Analysis of Voiding Levels under QFN Package Central Terminations and their Correlation to Paste Deposition Volumes and Propensity for Device Stand-off and Poor Joint Quality

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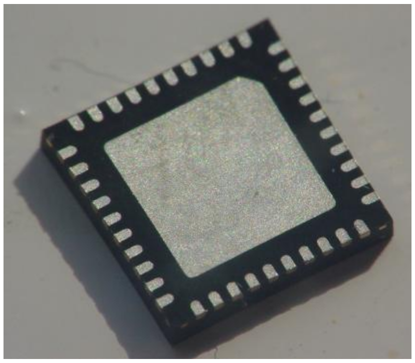
Abstract
The Quad Flat Pack No Leads (QFN) type of leadless package, also known as Land Grid Array (LGA), is rapidly increasing in use for wireless, automotive, telecom and many other areas because of its low cost, low stand-off height and excellent thermal and electrical properties. The implementation of any new package type always results in a learning curve for its use in design and processing, especially for the Process and Quality Engineers who have to get to grips with the challenges that these packages bring. In particular, the central termination of these QFN packages are prone, in most practical experience, to exhibit a high, or even excessive, level of voiding when seen under x-ray inspection. Such excessive voiding can not only affect the package's thermal performance during operation, but it can also increase the stand-off height from the board making the QFN float higher on the solder surface. Such action can apply stresses to the device outer terminations causing them to no longer remain planar and affect joint quality. Therefore, monitoring central termination voiding provides a valuable method to qualify the presence of unsuitable stand-off heights which, in turn, may increase the propensity for open joints during production.

This paper will discuss the results of experiments being undertaken on identical QFN devices where the quantity of solder under the central termination was varied and the ensuing voiding level calculated by x-ray inspection. The results will be discussed in line with correlating this data as a method to provide a suggested upper limit for QFN central termination voiding so as to minimise the possibility of open joints in production.

Key words: QFN, quad flat pack no leads, LGA, land grid array, x-ray inspection, voiding, defect, blind vias

Introduction
The Quad Flat Pack No Leads, or QFN, style of leadless packaging is increasingly used for many applications in printed circuit board assembly. This is because of its low cost, compared to other package types; its low stand-off height, enabling thinner final products; and its excellent thermal and electrical properties. Although most commonly known as QFNs, the same, or similar, package types can also be known as Land Grid Arrays (LGAs). A simple common description of these package types is of a number of planar connections located around the edge, with the bulk of the joint termination running back under the package. Often, the edge termination continues a small way up the vertical side of the moulded exterior. There may also be a further single large termination / heat sink under the majority of the central portion of the device (see image 1). It is not just the quality of the edge connections that must be ensured during board assembly, but also the level of voiding within the central, large pad in the centre (if present). If such a central pad is being used for removing heat from the component, then any reduction in the thermal efficiency, caused by the voids producing a poor thermal contact, may not only result in device overheating but also likely failure.

As the package terminations are all located under the device, it makes traditional Automated Optical Inspection (AOI) very difficult, if not impossible, as the main bulk of the edge joints, and the entire central joint, are hidden from view. In addition, should the side terminations on the package not wet during reflow then this will further mitigate the efficiency of AOI with these packages. Manual use of an edge viewing optical microscope does offer some good information as to the quality of the edge joints in these packages but, once again, the central joint is unable to be evaluated. In contrast, using x-ray inspection within the production environment offers a non-destructive method for investigating all of the package terminations, including the voiding under the central pad.



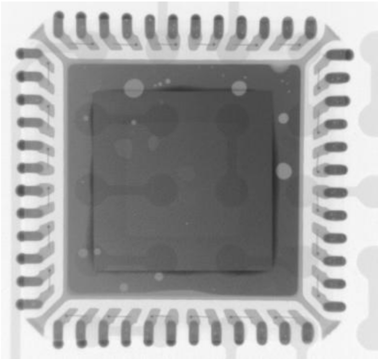


Image 1: Optical image of QFN package terminations **Image 2: X-ray image of QFN post reflow**

The use of x-ray inspection for investigating QFN packages has been helped by recent developments made in 2-dimensional (2D) x-ray inspection equipment (1–3). In particular, this relates to improvements in resolution, magnification and greyscale sensitivity, especially when inspecting at oblique angle views. In addition, new x-ray systems include digital x-ray imaging detectors, which have an enhanced greyscale range as standard, that enables far better visual separation of similarly dense features (3) so as to ensure the best effective identification and analysis (see image 2).

Together, these x-ray developments allow a relatively inexperienced operator to quickly assess and quantify the analysis within the production environment. Examples of what open terminations may look like under optical and x-ray inspection can be seen in images 3 and 4. However, it must be noted that using x-ray inspection equipment which lacks good magnification, resolution and contrast sensitivity may mean that the clarity of the x-ray analysis may be more difficult to achieve.

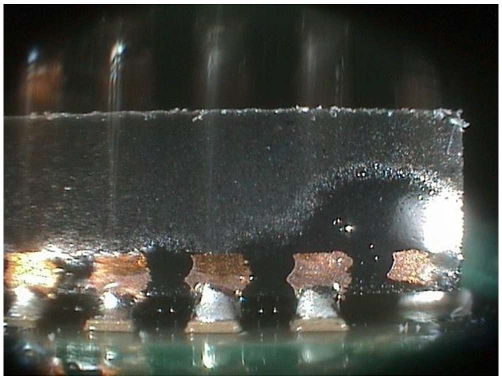


Image 3: Optical image of the edge of a QFN post reflow. The right most joint has not been made successfully and should be compared to the other joints shown.

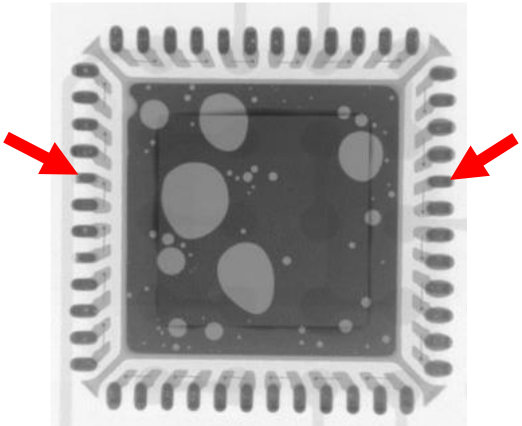


Image 4: X-ray image of a QFN post reflow showing open edge joints – see arrows and compare with adjoining joints as well as those in image 2. Note the substantial voiding under the central pad.

Defects of the type shown in image 4 are often caused by excessive paste being applied to the central QFN pad and / or excessive voiding occurring in the central pad during an inadequate reflow profile. These conditions make the QFN 'float' on the central pad during reflow, which raises the package above the board more than normal, and so interferes with the capillarity action of the reflow process. Issues with the QFN central pad cannot be seen by optical inspection and it is possible that other factors may also cause failed edge terminations. Only x-ray inspection allows a non-destructive view of the central QFN pad to confirm, or otherwise, the analysis.

This paper attempts to investigate further the impact of central pad voiding on the QFN stand-off height after reflow. It is well known that the applied solder paste volume, the presence of through-vias underneath the component and the reflow profile used during manufacture all have a marked effect on joint quality, but what is their effect on voiding? Is there a correlation between the quantity of voiding under a QFN (measured by the percentage voiding), the void location and the device's stand-off height after reflow? Variation on the stand off height may lead to open or weak connections. Therefore, if a correlation can be established between voiding and stand-off height using x-ray inspection then it may provide a useful production tool for in process quality control.

In addition to the investigation of QFN voiding, the same test board has also allowed examination of micro-via hole reliability. Previous lead-free trials (4) have allowed the testing of thousands of 0.2mm diameter conventional through-via holes, produced in 1.6 – 2.8mm laminate, after they have been through multiple soldering and thermal cycles, and all have come through without failure. So, in this experiment we continue to test 50 grouped vias, arranged in a daisy-chain pattern as before, but in addition we will test laser and control depth drilled blind vias in a similar way. These features will be tested for continuity after multiple soldering operations and then after thermal cycling. X-ray inspection and micro-section examination will asses the quality of these via types along with peel testing on the via plating adhesion to the capture pad, a technique previously covered in reference (5). X-ray images of these two types of blind vias are shown in image 5.

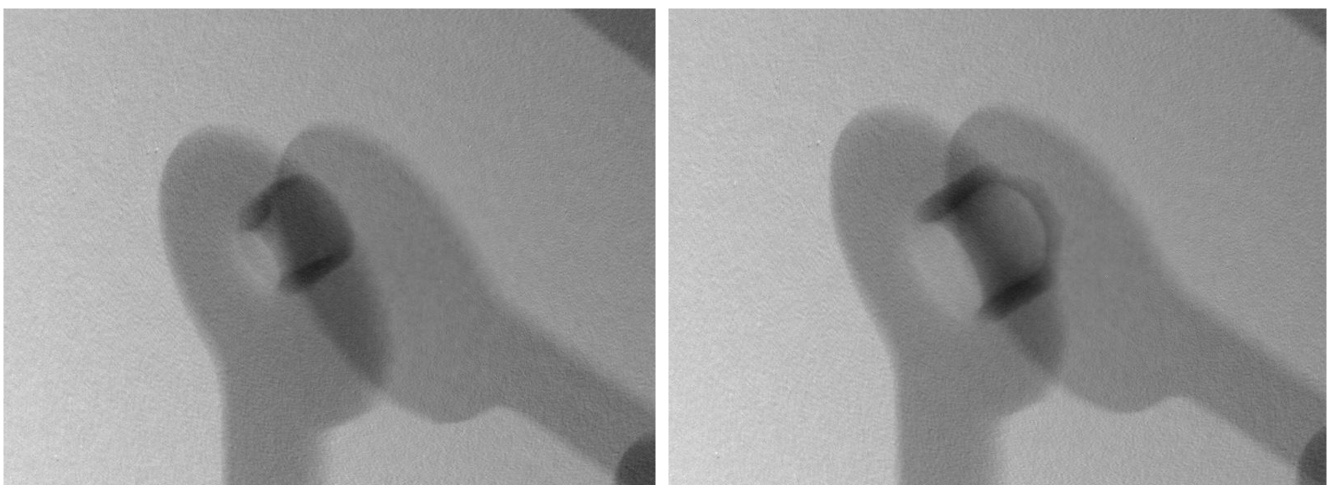


Image5: Oblique angle view x-ray images of blind via holes to a capture pad after plating within the test board. These blind via holes were produced by laser (left image) and controlled-depth mechanical drilling (right image).

Experimental Details

Figure 1 shows the design layout and side one of the circuit board used in the experiment. Image 6 shows the layout of the QFN footprint. The test board features two standard QFN devices with 40 edge terminations and a central thermal pad. In addition, we have incorporated two laminate QFN parts into the design to investigate the impact of via holes located in the central pad area. The via locations are either open, or resist-capped vias, which will not be printed over but will provide some stand-off height based on the thickness of the solder mask. Blind, or through-vias, in the centre pad have been known to influence the degree of voiding present and solder loss during reflow (4). So as this is a variable it needs to be eliminated in the experiment. A solution shown on a US design web site (6) suggests defining a solder mask area around the via hole. Depending on the via size, the material used and the application, the via may, or may not, be fully covered. This technique will be incorporated on both sizes of QFN on the test board. The stencil design will be modified to avoid printing paste on to the surface of the solder mask. If paste is present during reflow, the stand off height would be affected. The adjacent QFNs shown in image 6 illustrate the two via options. The laminate QFN parts are 16 x 16 mm in size and 1.6mm thick, produced as standard 1mm laminate with a silver finish. The parts are fabricated in a panel and V scored for separation. Parts like this are produced for cost reasons and make ideal training aids for everything except their thermal demand.

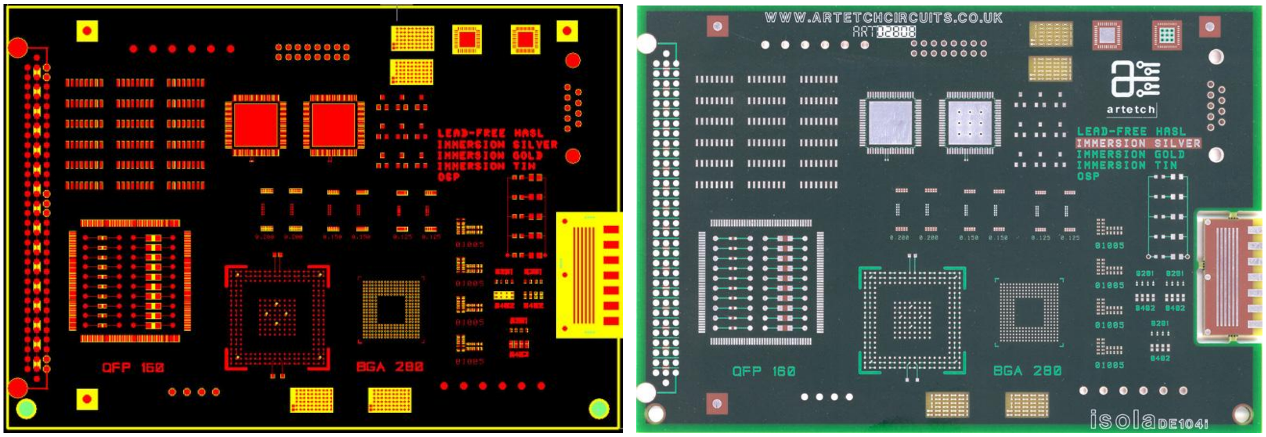


Figure 1: Test board layout showing side-one circuit and photo of the finished test board

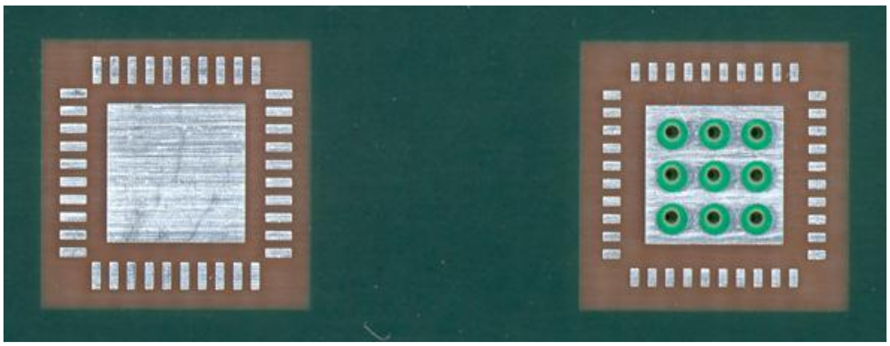


Image 6: QFN layout on two positions to see the impact of solder mask circled via holes

The sample boards will be assembled using standard manufacturing techniques with the following additional steps:

- 20 sample boards: numbered 1 – 20
- Different stencil designs used on the small and large QFNs giving a range of between 40 & 60% paste coverage of the central pad. A solderability dot pattern is featured on each board and will be compared with the wetting balance performance. X-ray CT scans will be subsequently conducted on any failures that are seen after thermal cycling and drop testing have been completed.

- 10 boards – convection reflowed, all with the same reflow profile
- 5 boards will have single sided reflow – this will be intrusive reflow with modifications to the stencil aperture of selected pins on the 96 way connector using a 0.005" stencil with different aperture sizes
- 5 boards will have double sided reflow – selective or hand soldered
- 2 boards will be conformally coated after reflow

- 10 boards – vapour phase reflowed, all with the same reflow profile
- 5 single sided reflow – selective or hand soldered
- 5 double sided reflow – intrusive reflow on side two
- 2 boards will be conformally coated

Temperature cycling will be conducted at the U.K. National Physical Laboratory (NPL) when a test chamber is available that is running a suitable profile for these boards. The boards will also be subjected to drop testing. Some of the via holes will micro-sectioned before and others after assembly. Should any failures occur following temperature cycling or drop testing, the inner layer connection to any via hole failures will be peel tested to look at the reliability of the board between the base of the via and capture pads. If more than one via fails during these tests then this will give an additional opportunity for x-ray CT examination to be performed.

Once the boards are assembled, the height of the four corners of the QFNs above the board will be taken by optical methods (see image 7). These measurements will be compared with the degree of voiding determined by x-ray inspection on the centre pad. The percentage voiding on the central pad is calculated by the x-ray system software. This is achieved by manually defining the pad outline, which therefore determines the area of the central pad and is clearly shown by the x-ray density variation in the central part of the device (see images 2 and 4). This gives the total number of pixels in the image that lie within the defined pad area. The software then looks for all void pixels that lie within the defined pad area. Void areas will be at a lower density (shown whiter in the image) than fully covered areas (see image 8). Void pixels are determined using an algorithm that thresholds density values to determine if a pixel is part of a void or is part of the background. Void percentage is calculated as the ratio of (the sum of all void pixels) to (the total pixel number in the pad area). The results are displayed on the image. In addition, the software can also calculate the void percentage contribution to the total from each individual void. This may be helpful to know in production as the functional properties of a device might be affected if larger voids are localised within a specific area of the pad, even though the total voiding may lie within an acceptable limit. For example, it might be necessary to define not only that the total voiding under the device must be less than a certain value (say 30%) to prevent inadequate heat dissipation but also that no single void may exceed another value (say 10%) in case a specific part of the device is more critically heat sensitive. The sample boards will be x-rayed before reflow and placement to monitor the degree of placement force paste displacement.

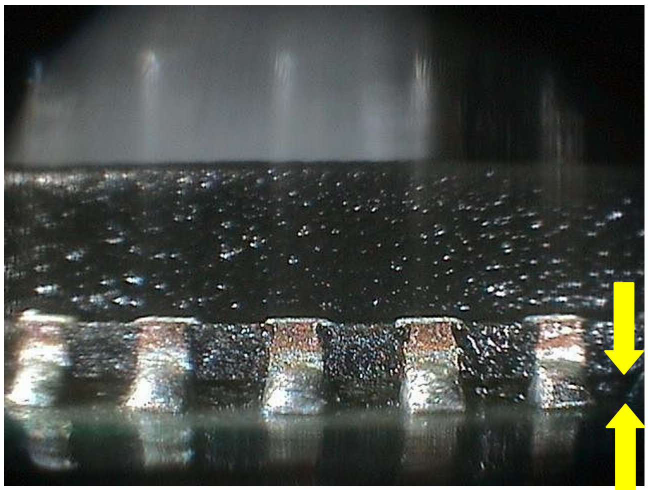


Image 7: Optical image showing the point of measurement on the corner of the QFN devices

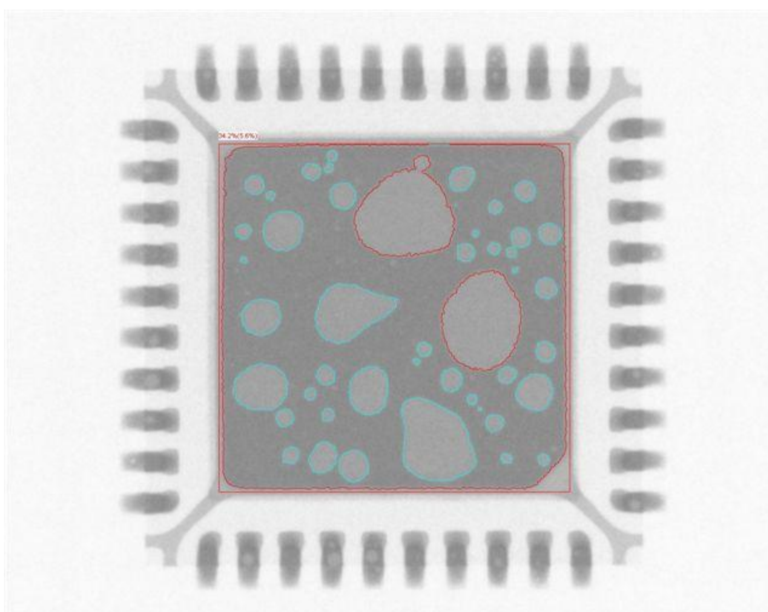


Image 8: X-ray image of QFN showing the calculation of the void percentage under the central pad. The total void percentage is shown as well as if any individual voids exceed a specific set limit. In this example, this QFN fails the total void percentage limit as well as two voids (shown in red) exceed the limit set for individual voids.

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