Optical Interconnection System Analysis using SPICE

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With the increasing speed and capacity of data transfer systems, there is a growing interest for optical interconnection systems. In designing optical interconnection systems, reliable and easy-to-use CAD tools are required that can handle both electrical and optical devices. One approach for realizing such CAD tools is using SPICE, a widely used electrical circuit simulator, with equivalent circuit models for optical devices. In this paper, equivalent SPICE circuit models for a laser diode(LD) and a photodetector(PD) are implemented and system analysis is performed for a simple optical interconnection system having LD, LD driver circuitry, fiber, PD, and receiver circuitry as shown in Fig. 1.

The equivalent SPICE model for LD is obtained from the LD rate equations and details can be found from [1]. The circuit model for PD consists of a current source, intrinsic and parasitic elements[2]. In this work, fiber is considered as having only a coupling loss(6dB). The optical signal dispersion in fiber is not considered as its influence is minimal for fiber length usually used in optical interconnection systems. LD driver and receiver circuits are made up of 0.6μm CMOS technology and the current mirror and the differential pair[3] are used for LD driver and transimpedance and voltage amplifiers for receiver[4]. For simplicity, the receiver circuit dose not have functions for auto offset nor auto gain controls. Parasitic elements are included between LD and LD driver, LD and fiber, and PD and receiver, as shown in Fig. 1. Parameters used for our analysis are obtained from the published results but a usual parameter extraction can be done for specific optical devices and parasitics in a given system. Figure 2 shows example of SPICE simulation results for LD drive currents, LD output power, and receiver output voltages. The LD bias current is 3.0mA and it is modulated with 3.76mA at 500Mbps.

In order to demonstrate the utility of our approach, bit error rate(BER) and eye diagrams were obtained from the SPICE simulation results. For BER calculation, it was assumed that the noise is dominated by the thermal noise. For eye diagrams, a pseudorandom NRZ data pattern with 2^7-1 bits was used. Figure 3 shows the transmitter powers required for 10^{-15} BER as function of desired transmission bit rates for two different bias schemes: one with the bias level at 1.2 times threshold current(I_{th}) and the other for zero bias. Zero bias requires less transmitter power but the resulting optical output suffers from LD turn-on delays. From the figure, it can be clearly seen that the zero-bias scheme has an advantage in transmitter power dissipation if the bit rate is not too high. The reason for poor performance of zero-bias scheme for high bit rates can be easily demonstrated from receiver output eye diagrams for 500Mbps as shown in Fig. 4. The transmitter power is selected so that 10^{-15} BER can be achieved in each case. There exist significant timing jitters that are resulted from LD turn-on delays when biased below threshold. Our simulation results agree quite well with results obtained using an analytical model[5]. But our approach based on SPICE can provide an environment in which system designers can perform various optimization processes for optical interconnection systems just like they do for electrical circuit systems.

In summary, SPICE is used as a CAD tool for optical interconnection systems by implementing SPICE models for optical devices. From the SPICE simulation results, optical interconnection system analysis is performed. We believe such an approach can be quite useful for designing and analyzing various optical interconnection systems.

Reference

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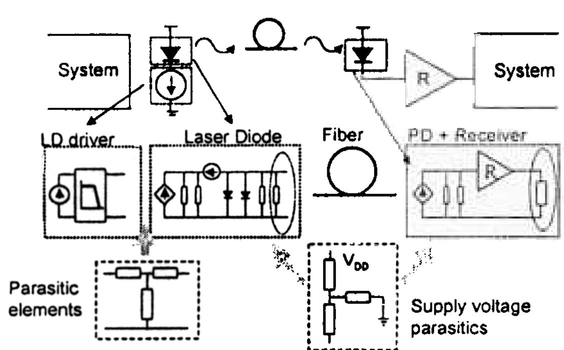

Figure 1. A schematic diagram for optical interconnection system investigated in the paper.

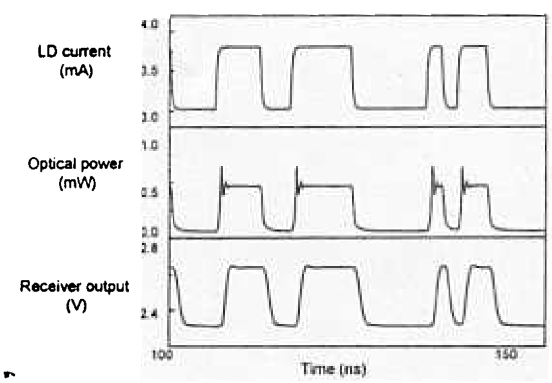

Figure 2. Waveforms of LD injected current, LD output power, and receiver output voltage.

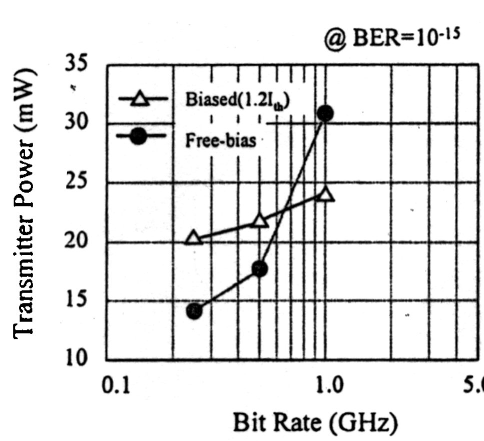

Figure 3. Relationship between min. transmitter power and bit rate for BER=10^{-15}

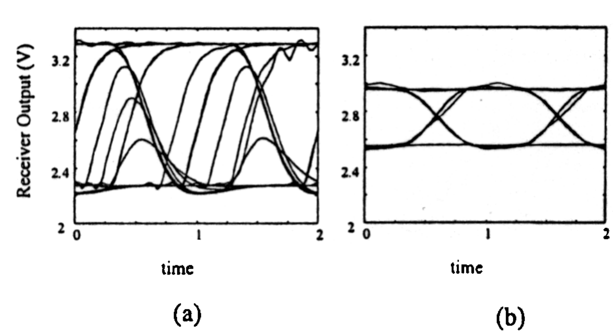

Figure 4. Receiver output eye diagrams for 500Mbps: (a) biased (b) zero-bias scheme. Transmitter powers are determined for 10^{-15} BER.