Examination of BGA and LGA Connections on the Booster LLRF DDS Module Prototype

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I. Introduction

A new module is being developed for the Booster Low Level RF system here at Fermilab. This module will be a standard 6U VME module providing four channels of direct digital synthesized RF outputs, four low frequency (< 2MHz) analog inputs and four low frequency analog outputs, and eight digital inputs and eight digital outputs. Besides the VME data interface, there is a four bit high-speed serial interface and connections through the J2/P2 connector to a rear VME transition module that can provide additional IO and communications.

Currently, the first three prototype modules are being assembled. Several components on the board require mounting be done at an outside assembly house. For this part of the assembly we had 6 different types of components, 19 components total. The three sub-assemblies were produced at a cost of $350.00. The components included 2 Ball Grid Arrays (BGA), 3 Leadless Grid Arrays (LGA), 4 Lead Frame Chip Scale Packages (LFCSP), 2 Leadless Lead Frame packages (LLC), and 8 other components that employed a thermal pad beneath the component for heat transfer. The last 8 components mentioned could have been assembled at the lab, but they are more complex and it was reasonable to include them in the outside assembly.

This document is written to capture the results of this first part of the assembly process. There is a brief explanation as to why we chose to have only a portion of the assembly done using an outside assembly house. Then we present an evaluation of the BGA and LGA component connections made using x-ray equipment belonging to the Computing Division.

II. Assembly Decisions

The assembly of the new LLRF DDS module prototypes is being accomplished in two steps. Most of the components are being mounted by a technician here at the lab with tweezers and a soldering station; however several of the essential components of the board require mounting by an outside assembly house with more sophisticated equipment. Bids were received for having the entire assembly done outside the lab, but this was found to be a much more expensive approach for our situation. This situation is not a rare one for the electronics designed for the lab. That is, we often need very few units of a complex assembly with a small number of prototypes. One of the biggest stumbling blocks is that assembly of printed circuits at an outside house requires that the components come on a reel or at least some minimum length of tape. When we wish to build only three prototypes we will certainly have several components for which the whole assembly run will require a total of three or possibly six pieces. It is currently not reasonable for our department to accumulate a stock of components on reels. The assembly house could be asked to provide/procure the needed components, but that would certainly send the cost of the three prototypes even higher. This approach is more appropriate for the production of larger quantities.

III. X-ray Photos of the BGA and LGA Connections

The caretakers of the x-ray inspection equipment at this time are Vince Pavlicek and Richard Mahlum. The equipment is located in the Feynman Computing Center. We are grateful that they have made this equipment available.

Figure III.1 is a photo of the partially assembled module. All three prototype boards were put through the x-ray inspection.

X-ray inspection of the LFCSP connections for the analog to digital converters was for the most part positive. There was no bridging, but we did detect some voids in some of the connections. The IPC-A-610 Rev D, "Acceptability of Electronic Assemblies" gives a rule of thumb stating that the connection is acceptable if the voids are less than 25% of the connection. Figure III.2 is an x-ray photo of some of the LFCSP connections showing the lands and pads and some of the larger voids seen. The void outlined in this photo is one of the largest voids and is approximately 16% of the connection area.

X-ray inspection of the BGA connections showed the connections to be in good shape. We found no bridging and could not detect any voids in the solder connections. Figure III.3 is a typical x-ray view of the BGA connections that was recorded during the inspection.

X-ray inspection of the LGA connections of the Linear Technologies regulators did concern us at first. However after some research we believe these connections will be acceptable. As can be seen in Figure III.4 there are numerous voids in the LGA pad connections. Some of the connections' voids come very close to exceeding the 25% rule of thumb. I was able to find two references that provide some confidence that these connections will still be reliable.

The first reference is Linear Technology Application Note 114, March 2009. The article does not directly address the presence of the voids but shows photos of LGA solder connections after a chip has been pried off the circuit board in a "Dye and Pry" test. The photos show circular voids similar to those in our x-ray photos. The chip was pried off the board but I would not attribute the voids in this photo to this action. The Linear Technology note declares that the connections in this photo were "good connections". Figure III.5 shows the photos from Application Note 100.

A more straight forward statement about the acceptability of voids is given in a Freescale Semiconductor, Inc. document number AN2920, Rev. 2, 12/2008. The text from this document and an x-ray photo of LGA connections on one of their parts is given in Figure III.6. Here, the photo is not presented as an example of an acceptable amount of voids, but rather as a good example of chip self alignment during reflow. It is my contention that this is a photo of a "good connection" that has the same occurrence of voiding that we see in our own connections. See Figure III.6.

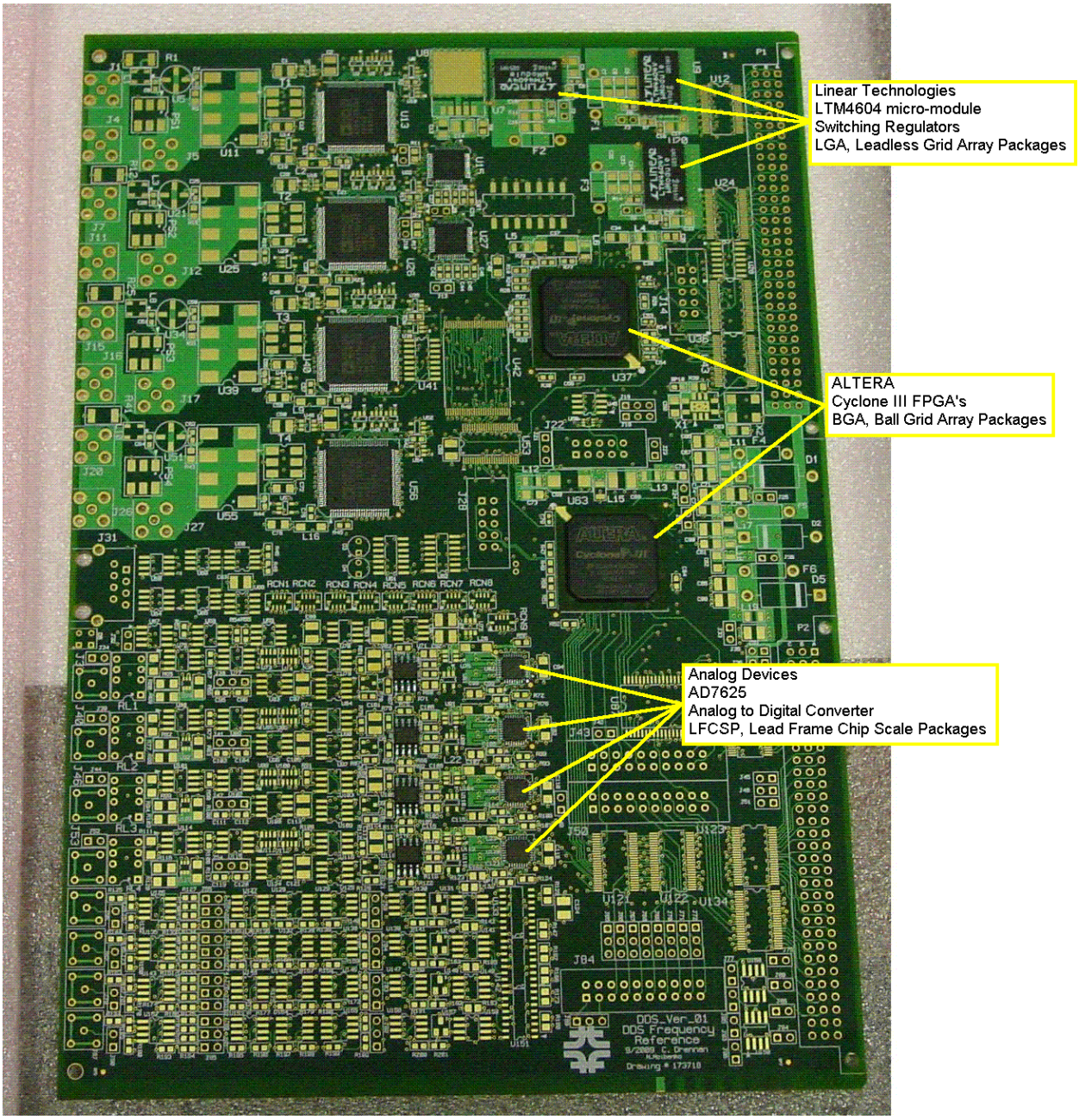

Figure III.1 Photo of the partially assembled module, identifying the components of interest.

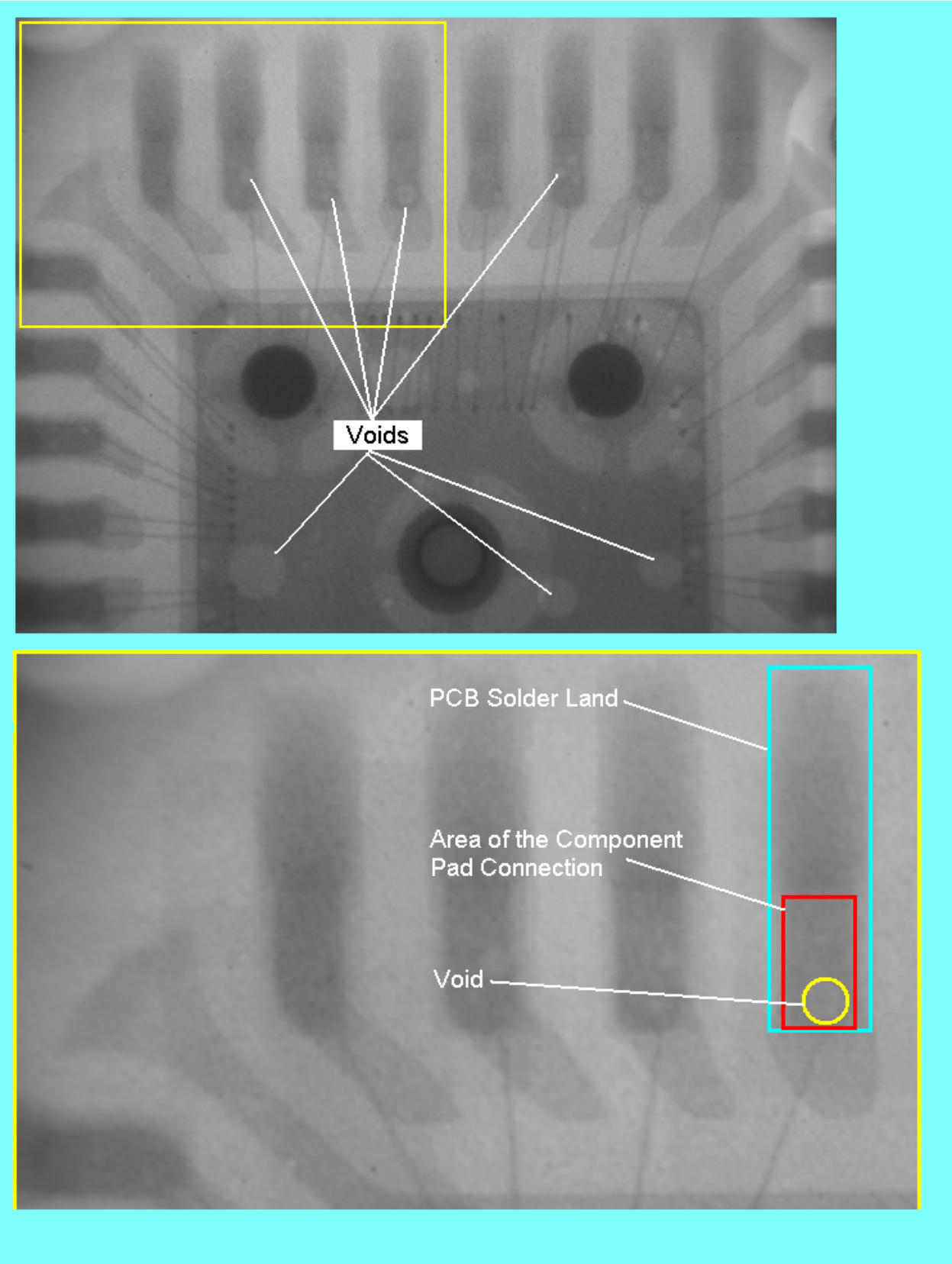

Figure III.2 X-Ray photo of some of the ADC LFCSP connections.

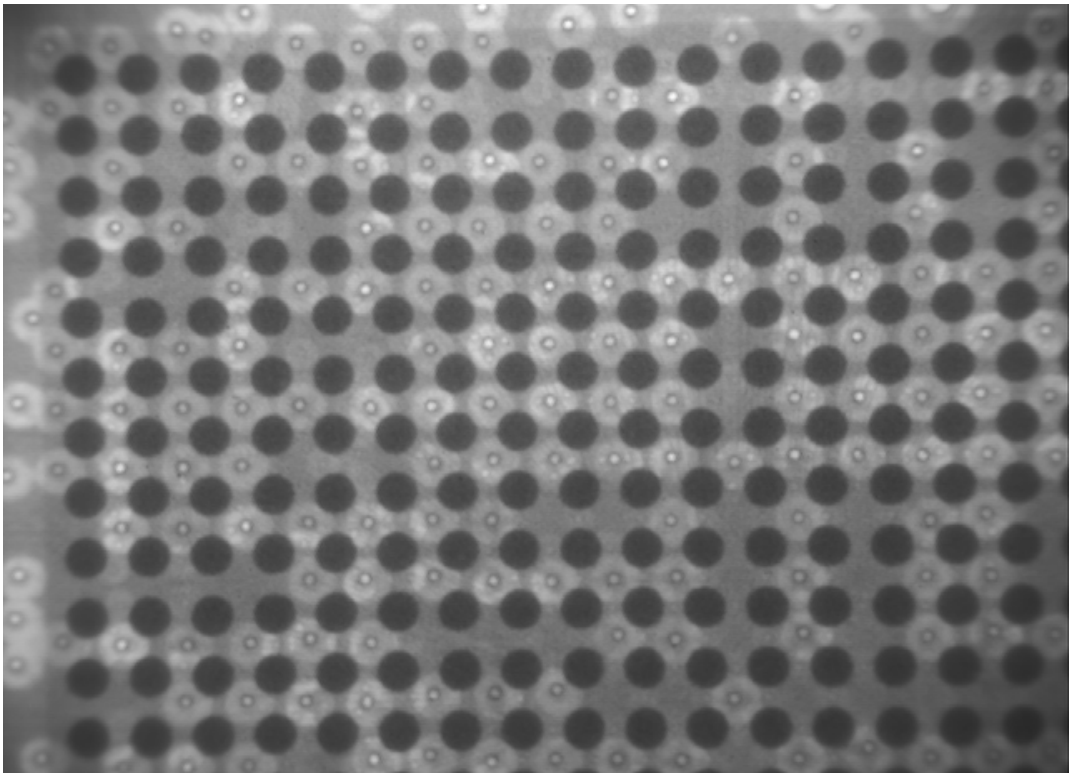

Figure III.3 Sample view of the BGA connections.

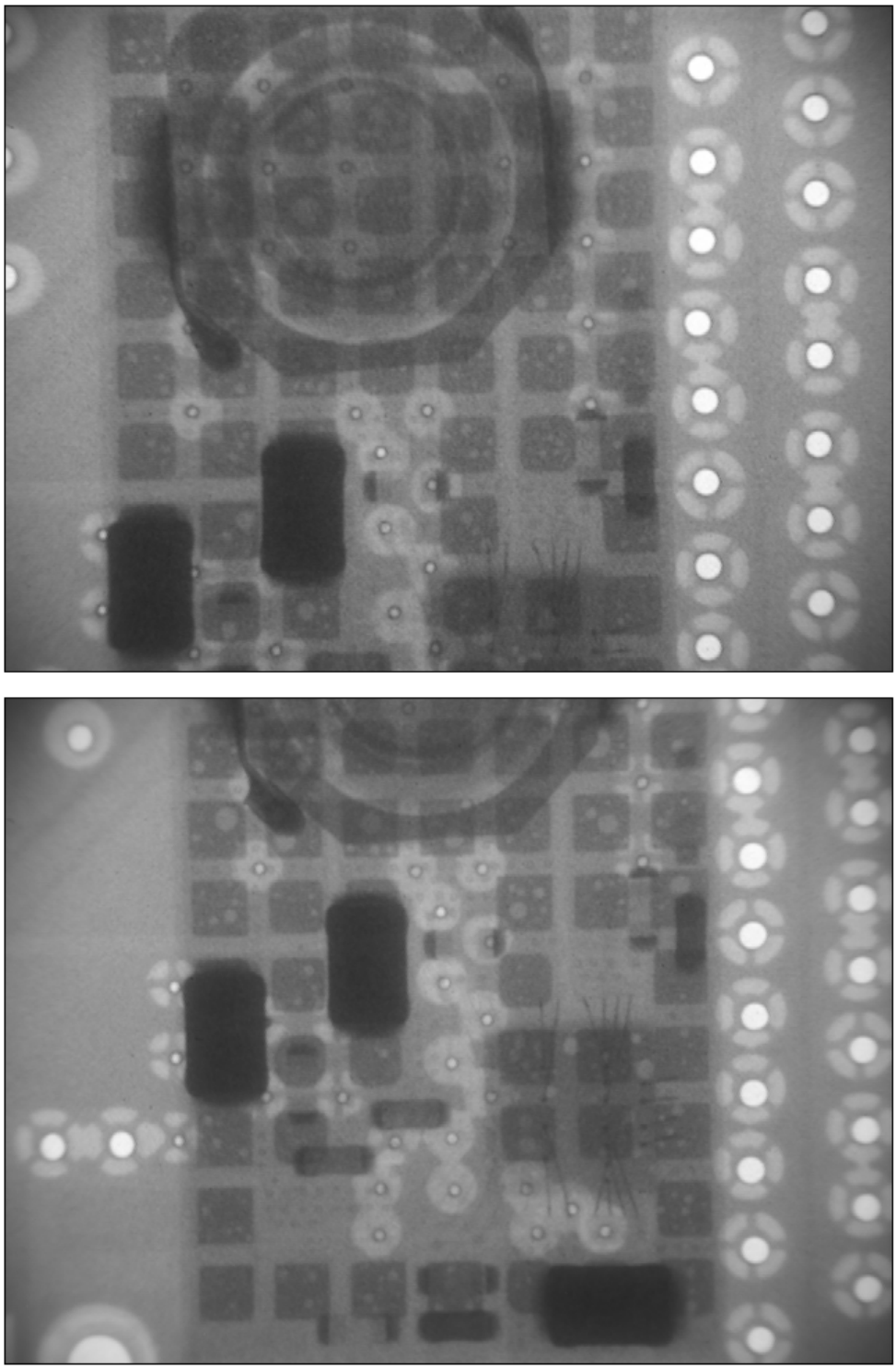

Figure III.4 X-ray photos of some of the LGA connections.

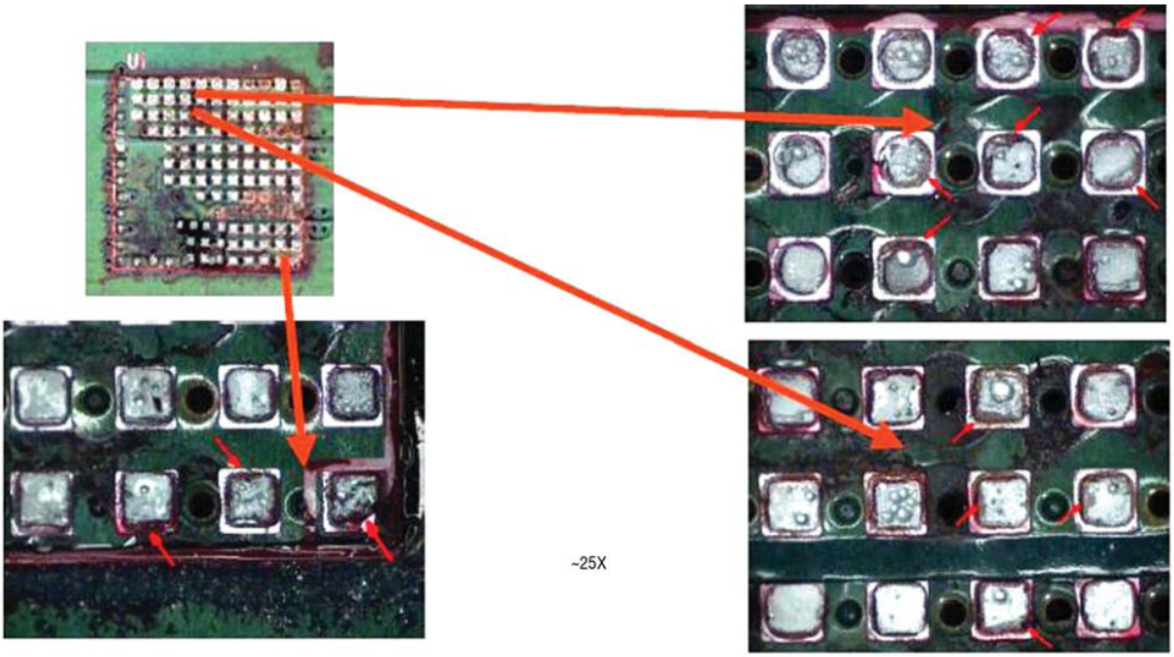

Figure 7. No Failure After 100,000 Cycles (50°C to 100°C)

Figure III.5 LGA Connections from Linear Technology Application Note 114.

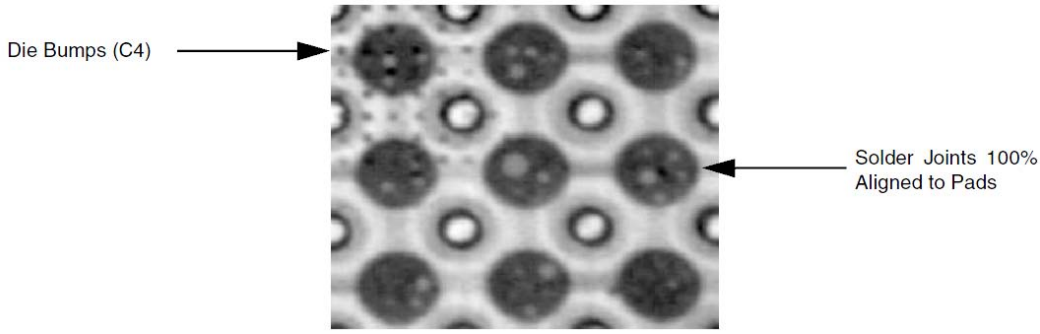

Figure 6. X-ray of Perfectly Self-Aligned LGA After Misplacement

5.2 Solder Joint Voiding

As with BGA, solder joint voids do occur in LGA. Voids in LGA can be larger due to geometry and greater ratio of flux to solder. IPC-A-610D specifies a greater than 25% voided area is a defect for BGA, however, it does not specify the defect limit for LGA. This specification applies only to collapsing spheres, which LGA does not have. Thermal cycling with LGA solder joint voiding of greater than 25% repeatedly shows excellent solder joint reliability. All studies referenced in this document use LGA devices that, when soldered to the test board, contained some joints with greater than 25% voiding.

The most significant factor in solder joint voiding is the solder paste formulation. Consult your solder paste supplier for what they believe to be a low voiding solder paste. Other influences to void formation are reflow profile, solder paste volume, PCB surface finish, and oxidation, as discussed in previous sections. Actions to reduce solder joint voids include using a nitrogen reflow atmosphere with less than 100 ppm oxygen and extending pre-heat times and/or time above liquidus in reflow.

After extensive thermal cycling, solder joint fractures appear similar to BGA joint fails. Fractures can occur through bulk solder at or near the package and/or PCB pad. Figure 10 shows a void in a cross-section of an LGA joint. This joint has been cycled to failure with a fracture propagating though bulk solder and through the void.

Studies are underway with various voiding levels to better understand the effect of voids on long term reliability.

Figure III.6 Text and figure from Freescale App Note AN2920.

IV. Conclusions

From these observations using the x-ray inspection equipment and from other visual inspections made under magnification, we are accepting the boards as they are and proceeding with the rest of the assembly. The x-ray inspection showed no sign of bridging and the amount of voids in the solder connections is considered acceptable. When on future modules we wish to mount LGA type components, we will review our experience with the assembler and inquire further into their knowledge of their reflow process and experience with LGA connections.

Once the boards are completely assembled we will precede making continuity and resistance measurements of the power and ground nets and then carefully powering the boards.