# INVESTIGATION OF SEASUREMENT OF NOISE IN LASER DIODES FOR HIGH DATA RATE BROADBAND TELECOMMUNICATION SYSTEMS

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**ABSTRACT**
The aim of this poster paper is two fold. Firstly to describe the importance of noise in laser diodes used in high data rate broadband telecommunication systems. Secondly to describe a novel technique for measuring the Relative Intensity Noise (RIN) as a function of frequency up to 20GHz with high sensitivities less than -171dBm/Hz. It will be shown that this technique provides an adjustable shot noise level and by comparing the adjustable flat noise spectrum with the test spectrum, the main traceable path is determined using measured DC photocurrent. Experimental results will be presented to illustrate that frequency dependence of errors, particularly those due to responsivity, gain and mismatch etc., are significantly reduced and precision <0.4dB have been achieved.

**KEYWORDDS**
Laser Diodes- Noise Measurement- Broadband Systems- Optical Communications

## 1. INTRODUCTION

As society is undergoing a fundamental change from an industrial society to an information society, the rapidly increasing bandwidth demand, driven by the Internet, has led to further growth in high data rate broadband telecommunication systems and devices used in these systems. The noise measurement reported here belong to optical lasers used in optical communication systems operating at 40Gb/s. Such system are rather complex, typically consist of devices and modules such as;

- Tunable InP Laser, NRZ High Speed GaAs Modulator with 10Gb/s Drivers & 10Gb/s GaAs TX
- Wavelength Division Multiplexing (WDM-MUX) and Variable Optical Attenuator (VAO)
- Array Waveguide Gratings (AWGs)
- Amplification & Optical Channel Monitor (OCM)
- Demultiplexing (DEMUX)
- Electronic Variable Optical Attenuator (8-EVOAs)
- 10 Gb/s Gb/s Receivers
- Integrated Transceiver modules using High Speed GaAs Photodiode and Amplifier
- Three functions on a single OCM chip (switching, DEMUX and detecting)

Tunable semiconductor lasers form the core of the transmitter in these high data rate broadband telecommunication systems. The wide tuning range allows a wide band to be covered with a single laser, cutting inventory costs and increasing manufacturing flexibility.

## 2. RELATIVE INTENSITY NOISE (RIN)

An important parameter in evaluating both laser and system performance for broadband digital and analogue systems is relative intensity noise (RIN). RIN is the ratio of the mean-squared-intensityfluctuation spectral density of the optical output to the square of the average optical power. It can be thought of as a type of inverse carrier-to-noise ratio indicating the maximum ratio obtainable in a Lightwave transmission system, where the dominant noise source is the laser intensity noise. RIN can also be expressed in terms of detected electrical powers;

$$RIN_{System} = \frac{N_T}{P_{AVG}} = \frac{N_L}{P_{AVG}} + \frac{N_q}{P_{AVG}} + \frac{N_{th}}{P_{AVG}} \quad / \, Hz \qquad \textbf{(Eqn 1)}$$

Where: $N_T$ is the total detected noise power per Hz;
$N_L$ is the laser intensity noise power per Hz;
$N_q$ is the photonic shot noise power per Hz;
$N_{th}$ is the contribution of thermal noise power per Hz;
$P_{AVG}$ is the average detected dc power.

The total system noise ($N_T$) is the linear summation of three fundamental noise sources, being: laser intensity noise primarily due to spontaneous light emissions; thermal noise from the electronics; and photonic shot noise [1].

Previous research in this area [2..6] has addressed the measurement of RIN, typically using a photodetector /preamplifier & spectrum analyser. This paper demonstrates a new RIN measurement system improving on previous technology and incorporating a novel technique based on a low noise (cold) optical source to provide sensitivity for today's telecommunication needs and to offer the highest precision required for a Primary National Standard.

## 2.1 Calibration System

The DERA RIN calibration standard can be seen in figure 1. It consists primarily of a New Focus ultra-fast photodetector, a Miteq high gain low noise rf amplifier and a Rohde & Schwarz low noise spectrum analyser (1Hz resolution bandwidth capability), together providing an enhance system sensitivity of <-171dBm/Hz. This has been confirmed by various techniques which includes broadband and narrowband 3dB assessments using direct and external modulation. Broadband noise errors in the spectrum analyser i.e. output envelope skewing, scaling error etc. have been directly observed. In the optical path isolation (>60dB) is inserted and counter angled fibre connectors are incorporated where ever possible thus minimising optical back reflections which can seriously degrade laser diode RIN performance [3,4].

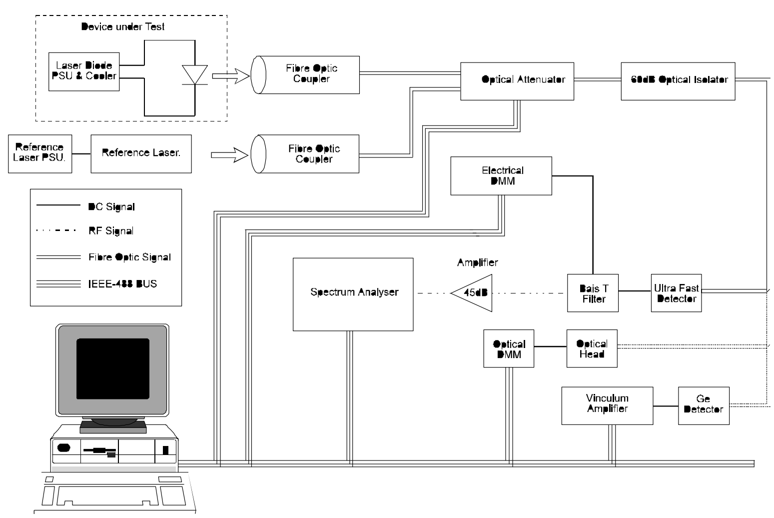


**Figure 1**

Traditionally to determine the laser relative intensity noise the other noise sources (Eqn 1) need to be determined and subtracted away from the total system RIN measured. This is achieved in two stages, i.e. with the laser on ($N_T$) and then laser light blocked ($N_{th}$). The average power and shot noise power terms can be derived from the dc photocurrent which is obtained via the digital voltmeter.

$$\text{Shot Noise Power} = N_q = 2qi_{dc}R \quad \text{(Eqn 2)}$$

$$\text{Average Power} = P_{AVG} = i_{dc}^2 R \quad \text{(Eqn 3)}$$

Where: q = electron charge = $1.6 \times 10^{-19}$ Coulomb
$i_{dc}$ = generated dc photocurrent
R = photodetector load resistance
All terms are linear values unless otherwise stated.

Calibration needs to be incorporated to account for system gain, noise, mismatch, detector capacitance etc. over a large frequency range typically 10MHz to 20GHz. This can be intensive, costly and involve significant measurement uncertainties.

In assessing these problems DERA has identified a unique measurement technique [9] where system calibration is simplified and significantly improved uncertainty levels result. The technique incorporates the use of a calculable cold reference level, being a ultra low noise laser source, to extract system calibration information and also to provide a like for like signal (i.e. broadband) to determine the shot noise component. *Referencing* is an established technique used in the rf & microwave field but does suffer from the introduction of additional noise under attenuation whereas this laser source does not. Reference noise level can be selected by adjusting the average optical power level.

### 2.2 Ultra Low Noise Reference Laser

The reference laser employed is a high finesse device developed by Lightwave Electronics, U.S.A. These devices are diode pumped Nd:Yag ring lasers incorporating a novel non-planar ring oscillator (NPRO), which have been quoted as being Shot noise limited for direct optical power levels of 5 mW above 20 MHz. This shot noise source generates a flat noise level over the entire frequency span, which can be varied by simply adjusting the dc optical power[10].

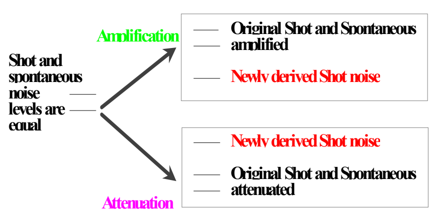


**Figure 2**

To ensure shot noise limited performance an optical attenuation technique is implemented, see figure 2. A high power, 100mW version of the NPRO laser is optically attenuated to power levels required in the RIN system. When attenuating by a factor of 100 the shot noise power will reduce by a factor of 100 and any spontaneous noise power will decrease by a factor of $100^2$. Thus, if the shot and spontaneous components from the unattenuated laser were equal then there will be a 20dB difference in their levels after attenuation. Thus by choosing a high power device and attenuating down, shot noise limited performance can be achieved.

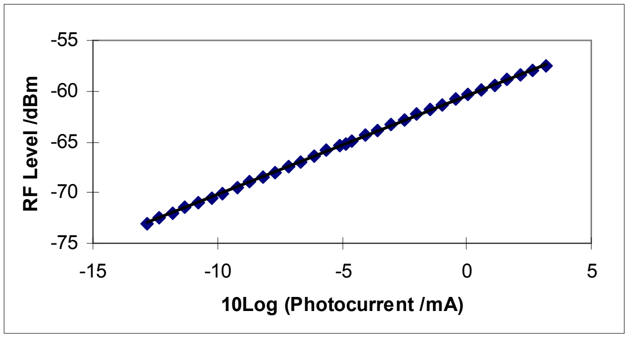


**Figure 3**

This has been extensively assessed by attenuating the reference laser optical power incident on the ultra fast detector and recording and plotting (in log terms) the dc and rf levels. Using least squares fitting a linear response with a gradient of 1 will be observed if the source is shot noise limited and a gradient of 2 will indicate the presence of spontaneous noise. Thus providing a measure of the reference lasers performance. Figure 3 demonstrates a typical response gained at 1GHz, giving a spontaneous noise content of <1% (0.043dB) and standard uncertainty of 0.008dB.

### 2.3 Experimental Results

The measurement consists of three stages. Firstly optical light is blocked to the detector and measurement of the dark noise (Dark) is recorded, over the frequency range of interest. Then the device under test (Dut) is applied to the detector and a second noise measurement trace recorded along with measurements of incident optical power and photocurrent. Finally the reference laser is applied to the detector (after disconnecting the Dut) and the optical attenuator adjusted to obtain the same photocurrent as for the Dut, i.e. shot noise matched. This trace (Ref) is then recorded along with the incident optical power and photocurrent. During all of these measurements the system set up parameters, e.g. spectrum analyser resolution bandwidth, should remain unchanged. With the aid of a GPIB controller and computer software the system calibration factor (Eqn 4) can be derived for each RIN measurement across the whole frequency range selected. This is achieved by linearity subtracting the dark noise from the reference noise and calculating the shot noise power ($N_q$) from the generated photocurrent at each frequency.

$$\text{Syscal} = \frac{B_{DUT}^2}{B_{REF}^2} \frac{(\text{Ref}) - (\text{Dark})}{2qi_{dc}R} \qquad \text{(Eqn 4)}$$

The $\beta_{dut}$ & $\beta_{ref}$ ratio allows for detector responsivity from the fixed reference laser wavelength, derived from the optical power and photocurrent measurements. This system calibration factor will naturally account for the frequency responsivity, gain, noise, mismatch losses, resolution bandwidth etc., of the system across the whole measurement range. Following this the laser noise term $N_L$ can simply be derived by subtracting the reference noise from the dut noise (as the photocurrents for both measurements have been matched i.e. equal shot noise) and then account for the system calibration previously calculated.

$$N_L = \frac{\text{(Dut) - (Ref)}}{\text{Syscal}} \qquad \text{(Eqn 5)}$$

The remaining noise power ($N_L$) is divided by the average electrical power to obtain the spontaneous RIN level of the DUT at each frequency (Eqn 6).

$$\text{RIN}_{\text{Laser}} = 10\ \text{LOG}_{10} \frac{N_L}{i_{dc}^{\,2} R}\ dB / Hz \qquad \text{(Eqn 6)}$$

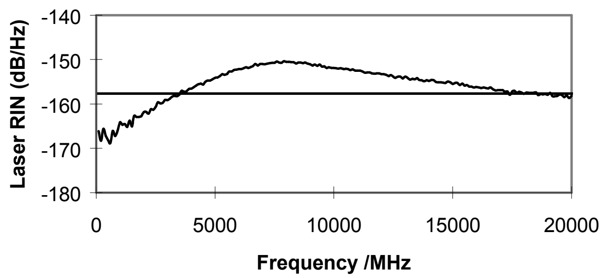


**Figure 4**

Figure 4 shows a typical laser RIN response of a DFB 1550nm Laser Diode with 2.7mW incident on the photodetector, having a lower frequency response below the Shot RIN level (horizontal line).
Using suitable optical isolation (>60dB) measurement uncertainty levels below 0.4dB are achievable and the sensitivity of the system allows laser RIN's 10dB below shot RIN to be assessed. Uncertainties are expected to be reduced once further confidence in the reference source has been gained.

## 3. DISCUSSIONS

The Primary Calibration Standard developed here is the U.K's first Laser Diode Noise National Standard offering the highest spectral sensitivity and precision in the world to date. Incorporation of the cold noise reference source minimises systematic errors such as:

- non-linear errors - as the adjustable reference noise level allows instant calibration of the system at the level of noise of the dut.
- shot noise subtraction errors - like for like signal source.
- system responsivity drift errors - calibration performed as a complete system at each measurement point.

Table 1: Capabilities of the Laser RIN

| **Optical Power** | **Wavelengths** | **Frequency Range** |
|---|---|---|
| 100 µW – 3mW | 1300 ± 50nm | 10MHz to 20GHz. |

The reference laser may be used for calibration of detector frequency response [11] but the reference source provides a useful alternative offering calculable noise signals across a wide frequency range. The capabilities of laser RIN are summarised in table 1.

## 4. CONCLUSION

A high sensitivity precision relative intensity noise calibration standard utilising a low noise reference laser source was described. Experimental results were presented to illustrate that the reference laser is proving to be a very powerful tool and it offers potential in other applications such as calibration of detector frequency response.

## 5. REFERENCES


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