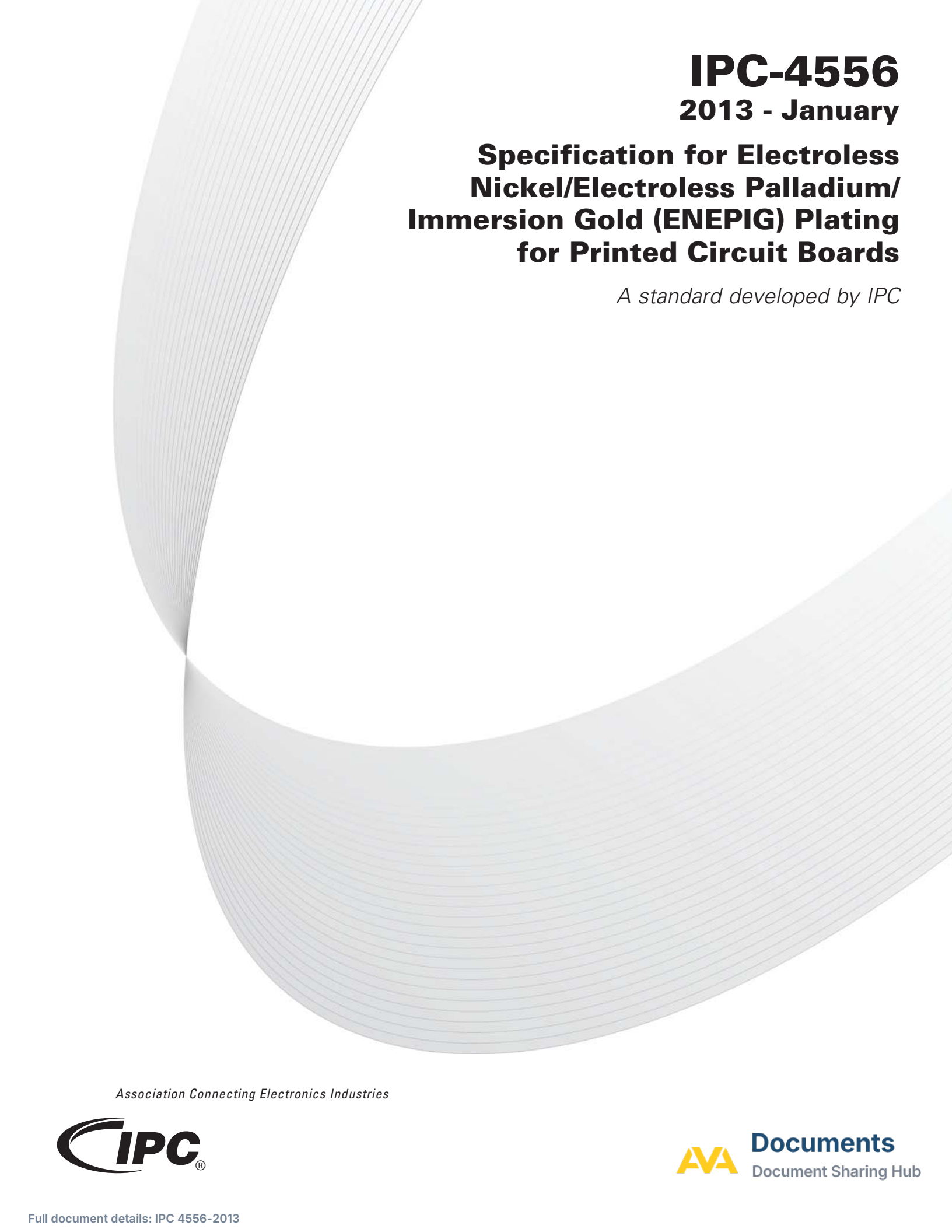




IPC-4556

2013 - January

**Specification for Electroless
Nickel/Electroless Palladium/
Immersion Gold (ENEPIG) Plating
for Printed Circuit Boards**

A standard developed by IPC

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Specification for Electroless Nickel/ Electroless Palladium/ Immersion Gold (ENEPIG) Plating for Printed Circuit Boards

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

Users of this publication are encouraged to participate in the
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Specification for Electroless Nickel/Electroless Palladium/Immersion Gold (ENEPIG) Plating for Printed Circuit Boards

1 SCOPE

1.1 Statement of Scope This specification sets the requirements for the use of Electroless Nickel/Electroless Palladium/Immersion Gold (ENEPIG) as a surface finish for printed boards. This specification sets requirements for ENEPIG 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).

1.2 Description ENEPIG is a tertiary layered surface finish plated over copper as the basis metal. ENEPIG consists of an electroless nickel base layer over which is plated an electroless palladium barrier layer followed by a deposit of a thin immersion gold as the final outer layer. For deposition process details, see APPENDIX 1 of this specification. It is a multi-functional surface finish, applicable to soldering and to gold, aluminum and copper wire bonding. It is also suitable as the mating surface for soft membrane and steel dome contacts. Additional applications include use in Low Insertion Force (LIF) and Zero Insertion Force (ZIF) edge connectors and for press-fit applications. The electroless palladium layer forms a diffusion barrier that impedes nickel diffusion to the gold surface. The immersion gold protects the palladium layer from reacting with contaminants prior to processing that might otherwise affect joining processes, such as wire bonding and soldering.

1.2.1 Electroless Nickel Reducing Agents - Phosphorus Content Phosphorus-containing, reducing agents are typically used for the reduction of the electroless nickel during the deposition process and phosphorus is incorporated in the nickel deposit. The level of this co-deposited element should be controlled within the suppliers specified process limits. Variation of phosphorus levels outside the specified process limits may have adverse effects on the performance of the finish.

1.2.2 Electroless Palladium Reducing Agents There are two distinct classes of reducing agents used in electroless palladium baths currently available for use in the ENEPIG process, those that produce deposits that contain a co-deposited element such as phosphorus, and those that produce an essentially pure palladium deposit. The level of the co-deposited elements should be controlled within the specified process limits. Examples of electroless palladium deposit from both these classes have been evaluated during the development of this specification and no perceivable differences in performance were observed in the tests of solderability or wire bondability.

1.3 Objective This specification sets the requirements for ENEPIG as a surface finish (see Table 3-1 for a summary of these requirements). As additional surface finishes require specifications, they will be addressed by the IPC Plating Processes Subcommittee as part of the IPC-455X specification family. This and other surface finish specifications are under continuous review. The 4-14 subcommittee will make appropriate amendments or revisions to these documents as required. The 4-14 Plating Processes Subcommittee undertook a "Round Robin" study to generate data to support the recommendations cited for the various aspects of this specification. For an outline of the study, refer to APPENDIX 2.

1.3.1 Order of Precedence In the event of conflict, the following order of precedence **shall** apply:

1. The purchase order. This includes AABUS exceptions to this specification.
2. The master drawing. This includes AABUS exceptions to this specification.
3. This specification.
4. Applicable documents as detailed in Section 2 of this document.

1.3.1.1 Appendices This specification contains eleven Appendices provided for information which are included after the main body of this document. Be aware that none of the content 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.

1.4 Performance Functions

1.4.1 Solderability One of the two primary functions of ENEPIG is to provide a solderable surface finish capable of providing IPC Category 3 shelf life (minimum 12 months) per IPC-J-STD-003 testing. This shelf life is suitable for all surface mount, hybrid and through-hole assembly applications. The use of electroless palladium as a diffusion barrier for immersion gold

nickel and the gold mitigates the potential for hyper-corrosion of the electroless nickel deposit, thus enhancing its solderability and solder joint reliability. The minimal thicknesses of the electroless palladium and of the immersion gold deposit make the possibility of embrittlement of the solder joint by palladium or gold negligible. It is the responsibility of the user to calculate the percentage of both gold and palladium in the resulting solder joint where mounting pad sizes associated with 0201 or smaller components are encountered and compare these calculated levels of gold or palladium to the 3% threshold values believed to give rise to solder joint embrittlement.

1.4.2 Wire Bonding The second primary function of ENEPIG is to provide a wire bondable surface finish suitable for gold, aluminum and copper wire applications. ENEPIG has been found to meet the requirements of MIL-STD-883, Method 2011.8. The committee has performed extensive testing with gold wire (see APPENDIX 8) and has received additional anecdotal data from members confirming the suitability of this finish for aluminum and copper wirebonding. Variables that are likely to affect performance include cleanliness, substrate materials, wire thickness and substrate copper surface roughness, as ENEPIG deposits are not capable of completely levelling the substrate surface. During the development of this specification, surface roughness values of up to an Ra value of 389 nm have been tested with no negative impacts on gold wire bond strength.

1.4.3 Contact Surface There is a substantial amount of experience using ENEPIG for the applications listed below in 1.4.3.1 and 1.4.3.2.

1.4.3.1 Membrane Switches ENEPIG is a de facto standard for soft touch membrane switches.

ENEPIG plated samples tested for 2 million contact actuations showed negligible change in contact resistance. For these actuations, the average deposit thicknesses were nominally: 4.65 μm [183 μin] of electroless nickel (EN), 0.13 μm [5.2 μin] of electroless palladium (EP) and 0.053 μm [2.1 μin] of immersion gold (IG).

Note: This test was run to the full number of cycles with no visible impact on the ENEPIG deposit.

1.4.3.2 Metallic Dome Contacts ENEPIG has been demonstrated to be suitable for use with metallic (stainless steel), circular dome contacts, based on testing to 1 million cycles. For this testing, the ENEPIG was deposited at nominal thicknesses of 5.38 μm [212 μin] of electroless nickel (EN), 0.081 μm [3.17 μin] of electroless palladium (EP) and 0.015 μm [0.58 μin] of immersion gold (IG).

Note: The committee continues to be interested in any additional test data using other metals and contact shapes for this particular application.

1.4.4 EMI Shielding ENEPIG can be used as a surface finish at the interface between electromagnetic interference (EMI) shielding materials and printed boards (PBs).

1.4.5 Interface for Conductive and/or Anisotropic Adhesives ENEPIG is suitable for use as an interface for conductive adhesives used as an alternative to solder. It is also suitable for anisotropic adhesive applications.

1.4.6 Connectors

1.4.6.1 Press-Fit Applications Press-fit performance for compliant pin applications should meet Telcordia GR-1217-CORE, MIL-C-28859 or equivalent. Excessive electroless nickel thicknesses can lead to concerns with excessive press-fit insertion forces. The additional thickness of the palladium specified either by this specification and/or a customer-specific requirement should be added to the electroless nickel thickness fit calculation when considering the type of application.

1.4.6.2 Edge Tab Contact Applications The ENEPIG surface finish is suitable for plug-to-install applications (twenty insertions/withdrawals or less) using low insertion force (LIF) or zero insertion force (ZIF) connectors. ENEPIG is not believed to be suitable as a surface finish for edge connectors that require multiple insertion/withdrawals (more than twenty) or high insertion force applications. This application generally requires an alternate metallic finish, such as electrolytic hard gold.

1.4.7 Limitations of ENEPIG

1.4.7.1 Creep Corrosion/Chemical Resistance ENEPIG, similar to the other alternate surface finishes addressed by the IPC-455X series specifications, is susceptible to creep corrosion in high sulfur and/or chlorine-containing atmospheres that are commonly also at high temperature and humidity. While mixed flowing gas (MFG) tests per Battelle Class 2 conditions have been performed and show sustained solderability with ENEPIG, it is recommended to test specific design applications.

if the end use environment is considered harsh. For additional information on ENEPIG corrosion resistance to MFG, see Appendix 11.

1.4.7.2 High Frequency Signal Loss Higher frequency (>3 GHz) applications may experience signal loss on full build (i.e., where ENEPIG 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.

2 APPLICABLE DOCUMENTS AND TERMS AND DEFINITIONS

2.1 IPC¹

J-STD-003 Solderability Tests for Printed Boards

IPC-1601 Printed Board Handling and Storage Guidelines

IPC-2221 Generic Standard on Printed Board Design

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 Printed Boards

IPC 5704 Cleanliness Requirements for Unpopulated Printed Boards

IPC-TM-650 Test Methods Manual²

2.3.25 Detection and Measurement of Ionizable Surface Contaminants by Resistivity of Solvent Extract (ROSE)

2.4.1 Adhesion, Tape Testing

2.6.3.5 Bare Board Cleanliness by Surface Insulation Resistance

2.6.14.1 Electrochemical Migration Resistance Test

2.2 American Society for Testing and Materials (ASTM International)³

ASTM B568 Standard Test Method for Measurement of Coating Thickness by X-Ray Spectrometry

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

ASTM B827 Standard Practice for Conducting Mixed Flowing Gas Environmental Tests

ASTM B845 Standard Guide for Mixed Flowing Gas Tests for Electrical Contacts

2.3 JEDEC⁴

JESD 213 Common Test Method for Detecting Component Surface Finish Materials

2.4 Defense Standardization Program⁵

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

MIL-STD-1580 Department of Defense Test Method Standard (Destructive Physical Analysis for Electronic, Electromagnetic, and Electromechanical Parts)

MIL-C-28859 General Specification for Connector Component Parts, Electrical Backplane, Printed-Wiring

2.5 Telcordia Technologies, Inc.⁶

Telcordia GR-1217-CORE Generic Requirements For Separable Electrical Connectors Used In Telecommunications Hardware

2.6 International Organization for Standardization (ISO)⁷

ISO-4527 Auto-Catalytic Nickel-Phosphorous Coatings; Specifications and Test Methods, Annex A: Determination of Coating Thickness and Annex D: Determination of Coating Composition (Nickel and Phosphorous Content).

1. www.ipc.org

2. Current and revised IPC Test Methods are available on the IPC Web site (www.ipc.org/html/testmethods.htm)

3. www.astm.org

4. www.jedec.org

5. www.dsp.dla.mil

6. www.telcordia.com

7. www.iso.org

2.7 Terms, Definitions and Acronyms The definition of all terms used herein shall be as specified in IPC-T-50 and as defined below:

MTO (Metal Turnover) – 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 5 grams per liter and the bath is 100 liters in size, then one MTO is the period of usage during which 500 grams 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.

3 REQUIREMENTS

Table 3-1 Requirements of Electroless Nickel Electroless Palladium Immersion Gold (ENEPIG) Plating

Inspection	Class/Test Frequency (A.Q.L.)				Requirements	
Tests	Test Method	1	2	3/3A	Paragraph	Remarks
General:						
Visual	Visual	4.0	2.5	1.0	3.1	Uniform color and complete coverage of surface to be coated.
Electroless Nickel Thickness	Appendices 4 and 9	6.5	4.0	2.5	3.2.1	3 to 6 μm [118.1 to 236.2 μin] at ± 4 sigma (standard deviations) from the mean 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.
Electroless Palladium Thickness	Appendices 4 and 9	6.5	4.0	2.5	3.2.2	0.05 to 0.30 μm [2 to 12 μin] at ± 4 sigma (standard deviations) from the mean 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.
Immersion Gold Thickness	Appendices 4 and 9	6.5	4.0	2.5	3.2.3	>0.030 μm [1.2 μin] at - 4 sigma (standard deviations) below the mean 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.
Physical:						
Adhesion/Tape Test	IPC-TM-650, Method 2.4.1	6.5	4.0	4.0	3.4	No evidence of plating and/or solder mask removed.
Solderability	J-STD-003	4.0	2.5	2.5	3.5	Refer to the applicable performance specification.
Force Measurement - When required, the specified provisions apply:	Force Measurement Test	4.0	2.5	2.5	3.5.1	0.14 mN/mm minimum for Eutectic SnPb testing. 0.19 mN/mm minimum for SAC 305 testing.
Environmental:						
Cleanliness	IPC- 5704	When tests required, AQL shall be AABUS			3.6	Refer to applicable performance specification.
SIR	IPC-TM-650, Method 2.6.3.5; GR78-Core	When tests required, AQL shall be AABUS			3.6 3.6	1.0E+08 ohms 1.0E+10 ohms
Electrolytic Corrosion	IPC-TM-650, Method 2.6.14.1	When tests required, AQL shall be AABUS			3.7	AABUS

3.1 Visual ENEPIG surfaces shall be inspected in accordance with the visual examination sections of the IPC-6010 series specifications, specifically IPC-6012 which specifies the use of a nominal magnification of 1.75X (approx. 3 diopters). The coverage shall be complete and the finish shall be uniform on the surfaces to be plated (see Figure 3-1). For higher magnification analysis, Figures 3-2 to 3-4 are offered for reference purposes. There shall be no extraneous plating or nickel foot (see Figure 3-2), edge pull back (see Figure 3-3) or skip plating (see Figures 3-4, 3-5 and 3-6) on the surfaces of all classes of product.

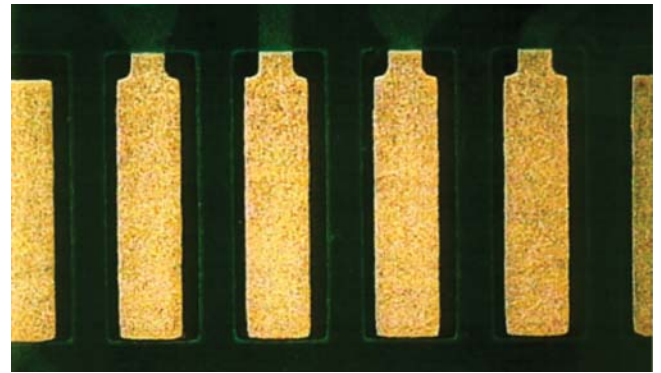


Figure 3-1 Uniform Plating

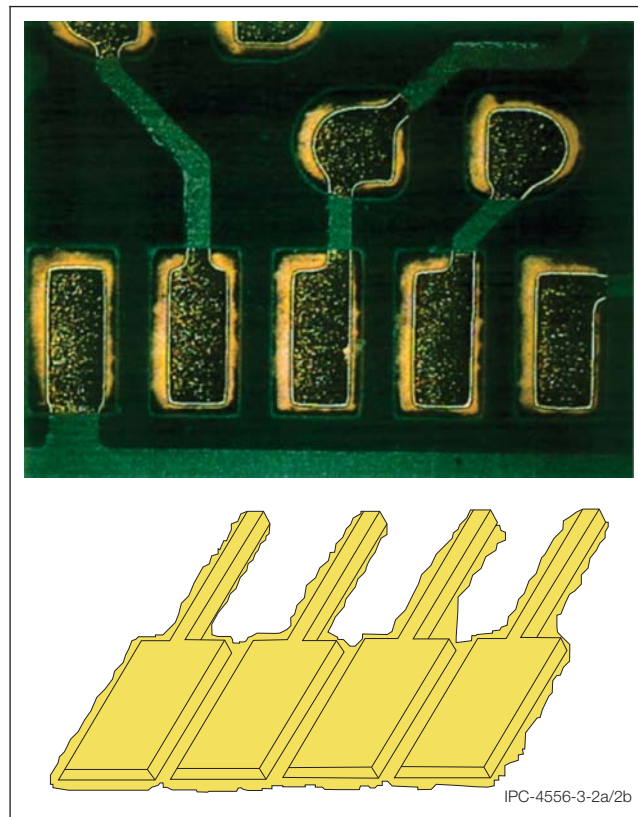


Figure 3-2 Extraneous Plating or Nickel Foot

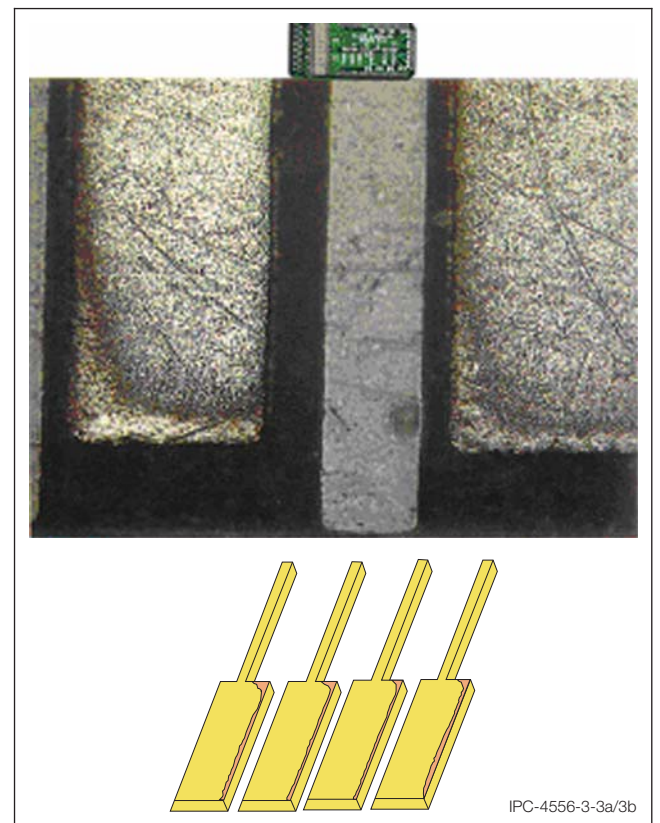


Figure 3-3 Edge Pull Back

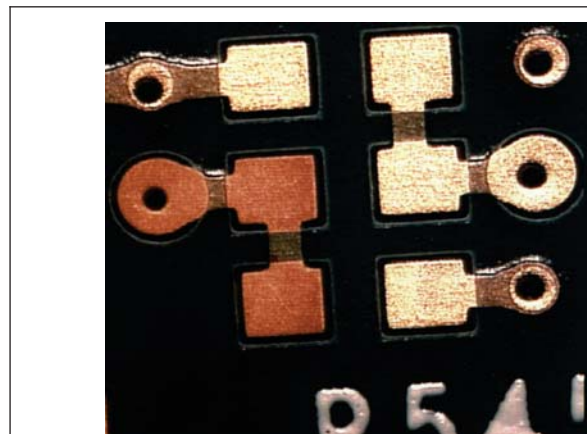
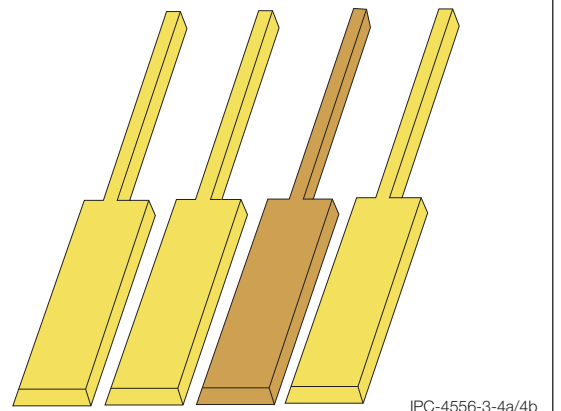


Figure 3-4 Skip Plating



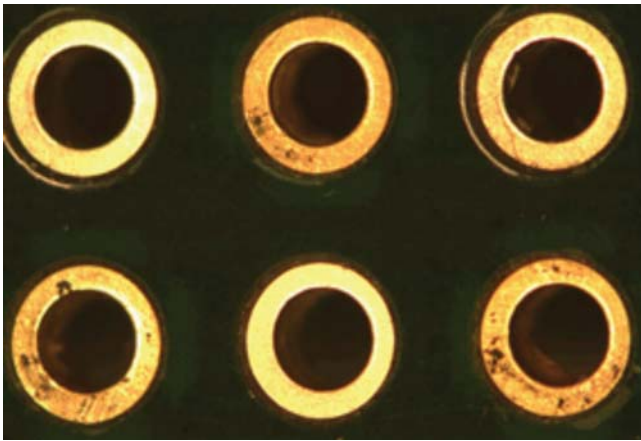


Figure 3-5 Skip Plating of Gold Over Palladium

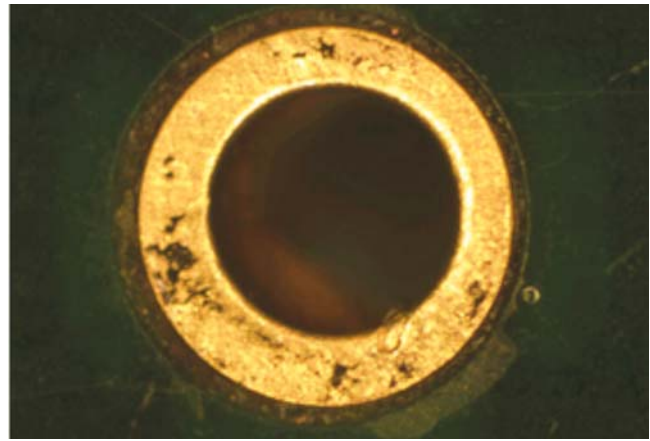


Figure 3-6 Skip Plating of Gold Over a Palladium Deposit

3.1.1 High Magnification Reference Images It may be necessary to evaluate the ENEPIG deposit using scanning electron microscopy (SEM), transmission electron microscopy (TEM) or focused ion beam (FIB) as part of a qualification plan and or for failure analysis. The images in Figures 3-7 through 3-12 in the following section are for reference purposes and were provided by several different suppliers of ENEPIG.

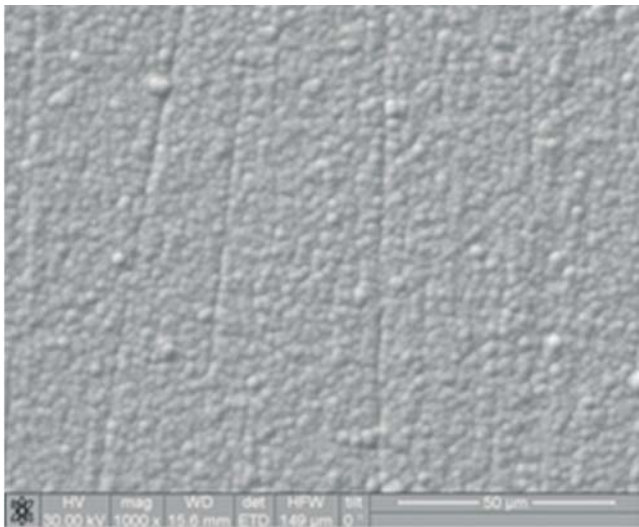


Figure 3-7 1000X SEM Image of a Normal ENEPIG Surface

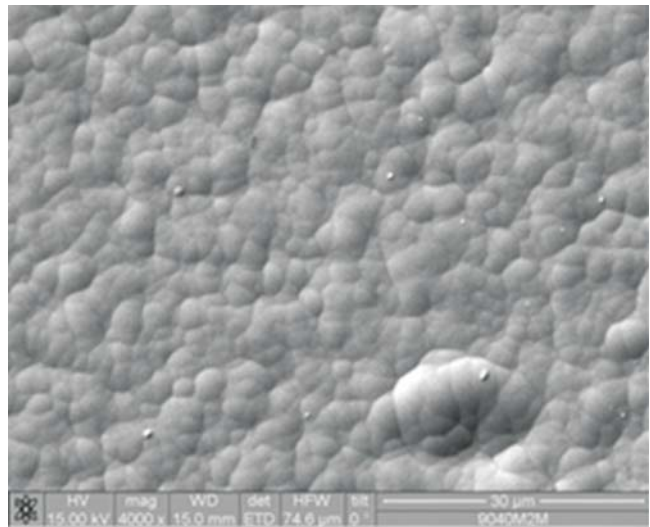


Figure 3-8 4000X SEM Image of a Normal ENEPIG Surface

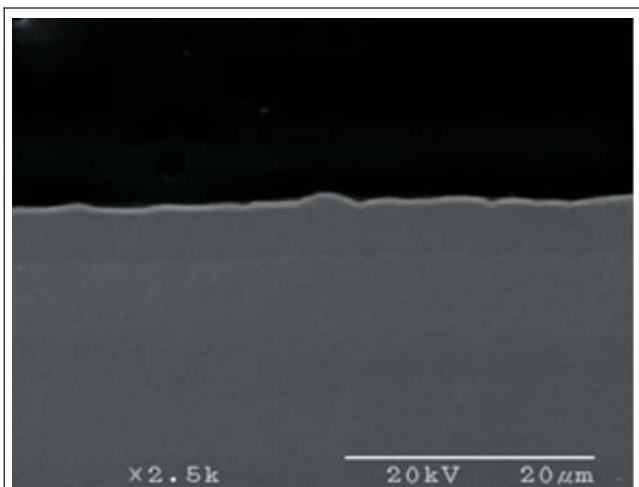


Figure 3-9 2500X FIB Image of a Normal ENEPIG Deposit

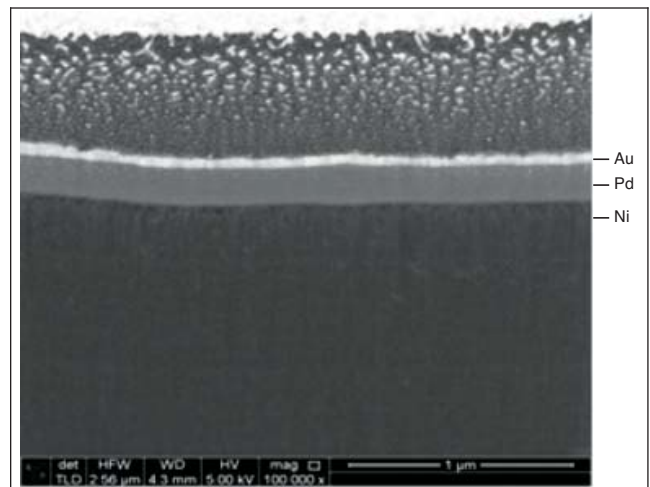


Figure 3-10 100,000X FIB Image of a Normal ENEPIG Deposit

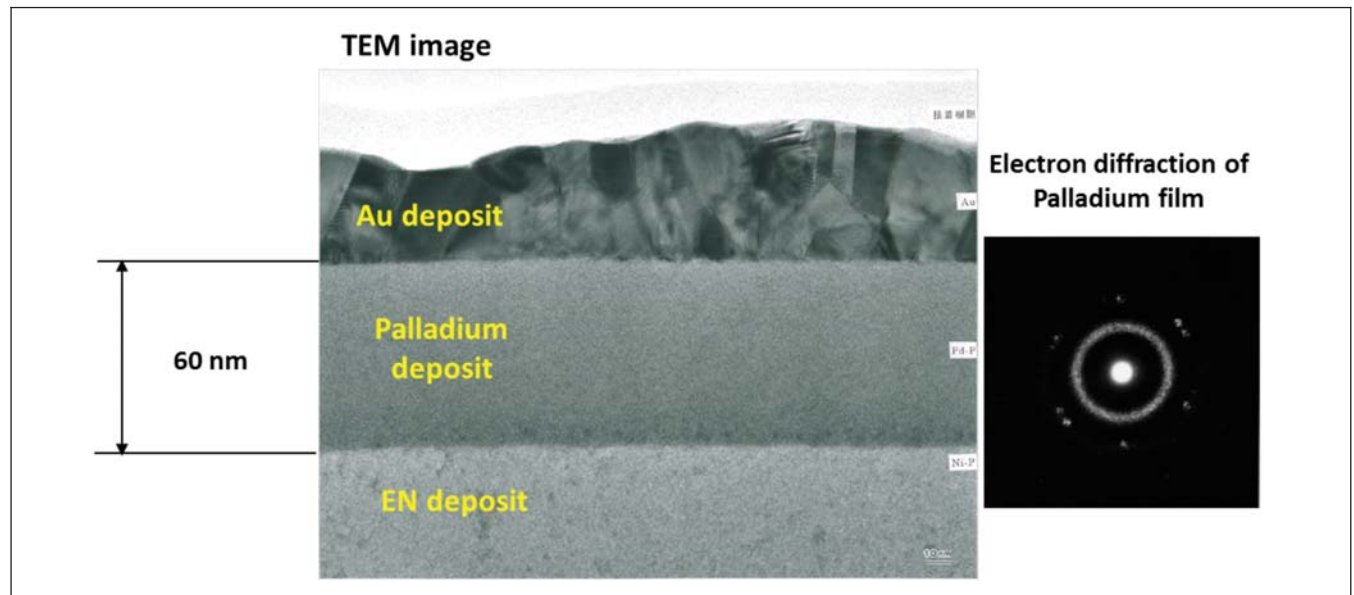


Figure 3-11 TEM Image of a Normal ENEPIG Deposit

[The Palladium-Phosphorus film is amorphous and very uniform whereas the gold (Au) deposit is crystalline in nature.]

3.2 Finish Thickness Thicknesses of the electroless nickel, electroless palladium and immersion gold layers **shall** be measured and verified following the completion of the ENEPIG plating operation in the printed board fabrication process. The use of X-ray fluorescence (XRF) methodology for thickness determination **shall** be in accordance with APPENDICES 4 and 9 of this document and shall employ XRF instrumentation equipped with software and hardware appropriate for ENEPIG measurement. The committee has performed extensive round robin testing of equipment capability to accurately measure this tertiary deposit (see APPENDICES 3, 9 and 10). The results showed a number of critical issues with equipment, set-up, measuring protocols and reference standards. It is imperative to demonstrate measurement capability in order to meet the following thickness specification.

3.2.1 Electroless Nickel Thickness The electroless nickel thickness **shall** be 3 to 6 μm [118.1 to 236.2 μin] at ± 4 sigma (standard deviations) from the mean 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 standard series, apply. This upper end of this thickness specification has been chosen based on concerns with insertion force issues for compliant pin applications **ONLY**. Use of thicknesses outside of this range **shall** be AABUS.

3.2.2 Electroless Palladium Thickness The electroless palladium thickness **shall** be 0.05 to 0.30 μm [2 to 12 μin] at ± 4 sigma (standard deviations) from the mean 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 standard series, apply. The upper thickness limit may be exceeded to meet specific design criteria (for example, applications requiring wire bonding but no soldering).

3.2.3 Immersion Gold Thickness The minimum immersion gold thickness **shall** be $>0.030 \mu\text{m}$ [1.2 μin] at -4 sigma (standard deviations) below the mean 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 standard series, apply. The specification is one sided, based on performance test results showing impaired solderability performance after accelerated aging at lower gold thicknesses. The nature of the reaction of immersion gold with electroless palladium is such that substantially greater thicknesses may not be achievable.

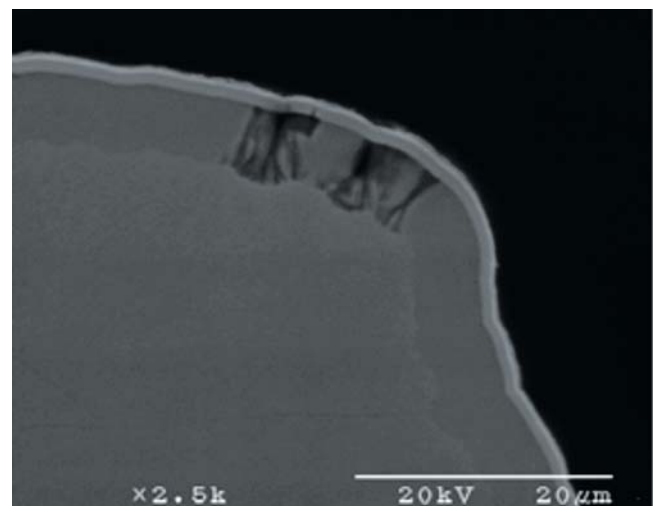


Figure 3-12 2500X Image of Nickel that is Hyper-Corroded
(This is due to excessive dwell time in the gold bath.)

Note: Some designs may not have feature sizes of this specified pad area and will require the use of alternate pad sizes. The XRF collimator used **shall** always be smaller than the pad used for measurement; and specifically, the collimator **shall not** exceed 30% of the feature pad size being measured. For smaller sized pads, the measurement time will need to increase proportionately as a function of collimator area reduction. Consistency of the pad size used for measurement is of primary concern in order to obtain a statistically valid result, due to the typical plating thickness variation seen as a function of pad size. In general, smaller features will plate thicker than larger features. The use of fiducial pads for this measurement is suggested for those designs not having the specified pad feature areas, described above.

3.2.4 XRF Calibration Standards The use of National Standards traceable calibration standards with similar thicknesses to the specified ENEPIG thicknesses which are to be measured, is recommended. Tri-layer standards where Au and Pd are plated directly on Ni/Cu/PCB should be used for calibration for Cu thicknesses $>30\text{ }\mu\text{m}$. Tri-layer foil standards where Au and Pd are plated on a Ni-foil should be used if boards with varying Cu-thicknesses are to be measured. Additional information can be found in Appendix 10.

For Cu thickness $>30\text{ }\mu\text{m}$, a combination of a minimum of two calibration standards with approximate thicknesses, as below, should be used.

- Au/Pd/Ni/Base $0.05\text{ }\mu\text{m}/0.02\text{ }\mu\text{m}/3\text{ }\mu\text{m}/>30\text{ }\mu\text{m}$
- Au/Pd/Ni/Base $0.05\text{ }\mu\text{m}/0.09\text{ }\mu\text{m}/3\text{ }\mu\text{m}/>30\text{ }\mu\text{m}$
- Au/Pd/Ni/Base $0.05\text{ }\mu\text{m}/0.3\text{ }\mu\text{m}/3\text{ }\mu\text{m}/>30\text{ }\mu\text{m}$
- Au/Pd/Ni/Base $0.1\text{ }\mu\text{m}/0.2\text{ }\mu\text{m}/3\text{ }\mu\text{m}/>30\text{ }\mu\text{m}$

For Cu thicknesses $<30\text{ }\mu\text{m}$ a combination of a minimum of two calibration foil standards with approximate thicknesses as below, should be used.

- Au/Pd/Ni/Base $0.06\text{ }\mu\text{m}/0.02\text{ }\mu\text{m}/4\text{ }\mu\text{m}/<30\text{ }\mu\text{m}$
- Au/Pd/Ni/Base $0.06\text{ }\mu\text{m}/0.06\text{ }\mu\text{m}/4\text{ }\mu\text{m}/<30\text{ }\mu\text{m}$
- Au/Pd/Ni/Base $0.05\text{ }\mu\text{m}/0.1\text{ }\mu\text{m}/4\text{ }\mu\text{m}/<30\text{ }\mu\text{m}$
- Au/Pd/Ni/Base $0.05\text{ }\mu\text{m}/0.25\text{ }\mu\text{m}/4\text{ }\mu\text{m}/<30\text{ }\mu\text{m}$

For additional details, see APPENDICES 4 and 9.

3.2.5 Use of Non-Statistical Thickness Specification For production lot sizes of ten printed boards or less, i.e., prototype builds, the need to demonstrate compliance to the statistical requirements above are 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 all three deposits. Any readings below or above the specified thickness range **shall** be cause for rejection of that board.

3.2.6 Production Overruns and/or Inventory Items When compliance testing of individual printed board(s) remaining in inventory is required, use the protocol of 3.2.5. For production overruns larger than ten, the sample statistic constraints **shall** apply.

3.3 Porosity An ENEPIG immersion gold layer is not totally impervious and is not able to pass the requirements of a 'classic' porosity test (for example, Nitric Acid per ASTM B 735).

3.4 Adhesion The purpose of adhesion testing for ENEPIG finished boards is twofold.

- 1) The primary purpose of the testing is to verify that there is no adhesion failure between the metallic layers of the finish, or the finish and the base metal. The tape testing **shall** be carried out in accordance with IPC-TM-650, Method 2.4.1, using a strip of pressure sensitive tape. There **shall** be no evidence of any portion of the surface finish being removed, as shown by particles of plated deposit/pattern adhering to the tape. If soldermask overhang breaks off and adheres to the tape, it is evidence of undercut but not of adhesion failure.
- 2) The secondary purpose is for testing the adhesion of the solder mask to both traces and laminate. Both the chemistry used in the ENEPIG process and the required dwell times and temperatures can have a negative impact on solder mask adhesion. – **Note:** Not all solder masks are compatible with an ENEPIG process.

In both cases, testing should be conducted on regions of high feature density on the board, such as BGA sites, dams between fine pitch leaded devices or over areas of high trace density. Using the same approach as for the test for metal adhesion, check for evidence of the soldermask being removed, as shown by particles of soldermask adhering to the tape.

Because of the requirement to test in high density areas, the potential to leave tape residue that could interfere with soldering exists, especially if an incorrect type of tape is used. Verification of zero impact to solderability must be demonstrated for the areas tested, or the area tested **shall not** be used for final product.

3.5 Solderability The thickness specification described herein **shall** meet the Category 3 coating durability requirements of J-STD-003, i.e., greater than 12 months shelf life.

Note 1: The use of steam exposure (conditioning) is not an applicable accelerated stress test method for ENEPIG.

Note 2: While adherence to the IPC-1601 recommendations for baking prior to assembly may have a negative impact on solderability performance, the requirements for solderability testing in this specification are for samples tested without baking. Any deviation from this **shall** be AABUS.

For details of the solder spread testing data from the round robin, see APPENDIX 6. Ball shear data from the same study is documented in APPENDIX 7.

3.5.1 Force Measurement Testing (Wetting Balance Testing) The following requirements are based on the use of the Standard IPC coupon, Figure 3-13, immersed to a depth of 0.6mm at 90 degrees incidence to the solder surface. The dwell time **shall** be ten seconds. For details of the wetting balance data from the round robin study, see APPENDIX 5.

- Force measurement testing of an “as received” sample with Eutectic SnPb solder, using the prescribed Test Flux # 1 at 235 °C, **shall** produce a positive wetting force within 2 seconds and a minimum wetting force of 0.14 mN/mm.
- For force measurement testing of samples stressed for 8 hours @ 72 °C [162 °F] and 85% R.H., the increase in wetting time **shall not** exceed 1 second. The wetting force **shall** be a minimum of 0.12 mN/mm.
- For force measurement testing of “as received” samples with SAC305 solder, using the prescribed Test Flux # 2 at 255 °C, **shall** produce a positive wetting force within 1.5 seconds and a minimum wetting force of 0.19 mN/mm.
- For force measurement testing of samples stressed for 8 hours @ 72 °C [162 °F] and 85% R.H., the increase in wetting time **shall not** exceed 1 second. The wetting force **shall** be a minimum of 0.17 mN/mm.

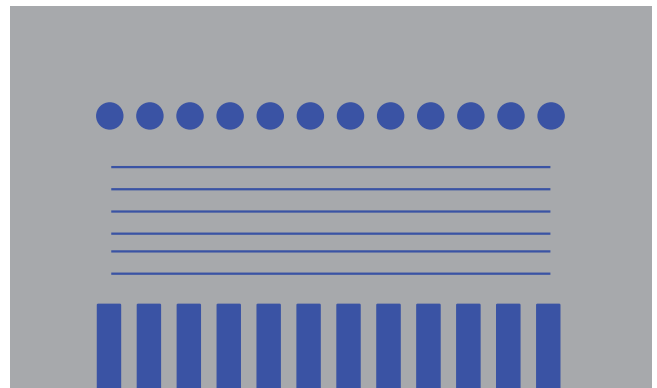


Figure 3-13 The Standard IPC Force Measurement Coupon

3.6 Cleanliness The surface of an ENEPIG finish is typically cleaner than most other surface finishes. Ionic cleanliness **shall** be established per the requirements of IPC-5704, which specifies a sample size of 11. It is recommended that solvent extract conductivity (SEC) testing per IPC-TM-650, Method 2.3.25, also be performed at the same time as the IPC-5704 qualification, to establish process control parameters. SIR testing **shall** be per IPC-TM-650, Method 2.6.3.5. The requirements for SIR test performance **shall** be as specified in Table 3-1. Failure to meet this cleanliness specification should trigger immediate process control corrective action.

3.7 Electrolytic Corrosion The ENEPIG process contains chemistries that are ionic in nature, but which are readily rinseable. Both the quality and volume of water used for the rinsing steps between process baths, and for the final rinsing of the product are critical if the potential for electrolytic corrosion is to be avoided. The use of IPC-TM-650, Method 2.6.14.1, “Electrochemical Migration Resistance Test” is recommended for high reliability applications, or for designs with high feature density. The resistance values **shall not** drop more than one order of magnitude after the test has been completed.

4 QUALITY ASSURANCE PROVISIONS

4.1 General Quality Assurance Provisions These are specified in IPC-6011 and each IPC-60XX sectional specification. Additional requirements for printed boards with electroless nickel/electroless palladium/immersion gold (ENEPIG) plating are specified herein for qualification, acceptance, and quality conformance.

4.1.1 Qualification Recommendations Qualification of a printed board supplier, supplying ENEPIG to this specification **shall** be AABUS (see IPC-6011). The process capability of a supplier of PWB with ENEPIG finish **shall** be established by demonstrating process control over time. Table 4-1 provides a listing of suggested qualification elements that should be exercised by the supplier. It includes the associated requirements and/or test methods when applicable.

4.1.2 Sample Test Coupons Test specimens used for qualification of printed boards with ENEPIG finish may be found in IPC-2221 and/or noted in IPC-6010 sectional specifications. Alternatively, the supplier may create test patterns or process control coupons to accommodate qualification testing and/or lot conformance deposit thickness measurements. Specimen(s) should be obtained or developed for qualification testing to the requirements listed in Table 4-1.

Table 4-1 Suggested Fabricator Qualification Plan

Requirement	Test Reference	Remarks
XRF Certification	Suitably calibrated XRF instrument with detector capable of measuring tri-level thin coatings. Use of certified national ENEPIG standards as referenced in Appendices 3, 4, 9 and 10. Note: Do not use electrodeposited standards or ones with thicknesses outside the target thickness range under evaluation.	Perform XRF certification by performing a gauge R&R or equivalent statistical approach. Use of the correct certified national standards is critical. This data may be used as to begin building a suitable deposit thickness distribution database.
Deposit Thickness Distribution	Suitable test pattern or production board/panel having the correct surface area pads as described in Appendices 3, 4, 9 and 10.	The deposit thickness database to demonstrate 4 sigma distribution should include sample readings from product processed through the production baths. Include readings from both front and back of the panels. Also, map thickness as a function of panel position within a basket. It is suggested that thickness measurements be made at panel locations that provide as complete panel coverage as possible, e.g., diagonal, four corners and center, each PWB within a panel.
Visual	Ref. paragraph 3.1	Perform visual inspection per applicable requirements at a production final inspection workstation and document the appearance of the finish. It is recommended to create an inspection checklist.
Solderability (Wetting Balance)	Use suitable coupon(s) to perform J-STD-003 Category 3 testing. See paragraphs 3.5 and 3.5.1. Note: IPC-1601 provides guidance on packaging and handling of coupons.	It is recommended to qualify to Category 3, the highest level of storage coating durability in J-STD-003.
Wire Bondability	Test specimen suitable for use with MIL-STD 883, METHOD 2011.8, or user defined test pattern/specification.	Method 2011.8 of MIL-STD-883 is the most commonly used test method requirement for determining wire bond strength. Other user-defined AABUS measurements may be required. Document a sufficient quantity of bond pulls to establish capability. Assistance by the user may be required to support this method.
Ionic Cleanliness	Suitable specimen for IPC-5704 Ion Chromatography (IC) Testing.	IC testing per IPC-5704 is recommended during qualification to confirm that the process and associated rinses are adequate to ensure that no contaminants remain that might not meet next level assembly requirements. Periodic re-qualification may be necessary to account for changes in materials and processes.
PTH Coverage	Suitable Through Hole specimens for microsectioning.	Microsection a number of "as received" specimen(s) using darkfield illumination (before solder float). Utilize coupon specimens from a variety of locations, for example, from the outside and center panels of a basket load.
Effect on Soldermask Adhesion	Para 3.4 - Suitable coupon of IPC-2221 or production part containing high density features.	Utilizing an appropriate specimen, benchmark adhesion of solder mask. Inspect to Quality conformance requirements, or as specified by User. Note whether the solder mask was applied before or after ENEPIG processing.
Repeatability at Various Stages of Loading and Bath Life	Applicable specimens of the Qual Plan.	Repeat aspects of the Qualification Testing at various bath life metal turn-over (MTO) stages, as applicable, looking for any impacts on deposition thickness or distribution, (for example, for new baths and late MTO).

Table 4-2 C=0 Sampling Plan (Sample Size for Specific Index Value¹)

Lot Size	Class 1			Class 2			Class 3			
	2.5 ¹	4.0 ¹	6.5 ¹	1.5 ¹	2.5 ¹	4.0 ¹	0.10 ¹	1.0 ¹	2.5 ¹	4.0 ¹
1-8	5	3	3	**	5	3	**	**	5	3
9-15	5	3	3	8	5	3	**	13	5	3
16-25	5	3	3	8	5	3	**	13	5	3
26-50	7	7	5	8	7	7	**	13	7	7
51-90	11	8	5	13	11	8	**	13	11	8
91-150	11	9	6	19	11	9	125	19	11	9
151-280	13	10	7	19	13	10	125	29	13	10
281-500	16	11	9	21	16	11	125	29	16	11
501-1200	19	15	11	27	19	15	125	34	19	15
1201-3200	23	18	13	35	23	18	125	42	23	18
3201-10,000	29	22	15	38	29	22	192	50	29	22
10,001-35,000	35	29	15	46	35	29	294	60	35	29

Note 1. Index Value is associated to the A.Q.L. value. If a particular product is determined to be "critical" by the user and a smaller index value is required, the user **shall** designate the requirement in the procurement document and should state the "critical" requirement on the master drawing. **Denotes inspect entire lot.

4.2 Quality Conformance Testing Quality conformance testing shall consist of inspections as specified in Table 3-1 and the IPC-6010 sectional specification.

4.2.1 Thickness Measurements Thickness measurement frequency shall be in accordance with Table 3-1. The number of readings per panel should be enough to calculate a significant standard deviation. A minimum of 20 readings per lot is suggested.

4.2.2 Qualified Processes If a qualified process has been established, the requirements of 4.1.1 for a minimum number of readings and calculation of an associated standard deviation can be waived. For a qualified process, demonstrating a process capability (± 4 sigma) within the appropriate specification, a sample measurement consistent with Table 3-1 may be used for lot conformance, provided all readings fall within the Qualified Process population (± 4 sigma). Alternative thickness inspection methodologies **shall** be AABUS.

For gauge capability and Gauge R & R, see APPENDIX 10.

APPENDIX 1

Chemical Definitions and Process Sequence

*Martin Bayes
Dow Electronic Materials*

Chemical Definitions

Electroless Process – This chemical process promotes sustained deposition of a metal or metal alloy onto either a dielectric or metallic PWB surface through an oxidation-reduction chemical reaction, without the application of an external electrical potential. Reducing agents, such as sodium hypophosphite or sodium formate, react at catalytic surfaces to release electrons, which immediately reduce the positively charged metal ions (e.g., nickel ions in ENIG and ENEPIG and palladium ions in ENEPIG), promoting their deposition onto the PWB.

This type of reaction is described as “autocatalytic,” as the deposition process will continue even after the substrate is completely covered by a continuous layer of the plated deposit. The deposit thickness will therefore continue to rise 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 will vary depending on the bath temperature, chemical parameters (such as solution pH) and the amount of time spent in the plating bath.

Immersion Process – This chemical process uses a chemical displacement reaction to deposit a layer of a second metal onto a base metal surface. In this reaction, the base metal dissolves, releasing the electrons that reduce the positively charged ions of the second metal present in solution. Driven by the electrochemical potential difference, the metal ions in solution (e.g., gold ions in ENIG or ENEPIG process) are deposited onto the surface of the board, simultaneously displacing ions of the surface metal into solution.

This type of reaction is described as “self-limiting” because, once the base metal is covered with a continuous layer of the deposited metal, there is no longer a source of electrons and the reaction ceases.

Process Sequence

1. **Cleaner** – The purpose of this step is to clean the copper surface in preparation for processing. The cleaner removes oxides and light surface contaminants, and ensures that the surface will be in a condition allowing it to be uniformly micro-etched. Vendor specifications for temperature, dwell time, agitation and bath chemical control should be followed.
2. **Microetch** – The purpose of this step is to produce a surface that may be uniformly catalyzed and plated with good deposit adhesion by removing some copper from the surface. A variety of different etchant types may be used (e.g., sodium persulfate, peroxide/sulfuric). Vendor specifications for temperature, dwell time, agitation and bath chemical control should be followed.
3. **Catalyst** – The purpose of this step is to deposit a material that is catalytic to electroless nickel plating on the copper surface. The catalyst lowers the activation energy for nickel deposition and allows plating to initiate on the copper surface. Examples of metal catalysts include palladium and ruthenium (typically deposited by an immersion reaction with the copper surface). Vendor specifications for temperature, dwell time, agitation and bath chemical control should be followed.
4. **Electroless Nickel** – The purpose of this bath is to deposit the required thickness of nickel on the catalyzed copper surface. The nickel thickness should be adequate to cover the copper with a substantially pore-free coating, to create a diffusion barrier to copper migration, and also serve as a solderable surface, depending on the intended application.

The nickel bath has a relatively high deposition rate and its active chemical components must be maintained in balance on a continuous basis, by addition of appropriate replenishment components. Electroless nickel baths typically run at high temperatures and extended dwell times to achieve the required deposit thickness. It is therefore important to ensure that compatible PWB substrate and solder mask materials are used. Vendor specifications for temperature, dwell time, agitation and bath chemical control should be followed.

5. **Electroless Palladium** – The purpose of this bath is to deposit the required thickness of palladium onto the initial electroless nickel deposit. The palladium thickness should be adequate to provide a surface with the desired solderability and/or wire bonding characteristics, depending on the intended application. This bath runs at moderately high temperatures. Dwell times will vary, depending on the required deposit thickness. Vendor specifications for temperature, dwell time, agitation and bath chemical control should be followed.
6. **Immersion Gold** – The purpose of this step is to deposit a thin, continuous layer of gold. The gold protects the underlying electroless nickel/electroless palladium layers from oxidation or passivation, and also serves as a conductive surface.

depending on the intended application. This bath runs at relatively high temperatures and dwell times. The user should ensure compatibility of substrate and solder mask, if used. Vendor specifications for temperature, dwell time, agitation and bath chemical control should be followed.

7. *Rinsing* – The purpose of these steps is to remove residual process chemicals from the PWB surface after each chemical processing step. This may be achieved in either a single step or with multiple rinses. In some instances, pre-dip and/or post-dip process steps may also be required for optimum process performance. Vendor specifications for temperature, dwell time, agitation and turn-over rate should be followed.
8. *Drying* – The purpose of this step is to ensure the boards are completely dry. This may be achieved by use of either in-line vertical, or off-line horizontal drying. Off-line horizontal drying should be preceded by a horizontal rinsing step and should be dedicated to the boards from the ENIG/ENEPIG processes. The time and temperature should be optimized to suit the type of product.
9. *ENIG/ENEPIG Process Combination* – Due to the very substantial overlap between the process flows for production of ENEPIG and ENIG, single process lines can be designed to be capable of producing either product type, by use of different line software control programs.

APPENDIX 2

Round Robin Test Summary

George Milad
Uyemura International Corporation

Objective To determine the appropriate specification limits for electroless palladium in ENEPIG for soldering and wire bonding applications.

Supplier Participation Six suppliers namely: Atotech, Cookson Electronics, Dow Electronics Materials, MacDermid, OMG and UIC Uyemura, committed to providing samples of the required finish for the Round Robin testing:

Thickness Measurement Industry capability to accurately measure the thickness of palladium in thickness ranges desired to be applied to the test vehicle (TV) values was questioned by members of the sub-committee. Prior to the preparation of the samples for the round robin testing of solderability and wire bonding performance, it was decided to obtain an ENEPIG test sample to be sent to interested participants with measuring equipment to determine industry capabilities to reproducibly measure thickness values. The test sample had 16 pads designated for measurement and recorded values were sent to Gerard O'Brien for compilation. The results are provided in the specific Appendix 3, authored by Gerard O'Brien. Participants in this study were able to use this data to confirm their own measurement capability and to identify any need for changes in their measurement protocols.

Solderability and Solder Joint Reliability Testing

The Test Coupon The "W Coupon" described in the IPC-6012 document was used for this phase of the Round Robin. The coupon is 16.5 cm X 14.0 cm [6.5 in X 5.5 in]. It has 18 sub-units as shown above, as well as 2 detachable BGA coupons. *All submitted samples will be subjected to the stress or conditioning for 8 hours at 72 °C [162 °F] and 85% RH.*

Thickness of the ENEPIG to be Tested After additional discussions, the thicknesses of the multiple layers to be tested were agreed upon and all suppliers targeted the desired thicknesses.

- Electroless Nickel (EN): 5 $\mu\text{m} \pm 1 \mu\text{m}$
- Electroless Palladium (EP): 0.1 μm , 0.2 μm , 0.3 μm and 0.5 μm^*
* (from only one supplier).
- Immersion Gold (IG): Supplier preferred immersion gold process (one supplier chose to supply a second ENEPIG sample set with a very thin immersion gold layer).

All combinations will be tested as follows:

- Soldering with eutectic solder
- Soldering with Lead Free SAC305 alloy

Sample Size Each supplier agreed to provide 6 "W Coupons" per thickness iteration. All samples were shipped to Gerard O'Brien for coding, prior to being sent to the test locations, to ensure anonymity of the supplier. Gerard will also maintain a record of the actual thickness plated on each set of coupons, based on measurements made at a single (referee) test location.

Solderability/Wettability This was evaluated using "Wetting Balance" testing as well as Spread test coupons. Wetting Balance tests were carried out by G. O'Brien of ST and S Group (see APPENDIX 5). Solder spread testing was conducted by Brian Madsen of Continental Automotive Systems (see APPENDIX 6).

Solder Joint Reliability Ball Shear testing on the BGA portion of the coupon was used to make this assessment. The testing was carried out at Rockwell Collins by David Hillman. Both force and fracture mode were recorded. Cross sections of representative samples were prepared to examine the composition of the intermetallic compound (IMC) and its configuration. The data is reported by David Hillman in APPENDIX 7.

Wire Bonding Evaluation

Wire Bonding Coupon The test coupon design was provided by Horst Clauberg of Kulick & Sofa. James Monarchio at TTM manufactured the test coupons. Jim supplied sets of test coupons at 2 different levels of surface roughness. One to be particularly coarse (RA ~ 380), utilizing mechanical scrubbing. The surface roughness was measured by profilometry at Enthone by Karl Wengenroth.

The Thickness of the ENEPIG to be Tested The thickness is the same as in the solderability test [see (1) above]. All combinations were tested as follows:

- Gold wire bonding utilizing ball, wedge or crescent.
- All samples are pre-conditioned for 4 hours at 150 °C [302 °F], before bonding.
- The wire bonding testing was done by Stephen Meeks of St. Jude Medical. For the protocol and results of the wire bonding evaluation, please refer to APPENDIX 8.

APPENDIX 3

ENEPIG PWB Surface Finish XRF Round Robin Testing

*Gerard O'Brien, President
S T and S Group*

INTRODUCTION

Measurement capability for thin immersion coatings has long been a concern for the 4-14 Subcommittee and with the introduction of Electroless Nickel/Electroless Palladium/Immersion Gold (ENEPIG), this has become a bigger issue with the need to measure three plated deposits. Additionally there is the impact of the phosphorus content in the Electroless Palladium that was present in the majority of samples submitted for the generation of this specification. For previous 455X family specifications, the committee has typically verified the deposits submitted by the chemical suppliers using a reference XRF (X-ray Fluorescence) and the delta between the readings shared with the suppliers and a general comparison chart generated. There were a significant number of ENEPIG users and printed board (PB) suppliers, as well as chemical suppliers involved with the generation of this specification, who expressed an interest in understanding the variability and accuracy issues with measuring using XRF and so it was decided to perform a round robin test with all interested parties measuring a previously "certified" coupon.

A previously plated test coupon for switch pad testing, but never tested, was chosen for this purpose at random and sixteen locations on the coupon were identified for measuring. A letter detailing the protocol was supplied with the sample and sent initially to the six chemical suppliers prior to plating their test submissions. The test vehicle was then forwarded around the world to OEMs, CEMs and PB suppliers. The data was returned to S T and S and coded to protect the source of the data. Feedback was provided to each test site as to where their readings were relative to the actual values for Ni, Pd and Au. Based on the data generated, some test locations asked for another chance to read the coupon after their XRF had been adjusted or repaired.

The XRF capability used for this round robin testing ranged from simple proportional counter systems all the way through vacuum assisted focused capillary systems costing \$200K+. It should be noted that the higher cost systems did not always produce the correct answers and that a correctly set up XRF system of any type with sufficient measurement time can be capable of correctly measuring the ENEPIG deposit.

It was discovered during this testing that the use of incorrect calibration standards is still a reality. Non-phosphorus containing nickel standards were a common occurrence as well as gold foil thicknesses outside the measurement range. It cannot be emphasized enough that correct measurements can only be obtained when using ENEPIG standards with the phosphorus content in the nickel and palladium matching that in the plated deposit.

Figure A3-1 shows the test coupon and pertinent information from the protocol sent to the test locations. Figures A3-3, A3-4, and A3-5 show the recorded test data for the Au, Pd, and Ni measurements, respectively. Level C shows the reference data.

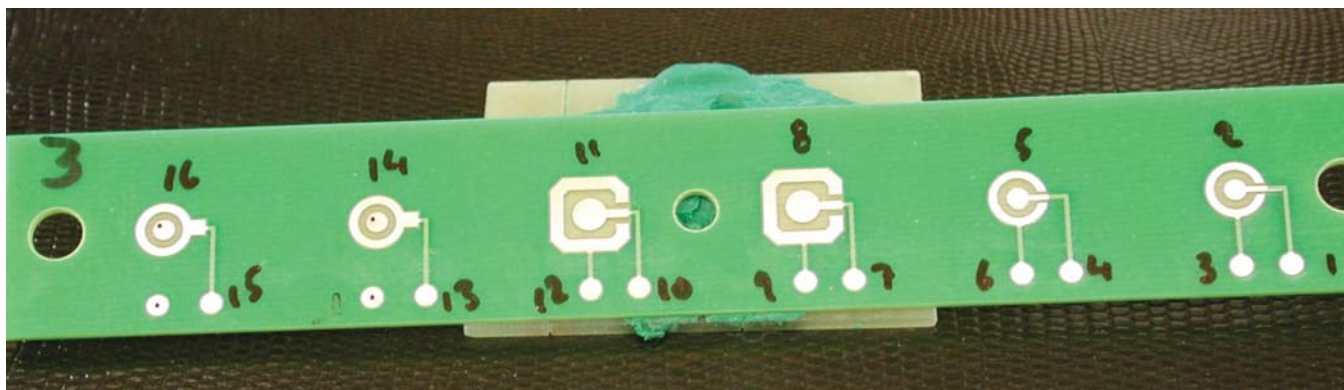


Figure A3-1 Test Coupon Used for XRF Round Robin Measurements

Pertinent Information from the Protocol Sent to All Round Robin Test Locations:

- 1) Record the collimator used for the measurements.
- 2) Record the measurement time.
- 3) Take only one reading per pad.
- 4) If multiple readings are taken to examine variability of the readings, record them on a separate sheet.
- 5) Record what material the coupon sat on when measured.
- 6) Include the calibration file parameters used to create the file, whether standards were used or just fundamental parameters.

Note: There were no measurements taken in the pads to the immediate left of pad #s 13 & 15, as they have a centered hole in them. For pads #s 14 and 16, there are also holes present but they were offset enough so as not to interfere with the XRF readings.

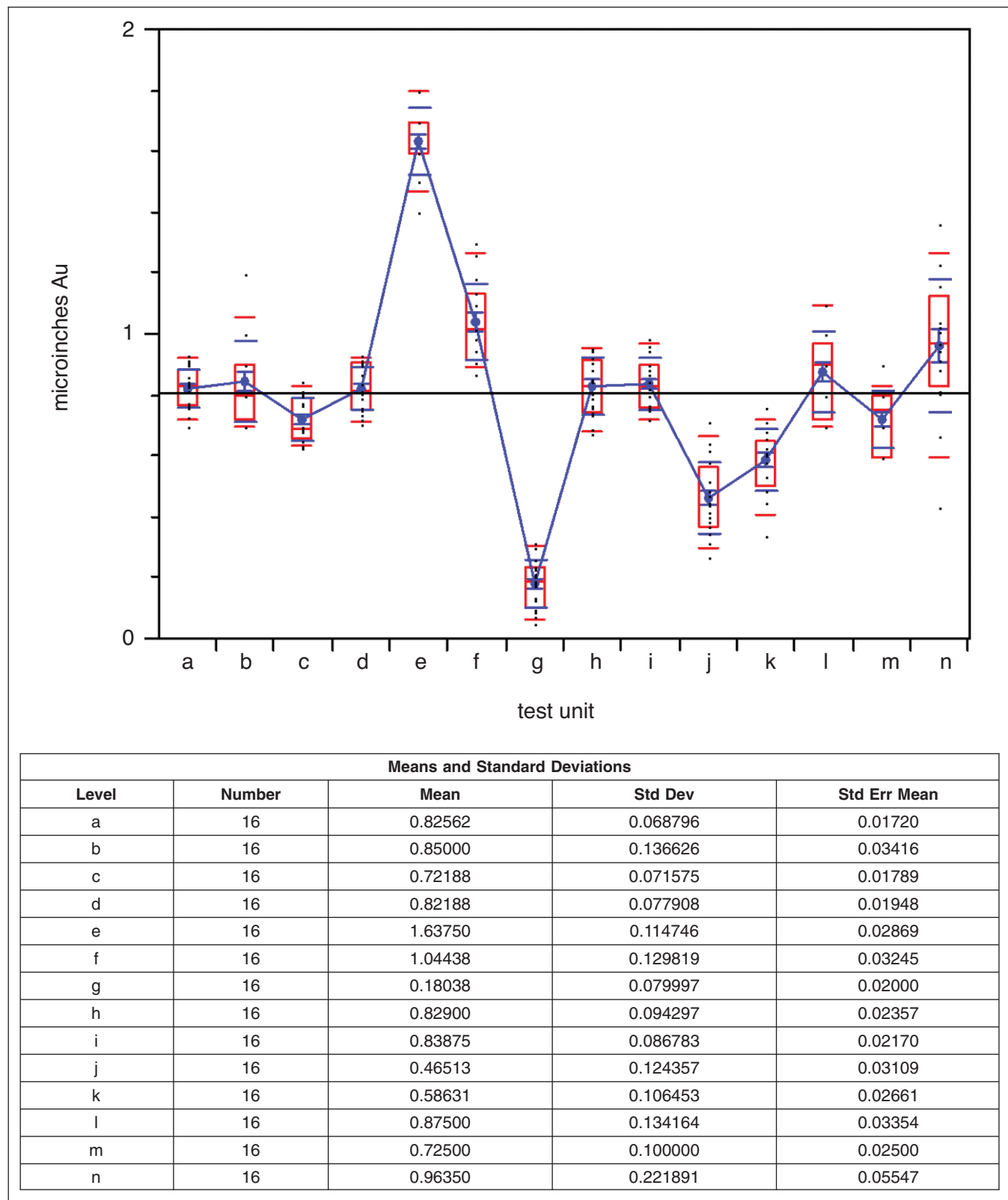


Figure A3-2 Immersion Gold Thickness Readings in Microinches for the Sixteen Test Pads Where C Is the Reference XRF