DESIGN OF 10 GIGABIT PMD SUBLAYER BY OPTSIM VIRTUAL INSTRUMENT

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ABSTRACT

Link level simulation is invaluable for optical communication system design. Complex systems can require hundreds or thousands of design decisions. Some of these decisions are wavelengths, range, type of fiber, laser (or LED), the type of modulation, the impact of fiber nonlinearities, dispersion, optical amplification(EDFA, SOA, Raman, etc) methods as well as the BER (Bit Error Ratio) of system and the distance before the eye closure. With the rapid development of Computer technologies, virtual instruments become attractive and it gets an alternative for traditional laboratories. System simulation enables detailed analysis and optimization without the need to build prototypes. In this paper, 10GBase-SR Ethernet standard is laid out and analyzed by using OPTSIM virtual instrument.

I. INTRODUCTION

Today, high order programming languages such as MATLAB, Pspice, Labview has been used for the establishment of virtual laboratories. In addition to these programs, there are virtual instruments such as Optisystem and OPTSIM which are only used to simulate optical links.

In this study, the OPTSIM virtual instrument (ModeSYS added version) has been preferred after in-depth and detailed research and comparisons. These are the key factors which make OPTSIM superior: OPTSIM provides the unique capability of simulating optical systems in both the time and frequency domains. More than 600 models are readily available to setup a wide range of optical communication systems, including Nonlinear Fiber, VCSEL(Vertical-Cavity Surface-Emitting Laser) laser, SOA(Semiconductor Optical Amplifier), EDFA(Erbium-doped fiber amplifiers) and Raman amplifier models. New models can be created incorporating, among others, MATLAB, C/C++, Fortran and Java code, allowing legacy code to be reused with minimal effort. OPTSIM can also be integrated with the RSoft Component Design Suites for a total application solution. Adding ModeSYS into OPTSIM gives extra features to the software. ModeSYS fully simulates multimode optical systems by taking into account the transverse mode profile propagating through the system. This unique capability ensures a correct signal shape and eye diagram and allows accurate performance estimates to be obtained. The inclusion of spatial effects into multimode models within a system-level simulation framework combines the accuracy of a device level simulation and the efficiency of a system-level simulation. ModeSYS provides, among others, the following key analyses: system bandwidth, launching condition, offset launch, arbitrary index profile, coupling, chromatic and modal dispersion, differential mode delay, and encircled flux.[6]

First of all, the studies made previously [1], [2] via this software have been carried out to find out if there is any coherency between the results. In conclusion, we have got the same results. Later on, analyses depending on variable parameters (bitrate, wavelength, power, attenuation, and distance) for different modulation, laser, fiber and different types of detectors have been performed for the receiver (photo receiver part), medium (fiber part) and transmitter (laser part) blocks on optical communication link. In the following sections, mathematical models of these blocks are explained.

Afterwards, 10GBase-SR PMD (Physical Medium Dependent) sublayer topology, which is an IEEE gigabit Ethernet standard, has been set up with models in OPTSIM library ensuring proper standards. The performance, validity, sensibility and worst case analyses of this link have been made through analyze devices built in OPTSIM and the results have been evaluated.

II. LASER DIODE

While there are many types of laser diodes, most of them can be described by the following rate equations[4]:

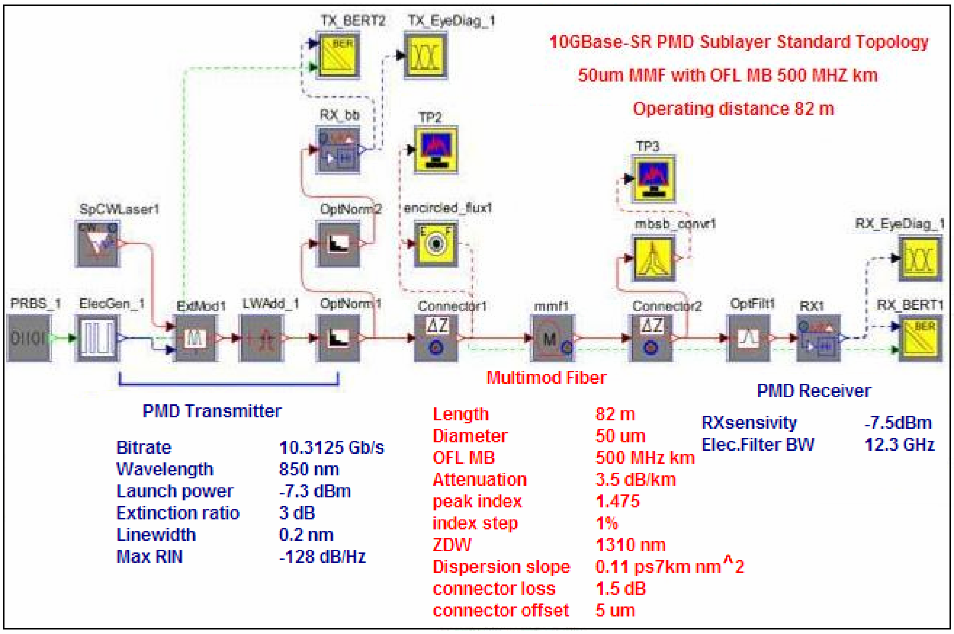


***Figure 1** 10GBASE-SR Gigabit Ethernet Topology*

$$\frac{dN}{dt} = \frac{I}{q} - \frac{N}{\tau_n} - G_o(N - N_o)S$$

$$\frac{dS}{dt} = \beta\frac{N}{\tau_n} + G_o(N - N_o)S - \frac{S}{\tau_s}$$

$$P = kS \qquad (1)$$

Here, N and S are the total electron and photon populations, respectively, in the laser cavity; τ_n and τ_s are the electron and photon lifetimes; G_o is the gain coefficient; N_o is the electron population at optical transparency; β is the spontaneous emission coupling coefficient; I is the injected current; q is the electron charge; t is time, and k is the output power coupling coefficient. In Figure 1, the CW laser source which is characterized completely by its power, wavelength, line width, relative intensity noise (RIN) and phase, is used.

III. OPTICAL FIBER

System-level link analysis tools must also be able to model the optical transmission medium. In this study, multimode fiber model is used to ensure standard. There are several ways to model multimode fibers; the most fundamental method is to analyze the fiber's refractive index profile and to extract information about the fiber's spatial modes and propagation constants [7].

Multimode fiber performance can be estimated from encircled flux measurements. Encircled flux is a measure of the amount of optical power that is contained inside the fiber within a given radial distance from the fiber axis as formula (2).The encircled flux model is used to analyze fiber in Figure 1. That model is a function of the spatial attributes of the CW laser output, the laser/fiber positioning, and the fiber's spatial mode distributions, link analyses. [4]

$$EF(r) \propto \int_0^{2\pi}\int_0^{r} I(r,\theta)\,r\,dr\,d\theta \qquad (2)$$

IV. PHOTORECEIVER

The photoreceiver is the final component in the optical link. As with the laser, a combination of optical and electrical measurements is necessary to accurately calibrate the photoreceiver. The photoreceiver can be modeled a number of ways ranging from physical to semi-physical to empirical. To better illustrate the measurement-based aspects of the Compound optical receiver model, in this study the empirical approach is chosen. The photoreceiver's frequency response $H(f)$ and noise spectral density $S_i(f)$ are represented as (8) and (9):

$$H(f) = Z_T\left(\frac{f}{jf_z + f}\right)\left(\frac{f_p}{jf + f_p}\right) \quad H(f)_{dB} = 20 \cdot \log_{10}|H(f)| \qquad (8)$$

$$S_i(f) = a_0 + a_2 f^2 + a_4 f^4 + a_6 f^6 \qquad (9)$$

Here, Z_T is the DC transimpedance, f is the baseband frequency, f_z is the zero frequency of the photoreceiver, f_p is the pole frequency, j is the imaginary constant, and a_0-a_6 are empirical fitting parameters. The photoreceiver's frequency-domain response can be calibrated by eliminating the zero frequency and setting the pole frequency to the measured 3-dB frequency. The input-referred photoreceiver noise for a transimpedance-amplifier-based photoreceiver is defined to be [6]:

$$\langle i_n^2 \rangle = \int_0^{\infty} \frac{|H(f)|^2}{|H(0)|^2} S_i(f) df \qquad (10)$$

If we assume the noise to be white, then *a*2-*a*6 in (9) can be considered to be zero and (10) is easily determined from (8) and (9). The bit-error rate (BER) of a receiver is expressed as [6]:

$$BER = \frac{1}{2} erfc\left(\frac{Q}{\sqrt{2}}\right) \qquad Q = \frac{I_1 - I_0}{\sqrt{\langle i_{n1}^2 \rangle} - \sqrt{\langle i_{n0}^2 \rangle}} \qquad (11)$$

V. TOPOLOGY

IEEE 802.3ae 10GBASE-SR Gigabit Ethernet standard link with short wavelength laser source at 850-nm and multimode fiber link of 50-um core diameter and 500 MHz km bandwidth is established and analyzed in many ways by using OPTSIM analysis models. Figure 1 shows the topology snapshot of our design.

Here PMD transmitter combines PRBS (PseudoRandom Binary Sequence Generator) data generator, NRZ(Non-return-to-zero) Driver (electrical signal generator), laser source, external modulator laser, linewidth adder, and optical power normalizer. At any point along the link, the signal waveforms can be viewed in the time or frequency domain using “virtual” measurement instruments such as oscilloscopes, spectrum analyzers, BER testers, and etc. Output signal from transmitter is connected to patch cord (Connector1) represented as coupler model. Output from transmitter is connected as well to PIN receiver and eye diagram analyzer to show transmitter eye diagram and receiver sensitivity. Output from first connector is sent to Multiplot Analyzer block and set as TP2 (test point #2). Also the same output is connected to Encircled Flux Analyzer to monitor the encircled flux requirement. Further the signal is launched to fiber and then to second connector. Output from Connector2 is sent to another Multiplot Analyzer and set as TP3. Then output from Connector2 is inserted into Receiver and to BER Tester block. Eye Diagram Analyzer after receiver is available as well. Characteristics of the blocks ensuring IEEE 10GBase-SR Ethernet standard are given in Figure 1.

VI. SIMULATION

After the topology setting is complete we can run the simulation. For our design the computed BER given in figure 2, is 1.7217e-014 better than BER requirement of 1e-12. According to Ref.[3] current 10GBase-SR link at operational distance 82 meter should have 5 dB allocation for penalties and additional 0.5 dB insertion loss is allowed.

Figure 3 shows the encircled flux plot for the fiber input signal. Encircled flux is a measure of the amount of optical power that is contained *inside the fiber* within a given radial distance from the fiber axis. The encircled flux mask is applied to demonstrate that optical signal satisfy the encircled flux requirement - 4.5-um < 30% and at 19-um > 86%.

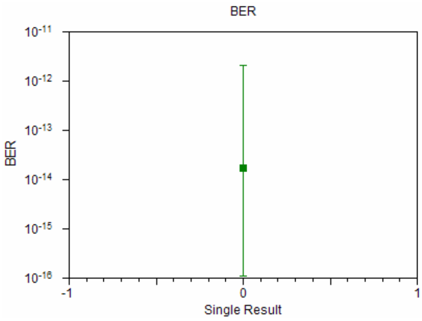


Figure 2 Single run BER result

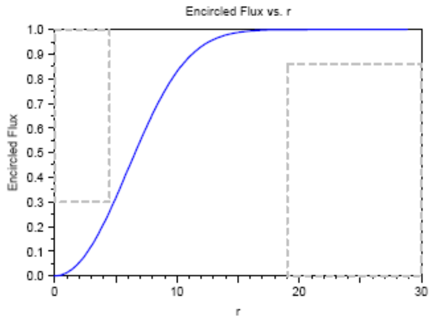
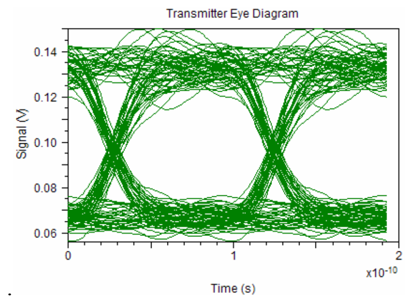
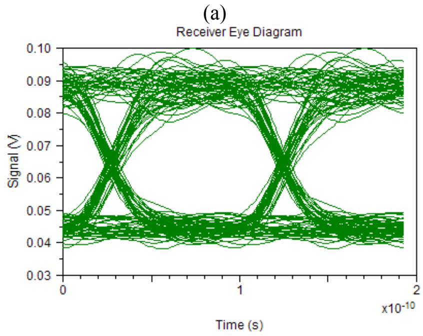


Figure 3 Encircled flux plot with the flux mask at 4.5-um < 30% and 19-um > 86%.



(a)



(b)

Figure4-(a) Transmittereye diagram at TP2, (b) Receiver eye diagram at TP3

Figure 4 shows the transmitter eye diagram and the receiver eye diagram. In this study, eye diagrams are used to obtain information and observe trends under system parameters. Because of the amplitude distortion in the data signal, the height of the eye opening in Figure 4(b) is smaller than in Figure 4(a). However, the signal can be detected without error. [5]

The link performance can then be recalculated at different operating points, such as fiber length, laser wavelength, bitrate, launch power, fiber loss by performing parametric scans. BER values depending on these parameters are illustrated in the Figure 5~9. Eye diagrams which emerge in case of bad case caused by these parameters are shown in the Figure 10~13.

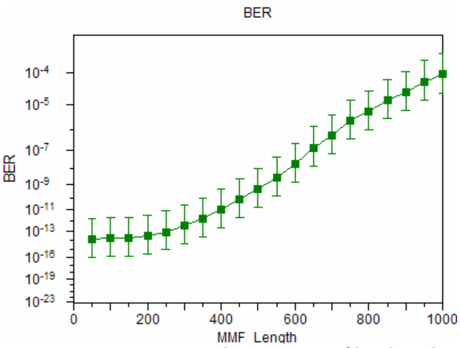


Figure 5 Link BER versus fiber length

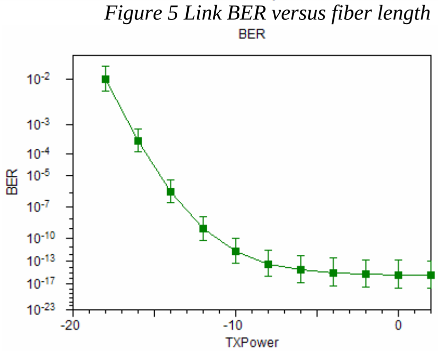


Figure 6 Link BER versus TXpower

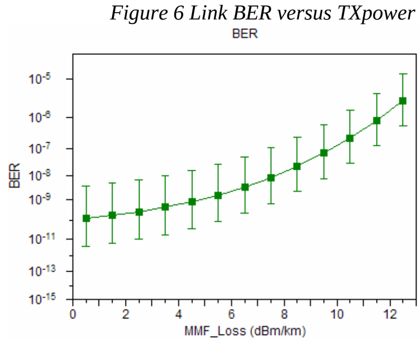


Figure 7 Link BER versus fiber loss

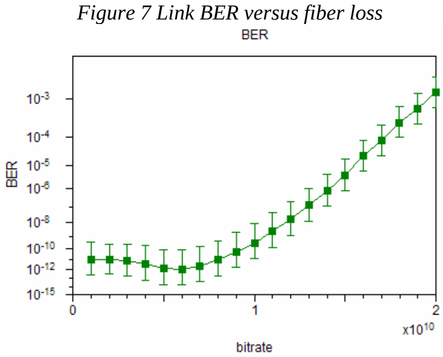


Figure 8 Link BER versus fiber bitrate

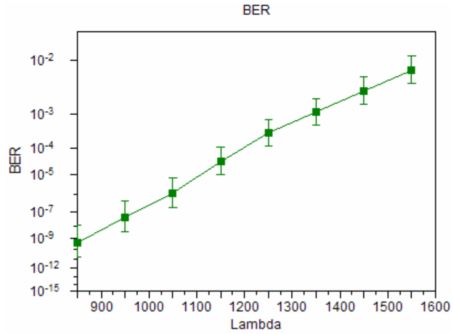


Figure 9 Link BER versus lambda

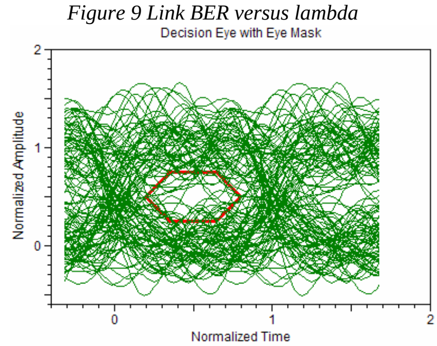


Figure 10 Decision eye with eye mask at -18dBm TXpower

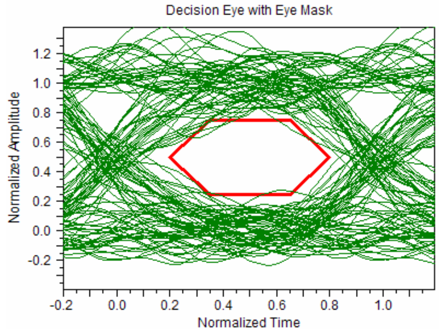


Figure 11 Decision eye with eye mask at 12,5dBm/km fiber loss

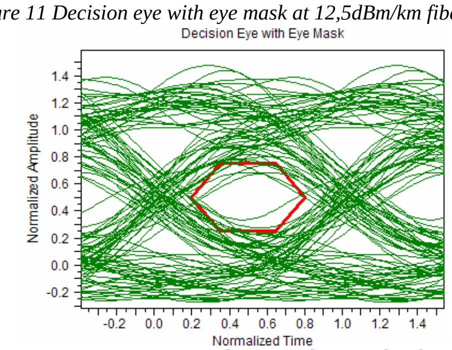


Figure 12 Decision eye with eye mask at 20Gbps bitrate

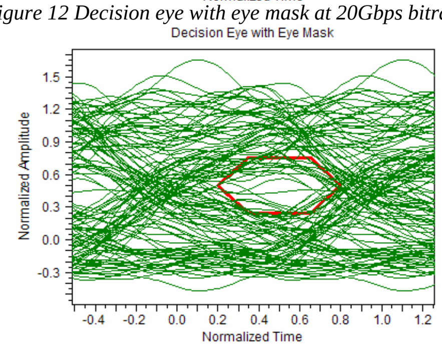


Figure 13 Decision eye with eye mask at 1550nm lambda

According to Figure 5, as the fiber length increases BER increases as well. This indicates that the probability of bit error increases as the performance decreases. Approximately after 350m, 10^{-12} BER value, which is regarded as the minimum BER in terms of LAN standards, can not be achieved.

Since BER is inverse proportional to power, the probability of bit error decreases as the power increases. It is clear in Figure 6. Eye diagram indicating one of the bad case examples is in the Figure 10 when the launched power is at -18dBm.

Since BER is direct proportional to fiber loss, the probability of bit error increases as the fiber loss increases. It is clear in Figure 7. Eye diagram indicating one of the bad case examples is in the Figure 11 when the fiber loss is at 12,5dBm/km

Since BER is direct proportional to bit rate, the probability of bit error increases as the bit rate increases. It is clear in Figure 8. Eye diagram indicating one of the bad case examples is in the Figure 12 when the bit rate is at 20Gbps.

Since BER is direct proportional to wavelength, the probability of bit error increases as the wavelength increases. It is clear in Figure 9. Eye diagram indicating one of the bad case examples is in the Figure 13 when the wavelength (lambda) is at 1550 nm.

VII. CONCLUSION

In this paper, 10GBASE-SR topology has build with OPTSIM tools. The link performance can then be recalculated at different operating points, such asfiber length, laser wavelength, launch power, etc. Obtained results and their getting methods show the advantages of using simulator for solving optic system design issues. Such as, system simulation enables detailed analysis and optimization without the need to build prototypes. Also, impact of statistical variations can be studied, easily. In addition, Link simulation can be combined with device simulation when necessary. Moreover, significant savings in cost, time, and man power.

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