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Troubleshooting for Printed Board Manufacture and Assembly

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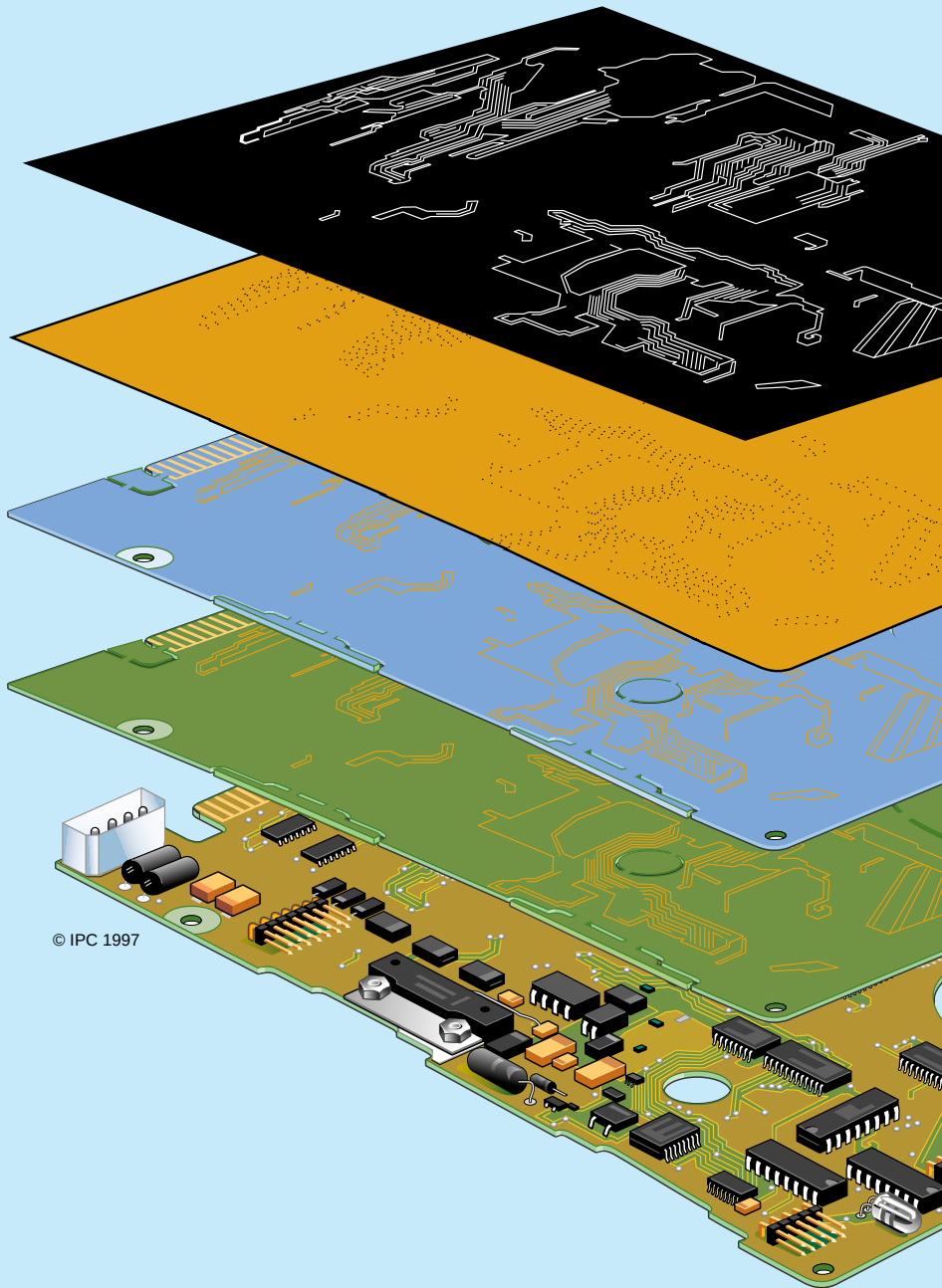
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Users of this standard are encouraged to participate in the
development of future revisions.

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Acknowledgment

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Section 1

General Information

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Section 1

General Introduction

1.0 GENERAL INTRODUCTION

The Process Effects Committee of the IPC has developed this Process Control Handbook for Printed Board Manufacture and Assembly, which is a documentation of problems, and the corrective action that may be taken. The inputs were voluntarily established by technical representatives of IPC member companies, and have been reviewed in open discussion at the Process Effects Handbook meetings prior to publication.

New inputs are encouraged to help assure that the future Process Control Handbooks are complete and match the latest state-of-the-art in a particular subject. All new or revised information will go through an approval cycle, so that the material contained in the Handbook represents the best consensus of the industry at large.

1.1 PURPOSE AND FORMAT The purpose of this Handbook is to provide guidance in the form of troubleshooting examples, process cause and effect information and statistical methods for correcting problems in all areas relating to the design, manufacture, assembly, and test of printed wiring products. A comprehensive Table of Contents deals with all of the various aspects of the design through delivery cycle. At times there may be duplication in the material presented, however, in many instances the material is cross referenced.

The Guide has been segmented into 21 major sections:

- 1.0 General Introduction
- 2.0 Design and Documentation
- 3.0 Phototooling
- 4.0 Base Materials
- 5.0 Mechanical Operations
- 6.0 Hole Preparation
- 7.0 Electroless Processes
- 8.0 Cleaning of Printed Boards
- 9.0 Imaging Processes
- 10.0 Electroplating
- 11.0 Etching
- 12.0 Innerlayer Fabrication
- 13.0 Lamination
- 14.0 Metallic Protective Coatings
- 15.0 Non-metallic Protective Coatings
- 16.0 Component Mounting
- 17.0 Soldering Processes
- 18.0 Cleaning of Printed Board Assemblies
- 19.0 Post Solder Process
- 20.0 Inspection and Test
- 21.0 Rework, Repair and Modification

The Handbook also contains an index which helps to provide the user with the relationship between the various sections. The Process Control Handbook follows a format:

1. Problem Identification (as specifically as possible)
2. Possible Causes
3. Methods to select which causes apply (when available)
4. Suggested corrective actions/control methods

Where available, an illustration is included to aid in clearly identifying the problem. Examples or tutorials (in bold outline) are provided in many areas. These may take several forms (e.g., SPC tools, recommended procedures, designed experiments, case histories, etc.) and should not be considered all-inclusive. All processes are, to some degree, unique and there is no substitute for thoughtful local input.

General instruction may at times be provided. Text will be printed across the page, dealing with the subject in general, and not highlighting a problem, cause, or corrective action.

1.2 GUIDELINES FOR EFFECTIVE TROUBLESHOOTING AND PROCESS CONTROL One of the keys to effective problem solving is a structured routine that addresses key points each time a problem is encountered. This section suggests steps to be taken in order to effectively find the cause of a problem and to solve it permanently. Refer to IPC-PC-90 for greater detail to suggested methodology for practical troubleshooting.

1.2.1 Problem Identification and Statement Before beginning a detailed troubleshooting project, use common sense in defining the problem. Verify that there is a problem. Observe the defective product and compare to the standard. Identify the standard process and product, then determine any present deviation from the standard, or any change in the product.

Establish whether operating procedures were followed and whether an assignable cause can be quickly identified as the reason behind the problem. Only continue into more detailed analysis if the initial questions do not lead to an obvious answer. Even if the answer appears to be obvious, confirm the answer by operation of the process before closing the project.

Develop a clear, concise problem statement that quantifies the problem whenever possible and reduces the scope of the investigation to a manageable size.

Gather all pertinent data and facts. Use SQC, historical data, records, logs, etc. This includes temperature charts, analysis records, maintenance logs and the like.

Existing process data can be used to identify the most important subsets of the problem and better focus troubleshooting efforts. If the requirement is qualitative, establish a clear, common and understood definition of acceptance criteria.

1.2.2 Immediate Action Plans Every problem experienced should be addressed, using an appropriate action plan, by someone designated as the individual responsible. The solution to each problem varies in urgency and intensity, however a documented procedure or plan should exist that describes the decision making processes, such as:

1. Emergency problems (fire, chemical spills, etc.) require immediate action.
2. Producing out-of-specification parts require immediate action (i.e., shut down the process).
3. Out-of-control processes require determination as to whether the process can continue to operate.
4. Severe process variation requires evaluation of the severity and effect of the problem on the final product.

The action plan should include the procedures for addressing products produced during out-of-specification or out-of-control conditions. The plan should also indicate who should make those decisions. These issues include but are not limited to:

- A. Disposition of the defective material (repair, scrap, replace, etc.)
- B. Checking the effect on scheduled delivery.
- C. Informing the effect on scheduled delivery.
- D. Request for non-conformance authority or Material Review Board (MRB) action.

Once the immediate problem is under control, the decision must be made to determine a failure analysis plan, responsibility and schedule in order to reduce or eliminate the likelihood of recurrence.

1.2.3 Measurement System Evaluation “Measurement System” in this context refers to the means used to detect and identify the problem. This includes not only the measuring apparatus, but also the sampling method, the measuring personnel (and their instructions), accuracy and calibration of equipment, and environmental factors (i.e., lighting, temperature, and relative humidity). The measurement system must adequately measure the variation in the parameter or attribute which is considered critical. Imprecision (inability to reliably measure changes large enough to have a process effect) and poor reproducibility of measurements undermine process control, much less troubleshooting efforts. Example: innerlayer line width require-

ments of 0.005 mm cannot reliably be measured with a 30 power shop scope with a reticle scaled in 2 mil increments.

Decisions based on poorly understood measurement systems can be a major cause of misapplied manpower and missed opportunities. Before any statistical decisions can be made, the variation in the measurement must be understood. Occasionally correction of a problem in measurement can be a solution.

The variation inherent in the measurement of attribute data and responses that are subjective in nature can be addressed. The evaluation is more complex in nature, but it is still an essential part of the analysis of the problem. Section 6.0 of IPC-PC-90 discusses this subject in greater detail.

1.2.4 Parameter Diagnostics The purpose of Parameter Analysis, as detailed in Section 9 of IPC-PC-90, is to identify, isolate and rank major sources of variation. Further evaluation of the problem can be better focused if the nature of the variation is understood. Common sources are Positional Variation (within a piece), Cyclical Variation (piece to piece) and Temporal Variation (over time). Information gathered in this effort can be used to modify the Problem Statement if appropriate.

1.2.5 Parameter Analysis The purpose of Parameter Analysis, as detailed in Section 9 of IPC-PC-90, is to identify cause-effect relationships. This step of the troubleshooting process can be handled in various ways, but a common and effective routine is given here as reference.

1.2.5.1 Brainstorming The development of a cause-and-effect diagram by a cross-functional problem solving team is critical to the identification of variables to be studied. Care should be taken to include representatives of the disciplines that are part of the process being studied, such as engineering, quality, manufacturing operators, analysis laboratory, etc.

Identify all possible causes of the problem, including process steps, raw materials, materials handling, inspection and personnel. The ranking of these factors by the problem solving team should be used to establish those factors that will be studied experimentally. While engineers are normally responsible for troubleshooting, they should take care to openly consider new ideas on the problem. The insight of manufacturing personnel that are intimate with a process can be invaluable.

Situations may occur where the formation of a team for brainstorming is inappropriate. Only someone with experience at troubleshooting should make the decision to approach a problem alone. Considerable time and effort can be wasted by failure to get input from all knowledgeable sources.

1.2.5.2 “Divide and Conquer” Approach List all process steps in sequence. Examine product halfway through process for defects or its possible cause (is the problem there yet?). Keep on dividing until the exact process step causing the problem is located. Also, make use of other information sources, such as suppliers and available literature (i.e., IPC-PE-740).

1.2.5.3 Process Audit Conduct a process audit by reviewing the entire operation (e.g., documentation, transfer, handling, processing, etc.). Identify current conditions and compare to the standard. Define process windows. An audit is best conducted by someone not directly involved in the day-to-day operation of the process.

1.2.5.4 Initial Capability Assessment Process Capability Studies ideally are done before the process is accepted for production. This means creating a match between the process and the product, and results in a Process Control Window that is capable of producing the product.

One approach to troubleshooting that quantifies improvement for reporting to management involves the use of Capability Assessment. Section 7 of IPC-PC-90 discusses the generation of capability indices in greater detail. This step promotes the clear understanding of the process matrices but does require time and resources.

1.2.5.5 Optimization This step includes the variety of techniques used to isolate factors that affect the response being studied. Full and fractional factorial matrices are the most common tools used for this purpose. While some simple problems may not seem to require rigorous experimentation, proper technique must still be used when making one-factor-at-a-time changes. Comparison of the output at both settings is mandatory to establish the real effect of the process change. Outside factors that are not controlled when a new factor setting is evaluated can cause incorrect conclusions to be drawn. Always run a control!

1.2.5.6 Confirmation and Final Capability Assessment After determination of preferred settings for those factors studied, a confirmation run must be performed to establish the performance of the modified process. This step often consists of a Short-Term Capability Analysis for comparison with the initial capability assessment. A quantitative comparison of indices can be easily understood by uninformed parties such as management. Only after confirmation of the test results should process changes be made.

1.2.5.7 Parameter Control At this point, the factors that significantly impact the identified problem are understood and must be controlled. Section 10 of IPC-PC-90 discusses Parameter Control in detail. If the Tolerance band for these parameters is not clearly understood, more advanced

experimental techniques can be used to establish specification limits.

A common misapplication of Control chart techniques occurs when variables that are easily measured are charted. Unless the relationship between a variable and the output of a process is understood, this data has little use. The main purpose of Parameter Control is the maintenance of the improvements achieved during earlier efforts. The knowledge gained in the Parameter diagnostics step must be used when establishing subgroups for control charting. Failure to capture the important sources of variation can lead to misleading control charts.

1.2.6 Corrective Action Plan When a problem is located, recommend required course of action, then follow it up to assure that it is understood and implemented.

Determine what measures must be taken to prevent recurrence. Document the problem and solution. Redefine the process control window. Set up permanent controls to keep the variables within the set limits. These may include:

- a. Process audits at specified intervals
- b. Process control or parameter measurement reporting (control charts, etc.).
- c. Preventative maintenance to keep equipment functioning at established levels.

Report the problem and the corrective action to the appropriate people.

1.3 APPLICABLE DOCUMENTS The following documents of the issue currently in effect, form a part of this Guide to the extent specified herein.

1.3.1 IPC

IPC-T-50 Terms and Definitions

IPC-PC-90 General Requirements for Implementation of Statistical Process Control

IPC-D-310 Guidelines for Artwork Generation and Measurement Techniques

IPC-D-325 Documentation Requirements for Printed Boards

IPC-A-600 Acceptability of Printed Boards

IPC-A-610 Acceptability of Printed Board Assemblies

IPC-TM-650 IPC Test Methods Manual

IPC-2221 Generic Standard on PWB Design

IPC-2222 Sectional Standard on Rigid PWB Design

IPC-6011 Generic Performance Specification for Printed Boards

IPC-6012 Qualification and Performance Specification for Rigid Printed Boards

IPC-7711 Rework of Electronic Assemblies

IPC-7721 Repair and Modification of Printed Boards and Electronic Assemblies

Other IPC documents are referenced in the text at the point of interest.

1.3.2 Government

1.3.2.1 Federal Specifications

PPP-B-566 Box, Folding, Paperboard

PPP-B-676 Boxes, Setup

1.4 HANDLING Handling of printed wiring products in all phases is often a major cause of problems and defects that are noted later in the end products. A general lack of concern for handling tools, raw materials, equipment, or end products can easily result in the production of a product that is substandard.

Many companies have adopted policies that strive to let the employees know the care and attention that must be placed on all aspects of the manufacturing and assembly cycles. This starts with the basis for handling and storage of incoming raw materials and continues into the attitude of personnel working in phototooling (handling of artwork area, humidity, and temperature control).

On the production line, discrepancies in procedures are many times noted where no rigid process controls are used to control layer placement procedures, drill speeds and feed rates, sharpening and replacing of drill bits, proper smear removal, insufficient baking and rinsing cycles, incorrect ratio of plating constituents, incorrect orientation of panels and plating tanks, contaminated plating baths, lack of plating bath analysis, and poor microsectioning - or no program at all.

The above list, although not exclusively dealing with handling procedures, provides an overview of the conditions that many times lead into the problems detailed in this Guide.

Appropriate employee attitude, coupled with concrete and well defined company procedures will help, not only to control the areas of problems, but to provide a trace back and identification of the failure mechanisms which caused a particular problem.

Unique handling requirements are detailed in the applicable sections, however, some general discussion of major handling defects is given here.

1.4.1 Scratches Copper-clad panels are surprisingly easily scratched—usually by another copper-clad panel. Scratches and gouges in the copper surface can affect the imaging and etching processes, creating opens or shorts. Panels should not be dragged across each other or across any abrasive surface.

Resist-coated panels (ready for etching or plating) are extremely vulnerable to scratches. While the resists are able to withstand corrosive plating solutions, they are fragile when it comes to mechanical damage. Be aware of sharp edges on racks or tanks or other panels. A scratch through the resist will create an open (in etching) or a short (in plating). Scratches on phototools can lead to similar defects.

1.4.2 Bending or Flexing Panels Thin material is somewhat more susceptible but the results can be the same. Excessive bending or flexing of panels can damage the resin-to-glass bond in the laminate. This can appear as crazing or measling and can affect the material dielectric and resistance to chemical baths. If a multilayer board is flexed, internal delamination can occur and the entire board integrity destroyed.

1.4.3 Fingerprints Fingerprints can be the scourge of a printed board shop, from the phototool area through final inspection, and all process steps in between. Fingerprints can affect light transmission and therefore the quality of the printing operation in the phototool area and in the imaging area. Fingerprints can affect adhesion—in the resist lamination area, in the plating areas, in the multilayer lamination area. Some fingerprints do not clean easily in electroless or electroplating cleaners. The copper does not microetch well and subsequent plating adhesion may suffer. Some people's fingerprints can actually etch the copper surface. In some cases heavy fingerprints may affect the electrical test operation by acting as an insulator. At final inspection, fingerprints could affect board cleanliness and ionic contamination levels.

Fingerprints, as with all handling defects, are preventable through proper operator training and constant concern and vigilance. The basic prevention method is to take all steps necessary to keep hands off panels. Everyone should be trained to handle panels by their outer edges only. When this is not possible, gloves can be worn, but operators (and all others) must be trained in proper glove usage. Gloves can be easily contaminated and end up creating as many problems as fingerprints. They should not come in contact with the face (make-up, body oils) or dirty areas (dust, chemicals, etc.). Some shops will not permit the use of gloves because they can create a false sense of cleanliness and the users become careless in their handling.

1.4.4 Storage Printed board manufacturing areas can be hostile environments to the very boards produced in them.

areas. High temperature and humidity can oxidize clean copper surfaces, as can chemical fumes from the plating area. Strong lighting may adversely affect resist-coated panels even after development. Boards in-process should be stored in clean, dry areas of the shop if at all possible, or processed as soon as possible. Other critical storage points are: oxide-coated innerlayers prior to lamination; prepreg which is temperature and humidity sensitive; all phototools and screens and their associated processing areas (imaging and screen-printing); panels prior to resist lamination through coat, image and develop; after electroless copper (the somewhat porous surface can absorb other airborne contaminants).

1.5 BAKING Laminate materials are baked several times during the manufacture of a printed wiring board. There are four major reasons for baking:

1. To insure proper cure of the laminate resin.
2. To relieve stresses that may impact the dimensional stability of the laminate.
3. To remove volatiles, e.g., moisture.
4. To cure any organic coatings that may be applied to the laminate (e.g., thermal cure solder mask).

1.5.1 General Problems Associated With Baking

1.5.1.1 Cross Contamination Certain baking operations volatilize (drive off) materials which may contaminate subsequent work process through the oven. Consider separate ovens for these functions, improved venting, or more frequent cleaning.

1.5.1.2 Excessive Baking (Over-Temperature Or Over-Time) In addition to excessive oxidation of metallic cladding, excessive baking can change mechanical and/or chemical properties of some laminates. Verification of actual oven temperatures (vs. set points) and a mechanism for enforcing removal at the specified time are required.

1.5.1.3 Improper Loading Stacking can result in uneven time/temperature profiles with variation in results. Stacking also has the potential for trapping contaminants between laminates at high temperatures, possibly degrading the metallic cladding's surface. Racks or frames improperly designed or maintained can lead to surface damage.

1.5.1.4 Hold Time After Bake Uncontrolled dwell times after bake can defeat the original purpose of the bake, especially moisture removal.

1.5.2 Resin Curing Fully curing the laminate resin is important to increase the laminate resistance to moisture absorption, to reduce drilling smear, and possibly to help

reduce the incidence of copper cracking by increasing the dimensional stability of the finished laminate. Generally, full cure of the initial core laminate is done by the supplier prior to shipment to printed board fabricators. Full cure of composite multilayer PWBs is done by the fabricator based on laminate suppliers recommendations for correct lamination and cure parameters.

A common measurement for completeness of cure is glass transition temperature (T_g) of the laminate resin. The T_g is an indicator of the laminate thermal performance capability and will vary accordingly to the resin system used. To achieve the T_g specified by the laminate supplier, the resin must be fully cured. Full cure is accomplished by heating the resin above the T_g and holding it here for a sufficient time to achieve maximum cross linking of the resin system. It is recommended that the PWB manufacturer check with his laminate supplier for the recommended time and temperature (to avoid thermally damaging the laminate or excessive cure). Any bake above the resin T_g should be done under pressure/weight.

Two IPC test methods are available to check laminate for its state of cure (evaluating its T_g). One is Thermal Mechanical Analysis of TMA method, IPC-TM-650 Method 2.4.23, the second is the Differential Scanning Calorimetry or DSC Method IPC-TM-650 Method 2.4.25. Because the two methods typically yield different values, the method used should be consistent with that used by the supplier. It is also wise to specify the test method to the supplier.

In order to determine if additional cure is needed, a single sample can be tested two successive times. During the first test, the sample's cure is advanced by the test which essentially acts as a bake (if undercured). If the second test differs significantly, baking is advised. If the two test values are nearly identical, further baking should not be required.

1.5.3 Stress Relief Stresses are inherent in the lamination process and are the result of the naturally occurring mismatch between the various constituents of the laminate coupled with the material manufacturing process. An example of this is the different coefficients of thermal expansion of the copper and resin system. Another example is the remaining stress from the original yarn fabrication where glass strands are twisted and plied.

Stress relief assists in improving dimensional stability of the laminate by relaxing the stresses prior to further processing. This is especially important for MLB core material. As with increasing cure of the resin, stress relieving requires that the laminate be elevated to a temperature above the glass transition temperature of the resin. Stress relief may well be accomplished at the same time as increased cure is being effected, as long as the temperature is above the T_g .

down is used. In order to prevent bow and twist, the bake and cool down should be done under low pressure or under a uniform weight.

Typical bake times and temperatures for the various laminate resins are shown below:

Table 1-1 Bake Times and Temperatures

Resin Type	T _g *	Bake Temperature	Time
Difunctional Epoxy	130°C	160°C (320°C)	2-4 hours
Multifunctional Epoxy	140-150°C	175°C (350°C)	2-4 hours
Tetrafunctional Epoxy	150-160°C	150°C (350°C)	2-4 hours
BT Epoxy	180°C	190°C (375°C)	2-4 hours
Cyanate Ester	245°C	220°C (425°C)	4 hours
Polyimide	260°C	220°C (425°C)	4 hours

*T_g data obtained using DSC Method (IPC-TM-650 method 2.4.25)

Bake times are “at temperature,” that is, after the material has reached the bake temperature.

1.5.4 Moisture Removal Resin systems used for PWB laminates vary in their tendency to absorb moisture. Some resin systems (such as PTFE) are virtually impervious, others can be rather hygroscopic. Residual moisture in the laminate has been shown to cause a variety of deleterious effects from measles to blow holes to excessive resin flow during lamination. Because of this, moisture removal baking is advantageous and may be employed at the following stages:

- After oxide coating of innerlayers
- After hole preparation
- Before fusing
- Before solder coating/solder leveling
- Before any soldering operation, including wave solder and rework

The bake for moisture and volatile removal is typically done at 100–125°C for 2–4 hours. Panels should be separated to permit air circulation: stacks of panels will not heat properly and the moisture will not be able to escape. The user must note that the most practical temperature and time conditions must be determined for each facility and each printed board assembly.

When assemblies must be set aside (e.g., secondary component mounting of soldering operations), the assembly should be stored in a desiccator cabinet at room temperature and 40% maximum relative humidity (Desiccants may be baked out and reused.)

1.5.5 Organic Coating Cure Follow supplier’s recommendations for each curing or drying process.

1.6 RINSING Water rinsing plays a very important role in the manufacture of printed wiring boards and assemblies. Rinsing is employed at nearly every process step beginning with phototool development. Proper rinsing is especially important in the wet processing cycles such as imaging, etching and plating. Generally, after each exposure to a chemical solution, the printed boards are rinsed by either immersion or spray techniques. This applies to both manually and automatically operated processes.

The quality of the rinsing operation can and does have direct influence on the quality of subsequent processing. Poor rinsing can result in both board and process tank contamination, as well as directly contribute to poor quality product and rejects. Improper rinsing can also cause frequent bath changes due to contamination, increase waste treatment costs, and create very elusive processing problems.

Improved rinsing techniques often do not require additional water use. Many techniques are both inexpensive and easily implemented, once understood. Some of these techniques include air agitation, sprays (continuous, time or pulsed), counterflows, tempering, longer drip times and new rack designs. The sections below discuss the many ways to improve board quality through improved rinsing.

In some areas, an understanding of the incoming water source (i.e., well vs. reservoir, pH, mineral quantity, filtration), as well as any changes in the source can help prevent problems before they occur - or at least provide a place to start pinpointing the problem. Water districts often change water sources at set times during the year. Well water may contain higher quantities of minerals, while reservoirs sometimes have a high content of organic matter, especially when their level is low. It may be necessary to filter or soften incoming water. Some heavily mineralized water can leave deposits on boards or cause precipitation in certain rinse tanks. Carbon filtration could prevent the introduction of organics into a critical process.

1.6.1 Rinse Time Longer rinse times generally result in a better rinsed board. Very small holes take longer due to the fluid dynamics involved. Alkaline or caustic solutions typically take longer to rinse than acids. Warm solutions rinse faster than cold. More concentrated solutions require a longer rinse time (and contaminate the rinse tank faster). Closely spaced panels (in a rack) are more difficult to rinse than those spaced far apart or singly.

Occasionally there are reasons to keep rinse times fairly short. Clean copper surfaces tend to oxidize readily which can inhibit the next operations.

1.6.2 Rinse Water Temperature Warm water will rinse a surface faster than cold water. The general rule for chemical reactions states that for every 10°C increase in temperature, the reaction rate doubles. Rinsing (dissolving a material off a surface) can be thought of as a type of reaction. An ideal cold water rinse temperature is 15–24°C. Hot water is usually recommended after alkaline cleaners to speed up the rinsing process. Extremely cold water rinses can be tempered by adding warm water through a commercially available mixing valve. Warm or hot water will oxidize clean copper surfaces faster than cold water.

1.6.3 Agitation to Improve Rinsing The most commonly employed method is air agitation. It is both inexpensive and extremely effective. Air agitation improves rinsing in two ways: by keeping the rinse water mixed so that concentrated pockets do not occur; and by continuously moving fresh water to the board surface. Air agitation should not be used in rinses immediately after cleaners that foam.

Mechanical agitation of the boards or rack of boards in the rinse tank also aids in rinsing—again by bringing fresh water to the board surface. When the motion is perpendicular to the board, this method also helps to rinse the through-holes by forcing water through them.

A third method of agitation, that is somewhat less effective, is the introduction of rinse water through a sparging system. Generally the water flow rate is not sufficient to make this as effective as air agitation, unless a pump is used.

1.6.4 Spray Rinsing Sprays can be a very effective way to rinse. Pressurized water quickly removes contaminants and supplies fresh water to the board surface. A single spray rinse tank can serve several processes. There are a few drawbacks to spray rinsing that should be taken into consideration when planning a spray rinse system:

- When in operation, sprays consume a tremendous amount of water. Therefore, they should be on only when boards are ready to be rinsed. Generally, the sprays are activated automatically by action of a hoist, or are timed. Often intermittent sprays are used.
- If spray nozzles become clogged, areas of the board may not be properly rinsed.
- Holes in the board do not rinse as well as the surface. Very small holes must rely on capillary action as the primary rinse mechanism. Since this is a slower process, more spray time may be necessary than would be expected for a surface. Consider a combination immersion rinse plus sprays.
- Sprays are only effective when both sides of the board can be sprayed. When boards are side-by-side in a basket-type rack (such as those used on an electroless line), sprays cannot adequately rinse the inside boards,

since they are shielded by other boards.

1.6.5 Counterflow Rinsing The diagram below (Figure 1–1) illustrates the principle of counterflow rinsing. Basically, a single water source flows through multiple rinses in a direction opposite or counter to the flow of the work being processed. Counterflow rinses provide the benefit of multiple rinse stations but use the water flow of a single rinse. Therefore, rinsing can be greatly improved without using additional water. Kushner (see references) gives an excellent technical discussion on the benefits of counterflow rinsing, including calculations to determine required water flow for a given number of rinses.

Both immersion rinse tanks and spray rinse systems can be counterflowed. In an immersion system, the water should be introduced at a spot as far as possible from the outlet. Generally counterflow rinse tanks are joined by a common wall that is an overflow weir, as shown in Figure 1–1. If a process tank separates two rinses, it is possible to externally counterflow the water by piping the outlet of the first to the inlet of the second. Remember that the water flow is by gravity, so the second rinse water height must be slightly lower than the first.

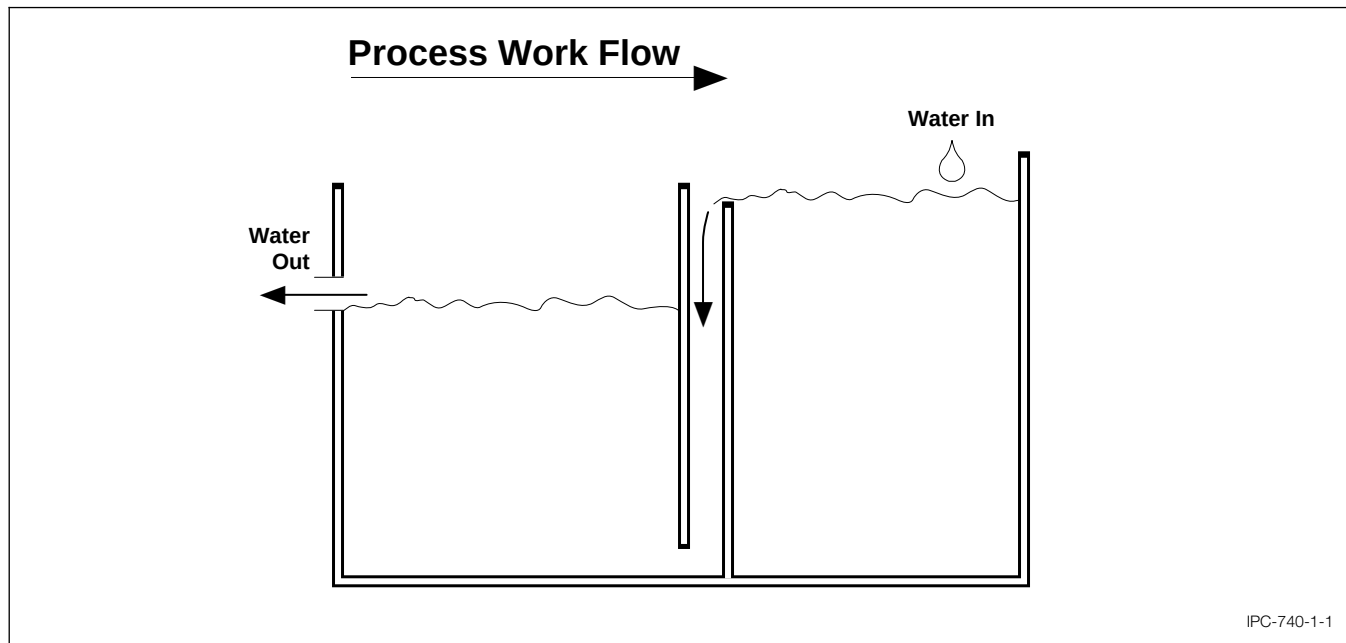
Sometimes the rinse water from one process step can be counterflowed and used at another process step. An example would be a sulfuric acid dip that follows a micro etch step. The rinse water from the acid can be used as rinse water for the micro etch step. It is best to consult the appropriate supplier(s) to insure process compatibility. Some incompatibilities could create precipitates or mix waste streams incorrectly or create later process problems.

In order to counterflow a spray system it is necessary to collect the water from the initial spray into a sump, then pump it to provide the necessary spray can also be reduced by use of a sump and pump system. Counterflowed spray rinses are very common in conveyORIZED equipment.

1.6.6 Drip Times A major contributing factor to the rinse process is the amount of material carried over on the board into the rinse. Obviously, the less process solution left on the board surface, the less to be rinsed off. There are several ways to reduce the amount of material carried over, including increased bath temperature and reduced bath concentration. However, these are limited by the process. A more practical way is to control the drip time of the board(s) over the process solution.

Kushner gives some examples that show the amount of material saved by increased drip times. The material savings and improved rinsing occur in several ways:

- Less material is dragged out of the process tank resulting in a chemistry savings.
- Less material enters the rinse tank resulting in cleaner, more efficient rinses.



IPC-740-1-1

Figure 1-1 Example of counterflow rinsing

- c. Less material is on the board surface so there is less to rinse off, therefore the rinse operation is more efficient.
- d. Less material needs to be waste treated resulting in a cost savings.

The trade-offs on drip times are time and oxidation of the panel surface. On some large automated lines, drip times can add up and increase the total cycle time. On some processes, a long drip time may affect the board surface. This generally occurs more easily with heated baths. Process solutions should never be allowed to dry on the board surface. Dried-on salts often will not redissolve in the rinse station.

Recommended drip times over process tanks are 10 to 30 seconds. Some drip times over rinse tanks (especially the one immediately following a process tank) are also beneficial. Generally 3 to 10 seconds are used. Angling the boards in their racks, so that a corner is the lowest point, also improves dripping.

In the case of conveyORIZED systems, whether vertical or horizontal, drip times must be re-thought in terms of the pinch rollers that tend to wipe the board surfaces of process chemistry. The tighter and more compliant these rollers are to the board surface, the better the surface is wiped and the less amount of material carried over. Also, the slower the conveyor speed, the less material carried over.

1.6.7 Special Rinse Techniques There are several specialized techniques that have been developed with the twin goals of improved rinsing and reduced water consumption. These include:

- a. Conductivity meters and/or flow restrictors. A conductivity meter will activate the water flow when contamination levels in the rinse tank exceed a certain limit. Restrictors simply limit the flow volume. Timers are also placed on rinses so that water is not wasted when no parts are being rinsed. These methods are fine, provided they have been properly set-up and are monitored.

Changes in incoming water pressure or quality, increased product flow through the rinses, or changes in the processes could all adversely affect the rinse quality. In addition, conductivity meters must be calibrated regularly. Flow restrictors tend to age and deteriorate (some actually shrink, further restricting flow). Actual rinse flow rates should be routinely measured as part of a preventive maintenance item.

- b. Pulse Sprays. Beyer discusses these in IPC Technical Paper IPC-TP-376. Basically, water sprays are on for several seconds, then off to allow contaminated water to drip off. This cycle is repeated until the board is sufficiently rinsed.
- c. Air Blow-off. Also discussed by Beyer, this procedure involves air knives near the solution surface. Care must be taken to not allow the board to dry or to create excess foam.
- d. Sweeping Sprays. Sometimes foam forms on rinse tanks that is then carried down the line. It can be a frustrating source of contamination and is often difficult to keep off the rinse water surface. Installation of a bank of sprays angled across the surface can serve to "sweep" the foam into the overflow weir. The sprays can be timed or hoist activated as necessary.

- e. Fog Sprays. Fog sprays use very little water and are designed to be used over a process tank. Their purpose is to aid in dripping, to keep process solution in the process tank.
- f. Top Sprays. To gain an extra rinse without additional space or tank, sprays can be installed at the top of an immersion rinse tank. As the boards exit the rinse tank, the top sprays are activated as a final clean rinse. The top spray water can also serve as the water input to the tank.
- g. Hoist Spray Systems. A design out of Europe encloses a spray rinse system in the hoist. This permits rinsing immediately after the boards have been drawn out of the solution and into the hoist chamber. Rinsing can be done while the hoist is traveling to its next position. There is a space savings in that no rinse tanks are needed on the process line.

1.6.8 References

Water and Waste Control for the Plating Shop, 2nd ed. Kushner and Kushner, Gardner Press

IPC-TP-376, Water Saving Concepts in Automatic Preplate/Electroplate Lines for Printed Circuits, Gustav H. Beyer

1.7 PACKAGING The packaging of printed wiring boards and/or raw materials at incoming is very important. Containers should be of material and form agreed upon by user and supplier, and related to the particular product being packaged or shipped.

The containers or material used for shipping should not introduce gases or chemicals that could be detrimental to the product itself or to the solderability of the board and later assembly steps. Bags or containers made of silicones, sulfur compounds, or polysulfides or processed with these compounds, should not be used.

All parts that are packaged should be clean, dry and packaged in a manner that will afford adequate protection against corrosion, deterioration and physical damage from supply source to the first receiving activity.

Where plastic bags are used for packaging printed wiring boards, they should be clean and free from ionic contaminants. Heat sealing of plastic bags may release volatiles that may contaminate board surfaces.

1.8 MAINTENANCE Maintenance concerns itself with maintaining the process as it was designed. This is needed to assure a consistent product and to prevent accidents.

It should cover everything from the equipment and instrumentation through process procedures and process controls to housekeeping and environmental controls.

1.8.1 Process Maintenance Process maintenance deals with replenishing process consumables with decontamination and wear of tooling inherent to the process. e.g., concentration of plating solutions, carbon treatment, drill bit wear, etc.

1.8.2 Preventative Maintenance Preventative maintenance is scheduled and designed to replace or repair before catastrophic failure occurs. By instituting a good preventative maintenance program, unscheduled breakdown can be essentially eliminated.

1.8.3 Corrective Maintenance Corrective maintenance is repair following breakdown.

1.8.4 Calibration Program A calibration program is a maintenance program for instruments, gauges and test sets. Periodic comparison with standards are checked and adjusted based on statistical evidence of an out-of-control condition. If the instrument is in control but out-of-spec, work needs to be done to reduce the inherent variation of the instrument to less than or equal to the specification at a 99.73% confidence interval (± 3 sigma). After this adjustment has been made the instrument should be recalibrated. Failure to do so may cause the process to go out of control while the controls appear to be within specification.

1.8.5 Housekeeping Housekeeping looks after removal of all unnecessary items from the work area. Clutter causes accidents, mistakes and delays. Also, good housekeeping reports any cleaning problems caused by equipment breakdown or poor maintenance. Getting a small crack repaired may prevent catastrophic failure later when the crack propagates. Good housekeeping shows regard for the equipment, the investment and the product.

Excessive variations in the environment may affect the process or the health or effectiveness of the workers. For example, photoprocesses are sensitive to dust, temperature and humidity. Workers are sensitive to chemicals, heat and RH.

1.8.6 Process Documentation and Procedures Process documentation and procedures must be maintained, because sloppy notes and unrecorded changes invariably lead to errors. Transfer of information between shifts should be clear and preferably in writing. Engineering changes always should be in writing, and be subjected to a time limit, leading to incorporation of the procedures.

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Section 2

Design and Documentation

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Section 2

Design and Documentation

2.0 DESIGN AND DOCUMENTATION

Design of printed boards and printed board assemblies requires a complete understanding of the board manufacturing process and the assembly and joining processes. Designers must consider manufacturing allowances for conductor definition and plated-through hole to land relationships in order to ensure adequate annular ring definition. In addition, proper clearances for automatic component insertion or placement equipment heads must be accommodated.

Choice of materials for board construction is important relative to the performance of the electronics assembly in its usage environment. High temperature laminate is used in products that must dissipate extreme heat or are subjected to the temperature gradients in the location where the assembly is used (i.e., automotive product that must operate under the hood).

The requirements of the design must be properly documented to ensure proper board fabrication and assembly conditions. Proper documentation requires the definition of all features and tolerances, plus references to any performance specifications to which the product must adhere. Customer dissatisfaction can result when product performance expectations are not properly documented and the manufacturer uses his best judgement in order to meet the assumed requirements. Refer to IPC-D-325, Documentation Requirements for Printed Boards.

Section 2 details some of the major problems that occur in the design and documentation processes.

2.1 DESIGN

Design disciplines use manual or automated techniques in order to describe the characteristic of the printed board or printed board assembly. The design principles may be applied to single-sided, double-sided, or multilayer structures. Materials may be organic in nature, either rigid or flexible, or non-organic, such as ceramic or porcelainized steel printed boards.

At times, combinations of different materials are chosen in order to satisfy the design objectives. An example of this would be a rigid-flex multilayer product with a metal core to dissipate the heat from several components. Choosing the proper materials requires an understanding of the end product usage environment and the manufacturing process in order to be able to build the final board at acceptable yield and cost.

There are many computer-aided (CAD) stations available to assist in the design process. Cost of hardware and software has dropped significantly, so most designers can take advantage of these automation tools. Unfortunately not all CAD systems provide the most manufacturable designs. Success or failure of a CAD system's performance may be measured in terms of design completion or number of electrical nets connected. Benchmarking may consist of the time it took the machine or man/machine combination to place all components and to interconnect all component leads on terminations. The measurement made did not include the requirements for manufacturability or testability of the board or assembly. In this case many designs are "thrown over the wall" to the manufacturer and many non-manufacturable designs are produced. This situation has led to coining of the phrases Design for Manufacturability (DFM) and Concurrent Engineering (CE) to reflect the needs of designs to be manufacturable. An understanding of appropriate design principles that address pertinent manufacturability, testing and quality issues must be applied during the design process. Refer to IPC publications for guidance, such as IPC-2221 & 2222 and IPC-D-330. Several others are available for specific applications (refer to IPC publication catalog).

A final concern is an industry characteristic that assumes the designer understands the manufacturing and assembly processes. After spending large sums for CAD hardware and software, CAD operators are expected to perform the design functions, as opposed to Printed Board Designers who have computer skills. Thus many designs produced are a product of the computer algorithms and the manner in which the operator was permitted to change or modify the system design rules to complete the component placement and interconnection functions. These conditions have resulted in many of the problems identified in this section.

2.2 LAYOUT PROBLEMS

A	PROBLEM	CAUSE	ACTION
Components and plated-through holes are not referenced to datum or grid outline.	Improper establishment of datum reference frame.		Re-evaluate board layout and identify a minimum of two features to establish the mutually perpendicular datum reference frame. Identify location of 0/0 datum feature so that all or most of the board characteristics are in a positive Cartesian coordinate zone.
	Intermixing of metric and inch based parts.		Establish majority of parts dimensional characteristics and choose that concept as the master grid. Identify all parts that do not fit that description as off-grid and code as such in the CAD library definition.
	Design completion technique. Establish an alternate or secondary grid system.		Re-layout board starting with a positioning approach and single grid system that comes closest to meeting initial objectives. As redesign proceeds, adjust room to accommodate problems forcing alternate grid systems.
	Density of layout prevented the datum reference from being on the board.		Establish off board tooling hole relationship to a conductor or land pattern cluster in order to be able to evaluate the end product board. Use automatic optical inspection techniques to evaluate artwork or conductive pattern.

B	PROBLEM	CAUSE	ACTION
Layout does not match schematic or logic diagram or CAE file.	Changes made to design were not incorporated in schematic/logic diagram.		Evaluate engineering change control procedures. Incorporate routine checks/check lists to insure that changes are appropriately made to the entire document set. Document policies and procedures, and enforce.
	Back Annotation never completed.		
	Handbook for equipment maintenance required reassignment of reference designators.		

C	PROBLEM	CAUSE	ACTION
Tooling holes not established or wrong size.	Design has not been coordinated with fabrication and assembly engineering.		Establish Design for Manufacturability (DfM) Standards which consider tooling hole location requirements for both fabrication and assembly. If board size and/or density prohibits internal tooling holes; panelize boards as part of design, with external tooling holes. Boards can be excized following fabrication and assembly processes.
	Board is very small and there is no room for tooling holes.		
	Board is very dense and there is no room for tooling holes.		

2.3 ELECTRICAL

A	PROBLEM	CAUSE	ACTION
Electrical arcing between adjacent conductors.	Improper conductor spacing.		Recalculate conductor spacing per IPC-2221 & 2222.

B	PROBLEM	CAUSE	ACTION
Unable to achieve functionality/reliability using high speed/high frequency devices.	HS/HF printed board design principles not followed for controlled impedance HS/HF applications.		Refer to IPC-D-316: High Frequency Design Guide and IPC-D-317: Design Guidelines for Electronic Packaging Utilizing High-Speed Techniques.

C	PROBLEM	CAUSE	ACTION
Conductor crosstalk and board radiation (RF).	Power distribution layout, causing high inductance and few adjacent signal return paths.		Redesign voltage and ground distribution layout, using design principles of IPC-2221 & 2222, see Figures 2-1, 2-2, 2-3.

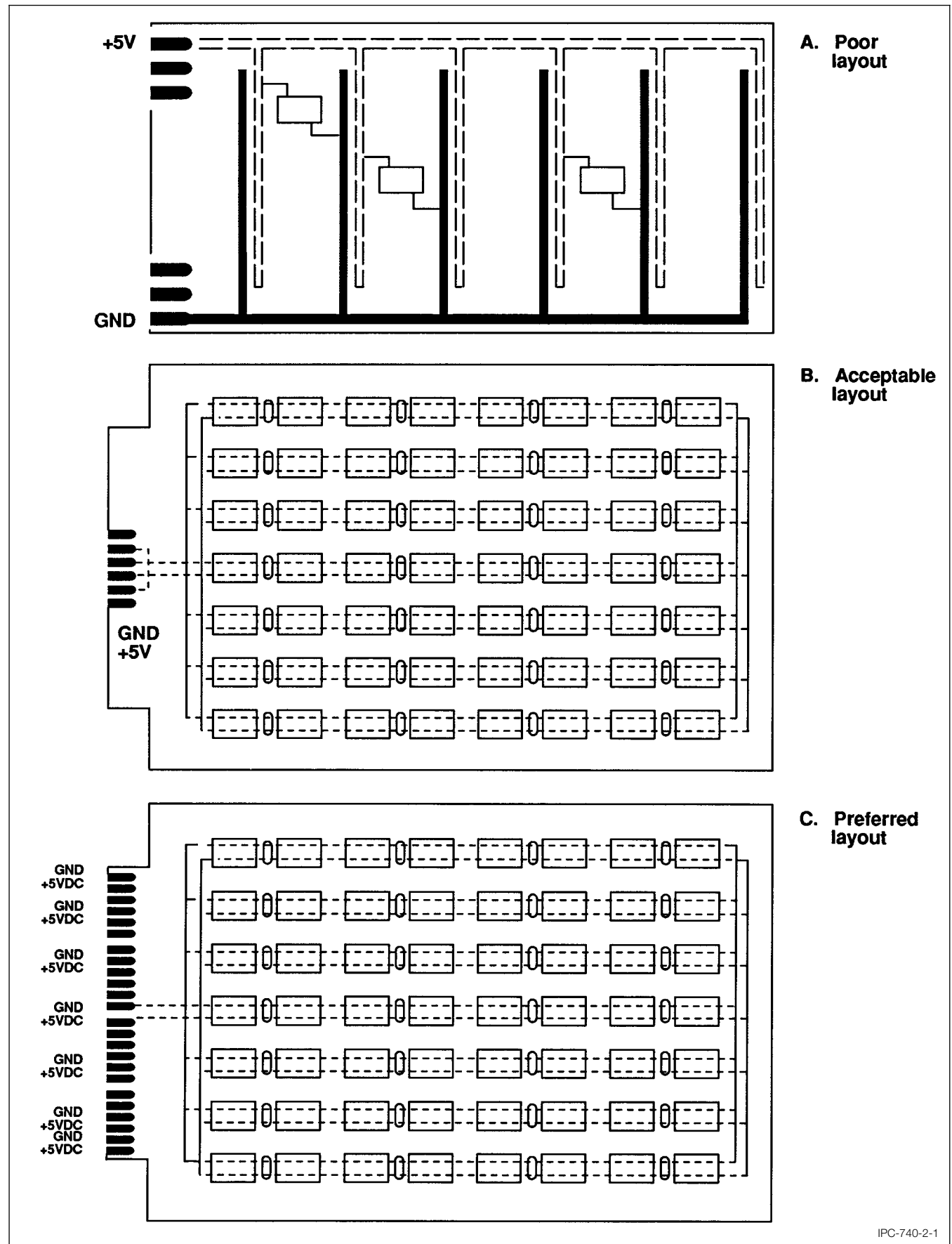


Figure 2-1 Voltage/Ground Distribution

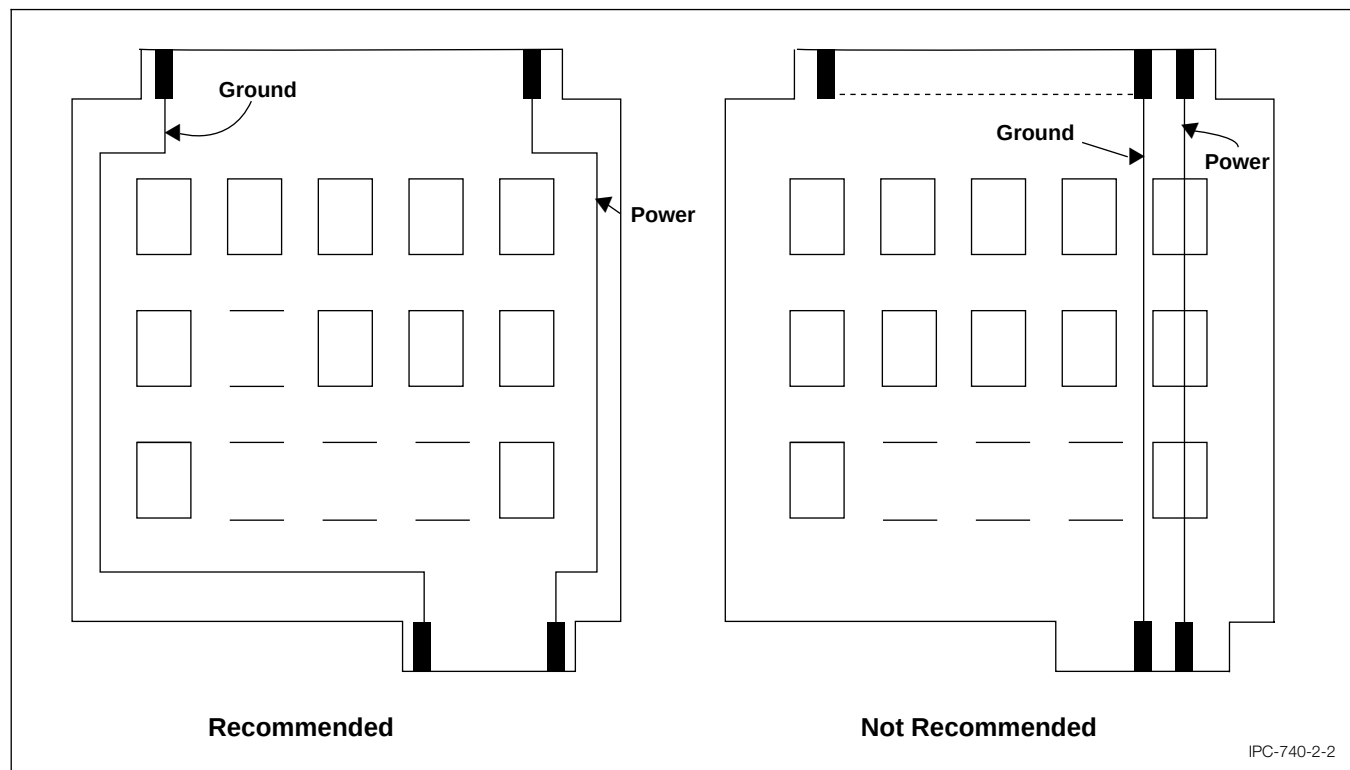


Figure 2-2 Single Reference Edge Routing

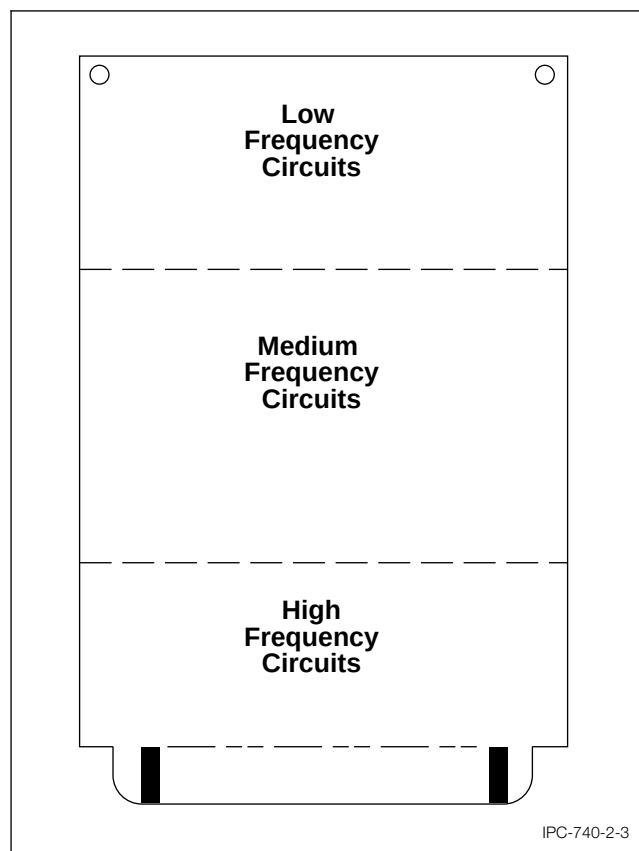


Figure 2-3 Circuit Frequency Distribution

2.4 MATERIAL

A	PROBLEM	CAUSE	ACTION
	Unable to optimize printed board construction because material specification is either incomplete or too restrictive.	Material specification is either incomplete or too restrictive. For example: If no material is specified, and no functional or performance requirements are given, manufacturer cannot produce boards; or, if construction requirements are too specific, manufacturer is prevented from choosing a more efficient, or more functional construction.	Consult with manufacturers to keep current with material technology. Document note call-out to give manufacturer maximum option to fabricate the printed boards to end product performance requirements, without the restriction of starting materials. (Define only requirements for dielectric separation, end product copper, impedance, solderability, protective coatings, etc.)

B	PROBLEM	CAUSE	ACTION
	Unable to optimize solder resist requirements because specification is either incomplete or too restrictive.	Incomplete notes; performance requirements for resist are not defined, or specification is restrictive in the use of a single type of resist.	Contact originator/customer for clarification; request update to documentation and purchase order/shop order. Also, run tests to evaluate solder resist compatibility with end product assembly and use requirements. (Detail the "class" of solder resist needed per IPC-SM-840, or describe required properties, such as abrasion resistance, resistance to solvents, adhesion, insulation, reversion, etc.)

2.5 COMPONENTS

A	PROBLEM	CAUSE	ACTION
	High degree of solder shorts for 1.27 mm lead pitch connectors at wave solder.	Printed board design based on 2.54 mm lead pitch. (Factors that affect yield are lead length, land geometry and pattern, and resist aperture.)	Elongate alternate lands on printed board design (Land pattern). This increases the separation points during wave soldering.

B	PROBLEM	CAUSE	ACTION
	Component package melts during soldering operations.	Package specification not thoroughly evaluated, related to assembly process conditions, when defining component/procurement specifications.	Understand and/or develop applicable assembly process standards, then limit approved supplier selection to packages which can withstand peak temperatures in production and rework.

C	PROBLEM	CAUSE	ACTION
	Excessive solder shorts at SOIC device locations.	Designed land width too wide.	Reduce land width to a width which will reduce solder shorts, while maintaining joint strength. (Refer to IPC-SM-782, and IPC-EM-782 electronic format which allows adjustments to solder requirements and resulting land patterns.)

2.6. ASSEMBLY

2.6.1 Component Positioning

A	PROBLEM	CAUSE	ACTION
	SMT chip components twist off lands during reflow.	Improper land pattern design.	Redesign land pattern per IPC-SM-782.

B	PROBLEM	CAUSE	ACTION
	Insufficient toe and heel fillets.	Improper land design.	Redesign land pattern per IPC-SM-782.
		Over-etched board.	Refer problem to PWB supplier.

C	PROBLEM	CAUSE	ACTION
	Through hole components do not consistently go into mounting holes during automatic assembly.	Component mounting holes too small.	Increase mounting hole size in accordance with IPC-2221 & 2222.
		Hole patterns not located to datum planes.	Locate hole pattern to datum planes.
		Assembly equipment not properly maintained.	Maintain assembly equipment within operational specifications

D	PROBLEM	CAUSE	ACTION
	Cannot access component for repair.	Incorrect component placement.	Provide sufficient spacing between components to facilitate repair equipment and tools.

E	PROBLEM	CAUSE	ACTION
	Delicate component bodies crack during the thermal cycles of assembly.	Insufficient lead stress relief for through-hole components.	Redesign through-hole component lead spacing to provide additional lead stress relief.
		Improper land design for surface mount components.	Redesign SMT land per IPC-SM-782.

F	PROBLEM	CAUSE	ACTION
	Small components exhibit poor solder joint formation.	Small components shadowed by larger components.	Relocate smaller components so that they are not shadowed by larger components.
		Improper land design.	Redesign land pattern per IPC-2221 & 2222 and IPC-SM-782.

2.6.2 Moving Substrates

A	PROBLEM	CAUSE	ACTION
	Feature locations beyond tolerance.	Instability of laminate material during processing.	Use higher performance laminate material with greater x-y stability.
		Board too large.	
		Improper board aspect ratio.	

B	PROBLEM	CAUSE	ACTION
	Panel array is too flexible for soldering operation.	Array designed in the wrong axis for soldering operation flow.	Rotate boards on panel array.
		Too much material removed between breakaway tabs.	Increase number of breakaway tabs. Leave copper strips between boards on panel arrays.

2.6.2 Moving Substrates (continued)

C	PROBLEM	CAUSE	ACTION
	Optical alignment at assembly is erratic.	Inconsistent fiducial design.	Design fiducials in accordance with IPC-2221 & 2222 and IPC-SM-782.
		Inconsistent fiducial finish.	Place fiducial control limits on master drawing.

2.6.3 Assembly Process

A	PROBLEM	CAUSE	ACTION
	Solder joints crack when excising PWB from a panel array.	Improper excising methodization.	Utilize excising fixture.
		Improper excise design.	Provide low force breakaway tab design.

B	PROBLEM	CAUSE	ACTION
	Cold solder joints on power or ground connections for through hole components.	Improperly designed thermal connections to power or ground planes.	Redesign thermal connections per IPC-2221 & 2222.

C	PROBLEM	CAUSE	ACTION
	Reflow soldered surface mount lands with via connections demonstrate solder depletion after wave solder.	Reflow solder migrating into vias during wave solder operation.	Provide thermal barrier (neck down) from via to surface mount land. Plug or mask via with solder mask. Provide solder mask dam across via connection to surface mount land.

D	PROBLEM	CAUSE	ACTION
	Inconsistent solder paste deposition on surface mount assembly.	Solder mask too thick.	Solder mask thickness should be no greater than 0.051 mm. Consult PWB supplier.
		Screen print legend interferes with solder paste stencil contact to board.	Discontinue use of screen print legend. Alternatively, use etched pin one identification and map referencing.

E	PROBLEM	CAUSE	ACTION
	Inconsistent solder volume when wave soldering surface mount components.	Incorrect component orientation.	Orient components in accordance with IPC-SM-782.

F	PROBLEM	CAUSE	ACTION
	Components damaged by assembly fixturing.	Components intrude in assembly fixturing area.	Add a breakaway portion of board material to facilitate assembly fixturing.

2.7 PRINTED BOARD FABRICATION

2.7.1 Holes

A	PROBLEM	CAUSE	ACTION
	Hole breakout in lands.	Incorrect annular ring calculation.	Recalculate using hole diameter (finished hole for external; drilled hole for internal lands) plus two annular rings and a manufacturer allowance.
		Incorrect standard fabrication allowance.	Recalculate using appropriate standard fabrication allowance per correct class identified in table of IPC-2221 & 2222.

B	PROBLEM	CAUSE	ACTION
	Holes in lands break out at conductor interfaces, resulting in open conductor continuity.	Insufficient annular ring specified in design.	Recalculate annular ring in accordance with IPC-2221 & 2222. Fillet conductor or use square lands with corner entry. (See Figure 2-4.)

C	PROBLEM	CAUSE	ACTION
	Barrel cracks in PTH after thermal stress.	Incorrect laminate material called out.	Use a higher performance laminate material with lower z-axis expansion.
		Improper hole diameter-to-board thickness ratio.	Reduce hole aspect ratio.
		Removal of non-functional lands on internal layers.	Add non-functional lands on internal layers.

D	PROBLEM	CAUSE	ACTION
	Holes off location causing hole breakout or shorting of lands to conductors.	Undimensioned, "off standard grid" are not specified by originator/designer; and/or incomplete notes.	Contact user/customer to determine correct location of holes; request update to documentation and purchase order/shop order.
		CAM data delivered does not match current design data.	Contact user/customer to determine correct location of holes; request update to documentation, CAM data, and purchase order/shop order.

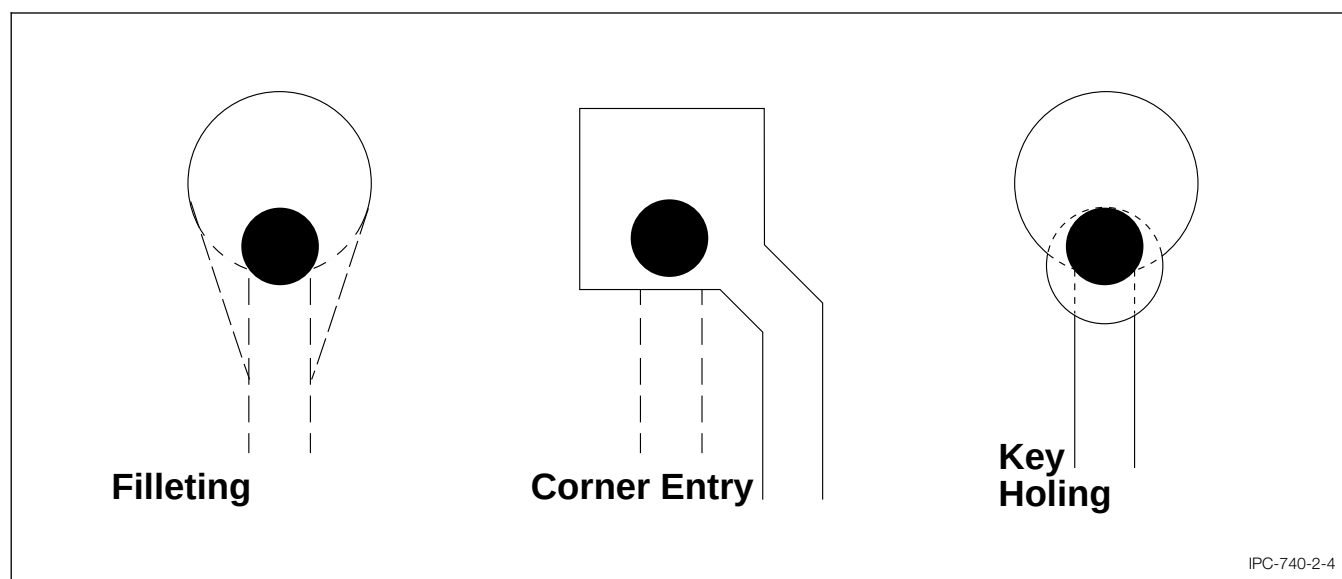


Figure 2-4 Modified Land Shapes

2.7.2 Conductors

A	PROBLEM	CAUSE	ACTION
	Edge conductors cut or damaged after board edge routing.	Conductors too close to board edge.	Locate conductors from board edge in accordance with design standard.
		Tolerance on edge too broad.	Tighten edge tolerance.

2.7.3 Construction

See Section 13.6 for design related problems at lamination.

A	PROBLEM	CAUSE	ACTION
	Unable to meet overall board thickness requirement.	Excessive dimensional detail specified in layer lay-up.	Define only overall board thickness and critical layer dimensions required for electrical criteria, leaving flexibility for fabricator to meet end requirements. (See IPC-2221 & 2222)

2.8 BOARD PHYSICAL CHARACTERISTICS

A	PROBLEM	CAUSE	ACTION
	Installed printed board assembly bows and fails in a horizontally mounted application.	Design incorporated material use that was not sufficiently rigid, with components mounted, in operational conditions.	Either select a different material, or incorporate stabilizing stiffeners or frames.

2.9 DOCUMENTATION

2.9.1 Printed Board Master Drawing

Printed board master drawings should be prepared, considering the following IPC standards:

IPC-D-325 Documentation Requirements for Printed Boards

IPC-D-300 Printed Board Dimensions and Tolerances

IPC-D-350 Printed Board Description in Digital Form

IPC-D-351 Printed Board Drawings in Digital Form

A check list should be developed between users (customers) and suppliers (vendors) which includes all documentation items needed, to determine that all details are covered, prior to beginning work. A documentation review based on such a check list, should reduce undesirable fabrication delays.

2.9.1.1 General

A	PROBLEM	CAUSE	ACTION
	Cannot begin fabrication of printed board because minimum conductor width and spacing are not detailed on the drawings, or are in conflict with applicable specifications and/or artwork supplied.	Design to documentation error and/or appropriate design principles not followed. Example: A board is designed with conductors on 25 mil centers, and there is no manufacturing tolerance allowed between end product conductor width and spacing requirements.	Inspect artwork compared to the master drawing, contact customer to agree on whether conductor width is measured at base or top, then request that the originator of the design/documentation make the appropriate changes. Also request update to original purchase order/shop order.

2.9.1.1 General (continued)

B	PROBLEM	CAUSE	ACTION
	Cannot begin fabrication of printed board because board thickness measurement method and location are not defined. (For example: Over conductors and platings, or at laminate?)	Details are incomplete, or relevant specification omitted from drawing details.	Request that the originator of the design/documentation make the appropriate changes. Also request update to original purchase order/shop order.

C	PROBLEM	CAUSE	ACTION
	Unable to complete and deliver printed boards because test methods, test patterns, and inspection criteria are not documented.	Details are incomplete, or relevant specification omitted from drawing details.	Contact originator/customer and evaluate the need for test method and inspection definition. Request that the originator of the design/documentation make the appropriate changes. Also request update to original purchase order/shop order.

D	PROBLEM	CAUSE	ACTION
	Unable to determine process capability to fabricate printed board, because manufacturing allowances are unknown.	Details are incomplete; manufacturing allowances incorporated into the design were not documented on the master drawing.	Request that the originator of the design/documentation make the appropriate changes. Also request update to original purchase order/shop order. If the originator is unable to supply information, evaluate artwork tooling compared to end product requirements to determine designed manufacturing allowance, and then determine if processes are capable of producing the printed boards within required tolerances.

E	PROBLEM	CAUSE	ACTION
	Cannot begin fabrication of printed boards, because finish/plating requirements are unknown or unclear. (This relates to bare copper, tin/lead reflowed, solder coating (HASL), organic solderable protective coatings (OSP), etc.)	Incomplete and/or inadequately defined drawing notes.	Contact originator/customer to determine requirements for finishes and platings. Request update to documentation and purchase contract or shop order. (User/customer and supplier/vendor should work together to determine best choice of finishes and platings.)

F	PROBLEM	CAUSE	ACTION
	Unsupported or optionally plated holes are mistakenly or unnecessarily plated.	Incomplete or incorrect notes on master drawing.	Contact originator/customer to request clarification; request update to documentation and purchase order/shop order.

2.9.1.2 Tolerances

A	PROBLEM	CAUSE	ACTION
	Unable, or difficult to produce printed boards within tolerances specified on master drawing.	Tolerances specified are inadequate or unreasonable. Originator/designer did not provide the customary, industry standard manufacturability allowances.	Contact originator/customer to request a tolerance analysis, based on manufacturability requirements. Request documentation change, as well as an update to the original purchase order/shop order. (Specified tolerance should be appropriately reflected in cost and price.)

B	PROBLEM	CAUSE	ACTION
	Unable to determine applicable manufacturing and acceptability tolerances.	Documented individual dimension tolerances are in conflict with accumulative tolerances.	Contact originator/customer and resolve conflict. (Suggested changes should be defined, prior to contact.)

C	PROBLEM	CAUSE	ACTION
	Unable to produce printed board to "Class" of tolerance specified in drawing notes.	Dimensions and tolerances specified on master drawing conflict with specification "Class" of build required by drawing notes.	Contact originator/customer and resolve conflict. (Suggested changes should be defined, prior to contact.)

D	PROBLEM	CAUSE	ACTION
	Unable to drill holes to size and tolerance, while maintaining annular ring requirements.	Hole legend tolerances are in conflict with available drill sizes.	Select correct drill bit for meeting the minimum annular ring; determine changes to be made to hole legend documentation; send to originator/customer for negotiation; request update to documentation and purchase contract or shop order. (Agree upon whether "Minimum annular ring" meaning includes plating, or not.)

2.9.1.3 Specifications

Evaluation of true end product functional, performance, and reliability requirements should be made, before any specification and/or related class is invoked. While specifications must address actual needs, they should be as flexible as possible, with as little restrictions as possible, to allow for developments in manufacturing and process technology.

A	PROBLEM	CAUSE	ACTION
	Unable to maximize manufacturing capability, or optimize construction and assembly choices to obtain best solutions for end product functionality and performance.	User defined manufacturing and process specifications attempt to define too many details, and are therefore restrictive or prohibitive to supplier technology for optimization.	User/customer and supplier/vendor should work together in developing specifications, in order to cover basic minimum requirements, while allowing flexibility in manufacturing and processing for optimization. Use industry standards, such as IPC, "as is," or draw from these standards when developing user specifications.

2.9.1.3 Specifications (continued)

B	PROBLEM	CAUSE	ACTION
Unable to determine acceptance criteria.	Specification requirements are in conflict with Master Drawing requirements.		Contact user/customer to resolve conflicts; determine if deviations are needed; request an update to documentation and purchase order or shop order.
	Acceptance, test, and inspection requirements are not defined.		Contact user/customer to determine if this is an omission. If specific actions are required, request update to documentation. Otherwise, acceptance, test, and inspection actions by the manufacturer should be based on statistically based process control.

2.9.2 Printed Board Assembly Documentation. Printed board assembly documentation should adequately define the following:

- Lead bend criteria.
- Clearance of components between the board and the bottom of the component.
- Cleaning requirements and test for cleanliness.
- Type of solder mask and conformal coating and imperfections that are allowed.
- Requirements for complete filling in the solder hole, or solder filling around the lead.
- The use of jumper or haywires and how they must be secured to the boards.
- The masking of components or areas of the board that do not get conformal coating.
- Requirements for stress relief bends on wires, components, etc.
- Location, identification and orientation of all components.
- The definition of projection or lead projection of straight through leads.

- For surface mounted components, the thickness of solder paste, solder callout, flux, inadequately defined, including all locations of solder paste/creams.
- For connectors that require keys, the assembly drawing should show the exact key position and assembly instructions.
- Any hardware that becomes part of the assembly and the torque requirements necessary to prevent damage to the printed board assembly.
- Bow and twist end product requirements after assembly.
- Electrical requirements for end product testing of the assembly, including go/no-go tests as well as diagnostics.
- Applicable ordering data.
- Structural details when required for support and rigidity.
- Markings (serial number, dash number, etc.) to be added as a result of the assembly operation.

A	PROBLEM	CAUSE	ACTION
Incomplete definition of assembly requirements.	Deficiencies in assembly master drawing.		Develop a checklist for master assembly drawings for printed board assembly drawings, or standard assembly specification. Evaluate each master drawing against the checklist or the specification to eliminate any inconsistencies, conflicts, or contact potential customer for missing information.

2.10 INSPECTION AND TEST

A	PROBLEM	CAUSE	ACTION
Unable to perform inspections and tests.	Master drawing/specification does not describe inspection and test requirements nor any deviations that may have been granted to the specification(s) invoked.		Examine the details of the master drawing to make certain that all features of the end product meet the detailed design and performance requirements of the applicable specifications. If conflicts or deviations are noted, they should be documented and resolved with the originator/customer.

B	PROBLEM	CAUSE	ACTION
Unable to perform and complete testing of printed boards.	Incomplete definition of test coupons, frequency of use, and tests to be performed.		Contact originator/customer; request update to documentation to add complete details, as agreed; also request update to purchase order/shop order.

2.11 RELIABILITY

A	PROBLEM	CAUSE	ACTION
	Installed printed board assembly experiences intermittent failures; returns to operational condition after being removed and reinstalled.	Printed board producing electromigration, due to either insufficient protection (permanent polymer coatings and/or conformal coating) in a hostile environment; and/or contaminants from fabrication or assembly processes.	Re-evaluate operating environment, and redesign to add appropriate, compatible coatings. Examine fabrication and assembly process specifications for cleaning and testing requirements.

B	PROBLEM	CAUSE	ACTION
	Installed printed board assembly fails in operational environment where equipment experiences shock and vibration.	Design principals for component mounting for shock and vibration not followed.	Use robust components, and provide proper mounting and support for components, per guidelines specified in IPC-2222 & 2221.

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Section 3

Phototooling

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Section 3

Phototooling

3.0 PHOTOTOOLING

Refer to IPC-D-310 for complete information regarding phototooling.

3.1 MATERIALS AND PROCESSES

3.1.1 General

A	PROBLEM	CAUSE	ACTION
	Image density line widths.	Image density too low.	Check that processing procedure conforms to manufacturer's recommendations. Check that exposure parameters are correct. Check processing equipment to ensure proper operation. Check processing chemistry and temperatures. Do not expose diazo film to white light before developing. Be sure diazo film is not overexposed; use step tablet.
		Background density too high.	Check that processing procedure conforms to manufacturer's recommendations. Check processing equipment. Check processing chemistry and temperatures. Do not expose silver film to white light before developing; do not overexpose to safelights. Do not expose diazo film to ammonia vapors before imaging.

3.1.2 Diazo Film

Diazo film is used for the working phototool, where the ability to see through the image to register the phototool on the board is required.

High quality diazo phototools, when properly exposed and processed, should have the following characteristics: D_{MAX} greater than 4.0 density, D_{MIN} below 0.15 density in the UV portion of the spectrum.

A	PROBLEM	CAUSE	ACTION
	Loss of line width over entire copy (image lines have become thinner or spaces larger).	Incorrect exposure.	Check for overexposure (positive image) or underexposure (negative image), using a 21-step tablet to determine proper exposure time.
		Bad original.	Evaluate original for unsharp edges.
		Reflective surface being employed on back-up board causing light bounce-back.	Change back-up board or check that matte black imaging board is behind diazo film.
		Master and film not emulsion-to-emulsion.	Check master and film for emulsion side. Place in contact emulsion-to-emulsion. Check that vacuum draw down is complete.

B	PROBLEM	CAUSE	ACTION
	Loss of line width at outer edges of copy.	Exposure equipment out of calibration.	Evaluate light fall-off from center to edges of exposure unit.
		Film too large for the equipment used.	UV light too close to film for size of film being used.
		Vacuum frame not functioning properly.	Check vacuum parameters and set-up.

3.1.2 Diazo Film (continued)

C	PROBLEM	CAUSE	ACTION
	Poor edge sharpness (blurred images).	Master and film not emulsion-to-emulsion.	Check master and film for emulsion side. Place in contact emulsion-to-emulsion. Check that vacuum draw down is complete.
		Bad original copy.	Check for poor edges on original.
		Vacuum frame not functioning properly.	Check for out-of-contact print as this will cause fuzzy or blurred edges. Check vacuum for poor pressure and hose for pinholes.
		Reflective surface being employed on back-up board causing light bounce-back.	Change back-up board or check that matte black imaging board is behind diazo film.
		Air pockets trapped between films during exposure.	Check for dirt on image tray. Check for indentations or warping of black image board behind film. Add "bleeder" strips to allow trapped air to escape. Try drawing down gradually or for a longer time.

D	PROBLEM	CAUSE	ACTION
	Image gain: background discoloration in clear area (D_{MIN} too high) - uniform high background (clear area) density.	Underexposure.	Increase exposure time to burn out residual diazo. Use 21-step tablet.
		Film exposed to ammonia vapor prior to processing.	Film stored too close to ammonia; remove storage of film away from possible ammonia contamination. If diazo master is being used, residual ammonia may remain in film. Air out prior to placing in contact with another piece of film.
		Background of master is opaque to UV light. High D_{MIN} on master.	Increase exposure time to permit passage of light through background of master. Replace master.
		Exposure to excessive heat prior to processing.	Keep film stored in cool, dry environment.
		Over-age film.	Obtain new product.

E	PROBLEM	CAUSE	ACTION
	Low D_{MAX} (inadequate image density): 100% of the time.	Improper development.	Check processor for poor development. Check ammonia supply and strength, ascertaining that it is at least 26° Baumé. Check film plane temperature; should register 60–71°C. Insure sufficient passes through processor.
		Incorrect exposure.	Make sure film is not overexposed.
		Improper material or material handling.	Evaluate film to assure that it is capable of 4.0+ UV density.
		Film exposed to white room light prior to processing.	Use yellow lights or yellow shields in the processing area.
		Master does not have adequate density in image area, causing light to pass through and reducing diazo image density.	Replace master.
		Improper film cleaner.	Film cleaner may be reducing image. Check cloth for excessive yellow which indicates coating is being removed. Change to supplier recommended film cleaner.

3.1.2 Diazo Film (continued)

F	PROBLEM	CAUSE	ACTION
	Low D_{MAX}: some of the time (occasionally one film will not block light after several exposures).	Incorrect development procedure.	Review development techniques of all employees handling films. Review when ammonia is turned off in developer and length of time before film is passed through developer when it is turned on again. Pass through ammonia to achieve original color.
		Improper material storage.	Be sure no light has struck film.
		Equipment not functioning properly.	Check temperature of developer - should be above 60-71°C - at film plane (not thermostat on developer). Use of temperature tapes is best check.

G	PROBLEM	CAUSE	ACTION
	Pinholes or voids in image.	Pinholes in original artwork master.	Check original artwork for pinholes. Opaque (touch up) if necessary. Image second film to see if pinholes reproduce - identical position indicates pinhole in original artwork.

H	PROBLEM	CAUSE	ACTION
	Specks in clear area of film.	Dust or particles on master or vacuum frame glass.	Clean exposure frame, film and original using anti-static film cleaner or glass cleaner. Review clean room procedures for area.
		Image dots on clear areas of original artwork master.	Eradicate or physically remove from master. Increase exposure to burn through existing dots.

J	PROBLEM	CAUSE	ACTION
	Image distortion.	Environment - temperature and humidity.	Install and maintain temperature and humidity controls to meet the film manufacturer's recommendations.
		Lack of equilcharate after processing.	Allow film to equilcharate for 10 minutes after development.
		Precondition of film.	Stabilize film for a minimum of 8 hours or open shelving in photo lab environment.
		Developing temperature.	Temperatures exceeding 77°C can cause distortion; reduce temperature if necessary.
		Insufficient equilibrium after processing.	Expose film to room air for 15 minutes after processing.

K	PROBLEM	CAUSE	ACTION
	Straight (stray) lines showing on processed film.	Usually caused by stripped or pasted-up masters. The edges of the paste-up cause distortion of the light.	Increase exposure time to burn through cut-lines. Physically remove lines from first duplicate and use the corrected dupe to make another print.

L	PROBLEM	CAUSE	ACTION
	Random yellow spots in image area.	If yellow spots appear after exposure onto photo-resist, cause is particles of resist adhering to phototool.	Check resist laminated boards for loose resist chips and remove.
		Improper film cleaner.	Check film cleaner. Do not apply directly to film. Apply to cloth and clean film. Some cleaners will bleach film image.

3.1.2 Diazo Film (continued)

M	PROBLEM	CAUSE	ACTION
Ammonia processor not developing properly, even with proper heat and temperature.	Too much exhaust.	Exhaust fan too strong, drawing ammonia out of the developer.	
	Blocked feed tubes to processor.	Feed tubes blocked, causing improper ammonia feed to chamber. Call for service.	
	Pump not operating properly.	Repair/service pump.	

N	PROBLEM	CAUSE	ACTION
Film sticking in processor.	Processor too hot.	Adjust temperature to 60-71°C on film plane using temperature tapes.	
	Dirty slip screen.	Deposits on slip screen causing film to stick. Remove and clean slip screen if developer has one.	

3.1.3 Silver Halide Film

Silver halide film is more versatile than diazo film. It can be imaged directly on photoplotters, contact frames, cameras, step-and-repeat machines, modifiers, etc. Most silver halide films are negative working (they reverse the image tone). All silver halide films must be processed (develop, fix, wash, dry) after exposure. Silver halide photoplotted films are suitable for first generation phototools. High quality silver halide films, when properly exposed and processed, should have the following characteristics:

- D_{MAX} greater than 3.8 density UV.
- D_{MIN} below 0.10 density UV.
- Sharp line edges, with minimal low density fringe.
- Fine line resolution to at least 1-mil line and space.
- Low pinhole levels.
- Scratch resistant structure.
- Anti-static protection to resist dirt and dust attraction.
- Good dimensional stability.

The following information is based on contact copies only, not master creation. (See Section 3.2.11 for laser-generated artwork.)

A	PROBLEM	CAUSE	ACTION
Line width - oversized or undersized.		Incorrect exposure.	Check for proper exposure settings on plotter.
		Incorrect development time.	Verify correct development time in processor.
		Incorrect development temperature.	Verify correct development temperature in processor.
		Improper developer dilution.	Ensure correct chemical mixing.
		Insufficient developer replenishment.	Check replenishment settings on processor and proper mixing.
		Exposed through the base side.	Ensure film is exposed to the emulsion side.

3.1.3 Silver Halide Film (continued)

B	PROBLEM	CAUSE	ACTION
	Low image density.	Incorrect exposure.	Verify that correct exposure is used.
		Improper development.	Use recommended developer time and temperature.
		Incorrect developer replenishment.	Check replenishment settings on processor and proper mixing.
		Exposed through the base side.	Ensure film is exposed to the emulsion side.

C	PROBLEM	CAUSE	ACTION
	Pinholes.	Pickoff in processing.	Clean crossovers and racks in processor. Check processor for correct crossover and film guide alignment. Check wash tank for bioslime. Treat with biocide. Replace filters in processor recirculation, and in incoming water line. Run tacky, roller transport clean-up sheets through processor, on a daily basis.
		Dirt on film during exposure.	Check for dust inside exposure machine. Vacuum as needed.
		Flakes in fixer.	Check electrolytic silver recovery for proper operating amperage.

D	PROBLEM	CAUSE	ACTION
	Poor line edge quality. (See Figures 3-1 and 3-2).	Incorrect exposure.	Check line width and exposure.
		Underdeveloped.	Follow manufacturer's recommendation for development, time, temperature, and developer concentration.
		Safelight fog.	Check darkroom safelights.
		Plotter out of focus.	Check plotter focus.

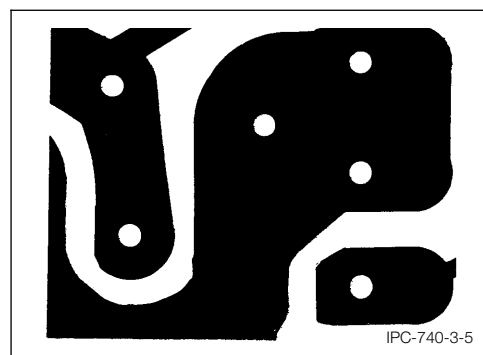


Figure 3-1.
Ragged edges.

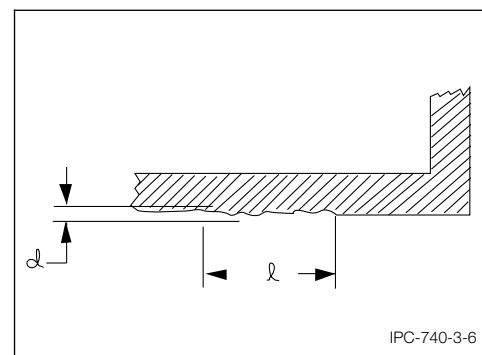


Figure 3-2.
Ragged edge.

3.1.3 Silver Halide Film (continued)

E	PROBLEM	CAUSE	ACTION
	Black speck redeposits in clear area - irregular shape. (See Figure 3-3).	Silver and gel particles in solutions.	Replace recirculation filters in processor. Run tacky, roller transport clean-up sheets through processor, on a daily basis.
		Dirty or inadequate wash water/tank.	Dump and clean wash tank and rack. Install clean filters on incoming water line.
		Dirt buildup on rollers.	Clean racks and crossovers in processor.

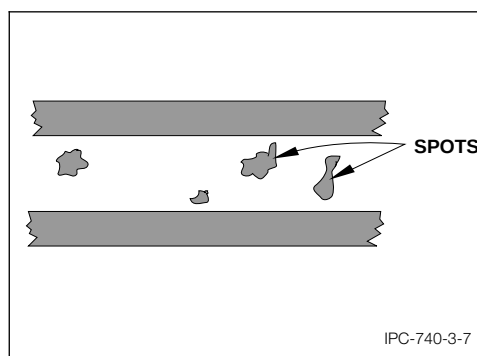


Figure 3-3.
Spots or flecks.

F	PROBLEM	CAUSE	ACTION
	Silver pepper spots in clear area - round shape.	Under-replenished developer.	Insure proper developer replenishment to processor.
		Overdeveloped film.	Check developer time and temperature.
		Oxidized developer.	Check recirculation pump on processor for proper operation.

G	PROBLEM	CAUSE	ACTION
	Yellow, orange-yellow, or brown deposits in clear areas of film.	Bioslime in wash tank.	Clean wash tank. Treat water with biocide. Run tacky, roller transport clean-up sheets through processor, on a daily basis.
		Bioslime in blender replenishment unit.	Clean water reservoir in blender with diluted household bleach.

H	PROBLEM	CAUSE	ACTION
	Powder deposits on film (yellow or white).	Sulfurized fixer.	Check fixer tank for particulates. Check electrolytic silver recovery unit for excessive plating amperage.
		Salts in wash water.	Dump and replace recirculating wash water tank.

J	PROBLEM	CAUSE	ACTION
	Black line abrasion.	Entrance roller scratch.	Check entrance rollers to processor for dirt, burrs, or hesitation.
		Cassette feed scratch.	Check film-cassette loading mechanism for potential scratching.
		Rough handling.	Insure good film handling practices to avoid scratching prior to processing.

3.1.3 Silver Halide Film (continued)

K	PROBLEM	CAUSE	ACTION
Poor dimensional stability.		Relative humidity variations.	Check humidity control for proper operation.
		Temperature variations.	Check temperature control.
		Dryer temperature set incorrectly.	Reset dryer temperature. Consult film manufacturer.
		Inadequate film equilibration procedures.	Ensure adequate film equilibration before and after processing.
		Improper vacuum draw in exposure frame.	Use longer/slower vacuum drawdown before exposure.

3.1.4 Glass - Silver Halide

Silver halide emulsion coated on glass is designed to produce phototools where maximum dimensional stability is desired. Insensitivity to relative humidity (RH) makes glass an ideal substrate for extremely critical size holding applications.

Glass is much more stable than film, as a comparison of humidity and temperature coefficients will show:

- Glass has a zero humidity coefficient.
- Polyester film base, 7-mil thick, has a humidity coefficient of 0.0008% per % RH.
- Glass has a thermal coefficient of 0.0008% per degree Celsius, as compared to 0.0018% per °C for polyester film, or about double that of glass.

Glass is used to produce either first generation phototools on flat-bed photoplotters, or to produce second generation phototools in a contact frame when imaged from a film original. High quality silver halide glass plates, when properly exposed and processed, should exhibit: (1) D_{MAX} greater than 4.0 density UV, and (2) D_{MIN} below 0.10 density UV.

A	PROBLEM	CAUSE	ACTION
Line width incorrect - oversized or undersized.		Incorrect exposure.	Check for proper exposure settings on plotter, or contact frame.
		Incorrect development time.	Verify correct development time.
		Incorrect development temperature.	Verify correct development temperature.
		Improper developer dilution.	Insure correct chemical mixing.
		Exhausted or unreplenished developer.	Mix fresh developer, or add replenishment.
		Exposed through the base side.	Ensure glass plates are exposed to emulsion side.
		Fall off in exposure near edges of contact frame.	Check exposing lamp for uniformity using a light meter. Or, expose and process plate with step tablets in center and around the outer edges of the glass.
		Light source too close to glass for size of glass being used.	Increase distance from lamp to glass.

3.1.4 Glass - Silver Halide (continued)

B	PROBLEM	CAUSE	ACTION
Low image density.		Incorrect exposure.	Verify that correct exposure is used.
		Improper development.	Use recommended developer time and temperature.
		Improper developer dilution.	Insure correct chemical mixing.
		Exhausted or unreplenished developer.	Mix fresh developer, or add replenishment.
		Exposed through the base side.	Ensure glass exposed to emulsion side on plotter.

C	PROBLEM	CAUSE	ACTION
Pinholes.		Pickoff in processing.	Avoid any contact with emulsion while wet. Handle glass only by edges when tray processing.
		Dirt or dust in exposing area.	Vacuum as needed. Clean exposing frame, glass cover, and film original.

D	PROBLEM	CAUSE	ACTION
Poor line edge quality.		Incorrect exposure.	Check line width and plotter exposure.
		Incorrect development.	Follow manufacturer's recommendation for development, time, temperature, and developer concentration.
		Poor contact between film and glass.	Check contact frame for adequate contact and vacuum drawdown.
		Safelight fog.	Check darkroom safelights.
		Plotter out of focus.	Check plotter focus.

E	PROBLEM	CAUSE	ACTION
Uneven density, mottle, or streaks.		Non-uniform immersion into developer.	Immerse glass plate into developer tray using one continuous movement, without stopping or hesitating.
		Non-uniform immersion into fixer.	Immerse glass plate into fixer tray using one continuous movement, without stopping or hesitating.
		Poor agitation.	Rock tray continuously throughout entire development time, using front-to-back and side-to-side rocking motions.
		Poor stop action of development.	Add acid hardener to fixer solution. Or use an acid "Stop Bath" between the developer and fixer processing steps. A Stop Bath (5% acetic acid) will usually ensure good stop action of development and minimizes potential streaks or other uneven continuation of development when going directly from developer to fixer.
		Exhausted fixer.	Mix fresh fixer.

F	PROBLEM	CAUSE	ACTION
Specks or deposits on processed glass plate.		Crystals of fixer as a result of insufficient washing.	Re-fix and re-wash. The white crystals, or frosty appearance, may not show up for possibly weeks or months after processing.
		Hard water. Calcium or magnesium scales.	May require water softener to supply fresh water.
		Emulsion particles of gelatin and silver (high temperature wash water).	Use colder wash water, 18° to 21°C. Warm water can cause gelatin to lift off the glass around the edges. These gel particles can be redeposited back onto the plate emulsion.

3.1.5 Glass - Hard Surface Image on Glass

Hard surface photomasks are noted for excellent dimensional stability and surface durability. Types of hard surface photo tools are chrome, iron oxide and silicon dioxide. Initial high costs are offset by longer life expectancy.

A	PROBLEM	CAUSE	ACTION
	Ragged lines.	Resist lift.	Metal surface not clean enough - use heavy duty glass cleaner. It is best to apply resist immediately after metal deposition.
		Resist not properly developed.	Develop resist according to manufacturer's recommendations.
		Metal etching not complete.	Metal etchant is spent. Phototool not etched long enough. Agitate phototool during etching to bring fresh solution to surface.

B	PROBLEM	CAUSE	ACTION
	Pinholes or voids.	Dust or particles in exposure area.	Clean exposure frame, glass and original.
		Bad original artwork master.	Check original artwork and touch up if necessary.
		Bad material.	Check fully exposed glass sheet - inspect for air bubbles - voids.

3.2 ARTWORK

This section is divided into five parts. The first contains problems of a general nature. The second part discussed problems associated with manually generated artwork (i.e., "taped up," etc.). The third part is on photoplotter generated artwork while the fourth deals with problems specific to laser-generated artwork. The final section discusses problems associated with the rework and repair of artwork.

Board artwork utilizes a system of punched holes which describe the center of the board. This punch system provides a means of interlayer registration. The punched holes must be parallel and symmetrical to the underlay centerline. Each punched underlay should be pinned and examined for buckling, which would prevent it from laying completely flat. With extensive use, the punched hole may wear or widen. This will result in misregistration between layers.

3.2.1 General

A	PROBLEM	CAUSE	ACTION
	Poor feature definition.	Poor workmanship for manual artwork. Dirt adhered to edges of top.	Photocopy tape master to eliminate tape adhesive squeeze-out which picks up dirt.
		Improper exposure.	The following items should be evaluated for automatic artwork: • Check light (laser) source and calibrate. • Run test plots to evaluate plotter movement related to conductor ends and flashed features. • Evaluate plotter commands to avoid double exposure. • Clean all lenses and filters.

B	PROBLEM	CAUSE	ACTION
	Incorrect feature location.	Non-dimensional stability positioning grid for land patterns.	Check grids being used for doing hand taping; inspect and calibrate.
		Tape was stretched (tape creep).	Institute procedures to avoid tape stretching. Avoid curved section or switch to non-creep tape.
		Artwork material deformed either at incoming or by improper handling.	Institute procedures, humidity and temperature control, and proper storage conditions for handling of artwork media. Incorporate improved registration system.

C	PROBLEM	CAUSE	ACTION
	Missing features.	Lands left off the master, either in hand taping or in plotter-generated artwork.	Institute proper checking procedures, comparing artwork layers to design layout or to other artwork layers. Contact customer.
		Missing plating bar for connector contacts.	Supplier to determine board profile and add plating bar as needed.
		Missing coupons on the artwork, as required by the master drawing.	Determine coupon requirements, make step and repeat master for production, and add coupons, as necessary. Examine location of coupons on the production master to make certain that they adequately represent the end product board.
		Nomenclature is missing from the symbolization master.	Send symbolization master back to customer or get permission to add nomenclature (after checking that location does not interfere with existing circuit pattern).

D	PROBLEM	CAUSE	ACTION
	Incorrect registration between layers of double-sided or multilayer boards.	Entire layer does not register because the artwork was generated at different times.	Institute procedures to ascertain that all artwork revision levels are the same generation from the original. Keep artwork masters in sets, so that if one in a set changes, the whole set is reproduced.
		Misregistration of localized area on artwork due to manual changes of a particular area, without change to remaining circuitry.	Institute checking procedures to verify registration of the entire pattern, either through manual checks (negative to positive comparisons) or by automatic optical inspection equipment.
		Center of lands left open to provide registration checking capability. Manufacturing wants the lands to be solid to avoid drill movement caused by the etched inside of the "doughnut."	Institute procedures for automatic artwork generation by using apertures that are solid. For manual artwork generation, institute procedures to fill in open areas of land patterns.