ABSTRACT
The transition to lead free electronics assembly materials has created a number of challenges for modern electronics manufacturing operations. One of the challenges is the propensity of solder paste to adhere to anything it comes into contact with, including the squeegees used for printing. This report describes a new device which has been used to eliminate this problem. Experimental data is provided to show the effectiveness of the solution. Various subjects related to modern solder paste printing are described, including comparisons between open dual squeegee printing methods, and closed head printing methods.

Keywords: lead free solder paste, reduction of defects in SMT printing, metal squeegees; closed head SMT printing.

INTRODUCTION
Solder paste printing for modern electronics is accomplished most commonly with dual squeegee open printing systems. This method of printing has provided adequate quality for current state of the art assembly lines. Recently there has been a sea change occurring in the electronics industry: the elimination of lead-based materials and the conversion to lead free solder paste. This change has exacerbated some problems with material deposition and has motivated a re-evaluation of the dual squeegee printing method. The most common reported problem known to the authors is the tendency of the printed material to adhere to the surrounding elements inside the printing system, and to dry and compact into an unprintable state. This report discloses a solution to this problem and offers data to support the effectiveness of this solution. In the course of this discussion, various helpful suggestions and observations are given to help understand and advance the state of the art in solder paste printing technology.

OVERVIEW AND HISTORY OF STENCIL PRINTING
Electronics Manufacturing for today’s advanced circuits is accomplished most commonly with the use of two metal squeegees, and a metal foil mask often referred to as a stencil. The process originally evolved from silk screening and screen printing technology. Screens gave way early on to stencils, as users realized the particle size and flux chemistry of solder paste were not compatible with screen openings, and screen printing methods. Screen printing was a “print transfer” process, where the open screen areas of a screen were wet with the printing material, and then the screen was pressed into contact with the target object to be printed. This technique would transfer and release nice patterns of any shape, lines, dots and open areas. Patterns used in SMT solder paste printing are most often very small rectangle or circular openings. When screen printing was first used for SMT solder paste printing, clogging and dry out were common and cleaning the screens after solder paste was applied with them was not easy.

The metal mask or “stencil” foil became popular quickly. The printing patterns common with SMT solder paste printing are easy to etch into metal foils, and the metal foils may be produced very consistently.

Silk screening and screen printing is an old technology dating back at least 100 years. The method of applying inks and various fluid materials in patterns using screens is well understood.

Another element of screen printing: the polymer squeegee was also relegated to second place in favor of metal squeegees. At the time, rubber and plastic were the only type of squeegees which would work with screens. The squeegee for screen printing needed to provide a fluid gasket seal with the screen surface which in most cases was not flat. The top surface of a screen has some smooth areas, and then where the screen is open for printing, there is a rough surface of screen material. So the polymer squeegee would ride over this area and force fluid in and along the top surface.

As stencils took over screens as the “mask” element, so too did metal squeegees take over rubber and polymer squeegees. Metal squeegees provided the needed “gross” flexibility, to maintain a fluid seal, however, they did not exhibit local deformation at the stencil apertures, and this resulted in a much more reliable deposit of solder paste. Also, since rubber squeegee deformation into apertures
was a transient effect while the squeegee passed over the apertures, bleeding and smearing were common with rubber squeegees. Metal squeegees do not dip into the stencil apertures and therefore can produce much cleaner and sharper printing quality. However, bleeding and smearing will occur after a set number of cycles, as the solder paste will accumulate around the apertures and it will build up, necessitating some under-stencil cleaning after a certain number of printing cycles.

With metal squeegees and a metal stencil foil, the SMT printing deposits are controlled and contained to a mechanical box represented by the aperture dimensions, and the squeegee blade shearing action on the top side of the stencil. (figure 1)

![Open Dual Sq. Printing](image)

**Figure 1.** Dual Squeegee Printing. 1. Solder Paste “rolling”, 2- Metal Squeegee blade, 3-Filled stencil apertures.

As users developed SMT stencil printing, one guideline emerged early and has become a standard reference for producing stencils: Aspect Ratio is a reference to the relative amount of surface area of the aperture opening, versus the aperture walls. Since solder paste sticks equally well to the squeegee, the aperture walls and the pc board land patterns, it only makes sense that if any one of these elements outweighs the other in terms of surface area, then the solder paste will stick there more. Since the target is to have the solder paste remain in a controlled “brick-like” shape on the pc board, after printing, any sticking of paste to the squeegee or stencil apertures is undesirable.

Normally an aspect ration of 0.5 is suitable for good printing and release from the stencil. Stated a different way, this means, the total surface area of the stencil walls inside the aperture is equal or less than ½ of the area of the aperture opening.

The history of SMT printing starting with its screen printing origins is useful background in any context of SMT printing technology, as it is important to realize that with most screen printing, the target goal is to cover the area to be printed, and not to go outside of this area. With SMT printing, the object is the same, but also to provide a certain thickness and volume of solder material.

Currently, SMT printing has produced satisfactory results, and the Electronics Manufacturing Industry has blossomed and produced an incredible array of high end, and densely packed electronics devices.

However, there continue to be setbacks and limitations to SMT printing. One big limitation is the inability for the SMT printer to run continuously without operator intervention. Solder paste is very sticky, and as a result it moves around within the printer and often, moves where it shouldn’t. With the introduction of lead-free solder pastes, there is a greater tendency for the solder paste to adhere to the squeegees, and this represents a difficult situation for modern manufacturers, as the correction of this problem involves direct operator intervention into the printing process, causing an interruption of the production line.

An overview of solder paste printing would not be complete without the mention of closed head printing systems. (Figure 2). This is an alternative approach motivated by the desire to contain the solder paste and keep it from being exposed to air. The basic idea is to “pump” the paste out of a closed circuit. The outlet for the paste is comprised of a small slot bounded by two inward mounted squeegees.

![Closed Head Printing](image)

**Figure 2.** Closed head printing. 1-Pressure forces solder paste out. 2-Solder paste can "impact" inside the chamber, 3- Void may develop if not “tuned” properly via speed and pressure settings, 4-dual inward mounted squeegees, both in contact to make seal.

While this technology has been shown to be effective for certain high volume dedicated production, it has also experienced some problems, most notably: the enclosing of the solder paste makes it difficult to service when the solder paste becomes unworkable. It is a worthy effort to seal the solder paste inside a closed circuit, however, if and when the solder paste does become unworkable, that
same closed circuit becomes difficult to purge and clear. Also, paste drying is only one failure mode. Paste also fails due to simply being left in a static state. The flux and paste particles separate, and therefore, a good printing operation must have active mixing of the solder paste. For this reason, dual squeegee printing has maintained the position as the preferred printing technology. There is a significant amount of experience with open rolling solder paste deposition, and many users have opted for this style printing, not only because of its historic roots to screen printing, but also because it produces very good results and is open and easy to trouble-shoot.

NEW PROBLEMS WITH SOLDER-PASTE PRINTING

There is a lot of ongoing research and process development to qualify lead-free solder pastes into existing SMT manufacturing operations. Lead Free solder pastes exhibit a greater tendency to adhere to metal squeegees. This may be due to the solder balls having a different surface finish which is not “bright”, and therefore the mass holds together with a little more strength, and also, the material is not as heavy as eutectic tin-lead solder paste. There are many suppliers of these materials and some have better sticking characteristics than others. However, the matter of solder paste sticking to squeegees has been a long term quality issue with SMT printing, even with lead based materials. It is desirable to have a very sticky solder paste, to hold components after pick and place operations. However, it is undesirable to have solder paste sticking anywhere else: to the stencil, to the squeegees, or anywhere inside the printer.

It was this conundrum which motivated an effort to see if a mechanical solution could be created which reduced solder paste sticking to squeegees. Figure 3 is an example of solder paste adhering to squeegees.

Figure 3. Solder paste adhesion to metal squeegee.

Recently, a new device was created to cause a cleaning action within a dual squeegee printing machine. The development has been tested and the following sections describe the experiments and results discovered.

NEW SQUEEGEE WITH INTEGRATED WIPING APPARATUS

It would not be obvious to introduce anything into solder paste to “clean it”, as most users know that whatever you place into solder paste will become covered and will also require cleaning. It takes dexterity to clean solder paste, and the basic method is to use opposing sharp edges, moving against each other to accumulated the paste and then to transfer it into the storage container. Most stencil printing operations have an assortment of putty knife style tools and scrapers to help manipulate and reposition solder paste in and around the solder paste printer.

It takes much of the dexterity of human hands and arms to effectively clean up an SMT printer either at the end of a production run, or to switch over from one production run to another. The new device which was created is unique in that it introduces a very minimum amount of surface area into the paste, and it moves, creating fluid cutting paths, with nothing to “grab”. Essentially, a thin wire is integrated into a squeegee blade holder, and its motion and speed are set to produce the best cleaning action: The motion is set such that the wire slides and pinches the solder paste from the squeegee blade. Figure 4 is a photo of the new device.

Figure 4. Integrated wiping apparatus attached to dual squeegee printing head.

Figure 5 shows the typical pattern left after the integrated wiper completes its action at the end of a squeegee stroke.

Figure 5. Typical cleaning pattern of integrated wiper.
EXPERIMENT TO MEASURE WIPE EFFECTIVENESS

The following outline describes the experiment we conducted to determine how effective this new integrated "self cleaning" squeegee system is compared to traditional dual squeegees.

Experimental Overview:
I. Data Groups (measure weight in gms):
   a. 200 print strokes Rear Squeegee, YES
      100 measurements Rear Squeegee
   b. 200 print strokes Front Squeegee YES
      100 measurements Front Squeegee
   c. 100 print strokes Rear Squeegee, NO
      100 measurements Rear Squeegee
   d. 100 print strokes Front Squeegee, NO
      0- measurements Front Squeegee

II. Date of Experiments:
   Groups a. and b. Wiper On: Sept. 29, 2005
   Groups c. and d. Wiper Off: Nov. 11, 2005

III. Temperature and Humidity: 64 Degrees F, RH: 20%
    Recorded on Nov. 11.

IV. Purpose of Experiment:
   a. To ascertain the effectiveness of an active wiper built into a metal squeegee holder, by measuring the weight of solder paste stuck to the squeegee, and comparing weights between data sets with wiper active, and with wiper inactive.
   b. To photograph and video tape action of the squeegee, with wiper active and without wiper, to determine relative surface area exposure differences which occur due to sticking solder paste, and to observe time delay differences of paste dripping, with wiper active and wiper inactive.
   c. To run the wiper device through an extended number of cycles to observe stability and durability of the mechanism.

V. Notes about the number or trials and the data sets (a, b, c, d above) We were looking for two complete data sets (weights), of qty 100 each, one set with wiper active, and one set with wiper inactive. Because it was easier to focus on one squeegee, we did 100 strokes of the rear squeegee, photographed it 100 times, and we ignored the front squeegee (data set a.) There was a second identical procedure for the front squeegee, in which we photographed and measured the front squeegee 100 times, and ignored the rear squeegee. So for a. and b. we generated 100 photos, and 100 measurements of each squeegee, but in doing so, there were 100 additional strokes of the opposing squeegee which were ignored.

With the wiper inactive, we decided to do 100 measurements and photos of the rear squeegee (data set c.), so that we would have a balanced comparison of data: wiper on, versus wiper off. We did not repeat this process for the front squeegee because we believed this information would be redundant. The group d. is simply the ignored 100 strokes of the front squeegee (no data set) while we collected data set c. From this information, we may be able to ascertain the consistency of the wiper system (data sets a versus b), and the effectiveness of the wiper system (data sets a. versus c.). The extra cycles with "ignored" front and rear squeegees simply provided extra cycles to see if the new device would hold up to a continuous run, and if there would be fatigue.

RESULTS OF THE TESTING

The above chart shows the three data groups together, and shows the reduction of solder paste sticking and also the more repeatable the amount of paste adhesion with the wiper active.

The data groups were also averaged, and their standard deviation was calculated as follows:

<table>
<thead>
<tr>
<th>Group</th>
<th>Average wt (gms)</th>
<th>Standard Dev.</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Wiper</td>
<td>46.0</td>
</tr>
<tr>
<td>B</td>
<td>Wiper</td>
<td>38.8</td>
</tr>
<tr>
<td>C</td>
<td>No Wiper</td>
<td>57.4</td>
</tr>
</tbody>
</table>

The results show that the wiper system produced a significant reduction in solder paste adhesion to the squeegee. While it is desirable to keep as much paste down on the stencil and off the squeegee blade, it is important to review why this is important.

It is not so much the amount of solder paste which adheres to the squeegee that is a problem, it is how it adheres. The way it adheres is by stretching out and forming a thin blanket hanging off the blade. The large surface area formed by this adhesion is much more detrimental to the quality of the printing operation, than is just the weight of solder paste adhesion.

The next two photo series, figure 7 and 8, show the example pattern of adhesion observed during the
CONCLUSION
This experiment reveals that the implementation of an active wiper system into dual squeegee printing will reduce the surface area of the solder paste exposed to air, and will likely extend the working life of the solder paste, and reduce undesirable lump and dry paste formations, which can reduce print quality and consistency.

During this testing we learned that solder paste “moves” out of the printing area because of the hanging and dripping strings and films of solder paste. There is a random falling and dripping action, and this causes the solder paste which drips to “flop” and walk out of the print area. Before this experiment, we believed that the major factor which made solder paste migrate was “oozing” during the print stroke. By cutting down dramatically on the dripping and blanket like surfaces hanging and dropping from the squeegee, the migration of the solder paste to the sides and outside the front and back of the squeegees was greatly reduced. We believe the use of an active wiper system may reduce the need for frequent operator service inside the printing workspace, in addition to extending the life and performance of solder paste in general.

Our future investigations will look into how much surface area reduction is occurring, and also, can solder paste be formulated to be less prone to dripping and stretching, (made thicker for example) without the concern for it sticking to the squeegees? By using the wiper system, we may be able to expand the range of solder paste viscosities and in the end find a much better formulation which produces super print quality, without having to worry about sticking to the squeegees.

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