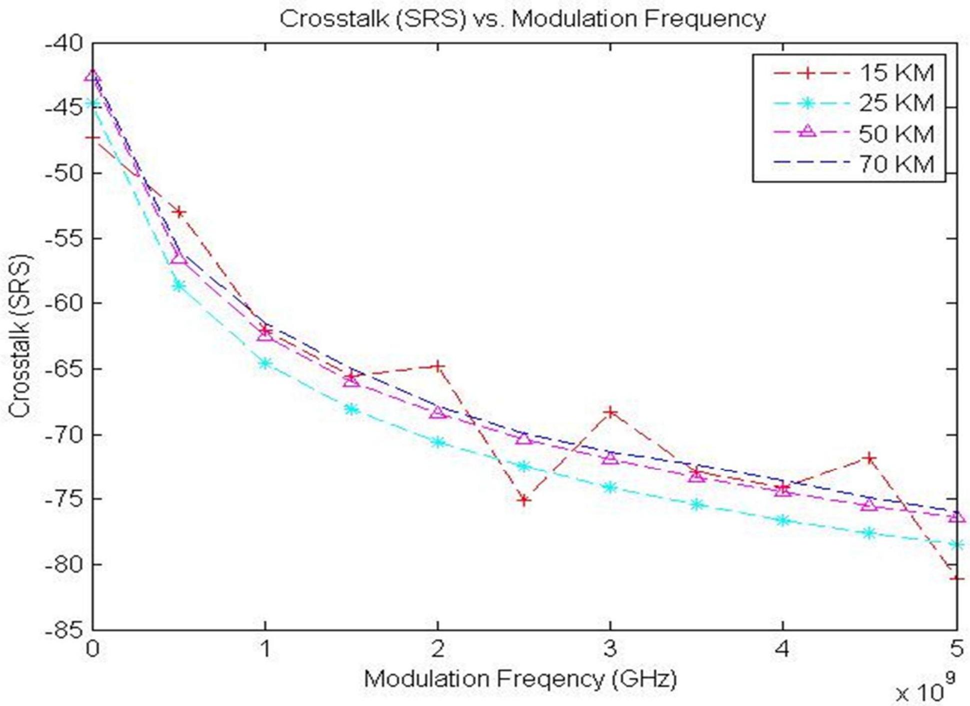
| Fiber type | $A_{eff}$ ($\mu m^2$) | $D_c$(ps/nm-km) | α (dB/Km) | γ ($W^{-1}$Km) |
|---|---|---|---|---|
| SMF | 80 | 17 | 0.2 | 2.5 |
| DCF | 20 | -80 | 0.29 | 3 |
| NZDF | 72 | -3 | 0.23 | 3.9 |
| NZDSF | 50 | 4.5 | 0.25 | 3.84 |

*A. SRS induced crosstalk*

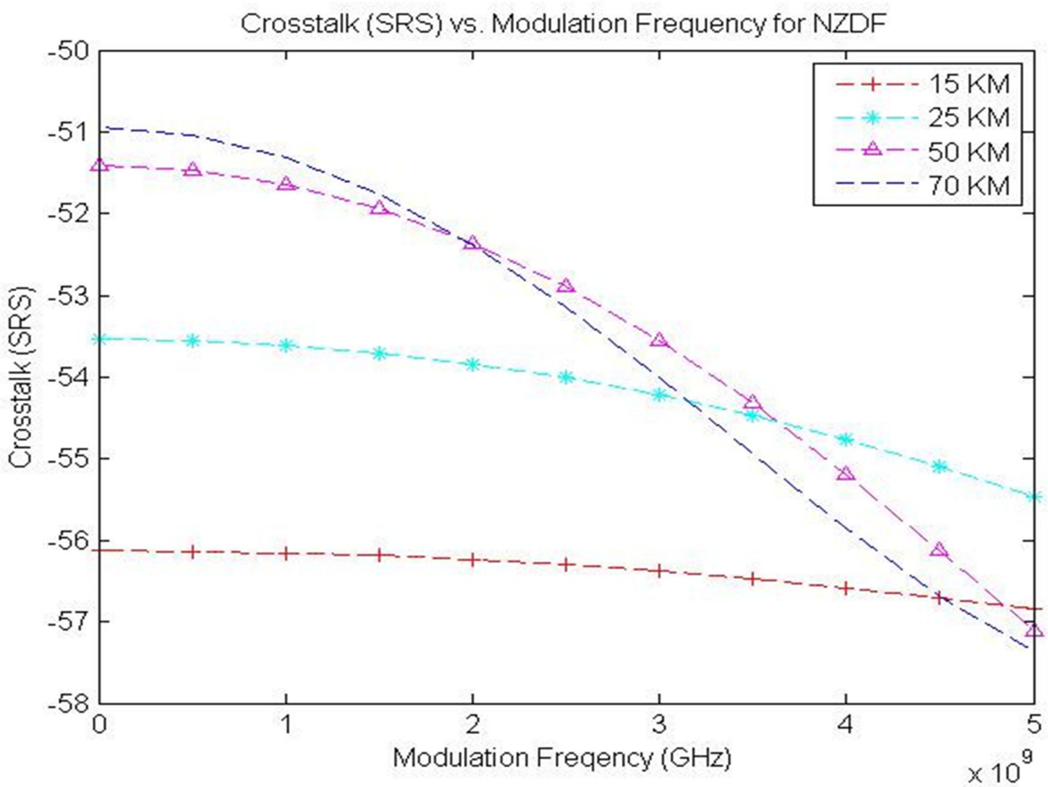
Fig 3.1(a) shows the graph between SRS induced crosstalk with modulation frequency with varied fiber parameters. The modulation frequency is varied from 0 to 5 GHz and different fibers are taken as SMF, DCF, NZDF and NZDSF. It has been observed that as the modulation frequency increases the SRS induced crosstalk decreases. Moreover the decrease in crosstalk depends on the fiber type used.




(i)


Crosstalk (SRS) vs. Modulation Frequency
15 KM
25 KM
50 KM
70 KM
Crosstalk (SRS)
Modulation Freqency (GHz)
x 10^9

(ii)


Crosstalk (SRS) vs. Modulation Frequency for NZDF
15 KM
25 KM
50 KM
70 KM
Crosstalk (SRS)
Modulation Freqency (GHz)
x 10^9

(iii)

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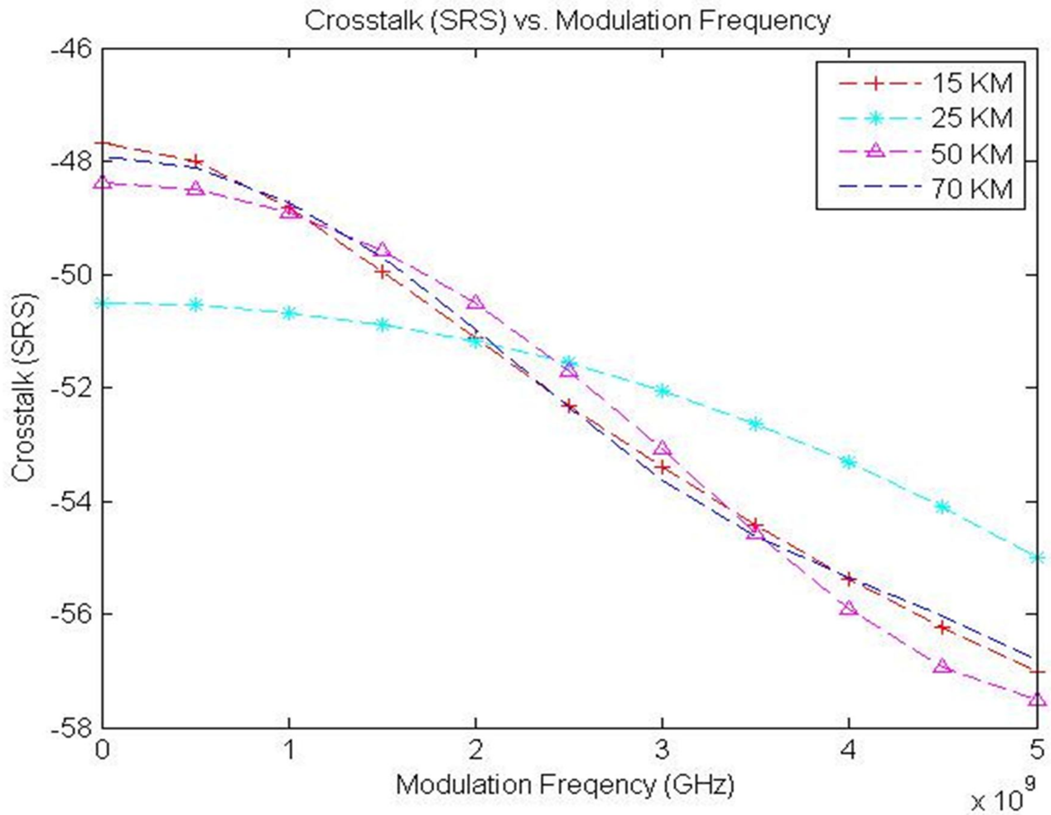
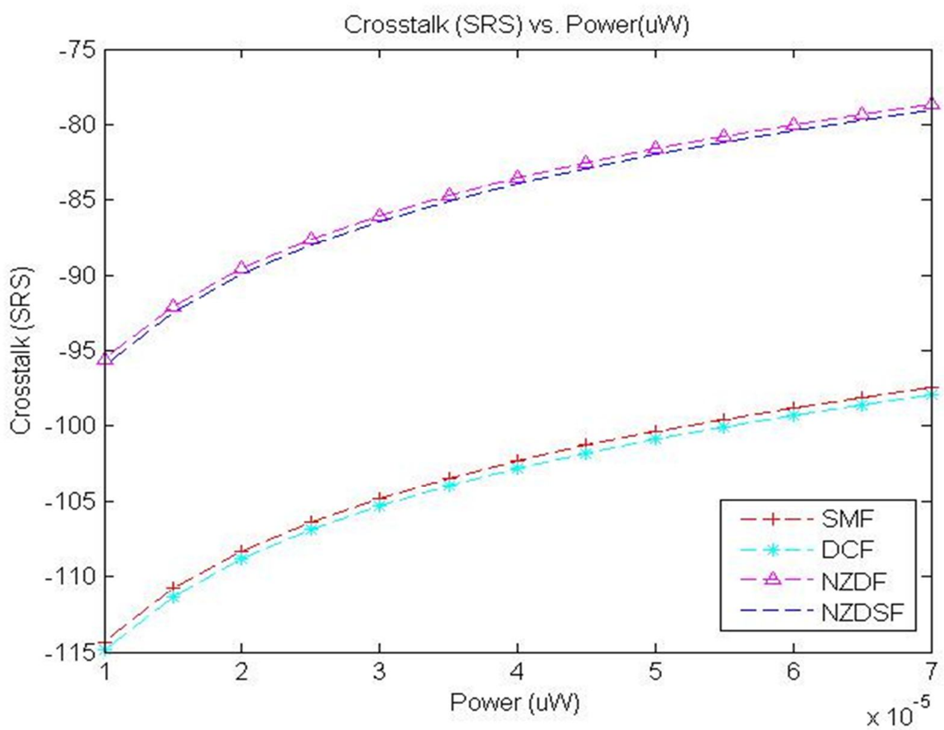



(iv)




(v)

Fig 3.1(a) Crosstalk( SRS) vs modulation frequencies (i) SMF (ii) DCF, (iii) NZDF, (iv) NZDSF, (v) Crosstalk vs Power for different optical fibers.

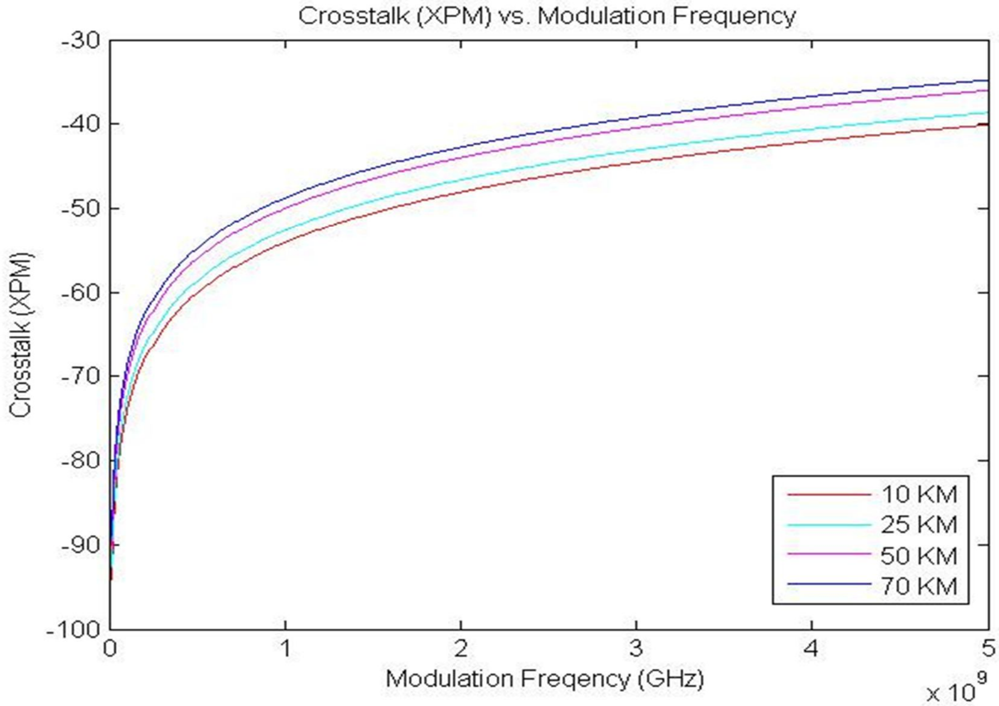
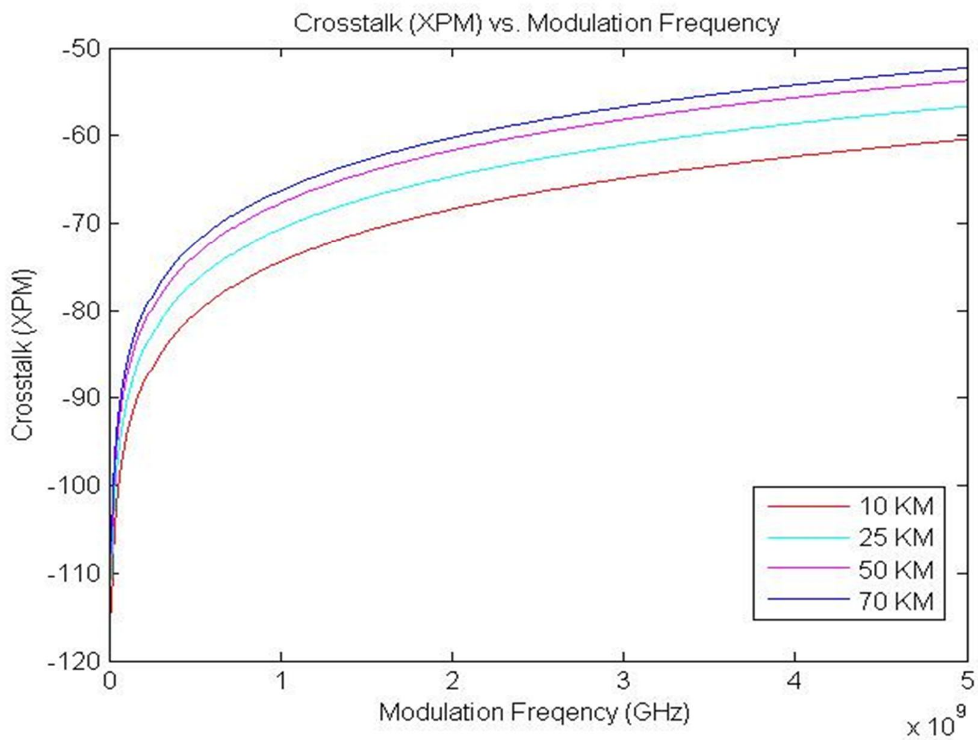
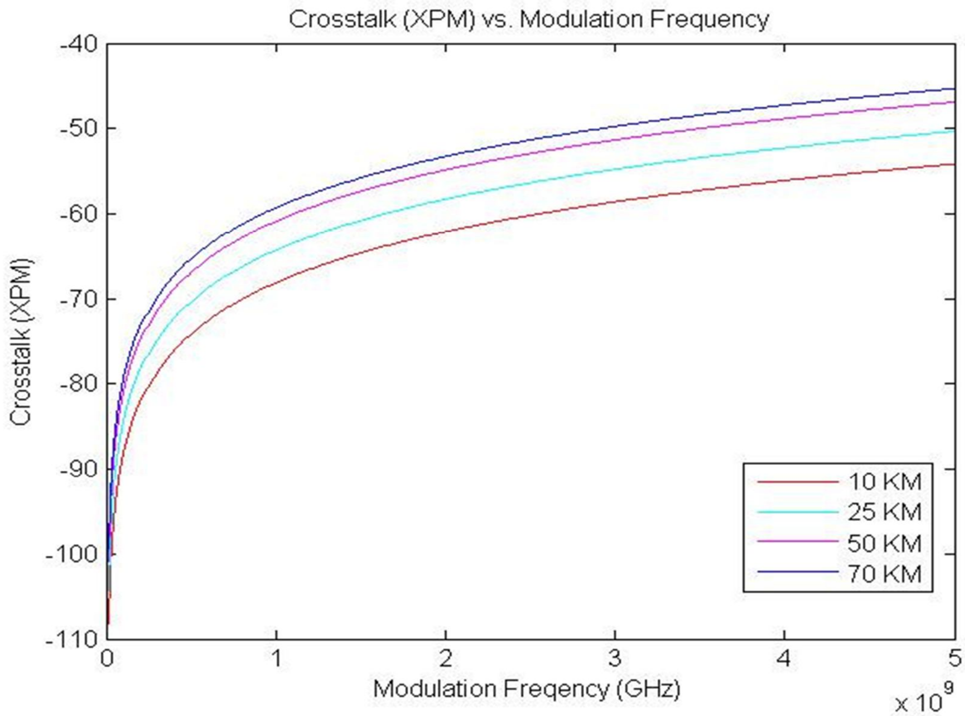

Crosstalk (XPM) vs. Modulation Frequency
-30
-40
-50
-60
-70
-80
-90
-100
Crosstalk (XPM)
0
1
2
3
4
5
Modulation Freqency (GHz)
x 10^9
10 KM
25 KM
50 KM
70 KM

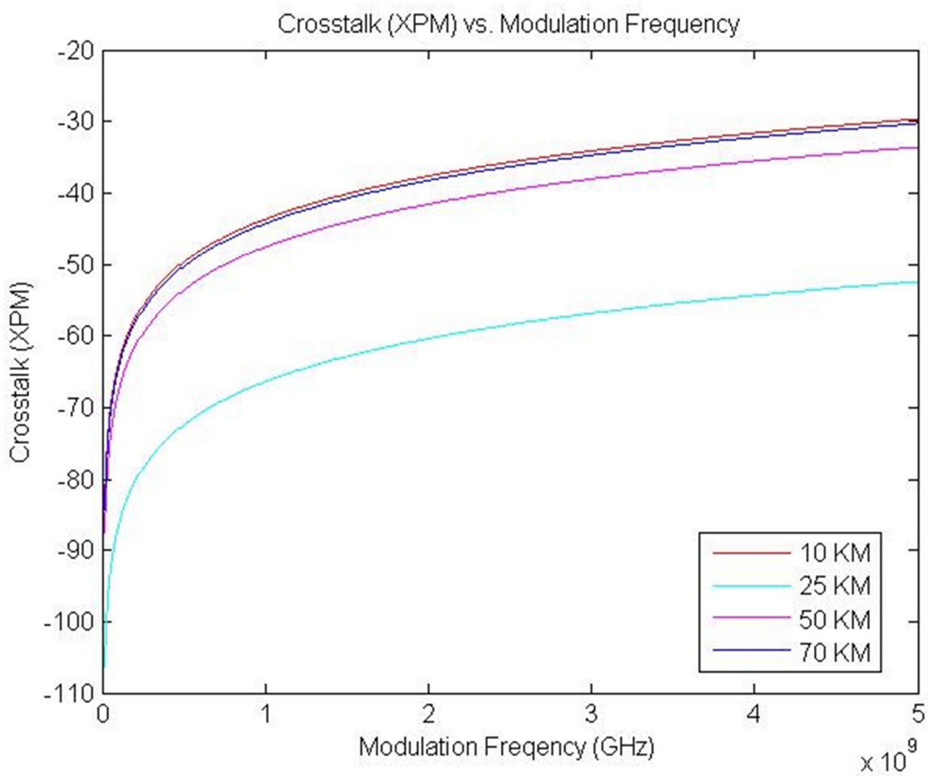
Fig 3.1 b (i)


Crosstalk (XPM) vs. Modulation Frequency
-50
-60
-70
-80
-90
-100
-110
-120
Crosstalk (XPM)
0
1
2
3
4
5
Modulation Freqency (GHz)
x 10^9
10 KM
25 KM
50 KM
70 KM

(ii)




(iii)




(iv)

Fig 3.1(b) Crosstalk( XPM) vs modulation frequencies (i) SMF (ii) DCF, (iii) NZDF, (iv) NZDSF

It shows the graph between SRS and XPM induced crosstalk with transmission length with varied fiber parameters. The transmission length has been varied in a range of 0 to 70 Km and it has been observed that the SRS induced crosstalk increases with the increase in length at constant modulation frequency.

## III. CONCLUSION

In this paper the impact of SRS induced crosstalk in an optical fiber communication transmission system for different types of optical fibers, modulation frequency, optical power and transmission length. It has been shown in the results that the crosstalk due to SRS increases with increase of transmission length and decreases with the increase in modulation frequency and optical power. By the above results the optical fiber communication transmission system can be optimized to select the minimum value of crosstalk in a given range of modulation frequency, transmission length and type of fiber used. Initially the crosstalk remains high and then it decreases with increase in modulation frequency. Out of four different types of fiber standards SMF and DCF have minimum crosstalk as (-61 to -74), (-46 to -79) in comparision with [10] and NZDSF had the maximum crosstalk of (-47 to -57). It has been shown in the results that the crosstalk due to SRS increases with increase of transmission length and decreases with the increase in modulation frequency and optical power. Crosstalk due to XPM in presence of higher order dispersion increases with increase in modulation frequency and transmission length. By the above results the optical fiber communication transmission system can be optimized to select the minimum value of crosstalk in a given range of modulation frequency, optical power, transmission length and type of fiber used.

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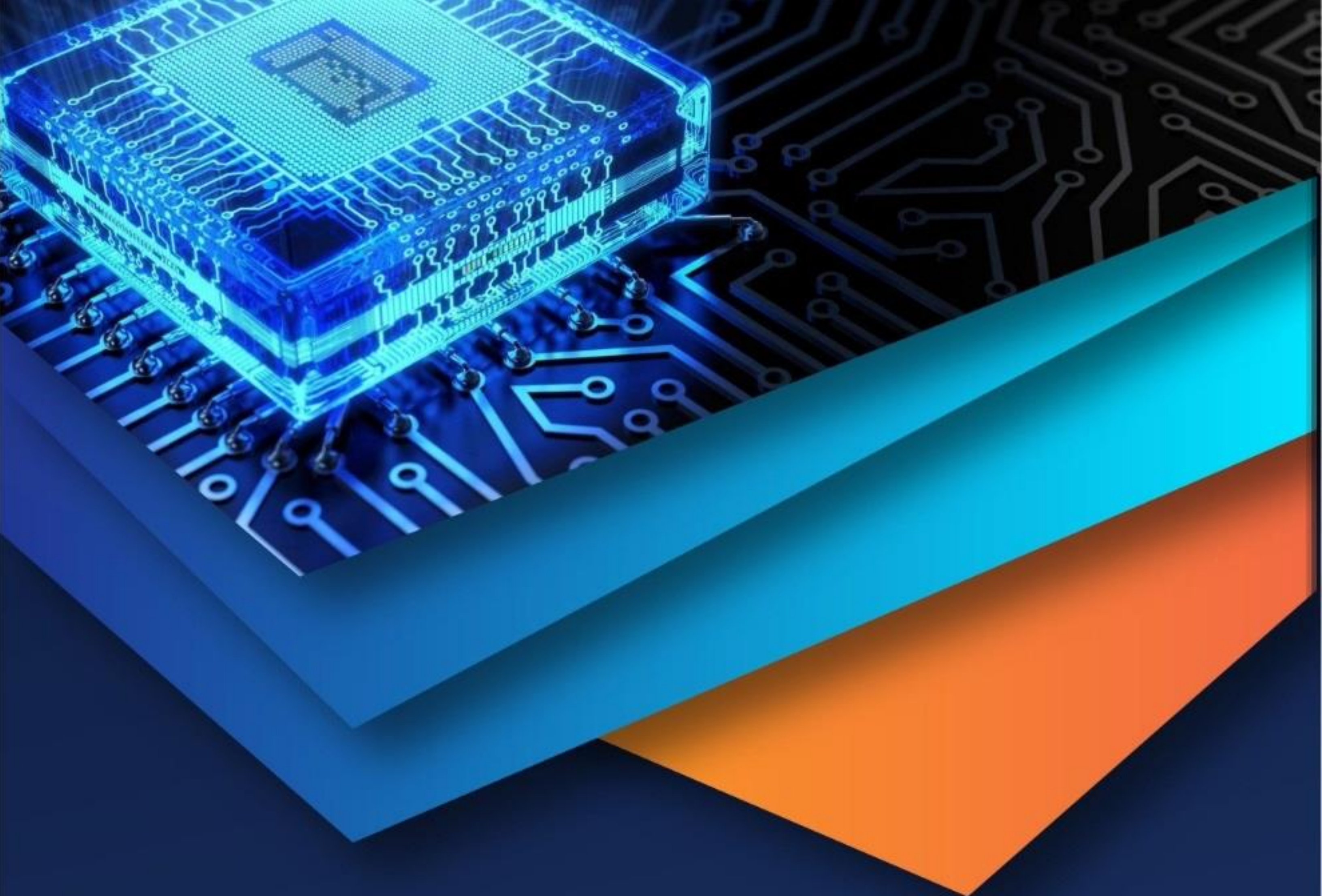


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