Abstract

Modeling VLSI Interconnections for Cross-Talk Simulation

by J. Poltz

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Introduction

Digital systems utilize frequencies into the GHz range. To achieve reasonable accuracy in simulating these circuits, one must include losses in the interconnect model. This paper presents modeling and simulation of a gate array interconnect. The SPICE model includes all the details which are important for the analysis like uniform and nonuniform multiconductor transmission lines and discontinuities like three-dimensional vias.

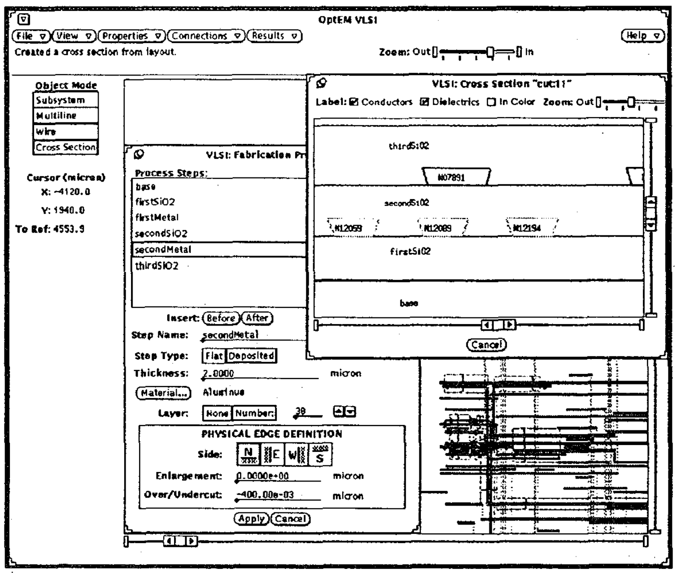

Fig. 1. Gate array layout with selected interconnect for analysis (bottom right), fabrication process steps (on the left) and one of the analyzed cross sections (top right).

Solution procedure

The complex Helmholtz equation was used to solve electromagnetic problems for lossy conductors and lossy dielectrics. The inductance and resistance matrices are calculated together as the imaginary and real parts of the impedance matrix. They are both related to the distribution of currents. Since the current distribution is frequency dependent, the resulting L and R matrices are affected by the selection of frequency. Capacitance and conductance matrices are calculated independently.

The calculation of L, R, C, and G matrices for selected cross sections allows one to build equivalent circuit models for uniform and lossy multiconductor transmission lines. A model of a complex 3d interconnect (Fig. 1) was assembled. Propagation parameters of each section were calculated in order to build an equivalent circuit model (Fig.2). Segments of wires which are not included in the uniform transmission lines are not ignored but are automatically interpolated between uniform sections or extrapolated to connection points. Finally, models of short three-dimensional discontinuities have been added to the simulated structure.

Electrically short transmission lines, like most VLSI applications, can be modeled accurately with lumped circuits. To minimize the number of components the program combines segments by integrating their unit parameters along the wire path. The optimized interconnect model in the form of a SPICE subcircuit can be inserted in the existing schematic to allow analysis of a realistic design. The external circuit has been selected as a voltage pulse driving a single node of the structure. The other 15 nodes have been terminated with 50 Ohm loads. The driving source uses different clock rates and proportionally changed rise- and fall-times. The time domain simulation results are presented in Figure 3. As a result of the inclusion of the interconnect models, noise levels substantially increased.

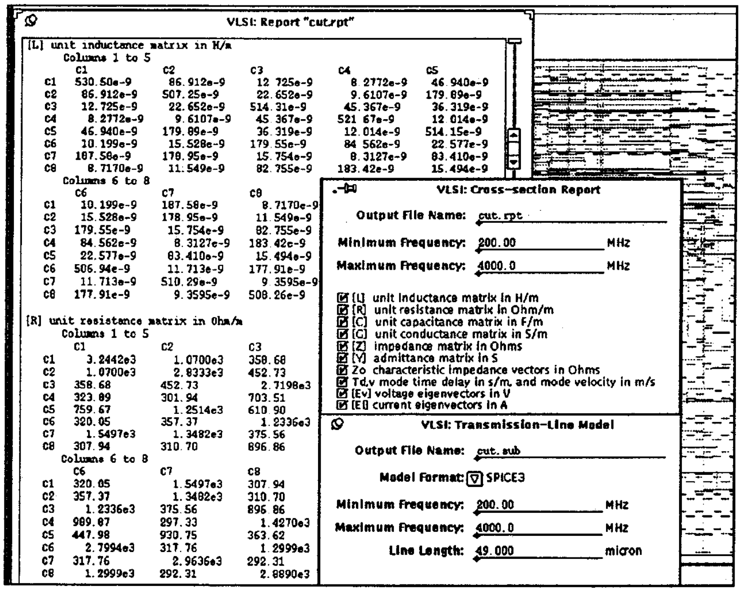

Fig. 2. Solution of the Helmholtz equation for the cross section presented in Figure 1 provides selected transmission line parameters like inductance and resistance matrices (on the left) and SPICE models.

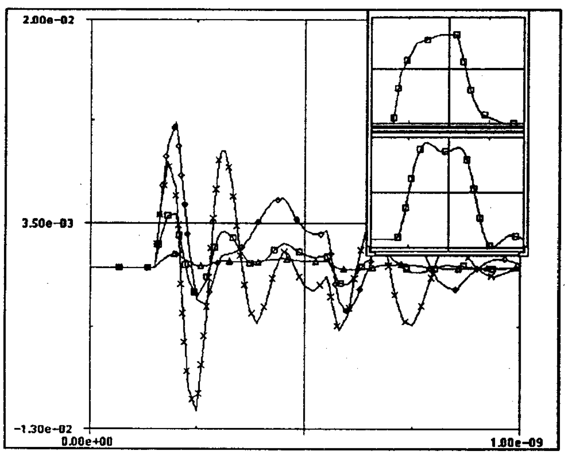

Fig. 3. Signal and cross-talk levels simulated for 1 GHz clock rate.

Results

All circuit simulations have been done for the same physical interconnect presented in Figure 1. The model, however, has been build for different frequencies. The method presented in this paper uses a frequency dependent field solver to calculate unit propagation parameters for a specific frequency (maximum value of the range). When increasing the frequency, an interconnect model was assembled using smaller and smaller lumped components. As a result, the subcircuit model was bigger for higher frequencies which caused the circuit simulation to be more expensive. It is necessary to coordinate the EM field analysis, circuit model building, and final SPICE simulation for the same frequency range. Circuit simulation was performed using Berkeley SPICE 3e1 and ContecSPICE. Very similar results were obtained. The cross-talk results calculated for a broad frequency range provide a strong warning for those who believe that a properly designed circuit (for a lower frequency) will perform equally well for fast clock rates.

Conclusions

- Properly designed circuits, operating at relatively low frequencies, may not perform equally well for fast clock rates; a simulation of the final design and verification of results is required.
- For realistic simulation of high performance systems one has to consider adding interconnect models to the already designed circuit.
- Since VLSI and package interconnects have cross sectional dimensions within the skin depth range, an accurate solution of Helmholtz equation is required. Helmholtz equation allows for the analysis of eddy-currents, proximity and skin effects for quasi-TEM propagation.
- The frequency range for interconnect modeling and for circuit simulation should overlap to allow fast analysis and accurate results.