Radiation Tolerance of End-Cap Alignment Electronics

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End-Cap Doses

Max EC Dose	1998 Calculation	2001 Color Map	ATLAS Document	Our Target
Neutrons	3 Tn*	1 Tn*	0.3 Tn*	10 Tn*
Ionizing	3 krad	10 krad	0.6 krad	100 krad
Hadrons	10×10^{10}	30×10^{10}	5×10^{10}	300×10^{10}

* 1 Tn = 1 MeV equivalent neutrons cm^{-2}

Our radiation tolerance policy:

design for 10 times maximum simulated doses

accepted by US management (1998)

accepted by CERN management (1998)

Safety factor of ten covers:

errors in simulation

changes in thickness of shielding

component variability

Sources

JPL and NASA web sites:

- database of component tests
- electronic books and presentations

ATLAS collaborators:

- Harry van der Graaf, NIKHEF
- (uses many of same components)

Our own tests:

- Lowell 1998 (neutrons)
- Prospero 1999 (neutrons)
- Prospero 2000 (neutrons)
- Pagure 2000 (ionizing)
- Pagure 2001 (ionizing)

ATLAS simulations:

- Ferrari et al 1998
- Shupe et al 2001

Design Rules

Design for 10 times maximum simulated dose.

Buy vulnerable components in one lot.

Test whole circuits in preference to individual parts.

Anneal circuits to deduce effects of slow doses:

irradiate quickly, wait eight weeks, test,
anneal 40˚C 168 hrs, test,
anneal 100˚C 24 hrs, test.

Avoid vulnerable classes of parts:

use NASA and JPL databases.

Assume SEE latch-up will occur:

design circuits to accommodate latch-up.

Sources: JPL and NASA guidelines.

Other Options

Replacement after installation violates our design specification.

But all components can be replaced easily without loss of calibration before installation, except:

- in-plane image sensors (TC255P CCDs)
- alignment bar internal LED arrays

And radiation dose decreases by factor of ten from inner to outer radius (EI and EM):

- only small fraction of devices need be replaced.

Device head circuits can be annealed in situ:

- A2036 reaches 40˚C in box when awake
- A2034 reaches 60˚C with LEDs turned on

Might use beam-off time to repair radiation damage.

Strategy

Determine radiation resistance of image sensors and light sources.

Design system to accommodate their vulnerabilities.

Choose auxiliary parts with the help literature.

Test prototype circuits in radiation.

Remove vulnerable parts or modify design.

Buy parts in large lots for mass-production.

Test random selection from mass-produced circuits.

If, despite precautions, final circuits are vulnerable:
- demonstrate self-annealing or
- replace with rad-hard circuits at inner radii.

Image Sensors and Neutron Radiation

Image sensor is TC255P CCD from TI

Neutrons increase TC255P dark current.

Can tolerate 10 Tn when we:

- read out pixels at 2 MPS
- keep exposure times <40 ms

Max end-cap dose (1998 calc) 3 Tn.
But max end-cap dose (2001 map) 1 Tn.

Purchased all CCDs in one order and tested.

Sources: MUON-98-253, MUON-2000-011.

IRLEDs and Neutron Radiation

Infra-Red LED is HSDL-4400 from HP.

Neutrons decrease IRLED power output.
HSDL-4400 most resistant LED we found.

Power loss can be 90% at 10 Tn.
Compensate for power loss with longer flash.
But CCD damage requires flashes <40 ms.

Can tolerate 10 Tn in CCD and IRLED if:

    0-Tn flash time is <4 ms

<u>or</u> LED and CCD at different radius

Purchased all LEDs in one order and tested.

Sources: NIKHEF report, KSH Exp. 32.1 V8.

Lasers and Neutron Radiation

Visible (655-nm) laser is DL3147 from Sanyo.

Contains laser diode and monitor photodiode.

Tested two other laser diodes, not DL3147.

At 10 Tn observed for both lasers:
- <10% change in laser power at 20 mA
- <20% reduction in photodiode efficiency

Conclude: lasers resistant to neutrons.

Purchasing DL3147s on consignment.
Will test when we have time.

Sources: KSH Exp. 32.1 V8

Image Sensors and Ionizing Radiation

TC255P made by ionizing-resistance process designed in conjunction with JPL for space use.

Exposed four CCDs at Pagure.

At dose of 60 krad, hardly any effect observed.

Slight increase in dark current.

If that is only effect, can tolerate 1.5 Mrad.

Conclude: TC255P resistant to ionizing radiation.

Sources: KSH report on web site.

IRLEDs and Ionizing Radiation

NIKHEF and BND use HSDL-4400.

Purchased LEDs together in one lot.

NIKHEF observes no loss of LED power after 40 krad and delay of one month.

One-month delay allowed auxiliary circuits to recover.

JPL: effect of annealing tells us the effect of low dose rates.

Conclude: HSDL-4400 resistant to low-rate ionizing radiation.

Sources: NIKHEF report.

Lasers and Ionizing Radiation

Tested BCAM Side Head (A2040) boards.

Two DL3147 lasers on each board.

At dose of 100 krad observed no effect upon A2040 laser power output.

One year later, still no effect.

Conclude: DL3147 resistant to ionizing radiation.

Sources: KSH Exp. 89.1 V8.

Auxiliary Components I

Resistors and Ceramic Capacitors

Ionizing 100 krad (KSH Exp.89.1 V8):

no effect on circuit operation

Neutrons 10 Tn (KSH Exp. 62.1 V7):

no effect on circuit operation

Diodes and Bipolar Transistors

Ionizing 100 krad (KSH Exp.89.1 V8):

no effect on circuit operation

Neutrons 10 Tn (KSH Exp. 62.1 V7):

no effect on circuit operation

Auxiliary Components II

MOSFETS

Ionizing 100 krad (KSH Exp. 89.1 V8):

no effect on circuit operation

Neutrons: parts irradiated but not returned

Literature: MOSFETs neutron-resistant

VHC Logic

Ionizing 40 krad (NIKHEF report):

damage heals at room temperature

Ionizing 100 krad (KSH Exp. 89.1 V8):

some ambiguity due to bad procedure

Neutrons 10 Tn (NIKHEF report):

no effect on circuit operation

Auxiliary Components III

SN65LVDS180D

Ionizing 100 krad (KSH Exp. 89.1 V8):

no effect on circuit operation

Neutrons parts not returned from CERN

Literature: CMOS neutron-resistant

DG411DY

Ionizing 100 krad (KSH Exp. 89.1 V8):

must allow for 100-μA leakage

Neutrons 10 Tn (KSH Exp. Exp 116.1 V7):

no effect on circuit operation

EL2244CS Bipolar Op-Amp

Ionizing 100 krad (KSH Exp.89.1 V8):

no effect on circuit operation

Neutrons 10 Tn (KSH Exp. 62.1 V7):

no effect on circuit operation

Auxiliary Components IV

Tantalum Capacitors

- Ionizing 100 krad (KSH Exp. 22.1 V9):
  - no effect on circuit operation
  - but 10-µF capacitor leakage to 2-µA
- Neutrons 10 Tn (KSH Exp. 62.1 V7):
  - no effect on circuit operation

MAX6329 3.3-V Regulator

- Ionizing 20 krad (KSH Exp. 89.1 V8):
  - output voltage risen to 3.5 V
- Ionizing 100 krad (KSH Exp. 89.1 V8):
  - output voltage risen to 4.1 V
  - reset output stuck low before annealing
- Neutrons: irradiated but not returned

INA155 CMOS Instrumentation Amp

- Ionizing: untested
- Neutrons: untested

In-Plane Sensor Head (A2036)

All 1200 boards required for ATLAS built:

All boards have MAX6329 regulator
No tantalum capacitors
Analog switch can leak up to 100-μA.
No other problem parts

20 krad < ionizing resistance < 100 krad

Will determine effect of room-temperature and in-situ annealing before installation.

If parts cannot endure 100 krad, will replace 64 inner-radius boards on EM layer (EI dose is only 2 krad).

Future Device Heads

Transistor-diode regulator.
Capacitor-resistor power-up reset.

Ionizing Radiation:

- Most vulnerable parts VHC logic
- Damage responds well to annealing.
- Resistance >100 krad for slow doses.

Neutron Radiation:

- Expect no problems below 10 Tn.

Uncertain Part:

- INA155 in Bar Head (A2044)
- A2044 already in initial production
- Expect no problems at 10 Tn and 100 krad
- Will test before installation of EI bars
- If vulnerable will replace with dual op-amp.

Multiplexers

Transistor-diode regulator.

Capacitor-resistor power-up reset.

Ionizing Radiation:

Most vulnerable parts VHC logic

Damage responds well to annealing.

Resistance >100 krad for slow doses.

No self-annealing possible on multiplexer.

Neutron Radiation:

Expect no problems below 10 Tn.

Uncertain Parts:

None.

Summary

No post-installation replacement necessary.

Radiation testing continues.

Do not expect pre-installation replacement.

If pre-installation replacement necessary:
    replace <5% of circuits