

Reflow Soldering of Through-hole Components

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The rallying cry of manufacturing has been “do it cheaper, faster, better”. Consequently there is a constant drive to reduce the cost of the product. After the cost of material, the cost of manufacturing is usually the most significant area contributor to product cost. The SMT manufacturing process is constantly being examined for ways of streamlining assembly. Aside from faster (and hopefully accurate) equipment, elimination of process steps is a practical approach to the enigma. Each process step carries with it related capital costs for the equipment utilized as well as recurring costs for process material, support labor, equipment spare parts, and, of course, overhead such as floor space, power, and other utilities. In many cases, steps can sometimes be eliminated through incorporation of advanced SMT manufacturing methods. Bear in mind that alteration of the assembly process in such a manner will entail formal process development using designed experiments and statistical studies if the manufacturing process is indeed to be optimized.

One such process that is gaining increased interest is *Reflow of Through-hole* (ROT). Known also as *Single Center Reflow Soldering* (SCRS), *Intrusive Reflow Soldering*, *Pin-in-Paste*, and by other terms, it is simply the reflow soldering of through-hole components. It is a fact that for the majority of electronic assemblies, there will always be a few

through-hole components remaining on the PCB amongst the surface mount components. Connectors, for example, for applications where robustness is required, as well as power related components, will continue to exist in through-hole configuration. Rather than subject these components to wave-soldering or, time consuming hand-soldering, why not reflow solder them alongside with the surface mount components in the reflow oven? Granted, some through-hole components will not be able to withstand the thermal excursions presented by the reflow cycle, however, many can. This will result in the elimination of the very costly and environmentally “unfriendly” wave-solder process.

ROT is by no means a new process. Various companies have been working with it for a number of years and many have incorporated it into at least a portion of their mixed technology (SMT and through-hole populated) assembly production. Among the more significant contributions through a detailed formal study of reflow soldering of through-hole components undertaken in 1986 by a major US electronic manufacturing corporation. Experiments were conducted to examine and define all of the critical operating parameters. The resulting processes have since produced hundreds of millions of solder joints over the past 10 years. There have been, to date, no documented field failures attributed to the

use of the process and its associated variations. In fact, the process has maintained a consistent solder defect rate in the range of from 4 to 7 PPM.

Single Center Reflow Soldering - Technical Overview

Double Sided Reflow Considerations

In addition to the aforementioned obvious process cost savings, Reflow of Through-hole (ROT) provides significant printed circuit board design flexibility. With wave-soldering, larger, high I/O components, such as Quad Flat Packs (QFP) and Ball Grid Arrays (BGA), are restricted from the substrate side that will be passing through the solder wave. ROT allows larger components to be placed on the either side of the board. The components can also be orientated to maximize circuit design, and the same component pad geometries to be used on both the top and bottom of the board. All of the design flexibility advantages may contribute to lower product cost by minimizing the necessary board size. In summary, from a board design point of view, the ROT process maximizes the

usable printed circuit board real estate available for component placement.

Of course, if large components previously soldered to the “A” side of the board are to pass through the reflow system inverted while the “B” side is reflowed, they must adhere to the assembly when their respective joints become liquidus. To determine which components are candidates for said bottom side attachment, a ratio that evaluates the mass of the component in relation to the lead/component pad contact area was derived. This ratio (see Table 1) avoids having to determine which components can be successfully mounted to the bottom side by experimentation. The experimentation would involve process and engineering time and the expense of the components and other materials. When a new component is being considered for bottom side attachment, this calculation will be done prior to approving the product design. The formula to complete the ratio calculation is included in the printed circuit board design standard, so the designer of the board can complete the calculation during the initial design layout.

Formula for Secondary Side Mounting

$$\frac{\text{Weight of components in grams}}{\text{Total pad mating area in square inches}}$$

Grams per square inch must be ≤ 30 for secondary side mounting

Table 1: Lead / Component Pad Contact Area Ratio

.Reflow Soldering of Through-hole Components

One of the additional benefits of the reflow soldering of through-hole components process allows the use of through-hole connectors that provide the mechanical integrity of a through-hole

solder joint while taking advantage of the SMT manufacturing process. As mentioned earlier, in many applications a SMT connector does not provide the mechanical strength necessary. In the case of connectors that will be used repeatably by customers, a mechanical solder joint as strong as possible is desired. Also on large printed circuit boards the flatness of the board will not allow all the pins on a SMT connector to make contact with the PCB pads.

In the aforementioned evaluation, testing of the reflowed through-hole solder joints was done with respect to a comparison to wave-soldered through-hole joints included pull testing and cross sectioning. "Raw" pull tests and pull tests after 500 cycles were conducted between - 40 degrees F (- 4.4 degrees C) and + 125 degrees F (+ 51.6 degrees C). In all cases the reflow soldered through-hole solder joint had a tensile strength that was the same as a wave-soldered through-hole solder joint: in excess of 20 pounds (9.1 Kg). Even if the lead is mounted so as not to protrude through the board (flush mount) the strength is still in excess of 20 pounds (9.1 Kg). A surface mount gull wing joint has a pull strength of 5 to 9 pounds (2.3 to 4.1 Kg). The cross sectioning of the reflow soldered solder joints demonstrated that the incidence of solder voids were the same as wave-soldered solder joints.

One factor that requires supplier support is the availability of through-hole components that can survive the reflow soldering temperature excursions. Unlike wave soldering where the printed circuit board insulates the components from the soldering temperature, the reflow soldering process exposes all of the components, in

their entirety, to the reflow solder temperature. In many applications a component may be exposed to temperatures up to 235 degrees C for a short period of time and in excess of 200 degrees C for 60 seconds or more. It is crucial to determine that the components will not be destroyed or damaged when exposed to the reflow soldering temperatures. As in the case with all reflow applications, the component with the lowest thermal threshold of pain - the Most Vulnerable Component (MVC) must be identified. In some cases, this will require working with the supplier to determine if the component is a candidate for reflow soldering and if not what substitute components may be to allow reflow soldering.

In reflow soldering of through-hole components, the component hole diameter is critical in acquiring the proper solder joint. The correct hole size is calculated for all the standard through-hole component lead sizes and included in the printed circuit board design standard. For through-hole lead sizes that are not included in the design standard, a formula is available to calculate the correct hole size for that particular lead size. The other major issue in ensuring an acceptable solder joint is the volume of solder paste needed to form the solder joint. The stencil aperture size and the stencil thickness will determine the volume of solder paste deposited on the board during the application process. The stencil aperture sizes are calculated from component lead size, hole diameter, board thickness, stencil thickness, and "inspection factor". The particular geometry of the solder deposit is determined by the available printed circuit board space available to print the solder. The solder paste deposit

does not have to be concentric to the hole. The solder paste deposit can be offset to accommodate areas that sufficient board space will not allow a concentric deposit. The “inspection factor” is how the solder joint will appear after reflow soldering. For example: a solder joint with a 100% “inspection factor” will look just like a traditional wave-soldered solder joint. Solder joints with less than 100% “inspection factors” will have solder joints that look somewhat different from a traditional wave-soldered joint. The “inspection factor” is necessary in situations where insufficient printed circuit board space is available to deposit the required solder paste volume. Reflowed solder joints that have less than 100% “inspection factor” are required to pass the same quality and reliability testing as 100% “inspection factor” and solder joints produced using the wave soldering process.

Many ROT process practitioners have found that the traditional solder joint, exemplified by the visual aspects of the 100% “inspection factor” has been an area of “re-thinking”. In most cases, though containing less solder volume than the wave-soldered through-hole joint, reflow soldered through-hole interconnections do indeed possess more than adequate pull strength and display similar quality and reliability aspects as their more massive counterparts. This is not surprising considering the amount of surface area comprising the interconnection with regard to the barrel of the hole and the outer surface of the inserted portion of the lead. In many instances, the leads do not protrude through the substrate, as the extra solder required to support this is extraneous.

***Procedure for determining the solder stencil
aperture size (print area) for through-hole components***

Known information: Component lead size, Stencil thickness, and Inspection factor

Determine board hole size based on lead size:

Round lead hole size = maximum diameter + .012"

Square or rectangular lead hole size = maximum diagonal measurement + .010"

Formula:

H = Hole diameter

L = Width of lead in the X direction

D = Lead diameter

W = Width of lead in the Y direction

T = Board thickness

$\pi = 3.14$

Hole Volume (HV) = $(\pi)(H/2)(H/2)(T)$

Lead Volume (LV) = $(\pi)(D/2)(D/2)(T)$

For round leads

Lead Volume (LV) = (L)(W)(T)

For square or rectangular leads

Required solder volume (SV) = HV - LV

Required Print Volume (PV) = (2)(SV)

50% shrinkage during reflow

Required Print Area (PA) = (F)(PV)/stencil thickness

F = Inspection factor

.7 = no fillet

.8 = fillet on primary side

.9 = fillet on both sides

1.0 = large fillet on both sides

Table 2: Stencil aperture calculations for ROT process

The calculation in Table 2 will provide the size in square inches of the solder paste area that must be deposited on the printed circuit board for that particular component lead. The exact geometry of the stencil aperture (length and width) will be determined by the amount of available printed circuit board space. Note that the geometry of the solder paste deposit may be rectangular, square, round, etc. The solder paste deposit does not have to be concentric with the plated through-hole.

The solder paste deposit may be "offset" from the plated through-hole. The exact limits of the "offset" will have to be determined by experimentation. As long as the solder paste deposit "offset" is adhered to and the correct reflow soldering profile is maintained, the solder paste will wet back to the solder pad, component lead, and plated through-hole.

Another important recommendation is for the component body in the lead area must be kept a minimum of .015" above the surface of the

board in order to aid proper formation of the solder joint. If the component body is placed into the paste, the paste will be pressed together under the component body resulting in numerous solder shorts. The specific distance between the top of the printed circuit board and the bottom of the through-hole component was included in the printed circuit board design standard.

Economics of the ROT Process

An examination of the economics of implementing Reflow of Through-hole must include the flexibility of the process. First of all, ROT embraces one of the ideal fundamentals of manufacturing engineering in that it uses existing machine centers already in place rather than requiring new and/or different equipment. Of course, the reflow system must be up to the task by having adequate thermal transfer capability in order to process assemblies that include the more massive through-hole components. However, most Convection Dominant (forced convection) reflow ovens on the market today have this capability. In any event, the process line configured for ROT can be used to run single-sided or double-sided assemblies. Line re-configuration, when required, is maximized due to the minimization of necessary equipment variation.

Deleting the wave-soldering machine from the assembly line and the related savings is only part of the picture. Since adhesives are not required to hold small components in place while they are wave-soldered, the gluing process and associated equipment centers (glue dispensing system, curing ovens) are also

eliminated. With the elimination of bar solder, adhesive, and liquid flux, solder paste may be the only material required. Manpower requirements will be less with reduction of operators. This, in turn, results in savings by minimizing operator and technician training. It should be noted that savings will also be realized through reduction of facilities as well as reducing the cost of environmental restriction compliance.

To illustrate the cost savings that can be realized by implementing Reflow of Through-hole, a sample board can be analyzed. A double-sided, mixed technology circuit board assembly with an assortment of passives and active components is to be built at a rate of 50 panels per hour (See Table 3). By performing a cost analysis using the S.P.A.C.E.¹ (Surface Mount Packaging Assembly Cost Estimator) cost estimation software, the capital and recurring cost savings between the traditional line incorporating wavesoldering and gluing and the advanced process utilizing ROT can be assessed (See Table 4).

¹ S.P.A.C.E. - Surface Mount Packaging Cost Estimator is trademarked by MPM Corporation.

PCB Dimensions:	3.0" x 6.0" x 0.062" thick
Panel Dimensions:	6.0" x 6.0" (two boards per panel)
Component Variety:	0603, 0805, 1206 chip components 20 pin PLCC 28 pin PLCC 208 pin QFP - 0.20" pitch (0.5mm) 225 position Ball Grid Array Through-hole Connectors and Sockets
Board Run Rate Capacity:	100 per hour (50 panels)

Table 3: Example printed circuit board specifications

Conclusion

Attaining defect rates of less than 4 ppm using ROT is not uncommon. On the other hand, a typical solder defect rate of 50 ppm is usually the norm for traditional soldering of SMT / through-hole (mixed technology) assemblies. Using our example PCB assembly (Table 3), assume a board run rate of 100 per hour with the line running 7600 hours per year (152 hours per week with 50 weeks per year).² As the assembly has 1,002_soldered interconnections, there are thus 656,640,000 defect opportunities. At a 50 ppm defect rate (traditional line), 32,832 soldering defects may occur. At a 4 ppm defect rate (ROT line), only 2,627 solder defects would likely occur. Assessing the cost of the 30,205 additional defects by where they are discovered and corrected in the process and distributing the defect cost through the stages of the product cycle they are discovered (from prior to the reflow oven to at the end-user's site), the cost of the additional defects is approximately \$307,758. ROT could reduce the cost of defects by 90%.

The implementation of significant SMT process improvements that will provide measurable cost, quality, design flexibility, and through-put improvements will require looking beyond the standard process steps. Small improvements can always be obtained by optimizing the traditional SMT process steps. However, improvements that will provide a competitive advantage in the market place can only be achieved by major modification to the traditional ways of doing things. The advanced SMT methods described in this paper can and are working in a seven day per week 24 hour per day SMT operation. Successful implementation requires a coordinated effort by the entire SMT manufacturing organization, the equipment, process material, and component suppliers, as well as the product development community, since the product must be designed using standards that optimize the advanced SMT methods.

² This is derived from a high volume application where a 152 hour week is comprised of four 20 hour days and 3 - 24 hour days (per week).

Defect Discovery Location	Cost of Defect	Percent of Defects	Number of Defects	Total Cost
Prior to Reflow Soldering	\$ 0.40	35%	10,572	\$ 4,229
After Reflow Prior to Board Test	\$ 1.50	30%	9,062	\$ 13,593
At Board Test Process	\$ 2.12	25%	7,552	\$ 16,010
Final Product Assembly	\$ 45.21	9%	2,719	\$122,926
In the Field at End-user's Site	\$500,000	1%	302	\$151,000
GRAND TOTAL				\$307,758

Table 4: Quality cost savings calculation for the 30,205 avoided defects.

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