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Investigating Compliant Tooling Solutions within a Mass Imaging Process

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Abstract
The printing process is always highlighted as contributing the most process defects to a surface mount manufacturing production facility; typical values presented are around the 60% range. Fact or not it does focus the mind on the component parts of a mass imaging process especially if it is "hidden" – such as Tooling.

The standard tooling solutions on offer are either fabricated tooling plates or manually located magnetic pins. Both of these solutions have several drawbacks with regards to set-up time, expense and the inability to support on components. It is the last issue mentioned which is becoming ever challenging, as substrates become smaller the real estate in which tooling support can be applied reduces, compound today's thinner substrates and a real yield risk emerges.

This paper is focused on a new breed of tooling which conforms around the substrate and underside components – *Compliant*. To carry out this investigation 3 tooling solutions will be tested, this will include a metal plate to form the benchmark test. The compliant tooling solutions will be based around modules of pins, which form around the substrates underside. The first system employs hydraulics to provide compliancy throughout the print cycle. The other solution utilises pneumatics, which locks the pins after each set-up to form a rigid system.

To investigate all tooling solutions fully a panellised test vehicle fabricated in 0.6mm, 1mm and 1.6mm FR4 with pre assembled SMT components and heavy routing will be utilised throughout.

An automatic laser optic system will be used to measure the solder paste volume, heights and area across the entire substrate. This data will establish any variation of system to system and indicate which systems have the greatest flexibility

Mass Imaging using an Automatic Printing Machine
An automatic stencil-printing machine utilising ProFlow applied the solder paste through an industrial standard 127µm thick laser cut stencil. A 180mm x 140mm double-sided test board was designed with Ni/Ag surface finish. The board was fabricated in three thickness, 1.6mm, 1.0mm and 0.6mm. A variety of surface mounted components were mounted on the first pass side to introduce the standard topography observed in every day surface mount technology fabrication refer to Figures 1-3 for images of the test substrate. The stencil printer was capable of fully closed loop control of the following process parameters. The parameters were derived from a previous set of experiments.

Print Speed – 80mm/s
ProFlow Pressure – 2.0 Kg
Paste Pressure -1.8 bar
Separation Speed – 10mm/s
Separation Distance – 1.0mm
Print Gap – 0mm

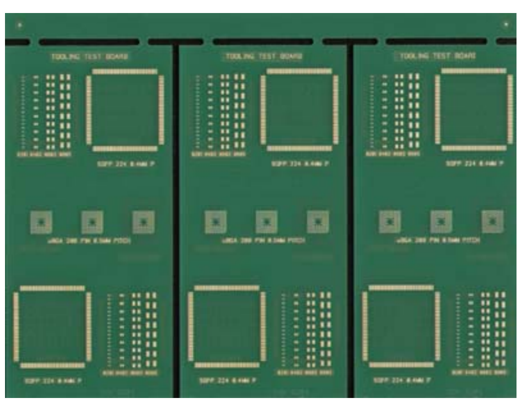


Figure 1 - Print Side

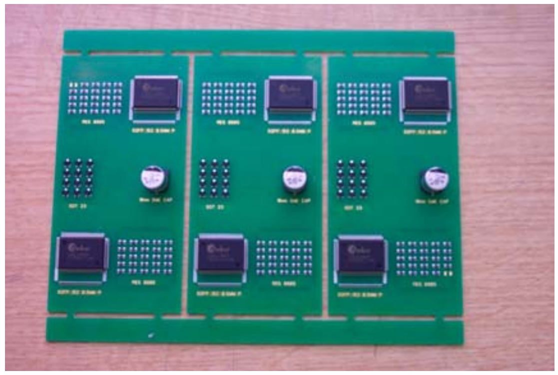


Figure 2 - Populated Side

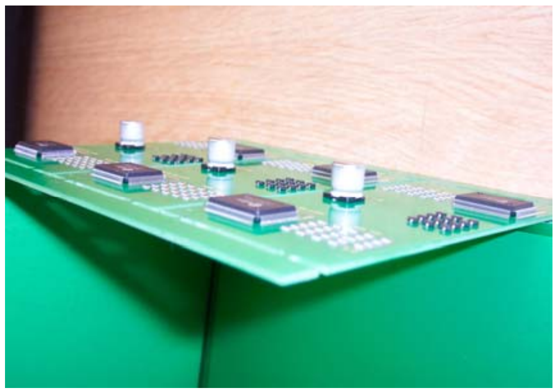


Figure 3 - Standoff Heights

Direct Imaging using an Enclosed Print Head with a Stencil Printer
Direct imaging with modern automated stencil printers has proven itself in the production environment for several years. The control and benefits of an enclosed print head for solder paste have expanded in scope to include the introduction of other viscous print media. The direct imaging system provides a more stable and repeatable process in most cases. This is important because a direct correlation can be drawn between successful stencil printing and low end-of-line defects. Studies over the past four years have shown the technology to offer benefits in terms of yield, throughput, and cost savings.

The main concept of direct imaging is that the speed of the transfer head and the pressure on the print media is independent. Therefore, the amount of transfer pressure may be tailored to a specific application. For example, if a relatively high viscosity/high metal content material must be printed, the speed may be reduced and the pressure increased to get maximum fill

The enclosed print head stores material internally and uses an independent transfer pressure mechanism. The material roll is well defined in volume and remains constant thorough two wiper blades, which also keep the stencil surface clean. Two silicon skis prevent material from escaping from the sides, and allow the unit to easily traverse the stencil. The unit resides on the stencil during operation so that the material is sealed on all sides. Pressure is applied directly to a rigid-walled cassette in the transfer head, forcing material through the stencil apertures. The trailing wiper foil returns the material to the conditioning chamber and cleans the stencils surface.

The fixed distance between wiper foils and constant transfer volume expose the stencil apertures to a well-defined amount of solder paste. This constant contact time between paste and stencil apertures create a consistent transfer force acting upon the solder paste through a batch run, and between batches of PCBs.

The Solutions
Dedicated - or custom - tooling has rightly been regarded as the Standard among tooling solutions, certainly for surface mount applications. (Figure 4) Modern production methods, which use original CAD data from the PCB assembly to generate an accurate CNC program, allow precision plates to be machined quickly and at a more competitive price.

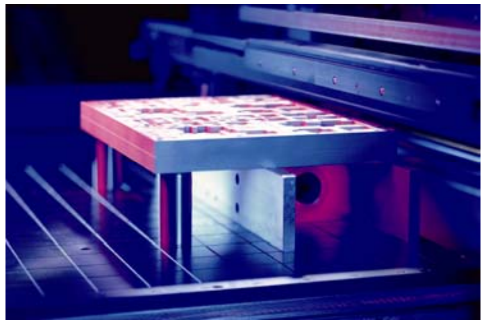


Figure 4 - Example of Dedicated Tooling

But in high-mix production, and particularly as increasing component density demands tooling solutions that can make contact with underside components, users need a new breed of reconfigurable tooling pin array.

DEK's FormFlex® tooling array system (referred to hereafter as the flexible array) is a hybrid system with interconnected fluid-filled cylinders that are pneumatically activated to drive the tooling pin into contact with the PCB surface or component body. During a product set-up, the tooling array is configured once using a known good board. The procedure calls for a set-up jig to be clamped to the stencil frame to prevent the set-up forces deflecting or distorting the board. Once set-up, the pneumatic supply to the array is cut and the fluid system is sealed. But because the fluid-filled cylinders are interconnected, the pin array can "float" a little to compensate for small production variations between individual assemblies entering the machine. (Figure 5)

Figure 5 - Example of Flexible Array

The same philosophy is also behind the GridLok tooling system (referred hereafter as the grid array). This system sets out to reduce product changeover time by automatically driving the pins up to the assembly each time a board enters the machine. The pins are then locked in place; there is no compliance within the pin array after configuration is completed. The system also has a "stealth" configuration mode, which uses very low contact pressures during set-up. Although the system needs to configure itself once every cycle, this can be done with little penalty in terms of cycle time. For high-mix, low volume production, the process is very fast because no set-up jig is required. (Figure 6)

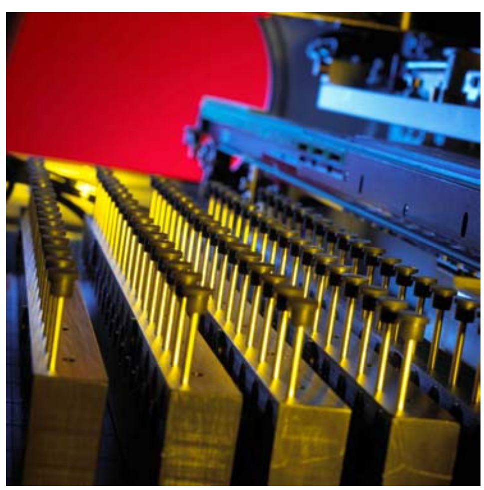


Figure 6 - Example of Grid Array

Statistical Capability Performance Testing of an Automatic Stencil-printing Machine

Prior to successful experimentation or production, electronic assembly equipment should be qualified to vendor recommended specifications. The stencil printer was verified prior to experimentation with a factory-standard qualification procedure, testing X, Y, and Ø axes as well as the front and rear pressure. By qualifying the machine, no equipment-related input variables were introduced, which could affect the output variables measured. The metric used was the Cp/Cpk values of each of the axes. For the stencil printer to be capable, all axes had to exceed Cp/Cpk values of 1.33.

Solder Paste Height, Area, and Volume Measurement Using Commercial Equipment

Three-dimensional solder paste measurement systems are capable of determining height, area, and volume of solder paste deposits on a PCB. The 3-D laser scanner is based upon triangulation and uses a solid-state scanning and detection system with

Signal processing capability to collect height data

This type of device has been fully described in other papers. The scanner is moved by a positioning system to collect successive lines of data. The speed of the system allows the scanner to collect full 3-D image data, across an entire PCB. In this experimentation, 100% of all the pads on the test PCB were scanned in under 25 seconds, providing about 3000 height/area/volume data points for consideration. Statistical analysis aided in the data reduction process, giving meaningful information from the data. A factory-trained representative programmed the equipment and conducted Gage Repeatability and Reproducibility testing.

Experimental Procedures

Nine sets of experiments were performed to cover the three-board thicknesses plus the three tooling solutions. The process parameters used were derived from previous material testing, the same parameter set were for all experiments. Before each experiment the process was reset to a known status quo to enable qualitative analysis to be undertaken. The output variables collected were Cp and Cpk of height, area and volume. The components selected on the PCB were 0.4mm pitch QFP, 0.5mm CSP, 0805,0603,0402 and 0201 resistor packs. For simplicity the Volume analysis focuses upon the BGA package.

2Kg of commercially available Type III lead free solder paste was filled into the enclosed head. Two blank panels were printed to establish proper rolling of the solder paste on the stencil surface. The automatic under stencil cleaner was deployed only when the print quality degraded to an unacceptable level; this frequency was recorded for analysis. The results are shown in Table 1a-1c.

Table 1a – Under Stencil Clean Rates for 1.6mm Substrate

Tooling Option	U.S.C Rate
Dedicated	10
Grid Array	7
Flexible Array	9

Table 1b – Under Stencil Clean Rates for 1.0mm Substrate

Tooling Option	U.S.C Rate
Dedicated	7
Grid Array	8
Flexible Array	9

Table 1c – Under Stencil Clean Rates for 0.6mm Substrate

Tooling Option	U.S.C Rate
Dedicated	5
Grid Array	3
Flexible Array	8

30 test boards were printed for each level of the experiment. After printing each board, the time of print, board identification number and print direction were recorded on a data sheet.

Results and Observations
A capability analysis was performed on the stencil printer prior the experiment. The x, y and Ø axes were measured using the vendors recommended test procedure. The results are shown in Table 2.

Table 2 – Results of the Stencil Printer Capability Study

Axis	Target Cp/Cpk	Actual Cp/Cpk
X	1.33	1.87/1.65
Y	1.33	1.65/1.45
Ø	1.33	2.7/2.6

Paste Height Results
Figure 7 shows the paste height data collected across the whole board. These measurements allow an overall view of the paste repeatability for each tooling solution and substrate thickness. It can be seen that the initial trend is towards dedicated tooling as a more suited solution towards the thicker substrate and compliant solutions to the thinner spectrum. Out of the two compliant solutions GridLok shows less capability on the ultra thin substrate. To further understand this trend the data was analysed to component level.

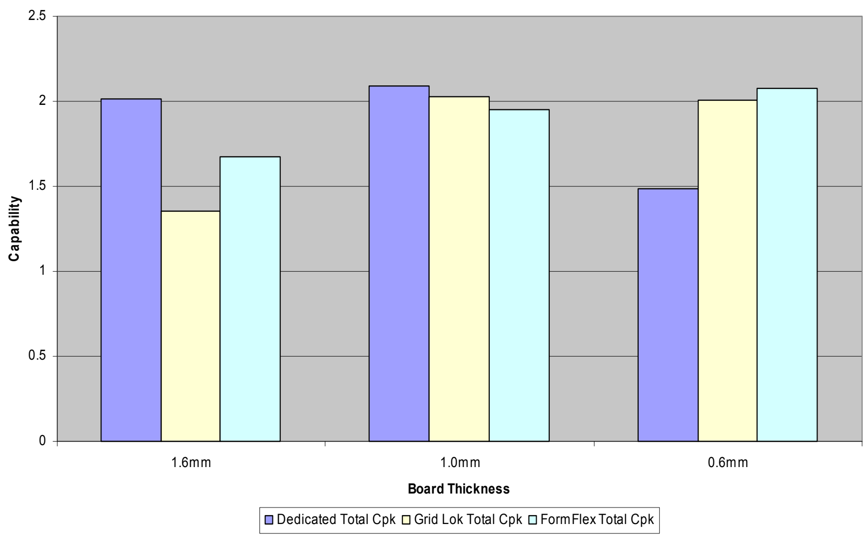


Figure 7 – Graph Showing Solder Paste Height

Figure 5a shows paste volume data collected at the BGA sites for each group substrate and tooling types. These measurements allow us to assess the effects of underside-mounted components on paste volume repeatability. Note that the component directly under BGA 4 was an electrolytic capacitor with a standoff height of 10mm. BGA 5 had no underside component and BGA 6 had an array of SOT 23 packs with a standoff height of 1.5mm.

Again as expected, dedicated tooling enabled the best paste volume deposition when working with 1.6mm thick boards. This finding concurs with industry's view that dedicated tooling delivers the best physical support for screen printing.

But as board thickness decreases, some surprising results emerge. Figure 8a-c clearly shows a marked fall-off in performance for dedicated tooling, as the compliant solutions come into their own. We first gained a foresight that something unexpected was happening as we recorded the frequency of USC cycles during the experiments (Table 1a-c). With decreasing board thickness, the print quality achieved with dedicated tooling became unacceptable more quickly. With 0.6mm panels, dedicated tooling required a cleaning operation every five cycles, compared to eight cycles when flexible array tooling was used.

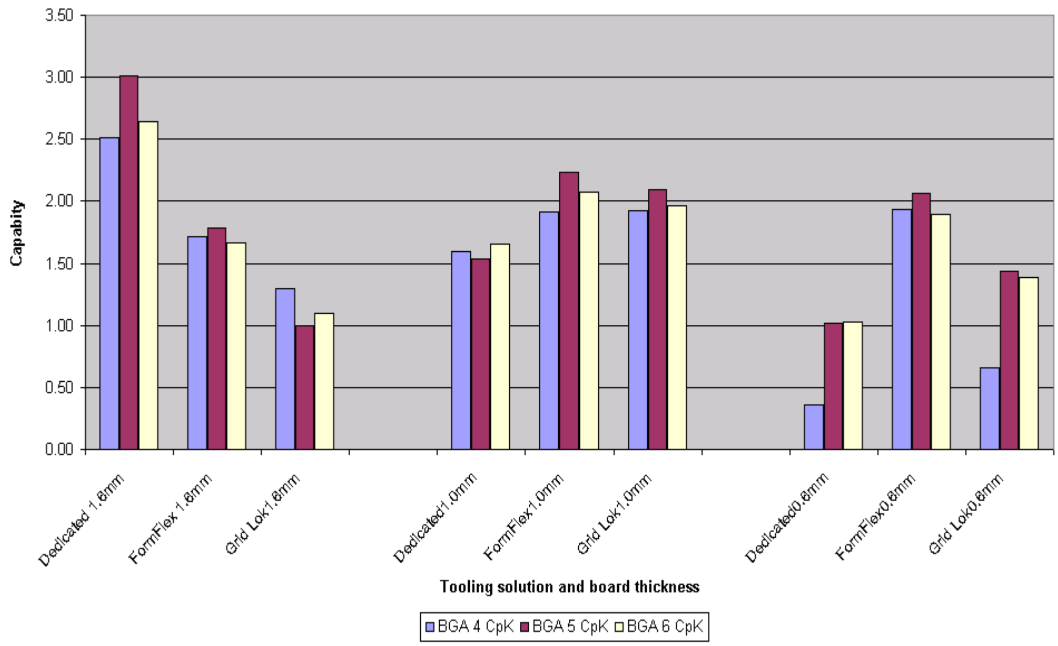


Figure 8a – Graph Showing Solder Paste Volume for BGA Packages

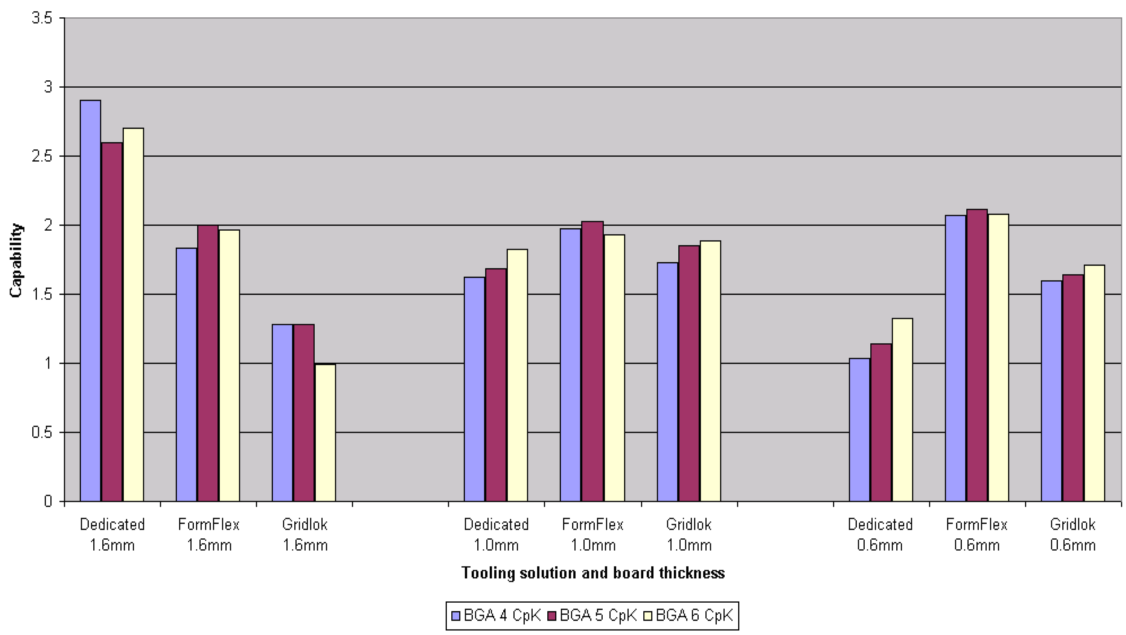


Figure 8b – Graph Showing Solder Paste Height for BGA Packages

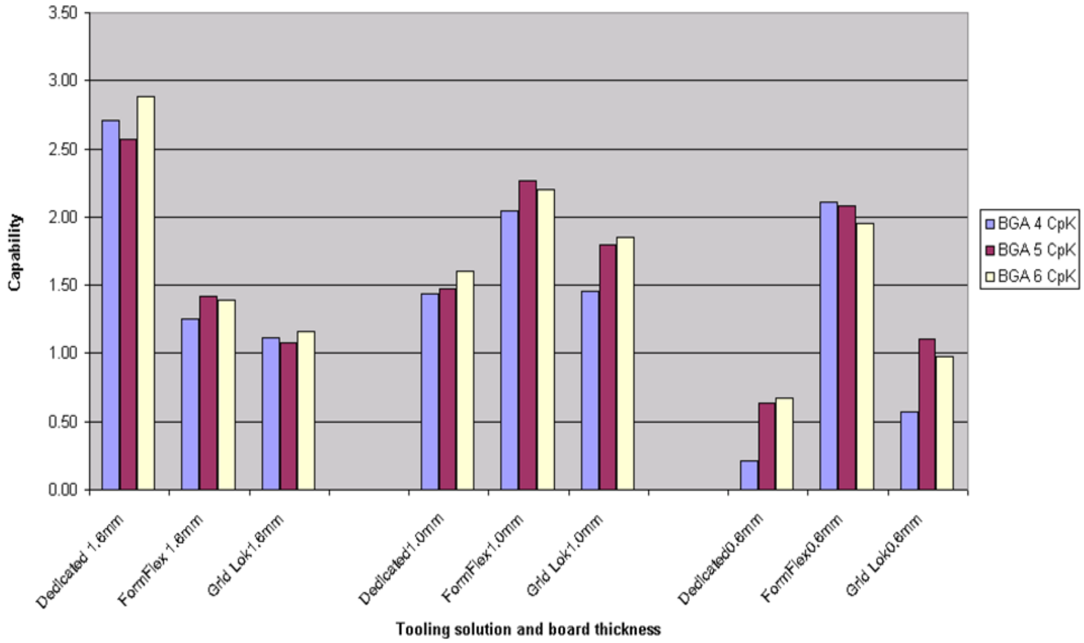


Figure 8c – Graph Showing Solder Paste Area for BGA Packages

Our intuitive observations were borne out by the data. Figures 9 to 11, showing paste volume measurements taken at the sites of QFP packages, further underline our observation.

Figures 9-11 shows the print deposition data across all QFP devices. The board layout ensured that the QFP components were located at the extremities of the board; this ensured that any co-planarity issues would be demonstrated.

It can be seen that the data for the grid array1.6mm substrate Figure 11a shows a definite trend of lower paste volume on QFP2, 4 and 6. This indicates that the board was not truly flat and parallel to the stencil during the print cycle. The results from the other tooling solutions are presented to show comparison but it is worth noticing that this GridLok trend is observed across all substrate thickness. This data concludes that unless the compliant tooling solution is set-up against a flat datum then the substrate to stencil parallelism is breached which will cause varying deposit volume across the substrate.

Other observations show again a clear trend with respect to board thickness. We can attribute the variance in paste volume to the inability of the dedicated plate to fully support the thinner panels Figure 9a-c. This allows the substrate to flex as the print head traverses the areas where tooling support cannot be provided, thereby breaking the gasket seal between stencil and substrate. The area of a printed deposit is strongly correlated to the gasket created during the printing cycle, if the gasket is broken due to support variation it is plausible that a reduction of capability and variation would be observed. The decay of dedicated tooling performance is most noticeable with the 0.6mm substrate.

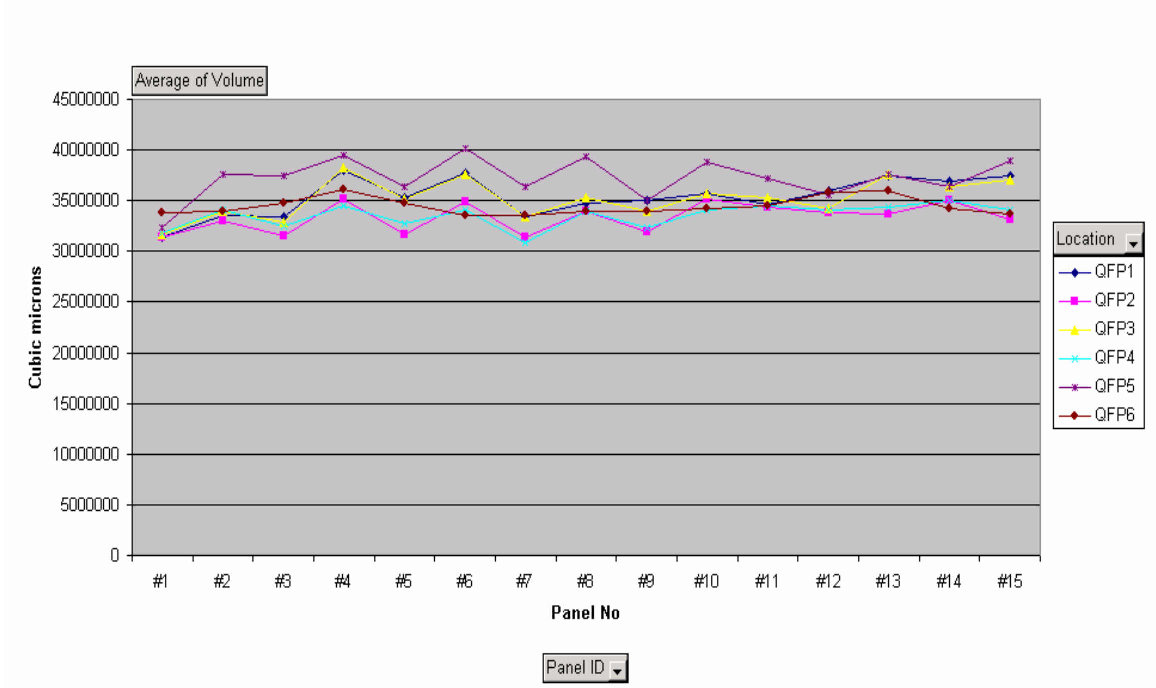


Figure 9a – Graph Showing Volume for Dedicated Tooling and 1.6mm Substrate

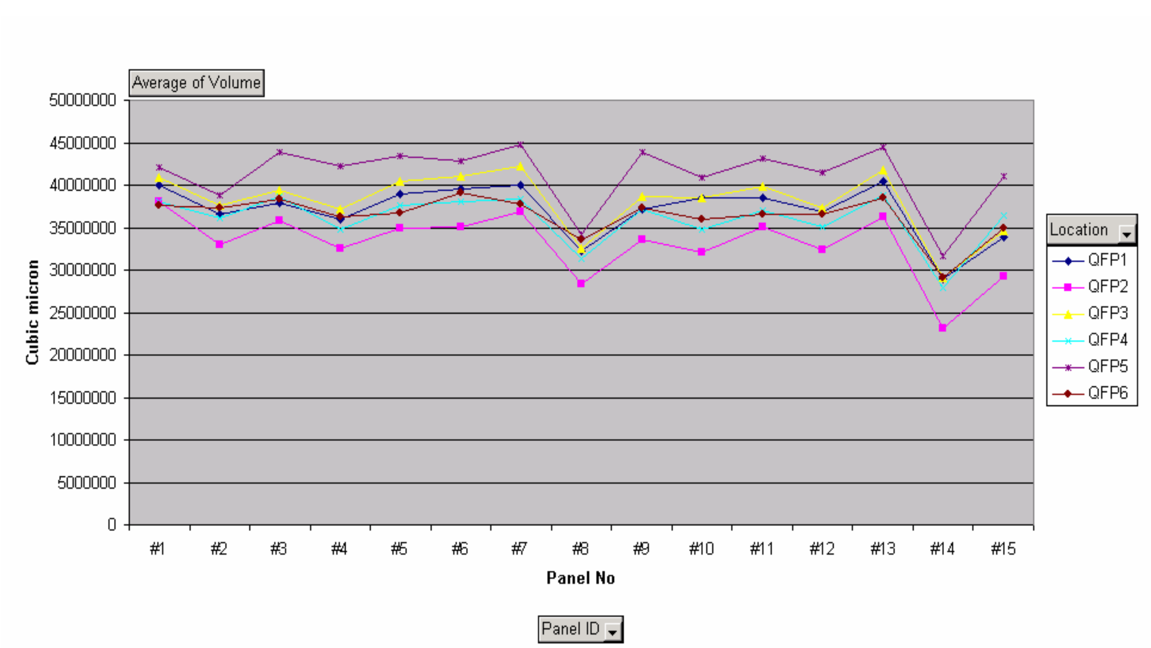


Figure 9b – Graph Showing Volume for Dedicated Tooling and 1.0mm Substrate

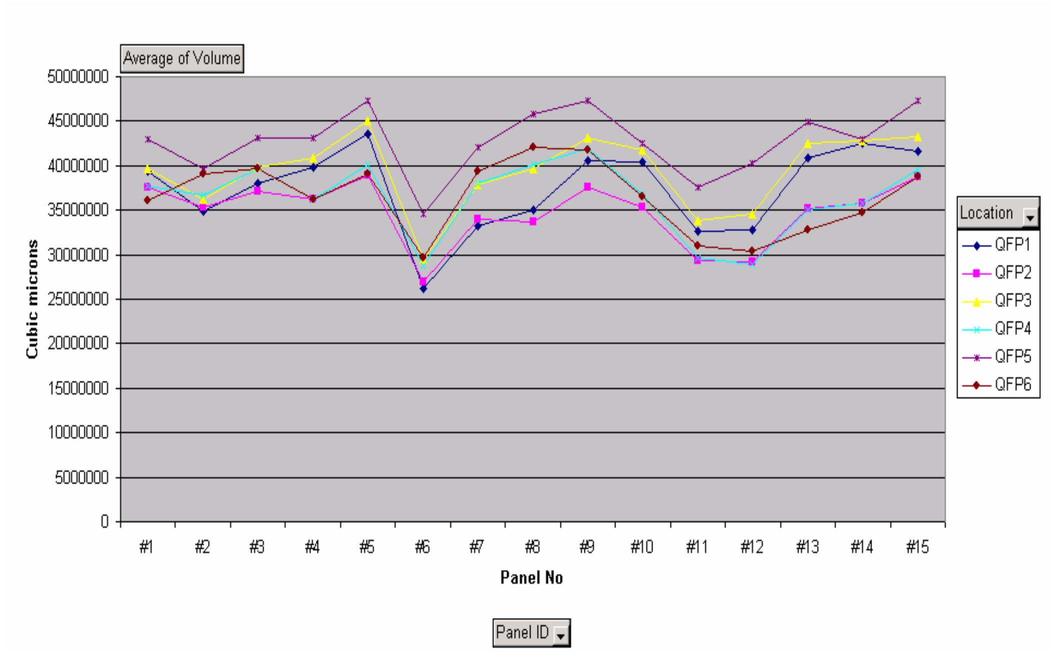


Figure 9c – Graph showing Volume for Dedicated tooling and 0.6mm substrate

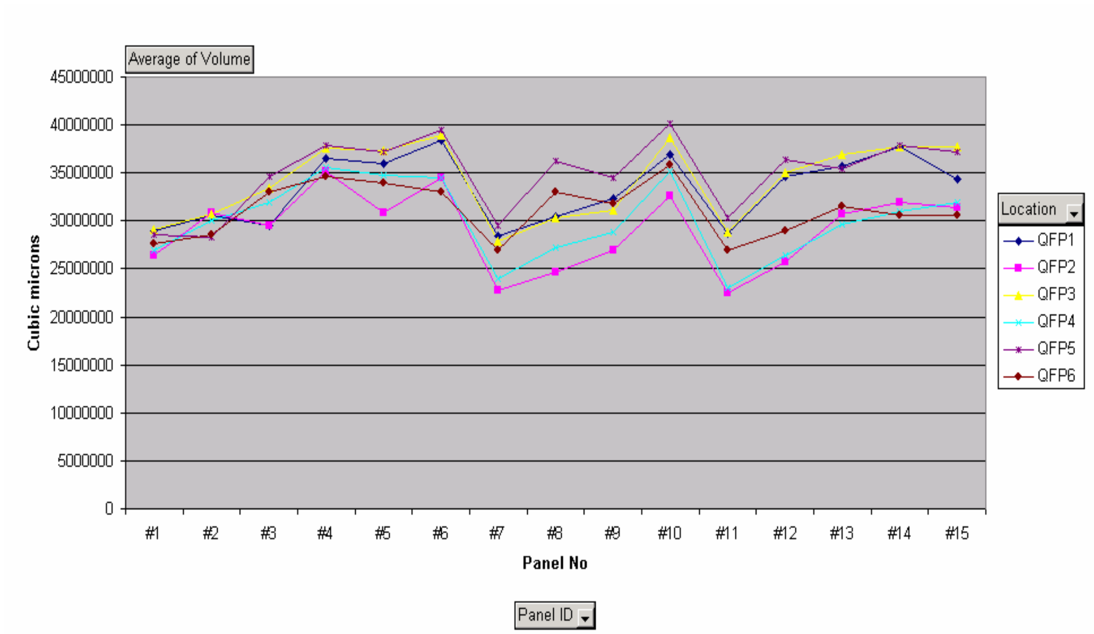


Figure 10a – Graph Showing Volume for FormFlex Tooling and 1.6mm Substrate

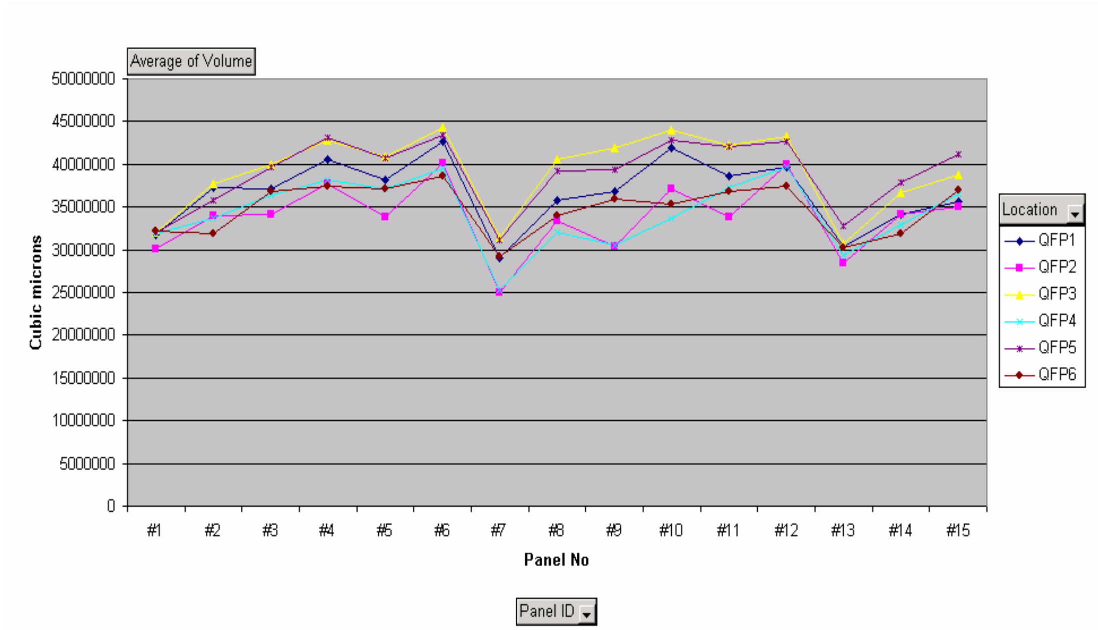


Figure 10b – Graph Showing Volume for flexible array tooling and 1.0mm Substrate

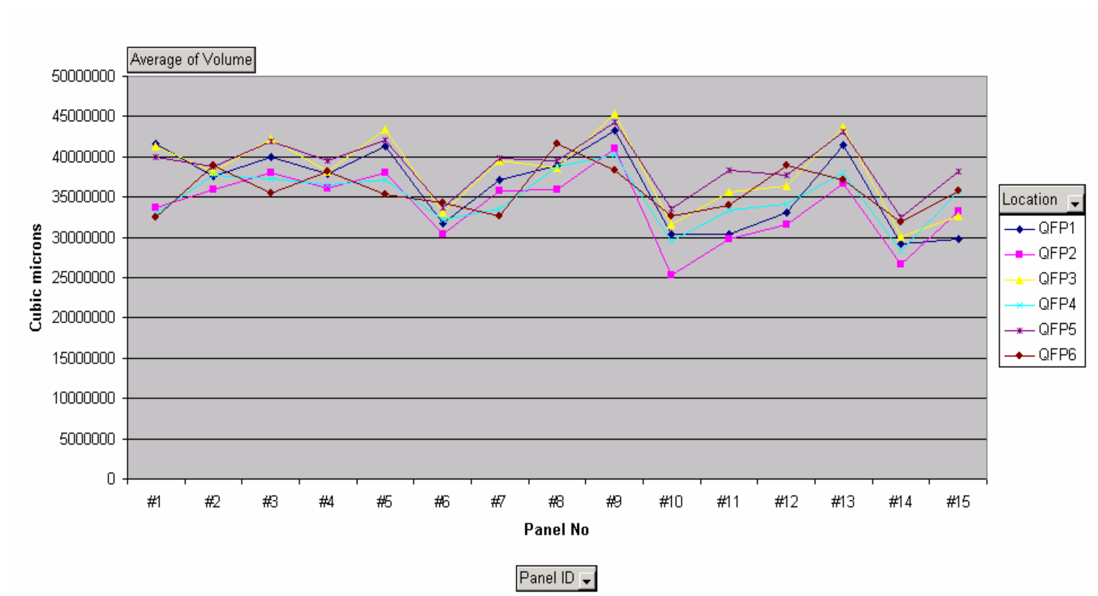


Figure 10c – Graph Showing Volume for flexible array tooling and 0.6mm Substrate

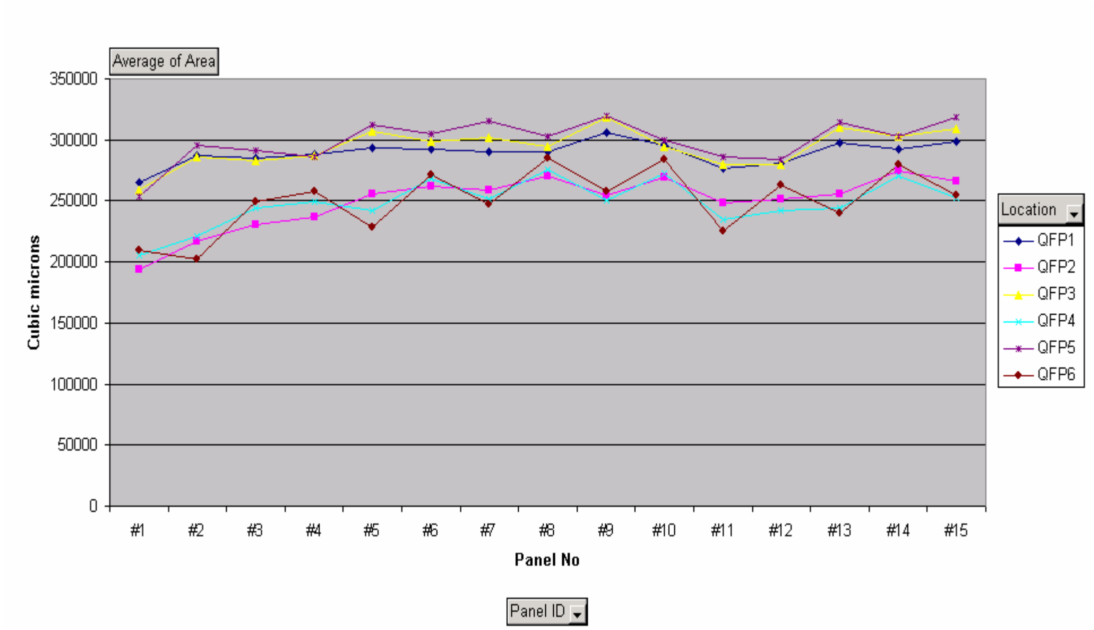


Figure 11a – Graph Showing Volume for grid array tooling and 1.6mm Substrate

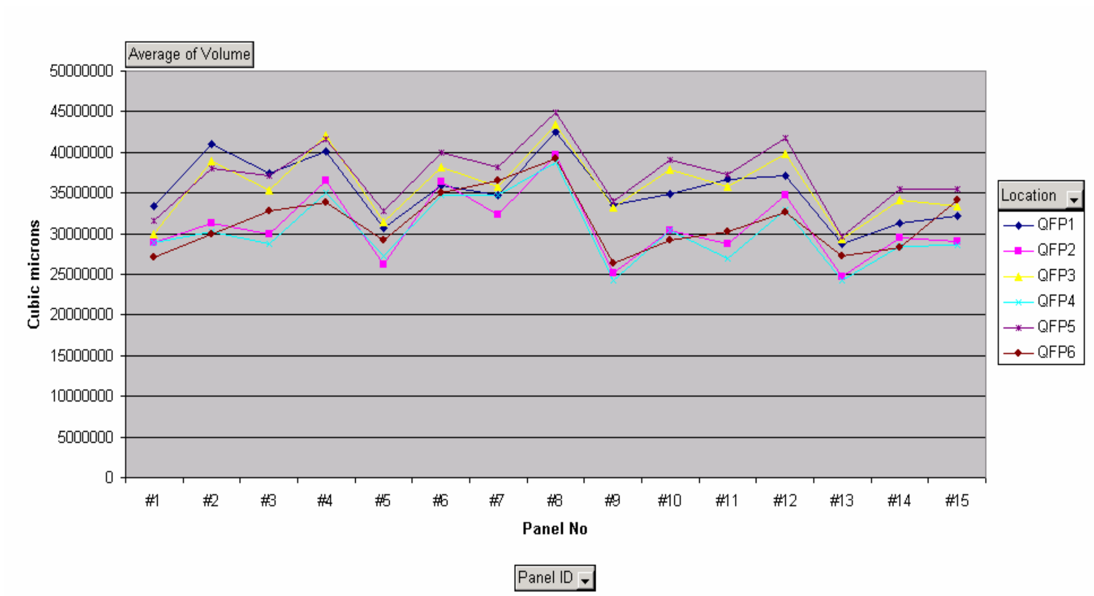


Figure 11b – Graph showing Volume for grid array tooling and 1.0mm Substrate

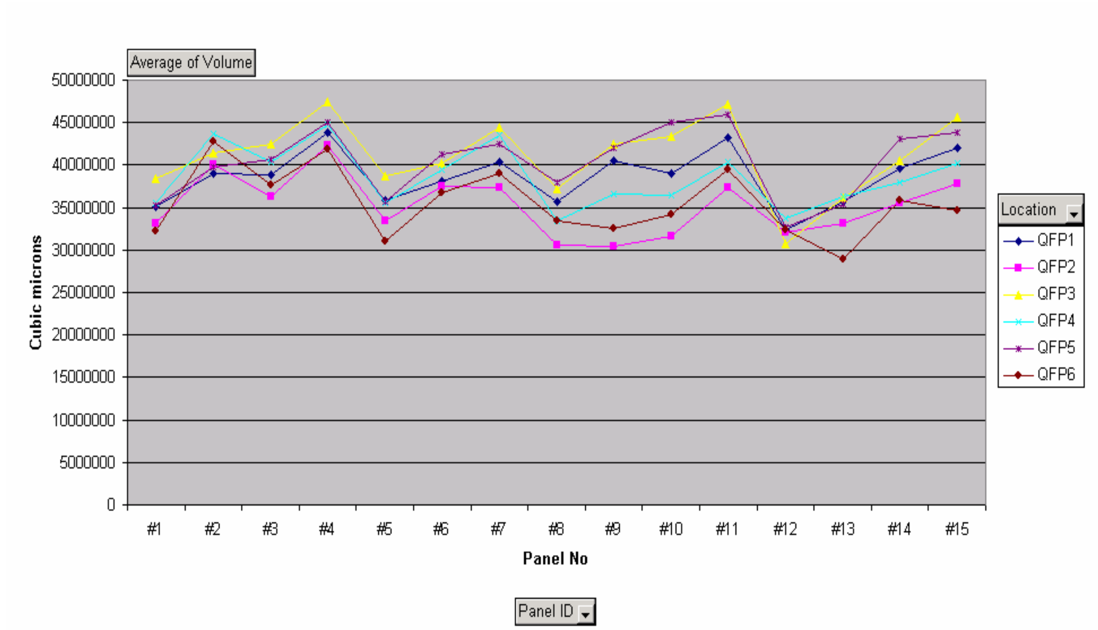


Figure 11c – Graph Showing Volume for the grid array tooling and 0.6mm Substrate

As a summary of the data collected at the QFP sites it again shows the compliant tooling systems trailing the performance of dedicated tooling on the 1.6mm substrate. But the performance of grid and flexible array tooling holds up much better with decreasing board thickness. This trend begins to become apparent with 1.0mm gauge boards.

But flexible array tooling significantly out-performs all tooling solutions at 0.6mm. We believe this is due to the independent “floating” property of each pin, which results from the interconnections between the fluid filled cylinders of the flexible array. This allows the tooling support to adjust to very small variations in component size and placement. Without this extra level of compliance, a slight increase or decrease in the pressure exerted by the pin against the component can cause a significant deflection in the thin substrate.

The important difference between flexible and grid tooling in this respect is that the flex array is set-up using a rigid jig that keeps even a very thin and flexible board extremely flat while set-up forces are applied. The array can then adjust minutely to maintain a perfectly flat support throughout the print cycle. The grid system showed a similar trend but with slightly poorer performance for the very thin 0.6mm substrates, possibly because it is not practical to install a reinforcing set-up jig during array’s “stealth mode” configuration.

Final Judgement

The test boards gather together a representative example of the technologies that challenge today’s manufacturers. With standard thickness FR4 substrate, in common use world-wide, dedicated tooling continues to offer a clear performance advantage, where production volumes and changeover rates make this a viable choice. For manufacturers with a greater mix of products reconfigurability and rapid changeover advantages are provided by the compliant systems.

But these latest experiments show a surprising fall-off of dedicated tooling performance with decreasing board gauge. This implies a greater role for compliant tooling systems in the future, as thinner boards enter common usage. The results enable us to suggest the tooling selection matrix of Figure 12, based on prevailing substrate technology.

As board thickness decrease in the future, electronic manufacturers will choose new compliant tooling technologies not only for their inherent speed, cost and flexibility advantages but also for superior paste volume repeatability.

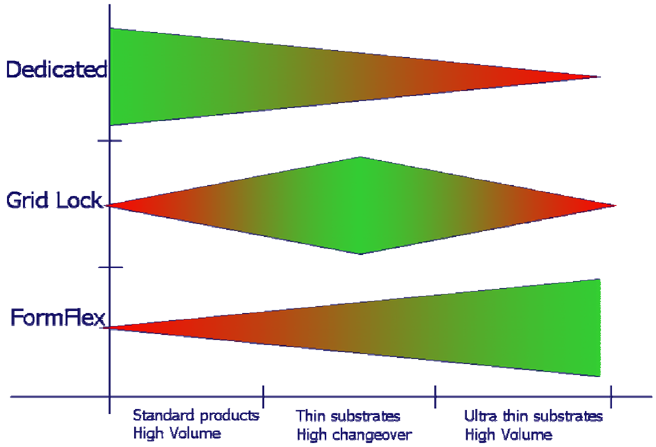


Figure 12 – Graph Showing Tooling Selection Matrix

Summary of Compliant Tooling Study

Project Scope

- The tooling solution is often the forgotten element – Let’s find out what the impact is !!
- To produce a clear statement on the process benefits of compliant tooling solutions.

Equipment used

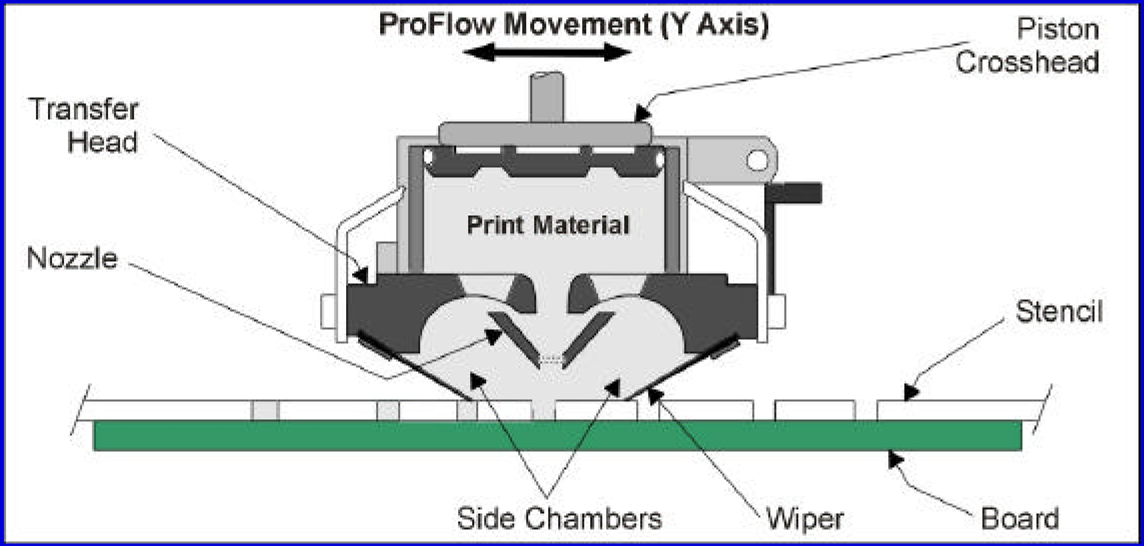
- DEK Horizon
- Commercially available Pb free Type III solder paste
- ProFlow – Enclosed head
- Cyberoptics SE300
- 1.6,1.0 and 0.6mm thick substrates
- FormFlex and Gridlok

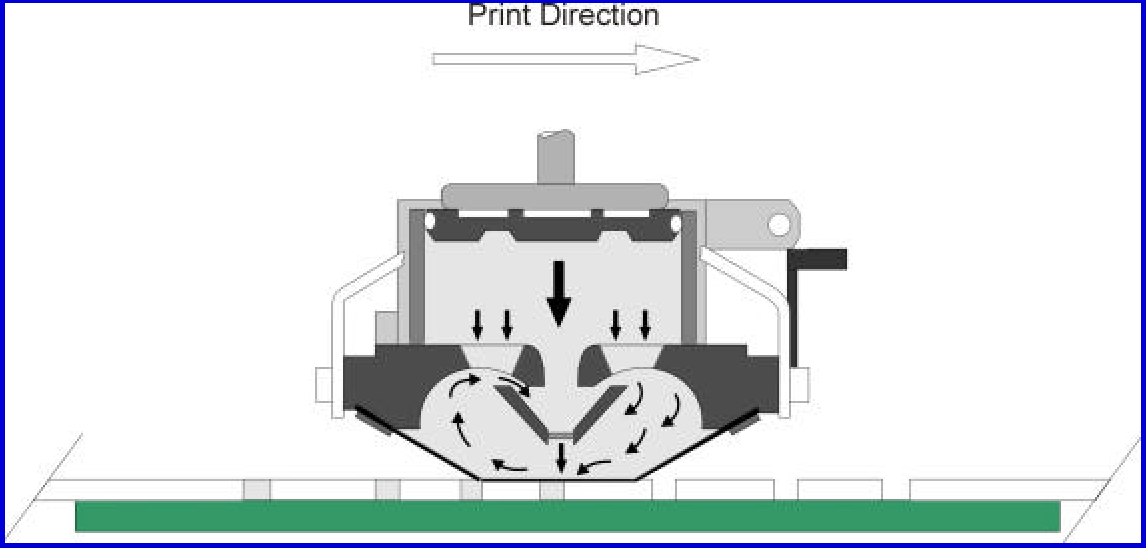
Print Parameters

- Print Speed – 80mm/s
- ProFlow Pressure – 2.0 Kg
- Paste Pressure -1.8 bar
- Separation Speed – 10mm/s
- Separation Distance – 1.0mm
- Print Gap – 0mm

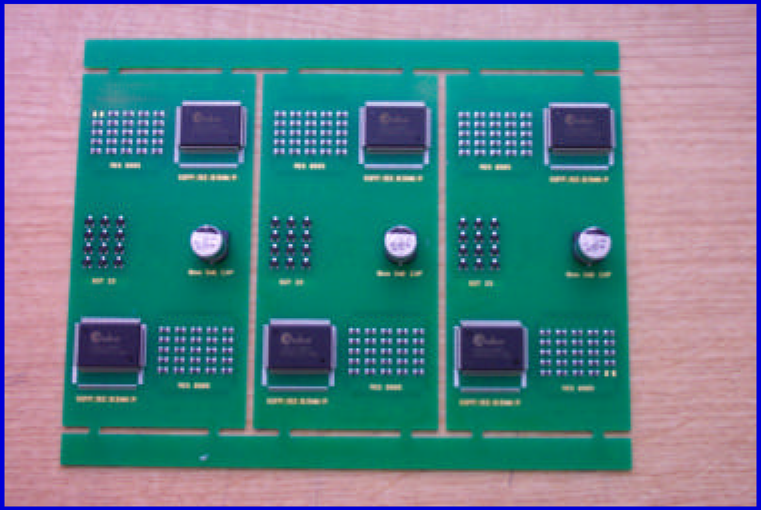
Parameters realised from previous Experiments

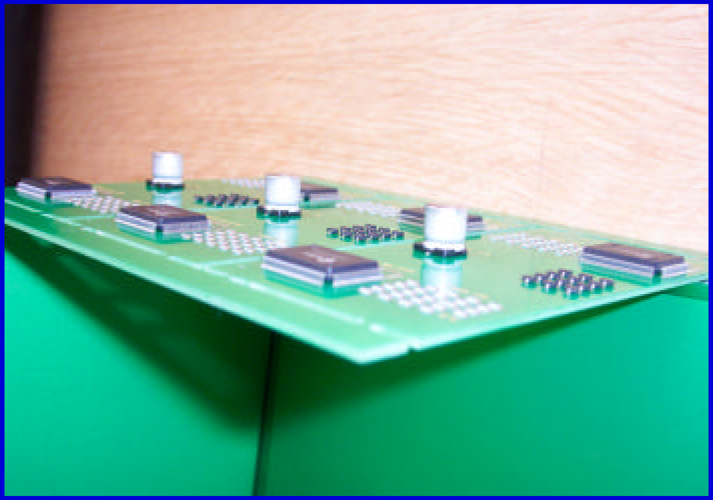
Enclosed Head Technology





Component Layout

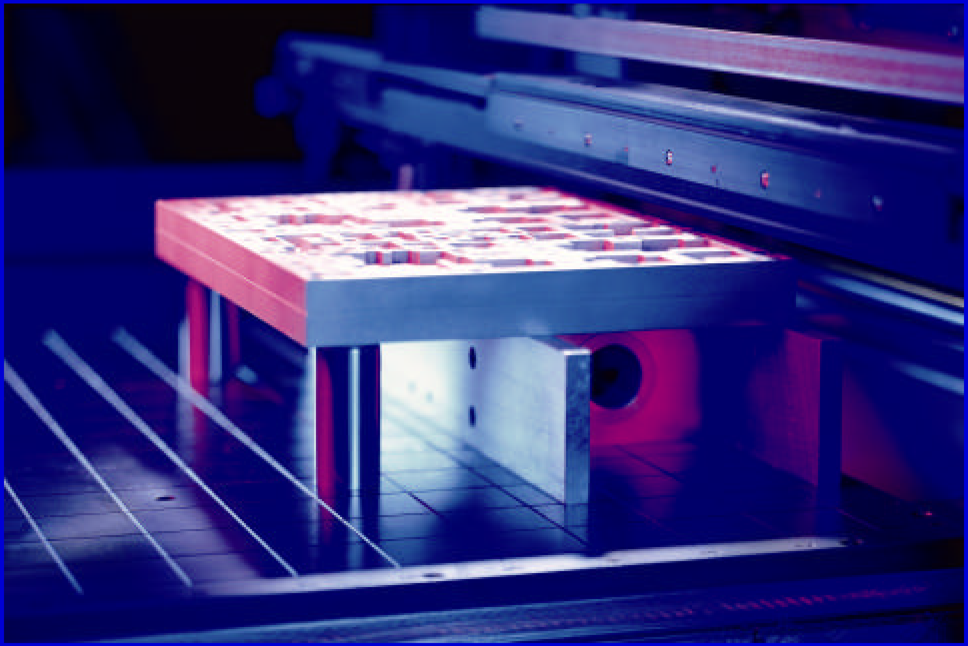




- 3 board thickness
- 1.6mm,1.0mm & 0.6mm

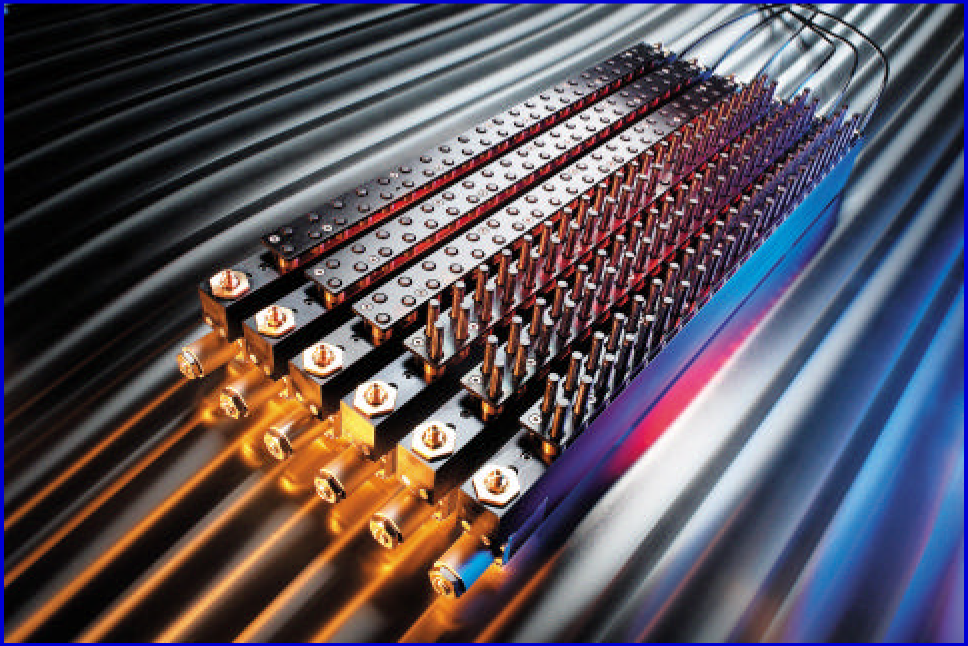
- Largest standoff height = 10mm

Solutions - Dedicated tooling



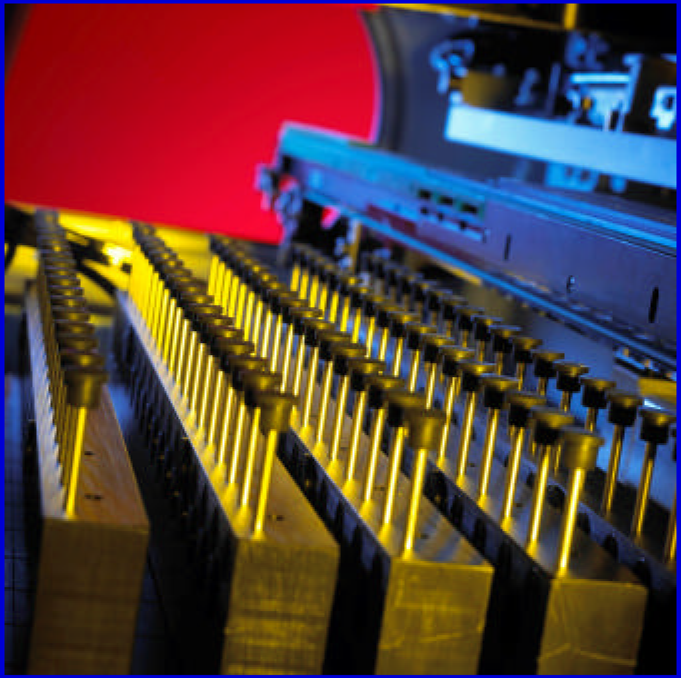
- Benefits
  - Industry standard
  - No mechanical parts
- Drawbacks
  - Board support only
  - Tool per product

Solutions - FormFlex tooling



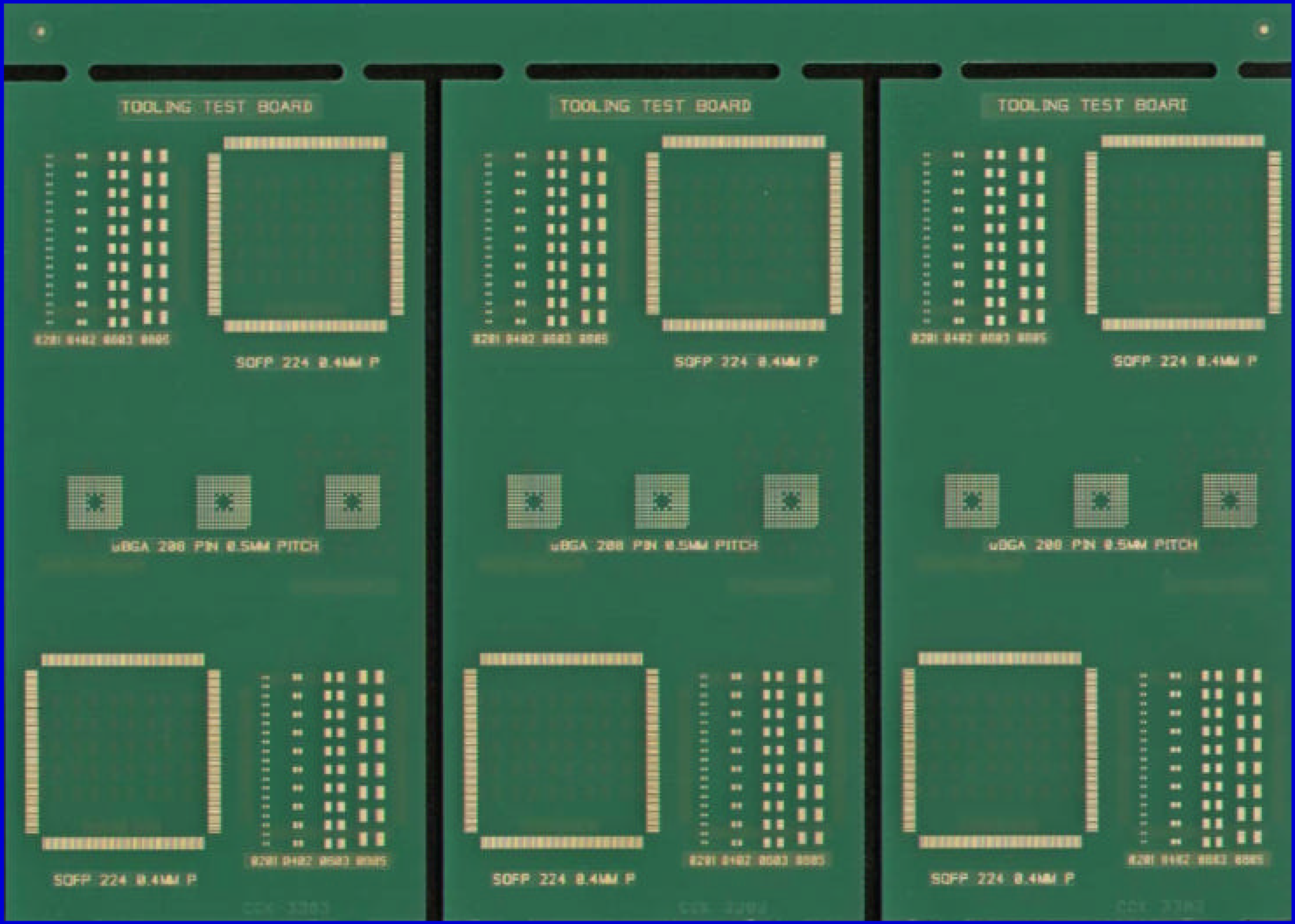
- Benefits
  - Fully compliant (board and components)
  - One solution for all products
- Drawbacks
  - $ outlay
  - New procedures

Solutions - Gridlok tooling

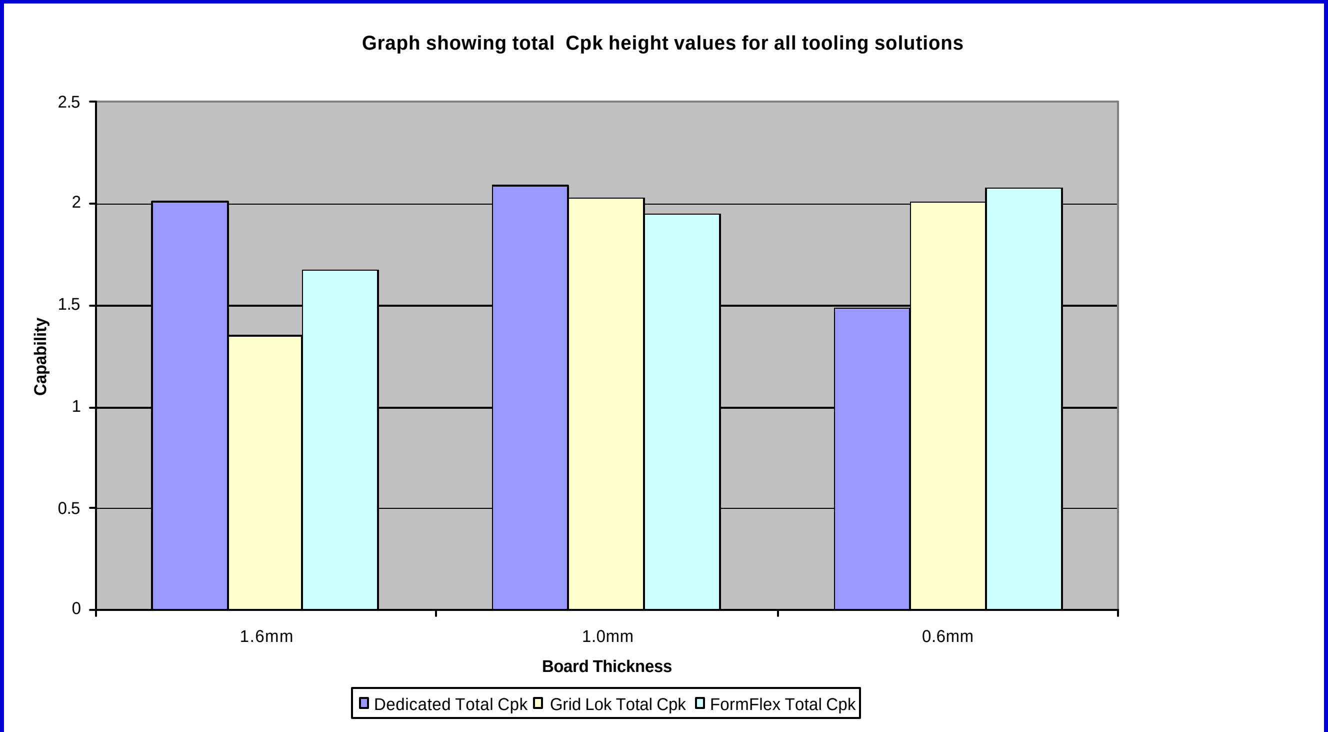


- Benefits
  - Partially compliant (board and components)
  - One solution for all products
- Drawbacks
  - $ outlay
  - New procedures

Board layout



Total Height Cpk results



- Observations
  - 1.6mm Dedicated clear winner
  - 1.0mm all about the same
  - 0.6mm Compliant tooling clear winner

All components

Summary of Height Results

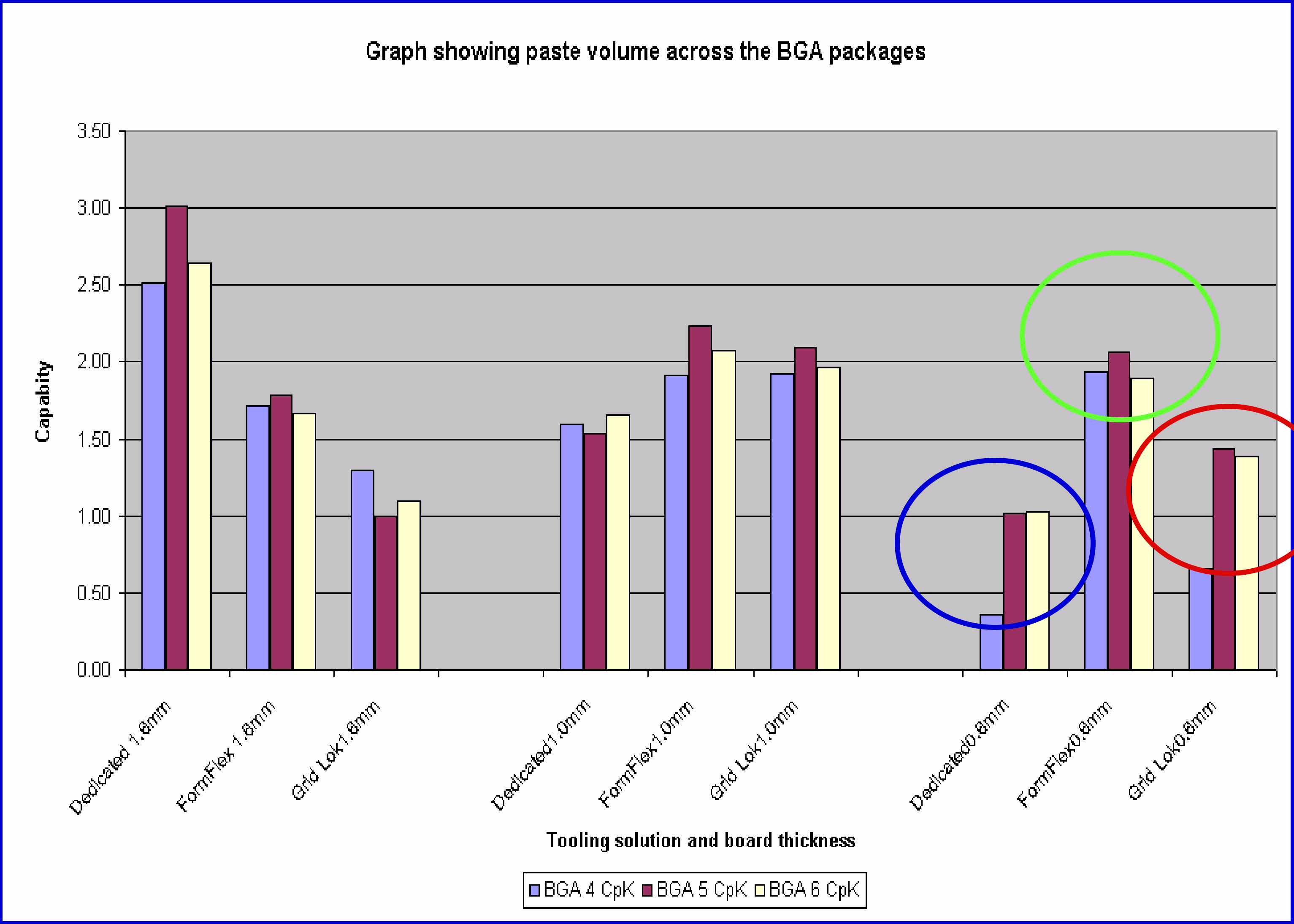
	Cpk Dedicated	Cpk FormFlex	Cpk GridLok
1.6mm	2	1.6	1.4
1.0mm	2.1	1.9	2.0
0.6mm	1.5	2.2	2.0

- The next series of slides show the ability to support on and around components. This is to test if compliant solutions show significant deposition improvements.

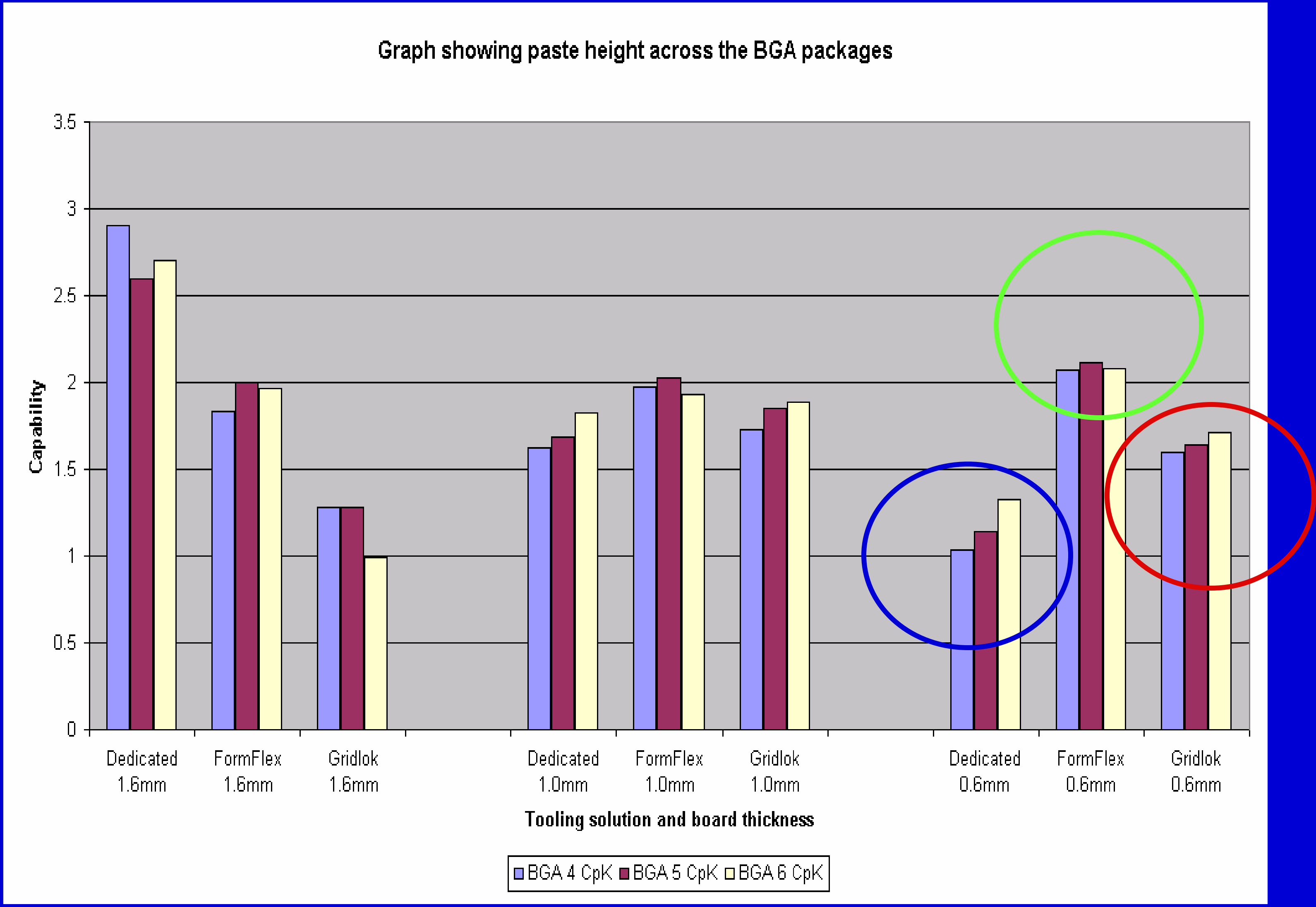
BGA layout

- As can be seen from the previous slide the BGA (4,5 & 6) components have the following components underside.
  - BGA4 – 10mm Cap
  - BGA5 – None
  - BGA6 – SOT 23
- The following slides show the capability of the tooling solutions at supporting on and around components.

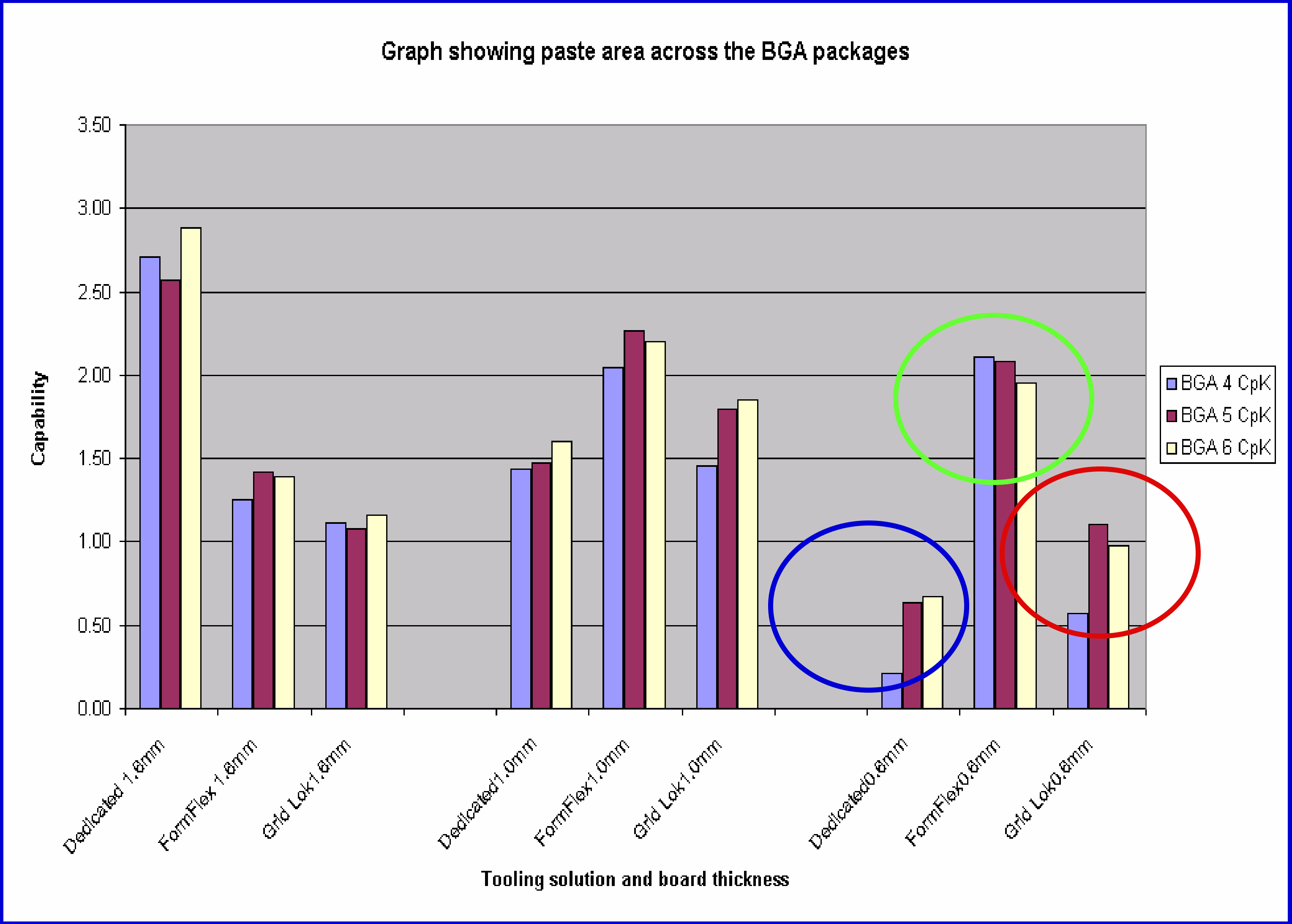
BGA Volume Results



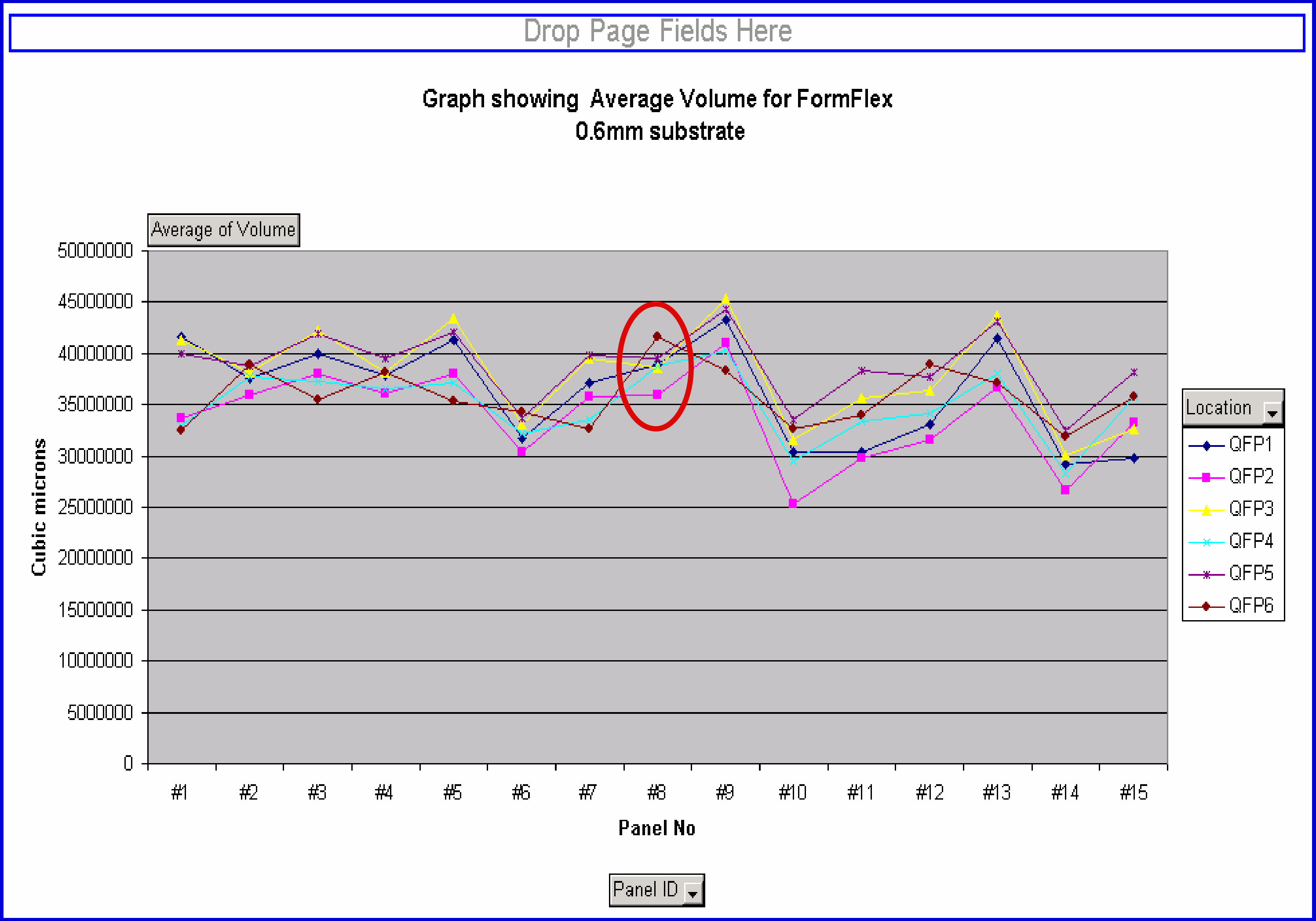
BGA Height Results



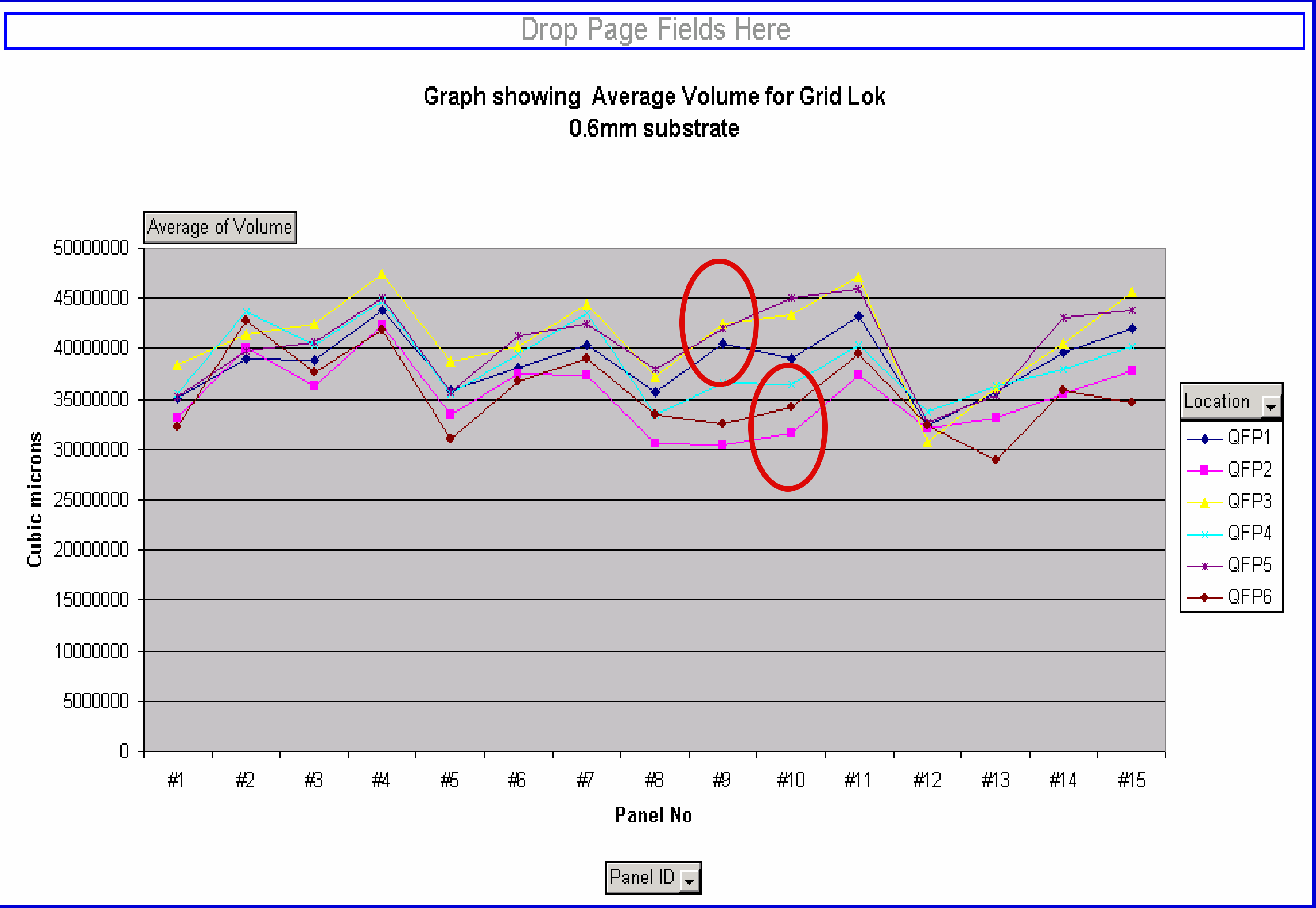
BGA Area Results



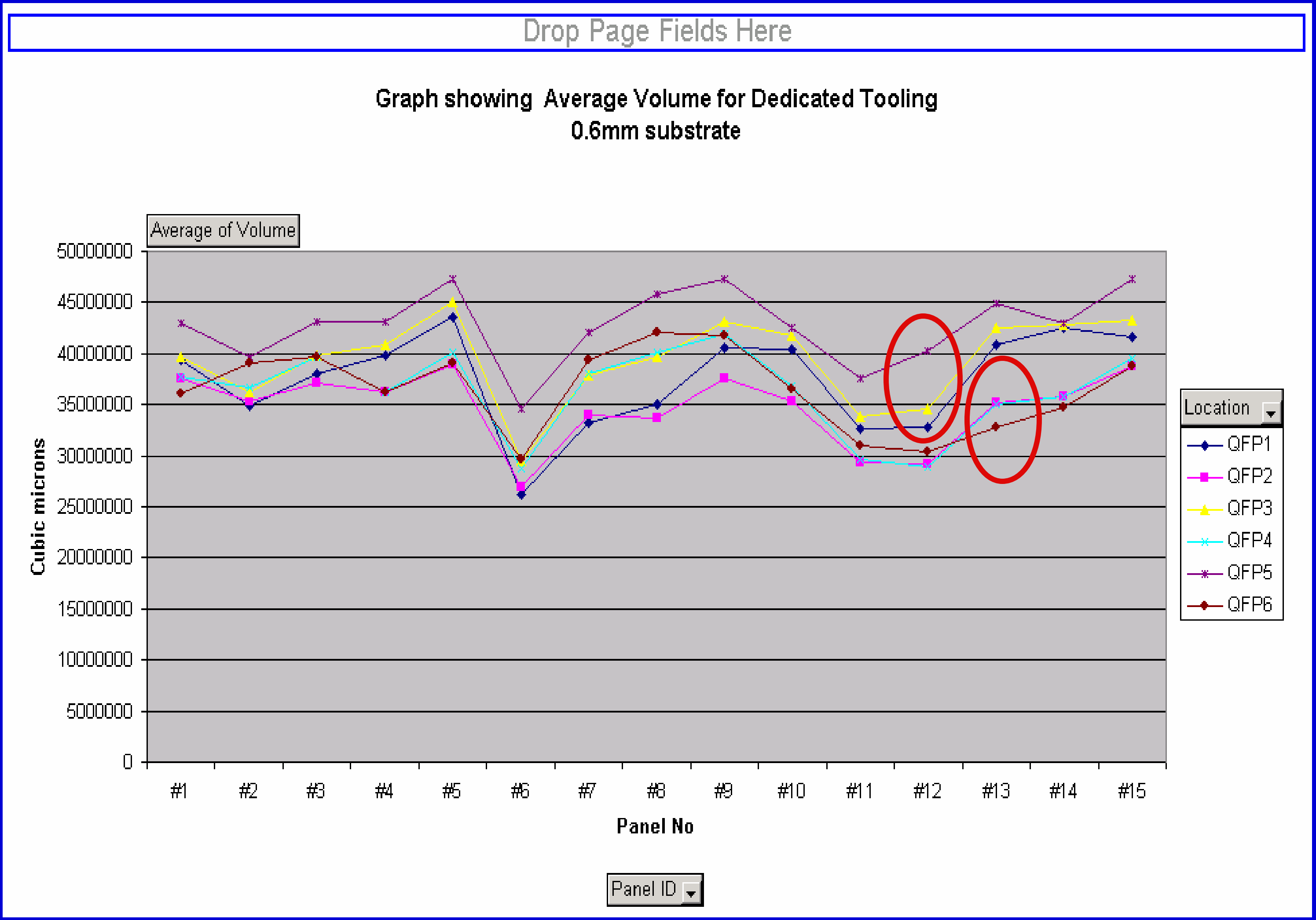
Further Analysis of results - FormFlex



Further Analysis of results - Gridlok



Further Analysis of results - Dedicated



Summary of VoI Results

	Cpk Dedicated	Cpk FormFlex	Cpk GridLok
1.6mm	2.7	1.6	1.2
1.0mm	1.6	1.9	1.8
0.6mm	0.8	1.9	1.1

Only BGA

Impact on under stencil cleaning

Under stencil clean rates for 1.6mm Substrate

Tooling Option	U.S.C Rate
Dedicated	10
GridLok	7
FormFlex	9

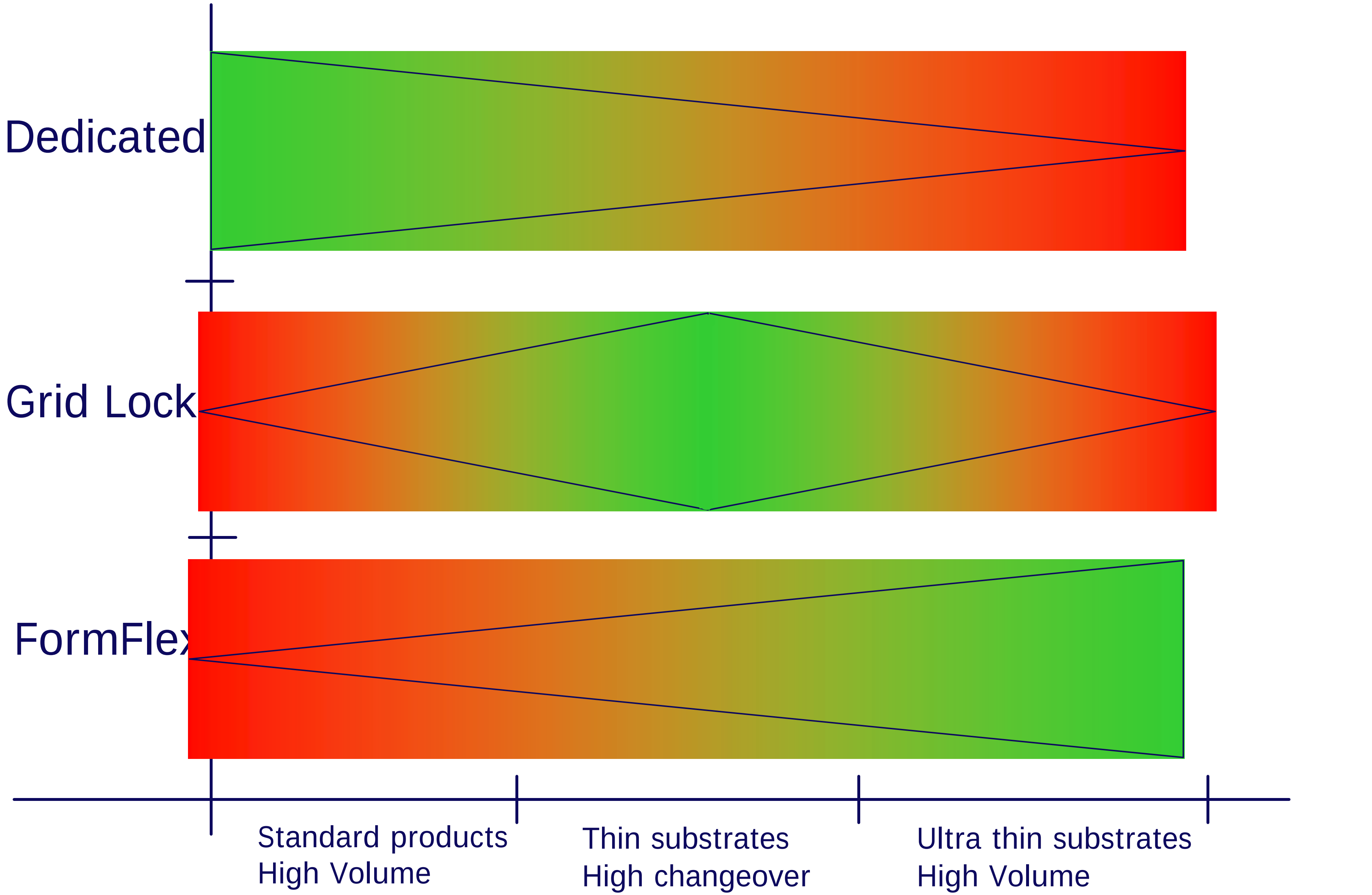
Under stencil clean rates for 1.0mm Substrate

Tooling Option	U.S.C Rate
Dedicated	7
GridLok	8
FormFlex	9

Under stencil clean rates for 0.6mm Substrate

Tooling Option	U.S.C Rate
Dedicated	5
GridLok	3
FormFlex	8

Tooling solution v Application



Summary

- Dedicated plate worked fine for 1.6mm but the performance starts to drop off <1.0mm
- GridLok works OK with 1.0mm boards but the volume results show an inability to comply around the underside components
- FormFlex shows good all-round capability. The performance of complying to the underside is excellent, especially with thin boards.