Whitepaper

Process requirements for high density SMD placement

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As the drive towards assembly miniaturization continues and Surface Mount Technology matures, components are becoming ever smaller and thinner. Despite considerable skepticism when 0201 devices were first introduced, they are now commonly used for high density board assembly. Now, it is the turn of 01005 components to enter production.

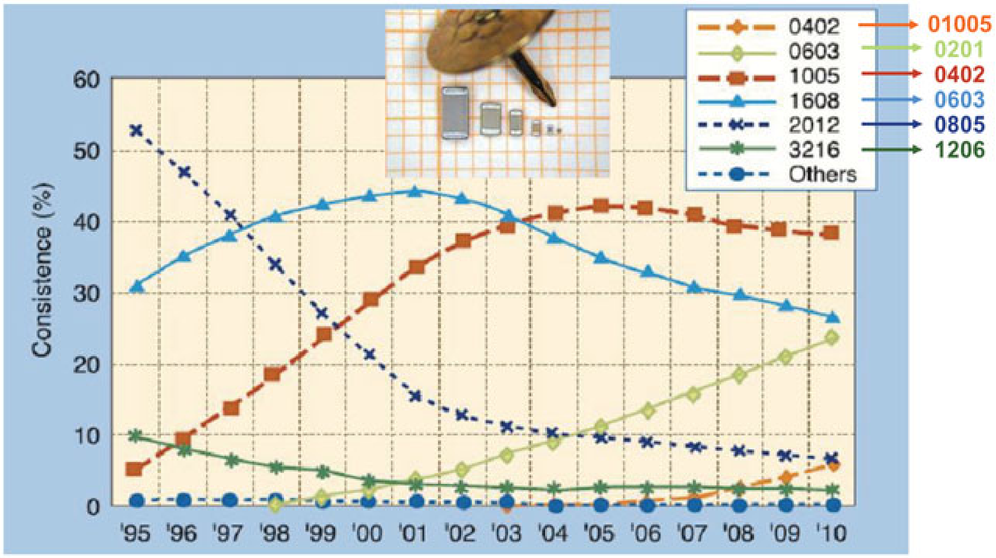
Although processors take the electronic headlines, to production equipment they are just singe components (admittedly with a lot of closely-spaced connections). The great majority of components by number are made up of chip resistors and capacitors, and these largely determine the board size of electronic end products . However, taking full advantage of this miniaturization demands a further reduction of component interspacing.

The 01005 chip components are so small (dimensions are just 0.4 mm long by 0.2 mm wide) that they place extra demands on soldering and assembly processes. Processes must be fully stable and capable before components can be placed reliably. That will need work on printing stencils, the placement process itself, and soldering conditions since the components cannot be used in mass production until defect per million levels are close to single digit figures.

INCREASING COMPONENT DENSITY

The dominant passive sizes from the 1990s have changed. The 1206 (3.2 x 1.6 mm) and 0805 (2.0 x 1.25 mm) chips no longer make up the majority of passives. These formats have generally migrated to 0603 (1.6 x 0.8 mm), 0402 (1.0 x 0.5 mm) and 0201 (0.6 x 0.3 mm) respectively. We have therefore seen a considerable reduction in occupied board area (Figure 1).

Figure 1: The relative sizes of 1206 to 0201 components



Source: Murata, November 2005

Limitations are sometimes admittedly set by the components themselves. A 100 µF capacitor will still need 1210 format chips. Similarly, a 47 µF capacitor needs the 1206 format, since the maximum capacitance of a 01005 chip (for example) is 0.01 µF. The demand for denser packing is also not universal - automotive components for example look set to remain at their maximum average density of 3 components/cm^2. There is little pressure to save space in a car, and there are other priorities.

It is portable equipment that has really driven component density, now already at over 50 components/cm^2 and predicted to rise to near 80 over the next 10 years. In response, the 0603 and 0402 types are now themselves migrating to 0201 and 01005 types in high density applications. Although these two packages are only beginning to emerge now, they are expected to claim an increasing market share, with the ITRS roadmap predicting that 01005 will remain the minimum size until at least 2012.

Interspacings also determine board density

The minimum interspacings of 0402 components have to be at least 150 µm, so even these relatively small components are limited to around 100 components/cm^2. Smaller 0201 types allow tighter 100 µm interspacings to triple the density to 300/cm^2. And, with 01005 components on 50 µm interspacings, the maximum density could double again to 600/cm$^{2.}$ Such densities are needed for integrating passive chip components into semiconductor 'modules' or Systems in Package (SiPs). These semiconductor modules can be found mainly in handheld applications (mobile phone, MP3 players, etc) and offer even more functions at reduced dimensions.

So, the smaller the component, the greater the influence of interspacing on component density. Component placement at small interspacing, however, has a much more critical process window. This is particularly true when the same process has to fit both large *and* small components.

Solder stencils determined by component size

The first of the interspacing-related issues is the solder stencil. Large components need thick stencils to deliver enough solder to make the chip attach properly. For small components a thick stencil is not appropriate since most solder paste will stay in the stencil apertures because of an inadequate thickness to aperture ratio. Consequently, small components need thin stencils. Unfortunately these will not carry enough solder paste to form a good joint for large components.

The solder process itself is critical too, particularly for the smallest components such as 01005 ones. Small components need a 'fast' reflow process to reduce flux evaporation, while large components need a 'slow' reflow process, since their thermal mass is much higher and hence more time is needed for heating up to reflow temperature.

It is therefore difficult to combine large and small components on the *same* printed circuit board. All this suggests that large and small components need to be treated differently. We are indeed seeing a trend to have the larger components (down to 0402 or 0201) on ‘main’ PCBs, with the smallest 01005 components migrating to modules. This is a good trend for manufacturers since, rather than upgrading the whole line, the ultra-high precision assembly is needed only for the modules.

Migrating from microchips to modules

The SiP approach brings equipment manufacturers several benefits. It starts by keeping signal lines short and local for best frequency response. That makes for more flexibility in mobile phone (for example) design, by increasing diversity from a modular architecture. High frequencies (and so smaller capacitors) can be kept within the modules – and less RF specific design competence is needed for the main board. In main board assembly there is no need for expensive wire bonders, flip-chip placers and so on. That reduces manufacturing investments and time-to-market, and increases off-the-shelf functionality.

It is estimated that around 70% of ICs are now placed on the main board, with 30% in modules. In 3 to 5 years this ratio will shift to 40/60.

PLACING 01005 COMPONENTS

The 01005 components must be placed on SiPs *reliably*, placement after placement. This also makes phenomenal demands on the Pick & Place machines, with accuracy and reliability of 01005 component placements being perhaps the two ultimate tests for a machine.

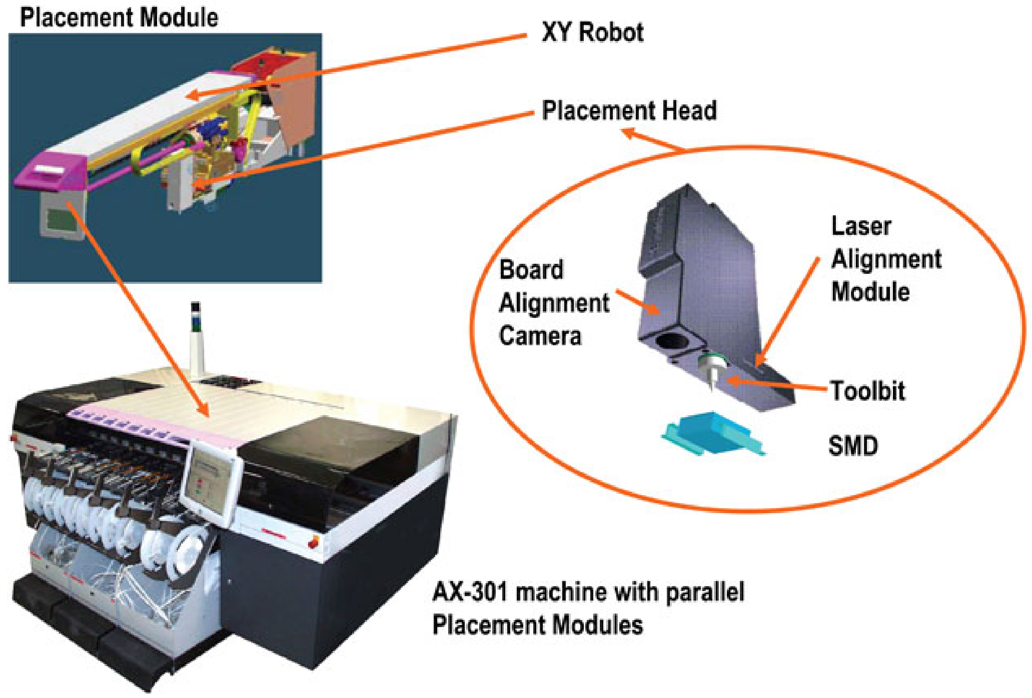
Assembléon’s A-Series of Pick & Place machines has dpm figures below 10 defects per million in full production runs at an accuracy of 40 μm – currently the industry benchmark. Getting figures this low means performing the same action time after time with minimum possible variation, so the placement process itself must be ultra repeatable.

Rather than placing components sequentially using large overhead gantry robots, as is the more usual Pick & Place operation, the A-Series has multiple modules placing components in parallel. Up to 20 modules on the AX-501 give placement rates of up to 165,000 components per hour (12 modules for the AX-301 place 90,000 components per hour) while maintaining 3-sigma accuracy to within 40 μm. For ‘end of line’, the 18,000 components-per-hour AX-201 also places bare die products, high-pin-count ICs and odd-form components at 20 μm accuracy. The three machines share a common user interface and software, feeder range, trolleys, trays and placement heads.

Parallel placement with multiple heads improves process control

Parallel placement means much smaller accelerations and decelerations, and therefore much less vibration. It gives the xy robots that drive the parallel placement modules (Figure 2) much more time to settle, and also to check the placement process. During the pick cycle, the A-Series checks the pick height, checks that a component is present, and corrects for any misalignments in component position. During the place cycle, it checks that the component is still there, places it with correct force, inspects the placed component, checks alignment, and detects any on-edge components

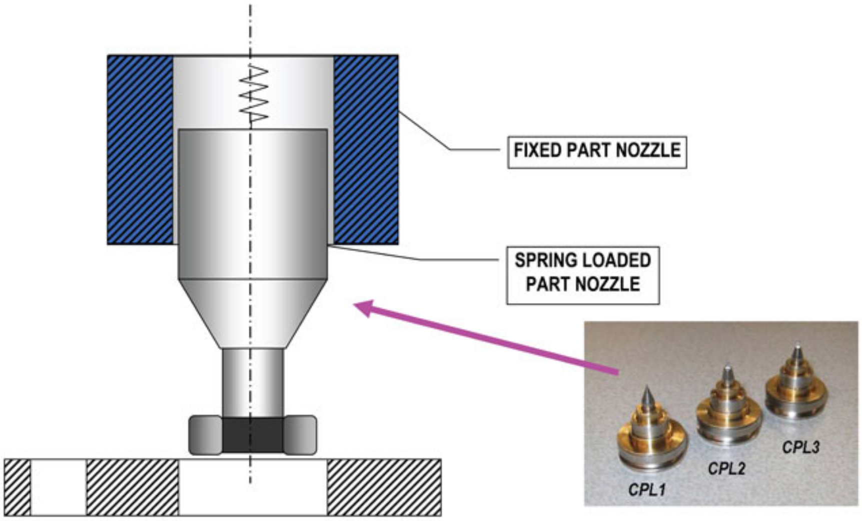
Figure 2: Assembléon’s A-Series design means much smaller vibration because many heads are placing components in parallel, so with more controlled movements.



Placement force is also much more accurate with a controlled Pick & Place operation. Connectors and larger components need high placement forces to ensure reliable placement, while small components generally need low placement forces (an extra risk with ultra-small components below 0603 is the possibility of component cracking because of excessive impact force). So placement forces need to be precise, and adjustable.

For the A-Series, they are adjustable per component between 1.5 and 40 N. The Pick & Place machine measures the board warpage and models the board surface to calculate the exact force needed. A spring-loaded Contact Pick Nozzle (Figure 3) actually picks and places the component.

Figure 3: Components on the A-Series are transferred by a spring-loaded Contact Pick Nozzle



Testing 01005 placement reliability

Assembléon has performed several large-scale tests of 01005 placements to decide on the manufacturability of the components. One test involved four reels each of 3,000 Murata capacitors using four Assembléon placement modules. It tested 60 µm interspacings in four possible component orientations (0, 90, 180 and 270°), with the results showing a pick ppm total of 583.

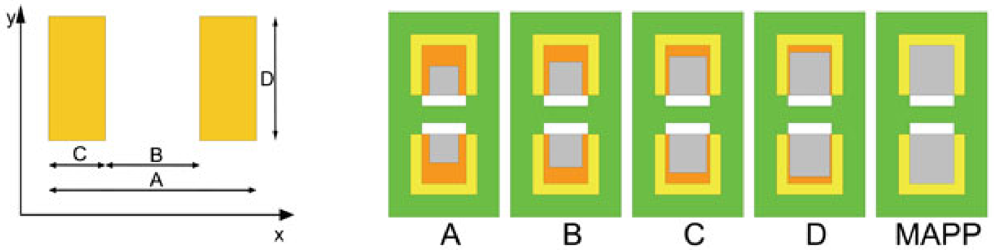
Another test used a reel of 5,000 Taiyo Yuden 01005 capacitors, testing interspacings from 50 µm down to 30 µm on four different substrates (FR-4 board with aluminum ‘accuracy’ tape, 50 µm grease layer and sticky tape, and rigid full aluminum board). Four different placement orientations were again used. The results indicate that 30 µm interspacing was only possible under ideal conditions. Even then, there were no visible errors, but that is pushing placement interspacing to its limits.

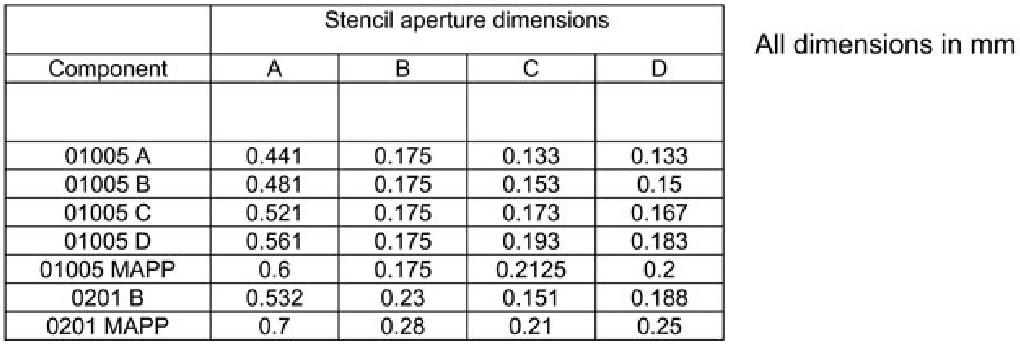
Process investigations: stencil printing, interspacing, results

Perhaps the most important questions for manufacturers considering 01005 components are which solder footprint to use, and the minimum layout interspacings for reliable placements. They were tested using over 40,000 components with a DEK Infinity stencil printer, an Assembléon AX-301 Pick & Place machine, and a Vitronics Soltec Model 7038 solder reflow oven.

The most logical first choice for 01005 footprint is to scale down existing design rules, and the experiments therefore started with Philips’ Miniature Assembly Process Platform (MAPP) design rules scaled down to 01005 size. Placement was however found to be impossible below 200 µm. There was too much solder paste, and it was located too far outside the component ends, so that it bulged upon placement. The next tests therefore aimed to select the best stencil size. Four stencil sizes from smallest A to largest D (Figure 4) were tested at interspacings ranging from an ultra conservative 200 µm right down to 30 µm.

Figure 4: Assembléon’s tests examined four stencil sizes from smallest (A) to largest (D) at interspacings down to 30 µm.

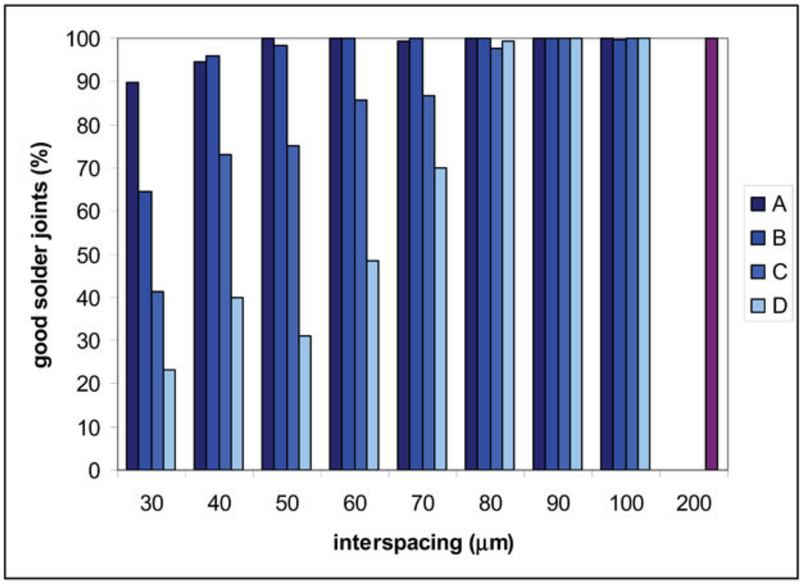




	Stencil aperture dimensions			
Component	A	B	C	D
01005 A	0.441	0.175	0.133	0.133
01005 B	0.481	0.175	0.153	0.15
01005 C	0.521	0.175	0.173	0.167
01005 D	0.561	0.175	0.193	0.183
01005 MAPP	0.6	0.175	0.2125	0.2
0201 B	0.532	0.23	0.151	0.188
0201 MAPP	0.7	0.28	0.21	0.25

All dimensions in mm

Figure 5: As a result of the tests, Assembléon is recommending 60 µm as minimum interspacing.



A,B,C,D: Refer to stencil apertures

The results (Figure 5) show larger percentages of good soldered joints as the interspacing increases, with all joints being ‘good’ for interspacings 90 µm and up. The results also show that the defect level generally goes up from A to D, i.e. with more printed solder paste.

The test results indicate that applying the least possible solder paste – stencil aperture A – gives the best result. However, smaller stencil apertures lead to distinct disadvantages. There is a larger probability of printing insufficient paste through improper paste release from the stencil. Less solder is available for solder joint formation, which means that the pads will not be wetted completely, and the joints look thin.

We are now therefore recommending Aperture A at interspacings of 30, 40, 50 and 60 µm, and Aperture B at interspacings of 70, 80, 90 and 100 µm.

Self-alignment of 01005 versus 0201

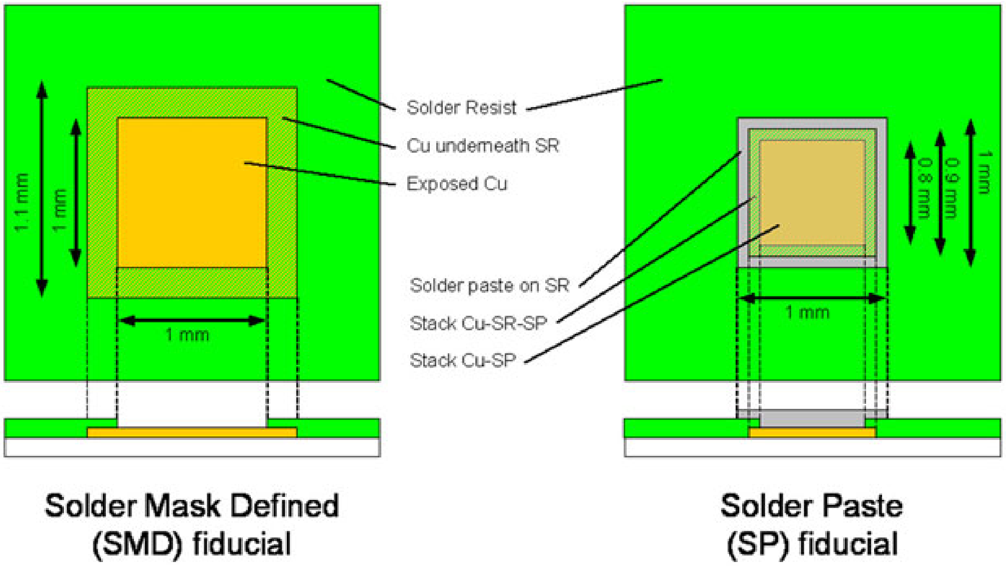
Slightly larger components like 0201 types show considerable resilience in full production, largely because of their tendency to self-align when placed on the solder footprint. We therefore needed to know whether 01005 will do the same. To find out, 01005 and 0201 components were placed at a range of offsets to the solder pads.

The test found that, logically enough, the greater the offset the higher the number of defects. The 0201 components however give far better results, and even the highest offsets caused very few defects. These components were all placed with accuracies of 50 µm to within 3-sigma limits, and this suggests they are better at self-aligning than 01005 components.

Choosing between SMD and SP fiducials

When placing components on solder mask defined pads (Figure 6), solder mask defined fiducials are normally used to ensure that components are properly aligned with pads. However, for very small components it could be better to align the components with the solder paste, as a small solder paste offset could result in the component not touching the paste, and hence a defect. Specially printed solder paste fiducials would then be needed to compensate for any paste offset due to an overall offset in the paste printing process.

Figure 6: Solder mask defined versus solder paste defined fiducials.



Solder Mask Defined (SMD) fiducial

Solder Paste (SP) fiducial

Another series of tests therefore gave the solder paste a deliberate offset by designing apertures in the stencil with an offset with respect to the pads on the board. One section of the test board had components placed using regular solder mask defined (SMD) fiducials, and another used solder paste fiducials. For SMD fiducials the component was aligned with the pad and, where the paste has an offset, there is only little overlap between the component and the paste. For solder paste fiducials, the component was aligned with the paste, giving smaller overlap with the pads. Solder paste was printed at offsets of 0, 50, 75 and 100 μm, in x and y directions simultaneously.

Out of the 1200 joints made using solder paste (SP) fiducials, only one component had a lifted end ('tombstoning'). For components placed with small offsets (0 and 50 μm), the results for the SMD fiducials are comparable to those for the SP fiducials. When the paste offset rose to 75 μm and 100 μm, however, the components placed with the SMD fiducials showed asymmetrical contacts and limited pull-back force for self-alignment. That gave a strong tendency toward tombstoning.

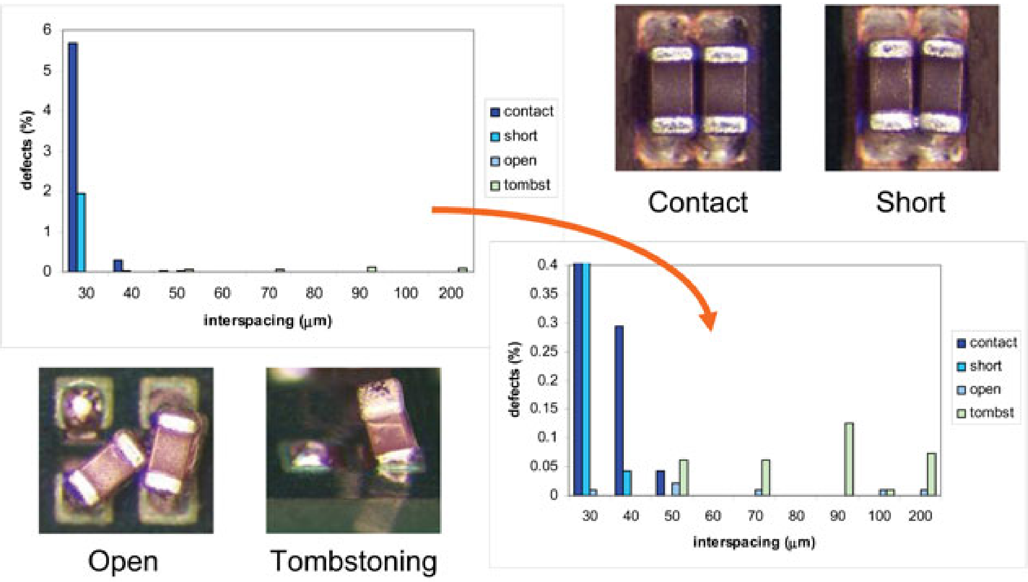
So, when placing tiny components, and when there is a risk of a large paste offset (larger than 50 μm), solder paste fiducials are advisable. When the paste offset is small (50 μm or less), either fiducial type will work.

Solder reflow process errors

The final major production stage is reflow soldering. Here, we found process errors to be either solder paste printing related or interspacing related.

Solder paste related errors divide into tombstoning and opens (Figure 7). Tombstoning is caused by solder paste offset causing asymmetric wetting and component lifting. Opens, where components are still on the board but do not make a solder joint at one end, are mostly caused by solder paste offset.

Figure 7: Defect types found at different interspacings



Interspacing related errors divide into contacts and shorts. Contacts indicate possible contact problems – either short or no contact – between component and board (shiny flux between components may cause reflections which look like problems but are not. Shorts can be caused by solder paste producing bridges at small interspacings.

We also found some differences between the performance of resistors and capacitors. Resistors give generally better results than capacitors (99.5% good joints versus 98.6%), most likely because capacitors are slightly wider and have more form variation. This effect becomes more important at small interspacings.

01005 proves to be ready for production at 60 µm interspacing

As a whole, we found solder paste printing to be perhaps the most critical stage, with thin vulnerable stencils needing frequent cleaning to prevent the stencil aperture blocking. If paste offsets are too large, 01005 components cannot self-align which makes production vulnerable to tombstoning.

If these factors are taken into account, we have found placement of 01005 size components to already be a robust process. For larger interspacings (90, 100 and 200 µm) we recommend an 80 µm stencil thickness, while for 60, 70 and 80 µm we recommend a stencil thickness of 50 µm – which will allow 0402, 0201 and 01005 components to be combined.

With a placement accuracy of within 50 µm at 3-sigma, our tests showed the minimum interspacing for 01005 components to be 60 µm. This translates into a placement quality of below 20 dpm, which easily classes as ‘production ready’.