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IPC/JEDEC-9704

# Printed Wiring Board Strain Gage Test Guideline

Developed by the JEDEC Reliability Test Methods for Packaged Devices Committee (JC-14.1) and the SMT Attachment Reliability Test Methods Task Group (6-10d) of the Product Reliability Committee (6-10) of IPC

Users of this publication are encouraged to participate in the development of future revisions.

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# Acknowledgment

Members of the JEDEC Reliability Test Methods for Packaged Devices Committee (JC-14.1) and the SMT Attachment Reliability Test Methods Task Group (6-10d) of the IPC Product Reliability Committee (6-10) have worked together to develop this document. We would like to thank them for their dedication to this effort. Any document involving a complex technology draws material from a vast number of sources. While the principal members of the SMT Attachment Reliability Test Methods Task Group are shown below, it is not possible to include all of those who assisted in the evolution of this standard. To each of them, the members of JEDEC and IPC extend their gratitude.

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# Printed Wiring Board Strain Gage Test Guideline

## 1 SCOPE

This document describes specific guidelines for strain gage testing for Printed Wiring Board (PWB) assemblies in the board manufacturing process including, assembly, test, system integration and board shipping.

The suggested procedure enables board assemblers to conduct required strain gage testing independently, and provides a quantitative method for measuring board flexure, and assessing risk levels.

The topics covered include:

- Test setup and equipment requirements
- Strain measurement
- Report format

This document assumes a surface mount device; Ball Grid Array (BGA), Small Outline Package (SOP) and Chip Scale (Size) Package (CSP) are typical device examples. Discrete Surface Mount Technology (SMT) devices, (e.g., capacitors, resistors, etc.) are outside the scope of this publication.

**1.1 Purpose** Strain gage testing allows objective analysis of the strain and strain rate levels that a SMT package is subjected to during PWB assembly, test and operation.

Characterization of worst-case PWB strain is critical due to the susceptibility of component solder joints to strain-induced failures. Excessive strain can result in solder joint damage for all package substrate plating finishes. Such failures include solder ball cracking, trace damage, pad lifting (shown in Figure 1-1) and substrate cracking during board manufacturing and test processes.

**1.2 Background** Board flexure control using strain gage measurement has proven very beneficial to the electronics industry, and continues to gain acceptance as a method to identify damaging manufacturing processes. However, as interconnect densities have increased and become more fragile, the potential for flexure-induced damage has increased. Many board assemblers are now required to operate under strain levels specified by their customers or component suppliers.

As strain measurement technology has matured, different methodologies have developed. Variations in strain gage methodology inhibit reliable data collection and prevent data comparison across the industry. This document addresses variations in gage mounting, gage placement, experiment design, data acquisition system variables, and strain metrics.

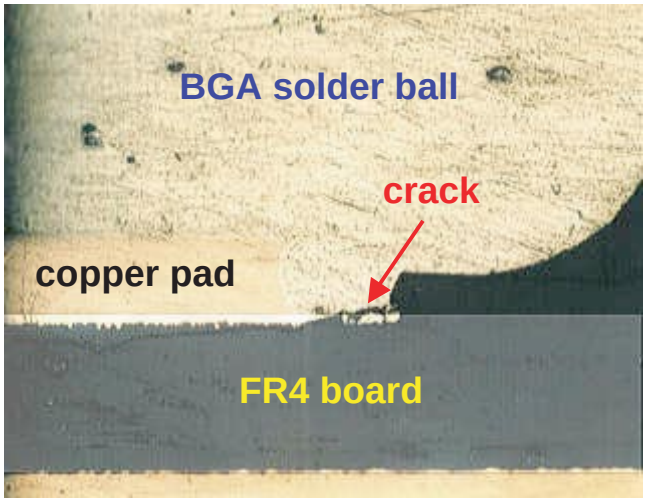


**Figure 1-1 Lifted Pad**

PWB strain measurement includes application of strain gages to the board at specified components, and then subjecting the instrumented board to various test and assembly operations. Test and assembly steps which exceed strain limits are deemed excessive and are identified so that corrective actions can be made. Strain limits may come from the customer, component supplier or internal best known practices. Examples of strain measurement criteria are shown in Appendix A.

By identifying areas sensitive to manufacturing variation, strain gage testing provides insight into the effects of a production ramp. Strain gage measurements become the baseline for future process improvement activities, and quantify the effectiveness of adjustments. Manufacturing steps that are typically characterized are listed below:

1. SMT assembly process:
   - Board depanelization (routing) processes
   - All manual handling processes
   - All rework and retouch processes
   - Connector installation
   - Component installation
2. Board test processes:
   - In-Circuit Test (ICT)
   - Board Functional Test (BFT), or equivalent functional test
3. Mechanical assembly:
   - Heat sink assembly
   - Board support/stiffener assembly

- System board integration, or system assembly
- Peripheral Component Interconnect (PCI) or daughter card installation
- Dual In-line Memory Module (DIMM) installation

4. Shipping Environment

Assembly processes for different boards and assemblers vary. Tests such as ICT and BFT are referred to generically in this document; nomenclature can vary at different manufacturing sites. In such cases, apply the same requirements to the equivalent test processes. However, the goal is to characterize all assembly steps involving mechanical loading. Do not constrain testing to the steps listed above, or only to perceived high risk areas. The data from these tests serve as a baseline for future reference.

**1.3 Terms and Definitions** The definition of all terms used herein shall be in accordance with IPC-T-50 and as defined below.

***Component*** Packaged semiconductor device

***Interconnect*** Conductive element used for electrical interconnection, e.g., solder ball, lead, etc.

***Microstrain*** Dimensionless unit, $10^6$ x (change in length) ÷ (original length)

***Principal Strain*** The maximum and minimum normal strains in a plane, always perpendicular to each other and oriented in directions for which the shear strains are zero.

***Rosette*** Strain gage containing two or more independent grids for making measurements of strain along each of their axes about a common point.

***Stacked Rosette Strain Gage*** Strain gage rosette constructed of grids stacked one above the other about a common point.

***Strain*** Dimensionless unit, (change in length) ÷ (original length)

***Strain-Rate*** Change in strain divided by the time interval during which this change is measured

***Strain Gage*** Planar metallic foil pattern that is adhered to an underlying surface and exhibits a change in resistance when subjected to a strain.

***Strain Gage Element*** Sensing area of strain gage defined by the serpentine metallic grid pattern.

**1.4 Future Studies** Continued research on this topic will focus on the refinement of prescribed strain limits, as well as research on dynamic impulse events (e.g., drop and shock for bare PWBs, assembled systems and shipping packages). This is important as there is increasing evidence of BGA brittle fractures that are induced outside of the manufacturing and test process. Printed Wiring Board Assemblies (PWBA) are just as susceptible during shipment. The presented guidelines will continue to be refined based on this research.

## 2 APPLICABLE DOCUMENTS

The following documents are applicable and constitute a part of this specification to the extent specified herein. Subsequent issues of, or amendments to, these documents will become a part of this specification. Documents are grouped under categories as IPC, Joint Electron Device Engineering Council (JEDEC), American Society for Testing and Materials (ASTM) and others depending on the source.

### 2.1 IPC[1]

**IPC-T-50** Terms and Definitions for Interconnecting and Packaging Electronic Circuits

**IPC-D-279** Design Guidelines for Reliable Surface Mount Technology Printed Board Assemblies

**IPC-7095** Design and Assembly Process Implementation for BGAs

**IPC-9701** Performance Test Methods and Qualification Requirements for Surface Mount Solder Attachments

**IPC/JEDEC-9702** Monotonic Bend Characterization of Board-Level Interconnects

### 2.2 ASTM[2]

**ASTM E1561-93** (Reaffirmed 2003) Standard Practices for Analysis of Strain Gage Rosette Data

### 2.3 Other Publications

Code of Practice, for installation of electrical resistance strain gauges, British Society of Strain Measurement (www.bssm.org)

## 3 GENERAL REQUIREMENTS/GUIDELINES

An overview of the strain gage measurement process for both board and system assembly is depicted in Figures 3-1 and 3-2.

Manufacturing assembly and test steps where strain measurements should typically be taken are depicted by the strain measurement icon in Figures 3-1 and 3-2. Multiple iterations or actuations of each process step can help characterize the associated process variance. This can also provide insight into situations where there is complex bending.

1. www.ipc.org
2. www.astm.org

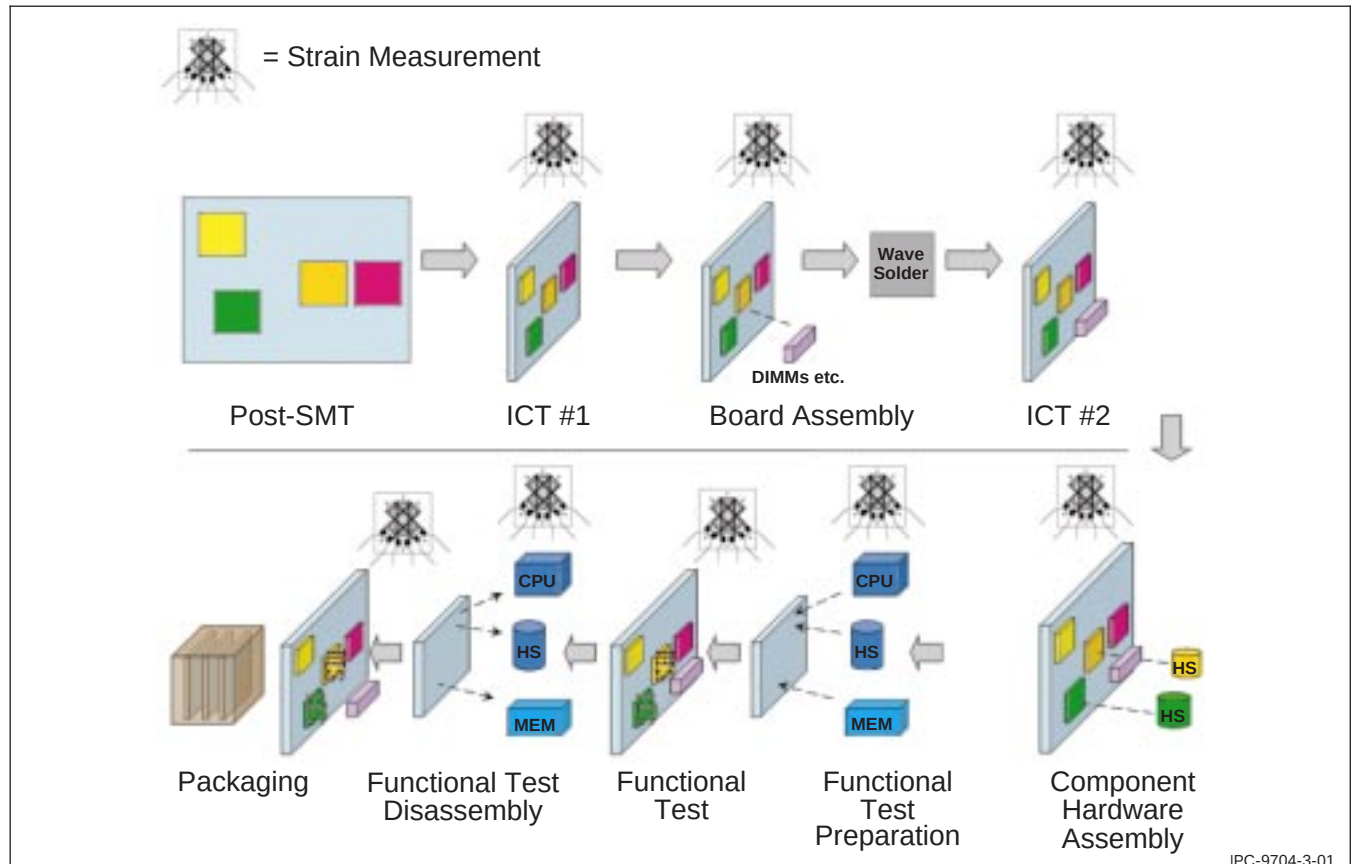


**Figure 3-1 Board Assembly Strain Measurement**

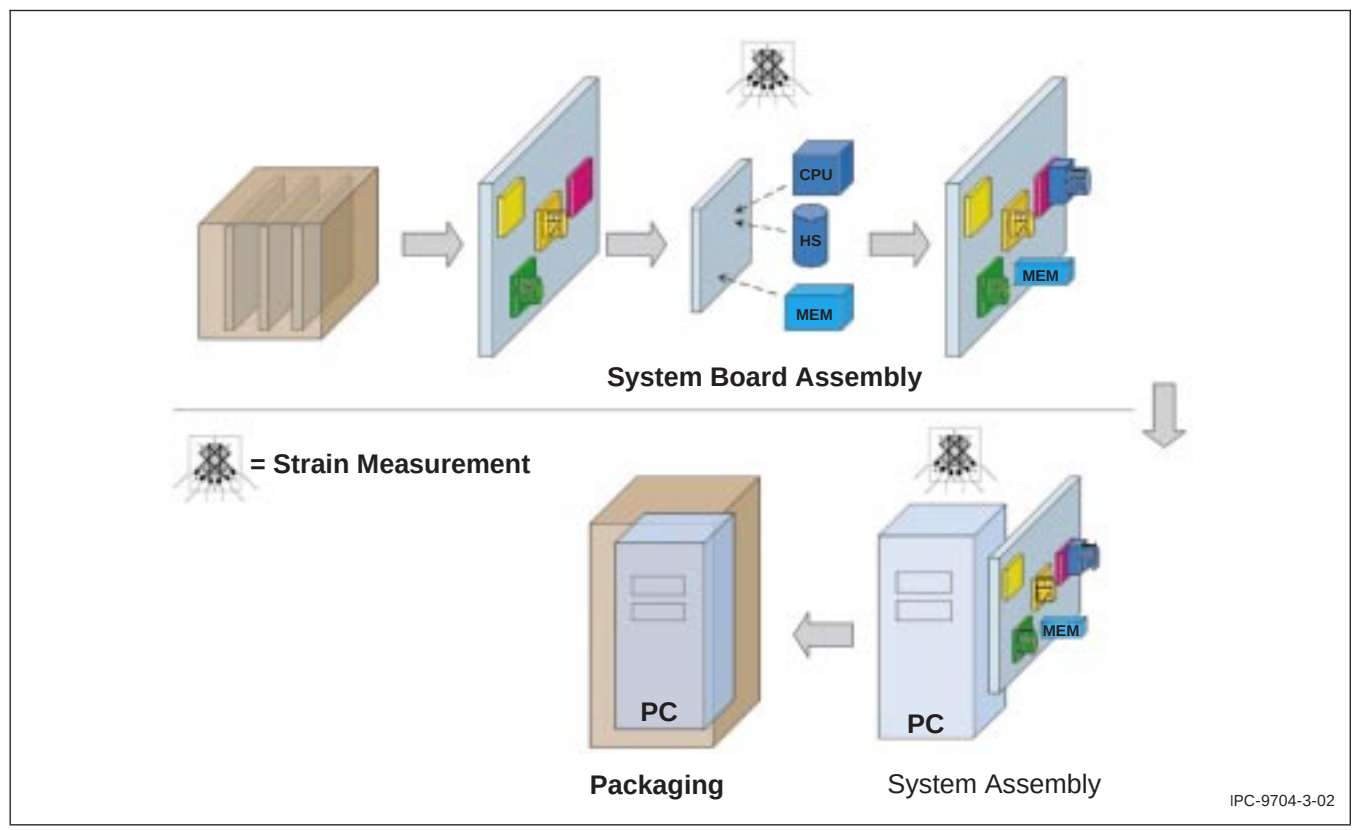


**Figure 3-2 System Assembly Strain Measurement**

**3.1 Boards** Due to the limited mechanical strain applied prior to SMT reflow, and more importantly because solder joints are formed only after reflow, strain characterization is required only for assembly and test operations following SMT reflow.

Typically, a minimum of two test boards are instrumented. They are not required to be electrically functional but must mechanically represent the latest design. At a minimum, evaluate the following two board types:

- Board with SMT components only (after SMT reflow).
- Boards with both SMT and through-hole components (after wave solder).

These are the minimum requirements. Characterization of the system assembly process might require additional test boards.

The first instrumented board reflects a PWBA that has been through SMT reflow, just prior to wave solder. Examples are depicted in Figures 3-3 and 3-4. At this stage, the board contains only SMT components. The objective at this stage is to characterize the strain/strain rate during manual handling, insertion of connectors and other through-hole components, and any electrical testing conducted prior to wave solder. This board should not be used for the characterization of assembly steps after wave solder.

The second instrumented board should be similar to PWBAs that have completed wave solder. An example is depicted in Figure 3-5. This board contains all SMT and through-hole components and is used to characterize all assembly steps after final reflow including (where applicable):

- Depanelization/routing
- Board support/stiffener assembly
- Final system assembly
- PCI card insertion
- DIMM module insertion
- Daughter card insertion
- Heat sink attachment
- Test operations (ICT, BFT)
- BGA and through-hole component rework

Although ICT and BFT are typical high strain/strain rate operations, damage is possible in any other step. A typical ICT strain gage test setup is illustrated in Figure 3-6.

All assembly steps should be characterized. Attention should also be paid to processes where mechanical fixtures are used, e.g., support fixtures, press fit fixtures, thumbscrew fixtures, etc. Where racks or trays are used, process steps such as storage and board transfer, should also be considered.

**Figure 3-3 Board with SMT Components Only (After SMT Reflow) Example 1**

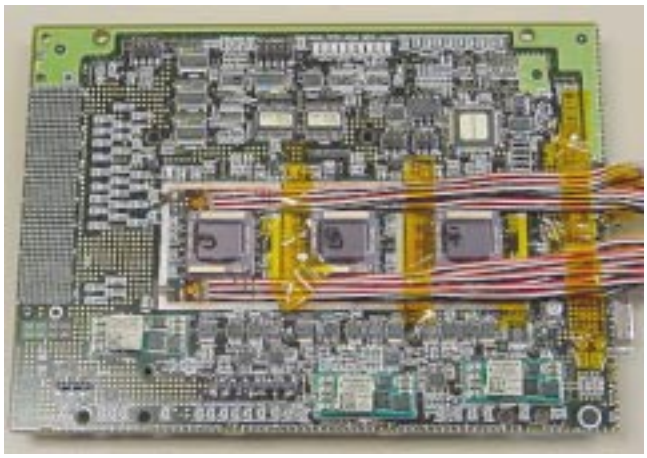

**Figure 3-4 Board with SMT Components Only (After SMT Reflow) Example 2**

**Figure 3-5 Board with Both SMT and Through-Hole Components (After Wave Solder)**

It is strongly recommended that any manual handling between assembly steps, with or without fixture, be characterized. If the manual handling steps are similar, combining the handling test into one test run representative of worst-case handling is acceptable. Details of this manual handling simulation must be documented in the test report.

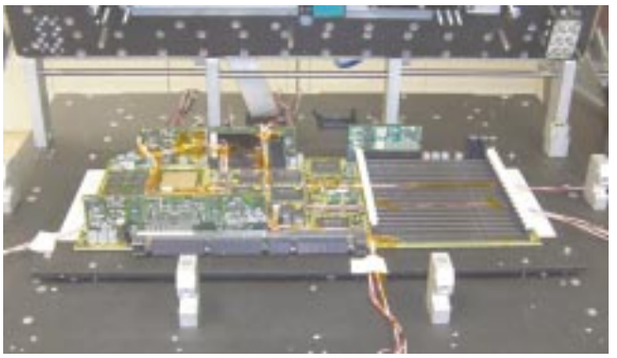

**Figure 3-6 ICT Fixture Strain Gage Test Setup**

Simulations should also be conducted to quantify the associated variability.

There could be unique manufacturing processes that require alternative configurations. For example, through-hole components typically require wave solder. Wave solder conventionally follows convection reflow (one or two passes depending on board layout). However, a PWB could have inductor coils manually inserted before SMT reflow and not require wave solder. In cases where assembly characterization prior to wave solder is required, the test board must be mechanically representative of boards prior to SMT reflow.

In such instances, alternative set-ups are acceptable as long as all mechanical loading characterization requirements are met. The following components must be also present on the board:

- Components of large physical size and/or mass.
- Components which mechanically constrain the board, e.g., bus bars, long connectors, etc.

It is recommended that test boards be inspected for excessive warpage prior to instrumentation. Another possible consideration would be the effect of solder aging, i.e., solder joints on instrumented test boards would have aged significantly longer then production boards. This should be considered when interpreting the results.

**3.2 Components and Devices** It is recommended that any BGA device with a package body size equal to or larger than 27 mm x 27 mm be measured. For example, Tape Ball Grid Array (TBGA), Flip Chip Ball Grid Array (FCBGA), Enhanced Ball Grid Array (eBGA), Ceramic BGA (CBGA), and low standoff BGA components that meet this requirement should be characterized.

Characterization should include electrolytic Ni/Au-plated substrates (typical for wirebond packages), even though some industry studies suggest they are less susceptible to solder joint failure than package substrates using other surface finishes, such as Electroless Nickel Immersion Gold (ENIG).

If all BGA devices on the PWB have a package body size smaller than 27 mm x 27 mm (e.g., handheld devices, cell phones, etc.), then the largest three BGA components, at a minimum, should be measured.

The above represents one of the methods that may be employed as a criterion for characterization. Alternative criteria to determine strain gage placement includes observed failure locations, historical failure rates, finite element analysis, assembly/test fixture configuration, board design, and BGA package design. Board and package design considerations include geometry, materials and configuration. Failure locations may be identified using dye (Dykem® or equivalent) penetration and component removal (“dye-and-pry”) techniques.

For boards with a larger number of BGA components (i.e., six or above) it is acceptable to rely first on a Finite Element Analysis (FEA) model, or other analytical and computation methods, to predict the optimized placement of strain gages. However, if initial testing identifies areas of high strain, this will be followed up with more focus testing in the subject area. ***CAUTION:** Where such methods are employed, it is important to recognize that one may not fully understand all the loads that will be applied, to all locations, at all loading operations.

**3.3 Strain Gage** Details of the recommended strain gage are as follows:

- Three element stacked rectangular (0/45/90) rosette strain gage
- 1.0 $mm^2$ to 2.0 $mm^2$, nominal, gage sensor size
- 120 Ω or 350 Ω strain gages
- Lead wire attach pads located at or lead wires attached on one side of strain gage

Examples of such gages are illustrated in Figures 3-7 and 3-8. The gage length should be as small as possible to minimize effects of nonuniform PWB strain gradients. However, strain gages should be large enough so that small features such as traces and vias, do not affect the strain reading.

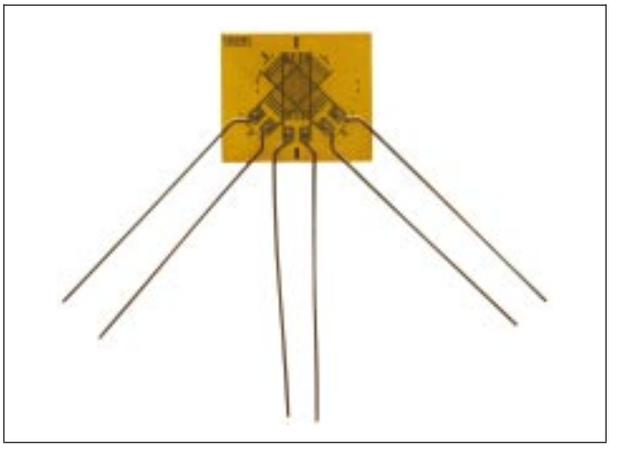

**Figure 3-7 Stacked Rosette Strain Gage**