

Application Note:

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Impact of Transmitter RIN on Optical Link Performance

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1 Overview

Semiconductor laser relative intensity noise (RIN) is an important parameter that, under certain circumstances, can cause a significant degradation on the performance of a fiber optic communications link. The output of a laser can fluctuate in both intensity and phase even when all operating conditions such as bias, optical reflections and temperature are maintained as a constant. The fluctuations in laser intensity result in the generation of RIN. Because the RIN is a noise associated with the transmitter source and not the receiver, RIN will limit the maximum Signal to Noise Ratio (SNR) achievable in a fiber optic link. RIN is broadband in nature with the upper frequency cutoff dependent on the response time of the laser under consideration. The goal in specifying and designing fiber optic links is to make certain the RIN contribution does not significantly degrade the link performance when compared to parameters such as receiver thermal noise.

This application note presents a brief overview of how RIN impacts the sensitivity of a fiber optic link followed by a summary of how RIN may be measured as outlined in the Fibre Channel standard. An alternate method is then presented in which RIN is measured in the time domain using a high speed sampling oscilloscope. There are specific advantages to performing RIN measurements in the time domain not achievable when employing a broadband power meter.

2 Estimating the RIN Penalty

An estimate of the RIN induced noise ratio from a DC biased but unmodulated laser appearing at the output of the receiver photodetector can be computed from the following expression:

$$\sigma = \sqrt{BW \times 10^{\frac{RIN}{10}}} \quad (1)$$

Where

BW is the receiver measurement bandwidth (Hz)

σ is the noise ratio (dimensionless)

RIN is expressed in dB/Hz and is a negative number. The above equation assumes RIN noise spectrum is constant over the frequency range specified by BW. There are more accurate expressions for computing the noise power resulting from RIN¹ but expression (1) is considered adequate for demonstration here. Figure 1 contains an example of what a RIN spectral plot might resemble for a high speed laser biased at a constant output power. The shape of the RIN curve is heavily dependent upon the operating point and speed of the laser. A Peak in the RIN curve is characteristic of semiconductor lasers. At lower output powers, the RIN peak decreases in frequency and increases in magnitude.

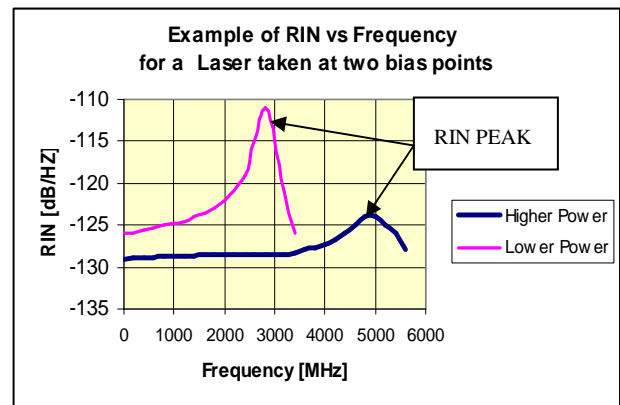


Figure 1: RIN spectral density

The degradation in link performance is a function of the desired SNR for a given bit error rate (BER) combined with the absolute level of RIN integrated over the receiver bandwidth in (1). The desired SNR can be specified in terms of the Q factor^{2, 3}. Q can be expressed by the following formula:

$$Q = \frac{(I_{\text{one}} - I_{\text{zero}})}{(\sigma_{\text{one}} + \sigma_{\text{zero}})} \quad (2)$$

Where

I_{one} and I_{zero} are the photo currents corresponding to the logic one and logic zero optical power levels. (amps)

σ_{one} and σ_{zero} are the corresponding rms noise currents (amps)

To establish a BER of 10^{-12} requires a Q of about 7. A RIN power penalty (Prin) in dB can be expressed in terms of the Q factor and RIN noise computed from (1)¹.

$$\text{Prin} = 10 \times \log \left(\frac{1}{\sqrt{1 - (Q \times \sigma)^2}} \right) \quad (3)$$

For example, given a RIN of -118 dB/Hz a Q factor of 7 and a receiver Bandwidth of 3 GHz, first computing the noise ratio σ using (1) we obtain a value of 0.069. Substituting this into (3) results in a power penalty of 0.58 dB which is the amount the transmit power must be increased to compensate for the presence of the RIN.

Equation (3) shows the nonlinear relationship between RIN and power penalty. Increasing the RIN by just a few dB can significantly increase power penalty. This effect is best observed visually in the series of BER curves plotted in Figure 2. In the example, 5 BER curves are shown. The leftmost curve is typical of what a BER curve might resemble with an ideal RIN free optical Transmitter connected to an optical Receiver through an adjustable attenuator. The four remaining curves show the effect of increasing RIN on the shape of the BER response. If the RIN component becomes large

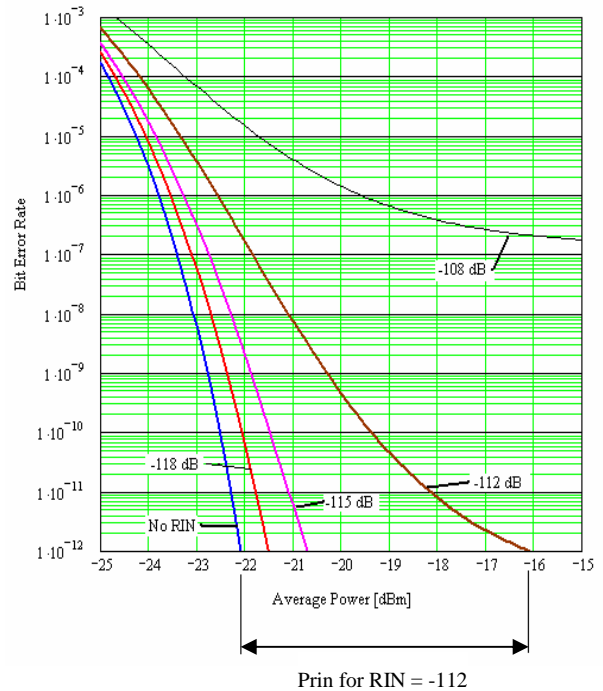


Figure 2: BER curves for various levels of RIN

enough, an error floor can result. The power penalty expressed in (3) is the difference in optical power between the leftmost reference curve, and the curve at the desired RIN value measured at a BER of 10^{-12} . As seen in Figure 2, the RIN penalty increases with decreasing BER (increasing Q).

The curves presented in Figure 2 assume that the laser is fully modulated. In order to achieve good eye quality in high speed optical transmitters, designers prefer to operate the laser at a reduced modulation amplitude. By reducing the optical modulation amplitude (OMA) while maintaining the same average power, the laser dynamic response characteristics such as edge speed and overall transmit eye quality generally improve. The Fibre Channel specification is specifically written to permit lasers to be operated at reduced modulation (reduced extinction ratio)⁴. Instead of specifying minimum average power and extinction ratio, a specification is only given for the minimum amount of transmit OMA. This is illustrated in Figure 3 and gives the designer freedom to select the optimum extinction ratio for best transmit eye quality. However, transmit RIN plays an important factor in determining how low an extinction ratio can be used.

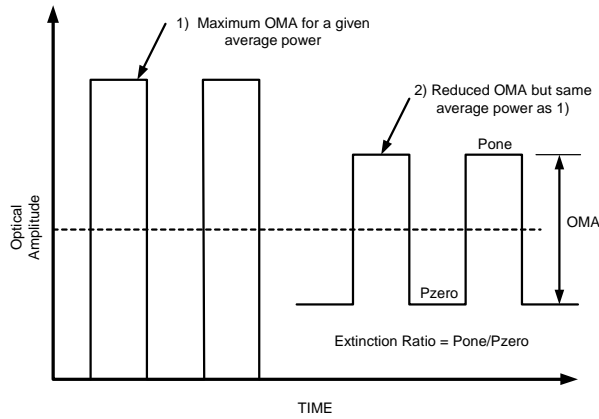


Figure 3: sketch showing full and reduced modulation

Figure 4 illustrates the impact of RIN on BER performance when the same laser employed in Figure 2 is operated at a reduced extinction ratio. Since the Extinction Ratio is less, the required average power for a given BER is higher as seen in the left most curve. But as RIN is increased in the same steps as figure 2, an error floor is reached at a lower RIN value.

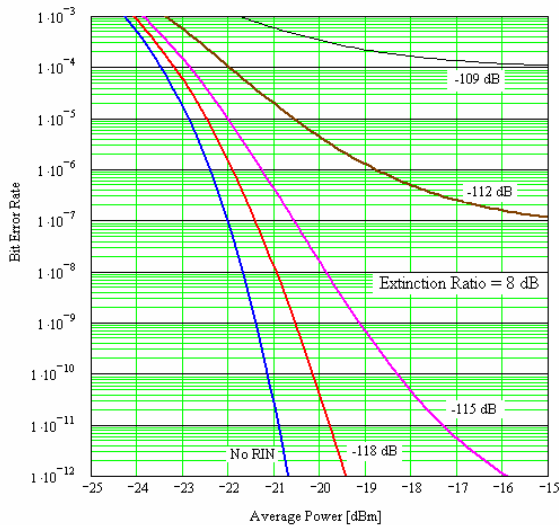


Figure 4: BER curves for same laser in Fig 2 but with Reduced Extinction Ratio.

To permit the operation of optical sources at levels other than full modulation, but not experience the added RIN degradation in Figure 4, the Fiber Channel standard and 10 Gigabit Ethernet adopted a more challenging specification for transmitter RIN identified as RIN(OMA). This requires that

transmitter RIN ratio be computed using the same rms modulation amplitude of the laser instead of an average DC level. RIN(OMA) is computed from the following expression:

$$RIN_{12}(OMA) = 10 \times \log \left(\frac{P_n}{BW \times P_m} \right) \quad (4)$$

Where:

RIN(OMA) is the relative intensity noise referred to optical modulation amplitude (dB/Hz)

P_n is the electrical noise power with laser modulation turned off (watts)

P_m is the electrical Noise power with laser modulation turned on (watts)

BW is the noise bandwidth of measuring system. (Hz).

The expression shows that as one attempts to reduce the extinction ratio of the laser by decreasing the modulation, the value of P_m will decrease proportionally resulting in a higher value of RIN (OMA).

3 Measuring RIN

A setup for measuring RIN is shown in Figure 5. It contains the transmitter under test, optical splitter, attenuator, polarization rotator, gold plated fiber tip plus the Optical to Electrical converter O/E and measuring equipment. The optical splitter permits the laser output to be monitored with the measurement equipment, while at the same time generating a controlled amount of reflection from the gold plated fiber back to the laser. Various link physical interface standards such as Fibre Channel, require that a portion of the light transmitted in the forward direction be reflected back towards the laser. This is to insure the transmitter RIN is being characterized under a more stressful, but realistic, link condition. Reflections can significantly degrade laser RIN performance as a portion of the light can couple back through the optics and into the laser die itself. This can create instabilities that appear RIN like in nature and increase the effective noise output of the laser. The potential exists in fiber optic links for back reflections to be

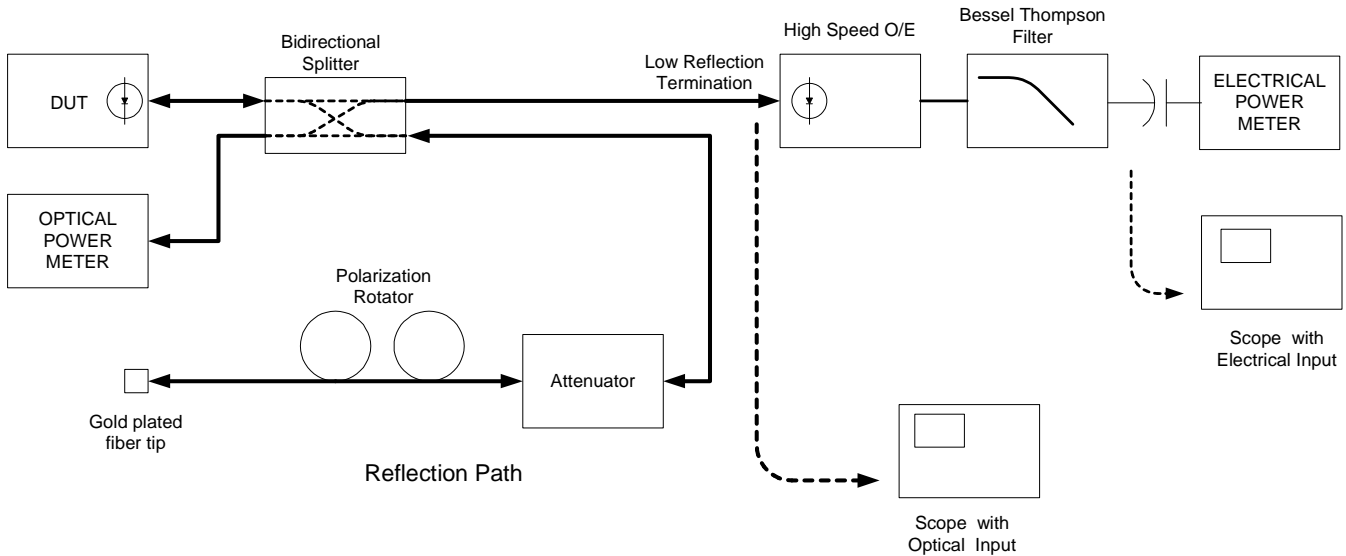


Figure 5. Set Up for measuring $RIN_{12}(OMA)$

present. The typical amount of back reflection specified is 12 dB from a single reflective plane. The RIN specification including back reflection is termed $RIN_{12}(OMA)$.

The optical attenuator is present to control the absolute level of reflected light from the plated fiber end and establish the 12 dB level. The insertion loss of the optical splitter is factored in when setting the 12 dB back reflection. A polarization rotator is used (in single mode applications) to adjust the polarization that produces the highest amount of RIN for a given back reflection power. The RIN measurement can be accomplished in one of three ways.

- 1) O/E converter with low pass filter and power meter (frequency domain approach)
- 2) O/E converter with low pass filter and oscilloscope with statistical measurement capability. (time domain approach)
- 3) O/E plug-in plus scope mainframe with statistical measurement capability. (time domain approach)

The optical power meter in the left of Figure 5 is used to monitor the back reflection so the correct

level can be set using the adjustable attenuator. The low pass Bessel Thompson (BT) filter is used to establish the desired noise measurement bandwidth. It is based on the bit rate of the application. A filter should be selected with 3 dB bandwidth equal to 0.75 times the maximum bit rate. The electrical power meter reads true rms (root mean square) and has a measurement bandwidth that exceeds that of the BT filter. The frequency domain approach (1) of measuring $RIN(OMA)$ with a broadband electrical power meter has the disadvantage that the transmit data must be disabled in order to measure the laser noise with no modulation present. This is not possible because in some optical modules removing the data from an AC coupled transmitter electrical input can sometimes result in an undefined optical output. In a situation such as this an alternate (time domain) approach (2) or (3) can be used. Time domain measurements also have the advantage that the RIN level can be observed at various points in the data sequence at the actual operating conditions of the laser. The RIN noise statistics can also be studied using the software available on most communication analyzers.

Figure 6 shows a time domain waveform obtained using an external O/E connected to an oscilloscope electrical input. In this example, a longwave multimode laser is connected to a Maxim laser driver and a 1.25 Gbps K28.5 test pattern applied.

In this figure no reflection has been induced. The data pattern appears relatively noise free. The Fiber Channel standard recommends a K28.7 pattern for this test but a K28.5 may also be used with certain conditions. More details on using k28.5 idle test patterns can be found in the reference⁴.

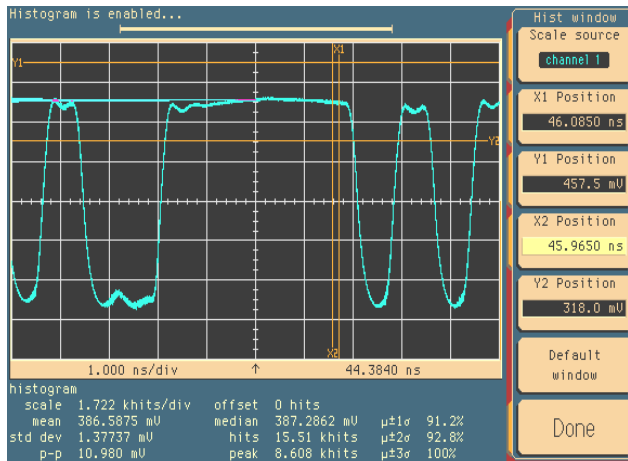


Figure 6. Transmit waveform with no back reflection present

Figure 7 shows the same test pattern in Figure 6 with a back reflection present. There is a larger amount of noise present on the optical signal than there is with

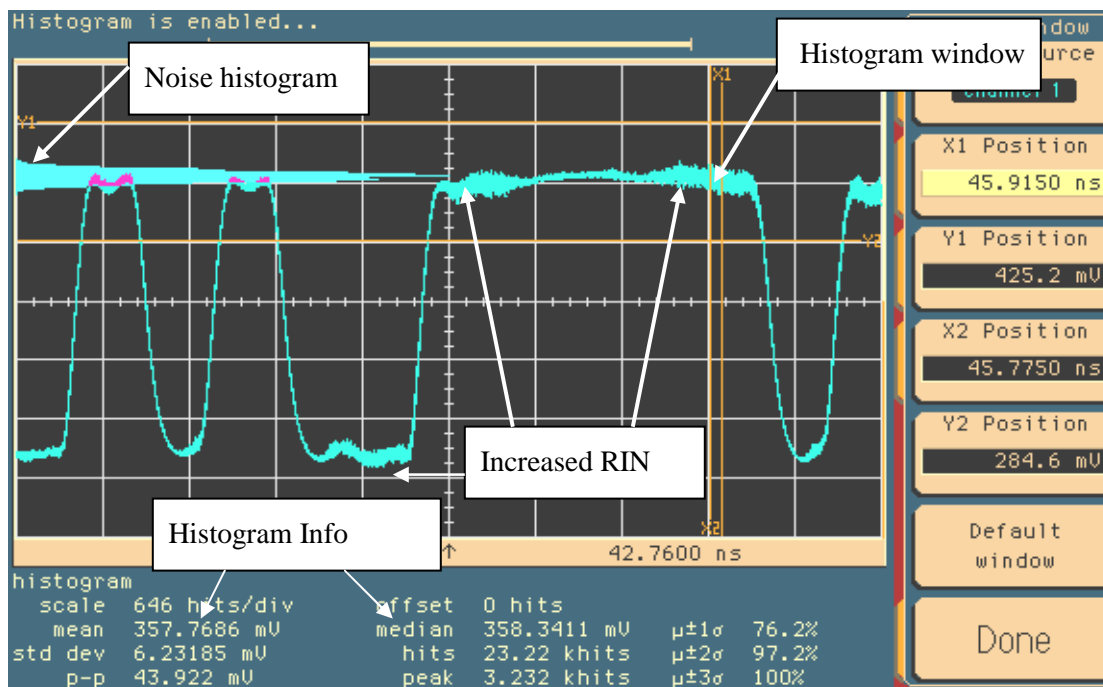


Figure 7. Transmit waveform with back reflection present. Since the transmitter is driven with a pattern and not a constant DC light level, the noise level also appears pattern like in nature.

no back reflection present. Also interesting to observe is that the noise only appears at certain points within the sequence. This is caused by the round trip time delay from transmitter source to reflection surface and back to source. When the laser is in the off or low state there is little or no energy present to be reflected back to the laser. When the laser turns on, the light pulse will propagate to the reflecting surface and arrive back at some arbitrary point in time. This gives the appearance of a periodic noise pattern riding on top of the optical signal.

The rms noise level taken in the narrow histogram window can be observed from the data displayed in Figure 7 (std dev) and is 6.23 mV rms. A narrow histogram window is required in the time domain so that the normal pattern ripple is not also included in the rms noise measurement. The histogram is positioned in a location in the data stream where the elevated noise level is present. A small portion of the random noise recorded is generated internally to the O/E and scope and should be subtracted from the 6.23 mV. A separate noise measurement conducted on the O/E and scope with no light presented yielded a value of 0.35 mV rms. Since rms quantities add as the square root of the sum of the squares:

$$V_n = \sqrt{V_t^2 - V_r^2} \quad (5)$$

Where V_n = noise voltage due to optical source

V_t = total noise measured

V_r = noise voltage of O/E and scope

Because V_r is so small the value of V_n is essentially V_t in this example.

Next, the rms value of the OMA needs to be determined. This can also be extracted from the oscilloscope statistics by expanding the histogram window to include multiple repetitions of the complete pattern. The rms value for the above waveform is about 142 mV (a small correction factor may be required per the Fibre Channel standard⁴). The equivalent modulation power expressed in watts is:

$$P_m = \frac{V_m^2}{50} \quad (6)$$

Substituting $V_m = 142$ mV, results in

$$P_m = 403 \text{ uwatts}$$

Noise power is also computed using the same formula (6) by inserting V_n of 6.23 mV rms.

$$P_n = 776 \text{ nwatts}$$

The RIN can then be computed from Equation (4). The noise bandwidth of the O/E used in this measurement was 1.8 GHz which would be appropriate for qualifying this particular laser sample up to 2.5 Gbps. In considering this sample for a 4.2 Gbps application, a wider noise measurement bandwidth would be required.

$$\begin{aligned} \text{RIN}_{12}(\text{OMA}) &= 10 \times \log \left(\frac{776 \times 10^{-9}}{403 \times 10^{-6} \times 1.8 \times 10^9} \right) \\ &= -119.7 \text{ dB/Hz} \end{aligned}$$

To place this number in perspective, the 2 Gbps Fibre Channel specification requires that maximum

RIN not exceed -117 dB/Hz. There is close to 3 dB of margin in this measurement example.

4) CONCLUSIONS

Power penalty due to RIN is a function of the RIN spectral density, link bandwidth plus the operating BER (Q) of the link. The RIN induced noise is generated in the transmitter and not the receiver. Increasing the optical power level at the receiver results in an increase in the relative contribution of RIN (transmitter noise) to receiver thermal noise. This increase in ratio begins to limit the improvement in Signal to Noise ratio at the receiver requiring even more power to overcome this effect. If the RIN level is large enough, it may not be possible to achieve a received optical power in which the BER is below a desired target. To prevent this from occurring, optical standards specify the maximum amount of RIN permitted in a link application.

References:

¹ David C Cunningham, William G Lane, Gigabit Ethernet Networking, Macmillan Technical Publishing, Indianapolis, 1999, pp. 301-336

² Govind P Agrawal, Fiber Optic Communication Systems, Second Edition, 1997, pp 170-172.

³ Maxim Integrated Products Application Note HFAN-9.0.2: Optical SNR and the Q factor; Feb 2002, http://dbserv.maxim-integrated.com/appnotes.cfm/appnote_number/985

⁴ Fibre Channel Physical Interfaces FC PI-2 rev 4.1; American National Standard for Information Technology, March 24, 2004, pp. 83-87.