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**THE MASSACHUSETTS  
TOXICS USE REDUCTION INSTITUTE**

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**EVALUATION AND IMPLEMENTATION  
OF NO-CLEAN SOLDER PASTE FOR  
SURFACE MOUNT TECHNOLOGY**

**WITH A FOCUS ON SMALL CONTRACT  
MANUFACTURERS**

**GRADUATE THESIS**

**Technical Report No. 40**

**1997**

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University of Massachusetts Lowell

# **Evaluation and Implementation of No-Clean Solder for Surface Mount Technology**

**With a Focus on Small Contract Manufacturers**

**Doug Sommer**

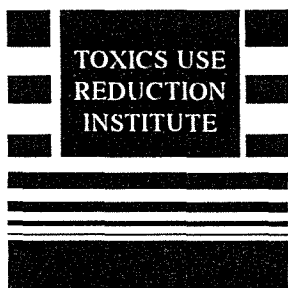
**Prof. Sammy G. Shina  
Mechanical Engineering Dept.**

**University of Massachusetts Lowell**

**The 1996 - 1997 Toxics Use Reduction Research Fellows Program**

**The Toxics Use Reduction Institute  
University of Massachusetts Lowell**

**1997**



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## **Toxics Use Reduction Institute Research Fellows Program**

In 1991, the Toxics Use Reduction Institute established the Research Fellows Program at the University of Massachusetts Lowell (UML). The Research Fellows Program funds toxics use reduction projects performed by a graduate student and his/her advisor. The goals of the Research Fellows Program are:

- to develop technologies, materials, processes, and methods for implementing toxics use reduction techniques
- to develop an understanding of toxics use reduction among UML graduate students and faculty
- to facilitate the integration of the concept of toxics use reduction into UML research projects
- to provide UML faculty with "incubator" funding for toxics use reduction related research, and
- to act as a liaison between Massachusetts industries and UML faculty.

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# **ABSTRACT**

For many decades, the electronics industry has utilized ozone depleting solvents to clean electronics assemblies. The cleaning of electronic assemblies has been necessary to ensure the removal of performance detrimental contaminants, such as soldering residues, that reduce the reliability of the electronic assembly. As the usage of these cleaning solvents continued, the harmful effects on the environment have become increasingly apparent. Legislation has forced electronics manufacturers to consider and adopt new alternatives from the environmentally deleterious cleaning practices previously deemed acceptable. One of the most advantageous methods to accomplish this has been to adopt a no-clean approach to soldering.

As the name implies, electronics assemblies that are soldered using no-clean materials do not need to be cleaned after assembly operations. The residues that they leave behind are benign to the end use reliability of the assembly. They also have inherent other benefits such as the elimination of cleaning equipment, waste effluent, and all its other related costs. Unfortunately, implementation of no-clean soldering has proven to be difficult for smaller assembly shops due to the many concerns associated with no-clean soldering. Many of these manufacturers lack the engineering resources, economic means, and the time to transition to a new process without loss of quality, throughput, and cost.

This study addresses the implementation of no-clean solder pastes for a small contract manufacturing situation. The issues regarding the cleaning of electronics are discussed as well as the mechanics of the no-clean materials involved. A general methodology for implementation was generated along with a research implementation methodology. Following the research implementation methodology, materials were qualified against industry standards for acceptability. Matrix experiment methods were utilized to model the manufacturing equipment at an actual small contract assembly house in Massachusetts. Results led to the statistical examination of their equipment and yielded the important factors involved with each piece of equipment. Optimization techniques were utilized to recommend the best settings for the manufacturing equipment, and the settings found were tested on a real world product of the contract assembler. The results obtained were excellent and the customer has subsequently changed the requirements of that particular product to be assembled exclusively using no-clean solder pastes. An economic analysis was also completed to determine the cost savings that would be realized if conversion was completed at the contract assembly house.

## **ACKNOWLEDGMENTS**

There are many individuals who had input in to this project without whom would have made it difficult or impossible to complete.

Extra special thanks to my brother Thomas for his technical and personal guidance throughout this project. Many aspects of this project would never have worked if it wasn't for your constant help and guidance.

Special thanks to Professor Sammy Shina for being my faculty advisor during this study. Your technical guidance was invaluable for completing this project.

Special thanks also to Monica Becker and the Toxic Use Reduction Institute for sponsoring this project. This project would never have been possible without your financial assistance and understanding. I have a new appreciation for the environmental issues which industry faces thanks to your guidance.

Thanks to Tristar Technologies Incorporated for the opportunity to use your equipment, perform the study in your facility, and the donation of test circuit boards. Your engineering support; Bob Laurenti and Lisa Labbe, were invaluable to completing the experiments. Lisa- Thanks for the materials.

Thanks also to the many other industry engineers, and suppliers whose donations of materials and technical advise made this study possible.

Thanks to Les Hymes, for your wonderful seminar and donation of IPC stadnards.

Thanks to Tim O'neal of ESP solders for your "value added" services and technical advise.

Thanks to Greg Tashjian of AT&T (Now Lucent Technology) for taking the time to steer the project in the right direction.

Thanks to Robby Zylich of Bull Information Systems for the use of your software

Thanks to Dr. Brett E. Hardie for your technical expertise.

Thanks to Les Hymes for the generous donation of IPC acceptability standards.

And finally, thanks to Doug Peck of AEIC for your technical support and breakfast at Bickfords.

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## List of Abbreviations

- ANOVA: **AN**alysis **Of** **VAR**iance; A statistical approach to analyzing the variability and percent contributions of factors in a matrix experiment.
- CFC: **Chloro-Fluoro-Carbon**; CFCs are compounds consisting of chlorine, fluorine, and carbon, which are very stable in the atmosphere near ground level because they do not readily break down under the action of the sun. They were utilized in chemical solvents commonly up until the early 1990's due to their excellent stability and cleaning properties. These compounds eventually ascend up to the stratospheric ozone layer and react detrimentally with the protective ozone compound and cause ozone depletion. It has subsequently been banned from production in many countries including the United States.
- DOE: **Design Of Experiments**; A set of experiments in which the settings of various process parameters are changed and the corresponding results obtained are analyzed statistically. The systematic approach inherently allows for parameter contribution analysis, interaction analysis, and process optimization.
- FP-SMT: **Fine Pitch Surface Mount Technology**; The usage of surface mounted electronic components which have a lead pitch spacing center to center below 50 mils and greater than 20 mils.
- HCFC: **Hydro-Chloro-Fluoro-Carbon**; HCFCs are compounds that are composed of chlorine, fluorine, carbon, and hydrogen. They are generally less stable than CFC based compounds, and the majority of them break down before they can ascend up to the stratospheric ozone layer. HCFCs typically have an ozone depletion potential of between 2% to 10% of CFCs.
- IPC: **The Institute for Packaging and interConnection**; The IPC is the group responsible for generating the most widely adopted acceptability standards for the electronics industry.
- ODC: **Ozone Depleting Compound**; Any chlorine and carbon containing compound such as CFC, HCFC, or others that has the potential to ascend to the stratospheric ozone layer and react adversely with the ozone compound and cause ozone depletion.
- ODP: **Ozone Depletion Potential**; ODP is the relative value of a substance's potential to deplete stratospheric ozone. It is compared to the reference gas trichlorofluoromethane (CFC11), which has an ODP of one (1).

## List of Abbreviations Continued

- PCB: **Printed Circuit Board**; A rigid substrate on which components are placed or inserted that has electrical traces on or within the substrate to allow for electrical connection between components.
- RMA: **Rosin Mildly Activated**; A common flux used for electronics assembly which uses colophony (rosin), a distillate of pine trees, as the major solids portion ingredient. Its inherent benign residue properties are what has led to research in to no-clean fluxes.
- SMT: **Surface Mount Technology**; An assembly technology in which components are placed on to electrically conductive areas on the surface of the printed circuit board instead of through plated through holes in the substrate. SMT is used primarily for its advantages over through hole technology for increased automation facilitation and increased circuit densities possible.
- UFP-SMT: **Ultra Fine Pitch Surface Mount Technology**; The usage of surface mounted electronic components which have a lead pitch spacing center to center of 20 mils or below.
- VOC: **Volatile Organic Compound**; VOCs contain one or more carbon atoms, and they may also contain chlorine, oxygen, and nitrogen atoms. They exist as gases or volatile liquids and are not as stable as CFCs, allowing them to break down at lower levels in the atmosphere than CFCs. Many common compounds such as isopropyl alcohol are considered VOCs.
- WS, OA: **Water Soluble, Organically Acid**; A classification of fluxes which utilize organic acids as activators and are generally water soluble or soluble with water and a saponifier added.



## **CHAPTER 1: INTRODUCTION**

### **1.1 BACKGROUND**

The electronics industry has changed and grown significantly in the past few decades. Along with great technological advancements however, growing environmental concerns over the cleaning of electronics have become an increasingly troublesome issue. Cleaning electronic assemblies is typically accomplished to ensure removal of performance detrimental contaminants such as printed circuit board fabrication and assembly soldering residues. Historically, electronics manufacturers have utilized ozone depleting chlorinated solvents for cleaning after assembly operations. As the usage of these chlorinated solvents continued over the years, the harmful effects on the environment of these chemicals have become apparent. Recently, many federal and international regulations, such as the Montreal Protocol, have emerged to restrict or eliminate the use of such chemicals.

A large part of the Massachusetts industry is centered around electronics manufacturing, and these environmental concerns affect them greatly. Many of the larger companies have already changed to more environmentally friendly manufacturing techniques. However, the changeover for some of the smaller companies to more environmentally friendly manufacturing techniques has shown to be very difficult. Many of these companies lack the engineering resources, economic means, and the time to transition to a new process without loss of quality, throughput, and cost.

One solution towards eliminating chlorinated solvent usage has been to adopt a no-clean soldering process. Here the idea is to use soldering materials which leave behind residues that do not compromise the end reliability of the assembly, and to leave them on the assembled printed circuit board. Thus, the cleaning step is completely eliminated, along with the environmentally damaging cleaning solvents and other related waste effluents. No-clean is the best long term approach to the problem and has other inherent advantages such as eliminating the capital investment of cleaning equipment as well as all its associated operating costs. Unfortunately, there are many concerns and

challenges to implementing a no-clean process because of tighter process control requirements, end use reliability concerns, and material uncertainties.

A great deal of information is available concerning no-clean, although it is difficult to understand how the material and implementation issues relate to each particular manufacturing setting. A consolidation of information about no-clean and a technique for implementation at a small electronic contract manufacturing company would be a valuable tool for other Massachusetts companies interested in switching to a no-clean process. The subject of this study is the qualification, evaluation, and implementation methods used to successfully implement a no-clean surface mount process at a local, low volume, high mix contract manufacturing company.

## **1.2 BACKGROUND ON SOLDERING**

Soldering is one of the oldest methods of joining metals. Soldering utilizes a filler metal to join two or more base metals which have a melting point above the filler metal. During soldering, a chemical called a flux, is applied to the base and filler metals which removes oxidation from them at elevated temperatures. This cleaning (fluxing) action is a required property for soldering. Once the solderable surfaces have been cleaned through this fluxing action, the melted solder alloy can then bond to the base metals resulting in an intermetallic bond. This intermetallic bond is a thin layer in which the solder alloy and the basis metals alloy to themselves and form an adhesive bond. In electronics, the solder alloy is utilized for its property of having both good electrical conductivity and good mechanical bonding strength to hold electronic components in place.

## **1.3 BACKGROUND ON SURFACE MOUNT TECHNOLOGY**

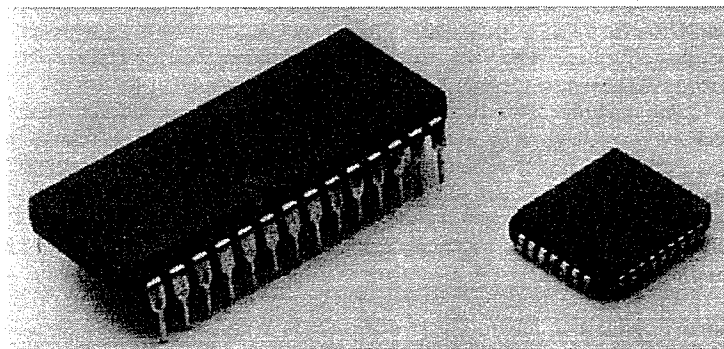
As the name implies, surface mount technology (SMT) is an assembly technology in which electronic components are placed on to electrically conductive areas on the surface of the printed circuit board instead of through plated through holes in the substrate (through hole technology). This concept has been utilized in hybrid assembly since the 1960's by interconnecting chip resistors, chip capacitors, and bare

semiconductor dies on hybrid substrates. However, the potential of surface mount technology was not fully utilized and explored until the early 1980's. It has shown to be one of the most significant developments in the electronics era.<sup>1</sup>

Surface mount technology has many inherent advantages over through hole technology. Some of the merits of an electronic assembly utilizing surface mount technology as compared with an equivalent through hole assembly include:

- Reduced weight,
- Reduced size,
- Increased circuit density,
- Improved automation facilitation,
- Improved electrical performance,
- Lower costs in volume production<sup>2</sup>

In an SMT assembly, the majority of component interconnection traces on the PCB are routed on intermediate layers of the circuit board which allow much greater real estate efficiency and permit usage of both sides of the board for component population. Factors such as shorter leads, and lead sizes required allow for component miniaturization to a degree which is simply not possible with through hole components. An example of this can be seen in Figure 1, which compares a through hole integrated circuit to its SMT equivalent. Note the size difference between the two packages.



**FIGURE 1: Comparison Between Equivalent SMT and Through Hole Integrated Circuits<sup>3</sup>**

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<sup>1</sup> Hwang, Jennie. Solder Paste in Electronics Packaging. Van Nostrand Reinhold, New York, 1992. Page 9.

<sup>2</sup> Hwang, Page 9.

<sup>3</sup> Prasad, Ray P. Surface Mount Technology. Van Nostrand Reinhold, New York, 1989. Page 6.

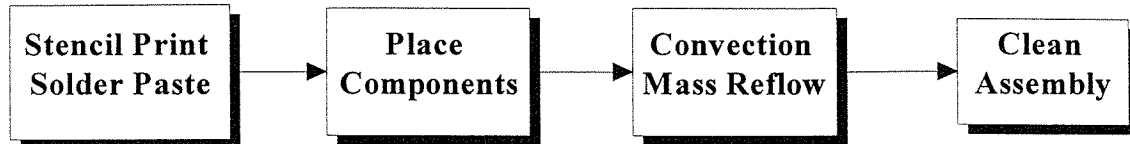
While through hole technology will continue to maintain usage within a large segment of the industry for various reasons, this brief presentation illustrates the simple point that SMT is where the market continues to move and where study should be focused. Even more specifically, fine pitch (FP-SMT) and ultra-fine pitch surface mount technology (UFP-SMT) is where study should be focused. FP-SMT is defined as the usage of lead pitch spacing in electronic components that is below 50 mils but above 20 mils, while UFP-SMT is defined as the usage of lead pitch spacing in electronic components that is below 20 mils. Presently, FP-SMT and UFP-SMT represents the widest used technological solution to the ubiquitous problem of miniaturization versus the pervasive push for increased input/output connections for integrated circuit packages.

#### **1.4 SURFACE MOUNT TECHNOLOGY ASSEMBLY PROCESS**

At its most basic level, the typical surface mount assembly process follows a series of fundamental discreet steps. Controlled volumes of solder in a paste form are placed on to electrically conductive land areas of the circuit board. Components are then placed on to the deposited solder paste which has sufficient tackiness to "hold" them in place. The entire assembly is then subjected to a thermal cycle which is called reflow. During the reflow process, the solder paste melts and coalesces to "wet" both the component leads and the printed circuit land areas and ultimately form the mechanical and electrical solder joint between the two. Traditionally, the final step has been to remove soldering residues from fluxes that are left behind after reflow by cleaning the assembly. Inspection, touch up, electrical test, or other operations may follow, but are not generally considered part of the SMT assembly process.

The process flow previously described is purposely generic. It does not specify how the paste is applied, through which process the components are placed, which technique for reflow is used, or how the assembly is cleaned. As SMT has evolved, many methods have been developed to suit the many diverse assembly types and manufacturing settings which exist. While there are many different techniques available for each step of

assembly, the one which will be studied here conforms to the event flow shown in Figure 2. This process flow is the most commonly used for SMT assembly in the industry.



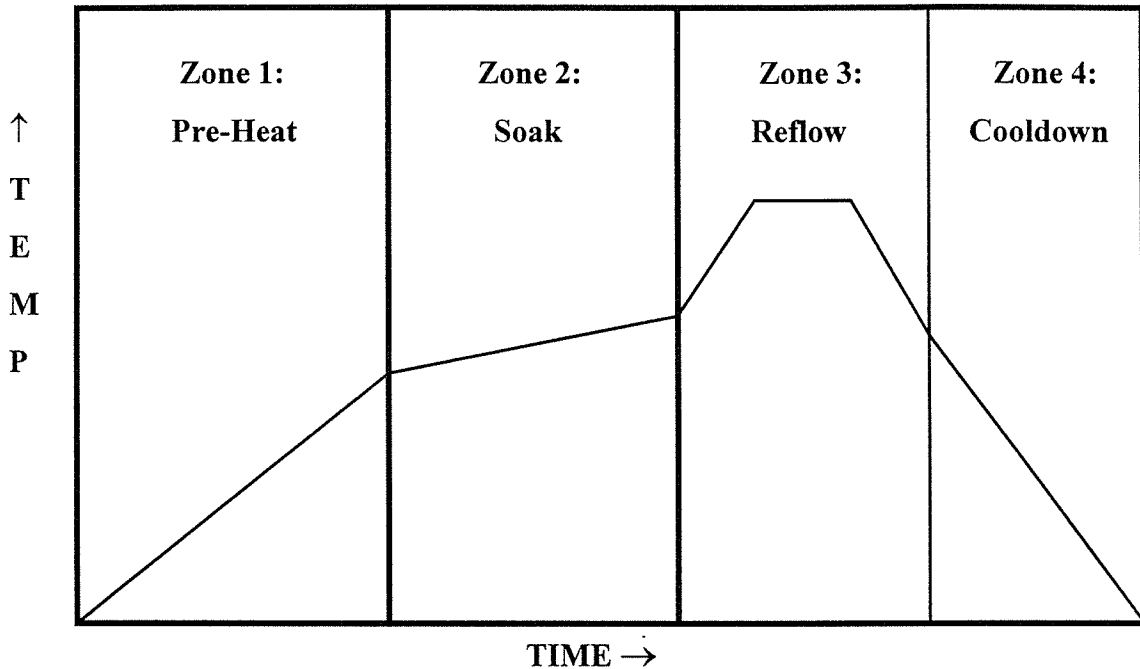
**FIGURE 2: Typical SMT Process Flow**

During the stencil printing process, a metal stencil which has openings called apertures is placed over the circuit board. The apertures on the stencil are aligned corresponding to areas on the circuit board where solder paste is to be deposited. The solder paste is then forced through the apertures by a squeegee as it wipes across the stencil. Finally, the stencil is removed to leave the deposited paste "bricks" on the circuit board. This method of deposition works very well once the printer is set correctly and proper process control guidelines are followed. Since printing is the foundation for all stages to follow, obtaining a satisfactory print is essential.

The next process step is component placement on to the solder bricks that were previously deposited. The paste has the property of being tacky, which holds the components in place once situated. Components can be placed either manually, semi-manually, or by a machine. Generally automation is accepted as the preferable alternative for reasons of repeatability, accuracy, and speed. Many types of machinery have been developed to quickly and accurately pick a component from feeders, orient it, and place it precisely on to the paste. Obviously, budget, product mix, volumes, setup times, handling difficulty, and other factors influence the utility of a pick and place machine.

The next step in the process is convection mass reflow. Convection heat transfer has become the most widely accepted method for reflowing solder paste. Other methods for reflow include infrared, laser, and vapor phase reflow. A typical convection oven has multiple upper and lower zones which emit heat at set temperatures. The assembly to be reflowed is placed on a moving belt or rail which moves it through the oven at a constant

speed. As the assembly passes through each zone, it is subjected to a specific thermal profile which serves many purposes for soldering. A generic convection reflow profile can be seen in Figure 3.



**FIGURE 3: Typical Convection Reflow Profile**

In the first zone, called the preheat zone, the temperature of the assembly is slowly ramped upwards in order to not thermally shock the board or components which could lead to unwanted stress and mechanical failure. The next zone is called the soak zone, which serves the function of evaporating solvents from the solder paste and allowing the flux in the paste to remove oxidation from the surfaces to be soldered. As the name implies, during the soak zone, the temperature change is kept fairly constant. After soak, the next zone is reflow. During reflow, the temperature is raised above the melting point of the solder alloy for a set period of time while the solder becomes liquidous and flows to generate the solder joint. The final zone is cool down, in which the temperature of the assembly is lowered back to room temperature at a relatively slow rate as to not thermally shock the board and components while cooling.

To properly solder, every paste manufactured is designed to have a set reflow profile which it should be subjected to. Oven zone temperatures must be programmed and changed for boards with large differences in component densities. Larger or increased component quantities on an assembly absorb more heat and thus increase the amount of heat that is needed for the assembly to realize the same thermal profile as it would with smaller or less components.

Traditionally, cleaning has been the final step in the assembly process. The cleaning of electronic assemblies has been necessary in the past to remove potentially harmful contaminants from the product. A detailed discussion of cleaning electronic assemblies is covered in Chapter 2.

## **CHAPTER 2: CLEANING ELECTRONIC ASSEMBLIES**

### **2.1 REASONS FOR CLEANING ELECTRONIC ASSEMBLIES**

Cleaning electronic assemblies has been necessary for a variety of reasons. The principle motive for cleaning is to remove potentially hazardous contaminants from the assembly which could adversely affect the reliability of the product. Depending on the type of contamination present, electrical degradation, corrosion, or mechanical damage/interference may occur over the life span of the device. The simplest approach to significantly reducing failure caused by these sources has simply been to tolerate a cleaning operation.

### **2.2 SOURCES OF CONTAMINANTS**

The sources of contaminants found on printed wiring assemblies can come from many sources and can be broken down in to many categories. Chemically, these categories can be classified as particulate, ionic, nonionic, polar, nonpolar, organic or inorganic.<sup>4</sup> Table 1 shows the classification of the chief types of contaminates found on both bare printed circuit boards (PCB's) and final assemblies.

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<sup>4</sup> Hymes, Les. Cleaning Printed Wiring Assemblies in Today's Environment. New York, 1991. Page 78.



**TABLE 1: Classification of Chief Contaminants on Electronic Assemblies<sup>5</sup>**

<b>Particulate</b>	<b>Polar, Ionic, or Inorganic</b>	<b>Nonpolar, Nonionic, or Organic</b>
Resin and fiberglass debris from board fabrication	Flux activators	Flux resin / rosin
Metal/plastic chips from machining operations	Activator residues	Grease
Dust	Soldering salts	Surfactants (non-ionic)
Handling soils	Handling soils	Synthetic polymers
Lint	Residual plating salts	Soldering oils
Hair/skin	Surfactants (ionic)	Metal oxides
	Neutralisers	Handling soils
	Ethanolamines	Hand creams
		Silicones

Ionic species are those that in solution form charged species and thus conduct electricity. A polar molecule is by definition one having a dipole moment. This means that there exists an uneven distribution of electrons in the molecule which produces a dipole molecule.<sup>6</sup>

Depending on the end use of the electronics assembly, every contaminate has the potential to be detrimental to product reliability. Contaminants can be damaging mechanically, electrically, and chemically. Obviously, the higher up on the quality spectrum a product lies, such as a military or medical product, the more imperative the quality and reliability becomes.

### **2.3 ENVIRONMENTAL IMPACTS FROM CLEANING ELECTRONICS**

Traditionally, electronic assemblies have been cleaned with solvents that contain ozone depleting compounds (ODCs). ODCs are compounds which contain chlorine and carbon, which are very stable in the environment near ground level because they do not

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<sup>5</sup> Hymes, Page 79.

<sup>6</sup> Hymes, Page 79.

readily break down under the action of the sun. It was common place to see the usage of chemicals such as CFC-113, and 1,1,1 Trichloroethane in electronic assembly houses for many years during the 1980's and early 1990's. They were used on a widespread basis due to favorable inherent properties such as excellent stability, material compatibility, relatively low toxicity, non-flammability, and most importantly superb cleaning ability. As these solvents would evaporate, they would eventually ascend to the ozone layer in the upper stratosphere because they were so stable near ground level they would not break down beforehand. Once these ODCs would reach the stratospheric ozone layer, they would react detrimentally with the ozone molecule and cause ozone depletion. Chlorofluorocarbons (CFCs), and hydrochlorofluorocarbons (HCFCs) were the major classifications of ODCs which were utilized in solvents. Depending upon the chemical makeup of the solvent, each ODC had a varying degree of detrimental effect upon the ozone molecule. This varying detrimental effect is usually expressed in terms of a solvents ozone depletion potential (ODP), as compared to the reference gas trichlorofluoromethane (CFC11), which has an ODP of one. CFCs are generally considered to have the highest ODP numbers, while HCFCs have ODPs of typically 2% to 10% of CFCs.<sup>7</sup>

As the usage of these ODCs has continued over the years, the harmful effects on the ozone layer in the upper stratosphere have become very apparent. As the ozone layer is slowly depleted, it allows more ultraviolet radiation from the sun to penetrate through the atmosphere and ultimately cause global warming.<sup>8</sup>

Recent years have seen the introduction and adoption of many federal and international mandates such as the Montreal Protocol, London Amendment, and the George Bush Proclamation emerge to pose restrictions and elimination deadlines for the usage of CFC based solvents. Many countries agreed to abide by the mandates and the end of 1995 saw the elimination of production of CFC based solvents by many countries including the United States. Less harmful solvents, such as HCFC based solvents have also been blacklisted for elimination but have a slightly longer timetable for elimination.

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<sup>7</sup> 1996 Contact East Supply Catalog, Page 178.

<sup>8</sup> Lea, Colin. After CFCs. Electrochemical Publications, British Isles, 1992. Page 3.

## **2.4 CURRENT CLEANING OPTIONS AVAILABLE**

Currently, since it is very difficult or impossible to obtain CFC-based solvents, electronics assembly houses have been forced to adopt alternative cleaning methods. Presently there exists five choices for manufacturers. Table 2 summarizes the options available.

**TABLE 2: Current Electronics Cleaning Alternatives**

<b>Alternative</b>	<b>Description</b>	<b>Advantages</b>	<b>Disadvantages</b>
Aqueous	Pure water cleans assembly	Relatively inexpensive, least exposure hazards, good cleaning ability	Limited flux options, reduced cleaning ability, waste effluent
Aqueous w/sapponifier	Pure water with sapponifier cleaning aid added	Wide range of fluxes cleanable, good cleaning ability	Waste effluent
Semi-aqueous	Pure water and alcohol mixture	Wide range of fluxes cleanable, good cleaning ability	Some exposure (VOCs) hazards, waste effluents
Solvents with reduced ODP	HCFCs, or other chlorine based solvents	Excellent cleaning ability	Availability, cost, waste effluent, ODP
No-clean	Benign soldering residues left after soldering	No waste effluent or associated costs, increased throughput	Tighter process and material requirements

The choice of an alternative is subject to many factors such as the type of assembly, cleanliness required, soldering materials used, budget, and many other factors.

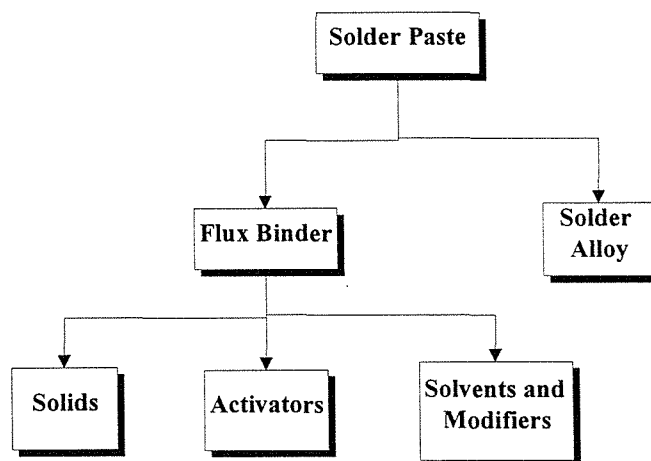
All the options listed except for no-clean still have negative environmental effects however. If cleaning is performed, waste effluent is generated either continuously or through periodic purging of cleaner filtration systems. Others factors make cleaning options less desirable also, such as cleaning system maintenance requirements, capital investment, electricity usage and floor space expenses. A no-clean process in which the electronics assemblies would not have to be cleaned at all would prove to be the best long term solution.

## **CHAPTER 3: SOLDER PASTE MECHANICS**

### **3.1 SOLDER PASTE BACKGROUND**

In SMT, since soldering is used for both the mechanical and electrical connection, it is imperative that an understanding of the mechanics of solder paste develop. Solder paste is a thixotropic mixture which has a consistency similar to peanut butter. Its thixotropic nature allows it to thin while under the pressure of shear from the squeegee during the printing operation and be deposited through the stencil apertures. Once shearing force is removed however, it immediately thickens and retains its shape. In this thickened state the paste can then release from the stencil as it is raised away from the stenciled circuit board.

A typical solder paste for printing consists of between 88 and 92 percent metal by weight, or approximately 50% by volume. The solder metal is in the form of small, round particles of the solder alloy suspended in a flux binding matrix. This combination gives the paste the proper viscosity and rheological properties to allow it to be printed. As such, a solder paste is a highly sophisticated formulation and offers a wide range of possible formulations.<sup>9</sup> Figure 4 shows a pictorial representation of the major constituents of solder paste.



**FIGURE 4: Solder Paste Constituents**

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<sup>9</sup> Hutchins, Charles L. Understanding and Using Surface Mount and Fine Pitch Technology. North Carolina, 1995. Page 5.

### 3.2 SOLDER ALLOY

The solder material requirements for most electronic assemblies are met with an alloy of tin and lead. Typically a ratio of 63% tin and 37% lead is used although different ratios or materials such as gold, silver, indium, or others are sometimes substituted to provide variations in solder properties. The 63/37 alloy is a eutectic alloy, indicating that it changes directly from solid to liquid at 183 degrees Celsius, and does not have a plastic state. This common solder alloy was the type used for this study. Figure 5 shows the tin, lead phase diagram which illustrates the different melting temperatures of various weight combination ratios for the tin and lead.

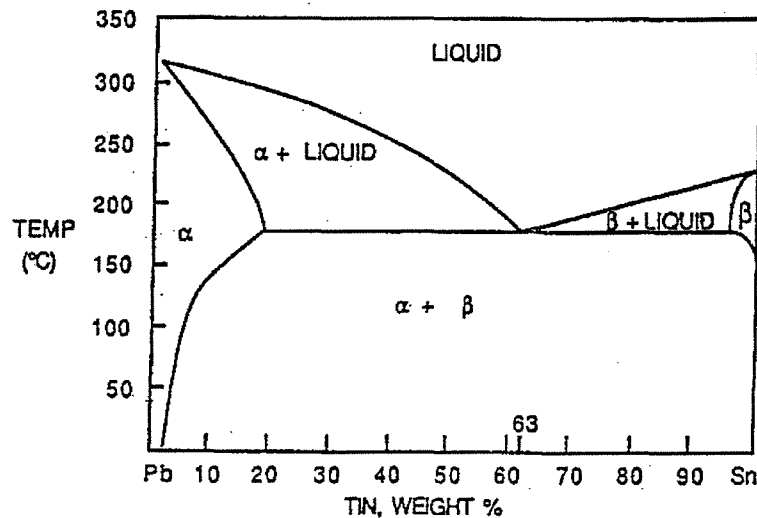


FIGURE 5: Tin Lead Phase Diagram<sup>10</sup>

There are six separate phases depending upon the temperature and the ratio. There are two crystalline forms of tin-lead commonly referred to as alpha and beta. These crystals exist singularly at the temperatures and ratios shown in the phase diagram.<sup>11</sup>

<sup>10</sup> Hutchins, Page 73.

<sup>11</sup> Hutchins, Page 74.

### **3.2.1 SOLDER ALLOY PARTICLE SIZE**

Solder alloy particle sizes have variation within a paste. Particle size of a solder paste is generally specified in terms of the size of a mesh that it will pass through. A paste with a mesh of -200 to +325 (diameter range of 45 to 75 microns) means that it would pass through a 200 mesh screen but not through a 325 mesh screen.<sup>12</sup> Generally, a paste of -325 to +500 (Type 3) is used for stencil printing because it has empirically shown to give the best compromise of results between standard pitch, fine pitch, and ultra-fine pitch spacing. Type 3 solder pastes were the particle size used for this study.

### **3.3 FLUX BINDER**

The flux binder is the most sophisticated ingredient present in a solder paste. It is essential that the flux binder system be understood since issues with the resulting residues are one of the largest reasons for cleaning or not cleaning a soldered assembly.

The flux binder system serves many essential roles in soldering without which solder paste and surface mount technology would not be possible. It must suspend the solder particles to give the paste its necessary rheological properties for printing. It must also provide adequate ability for the paste to hold components once placed. Most importantly, it must provide adequate fluxing action to remove the oxides on the solder particles and base metals for soldering to occur. The major constituents of a typical flux binder are the solids portion, solvents and rheological modifiers, and flux activator(s). Detailed descriptions of the materials and issues involved with each of these components for no-clean fluxes are discussed in Chapter 4.

#### **3.3.1 FLUX BINDER SOLIDS PORTION**

As the name implies, the solids portion of the flux consists of non-volatile material which remains on and around the solder joint after soldering procedures. The solids portion provides many necessary functions in the flux binder matrix. The first function which the flux solids performs is that it thickens the remainder of the flux

materials for maintaining rheological properties. The viscosity and make up of the binder must be adequate to suspend the solder particles in order for the paste mixture to be homogeneous. The solids portion melts at elevated temperatures below the solder alloy melting point and coats the surfaces to be soldered, protecting them against re-oxidation once it has been removed. When melted, the solder alloy “pushes” the flux solids to the periphery of the solder joint. Once cooled, the flux solids re-solidify and remain around the periphery of the solder joint.

### **3.3.2 FLUX BINDER SOLVENTS AND MODIFIERS PORTION**

The solvents and modifiers in a solder paste serve the function of dissolving the solids portion of the flux binder and combine to give it the proper viscosity and rheological properties required. During the soak zone period of reflow, the solvents and modifiers evaporate leaving behind the alloy, flux solids, and activator(s).

Depending on the formulation of the paste used, the solids portion of the flux binder may contain some inherent ability to remove oxides from the solder particles and base metals at elevated temperatures. Generally however, this fluxing action is not sufficient to remove the oxides on most solderable surfaces. To solve this problem, activator(s) are added to the flux binder system whose sole purpose is to remove oxidation from the surfaces.

### **3.3.3 FLUX BINDER ACTIVATORS PORTION**

The role of the activators that are added to fluxes has been previously stated. Essentially, they are materials which are added to the flux to provide the majority of its ability to remove the oxides from the solderable surfaces at elevated temperatures. The materials that are added as activators vary considerably depending on the type of flux being utilized. Generally, the activators present in a solder paste are ionic and consist of acids and/or salts, which remove the oxidation through standard chemistry oxidation reduction reactions. Being ionic, they dissolve readily in moisture, which affects the

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<sup>12</sup> Hutchins, Page 76.

surface resistivity of the assembly and leads to the potential to cause major corrosion and electrical leakage problems if not cleaned from the assembly.<sup>13</sup>

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<sup>13</sup> Lea, Page 106.



## **CHAPTER 4: NO-CLEAN SOLDERING**

### **4.1 NO-CLEAN BACKGROUND**

The principle of not cleaning electronics assemblies after soldering is not new. For many years huge quantities of inexpensive, low performance or short lifetime consumer electronics goods have been produced without cleaning. For higher reliability electronic assemblies, the expense and procedural problems of cleaning have been tolerated because at worst the effects may be catastrophic.<sup>14</sup>

A no-clean flux is simply a flux which can be left on the assembly without detrimental effects to the end use of the product. Rosin, a flux solid, has been used for decades in fluxes and has been left on many electronic assemblies over the years. It has even been shown that rosin provides many inherent properties which show little potential for corrosion or electrical failure. This physical nature of rosin based flux residues has been the cause of research towards new generations of no-clean flux formulations. Rosin based fluxes tend to leave large quantities of residues behind, which can be frustrating to automatic electrical test procedures and obscuring to visual inspections. This has lead to significant research in to alternative chemistries to produce no-clean fluxes with little to no solids portion remaining after soldering, and the development of fluxes which are resin based instead of rosin based. Rosin is a distillate of naturally occurring pine sap whose source has its own chemical fingerprint and variability. Resin on the other hand, is a man-made substance which is more reproducible.<sup>15</sup> Generally speaking, no-clean fluxes have the following characteristics:

- Low solids content
- Low residue
- Non-tacky surface hardness
- Lower fluxing ability
- Low potential for corrosion or electrical degradation<sup>16</sup>

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<sup>14</sup> Lea, Page 295.

<sup>15</sup> Lea, Page 296.

<sup>16</sup> Lea, Page 297.

## **4.2 FLUX AND NO-CLEAN FLUX MATERIALS**

The activity level, the ability to remove oxides from the soldering materials and surfaces, varies depending on the type of flux. The most aggressive acid based fluxes are too corrosive and consequently are not used in the assembly of electronics. For many years during the height of CFC based cleaning, rosin mildly activated (RMA) fluxes were the workhorses of most assembly shops. They offered long tack times, excellent printability, and good fluxing action. Their relatively high quantity of residue levels were not an issue due to their almost effortless clean up with CFC based solvents. Organic acid water soluble fluxes (WS, OA) became and have remained popular since CFC reduction began. They maintain a relatively high activation level and could can be cleaned easily with plain water or water with a soaponifier added. However, water soluble fluxes exhibit significantly less work life than their RMA counterparts. All fluxes available for soldering fall under one of the classes shown in Table 3.

**TABLE 3: Classification of Soldering Fluxes By Main Ingredients<sup>17</sup>**

<b>Flux Type</b>	<b>Flux Base</b>	<b>Activation Methods</b>
Resin	Rosin (Natural)	No Acivator, Halogen Activated, Non-Halogen Activated
	Resin (Man Made)	No Acivator, Halogen Activated, Non-Halogen Activated
Organic	Water Soluble	No Acivator, Halogen Activated, Non-Halogen Activated
	Non-Water Soluble	No Acivator, Halogen Activated, Non-Halogen Activated
Inorganic	Salts	With or Without Ammonium Chloride
	Acids	Various Types
	Alkalis	Amines, Others

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<sup>17</sup> Hymes, Page 54.

No-clean fluxes are taking more of a foot hold in the industry now that companies are realizing their potential benefits. The solids percentage in no-clean fluxes are reduced in order to decrease the amount of residual material which has the potential for ionic reaction and thus potentially increase reliability. In addition, the activators are much less aggressive than the previously mentioned fluxes in order to reduce the possibility of ionic reaction. The chemical breakdown of these activators is proprietary and thus impossible to specify here. As manufacturers push the solids and activity levels of no-clean fluxes downward however, sometimes reflow in an inert atmosphere such as nitrogen must be performed to compensate for the reduced fluxing levels. The nitrogen helps to protect soldering surfaces from re-oxidation once removed which would previously be accomplished by a higher volume of flux solids in the paste.

No-clean pastes are generally categorized, depending upon the type and amount of flux solids, and the recommended reflow environment. Table 4 shows the generally accepted classifications for no-clean solder pastes.

**TABLE 4: Typical No-clean Specification Breakdown**

<b>Residue Classification (Typical)</b>	<b>Solids Percent</b>	<b>Solids Material</b>	<b>Reflow Atmosphere (Typical)</b>
Standard	$\geq 3.5\%$ OVERALL WEIGHT	Rosin	Air
Low	$3.5\% \geq \text{WEIGHT}$ $\geq 1\%$	Rosin/Resin	Air / Nitrogen
Ultra-low	$1\% \geq \text{WEIGHT}$	Resin	Nitrogen

#### **4.3 NO-CLEAN ADVANTAGES**

The elimination of a post solder cleaning step offers many potential advantages to those processes which do require cleaning. A list of benefits include:

- Elimination of environmentally damaging solvents, and other waste effluents

- Potentially, the complete elimination of all cleaning equipment and associated costs such as capital investment, maintenance, floor space, energy usage, etc.
- Compatibility with non-washable components that would otherwise have to be added post wash
- Generally, a longer processing window due to the less hygroscopic nature of no-clean fluxes
- Increased throughput resulting from elimination of time used for a cleaning operation
- Elimination of concern about hard to clean areas such as under lower profile components<sup>18</sup>

All these benefits are very desirable for electronics assembly manufacturers. However, as in any newer process there are concerns.

#### **4.4 NO-CLEAN CONCERNS**

Unfortunately, no-clean fluxes are not usually a direct drop in replacement for cleaned fluxes. As previously stated there are many concerns which plague its adaptability for a given process. Some of the concerns associated with no-clean fluxes include:

- Tighter manufacturing process control and incoming material solderability control procedures must be adopted because no-clean fluxes generally have lower fluxing activity than fluxes designed to be cleaned off a board
- Testing must be accomplished to ensure equal or better end reliability of the manufactured product against previous manufacturing processes
- Material compatibility's and their effect on reliability must be ascertained
- Aesthetic misconceptions resulting from the visibility of residues left behind must be overcome
- If probe or bed of nails type testing is to be done, the residue's effect on the ability and level of probes contamination must be determined
- If required, effects on the ability of post assembly coatings (conformal coatings) to adhere reliably to flux residues must be examined
- Strict process control on manufacturing handling must be implemented to ensure the elimination of handling related contamination
- Contaminants other than flux residues such as component residues, solder balls, and PCB fabrication residues must be controlled and monitored
- Customer acceptance and perception of quality must be addressed<sup>19</sup>

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<sup>18</sup> Hymes, Page 5.

<sup>19</sup> Hymes, Page 5.

While these are serious issues which must be addressed, if proper care and qualification is completed, these factors can be overcome, even in a difficult manufacturing setting.

## **CHAPTER 5: IMPLEMENTATION METHODOLOGY**

### **5.1 INTRODUCTION**

No-clean solder pastes would seem to be the ideal replacement for pastes that are cleaned. However, they are not simply direct drop in replacements for current processes. Proper evaluation, qualification, and education must occur before implementation should be attempted. The main areas of concern when implementing no-clean have been previously stated, although it should be noted that each point has a varying degree of importance depending on the specific product and manufacturing setting. For example, it would be easier for a manufacturer who has a dedicated automated assembly line to implement no-clean than a contract manufacturer with a smaller throughput and larger product mix. Issues such as handling contamination potential decrease with an increase in the level of automation. Process parameters can be adjusted less frequently for a dedicated production line; making process control simpler than on lines with constant product changeovers. These differences though, do not change the impetus for all manufacturing settings to change from environmentally deleterious cleaning methods to friendlier techniques.

Some of the larger companies in Massachusetts have already converted to a no-clean process. However many of the smaller contract manufacturing houses have had difficulty converting immediately to a no-clean process and have opted to go with a more forgiving non CFC based cleaning option such as water based cleaning. Many of these companies lack the time, money and engineering resources to properly investigate, qualify, and implement no-clean.

### **5.2 GENERAL IMPLEMENTATION STRATEGY**

All implementation methodologies will vary, just as no two electronic assembly companies are the same. Factors such as product type, product mix, volume, and budget will greatly impact the implementation scheme. There are some general milestones and rules that tend to stay the same however. Figure 6 shows a flow chart of what the

milestones for a general implementation plan may look like. This is obviously not the only way to approach the problem, and should be taken in such context.

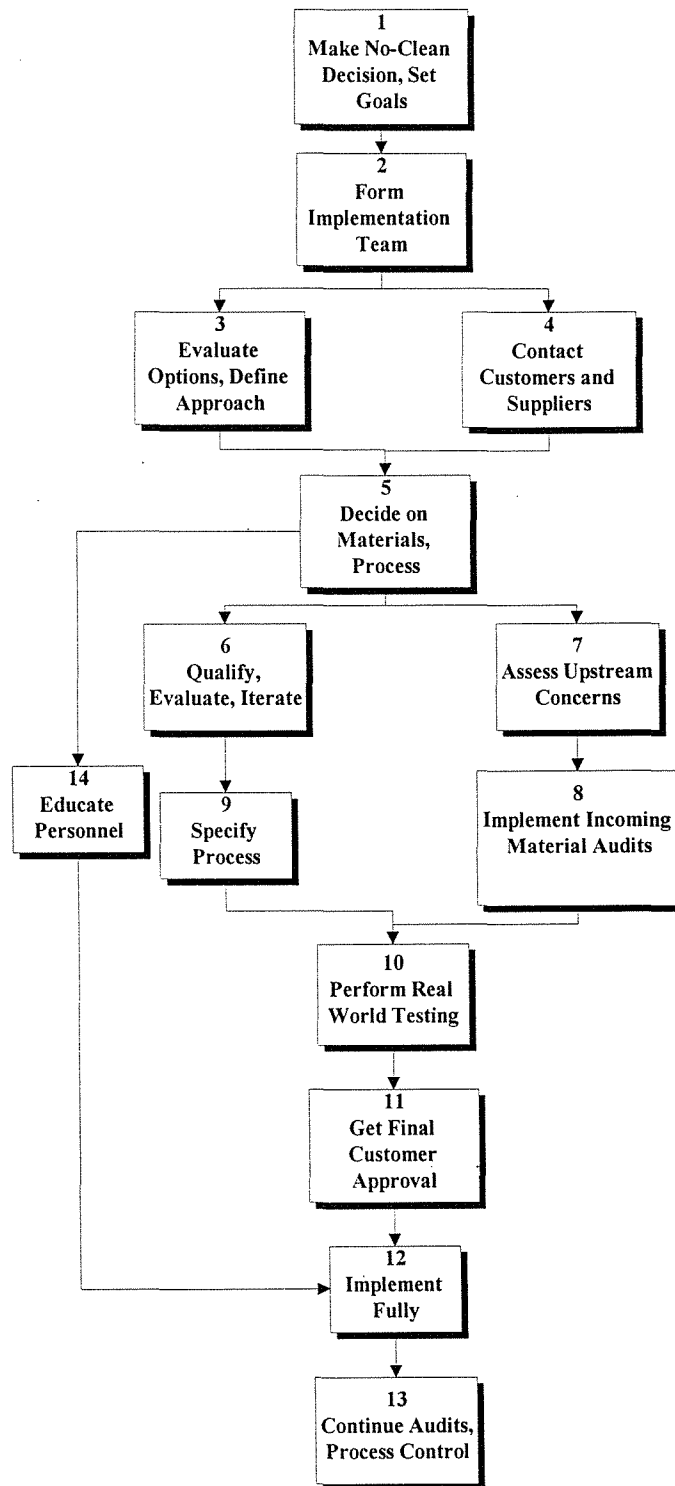


FIGURE 6: General Implementation Approach

1) ***MAKE NO-CLEAN DECISION, SET GOALS***

One of the most important steps in any no-clean implementation is the initial decision to achieve a no-clean process. It must be decided at this initial step how serious the effort will be and what the goals are. How imperative the change is will directly influence the effort given. The most important point of this step to remember is- “the success of implementation realized is directly related to the effort and time spent evaluating and qualifying”.<sup>20</sup>

2) ***FORM IMPLEMENTATION TEAM***

Forming a team to follow the process from start to finish is a very important point to obtaining successful results. The team should consist of members of every aspect of the business who have any input to the assembly process. This includes everyone from upper management, quality control, material acquisition, process control engineers, technicians, and assembly workers. If outside help is needed through consultants or other professionals, it should be sought. Involvement should come from all members.

3) ***EVALUATE OPTIONS, DEFINE APPROACH***

As this will vary with each specific situation, it is possibly the most important step of the entire implementation process. Research must be accomplished to understand all options available. A realistic approach needs to be derived, along with a timetable and cost benefit analysis. Which qualification measures that are relevant to the manufacturing setting must be defined at this stage.

4) ***CONTACT CUSTOMERS AND SUPPLIERS***

Customers and suppliers must be involved at an early stage of implementation. Customers must be contacted and not only be made aware of the intention to convert to no-clean, but be asked to provide any specific requirements they may have. Suppliers must also be informed as to what is acceptable and what is not. Because of the reduced

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<sup>20</sup> Interview with Dr. Brett E. Hardie, Hardie Consulting Co., Austin, Texas. 1/6/96



activity level of no-clean fluxes, incoming material solderability guidelines must be generated.

5) ***DECIDE ON MATERIALS, PROCESS***

Once the previous milestones are completed, the decision of which materials and process best suits the situation must be made. The results from the previous stages must be assessed, evaluated, and a final approach be derived.

6) ***QUALIFY, EVALUATE, ITERATE***

The validation of the materials and the process must be tested to ensure that they will be acceptable. Verifying the end product performance is one of the most important steps during implementation.

7), 8) ***ASSESS AND CONTROL INCOMING MATERIALS***

The extent, tests, and measures for controlling incoming materials for solderability and residual fabrication residues must be addressed at this stage. Verification that what is specified is indeed what is supplied is of the utmost importance for successful implementation and maintaining process controls.

9), 10) ***SPECIFY PROCESS, TEST ON PRODUCT***

Once evaluation is completed and a process is specified, it must be tested on an actual product. Good laboratory results do not necessarily correlate to good real world results.

11) ***FINAL CUSTOMER APPROVAL***

Once the materials and the process have been qualified and implemented successfully, results must be supplied to customers for final approval and acceptance.

12), 13)      ***IMPLEMENT FULLY, MAINTAIN PROCESS CONTROL***

These two steps go together intimately. Changes in process control, especially for incoming materials, must be closely monitored through audits and changed as required.

14)      ***EDUCATE PERSONNEL***

While this step is listed last in this list, it should never be considered last. Proper education of personnel as to specific no-clean issues such as handling changes and visible residues should occur in parallel throughout the implementation process.

### **5.3 RESEARCH IMPLEMENTATION METHODOLOGY**

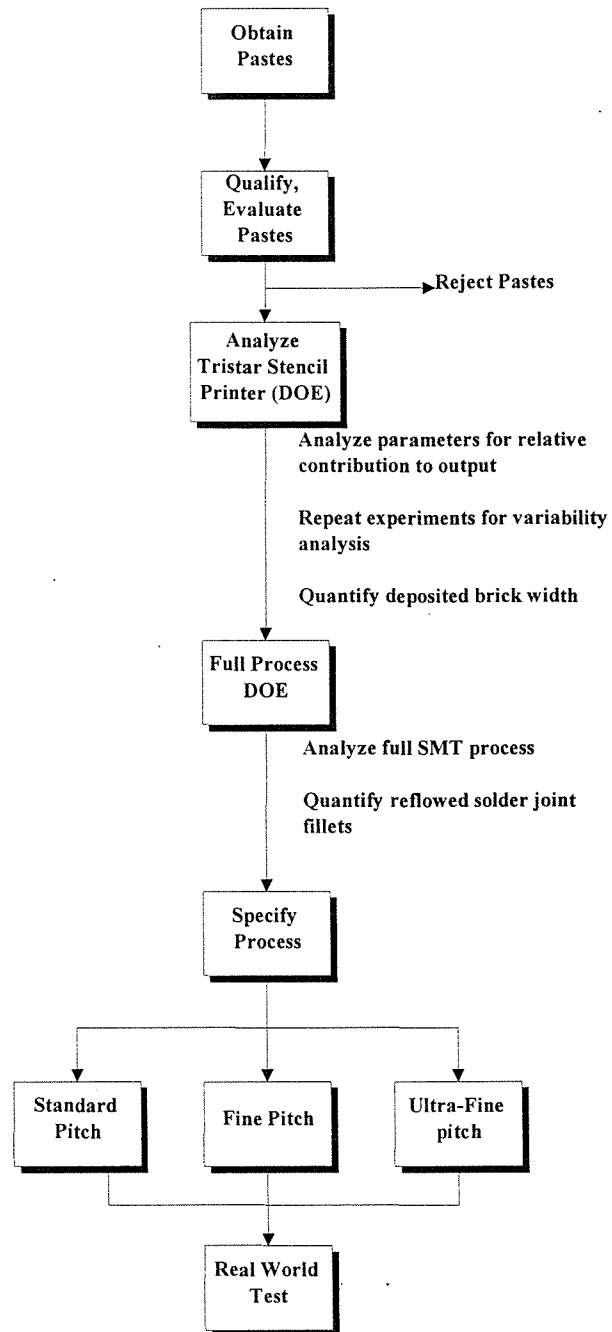
Tristar Technologies Incorporated was the electronic manufacturer chosen for implementation. Tristar is located in Methuen Massachusetts and provides a full range of services relating to printed circuit boards and electronics. They offer design, fabrication, and assembly services to customers. Tristar employs a work force of approximately 250 employees on three shifts in a 120,000 square foot facility. They became ISO 9002 certified in 1995 and had gross sales of 26 million dollars in fiscal year 1996. Some of their customers include Zenith Data Systems, Teradyne, Inframetrics, and Fostex Research.

Currently they utilize a closed loop 100% aqueous cleaning system for assembly in conjunction with an organic acid water soluble solder paste. While they have a desire to convert a percentage of their throughput to no-clean, they have not had the time, resources, or means to properly qualify and implement a no-clean process.

Many industry standards are available for the evaluation of no-clean solder pastes for surface mount technology. While these standards help to define acceptability for reliability issues, they do not offer much help in process implementation.

It was decided that multiple pastes from all major solder paste vendors would be obtained and qualified against criteria specifically relevant to Tristars assembly setting. The two most robust pastes which were found to provide the best relative results would then be allowed to pass to process implementation.

For implementation, the parameter settings for the SMT assembly equipment using no-clean pastes had to be found. To accomplish this, it was decided that design of experiments (DOE) methodology offered the best alternative for isolating and optimizing parameter settings for Tristars assembly line. Design of experiments (or matrix experiments) was chosen due to its statistical approach and could be completed for ultra-fine pitch, fine pitch, and standard pitch surface mount technology. After factors were analyzed, the final result would be process parameter specifications which would yield acceptable results for each case of standard, fine pitch, or ultra-fine pitch surface mount technology. A flow diagram of the implementation methodology can be seen in Figure 7.



**FIGURE 7: Research Implementation Methodology**

## **CHAPTER 6: MATERIAL QUALIFICATION AND EVALUATION**

### **RESULTS**

#### **6.1 INTRODUCTION**

Ten standard residue no-clean soldering pastes from nine different manufacturers were obtained. They were designated pastes A through J to retain anonymity. Standard residue level pastes were used due to Tristars air reflow environment within the reflow oven. While some of the properties, such as viscosity, varied slightly between pastes and manufacturers, all pastes were off the shelf formulations.

Many standardized tests exist for qualifying pastes. The Institute for Packaging and interConnection (IPC) has been responsible for generating the most widely adopted industry standards at this time. Some of these evaluation measures were not attempted for this study due to either lack of access to very expensive equipment or subjectively low relevance when compared to Tristars specific requirements.

Evaluation tests that were adopted were designed based on research, suggestions by experienced industry contacts, and Tristars specific requirements. It was decided that performing decided upon qualification measures on all pastes and placing the results in to a rating matrix for an overall relative performance rating offered the best method for selection. Only the two highest ranking pastes would be allowed to proceed beyond the initial qualification round. The Evaluation measures were broken down in to two categories: pre-reflow and post- reflow qualifications. Where applicable a four hour process window was assumed which is specific to Tristars manufacturing setting. This was agreed upon by Tristar engineering support as a realistic production window for the worst case lag between printing and reflow. Besides pastes, other materials which were obtained to be used in the this study included test circuit boards for both standard, fine pitch, and ultra-fine pitch SMT. A picture of each can be seen in Figures 8 and 9.

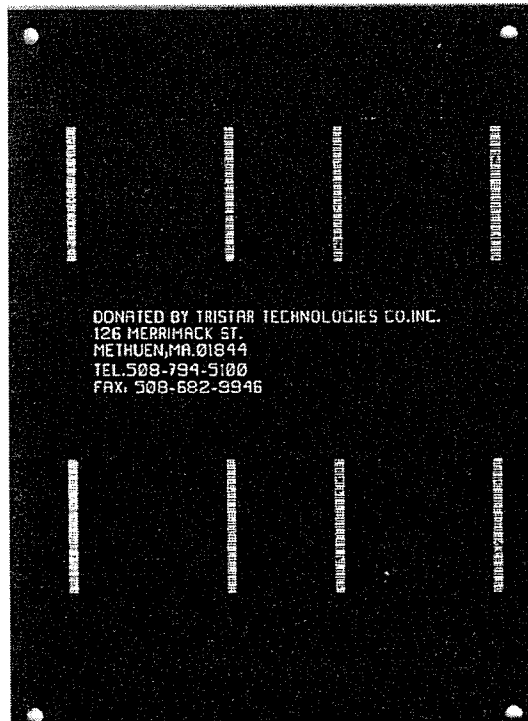


FIGURE 8: Tristar Donated Ultra-Fine Pitch SMT Test Board

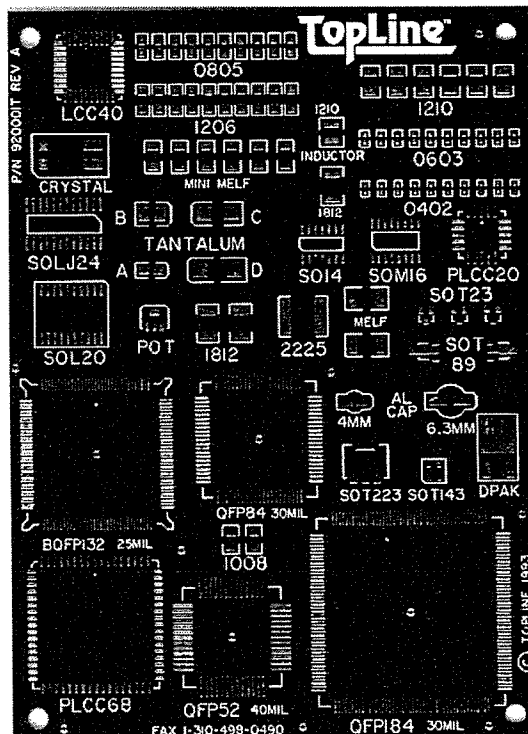


FIGURE 9: Topline Brand SMT Test Board

Dummy electronic components were also obtained to mate to the land areas of each of the test boards. For stenciling purposes, five and six mil thick framed electroformed stencils were obtained for the ultra-fine pitch case. Five and eight mil thick chemically etched framed stencils were obtained for the fine pitch and standard pitch cases.

## **6.2 PRE-REFLOW PASTE EVALUATION RESULTS**

### **6.2.1 APPEARANCE**

Appearance is considered to be subjective, but is the quickest initial way to distinguish differences between pastes. While appearance is not a necessary condition for acceptability, it offers a quick initial way to find distinctions in pastes.

All ten samples were opened and stirred to ensure homogeneity. The pastes were then inspected for consistency, air voids, smell, and any other noteworthy conditions. While this is a subjective test at best, it did offer the initial groundwork to note differences between pastes. The main differences between pastes that were observed were in the viscosity and odor. It was not surprising to find differences here due to the “off the shelf criteria” that was followed. Some pastes were noticeably thicker than others. Some pastes emitted an unpleasant odor but after consulting operators who would have to work with the pastes on a daily basis it was decided that the extent of even the worst odors were acceptable. It was decided that all pastes were acceptable and would receive a "Pass" for the rating matrix.

### **6.2.2 TACKINESS AND ADHESION**

One of the major requirements of a solder paste is its ability to hold the components placed on it through successive component placement operations without allowing components to move or fall off until permanent mechanical solder joints can be formed through the reflow process. The tackiness is one of the main requirements for performance in order to accommodate the lag between paste deposition on the board and reflow.<sup>21</sup> The amount of adhesiveness exhibited by the paste is a function of the rheological properties of any given paste and the exposure time to the ambient

environment. A fresh paste possesses a greater adhesive ability than a paste subjected to ambient conditions for a period of time. As the solvents in the paste volatilizes, the paste thickens and loses its adhesive ability.

The IPC standard test method for tack measurement is completed using a dedicated tack tester. Essentially, the tack force is measured by bringing a stainless steel probe in contact with the paste and slowly removing it at a given rate while registering the force required to remove it. The same procedure is repeated at various time intervals to take in to account the tackiness relative to the rate at which the solvents in the paste volatilize.

In the absence of a dedicated tack tester, an alternate method for measuring was established. This procedure was based on one proposed by J. Hwang in her book "Solder Paste in Electronics Packaging". The measuring technique entails printing a given pattern on to a blank flat substrate and placing a component on the printed pattern. Once intimate contact has been established between the two, the unit is inverted and the time until the component drops off is recorded. This procedure is repeated at various time intervals after the paste has been printed and subjected to ambient conditions to ascertain the differences in tack relative to the drying rate of the paste. While this is a qualitative measurement at best, it experimentally worked well to characterize performance. The procedure was repeated hourly for a four hour period after printing. This was based on the four hour process window which was assumed for Tristars assembly process.

The results obtained were averaged and a relative scale for rating was used between 5 and 1 where 5 was best and 1 was poor. A summary of the overall ratings for each paste tested can be seen in Table 5.

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<sup>21</sup> Hwang, Page 50.



**TABLE 5: Subjective Rating for Paste Tackiness Ability**

Paste	A	B	C	D	E	F	G	H	I	J
Rating	3	4	5	1	3	4	1	3	1	5

It is apparent that there exists a wide range of performance between pastes for tackiness ability.

### **6.2.3 SLUMP**

The slump of solder pastes is defined as the spread of deposited paste under its own weight from factors such as temperature and humidity. This is obviously an undesirable property which could lead to bridging of adjacent conductors on the circuit board which would require rework. The mechanical and chemical formulation of a paste determines its ability to resist slumping. No-clean pastes are less hygroscopic than water soluble pastes and generally show much greater humidity resistance.

The IPC test method for slump evaluation (IPC-TM-650.2.4.35) entails printing two different set patterns on to non-wettable substrates. The test specimen are then subjected to specific environmental conditions and evaluated for the extent of slumping which occurred. The IPC test method procedure may be viewed in Appendix B.

For this study, stencils with the specified IPC test apertures were not available so the 6 mil thick electroformed UFP (15.7 mil pitch) stencil was substituted. By using this combination (the lowest pitch and thickest print available), the worst case scenario for Tristars assembly area was taken in to consideration. Five samples of test boards were hand printed and subjected to the IPC specified conditions in the University of Massachusetts at Lowell Electronics Manufacturing Laboratory environmental chamber. The width of each printed pattern was monitored using a video microscope measurement system. Virtually no slumping occurred and it was determined that all pastes provided excellent slump resistance under these conditions, and would receive a "Pass" rating.

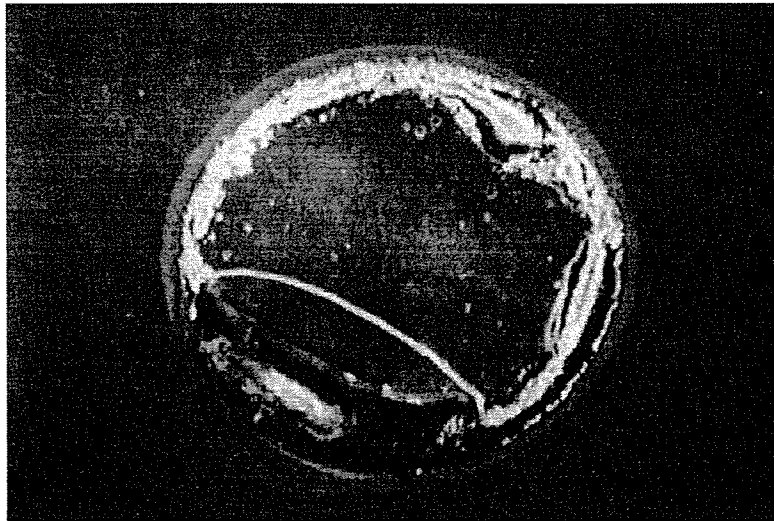
#### **6.2.4 DISPENSABILITY**

The dispensability of a paste through a syringe is an important property of solder pastes. Dispensing set amounts of paste on to areas of the board which may have been missed due to mistakes from stenciling or if a stencil is not available for use. There is no IPC standard for rating dispensability so a method had to be developed. After consulting with engineering support at Tristar it was determined that the following method would be performed. The method entails loading syringes with a given paste, and applying a set quantity of dots on to a substrate using a pneumatic dispensing station. The weights before and after dispensing were recorded. The same procedure was repeated after the syringes had been stored for a one week storage period in ambient conditions. The weights between the two runs were compared, which would be a pointer for separation in the paste along with dispensing ability. After a one week period there were no weight differences larger than 5% and it was concluded that all pastes performed adequately enough to receive a "Pass" for the final rating matrix.

### **6.3 POST REFLOW EVALUATION MEASURES**

#### **6.3.1 WETTABILITY OF FLUX (FLUX EFFICACY)**

The ability of each paste to properly wet and adhere to an oxidized copper surface is important to determine the efficacy of the activators in the flux portion of a paste and the overall solderability of the paste. According to IPC test method 650.2.4.45, three 8 mil thick by 0.25 inch diameter solder bricks are to be printed on to an oxidized copper coupon and reflowed. The IPC test method procedure may be viewed in Appendix B. The results are then compared at 10X for any signs of dewetting, or other undesirable effects. This test procedure was performed on equally oxidized copper coupons and it was determined that all pastes except for paste "A" exhibited acceptable solderability and wetting. Paste "A" showed severe signs of inability to overcome oxidation on the copper coupon. An example of the dewetting found by paste A can be seen in Figure 10.



**FIGURE 10: Paste "A" Dewetting Example**

All pastes except for paste A received a "Pass" for the final rating matrix.

### **6.3.2 SOLDER BALLING**

Solder balling is a phenomenon of solder pastes in which some of the tiny solder particles do not coalesce with the remainder of the solder during reflow and are left around the periphery of the solder joint. Normally, the solder balls are entrapped in the residue where they remain harmless. However, they have the potential to break loose and short out adjacent conductors which is obviously a very serious threat to reliability. This becomes a large issue when no-clean is concerned because previously cleaning would remove all of these solder balls, and residues.

Solder balling can potentially be caused by many factors. One of the main factors causing solder balling is highly oxidized solder particles which fluxing activity can not overcome, which essentially get "spit" out and do not reflow with the rest of the solder joint. Another common cause for solder balling is an incorrect reflow profile which evaporates the solvents in the flux binder too violently causing spattering of solder particles. Yet another factor which may cause solder balling is material incompatibilities between the printed circuit board surface, the solder alloy, and soldering residues.

According to IPC test method 650.2.4.43, a 0.25" diameter by 8 mil thick pattern is reflowed on a non-wettable surface such as alumina and examined for solder ball presence under 10X to 20X magnification. The same pattern is printed and allowed to be subjected to ambient conditions and reflowed hourly for the four hour process window. This is to examine the differences in solder balling relative to the paste solvents evaporating for actual processing requirements. The IPC test method procedure may be viewed in Appendix B.

The IPC test method was followed and the outcomes showed a wide variety of results. A graph of the quantities of solder balls present versus time can be seen in Figure 11, and the numerical results may be viewed in Appendix A.

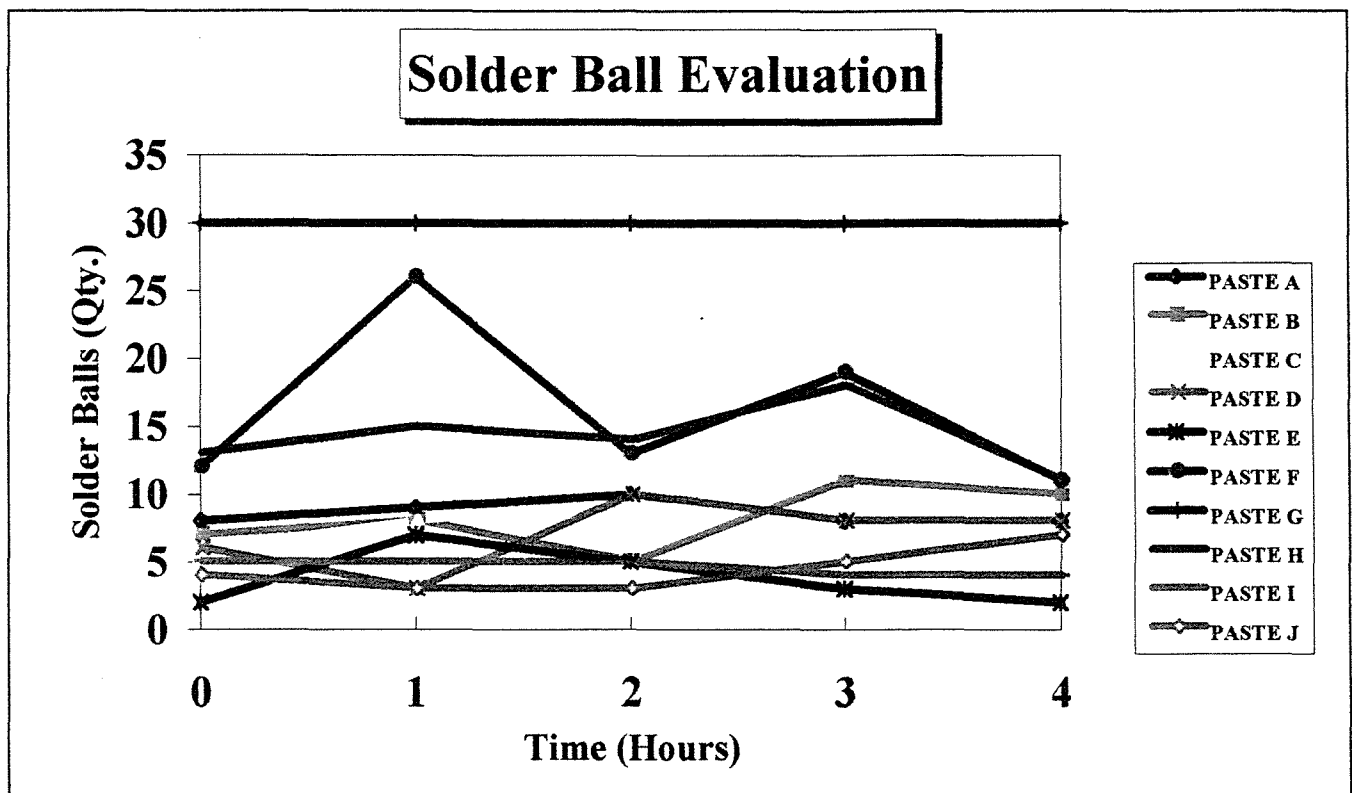
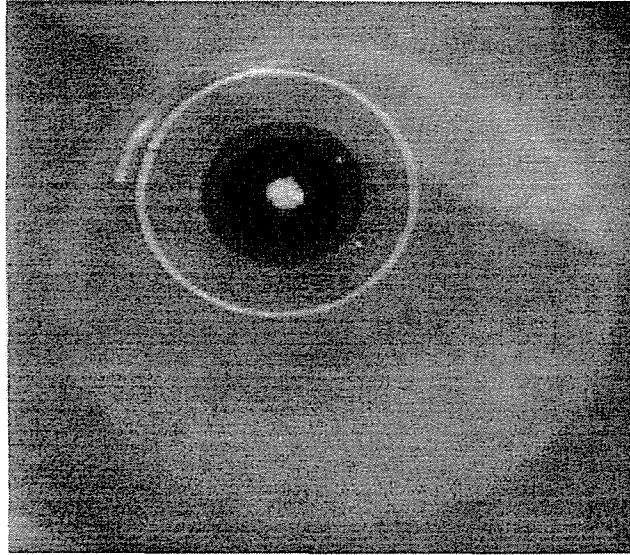


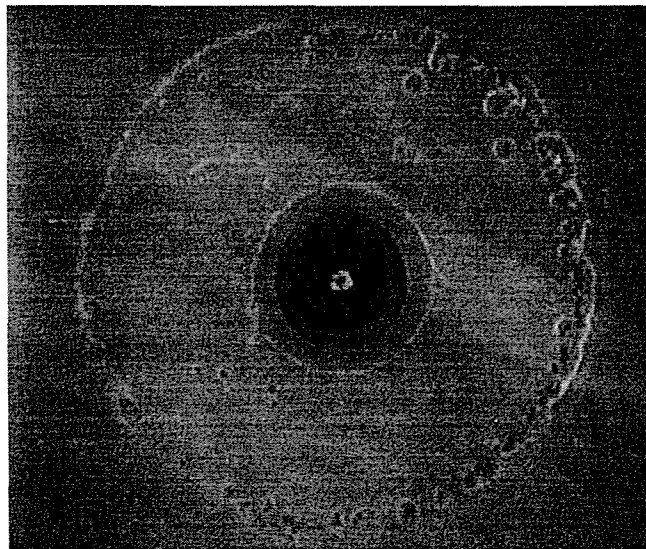
Figure 11: Graph of Solder Ball Test Results

The results showed that paste G exhibited completely unacceptable solder balling levels along with paste F and H to a lesser extent. These vendors were contacted and ultimately conceded that these lots exhibited poor solder ball resistance. This did not bode well for confidence in their product consistency. The control metric which was used for the final

rating matrix was an average of ten solder balls. If the overall average for a paste exceeded this, then it received a "Fail". An example of results obtained from paste G and paste J can be seen in Figure 12. Note the significant differences between a good performing paste versus a poorly performing paste.



**Sample Solder Balling Results From Paste J (EXCELLENT)**



**Sample Solder Balling Results From Paste G (POOR)**

**FIGURE 12: Visual Comparison Between Solder Balling Results**

### **6.3.3 ELECTRICAL CLEANLINESS (IONIC CONTAMINATION)**

Ionic contamination represents one of the most significant factors causing degradation and failure of electronic assemblies. Very small quantities of residual ionic contamination can cause catastrophic failure of components and circuits under certain conditions. Residual ionic contamination can cause surface electrical leakage, chemical, galvanic, and electrolytic corrosion.<sup>22</sup> Two methods which exist for quantifying the ionic contamination present which were used for this study include: resistivity of solvent extract and surface insulation resistance measurements.

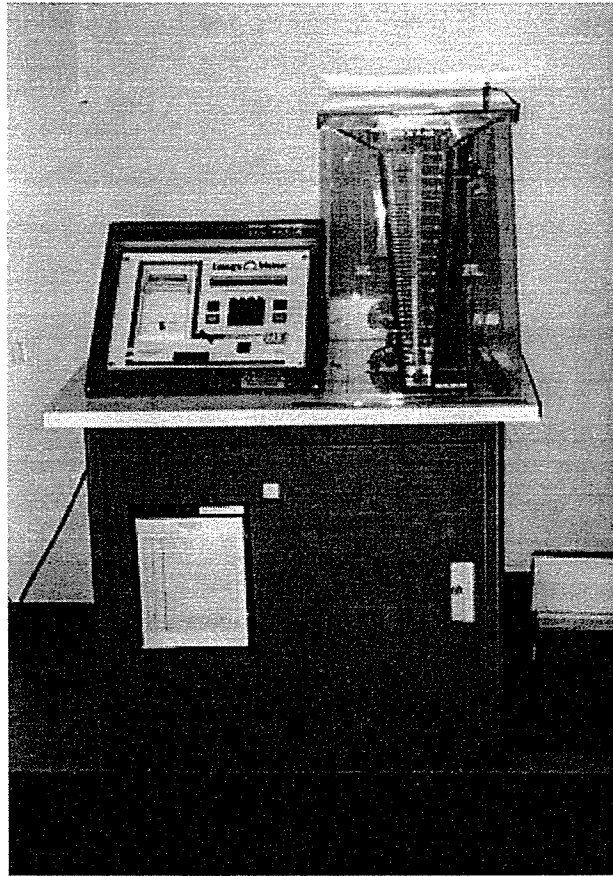
#### **6.3.3.1 RESISTIVITY OF SOLVENT EXTRACT**

The measurement of the concentration of ionic species left on an assembly is an important pointer to the reliability of an assembly. As previously presented, ionic residues are the chief source of electrical and corrosive properties of flux residues. IPC test method 650.2.3.26.1 has specified a method of measuring such ionic residues. A soldered assembly is placed in a bath containing a semi-aqueous solution (approximately 75% alcohol and 25% water mixture) which dissolves the ionic species on the assembly. As the ions are dissolved, the resistance of the solution changes and can be recorded. By knowing the area of the board, the solution volume, and the change in the solution resistivity, the concentration of ionic residues can be equated to equivalent concentration of NaCl. The IPC test method procedure may be viewed in Appendix B.

There are many types of equipment available to accomplish this measurement. For this study, an Alpha brand Omega Meter was used. The unit utilized for this study can be seen in Figure 13.

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<sup>22</sup> Omega Meter Users Manual, Page 1.



**FIGURE 13: Alpha Brand Omega Meter**

Four boards of each paste utilizing the Toplevel boards were stenciled and reflowed using each manufacturers recommended reflow profile. The Toplevel test boards were used for their increased solder quantity density present on the surface of the substrate. The tests were run four times for result confidence and the resulting contamination quantities found were averaged. A summary of the results obtained can be seen in Table 6.

**TABLE 6: Experimental Solvent Extract Resistivity Results.**

Paste	Equivalent Micrograms of NaCl / in <sup>2</sup>	Pass /Fail
A	23.8	F
B	4.9	P
C	4.9	P
D	16.6	F
E	12	F
F	14.1	F
G	12.6	F
H	1.3	P
I	6.5	P
J	9	P

According to the IPC standard test method, an equivalent contamination exceeding 10 micrograms per square inch is considered a failure. It is interesting to note that half of the pastes tested failed this test.

#### **6.3.3.2 SURFACE INSULATION RESISTANCE**

Surface insulation resistance (SIR) was the most lengthy and difficult evaluation measure that was accomplished for this study. The measurement of cleanliness previously described depends on a change in the property of a solvent used to remove contamination from the assembly. The solvent extract method was carried out on the assumption that the contamination is detrimental to the electrical functioning of the circuit and that the disolvability rate of each residue was very similar in the semi-aqueous solution. Surface insulation measurements attempt to directly link the contamination to the reliability of a circuit.<sup>23</sup>

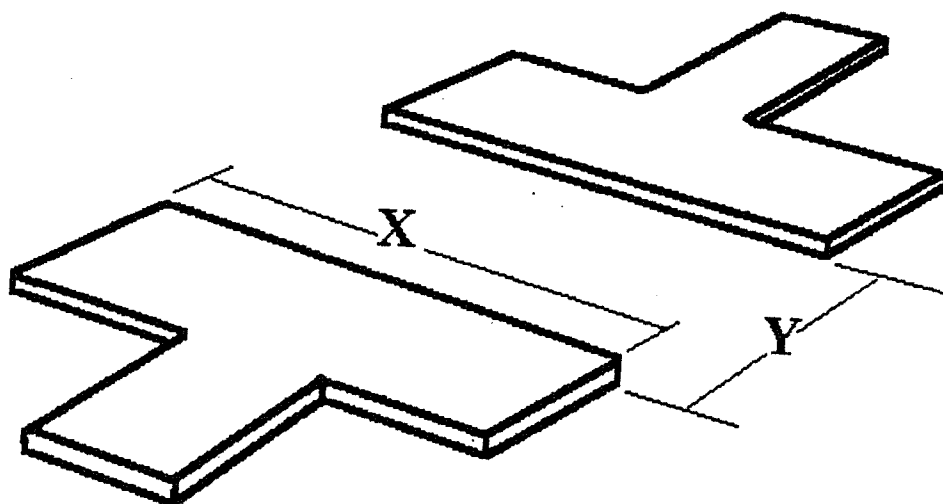
SIR tests measure the surface resistance between two adjacent conductors on a circuit board under artificially hostile conditions over at set time period, the principle



being that ionic contamination on the board surface will lower the surface resistance and degrade electrical performance. There are potential drawbacks to this method and it should be taken as a complementary measurement to solvent extraction, although it does offer the a better link to product reliability.

#### **6.3.3.2.1 SIR THEORY**

Surface resistivity has the unit of ohms per square. If a square is considered having length  $X$  on the conductive side and length  $Y$  on the insulating side (See Figure 14), then the electrical resistance measured between the two increases linearly as  $Y$  increases but decreases linearly as  $X$  increases. Therefore the measured resistance is not affected by the size of the square, only the number of squares present.



**FIGURE 14: Adjacent Conductors For SIR Testing**

IPC test method 650.2.6.3.3 states that a test coupon with a known trace pattern be subjected to 85% relative humidity, 85 degrees Celsius, while under a bias voltage of 50 Volts DC. The electrical resistance is measured using either a pico-ammeter and Ohms law, or directly with a high magnitude resistance meter at various time intervals over the course of a week under a measurement voltage of -100 Volts DC. The

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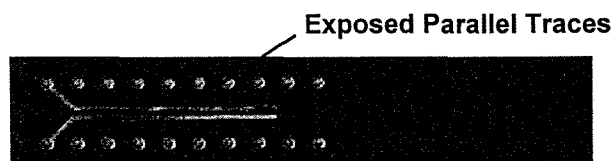
<sup>23</sup> Lea, Page 19.

resistance per square can found and should not drop below  $10^9$  Ohms/Square. The IPC test method procedure may be viewed in Appendix B.

#### **6.3.3.2.2 EXPERIMENTAL SETUP**

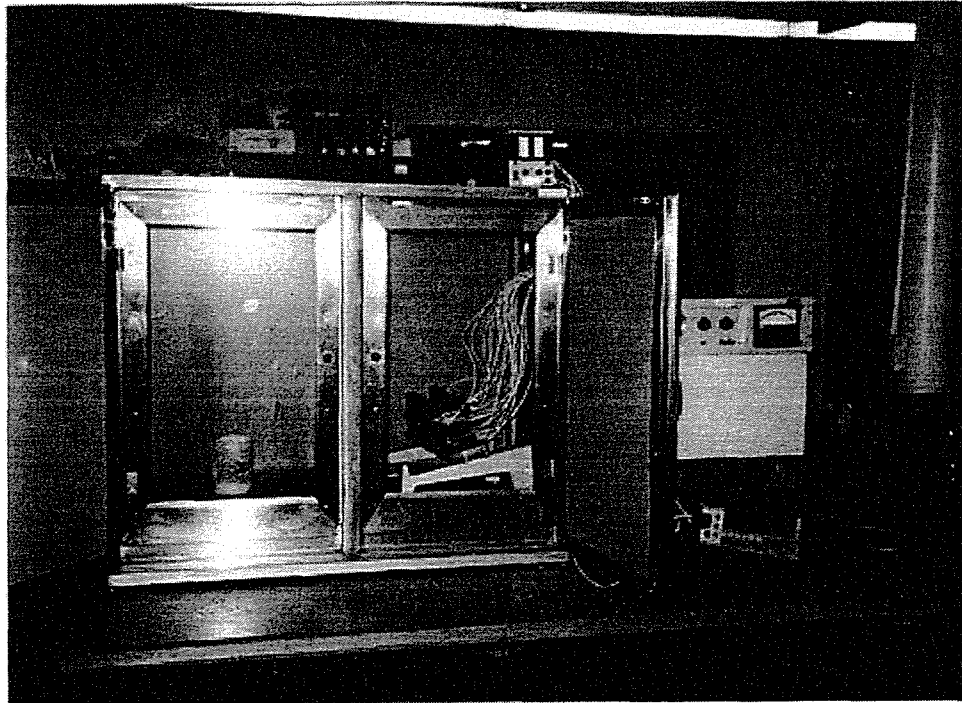
In the absence of an environmental chamber which could obtain the extremely harsh conditions specified, an alternate method was used. A constant humidity solution, potassium bromide (KBr) dissolved in de-ionized water, was placed in a sealed oven at 85 degrees Celsius. KBr dissolved in de-ionized water at 85 degrees has the property of maintaining a relative humidity of 80% in a closed area once equilibrium is achieved. This five percent difference between the specified and obtainable humidities was deemed acceptable.

The IPC test method specifies that an interdigitated comb pattern be used to measure the SIR. In the absence of obtaining such coupons, a slightly older style military "Y" coupon was used. An example of the test coupon used can be seen in Figure 15. Note the exposed parallel conductive traces.



**FIGURE 15: Military "Y" Coupon Used for SIR Testing**

The test coupons were reflowed with each no-clean paste and soldered to coaxial cable to eliminate electrical noise. A coupon was also reflowed using Tristars current water soluble paste and cleaning equipment for a baseline indicator. The test coupons were then mounted to a fixture, placed in the chamber, and connected to a variable power supply and a pico-ammeter. A pico-ammeter was used in the absence of availability of an adequate ohmmeter. The experimental setup used can be seen in Figure 16.



**Note Constant Humidity Solution on Left Side of Oven and Test Coupons on Right Side**

**FIGURE 16: Experimental SIR Set Up**

#### **6.3.3.2.3 EXPERIMENTAL RESULTS**

The experimental set up that was utilized worked well to record the insulation resistance degradation over the course of the experiment. Measurements were taken once a day for the duration of the seven day test. All reflowed coupons maintained an insulation resistance above  $10^9$  ohms/square except for paste "A", which stayed below the pass/fail criteria for the final four of the seven days. This SIR failure correlated with the poor performance of paste "A" for solvent extract resistivity measurements. All pastes except for "A" received a "PASS" for the rating matrix.

#### **6.4 SIGNIFICANT TESTS NOT PERFORMED**

While many evaluation measures were accomplished, there exists literally dozens of potential qualification measures which can be performed on a solder paste. For the

purposes of this study, the following tests would have been run but could not for varying reasons.

#### **6.4.1 ELECTRO-CHEMICAL-MIGRATION**

The electro-chemical-migration of metals in electronics has been recognized for over 30 years. The phenomenon causes electrical shorts as two adjacent conductors are bridged by a growth of metal dendrites. A metal which can form ions in the presence of moisture, and have mobility under electrical voltage potential can exhibit electro-migration. Therefore the requirements for electro-chemical-migration are: voltage potential, temperature, time, and electrolyte (humidity).<sup>24</sup>

Under favorable conditions, the metal ions will literally migrate from cathode to anode and form dendrite like structures between the two electrodes. While this is an important test to be completed, the IPC specification calls for a test with a duration of thirty days which was not feasible for the purposes of this study.

#### **6.4.2 PRE-REFLOW CORROSION**

Many tests are available to qualitatively and quantitatively rate the corrosivity of a paste prior to reflow. In the absence of the equipment and materials to properly perform this test, it was assumed that each manufacturers specification of acceptability for this measure would be satisfactory.

#### **6.4.3 HALIDE PRESENCE**

The significance of determining the quantity of halide present in a solder paste relates to its historical use as an activator. For many years, halides (fluorides, chlorides, bromides) were used as activators in pastes that were cleaned because they exhibited excellent fluxing action. They presented no threat to product reliability as long as they were cleaned off the board relatively soon after soldering. Unfortunately, they react with lead, water and air to produce a very corrosive chemical reaction which makes them detrimental for no-clean usage.

While manufacturers of the pastes examined claim a "halide free" product, interviews with industry experts suggested that small amounts of halide are still sometimes used. Due to the complexity and difficulty of quantifying halides, this test was not performed.

## **6.5 PASTE EVALUATION CONCLUSIONS**

The original goal of the qualification and evaluation round was to find the best performing pastes relative to requirements for Tristars specific assembly environment. It became apparent during testing that there existed distinct differences between the different pastes performance despite manufacturers claims of meeting or exceeding similar specifications. The results for each qualification were input in to the rating matrix and can be seen in Table 7.

**TABLE 7: Paste Evaluation Rating Matrix**

PASTE	A	B	C	D	E	F	G	H	I	J	WEIGHT
APPEARANCE	2	2	1	0	0	0	1	2	0	2	
DISPENSING	P	P	P	P	P	P	P	P	P	P	5
TACKINESS	3	3	5	1	3	4	1	3	1	5	
SLUMP	P	P	P	P	P	P	P	P	P	P	10
EFFICACY	F	P	P	P	P	P	P	P	P	P	10
SOLDER BALL	P	P	P	P	P	F	F	F	P	P	10
SOLVENT RESISTIVITY	F	P	P	F	F	F	F	P	P	P	10
SIR	F	P	P	P	P	P	P	P	P	P	10
TOTAL	30	60	<b>61*</b>	46	48	39	37	50	56	<b>62*</b>	

**\* Selected Best Performing Pastes**

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<sup>24</sup> Hwang, Page 319.

Relative weights for each test were generated by discussion with Tristar engineering to rate the relative importance of each quality for its manufacturing setting. Weights for the relative importance of each qualification measure were multiplied by the response found and totaled. A "Pass" was considered a one, while a "Fail" was treated as a zero.

Pastes C and J were found to have the best overall performance for the tests performed and would be the only pastes to pass beyond the qualification round for further analysis. The tabular rating matrix method worked well to scale the pastes for robustness required for Tristars assembly line.

## **CHAPTER 7: STENCIL PRINTING ANALYSIS**

### **7.1 INTRODUCTION**

Being the initial procedure in the surface mount technology assembly process, stencil printing is generally considered to be the most significant process step affecting defect variability in the end product. The considerable number of adjustable factors involved with stencil printing require that a systematic approach to analyzing and understanding consequential factors affecting the response of the system be accomplished. Design of experiments (DOE) or matrix experiments is one such technique for analyzing and controlling an industrial process.

A matrix experiment consists of a set of experiments in which the settings of various process parameters are changed and the corresponding results obtained are analyzed statistically. This statistical analysis has many beneficial inherent properties such as parameter contribution analysis, interaction examination, and process optimization techniques. For these reasons, a DOE approach to analysis of the stencil printing process at Tristar was chosen as the best way to identify the significant parameters in obtaining an acceptable solder paste print.

### **7.2 STENCIL PRINTER EQUIPMENT**

Tristar utilizes a DEK brand model 249 semi-automatic stencil printer for its printing process. It is an exceptional machine with features such as vision alignment, fully adjustable tooling table, and repeatability rated at  $\pm 0.0004$  inches. The DEK 249 is used on a daily basis and could be used in almost any manufacturing setting with variants available for conveyORIZED lines. The DEK 249 can be seen in Figure 17.



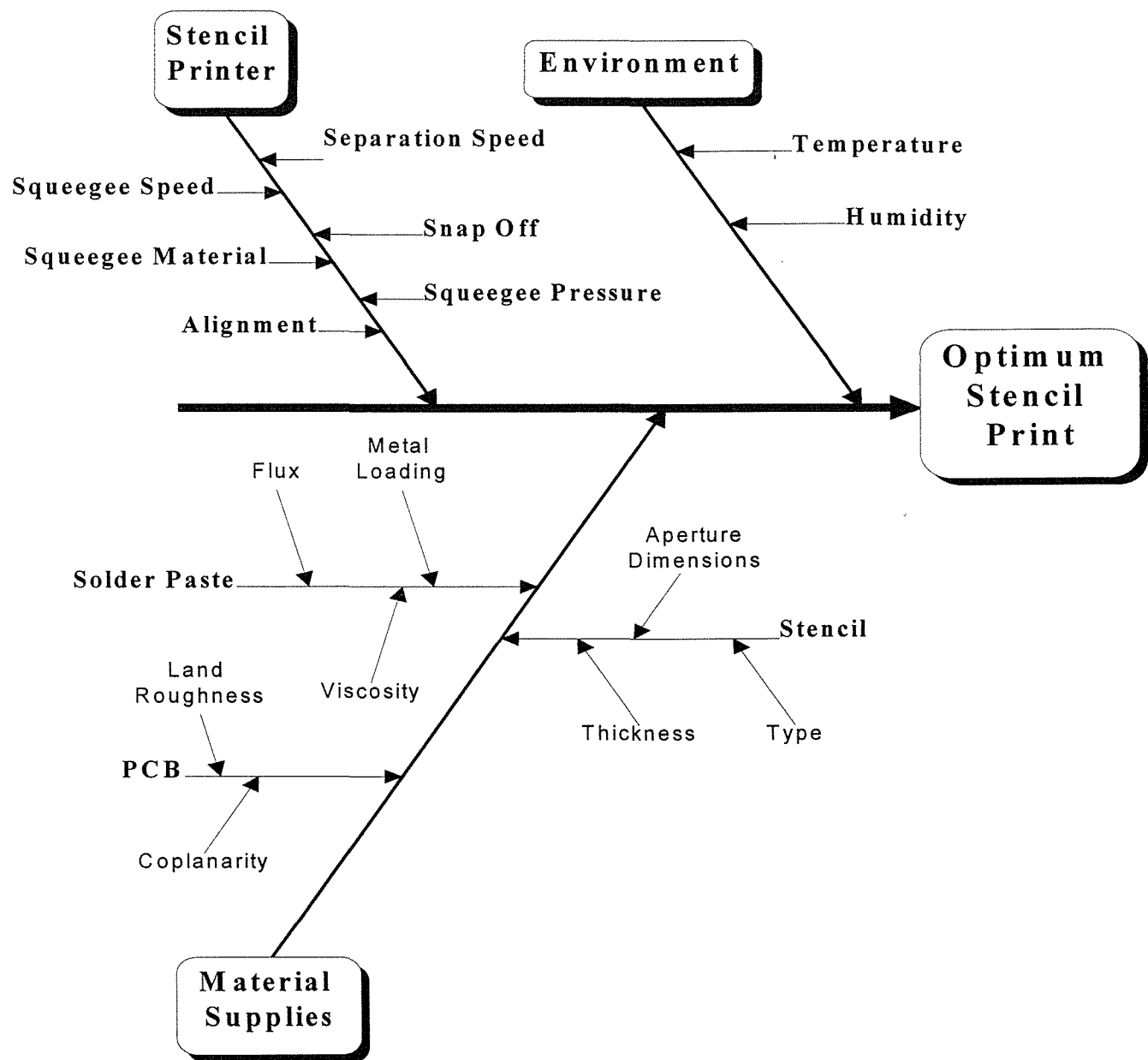
**FIGURE 17: DEK 249 Semi-Automatic Stencil Printer**

While some prototype jobs are still hand printed, the overall majority are run on the DEK printer for better result consistency and reduction of defects caused by human error.

### **7.3 STENCIL PRINTER PARAMETER SELECTION FOR ANALYSIS**

Before the DOE matrix could be designed, the scope of the experiment had to be addressed as to how many parameters and levels would be examined. To help determine the important factors for stencil printing, a brainstorming session was held with Tristar engineers and operators who work with the machine on a daily basis. A list of potential output affecting contributors was generated and categorized. The categorized list was then input into a cause and effect diagram for improved visual interpretation. The cause and effect diagram produced can be seen in Figure 18.





**FIGURE 18: Cause and Effect Diagram of Potential Factors Affecting Stencil Printing**

Since a great deal of knowledge and experience with the stencil printer existed at Tristar, it was decided that a three or higher level experiment was not required and a carefully chosen two level experiment would provide adequate process modeling. After further discussions with Tristar personnel, it was felt that the number of factors available in an L8 orthogonal array presented an adequate number to be studied. What was believed to

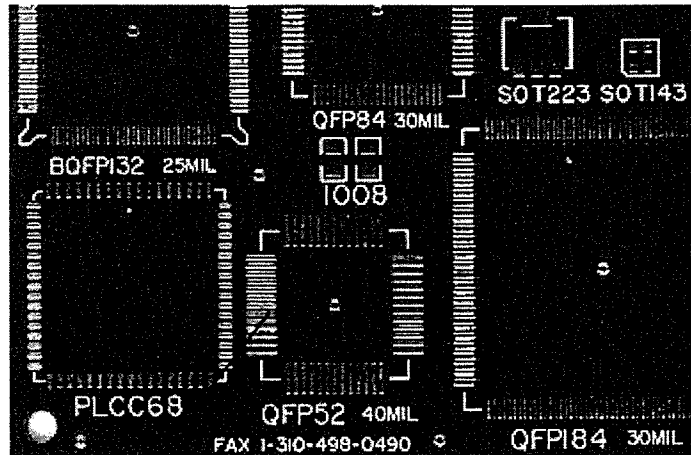
be the five most significant factors along with two interactions between factors were chosen for examination. Levels for the factors were carefully chosen so that the levels represented a realistic operating range for the Dek 249 stencil printer. The chosen factors and their levels can be seen in Table 8:

**TABLE 8: Selected Parameters and Levels**

FACTOR	LEVEL 1	LEVEL 2
SQUEEGEE PRESSURE(RELATIVE SETTING)	2	12
SQUEEGEE SPEED	20 mm/sec.	60 mm/sec.
INTERACTION: PRESSURE AND SPEED		
SQUEEGEE MATERIAL	POLYURETHANE	METAL
INTERACTION: PRESSURE AND MATERIAL		
STENCIL THICKNESS	0.005"	0.008"
PASTE	B	J

Of the many potential output metrics, the critical parameter of deposited brick width was chosen as the output characteristic to be quantified. Unacceptable deposit widths can potentially cause defects due to reasons such as inadequate or excessive solder volumes when components are soldered. For measurement of the deposited solder paste width, a video measurement system was utilized. A 25 mil wide 40 mil pitch land pattern was chosen for analysis on the Topline test boards, which accounts for a good representation of the majority of the component pitch assembled at Tristar. The test area on the Topline test boards can be seen in Figure 19.

Note: Surrounding Board Area Truncated in Figure



Test Pattern Area Used for Measurement

FIGURE 19: Test Pattern Area on Topline Test Boards for Stencil Printer Analysis

The chosen factors for analysis were allocated to a modified linear graph for assignment to the proper columns in the Taguchi L8 orthogonal array. The modified linear graph can be seen in Figure 20.

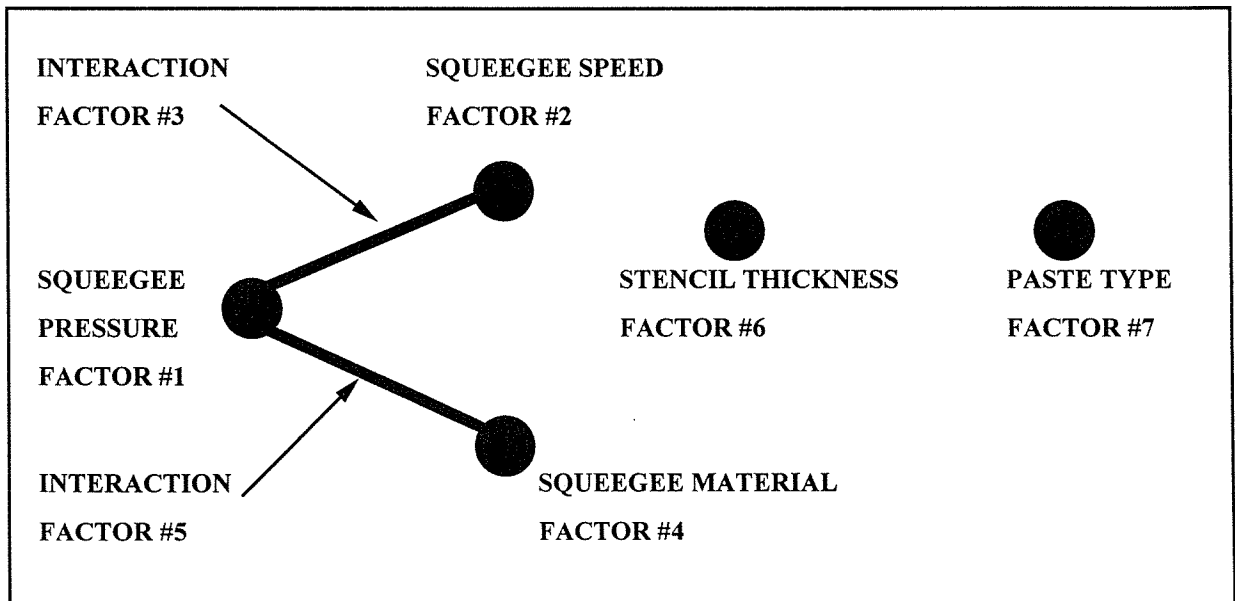


FIGURE 20: Linear Graph of Factors for Column Assignment in L8 Array

The L8 array with chosen parameters, levels, and column assignment can be seen in Table 9.

**TABLE 9: L8 Array with Chosen Parameters and Levels**

	FACTOR A	FACTOR B	FACTOR C	FACTOR D	FACTOR E	FACTOR F	FACTOR G
EXP. #	SQUEEGEE PRESSURE	SQUEEGEE SPEED	1&2	SQUEEGEE MATERIAL	1&4	STENCIL THICKNES S	PASTE
1	2	20		P		5	B
2	2	20		M		8	J
3	2	60		P		8	J
4	2	60		M		5	B
5	12	20		P		5	J
6	12	20		M		8	B
7	12	60		P		8	B
8	12	60		M		5	J

#### **7.4 DESIGNED EXPERIMENT ANALYSIS AND RESULTS:**

The proper level settings for each experiment were set and run with three repetitions for each experiment. The target value was 25 mils, which is the width of the aperture in the stencil. Stencil wiping between runs was done to ensure consistency between trials. The experimental results obtained can be seen in Table 10.

**TABLE 10: Experimental Results**

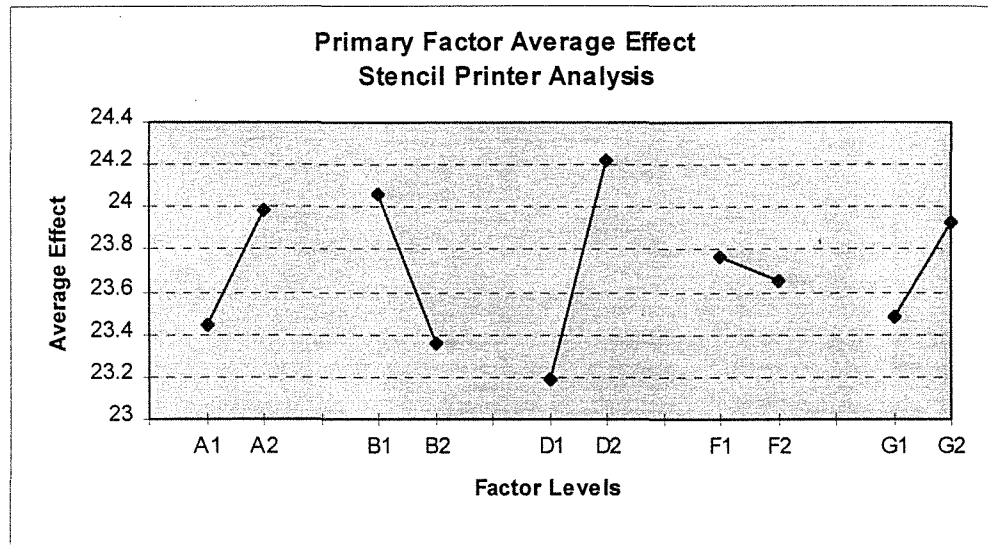
EXPERIMENT #	REPLICATION #1	REPLICATION #2	REPLICATION #3
1	23.86 mils	23.33	24.3
2	24.3	23.91	24.08
3	22.96	22.73	23.64
4	22.37	22.81	22.94
5	23.38	23.33	23.42
6	25	24.83	24.96
7	22.38	22.28	22.72
8	25.58	24.83	25.05

#### **7.4.1 AVERAGE ANALYSIS**

The results obtained were input in to a DOE analysis software package (ANOVA-TM) and analyzed for contribution to the average effect. The results obtained for the primary factor effects on the average can be seen numerically in Table 11 and visually in Figure 21 below.

**TABLE 11: Average Effects of Primary Factors**

FACTOR	NAME	LEVEL 1	LEVEL 2
A	SQUEEGEE PRESSURE	23.44	23.98
B	SQUEEGEE SPEED	24.06	23.36
D	SQUEEGEE MATERIAL	23.19	24.22
F	STENCIL THICKNESS	23.77	23.65
G	PASTE	23.48	23.93



**FIGURE 21: Plot of Primary Factor Average Effects**

The plots of the average effects of the primary factors show that the impact on the output characteristic due to the different factors varies. The effect of parameter D (squeegee material) shows the largest influence on the average brick width. Other parameters such as F (stencil thickness) show much a smaller influence.

The effects of the interactions that were studied can be seen in Appendix A. The response between all the studied interactions are not parallel indicating that interactions are indeed present. The significance of the interaction analysis shows that the squeegee pressure, speed, and material parameters are not isolated factors when analyzed for their affects on the average. When one parameter is changed it will affect the others. This must be taken in to account when adjusting these parameters when optimization is attempted.

To numerically quantify the differences in the percent contribution to the output metric, an analysis of variance (ANOVA) on the average results was completed. The ANOVA table generated can be seen in Table 12.

**TABLE 12: ANOVA Results for Average Data**

Factor	Pool	Dof	S	V	F	S'	% Contribution
A	N	1	1.78	1.78	13.14	1.64	7.49
B	N	1	2.94	2.94	21.8	2.81	12.82
C	Y	1	0.75	0.75			
D	N	1	6.33	6.33	46.86	6.2	28.27
E	N	1	7.2	7.2	53.3	7.07	32.25
F	Y	1	0.08	0.08			
G	N	1	1.23	1.23	9.1	1.09	4.99
Error		18	2.43	0.14		3.11	14.18
Total		23	21.93	0.95			100

Parameters which exhibited less than five percent contribution to the output effect were pooled as error (noise). A summary from the ANOVA table of the percent contributions of the factors found significant can be seen in Table 13.

**TABLE 13: Percent Contribution of Factors Affecting Average**

FACTOR	PERCENT CONTRIBUTION
SQUEEGEE PRESSURE	7.5%
SQUEEGEE SPEED	12.8%
SQUEEGEE MATERIAL	28.3%
INTERACTION: PRESSURE & MATERIAL	32.3%
PASTE TYPE	5%
NOISE (Error)	14.1%

The fact that all but 14.1% of the response of the system could be accounted for was excellent, and showed that the process model chosen to analyze the system worked well.

#### **7.4.2 VARIABILITY ANALYSIS**

To analyze the effect of the factors on the variability of the output characteristic, a Taguchi signal to noise analysis was performed. The results obtained from performing

the experiment were input in to the Taguchi signal to noise equation:

$$S/N = 10 \log 1/n ((Vm - Ve) / Ve)$$

Where:  $Vm = (\sum y)^2 / n$

$Ve = (\sum y^2 - \text{Variance of Error}) / (n - 1)$

**y = Result Obtained**

**n = Number of Experiments Completed**

The signal to noise values calculated for each experiment can be seen in Table 14.

**TABLE 14: Calculated S/N Values for Results**

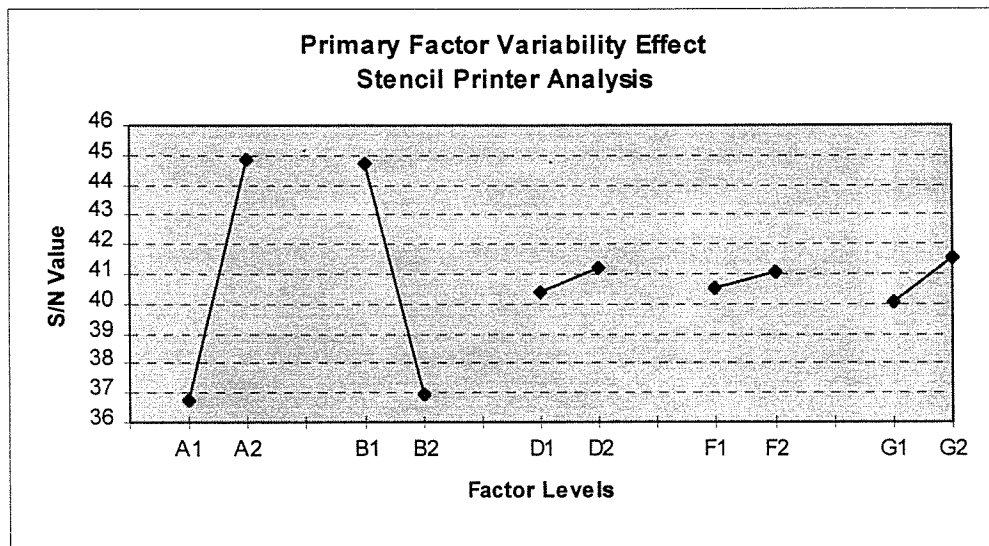
EXPERIMENT #	S/N VALUE
1	33.82
2	41.82
3	33.78
4	37.62
5	54.29
6	48.96
7	39.77
8	36.29

A level analysis for the S/N data was performed using the ANOVA-TM software package. The results obtained for the primary factor effects on the variability of the brick width can be seen below.



**TABLE 15: Variability Effect of Primary Factors**

FACTOR	NAME	LEVEL 1	LEVEL 2
A	SQUEEGEE PRESSURE	36.76	44.83
B	SQUEEGEE SPEED	44.72	36.96
D	SQUEEGEE MATERIAL	40.41	41.17
F	STENCIL THICKNESS	40.5	41.1
G	PASTE	40.04	41.54

**FIGURE 22: Plot of Primary Factor Variability Effect**

The plots of the effect on the variability of the output characteristic show that similar to the average analysis, some of the factors exhibit larger influence on the variability than others. Squeegee pressure and speed for example exhibited larger contributions than the other factors.

The effects of the interactions studied can be seen in Appendix A. Similar to the average analysis, both interactions studied exhibited the presence of an interaction between factors. The squeegee pressure and material interaction showed more impact on the variability than the pressure and speed interaction.

An ANOVA analysis was completed to find the percent contribution of the factors to the variability of the brick width. The ANOVA table generated for variability analysis can be seen in Table 16.

**TABLE 16: ANOVA Results for S/N Variability Data**

Factor	Pool	Dof	S	V	F	S'	% Contribution
A	N	1	130.33	130.33	61.77	128.22	33.8
B	N	1	123.47	123.47	58.52	121.36	31.99
C	N	1	65.87	65.87	31.22	63.76	16.81
D	Y	1	1.15	1.15			
E	N	1	53.34	53.34	25.28	51.23	13.5
F	Y	1	0.66	0.66			
G	Y	1	4.52	4.52			
Error		3	6.33	2.11		14.77	3.89
Total		7	379.34	54.19			100

Again, parameters which exhibited less than five percent contribution to the output effect were pooled as noise factors. A summary of the percent contributions of the factors effecting variability can be seen in Table 17.

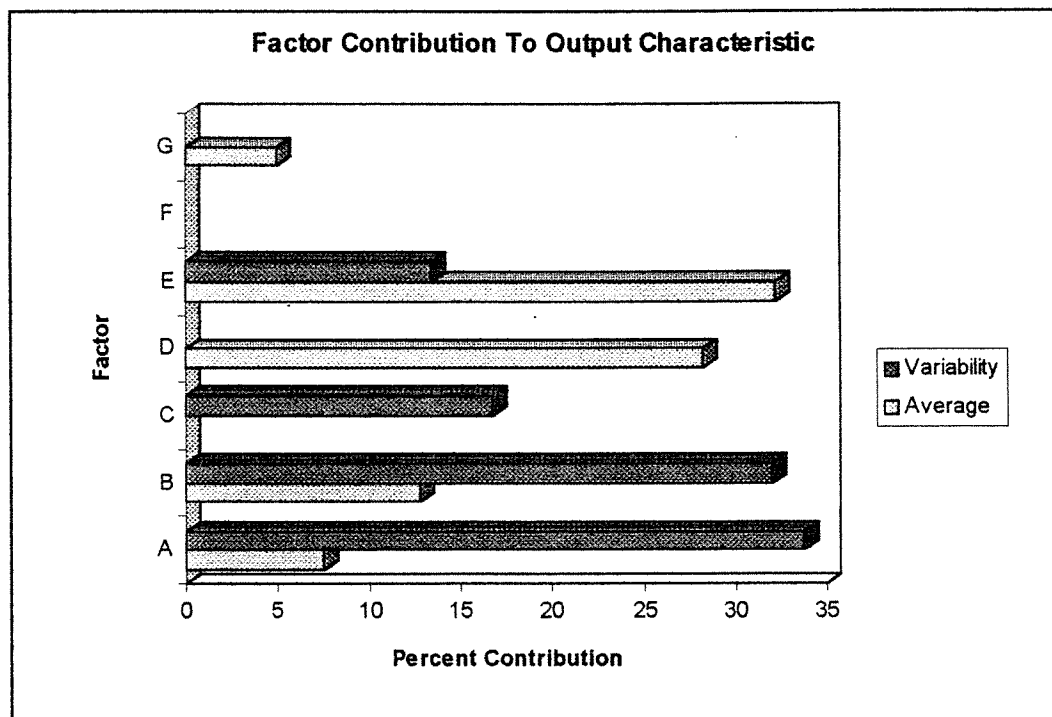
**TABLE 17: Percent Contribution of Factors Effecting Variability**

FACTOR	PERCENT CONTRIBUTION
SQUEEGEE PRESSURE	33.8%
SQUEEGEE SPEED	32%
INTERACTION: PRESSURE & SPEED	16.8%
INTERACTION: PRESSURE & MATERIAL	13.5%
NOISE (Error)	3.9%

The process model chosen to analyze the system worked well, accounting for all but approximately 4% of the response of the system.

### **7.5 STENCIL PRINTER ANALYSIS CONCLUSIONS:**

The designed experiment approach to analyzing the surface mount technology stencil printing process worked well to analyze the important factors affecting the response of the system. Analysis of variance calculations led to the interesting result that parameters which effect variability do not necessarily effect the average. This is clearly demonstrated in Figure 23, which compares the percent contribution of each factor to the output characteristic for variability and average results.



**FIGURE 23: Comparison of Parameter Contribution Effecting Average and Variability**

Careful selection of the parameters and factor levels led to a model in which 86 percent and 96 percent of the response for average and variability respectively could be accounted for.

## **CHAPTER 8: FULL SMT PROCESS ANALYSIS**

### **8.1 INTRODUCTION AND APPROACH**

The next step in the research implementation methodology was to perform a designed experiment on the entire SMT process line at Tristar. After analysis, it would then be possible to specify the optimum parameter settings for the process based on the results found. To accomplish this, the scope, parameters, and the layout of the experiment had to be determined. Based upon the analysis of the stencil printing results found for the Dek 249 stencil printer previously and discussions with Tristar engineering, the layout of the experiment was determined.

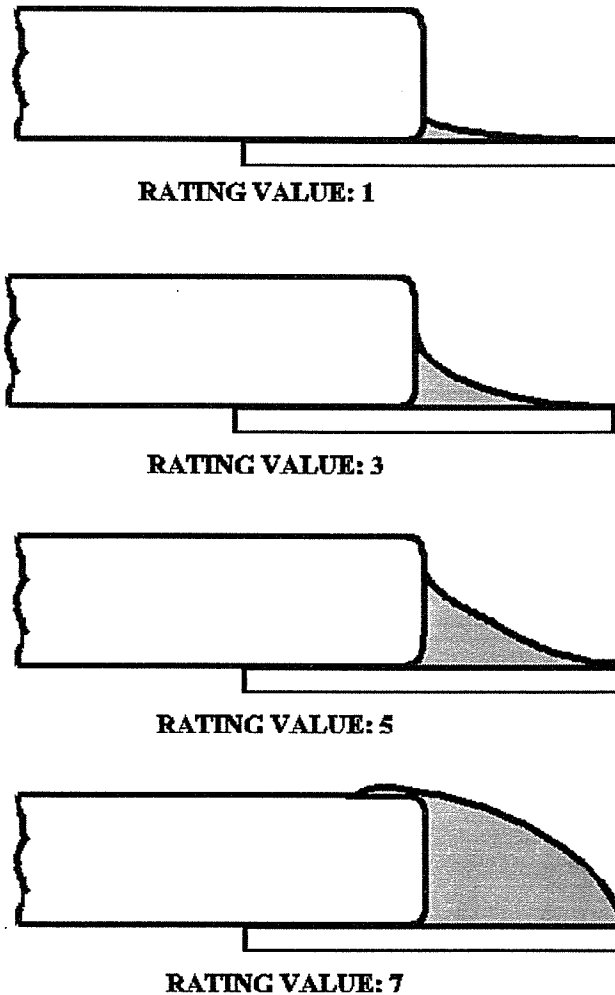
In order to analyze the three different lead spacing pitches to be examined, it was decided that three separate designed experiments would be performed. Here, the idea was to take the results found for each examination and to combine them mathematically to specify process setting guidelines for all possible pitch mixes assembled at Tristar.

### **8.2 EXPERIMENTAL PARAMETERS AND LAYOUT OF MATRIX ARRAY**

It was decided the standard Taguchi L8 orthogonal array that was used for the stencil analysis would be employed again. This array and not a larger one with more levels was chosen because of the substantial increase of processing steps, increase in process parameters, and the fact that three different experimental arrays had to be run. With the expansion of the array parameters extending to investigating the full process, careful consideration had to be given to which parameters would be examined or held constant and what the measured output would be.

Since the solder joint is responsible for both the mechanical bond and the electrical connection, it was the criteria which was decided on for the characteristic measured output metric. Industry standards, such as the IPC and Military specifications have been established as guidelines of acceptability for such criterion. Based upon these guidelines, a rating system was established to numerically assess the quality of the solder joints that were formed resultant from each experiment trial. Fillet geometry was decided

upon as the qualification metric. The fillet shape geometry rating followed the guidelines shown below in Figure 24, where a four (4) was the target condition.



**FIGURE 24: Rating Criterion for Solder Joint Fillet Geometry**

To aid inspection a 20X microscope was used. Cross sectioning was also accomplished to properly relate outside inspection of the solder joint to the actual cross sectional appearance of the fillet.

### **8.3.1 STENCIL PRINTER PARAMETERS**

The knowledge gained from the stencil printing analysis helped to determine which stencil printer parameters would be analyzed in the full process array. However, it

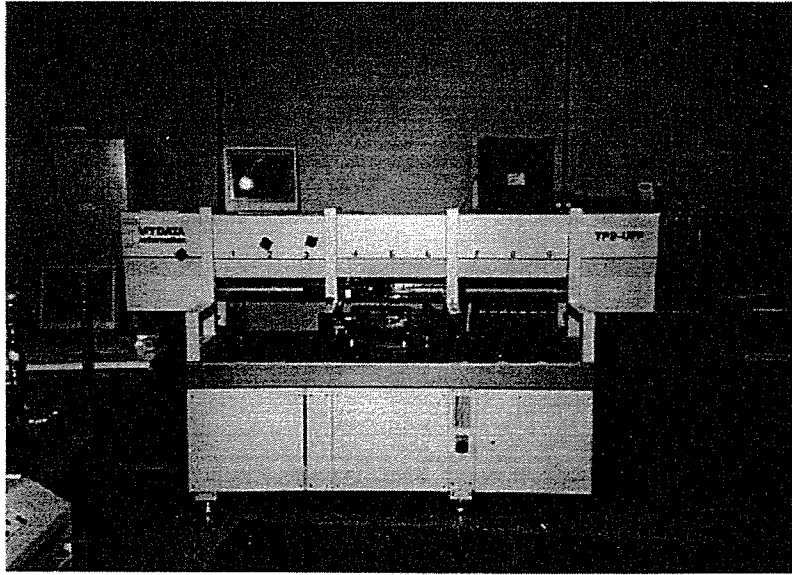
must be noted that the output metrics quantified between the stencil printer analysis (deposited brick width) and the full process analysis (reflowed joint appearance) do not necessarily have a direct relationship. Because of this, some parameter modification was necessary. Based upon the knowledge gained from the stencil printing analysis, the following stencil printing related parameters were included in the full process experimental array:

- Squeegee Pressure
- Squeegee Speed
- Interaction of Squeegee Pressure and Speed
- Stencil Thickness
- Interaction of Stencil Thickness and Squeegee Pressure
- Paste Type

Stencil thickness was added to the factors being examined despite showing up as not significant from the previous printer analysis. This was done because the thickness of the stencil greatly affects the volume of paste deposited and consequently the shape of the solder joint fillet. Use of a metal squeegee was selected as the squeegee type to be used exclusively because of the high effect on the results found from the stencil DOE analysis previously. Stencil wiping and cleaning was held constant throughout the entire experiment run.

### **8.3.2 PICK AND PLACE PARAMETERS**

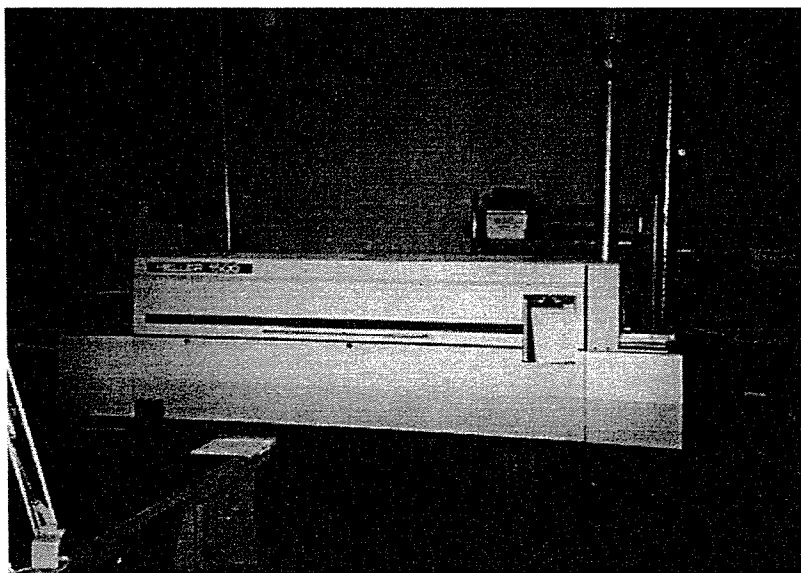
Tristar utilizes a Mydata brand TP9-UFP pick and place machine for component placement. It is considered throughout the industry as one of the best machines for a non-dedicated assembly environment. Its flexible design permits virtually all relevant parameters to be adjusted. For this investigation, it was decided that the placement pressure of the components in to the paste would be the only factor introduced to the array for the pick and place process step. All other adjustable factors would be held constant. The Mydata TP9-UFP can be seen in Figure 25.



**FIGURE 25: Mydata TP9-UFP Pick and Place Machine**

### **8.3.3 REFLOW OVEN PARAMETERS AND OTHER FACTORS**

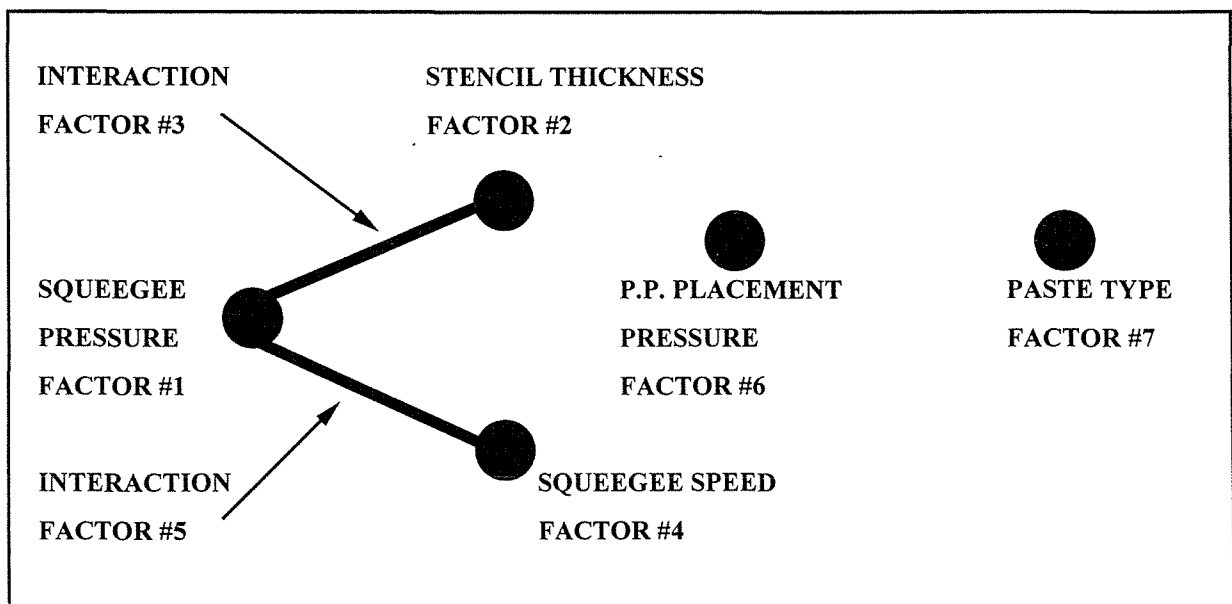
Tristar uses a Heller 1500 forced convection reflow oven for solder paste reflow in their SMT manufacturing line. The oven has five heating zones, each with both top and bottom separately adjustable heater controls. The Heller 1500 convection reflow oven can be seen in Figure 26.



**FIGURE 26: Heller 1500 Forced Convection Reflow Oven**

The manufacturers recommended thermal profiles for each of the two pastes that were advanced to this point from the qualification round were matched and stored in the ovens memory. The profile for whichever paste that was specified to be used in any experiment trial was recalled and used only for that given paste. For the purposes of this experiment, the reflow oven factors were therefore considered held constant. Other factors that were considered held constant were the environmental conditions in Tristars manufacturing area. Ambient conditions were set to 65 degrees Fahrenheit and kept within a range of between 25 and 75% relative humidity. Since there are no humidity controls in Tristars assembly area, the relative humidity was monitored so that it stayed between these levels.

Once the factors for the process were determined, assignment in to the array had to be determined. Figure 29 below shows the linear graph of the factors for the array.



**FIGURE 27: Assignment of Parameters to Array for Full Process Analysis**

The levels for each factor that were chosen can be seen in Table 18 below.



**TABLE 18: Selected Parameters and Levels for Full Process DOE Analysis**

Factor #	Factor Name	Level 1	Level 2
A	Squeegee Pressure	2	12
B	Stencil Thickness	5 mil	8 mil*
C	Interaction of 1&2		
D	Squeegee Speed	20 mm/sec.	60 mm/sec.
E	Interaction 1&4		
F	P.P. Placement Pressure	0 mN**	500mN**
G	Paste Type	B	J

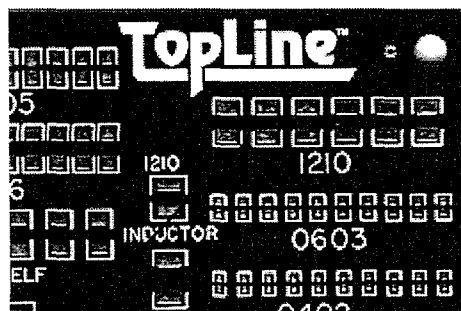
\* A 6 mil thick stencil was substituted for the ultra-fine pitch experiment array

\*\* mN: milli-Newton unit of force

#### **8.4 STANDARD PITCH RESULTS AND DISCUSSION**

The standard pitch DOE was run using the layout discussed previously for four repetitions. The components utilized were 1210 sized passive chip resistors mounted on their corresponding land patterns on the Topline test boards. The test site can be seen in Figure 30 below.

**Note: Surrounding Board Area Truncated in Figure**



**Test Pattern Area Used for Standard Pitch Measurement**

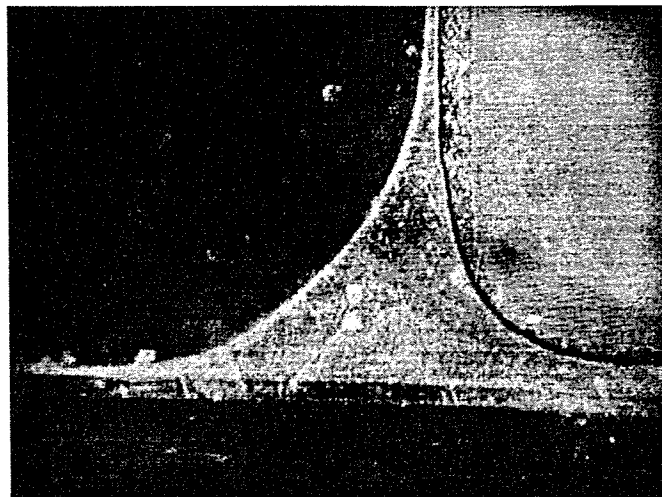
**FIGURE 28: Test Site Used for Standard Pitch Measurement on Topline Test Boards**

The results between the four repetitions were the same which eliminated the possibility of analyzing variability. The results found can be seen below in Table 19.

**TABLE 19: Results for Standard Pitch DOE**

Experiment #	Result
1	3
2	3
3	5
4	5
5	3
6	3
7	5
8	5

Plugging in the results to an analysis of variance table yields the result that the difference in fillet shapes were entirely due to the stencil thickness. This is most likely due to the process being robust enough at 50 mil pitch that the other process parameter levels were not set wide enough to affect the output. An example of a cross-section and its corresponding rating can be seen below in Figure 29.



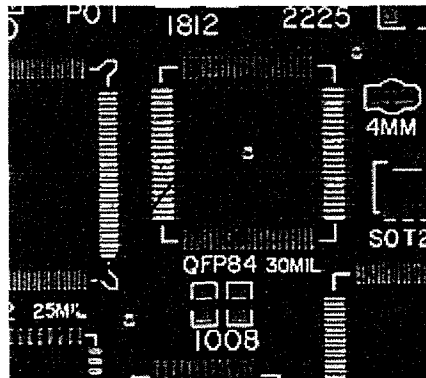
**FIGURE 29: Cross-Section of Standard Pitch Lead; Rating = 3**

The conclusion for the case of 50 mil and above pitch is therefore that the process is robust enough to yield acceptable results for any setting within the range of the settings tested.

## **8.5 FINE PITCH ANALYSIS AND DISCUSSION**

The fine pitch DOE was run using the layout and with four repetitions also. The components utilized were 30 mil pitch 84 leaded quad-flat-packs mounted on their corresponding land patterns on the Topline test boards. The test site can be seen in Figure 31 below.

**Note: Surrounding Board Area Truncated in Figure**



**Test Pattern Area Used for Fine Pitch Measurement**

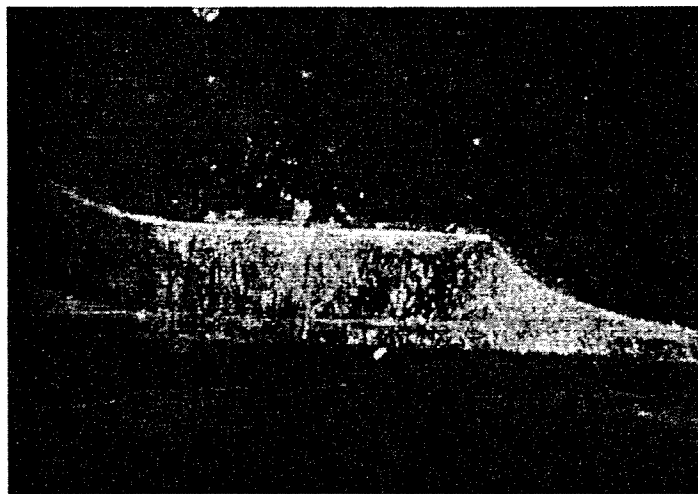
**FIGURE 30: Test Site Used for Fine Pitch Measurement on Topline Test Boards**

Similarly to the results found for the standard pitch experiment, there was no variation in the results between repetitions. So once again, no variance analysis could take place. The results found can be seen in Table 20.

**TABLE 20: Experimental Results for Fine-Pitch DOE**

Experiment #	Result
1	4
2	3
3	5
4	5
5	3
6	3
7	6
8	5

An example a cross-section and its corresponding rating can be seen below in Figure 31.



**FIGURE 31: Cross-Section of Fine Pitch Component Lead; Rating = 6**

An ANOVA analysis was completed for the results found using the ANOVA-TM software and can be seen in Table 21.

**TABLE 21: ANOVA Results for Fine Pitch Process DOE**

Factor	Pool	Dof	S	V	F	S'	% Contribution
A	Y	1	0	0			
B	N	1	8.0	8.0	32.0	7.75	81.58%
C	Y	1	0.5	0.5			
D	Y	1	0.5	0.5			
E	Y	1	0	0			
F	Y	1	0	0			
G	Y	1	0.5	0.5			
(Error)	Y	6	1.5	0.25			18.42%
Total		7	9.5	1.35714			100%

The results show that the stencil thickness has an unusually large contribution on the output effect. The fact that this factor showed up as much more significant than the other factors could be explained by the levels of the other factors not being set wide enough or the stencil thickness levels being too wide as to swamp the other effects. Besides stencil thickness, squeegee speed and paste type were found to be marginally important but were discounted due to having slightly less than a 5% contribution. The effect of the paste type could be explained by the difference in the two pastes viscosity. The effect of the squeegee speed is possibly explained by the fact that as the squeegee moves across the apertures in the stencil, paste deposition is affected by the rheology of the paste and the squeegee speed to accommodate deposition. With the large bias of the results towards the stencil thickness, it is impossible to analyze the average effects with any confidence. Therefore, the average of the levels except for the paste type and stencil thickness were used for the recommendations for optimum level settings. For the stencil thickness, the 8 mil thick was chosen because it would yield a more robust solder joint. The paste chosen was Paste J because it had a thinner viscosity than paste B and seemed to print slightly better than paste B.

## **8.6 ULTRA-FINE PITCH RESULTS AND DISCUSSION**

The DOE was set up and run for the ultra-fine pitch pattern on the Tristar donated test boards. Using the levels set up in the design, no acceptable solder joints resulted. Virtually all leads after reflow were bridged across with solder. It is most likely that this was caused by unacceptable printing resolution during the stencil printing stage of the processing. The poor printing could be resultant from many factors such as:

- Incorrect level settings
- Incorrect stencil aperture design
- Stencil printer inherent limitations
- Other factors

Because of the experimental array and the way it was designed, the factors could not be changed after this was found.

## **8.7 FULL PROCESS DOE CONCLUSIONS**

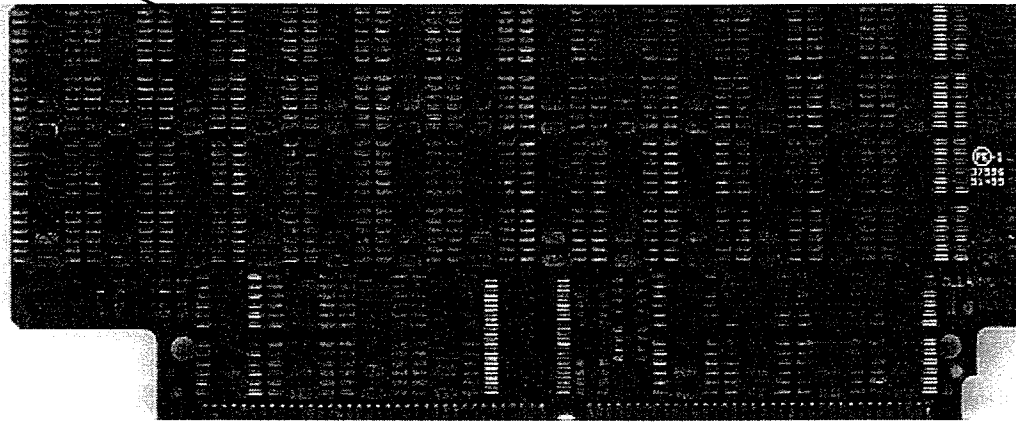
Despite the fact that unacceptable results were found for the ultra-fine pitch condition, good results were obtained for the fine-pitch and standard pitch conditions. Because the standard pitch results were found to be so robust, it can be concluded that the optimum parameter settings are the average of the fine-pitch experiment setting levels. For the purposes of this experiment, it is concluded that acceptable ultra-fine pitch results were unobtainable for the levels chosen and that further research in to this area would have to be completed if ultra-fine pitch patterns were to be accomplished properly.

## **8.8 CONFIRMING EXPERIMENT RESULTS AND DISCUSSION**

To confirm that the results found for the full process DOE would work for an actual product, a confirming experiment was completed. One of Tristars customers, Clearpoint Research in Milford Massachusetts, was contacted and agreed to allow one of their product types to be soldered using the no-clean process. The product was a specialized memory module which utilized capacitor mounting under integrated circuits. Because these areas are very difficult to clean, this particular product lent itself very well

to no-clean technology. A picture of the un-populated circuit board can be seen in Figure 32 below.

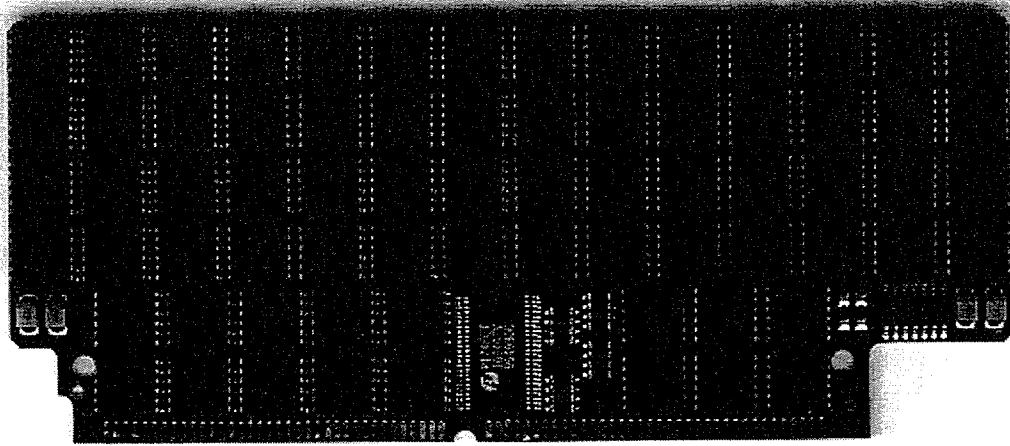
**Note Capacitor Mounting Areas Under All Integrated Circuit Mounting Lands**



**FIGURE 32: Real World PCB Used for Confirming Experiment**

The equipment was set to the average levels recommended from the fine-pitch DOE. The assumption here was that the requirements for the fine pitch components on the board would be targeted and the standard pitch components on the board would be robust enough to yield acceptable results.

Thirty PCB's in total were run through the process and analyzed afterwards. The results showed excellent solder joints formed that were all acceptable. Some integrated circuits were removed to facilitate inspection of the capacitors below them. Careful examination under 20X magnification revealed that they too soldered very well with good fillets. Clearpoint Research performed a source inspection of the assemblies and was very pleased. They have subsequently requested that all of this type of product for future build runs be soldered using a no-clean process. A picture of the assembled circuit board can be seen in Figure 33.



**Note Hidden Capacitors Under Integrated Circuits**  
**FIGURE 33: Assembled Real World Test Circuit Board**

Overall, the confirming experiment results for this real world test on an actual customers product performed very well.

## **8.9 IMPLEMENTATION CONCLUSIONS AND RECOMMENDATIONS**

The results found for the standard pitch SMT components was so robust that it did not matter what the parameter settings were set to within the range specified. Further analysis for the ultra-fine pitch condition would have to be completed before any further comments could be made regarding that area. The fine-pitch results showed that there was a large bias in the experiment resulting in the majority of the characteristic effect being accounted for by the stencil thickness. This could be accounted for by the thickness levels being too wide or the other factors levels not being wide enough for the fine-pitch case. With the large number of other possible factors contributing and their potential interplay, further analysis would have to occur to be certain. Despite the somewhat confusing results found for this case, setting the parameter levels to their average, choosing the 8 mil thick stencil, and selecting paste J worked well for a



combination of standard and fine pitch components for the confirming experiment. It is recommended that these settings be used as a starting point for all boards and the settings be tweaked as necessary. If solder volumes are the largest difficulty encountered, the stencil design would most likely be the suspect as supported by the fine-pitch ANOVA analysis.

#### **8.10 FUTURE IMPLEMENTATION AT TRISTAR TECHNOLOGIES**

While the initial implementation attempt at Tristar went well, there are many other areas that need to be addressed. First and foremost, the no-clean SMT process that was specified needs to be attempted and successfully run for additional customer products. Issues such as the solderability of the components, handling of the PCB's and components, and inspection were all closely monitored and controlled for the test case. Further control mechanisms and procedures need to be implemented so that these areas are controlled for all assembly jobs that are to be utilized with no-clean. Education of personnel as to these issues and how they affect them must occur also. Finally, the areas of assembly beyond the scope of the SMT process, such as through hole wave soldering, hand assembly, and SMT and through hole touch up must also be addressed.

The groundwork for further implementation of no-clean at Tristar has been laid through this study. It is up to Tristars managers, assembly personnel, and customers as to where the path will go from here.

## **CHAPTER 9: FINANCIAL IMPLICATIONS OF CONVERSION**

### **9.1 INTRODUCTION**

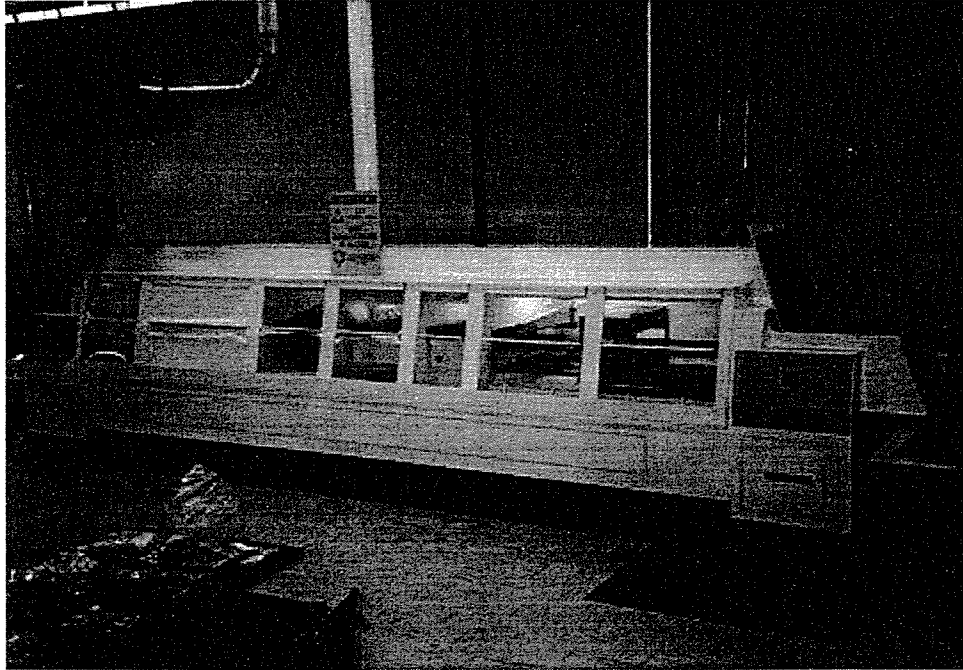
One of the main reasons for converting to a no-clean operation is to benefit from the economic advantages of implementing such a process. Potential savings stem from the reduction, or elimination of processing time, equipment, and material costs. Obviously however, every manufacturing setting is different, so financial calculations should be approached as such.

### **9.2 FINANCIAL IMPACTS AT TRISTAR TECHNOLOGIES**

For the specific situation of conversion at Tristar, it was decided that the financial factors relating to the cleaner usage and the soldering materials would be analyzed. More specifically, each financial expenditure under each topic would be separated, calculated, and recombined so that an over-all cost savings relative to the desired percent conversion could be discerned.

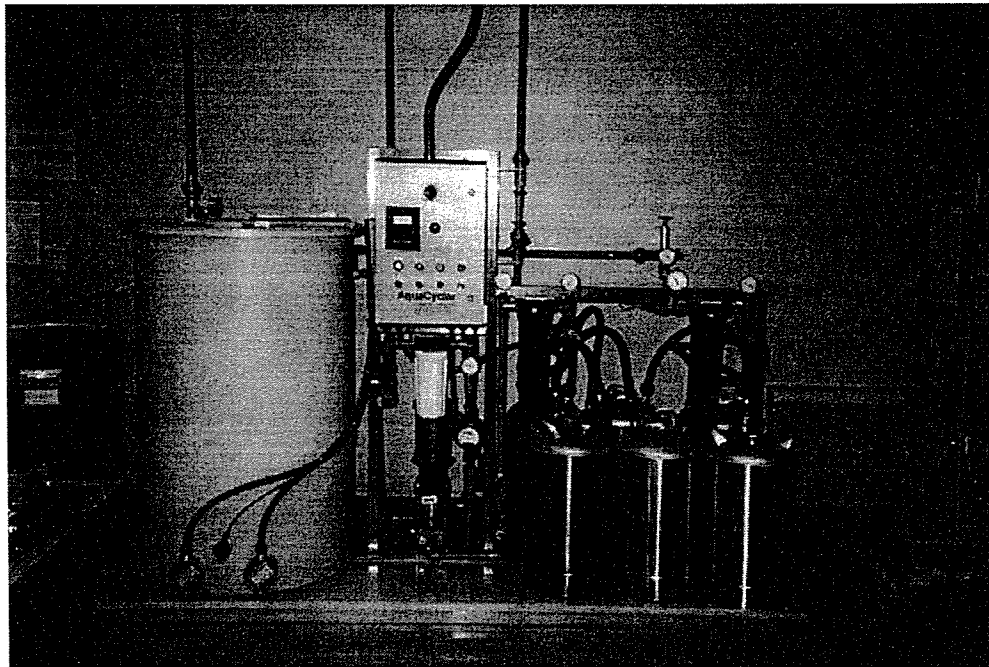
### **9.3 AQUEOUS CLEANER RELATED COSTS**

For their current cleaning process, Tristar employs a Trieber TRM-SMD Series 400 in-line aqueous cleaning system with a complementary closed loop water recycling system. The in-line cleaning portion of the system uses a serial cascading cleaning then drying scheme. The final washing zone utilizes the cleanest water which is then pumped to the previous wash area, and repeated. A picture of the Trieber in-line system can be seen in Figure 34.



**FIGURE 34: Trieber TRM-SMD Series 400 In-line Cleaner**

The recycled water which is fed in to the in-line portion of the system originates from the recycling system. The recycling system can be seen in Figure 35.



**FIGURE 35: Trieber Water Recycling System**

The separate cost factors relating to cleaner system usage at Tristar that were broken down can be seen in Table 22.

**TABLE 22: Tristar Cleaner System Related Cost Breakdown**

<b>Cleaner System Related Cost Breakdown</b>
Electricity Consumption
Water Consumption
Processing Labor During Cleaning Operations
Filter Replacement
Miscellaneous Maintenance Materials
Maintenance Labor
Floor Space
Equipment Purchase Price

In order to facilitate a final total, the cost of each of these factors must be calculated separately using the same units. The standardized units chosen for this analysis were relative cost per work hour.

### **9.3.1 ELECTRICITY CONSUMPTION**

The electricity consumption of the aqueous cleaner is somewhat variant and dependent upon many factors. The major factors affecting this include how often the washer is actually utilized for assembly cleaning, and how often the internal heaters are used to keep the water at set temperatures. Due to the high mix of products and volumes at Tristar, the throughput and work in progress vary widely and thus washer usage consequently varies. In order to make any calculations in this situation, certain assumptions were made. These assumptions included:

- Cleaner usage is approximately 25% of manufacturing time during working day
- Electricity cost is \$0.10 per kWh
- Internal heaters are utilized for 50% of cleaner operation time

Once these assumptions are made, the calculation of electricity cost per hour of cleaner system usage becomes straight forward and can be seen in Table 23 below.

**TABLE 23: Aqueous Cleaner Electricity Consumption Per Hour**

Factor	Calculation	Total
Instantaneous power consumption with heaters running:	Actual reading taken with watt meter from cleaner	1.6 kW
Instantaneous power consumption without heaters:	Actual reading taken with watt meter from cleaner	0.5 kW
Average instantaneous power consumption:	$(1.6\text{kW} + 0.5\text{kW}) / 2$	1.05 kW
Power consumption per hour	$1.05\text{kWh} * 25\%$	0.2625 kWh
Total electricity cost per hour of manufacturing:	$0.2625\text{kWh} * \$0.1/\text{kWh}$	<b>\$0.026 / hour</b>

Therefore, the electricity cost for operating the cleaning system is \$0.026 per given work hour, based upon the assumptions made.

### **9.3.2 WATER CONSUMPTION**

Being a closed loop system, the cleaning system should theoretically not require the influx of any additional water volume because of recycling. Unfortunately however, water is lost by evaporation through vents, and entrance and exit areas which are open. This leads to the inevitable fact that water is input to the system as needed to replace the evaporated water. Fortunately for this calculation, there is a built in inflow water meter on the inflow water pipe. Assumptions made for calculation included:

- The built in volume flow meter is calibrated correctly and yielded correct readings
- There are 52 work weeks in a year with 5 work days per week
- There are two 8 hour shifts utilized per work day
- Deionized water in this industrial setting costs \$0.05 per gallon

The calculation of the water consumption cost per hour based on these assumption can be seen below in Table 24.

**TABLE 24: Water Consumption Cost Calculation**

Factor	Calculation	Total
Gallons consumed between 8/1/94 (installation date) and 7/1/96	Actual reading taken from influx volume flow meter	9821 Gallons
Work days between readings	100 Weeks * 5 Days / Week	500 Work Days
Work hours between readings	500 Days * 16 Hours / Day	8000 Work Hours
Gallons consumed per work hour	9821 Gallons / 8000 Hours	1.23 Gallons / Work Hour
Water cost per work hour	1.23 Gallons * \$0.05 / Gallon	<b>\$0.06 Per Hour</b>

Therefore, the water consumption cost per given work hour is \$0.06 per hour based upon the assumptions made.

### **9.3.3 PROCESSING LABOR DURING CLEANING**

A portion of an assemblers time is required operate the cleaner for cleaning operations. This time includes placing and removing the assembly in to the washer and monitoring the system during cleaning. To perform this calculation, the assumptions included:

- Cleaner is utilized 25% of manufacturing time per hour
- The average assembler labor rate is \$8.00 per hour

The calculation for processing labor cost required for cleaner operation is therefore:

$$0.25 \text{ Hours Usage / Work Hour} * \$8.00 \text{ Labor / Work Hour} = \mathbf{\$2.00 \text{ Labor / Work Hour}}$$

#### **9.3.4 FILTER REPLACEMENT**

Although there is no steady stream of waste effluent from this type of recycling system, the filters do periodically wear out and require replacement. There are two types of filters used in series for the recycling system; ion exchange filters to remove ionized materials, and mechanical filters to remove particulate matter. The time between replacement of the filters is dependent upon the actual amount the cleaner is used and the volume of the ionic materials cleaned off of assemblies. Since this varies considerably for Tristars manufacturing setting, the assumption that filter replacement intervals occur every six months was made. This is based upon the empirical intervals for replacement seen at Tristar, which have been close to that value. Other assumptions included:

- The washer is utilized 25% of a given work hour
- There are 52 work weeks in a year with 5 work days per week
- There are two 8 hour shifts utilized per work day

The calculation of the cost of filter replacement can be seen in Table 25.

**TABLE 25: Filter Replacement Cost Breakdown Per Work Hour Used**

Factor	Calculation	Total
Cost per filter change	Quote from manufacturer	\$2000.00
Work days in six month period	26 Weeks * 5 Work Days / Week	130 Work Days
Hours utilized in six month period	130 Days * 16 Work Hours / Day	2080 Work Hours
Cost of filter change per work hour used	\$2000.00 / 2080 Work Hours	<b>\$0.96 Per Work Hour</b>

The filter replacement cost relative to each work hour used is therefore \$0.96.

### **9.3.5 MISCELLANEOUS MAINTENANCE MATERIALS**

Due to wear and tear, other materials besides filters require replacement periodically. These include pumps, gaskets, hoses, and other similar components. Based upon maintenance records for the period of the previous year, the maintenance materials required to maintain operation can be estimated. The assumptions made for this calculation include:

- The materials required for the previous year are representative of costs every year
- There are 52 work weeks per year, 5 work days per week, and 16 work hours per day

The calculation of the material cost per work hour can be seen in Table 26.

**TABLE 26: Miscellaneous Cleaner Material Maintenance Cost**

Factor	Calculation	Total
Total misc. material cost for fiscal year '95	Based on receipts	\$473.00
Work hours per year	52 Weeks * 5 Work Days/Week * 16 Work Hours/day	4160 Work Hours
Misc. material cost per work hour	\$473.00 / 4160 Hours	<b>\$0.11 / Work Hour</b>

Therefore, the total miscellaneous material cost for maintaining the cleaner is \$0.11 per work hour.

### **9.3.6 MAINTENANCE LABOR COSTS**

To perform maintenance on the cleaning system, maintenance personnel labor is utilized. To accurately determine the percentage of time maintenance personnel work on the cleaning system is very difficult to determine. The maintenance logs at Tristar do not



reflect the amount of time spent, but rather only the dates and specific problem fixed. Conversations with maintenance personnel led to the guesstimate of total percentage of work time spent on cleaner to be 2.5% of each work day. The assumptions for this calculation included:

- The percentage of a given work period that is spent maintaining the cleaner is 2.5%
- The average maintenance labor cost is \$12.00 per hour

The calculation for total maintenance labor cost per hour is therefore:

$$\text{\$12.00 Labor / Hour} * 0.025 \text{ Hours Labor / Work Hour} = \text{\$0.30 / Work Hour}$$

### **9.3.7 FLOOR SPACE**

Although the building and floor space is owned by Tristar, it constitutes space which could be utilized alternately. The value of the floor space must therefore be considered in the calculations. Assumptions made for this calculation include:

- Total floor space occupied by in-line and recycling system with surrounding access areas is approximately 1000 square feet
- Floor space cost per year = \$10.00/square foot

The calculation of the floor space cost per hour is therefore:

$$(\text{1000 Square Feet Total} * \text{\$10.00/Square foot per Year}) / (\text{365 Days/Year} * \text{24 Hours/Day}) = \text{\$1.14/Hour}$$

It should be noted that this floor space cost is entirely independent of the degree to which the cleaner is utilized. The floor space cost is present as long as the washer is occupying space on the floor, and can not be eliminated unless 100% conversion to a no-clean process occurs.

### **9.3.8 CLEANER EQUIPMENT CAPITAL COST**

The original cost that was spent to purchase the cleaning system with all its options was \$76,010.00. Because this is a one time cost, it can not be equated to relative cost per hour. Savings from the purchase price of the cleaner equipment can only be

realized if 100% conversion to a no-clean process is implemented, and the cleaner can be eliminated.

### **9.3.9 AQUEOUS CLEANER TOTAL COSTS**

**TABLE 27: Total Cleaner Operation Cost Per Work Hour**

<b>Cost Factor</b>	<b>Cost Per Work Hour</b>
Electricity Consumption	\$0.026
Water Consumption	\$0.06
Processing Labor During Cleaning Operations	\$2.00
Filter Replacement	\$0.96
Miscellaneous Maintenance Materials	\$0.11
Maintenance Labor	\$0.30
Floor Space	\$1.14
Capital Equipment Purchase Price	Not Applicable
<b>TOTAL</b>	<b>\$4.60 / Work Hour</b>

Therefore, the total cost to operate the cleaning system per work hour is \$4.60, based upon the assumptions made. Essentially what this number means is that for every work hour, all the associated costs for running and maintaining the cleaner total \$4.60 per work hour for Tristars current process.

### **9.3.10 CLEANER OPERATION SAVINGS FROM PERCENTAGE CONVERSION TO NO-CLEAN**

If a certain percentage of product types are switched to a no-clean process, the cleaner system would not be used for those products. This reduced usage would therefore result in a corresponding decrease in cleaner operation cost per work hour. To determine this operational cost savings, the factors which are independent of usage must be subtracted from the total. In this case, the cost factors which have no dependence

upon the usage of the machine include the floor space and the capital investment. Since the capital cost is not applicable to this calculation, only the floor space cost is a constant and is subtracted from the total. Therefore the equation to determine the cleaner operation savings for a given fraction of conversion is:

$$Y - (((1-X) * Z) + C) = \text{Cleaner Operation Savings Cost For Given Percent No-clean Conversion Per Work Hour}$$

Where:

X = Fraction of production converted to no-clean

Y = Total cleaner operational cost for current cleaning process<sup>φ</sup>

Z = Variable cleaner operational cost for current cleaning process<sup>φ</sup>

C = Volume independent (constant) cleaner operational cost<sup>φ</sup>

φ: Normalized to units per work hour

Example; If 25% of production was converted to no-clean, then the cleaner operational cost savings would be:

$$4.60 - (((1-0.25)*(3.46))+1.14) = \$0.86 \text{ Per Work Hour}$$

Cleaner operational cost savings for any fraction of no-clean conversion would be calculated the same way.

#### **9.4 NO-CLEAN SOLDERING MATERIAL CONVERSION COSTS**

Unfortunately, no-clean solder pastes tend to be slightly more expensive than their cleaned counterparts. Instead of cost savings in this case, some additional costs are incurred when no-clean solder paste is utilized. To quantify this, the throughput and the amount of solder paste used for each product must be known. For a contract manufacturing situation such as Tristar, these values vary widely and representative assumptions must be made.

To establish some basis for quantities of paste used per board, the weights of paste deposited on to each of ten different product types were weighed and averaged. The average weight was found to be 15 grams. This value was used as representative. Looking at the shipping backlog for a one month period, a representative quantity of

SMT boards assembled per day of approximately ten was found. Dividing 10 boards by an assumed 16 hour work day yields an average of 0.625 SMT assemblies produced per work hour. This means that a total of 9.375 grams of paste are used per work hour (0.625 units times 15 grams per unit). To be converted to cost liability per work hour, the difference in price between no-clean current aqueous clean pastes had to be found. Based upon standard purchase quantities of Tristar, the costs of no-clean (PASTE C) and aqueous (TRISTAR CURRENT) pastes are \$0.229/gram<sup>25</sup> and \$0.21/gram respectively. Therefore, the cost liability of using no-clean solder paste based upon these assumptions is:

$$\text{Solder Paste Cost Liability of Conversion} = -(\text{X})((\text{Price of no-clean paste/gram} - \text{Price of current paste/gram}) * \text{Grams used per Hour})$$

Where:

X = Fraction of production converted to no-clean  
The negative sign is indicative of the liability

Example; If 25% of SMT production were converted to no-clean solder paste, then the increased cost of no-clean solder paste would result in a cost liability per work hour of:

$$-(0.25)((\$0.229 - \$0.21) * 9.375) = -\$0.045 \text{ Per Work Hour}$$

Although extreme assumptions were made to determine this value, any fraction of conversion could be calculated the same way.

## **9.5 TOTAL COST SAVINGS OR LIABILITY FOR NO-CLEAN CONVERSION**

To find the total savings or liability between the solder paste and the cleaner operational costs, the two numbers are simply combined. The calculation is simply:

$$\text{Total Cost Savings per Work Hour} = (\text{Cost of cleaner operation per work hour}) + (\text{Cost of solder paste conversion per work hour})$$

---

<sup>25</sup> Purchase quote from Dyess Supply Company, Fort Worth Texas, 7/28/96.

For the example of 25% conversion:

$$\begin{aligned} \text{Total Cost Savings per Work Hour} = \\ (\$0.86 + (-\$0.045)) = \$0.815 \text{ per Work Hour} \end{aligned}$$

It should be noted that if 100% conversion to a no-clean process were accomplished, then the constant costs such as capital and floor space costs would be considered savings and not liabilities.

This technique presented made many assumptions, which may or may not be realistic. In such a variable situation as contract manufacturing, without considerable long term data to substantiate values for these parameters, these types of assumptions must be made. Although this technique only takes cleaner savings costs and solder paste liability costs in to consideration, it should be noted that there are other less easily quantified considerations of conversion which must be taken into account.

## **9.6 FINANCIAL IMPLICATIONS OF CONVERSION CONCLUSIONS**

The impetus for conversion to a no-clean process may be driven by many factors, as previously mentioned. If cost is the main driver, it must be understood that in any manufacturing setting, the up front cost will likely be high but can potentially open the door for a more cost effective process after conversion. Because every manufacturing setting is different, the economic analysis for each should be approached as such. There is no right or wrong way to perform a financial analysis for conversion. The procedure presented in this study is merely one way of approaching quantifying conversion. It only considers the cost savings and liabilities resulting from less cleaner operation when a fraction of production utilizes no-clean and the change in solder paste costs for a no-clean process.

As is usually true for any new process change, there are many difficult to quantify areas where costs may be saved or incurred. Some of these areas include the potential throughput increases from eliminating the cleaning step from processing and the up front engineering time spent qualifying and changing to the new process. For the purposes of this study, these areas were not addressed. For a more complete listing of savings or liability concern areas, see the section in Chapter 4 on no-clean advantages and concerns.

## **CHAPTER 10: OVERALL CONCLUSIONS AND RECOMMENDATIONS**

### **10.1 OVERALL CONCLUSIONS**

No-clean soldering is a viable alternative to cleaning assembled PCB's. Utilization of no-clean solder pastes will allow many benefits to be realized. Some of these benefits include the elimination of all previous cleaning waste effluents, the capital investment along with other associated costs of cleaning equipment, increased throughput, and many others. To obtain satisfactory results however, the many concerns of no-clean soldering must be addressed such as firm up front commitment, proper testing, qualification and education of associated personnel. For many cases, existing manufacturing equipment can be utilized successfully with no-clean solder pastes. Some processing changes will undoubtedly have to be made though, to ensure equal or better quality than current processes. Some of these areas include tighter incoming material controls, handling practices, and more frequent audits. With proper care and time, no-clean soldering can be successfully implemented in to both high and low quantity assembly environments with small or large product mixes.

### **10.2 RECOMMENDATIONS FOR FUTURE RESEARCH**

While many qualification tests were performed for this study, this implementation strategy is merely one approach to implementing no-clean soldering for SMT. Some areas of research that were over looked during this examination include:

- Comparing current and future stencil manufacturing/design technologies and the performance of no-clean pastes with them
- The effect on no-clean residue composition resulting from reflow profile changes
- The effect of soldering performance when utilizing an inert reflow environment such as nitrogen
- No-clean wave soldering and hand soldering
- Conformal coating adhesion and testing issues
- Solderless no-clean (conductive polymer) materials

- Other evaluation tests that were not completed for this study

As new innovative soldering materials and processes push the boundaries of electronics assembly, there will always be countless areas of research that may be accomplished.

# APPENDIX A

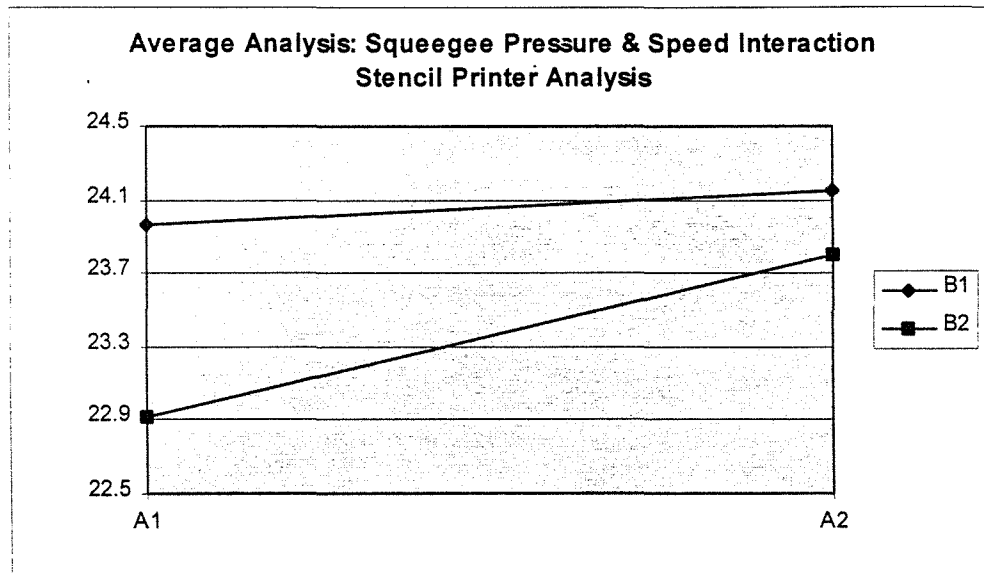
**TABLE A-1: Solder Balling Test Results**

TIME (HOURS)	PASTE A	PASTE B	PASTE C	PASTE D	PASTE E	PASTE F	PASTE G	PASTE H	PASTE I	PASTE J
0	8	7	6	6	2	12	30	13	5	4
1	9	8	8	3	7	26	30	15	5	3
2	10	5	9	10	5	13	30	14	5	3
3	8	11	12	8	3	19	30	18	4	5
4	8	10	11	8	2	11	30	11	4	7
Average	8.6	8.2	9.2	7	3.8	16.2*	30*	14.2*	4.6	4.4

\* Designates Unacceptable Solder Balling Levels

**TABLE A-2: Interaction Effect on Average For Squeegee Pressure and Speed**

	B1	B2
A1	23.96	22.91
A2	24.15	23.8

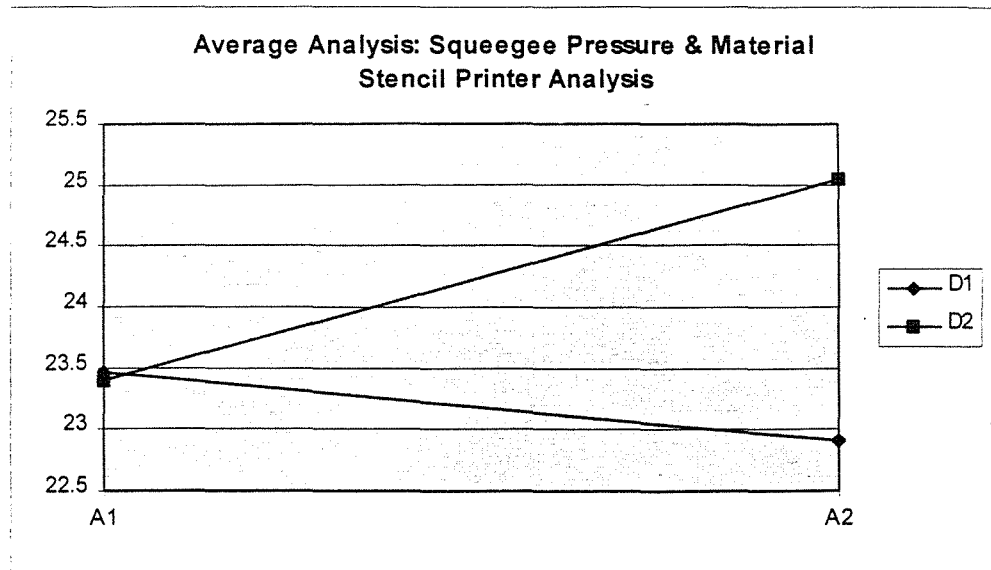


**FIGURE A-1: Interaction Effect on Average For Squeegee Pressure and Speed**

**TABLE A-3: Interaction Effect on Average For Squeegee Pressure and Material**

	D1	D2
A1	23.47	23.4
A2	22.91	25.04

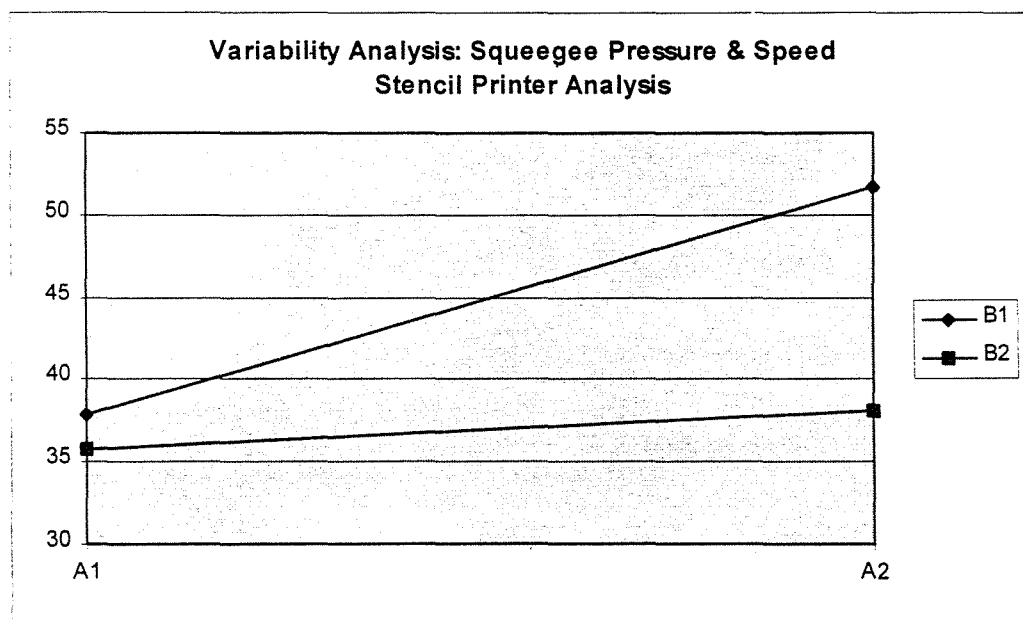




**FIGURE A-2: Interaction Effect on Average For Squeegee Pressure and Material**

**TABLE A-4: Interaction Effect on Variability For Squeegee Pressure and Speed**

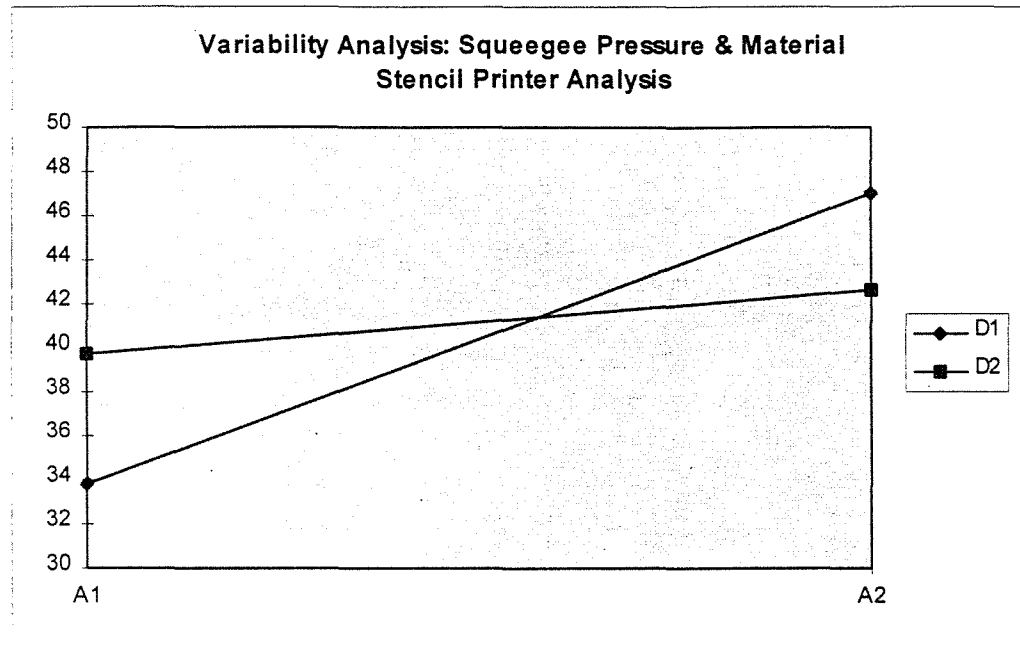
	B1	B2
A1	37.81	35.7
A2	51.63	38.03



**FIGURE A-3: Interaction Effect on Variability For Squeegee Pressure and Speed**

**TABLE A-5: Interaction Effect on Variability For Squeegee Pressure and Material**

	D1	D2
A1	33.79	39.72
A2	47.03	42.62



**FIGURE A-4: Interaction Effect on Variability For Squeegee Pressure and Material**

# APPENDIX B

## IPC Industry Standard Test Methods

### IPC-TM-650-2.4.35: Solder Paste-Slump Test

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#### IPC-TM-650 TEST METHODS MANUAL

**1.0 Scope** This procedure determines vertical and horizontal slump for solder pastes.

**2.0 Applicable Documents** None

**3.0 Test Specimen** A standard specimen shall be prepared using a clean frosted glass microscope slide measuring 7.6 cm x 2.5 cm, minimum 1 mm thick. An equivalent alumina or glass epoxy substrate may be used.

**4.0 Equipment/Apparatus**

Stencils

IPC-A-21, IPC-A-20

Steel Squeegee (razor blade)

Oven

Microscope

**5.0 Procedure**

**5.1 Preparation**

**5.1.1** Specimen preparation using appropriate stencil pattern IPC-A-21 or IPC-A-20. (Figures 1 & 2) Deposit solder paste patterns on 2 substrates for each stencil pattern. The printed pattern shall be uniform in thickness with no solder particles separated from the pads. The vendor and user should use the same printing method.

Table 1

Stencil IPC-A-21 (0.2 mm Thick)					
Pad size 0.63 x 2.03 mm			Pad size 0.33 x 2.03 mm		
Spacing mm	Hor.	Vert.	Spacing mm	Hor.	Vert.
0.79			0.45		
0.71			0.40		
0.63			0.35		
0.56			0.30		
0.48			0.25		
0.41			0.20		
0.33			0.15		
			0.10		
			0.08		

Table 2

Stencil IPC-A-20 (0.1 mm Thick)					
Pad size 0.33 x 2.03 mm			Pad size 0.2 x 2.03 mm		
Spacing mm	Hor.	Vert.	Spacing mm	Hor.	Vert.
0.45			0.30		
0.40			0.25		
0.35			0.20		
0.30			0.175		
0.25			0.15		
0.20			0.125		
0.15			0.10		
0.10			0.075		
0.08					

Number <b>2.4.35</b>	
Subject <b>Solder Paste—Slump Test</b>	
Date <b>1/95</b>	Revision
Originating Task Group <b>Solder Paste Task Group (5-22b)</b>	

**5.1.2** One test specimen shall be marked as specimen #1 and one specimen as #2 and processed in accordance with paragraphs 5.2.1 and 5.2.2.

**5.2 Test**

**5.2.1** The specimens shall be stored for 10 to 20 minutes at 25 +/-5°C and 50% relative humidity +/-10% and specimen #1 examined for slump.

**5.2.2** Specimen #2 from 5.2.1 shall be heated to 150 +/-10°C for 10 to 15 minutes, cooled to ambient and examined for slump.

**5.3 Evaluation** Enter data in Table 1 and/or Table 2 by entering spacings which have bridged with a suitable check mark.

# IPC-TM-650-2.4.35: Solder Paste-Slump Test Continued

IPC-TM-650		
Number 2.4.35	Subject Solder Paste—Slump Test	Date 1/95
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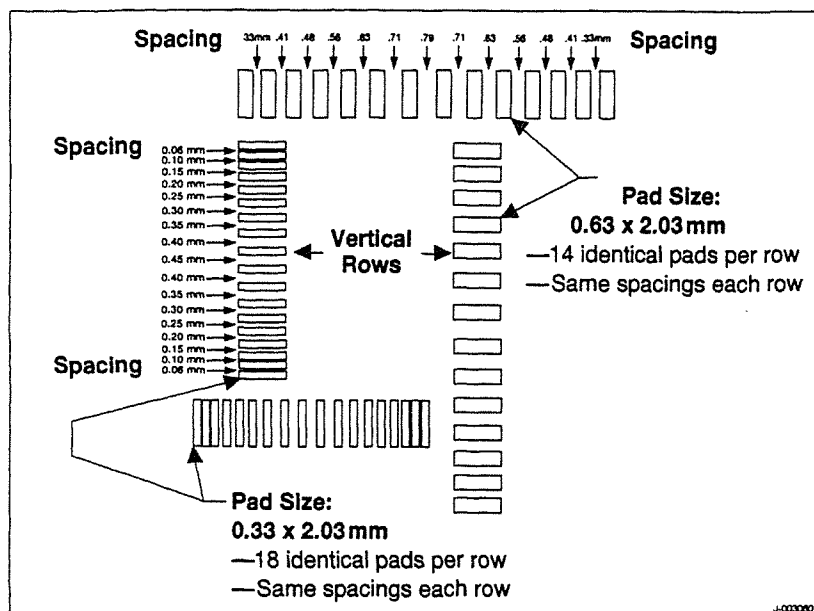


Figure 1 Slump test stencil, IPC-A-21

IPC-TM-650		
Number 2.4.35	Subject Solder Paste—Slump Test	Date 1/95
Revision		

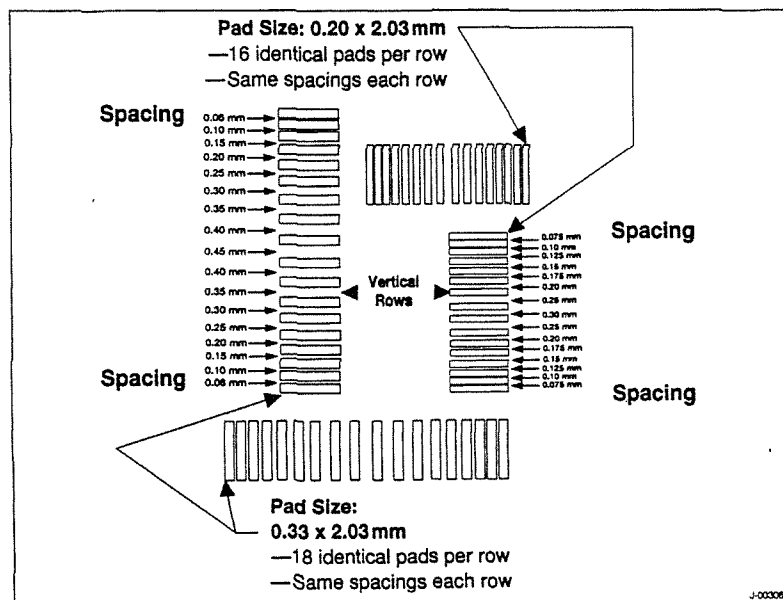


Figure 2 Slump test stencil, IPC-A-20

# IPC-TM-650-2.4.45: Solder Paste- Wetting Test

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## IPC-TM-650 TEST METHODS MANUAL

Number <b>2.4.45</b>	
Subject <b>Solder Paste—Wetting Test</b>	
Date <b>1/95</b>	Revision
Originating Task Group <b>Solder Paste Task Group (5-22b)</b>	

**1.0 Scope** Determine the ability of a solder paste to wet an oxidized copper surface and to qualitatively examine the amount of spatter of the solder paste during reflow.

**2.0 Applicable Documents** None

**IPC-TM-650 Test Methods Manual**

2.4.43 Solder Paste—Solder Ball Test

### 3.0 Test Specimen

7.6 cm x 2.5 cm x 0.8 mm specimen of 1 ounce oxygen-free high conductivity (OFHC) copper.

### 4.0 Equipment/Materials/Apparatus

Flat hot plate

Specimen tongs

Beaker 400 cc

Magnifying glass with 10 times magnification

Liquid copper cleaner

Deionized water

Isopropyl alcohol

Solvent for residual flux removal

**4.1** Stencil 76 mm x 25 mm x 0.2 mm provided with at least 3 round holes or 6.5 mm diameter aperture with a minimum between centers of 10 mm.

### 5.0 Procedure

#### 5.1 Preparation

**5.1.1** The specimen shall be cleaned with a liquid copper cleaner, washed thoroughly with water, rinsed with isopropyl alcohol, dried and then placed in boiling deionized water for 10 minutes and air dried

#### 5.2 Test

**5.2.1** Place stencil on test specimen and print solder paste test pattern.

**5.2.2** Reflow using the procedure outlined in paragraph 5.2.3.2 of IPC-TM-650, Test Method 2.4.43.

**5.2.3** After reflow, the residual flux shall be removed with a suitable solvent.

**5.3 Evaluation** When examined visually at 10X, the solder shall uniformly wet the copper and there should be no evidence of dewetting or non-wetting of the copper and there shall be no solder spatter around the printed dots.

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## IPC-TM-650 TEST METHODS MANUAL

**1.0 Scope** This test method is designed to determine the corrosive properties of flux residues under extreme environmental conditions. A pellet of solder is melted in contact with the test flux on a sheet metal test piece. The solder is then exposed to prescribed conditions of humidity and the resulting corrosion, if any, is assessed visually.

### 2.0 Applicable Documents

IPC-TM-650 Test Methods Manual

#### 2.3.34 Solids Content, Flux

**British Standard Institute BS5625** Specification of Purchasing Requirements and Methods of Test for Fluxes for Soft Soldering

**3.0 Test Specimen** At least 0.035 g of flux solids, 1 g solder paste, 1 g wire, or 1 g preform with an equivalent amount of solids. Flux solids are defined as the residue from the solids content, fluxes test described in IPC-TM-650, Test Method 2.3.34. All solvent must have been evaporated from the specimen in a chemical fume hood.

### 4.0 Apparatus and Reagents

1. Solder pot
2. Humidity chamber capable of achieving  $50 \pm 2^\circ\text{C}$  and  $95 \pm 2\%$  relative humidity.
3. Air circulating drying oven
4. Microscope having 20X minimum
5. Chemicals: All chemicals must be reagent grade and water must be distilled or demineralized:
  - a. Ammonium persulphate
  - b. Sulfuric acid, % v/v
  - c. Degreasing agent, Acetone, Toluene, or Petroleum ether.
6. Analytical balance capable of weighing 0.001 g

### 5.0 Procedures

#### 5.1 Preparation

##### 5.1.1 Chemicals

Number <b>2.6.15</b>	
Subject <b>Corrosion, Flux</b>	
Date <b>1/95</b>	Revision <b>B</b>
Originating Task Group <b>Flux Specifications Task Group (5-22d)</b>	

**5.1.1.1** Ammonium persulphate (25% m/v in 0.5% v/v sulfuric acid). Dissolve 250 g of ammonium persulphate in water and add cautiously 5 ml of 5% sulphuric acid (relative density 1.84). Mix, cool, dilute to 1 liter and mix. This solution should be freshly prepared.

**5.1.1.2** Sulfuric acid (5% v/v). To 400 ml of water cautiously add 50 ml of sulfuric acid (relative density 1.84). Mix, cool, dilute to 1 liter and mix.

#### 5.1.2 Test Panel

**5.1.2.1** Cut a  $0.50 \pm 0.05$  mm thick piece of 99% pure copper 51 mm x 51 mm for each test.

**5.1.2.2** Form a circular depression in the center of each test panel 3.2 mm deep by forcing a 19 mm steel ball into a 25.4 mm hole to form a cup.

**5.1.2.3** Bend one corner of each test panel up to facilitate subsequent handling with tongs.

#### 5.1.3 Pre-treating Test Panels

**5.1.3.1** Immediately before performing test, pretreat as follows using clean tongs for handling.

- A. Degrease with a suitable neutral organic solvent such as acetone, toluene, or petroleum ether.
- B. Immerse in 5% sulfuric acid (by volume) at  $65 \pm 5^\circ\text{C}$  for 1 minute to remove the tarnish film.
- C. Immerse in a solution of 25% m/v ammonium persulphate (0.5% v/v sulfuric acid) at  $23 \pm 2^\circ\text{C}$  for 1 minute to etch the surface uniformly.
- D. Wash in running tap water for a maximum of 5 seconds.
- E. Immerse in 5% sulfuric acid (by volume) at  $23 \pm 2^\circ\text{C}$  for 1 minute.
- F. Wash for 5 seconds in running tap water, then rinse thoroughly in demineralized water.
- G. Rinse with acetone.
- H. Allow to dry in clean air.

**5.1.3.2** Use the test piece as soon as possible or store up to 1 hour in a closed container.

IPC-TM-650		
Number <b>2.6.15</b>	Subject <b>Corrosion, Flux</b>	Date <b>1/95</b>
Revision <b>B</b>		

**5.1.4 Preparation of Test Solder**

**5.1.4.1** Weigh 1.00 gram  $\pm 0.05$  gram specimen of solder for each test and place in center of depression of each test panel.

**5.1.4.2** Degrease solder specimen with a suitable neutral organic solvent such as acetone, toluene, or petroleum ether.

**5.1.4.3** Solder may be in the form of pellets or by forming tight spirals of solder wire.

**5.2 Test**

**5.2.1** Heat solder pot so that solder bath stabilizes at  $235 \pm 5^\circ\text{C}$ .

**5.2.2 Liquid Flux** Place 0.035 g of flux solids into the depression in the test panel. Add solder sample.

**5.2.2.1 Solder Paste, Cored-Wire or Cored-Preform**

Place 1 g of solder paste, flux-cored wire or cored-preform into the depression in the test panel.

**5.2.3** Using tongs, lower each test panel onto the surface of the molten solder.

**5.2.4** Allow the test panel to remain in contact until solder specimen in the depression of the test panel melts. Maintain this position for  $5 \pm 1$  seconds.

**5.2.5** Carefully examine test specimen at 20X magnification for subsequent comparison after humidity exposure. Record observations, especially any discoloration.

**5.2.6** Preheat test panel to  $40 \pm 1^\circ\text{C}$  for  $30 \pm 2$  minutes.

**5.2.7** Preset humidity chamber to  $40 \pm 1^\circ\text{C}$  and  $93 \pm 2\%$  relative humidity.

**5.2.8** Suspend each test specimen vertically (and separately) in the humidity chamber.

**5.2.9** Expose specimens to the above environment for 240 hours (10 days). M and H may be tested in the cleaned, as well as uncleaned, condition.

**5.3 Evaluation** Carefully examine specimens prior to placing them in the environmental chamber. Note any discoloration.

**5.3.1** After the appropriate exposure period, remove test specimens from humidity chamber, examine at 20X magnification and compare with observations noted in paragraph 5.2.5.

**5.3.2** Corrosion is described as follows:

A. Excrescences at the interfaces of the flux residue and copper boundary, or the residues or discontinuities in the residues.

B. Discrete white or colored spots in the flux residues.

**5.3.3** An initial change of color which may develop when the test panel is heated during soldering is disregarded, but subsequent development of green-blue discoloration with observation of pitting of the copper panel is regarded as corrosion.

**6.0 Notes**

**6.1 Definition of Corrosion** For purposes of this test method, the following definition of corrosion shall prevail. "A chemical reaction between the copper, the solder, and the constituents of the flux residues, which occurs after soldering and during exposure to the above environmental conditions."

**6.2** Color photos before and after the test are valuable tools in identifying corrosion. (See 5.2.5.)

**6.3 Safety** Observe all appropriate precautions on MSDS for chemicals involved in this test method.

# IPC-TM-650-2.4.43: Solder Paste- Solder Ball Test

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7380 N. Lincoln Avenue • Lincolnwood, IL 60466-1705



## IPC-TM-650 TEST METHODS MANUAL

**1.0 Scope** This test is carried out to determine the reflow properties of the solder paste. The ability of the prealloyed solder particles in the paste to reflow into a sphere on a non-wettable substrate is determined under defined test conditions.

**2.0 Applicable Documents** None

**3.0 Test Specimen** Frosted glass microscope slide, alumina substrate or glass/epoxy printed circuit board with a thickness of 0.60 to 0.80 mm and a minimum length and width dimension of 76 mm and 25 mm, respectively.

### 4.0 Equipment/Apparatus

#### 4.1 Metal Stencils

**4.1.1 Stencil for Type 1-4** Stencil 76 mm x 25 mm x 0.2 mm provided with at least 3 round holes of 6.5 mm diameter apertures with a minimum distance between centers of 10 mm.

**4.1.2 Stencil for Type 5-6** Stencil 76 mm x 25 mm x 0.1 mm provided with at least 3 round holes of 1.5 mm diameter apertures with a minimum distance between centers of 10 mm.

#### 4.2 Spatula

**4.3** Solder bath not less than 100 mm x 100 mm x 75 mm deep containing solder suitable to maintain a temperature of 25°C above the liquidus temperature of the solder paste being evaluated.

#### 4.4 Flat hot plate

#### 4.5 Surface temperature thermometer

#### 4.6 Magnifying glass with a 10 to 20 times magnification.

### 5.0 Procedure

#### 5.1 Preparation

**5.1.1** Set the temperature of the solder bath or hot plate at a temperature of 25°C +/-3°C above the liquidus temperature of the solder alloy.

Number <b>2.4.43</b>	
Subject <b>Solder Paste—Solder Ball Test</b>	
Date <b>1/95</b>	Revision
Originating Task Group <b>Solder Paste Task Group (5-22b)</b>	

**5.1.2** Homogenize the solder paste by hand stirring with a spatula.

**5.1.3** Condition the paste to uniform temperature of 25° C +/-2°C.

**5.1.4** Prepare two test specimens with either/or both stencils listed above (4.1.1 and 4.1.2). The solder paste should be squeezed with the spatula to fill and level each hole.

### 5.2 Test

#### 5.2.1 Test Conditions

**5.2.1.1** Test one specimen within 15 +/-5 minutes after placement of solder paste on test coupon.

**5.2.1.2** Test the second specimen 4 hours +/-15 minutes after placement of solder paste on test coupon. Storage for 4 hours shall be at 25°C +/-3°C and 50 +/-10% RH.

#### 5.2.2 Conditioning Heating Equipment

**5.2.2.1** Clean the surface of the solder bath with the scraper.

**5.2.2.2** Remove all foreign material from the surface of the hot plate to ensure proper control.

**5.2.3 Solder Reflow** Reflow specimens by one of the following two methods.

**5.2.3.1** Lower the substrate, in a horizontal position with the paste deposit on top, into the solder bath at a speed of 25 +/-2 mm/second until the substrate is 50% submerged. It is important that good thermal contact is achieved between the molten solder and the substrate. As soon as the solder has melted, withdraw the substrate from the solder bath maintaining it in a horizontal position. The total time on the solder bath shall not exceed 20 seconds.

**5.2.3.2** Place the substrate on the hot plate. As soon as the solder has melted, withdraw the substrate from the hot plate maintaining a horizontal position. The reflow shall occur within 20 seconds after the specimen is placed in contact with the hot plate.



## IPC-TM-650-2.4.43: Solder Paste- Solder Ball Test Continued

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### 5.3 Evaluation

**5.3.1** Examine the reflowed specimens under 10X to 20X magnification.

**5.3.2** Solder ball size and number should be compared with Figure 1.

**5.3.3** Record the degree of reflow in comparison with Figure 1 for the 6.5 cm and 1.5 cm acceptance/reject conditions, respectively.

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Number <b>2.4.43</b>	Subject <b>Solder Paste—Solder Ball Test</b>	Date <b>1/95</b>
Revision		

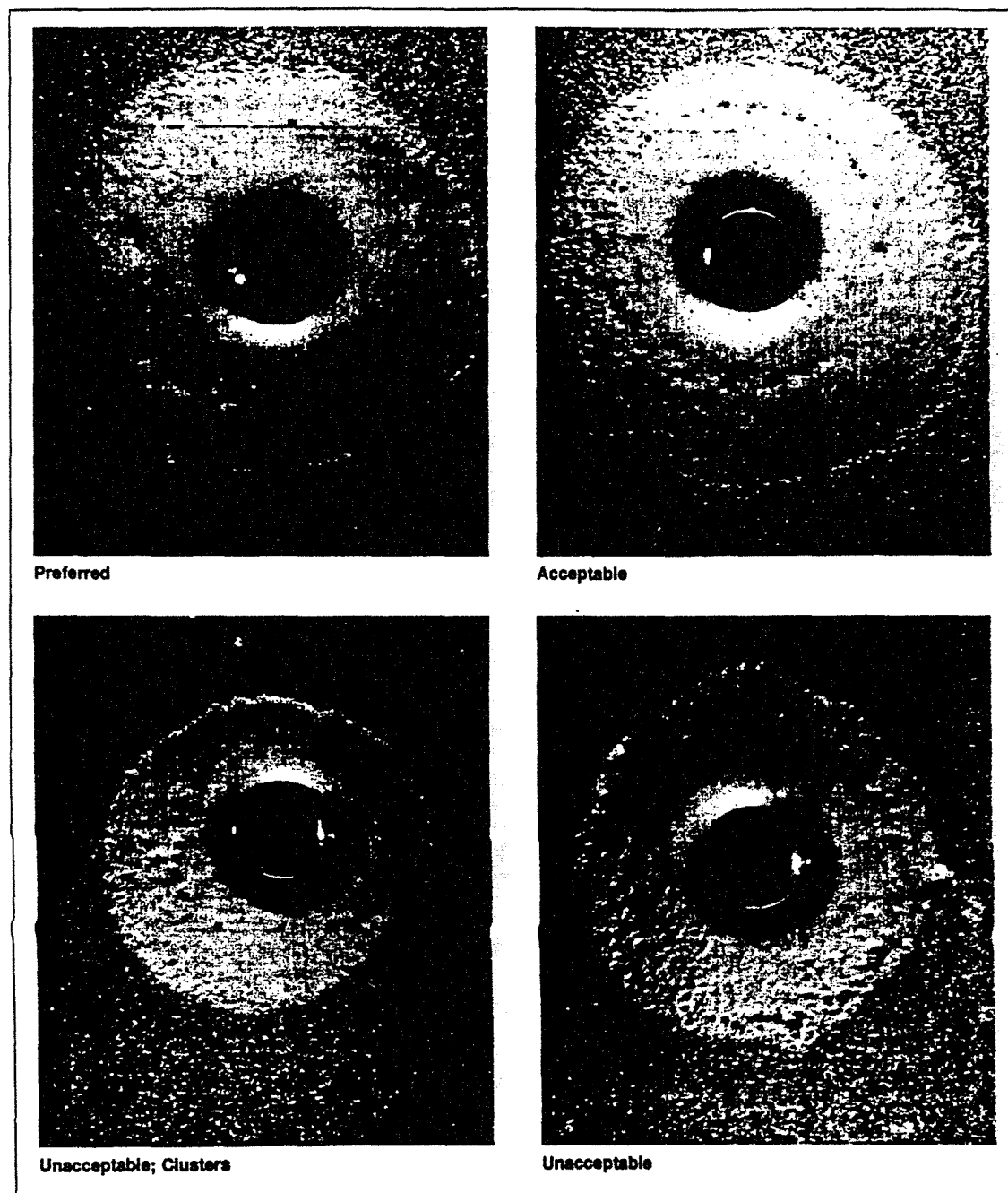


Figure 1 Solder ball test standards

## Appendix F

### Resistivity of Solvent Extract

**F-1** This appendix defines standard resistivity of solvent extract test methods for determining printed wiring assembly cleanliness.

#### F-2 GENERAL REQUIREMENTS

**F-2.1 Resistivity of solvent extract** Solvent extract resistivity shall be measured as follows:

- a. Prepare a test solution of 75+0/-2 percent by volume of reagent grade isopropyl alcohol, with the remainder being deionized water. Pass this solution through a mixed bed deionizer cartridge. After passing through the cartridge the resistivity of the solution shall be greater than or equal to 6±0.5 megohm-centimeters (conductivity shall be less than 0.166 microhms/cm).
- b. Use a clean plastic bag, which can be sealed, which is free of ionic contamination. It is recommended that a heat sealable bag (e.g., Kapak® type or equivalent) which contributes no ionic contamination, be used. Another option uses a plastic "zipper locking" type bag, that has been rinsed with a portion of test solution. Measure 1.55 milliliters of fresh test solution for each square centimeter of assembly area (10ml/sq.in.) into the clean plastic bag. The assembly area includes the areas of both sides of the board plus the components.
- c. Place the circuit board into the plastic bag with the test solution and seal the bag. The bag should be sufficiently large enough for the board, and the test solution shall be allowed to wash the surface of the board while in the bag. Shake the bag containing the circuit board and the test solution for approximately 10 minutes. Let the bag sit for 5 minutes with the assembly immersed in solution, then shake for an additional 5 minutes. Be careful not to let the corners of the board tear the bag while shaking.
- d. Remove the circuit assembly, and measure the ionic contamination of the test solution. The final resistivity shall not be below 2 megohm-centimeters (conductivity is 0.5 microhms/cm). A resistivity change from 6 to 2 megohm-centimeters indicates a contaminant level of 1.55 micrograms of ionic contaminant per square centimeter of board surface area.

**F-2.2 Sodium chloride salt equivalent ionic contamination test** Sodium chloride salt equivalent ionic contamination shall be measured as follows:

- a. The sodium chloride salt equivalent ionic contamination test shall use a solution of 75+0/-2 percent by volume of reagent grade of isopropyl alcohol with the remainder being deionized water. The solution shall be

verified for correct composition upon initial use, each shift, and according to manufacturers recommendations. The time limit may be extended when the results of data provide a definite indication that such actions will not adversely affect the results of the test.

- b. The equipment must be validated using a known amount of sodium chloride standard on the same schedule as the percentage composition verification.
- c. The starting, or reference, purity of the solution shall be greater than 20 megohm-centimeters, (conductivity shall be less than 0.05 microhms/centimeter) before each sample is tested.
- d. The test length shall be in accordance with manufacturers' recommendations, but in no case shall be less than 10 minutes.
- e. The final conductivity is based on reference to the NaCl standard. However, the final ionic contamination shall be less than 1.55 micrograms per square centimeter of board surface area.

**F-2.3 Alternate methods** Alternative equipment, with the appropriate equivalence values, may be used to verify cleanliness. The contractor shall develop equivalency factors for each individual system.

**NOTE:** There are several commercially available ionic cleanliness testers that have shown to be equivalent to or more efficient than resistivity of solvent extract method of paragraph F-2.1. These alternative equipments may be either a static method, where the test solution is continually circulated in the test cell at a fixed volume and then measured, or a dynamic method, where the test solution is constantly being measured as the volume flows past the assembly. There are many variables of each system that will affect the final resistivity, i.e., heat, solution volume, or sprays.

**NOTE:** Test procedures and calibration techniques for these methods are documented in Materials Research Report 3-78 "Review of Data Generated with Instruments Used to Detect and Measure Ionic Contaminants on Printed Wiring Assemblies." Application for copies of this report should be addressed to the Commanding Officer, Naval Air Warfare Center, Aircraft Division Indianapolis, Code DP3070N/MS-79, 6000 E. 21st Street, Indianapolis, IN 46219-2189.

# IPC-TM-650-2.3.25: Resistivity of Solvent Extract

The Institute for Interconnecting and Packaging Electronic Circuits  
7380 N. Lincoln Avenue • Lincolnwood, IL 60466-1705



## IPC-TM-650 TEST METHODS MANUAL

**1.0 Scope** This test method is designed for determining the presence of ionizable surface contaminants on printed-wiring boards and assemblies. The basis of the test is the change in electrical resistivity of the solvent used to wash the printed-wiring board or assembly. The resistivity is lowered when contaminants, such as plating salts, flux residues, etchants, or detergents, are dissolved.

### 2.0 Applicable Documents

**2.1** See 6.1, References

**3.0 Test Specimen** Any printed-wiring board or assembly of sufficient area to provide enough the solvent to determine its resistivity.

### 4.0 Test Equipment

**4.1** Miscellaneous laboratory ware such as beakers, funnels, storage and wash bottles. The laboratory ware may be made of glass or polyethylene but it is imperative that all apparatus used in this procedure be scrupulously clean.

**4.2** Conductivity Bridge, Barnstead Model PM-70CB or equivalent.

**4.3** Conductivity Cell, Beckman Model CEL-A01-Y87-CERT with a cell constant  $K = 0.10/\text{cm}$  or equivalent.

**4.4** Wash solution composed of 75% by volume, ASC Reagent Grade isopropyl alcohol, 25% by volume distilled water with a minimum resistivity of  $6.0 \times 10^6 \text{ ohm-cm}$ .

**4.5** Linear measuring device such as calipers' capable of measuring the area of the printed-wiring board or assembly to the nearest  $25.4 \text{ mm}^2$  [ $1.0 \text{ in.}^2$ ].

### 5.0 Test Procedure

**5.1** Determine the surface area of the printed-wiring board or assembly including both sides of the board and an estimate of the area of any components mounted thereon.

**5.2** Suspend the test specimen within a convenient sized funnel positioned over a collection breaker.

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**5.3** Use 100 milliliters of wash solution for each  $250 \text{ mm}^2$  [ $10 \text{ in.}^2$ ] of the board or assembly area and direct in a fine stream on both sides of the test specimen. The wash activity shall occur for a minimum of one (1) minute. It is imperative that the initial washings be included in the sample to be measured for resistivity.

**5.4** Measure the resistivity of the collected wash solution in accordance with the conductivity bridge manufacturer's instructions.

### 6.0 Notes

**6.1 References** This test procedure, including solution preparation and a laboratory ware cleaning procedure, is documented in Materials Research Report No. 3-72. "Printed- wiring assemblies; Detection of ionic contaminants on". Application for copies of this report should be addressed to:

Freedom of Information Act Office  
Naval Avionics Center  
6000 East 21st Street  
Indianapolis, IN 46219-2189

# IPC-TM-650-2.6.3.3: Surface Insulation Resistance, Fluxes

The Institute for Interconnecting and Packaging Electronic Circuits  
7360 N. Lincoln Avenue • Lincolnwood, IL 60465-1705



## IPC-TM-650 TEST METHODS MANUAL

**1.0 Scope** This test method is to characterize fluxes by determining the degradation of electrical insulation resistance of rigid printed wiring board specimens after exposure to the specified flux. This test is carried out at high humidity and heat conditions.

### 2.0 Applicable Documents

IPC-B-24 Surface Insulation Resistance Test Board

IPC-A-600 Acceptability Guidelines

### 3.0 Test Specimens

**3.1 Comb Patterns** Use the IPC-B-24 test pattern which consists of four comb patterns per coupon. The individual comb, pictured in Figure 1, has 0.4 mm lines and 0.5 mm spacing. The test coupon shall be unpreserved bare copper metallization.

**3.2 Laminate** The laminate material for this test shall be FR-4 epoxy-glass.

### 4.0 Apparatus

**4.1** A clean test chamber capable of programming and recording an environment of  $25 \pm 10/-2^\circ\text{C}$  to at least  $85 \pm 2^\circ\text{C}$  and  $85\% \pm 2\%$  relative humidity. A salt solution and desiccator may be used to maintain humidity if a tight temperature control is maintained on the temperature of the chamber.

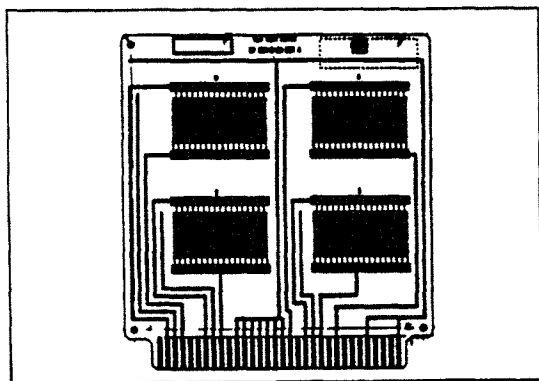


Figure 1 Typical "Comb Pattern" (from IPC-B-24)

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**4.2** A power supply capable of producing a standing bias potential of 45–50 volts DC with a tolerance of  $\pm 10\%$ .

**4.3** A resistance meter capable of reading high resistance ( $10^{12}$  ohms) with a test voltage of 100 volts or an ammeter capable of reading  $10^{-10}$  amps in combination with 100 volts DC power supply.

**4.4** Three 2000 ml beakers

**4.5** Exhaust ventilation hood.

**4.6** Metal tongs.

**4.7** Soft bristle brush

**4.8** Deionized or distilled water (2 megohm-cm, minimum resistivity recommended).

**4.9** Drying oven capable of maintaining at least  $50^\circ\text{C}$ .

### 5.0 Test

**5.1 Test Conditions** All fluxes will be tested at  $85 \pm 2^\circ\text{C}$ ,  $85 \pm 2\%$  relative humidity for 168 hours.

**5.2 Specimen Preparation** There shall be 3 test coupons for each liquid flux to be tested in the cleaned state (see Table 1, A). When testing liquid fluxes which are intended to remain in the uncleaned state, six test coupons are required. Three uncleaned test coupons shall be wave soldered pattern side down (Table 1, B) and three shall be wave soldered pattern side up (Table 1, C).

Solder paste coupons shall be reflowed pattern side up and either cleaned (Table 1, D) or not cleaned (Table 1, E). In addition, there shall be at least 2 unprocessed control coupons for comparison purposes (Table 1, F).

**5.2.1** Positive, permanent and non-contaminating identification of test specimens is of paramount importance. (For example, a vibrating scribe.)

**5.2.2** Visually inspect the test specimens for any obvious defects, as described in IPC-A-600. If there is any doubt about the overall quality of any test specimen, the test specimen should be discarded.

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Table 1 Coupons for SIR Testing

Sample Group	Flux/Solder	Clean	Number of Coupons
A	yes	yes	3
B	yes	no	3
C	yes	no	3
D	yes	yes	3
E	yes	no	3
F	no	no	2

A = Pattern down/clean

B = Pattern down/no clean

C = Pattern up/no clean

D = Solder paste/reflow/clean

E = Solder paste/reflow/no clean

F = Control (precleaned, unprocessed)

**5.2.3** Clean the test coupon with deionized or distilled water and scrub with a soft bristle brush for a minimum of 30 seconds. Spray rinse thoroughly with deionized or distilled water. Rinse cleaned area thoroughly with fresh 2-propanol.

An alternative cleaning method is to place the test coupon in an ionic contamination tester containing 75% 2-propanol, 25% deionized water and process the solution until all ionics have been removed.

During the remainder of the specimen preparation, handle test specimens by the edges only, or use non-contaminating rubber gloves.

**5.2.4** If boards are to be stored before treatment, place the boards in Kapak bags or other contamination-free containers and close bags (do not heat seal). (Kapak bags are available from Fischer, VWR and other distributors).

### 5.3 Procedure

#### 5.3.1 Sample Preparation Flux application and soldering.

**5.3.1.1 Liquid Flux or Flux Extract** Coat the comb pattern with a thin coating of the liquid flux or flux extract under test.

**5.3.1.1.1** The test coupons shall be exposed to solder by floating the fluxed comb patterns of the test specimens face down on the solder pot at 245-260°C for 4 ± 1 seconds. Wave solder of comb patterns face down at 245-260°C and a conveyor speed with a contact time of 3 ± seconds. For fluxes to be tested in the uncleaned state, a second set of comb patterns shall be fluxed and floated pattern up on the solder pot or passed pattern up over the solder wave.

**5.3.1.2 Solder Paste** Stencil print the solder paste on to the comb pattern using a 0.2 mm thick stencil (the IPC-A-24 artwork contains the stencil design).

**5.3.1.2.1** The samples shall be run through a reflow soldering process using the temperature profile recommended by the vendor.

#### 5.3.2 Cleaning of Samples

**5.3.2.1** After exposure to flux and solder, samples to be tested in an uncleaned state shall be evaluated as in 5.3.3 through 5.4.1.

**5.3.2.2** After exposure to flux and solder, samples to be tested in the cleaned state shall be cleaned using one of the procedures listed below. The cleaning parameters shall be reported in the Qualification Test Report (Appendix A).

**5.3.2.2.1** The samples to be cleaned shall be cleaned with an appropriate environmentally safe solvent or aqueous cleaning medium. The use of a commercial in-line or batch cleaner is preferred. If this is not available, the following laboratory cleaning process shall be followed.

Three samples shall be cleaned (within 30 minutes or less) after soldering. For solvent or aqueous detergent cleaning, three 2000 ml beakers each containing 1000 ml of solvent shall be used such that one beaker serves as the primary cleaning stage and the other two are used for rinsing purposes. Each test coupon shall be agitated in each beaker for 1 minute. In the case of aqueous detergent, one beaker shall contain the cleaning agent and the remaining beakers shall contain deionized water for rinsing purposes. After the cleaning procedure is complete, samples are dried for 2 hours at 50°C. Following cleaning, the specimens shall be tested as outlined in 5.3.3 through 5.4.1.

**5.3.3 Preparation of Samples for Chamber** Visually inspect all combs and discard any combs with bridging of conductors. Use water white rosin to solder teflon-insulated wires to the connection points of the specimens. Do not attempt to remove the flux residues. Connectors may be used in lieu of soldering wires but are not recommended. In the event of a dispute, the samples with soldered wires shall be used as a referee.

**5.3.4** Place the specimens in the environmental chamber in a vertical position such that the air flow is parallel to the direction of the board in the chamber. Set the chamber temperature at 85 ± 2°C and humidity at 20% RH and allow the oven to stabilize at this temperature for 3 hours. Then, slowly ramp the humidity to 85 ± 2% over a minimum 15 minute period.

## IPC-TM-650-2.6.3.3: Surface Insulation Resistance, Fluxes Continued

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Allow the specimens to come to equilibrium for at least 1 hour before applying the bias voltage to begin the test. If a salt solution and dessicator are used for humidity, specimens shall be held for 24 hours before beginning the test.

**5.3.5** Connect the 45-50v DC voltage source to the specimen test points to apply the bias voltage to all specimens.

### **5.4 Measurements**

**5.4.1** Measurements shall be made with test specimens in the chamber under the test conditions of temperature and humidity at 24, 96 and 168 hours. To take these measurements, the 45 - 50v DC bias voltage source must be removed from the test specimen and a test voltage of -100v DC shall be applied. (Test voltage polarity is opposite the bias polarity.)

### **5.5 Evaluation**

**5.5.1** Each comb pattern on each test specimen shall be evaluated by the insulation resistance values obtained at 96 and 168 hours. If the control coupon readings are less than 1000 megohms, a new set of test coupons shall be obtained and the entire test repeated. The reading at 24 hours may fall below the required value provided that it recovers by 96 hours. Any reason for deleting values (scratches, condensation, bridged conductors, outlying points, etc., must be noted).

**5.5.2** All specimens shall also be examined under a 10x to 30x microscope using backlighting. If dendritic growth or corrosion is observed, it shall be determined if the dendrite spans 25% or more of the original spacing. This latter condition will constitute a failure. It should be determined whether dendritic growth is due to condensation from the chamber (see paragraph 6.1).

**5.5.3** Rejection of results for more than 2 combs for a given condition shall require the test to be repeated.

### **6.0 Notes**

**6.1** If condensation occurs on the test specimens in the environmental chamber while the samples are under voltage, dendritic growth will occur. This can be caused by a lack of sufficient control of the humidification of the oven. Water spotting may also be observed in some ovens where the air flow in the chamber is from back to front. In this case, water condensation on the cooler oven window can be blown around the oven as microdroplets which deposit on test specimens and cause dendritic growth if the spots bridge the distance

between two electrified conductors. Both of these conditions must be eliminated for proper testing.

**6.2** IPC-B-24 test board artwork and electronic data is available from IPC.

**APPENDIX C**  
**List of Industry Contacts**

Greg Tashjian  
Lucent Network Systems Technologies  
1600 Osgood St.  
No. Andover, Ma. 01845  
508-960-2496  
Fax: 508-960-1187

Les Hymes  
PWA Manufacturing Consultants  
W137N8180 River Park Dr.  
Menomonee Falls, WI 53051  
414-251-4222  
Fax: 414-255-8128

Thomas Sommer  
TMS Consulting Co.  
148 Townsend Rd.  
Groton, Ma. 01450  
508-448-6005

Doug Peck  
Advanced Electronics Interconnect Center  
25 Iris Way  
Haverhill, Ma. 01830  
508-373-2600

Robert Laurenti  
Tristar Technologies Inc  
128 Merrimack St.  
Methuen, Ma. 01844  
508-794-5100

Tim O'neal  
ESP solders  
14 Blackstone Valley Place  
Lincoln, RI 02865  
1-800-338-4353  
Fax: 401-333-4954

Sammy Shina  
University of Massachusetts at Lowell  
One University Ave  
Lowell, Ma. 01854  
508-934-2590  
Fax: 508-877-7071

Richard Cloutier  
AMTX Stencils  
5450 Campus Drive  
Canandaigua, NY 14425  
716-396-6974  
Fax: 716-396-6868

Dr. Brett E. Hardie  
Hardie Consulting Co.  
7117 Woodhollow Drive #517  
Austin, Tx. 78731  
512-338-9884