

IPC-4552B

2021 - April

Specification for Electroless Nickel/Immersion Gold (ENIG) Plating for Printed Boards

Supersedes IPC-4552A

August 2017

An international standard developed by IPC



BUILD ELECTRONICS BETTER



Documents

Document Sharing Hub

The Principles of Standardization

In May 1995 the IPC's Technical Activities Executive Committee (TAEC) adopted Principles of Standardization as a guiding principle of IPC's standardization efforts.

Standards Should:

- Show relationship to Design for Manufacturability (DFM) and Design for the Environment (DFE)
- Minimize time to market
- Contain simple (simplified) language
- Just include spec information
- Focus on end product performance
- Include a feedback system on use and problems for future improvement

Standards Should Not:

- Inhibit innovation
- Increase time-to-market
- Keep people out
- Increase cycle time
- Tell you how to make something
- Contain anything that cannot be defended with data

Notice

IPC Standards and Publications are designed to serve the public interest through eliminating misunderstandings between manufacturers and purchasers, facilitating interchangeability and improvement of products, and assisting the purchaser in selecting and obtaining with minimum delay the proper product for his particular need. Existence of such Standards and Publications shall not in any respect preclude any member or nonmember of IPC from manufacturing or selling products not conforming to such Standards and Publication, nor shall the existence of such Standards and Publications preclude their voluntary use by those other than IPC members, whether the standard is to be used either domestically or internationally.

Recommended Standards and Publications are adopted by IPC without regard to whether their adoption may involve patents on articles, materials, or processes. By such action, IPC does not assume any liability to any patent owner, nor do they assume any obligation whatever to parties adopting the Recommended Standard or Publication. Users are also wholly responsible for protecting themselves against all claims of liabilities for patent infringement.

IPC Position Statement on Specification Revision Change

It is the position of IPC's Technical Activities Executive Committee that the use and implementation of IPC publications is voluntary and is part of a relationship entered into by customer and supplier. When an IPC publication is updated and a new revision is published, it is the opinion of the TAEC that the use of the new revision as part of an existing relationship is not automatic unless required by the contract. The TAEC recommends the use of the latest revision. Adopted October 6, 1998

Why is there a charge for this document?

Your purchase of this document contributes to the ongoing development of new and updated industry standards and publications. Standards allow manufacturers, customers, and suppliers to understand one another better. Standards allow manufacturers greater efficiencies when they can set up their processes to meet industry standards, allowing them to offer their customers lower costs.

IPC spends hundreds of thousands of dollars annually to support IPC's volunteers in the standards and publications development process. There are many rounds of drafts sent out for review and the committees spend hundreds of hours in review and development. IPC's staff attends and participates in committee activities, typesets and circulates document drafts, and follows all necessary procedures to qualify for ANSI approval.

IPC's membership dues have been kept low to allow as many companies as possible to participate. Therefore, the standards and publications revenue is necessary to complement dues revenue. The price schedule offers a 50% discount to IPC members. If your company buys IPC standards and publications, why not take advantage of this and the many other benefits of IPC membership as well? For more information on membership in IPC, please visit www.ipc.org or call 847/597-2809.

Thank you for your continued support.



IPC-4552B

Specification for Electroless Nickel/ Immersion Gold (ENIG) Plating for Printed Boards

Developed by the Plating Processes Subcommittee (4-14) of the
Fabrication Processes Committee (4-10) of IPC

Supersedes:

IPC-4552A – August 2017
IPC-4552 with Amendments
1 & 2 – December 2012
IPC-4552 – October 2002

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

Contact:

IPC
3000 Lakeside Drive, Suite 105N
Bannockburn, Illinois
60015-1249
Tel 847 615.7100
Fax 847 615.7105

This Page Intentionally Left Blank

Acknowledgment

Any document involving a complex technology draws material from a vast number of sources across many continents. While the principal members of the Plating Processes Subcommittee (4-14) of the Fabrication Processes Committee (4-10) 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 the IPC extend their gratitude.

Fabrication Processes Committee	Plating Processes Subcommittee	Technical Liaison of the IPC Board of Directors
Chair Karl Sauter Oracle America Inc.	Co-Chairs Ingrid Swenson TTM Technologies	Bob Neves Microtek (Changzhou) Laboratories
Vice-Chair Richard DePoto Uyemura International Corp.	Jose Rios Raytheon Company	
Plating Processes Subcommittee		
Rick Bauer	Brian Hess, Calumet Electronics Corp.	Tim McKliget, Holaday Circuits Inc.
Gianluca Esposito	John Bauer, Collins Aerospace	Vicka Hammill, Honeywell Inc. Air Transport Systems
Dirk Tews	David Hillman, Collins Aerospace	Kristen Troxel, HP Inc.
Donald Banks, Abbott	Brian Madsen, Continental Automotive GmbH	Jennie Hwang, H-Technologies Group
Constantino Gonzalez, ACME Training & Consulting	Miguel Dominguez, Continental Temic SA de CV	Joe Hughes, Hughes Circuits, Inc.
Pierre-Emmanuel Goutorbe, Airbus Defence & Space	Jose Servin Olivares, Continental Temic SA de CV	Thomas Romont, IFTEC
Robert Peterson, Alternate Finishing Inc.	Wallace Ables, Dell Inc.	Ife Hsu, Intel Corporation
Keith Newman, AMD	Steven Ethridge, Dell Inc.	Satish Parupalli, Intel Corporation
Denise Charest, Amphenol Printed Circuits, Inc.	Dimple Bhuva, Delta Circuits Inc.	Dana Korf, Korf Consultancy LLC
Leo Huang, APCB Electronics (Thailand) Co., Ltd	Dock Brown, DfR Solutions	Dan Loew, L3Harris
Gustavo Ramos, Atotech Deutschland GmbH	David Corbett, DLA Land and Maritime	Peter Menuetz, L3Harris Technologies, Inc.
Mario Rosin, Atotech Deutschland GmbH	Carl Colangelo, Dow Electronic Materials	Kunal Shah, LiloTree
Timo Schlosser, Atotech Deutschland GmbH	Gerald Gagnon, Extech Instruments Corporation	Steven Bowles, Lockheed Martin Corporation
Michael Schwaemmlein, Atotech Deutschland GmbH	John Cestaric, FTG Circuits Fredericksburg	Scott Bowles, Lockheed Martin Corporation
Christopher Daczkowski, Atotech USA Inc.	Henrik Jensen, Gaasdal Bygningsindustri A/S	Kevin Kusiak, Lockheed Martin Corporation
Kuldip Johal, Atotech USA Inc.	C.J. Long, Gold Circuit Electronics Ltd.	William Fox, Lockheed Martin Missile & Fire Control
Joe McGurran, Atotech USA Inc.	David Sommervold, Henkel US Operations Corp.	Thi Nguyen, Lockheed Martin Missile & Fire Control
Kelly Kovalovsky, BAE Systems	Elizabeth Benedetto, Hewlett-Packard Company	Don Dupriest, Lockheed Martin Missiles & Fire Control
David Cavanaugh, Benchmark Electronics Inc.	Matthew Kreiner, Hitachi High-Tech Analytical Science	Owen Reid, Lockheed Martin Missiles & Fire Control
Daniel Violette, Boeing Company	Herb Girtz, Holaday Circuits Inc.	Tim Dougherty, Lockheed Martin Mission Systems & Training
Keren Freedy, Boeing Research & Development		Curtis Ricotta, Lockheed Martin Space Systems Company



Martin Bunce, MacDermid Alpha Automotive	Randy Reed, R. Reed Consultancy LLC	Thomas Kibler, Thomas Kibler
Lenora Clark, MacDermid Alpha Automotive	Philip Henault, Raytheon	Thomas Stewart, Topline Consulting
Donald Cullen, MacDermid Alpha Automotive	Jose Rios, Raytheon	Kazunori Nishihara, Toyota Motor Corporation
John Fudala, MacDermid Enthone Electronics Solutions	David Anderson, Raytheon Company	Julie Ellis, TTM Technologies
Gary Nicholls, Metalor Technologies USA	Michael Wolverton, Raytheon Systems Company	Robert Farfan, TTM Technologies
Arturo Garcia, MicroConnex Corporation	Martin Scionti, Raytheon Vision Systems	John Konrad, TTM Technologies
Robert Neves, Microtek Laboratories China	Michael Carano, RBP Chemical Technology, Inc.	Nick Koop, TTM Technologies
Keith Peterson, Missile Defense Agency	Werner Huegel, Robert Bosch GmbH	Rajesh Kumar, TTM Technologies
Stephen Tisdale, Environmental Consulting LLC	Chris Mahanna, Robisan Laboratory Inc.	Tabishur Malik, TTM Technologies
Bhanu Sood, NASA Goddard Space Flight Center	Paul Vianco, Sandia National Labs Albuquerque	James Monarchio, TTM Technologies
Albert Block, National Instruments	Suriyakan Kleitz, Schlumberger Well Services	John Palmer, TTM Technologies
Brian Flemming, National Instruments	Henry Rekers, Schneider Electric Systems USA, Inc.	Alan Preston, TTM Technologies
Naji Norder, National Instruments	Jefferson Mao, Schweizer Electronic (Jiangsu) Co.,Ltd.	Brody Stapelmann, TTM Technologies
Michael DiCicco, Northrop Grumman Corporation	Jiong (Crystal) Dai, Shennan Circuits Co. Ltd.	Lee Swanson, TTM Technologies
Mahendra Gandhi, Northrop Grumman Space Systems	Gerard O'Brien, Solderability Testing & Solutions, Inc.	Walter Wiebelhaus, TTM Technologies
Russell Shepherd, NTS - Anaheim	Srinivas Chada, Stryker Instruments	Glenn Ames, TTM Technologies - Logan Division
Keith Sellers, NTS - Baltimore	Gerry Partida, Summit Interconnect - Anaheim	Ingrid Swenson, TTM Technologies, Inc.
Bruce Hughes, Nvidia Corporation	Scott Bryan, Superior Processing	Michael Moore, U.S. Army Aviation & Missile Command
Karl Sauter, Oracle America, Inc.	Gordon Simmons, Superior Processing	Donald Gudecuskas, Uyemura International Corp.
Mumtaz Bora, Peregrine Semiconductor	Martin Bayes, TE Connectivity	George Milad, Uyemura International Corp.
Michah Pledger, Pledger LLC	Eric Stafstrom, Technic Inc.	Patrick Valentine, Uyemura International Corp.
	Vanja Bukva, Teledyne Dalsa	Jesse Vaughan, Zentech Manufacturing
		Zhiman Chen, Zhuzhou CRRC Times Electric Co., LTD.

A special thank you to the Tiger Team for their dedication and commitment to this effort. Their support and time during the development of this document is greatly appreciated.

Denise Charest, Amphenol Printed Circuits, Inc.	Scott Bowles, Lockheed Martin Corporation	Ingrid Swenson, TTM Technologies
David Sommervold, Henkel US Operations Corp.	Don Dupriest, Lockheed Martin Missile & Fire Control	George Milad, Uyemura International Corp.
	Jose Rios, Raytheon	

The committee would also like to thank the outgoing leaders for their significant contributions.

George Milad, Uyemura International Corp.	Gerard O'Brien, Solderability Testing & Solutions, Inc.
---	---

Table of Contents

1 SCOPE	1	3.2.1 Shelf Life	16
1.1 Purpose	1	3.2.2 Humidity Indicator Card (HIC)	19
1.2 Description	1	3.2.3 Aluminum and Copper Wire (Wedge) Bonding	19
1.3 Classification	1	3.2.4 Contact Surface	19
1.4 Measurement Units	1	3.2.5 EMI Shielding	19
1.5 Definition of Requirements	1	3.2.6 Conductive and/or Anisotropic Adhesive Interface (Replacement for Solder)	20
1.6 Process Control Requirements	2	3.2.7 Connectors	20
1.7 Order of Precedence	2	3.2.8 Limitations of ENIG	20
1.7.1 Conflict	2	3.3 Visual	20
1.7.2 Clause References	2	3.4 Selective Annular Ring Dewetting (SAD)	21
1.7.3 Appendices	2	3.5 Finish Thickness	22
1.8 Use of "Lead"	3	3.5.1 Electroless Nickel Thickness	22
1.9 Abbreviations and Acronyms	3	3.5.2 Immersion Gold Thickness	24
1.10 Terms and Definitions	3	3.5.3 Exceptions to the Required Thickness Ranges	25
1.10.1 Electroless Process	3	3.6 Nickel Corrosion	27
1.10.2 Hyperactive Corrosion Deposit	3	3.6.1 Morphologies of Features at Electroless Nickel – Immersion Gold Interfaces	28
1.10.3 Immersion Process	3	3.6.2 Corrosion Level Definition	30
1.10.4 Metal Turnover (MTO)	3	3.6.3 Corrosion Level Evaluation of an As-Plated ENIG Deposit by Cross Section	32
1.10.5 Reduction Assisted Immersion Gold Also known as: Mixed Reaction Immersion Gold	3	3.6.4 ENIG Baselineing	38
1.10.6 Selective Annular Ring Dewetting (SAD)	4	3.6.5 ENIG Corrosion Performance Monitoring	38
2 APPLICABLE DOCUMENTS	4	3.6.6 Optional Testing to Determine IMC Formation on Boards Showing Product Rating 2	39
2.1 IPC	4	3.7 Porosity	40
2.2 Joint Standards	5	3.8 Adhesion	40
2.3 ASTM International (ASTM)	5	3.9 Solderability	41
2.4 JEDEC	5	3.9.1 Stressing of the Deposit Prior to Solderability Testing	41
2.5 Defense Standardization Program	5	3.9.2 Force Measurement Testing (Wetting Balance Testing)	41
2.6 Telcordia Technologies, Inc.	5	3.10 Cleanliness	42
2.7 International Electrotechnical Commission (IEC)	5	3.11 Electrolytic Corrosion	42
2.8 International Organization for Standardization (ISO)	5	3.12 Chemical Resistance	42
3 REQUIREMENTS of ENIG DEPOSIT	6	4 QUALITY ASSURANCE PROVISIONS	42
3.1 Printed Board Fabrication Supplier Process Requirements	7	4.1 General Quality Assurance Provisions	42
3.1.1 General Plating Line Requirements	7	4.1.1 Qualification Recommendations	42
3.1.2 ENIG XRF Calibration Standards	12	4.1.2 Sample Test Coupons	42
3.1.3 XRF Zero Offset Acceptability	12	4.2 Quality Conformance Testing	44
3.1.4 Process Qualification Measurement Requirements	13	4.2.1 Thickness	44
3.1.5 Electroless Nickel Reducing Agents – Phosphorus Content	14	4.2.2 Qualified Process	44
3.1.6 Gold Stripping of Plated Deposits for Evaluation of Corrosion Level	16		
3.2 Performance Functions	16		

APPENDIX 1	Abbreviations and Acronyms	45	Figure 3-1d	Graphical and Statistical Evaluation of Data from XRF Tool # 3	11
APPENDIX 2	ENIG Process Sequence	47	Figure 3-2	Potassium Iodide/Iodine (KI / I ₂) at 15 sec. dwell (left) vs. 60 sec. dwell (right)	17
APPENDIX 3	XRF Thickness Measurements of Thin Au (ENIG): Recommendations for Instrumentation (Detectors) and Their Limitations	48	Figure 3-3	Cyanide-Based Stripping at 15 sec. dwell (left) vs. 60 sec. dwell (right)	17
APPENDIX 4	ENIG PWB Surface Finish Wetting Balance Testing	50	Figure 3-4	Cyanide Stripping (left) vs. KI/I ₂ Stripping (right) Using Focused Ion Beam (FIB)	17
APPENDIX 5	IPC 4-14 SC ENIG Round Robin Solder Spread Testing	68	Figure 3-5	25,000X FIB Images – Cyanide (left) vs. KI / I ₂ (right) – Same Dwell Time	18
APPENDIX 6	Wire Bonding to ENIG	74	Figure 3-6	Ion Mill Stripping of Defect-Free Nickel (left) vs. Hyper-Corroded Nickel (right)	18
APPENDIX 7	Through Hole Solderability Testing	75	Figure 3-7	Humidity Indicator Card (HIC) Example	19
APPENDIX 8	Evaluation of Electroless Nickel Corrosion Due to Immersion Gold Plating, Using 3000X Magnification After Gold Stripping	90	Figure 3-8	Uniform Plating	20
APPENDIX 9-A	Cyanide Gold Stripping for ENIG	95	Figure 3-9	Extraneous Plating or Nickel Foot	21
APPENDIX 9-B	Test Method for Potassium Iodide/ Iodine (Non-Cyanide) ENIG Gold Stripping Procedure	96	Figure 3-10	Skip Plating (No Ni plating)	21
APPENDIX 9-C	Method for Stripping Gold Plating from ENIG Finished PCBs by Broad Beam Argon Ion Milling	98	Figure 3-11	Edge Pull Back	21
APPENDIX 10	Determination of Thickness and Phosphorus Content in Electroless Nickel (EN) Layers X-Ray Fluorescence (XRF) Spectrometry [IPC-TM-650, Method 2.3.44]	103	Figure 3-12	Example of SAD (Selective Annular Ring Dewetting)	22
APPENDIX 11	Phosphorus Content Measurement in ENIG Using Electron Dispersive Spectroscopy EDS	110	Figure 3-13	Another Example of the SAD Defect	22
APPENDIX 12	Standard Developments Efforts of Electroless Nickel Immersion Gold	115	Figure 3-14	Selective Annular Ring Dewetting Defect	22
APPENDIX 13	Using Guard Bands or a Gauge Correction Factor to Accommodate Type 1 Gauge Study Measurement Uncertainty	134	Figure 3-15	Grain Structure of Conventional Nickel Deposit	23
APPENDIX 14	Worked Examples of Hyper-Corrosion Evaluations	139	Figure 3-16	Grain Structure of Nickel Deposit Modified for Dynamic Flex Applications	23
Figures			Figure 3-17	Example of Fracture in Conventional Nickel Deposit	23
Figure 3-1a	Example of Repeat Measurement Data from Three Different XRF Tools	8	Figure 3-18	Modified Nickel Deposit Showing No Fracture with Same Number of Cycles	23
Figure 3-1b	Graphical and Statistical Evaluation of Data from XRF Tool # 1	9	Figure 3-19	Example of Multiple Spike Defects on the Knee of a Hole at 1000X	28
Figure 3-1c	Graphical and Statistical Evaluation of Data from XRF Tool # 2	10	Figure 3-20	Example of an Isolated Spreader Defect at 1000X (Rate as Level 1, if < 40%)	29
			Figure 3-21	Example of Multiple Spreader Defects on the Knee of a Hole at 1000X	29
			Figure 3-22	Example of Black Band Defect (Jagged in Nature) with Varying Depth of Penetration Type of Corrosion at 1000X	29
			Figure 3-23	Example of Black Band That Would be Rejectable if It Met the Minimum 30% Coverage of the Field of View at 1000X	29
			Figure 3-24	Example of a Crack in the Nickel Deposit at 1000X	30
			Figure 3-25	Example of Level 0 Corrosion – Knee of Hole at 1000X	31
			Figure 3-26	Example of Level 0 Corrosion – SMT Feature at 1000X	31
			Figure 3-27	Level 1 Corrosion – SMT Feature at 1000X	31
			Figure 3-28	Level 1 Corrosion – Knee of Hole at 1000X	31
			Figure 3-29	Level 2 Corrosion – Knee of Hole at 1000X	32
			Figure 3-30	Level 2 Corrosion – SMT Feature at 1000X	32

Figure 3-31	Level 3 Hyperactive Corrosion – Knee of Hole at 1000X	32	Figure 3-49	Example of Run Chart Created for Recording Product Rating	38
Figure 3-32	Level 3 Hyperactive Corrosion – SMT Feature at 1000X	32	Figure 3-50	Example of an Acceptable Contiguous IMC Layer at 1000X	40
Figure 3-33	Etched Defined PTH	33	Figure 3-51	Example of a Rejectable Non- Contiguous IMC Layer at 1000X	40
Figure 3-34	Solder Mask Defined Features	33	Figure 3-52	Example – Rejectable with Little-to-No IMC Formation at 1000X	40
Figure 3-35	Solder Mask Defined SMT Pad	33	Figure 3-53	Example – Rejectable with Little-to-No IMC Formation at Annular Ring for Through Hole with Level 2 Corrosion Level at 1000X	41
Figure 3-36	Etched Defined SMT Pad (non-supported PTH are treated as SMT Pad)	33	Figure 3-54	Standard IPC Force Measurement Coupon	41
Figure 3-37	Blank Product Rating Spread Sheet	34			
Figure 3-38	Example Product Rating for 5 Different Panels	35			
Figure 3-39	Decision Tree Based on Product Rating Evaluation	35			
Figure 3-40	Through Holes to be Evaluated for Corrosion at 25X	36			
Figure 3-41	Location 1 Worked Example – Rating Is a Level 2 at 1000X	36	Table 3-1	Requirements of Electroless Nickel/ Immersion Gold Plating	6
Figure 3-42	Location 2 Worked Example – Rating Is a Level 1 at 1000X	36	Table 3-2	Twelve (12) Repeat Au Measurements and the Mean Value	13
Figure 3-43	Location 3 Worked Example – Rating Is a Level 2 at 1000X	36	Table 3-3	Example of Phosphorus Content Analysis Over a 4-Quarter Period	15
Figure 3-44	Location 4 Worked Example – Rating Is a Level 0 at 1000X	36	Table 3-4	Three Examples of XRF Data Sets (μm [μin])	24
Figure 3-45	Location 5 Worked Example – Rating Is a Level 2 at 1000X	36	Table 3-5	One More Example of XRF Data (μm [μin])	25
Figure 3-46	Location 6 Worked Example – Rating Is a Level 0 at 1000X	37	Table 3-6	Identification of Corrosion Level of a Location	30
Figure 3-47	Location 7 Worked Example – Rating Is a Level 0 at 1000X	37	Table 3-7	Product Rating based on Corrosion Investigation	34
Figure 3-48	Product Rating for the Worked Example	37	Table 4-1	Suggested Fabricator Qualification Plan	43
			Table 4-2	C=0 Sampling Plan per Lot Size	44

Tables

Table 3-1	Requirements of Electroless Nickel/ Immersion Gold Plating	6
Table 3-2	Twelve (12) Repeat Au Measurements and the Mean Value	13
Table 3-3	Example of Phosphorus Content Analysis Over a 4-Quarter Period	15
Table 3-4	Three Examples of XRF Data Sets (μm [μin])	24
Table 3-5	One More Example of XRF Data (μm [μin])	25
Table 3-6	Identification of Corrosion Level of a Location	30
Table 3-7	Product Rating based on Corrosion Investigation	34
Table 4-1	Suggested Fabricator Qualification Plan	43
Table 4-2	C=0 Sampling Plan per Lot Size	44

This Page Intentionally Left Blank

Performance Specification for Electroless Nickel/Immersion Gold (ENIG) Plating for Printed Boards

1 SCOPE

This performance specification sets requirements for Electroless Nickel/Immersion Gold (ENIG) deposit thicknesses for applications including soldering, wire bonding and as a contact finish. It is intended for use by chemical suppliers, printed board manufacturers, electronics manufacturing services (EMS) and original equipment manufacturers (OEM). This standard may be used to specify acceptance criteria to meet performance requirements in addition to those found in the IPC-6010 series (IPC-6012, IPC-6013 and IPC-6018) of standards. The ENIG deposit specified by using this document will meet the highest coating durability rating as specified in the J-STD-003 printed board solderability specification.

This specification is based on three critical factors:

- 1) The ENIG plating process is in control producing a normal distribution for nickel and gold deposit thickness.
- 2) That the tool used to measure the deposit and therefore control the process is accurate and reproducible for the thickness range specified.
- 3) That the ENIG plating process results in uniform deposit characteristics.

If any of these three critical factors are not met, then the deposit produced will not meet the performance criteria defined herein.

1.1 Purpose This specification sets the requirements specific to ENIG as a surface finish (see Table 3-1 for a summary of these requirements).

1.2 Description ENIG is an electroless nickel layer capped with a thin layer of immersion gold (IAu). It is a multifunctional surface finish, applicable to soldering, aluminum and copper wedge wire bonding, press fit connections, and as a contact surface. The immersion gold layer protects the underlying nickel from oxidation/passivation over its intended life. However, this layer is not impervious and it will not pass the requirements of a “classic” porosity test as defined in ASTM B735 and IPC-TM-650, Methods 2.3.24, 2.3.24.1 and 2.3.24.2.

1.3 Classification IPC standards recognize that electrical and electronic assemblies are subject to classifications by intended end-item use. Three general end-product classes have been established to reflect differences in manufacturability, complexity, functional performance requirements, and verification (inspection/test) frequency. It should be recognized that there may be overlaps of equipment between classes.

CLASS 1 General Electronic Products

Includes products suitable for applications where the major requirement is function of the completed assembly.

CLASS 2 Dedicated Service Electronic Products

Includes products where continued performance and extended life is required, and for which uninterrupted service is desired but not critical. Typically, the end-use environment would not cause failures.

CLASS 3 High Performance/Harsh Environment Electronic Products

Includes products where continued high performance or performance-on-demand is critical, equipment downtime cannot be tolerated, end-use environment may be uncommonly harsh, and the equipment must function when required, such as life support or other critical systems.

1.4 Measurement Units All dimensions and tolerances in this specification are expressed in hard SI (metric) units and bracketed soft imperial [inch] units. Users of this specification are expected to use metric dimensions. All dimensions ≥ 1 mm [0.0394 in] will be expressed in millimeters and inches. All dimensions < 1 mm [0.0394 in] will be expressed in micrometers and microinches.

1.5 Definition of Requirements The words **shall** or **shall not** are used in the text of this document wherever there is a requirement for materials, preparation, process control or acceptance.

The word “should” reflects recommendations and is used to reflect general industry practices and procedures for guidance only.

Line drawings and illustrations are depicted herein to assist in the interpretation of the written requirements of this standard. The text takes precedence over the figures.

1.6 Process Control Requirements The primary goal of process control is to continually reduce variation in the processes, products, or services to provide products or processes meeting or exceeding User requirements. Process control tools such as IPC-9191, JESD557 or other User-approved system may be used as guidelines for implementing process control.

Manufacturers of Class 3 products **shall** develop and implement a documented process control system.

A documented process control system, if established, **shall** define process control and corrective action limits.

This may or may not be a statistical process control system. The use of “statistical process control” (SPC) is optional unless specified otherwise within a subsection and should be based on factors such as design stability, lot size, production quantities, and the needs of the Manufacturer, see 3.1.1.3 and 3.5.3.4.

Process control methodologies **shall** be used in the planning, implementation and evaluation of the manufacturing processes used to produce soldered electrical and electronic assemblies. The philosophy, implementation strategies, tools and techniques may be applied in different sequences depending on the specific company, operation, or variable under consideration to relate process control and capability to end product requirements.

When a decision or requirement is to use a documented process control system, failure to implement process corrective action and/or the use of continually ineffective corrective actions **shall** be grounds for disapproval of the process and associated documentation.

1.7 Order of Precedence The contract **shall** take precedence over this standard, referenced standards and drawings.

In the event of conflict, the following order of precedence applies:

1. Procurement as agreed and documented between customer and supplier.
2. Master drawing reflecting the customer’s detailed requirements.
3. When invoked by the customer or per contractual agreement, this standard.

When documents other than this standard are cited, the order of precedence **shall** be defined in the procurement documents.

The User has the opportunity to specify alternate acceptance criteria.

1.7.1 Conflict In the event of conflict between the requirements of this standard and the applicable drawing(s) and documentation, the applicable user-approved drawing(s) and documentation govern.

Some examples of documentation include the contract, purchase order, technical data package, engineering specification or performance specification. In the event of a conflict between the text of this standard and the applicable documents cited herein, the text of this standard takes precedence. In the event of conflict between the requirements of this standard and drawing(s) and documentation that has not been user approved, this standard governs.

1.7.2 Clause References When a clause in this document is referenced its subordinate clauses apply, unless the requirement references specific subordinate clauses.

1.7.3 Appendices Appendices to this standard are not binding requirements unless separately and specifically required by this standard, the applicable contracts, assembly drawing(s), documentation or purchase orders.

This specification contains fifteen appendices provided for information which are included after the main body of this document. Be aware that none of the contents of these appendices are binding requirements unless separately and specifically specified herein, or as required by purchase order, master drawing, other applicable documents, or as established AABUS.

– Appendix 1 Abbreviations and Acronyms

– Appendix 2 ENIG Process Sequence

– Appendix 3 XRF Thickness Measurements of Thin Au (ENIG): Recommendations for Instrumentation (Detectors) and Their Limitations

- Appendix 4 ENIG PWB Surface Finish Wetting Balance Testing
- Appendix 5 IPC 4-14 SC ENIG Round Robin Solder Spread Testing
- Appendix 6 Wire Bonding to ENIG
- Appendix 7 Through-Hole Solderability Testing
- Appendix 8 Evaluation of Electroless Nickel Corrosion Due to Immersion Gold Plating, Using 3000X Magnification After Gold Stripping
- Appendix 9a Cyanide Gold Stripping for ENIG
- Appendix 9b Test Method for Potassium Iodide/Iodine (Non-Cyanide) ENIG Gold Stripping Procedure
- Appendix 9c Method for Stripping Gold Plating from ENIG Finished PCBs by Broad Beam Argon Ion Milling
- Appendix 10 Determination of Thickness and Phosphorus Content In Electroless Nickel (EN) Layers X-Ray Fluorescence (XRF) Spectrometry [IPC-TM-650, Method 2.3.44]
- Appendix 11 Phosphorus Content Measurement in ENIG Using Electron Dispersive Spectroscopy EDS
- Appendix 12 Standard Developments Efforts of Electroless Nickel Immersion Gold
- Appendix 13 Using Guard Bands or a Gauge Correction Factor to Accommodate Type 1 Gauge Study Measurement Uncertainty
- Appendix 14 Worked Examples of Hyper-Corrosion Evaluations

1.8 Use of “Lead” For readability and translation, this document uses the noun lead only to describe leads of a component. The metallic element lead is always written as Pb.

1.9 Abbreviations and Acronyms Periodic table elements may be abbreviated in the standard. See Appendix 1 for full spellings of abbreviations (including elements) and acronyms used in this standard.

1.10 Terms and Definitions Other than those terms listed below, the definitions of terms used in this standard are in accordance with IPC-T-50.

1.10.1 Electroless Process This chemical process promotes continuous deposition of a metal onto the printed board surface through an oxidation-reduction chemical reaction, without the use of an external electrical potential. A reducing agent, such as sodium hypophosphite, reacts at a catalytically active surface to yield electrons which reduce metal ions which are at the surface which donates electrons to the positively charged metal ions in solution, thereby reducing the metal and promoting its metal deposition onto the catalyzed metal surfaces of the printed board. This reaction is considered autocatalytic because it will continue to plate in the presence of source metal ions and a reducing agent until the board is removed from the plating bath. The thickness of plated deposits varies according to temperature, chemical parameters and the amount of time spent in the plating bath.

1.10.2 Hyperactive Corrosion Deposit An electroless nickel/immersion gold deposit which has a degree of localized corrosion at the electroless nickel/immersion gold interface sufficient to degrade the performance characteristics of the deposit.

1.10.3 Immersion Process This chemical process uses a chemical displacement reaction to deposit a metal layer onto the exposed metal surface of the printed board. In this reaction, the base metal donates the electrons that reduce the positively charged metal ions in the solution. Driven by the electrochemical potential difference, the metal ions in solution (e.g., gold ions in the ENIG process) are deposited onto the surface of the board, simultaneously displacing ions of the surface metal (e.g., nickel ions in the ENIG process) back into solution. This reaction is considered self-limiting, because once the surface metal is plated, there is no longer a source of electrons and the reaction stops.

1.10.4 Metal Turnover (MTO) A measure of electroless or immersion plating bath “age,” MTO is a period of operation during which the sum of the periodic replenishments of the metal being deposited is equal to the amount of metal in the initial bath makeup. For example, if the metal concentration in an electroless bath is five grams per liter [0.04 lbs per gallon] and the bath is 100 liters [26.4 gal] in size, then one MTO is the period of usage during which 500 grams [1.1 lb] of metal is added back into the bath by replenishment as the metal is actively being deposited out of the bath. Depending on how heavily an electroless or immersion bath is being “worked,” the time taken for one MTO may range from as little as a few hours to a week or more. It is common for an electroless or immersion plating bath to last for multiple MTOs before being removed from service and fully replaced.

1.10.5 Reduction Assisted Immersion Gold Also known as: **Mixed Reaction Immersion Gold** The deposition of a gold coating by using two different chemical mechanisms in the same process chemistry to achieve desired plating thickness. This gold plating solution initiates as a combined immersion reaction between the substrate and gold ions and a chemical reduction reaction between the nickel substrate and a reducing agent that is subsequently assisted by chemical reduction, similar to electroless gold to achieve the desired thickness. The contribution from the reducer-substrate reaction reduces the degree of substrate dissolution and the likelihood of compromising the nickel layer. Presently, most mixed reaction plating chemistries are limited to a deposit thickness below 0.3 μm [12 μins].

1.10.6 Selective Annular Ring Dewetting (SAD) This is a chronic dewetting defect that selectively affects ONLY the contact side annular rings during Pb-free wave soldering assembly. The component holes will show evidence of complete hole fill and possibly even destination side wetting depending on the quality of soldering. It has been shown to be lot specific ONLY and impacts double-sided and multilayer designs.

2 APPLICABLE DOCUMENTS

2.1 IPC¹

IPC-A-610 Acceptability of Electronic Assemblies

IPC-TM-650 Test Method Manual²

- 2.1.1 Microsectioning, Manual and Semi or Automatic
- 2.3.24 Porosity of Gold Plating
 - 2.3.24.1 Porosity Testing of Gold Electrodeposited on a Nickel Plated Copper Substrate Electrographic Method
 - 2.3.24.2 Porosity of Metallic Coatings on Copper-Based Alloys and Nickel (Nitric Acid Vapor Test)
- 2.3.25 Detection and Measurement of Ionizable Surface Contaminants by Resistivity of Solvent Extract (ROSE)
- 2.3.44 Determination of Thickness and Phosphorus Content in Electroless Nickel (EN) Layers by X-Ray Fluorescence (XRF) Spectrometry
- 2.6.3.5 Bare Board Cleanliness by Surface Insulation Resistance
- 2.6.14.1 Electrochemical Migration Resistance Test
- 2.6.27 Thermal Stress, Convection Reflow Assembly Simulation
- 2.4.1 Adhesion, Tape Testing

IPC-1601 Printed Board Handling and Storage Guidelines

IPC-2221 Generic Standard on Printed Board Design

IPC-5704 Cleanliness Requirements for Unpopulated Printed Boards

IPC-6010-FAM Printed Board Performance Specifications

IPC-6011 Generic Performance Specification for Printed Boards

IPC-6012 Qualification and Performance Specification for Rigid Printed Boards

IPC-6013 Qualification and Performance Specification for Flexible/Rigid-Flexible Printed Boards

IPC-6018 Qualification and Performance Specification for High Frequency (Microwave) Printed Boards

1. www.ipc.org

2. Current and revised test methods are available on the IPC website (www.ipc.org/test-methods.aspx)

2.2 Joint Standards³

J-STD-001 Requirements for Soldered Electrical and Electronic Assemblies

J-STD-003 Solderability Tests for Printed Boards

J-STD-033 Handling, Packing, Shipping and Use of Moisture, Reflow, and Process Sensitive Devices

2.3 ASTM International (ASTM)⁴

ASTM B733 Standard Specification for Autocatalytic (Electroless) Nickel-Phosphorus Coatings on Metal

ASTM B735 Standard Test Method for Porosity in Gold Coatings on Metal Substrates by Nitric Acid Vapor

2.4 JEDEC⁵

JESD557 Statistical Process Control Systems

2.5 Defense Standardization Program⁶

MIL-STD-883, Method 2011.7 Test Method Standard, Microcircuits - Bond Strength (Destructive Bond Pull Test)

2.6 Telcordia Technologies, Inc.⁷

Telcordia GR-1217-CORE Generic Requirements for Separable Electrical Connectors Used in Telecommunications Hardware

2.7 International Electrotechnical Commission (IEC)⁸

IEC 60352-5 Solderless connections - Part 5: Press-in connections - General requirements, test methods and practical guidance

2.8 International Organization for Standardization (ISO)⁹

ISO/IEC-17025 General Requirements for the Competence of Testing and Calibration Laboratories

3. www.ipc.org

4. www.astm.org

5. www.jedec.org

6. <https://www.dsp.dla.mil>

7. telecom-info.telcordia.com

8. www.iec.ch

9. www.iso.org

3 REQUIREMENTS of ENIG DEPOSIT

Table 3-1 describes the requirements for the ENIG deposit layer.

Table_3-1 Requirements of Electroless Nickel/Immersion Gold Plating

Tests	Test Method	Requirement Paragraph	Class 1	Class 2	Class 3
GENERAL					
Measurement Capability	XRF	3.1.1.3	Gauge capability $C_g \geq 1.33^{(1)}$		
XRF Thickness Sample Size	XRF	3.5.3.2 4.2.1	$C=0$ with n (minimum per panel of the AQL) = $[2/C_g]^2$ as necessary		
Visual	Visual	3.3	Uniform plating and complete coverage of surfaces to be plated		
Electroless Nickel Thickness Rigid Printed Board	Appendix 3	3.5.1.1	3 to 6 μm [118.1 to 236.2 μin]		
Electroless Nickel Thickness Flex Printed Board ⁽²⁾	Appendix 3	3.5.1.4	1.27 to 6 μm [50.0 to 236.2 μin]		
Immersion Gold Thickness (Exception Required on Procurement Documentation)	Appendix 3	3.5.2	The minimum immersion gold deposit thickness is $\bar{x} - 3 \sigma \geq 0.04 \mu\text{m}$ [$\geq 1.58 \mu\text{in}$] The maximum immersion gold deposit thickness is $\bar{x} + 3 \sigma \leq 0.1 \mu\text{m}$ [$\leq 3.94 \mu\text{in}$] as measured on a pad size of 1.5 mm x 1.5 mm [0.060 in x 0.060 in] or equivalent area, $\pm 10\%$. Where: $\bar{x}$ = the mean gold thickness σ = the standard deviation of a sample		
Nickel Bath MTO's	Process Record	3.6.4	Baselining for nickel corrosion not to be processed beyond maximum bath MTO qualified per requirements in Table 4-1.		
Nickel Corrosion	Cross-section inspection at 1000X	3.6	Production monitoring per 3.6.5 ⁽⁴⁾ and Table 3-7 ⁽³⁾		
PHYSICAL					
Adhesion/Tape Test	IPC-TM-650, Method 2.4.1	3.8	No evidence of plating removed		
Shelf Life	J-STD-003	3.9	Minimum of twelve months when left in original packaging and following recommendations of IPC-1601.		
Solderability ⁽³⁾	J-STD-003	3.9	Meet solderability requirements of Category B durability.		
CHEMICAL					
Phosphorous content	3.1.5	3.1.5	Per chemical supplier's specification		
Creep Corrosion/ Chemical Resistance	N/A	3.2.8.1	When specified		
Chemical Resistance	IPC-TM-650, Method 2.3.4.2	3.12	Not applicable to ENIG finishes		
ENVIRONMENTAL					
Cleanliness ^(4, 5)	IPC-5704	3.10	Refer to applicable performance specification		
SIR ^(4,5)	IPC-TM-650, Method 2.6.3.5; GR78-Core	3.10	1.0E+8 ohms		
Electrolytic Corrosion ^(4,5)	IPC-TM-650, Method 2.6.14.1	3.11	The resistance values shall not drop more than one order of magnitude after the test has been completed.		

(1) Confirm C_g as part of instrument validation, prior to releasing the instrument for lot acceptance testing. The use of guard bands is an acceptable method to deal with XRF equipment of lower capability. This will reduce the operating thickness range for a given process. The use of guard bands and their values are to be documented in conformance testing documents accompanying product shipment.

(2) The use of modified grain structure nickel is recommended for dynamic flex applications.

(3) This applies to the default Immersion Au thickness, only.

(4) When specified by procurement documentation.

(5) There is an associated cost for inspection at this level.

3.1 Printed Board Fabrication Supplier Process Requirements

3.1.1 General Plating Line Requirements The plating line should be configured and maintained as per the specifications of the chemical supplier. There are many chemical process tanks utilized in the plating of ENIG that all require chemical analysis and control. It is strongly suggested that the analytical data generated be charted to aid with overall process control and to identify trends in chemical concentration usage that could be a precursor to generating defects. The Nickel plating chemistry requires constant replenishment to maintain a consistent deposit. It is strongly suggested that an automatic chemical controller and replenisher system be used to control the nickel bath. If no controller is used, small frequent chemical replenishments are preferable to a single large replenishment.

3.1.1.1 ENIG Deposit Thickness Measurement The XRF ENIG deposit thickness **shall** be measured by XRF. See Appendix 3 for guidance.

3.1.1.2 Feature Size for Thickness Measurement This performance specification has been generated based on a deposit thickness measured ONLY on feature sizes of 1.5 mm x 1.5 mm [0.060 in X 0.060 in] or equivalent area ($\pm 10\%$). Measurement of non-standard feature sizes and/or a combination of different feature sizes will prevent compliance to the statistical requirements of this specification. Requirements to measure non-standard sized features is AABUS and the supplier of the printed board is not responsible for the performance of the deposit as specified in this document.

3.1.1.3 Gauge Capability, Gauge R&R Type 1 Study A Type 1 Gauge study **shall** be performed for each XRF tool used for plating thickness measurement of the ENIG deposit in the same location, i.e., XRF used for in-process measurement and the XRF used at final QC. The collimator size used and appropriate measurement times **shall** be per 3.1.1.4. The purpose of performing this study is a test of Gauge Capability with respect to repeatability and mean of measurement values for a given tolerance. It is required that this study **shall** be performed with a calibrated reference standard, preferably with its reference value in the nominal middle of the tolerance field, $\pm 10\%$. Without a calibrated reference standard, the Type 1 Gauge study only measures repeatability. Bias, a measure of accuracy, becomes invalid.

At defined measurement points the reference standard is to be measured with $n \geq 30$ times under repeatability conditions.

- For measurement criteria with Upper and Lower Specification Limits (USL and LSL); $T = USL - LSL$.
- For measurement criteria with only a one-sided specification limit (USL or LSL); T is non-existent.

In this case the allowable measurement value lies below $USL - 3\sigma$ or above $LSL + 3\sigma$.

The value of the reference standard ideally should be at the nominal value ($[USL + LSL]/2$). The reference value should be no greater than $+10\%$ of the USL or -10% of the LSL.

If Gauge Capability Indexes are to be calculated, use the following formulas.

The instrument capability is checked thru the C_g and C_{gk} values which are defined as Gauge Capability:

$$C_g = \frac{0.2 \cdot T}{6 \cdot \sigma}$$

$$C_{gk} = \frac{0.1 \cdot T - |\bar{x} - x_m|}{3 \cdot \sigma}$$

T = tolerance, σ = standard deviation), x_m = mean of standard, $\bar{x}$ = mean value measurement

A gauge index is considered capable if $C_g \geq 1.33$ and $C_{gk} \geq 1.33$.

This can also be interpreted as: In order to meet the Gauge Capability, the index **shall** be > 1.33 .

Failure to meet these required gauge capabilities may be addressed by taking one or more of the following actions:

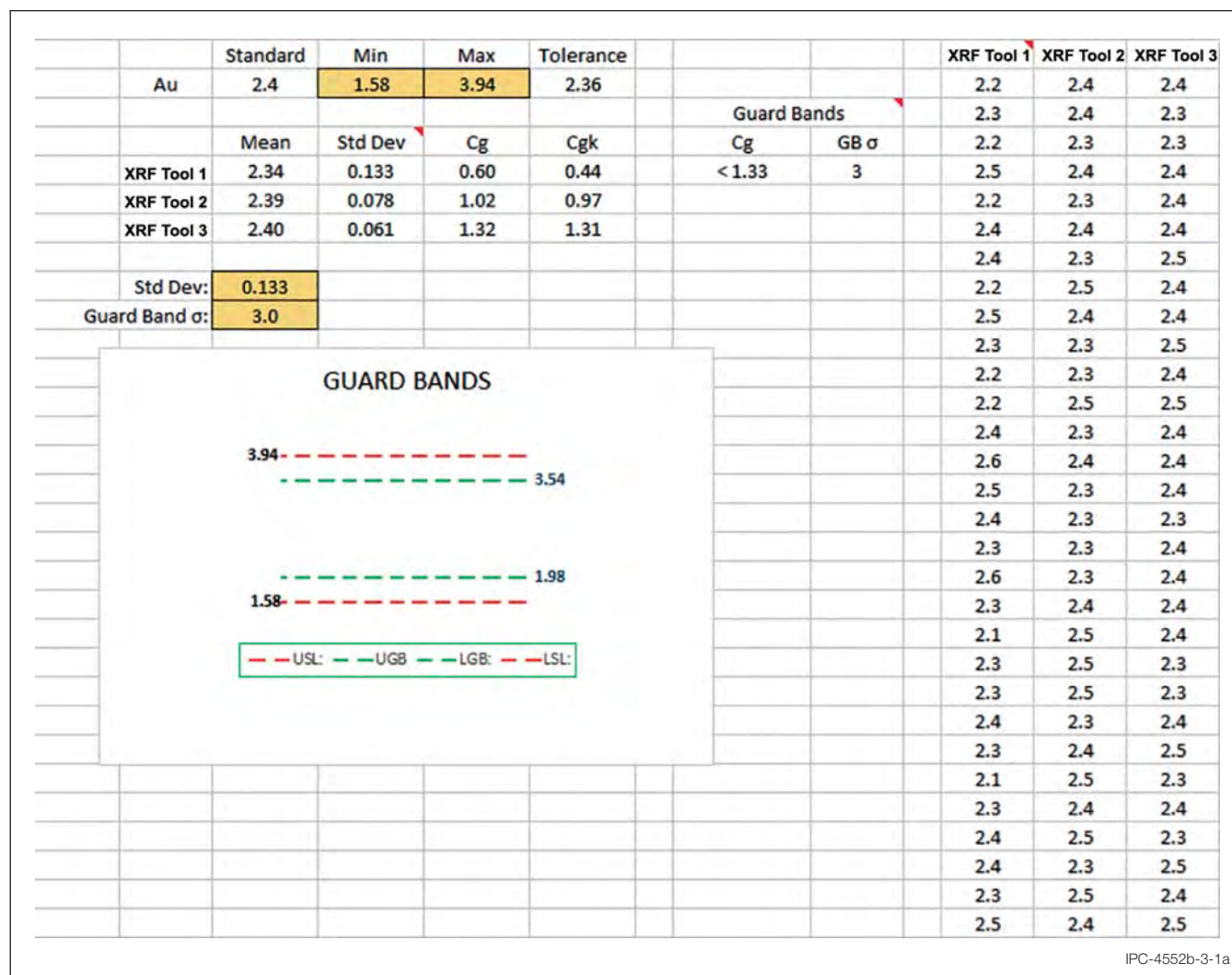
- 1) The XRF unit may need to be serviced or in some instances replaced with a more capable unit.
- 2) Verification and recreation of the ENIG calibration file may improve the accuracy of the measurement but will not impact the CV% (A measure of relative variability, equal to the standard deviation divided by the mean, multiplied by 100. CV is a dimensionless number, and is useful in comparing the dispersion of samples with different means).
- 3) Recertifying the traceable standard or obtaining a "correctly specified" ENIG standard will again improve the accuracy of the XRF tool but not impact the CV % of the system.

- 4) Provided that the ENIG plating process can be shown to have a normal distribution, an acceptable interim (AABUS) alternative is to use “guard bands” on the plating range to ensure compliance with the thickness requirements of this specification, (see Figures 3-1a through 3-1d). The operating limits (USL & LSL) for plating thickness will be reduced by three standard deviations (obtained from the Type 1 gauge study).
- 5) Use the gauge correction factor to determine the number (n) of measurements required to adjust the XRF C_g value to an acceptable value.
- 6) Increase measurement time in an attempt to achieve minimally acceptable C_g and C_{gk} indices.

Note: Quadrupling the measurement time will reduce the measurement error in half. This is generally not a practical solution.

Note: Calculated measurement standard deviations in excess of $0.010\ \mu\text{m}$ [$0.41\ \mu\text{in}$] (based on $\pm 3\ \sigma$) for the immersion gold deposit thickness requires immediate action as the plating will be outside the limits of this specification.

Worked Examples from Type 1 Gauge Studies demonstrating Guard Bands and the Gauge Correction Factor are shown in Figures 3-1a, 3-1b, 3-1c and 3-1d. These figures provide examples of Gauge R&R information that is useful in validating XRF as a valid test method.



IPC-4552b-3-1a

Figure 3-1a Example of Repeat Measurement Data from Three Different XRF Tools

USL – Upper Spec Limit
 UGB – Upper Guard Bands
 LGB – Lower Guard Bands
 LSL – Lower Spec Limit

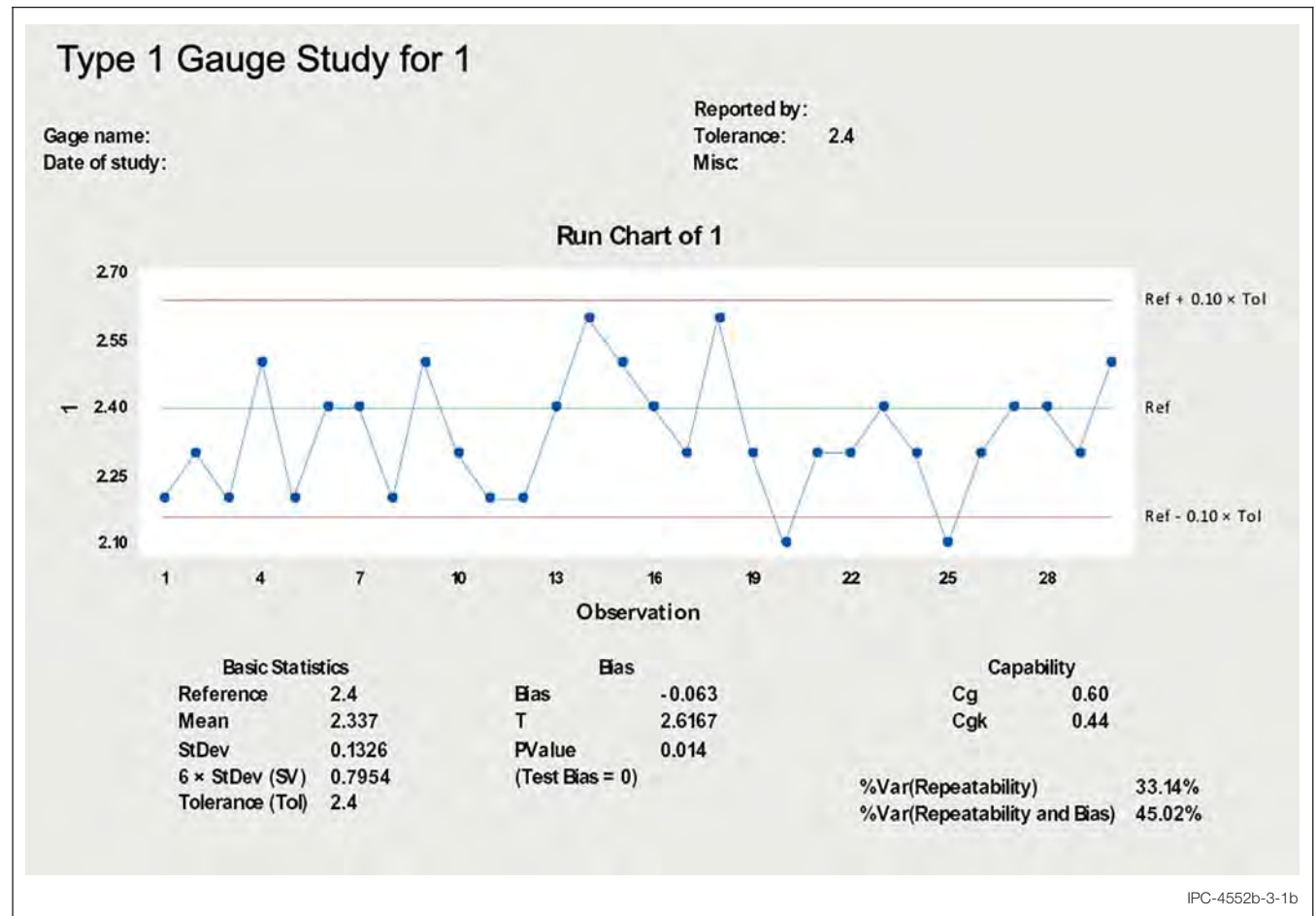


Figure 3-1b Graphical and Statistical Evaluation of Data from XRF Tool # 1

C_g is less than 1.33, (0.6), and Gauge standard deviation is 0.133. There are two options:

1. Use Gauge correction $[2/C_g]^2 = [2/0.6]^2 = 11.09$, rounded up to 12 measurements minimum required.
2. 3 sigma Guard Bands
 - a. $LGB = 1.58 + (3 \cdot 0.133) = 0.050 \mu\text{m}$ [1.98 μin]
 - b. $UGB = 3.94 - (3 \cdot 0.133) = 0.090 \mu\text{m}$ [3.54 μin]

Accordingly, with this example, the guard bands now become the operating limits and supersede the specification limits in this document. In this example, using Guard Bands are preferred over the Gauge Correction Factor.

Note: When using the Gauge correction factor, always round up n (minimum) to the next whole number. The minimum number of measurements is ≥ 2 when using the Gauge correction factor, using Guard Bands, or when the Gauge $C_g \geq 1.33$.

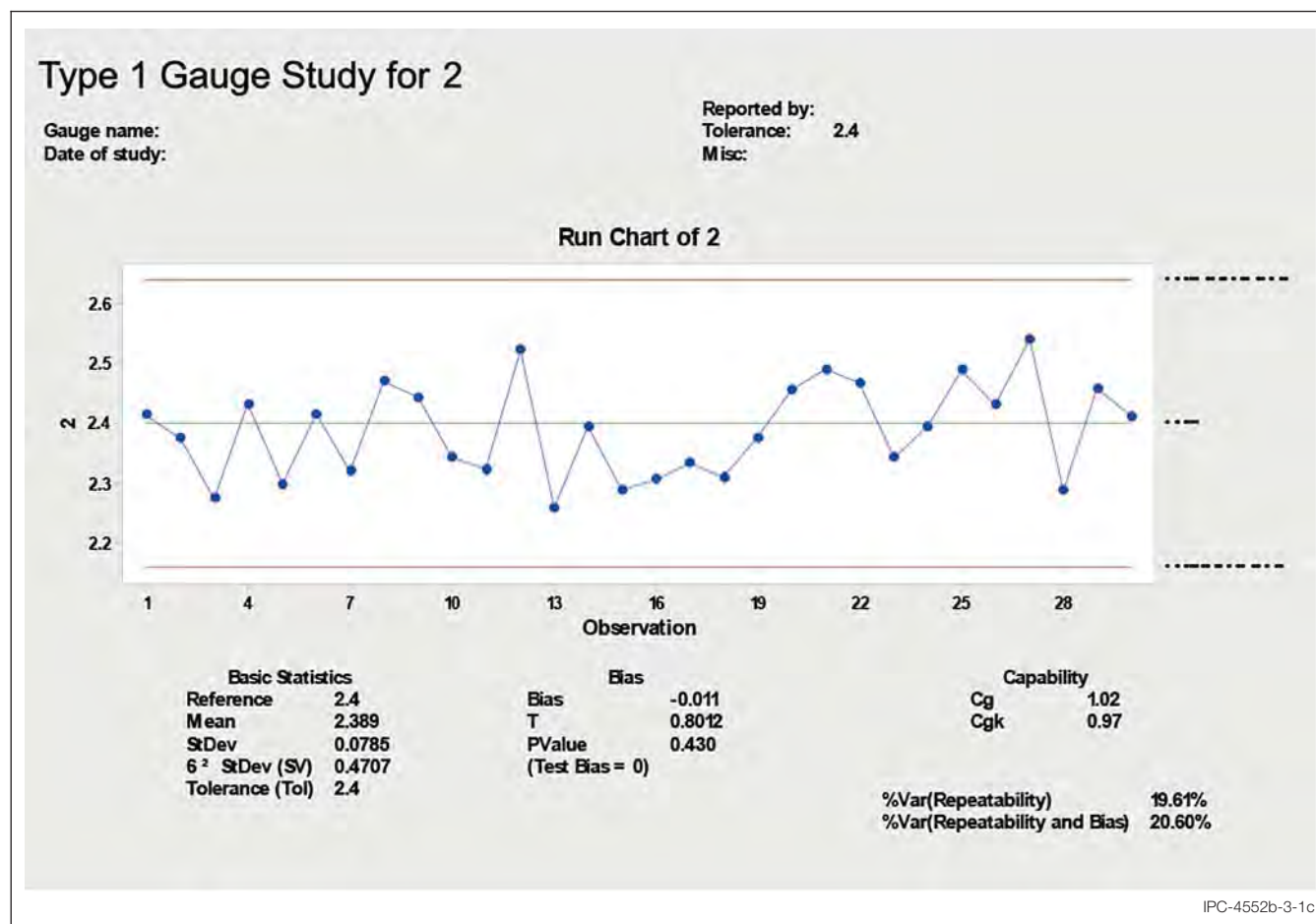


Figure 3-1c Graphical and Statistical Evaluation of Data from XRF Tool # 2

C_g is less than 1.33, (1.02), and Gauge standard deviation is 0.078. There are two options:

1. Use Gauge correction $[2/C_g]^2 = [2/0.078]^2 = 3.84$, rounded up to 4 measurements minimum required.
2. 3 sigma Guard Bands
 - a. LGB = $1.58 + (3 \cdot 0.078) = 0.046 \mu\text{m}$ [1.81 μin]
 - b. UGB = $3.94 - (3 \cdot 0.078) = 0.094 \mu\text{m}$ [3.71 μin]

Accordingly, with this example, the guard bands now become the operating limits and supersede the specification limits in this document. In this example, using the Gauge correction factor may be preferred over Guard Bands.

Note: When using the Gauge correction factor, always round up n (minimum) to the next whole number. The minimum number of measurements is ≥ 2 when using the Gauge correction factor, using Guard Bands, or when the Gauge $C_g \geq 1.33$.

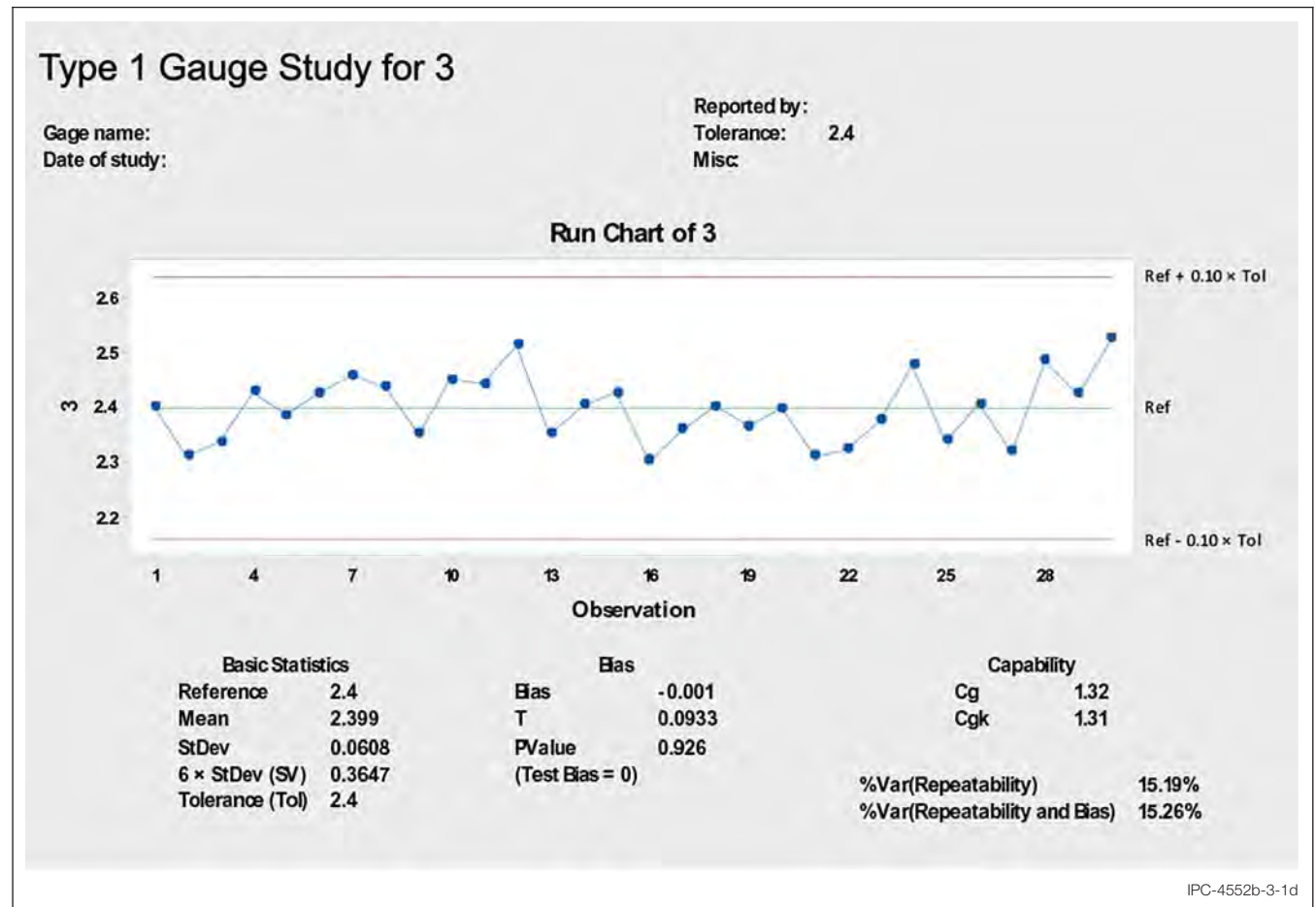


Figure 3-1d Graphical and Statistical Evaluation of Data from XRF Tool # 3

In this case, the C_g is at 1.32 indicating a very capable XRF tool, but C_g is less than 1.33, (1.32), and Gauge standard deviation is 0.061. There are two options:

1. Use Gauge correction $[2/C_g]^2 = [2/0.132]^2 = 2.29$, rounded up to 3 measurements minimum required.
2. 3 sigma Guard Bands
 - a. LGB = $1.58 + (3 \cdot 0.061) = 0.045 \mu\text{m}$ [1.76 μin]
 - b. UGB = $3.94 - (3 \cdot 0.061) = 0.096 \mu\text{in}$ [3.76 μin]

Accordingly, with this example, the guard bands now become the operating limits and supersede the specification limits in this document. In this example, using the Gauge correction factor is preferred over Guard Bands.

Note: When using the Gauge correction factor, always round up n (minimum) to the next whole number. The minimum number of measurements is ≥ 2 when using the Gauge correction factor, using Guard Bands, or when the Gauge $C_g \geq 1.33$.

3.1.1.4 Collimator Size and Measurement Times Thickness of the nickel and gold layers **shall** be measured using X-ray Fluorescence with a mechanical collimator 0.3 mm to 0.6 mm [0.012 to 0.024 in] in diameter. Polycapillary XRF systems **shall** scan the beam over the feature being measured. The measurement time is dictated by the need to meet passing C_g/C_{gk} values and will be influenced by the type of XRF system and the collimator diameter being used. The actual required measurement time to meet the performance specification **shall** be determined from the data generated while performing repeated measurements on a certified and traceable ENIG standard. A minimum of thirty repeated measurements **shall** be used for each collimator size available in a range of 0.3 mm to 0.6 mm [0.012 to 0.024 in] in diameter for each time interval to be evaluated. Standard deviation of the XRF instruments are based on counting statistics, which directly relate to total intensity and measurement time. As a rule, to improve the repeatability precision by a factor of 2, an increase in intensity or measurement time of a factor of 4 is required, because it is a square root function. Measurement times in the 30 seconds or less range have been shown not to be capable of meeting the required specification values regardless of the system being used.

3.1.1.5 Guard Bands and Lot Conformance Testing The need to use guard bands will have an impact on the ability to meet the CV% specified in 3.1.1.3. Conformance testing quality documentation supplied with finished product **shall** reflect the use of guard bands and the associated CV% values obtained for both nickel and gold thickness measurements. XRF tools capable of meeting the CV% requirements **shall** simply state that the reported thickness meets the requirements of this specification.

3.1.2 ENIG XRF Calibration Standards The use of calibration standards traceable to an internationally recognizable national metrology lab, with similar thicknesses to the specified ENIG thicknesses that are to be measured, **shall** be used. Dual-layer standards where Au is plated **directly** on Ni/Cu/printed board or EN/Cu/printed board should be used for calibration for Cu thicknesses **> 30 μm [1181 μin]**. Dual-layer foil standards where Au is plated on a **Ni-foil** or an **EN-foil** should be used if boards with varying Cu-thickness are to be measured. The foils allow for great flexibility since they can be placed on various base materials, therefore achieving optimal accuracy. Additional information can be found in Appendix 3. With decreasing Cu thickness, the influence of the printed board material becomes more significant and requires careful calibration.

- **For Cu thickness $\geq 30 \mu\text{m}$ [1181 μin]**, a single plated calibration standard with Au and Ni thickness in the mid point of the thickness range is preferred, i.e., $0.07 \mu\text{m}$ [2.76 μin] Au / $4.5 \mu\text{m}$ [177 μin] Ni. This is a readily available from suppliers of XRF standards.
- If this standard is not available then a combination of a minimum of **two plated** calibration standards with approximate thicknesses, as below, should be used:
 $\text{Au/Ni or EN/Base } 0.020 - 0.030 \mu\text{m} / 4 - 5 \mu\text{m}$ [0.79 - 1.18 μin / 157 - 197 μin]
 $\text{Au/Ni or EN/Base } 0.050 - 0.100 \mu\text{m} / 4 - 5 \mu\text{m}$ [1.97 - 3.94 μin / 157 - 197 μin]
- **For Cu thicknesses $< 30 \mu\text{m}$ [1181 μin]**, a combination of a minimum of **two dual layer** calibration foil standards with approximate thicknesses, as below, should be used:
 $\text{Au/Ni or EN } 0.020 - 0.030 \mu\text{m} / 4 - 5 \mu\text{m}$ [0.79 - 1.18 μin / 157 - 197 μin]
 $\text{Au/Ni or EN } 0.050 - 0.100 \mu\text{m} / 4 - 5 \mu\text{m}$ [1.97 - 3.94 μin / 157 - 197 μin]

3.1.3 XRF Zero Offset Acceptability To determine the accurate measurement of the Immersion Gold layer in ENIG surface finishes, it is important to determine that the XRF instrument accurately measures the immersion Au layer correctly as zero in its absence.

Scattering of X-Rays by the printed board and non-uniform distribution of bromine in the board contribute to high background count rates that can falsify gold readings by creating an offset of the true zero value.

To determine if the offset value of zero is within acceptability limits, one needs to consider systematic and statistical uncertainties of the measurement.

Uncertainties

Systematic Uncertainties: Errors caused by calibration issues in the equipment or methods used to take the measurements. Offset error occurs when the instrument does not read zero when the quantity to be measured is actually zero. Accuracy is reduced by this measurement error. An offset error of $0 \pm 3 \text{ nm}$ [$0 \pm 0.118 \mu\text{in}$] is acceptable.

Statistical Uncertainties: Random fluctuations caused by unknown and unpredictable changes in the measurement equipment. Random errors often have a normal distribution, and tend towards zero as the number of measurements increase. Precision is reduced by these random measurement fluctuations.

Procedure

1. Take twelve (12) repeated measurement on a Ni/Cu/Printed Board Sample (no gold [Au] layer), i.e.,
The number of measurements **shall** be twelve (12) to minimize the statistical uncertainty (van Belle, 2008)¹⁰
2. Calculate the mean value of the Au readings.
3. Determine if the mean value is within $0 \pm 3 \text{ nm}$ [$0 \pm 0.118 \text{ }\mu\text{in}$].

Example:

The following serves as an example for the procedure, calculation and interpretation of the results. All measurements **shall** be done with the same instrument setup, instrument calibration, and measurement time and collimator size as used for the Type 1 Gauge Capability test.

Table 3-2 lists the twelve (12) repeated measurements taken on a Ni/Cu/ printed board sample analyzing the Au thickness.

Note: Both nanometer and micro-inch units are shown.

Table 3-2 Twelve (12) Repeat Au Measurements and the Mean Value

N	Au [nm]	Au [μin]
1	0.37	0.0145
2	-0.43	-0.0169
3	-0.24	-0.0094
4	-0.13	-0.0051
5	0.19	0.0075
6	-0.05	-0.0020
7	0.23	0.0091
8	0.44	0.0173
9	-0.37	-0.0146
10	0.27	0.0163
11	-0.08	-0.0031
12	0.10	0.0039
Mean $\bar{X}$	0.025	0.0098

Nanometer: $-3.0 \leq 0.025 \leq +3.0$ $\mu\text{-inch}$: $[-0.118 \leq 0.0098 \leq +0.118]$

The mean value of 0.025 nm [0.0098 μin] is contained within $0 \pm 3 \text{ nm}$ [$0 \pm 0.118 \text{ }\mu\text{in}$], and is therefore acceptable. If the mean value is not contained within $0 \pm 3 \text{ nm}$ [$0 \pm 0.118 \text{ }\mu\text{in}$], the producer or user **shall** check calibration and instrument setup to correct for systematic uncertainties (errors).

3.1.4 Process Qualification Measurement Requirements Prior to commencement of this process, the requirements detailed in 3.1.1.1, 3.1.1.2 and 3.1.1.3 **shall** have been met. The C_g for the XRF tool will have a direct impact on the number of measurements per pad to be taken for process validation and conformance testing. For XRF tools with a C_g more than 1.33, five individual measurements per panel side, the four corners and a center point, and all panels in the basket **shall** be measured. For XRF tools with C_g values less than 1.33, the following equation **shall** be used to ensure the correct number of readings is taken:

$$n(\text{minimum}) = [2/C_g]^2$$

Always round up $n(\text{minimum})$ to the next whole number. The minimum number of measurements **shall** always be ≥ 2 .

Worked example:

$$C_g = 1.02$$

Required minimum number of measurements $n(\text{minimum})$ per sample(pad) is:

$$n(\text{minimum}) = [2/1.02]^2 = 3.84, \text{ rounded up} = 4$$

Samples (pads) per panel side for qualification = 5

10. van Belle, *Statistical Rules of Thumb 2nd edition 2008*

Measurements: 4 (each of the five pads will be measured four times and the **average** value reported for **each** pad)

Total Measurements: $5 \times 4 = 20$ per panel side

Pads of 1.5 mm x 1.5 mm [0.060 in X 0.060 in] or equivalent area ($\pm 10\%$) **shall** be used, as prescribed in paragraph 1.1.1. If there are multiple nickel and gold tanks on the plating line, then all combinations of nickel and gold plating tanks **shall** be measured. The mean and standard deviation **shall** be calculated for each pair of plating tanks. The standard deviation is a critical parameter and should not exceed 0.003 μm [0.12 μin] for the gold plating process. The standard deviation for the nickel deposit should not exceed 0.13 μm [5 μin]. Standard deviation is a critical parameter for process control but these values are not to be used for lot acceptance. Values more than these should require engineering input to determine the source of the variation: tank design, bath loading, rack design allowing panels to touch, solution flow, etc.

3.1.5 Electroless Nickel Reducing Agents - Phosphorus Content Phosphorus-containing, reducing agents are used for the reduction of the electroless nickel during the deposition process and phosphorus is incorporated in the nickel deposit. Currently there are two levels of phosphorus found in electroless nickel deposits used for ENIG:

- 1) A mid-phosphorus nickel with phosphorus levels ranging from 5 wt.% to 10 wt.%
- 2) A high phosphorus nickel with phosphorus levels greater than 10.0 wt.%.

The level of this co-deposited element should be controlled within the chemical supplier's specified process limits. Variation of phosphorus levels outside the specified process limits may have adverse effects on the performance of the finish and/or potentially increase the occurrence and/or severity of hyperactive corrosion.

The phosphorus content within the interfacial region between the electroless nickel and immersion gold layers is higher than that found in the bulk deposit. After soldering, the phosphorus levels at the interface between solder and the electroless nickel will always be higher than that found on a non-soldered pad, as the tin in the solder preferentially reacts with the nickel, leaving a phosphorus-rich layer behind. This is a NORMAL and expected occurrence.

The phosphorus content in an ENIG deposit is an integral component of line process control and as such is checked periodically. The phosphorus content of a plated sample **shall** be checked quarterly at a minimum and should cover the working metal turn over (MTO) operating range for the nickel bath. See an example of a testing schedule, as shown in Table 3-3.

3.1.5.1 Measuring Phosphorus Content in an ENIG Deposit For determining the level of phosphorus in a chemically stripped EN deposit, Inductively Coupled Plasma Mass Spectrometry (ICP-MS) **shall** be the preferred method used as it is the defacto method based on sensitivity and accuracy. Other techniques such as Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) or Atomic Emission Spectroscopy (AES) of equivalent sensitivity and accuracy may also be used. An electroless nickel sample of sufficient mass will need to be plated onto a large coupon as ICP-MS requires grams of material to be dissolved prior to testing. This method is not appropriate for establishing phosphorus content in ENIG-finished printed boards.

To determine the level of phosphorus in an electroless nickel deposit on a printed board, there are two methods that can be used:

3.1.5.2 Measurement of % Phosphorous (P) Content in Electroless Nickel (EN) Layers with Energy Dispersive X-ray Spectroscopy (EDS) Energy Dispersive X-ray Spectroscopy is the most common method for measuring phosphorus content in an ENIG deposit. It is normally carried out with a scanning electron microscope (SEM) and used during "failure" analysis. The variation in results using EDS at varying accelerating voltages by multiple locations may not render it as a suitable method. An ongoing effort with the manufacturers of the EDS equipment is underway and an IPC-TM-650 test method will be issued, subject to successful completion of this work. To maximize the accuracy of the results obtained from using EDS for phosphorus content analysis, the following suggestions are made:

- 1) The Phosphorus content should be measured in a cross-section if the sample has been previously plated with gold. If the sample was removed directly following nickel plating, then either a surface or cross-section evaluation is acceptable.
- 2) The samples should be sputtered with either carbon or palladium but not gold. The energy values of P ($K\beta$ line at 2.139 keV) and Au ($M\alpha$ line at 2.123 keV) are very close together. The detector cannot differentiate the energy between Au and P, precisely. It may happen that some incoming signals from the element Au are counted as a signal from phosphorous. For this reason, it is advisable to sputter with carbon (energy value peak at 0.277 keV) or palladium (energy value of 2.838 keV) which helps with peak deconvolution.
- 3) As each "system" is different, refer to the manufacture's manual for working distance for the sample and the acceleration voltage. It is noted that as a general rule of thumb, the acceleration voltage used should be 2X the highest keV value. For nickel, this would be 7.477 keV, so an acceleration voltage of 15 keV should be used.

- 4) The filament should be in a saturated area of emission, the electron beam in a stable position and the sample in focus.
- 5) The dead time for system should be in the 40% to 50% range – again specific to different systems.
- 6) The measurement time **shall** be 100 seconds.
- 7) The detector **shall** be calibrated using the system's normal standards prior to any phosphorus content measurements – this may use Co, Cu, Mn, etc., again depending on the system.
- 8) A traceable reference standard or standards of known phosphorus content **shall** be used to calibrate the system prior to any measurements being made. The same magnification used for measurement of the sample **shall** be used for calibration of the detector with both the system element and the phosphorus containing standards.
- 9) Where possible, multiple calibration phosphorus content standards should be used and a linear regression curve generated relative to the certified calibration values. These should be “working” standards with nickel plated over copper on laminate that has been certified by an ISO/IEC-17025 accredited calibration laboratory. These standards will have a finite life due to electron gun damage to the surface of the nickel.
- 10) Where multiple calibration standards are not available, a single standard in the appropriate phosphorus content range **shall** be used. The measured value of this standard **shall** be within ± 0.75 wt.% and the spectrum submitted as part of the analysis report.
- 11) Variation of composition, make up geometry and surface preparation between reference standard and sample to be measured can have a significant influence on the EDS- readings.
- 12) For a bare board, reported values exceeding 13 wt. % for phosphorus should be considered an indication of incorrect calibration of the EDX system, provided the surface morphology of the nickel deposit looks normal, i.e., nodular in appearance.
- 13) EDS is not a suitable tool for surface analysis due to the depth of penetration of the X-rays. Using lower gun voltage will reduce penetration depth but not sufficiently to allow for surface analysis. Auger Electron Spectroscopy (AES) or X-ray photoelectron spectroscopy (XPS) **shall** be used for surface analysis.

3.1.5.3 Measurement of % Phosphorous (P) Content in Electroless Nickel (EN) Layers with Energy Dispersive X-ray Fluorescence (EDXRF) The EDXRF is an excellent method to not only measure plating thickness, but also weight percent elemental composition of coatings. Advances in X-ray detector technology utilizing Silicon Drift Detector (SDD) technology now make it possible to directly measure the phosphorous (P) concentration of electroless deposited nickel (Ni) coatings on printed boards by EDXRF. This measurement can be performed in air (no vacuum requirement). It is nondestructive, non-contact method and requires no sample preparation.

This method is detailed in the IPC-TM-650, Method 2.3.44.

Table 3-3 Example of Phosphorus Content Analysis Over a 4-Quarter Period

Quarter # and date	Bath MTO	Measured Phos wt.% content
One - February 17th	New bath	6.3 wt.%
Two - June 3rd	1.5 MTO	6.9 wt.%
Three - September 24th	2.7 MTO	7.3 wt.%
Four - December 12th	3.9 MTO	7.8 wt.%

Note: This may or may not be the same original bath being tested each quarter. However, the sampling dates were adjusted so that the MTO level of the sampled bath was increased quarterly when the sample was taken to cover the full operating range.

3.1.5.3.1 Instrument Calibration for Phosphorus Content The Calibration **shall** be performed with certified reference materials (CRMs) according to the instrument manufacturer instructions. The CRMs **shall** be traceable to national laboratories. The structure of the reference material has to be similar to the samples under investigation. Individual calibration foils **shall not** be used for multilayer coatings. Stacking of multiple foils introduces large errors due to air gaps and height variation that are not representative of an actual printed circuit board. The certified reference standards **shall** have similar composition and thickness as the samples to be measured.

It is possible to calibrate an instrument over the full low- to high- phosphorous range. However, optimum accuracy will be achieved by calibrating each phosphorous range: low, mid, and high, separately. Each phosphorous content range should be calibrated with no less than 4 standards per range. A combination of standards that cover the thickness range 3 to 6 μm [118 to 236 μin] and % phosphorous composition can be used.

No less than 3 measurements per calibration standard **shall** be performed. Calibration checks should be performed after each calibration and periodically by re-measuring the calibration standards. When the results are within the measurement uncertainty of the standards and the uncertainty of the measurement itself, no action is required. If not, a recalibration of the instrument is required.

Standard measurement uncertainties of better than 1% can be achieved when using traceable CRMs and an XRF instrument with an SDD detector.

3.1.6 Gold Stripping of Plated Deposits for Evaluation of Corrosion Level There are multiple procedures for removing the immersion gold deposit in order to evaluate for the presence of hyperactive corrosion of the nickel. However, it is possible to produce false positives for hyperactive corrosion if care and attention to detail are not exercised.

The following are issued as guidelines for gold stripping of an ENIG deposit. For more detailed information, see Appendix 9-A, 9-B, and 9-C.

3.1.6.1 Recognized Methods for Gold Stripping

1. Buffered Cyanide Based Solution – This is the most common solution used for gold stripping with the majority of chemistry being used at room temperature. There are exceptions to this and it is recommended to read the manufacturer's data sheet carefully.
2. Potassium Iodide / Iodine Solution – This solution may be used to remove gold, but has been observed to create a more aggressive grain boundary attack than a cyanide-based solution. This should be taken into account when interpreting results. This solution needs to be made up freshly each time it is used.
3. Ion Milling of the Gold Under Vacuum – This method does not attack the grain boundaries but does require the use of specialized equipment. Also, the removal rate of the gold is very sample dependent.

3.1.6.1.1 Chemical Stripping Solution Dwell Times and Process Steps These dwell times provided are strictly guideline times, based upon testing performed for initial IPC-TM-650 test method generation. Stripped samples **shall** be rinsed in DI water and dried immediately using clean, oil-free air.

1. Cyanide Based Stripping Solutions – These are generally operated at room temperature (22 °C [72 °F]). The dwell times are commonly between 15 to 30 seconds for a deposit thickness that meets this specification.
2. Potassium Iodide / Iodine Stripping Solutions – These are “freshly” made stripping solutions used at room temperature (22 °C [72 °F]). The dwell times should not exceed 15 seconds. Note: Potassium iodide/iodine stripping should not be used for microsectioning analysis.

3.1.6.1.2 Evaluation Using SEM For evidence of hyperactive corrosion, gold-stripped samples **shall** be examined using SEM, performed at 3000X with SE detector. Evaluation at higher magnifications may find evidence of single point occurrences that would not be rejectable per the corrosion evaluation in Table 3-7.

3.1.6.1.3 Grain Boundary Enhancement vs. Hyperactive Corrosion It is imperative to distinguish between grain boundary enhancement from gold stripping and the presence of hyperactive corrosion. Hyperactive corrosion will be present on the surface of the nickel nodules as well as showing grain boundary enhancement (see Figure 3-2 to Figure 3-6 below).

3.1.6.1.4 Verification of Hyperactive Corrosion Suspected hyperactive corrosion, once found after gold stripping, needs to be verified by evaluation of a cross-section against the criteria described relative to the corrosion per Tables 3-6 and 3-7 prior to rejection or acceptance of the sample lot being evaluated.

3.2 Performance Functions This primary function of ENIG is to provide a solderable surface finish that has extended shelf life and that is suitable for all surface mount and through-hole assembly applications.

3.2.1 Shelf Life Printed boards plated to the requirements of this specification and stored in their original packaging **shall** have a shelf life of **12 months minimum**. The “final” shelf life of the ENIG finish has been shown to exceed four years, established as part of the original testing used to create this document. For supplier-owned inventory of printed boards stored in excess of 12 months from date of manufacture, an acceptance solderability test per the requirements of J-STD-003 **shall** be performed. If failures are found using the standard Liquid test fluxes # 1 or 2, a test **shall** be performed using the production flux/solder paste and assembly method simulation. Acceptable results using the production flux **shall** indicate acceptance of the parts but caution should be raised about extending the shelf life any further. Storage and packaging guidelines from the IPC-1601 should be utilized for product that may not be used immediately to guarantee extended shelf life.

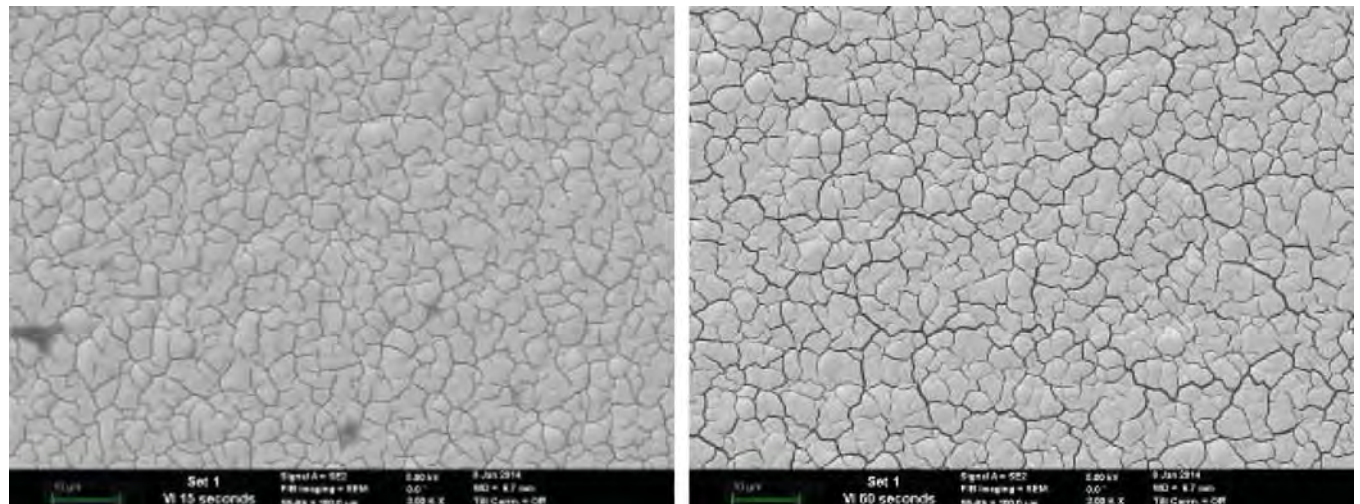


Figure 3-2 Potassium Iodide/Iodine (KI / I₂) at 15 sec. dwell (left) vs. 60 sec. dwell (right)

KI / I₂-based stripping shows more grain boundary enhancement as a function of greater dwell time.

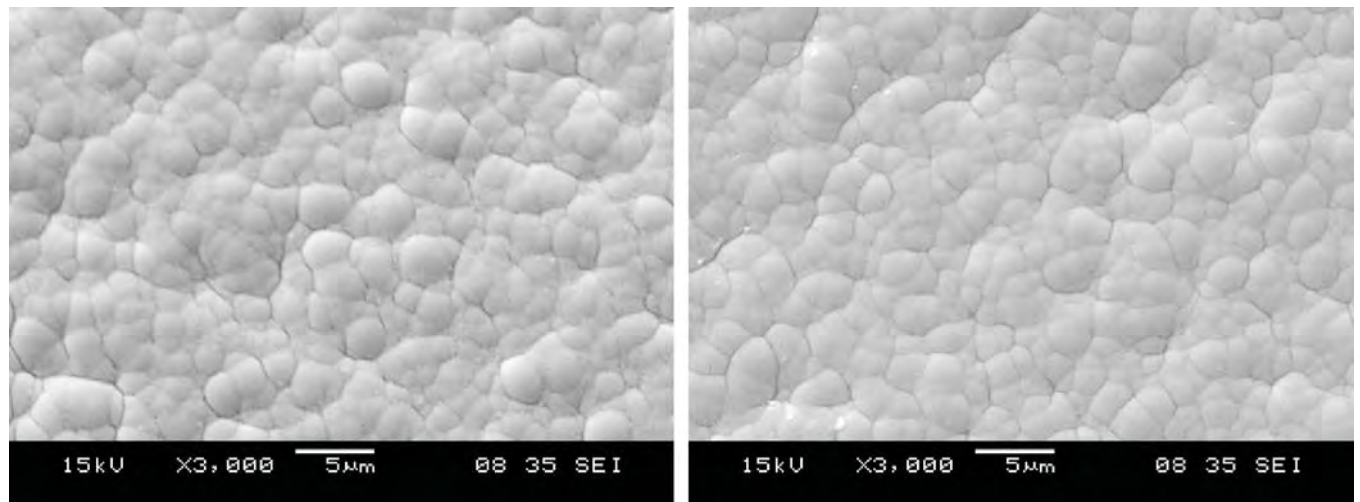


Figure 3-3 Cyanide-Based Stripping at 15 sec. dwell (left) vs. 60 sec. dwell (right)

Cyanide-based stripping shows no impact on grain boundary enhancement with Immersion Au.

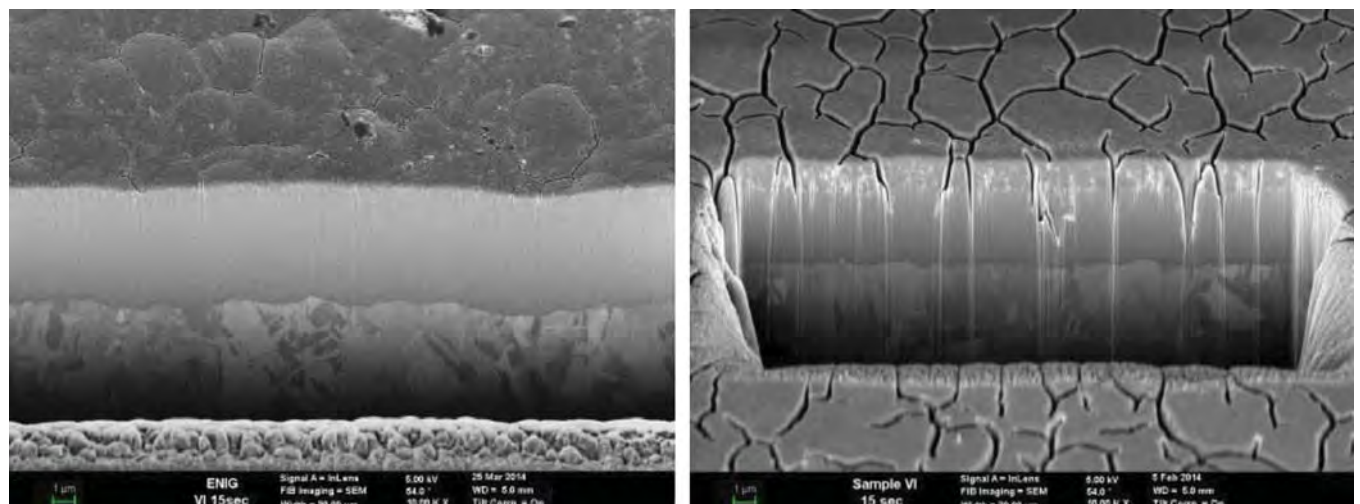


Figure 3-4 Cyanide Stripping (left) vs. KI/I₂ Stripping (right) Using Focused Ion Beam (FIB)

10000X comparison of cyanide vs. Potassium Iodide – KI/I₂ stripping shows enhanced grain boundaries.

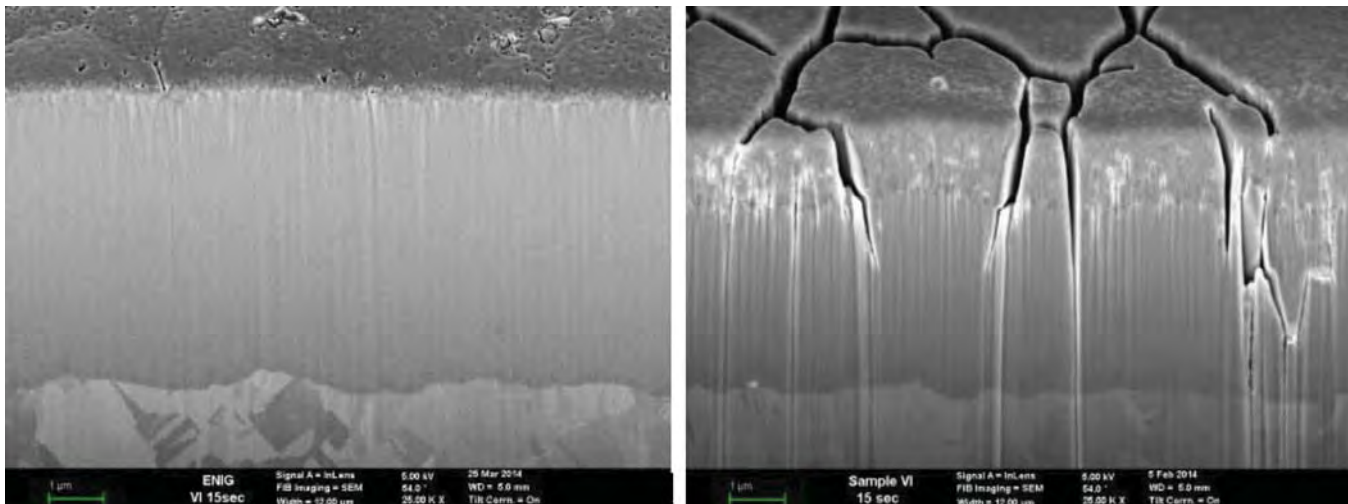


Figure 3-5 25,000X FIB Images – Cyanide (left) vs. KI / I₂ (right) – Same Dwell Time

Same sample showing enhanced grain boundary attack using KI / I₂ stripping.

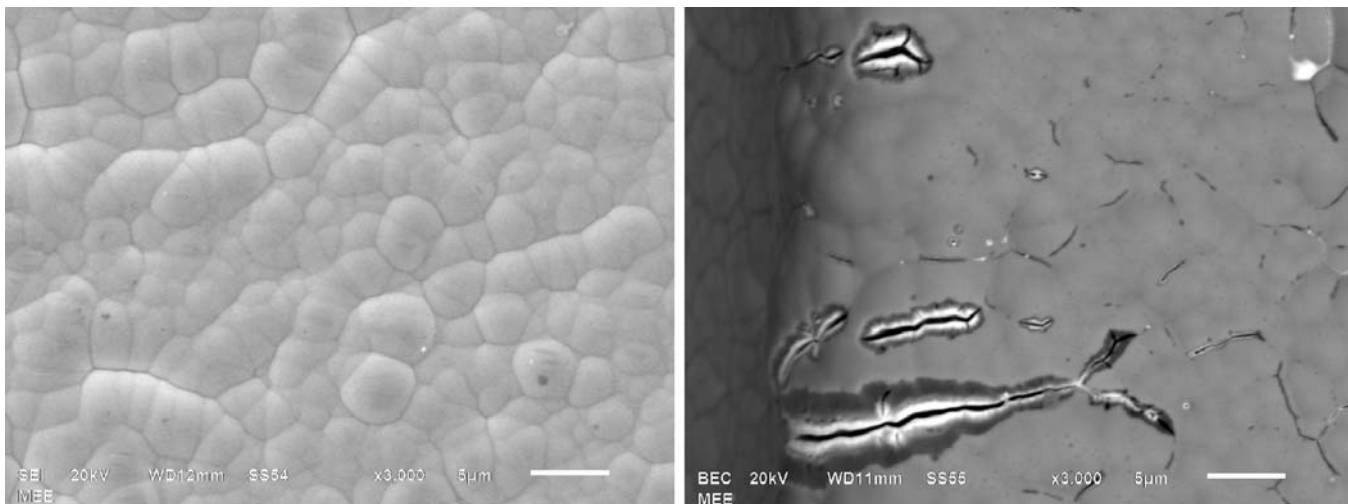


Figure 3-6 Ion Mill Stripping of Defect-Free Nickel (left) vs. Hyper-Corroded Nickel (right)

Post-stripping of gold examples of defect free nickel (left) vs. hyper-corroded nickel (right) @ 3000X.

3.2.1.1 Solderability One of the two primary functions of ENIG is to provide a solderable surface finish capable of providing a coating durability rating of B, per the IPC J-STD-003. Coating Durability B is defined as: “Intended for boards likely to experience multiple soldering processes and/or other process steps using SnPb or Pb-free assembly profiles.” This Surface finish is suitable for all surface mount, hybrid and through-hole assembly applications. The solderability requirement is for all ENIG plated SMT features tested to wet with solder covering at least 95% of each feature. Non-wetting and dewetting of the remaining 5% of the feature is allowed, provided no individual soldering defect accounts for more than 1% of the feature area. For through-hole solderability, the requirement is to wet to the knee of the hole. It is noted that, if a static solder float test is utilized, factors including board thickness, feature hole aspect ratio, number of internal copper planes, etc. will have an impact on solderability testing results. For challenging designs, it is recommended to use a solderability test method that simulates the users own assembly process conditions AABUS.

Most printed boards with ENIG final finish are produced using a solder mask over bare copper (SMOBC) process flow. This process flow was used for the test samples used during the generation of this standard. This was primarily done to eliminate the effects of post ENIG solder mask application process. The process for application of solder mask after ENIG in the alternate “full build” ENIG process may have a negative impact on the final solderability performance rating of Category B. During process qualifications, the possible impact of the specific ENIG application process on solderability should be reviewed.

3.2.1.2 Gold Embrittlement When the gold content in a solder joint exceeds 5 wt.%, embrittlement of the joint and premature failure has been well documented. A lower value of 3 wt.% is cited to allow for a safety margin.

The possibility of gold embrittlement of the solder joint is negligible when following the specified 0.1 μm [3.94 μin] maximum thickness of the immersion gold layer on the specified 1.5 mm x 1.5 mm [0.06 in x 0.06 in] or equivalent feature. Exceeding the specified gold thickness range may be detrimental relative to gold embrittlement on very small features.

It is the responsibility of the designer to calculate the percentage of gold in the resulting solder joint where printed board pad sizes associated with 0201-sized discrete chips or smaller components are encountered and compare these calculated levels of gold to the 3-5 wt.% threshold values.

3.2.2 Humidity Indicator Card (HIC) The HIC **shall** have three (3) color spots with sensitivity values of 5%, 10%, and 60% RH as shown in Figure 3-7 and should be sulfur-free in accordance with IPC/JEDEC J-STD-033. Cobalt-free HIC cards are available. The HIC is packed inside the moisture barrier bag (MBB), along with a desiccant to allow the user or assembler to determine the relative humidity inside the bag when they open it. If the color spots have changed color, this could indicate that desiccant has become saturated, that the bag seal is incomplete, or that the bag has been punctured. Criteria for actions to be taken based on color changes in the HIC **shall** be documented by the manufacturer. Additional information on HIC cards may be found in IPC-1601.

Note: Cobalt-free HIC cards are available and may be required by applicable laws or regulations. Cobalt-free HICs should not be placed in contact with bare metal, including on the printed board.

HICs with cobalt bromide have caused corrosion of ENIG finish. When an MBB is sealed, a cobalt bromide HIC **shall not** be placed in contact with an ENIG printed board. HICs with cobalt bromide may be enclosed in a separate plastic or sulfur-free paper envelope (sealed or unsealed) that is permeable to moisture, and then placed inside the moisture barrier bag.

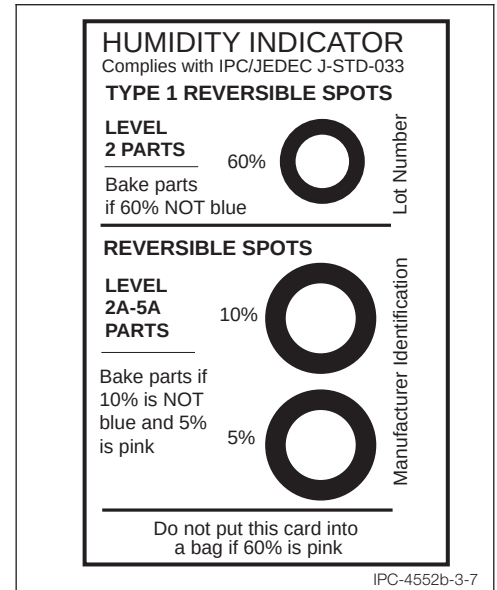


Figure 3-7 Humidity Indicator Card (HIC) Example

3.2.3 Aluminum and Copper Wire (Wedge) Bonding ENIG meets the requirements of MIL-STD-883, Method 2011.7 for aluminum wire bonding and current industry requirements for copper wire bonding. Appendix 6 details testing results from both aluminum and copper wire (wedge) bonding. Variables that are likely to affect performance include cleanliness, substrate materials, wire thickness and substrate copper surface roughness, as ENIG deposits are not capable of completely levelling the substrate surface.

3.2.3.1 Gold Wire Bonding ENIG is not a suitable surface finish for gold wire bonding. Wire wedge bonds can be made to ENIG, but the reliability of the bond is poor due to the metallurgical incompatibility.

3.2.4 Contact Surface There is a substantial amount of experience using ENIG for numerous applications (see 1.2). Workmanship requirements for contact surface finishes are as per surface mount features in IPC-6010-FAM and defects **shall not** encroach the pristine area of the surface mount lands. The pristine area is defined as the central 80% of the land area.

3.2.4.1 Soft Membrane Switches ENIG is the de facto standard for soft membrane switches (i.e., carbon). The ENIG surface finish has demonstrated that immersion gold at 0.05 μm [1.96 μin] is suitable for 1.5 million actuations with negligible resistance change. The contact resistance is, in fact, reduced over time due to the compression of the conductive material in the membrane coverlay.

3.2.4.2 Metallic Dome Contacts Testing by suppliers of metallic dome contacts have reported that ENIG is a suitable surface finish but with a reduced number of actuations prior to an unacceptable increase in contact resistance. Cycle numbers of 100,000 have been reported but not verified independently. The use of this finish with a metallic dome contact is very application-specific and should be tested, prior to its adoption.

3.2.5 EMI Shielding ENIG is one of the surface finishes used as an interface between electromagnetic interference (EMI) shielding and the printed board. Nickel has traditionally not been used for applications above 3 GHz but may work in specific applications as a shielding interface above this frequency. Testing is recommended for uses above 3 GHz.

3.2.6 Conductive and/or Anisotropic Adhesive Interface (Replacement for Solder) ENIG is ideally suited as an interface for anisotropic adhesive applications (the use of a conductive adhesive as an alternative to solder).

3.2.7 Connectors

3.2.7.1 Press Fit Connectors Press fit requirements **shall** meet Telcordia GR-1217-CORE and IEC 60352-5. Press fit connectors can be used successfully with ENIG; however, there are several considerations:

- 1) Size of connector pins, configuration of the pins, coating on the printed board (Parylene™ or other coatings), finish of the connector pins (solder or Gold) and finish on the printed board holes.
- 2) Small connector pins such as VPX connectors **shall not** pierce Parylene™.
- 3) Small connector pins with solder and ENIG on the printed board are allowed, as solder acts as a lubricant.
- 4) Large connector pins such as NAFI connectors could “tear” the gold on ENIG finish and have contact issues.

It is important to recognize and understand the coefficient of variance in the nickel plating of the printed board supplier to ensure that the correct compression fit is achieved, thereby providing long term reliability of the connector. Excessive nickel thickness of > 6 microns can lead to concerns with press fit insertion forces that may damage the pin or the hole wall of the printed board. Finally, it is suggested to contact the connector manufacturer to determine if the ENIG finish will work with their specific connector.

Additional guidance relative to press fit and surfaces finishes including ENIG can be found in IPC-9797.

3.2.7.2 Edge Tab The ENIG surface finish is suitable for plug-to-install applications for up to five insertions and/or withdrawals using low insertion force (LIF) or zero insertion force (ZIF) connectors. These utilize the original immersion gold thickness of 0.05 µm [1.97 µin] at -4 σ from the production mean, minimum gold thickness. It has NOT been tested at the reduced thickness of 0.04 µm [1.57 µin] at -4 σ from the production mean. ENIG is not suitable as an edge connector for multiple (more than five) insertions and/or withdrawals or high insertion force applications. This application generally requires an alternate metallic finish, such as electrolytic hard gold.

3.2.8 Limitations of ENIG

3.2.8.1 Creep Corrosion/Chemical Resistance ENIG, similar to the other alternate surface finishes addressed by the IPC-4550-FAM specifications, is susceptible to creep corrosion in high sulfur and/or chlorine-containing atmospheres that are commonly also at high temperature and humidity. While solderability testing of ENIG deposits after mixed flowing gas (MFG) tests per Battelle Class 2 conditions has been performed and showed acceptable solderability, it is recommended to test specific design applications if the end use environment is considered harsh.

3.2.8.2 High Frequency Signal Loss Higher frequency (> 3 GHz) applications may experience signal loss on full build (i.e., where ENIG is applied over both traces and pads) designs. Signal loss is minimal when only the pads (but not the traces) are plated with the finish. Reduction in nickel thickness may facilitate the use of ENIG at higher frequencies.

3.3 Visual ENIG surfaces **shall** be inspected in accordance with the visual examination sections of IPC-6010-FAM for all classes of product. The coverage **shall** be complete and the finish **shall** be uniform on the surface to be plated (Figure 3-8). Extraneous plating (Figure 3-9) is a process indicator but is not rejectable if there is no surface plating or nickel foot in excess of the minimum allowable conductor spacing requirement. There **shall** be no skip plating (Figure 3-10) or edge pull back (Figure 3-11) on the plated surface.

Poor copper etching quality may result in extraneous copper at the base of a feature that will subsequently plate up with ENIG and result in a nickel foot defect. Cross-sectional analysis of features exhibiting nickel foot **shall** be used to confirm the root cause of the defect. If copper is found to be present, then the requirement pertaining to minimum spacing violation

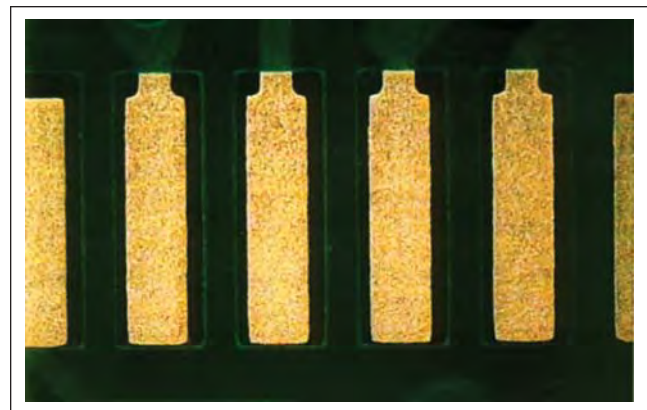


Figure 3-8 Uniform Plating

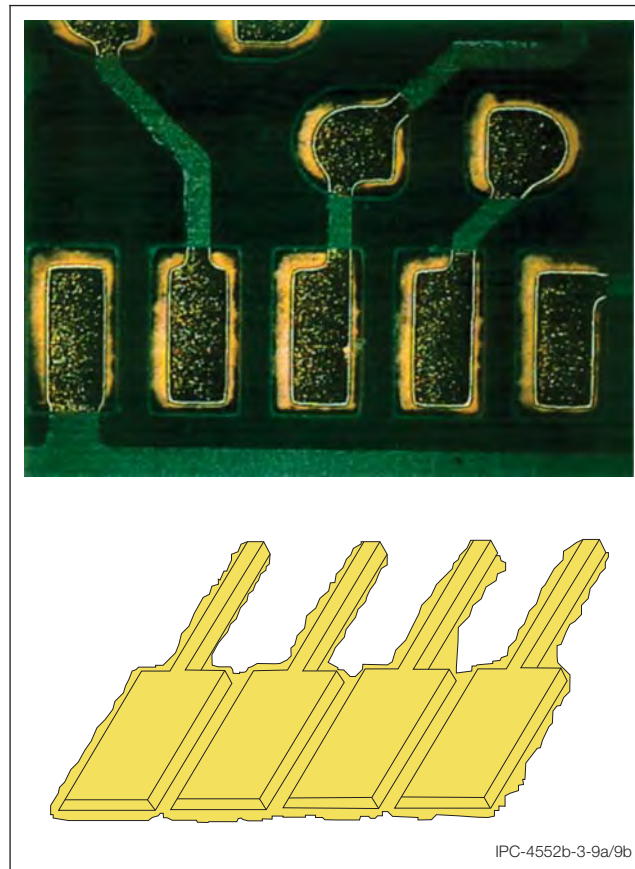


Figure 3-9 Extraneous Plating or Nickel Foot

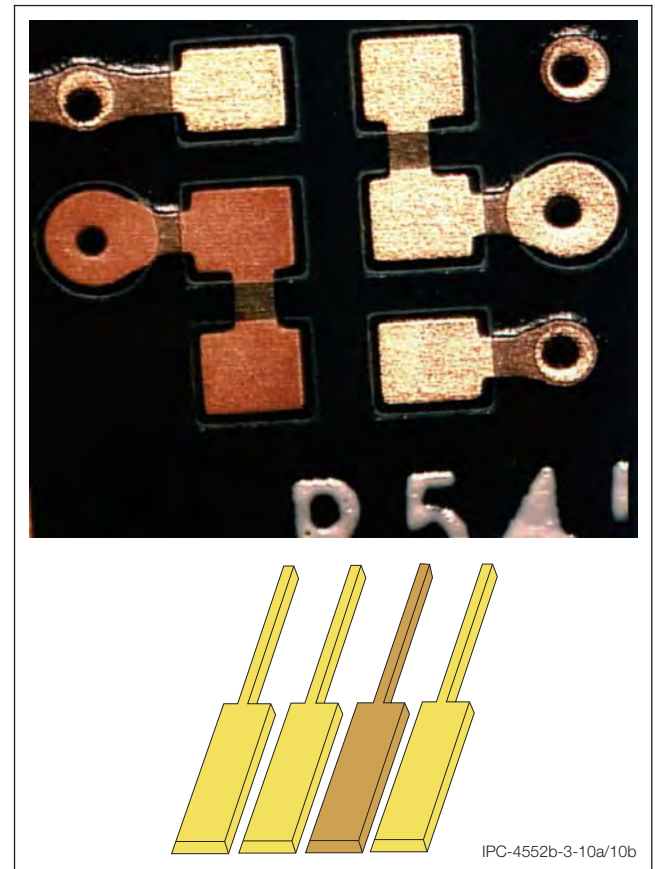


Figure 3-10 Skip Plating (No Ni plating)

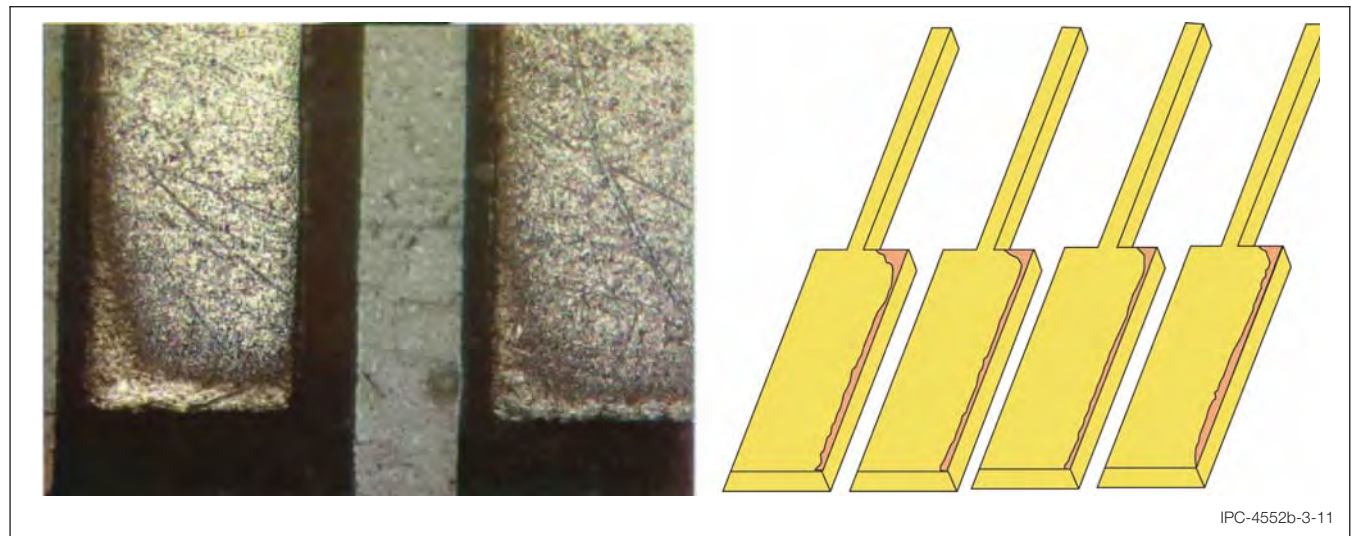


Figure 3-11 Edge Pull Back

shall be used to accept or reject the lot with the worst case(s) samples being used for evaluation. The rejection **shall** be for poor etch quality, spacing violation and not associated with the surface finish application. If no extraneous copper is found, the board is rejectable for an ENIG plating defect.

3.4 Selective Annular Ring Dewetting (SAD) This is a contact side Pb-free dynamic solder (wave or selective wave) defect that affects selective and random annular rings. The defect is rejectable per the requirements of the IPC J-STD-001, IPC-A-610 and IPC-6010 documents as defined by dewetting criteria. What is unique to this defect is the following that separates it from other dewetting anomalies that may be seen in an assembly process:

- 1) The annular rings may be connected to a trace, a plane or have a spoked connection and may impact a single annular ring or the majority across the printed board.
- 2) The solderability for the rest of the printed board is found to be excellent with no visible solder fillet defects present, and if cross-sectioned, a uniform contiguous intermetallic compound (IMC) layer is present.
- 3) Cross-sectioning of the affected through-hole joints will show dewetting on the contact side annular ring ONLY but perfect wetting and IMC formation to the hole wall and the device pin.
- 4) The defect is still being researched and, so far, is shown to be ENIG-manufacturing lot specific. Also, static lot testing does not show the defect.
- 5) The “responsibility” for the defect relative to contractual obligations and any associated costs have as yet not been assigned to any of the parties in the supply chain, i.e., from chemical supplier to printed board fabricator to assembler.

As in the majority of dewetting defects, SAD is not reworkable. Figure 3-12, Figure 3-13 and Figure 3-14 are images of the defect:



Figure 3-12 Example of SAD (Selective Annular Ring Dewetting)

This figure shows varying degrees of the defect ranging from complete annular ring dewetting to portions of the annular ring exhibiting dewetting.



Figure 3-13 Another Example of the SAD Defect

This figure shows a range of wetting from perfect to near complete dewetting.

3.5 Finish Thickness

3.5.1 Electroless Nickel Thickness

3.5.1.1 Electroless Nickel for Rigid Printed Boards The electroless nickel thickness **shall** be 3 to 6 μm [118 to 236 μin] as measured on a nominal pad size of 1.5 mm x 1.5 mm [0.060 in x 0.060 in] or equivalent area ($\pm 10\%$), where standard feature size tolerances as expressed in IPC-6010-FAM apply.

Note: Thickness measurements on pad sizes other than the nominal pad sizes of 1.5 mm x 1.5 mm [0.060 in x 0.060 in] or equivalent area ($\pm 10\%$) are exempt from this specification.

3.5.1.2 Deposits More Than the Upper Limit Electroless nickel deposits in excess of the upper limit may negatively impact insertion forces for compliant pin designs.

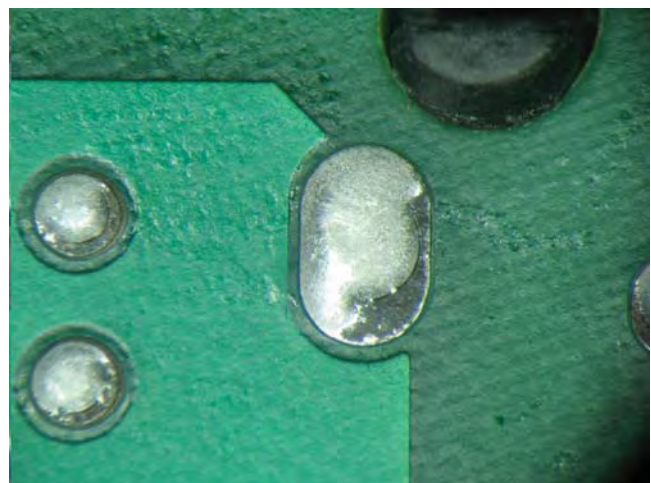


Figure 3-14 Selective Annular Ring Dewetting Defect

This figure shows some directionality relative to wave solder travel direction but this has not been shown to be the root cause of the defect; the wave solder process just exposes the defect.

3.5.1.3 Deposits Less Than the Minimum Thickness Limit Electroless nickel deposits less than the minimum limit are sometimes used for higher frequency applications. In such cases, it is not recommended to use a deposit less than 1.27 μm [50 μin] due to increased risk of copper diffusion through the electroless nickel layer.

3.5.1.4 Electroless Nickel for Flexible Circuits The electroless nickel thickness for flexible circuits **shall** be 1.27 to 6 μm [50 to 236 μin] or AABUS as measured on a nominal pad size of 1.5 mm x 1.5 mm [0.060 in x 0.060 in] or equivalent area, where standard feature size tolerances as expressed in the IPC-6010-FAM apply. Use of lower nickel thicknesses for dynamic flex applications may reduce copper and nickel cracking. Measuring the deposit as plated on flexible circuits by XRF can be a challenge due to the possible contribution of the deposit plated to a feature on the opposite side of the circuit. Measurements should be taken in areas with no plated nickel feature on the opposite side of the circuit. It is suggested to contact the manufacturer of the XRF equipment to assist with the correct set up of the equipment.

3.5.1.5 Modifications to the Base Structure of the Electroless Nickel Deposits with Flexible Circuits Such modifications have been made by multiple chemical suppliers to allow its use for dynamic flexible circuit applications. The use of conventional nickel in a dynamic application results in fractures in the nickel deposit that can extend into the basis copper and result in an open condition. The modified grain structure allows for dynamic applications without fracture propagation into the basis copper. This chemistry may not be installed at all suppliers of flexible circuits and its use **shall** be specified on the procurement documentation (see Figure 3-15, Figure 3-16, Figure 3-17 and Figure 3-18).

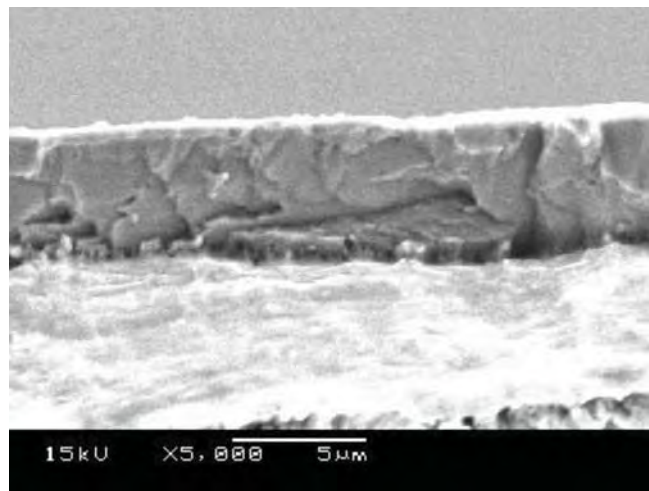


Figure 3-15 Grain Structure of Conventional Nickel Deposit

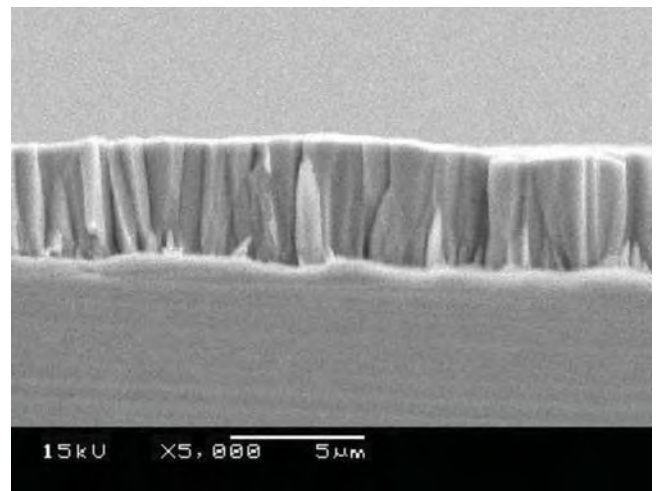


Figure 3-16 Grain Structure of Nickel Deposit Modified for Dynamic Flex Applications

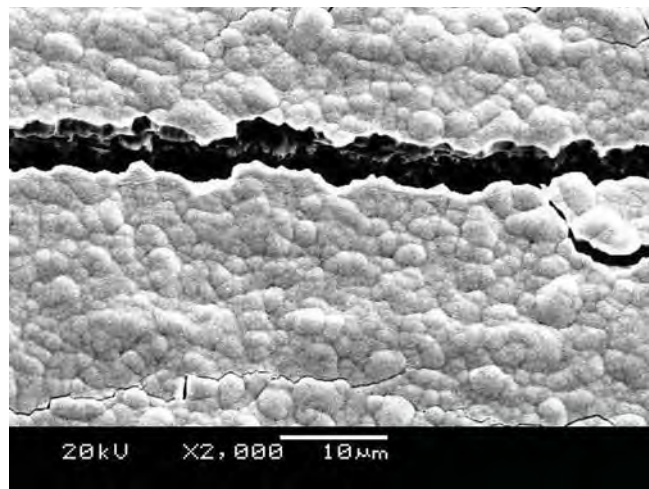


Figure 3-17 Example of Fracture in Conventional Nickel Deposit

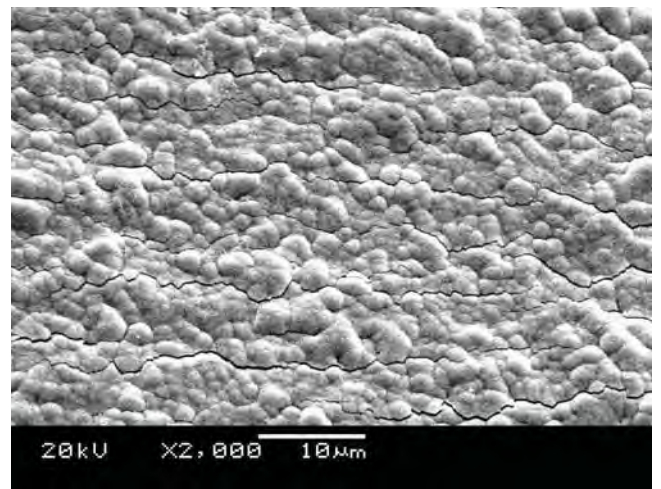


Figure 3-18 Modified Nickel Deposit Showing No Fracture with Same Number of Cycles

3.5.2 Immersion Gold Thickness The gold thickness is measured on a pad size of 1.5 mm x 1.5 mm [0.060 in x 0.060 in], or equivalent area, $\pm 10\%$, where standard feature size tolerances as expressed in IPC-6010-FAM apply.

Note: Thickness measurements on pad sizes other than the nominal pad sizes of 1.5 mm x 1.5 mm [0.060 in x 0.060 in] or equivalent area ($\pm 10\%$) are exempt from this specification.

The acceptable minimum gold thickness using this measurement method is determined using the following statistical calculation:

$$\bar{x} - 3\sigma \geq 0.04 \mu\text{m} [\geq 1.58 \mu\text{in}]$$

Where:

$\bar{x}$ = the mean gold thickness

σ = the standard deviation of the sample

Thus, the mean gold thickness measured **shall** be above the 0.04 μm [1.58 μin] minimum, but the difference between the mean and this value is determined by the variability in the gold deposit thickness.

The acceptable maximum gold thickness using this measurement method is determined using the following statistical calculation:

$$\bar{x} + 3\sigma \leq 0.1 \mu\text{m} [\leq 3.94 \mu\text{in}]$$

Where:

$\bar{x}$ = the mean gold thickness

σ = the standard deviation of the sample

Thus, the mean gold thickness measured **shall** be below the 0.1 μm [3.94 μin] maximum, but the difference between the mean and this value is determined by the variability in the gold deposit thickness.

Table 3-4 and Table 3-5 show examples of thickness reading sets that meet and that fail to meet this requirement.

Thicker gold than the upper end of the specification would normally require extended solution dwell time and/or increased solution temperature. Either of these two process changes can increase the risk of compromising the integrity of the nickel undercoat due to excessive corrosion during the deposition of the immersion gold.

Production lot acceptance where thickness readings are found in excess of these requirements are AABUS. Demonstration of the nickel deposit integrity **shall** be a key consideration for lot acceptance and **shall** require the evaluation of susceptible areas of the board to hyperactive corrosion by cross-section, i.e., BGA features and/or the knees of vias.

Table 3-4 Three Examples of XRF Data Sets (μm [μin])

BELOW SPECIFICATION			MEETS SPECIFICATION			EXCEEDS SPECIFICATION		
Reading#	Au	NiP	Reading#	Au	NiP	Reading#	Au	NiP
one	0.0472 [1.86]	5.5169 [217.20]	one	0.0856 [3.37]	5.2172 [205.4]	one	0.0856 [3.37]	5.2172 [205.4]
two	0.0478 [1.88]	5.6083 [220.80]	two	0.0856 [3.37]	5.3315 [209.9]	two	0.0856 [3.37]	5.3315 [209.9]
three	0.0480 [1.89]	5.8039 [228.50]	three	0.0787 [3.10]	5.2553 [206.9]	three	0.0787 [2.90]	5.2553 [206.9]
four	0.0540 [2.11]	5.8319 [229.60]	four	0.0820 [3.23]	5.1715 [203.6]	four	0.0904 [3.56]	5.1715 [203.6]
five	0.0550 [2.14]	5.8394 [229.90]	five	0.0838 [3.30]	5.1359 [202.2]	five	0.0699 [2.75]	5.1359 [202.2]
six	0.0470 [1.87]	5.7252 [225.40]	six	0.0851 [3.35]	5.2756 [207.7]	six	0.0796 [3.13]	5.1969 [204.6]
mean	0.0497 [1.96]		mean	0.0836 [3.29]		mean	0.0808 [3.18]	
std dev	0.0033 [0.13]		std dev	0.0028 [0.11]		std dev	0.0079 [0.31]	
Mean -3 std dev	0.0399 [1.57]		Mean -3 std dev	0.0754 [2.97]		Mean -3 std dev	0.0576 [2.25]	
Mean +3 std dev	0.0597 [2.35]		Mean +3 std dev	0.0914 [3.60]		Mean +3 std dev	0.1044 [4.11]	

These examples show where individual readings do not exceed either side of the $\pm 3 \sigma$ but only the middle set of data is acceptable.

Table 3-5 One More Example of XRF Data (μm [μin])

FAILS TO MEET SPECIFICATION		
Reading#	Au	NiP
one	0.0653 [2.57]	4.815 [189.56]
two	0.0734 [2.89]	2.0725 [193.51]
three	0.0853 [3.36]	5.1140 [201.34]
four	0.0571 [2.25]	5.0394 [198.40]
five	0.0503 [1.98]	5.3798 [211.80]
six	0.0782 [3.08]	5.2172 [205.40]
mean	0.0683 [2.69]	
std dev	0.0132 [0.52]	
Mean -3 std dev	0.0287 [1.13]	
Mean +3 std dev	0.1080 [4.25]	

This example as seen in Table 3-5 shows where no individual reading is outside of the specification range but the standard deviations are so large as to indicate the possibility that:

- 1) The XRF equipment is not calibrated correctly.
- 2) The XRF is not capable of measuring in this thickness range.
- 3) The operator has failed to follow the requirement of measuring the same feature size for ALL five measurements.
- 4) The plating process is not in control.

3.5.3 Exceptions to the Required Thickness Ranges

3.5.3.1 Immersion Gold Thicker Than Specification by Design If a gold deposit thicker than the specified upper limit of $0.1 \mu\text{m}$ ($\bar{x} + 3 \sigma \leq 0.1 \mu\text{m}$ [3.94 μin]) is a design requirement, alternate methods of gold deposition (other than immersion gold) should be considered, and that Au thicknesses greater than the specified upper limit of $0.1 \mu\text{m}$ [3.94 μin] are exempt from this specification, even when either of the following two alternate methods are used.

Note: The following two are examples of alternate methods. These methods are outside the scope of this specification and have not been evaluated by this committee:

Autocatalytic/Electroless Gold: These plating solutions have inherent chemical reduction capabilities that do not rely on displacement of the nickel substrate for gold deposition. Electroless/autocatalytic plating chemistries can achieve gold deposit thickness more than $1.0 \mu\text{m}$ [40 μin].

Reducer Assisted Immersion Gold/Mixed Reaction Immersion Gold: This bath combines immersion and autocatalytic reactions. The immersion reaction is limited by the availability of the substrate while the autocatalytic reaction can continue as long as the reducing agent is available.

3.5.3.2 Production Conformance Testing For production systems that utilize individual lot acceptance measurements the use of the C=0 sample plan in combination with the C_g value for the XRF **shall** be used. For XRF tools with C_g values < 1.33 , the minimum number of measurements (n) **shall** be determined by the following equation:

$$n \text{ (minimum)} = [2/C_g]^2$$

Always round up n (minimum) to the next whole number. The minimum number of measurements **shall** always be ≥ 2 .

3.5.3.3 Production Measurement Exceptions When a 1.5 mm [0.06 in] x 1.524 mm [0.06 in] or equivalent area pad ($\pm 10\%$) is not available on the board, a suitable alternative of equivalent area, such as a fiducial or feature on a test coupon on the same panel may be used. When an alternate is used, all the production validation readings **shall** be generated from the same feature across the production lot to minimize variation in the thickness data and statistics generated. The same required number of measurements **shall** be taken as if the prescribed feature size was present. If no such feature is available, acceptance of the thickness measurements **shall** be AABUS.

3.5.3.4 Statistical Process Control The primary goal of process control is to continually reduce variation in the process, products, or services to provide products or processes meeting or exceeding customer requirements. Process control tools such as IPC-9191, JESD557 or other user-approved systems may be used as guidelines for implementing process control.

The use of statistical process control is encouraged.

When using statistical process control, it is assumed the XRF tool is accurate and repeatable. The ENIG process is considered a batch process which should have a very tight range in the data based on the requirements of feature size to be measured. It is recommended for the thickness data to be charted using either a Xbar-mR or Xbar-S chart. The mean of each production lot (20 panels or less) and subsequent twenty panel increments should be charted on the X-bar chart. The mR chart should be used to monitor the variation in range between 20 consecutive panels or less subgroups. The S chart should be used to monitor the variation within the 20 panel or less subgroups. Because the subgroup size $n \geq 6$, the S chart is preferred over the R chart because the R chart only uses two data points, whereas the S chart uses all the data within the subgroup. The six measurements **shall** be taken on a single panel. Software is available to automatically calculate control limits and plot the data.

The chart data needs to be reviewed daily by the appropriate qualified personnel for evidence of non-randomness that indicate the process drifting out of control and action to be taken prior to rejectable product being manufactured. Indicators of this would be:

- 1) 1 point more than 3 standard deviations from the center line
- 2) 2 out of 3 points > 2 standard deviations from the center line (same side)
- 3) 4 out of 5 points > 1 standard deviation from the center line (same side)
- 4) 9 points in a row on the same side of the center line
- 5) 6 points in a row, all increasing or all decreasing
- 6) 14 points in a row, alternating up and down
- 7) 15 points in a row within 1 standard deviation of the center line (either side)
- 8) 8 points in a row > 1 standard deviation from the center line (either side)
- 9) An unusual or nonrandom pattern in the data
- 10) One or more points near a warning or control limit.

Note: The first four detection rules are known as the Western Electric Rules.

Corrections to the process to return the product measurement data to within precalculated control limits **shall** be noted for future audit reviews and overall process improvement activity.

The number of readings per production lot may be reduced based on the process being shown to be in statistical control, which is where either the Xbar-mR or Xbar-S chart show no unexplainable, out of control data points. The same number of readings, 6 minimum, **shall** continue to be used per subgroup but only three times per production shift/day.

3.5.3.5 Population Measurements Statistical requirements above is negated, provided that measurements are taken on 100% of all printed boards/panel coupons, thus providing population parameters rather than sample statistics. All such readings **shall** fall within the thickness ranges specified above for both deposits. Any readings below or above the specified thickness range **shall** be cause for rejection of that board.

3.5.3.6 Production Overruns and/or Inventory Items When compliance testing of individual printed board(s) remaining in inventory is required, use the protocol of 3.5.3.5. For production overruns larger than ten, the sample statistic constraints **shall** apply.

3.5.3.7 Reworking/Repair of ENIG Reworking of ENIG that involves either partial or complete stripping of immersion gold and/or electroless nickel **shall not** be permitted. Similarly, repair of skip plating defects with the use of electrolytic plating systems for nickel and/or gold **shall not** be permitted. Additional processing in immersion gold to meet gold thickness requirements **shall** be allowed, provided that subsequent adhesion testing is performed. Panels removed from the plating line after electroless nickel plating but prior to immersion gold plating may be plated with additional electroless nickel and then immersion gold, provided that the electroless nickel surface is reactivated with recommendations of the chemical supplier prior to plating, and that both adhesion testing and solderability testing are performed prior to shipment of the printed boards. Any deviations from the requirements of this paragraph **shall** only be AABUS.

3.6 Nickel Corrosion The Immersion Gold plating process involves a displacement reaction in which the electroless nickel deposit is dissolved and a proportionate quantity of gold is deposited. This process is, by definition, a corrosion reaction. In an ideal immersion reaction, the degree of dissolution of the substrate material would be identical at all locations across the surface. In practice, substrate dissolution may be non-uniform, and, in some cases, sufficiently localized to form dark colored features at the electroless nickel-gold interface which are visible by examination of cross-sections of the ENIG deposit or top-down evaluations of ENIG surfaces from which the immersion gold layer has been stripped. When the dimensions and density of these localized corrosion features become sufficiently large, the electroless nickel gold interface will have substantial areas that show a dark appearance. When this level is reached, the phenomenon is known as hyperactive corrosion of the nickel, sometimes referred to as black pad.

When present at high levels and on a significant fraction of printed board features, hyperactive corrosion may have an unacceptable impact on solder joint formation and consequently on solder joint reliability.

ENIG deposits range from showing no significant localized interfacial corrosion, through minor levels that have no impact on the solderability of the deposit (relevant only as a process indicator), to extreme conditions where a significant fraction of printed board features are sufficiently degraded that solder joints may have unacceptably low or no joint strength or solder wetting is visibly degraded.

The mechanism by which hyperactive corrosion affects solder joint formation is through inhibition of formation of a nickel-tin Intermetallic Compound (IMC) layer of appropriate thickness and coverage, even when the surface layer of immersion gold has been completely dissolved.

Degrees of corrosion that do not interfere with the formation of a contiguous IMC layer of normal thickness are **not** considered to be rejectable.

Severe hyperactive corrosion where either solder wetting or proper IMC formation are negatively impacted is a rejectable condition.

Accurate assessment of the degree of corrosion and the proportion of pads affected is only possible on features that have **not** been soldered or further treated (e.g., OSP-treated). Examples would include ENIG features on unassembled printed board or unsoldered features on assembled printed board, such as fiducials.

This is a consequence of the modification of the electroless nickel - gold interface which takes place during the soldering process, as solder joint formation on ENIG involves complete dissolution of the gold layer immediately followed by wetting and partial dissolution of the electroless nickel surface, to form an interface with an intermetallic compound layer between the substrate and the solder material. Depending on soldering process conditions, including solder alloy, temperature and time above liquidus, the degree of dissolution of the electroless nickel may be enough to significantly alter the appearance of the electroless nickel surface region.

Evaluation of an electroless nickel surface for corrosion after removal of gold (for example by chemical stripping) is also subject to the risk that the gold removal process modifies the surface structure. For this reason, while evaluation of surfaces after gold stripping may be carried out as a screening test for the possible presence of hyperactive corrosion, final conclusions about the degree of corrosion that might be present can only be made based on evaluations of cross-sections of unsoldered features with the gold layer still present, using the sample preparation and magnification described in section 3.6.3.

It is important to note that if a very large number of samples from a printed board are cross-sectioned, a few locations may be found where hyperactive corrosion is present. Similarly, if excessive magnification is used for evaluation, features may be improperly identified as being defective.

The impact of hyperactive corrosion on solder joint reliability has been shown to be a consequence of the effect occurring sufficiently often that significant portions of the surfaces of multiple pads are affected. Consequently, a single occurrence of corrosion is **not** rejectable.

Several different root causes for hyperactive corrosion have been identified. The following three conditions have been strongly correlated to the issue:

- 1) Electroless nickel deposit physical characteristics outside of the chemical supplier's guidelines;
- 2) Higher than normal activity of the immersion gold bath, because of either abnormal chemical concentrations or bath operating conditions, for example, the bath temperature;
- 3) Leach out of materials from under-cured soldermask, some dry film photoresists used for selective ENIG plating and/or some laminate base materials

Note: When using ENIG as a selective finish, specifically when using dry film resist to mask areas not intended to have nickel gold, performance versus nickel bath MTO's should be monitored, and the maximum bath MTO potentially lowered to prevent the occurrence of hyperactive corrosion caused by organic contamination coming from the leach-out products of the dry film resist.

If either the nickel deposit or the immersion gold bath are outside normal operating conditions, the possibility exists for excessive vulnerability of the nickel deposit to attack, or excessive aggressiveness of the gold process towards the nickel.

Evaluation of the deposit using Scanning Electron Microscopy (SEM) is for failure analysis **only**; the disposition of the printed boards being AABUS.

Evaluation of a gold stripped surface using SEM **shall** also require that a non-gold stripped cross-section exhibit the defect prior to rejecting the sample or lot. It has been shown that gold stripping can, in some cases, excessively enhance the grain boundaries such that the nickel deposit is incorrectly identified as showing hyperactive corrosion.

3.6.1 Morphologies of Features at Electroless Nickel – Immersion Gold Interfaces

3.6.1.1 Definition of Spike Defects A spike is a narrow, < 2.54 μm [100 μin] wide, dark, isolated feature extending downwards from the electroless nickel surface into the electroless nickel deposit. Examples of spikes are shown in Figure 3-19.

3.6.1.2 Definition of Spreader Defects Spreader defects are a single, contiguous feature that is $\geq 2.54 \mu\text{m}$ [100 μin] in width extending from the electroless nickel/immersion gold interface into the electroless nickel deposit. (see Figure 3-20 and Figure 3-21)

3.6.1.3 Definition of Black Band Defects Black band defects are a contiguous layer of corrosion that extends across the nickel surface for a minimum of 30% of the field of view at 1000X. Black band defects have several different appearances, with and without gold being visible, deep penetration into the nickel deposit in a jagged pattern or shallow in nature but to a uniform depth. The contiguous layer is what defines the black band, not the shape of the corrosion. It is noted that different magnification lenses are used to connect the microscope to the computer screen, 0.45X, 0.63X or 1X for example. This will change the length of the field of view as seen on the monitor. For a rejection for black band, the magnification factor of the lens **shall** be noted on the rejection report. Examples of black band defects are shown in Figure 3-22 and Figure 3-23.

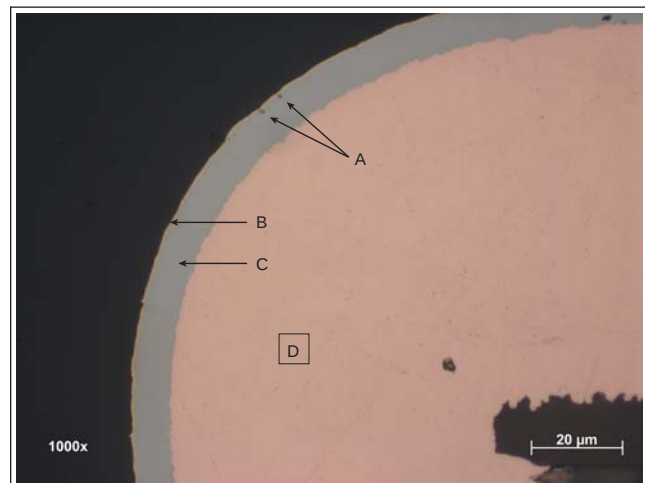


Figure 3-19 Example of Multiple Spike Defects on the Knee of a Hole at 1000X

A – Spikes
B – I Au (Immersion Gold) deposit
C – E-Ni (Electroless Nickel) deposit
D – Electrolytic copper

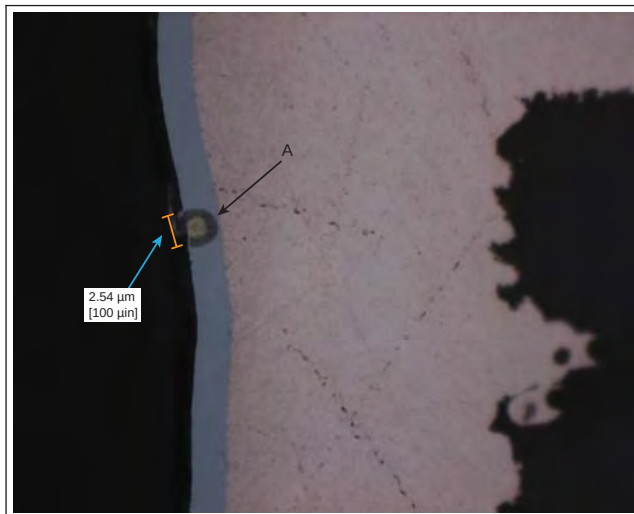


Figure 3-20 Example of an Isolated Spreader Defect at 1000X (Rate as Level 1, if < 40 %)

A – Spreader

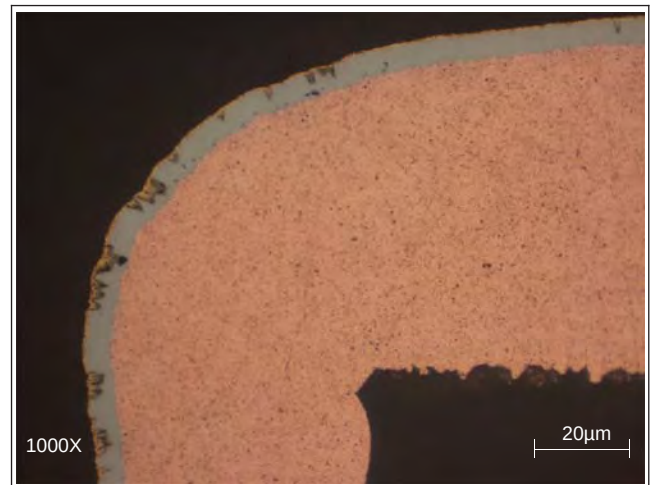


Figure 3-21 Example of Multiple Spreader Defects on the Knee of a Hole at 1000X

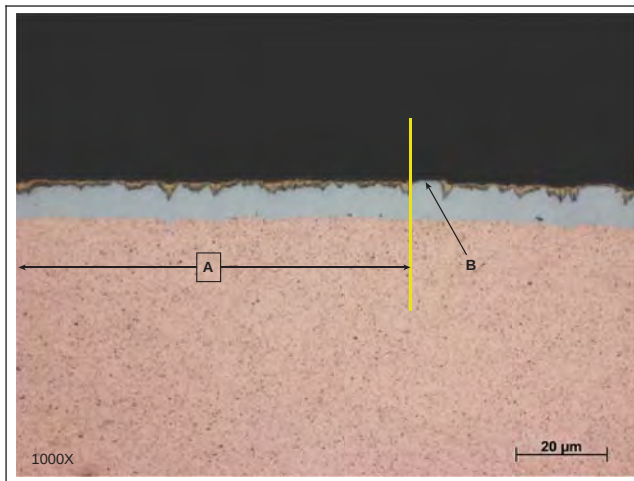


Figure 3-22 Example of Black Band Defect (Jagged in Nature) with Varying Depth of Penetration Type of Corrosion at 1000X

A – Contiguous corrosion > 30% of field of view – black band
B – Break in the contiguous corrosion in this location

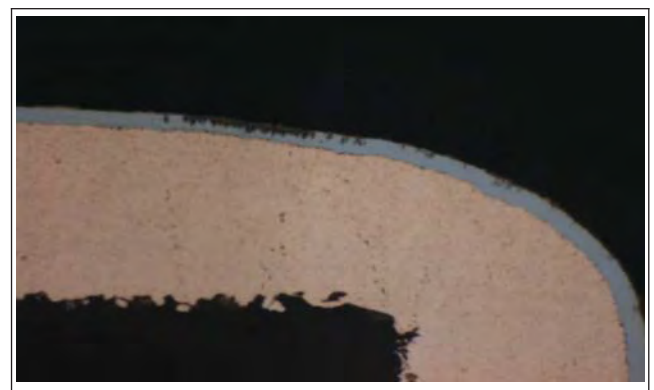


Figure 3-23 Example of Black Band That Would be Rejectable if it Met the Minimum 30% Coverage of the Field of View at 1000X

3.6.1.4 Nickel Cracks Cracks in the nickel deposit are not corrosion defects. They may be the result of a defective nickel deposit, damage due to sample preparation or from aggressive grinding during cross-sectioning. Cracks in the nickel are **not** rejectable per the standards in the IPC-6010-FAM. They are a process indicator for either control of the plating chemistry or sample preparation (see Figure 3-24).

3.6.2 Corrosion Level Definition Based on optical inspection of an individual location on a cross-sectioned feature, four different levels of corrosion are defined, as follows in Table 3-6. The reference basis for all four levels of defects **shall** be the field of view at 1000X magnification. After the corrosion evaluation based on Table 3-6 is complete, the Product Rating will be determined as shown in Table 3-7.

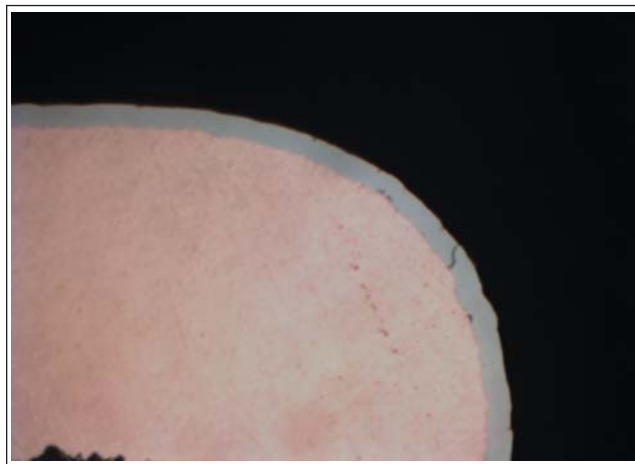


Figure 3-24 Example of a Crack in the Nickel Deposit at 1000X

This is **not** Corrosion

Table 3-6 Identification of Corrosion Level of a Location

Observations	Level 0	Level 1	Level 2	Level 3 ^[1]
Evaluate Within the Field of View at 1000 X by Optical Microscopy	Defect Free ENIG Deposit	Number of Spike Type Defects Observed < 10 and All corrosion spike depths are ≤ 20% of the nickel deposit thickness or Single occurrence (spike/spreader) < 40% of the nickel deposit thickness	ALL OTHER OBSERVATIONS	Number of Spike Type and/or Spreader Type Defects Observed ≥ 10 and > 5 of the observed defects have a depth > 40% of the nickel deposit thickness or Black Band Type defect(s) present that extend to > 30% of the field of view (see 3.6.1.3)

[1] Level 3 is considered hyperactive corrosion.

3.6.2.1 Photomicrographs of Corrosion Evaluation The following sections contain images at the prescribed 1000X magnification of potential occurrences during a corrosion investigation.

3.6.2.2 Photomicrographs of Defect Free ENIG Deposits (also Termed Level 0 Corrosion) Level 0 corrosion is evidenced in both Figure 3-25 and Figure 3-26.

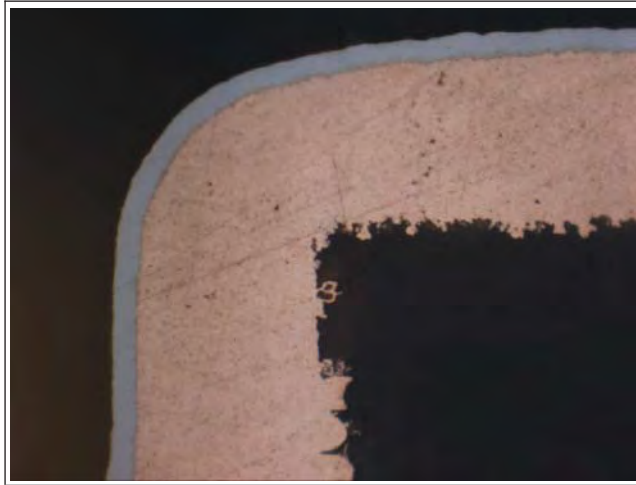


Figure 3-25 Example of Level 0 Corrosion – Knee of Hole at 1000X

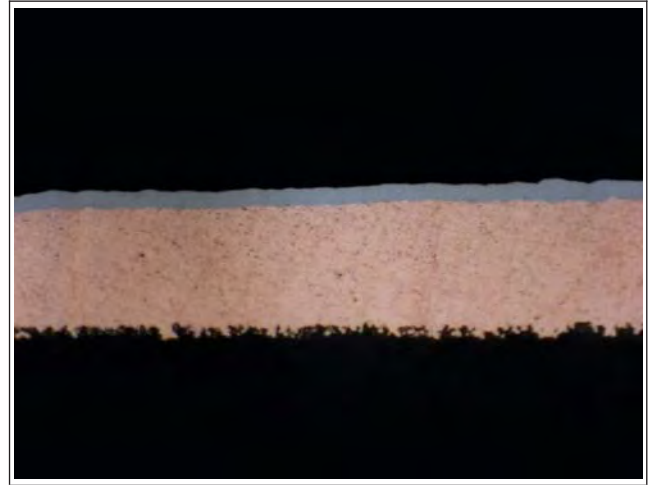


Figure 3-26 Example of Level 0 Corrosion – SMT Feature at 1000X

3.6.2.3 Photomicrograph Examples of Level 1 Corrosion Level 1 Corrosion is evidenced in both Figure 3-27 and Figure 3-28.

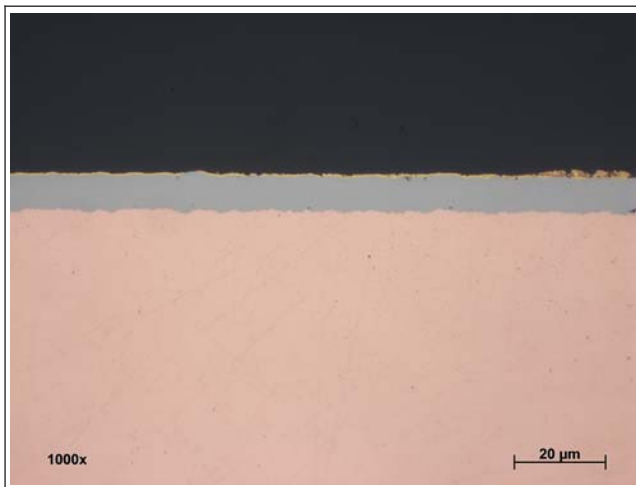


Figure 3-27 Level 1 Corrosion – SMT Feature at 1000X

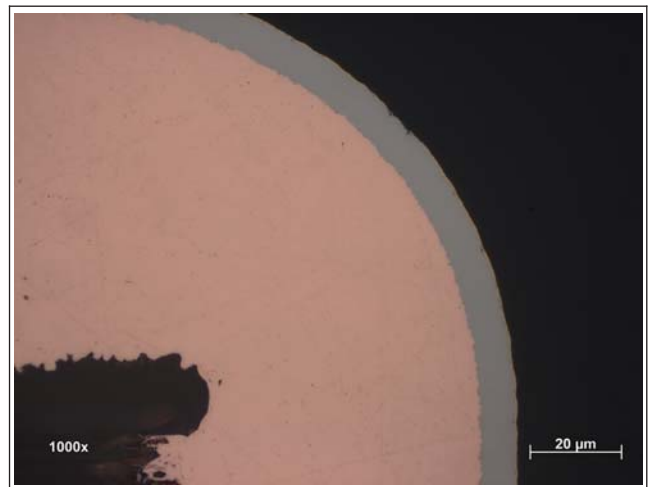


Figure 3-28 Level 1 Corrosion – Knee of Hole at 1000X

3.6.2.4 Photomicrograph Examples of Level 2 Corrosion Level 2 Corrosion is evidenced in both Figure 3-29 and Figure 3-30.

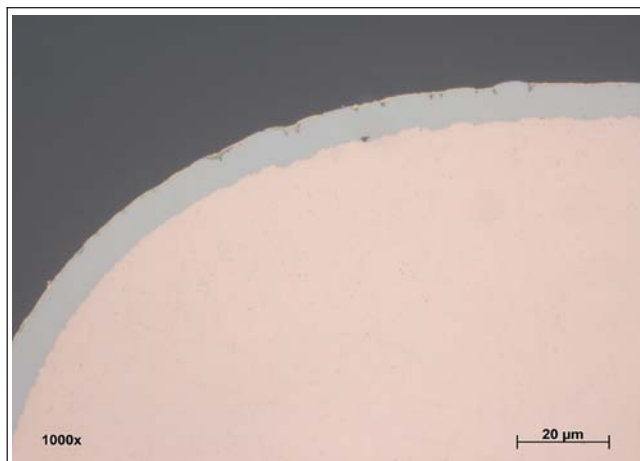


Figure 3-29 Level 2 Corrosion – Knee of Hole at 1000X

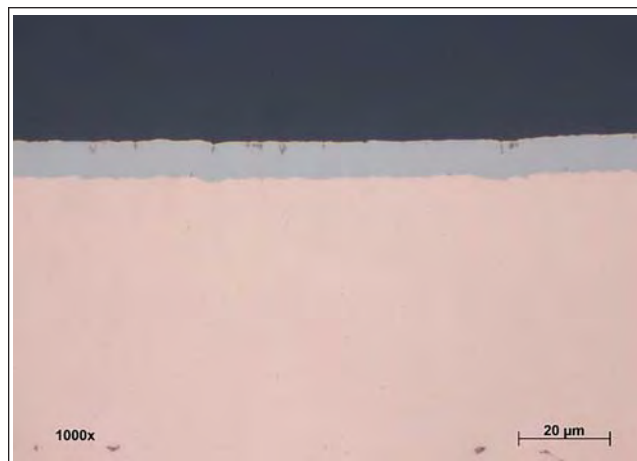


Figure 3-30 Level 2 Corrosion – SMT Feature at 1000X

3.6.2.5 Photomicrograph Examples of Level 3 Corrosion Level 3 Hyperactive Corrosion is evidenced in both Figure 3-31 and Figure 3-32.

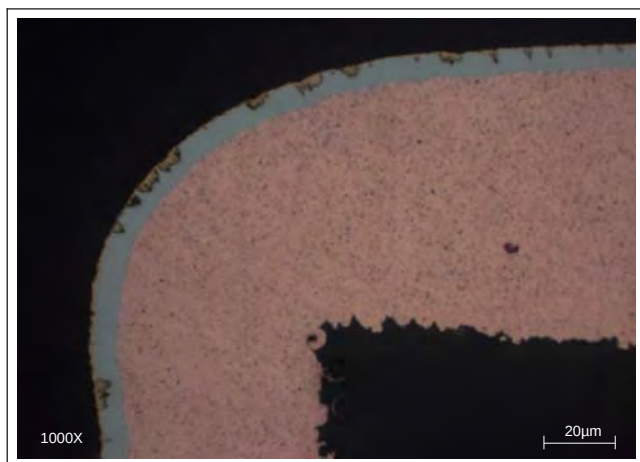


Figure 3-31 Level 3 Hyperactive Corrosion – Knee of Hole at 1000X



Figure 3-32 Level 3 Hyperactive Corrosion – SMT Feature at 1000X

3.6.3 Corrosion Level Evaluation of an As-Plated ENIG Deposit by Cross Section

3.6.3.1 Samples for Corrosion Evaluation These **shall** be in the as-plated (not soldered or OSP-treated) condition. Suitable samples include conformance coupons or samples cut from the actual printed board. Samples **shall** be prepared in a cross-section mount that has **not** been etched in any manner. The cross-section mount **shall** contain two or more features. A feature may be a through-hole with associated annular ring areas, or a surface mount pad. Only one feature type is used for evaluation.

It is recommended to evaluate annular rings of through-holes and features of high density such as BGA features for this evaluation. Vias may be more likely to show the presence of the defect and can be used for acceptance or rejection evaluations, even in cases where those features would not normally be soldered.

The evaluation is to be carried out in two stages:

- 1) An initial evaluation of two or more features at lower magnification
- 2) A printed board acceptance evaluation of the worst of the features at higher magnification, recording the corrosion level at each of the corresponding locations as specified per 3.6.3.4.

3.6.3.2 Initial Inspection Such inspection to determine which of the features shows the highest degree of electroless nickel interfacial corrosion **shall** use optical microscopy at a minimum of 200X magnification, using brightfield microscopy or Nomarski DIC (differential interference contrast).

3.6.3.3 Inspection for Corrosion of the Feature Selected in 3.6.3.1 The feature selected in 3.6.3.1 for the purposes of printed board acceptance **shall** use optical microscopy at 1000X magnification, using brightfield microscopy or Nomarski DIC.

3.6.3.4 Locations for Corrosion Investigation For PTHs with associated annular rings, seven locations **shall** be evaluated as shown in Figures 3-33 and 3-34. For SMT pads, five locations **shall** be evaluated as shown in Figures 3-35 and 3-36. The corrosion evaluation **shall** have a clear separation between the different locations to be evaluated (B in Figures 3-32 to 3-35).

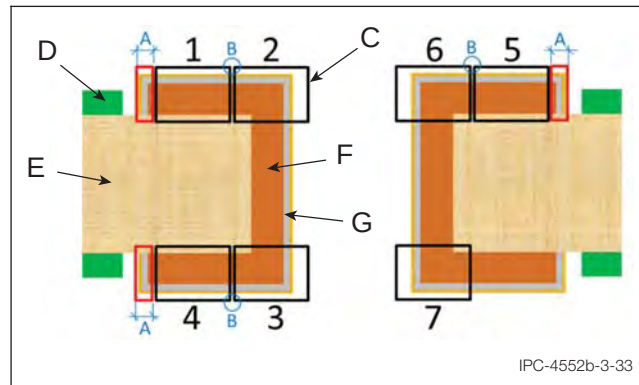


Figure 3-33 Etched Defined PTH

- A. Do not record observations on side wall; A = 25.4 μm [1000 μin]
- B. No overlapping of inspection areas allowed
- C. Inspection area 1 – 7 for optical microscope (magnification 1000X)
- D. Soldermask
- E. Base material
- F. Copper
- G. ENIG

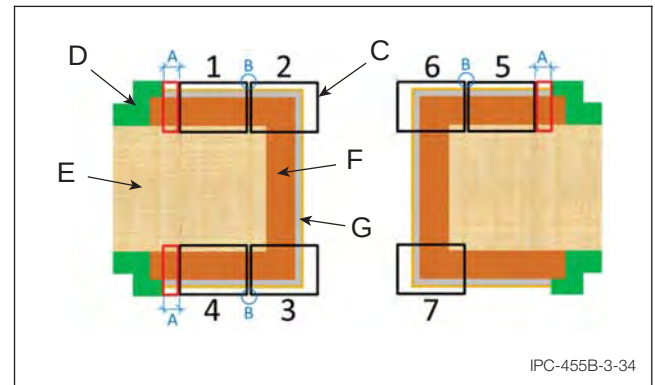


Figure 3-34 Solder Mask Defined Features

- A. Do not record observations close to solder mask interface; A = 25.4 μm [1000 μin]
- B. No overlapping of inspection areas allowed
- C. Inspection area 1 – 7 for optical microscope (magnification 1000X)
- D. Soldermask
- E. Base material
- F. Copper
- G. ENIG

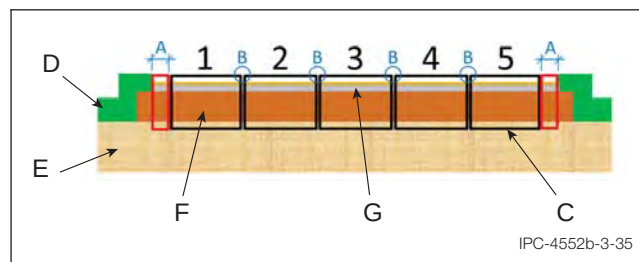


Figure 3-35 Solder Mask Defined SMT Pad

- A. Do not record observations close to solder mask interface; A = 25.4 μm [1000 μin]
- B. No overlapping of inspection areas allowed
- C. Inspection area 1 – 5 for optical microscope (magnification 1000X)
- D. Soldermask
- E. Base material
- F. Copper
- G. ENIG

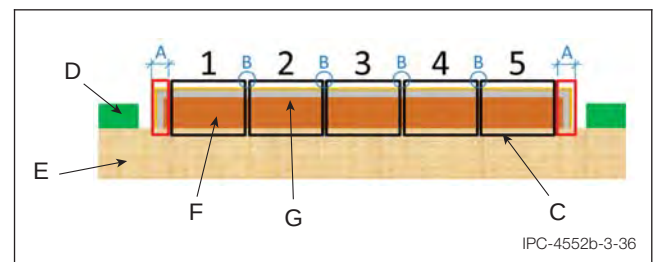


Figure 3-36 Etched Defined SMT Pad (non-supported PTH are treated as SMT Pad)

- A. Do not record observations close on side wall; A = 25.4 μm [1000 μin]
- B. No overlapping of inspection areas allowed
- C. Inspection area 1 – 5 for optical microscope (magnification 1000X)
- D. Soldermask
- E. Base material
- F. Copper
- G. ENIG

3.6.3.5 Exception to Implementation of Requirement It is understood that at the time of the release of this document that some printed board manufacturers may not have the necessary equipment and skill set to evaluate at 1000X. An initial acceptable alternative is to utilize an external laboratory or “sister” facility that has demonstrated capability and can provide inspection in a timely manner. A detailed plan **shall** be implemented to deal with the lag in inspection time relative to date that the product was plated. The plan **shall** address the eventuality of discovering level 3 hyperactive corrosion and how to prevent shipping of product and/or possible recall. The external inspection source **shall** provide a copy of their inspection protocol for inspection at 1000X, this **shall** be available for review during audits in the interim period until inspection is available at the plating source.

When a subtier is used for ENIG, roles and responsibilities for corrosion evaluation **shall** be agreed upon between the supplier and their subtier.

3.6.3.6 Documentation for Corrosion Investigation For each location evaluated, determine the corrosion level (using the criteria described in Table 3-6), entering the information in the format shown in the Figure 3-37. After the data has been entered, determine the Product Rating using the criteria in Table 3-7. Appendix 14 contains the spreadsheet logic to calculate product rating. The use of alternate spreadsheets for documenting the corrosion observations is at the discretion of the supplier but **shall** clearly show the end product rating value.

Figure 3-37 Blank Product Rating Spread Sheet

Table 3-7 Product Rating based on Corrosion Investigation

Product Rating	Corrosion Investigation	Disposition
0	Defect-Free ENIG Deposit - Zero Evidence of Corrosion	Acceptable
1	≥ 60% of Investigated Locations Show Level 0 or 1	Acceptable – This level of corrosion activity will not degrade solder joint integrity.
2	All Other Observations	Acceptable – Provided that solderability meets requirements per section 3.9. ⁽¹⁾
3	> 40% of Investigated Locations Show Level 3	Nonconforming – This level of hyperactive corrosion will degrade solder joint integrity. ⁽²⁾

(1) When specified in procurement documentation, evaluate IMC as outlined in 3.6.6.

(2) With customer concurrence, testing of a board referee may be used for disposition to satisfy the solderability and IMC outlined in sections 3.9 and 3.6.6.

3.6.3.7 Examples of Corrosion Evaluations In order to make the evaluation of corrosion easier and more consistent, a number of examples have been provided. Figure 3-38 and Figure 3-39 shows the rating scheme of product and a decision tree for evaluating panels respectively. Figure 3-40 shows a PTH to be evaluated. Figure 3-41 through Figure 3-47 show actual micrographs of examples with various ratings. Figure 3-48 shows a product rating for the worked example. Figure 3-49 shows an example of run chart created for recording corrosion. Product rating evaluation is outlined in Table 3-7 and Appendix 14.

	Example 1	Example 2	Example 3	Example 4	Example 5
PTH	Level	Level	Level	Level	Level
Location 1	1	1	1	1	1
Location 2	1	1	1	1	1
Location 3	1	1	3	1	1
Location 4	1	1	3	1	1
Location 5	1	1	3	3	2
Location 6	3	3	2	3	3
Location 7	3	2	2	3	3

	Example 1	Example 2	Example 3	Example 4	Example 5
Pad	Level	Level	Level	Level	Level
Location 1	1	1	1	2	2
Location 2	1	1	2	2	2
Location 3	1	1	3	3	2
Location 4	2	3	3	3	3
Location 5	3	3	3	3	3

	Total Count	Total Count	Total Count	Total Count	Total Count
Level 0	0	0	0	0	0
Level 1	5	5	2	4	4
Level 2	0	1	2	0	1
Level 3	2	1	3	3	2

	Total Count	Total Count	Total Count	Total Count	Total Count
Level 0	0	0	0	0	0
Level 1	3	3	1	0	0
Level 2	1	0	1	2	3
Level 3	1	2	3	3	2

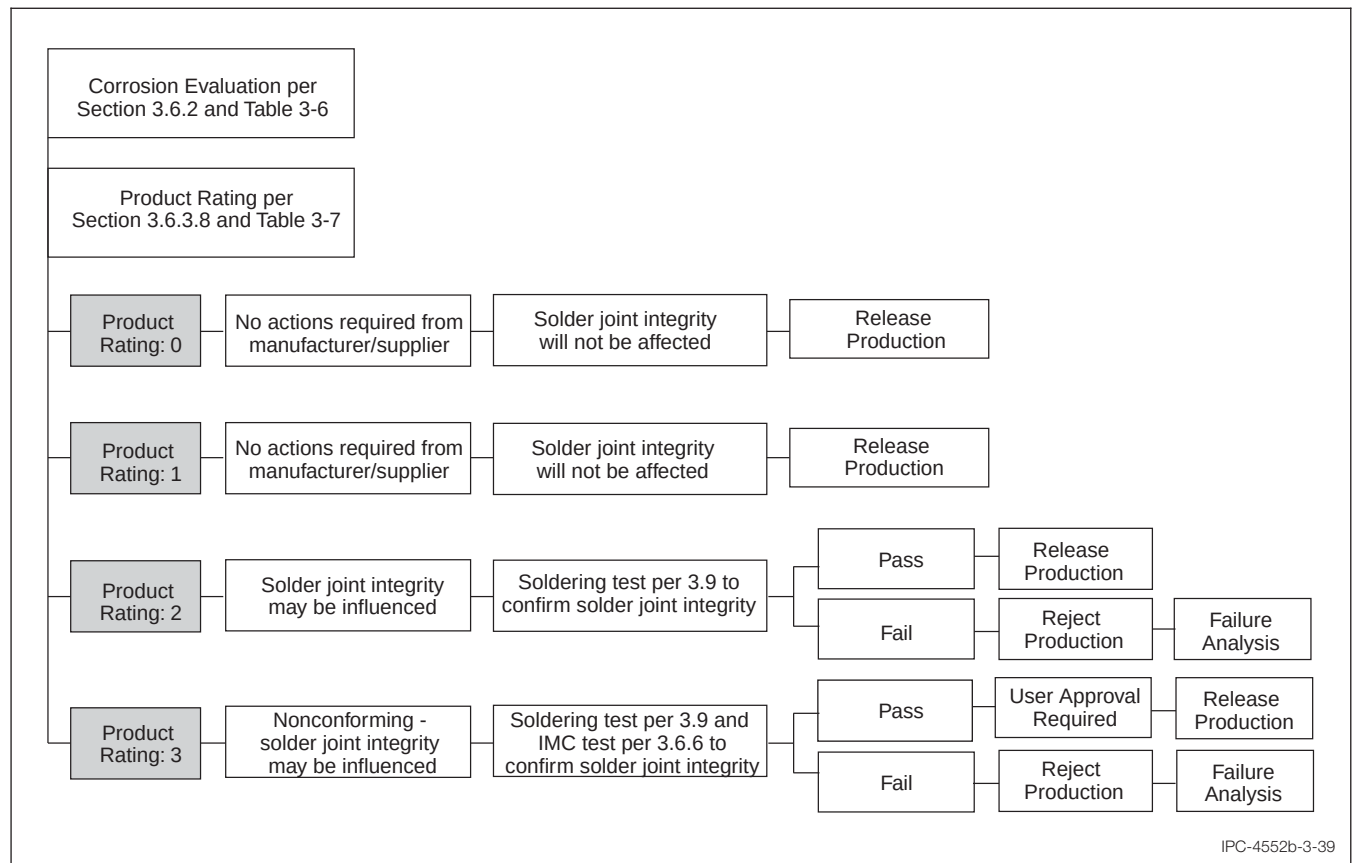
Product Rating	1	1	3	3	2
----------------	---	---	---	---	---

Product Rating	1	1	3	3	2
----------------	---	---	---	---	---

IPC-4552b-3-38

Figure 3-38 Example Product Rating for 5 Different Panels

Note: Appendix 14 contains the spreadsheet logic to calculate product rating.



IPC-4552b-3-39

Figure 3-39 Decision Tree Based on Product Rating Evaluation

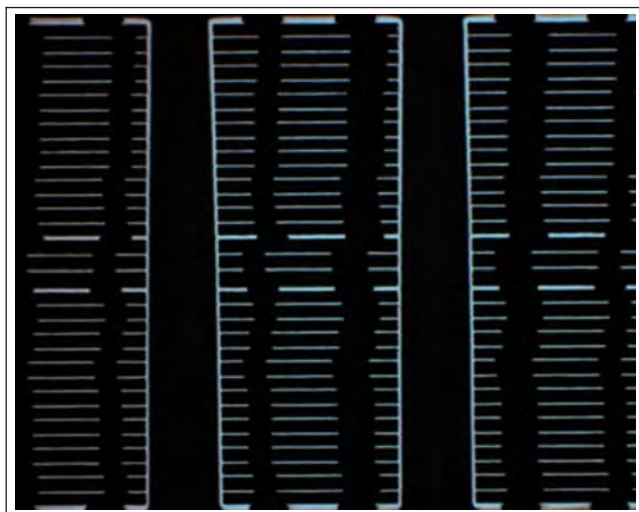


Figure 3-40 Through-Holes to be Evaluated for Corrosion at 25X

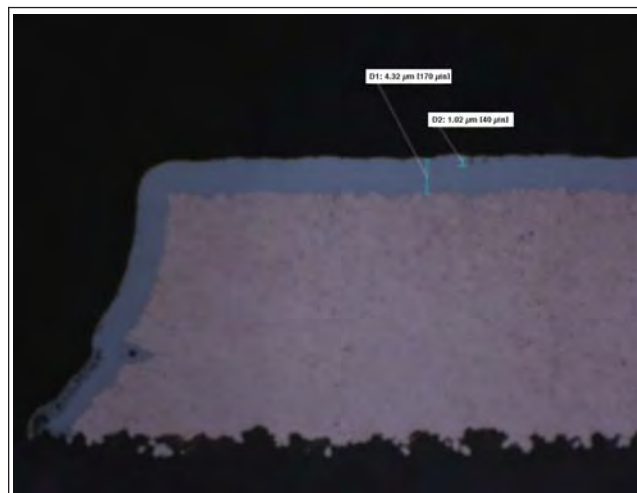


Figure 3-41 Location 1 Worked Example – Rating Is a Level 2 at 1000X

(Note: Corrosion at the base of the side wall is **not** evaluated.)

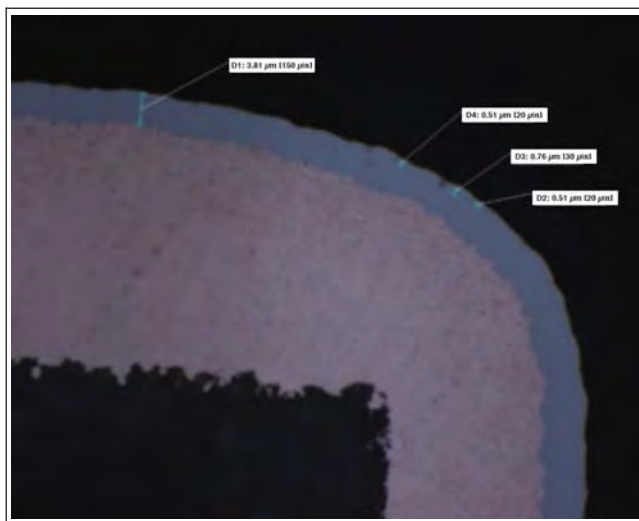


Figure 3-42 Location 2 Worked Example – Rating Is a Level 1 at 1000X

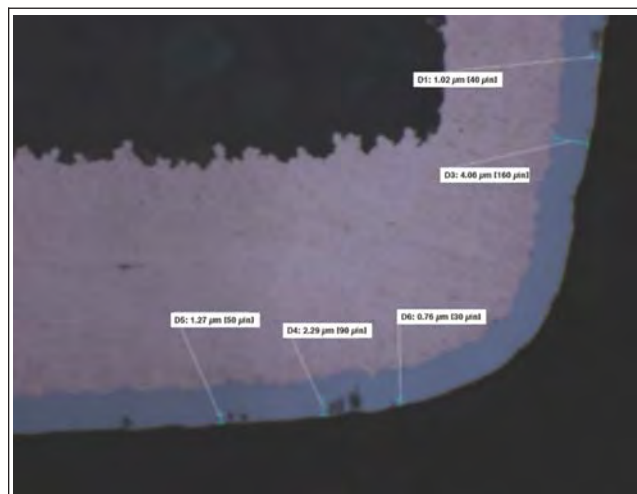


Figure 3-43 Location 3 Worked Example – Rating Is a Level 2 at 1000X

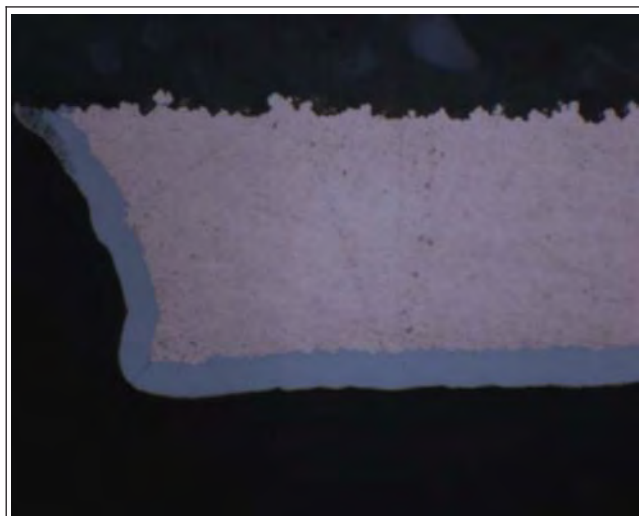


Figure 3-44 Location 4 Worked Example – Rating Is a Level 0 at 1000X

Note: Corrosion at base of side wall is not evaluated.

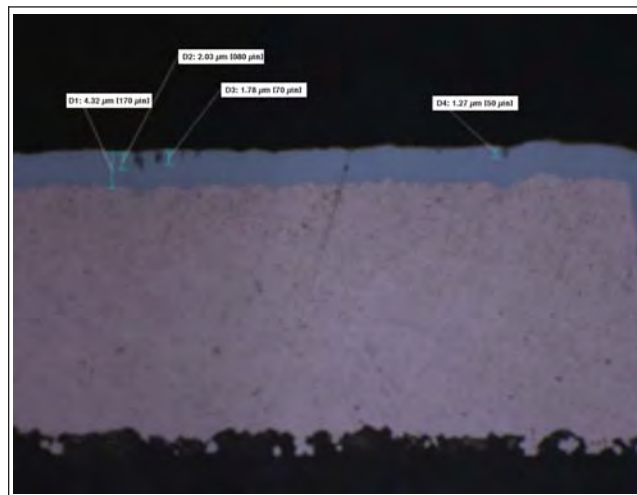


Figure 3-45 Location 5 Worked Example – Rating Is a Level 2 at 1000X



Figure 3-46 Location 6 Worked Example – Rating Is a Level 0 at 1000X

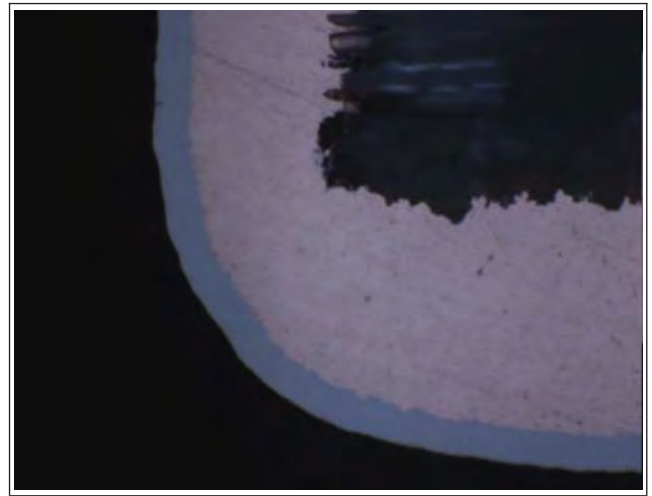


Figure 3-47 Location 7 Worked Example – Rating Is a Level 0 at 1000X

Sample ID 4552B	PTH x	Panel x Level
	Location 1	2
	Location 2	1
	Location 3	2
	Location 4	0
	Location 5	2
	Location 6	0
	Location 7	0

Total Count	
Level 0	3
Level 1	1
Level 2	3
Level 3	0

Product Rating	
0	
1	
2	
3	

Product Rating	
	1

IPC-4552b-3-48

Figure 3-48 Product Rating for the Worked Example

3.6.3.8 Product Rating Description

Product Rating 0: There is **no** evidence of any corrosion.

Product Rating 1: Corrosion is considered to have no effect on the functional performance of an ENIG deposit.

Product Rating 2: Corrosion requires to pass solderability testing per 3.9 to assure the functional performance of an electroless nickel – immersion gold deposit.

Product Rating 3: Hyperactive corrosion is considered nonconforming and may pose an unacceptably high risk of degraded functional performance of an electroless nickel – immersion gold deposit.

Note: With customer concurrence, testing of a board referee may be used for disposition to satisfy the solderability and IMC outlined in sections 3.9 and 3.6.6.