PRELIMINARY REPORT

VERSION 1.0

Broadband Analog Fiber Optic Link Performance

– A MATLAB Simulation

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Abstract

This report is to present the results of Broadband Analog Fiber Optic Link simulation done to study the various performance parameters of the link designed for GMRT Upgrade using various commercial Lasers used for digital application and lasers used for wireless application. The digital laser is of DWDM application and the analog laser is for CWDM application. The simulation results of DWDM laser are compared with the measured results to validate the simulation method.

Introduction

The broadband analog fiber optic link is designed to upgrade the existing GMRT links connecting 30 remote antennas bringing in the astronomy signals. The link design is optimized for better performance and cost effective. The objective of this work is to simulate the designed link and compare the performance with the measured results.

Performance parameters of analog fiber optic link

Link Gain

The link gain G_{link} is expressed as in equation 1, where η_l be slope efficiency of laser, R be the responsivity of the photodiode and α be the optical loss in ratio. [1]

$$G_{link} = \left(\frac{\eta_l \alpha R}{2}\right)^2 \qquad (1)$$

The link gain is also called as conversion loss of the link which results when you convert an electrical signal to optical at Laser transmitter and convert the modulated optical signal to electrical signal at photodiode receiver.

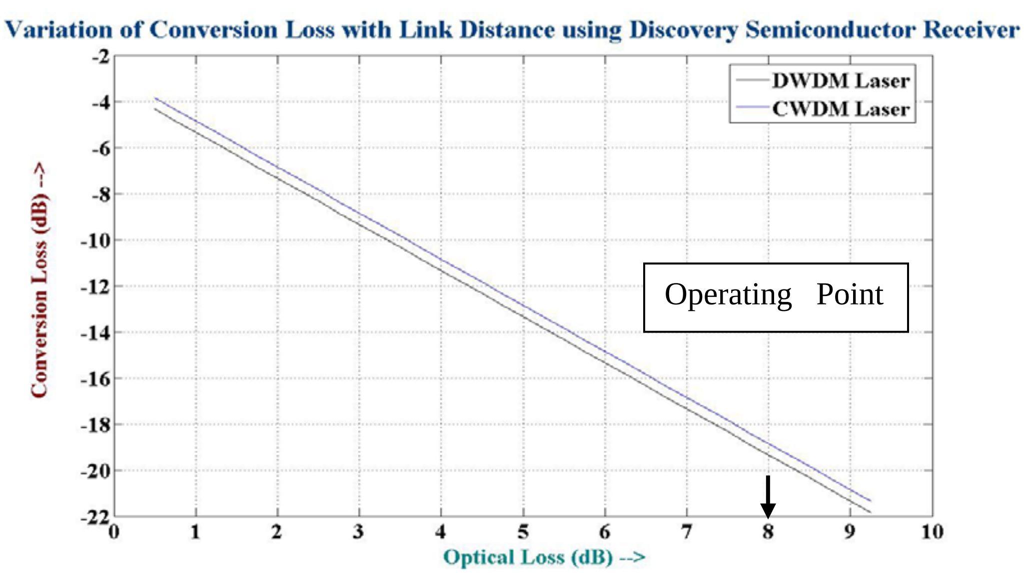

Fig. 1: Conversion Loss Variation

Noise Figure

Noise Figure of the link is obtained from the total noise generated in the analog fiber optic link. The link noise consists of Laser Noise, shot noise and thermal noise of the receiver. The Laser noise is estimated from the RIN_{Laser} (Relative Intensity Noise) of the laser used in the design. Laser noise power is expressed in equation 2 where R_l be the load resistance at the receiver photodiode and I_{Ph} be the bias current I_{Bias} above threshold I_{Th} .

$$P_{Laser} = RIN_{Laser} \left(\frac{I_{Ph}}{2}\right)^2 R_l \quad (2)$$

$$\text{where } I_{Ph} = (I_{Bias} - I_{Th})\eta_l R\alpha$$

The shot noise of the link is obtained from equation 3, where e be the electronic charge, Δf be the bandwidth and I be the average current. The resulting noise power P_{shot} generated by this noise current is given by equation 4, where I_d be the dark current of photodiode.

$$\sigma_i = \sqrt{2eI\Delta f} \quad (3)$$

$$P_{shot} = 2e\left(\frac{I_{Ph} + I_d}{2}\right)R_l \quad (4)$$

Thermal Noise power spectral density can be obtained from equation 5, where k is Boltzmann Constant, T_0 is absolute temperature of the resistor, F is the noise figure of the receiver and R_1 be resistor used.

$$\sigma^2 = \frac{4kT_0F}{R_1} \quad (5)$$

In a circuit, it is generated in the load as given in equation 6 provided maximum power transfer occurs.

$$P_{Thermal} = kT_0 \quad (6)$$

The total noise power is given by the summation of three noise powers, i.e., laser noise, shot noise and thermal noise, as given by equation 7.

$$P_{n,Total} = P_{Laser} + P_{shot} + P_{Thermal} \quad (7)$$

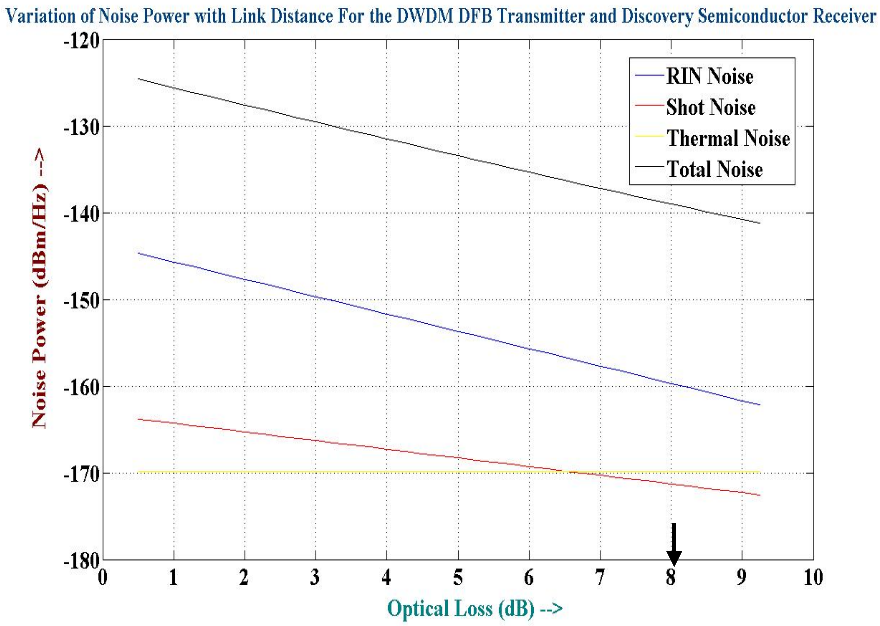

Fig. 2(a): Noise Power Variation for DWDM

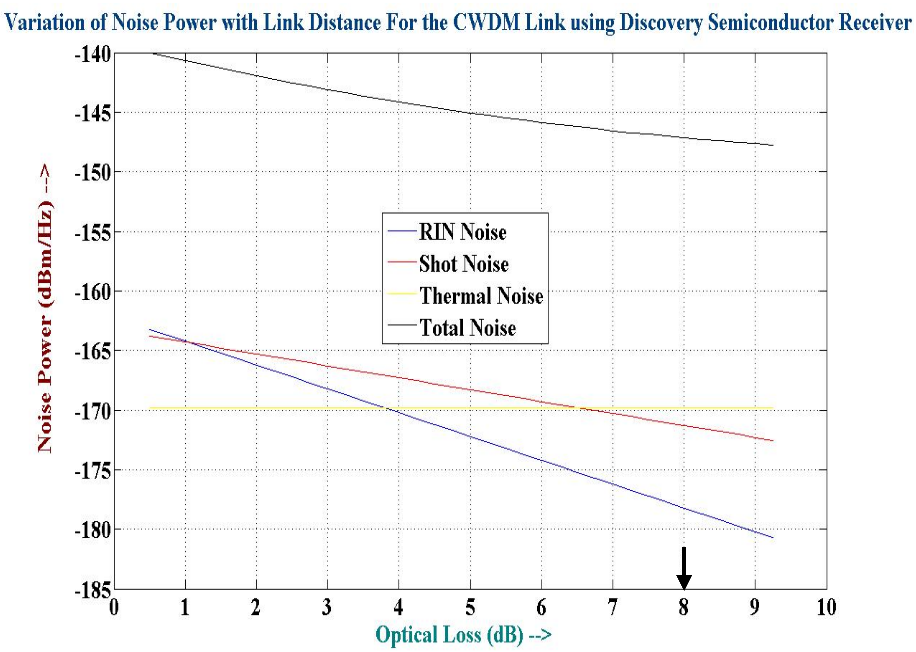

Fig. 2(b): Noise Power Variation for CWDM

Equivalent Input Noise (EIN) is given by equation 8.

$$EIN_{link} = \frac{P_{n,Total}}{G_{link}} \tag{8}$$

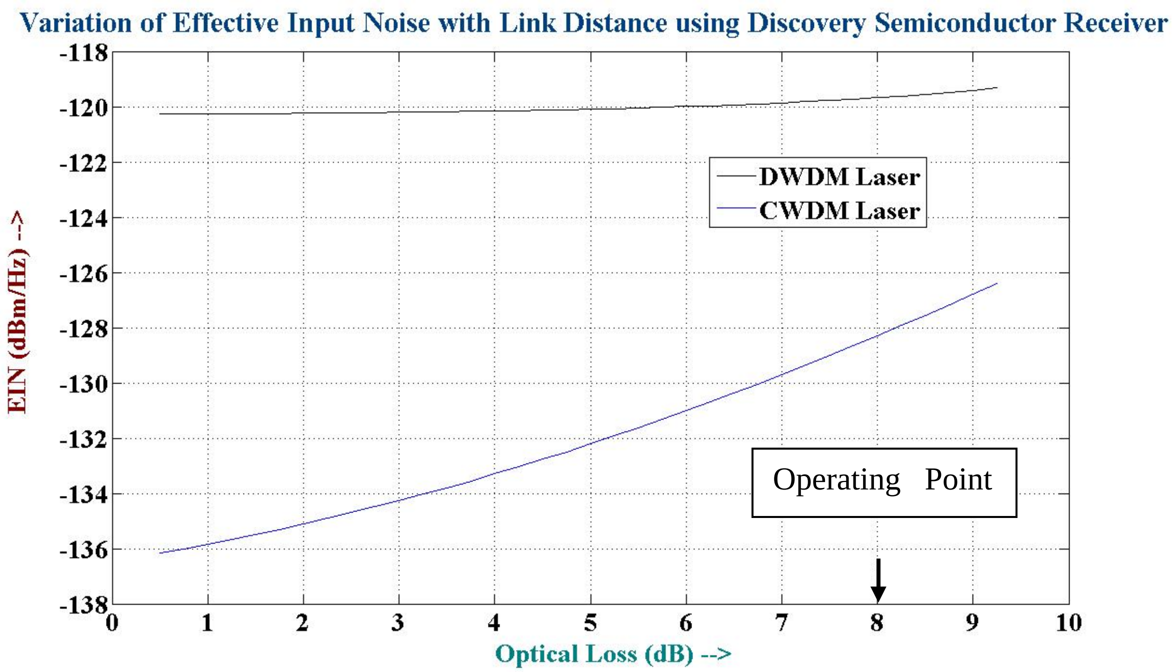

Fig.3: EIN Variation

The noise figure in dB in terms of EIN can be defined as in equation 9, [1] where EIN_{link} is expressed in $dBmHz^{-1}$.

$$NF_{link} = EIN(dBmHz^{-1}) + 174 \tag{9}$$

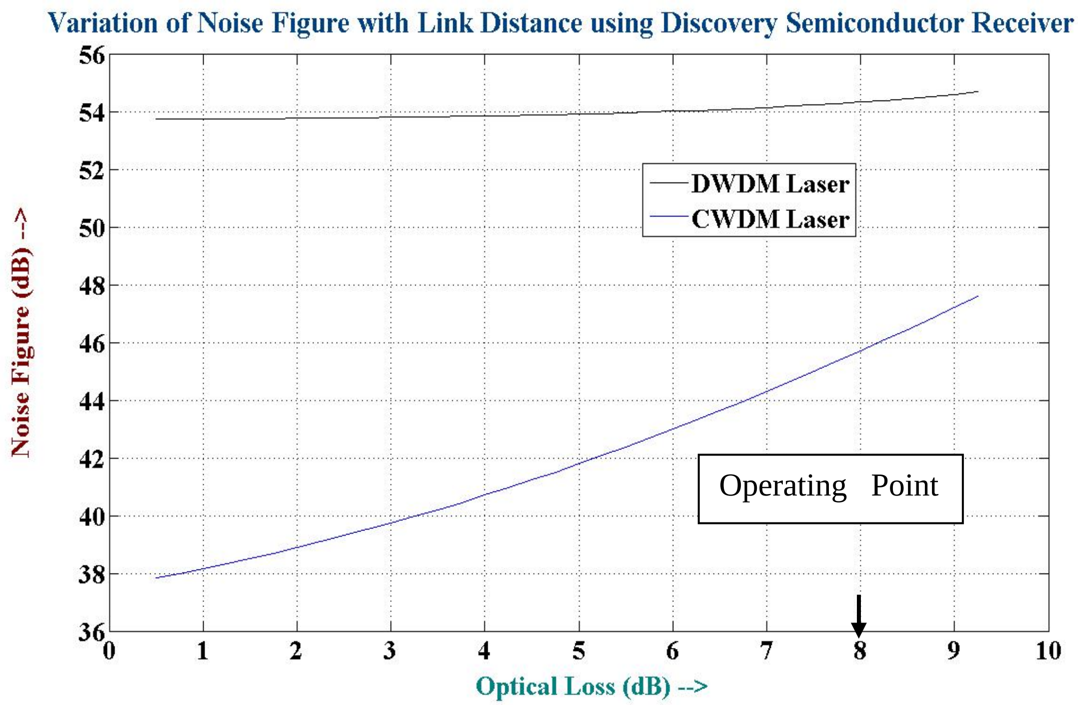

Fig. 4: Noise Figure Variation

SNR Performance

With the assumption that the input RF power is 0 dBm, the link output power will be equal to the conversion loss in comparison with the noise power of the link, the SNR is obtained per unit bandwidth.

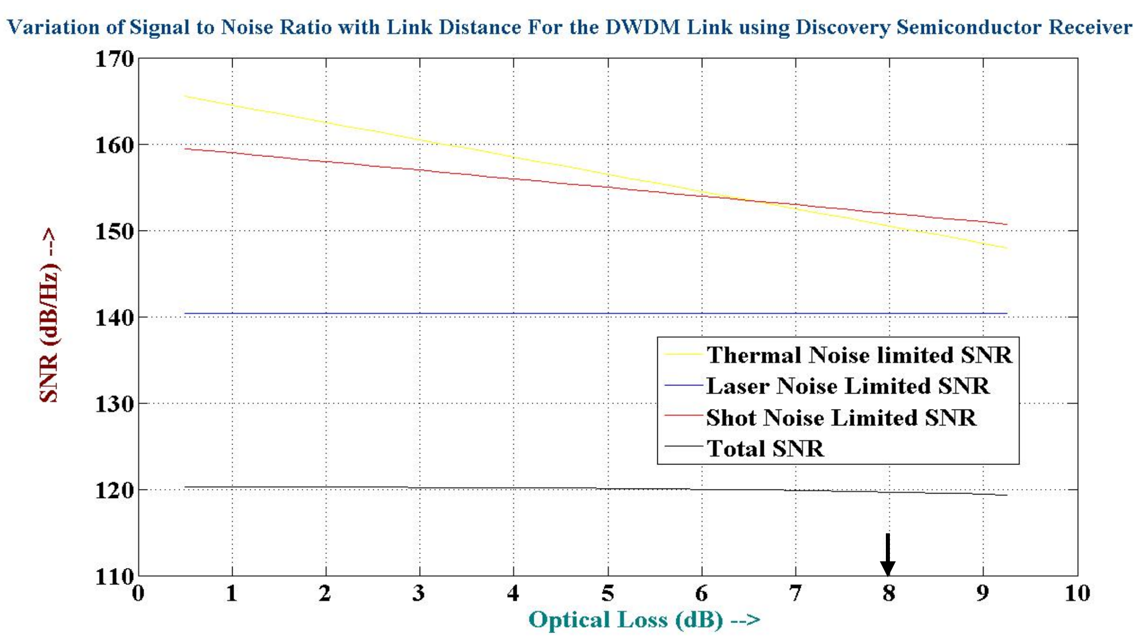

Fig. 5(a): SNR Variation for DWDM

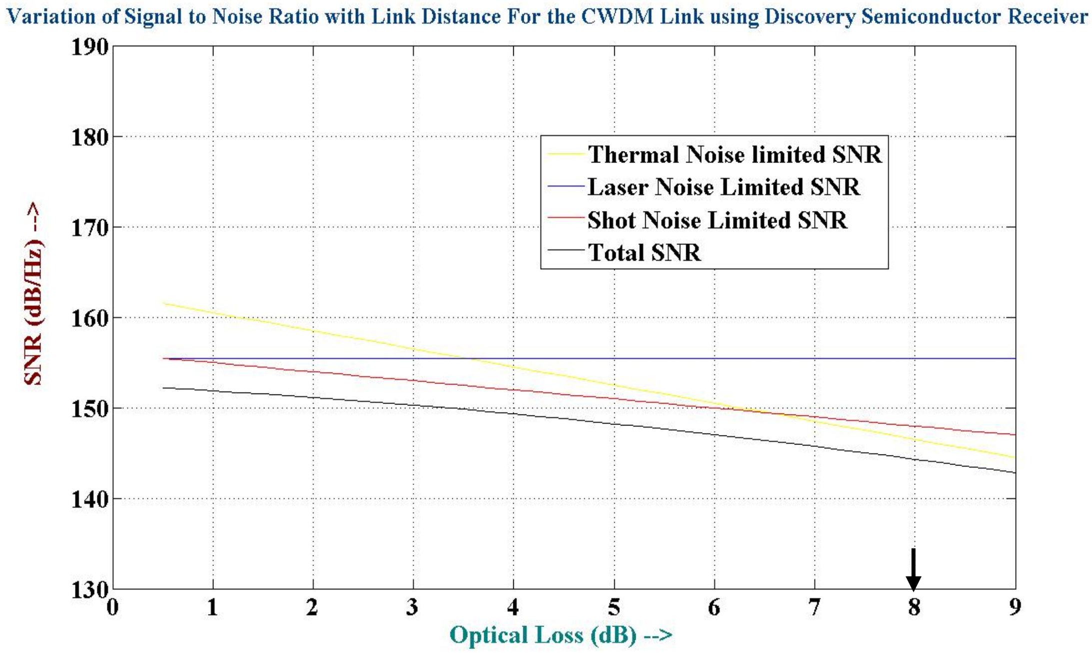

Fig. 5(b): SNR Variation for CWDM

SFDR Performance

SFDR and input third-order intercept point are related as given by equation 10, where IP_3 is the third order intercept point and NF_{total} be the noise figure in dB and SFDR is calculated in a bandwidth of 1-Hz [2].

$$SFDR = \frac{2}{3}(IP_3 + 174 - NF_{total}) \tag{10}$$

If I_{rms} be the rms value of the peak-to-peak current I_{peak}, which is flowing through the resistance R, then the maximum power $P_{\max}$ used can be calculated from equation 11. These sets up the third-order intercept point, which is normally 10 dB above the maximum power level for a linear operation. The corresponding logarithmic value is the third-order intercept point in dBm, as shown in equation 14.

$$P_{\max} = I_{rms}^2 R = (\frac{I_{peak}}{\sqrt{2}})^2 R \tag{11}$$

Note: $P_{\max}$ should be in mW for validity of equation 12

$$IIP_3 = 10\log_{10}(P_{\max}) + 10 \tag{12}$$

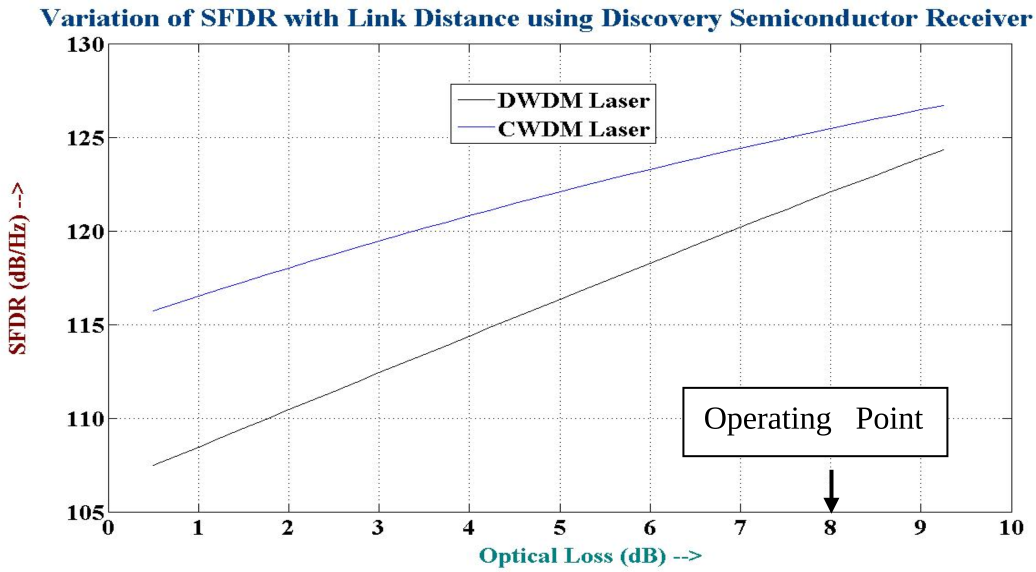

Fig. 6: SFDR Variation

Minimum Input Power Required for output SNR of 20 dB over 400 MHz Bandwidth

From the total noise power level computed from equation 7, the noise power at different frequencies can be calculated from equation 13, where $P_{n,BW}$ be the signal power in dBm at frequency BW and the minimum input power $P_{\min}$ can be determined from equation 14 for the link to have a 20 dB SNR.

$$P_{n,BW} = P_{n,Total} + 10\log_{10}(BW) \quad (13)$$

$$P_{\min} = P_{n,BW} + 20 + G_{Link} \quad (14)$$

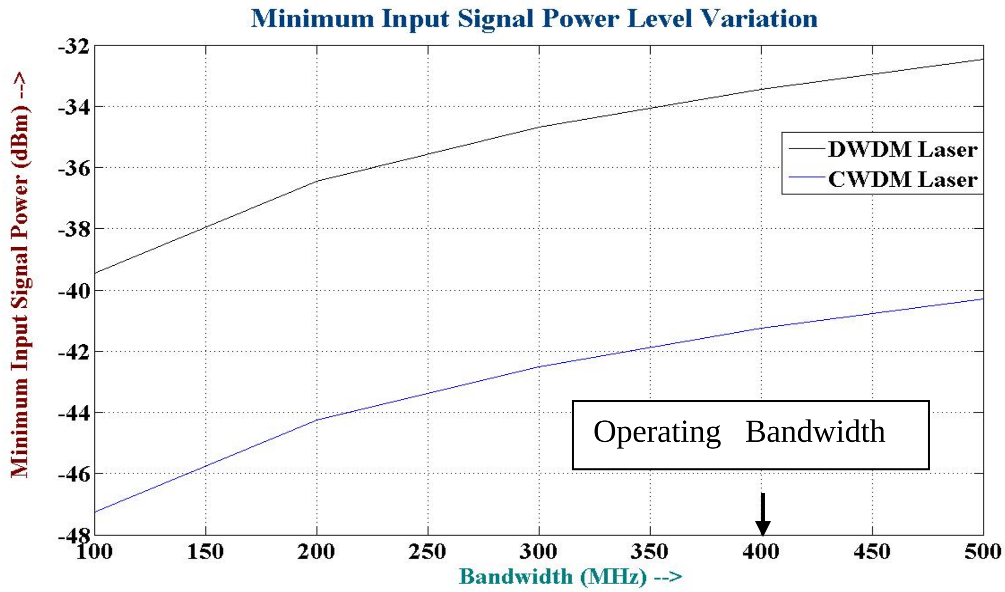

Fig. 7: Minimum Input Power Strength Variation

Comparison between simulated and measured data for DWDM-based link

The SNR obtained from the simulations using MATLAB and the experimental data using DWDM link installed at C-11 antenna has been studied and plotted.

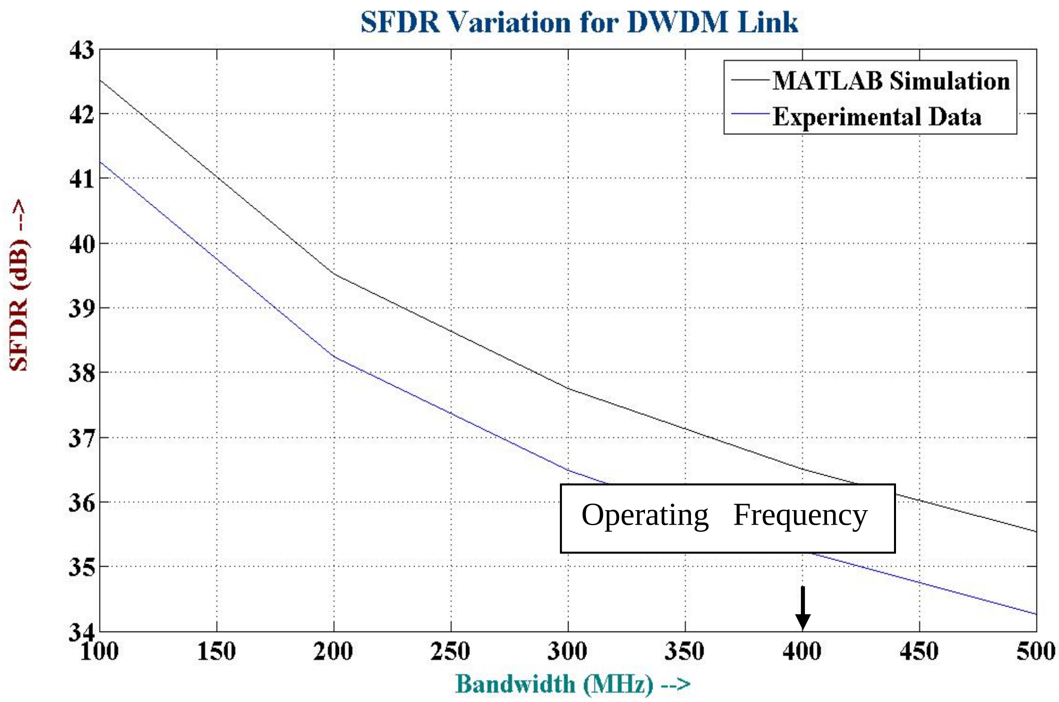

Fig. 8: SFDR Comparison with Frequency

Link with high dynamic range amplifier

If there are n no. of amplifiers in a link of gains G_1, G_2, G_3,G_n respectively and the noise figures of the stages are F_1, F_2, F_3, ..F_n respectively and of noise equivalent temperatures T_1, T_2, T_3,T_n respectively, then the equivalent noise figure F_{eq} and the equivalent noise temperature T_{eq} are given as in equations 15 and 16 respectively.

$$F_{eq} = 10\log(F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + ... + \frac{F_n - 1}{G_1 G_2 ......G_{n-1}}) \quad (15)$$

$$T_{eq} = T_1 + \frac{T_2}{G_1} + \frac{T_3}{G_1 G_2} + ... + \frac{T_n}{G_1 G_2 ......G_{n-1}}) \quad (16)$$

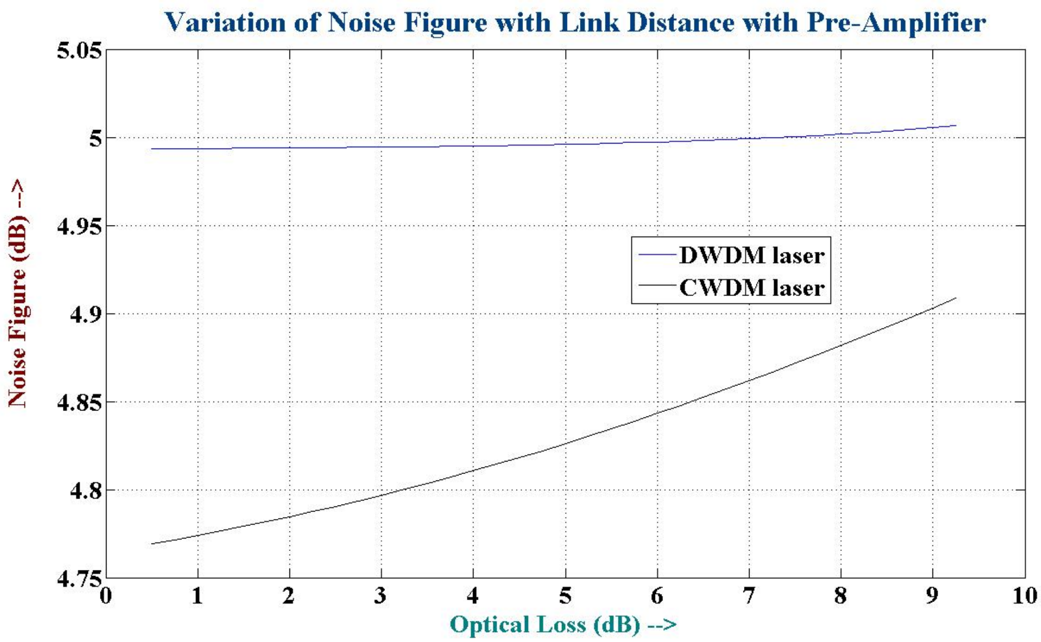

Fig. 9: Noise Figure Variation with Pre-Amplifier

Fig. 10: Minimum RF Input Power with Pre-Amplifier

Conclusion

In CWDM-based system, the Relative Intensity Noise is lower leading to lower laser noise than the DWDM-based system. CWDM system gives a 15 dB improvement in SNR performance when compared with DWDM system. For a bandwidth of 400 MHz, the DWDM based system requires a minimum input power of -33 dBm for 20 dB SNR at output whereas the CWDM system requires only -41 dBm. The dynamic range of CWDM is 10 dB higher than the DWDM based system. The noise figure of CWDM system with pre-amplifier is lower by 0.1 to 0.2 dB than the DWDM system. An input RF power of nearly -61 dBm at the input of the pre-amplifier will provide a signal-to-noise ratio of 20 dB at the output of the receiver system which is nearly 8 dB lower than the corresponding DWDM system to have the same amount of signal-to-noise ratio at output.

REFERENCES

[1] Sureshkumar, S., "A low cost short reach analog fiber optic link for EMBRACE", *Netherlands Foundation for Research in Astronomy, ASTRON*, pp. 1-18, October, 2004.

[2] Bhattacharyya, S., Sureshkumar, S., and Paul, A., "Performance, Analysis and Implementation of Analog Broadband Link for GMRT", *M.Tech Dissertation*, pp. 69-74, 2008.

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