GLAST BEAM TEST ENGINEERING MODEL
LARGE AREA SILICON TRACKER CONSTRUCTION

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In November 1999 the GLAST BTEM was completed and sent to SLAC for testing. Much was learned during the process of developing tools and techniques for assembly and the building of the tracker. What follows is a brief summary of the procedures, their pros and cons, and recommendations for the final GLAST production line. We attempt at an exhaustive list of problems we encountered to try and make sure that the same mistakes are not made a second time. Finally, some yield data is presented.

1. DETECTOR TESTING

Overview: Detectors arrive from Hamamatsu in paper envelopes. They need to be removed from the envelopes, tested electrically (IV curve) and visually inspected. Detectors are expensive and fragile, requiring careful handling.
Proto-Tower technique: The detectors were removed from their packages by hand, then picked up with a rubber tipped vacuum tool and placed on a fixture in an automatic probe station. The fixture was made to hold 3 detectors to speed up the testing process. The fixture had a vacuum chuck and an alignment rail and was made very flat and parallel to the probe station platen. To keep salts off of detector surfaces gloves were worn at all times and the pickup tool and fixture were regularly cleaned with alcohol. Some detectors were visually scanned for defects, contamination, and scratches.
Advantages: Testing multiple detectors was useful for both safety and speed.
Problems: 1) Moving the detectors by hand was the scariest part of the operation. No major mishaps occurred during testing. 2) Visual inspection over such a large

area without a motor driven stage was tedious. There was no easy way to document the results of visual inspections.

Recommendations: 1) Pattern recognition for aligning probe tip(s). 2) Measure C-V curve for all detectors to find their depletion voltage. 3) Design a 4x4 detector testing jig for possibility of I-V and C-V testing simultaneously. This may require a larger bias pad size to allow for alignment fluctuations. 4) Purchase or build an inspection station with high quality optics, programmable motor driven stage, and image capture/archiving features. Such a tool would be useful throughout the tracker construction.

2. LADDER ASSEMBLY

Overview: Three or five detectors (6.4 cm. or 10.67 cm.) were precision aligned, edge glued together, wire bonded together, and the wire bonds were encapsulated. Ladder assembly was a fairly involved process with many separate procedures. These process steps occurred alternately at both SCIPP and SLAC.

Proto-Tower technique: . A special "universal" fixture (SA-245-101-04) was designed which could interface with as many process steps as possible and also could double as a carrying case. A vacuum pickup tool (SA-245-101-18) with three rubber cups was built to transfer ladders into gluing and potting fixtures for processes which the "universal fixture" could not accommodate.

A program for electrical testing was used to QC each step. I-V curves were taken in between every handling, wire bonding, and encapsulation step.

BREAKDOWN OF LADDER ASSEMBLY STEPS

GLUING**:** Detector edge gluing procedure was developed at SLAC. One detector edge was dipped in a 2-mil thick film of glue and then hand placed on an alignment jig. The jig used Teflon pins for alignment in X, Y, And Z. Then the jigs (there were 5) were placed in a 60 C oven for ~ 2 hrs.. After cure the ladders were surveyed optically in X and Y (Z was not working yet).

Advantages: The SLAC procedure was simple and required very little tooling. Allowing the detectors to float on pins with only gravity holding them in place allowed the glue to set its own bond line thickness by surface tension.

Problems: 1) This procedure required a lot of detector manipulation by hand. 2) Alignment was not consistent and in some cases outside the specified tolerances. Some misalignments in Z were large enough to complicate mounting the ladders in the wire bonding jig (would not vacuum down) and caused difficulty probing. 3) Some glue joints were starved. This was later eliminated by inspecting the joints under a microscope before curing. A few ladder glue joints failed during assembly but these could be explained by either a starved joint or mishandling. 4) There was an electrical connection between the backplane of the detectors through most of the glue joints (not all) which complicated measurements of individual detector currents.

Recommendations: 1) Build ladders on jig with vacuum chuck to guarantee alignment in X, Y and Z (watch thermal mismatch between jig and silicon with high temp. cure). Consider curing epoxy with a localized heat source such as a hot wire or using UV cure epoxy. 2) Improve consistency of glue dispensing. 3) This is one of the steps where a “universal” fixture could not be used. It would be good to look for a way to incorporate gluing into this “universal” fixture. 4) Control edge gluing so as to not create an electrical connection between detectors. This probably just means guaranteeing a space sufficient to keep detectors from touching.

WIRE BONDING**:** Ladders arrived at the wire bonder housed in their fixture/ transport case. The fixture had a male dovetail for quick mounting and adjustability in a female dovetail mount on the wire bonder. For safety the fixture was mounted on the wire bonder before removing the Plexiglas cover. A bonding program was called up which would automatically search for fiducials and make one set of detector-detector wire bonds (322 bonds). This was repeated for the other detector junctions and repairs were made as required.
Advantages: The tooling worked very well. Using pattern recognition was desirable since operator error became more likely after bonding many devices.
Problems: For the prototype tower many of the ladders were made with a separate wire bonding fixture which the ladders had to be transferred to. It was during this transfer that 2 ladders broke.
Recommendations: 1) Bonding fixtures and support structures need to be flat and stiff. 2) Many bond failures were due to dust contamination on the bond pad aluminization. Detectors need to always be handled in a class 10,000 clean environment and the wire bonder should be in class 1000 area. Most dust that had settled on the bonding pads could be blown off with a clean air duster. 3) Detectors should be designed with redundant or oversize bonding pads for re-bonding.

TESTING**:** I-V curves were taken on the detectors and ladders throughout the assembly. Damage to detectors was noticed and repair initiated. After wire bonding the capacitance of each strip was measured. Capacitance data gave indications of missing bonds, shorted bonds or strips, broken strips, and oxide punch through. All wire-bond removal or re-bonding needed to be done before encapsulation.
Advantages: The universal fixture made it easy to put the detectors in the test station. This allowed us to safely test the ladders as frequently as we desired (such as after some accident). A special tool was designed which contacted the backplane of the detectors electrically through ¼” holes in the universal fixture.
Problems: Measuring strip capacitance occasionally gave information indicating the removal of some wire bonds. This operation was dangerous and cumbersome in the Wentworth probe station.
Recommendations: 1) Build a tool attached to a micro-positioner for safe wire bond removal. 2) Consider doing bond removal outside the probe station. This would probably be safer, but would take more time since the strip capacitance needs to be re-measured after bond removal. Repairs will probably be infrequent enough to be done outside the production line.

ENCAPSULATION**:** The only way we found to get glue cleanly into the row of tight wire bonds is to spray it. The ladder was aligned with a mask that left only the wire bonds exposed to the epoxy spray. For the second time the detectors needed to be removed from the universal fixture and placed in a new fixture. The encapsulation fixture aligned the ladder in X, Y, and Z and had pinholes for registering the mask. After the line of wire bonds was fully filled with glue the mask was removed and the ladder plus base jig was put in an oven for cure.

Advantages: Spray was the only method that worked for getting epoxy into the bonds. Masking plus spray eliminated the need to have any precision aligned glue dispenser.

Problems: 1) There were many problems with this setup since there are many parameters which are difficult to control. Successful encapsulation depended heavily on the experience of the operator and even with the most experienced people the results were very inconsistent. 2) A few ladders had epoxy flow over the edge and onto the back plane of the detectors which later caused problems mounting the ladders to trays. 3) Test ladders were put in the curing oven with vacuum still holding them down to the fixture. Because of the high CTE of the Al jig, the bonds between ladders were pulled apart. 4) Associated to problem 2, two ladders were not fully cured after potting and the epoxy on their backplanes adhered to the storage shelves. Removing these ladders from the storage shelves chipped and destroyed the detector where the glue had stuck. To salvage part of one ladder we machined all the wire bonds off between the live and dead detectors.

Recommendations: Develop a new potting procedure. Some requirements are precise volume control and placement. Possible solutions: 1) Spray a fast curing (UV-cure or lacquer) material which would cure in successive layers; 2) Turn the ladder upside down and dip the wire-bonds in a bath of epoxy which should wick into to bonds. 3) If elevated temp cure is used, don't vacuum detectors down, or use a low CTE jig (Invar, glass, carbon). 4) Or try to improve the current system with automation.

3. TRAY PANEL CONSTRUCTION

Overview: Fabrication of a tray panel consists of bonding the tray closeout, honeycomb core, and face sheets together in a constraining jig. This jig had to guarantee the X,Y,Z alignment and flatness specs required for tower assembly and detector alignment. For the prototype tower the lead and Kapton bias sheet were also bonded to the tray surface. On the bottom of each tray there is a pattern of lead rectangles and a Kapton bias sheet. The top of a tray has only the Kapton bias sheet.

Proto-Tower technique: Done by John Broeder.

Advantages:

Problems: 1) For the proto-tower the closeout frames were not machined to the drawing tolerances which caused complications for the tooling during electronics assembly. 2) Asymmetry and non-uniformity of the trays greatly complicated the tower construction (both tooling and database). There is a fundamental tray asymmetry caused by the lead foils. We partially compensated for this by moving the HDI mounting hole locations on the drawing prior to machining. Five different types of trays were constructed for the prototype tower: top, bottom, super GLAST, no lead, baseline. Procedural steps such as wire bonding and detector mounting had to have alternate tooling for the top and bottom of the trays. 3) There originally was no reference mark on the tray closeout which resulted in some trays being fabricated in the wrong orientation. 4) Wire bond traces on the Kapton were occasionally damaged and contaminated with epoxy. This is another reason to separate the right angle interconnect (Kapton bend) from the tray. The issue of Kapton QC is included in appendix A.

Recommendations: Re-design closeouts to include: 1) An alternate datum than the pin holes such as a contact area on the closeout surface; 2) Pin holes for aligning the Hybrid circuit (these need to be placed in locations where there is available real estate on the circuit board to bore more holes); 3) Clearly label one corner (X,Y,Z) as the tray origin. Also put an arrow and lettering "down", or "lead" on all four corner posts. 4) Perform careful surveys of machined pieces to qualify perspective shops who will deliver the closeouts and place orders per 1st. article closeouts.

* The procedure for fabricating the tray should change significantly when we move to a carbon structure.

4. HDI ASSEMBLY

Overview: The hybrid electronics board (or "multi chip module" as industry calls it) consists of 27 silicon die attached directly to the board, surface mount passive components, and 2 miniature 25 pin connectors. All board fabrication and assembly was done in industry. Electrical testing was done in Santa Cruz between each step of the tray assembly. The primary complication of building a HDI is the large number of die, tightly spaced, with a large number of wire bonds.

Proto-Tower technique: Circuit boards were manufactured and tested by Data Circuit Systems. Passive components and connectors were loaded by Promex and the boards were returned to SCIPP for testing and debugging. At this point the board was mounted on a base plate with an identical, male dovetail, interface to our wire bonder and a protective plexiglass cover. Lastly the boards and chips were sent back to Promex for die attach and wire bonding. We provided Promex with the tooling necessary to interface to their wire bonder.

Advantages:

Problems: 1) Some tightly spaced passive components had solder bridging causing shorts. 2) Narrow traces near the edge of the board were damaged during handling at Promex. 3) Power traces underneath the front-end chips shorted to the chip substrate when there was insufficient glue. 4) Bond pads were not consistently located relative to fiducials. One pad was too close to the chip. 5) Chip addressing was complicated by requiring a different bond pattern for each chip. 6) Bond quality was generally poor which may have been due to low QA at Promex. Poor bond quality lead to occasional bond lift off during production. 7) Chip bond pads were very small and therefor difficult to re-bond. 8) After the HDI was wire-bonded handling became an issue. There is very little safe space to grab onto the board and the only mounting technique is by screwing in the 1 mm screws very near to the chips.

Recommendations: 1) Widen all traces, if possible, to 8 mils. 2) Silkscreen a solder mask over the board, leaving holes for passive components and wire bonding pads. 3) Draw an optimal bond pad and fiducial layout pattern for one chip (excluding address bonds) and repeat for all the chips. Locate the pattern based on the chip positions that are determined from the "right angle interconnect" circuit (Kapton). 4) Layout address bond pad locations so that the same bond pattern/location is used on every chip. This means the board trace layout will be different for every chip. 5) Consider use of a plasma/ vapor cleaning process step before wire bonding. Bond pads are contaminated by VOC's during adhesive curing and by dust if the boards are not continually in a clean room environment. 6) Re-design the HDI to incorporate a "right angle interconnect" (Kapton circuit) onto the board. This circuit would be permanently attached to the board and serve the function of the existing Kapton circuit. 7) Increase size of bond pads on both chips enough to make 2 bonds. 8) Explore new procedures for handling and mounting the HDI's during burn in, testing, and repair. The goal is to keep the sensitive areas of the board, chips and bonds, protected by a cover at all times. 9) Maximize size of HDI and component clearances. 10) Find an assembly house other than Promex qualified to perform space qualified assembly.

5. HDI INTEGRATION ONTO TRAYS

Overview:. The HDI was aligned to the tray and glued to the Kapton in a horizontal position. Wire bonds were made between the front end chips and the Kapton. The assembly was electrically tested and then encapsulated with a flexible, repairable silicone. Finally the HDI was bent down vertically to the tray closeout and screwed into place.

Proto-Tower technique: The prototype tower technique required that the HDI's be attached to the trays before the detectors. A precision jig was used to align the circuit board to the tray and glue the board to the Kapton. This same jig acted as support for the board during wire bonding. A masking strip was placed along the Kapton to keep the silicone encapsulation from flowing onto the detector side bond pads.

Advantages: 1) Doing assembly, wire bonding, and testing in a horizontal position allowed for repairs such as chip replacement and re-bonding. 2) Soft silicone encapsulation was easily removable for repairing chips.

Problems: 1) Tight geometry required that the jig be machined to very tight tolerances. Since the tray was not machined to spec, each HDI assembly jig had to be custom shimmed. 2) Handling the HDI was dangerous since there were so many exposed wire bonds and no safe place to grab the board. Also the 1 mm screws are placed very close to chips and are difficult to handle. Wire bonds were damaged by falling screws and by being bumped against the tray cover. 3) On one tray the Kapton started to peel off the board after it was bent down. Inspection showed sufficient epoxy which means that there was probably some kind of contaminant on the board or Kapton before gluing. Also the glue lap is only 1 mm and has to support a fair amount of stress. 4) The silicone encapsulation was not tough enough to guard against damage. Some chips were destroyed by misplaced screws while putting on a cover. 5) While repairing one of the boards, one chip died, most likely from electrostatic discharge.

Recommendations: 1) Discard the Kapton bending concept and make a "right angle interconnect" which is integrated onto the HDI thus separating the tray and HDI into two separate modular components. 2) Encapsulate the HDI with a hard tough epoxy after thorough testing. Manufacture enough HDI's to allow for yield and discard any that fail after encapsulation. 3) Handle HDI at ESD safe work station and always were grounded wrist strap.

6. LADDER INTEGRATION ONTO TRAYS

Overview: Align 5 detector ladders to better than 50 microns in X, Y, and Z relative to tray reference features. Glue ladder to Kapton bias circuit with conductive epoxy. Wire bond detectors to Kapton traces.

Proto-Tower technique: Alignment in Z was based on an assumption that the Kapton surface was precise enough. We placed 1.9 mil thick, ¼ in. wide spacer tape along the long edge of each ladder to keep the detectors parallel to the tray. The tape also guaranteed a consistent adhesive thickness. A three component jig and spacers were used to align the ladders in X and Y. The jig base plate had 4 pins to mate to the tray corner posts. After the tray was mated to the base plate the protective cover was removed and the X and Y alignment rails were positioned. Conductive silver glue was applied to the bias circuit in small dots with a volume-controlled dispenser. The same glue was also applied along the edge of the ladder where the wire bonds are made to provide support under the bonding pads. Ladders were removed from their carrying cases and positioned on the tray by hand with a special vacuum pickup tool. Spacers with three small contact points were put in between ladders (long direction). After curing the trays were put in the wire bonder and the detector-Kapton wire bonds were made.

Advantages: The jigs were designed to accept the tray with all of its protective covers. This made the operation fairly safe.

Problems: 1) The asymmetry of the height of the trays required a different setup for the top and bottom of the trays. If a shim wasn't put under the rails for the lead side the Kapton traces could be damaged by contact with a rail. 2) Applying conductive glue along the ladder edge for support under the wire bonds was risky since the fine traces were very near. Glue squeeze out from the edge of the ladder would have been disastrous. 3) A couple ladders had globs of encapsulation epoxy that had crept to the backside of the ladder. These globs were much thicker than 2 mils and therefore ruined Z alignment. 4) Picking up the ladders and placing them by hand was dangerous. 5) For higher quality wire bonds it is desirable to make the first bond on the Kapton. Our jigs and tray geometry thus required a "reverse" bond that could not be observed through the microscope. An extra CCD camera and optics gave us visual access to the bonding. 6) After the beam test 6 ladders had de-bonded from the Kapton from failed glue joints. Silver epoxy was stuck to both Kapton and detector surfaces. Initial inspection indicated that there may have been too little glue used for these ladders.

Recommendations: 1) Increase the spacer tape thickness to at least 4 mils. This will provide more space for clearance of irregularities on the bottom of the ladder and also increase the epoxy bond strength. This affects tower geometry! 2) Placement of ladders on trays should be robotic or at least done with tooling that removes any danger of "crashing". 3) Place Teflon coated weights on ladders after alignment to assure Z alignment and strong adhesion. 4)..Develop technique for encapsulating the detector-Kapton bonds. This will probably require plugging the gaps between detectors where epoxy wants to flow away by capillary action. The new concept of a modular HDI will also create a capillary path away from the bonds. 5) Study silver adhesive strength, thermal effects, and dispensing procedure to guarantee the bond strength over time.

7. TOWER ASSEMBLY

Overview:. Tower assembly consisted of stacking 17 trays on a simulated grid base, threading Vectran cables through the corner posts, tensioning the cables, connecting 8 Kapton cables to the HDI's, and mounting the tower walls.

Proto-Tower technique: The simulated grid base plate was positioned on a surface plate to keep the whole assembly flat. Trays were placed on the stack with all their protective covers on accept the bottom one. Alignment pins and spacers were put in the corner posts, the top cover was removed and then the next tray was positioned. We inspected the spacers as we stacked each tray to assure there were no gaps. After stacking, 4 Kapton cables were plugged into the HDI's and the tower was tested electrically. After verifying that the tower worked the rest of the cables were plugged in and the tower walls were loosely attached. Finally the Vectran Cables were threaded through the corners and tensioned to 25 lbs. A special tool was needed to screw in the jack screws on the Nanonics connects since the connectors are fragile and there was no direct access to the screw heads. The tool consisted of a miniature torque wrench with a ¾ in. flexible shaft ending in a short piece of hex driver.

Advantages: Tray stacking was done easily and quickly by hand with 2 people and a spotter. After tensioning the Vectran we were able to remove any side wall without fear of losing alignment.

Problems: 1) The primary complication with tray stacking was putting in the alignment pins and spacers. These consisted of 2 pins and a spacer which had to be pressed into the corner post hole very close to nearby detectors and wire bonds. A special tool helped with this step. 2) There is an interference between the Kapton cable and the closeouts which made it so some connectors were impossible to mate. This was solved by unscrewing the HDI mounting screws slightly and bending the board out enough to mate the connectors. 3) Tapped holes in the bottom closeout for mounting to the grid and for the tower walls were on the same pattern which required special short screws. 4) Both the bottom and top closeout needed spacers to hold the Kapton cables from touching the HDI. If the HDI had a robust encapsulation the spacers wouldn't be needed. 5) Our tests of the pull strength of the Vectran cable indicated that the pull strength was lower than Hytec's result. Accounting for this we decided to tension the cables to a conservative 25 lbs. The cables relaxed to around 17 lbs. after 24 hours and we left them that way. 6) The nicopress sleeves used to terminate the Vectran cables could not be crimped with the nicopress tool because of an interference with the tray. For the tower we used 2 sleeves and crimped the top one which had clear acess.

Recommendations: 1) Use one single alignment pin between trays. Consider integrating an alignment pin and the spacer into one piece. 2) Re-design tray to provide clearance between the tray closeout and Kapton cables. 3) Offset screw holes in bottom closeout. 4) Make a flush crimping tool to terminate Vectran cables.

Appendix A: Kapton Bias Circuit QC

The Kapton Bias Circuit consisted of a large square area (13 in.) with 1605 fine gold plated traces along the edge. There are many reasons why these traces are difficult to wire bond to, such as: soft Kapton substrate, fine traces, non-uniform metalization, and dimension fluctuations. Since the integrity and wire-bondability of every trace was desired we performed detailed inspections of the Kapton after fabrication and after they were glued onto trays. Inspections helped identify damage and contaminants to the Kapton such as scratches, dirt, and epoxy and showed the need for better inspection equipment. Some circuits were rejected straight from the manufacturer. A fair amount of contamination and damage occurred during fabrication of the trays. A few traces were covered in polyamide presumably due to incorrect mask registration.

Recommendations:
- Manufacture test pieces of every circuit for wire-bonding tests.
- Perform initial inspection of circuits and then mask them (if possible).
- Before bonding, clean the traces to remove VOC’s.

Appendix B: Nanonics Connectors

The Nanonics connectors are fragile and needed to be handled carefully. A flaw in the design of the connects kept Nanonics from making the jack screws long enough to do their job properly. If you use the connector in a standard fashion, the screws only have one thread engaged when significant force starts to develop between the mating connectors. This problem was solved with a special tool which pre-mates the connectors before you turn the screws. Also, since the connector bodies are made of plastic a torque limiting screwdriver is required or there is potential to destroy connectors.

Recommendations:
- Pre-test all connectors, maybe in matched pairs, for ease of insertion
- Investigate the possibility of metal inserts for more robust threads.
- Use torque limiting screwdriver at all times.
- Design a pig-tail cable to plug into the HDI connectors during testing which will be removed only before final assembly.

Appendix C: Kapton Cables

Recommendations:
- Align connectors square and flat on the cable (very little flexibility and clearance on tower).
- Encapsulate connector leads where they are soldered to the Kapton
- Encapsulate components on the back of the cable

Appendix D: Tray Burn in Fixture

A special tray burn in fixture was designed which could accommodate 8 trays connected with the real tower Kapton cable. The setup needed to hold the trays with all their protective covers on and have clearance for the cable to reach all the connectors. The solution required a stair-step stack so that their was clearance to access the connector jack screws. Another use of a “stacked” burn in station is that it allows you to track cosmic rays to verify the tray performance.

Appendix E: Production and Yield Data

Component Count

All working pieces in the finished tower.

DETECTORS:	531
♦ 10.68 cm x 6.4 cm	246
♦ 6.4 cm x 6.4 cm	285
CHIPS	864
HDI’S	32
LADDERS	130
TRAYS	17
KAPTON CABLES	8

Manufacturing Yields for the GLAST Prototype Tower

For a complete list problems with the detectors, ladders, and hybrids, see http://scipp.ucsc.edu/~hirayama/glast/btem_stats.html

WIRE BONDING YIELDS:

Bond Type	# Bonds Counted	# Failed	Percent Failure
LADDER	110,768	71	0.06
DETECTOR-KAPTON	41,600	98	0.24
CHIP KAPTON	46,400	143	0.30