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Finite element model verification for packaged printed circuit board by experimental modal analysis

Ying-Chih Lee [a,b], Bor-Tsuen Wang [c], Yi-Shao Lai [a], Chang-Lin Yeh [d], Rong-Sheng Chen [b,*]

[a] *Central Labs, Advanced Semiconductor Engineering, Inc., Kaohsiung 811, Taiwan*
[b] *Department of Engineering Science, National Cheng Kung University, Tainan 701, Taiwan*
[c] *Department of Mechanical Engineering, National Pingtung University of Science and Technology, Pingtung 912, Taiwan*
[d] *Shanghai Engineering Center, Advanced Semiconductor Engineering, Inc., Shanghai 201203, China*

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ABSTRACT

In this work, the experimental modal analysis (EMA) was performed to establish an equivalent finite element (FE) model for a standard Joint Electron Device Engineering Council (JEDEC) drop test printed circuit board (PCB) mounted with packages in a full array. Material properties of the equivalent FE model of the packaged PCB were calibrated through an optimization process with respect to natural frequencies based on EMA results obtained with a free boundary condition. The model was then applied to determine screwing tightness of the packaged PCB corresponding to a fixed boundary condition with the four corners of the PCB constrained, as defined by JEDEC for a board-level drop test. Modal damping ratios of the packaged PCB were also provided.

1. Introduction

The integrity of solder joints in electronic packages under medium to harsh dynamic loading environments has become a critical issue with the prevalence of portable electronic devices as well as the introduction of stiff and brittle Pb-free solder alloys [1,2]. Several accelerated board-level reliability testing standards aiming at evaluating solder joint reliability that corresponds to these dynamic loading environments, such as cyclic bend [3,4], drop impact [5,6], or vibration [7–12], have been proposed by the Joint Electron Device Engineering Council (JEDEC) [13–16] and have been followed by the industry in qualifying the products.

For the design purpose, the finite element analysis (FEA) has long been proven to be conducive in selecting proper structural configurations and materials for electronic packages without the need of costly and time consuming experiments. However, the accuracy of numerical solutions depends greatly on the feasibility of modeling that includes proper settings of geometry, boundary and loading conditions, and material properties. For FEA of a board-level test, modeling of the printed circuit board (PCB) is generally considered as the source that brings the most uncertainty to the numerical solutions. Overall mechanical properties of the PCB can vary according to different numbers of metal layers, different layouts of circuits, and different polymeric and composite reinforcing materials used in the fabrication. Tiny circuits and their complex layouts inside the PCB also limit the possibility of comprehensive modeling of the PCB.

We note, however, if the concern is only with overall mechanical properties of the PCB or the board- or system-level test vehicle that contains PCB and packages mounted onto it, an experimental modal analysis (EMA) [17] can practically determine modal parameters, including natural frequencies, mode shapes, and damping ratios, of the specific PCB or board- or system-level test vehicle without the need of prerequisite information of material properties and layouts of its individual constituent components [18–20]. An equivalent finite element (FE) model calibrated by modal parameters obtained from EMA can thus be used with more flexibility for the design purpose [5,21].

In the present work, we followed EMA to characterize modal parameters of a standard 132 × 77 × 1 mm JEDEC drop test board [13,15] mounted with 13 × 13 mm packages in a 3 × 5 full array, as shown in Fig. 1. The packaged PCB arranged with free and fixed boundary conditions are shown in Fig. 2. As depicted by the procedure in Fig. 3, material properties of the equivalent FE model of the packaged PCB were calibrated through an optimization process based on EMA results obtained with a free boundary condition. The model was then applied to determine screwing tightness of the packaged PCB corresponding to a fixed boundary condition with the four corners of the PCB constrained, as defined by JEDEC for a board-level drop test [13,15].

2. EMA and FEA

Experimental setups for EMA on the packaged PCB with free and fixed boundary conditions have been shown in Fig. 2. To avoid interference, hammering was performed on the reversed side of

* Corresponding author. Tel.: +886 6 2757575x63328; fax: +886 6 2766549.
E-mail address: rschen@mail.ncku.edu.tw (R.-S. Chen).

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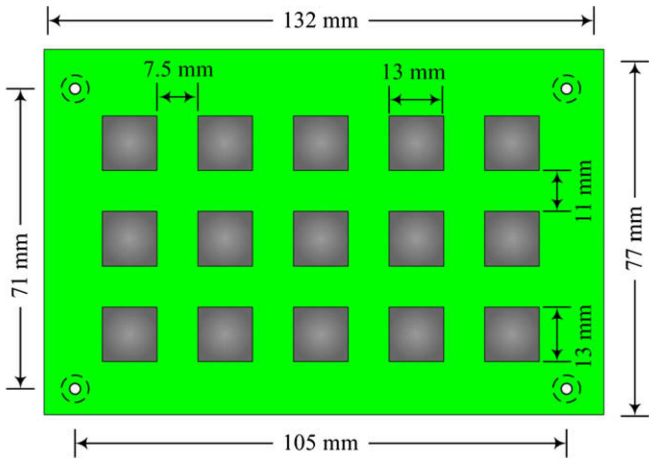

Fig. 1. Schematic of packaged PCB (not to the scale).

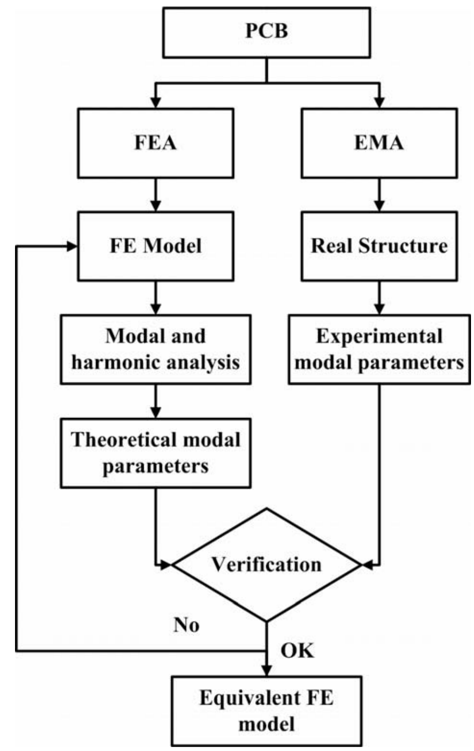

Fig. 3. Procedure for equivalent FE model establishment.

the packaged surface, Fig. 4, in which the locations where the accelerometer was affixed are labeled. For the free boundary condition, we measured hammering force and acceleration responses corresponding to hammering locations in a 17 (vertical) × 29 (horizontal) array on the surface, shown by the black dots in Fig. 4. For the fixed boundary condition, hammering force and acceleration responses corresponding to 88 hammering locations along the A1 through A4 lines shown in Fig. 4 were measured. The frequency response functions (FRFs) between measured hammering force and acceleration responses were then curve-fitted to extract experimental modal parameters of the packaged PCB.

Fig. 5 shows full three-dimensional FE models built for the packaged PCB with free and fixed boundary conditions. The model for the packaged PCB contained 12,335 linear hexahedral solid elements along with 24 mass elements to take into account the accelerometer mass. For the fixed boundary condition, 192 additional linear spring-damper elements were employed to account for the tightness of screws at the four corners; the torque applied to tighten the screws was 8 kgf-m. The damping effect of the screws was neglected in this study while only the spring effect was considered. The spring constant was assumed to be constant and was to be determined in the subsequent optimization procedure after the material properties of the packaged PCB were determined from the optimization based on EMA and FEA results for the free boundary condition.

Initial material properties extracted from Yeh and Lai [22], listed in Table 1, were specified to PCB and packages. We assume that the packages are isotropic while the PCB is cubic with three

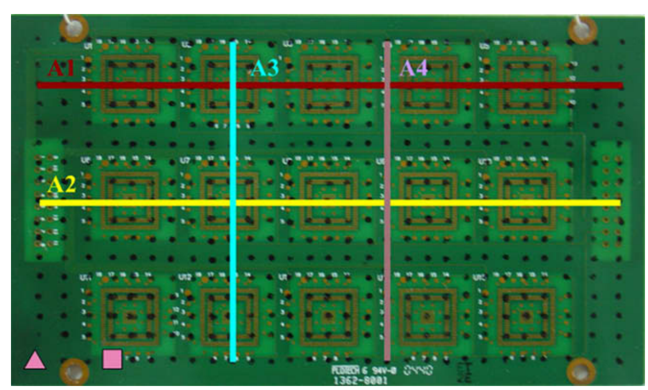

Fig. 4. Grid of measurement points (Accelerometer locations: ▲ for free; ■ for fixed).

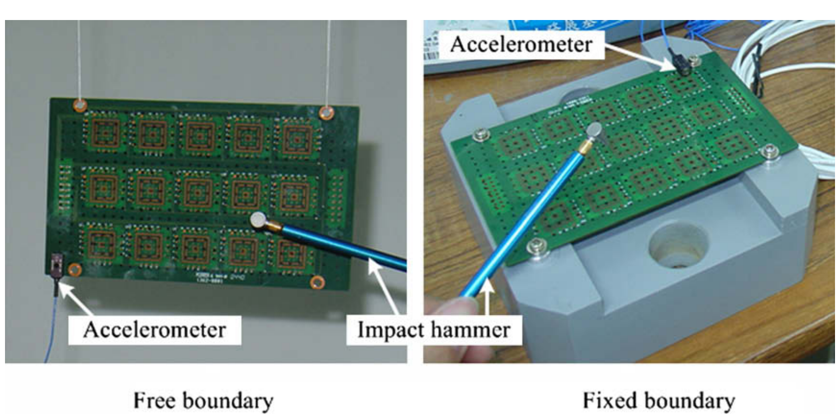

Fig. 2. Packaged PCB with free and fixed boundary conditions (packages on reversed side).