How to Achieve 40 Microns (1.6 Mil) Placement Spacing with E01005/M0402

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Abstract
When trying to achieve 40 microns of placement spacing, bridges and tombstones may occur due to the variation of the component dimensions, equipment accuracy and pickup position variations.

Hawse have developed and patented a new process to achieve this type of spacing. This new process will be described in this paper.

Mounting components on product with 40 microns (1.6 mil) spacing is difficult due to material variations; so it is necessary to expand the spaces for mounting. By design the print deposits are shifted to the right and left of the pads. Solder paste deposits are then applied off the center of the pads. The system measures this misalignment for each deposit and feeds forward this information to the placement machine or machines to shift the placement position to match the location of the solder paste.

Controlling the position of the solder paste is very important to prevent bridges. The allowable tolerance for misalignment is about 30 microns and constantly maintaining this accuracy is extremely important. The system measures the position of the solder paste and feedbacks this information to the screen printer to maintain a constant solder paste position. Therefore it is imperative that the print position be constantly monitored. The printing condition of solder paste is controlled with the feedback feature of the system.

This system uses the properties of self-alignment of the solder paste to achieve the final result of 40 microns placement spacing. Self-alignment can be used with lead free solder paste by setting the proper reflow conditions or temperature profiles.

Key Words: APC, spacing, printed solder, feedback, feed-forward, defects.

Introduction

Cellular phone and device manufacturers are facing higher demand for miniaturization. Miniaturization can be achieved by mounting 0402-sized (0.4x0.2mm) components and even higher density placement. Miniaturization requires higher placement accuracy and board quality.

Variations in land positions on the printed boards are inevitable due to the inconsistencies in the manufacturing process of the PC boards and the environment. Therefore, a land position varies from board to board. Current SMT processes require having stencil (metal mask) on a fixed location on the screen printer, so the aperture position is the same. Even though, the screen printer measures the expansion and contraction, it will compensate the same amount for all the land positions of the board. This means that the printed solder positions inevitably changes with respect to the land position. In addition, current process and machine capabilities requires the placement machine to mount components based on the land position. Placement machines measures the expansion and contraction of the PC board (similar to screen printer) using board recognition (fiducials), then it corrects the mount position of the components by the measured value.

A technology has been introduced which absorbs irregularities in solder printing positions for mounting 0402 (01005) components with an extremely narrow placement gaps between such components.

The basis of this development lies in endless pursuit of quality. While high speed and low cost are important to customers, it is not the only the things that customers demand. The most important aspect of the manufacturing environment is the quality of products.

Automated Optical Inspection (AOI) machines have long been in use in the electronics industry to control many quality related issues. Some of these issues are related to screen printing, others to placement equipment and other still with the reflow process. The process for electronic PCB assembly begins with the screen printer. The screen printer introduces solder paste to the PCB. Next, the placement equipment does its normal function by placing the component centered with respect to its CAD data. Then the reflow oven heats up the PCB with the correct heating profile. Finally, the AOI analyzes the PCB and there may be several defects due to insufficient solder, poor component placement, etc. While the AOI is useful to determine the type of defects, the AOI still needs an operator to take the corrective action. Also, the introduction of small components such as M0402 and lead free solder paste requires tighter tolerances on equipment. All these issues limit the efficiency of the production line. Here is where the our system, which we call Advanced Process Control or APC, is used to improve quality control.

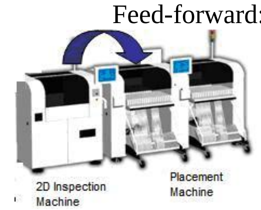
The basis of the system is an inspection machine located between the screen printer and the placement machine. In addition, to inspecting every solder paste deposition for quality such as area and position, each position of the solder paste deposition is measured with respect to its land position. This value is used to feedback the screen printer if a stencil adjustment is needed or cleaning is required. The measured values of the solder paste deposition are then used on the placement machine to compensate and adjust the placement location. The placement machine mount components based on the solder paste position and not on the land position. The basic functions of the system include feedback to the screen printer and feed-forward to the placement machine.

The following information is transferred within the system. Please refer to Figure 1.

Back-feed:

1) Trigger a stencil cleaning action.
2) **Printing position correction**

Feed-forward:



1) Skip function for defects, position or area.
2) Bad mark communication
3) Solder Paste position

The basis of the system is a 2D inspection machine. The AOI inspects the printed board for printing defects and position of the solder paste deposition. The offset for each solder deposition is used to correct the printing position and offset each placement.

Figure 1 - Basic Functions of System

System Description

Due to component variations, placement accuracy and variations in pickup positions it is extremely difficult to achieve 40 microns placement spacing. In order to achieve 40 microns spacing, we need to intentionally displace the solder paste deposition with respect to the land position. After displacing the position of the solder paste, the placement machine must follow the position of the solder paste and not the position of the land. Figure 2 shows an example when this technique is needed. There are six M0603 components in a row with 40 microns gap between components. Component width dimension is 300 microns plus/minus 30 microns. If all of the components are placed are oversized, the gap is only 10 microns. With the machine accuracy at 25 microns, there is a high probability of component collision during placement. Achieving 40 microns placement spacing with current manufacturing processes is impossible due to high probability of component collision.

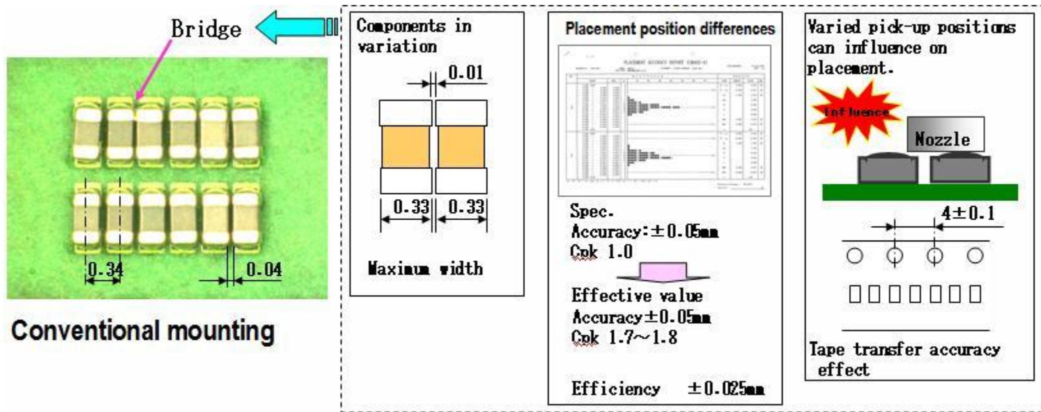


Figure 2 - Current Process Limitations

Traditional placement systems will mount the components based on the land position. If the solder paste position is not on the land, the contact area between the component and the solder paste will be reduced depending on the shift on the solder paste and it will caused quality errors such as tomb-stoning or lifted components. The component electrodes will not be placed evenly on the solder paste thus affecting the board quality after reflow. Please refer to Figures 3 & 4.

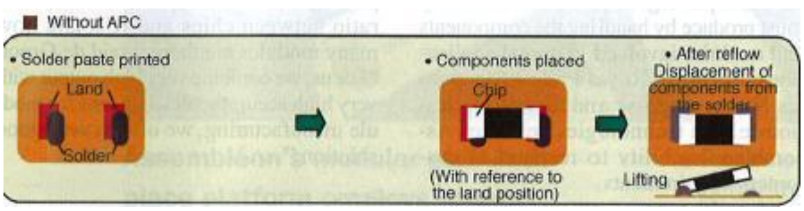


Figure 3 - Current Placement Systems [1]

Even though standard SMT process may inspect the printed solder position, this information is only used to detect acceptable or bad print. This information is not used to control the component placement or adjust the printing position by adding an offset to the screen printer.

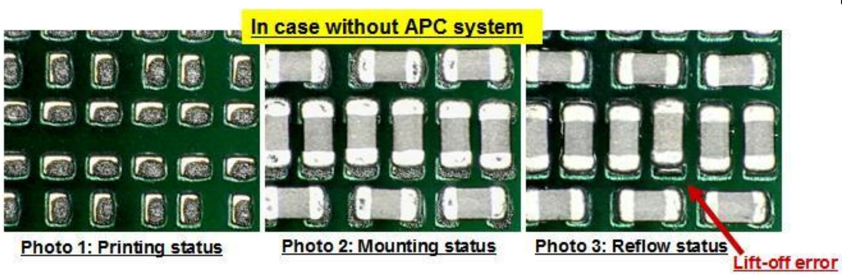


Figure 4 - Current Placement Systems

By using the system, the printed board will be inspected before the placement machine. Then position of the solder paste will be measured and this information be will feed-forward to the placement machine. Lastly, the components will be mounted on the new position of the solder paste thus improving the quality of the board after reflow by using the properties of self-alignment of the solder paste. Please refer to Figures 5 & 6.

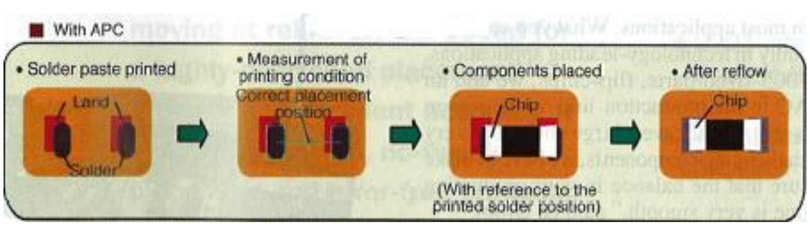


Figure 5

Even though the APC allows the placement of the components to be off centered, the end result is centered components after reflow. This is due to the self-alignment properties of the solder paste and the use proper reflow profiles.

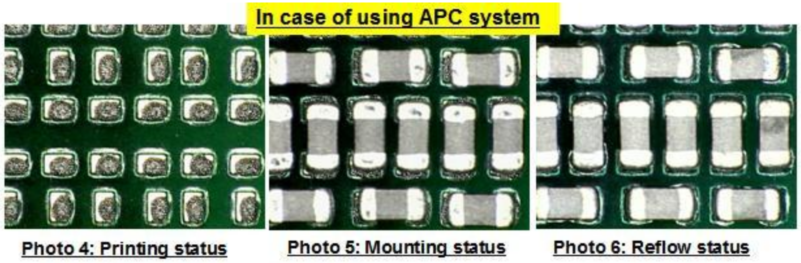


Figure 6

The system is capable of controlling several aspects of the production line as previously mentioned. The system controls the upstream screen printer, the AOI machine and the downstream placement equipment. With these three machines the APC system improves the defect rate that occurs due to insufficient solder, excess solder and poor component placement. The system also improves the cycle time of the production line due to its control of the surface mount assembly equipment and the sending data ahead of time before a component is placed.

The system takes into account the setup parameters and different lots of the PCB to control the printing process. The system uses the AOI to measure area coverage and position of the solder paste. If needed the system sends back a signal to the screen printer to begin a cleaning cycle after measurements are taken. The most beneficial part of our system is in controlling the print position. If the system detects a shift of the solder print in the X, Y or theta axis, the system corrects the shift on the incoming PCB. The screen printer receives a signal to adjust the print position the correct amount before printing. This type of print position control is critical when dealing with tight spacing of M0402 and M0603 components.

The inspection machine is the heart of the APC system. The inspection machine controls the feedback and feed forward function of the system. During the AOI process, the inspection machine judges pass/fail on various features that the user can control such as bad mark information and pass it along to the placement equipment. All the information gathered from the inspection machine is fed forward to all the placement equipment on the line.

Reduction in cycle time is achieved on the placement machine because it does not need to recognize the bad marks to identify if it needs to place components. The bad marks are identified by the inspection machine and this information is sent to the placement equipment, thus reducing the cycle times with better yields.

Along with the reduction of cycle time and scrap, the system opens up the operating window to achieve 40 microns placement spacing. A technique has been developed to achieve this type of placement spacing. This technique is called the spread mounting technique and is based on our system. Normal printing operations have the stencil apertures centered with respect to the lands. This printing operation works well with most components and spacing gaps. However, with the reduction of real estate, higher density placement and increase use of M0402 and M0603 components, the normal printing operation is no longer valid. Spread mounting technique allows the apertures of a stencil to be slightly offset from the center. Since the system can detect this offset, the system correctly places the components centered on the solder paste position and not to the pads. Once the PCB goes through the reflow oven the components reflow back centered on the pads.

How to achieve 40 microns placement spacing

By using the spread mounting technique is possible to achieve 40 microns placement spacing. By intentionally switching the position of the solder paste on the board a greater gap is created before placing the components. In order to achieve this placement spacing, it is necessary to expand the spaces for mounting by shifting the print positions to right and left of the land position as shown in Figure 7. As previously mentioned, achieving 40 microns placement spacing with current manufacturing processes is almost impossible. With the spread mounting technique the solder paste is offset either to the left or right from the center most components. By offsetting the print by 30 microns to right on one component and 30 microns to the left on the other component, the effective gap at placement will be greater that 40 microns, thus reducing the probability of component collisions. The system detects this offset and controls all of the placement machines, so that the components are centered on the print position, thereby reducing the chance of component collision and other defects.

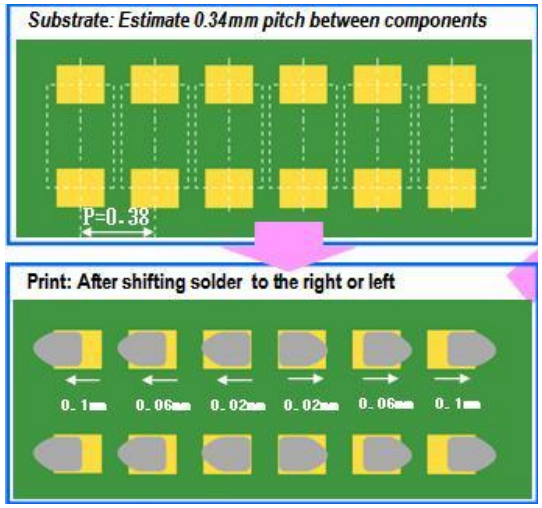


Figure 7 - Solder Paste Position

In order to prove out the spread mounting process, Panasonic Factory Solutions has developed a test board with M0402 and M0603 placement with placement pitch of 0.34 – 0.40 mm between components. Please refer to Figure 8.

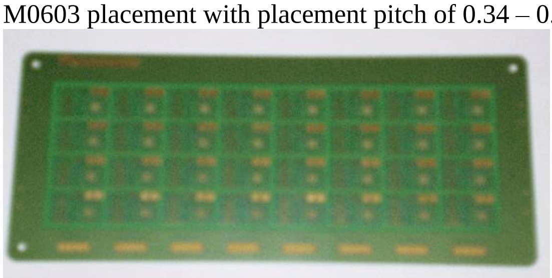


Figure 8 - Test Board

This test board has the following dimensions 140x60 mm and thickness of 0.4 mm. The PCB board has 32 panels with total of 96 placements per panel. Total placement count is 3072. The component distribution is as follow 48 placements for M0402 and 48 for M0603 per panel. 24 of the 48 placements were M0402 capacitors and the other 24 were M0402 resistors. M0603 has the same placement distribution. 12 of the 24 placements were designed to have 0.4 mm between the placements.

The printing position was shifted as detailed on Figure No.9. The shifted was achieved by changing the position of the apertures of the stencil. The stencil was designed with this shift. The shift was added to increase the gap between components. By using the system, the placement equipment will place the components on the center of the solder paste and not centered on the pads. Figure 9 shows the position of the solder paste.

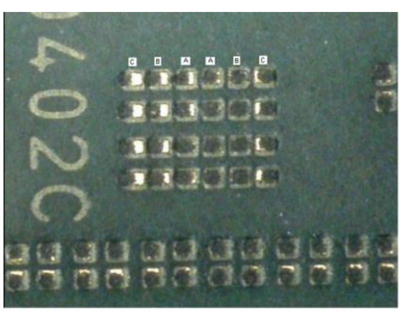
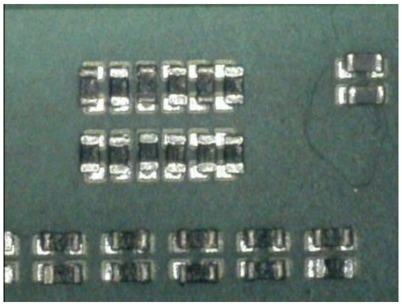


Figure 9 - Solder Paste

Columns A are shift by 0.02 mm; columns B are shifted 0.06 mm and columns C are shifted by 0.1 mm on opposite directions. All these shifts are added to the stencil to increase the gap between placements.

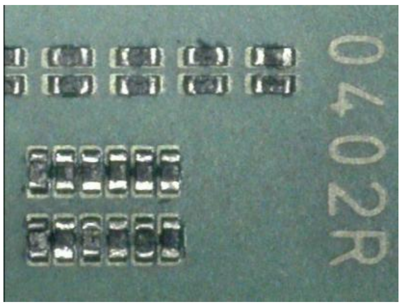
After the screen printer; the board is inspected by the AOI and every single solder paste deposition offset is measured for the following two reasons: to keep control of the printing position and for the placement machine. In order to keep control of the printing position, an average value is used. Even though the entire PC board is inspected, only a portion of the measure offset are used to calculate the average value to control the printing position. This average value is used to change the printing offset. The screen printer has the ability to adjust the printing position on both printing directions by changing the printing offset for each direction. In addition each measured printing position is used by the placement machine to adjust every single placement position. Each placement is centered on the position of the solder paste deposition and not of the position of each pad as show of Figure 10.



Even though the program used by the placement machine was made using the CAD data for the center of a pair of pads. The system corrects the placement position for each board after its inspection. After inspecting the board, the position of the solder paste deposition is measured and the offset is send to the placement machine to correct each placement. With this correction, each placement is now centered on the position of the solder paste deposition and not on the position of the pads.

Figure 10 - New Placement Position

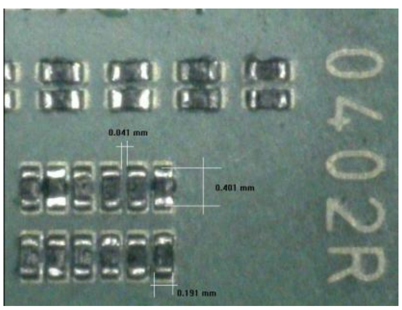
By using the self alignment properties of the solder paste, the placement will move to the center of the pads and 40 microns placement gap is achieved. Please refer to Figure 11.



After reflow, all the placements move to the center of the pads due to the self-alignment properties of the solder paste.

Figure 11 - After Reflow

By using the spread mount technique, 40 microns spacing is achieve as described on Figure 12.



The component dimensions are: length 0.401 mm and width 0.191 mm. The spacing gap between the lands is 0.0401 mm or 40 microns. If the solder paste deposition is set to the center of the land, it will be very difficult to achieve this spacing gap.

Figure 12 - 40 Microns Spacing

Additional Benefits of the system

Placement yield improvement

In addition to 40 microns placement spacing, the system improves the placement yield of M0402. Using the same PC board, an extensive build test was performed with the following results:

Test 1 – For this test, 50 boards were built to compare the yields when using the system and a traditional SMT system without automatic control. Each board was visually inspected after the placement machine and the reflow oven. Please refer to Table 1 for the results.

Table 1 – Test 1 Yield Results

		Yield (%)	
Condition	Modules	After Placement	After Reflow
1 reel - NO APC	1,584	99.68%	99.75%
1 reel - APC	1,584	100.00%	100.00%
6 reel - NO APC	1,584	99.62%	100.00%
6 reel - APC	1,584	99.75%	100.00%

Test No. 1 – 50 boards were built with the following conditions:
1-50 System on and one reel per part number
51- 100 System on and one reel per part number
101 – 150 System off and up to six reels per part number for gang pick
151 – 200 System on and up to six reels per part number for gang pick
System on improve yields after placement and reflow versus the boards built without the system on.

Test 2 – For this test, a higher number of boards were built with and without the system. Once again, each board was inspected after the placement machine and reflow oven. These inspections were performed by experienced operator; the operator inspected each board under a microscope. Please refer to Table 2 for the results of this test.

Table 2 – Test 2 Results

No APC	
PCBs	84
Modules	2,688
After Placement	
Defective Modules	182
Yield	**93.23%**
After Reflow	
Defective Modules	175
Yield	**93.49%**

APC	
PCBs	75
Modules	2,400
After Placement	
Defective Modules	8
Yield	**99.67%**
After Reflow	
Defective Modules	1
Yield	**99.96%**

The system greatly improves the yield of the manufacturing system.

Test 3 – This test was designed to identify if the system actually corrects the printing position of the screen printer and to identify if the self-alignment properties of the solder paste will pull the components to the center of the land. Each axis (X, Y and theta) was modified by adding an offset; then the board was built on the line. Please refer to Table 3 for the results of this test.

Table 3 – Test 3 Yield Results

	Missa.	APC	Modules	Defects	Yield
Run 1	0%	ON	1188	3	99.75%
Run 2	0%	OFF	1188	12	98.99%
Run 3	XY - 30%	ON	1188	9	99.24%
Run 4	XY - 30%	OFF	1188	102	91.41%
Run 5	θ - 30%	OFF	1188	112	90.57%
Run 6	θ - 30%	ON	1188	21	98.23%

Figure 15 - Test 3 Results

Conclusions

Our system allows the overall efficiency of the factory line to increase due to reduction in cycle time, increase yield and widening the operating window of the equipment. The reduction in cycle time is due to the feed forward function of the system and the ability talk to all proceeding modular machines in the line. The increase of yield is due to the print quality, print offset and component placement control of the system. Lastly the widening of the operating window is due to the spread mounting technique that is used with the system to increase the gap of components during placement. The system enables customers to improve the overall productivity of the factory line. With the ability to control the screen printer, AOI and the modular placement equipment, the system is a beneficial and critical aspect of today's electronic assembly. The system allows the achievement of 40 microns (1.6 mil) placement spacing with M0402/E01005 using today's equipment.

[1] "APC Technology Lowers Costs of High-Density Mounting" AEI October 2005, Masafumi Inoue; Inspection and Measuring Team; Product Development Group 3; Electronic Component Mounting Systems Business Unit; Panasonic Factory Solutions Co., Ltd.

How to Achieve 40 Microns (1.6 mil) Placement Spacing with E01005/M0402

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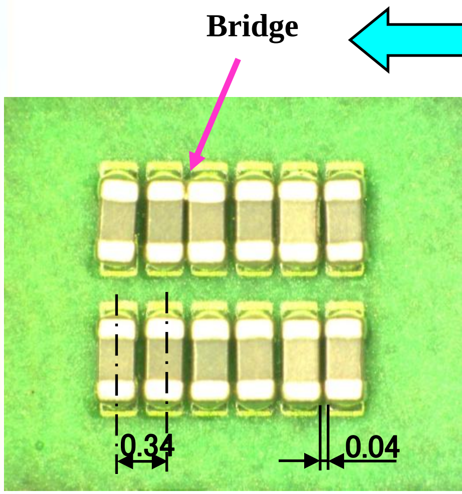
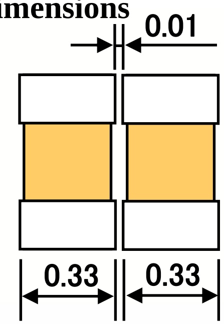
Pursuit of 0.04mm tight spacing!



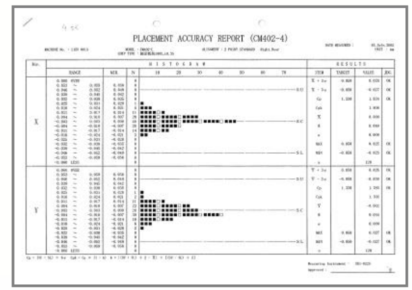
Conventional SMT processes

Variation in component dimensions



Maximum width

Differences in placement positions

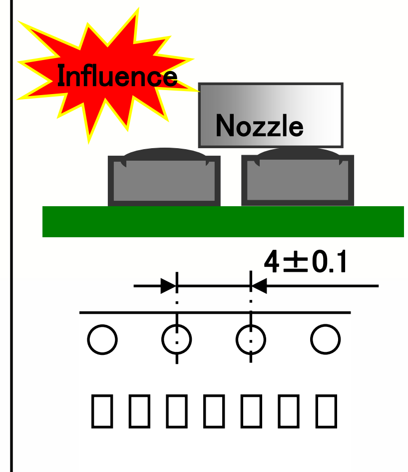


Spec.
Accuracy: ±0.05mm
Cpk 1.0

Effective value
Accuracy ±0.05mm
Cpk 1.7〜1.8

Efficiency ±0.025mm

Varied pick-up positions can influence on placement.

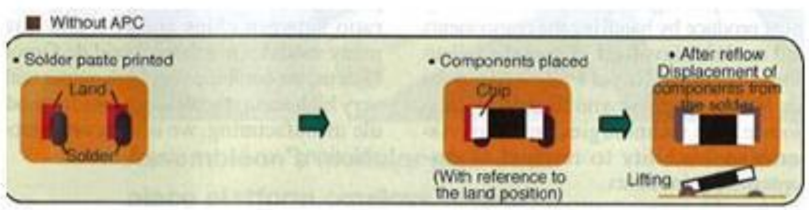


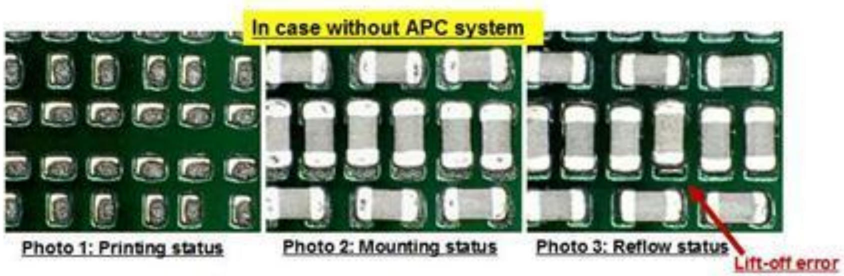
Carrier Tape transfer accuracy effect

Due to component variations, placement accuracy and variations in pickup positions it is extremely difficult to achieve 40 microns placement spacing.

Traditional vs. APC Process

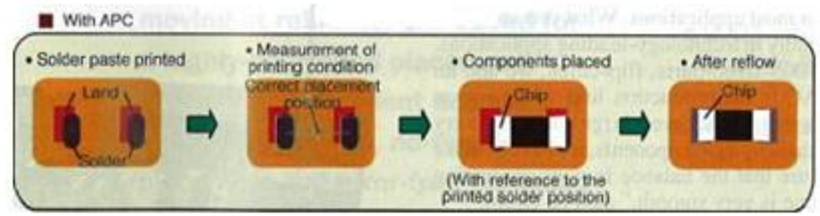
Conventional SMT Process





Even though standard SMT process may inspect the printed solder position, this information is only used to detect acceptable or bad print. This information is not used to control the component placement or adjust the printing position by adding an offset to the screen printer.

APC



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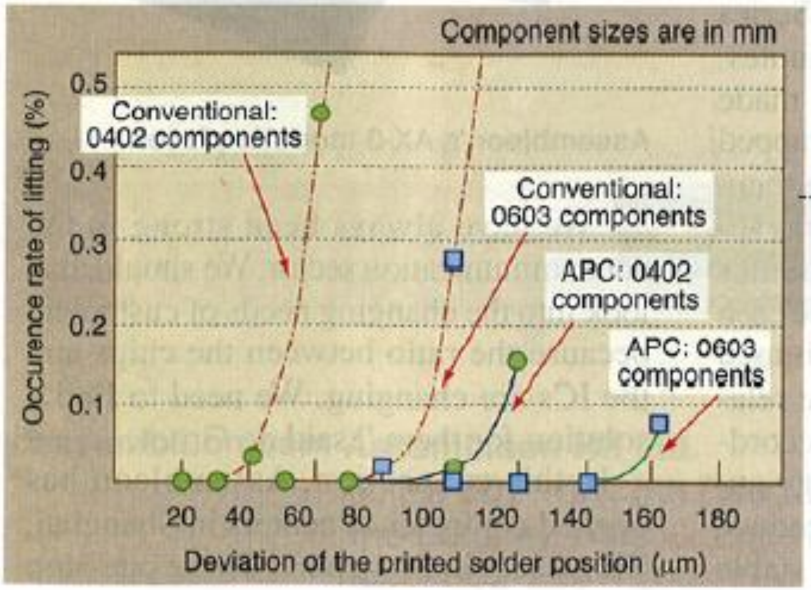
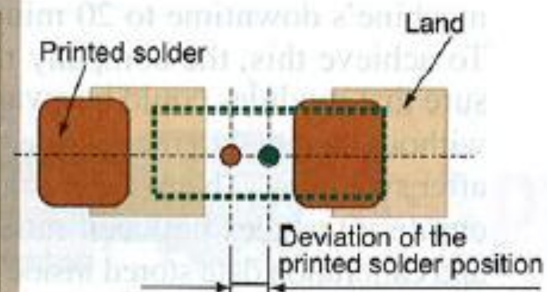
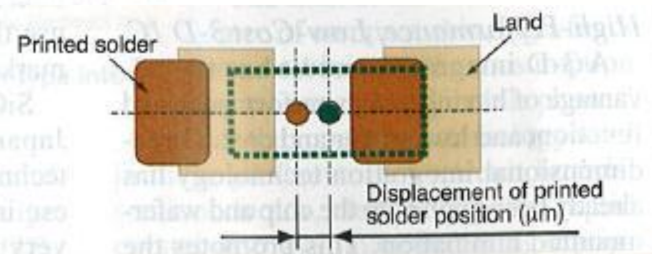
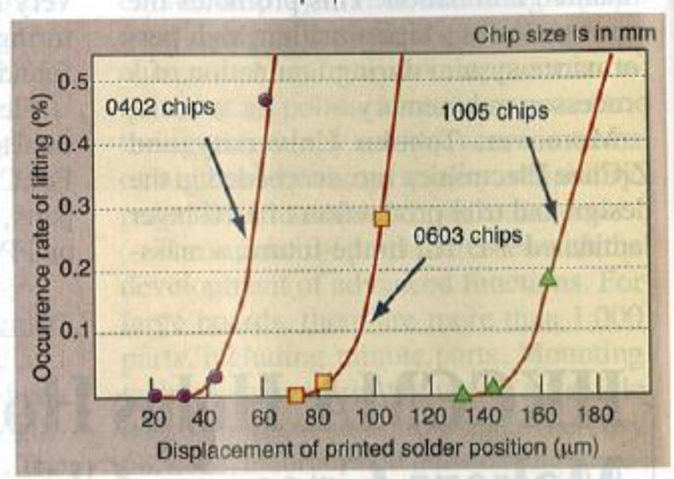
Advanced Process Control - APC





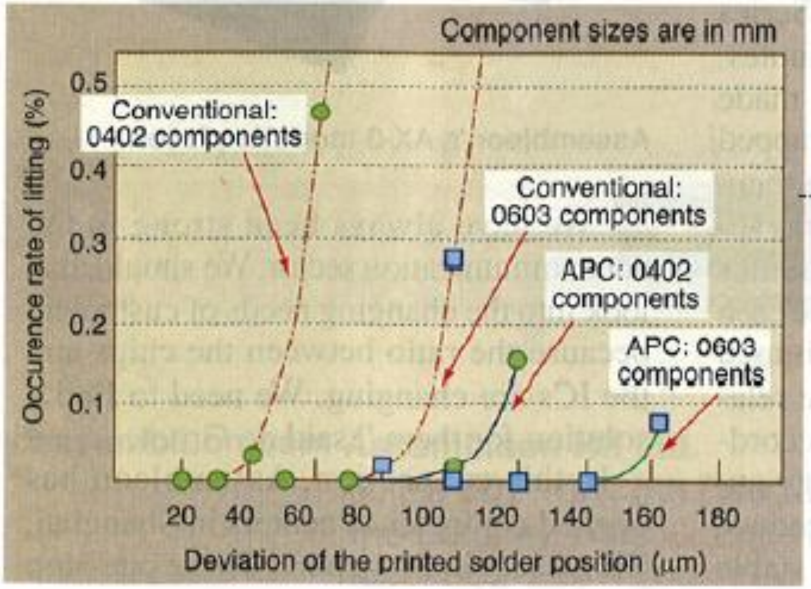
Effects of APC on the relationship between printed solder paste position and lifting

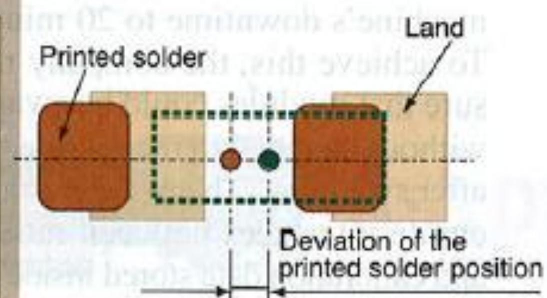




Relationship between printed solder paste position and lifting.

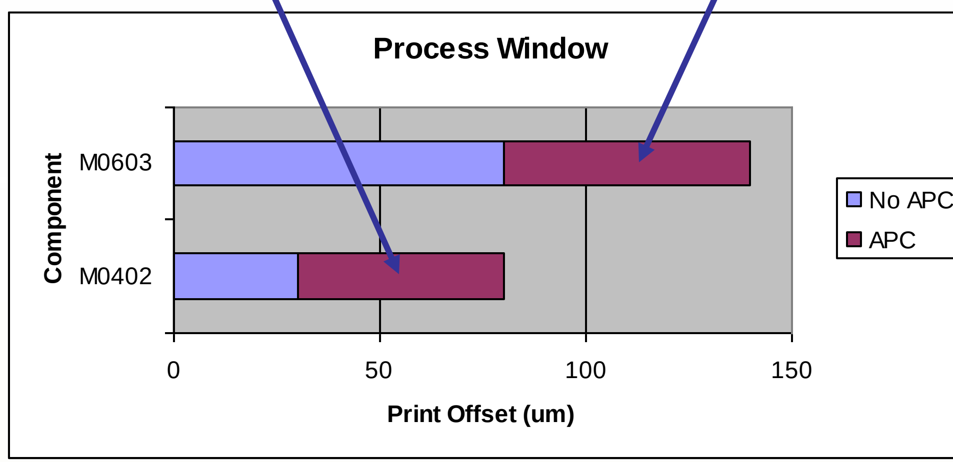
Advanced Process Control - APC



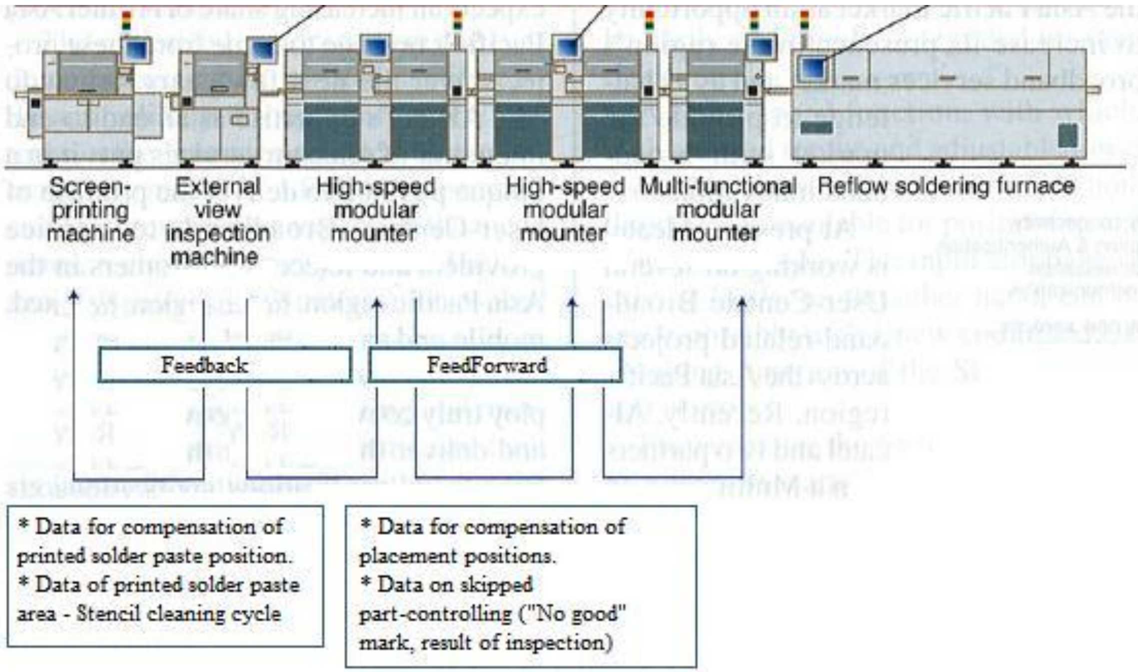


Overall Process Improvement

Effects of APC on the relationship between printed solder paste position and lifting



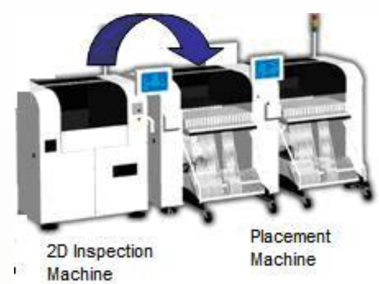
Advanced Process Control - APC



This system enables the inspection and measurement of printed solder in the inspection machine, and the controlling of the placement of components on the modular line.

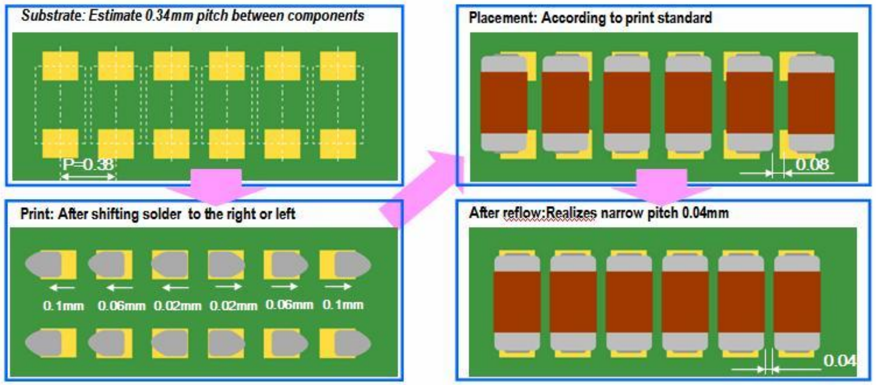
The quality of the SMT placement line is improved.

1) Trigger a stencil cleaning action.
2) Printing position correction

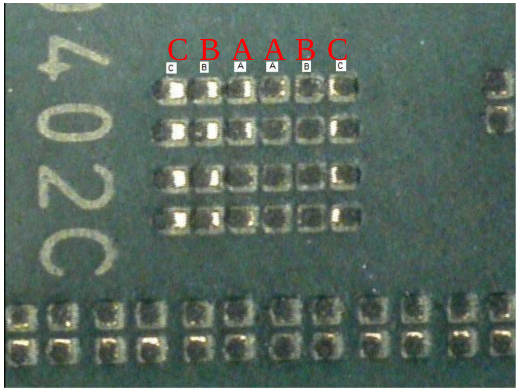


1) Skip function for defects, position or area.
2) Bad mark communication
3) Solder Paste position

Pursuit of 0.04mm tight spacing!



By using the spread mounting technique is possible to achieve 40 microns placement spacing. By intentionally switching the position of the solder paste on the board a greater gap is created before placing the components. In order to achieve this placement spacing, it is necessary to expand the spaces for mounting by shifting the print positions to right and left.



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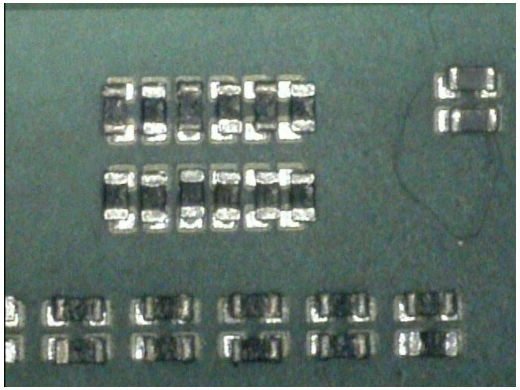
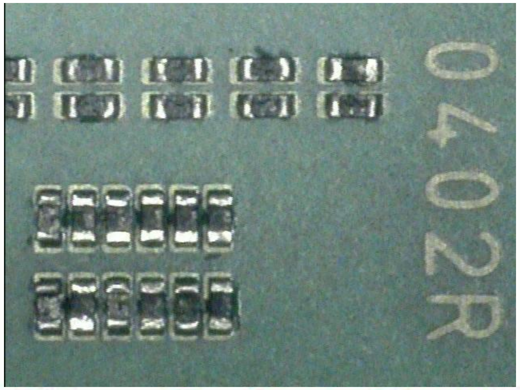


Even though the program used by the placement machine was made using the CAD data for the center of a pair of pads. Each placement is now centered on the position of the solder paste deposition and not on the position of the pads.

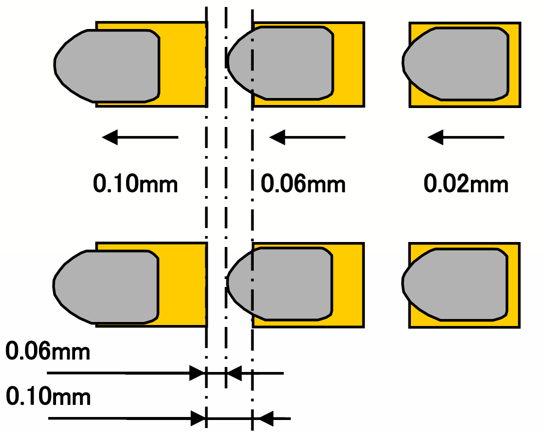


After reflow, all the placements move to the center of the pads due to the self-alignment properties of the solder paste.

Pursuit of 0.04mm tight spacing!

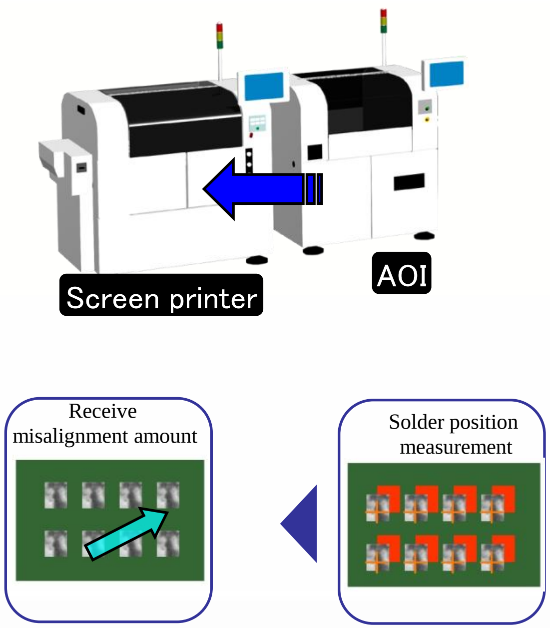
Pursuit of 0.04mm tight spacing!

Spread Mounting Process through APC method (1) Solder position feedback function



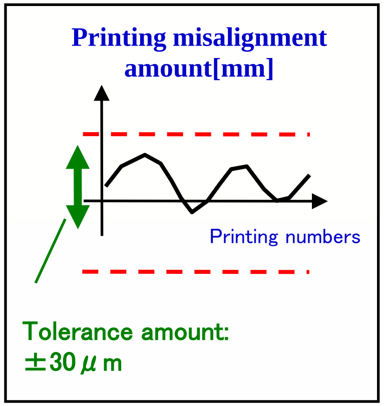
Controlling solder position is important to prevent bridges.

→ Shift: about±30μm



Auto-correction for positions

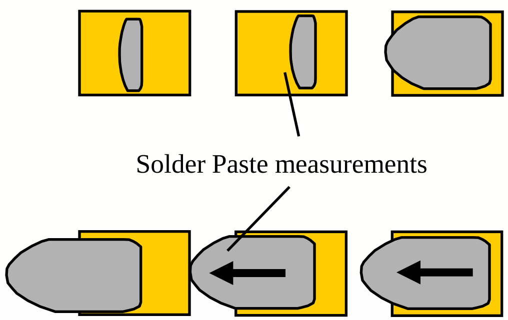
Calculation of corrected amounts



Solder positions can be fed back to the screen printer. Printing misalignment can be maintained within the tolerance.

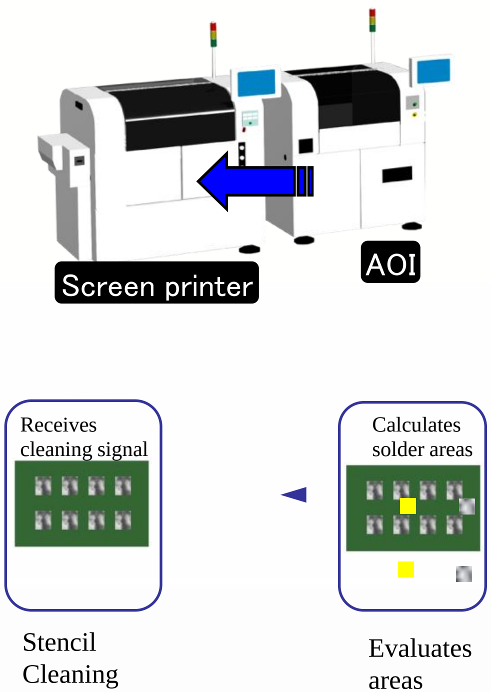
Pursuit of 0.04mm tight spacing!

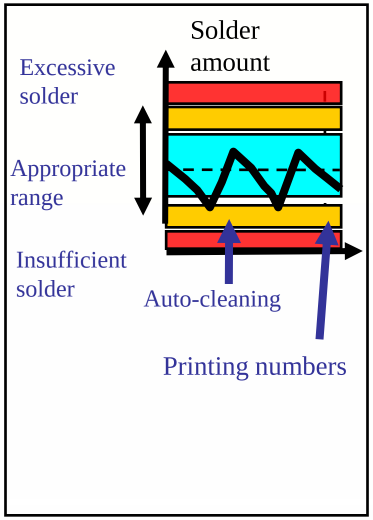
Spread Mounting Process through APC method (2)
Automatic mask cleaning function



Controlling solder areas is important to prevent bridges or insufficient solder amount.

→Appropriate areas are indispensable.

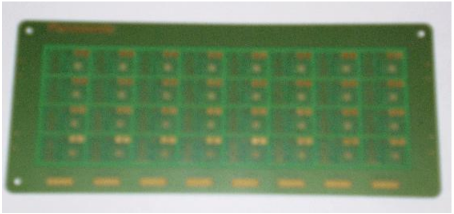




When solder areas deviate from appropriate rages, the mask cleaning is automatically applied. Therefore, the solder areas can be maintained within a fixed range.

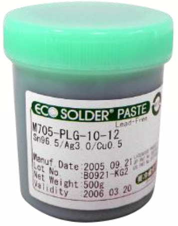
Yield Improvement

Specs of Experimental Equipment



PC board: PFSC demonstration Board

Cream solder:



Squeegee: Plastic squeegee

Stencil:

Print Screen Machine: SP60-L

Placement Machine: CM602-L

Placement control: APC80 – No APC

40 microns spacing: No

Yield Improvement

Table 1 – Test 1 Yield Results

Condition	Modules	Yield (%) After Placement	Yield (%) After Reflow
1 reel - NO APC	1,584	99.68%	99.75%
1 reel - APC	1,584	100.00%	100.00%
6 reel - NO APC	1,584	99.62%	100.00%
6 reel - APC	1,584	99.75%	100.00%

Test 1 – For this test, 50 boards were built to compare the yields when using the APC system and traditional SMT system without APC. Each board was visually inspected after the placement machine and the reflow oven. Please refer to Table 1 for the results.

No APC	
PCBs	84
Modules	2,688
After Placement	
Defective Modules	182
Yield	**93.23%**
After Reflow	
Defective Modules	175
Yield	**93.49%**

APC	
PCBs	75
Modules	2,400
After Placement	
Defective Modules	8
Yield	**99.67%**
After Reflow	
Defective Modules	1
Yield	**99.96%**

Test 2 – For this test, a higher number of boards were built with and without the APC system. Once again, each board was inspected after the placement machine and reflow oven. These inspections were performed by experienced operator; the operator inspected each board under a microscope. Please refer to Table 2 for the results of this test.

Table 2 – Test 2 Yield Results

Yield Improvement

Test 3 – This test was designed to identify if the APC system actually corrects the printing position of the screen printer and to identify if the self-alignment properties of the solder paste will pull the components to the center of the land. Each axis (X, Y and theta) was modified by adding an offset; then the board was built on the line. Please refer to Table 3 for the results of this test

	Missa.	APC	Modules	Defects	Yield
Run 1	0%	ON	1188	3	99.75%
Run 2	0%	OFF	1188	12	98.99%
Run 3	XY - 30%	ON	1188	9	99.24%
Run 4	XY - 30%	OFF	1188	102	91.41%
Run 5	θ - 30%	OFF	1188	112	90.57%
Run 6	θ - 30%	ON	1188	21	98.23%

Table 3 – Test 3 Yield Results

Centered Paste

Missaligned Paste

Cost Of Defects

If we discuss in terms of Cost of Defects or Six Sigma Levels the affect of APC is more evident.

- **Test Two**
  - **No APC→93.49 % Yield**
    - **3 Sigma Level→15-30 % COD**
  - **APC On→99.96 % Yield**
    - **Approaching 5 Sigma Level→ Less than 10 % COD**
- **Test Three X/Y 30 % deviation**
  - **No APC→91.41 % Yield**
    - **Below 3 Sigma Level→ Greater than 30% COD**
  - **APC On→99.24%**
    - **Approaching 4 Sigma Level→ around 15 % COD**

Results

- Keeps your SMT process in Control
- Widens your process operating window
- Increases your yield
- Impacts your overall profitability

Thank you