FINAL DESIGN REVIEW OF THE ATLAS PIXEL DETECTOR FLEX HYBRIDS DESIGN

The University of Oklahoma
R. Boyd
11 December, 2000
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- Radiation Length
- Component Irradiation Tests
- Yield Model
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Changes to Document Function

- Provide connection for:
  - Power
  - Clock
  - Data In
  - Data Out

- Between module and:
  - Power supply
  - Optical link

Diagram:

- DCS
- Power Supply
- Reset
- Optical Link
- ROD*
- Flex Hybrid Module

* Read Out Driver
Changes to Document

- **Power Requirements**
  - Emphasis that currents listed in Table 1 are maximums expected, regardless of technology
- Maximum expected dose is $10^{15} \text{n/cm}^2$ equivalent
- Number of bump bonds is 46080

<table>
<thead>
<tr>
<th>Power Supply</th>
<th>Voltage</th>
<th>Current</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Max</td>
<td>Nominal</td>
</tr>
<tr>
<td>VDDA</td>
<td>6.000</td>
<td>3.5</td>
</tr>
<tr>
<td>VCCA</td>
<td>4.000</td>
<td>1.75</td>
</tr>
<tr>
<td>VDD</td>
<td>6.000</td>
<td>4</td>
</tr>
<tr>
<td>( V_{\text{det}} )</td>
<td>700</td>
<td>-</td>
</tr>
</tbody>
</table>

*Table 1 - Power supplies on the flex hybrid.*
## Radiation Length

- Values for components are estimates

<table>
<thead>
<tr>
<th>Flex parts</th>
<th>#</th>
<th>thickness</th>
<th>area</th>
<th>&lt;area&gt;</th>
<th>&lt;thickness&gt;</th>
<th>&lt;X0&gt;</th>
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<tr>
<td>Kapton</td>
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<td>0.0025</td>
<td>11.59</td>
<td>13.471608</td>
<td>0.002906</td>
<td>0.000102</td>
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<tr>
<td>Coverlay</td>
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<td>0.0025</td>
<td>10.431</td>
<td>21.824005</td>
<td>0.005231</td>
<td>0.000184</td>
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<tr>
<td>Cu- traces</td>
<td>2</td>
<td>0.0015</td>
<td>3.477</td>
<td>2.424889</td>
<td>0.001046</td>
<td>0.000732</td>
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<tr>
<td>MCC</td>
<td>1</td>
<td>0.025</td>
<td>0.7</td>
<td>0.049142</td>
<td>0.001755</td>
<td>0.000187</td>
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<tr>
<td>MCC glue</td>
<td>1</td>
<td>0.005</td>
<td>0.7</td>
<td>0.049142</td>
<td>0.000351</td>
<td>0.000014</td>
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<tr>
<td>Wire bonds</td>
<td>416</td>
<td>0.002</td>
<td>0.0004</td>
<td>0.000007</td>
<td>0.000033</td>
<td>0.000004</td>
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<tr>
<td>Capacitors</td>
<td>48</td>
<td>0.05</td>
<td>0.005</td>
<td>0.00120</td>
<td>0.001203</td>
<td>0.000160</td>
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<tr>
<td>Large capacitors</td>
<td>3</td>
<td>0.18</td>
<td>0.0576</td>
<td>0.000998</td>
<td>0.003119</td>
<td>0.000416</td>
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<tr>
<td>Resistors</td>
<td>8</td>
<td>0.05</td>
<td>0.005</td>
<td>0.00020</td>
<td>0.000201</td>
<td>0.000027</td>
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<tr>
<td>NTC</td>
<td>1</td>
<td>0.05</td>
<td>0.005</td>
<td>0.000003</td>
<td>0.000025</td>
<td>0.000003</td>
</tr>
<tr>
<td>solder (on pads)</td>
<td>120</td>
<td>0.01</td>
<td>0.0025</td>
<td>0.000251</td>
<td>0.000301</td>
<td>0.000376</td>
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<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.001829</td>
</tr>
</tbody>
</table>
Component Irradiation Tests

- Don't have data here to support claim that resistors don't change
- Capacitors
  - CERN PS/T7
  - 24 Gev protons
  - $1.67 \times 10^{15}$ p/cm$^2$
  - 3.5 V applied during irradiation

<table>
<thead>
<tr>
<th>Slide</th>
<th>Column</th>
<th>Nominal</th>
<th>-20%</th>
<th>Post irradiation</th>
<th>+20%</th>
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<tbody>
<tr>
<td>9</td>
<td>1</td>
<td>1.00E-008</td>
<td>8.0E-009</td>
<td>9.52E-009</td>
<td>1.2E-008</td>
</tr>
<tr>
<td>9</td>
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<td>1.00E-008</td>
<td>8.0E-009</td>
<td>9.48E-009</td>
<td>1.2E-008</td>
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<tr>
<td>11</td>
<td>2</td>
<td>1.0E-007</td>
<td>8.0E-008</td>
<td>8.71E-008</td>
<td>1.2E-007</td>
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<tr>
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<td>3</td>
<td>1.0E-007</td>
<td>8.0E-008</td>
<td>8.92E-008</td>
<td>1.2E-007</td>
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<tr>
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<td>1</td>
<td>1.2E-007</td>
<td>9.6E-008</td>
<td>1.04E-006</td>
<td>1.4E-007</td>
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<tr>
<td>5</td>
<td>2</td>
<td>1.2E-007</td>
<td>9.6E-008</td>
<td>1.05E-006</td>
<td>1.4E-007</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>3.3E-007</td>
<td>2.6E-007</td>
<td>2.73E-006</td>
<td>4.0E-007</td>
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<tr>
<td>2</td>
<td>2</td>
<td>3.3E-007</td>
<td>2.6E-007</td>
<td>2.75E-006</td>
<td>4.0E-007</td>
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</tbody>
</table>
Yield Model

<table>
<thead>
<tr>
<th>Yield(%)</th>
<th>Step</th>
</tr>
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<tbody>
<tr>
<td>100.0% Fab</td>
<td></td>
</tr>
<tr>
<td>85.0% Inspect/destruct test</td>
<td></td>
</tr>
<tr>
<td>99.5% Ship</td>
<td></td>
</tr>
<tr>
<td>99.0% Cut</td>
<td></td>
</tr>
<tr>
<td>99.5% Ship</td>
<td></td>
</tr>
<tr>
<td>90.0% Mount components</td>
<td></td>
</tr>
<tr>
<td>99.5% Ship</td>
<td></td>
</tr>
<tr>
<td>97.0% Wire bond MCC</td>
<td></td>
</tr>
<tr>
<td>99.5% Ship</td>
<td></td>
</tr>
<tr>
<td>95.0% Probe/burn-in</td>
<td></td>
</tr>
<tr>
<td>99.5% Ship</td>
<td></td>
</tr>
</tbody>
</table>

68% per flex

- Based on estimates and past experience (CLEOIII, Si3, CDF)
- Note that cutting may take place after assembly
Layout Features
Layout Features (continued)
Layout Features (continued)
Possible local decoupling capacitor layout for final version
Layout Features (continued)
Flex Vendors

- CERN PCB facility
  - Charge for materials only, but:
    - Two tests required (outside vendor):
      - Before defect repair
      - After Ni/Au plating
    - More expensive shipping (to US)
    - Laser cutting not provided
  - In house electroless Ni and Au plating
  - Has fabricated v1.0, v1.1, v1.1, v1.4 and v2.2 flex

- Compunetics (Monroeville, PA)
  - In house testing (two tests required, also)
  - Out-sourced Ni and Au plating (has been source of some problems)
  - Domestic shipping
  - In house laser cutting
  - Commercial production facility
  - Has produced v1.1 and v2.1 flex
Flex Vendors (continued)

- Many other potential vendors have been contacted, those that have technology tend to not be interested in small orders (<100k units), most that will do small orders don't have technology
- R & D Circuits (Edison, NJ): tried for over 1 year
- General Electric Corporate Research and Development (Schenectady, NY)
  - Built ~600 flex for CLEOIII, Si3 over 2 year period (more aggressive design than ATLAS Pixels)
  - Limited production capability
  - More expensive
  - Dyoconex (Switzerland) and Century Circuits and Electronics (Minneapolis, MN) are other possible vendors
Production

Deliverables (UOK)

- Layout of prototype and final designs
- Simulations of flex hybrid power traces and decoupling
- Flex Hybrid test design
- 100% Flex Hybrids
  - 50% at CERN, 50% at Compunetics
  - All components mounted except MCC
- Attachment & wire bonding 50% MCC's
- Testing of 50% of Flex Hybrids in US (+Albany)
Production (continued)

- Flex fabrication
  - Compunetics - 200 flex/week after "ramp up"
  - CERN - 200 flex/mo.
- Assembly of components onto Flex Hybrids
  - Entire production can be done in less than one week with automated pick & place (including part tolerance verification)
  - Assembly in panel - singulation afterwards at Compunetics and outside vendor for CERN (Spectralytics used for CLEOIII, Si3)
  - Attachment and wire bonding of MCC (UOK) - estimate 16/day
- Testing
  - CERN flex tests at Microcontact (Switzerland)
  - Test for pinholes in bottom cover layer
  - Test of complete Flex Hybrid
    - C - F test of power busses
    - Functionality test with Genova MCC/Hybrid test stand
Production (continued)

Production Flow

Flex Fab. Compunetics - 50%

Flex Fab. CERN - 50%

Final Test

Test

Assembly

Hole Test

return to Compunetics or independent firm for CERN

Singulation

Mount MCC

Mount MCC

UOK, Albany

Europe

Final Test

Final Test

Mount MCC

University of Oklahoma, R. Boyd, 2 November, 2000

ATLAS Pixel Detector Flex Hybrids
Production (continued)

- CERN has no in house testing capability .. sent out twice for probing
- After fabrication
  - ID number -> Production database (PDB)
  - Visual inspection: contamination, discoloration, over-etching (?)
  - Pinhole test
- After assembly
  - Visual inspection: solder splatter, components mounted properly, damage (tears, broken traces)
Production (continued)

- After assembly and cutting
  - Visual inspection .. tears, cover layer damage
  - Optical comparator inspection
    - Component height in critical areas
    - Cut dimensions
  - Electrical tests
    - C-F sweep of all power inputs (test connector)
    - Check resistor values/connections
    - Test of all nets?
Production *(continued)*

- After MCC attach, wire bond
  - MCC test stand
    - Probe card FE emulator in each FE position
    - Full test vector suite for MCC
  - Visual inspection of wire bond pads for damage from probing
  - Inspect cover layers
  - Last opportunity for rejection/rework before mounting on module
Early Flex Hybrid module concept
Optical link no longer included on module
Function (continued)

- The Flex Hybrid also provides interconnection between the 16 FE's (Front End chips) and the MCC (Module Control Chip)
Specifications

- Pixel detector specifications:
  - Power: Current spec calls for no greater than 50 mV drop round trip for any power + return trace on Flex Hybrid
  - 150 μm pitch on FE wire bond pads -> 75 μm traces and spaces for Flex Hybrid
  - Design must accommodate 700 V sensor bias
  - Barrel module envelope constrains component heights in some areas of flex to less than 0.6 mm
  - 0402 0.1 mF capacitors are spec.'d at 0.5 mm ± 0.1 mm
Specifications (continued)

- Flex fabrication specifications
  - Overall size approx. 86.5 mm x 19.6 mm
  - Substrate of 25.4 μm polyimide (Kapton or Upilex)
  - Two metal layers connected by through-hole vias with no break out of via cover pads
  - Patterned cover layers top and bottom of 25.4 μm Pyralux with placement accuracy of ± 125 μm
  - Sputtered seed metal (Cr or Ti) on polyimide
  - 75 μm traces and spaces (less between via cover pads and adjacent trace, depending vendor technology)
  - 100 μm x 300 μm bond pads with 50 μm space
  - 15 μm - 18 μm Cu, 1 μm - 2 μm Ni, 0.1 μm - 0.2 μm Au compatible with Al ultrasonic wire bonding
  - Final dimension tolerance: ± 75 μm
Prototypes

- v1.0
  - Required support card
  - Fabricated by CERN in 1998
    - 50.8 μm Kapton substrate
    - No cover layers
  - Supported FE-A, FE-B, FE-C, AMS MCC
  - Did not include Vcal
  - First "working" Flex Hybrid Modules
Prototypes *(continued)*

- **V1.x**
  - All signals implemented
  - Improved sensor bias routing
  - Other routing improvements
  - Supported FE-A, FE-B, FE-C, AMS MCC
  - Increased power supply bypass capacitor size
  - Included test structures coupon for verifying impedance of signal busses, via resistance and trace resistance
  - Fabricated at CERN and Compunetics
  - v1.1, v1.4 (only minor routing differences) fabricated at CERN in 1999
    - 50.8 μm Kapton substrate
    - Patterned 60 μm Pyralux cover layers on both sides
  - v1.3 fabricated at Compunetics in 1999
    - 25.4 μm Upilex substrate
    - Patterned ~20 μm Imageflex flexible solder mask on both sides
    - 2.0 μm Au on wire bond pads
    - Intek organic protectant/solder flux on solder pads

大学oft Oklahoma, R. Boyd, 2 November, 2000

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Prototypes (continued)

- v2.x
  - Respects barrel module envelope, except FE wire bond pad layout and MCC
  - Wire bond connections for barrel services
  - Solder connections on "tab" for disk services
  - Test connector on "tab" for QA/QC during Flex Hybrid and module assembly
  - Stand alone operational capability but can also be used with support card

v2.x layout showing top traces and barrel module envelope
Prototypes (continued)

- v2.x (cont.)
  - Compunetics v2.1 delivered Aug. 2000
    - 25.4 μm Upilex substrate
    - Patterned ~25.4 μm Pyralux cover layer on both sides
    - 2 μm Ni, 0.2 μm Au on all traces
  - CERN delivered v2.2 Sept. 2000
    - 25.4 μm Kapton substrate
    - Patterned 25.4 μm Pyralux cover layer on both sides on 40 pieces
    - Patterned ~10 μm Liquid Photo Imagable cover layer on 10 pieces (lower thermal coefficient of expansion than Pyralux)
    - 2 μm Ni, 0.2 μm Au on all traces
Assembly

- At present (v2.x) there are:
  - 51 0402 capacitors
  - 3 1206 capacitors
  - 10 0402 resistors
  - 1 0603 NTC temperature sensor
  - 1 30 pin connector
  - 1 MCC - still attached and wire bonded in labs
- Assembly of 1.0 and most of 1.x done in labs
- 10 v1.x assembled at AMA (CA)
- 4 v2.1 assembled at Flex One (CA)
  - "Dummy" components used
  - Paste applied through stencil and reflow
- 5 good and 5 electrically bad v2.1 flex assembled at Surface Mount Depot (OK)
  - Used real components
  - Hand soldered
Results

- Both vendors have been slow to produce prototypes
- v1.0 Flex Hybrids
  - Work - two modules built (see Electronics)
- v1.x
  - 4 Flex Hybrid modules constructed show that v1.x works
  - Assembly at AMA - minor problems, such as misplaced components, generally good quality work
- v2.x
- CERN delivered 50, Compunetics delivered 41
  - Test coupons good on electrically good flex
    - Indicates via resistance of $\sim 10$ m$\Omega$
    - Other tests performed, but results yet to be compiled
  - Some variability of wire bonding results on v2.1
    - Bond pad lift off on electrically bad flex (show evidence of over etching)
    - Results good on good flex when cleaned first (Bonn), inconsistent pull strength (LBL)
Results (continued)

- v2.x (cont.)
  - Assembly
    - Surface Mount Depot
      - Solder quality good, parts clean, labeled for tracking
      - Component placement good, but not flush to surface everywhere
      - Two flex "ruined" by solder on bond pads
    - Flex One
      - Solder quality good and parts clean
      - Component placement good (height unknown)
      - Some solder seepage under cover layer
      - Solder flowing onto sensor bias bond pad

v2.1 Flex Hybrid assembled by Surface Mount Depot, less MCC
Results (continued)

- **Irradiation**
  - First irradiation of resistors, ceramic capacitors and flex with $^{60}$Co gamma to 30 Mrad show no significant changes, but samples were small.
  - Irradiation at CERN June, 2000, to full fluence $1.9 \times 10^{15}$ p/cm$^2$ (24 Gev) of resistors, ceramic capacitors and flex.
    - Capacitors show no catastrophic failure (large value changes, shorts), but analysis not complete.
    - Analysis of resistors and flex not complete.
  - Devices irradiated by $^{60}$Co to 60 Mrad not yet analyzed.
Results (continued)

- Remaining to be done
  - Complete electrical tests on v2.2 flex (Europe)
  - Test bottom cover layers for pinholes
  - More components submitted in October irradiation run at CERN to settle some ambiguities in first CERN run - test and analyze data
  - Further assembly tests at Surface Mount Depot (stencil and jigs to be built) and Flex One (underway)
  - Next prototype design - 3.x
    - Awaiting bond pad layout for FE-I and MCC-(?)
    - Final position/pinout of barrel and disk services connections
    - 32 pin test connector for greater isolation of detector high voltage
  - Final design - optimize power routing for known current requirements