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Electrical modeling of ball grid array packages based on one-port S-parameter measurement for electrical evaluation of high-speed test board ☆

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Abstract

To electrically characterize ball grid array (BGA) packages, one-port S-parameter measurements have been performed. Equivalent circuit parameters using the Γ and T models are extracted from measured S-parameters for three different frequency ranges. The accuracy of two selected equivalent circuits is evaluated by comparison between the re-calculated S_{11} using the extracted equivalent circuit parameters and measured S-parameters. The results show that the T lumped model can be used to represent S-parameters of BGA packages without distributed elements up to 2 GHz.

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1. Introduction

Recently, as packages for computer and other telecommunication products require many input/output pins to adopt high signal density, ball grid array (BGA) packages have been used for these applications due to their improved thermal and electrical performances with relatively low cost [1,2]. Besides their superior electrical performance, the advantage of these packages includes easy surface mounting and easy board level assembly due to relaxed lead pitch.

As clock speeds in digital circuits and operating frequency in RF devices are increased [3,4], electrical characteristics of interconnection lines in test boards, such as propagation delay, trace parasitics and impedance mismatch, should be considered in procedure for test board design. Estimation of electrical performance of test boards including connectors, transmission lines, chip inductors, chip capacitors, sockets, and packages is important to design test boards with good performance for accurate chip test. Moreover, since the rising and falling times of digital signals in packages are very short for the applications of computers and communication products, interconnection lines in packages can not be considered single capacitor simply. Therefore, the accurate and simple model including high-frequency effects of used various components in test boards and device packages can be needed for SPICE simulation at test board design process.

Various methods to extract equivalent circuit parameters from S-parameter measurements have been reported. The distributed equivalent circuit parameters can be extracted from two-port S-parameters using optimization procedure in microwave circuit simulator [5], and the frequency dependent parameters can be calculated using relationship between S-parameters and impedance parameters or ABCD parameters [6,7]. For the BGA packages, however, we cannot apply these

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reported methods because the two-port *S*-parameter measurements are not easily applicable.

In this paper, we focused on modeling of BGA packages from one-port *S*-parameter measurements and validation of the accuracy of extracted model parameters. Extracted equivalent circuit parameters of BGA packages are useful to design boards and estimate performance of test boards with models of other components.

2. Measurement of one-port *S*-parameters from BGA packages

The cross-sectional view of an 119 pin BGA package used in our measurements is shown in Fig. 1 and signal paths of selected three traces are depicted in Fig. 2. BGA packages consist of two signal layers with 0.03 mm thickness, four power/ground layers with 0.018 mm thickness and 36 signal traces. The vertical connections are formed by several vias between signal layers (layers 1 and 6) and between power/ground layers. Signal traces on the top layer are microstrip lines with 0.1 mm width and 50 Ω characteristic impedance, and mid-layer traces on layer 3 and layer 4 are striplines with 0.1 mm width and 34 Ω characteristic impedance. The hole and pad diameters of vias are 0.1 and 0.2 mm, respectively. The ball diameter is 0.6 mm and pitch between balls of 119 pin BGA package is 1.3 mm. BT resin, its dielectric constant of 4.5, was used for the substrate material for the BGA package.

For the 119 pin BGA package, the signal pins in the top layer are placed between ground pins to reduce crosstalk between signal pins, and these configurations form the ground–signal–ground structures as shown in Fig. 2 [8]. Due to these configurations, signal pins could be accessed by direct probing with a GSG-type microwave probe, its pitch of 150 μm, to measure *S*-parameters of BGA packages.

If two-port *S*-parameters were available by measurements, the characterization of traces in BGA packages could be achieved easily. However, two-port *S*-parameter measurements were not easily applicable for BGA packages because the ball side of BGA packages was difficult to be accessed by microwave probe station or network analyzer. Instead of measuring of the two-port *S*-parameters, we measured one-port *S*-parameters up to 2 GHz using an HP 8753C network analyzer either by shorting or opening ball side of BGA packages. Measurements of one-port *S*-parameters for open load and short load from the 119 pin BGA package were performed without and with gold plated Cu block in Fig. 1, respectively. We extracted the equivalent circuit parameters from measured one-port *S*-parameters to characterize the traces in BGA packages.

Before measurements, one-port full calibration with an impedance standard substrate was carefully performed to de-embed parasitics of probe and cable.

3. Parameter extraction using Γ and T equivalent circuit models

For the multilayer packages such as BGA packages, the signal traces including the transmission lines, vias, and several discontinuities can be modeled by a lumped equivalent circuit using resistance, inductance, capacitance and conductance when the rising and falling times of signals are very larger than delay time due to the signal traces of packages [9]. In BGA packages, the mutual effect between adjacent signal traces is very small enough to neglect because the signal traces are placed between ground traces. Self-capacitance and inductance values are much interesting than the mutual capacitance and inductance values in the capacitance and inductance matrices.

We selected the lumped Γ and T models, generally used for circuit modeling of transmission lines, as equivalent circuit models for interconnection lines of BGA packages because of simplicity of these models. Among *RLCG* parameters in these models, *G* parameters can be ignored because their values are too small to affect the electrical performance due to low dielectric

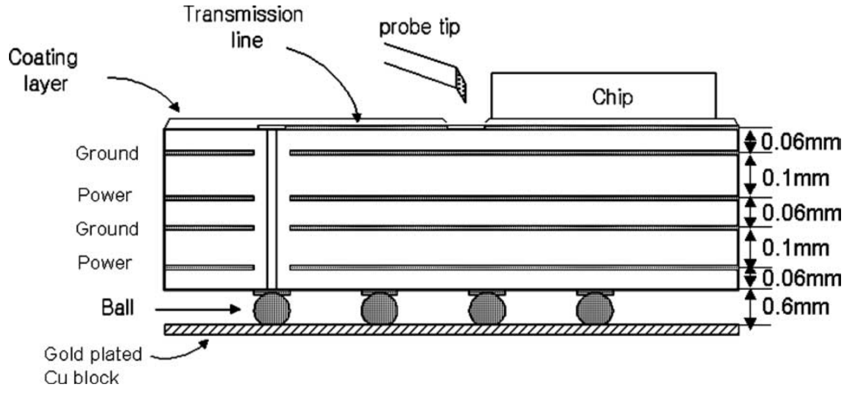

Fig. 1. Cross-sectional view of BGA packages electrically analyzed using measurements. The ball side of BGA packages is shorted in this figure. For open load, gold plated Cu block is excluded.