Fast Electromagnetic Modeling of Massively Coupled Vias in 3-D Interconnects

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For 25 Gbps (clock frequency exceeding ~10 GHz) on-board signals, where the channel link becomes significantly noisy, active-circuit compensation techniques (e.g., pre-emphasis, adaptive equalization, etc.) are used to flatten the roll-off of the channel's insertion loss, to increase the signal-to-noise ratio (SNR). Due to the fact that these active circuits usually need the response of the channel ahead of time, it is critical to build accurate models for the via interconnects.

The dimensions of the via interconnects are comparatively large relative to a wavelength, especially for massively-coupled vias, and hence they become good radiators. This parallel-plate via radiation gives rise to significant electromagnetic interference (EMI), resulting in electromagnetic compatibility (EMC) issues, and it deteriorates the signal integrity (SI). In order to predict the frequency response of a complex multiple via structure, with many vias existing between two metallic plates, we propose a 3D full-wave approach that is based on reciprocity and cylindrical-wave modal expansions. The cylindrical waves are expressed in terms of parallel-plate waveguide modes having vertical and azimuth variations.

In order to compute the Y parameter Y_{mn} of a multiple via structure, the voltage excitation of port n is first replaced by an equivalent magnetic surface current (source frill). Since the dimensions of the antipads (i.e., the port apertures in the ground plane) are much smaller than a wavelength, the field inside the driven (source) antipad is assumed to be that of a TEM mode. The short-circuit port current at any other port is then calculated from the reaction between this source frill and a testing magnetic frill, which is a unit-amplitude magnetic line current that circulates around one of the vias in the azimuth direction at the port m of interest. From reciprocity, this reaction is equivalent to integrating the magnetic field from the testing frill over the magnetic current of the source frill at port n. This surface integral is then reduced to a line integral along the conductor contour of the via/antipad at port n using vector identities. The line integral involves the magnetic vector potential from the testing frill multiplied with the surface charge density of the TEM mode on the via/antipad conductors at the source frill on port n. The surface charge density at the source antipad n is computed from a static potential integral equation using the moment method, and the radiation from the testing frill is calculated from the induced currents on all the posts, found by enforcing the electric field integral equation (EFIE) on the posts.

The simulation results using the proposed approach accurate within 0.1 dB for the insertion loss and 5 dB for the return loss and crosstalk, compared with the commercial general-purpose field solver Ansoft HFSS. The CPU time of this approach is much less than that of HFSS, however.