Abstract

The problem of analysis of the effects of discontinuities in high speed VLSI interconnects has been studied in this work. For sub-nanosecond rise-time of the propagating pulses, the VLSI interconnects are modeled as microstrip lines.

For an uncoupled microstrip line with single or multiple right angle bend discontinuity, the analysis has been carried out by using mode matching technique (MMT). In MMT the microstrip lines are divided into different regions. The fields in these regions are either propagating waves or standing waves. The fields are of fundamental as well as higher order modes. The tangential electric and magnetic fields are matched across the region boundaries and thus one system of linear algebraic equations is formed. This system of equations is solved for the unknown wave amplitudes. These wave amplitudes give the scattering parameters (S-parameters). These S-parameters are used for obtaining pulse response of the microstrip line.

In MMT the microstrip lines are modeled as planar waveguides. The planar waveguides are bounded by magnetic walls on the two sides and electric walls on top and bottom. Thus the effects of coupling, radiation and surface wave are impossible to account for by MMT. Also the question of validity of planar waveguide model at high frequencies poses a limit to MMT. Thus, to take care of the full wave effects like coupling, radiation and surface wave, finite difference time domain (FDTD) method has been used.

Due to limited computer memory the FDTD computation domain has to be truncated by absorbing boundary condition (ABC). For this purpose we have implemented uniaxial perfectly matched layer (UPML) boundary. We have found the optimum UPML parameters to achieve best performance from the UPML.

It is shown by Berenger that PML has a cutoff time and beyond this the FDTD simulation becomes invalid. We have shown that the scaling of permittivity and permeability within the UPML region increases the cutoff time. This increase in cutoff time makes possible the simulation of electrically large structures.

For the structures taken for analysis, it is advantageous to use non-uniform grid. Fine grid spacing is used along the width of the strips while the grid is kept coarse along the length of the strips. The regions outside the strips are discretized using coarse grid. This scheme saves both memory and computer time. Also, this non-uniform grid helps in fitting the structure exactly with the Yee cell faces. This may not be

possible if uniform grid is used.

The VLSI interconnects may not be terminated by matched loads and the source may not be matched. Mostly, interconnects are terminated by capacitances. In order to take the effects of these mismatches, the equation describing the current-voltage relation of the lumped capacitance and resistance are to be solved along with the Maxwell's equations by FDTD. The lumped element is accounted for by adding an additional electric current density term J_L to the Maxwell's equations. The electric current density J_L is found from the current-voltage relationship of that particular lumped element. Let the lumped element to be oriented in the z direction and the current through it is in z direction. The current $I_L = J_L \Delta x \Delta y$ through the lumped element is either proportional to the electric potential or to its time derivative depending upon the passive component modeled, i.e. resistance or capacitance. Other passive and active devices may also be accounted for in the same way.

From the FDTD simulations, the TDRs are found for single and coupled microstrip lines with single or multiple right angle bend discontinuities. As in VLSI the pulses are of trapezoidal nature, we have excited the structures by trapezoidal pulses and found the pulse responses. For obtaining S-parameters, the excitation pulse is taken as Gaussian. The total loss can be found from $1 - \sum\limits_{i=1}^{N} |S_{ij}|^2$; where j is the incident port (j$\leq$N), N being the number of ports.

Radiation loss can be computed by FDTD. For computation of radiation loss, we have used near field to far field transformation (NFFF). The time domain far fields, obtained by FDTD, are then Fourier transformed to get the radiation loss.

For incorporation of conductor loss, surface impedance boundary condition (SIBC) has been used. Recursive convolution has been implemented to account for the frequency dependent nature of the surface impedance. Dielectric loss has been accounted for by taking the non-zero value of conductivity of the dielectric.

The computation of surface wave loss using FDTD method has been illustrated in the literature. It is observed that, like computation of radiation loss, the computation of surface wave loss is also very time consuming. Instead of calculating surface wave loss directly by FDTD method, we have calculated it from the knowledge of S-parameters and the dielectric, conductor and radiation losses. The total loss α_t has been calculated from the knowledge of S-parameters. This total loss has four components: dielectric loss α_d, conductor loss α_c, radiation loss α_r and surface wave loss α_s. The surface wave loss is calculated from $\alpha_s = \alpha_t - \alpha_d - \alpha_c - \alpha_r$.

The FDTD method has also been used for analyzing multi-level microstrip lines. Trapezoidal pulse response and losses (conductor, dielectric, radiation and surface wave) in multilevel crossover with and without bend on SiO_2 substrate has been found.