Exposed Pad Algorithm for the *Medalist x6000* Automated X-Ray Inspection System

Application Note

**Introduction**

A new package design has recently emerged to address heat dissipation issues in printed circuit board (PCB) with high speed processor and memory devices. Such a design uses a heat slug inside the package to conduct heat from the die to the PCB. The heat slug is soldered to a pad that may have vias to conduct heat to internal PCB layers, to the extent of allowing an additional heat sink to be placed on the other side of the board for better heat transfer.

Different package designs have different pad patterns that connect to the heat slug. Some packages such as the Quad Flat No Lead (QFN) may have a simple rectangular pad surrounded by smaller perimeter pads. Other designs contain varying number of gaps around the edge of the pad. Yet, certain FET (Field Effect Transistor) packages can have isolated sub-pads.

Due to the crucial requirement to dissipate heat in the fastest and most efficient way, it is important to ensure good solder connection at the pad-device interface.

The Exposed Pad Algorithm in the *Medalist x6000* Automated X-Ray Inspection software is designed to test all varieties of these package types for defects such as open and voiding.

*Figure 1. Examples exposed pad packages*

*Figure 2. Exposed pad joints with gaps and isolated pads*
Setting Up Measurement Profiles

Depending on the package design, some pads may have intentional gaps within the pad, or consist of individual sub-pads.

The Measurement tab contains a selection of parameters used to enable measurement profiles in order to perform analysis on the gaps.

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**Additional selection**

*Figure 3. Parameters to set up measurement profiles*
Setting Up Measurement Profiles

Profile parameters

- Sets the number of measurement profiles along and across the joint
- Allows a maximum of three profiles per Along and Across direction

If the user has a device package with a joint shape shown in Figure 7, it is appropriate to create two Along profiles and two Across profiles to measure the gap widths.

![Figure 4. Enabling Along and Across profile measurements](image)

NOTE

If the joint is a simple rectangular or square pad without intentional gaps, it is not necessary to define Along and Across profiles.
Setting Up Measurement Profiles
Profile parameters (continued)

Profile Along location/profile Across location

- Sets the position of the Across and Along profiles
- This is measured as a percentage of pad width along and across, respectively
- Places the white profile boxes on the joint so that optimal gap measurements can be taken during analysis

If there are three profiles enabled, the values for the Along profile location and Across profile location do not change the location of the middle profile. For example, if there are three Along profiles enabled, a change in the value of the Along profile location affects only the top and bottom profiles. The middle profile is not affected.

NOTE
Setting Up Measurement Profiles
Profile parameters (continued)

Profile width Along/profile width Across

- Sets the width of the profile boxes
- This is measured as a percentage of pad width Along and Across, respectively

Figure 6. Effect of profile width Along

Profile width Along = 10%
Profile width Along = 17%
Setting Up Measurement Profiles

Gap parameters

- Sets the number of gaps in each of the Along and Across profile boxes

The following images show the recommended number of measurement profiles and gaps enabled for the exposed pad joint.

![Figure 7. Setting the number of gap measurements in profile](image)

- Number of profile Along measurements = 2
- Number of profile Across measurements = 2
- Number of gap Along measurements = 2
- Number of gap Across measurements = 1

Outer gap, inner gap and gap width

When gap measurements are enabled, the algorithm will attempt to detect the gaps on the joint. The inner gap (brown) and outer gap (green) are profiles used to actually perform the gap measurements, specifically the gap widths.

Sometimes the outer and inner gap profiles are not set up properly after initial tuning. Therefore user is required to fine tune using specific thresholds for more accurate gap measurements.

![Figure 8. Gap terminology on the solder profile](image)
Setting Up Measurement Profiles

Gap parameters (continued)

Gap offset Along/gap offset Across

When there are two or more gaps enabled in a profile, the user may have to specify an offset to put the gap measurement profiles in the correct locations.

An increased value tends to push the gaps further away from each other.

Set appropriate values to ensure that all the gap profiles in the joint contain the outer gap and inner gap.

![Image of gap detection with different offset values]

**Figure 9. Effect of gap offset Along on gap detection**

**NOTE**

If there are three gap measurements expected for a profile, the gap offset value does not affect the location of the middle gap measurement profile. For example, if there are three gap measurements enabled for the Along profile, change in value of gap offset Along affects only the left and right gap profiles. The middle gap profile is not affected.

If there are four gap measurements, the gap offset value affects all the gap measurement profiles.
Setting Up Measurement Profiles
Gap parameters (continued)

Single, non-centered gap

Certain exposed pad joints are designed such that there is only one intentional gap that is not centered on the joint. Enabling one profile with one gap measurement does not work since the gap offset does not change the expected gap location.

The following strategy is proposed for the above joint:

i. Enable one profile across the gap with two gap measurements
ii. Configure gap offset value until intentional gap can be detected
iii. Go to Open defect tab with Additional selected. Set Allowed Gap Failures to 1

When both gap measurements fail, the joint will be flagged as Open defect.

Center search distance

- Determines the size of the search area for profile gaps
- Search area is nominally centered in a segment of the profile determined by the expected number of gaps to be measured
- Default is 20 mils

If there are three gap measurements, the gap search region for each segment is centered on each 1/3 of the whole profile; for four gaps the gap search region is centered on each quarter of the whole profile.

Figure 10. Single, non-centered gap in joint

Figure 11. Position of gap search region
Setting Up Measurement Profiles

Gap parameters (continued)

Gap cliff slope and gap falloff slope

These values are used to determine the inner gap edges. The algorithm begins searching for the inner gap when the slope is greater than the gap cliff slope. Then it tries to find the maximum slope of the gap edge. The inner gap will be detected if either of these conditions is met first:

a) the value of (0.5 \times \text{maximum slope}) is less than gap falloff slope

b) current slope is less than gap falloff slope (default 0.03)

If the gap cliff slope value (default 0.1) is not exceeded, the inner gap will not be found. If you need to alter default values, the gap falloff slope should be set less than or equal to the gap cliff slope to prevent the inner gap edge to be right next to outer gap edge.

The default values usually work fine. But if you find that the gap profile locations are placed correctly with appropriate center search distance, and yet the software could not detect the inner gap, you may need to reduce the gap cliff slope.
Profile and Gap Naming Convention

The exposed pad algorithm can have a maximum of three profiles defined for each of the Along and Across direction. For each profile, a maximum of four gap profiles can be defined. During diagnostics the software uses a specific naming convention in order to distinguish each measurement profile.

Along profiles are identified as Top, Middle and Bottom; Across profiles are identified as West, Center and East.

Each gap profile is numbered from 1 to 4 from left-to-right or top-to-bottom, depending on the orientation.

Below are graphical representations of the profiles, assuming no component/board/panel rotation, and board is not flipped.

![Profile and gap naming conventions](Figure 13. Profile and gap naming conventions)

NOTE

The profiles and gaps seen in the pictures above are for illustration only. They do not imply that the joint is tested will all the profiles and gaps enabled.
Verify Background Profile Method and Location

Some x-ray images of joints may have uneven background due to shading from other components. As such, it may be necessary to use the background within the joint itself in order to produce more accurate joint profiles. The position of the background profiles can be changed.

Exposed pad joints may have heat conduction vias around the area of the joint. The default placement of background profiles around the joint on these vias results in inaccurate solder thickness measurements due to varying gray levels around the vias.

The user can select to use the Interior background profile that places a single background profile at the center of the Along or Across pad profile. The average of the gray levels in this region is used to determine the background for the along or across profile. The location of the Interior background profile cannot be changed.

*Figure 14. Average and interior background profiles*

For the joint above, it is recommended to leave the background Along method as average. Putting it to interior would create an inaccurate background profile due to the presence of solder in the center.
Verify Background Profile Method and Location

Background Along location/
background Across location

- Measured as a percentage of inter-pad distance, default 50%
- Applies only if average method selected
- A larger value pushes the background profiles further away

If the default background profile locations are touching neighboring joints, or the difference in gray levels around the background profiles are too great, adjust the background profile locations so that the solder thickness measurements can be more consistent and accurate.

![Background Along location = 50%](image1.png)

![Background Along location = 10%](image2.png)

*Figure 15. Effects of background Along location values*

**NOTE**

The background Across/Along location values do not affect the location of the background profile if interior method is selected.
Profile smoothing length

- Reduces ‘noise’ on a joint profile. No units.
- A larger value creates a less erratic profile.

Caution must be taken when setting this value so that the important features of the joint are not hidden after smoothing. Otherwise, this may create inaccurate voiding measurements.

In most cases, leaving the value at the default of 6 is adequate.

\[ \text{Profile smoothing length} = 1 \]

\[ \text{Profile smoothing length} = 6 \text{ (default)} \]

*Figure 16. Profile smoothing length reduces noise in joint profile*
Setting Up Voiding Parameters

The voiding algorithm uses the learned or “expected” image concept to determine voiding in joints. In order for this to work properly, certain parameters have to be set up due to the different characteristics of joints. The default values may produce inaccurate voiding measurements, leading to possible escapes and false calls.

Use the following procedure to set up the voiding parameters:

1. Enable Measurement and Voiding diagnostics in Fine Tuning. Select available image sets.
2. Perform a single-step through the diagnostics until a dark yellow graphic overlay appears over the joint. This represents the detected solder areas.
3. Adjust the Maximum Expected Thickness value found under Measurement with Additional selected, until the dark yellow region fills the areas that are expected to have solder.
4. Under the Voiding tab with Standard select, adjust the Solder Thickness and run diagnostics, till the obvious voids are not highlighted in dark yellow. For example in the images below, solder thickness of 1 mil is good.
5. Perform the above steps of setting maximum expected thickness and solder thickness values for all exposed pad subtypes.

![Figure 17. Effects of solder thickness on detected solder areas]

Solder thickness = 1 mil

Solder thickness = 2.5 mils
Setting Up Voiding Parameters

Learning exposed pad images

Once the voiding parameters are set up, the exposed pad images are learned for each subtype.

NOTE

It is important that only good exposed pad joint images are used in learning

1. Go to Initial Tuning task. Select Exposed Pad joint type and All subtypes.
2. Check only the Exposed Pad Voiding Images box.
3. Click Interactive Learning. A dialog box is presented.
4. Determine if the cumulative image on the right represents a good joint and click Accept Current Image. Otherwise, click Reject Current Image. Note that a bad joint on Current Image window can cause the Current+Expected Image to be non-optimal.
5. Once learning is completed, the learning status of the exposed pad is shown in Current Status panel.

![Figure 18. Interactive learning dialog box](image-url)
Setting Up Voiding Parameters

Controlling voiding sensitivity

Once the exposed pad images are learned, it is necessary to determine if the amount of voiding detected on a bad image is appropriate.

1. Perform single-step through the joints until a bad joint with voids is shown.

![Image of joint with voids highlighted in bright yellow.](image1)

*Figure 19. Detected voiding in joint image*

2. Determine if the highlighted void areas correctly represent the areas you want to be included in voiding analysis. Voiding sensitivity can be controlled by managing the following:

- **Maximum gray level difference**
  - Measured in units of gray level, default is 8.
  - A comparison is made between a pixel in the image under analysis and the learned image. If the gray level difference is more than this set value, that pixel is counted as a void.

The default value of 8 typically can work for most joints as it helps to exclude insignificant small voiding areas in the joint. Increasing this value has a tendency to decrease the detected void area.

![Images showing different void areas.](image2)

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<td>4</td>
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*Figure 20. Void sensitivity using maximum gray level difference threshold*
Setting Up Voiding Parameters

Minimum void area

- Measured as percentage of void area
- If the total area of contiguous voided pixels grouped together is greater than this value, the group of pixels is considered a void. This allows the user to ignore pinhole voids or voids that are due to imaging noise.

Minimum void area = 10
Void area = 4.6%

Minimum void area = 20
Void area = 3.9%

*Figure 21. Void sensitivity using maximum gray level difference*
Setting Up Voiding Parameters

Set voiding threshold

Once the appropriate voiding parameters have been established, set a threshold that determines whether the joint under analysis passes or fails:

![Figure 22. Set voiding threshold](image)

If left at default, the joint fails voiding if the calculated void area is more than 30%.

Figure 23 shows the X-plot chart of two joints with one failing voiding.

![Figure 23. Void area X-plot](image)
Setting Up Open Thresholds

The available thresholds under the Open defect tab are used mainly for gap measurements.

**Standard selection**

**Additional selection**

*Figure 24. Available Open defect thresholds*
Setting Up Open Thresholds

**Maximum inner percentage of outer gap Along/Across**

- Determines the maximum allowed ratio between inner gap and outer gap distances for Along and Across profiles, respectively
- Default is 30%

The following chart in Figure 25 shows how the above measurement may be used to distinguish between a good and bad joint.

*Figure 25. X-plot chart of inner % outer gap*
Setting Up Open Thresholds

Maximum outer gap length
Along/Across

- Determines the maximum allowed outer gap distance
- Default is 50 mils for both along and across profiles
- Gap fails if measured value is larger than set threshold

Minimum outer gap thickness
Along/Across

- Determines the minimum outer gap thickness
- Default is 2 mils for both Along and Across profiles
- Gap fails if measured value is smaller than set threshold

Maximum inner gap length
Along/Across

- Determines the maximum allowed inner gap distance
- Default is 15 mils for both along and across profiles
- Gap fails if measured value is larger than set threshold

Allowed gap failures

- Sets the maximum allowed gaps to fail, before flagging the joint to fail for open
- Default is 0

Summary

By reviewing images of good joints and analyzing the gap and voiding measurements, it is possible to set thresholds for the above parameters such that defects are detected accurately and efficiently.
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