Modeling of High-speed Printed Circuit Board

Abstract

This thesis is an exercise to investigate the various methods of creating an equivalent circuit model for a high-speed digital printed circuit board (PCB) assembly and to perform computer simulation on such a system. The term high-speed printed circuit board is widely accepted in the engineering community to be refering to PCB which is applied to digital system with operating frequency in excess of 100MHz and transition period of signal (rise time and fall time) less than a nanosecond. Such a digital system can often be found in computer motherboard, plug-in card and communication network card. Due to the high operating frequency and rapid signal transition rate, harmonics up to gigahertz range can often exist during operation. Every physical aspects of the printed circuit board assembly including the components and all metallic structures have to be carefully considered in order for such a system to function properly. A structural approach to modeling the PCB assembly is adopted. The assembly is considered as an integration of parts such as integrated circuits, sockets, connectors, printed circuit board traces, cables, vias, power supply, power planes and discrete components including resistors and capacitors. The structural approach assigns an equivalent circuit to each of the components described above in terms of linear and non-linear circuit elements. The equivalent circuits can be lumped or distributed as in the case of transmission lines. These equivalent circuits are then linked together to form a complete equivalent circuit for a digital printed circuit board assembly. Computer simulation is subsequently performed using commercial SPICE circuit simulator and characteristics of the system can be studied. The range of validity for the equivalent circuit models considered in this thesis is restricted from d.c. to 5GHz or where quasi-TEM approximation applies, whichever is lower. This range is sufficient for present day digital systems with operating frequency not exceeding 500MHz.

Methods for derivation of equivalent circuits can be divided into three categories, i.e. through theoritical analysis, through field solution employing

numerical methods, through measurement in time and frequency domain. Many authors had contributed to the development of modeling and simulation in the past. The author thus strives to consolidate these pieces of information from as many different literatures and journals as possible. Theories of the methods and practical examples of modeling will be presented. For certain component one method is more convenient than the other and this will be pointed out. In addition the following improvements have been archieved during this exercise : (a) Improvement to modeling of power planes in printed circuit board is proposed using planar circuit approach. (b) Extension of the capability of time domain reflectometry with the application of inverse Laplace transformation to derive expressions for estimating stray parameters of discrete components such as resistors, capacitors and inductors. (c) Derivation of lossy resistance matrix for three dimensional structures such as socket and integrated circuit packaging.

Procedures for full system modeling are also considered. A complete system modeling will be carried out as an example. Time domain and frequency domain circuit simulation are performed for the example using IBM compatible PC to illustrate a possible use of the procedures to actual digital system design and printed circuit board layout. Since a complete digital printed circuit board contains hundreds of interconnections and various components scattered on the printed circuit board surface, it is extremely difficult to predict the effect on the system integrity due to certain design decisions. Using structural system modeling and simulation approach provides a real time view of interaction between components and cumulative effects of the system.