Development of a Novel Approach for Accurate Measurement of Noise in Laser Diodes used as Transmitters for Broadband Communication Networks: Relative Intensity Noise

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ABSTRACT - This paper is focused on the Relative Intensity Noise (RIN) aspect of a research project on development of a novel approach for accurate measurement of RIN and Frequency Excursion (Chirp) in Laser Diodes as Transmitters for Optical Communication Networks. The desired metrology capabilities have been developed and demonstrated, providing significantly improved sensitivity and accuracy than existing methods. RIN is a key parameter for laser components used in telecommunication systems due to the drive to reduce inherent noise, improve overall signal-to-noise ratio and thus increasing achievable communication link length and reduce required component specification. The novelty of our approach has resulted significant advantages, achieving improved sensitivity, improving measurement accuracy as low as ±1dB and simplifying the system calibration methodology thus improving flexibility. Laser RIN's of between 10 to 14dB below the Shot RIN have been shown (typically -170dB/Hz) which is a direct result of the improved system sensitivity.

Index Terms- Laser Transmitters, Relative Intensity Noise, Optical Networks, Shot Noise, Signal To Noise Ratio

1. INTRODUCTION

Today's telecomm links typically operate from Mb/s to 10Gb/s per channel but market demands in the broadband communications are forcing manufacturers and systems designers to increase data rate capacity of optical links to meet future communications use [1-3]. The noise level within a system is one of the key factors which ultimately restrict data rate capacity and hence *cleaner* optoelectronic components are sought. From simple estimations, increasing the bit rate from 10Gb/s to 40Gb/s requires a 6dB improvement in signal to noise ratio in order to maintain the same link spacing[4]. Future advances in system components needs to be met by an equivalent ability to measure their performance [5]. Key forms of transmitter noise concern AM and FM optical noise which are commonly expressed under the parameters Relative Intensity Noise (RIN) and Frequency Excursion (Chirp) [6] which is the subject of a future publication.

Coherent transmission systems are substantially formed by light generators whose radiation spectral width is smaller than 0.1nm. Particular laser structures have been developed to meet this goal such as distributed Bragg reflection (DBR) lasers and predominately distributed feedback (DFB) lasers. These laser sources themselves generate significant RIN[6].

2. DEVELOPMENT OF A NOVEL APPRAOCH FOR MEASURING RELATIVE INTENSITY NOISE

2.1 Theoretical Aspects

Laser RIN characteristics provide both systems designers and laser diode designers with valuable information[7]. From the systems designer's point of view even an ideal receiver generates quantum noise (shot) which yields a lower limit for detectable noise and signals. Hence any additional laser noise will add to the receiver RIN and therefore reduces the signal-to-noise ratio (SNR), limiting system performance. The theoretical relationship between RIN, SNR and optical modulation index is [8].

$$SNR = \frac{m^2}{2RIN} \qquad \textbf{(1)}$$

where: m is the optical modulation index and RIN is the total receiver noise over 1Hz bandwidth. It can be shown that the system RIN is given by [9]

$$RIN_{System} = \frac{N_T}{P_{AVG}} = \frac{N_L}{P_{AVG}} + \frac{N_q}{P_{AVG}} + \frac{N_{th}}{P_{AVG}} Hz^{-1} \qquad \textbf{(2)}$$

where: N_T is the total 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 power of the photocurrent

After contacting various optical test equipment manufacturers, it was concluded that HP were the only equipment manufacture's supporting RIN and chirp measurements. The system, known as the Lightwave Analyser, basically consists of an rf spectrum analyser (HP 71400C) coupled to a photo-receiver high speed PIN via an rf amplifier (HP70810B). Today's laser diodes now have RIN specifications beyond the scope of this system, some typically achieving (or claiming) -170dB/Hz at 1mW optical power. From our detailed technical review, it became apparent that there is a short fall in sensitivity for RIN measurements of typical DFB lasers encountered today. Additionally the techniques are generally tedious in the number of measurements required and also in the test equipment required, especially when incorporating an optical chopper. Measurement uncertainty of any of the RIN or Chirp setups is unclear and in the commercial world this often leads to disagreements within industry and between suppliers/customers. It is vital, in forming a national standard that all uncertainty terms are thoroughly investigated and accounted for. Additionally, the highest confidence level should be targeted. To this end, system complexity needs to be minimised which would otherwise contribute to overall measurement uncertainty and test time.

2.2 Outline of the Novel Relative Intensity Noise Measurement Techniques

Sensitivity is severely governed by the system noise figure, predominately from the amplifier, but also the detector and analyser. Thus, to start with a fighting chance of measuring low noise levels, the latest rf component technology was reviewed and engaged, being summarised in this paper

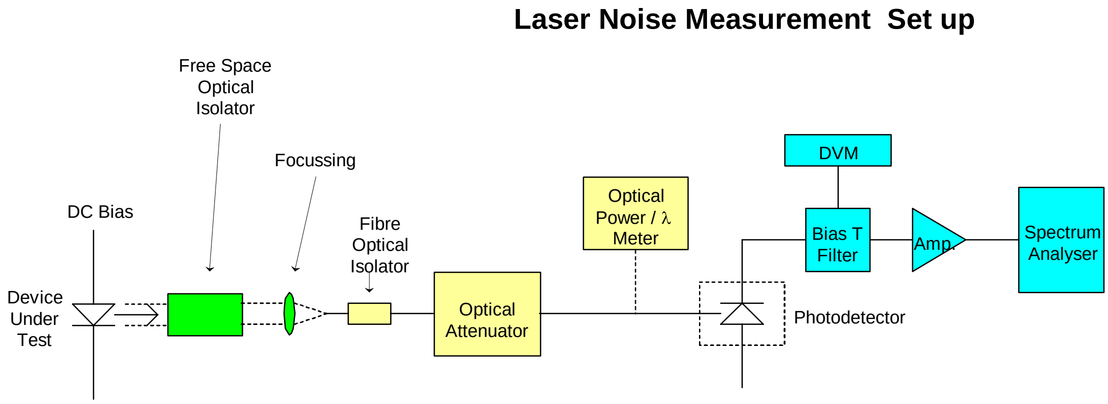

Figure 1: *Basic laser noise measurement set up*

Among different experimental apparatus developed, the one for the basic laser noise measurement is considered here. Fig 1 shows the block diagram of the apparatus. From left to right we have the laser to be characterised which is coupled into an optical interface stage ending with an optical detector. This transfers the noise signal into the electrical domain where the rf is amplified and passed onto a spectrum analyser. Detailed assessment of each of these elements and their contribution to the overall system is beyond the scope of this paper but an outline is given below.

Optical System: The main aim of this stage is to gather the optical signal of the laser to be characterised into fibre, if not already so and applied to the photodetector in a controlled manor. With communications lasers coming in various guises, such as; fibre coupled (various connector styles), free space (collimated or diverging beam), with built in driver or without etc, a flexible system has been built up. This includes fibre couplers, fibre connectors, isolators, and attenuators.

Electro optical Interface ; Three key properties, each having their own specific requirement need to be extracted from the optical signal being analysed. These are 1) the rf noise signal, 2) incident optical power and 3) the signal wavelength. Power and wavelength is gained using a dedicated fibre optic multimeter. An ultra fast, wide band detector (InGaAs) provides demodulation from light to rf electrical domain.

Biased T / DVM : Following the detector the dc component of the electrical signal needs to be filtered from the noise signal to avoid saturation of the rf amplifier.

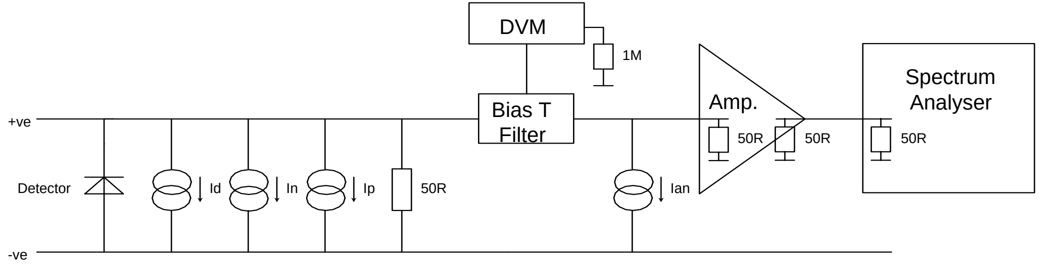

Fig 2: *Block diagram of the Shot noise, bias T, amplifier and the spectrum analyser.*

The above figure shows the bias T filter allowing the RF component (typically frequencies > 10MHz) to pass through to the amplifier / spectrum analyser and the DC component coupled out to a digital volt meter (DVM). Note that Id = dark current, In = detector current, Ip= Photocurrent and Ian = Amplifier Noise Current.

Since, the DC component is coupled out at this stage, the voltage measured by the meter will represent the voltage across the input termination resistor only (since no influence of the spectrum analyser impedance is seen by the DVM). Whereas the RF voltage passing through the bias T will be influenced.

Spectrum Analyser + Pre Amp: The spectrum analyser (FSEM30) boasts the lowest noise figure in its class of approximately 23dB for an operating range of 20Hz to 26.5GHz. Frequency resolution is 0.01Hz and resolution bandwidths of 1Hz to 10MHz are available. In terms of the rf power range this is commonly referenced as the 1dB compression point and in this case occurs at +10dBm. Two very high gain preamplifiers with gain levels of 35 and 45 dB were sourced from Miteq, Inc. It is not feasible to increase the gain indefinitely since the dynamic range of the spectrum analyser is decreased.

Other important aspects: It should be noted that there are other important aspects associated with the development of our novel measurement techniques including broadband noise smoothing, sensitivity correction for responsivity & gain of rf components and extraction of RIN. However, these will be discussed in future publications.

2.3 Illustration of Typical Experimental Results

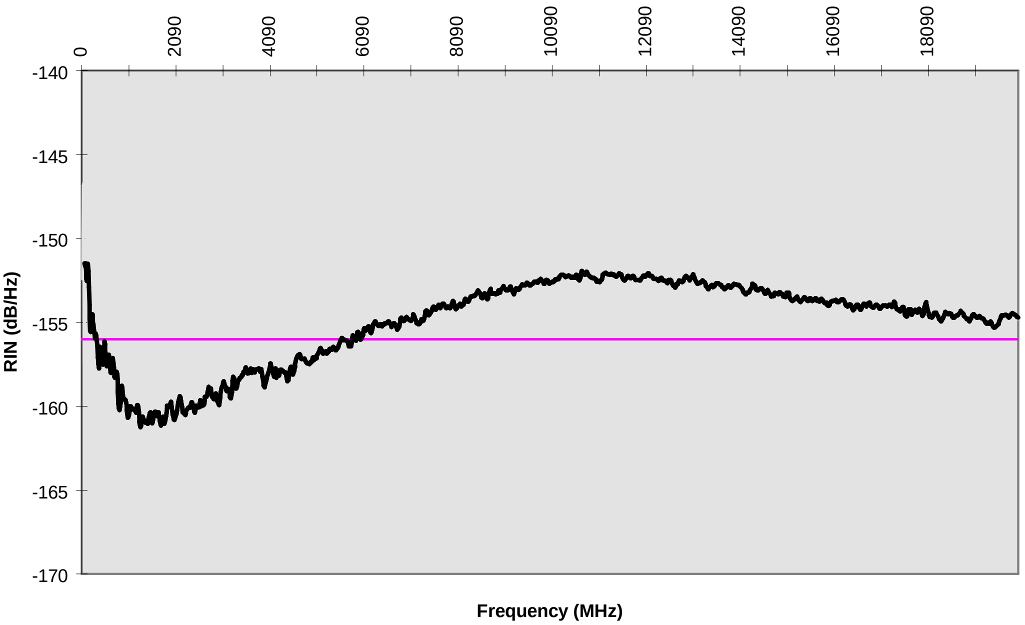

Figure 3 : *The final RIN data for the DFB laser diode system*

Above Fig shows the spontaneous noise spectrum in the classical units of RIN (dB/Hz) after compensating for system frequency response. Also plotted is the shot noise of the system at the tested optical power (the solid straight line). It can be seen that the spontaneous noise of the laser under test is greater than the shot noise except for the frequency band from 200MHz to 5.5GHz. This is the main modulation bandwidth window for sub 2.5Gb/s systems which this laser is intended.

3. DISCUSSION

Initial measurements during the construction of the detector/amplifier/spectrum analyser system confirmed the expected performance of each of the components and the suitability to the overall system. Noise figure for the combined spectrum analyser and rf amplifier was, as predicted, dominated by the amplifier noise, established as typically better than 3.5dB thus providing sensitivity to -170.5dBm. This is some 4-5dB better than any previously published work for amplifier / spectrum analyser configuration and at some frequencies sensitivities, better than -172dBm. Techniques explored were based on ‘3dB’ rise and subtraction of ‘average displayed noise floor’, both correlating well.

Experimental measurements of the photo detector established the optical connector repeatability to be sufficient, <1% and local temperature dependence as being insignificant in a temperature controlled laboratory. The detectors own DC port trans-impedance amplifier was discovered to introduce 2dB of noise and had a poor linear response at power levels below 0.5mW. By isolating the DC port circuitry and inserting an external bias-T device to the rf port we effectively provided an alternative DC port to measure the photocurrent without any significant noise being introduced and minimal rf signal loss (0.6dB).

Integrating the photo detector to the rf amplifier / spectrum analysers combination gave, for the first time the ability to assess the system sensitivity optically. Here, a ‘shot noise limited’ reference laser was used as a source, whose power level was controlled by an optical attenuator and monitored by way of an external optical power meter, traceable to national standards. Extensive data over the wide frequency range 10MHz to 20GHz was gathered plotting rf noise level as a function of applied optical power, thus allowing the ‘3dB rise’ sensitivity to be calculated. Linear fitting to this data provided a measure of the systems error at each frequency. By compensating for this derived error the ‘true’ system noise figure and thus system sensitivity has been found. Results show approximately 2dB noise figure for frequencies to 12GHz rising to a peak at 18GHz of <3dB, thus providing sensitivity levels of -172dBm and <-171dBm respectively. A peak is evident at 14GHz similarly found with the rf amplifier / spectrum analyser combination but with an improvement in noise figure at 20GHz thought to be attributed to the photo detector introduction having responsivity variations at these higher frequencies.

Calibration for improved accuracy, measurement of uncertainty and RIN traceability are other important aspects of the project not discussed here but will be the subject of future publications.

4. CONCLUSION

The novel development outlined in this paper is believed to have the greatest sensitivity and most accurate RIN capability achieved to date, demonstrating enhanced performance over the equipment available in the market. The research has improved our understanding of systematic noise contributions and demonstrated good agreement between sensitivity techniques. Application of the 'shot noise limited' reference source has been demonstrated with further key advantages explored which are outside the scope of this paper.

A number of laser diode companies have utilised the facility, specifically looking at better defining their products noise contribution.

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