Modeling and Simulation of Optoelectronic Systems Using VHDL

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Abstract

In this article, use of VHDL to model and simulate optoelectronic devices and interconnection networks is presented. In order to model the optoelectronic devices such as waveguide splitter, waveguide bending, wavelength division (De)multiplexing, an optical package was designed. In this package we defined the optical signal properties and the corresponding computation modules needed to determine the optical signal propagation delay, loss and other parameters. We then build an optical link network using the optical device models we developed. Simulation results show that the use of VHDL and EDA system based on VHDL to model and simulate optoelectronic systems reduces the design and verification time, improves productivity, yields technology-independent system designs, and makes the design refinement process efficient and fast.

Keywords: VHDL. Simulation, Optoelectronic Link Simulation.

1 Introduction

The relatively low loss, virtually interference free and ultra-high bandwidth of optical fiber-based systems for applications ranging from long distance communications to MCM clock distribution networks indicate that optoelectronic subsystems will be found in more and more computer and communication systems. The design and verification processes of VLSI systems benefit greatly from the use of Electronic Design Automation (EDA) tools in all phases of product development. The technology for development and design refinement of optoelectronic systems should migrate from present day bread-boarding to a new step where design automation technologies, such as those for VLSI systems, can be effectively utilized. The ability to model and simulate electronic and optical systems in a unified environment is highly desired. There are no dedicated design automation tools to date for optoelectronic systems that can model and simulate the system in an integrated manner and at various levels of abstraction. Here we introduce automated systems which can perform the modeling and verification tasks for today's large scale, highly complex optoelectronic systems in a reasonable amount of time and at a relatively low cost.

More and more EDA tools use VHDL as their system specification language. VHDL is an imperative programming language that can best be used to model systems' structure or behavior at all levels of abstraction, from abstract system behavioral level to logic level (even circuit level with the introduction of VHDL-A). Moreover, VHDL has concurrent language constructs that can be used to describe electronic/optical signal propagations [1, 2, 4, 6, 12].

Optical signals are ideal for illustrating the VHDL "transport" VHDL concept. The presence, absence, or propagations of light signals in waveguide have no inertial delays. However, the light signals do carry intensity information in the simulation we describe here. If the intensity information is not of importance in a simulation, the bits '1' and '0' can be used to denote the presence and absence of light signals in the waveguide. When the optical

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signal intensity information is desired in the simulation, VHDL type `real` is used to represent the optical signal intensity as a real number.

Since VHDL is primarily used as a digital hardware description language, it is not possible to directly model light beam propagation in waveguide in great physical detail using methods such Beam Propagation or the Finite Element Method [10]. However, for the study of the behavior of a large scale system, it is not efficient to simulate the entire system at a very low level. Higher than physical device modeling level can be used to perform efficient simulation for system behavior evaluation using different system configurations and parameters. In VHDL, this can be efficiently achieved. In the simulation model we use in this paper, we build a 16-node H-tree optical signal linking network using a few basic simple devices[7, 8], and by varying the parameters of the basic devices, we can observe the effects on the network performance. It is also very convenient to construct different optical network configurations using the basic devices described in VHDL. As a result, the behavior of optical signal propagation in different network configurations and various device parameters can be evaluated with very little effort in high level programming and virtually no hardware cost.

In the following section, we briefly describe the basic photonic devices and their VHDL descriptions at behavioral level. We then construct a 16-node H-tree optical network using the basic devices that are built. In section 3 we discuss simulation method and results for different system configuration parameters. Section 4 is the conclusion of this article.

2 Photonic Devices and Optical Network in VHDL

We used pure VHDL to model the basic optical devices. The basic devices are ***straight waveguide, waveguide bending, beam splitter, input coupler, output coupler, wavelength division multiplexor,*** and ***wavelength division de-multiplexor***. The corresponding models for the basic devices are described at behavioral level. The models are based on the coupled mode theory. The straight waveguide, the waveguide bending and the beam splitter are used as building blocks to construct a 'T' shaped basic entity in Figure 1. Three 'T' shaped basic entities are in turn used to build a 'H' block. The 16-node

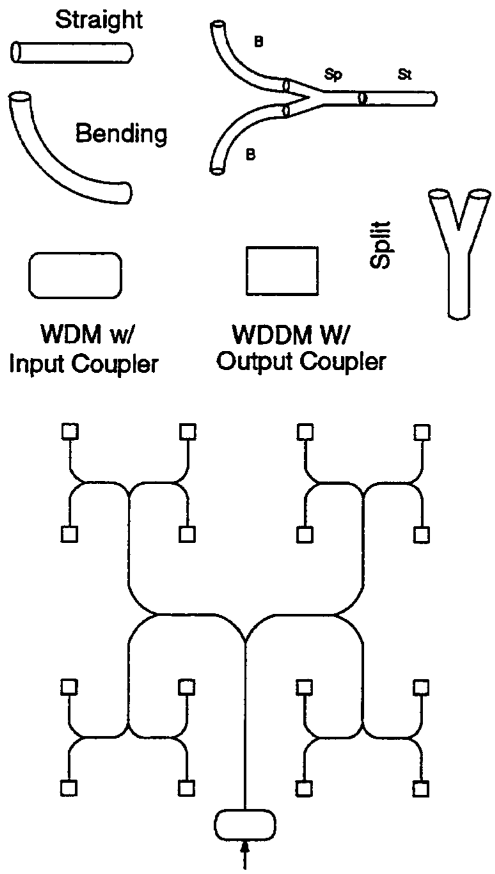

Figure 1: Basic Optical Devices and H-tree

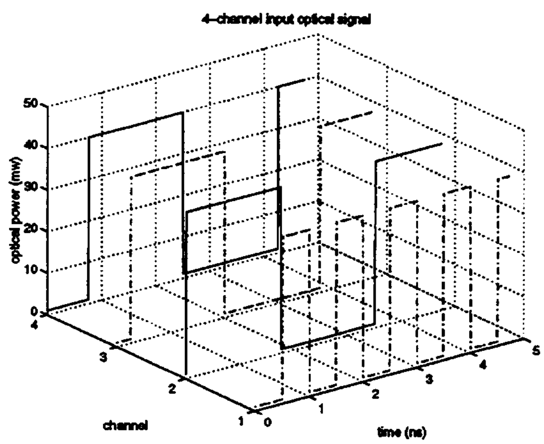

Figure 2: 4-channel Optical Input Signals

H-tree is then constructed using 5 `'H'` blocks [9]. Figure 1 are the basic devices and the 16-node H-tree built using the basic blocks. For the H-tree, there is one `WDM/Input Coupler` connected to the input waveguide for the network, and there is one `WDDM/Output Coupler` connected to each of the 16 output nodes of the H-tree. For the 4-channel 16-node H-tree, a total of 145 basic devices are used, including the multi-channel input/output couplers. The WDM and WDDM channels of the H-tree network are scalable by simply altering the parameter that specify the WDM and WDDM channels.

For wavelength division multiplexor, we assume that each channel (wavelength) only couples with two channels that are adjacent to it. This is a simple first order approximation [3, 5, 11]. More complicated models can be specified for more accurate coupling effect behavior modeling.

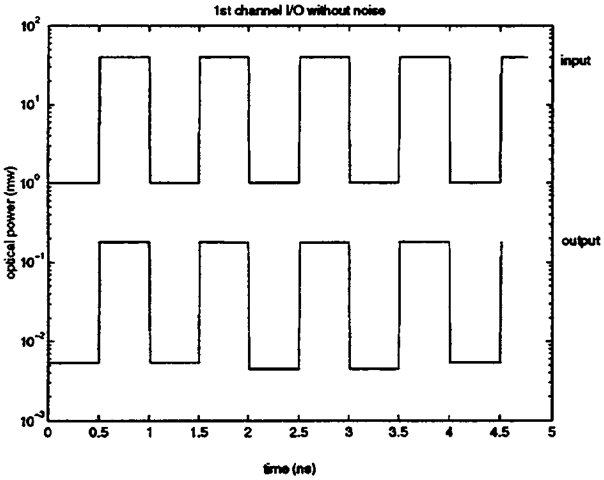

Figure 3: 1st Channel I/O Signals (No Noise)

3 Simulation of the Optical Link Network

For the wavelength division multiplexor and demultiplexor, we assume 4 channels are used. The simulation program in VHDL is written in a way such that any number of channels can be specified by giving an integer to a VHDL generic. Simulation of the 16-node 4-channel H-tree are discussed in this section. The input optical signals are illustrated in Figure 2.

The first channel input signal is a 1 *GZ* non-return-to-zero signal. The 2nd, 3rd and 4th channel input signals are 0.2857142 *GZ* non-return-to-zero signals, with a delay of 0.25 ns and 0.75 ns for the 3rd and 4th channel relative from 2nd channel. the waveforms for the channels are (0,1,0,1,0,1,0,1,0,1), (1,0,1), (0,1,0,1) and (0,1,0,1).

3.1 Simulation with No Noise

The first simulation we presently conducted is a noise-free optical signal propagation simulation, with the noise index for all devices set to 0.0. For the beam splitter, the splitting ratio is set to 0.5. The output optical signal from each channel of one node in the H-tree should be of the same shape as its corresponding inout signal, with loss in signal intensity and some delay in the signal waveform. Since the size of the network is very small, the delay in optical signal propagation is negligible. Figure 3 is the input/output optical signal power waveform for the first channel. In the simulation we assume zero WDM coupling factor and 0.01 WDDM coupling factor. With the signal propagation loss dominating the the signal intensity, the 0.01 coupling factor in the WDDM is hardly visible in a plot. For this reason the coupling factor is enlarged in later simulation deliberately to see its effects on the system behavior.

3.2 Simulation with Noise

When the noise effect is simulated, we assume the WDM generates a 10% noise relative to the input signal. The noise source is isolated to WDM only. The rest of the basic optical devices are assumed to be noise-free. By isolating noise source to some devices, it is possible to study the effect of noise in the propagation of optical signals in the optical network. The noise is generated by a uniform pseudo random number generator. The noise effect can be easily examined by varying the noise-index magnitude for each device via VHDL generic map. When the noise-index for a particular device is set to zero, it is assumed that this particular device does not generates any noise to the optical signals propagates through it. Figure 4 is the illustration of a 10% noise generated by the WDM. The noise is applied to all 4 channels.

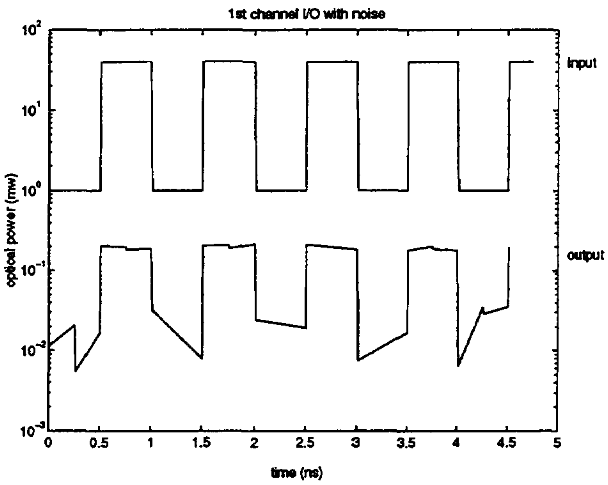

Figure 4: 1st channel I/O Signals with 10% Noise

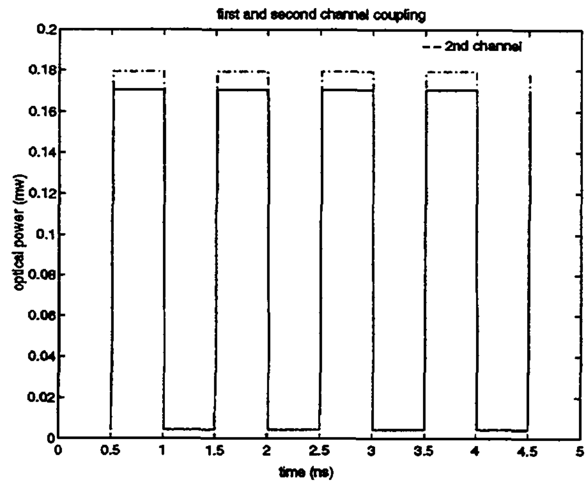

Figure 5: Coupling of 1st and 2nd Channel

3.3 Simulation with Varying Splitting Ratios

The splitting ratio for a beam splitter is 0.5 for the previous simulations. That is, a symmetric beam splitter is assumed. However, the effects of asymmetric beam splitter can also be studied by varying the beam splitting ratio. In the simulations, the splitting ratios used are 0.5, 0.55, 0.6, 0.65. In the case of a 0.65 splitting ratio, 65% of the optical power propagates to one branch of the beam splitter, 45% to the other branch of the beam splitter. Tabel 3.3 shows the simulation results of the first channel output signal power from two output nodes in the H-tree, one node has the X splitting ration path, the other node has a $1 - X$ splitting ration path, where X is one of $\{0.5, 0.55, 0.60, 0.65\}$.

x	Power x	Power 1-x	x/(1-x)
0.50	0.1776765	0.1776765	1.000000
0.55	0.2601362	0.2128387	1.222222
0.60	0.3684300	0.2456200	1.500000
0.65	0.5074619	0.2732487	1.857143

3.4 Wavelength Coupling Effects

In order to study the coupling effects of wavelength division multiplexor, the wavelength division multiplexor coupling factor for WDM is set to 0.1 for a relatively strong coupling effects. Figure 5 shows the effects of a simple first order coupling mode. From the illustration it is obvious that the two wavelengths that have two neighbor wavelengths have a stronger coupling effects (the optical power magnitude is higher). The two wavelengths that have only one neighbor wavelength demonstrates a relatively smaller effects (a lower optical power magnitude).

4 Conclusions

The use of VHDL to simulate optical network consisting of several basic devices is demonstrated. It is shown here that VHDL can be used to conduct behavioral level and structural style modeling and simulation, thus provides efficient non-physical simulation for optoelectronic systems. The use of VHDL to model photonic devices and circuits is a efficient way to study the behavior of optical links and photonic integrated circuits. The simulation examples presented in this paper shows that using VHDL to simulate optoelectronic systems is viable. By using VHDL, many EDA tools and design methodologies can be employed to carry out mixed electronic/photonic systems simulation. With the introduction of VHDL-A, it is expected that the mixed electronic/photonic systems simulation can be used at physical level for both electronic and photonic devices and more accurate simulation can be performed.

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