QUANTIFI PHOTONICS™

RELATIVE INTENSITY NOISE (RIN)

APPLICATION NOTE

Semiconductor laser **Relative Intensity Noise (RIN)** is an important parameter that can cause significant degradation to the performance of fibre optic communications links. It is important for both laser manufacturers and systems designers in understanding how RIN is measured to ensure reliable, accurate and repeatable results.

QP **O2E PXIe** Module

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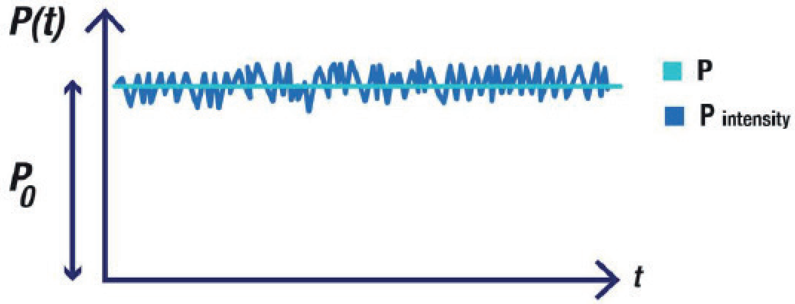
RIN is defined as a measure of the **intensity noise** from the laser, which has an important impact on intensity modulated signals such as NRZ and PAM4 optical modulation formats. The RIN is one contribution to laser linewidth with the other contribution being phase noise. The ideal output intensity of a laser biased at a D.C. level when all the parameters influencing the laser, such as bias, optical reflection and temperature, are assumed to be constant is shown in **Figure 1** and is represented by the light blue line. In practice, the output of a laser can fluctuate in both intensity and phase. The fluctuation in intensity causes a disturbance in the output laser signal as shown in **Figure 1 (Pintensity).**

Figure 1:

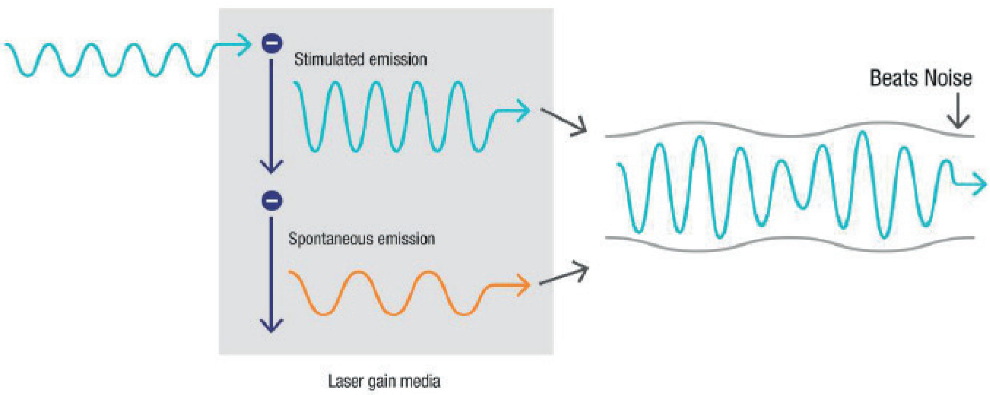
Ideal output power for a laser with DC bias (P), and real laser output power having intensity noise (P intensity)



The laser intensity fluctuation is due primarily to the interference between the stimulated emission and the spontaneous emission from the source. In a direct detection system, these two different frequencies beat since the electric field is squared in the photodetector. The intensity noise of a laser can vary based on the laser design and its properties. **Figure 2** represents an event where the two emissions interfere with each other.

Figure 2:

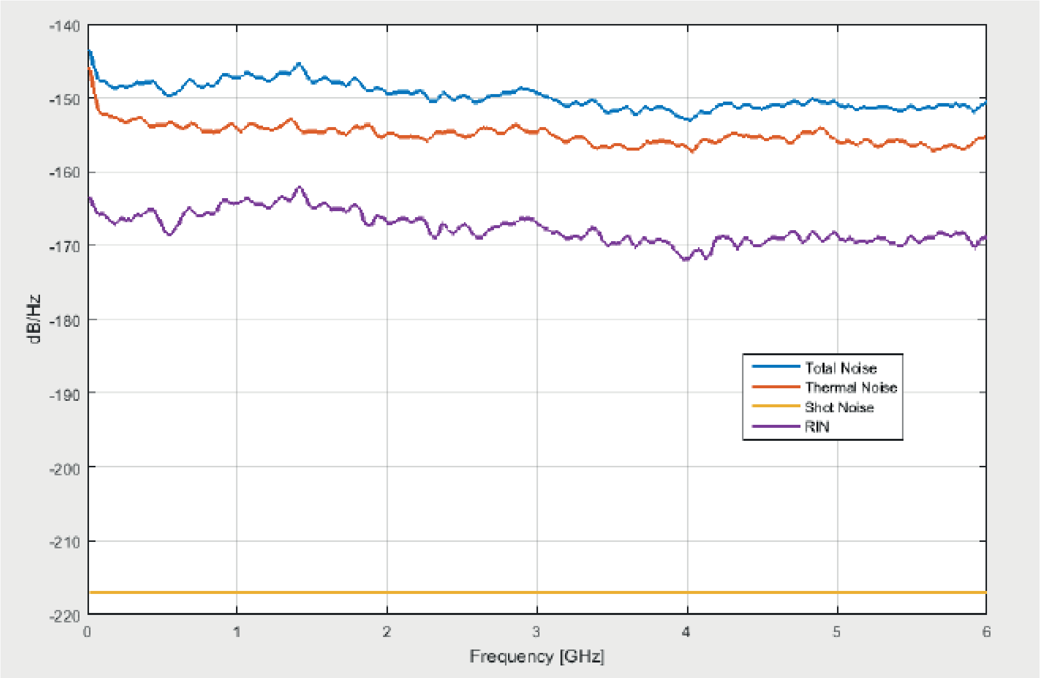
Laser intensity noise - an event where two emissions interfere with each other.



The unit for RIN is dB/Hz and is relative to the average power of laser under test. The rule of thumb is the higher the RIN, the more noise is present in the laser. **Figure 3** gives an example of a RIN measurement for a commercially available ITLA laser.

Figure 3:

RIN measurement example from a ITLA laser.



CALCULATING RIN

RIN is calculated from electrical power densities and not from optical power densities. It is performed in this manner since the intensity noise is a result of beating at the photodetector and historically the measurement arises from intensity based signal to noise.

This is a problem since the average power and the time varying power might be measured in different instruments with different photodetector responsivities, different load impedance and different transimpedance gains.
In most cases the average power of the measurement will be obtained from very accurate optical power meters. The electrical power densities are usually measured with an RF spectrum analyzer or real-time digitizers (Fast Fourier transforms). So it is important to properly reference them back to the correct domain to get the appropriate results.

RIN is expressed as;

$$RIN = \frac{\langle P_{intensity(t)^2} \rangle}{p^2} \text{ , 1/Hz}$$

And; $RIN_{dB} = 10 * log_{10}(RIN)$ dB/Hz

where P intensity (t) is the time varying optical power and P is the average optical Power. P intensity $(t)^2$ is usually measured in the electrical domain using an RF spectrum analyser and integrated over a 1Hz frequency band.

RIN is relevant for intensity modulation formats and so the power of the noise after photo detection is most important. By using an RF spectrum analyzer, which measures the power spectral density of the electrical signal, we measure the electrical power which is proportional to optical power squared:

$$Power_{elec} a\ i^2_{rms}\ a\ v^2_{rms}\ a\ P^2_{rms}$$

Other noise sources in a RIN measurement setup

The total noise in a measurement setup, P Total $(t)^2$, is the linear summation of three different noise sources. It is necessary to first characterize and remove the contributions of Thermal Noise and Shot Noise from the measurement setup in order to get accurate RIN measurements.

$$P_{Total}(t)^2 = P_{intensity}(t)^2 + P_{thermal}(t)^2 + P_{shot}(t)^2\ ,\ W^2/Hz$$

P thermal (t) is the thermal noise of the load impedance (or noise floor of the transimpedance amplifier). It occurs at the amplifier that follows the photodiode. By disabling the Laser Source under test, we obtain:

$$P_{thermal}(t)^2 = P_{Total}(t)^2 \quad W^2/Hz$$

P Shot (t) is the shot noise of the photodetector, P Shot (t)2 = hcP/ λ W2/Hz, where P is the average optical power of the laser under test, h is the Planck constant, c is the speed of light and λ is the wavelength of the light source. Shot noise is generated by the discrete nature of photons arriving at the detector. The amount of shot noise is related to the amount of photons (or average Power) at the detector.

This leads us to the following equation for the intensity noise:

$$P_{intensity}(t)^2 = P_{Total}(t)^2 - P_{thermal}(t)^2 - 2hcP/\lambda \quad W2/Hz$$

De-Embedding the receiver from the RIN measurement

The RIN measurement is intended to measure the intensity noise of the laser under test. Transimpedance gain of the receiver will amplify this noise and the frequency response of the receiver will filter the noise. It is important to remove the receiver's contribution from the RIN measurement in order to get accurate and repeatable results.

A fast detector is used to convert P (t) in Watts into a current through its responsivity R (Amps/Watt)

$$i(t) = R * P_{Total}(t)\ ,Amps$$

The internal impedance of the instrument connected to the detector (often 50Ω) or the detector's transimpedance amplifier converts this photocurrent to voltage.

$$V(t) = T_z * R * P_{Total}(t), \text{ Volts}$$

The transimpedance gain, T_z (Ohms or Volts/Amps), and the detector's responsivity (Amps/Watt) are often combined into a single conversion gain parameter, C^g:

$$C_g = T_z * R, \text{ V/M}$$

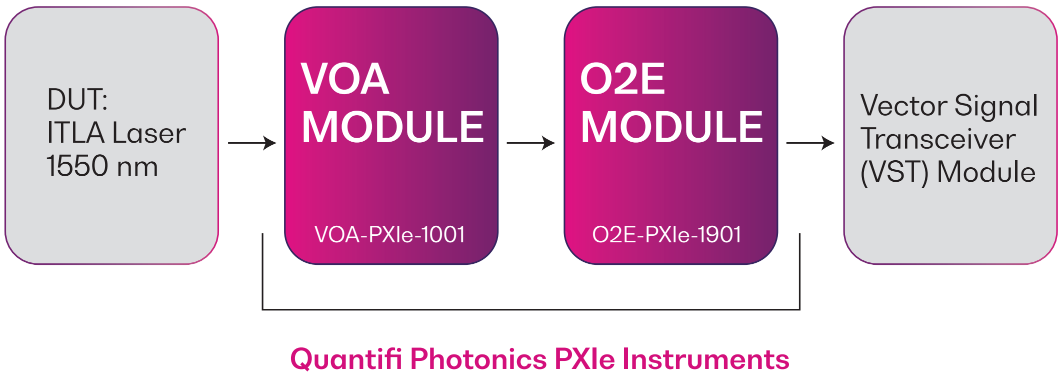
So, by measuring the rms voltage; $\sqrt{< V(t)^2 >}$ or the power spectral density $< V(t)^2 >$, we can relate it back to the optical power through;

$$< P_{Total}(t)^2 > = \frac{< V(t)^2 >}{C_g^2}$$

Example

Figure 4:

Block diagram of instruments used for the RIN test.



In this experiment the following equipment was used:

1. Laser Under Test: Commercially available ITLA set to 1550nm and 6dBm output power
2. Quantifi Photonics VOAPXIe-1001: Attenuator and active power control loop to set the average optical power to the desired set point
3. Quantifi Photonics O2EPXIe-1901: Optical Receiver with 10GHz of bandwidth and 10,000 V/W of conversion Gain
4. National Instrument PXIe-5840: Fast Spectrum Analyzer with a frequency range of 9kHz to 6GHz

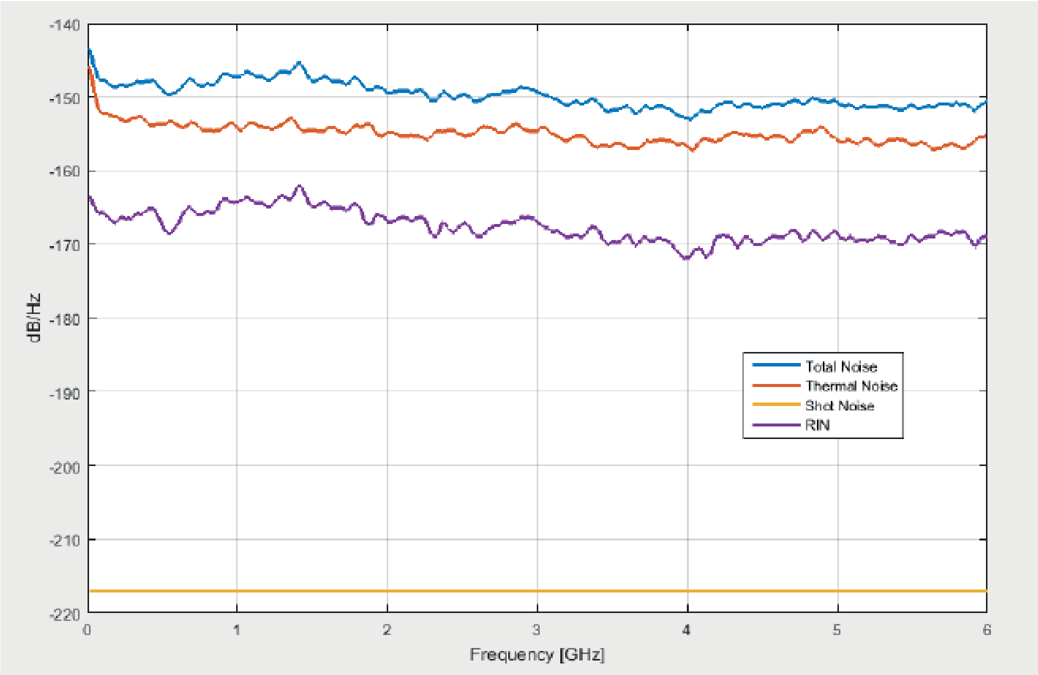
Using the Spectrum Analyzer, the Thermal Noise was obtained by disabling the laser. The measured Thermal Noise is shown as the orange line in Figure 5.

After enabling the laser, the VoaPXIe-1001 was used to set the average power into the O2EPXIe-1901 to be –2.00dBm or 0.63 mW and the Shot Noise from the average Power. The Shot Noise is shown as the yellow line in figure 5.

Again using the Spectrum Analyzer, the Total Noise was measured and is shown as the blue line in Figure 5. We have all the information required to solve for P Intensity $(t)^2$ as described in the steps above making sure to correct for the conversion gain of the O2EPXIe-1901 and its frequency response. We can now solve for RIN shown as the purple line in Figure 5:

Figure 5:

Noise measurements from the RIN test set up displayed on a graph.



Information about O2EPXIe-1901

Quantifi Photonics O2E-PXIe-1901, is a fast optical to electrical converter to convert optical noise to electrical noise. The O2EPXIe-1901 is AC-coupled making its output well-suited to use with the RF spectrum analyzer to measure small variations in optical intensity.

The O2EPXIe-1901 is an excellent choice for this measurement due to the following features;

- High conversion gain of 10,000 V/W enables the measurement of very low RIN.
- Built–in optical power meter to provide the average optical power at the same reference point as the AC analog output.
- Wide bandwidth range enabling the RIN measurement up to 10Ghz.

The frequency response (S21), AC conversion gain and average power are all available through the remote control interfaces (SCPI, LabVIEW, web GUI), making it possible to build a simple, cost-effective and reliable RIN measurement system by incorporating these calibration parameters.

https://www.quantifiphotonics.com/products/optical-electrical-converters/

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Solve.™

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