True 2 ½ D™ Solder Paste Inspection

Process control of the Stencil Printing operation is a key factor in SMT manufacturing. As the first step in the Surface Mount Manufacturing Assembly, the stencil printer is the deciding factor of quality throughout the entire process. Several studies have shown that a large percentage of all process defects can be attributed to the printing process due to complexity of the process and the large number of outside factors that can affect printing performance. The patented 2 ½ D™ inspection system from EKRA was designed to monitor the process, prevent, and identify defects before reaching the next stage of the process. This important asset can significantly reduce overall defect rates in the overall SMT process. The system can identify possible print failures before printing as well as recognize and react to faults that have occurred immediately upon completion of the print cycle before they become issues downstream.

Printing defects can be broken down to two distinct categories, **Opens** and **Bridges**. Opens, or insufficient paste deposits, can be attributed to paste conditioning and clogged stencil aperture openings. Bridging, on the other hand, can result from poor board to stencil gasketing or board to stencil release issues. Preventing or identifying these issues can eliminate a vast majority of defects from the process.

The unique technology of the **EKRA 2 ½ D™** inspection system, addresses both of the defect categories by providing three distinct inspection modes.

- **Stencil Inspection** - Stencil inspection is performed prior to the print cycle’s initiation. If a partially or fully clogged aperture is detected the system software will automatically initialize a wipe/vacuum cycle thus eliminating the potential defect condition. The system has the option to re-check the aperture to ensure that the aperture has been cleared and initiate another wipe/vacuum if needed. If the aperture remains clogged then an error condition will be displayed to alert the operator that a defect condition exists. In either case, the result is that a potential defect is eliminated before it occurs.

- **Paste Coverage** - Paste coverage is performed as a post-print operation that determines the proper coverage of paste over the PCB pad. If the amount of paste coverage falls below the set quality levels, an error condition will be displayed to warn the operator that the paste coverage is insufficient.

- **Bridge Detection** - Bridge detection is a post print operation that inspects the area between the pads to detect any encroachment or contact of paste that will cause an unwanted short. Any area that has a short will set an error condition that will warn the operator that a bridge has been detected.

Although looking for two distinct errors, the **EKRA 2 ½ D™** performs both paste coverage and bridge inspection simultaneously minimizing cycle time. The system is very robust and can adapt to different board mask variations on the same product. Teaching the inspection program is simple and straightforward and has the tools to be flexible to handle any PCB or component pattern.
Theory of Operation

Overview: The name 2 ½ D™ comes from the fact that, while the system does not provide full 3D inspection capability, it does provide much more capability than other standard 2D systems. The fact that the system can actually “see” the gray scale of the solder paste, can detect bridging, and can inspect for stencil clogging, supports this premise.

The inspection is separated into three different forms of inspection:
- Stencil Inspection
- Paste coverage of the pad
- Bridging or shorts between the pad

Other factors in the inspection process are:
- Camera operations
- Lighting applications
- Grey Scale determination

Each of these factors will be now be discussed in detail:

Camera Operations

Figure 1

The EKRA 2 ½ D™ inspection system utilizes the EKRA Vision Alignment (EVA) system to obtain inspection information. Figure 1 displays the EVA system schematic. The system utilizes two separate and independent CCD cameras. Each camera is dedicated either to the stencil or the PCB. Each CCD camera is attached to a lens that is connected to an illuminated cube. Each illumination cube has an independent spotlight that is used for direct lighting. The schematic shows the CCD camera on the right using spotlight B to direct light on to the stencil. The camera on the left is using spotlight A as well as a diffused light source that can be used in unison with the spotlight for inspection applications. Each camera ties into a reflector cube that directs the camera’s view to either the stencil or the PCB. The use of the two different light sources is unique to the EKRA vision system and is the key technology that provides the ability to actually differentiate between the gray scales of solder paste, mask, and pads.
Stencil Inspection

Stencil inspection is achieved through a combination of direct spot lighting from under the stencil and background lighting above the stencil. Spot lighting is directed to the bottom of the stencil surface through the EVA camera system (Figure 2). This same lighting is used for fiducial recognition to align the stencil to the PCB as well as to find the particular position of the apertures that will be taught. Once the aperture position has been determined, the spotlight is turned off. This allows the camera to see the stencil surface as a black background. The ability to be able to differentiate between the stencil surface and the actual aperture is then achieved through the exclusive EKRA background lighting technique. The unassuming lighting system shown in Figure 3 supplies lighting to the print chamber when the covers are raised as well as playing an important role in the stencil inspection process. During the teach cycle the print chamber lighting system is automatically adjusted to illuminate the stencil apertures and make them visible to the camera system and thus making the camera system able to calculate the aperture dimensions.

Figure 2

The system utilizes the teaching of the aperture for the dual purpose of determining not only the aperture size but also what the paste deposit area will be. The aperture area is calculated by a pixel count of the area and is stored for that location with a colored overlay, or mask, representing the area calculated. Each pixel size is approximately 0.0006” in diameter. The system simply recognizes dark versus light pixels in order to determining the area. For example, if an aperture allows light through that is determined to be 100 pixels that area is saved for that location. Later when that same aperture is inspected, it performs the same calculation of available light versus dark pixels and references the original calculated area of 100 pixels. If after inspecting that particular opening the system calculated seeing 80 pixels, the simple math is performed and the result is that the aperture is now 20% clogged or 80% open.

PCB Inspection

The camera system for the inspection of the PCB is identical to the stencil camera system with the exception of additional indirect led ring lighting at the base of the camera. This form of indirect diffused lighting allows the system to actually detect the gray scale of the solder paste. Older technology post print inspection systems only employ direct lighting for PCB inspection. This limits the capability of these systems to only have the ability to see the pads on the board as bright objects. They can only detect how much of the model is covered when inspecting. This type of inspection is not only limited but is also prone to inaccuracies. The elements of the unique EKRA PCB camera can be seen in Figure 4.
As a general rule, direct lighting is available to the CCD camera for fiducial recognition and plays a major role in the detection of paste coverage. While diffused lighting plays the major role in the detection of bridging. These general rules can change depending on the application and the gray scale relationship of the material being printed, the substrate, and the pads being printed on. Ultimately, the EKRA Vision System provides capability and flexibility that is unique from any other system available.

**Direct and Diffused Lighting**

The EKRA 2 ½ D™ uses a gray scale vision recognition system to inspect for solder paste coverage and bridging. The full 256 levels of gray scale are utilized during the inspection. The difficulty is being able to differentiate between the gray scale of the paste, the substrate, and the substrate pads. When direct lighting is applied, two of these individual components’ gray scale values overlap, the substrate and the paste. As such, we need to approach the detection of paste on the pad and the presence of paste on the substrate with two individual lighting schemes. In the situation where the goal is to detect solder paste coverage on a substrate pad, the solder paste image needs to appear dark and the pad image needs to appear bright. To accomplish this, a lighting scheme that is primarily direct lighting and no diffused lighting is used. In the case of detecting the presence of solder paste between the pads on the substrate, the inverse lighting scheme must be applied. The solder paste will now need to appear bright and the substrate dark. To accomplish this, a lighting scheme of primarily diffused lighting and no direct lighting is used. Figures 5 and 6 illustrate the results of the two lighting schemes.

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**Figure 4**

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**Figure 5**
Gray Scale Levels

To accomplish the two inspection applications the EKRA 2 ½ D™ inspection system applies the two lighting schemes by the use of filters. The lighting scheme is determined automatically by the system when the gray scale of the paste, pad, and substrate are learned by where gray scale values transition from one peak to the next. This determination is made during the teach paste function and displayed graphically in Figure 7. During this function, the system will determine what the correct lighting levels for both paste coverage and solder bridging should be in order to get a clear contrast between materials. Once the lighting has been established, the inspection system will then be able to make a determination of what is paste and what is substrate. On the left graph the light application is for paste coverage (spot/diffused 100/1). The limits are set so that anything visually inspected within the lines is considered solder paste and outside the lines will be considered pad. The graph on the right indicates a light application for bridge detection (spot/diffused 1/68). The limits are set so that anything inspected within the lines will be considered to be solder paste and outside the line will be considered solder mask. The limits of what is considered paste and mask are automatically set or can be adjusted manually. It can be seen from these two graphs how important the lighting can be as well as how distinctive each application for paste coverage or bridge detection are.

Figure 6

Solder Paste
(Appears dark as light is Deflected away from the camera)

Substrate
Pad

CCD Camera

Light scattered away due to solder balls deflecting light

Pad surface reflects light Back to camera

Diffused light is OFF and Spotlight is ON

Figure 7

Histograms

Filter 1 (on)
Light: spot/diffuse: 100/1
Gray levels paste: 36-84

Filter 2 (on)
Light: spot/diffuse: 1/68
Gray levels paste: 85-184

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**Paste Coverage**

Paste coverage is performed in a similar way that paste is detected in the aperture when inspecting the stencil. The area of the stencil aperture, calculated during the teach function, is duplicated in a color overlay and is projected over the image of the pad. With the lighting scheme applied so that the pad is bright and the paste dark, the system then determines the amount of solder coverage. The software applies the masking technique so that only the pixels within the area representing the stencil aperture are counted. The system looks for reflected pixels and deems them as exposed pad. Dark pixels within this area are deemed as solder paste. The system then calculates the area of coverage. For example, if the aperture area was determined to have an area pixel count of 100 and during inspection 20 pixels were reflected back, the calculated coverage of the pad would be 80%. This is represented in **Figure 8**.

![Figure 8](image1.png)

**Bridge Detection**

During the inspection process for detecting solder paste on the substrate, or bridge detection, the use of a lighting scheme that is primarily diffused lighting makes the solder paste appear light and the mask dark. The location of the pads was determined during the stencil teach process. The area is transposed to the pad and the distance between paste deposits is determined. Once the distance is known the mid-point between the pads is calculated. An inspection area that is approximately four pixels wide (0.0024”) is applied between the pads that will be the area that will be inspected for the presence of paste. See **Figure 9**.

![Figure 9](image2.png)
**Results** – The following graphics show the results of the inspection screens as displayed after the inspection sequence has completed.

**Figure 10**

*Figure 10* shows the stencil inspection screen. The green indicates the mask and the calculated area of the aperture acquired during the LEARN function. The dotted border indicates the field of view and is green if inspection parameters were within specification and red if an error has occurred. The apertures for this picture were blocked to show an error condition. The lowest reading will be displayed in the lower left hand corner. Each aperture will have its own individual display of values found during the inspection sequence.
The screen shown in Figure 11 is the Inspection screen for the PCB. The green mask over the pads is the expected area transposed from the stencil apertures. This is important as most critical apertures are reduced from the pad area; as this technique will give a true representation of the actual paste deposit. There is also a mask transposed between the pads. This is the area that will be inspected for Bridging or Shortcuts. This board was smudged to show an error condition. Areas shown in red on the pads indicate a lack of solder in the area where the software mask indicates there should be. The opposite is true in the Bridge detection area (also known as the “trench”) where red indicates that paste is present where there should not be paste. The lowest reading for Coverage and Shortcuts is indicated in the lower left hand corner. In the event that there is no errors found this number will be in green.

**Conclusion**

This paper explains in detail what technology is required to provide true solder paste inspection within a printer. Recent developments have increased the speed of 2 ½ D to levels that match most line throughput rates. The 2 1/2D PLUS system doubles the speed for conventional non scanning inspection systems while maintaining the full capability of 2 ½ D. While the 2 ½ D H S I system provides full 2 ½ D inspection at speeds greater than line scan systems available from other manufacturers that only provide presence and absence. If you need full capability high speed inspection, EKRA is the only game in town.