Measurement Techniques for Extraction of Parameters in Lightwave Systems for Simulation Purposes

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Abstract

This paper presents the measurement techniques for extracting the parameters in lightwave systems for the purpose of system simulation. The components commercially employed in a metro link system are considered with a DFB laser incorporated into the transmitter and an APD-FET detector used at the receiver end. Simulation results for a 2.5 Gbit/s transmission system using the extracted parameters are compared with experimental data.

I. Introduction

Lightwave systems have steadily been pushed to bit rates up to 10 Gbit/s. Due to the complexity of modern optical communication systems, computer simulations are necessary to predict and optimise transmission performance [1]. However, this application requires the parameters of the key components in the transmission link to be known with high accuracy for the simulation to predict realistic results. The basic formalisms used to extract the parameters based on relatively simple measurements and data analysis are discussed. The parameters in the laser rate equations are extracted from the measured relative intensity noise (RIN) spectra at different injection current levels. The receiver is characterised using the optical pulse measurement technique and the noise sources are measured using a calibrated electrical spectrum analyser (ESA). The simulated BER curves after transmission over 108 km of single-mode fibre are compared with experimental data.

II. Parameter Extraction

A. DFB Laser

The optical field amplitude and phase of the laser output in the transmitter are computed by solving the large signal rate equations with Langevin noise sources, which describe the relation between the carrier number, photon number, and optical phase. The parameters in the rate equations are extracted as described in [2] from the measured RIN spectra at different injection current levels. The experimental setup for measuring the RIN spectra of the DFB laser is shown in Fig 1. below.

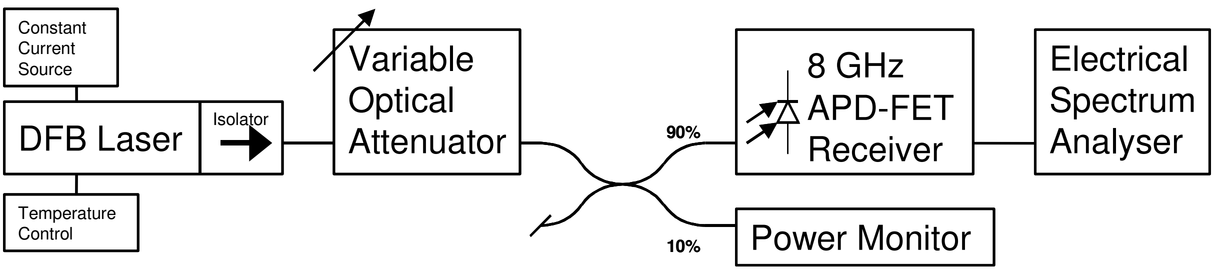

Figure 1. Experimental setup for RIN measurements.

B. APD-FET Receiver

An APD-FET detector employing a transimpedance front end amplifier to achieve high sensitivity was considered. We first measured the impulse response by exciting the detector with a short (<100ps) optical pulse and connecting the output of the receiver to a sampling oscilloscope. The frequency response of the receiver was then obtained by calculating the

Fourier transform of the measured time response of the optical pulse. The measured data was fitted to a polynomial to provide a generic model for the simulation. The 3 dB bandwidth of the receiver response was found to be about 2 GHz as shown in Fig. 2 along with the phase variation with frequency.

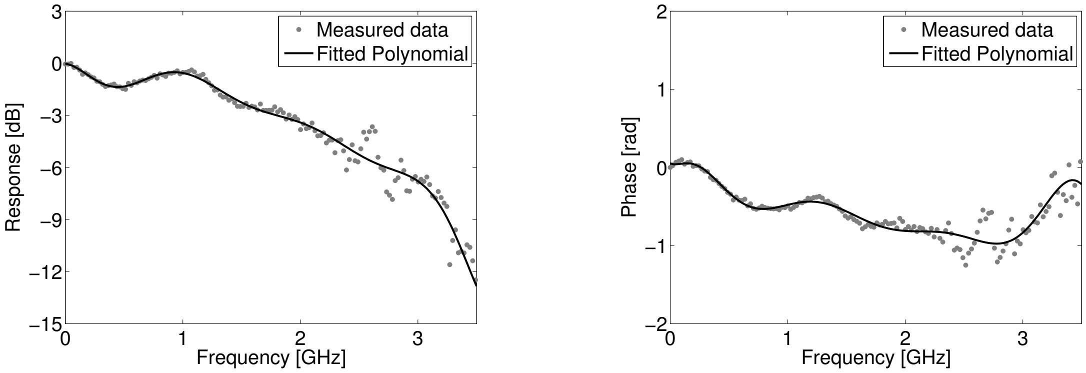

Figure 2. The extracted amplitude and phase receiver response function.

Several noise mechanisms determine the receiver sensitivity [3]. In particular, shot and thermal noise in the receiver ultimately limit the performance of the transmission system causing degradation in the BER. To include accurate models of these noise sources in simulation, we measured both the shot and thermal noise spectra in the receiver using a calibrated ESA and the DFB laser under CW operation. The combined shot and thermal noise was measured by driving the laser at 6 times the threshold current such that the RIN is insignificant. The thermal noise was measured by turning the laser off. The shot noise spectrum after subtracting the receiver response was found to be flat. The thermal noise is generated at multiple places through the receiver such that the thermal noise spectrum after subtracting the receiver response was observed to have the functional form

$$H_{th}(f) = 10 \cdot \log\left[1 + \left|\frac{A_{th}}{1 + j(f_{th}/f)}\right|^2\right] \tag{1}$$

where the constants A_{th} and f_{th} were found to be 2.8 and 1.2 GHz, respectively, to produce the best fit to the measured spectrum.

The noise contributions at the APD receiver were implemented in the simulation using the reference values of the noise power measured at a frequency of 1 GHz from the ESA. The shot, V_{sh}, and thermal, V_{th}, noise values in the simulation were calculated as follows

$$V_{sh} = \sqrt{\frac{6.47\times10^{-15}}{2\Delta t}\left(\frac{V_s}{V_{ref}}\right)} \times x_{sh} \tag{2}$$

$$V_{th} = \sqrt{\frac{1.47\times10^{-15}}{2\Delta t}} \times x_{th} \tag{3}$$

where x_{sh} and x_{th} are random numbers taken from a Gaussian distribution with zero mean values and unity variances, V_s is the detected voltage, Δt is the sampling time and V_{ref} (=4.02x10^{-2} V) is the reference voltage detected at the receiver for the power level at which the shot noise was measured. In simulating the noise sources for the receiver, the thermal noise was first filtered using the transfer function of equation (1) and added to the shot noise. The combined noise in the receiver was then added to the detected signal as shown in Fig. 3.

Finally, the signal was filtered through the receiver response shown in Fig. 2 to simulate the results measured on the ESA.

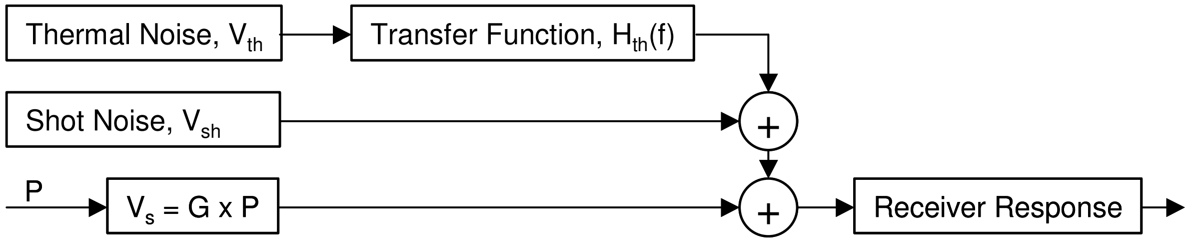

Figure 3. Addition of the receiver noise sources in the simulation.

The measured and the simulated shot and thermal noise spectra for the APD-FET receiver are shown in Fig. 4. The resolution bandwidth of the ESA was 1.2 MHz. As can be seen in Fig. 4, reasonable agreement was obtained between the simulated and the measured noise spectra, for frequencies < 2.5 GHz, at the receiver end using the simulation approach discussed above.

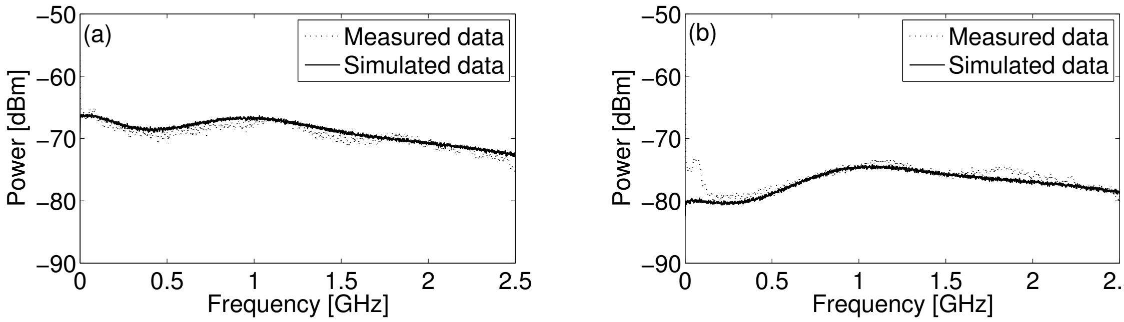

Figure 4. Measured and simulated shot noise (a) and thermal noise (b) spectra. The resolution bandwith of the ESA was 1.2 MHz.

III. Simulation results of a 2.5 Gbit/s transmission system

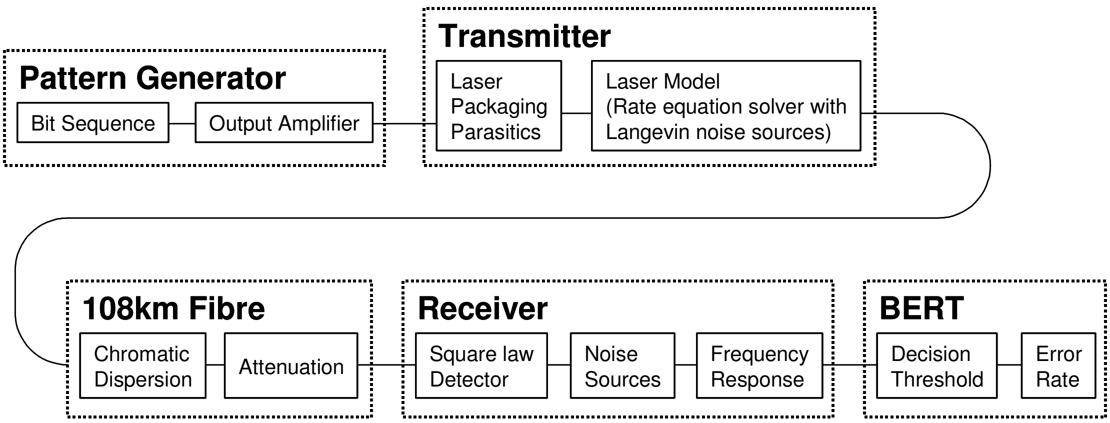

Figure 5. Typical steps involved in the simulation of a metro link system

The numerical simulation of the transmission system shown in Fig. 5. is performed in this section using the extracted parameters for the different components in the system. A 2^7-1 pseudo-random bit sequence (PRBS) was generated and filtered by the pattern generator and laser package parasitics. The signal waveform from the laser was generated by numerical integration (Runge-Kutta method) of the large-signal rate equations driven by direct modulation. The optical signal was transmitted through 108 km of single-mode fibre by simulation of the chromatic dispersion and attenuation. The optical signal was detected and the contributions of the shot and thermal noise in the receiver were implemented in the numerical simulation as discussed in Section II. The BER was evaluated by taking the mean error probabilities over the bit sequence using

$$BER = \frac{1}{N}\sum_{n=1}^{N} \text{erfc}\left(\frac{|V(n) - D|}{\sqrt{2}\sigma(n)}\right) \tag{4}$$

where N = 127, D is the decision threshold voltage, $V(n)$ and $\sigma^2(n)$ denote the mean voltage and voltage variance of the nth bit.

The transmission system shown in Fig 5 was physically constructed with the inclusion of an optical attenuator to vary the optical power levels. The BER was measured at different optical power levels using a commercially available BER tester. Fig. 6 shows the measured and the simulated BER curves for different optical power levels detected at the receiver and also the BER at different decision threshold. The simulated BER curves are within a factor of 2 of the measured curves. This compares well with typical experimental variations of ±3 times in BER.

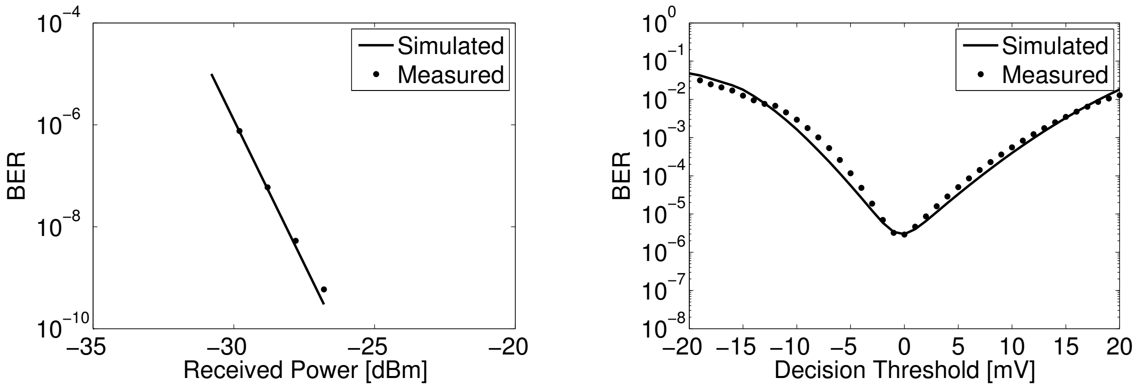

Figure 6. Simulated and measured BER curves for different optical power levels at the detector and for different decision threshold levels

IV. Conclusions

The measurement techniques used to accurately extract the parameters for lightwave systems for simulation purposes have been presented. The parameters of the rate-equations for DFB laser commonly employed in transmission link were extracted from the measured RIN spectra of the laser. The receiver noise sources were measured using a calibrated ESA. A model suitable for computer-aided analysis of the performance of a typical metro link system has also been presented and has been used to analyse the system performance of a 108 km, 2.5 Gbit/s transmission link in terms of the BER.

Acknowledgements

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