5D solder paste inspection—merits beyond 3D technology

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With 3D SPI becoming more and more established and offered by multiple suppliers, it is often assumed that this is the final stage in solder paste inspection. A closer look as to what 3D-only systems can and—specially—cannot detect shows that there is room for further yield improvement. By looking at the traditional characteristics of advanced 3D and 2D imaging, strengths of both can be utilized, especially if combined within the same measurement cycle. With the introduction of "5D" SPI, all types of print process errors can be reliably identified and prevented. Two dimensions (X and Y) are needed to measure area parameters, such as offset, smearing, shape and bridging. The third dimension (Z) adds additional height and volume information. Combining the best techniques to identify anomalies in each axis clearly improves the ROI for SPI equipment and enables a next generation of closed loop process control.

Keywords: Solder Paste Inspection, 2D Techniques, 3D Techniques, Moiré Topography, Dual Multisampling Laser, SPC

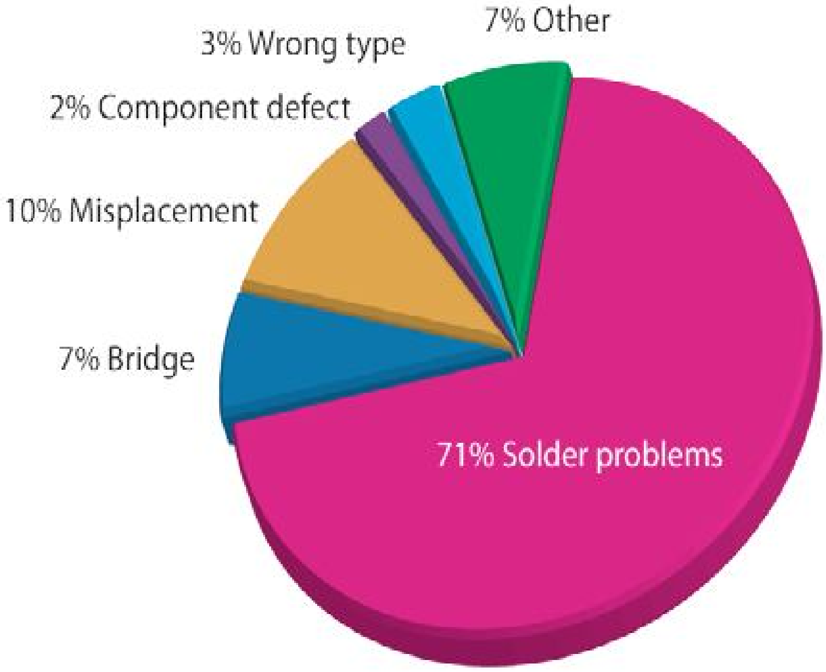


Figure 1. Assembly defect analysis. Source: SMTA

Post-print solder paste inspection (SPI)

Many process engineers and quality managers still question the value of solder paste inspection (SPI). Though it has been agreed for years that high percentages of end-of-line defects can be traced back to the print process, SPI has not been deployed in a significant percentage of SMT lines. Many still question the ROI analysis. Others consider the need for SPI critical during the new product introduction (NPI) phase or production ramp-ups, but not beneficial for mature, established processes. For them, the information provided by the SPI doesn't bring any relevant product quality improvements, or they perhaps are unable to usefully apply the improvements. Nonetheless, research done at IBM in Austin almost two decades ago clearly identified solder paste volume as the most important characteristic contributing to good solder joints. Unlike the "random number generators" (to quote the late Dr Steve Case, a pioneer in 3D SPI) that no doubt impacted the attitudes of many production engineers, today's technologies can provide reliable volumetric data as well as crucially important X-Y data.

Structural test verification technology clearly identifies the value of adding SPI, and while typically the need for inline solder paste inspection is driven by maintaining production line stability and providing notification of process deviation, frequent change over and smaller run sizes demand special performance capabilities to properly serve such manufacturing environments:

- Printer verification, even on first time builds
- 30 minute or less CAM to board test time
- Minimal false calls

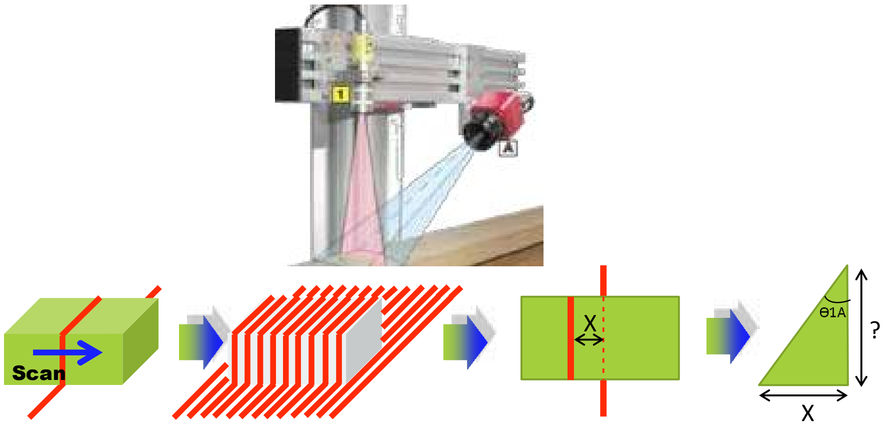


Figure 2. Basic principle of a laser triangulation for solder paste height measurement.

- Data with traceability to downstream inspection and test

Modern manufacturing trends are increasingly abandoning repairs in favor of prevention through improved process control. This is particularly the case in automotive electronics. The typical printing problems causing end-of-line defects can be detected by SPI and therefore offer significant opportunity for permanent yield improvement and reduced cost to manufacture.

2D techniques

In the first automated solder paste inspection applications, conventional AOI machines were used to verify correctness of the solder paste deposit after print. Specially developed algorithms were able to measure important 2D parameters such as coverage, offset, shape, smearing, slumping and bridging of the paste by using the stencil's Gerber data as a programming input file. Defects from those parameters can all be detected by a 2D analysis in combination with tolerances set onto the Gerber reference.

Later, the 2D SPI inspection evolved to better algorithms and better capturing systems. The use of RGB lighting systems in combination with different lighting angles dramatically improved the detection capabilities by isolating the solder paste from any type of PCB background, such as PCB color, copper, gold, solder resist, silkscreen, tracks and vias. After isolation of solder paste is successful, reliable 2D measurements can be obtained. 2D inspection methodologies are line scanning (line sensor) in greyscale or color or area scanning (field sensor) in greyscale or color.

Using 2D technology, two parameters cannot be obtained: height and volume of the solder paste deposit. 3D technology is needed to capture these parameters.

The additional benefit of 3D versus 2D is often questioned, as 2D will capture most of the defects appearing in the printing process. On the other hand, what could be the added value to measure 3D parameters such as height and volume?

3D techniques

Laser triangulation and phase shift moiré are the most commonly utilized techniques to measure solder paste height in 3D SPI, and both methods have strengths and weaknesses.

Common for both methods is to measure only the height of the deposit. By integration of the height data of each XY pixel, the corresponding area and volume data is calculated.

To obtain accurate height data of the deposit, which is typically between 50 µm and 300 µm in a normal printing process, it is crucial to measure the height from the correct reference. This zero reference is typically the surface of the pad onto where the paste is printed. Because the solder paste is covering the pad after printing, the pad surface cannot be used as reference for the height measurement. To create a decent accuracy, usually the pad surrounding is used as zero reference, and this also compensates for inevitable board warp. If the board warp is significant and the pads are not horizontal, the zero reference can be obtained by applying a 3D reference plane that follows the board warp over the pad to be measured.

By using the surrounding of the pad for zero referencing, a correction has to be applied, because the surrounding of the pad has a height offset compared to the pad surface. To obtain this height offset, usually a golden board is used to capture the offset data of each pad. The use of a golden board in the programming stage to obtain height offsets, only gives accurate results if the production boards are identical to the golden board (same batch) and different surface layers onto the PCB are not varying in thickness (stable PCB manufacturing

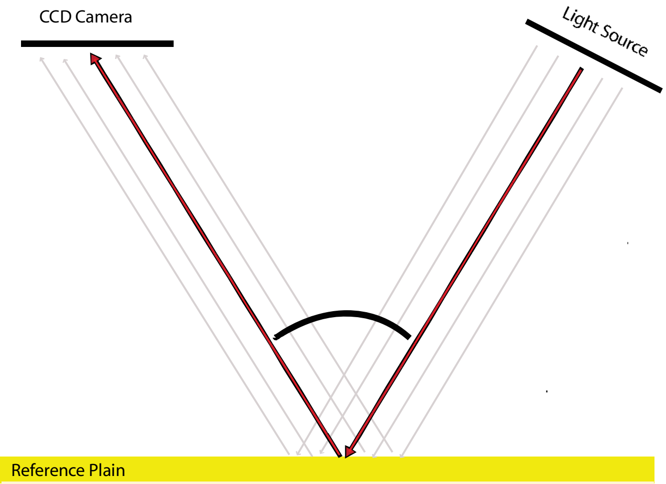


Figure 3. Moiré principle for golden board scanning.

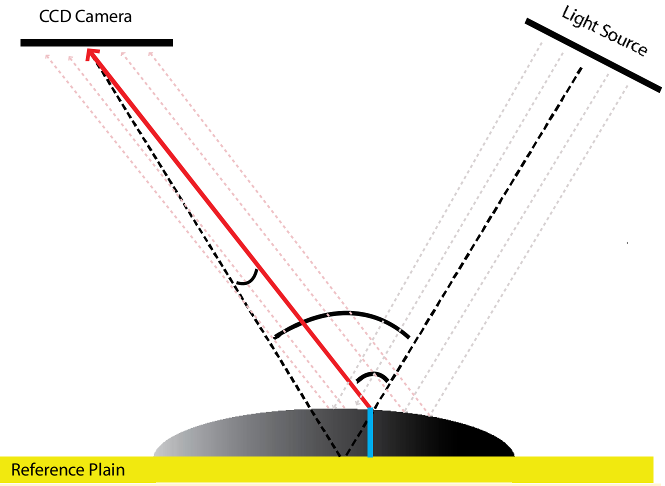


Figure 4. Moiré principle on a deposit.

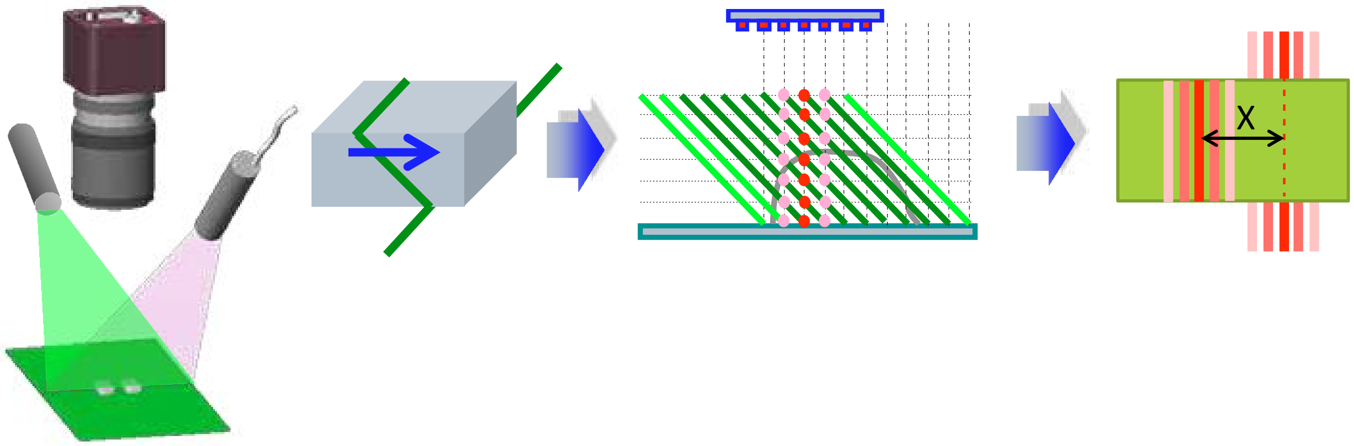


Figure 5. Dual multi-sampling laser technology.

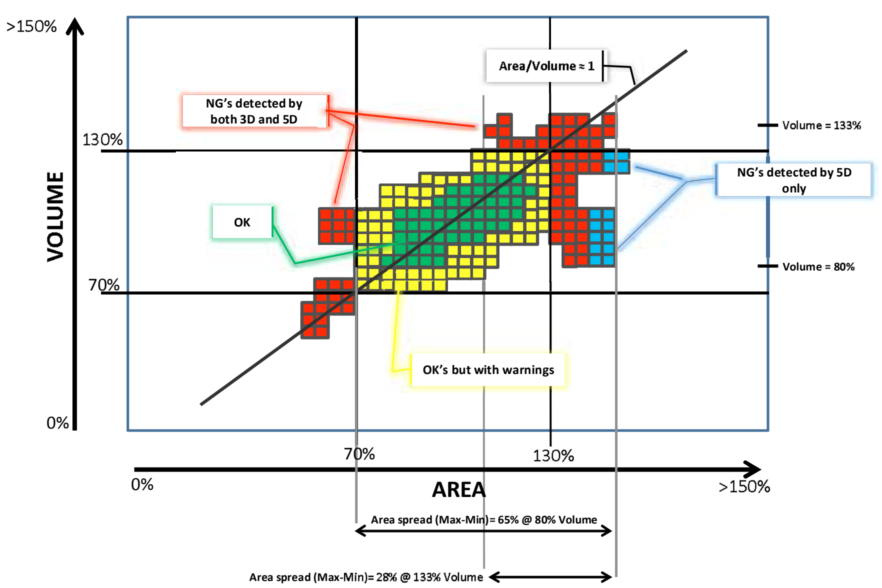


Figure 6. The relation between volume and area measurements is not linear, and defects can appear independently.

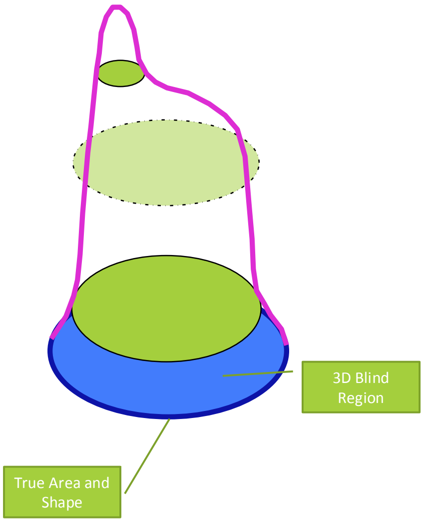


Figure 7. True area, shape and volume measurement by combining 2D and 3D technology.

process). In reality both are rather uncommon.

Laser triangulation is amongst the oldest technology to measure the height of solder paste deposits.

The laser projects a top-down laser slit beam, and a camera is used to capture the reflected laser lines. The laser head is moved in in defined pitches to cover the target area. The triangulation method is used to calculate the height.

To obtain a better repeatability, two lasers can be used in a 180° setup. The height data from both measurements is averaged to reduce the effect of the deposit shadowing itself near steep edges.

Moiré topography is a method of tridimensional measurement by phase modulation. In the moiré method, lines are projected on an object as modulated interference fringes, and by moving the observation grating that creates the lines, the height of the object can be measured.

The grated light is projected on a target, and the resulting image is captured at known angles, using an area scan sensor and its height calculated with basic triangulation mathematics.

Inspection of a large area is done by merging a sequence of small area scans (the sensor's field of view (FOV)), sometimes with an optional Z-adjustment for focus to compensate for board warp. The method becomes repeatable by incorporating oversampling techniques. At the same time, variations due to color and reflection changes are reduced through the use of a white light source. However, the range of measurable height is narrow and particularly inconsistent at low heights (i.e. below 50 µm). Near the merge of 2 FOVs, covering the same area (e.g. the print of a large BGA type), the focal references and optical distortion can vary and result in differences in height or volume measurements. This in turn can produce inaccurate indications of solder paste quality, even when measurement results are very repeatable. Board warp further complicates the measurements and usually degrades accuracy and repeatability figures.

Dual multisampling laser systems combine the advantages of moiré systems and laser. Dual multi-angle color lasers can accommodate different PCB colors and eliminate the shadow effects at the same time. The multi-sampling technology of doing multiple measurements on each object detail boosts the resolution, accuracy and the repeatability figures while maintaining the fast speed of a scanning laser and XY accuracy.

Where 2D inspection detects nearly all possible defects, 3D inspection gives quantifiable volumetric data. This volumetric data can be used for process control in order to adjust printing parameters and settings before defects occur.

In the graph below, an example is given of multiple inspections on a specific aperture size. The area and volume data are compared. If the relation between volume and area was linear, the result would be represented by the 1:1 line. In this graph the deposit volumes vary by more than 50% for the same area. This could occur if not all deposit leaves the apertures while releasing the stencil.

On the other hand, for the same volume, the area spread is up to 65% for equal volume. This could occur if paste slumps underneath the stencil and could lead to bridging or poor wetting. For tight process control, both area and volumetric data have to be monitored carefully.

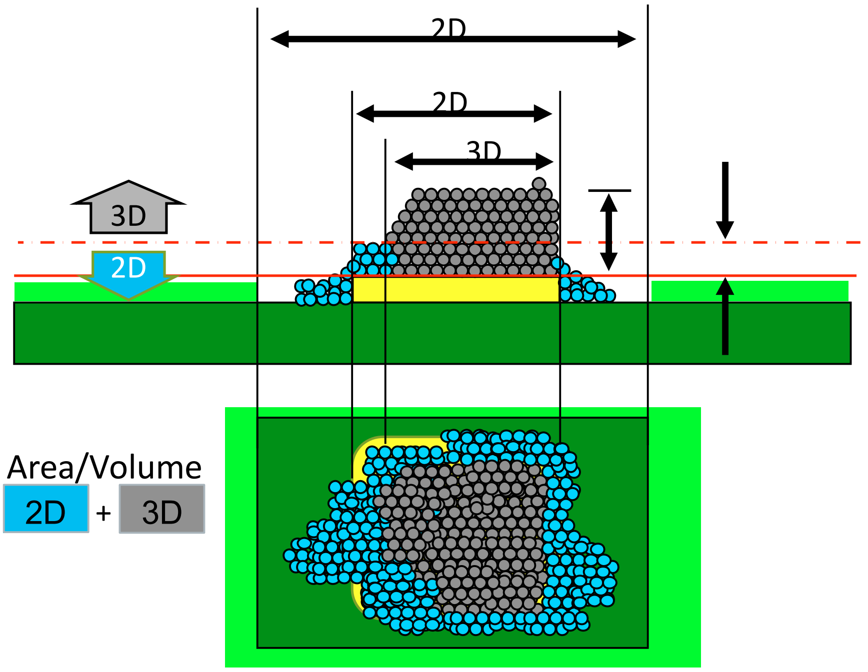


Figure 8. Combined advantages of using 2D and 3D inspection techniques.

The introduction of 5D SPI

A brand new approach to SPI enhances the benefits of 3D imaging with the addition of the strengths of advanced 2D inspection using a top-down sensor and making use of lighting in different colors and angles and directions to emphasize points of interest. This provides much more reliable data in the typical 2D domain:

- Area measurement (coverage, shape, smearing, slumping)
- Bridge detection
- Offset measurement

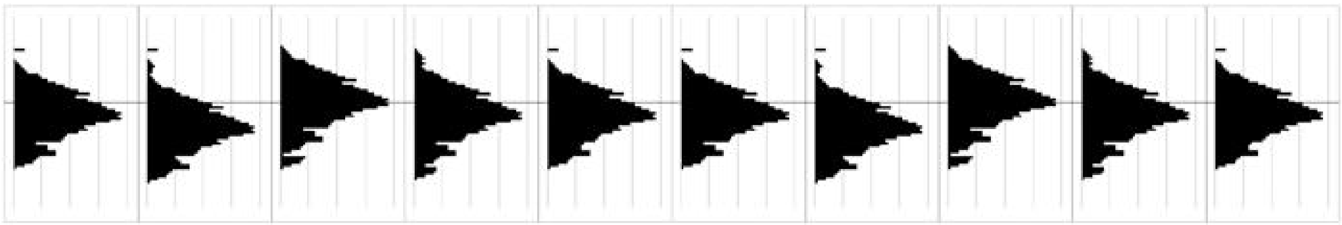
As noted previously, 3D technology cannot measure reliably below 50 µm, and therefore important area information is ignored. In addition, area data is calculated from height measurements rather than true area measurements, which leads to less accurate results.

2D on the other hand, measures all area information with a different technology, and with shape being detected correctly, a correct center of the paste brick can be calculated, and thus the distance to pad center can be determined more reliably for offset adjustments.

The combination of 2D and 3D measurements, using different optimized technologies, results in lower escape rates, tighter tolerance setting and improved process control.

Perhaps the most critical advantage provided by the inclusion of 2D imaging is the dramatic improvement in zero referencing for the 3D measurements.

3D-only systems, because of the inability to analyze PCB surface layers and the difficulty in measurements of low heights, cannot determine the best zero leveling measurement location around each pad. Height variations around a pad can be large, not only because of the variations caused by design—vias, solder mask, silk screen legends and the pads themselves— but also due to the variations caused by differences in individual PCBs and production batches. 3D-only systems estimate the zero reference level by averaging the height of a line surrounding the pad measured by golden board scanning. With 5D systems, by using 2D information, three or more reference points with equal base for height measurement can be used to set the zero reference, independent of any varying heights between golden and production boards.



SPC for SPI

SPI has been proven of value in recent years not only to find print defects and improve end of line yields, but also as a process control tool that can reduce the occurrence of defects and thus improve overall print quality. However, to be effective as a process control tool the SPI system needs built-in real-time SPC software that is simple and easy to use. Typical generic offline-SPC packages generally prove too difficult and too slow in use to be effective.

For example, by displaying a history of the previous 10 cycles as histograms, a quick understanding of the process stability can be gained. Cyclical and wide distribution of measured results can easily be spotted and understood. CPK plots can provide understanding if a series of prints are stable and whether particular printing machine adjustments can provide more stable results. By changing one print setting at a time and running several boards after each change, the system enables the process engineer to readily gauge if the new setting provides increased or reduced stability.

A further improvement can be made if SPI and AOI data is merged to analyze if a defect found by AOI has its origin in the printing process or to readjust AOI tolerances upon inspection of certain solder joints.

5D SPI, an improvement in ROI

With the introduction of 5D SPI, all categories of print process errors can be reliably identified and managed. Three dimensions (X, Y, Z) are needed to cover the wide range of printing defects, all printing process errors. Two Dimensions (X and Y) are needed to cover errors linked to area, offset, smearing and bridging. The third dimension (Z) is required to identify errors related to height and volume. Combining the best techniques to identify errors in each axis clearly improves the ROI for SPI equipment, and enables a next generation of closed loop process control.

The Marantz PowerSpector S1 employs the new "5D" technology to deliver true area, shape, offset, volume and height measurement in one cycle for the first time.

This high speed post-print solder paste inspection system incorporates patented new sensor technology and simultaneously combines 3D and 2D image processing methodologies for enhanced defect detection and process control.

Intercepting these defects before they happen reduces rework costs, provides instant yield improvement and accelerates return on investment. The enhanced process control empowered by 5D technology provides the perfect solder paste printer adjustment tool, enabling the correction of printer settings or paste problems before a problem spreads across an entire product.

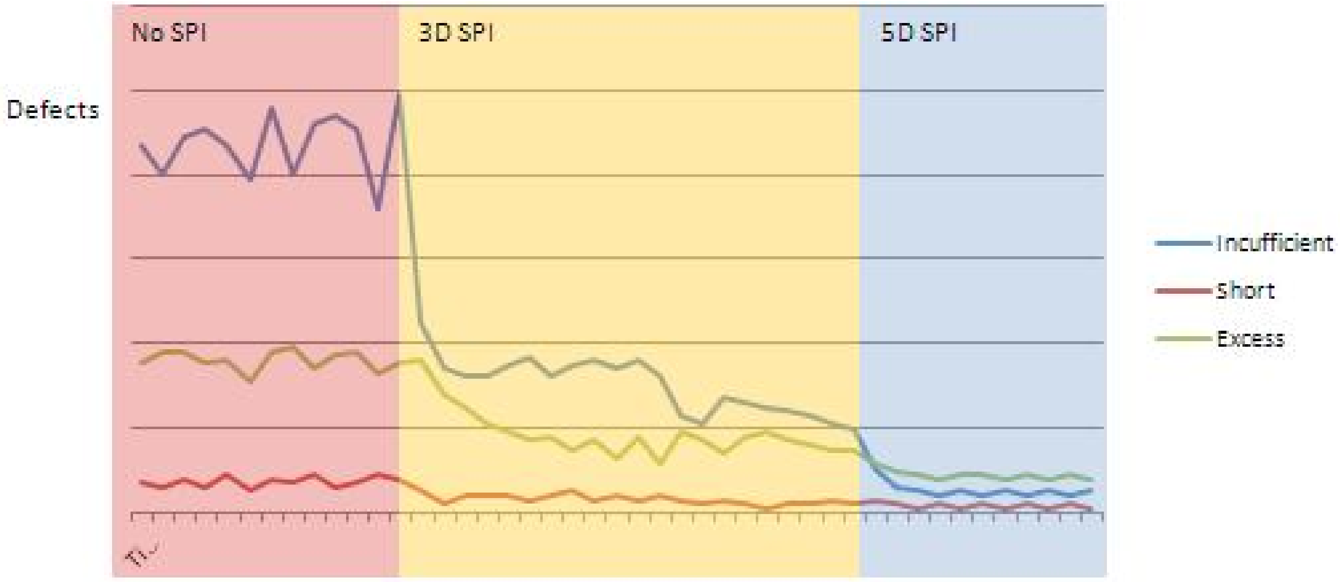


Figure 10. Integrated SPI deployment offers significant opportunity for permanent yield improvement and reduced cost to manufacture.