

SIMULATIONS FOR FREE-SPACE INTERCONNECTS

Steven P. Levitan, Timothy P. Kurzweg, Jose A. Martinez, Donald M. Chiarulli

University of Pittsburgh, Pittsburgh, PA

Philippe J. Marchand

Optical Micro Machines, San Diego, CA

Abstract: Chatoyant is an opto-electro-mechanical CAD tool developed to meet the needs of systems designers. In this paper, we present the modeling techniques we have implemented in Chatoyant for system level design of mixed technology micro-systems along with simulation results.

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1. INTRODUCTION

We have developed Chatoyant to support modeling and simulation of micro-opto-electro-mechanical systems including micro-optical and mechanical components [1,2]. Chatoyant is built upon the object-oriented simulation engine Ptolemy [3]. Chatoyant's component models are written in C++ with sets of user defined parameters for the characteristics of each module instance. Chatoyant performs static simulations to analyze such effects as mechanical tolerancing, power loss, insertion loss, and crosstalk, while dynamic simulations analyze data streams with techniques such as noise analysis and BER calculation. To maximize our modeling flexibility, our signals are composite types, representing the attributes of force, displacement, velocity and acceleration for mechanical signals, voltages and impedances for electronic signals, and wavefront, phase, orientation and intensity for optical signals. The composite type is extensible, allowing us to add new signal characteristics as needed.

In the remainder of this paper, we present our techniques for system level modeling of optics, electronics, and mechanics. We conclude with an example of a complete multi-domain system.

2. SYSTEM LEVEL MODELING

2.1 *Optical Simulation Method*

For macro-scale systems, on the order of tens of millimeters to meters, we support Gaussian propagation, which characterizes an optical signal as a Gaussian beam. Not having to perform an explicit integration of the optical wavefront at each component results in an accurate simulation with a fast computation time.

However, as we extend Chatoyant to support micro systems, where we are required to model diffractive propagation effects through the refractive and diffractive components (e.g., lenses, apertures, gratings, and mirrors), Gaussian propagation breaks down and a diffractive propagation method must be used. For our diffractive modeling, we have chosen to implement the Rayleigh-Sommerfeld scalar formulation [4], using a Gaussian quadrature method for our integration technique. This choice gives us the diffractive accuracy that we require for micro systems in a reasonable computation time for an interactive simulation tool.

2.2 *Electrical PWL Simulation Method*

For each electrical component, we perform sub-block decomposition of the circuit model of the device, decomposing the design into a linear multi-port sub-block section (including, passive and parasitic devices) and non-linear (i.e., active devices) sub-blocks. Modified Nodal Analysis (MNA) [5] is then used to create a matrix representation for the device. The linear sub-block elements can be directly matched to this representation but the non-linear elements need to first undergo a further transformation. We perform piecewise modeling of the active devices for each non-linear sub-block [6]. When we form each non-linear sub-block, a MNA template is used for each device in the network. The use of piecewise linear (PWL) models is based on the ability to change these models for the active devices depending on the changes in conditions in the circuit, and thus the regions of operation.

The templates generated can be integrated to the general MNA containing the linear components adding their matrix contents to their corresponding counterparts. The size of each of the template matrices is bounded to the number of nodes connected to the non-linear element.

Once the integrated MNA is formed, a linear analysis in the frequency domain can be performed to obtain the solution of the system. Constraining the signals in the system to be piecewise in nature allows us to use simple transformations to and from the time domain without the use of costly numerical integration.

During each time step in the simulation, the state variables in the module will change and might cause the active devices to change their modes of operation. Therefore, we re-compute and re-characterize the PWL solution caused by changes between piecewise models. Depending on the number of segments used in the piecewise linear model, on average there will be a large number of time steps during which the system representation is unchanged, justifying the computational savings of this technique.

2.3 Mechanical Modeling Using PWL Techniques

The general method for solving sets of non-linear differential equations using PWL can also be used to integrate complex mechanical models. The model for a mechanical device can be summarized in a set of differential equations that define its dynamics as a reaction to external forces and given to the PWL solver for evaluation. Our technique models a MEMS device by characterizing its different basic components such as beams, plate-masses, joints, and electrostatic gaps and then using local interactions between components.

Typically, these basic components are only a part of a bigger device made from components that will be characterized using similar expressions. The interaction between components will be constrained to the joint points and also described using similar matrix expressions that interact across mixed domains.

The final step in this method involves the use of a traditional non-linear solver to find the solution for the matrix sets. Our use of a PWL general solver in this phase decreases the computational task even more and allows for a trade-off between accuracy and speed. The additional advantage of using the same technique to characterize electrical and mechanical models allows us to easily merge mechanical, optical and electronic technologies in complex devices.

3. SIMULATION RESULTS

A complete optoelectronic simulation of a 4f optical communication link is presented in Figure 1. The top

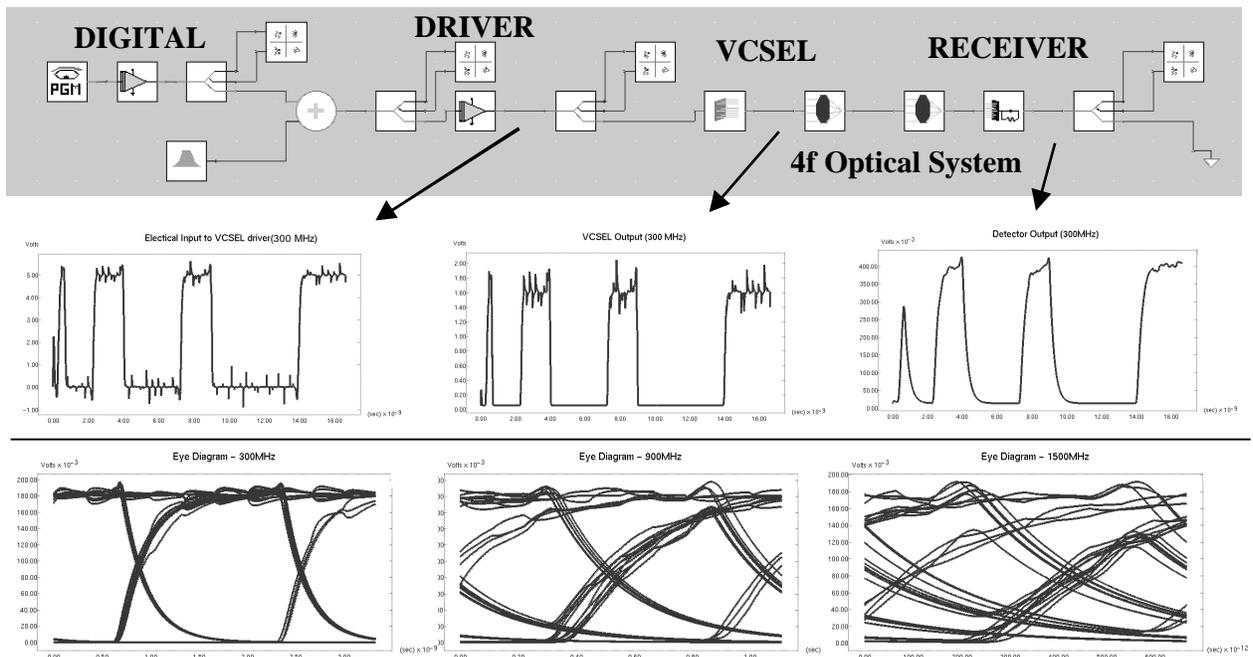


Figure 1. 4f system performance at 300, 900, 1500 MHz

half of the figure shows the system as represented in Chatoyant. Each icon represents a component model, and each line represents a signal path (either optical or electrical) connecting the outputs of one component to the inputs of the next. The input to the system is a signal with speed varying from 300MHz to 1.5GHz.

A Gaussian noise with variance of 0.5V has been added to the multistage driver system to show the ability of PWL models to respond to arbitrary waveforms. In the figure, several snapshots show the behavior of the CMOS drivers under a 300MHz noisy signal. It is interesting to make three observations from the figure: the difference in amplifications in the noise depends on the output level, the immunity to noise and recovery of the signal due to the inverter CMOS sections, and the clipping of negative noise spikes in the source because of the VCSEL threshold.

The three eye diagrams, shown in Figure 1, (at 300MHz, 900MHz, and 1.5GHz) denote the effects of frequency on the quality of the received signal. For the component values chosen, the system operates with reasonable BER up to about 1GHz. Of course, many factors affect this performance and by making different assumptions on component values we can show systems with arbitrarily good (or poor) performance. Our goal here is not to model a particular real system, but to show how we can model a variety of systems, with different component values.

The next example shows a free-space optical MEM switch working in both the bar and cross states. We have interfaced Chatoyant with the fiber propagation package BeamPROP [7] through the use of data files. This allows for the simulation of systems in which light propagates in both fiber and free space. The system setup and simulation results for both switching states are seen in Figure 2. Chatoyant intensity outputs are seen at each component throughout the system. If no mirror is present, the light propagates straight through and achieves a cross connection, as shown by the “light” arrow. However, with the addition of the mirror, the optical path is reflected 90 degrees, as shown by the “dark” arrow, and the bar state is connected. In these simulations, the mirror model is assumed to be ideal, with a 100% reflectivity. As the light propagates through free-space, one can see how the beam waist expands and is focused back onto the fiber. Both the cross and the bar states have less than 1dB of loss through the free-space switching system.

4. References

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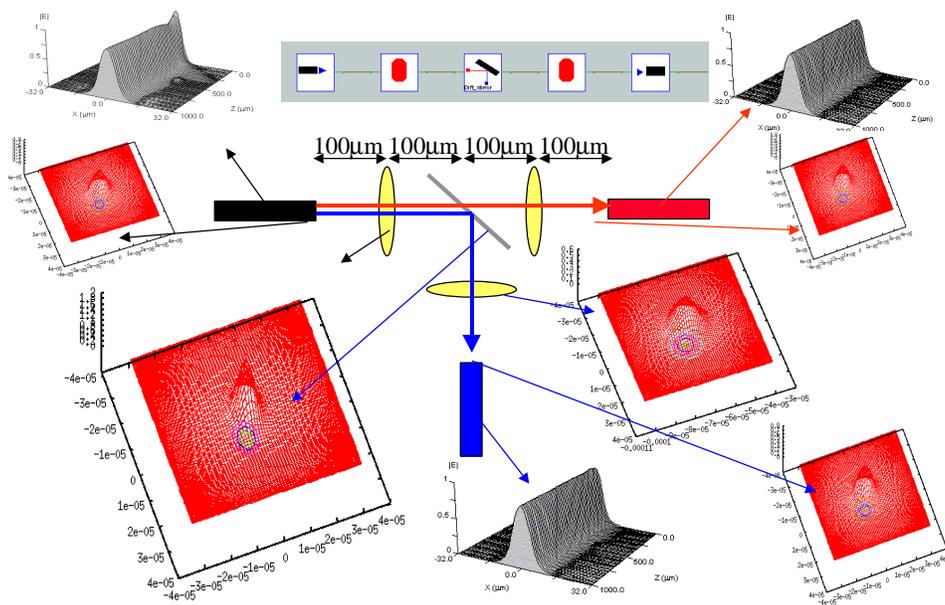


Figure 2. Optical MEM switch simulation