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	Author(s)	Supersedes
	T. Handa, T. Ohsugi, H. Sadrozinski, A. Brez	
GLAST LAT TECHNICAL NOTE	Subsystem/Office	
	Tracker	
Document Title		
Results from the Testing of the GLAST LAT SSD Prototypes		

Gamma-ray Large Area Space Telescope

(GLAST)

Large Area Telescope (LAT)

Results from the Testing of the GLAST LAT SSD Prototypes

(Copies of Transparencies from the GLAST LAT SSD Review Jan 30, 2001)

CHANGE HISTORY LOG

Revision	Effective Date	Description of Changes

1. PURPOSE
The results from the test of 35 GLAST LAT SSD prototypes are presented. The test were performed to qualify HPK as a GLAST SSD vendor.

2. SCOPE
The results of electrical and mechanical test of the GLAST LAT SSD prototypes are presented. Both the GLAST LAT SSD and test structures were tested at SLAC/UCSC, Hiroshima U. and INFN-Pisa and compared to the tests performed at the manufacturer HPK.

3. DEFINITIONS

3.1 Acronyms

GLAST	Gamma-ray Large Area Space Telescope
LAT	Large Area Telescope
SSD	Silicon Strip Detector
TBR	To Be Resolved
TBB	To Be Determined

3.2 Definitions

AC Coupling The Al metal electrode is covering almost the whole length of the p+ implant, separated from it by a dielectric material

AC Pad	Pad to access the Al metal electrode on the strips
Active Area	Area of the Volume from which charge is collected on the strips in <<1us
Buyer	Institution procuring GLAST LAT SSD
C	Capacitance
Contract	Purchase agreement to procure GLAST LAT SSD's
Coupling Capacitor	Capacitor formed by Al metal electrode, dielectric and implant
Customer	Institution involved in the procurement and testing of GLAST LAT SSD's
C-V	Measurement of body capacitance (C) as a function of voltage (V)
DC coupling	Al metal electrode and implant in ohmic contact.
DC Pad	Pad to access the strip implant
Bias Resistor	Resistor connecting every implant to the bias ring
Bias Ring	Implant surrounding the active area, connects to bias resistors
Fiducial	Physical mark in the Al metal layers for alignment and metrology
Guard Ring	Implant ring outside the bias ring without bias connection ("floating")
HPK	Hamamatsu Photonics
I-V	Measurement of leakage current (I) as a function of voltage (V)
N-sub	Substrate contact on the detector front
Pad	Area of the Al metal layer accessible through the passivation The pad area is defined as the bondable area.
Pitch	Distance between strip centers
Passivation	Topmost layer covering of inert translucent material
Seller	SSD Manufacturer, Vendor,
Sensor	Silicon Strip Detector (SSD)
um	Micro meter (10^{-6}meter)
us	Micro second (10^{-6}second)
V	Voltage, Volt

4. REFERENCES

GLAST LAT AO Response		P. Michelson *et al,* Nov 1999.
Strip Technology		T. Ohsugi *et al.,* NIM A, 383 (1996) 167.
BTEM prototype detectors		P. Allport *et al,* SLAC-Pub-8471, June 2000.
Flow-down of GLAST LAT SSD Spec's		H. Sadrozinski, SCIPP 00/33.
GLAST LAT SSD Specifications		LAT-DS-00011-08
GLAST LAT SSD QA Provisions		LAT-DS-00082-01
GLAST LAT SSD Testing Procedures		LAT-DS-00085-01
Drawings	SSD	LAT-DS-00026
	Test structures	LAT-DS-00027

5. SSD TESTING RESULTS

Tests were performed as required in LAT-DS-00011-08 and described in LAT-DS-00085-01. A data base developed by INFN-Pisa was used to store the data (www.pi.infn.it/glast)

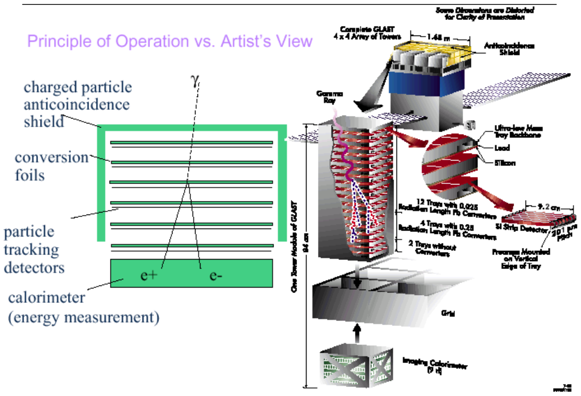
a. Overview: H. Sadrozinski (UC Santa Cruz)

Specifications of the GLAST Silicon Strip Detectors (SSD's)

Hartmut F.-W. Sadrozinski
Univ. of California Santa Cruz

- GLAST Overview: Instrument -> Tracker (TKR) -> SSD
- Requirements
- Prototyping History
- Procurement History and Schedule
- Testing and QA
- Validation -> next talk (T. Ohsugi: electrical, A. Brez: mechanical, T. Handa: Irradiation)

Principle of Operation vs. Artist's View



Interface Requirements Document (IRD)

defines the Space environment and the limited resources, including engineering margins (e.g. 5x for total dose).

The IRD requires trades in:

- **Power**
  number of channels (SSD pitch),
  ASIC power consumption
  SSD strip capacitance (ladder length - ~36cm-, strip geometry),
  SSD biasing power <4W for 10k SSD
- **Radiation**
  Expected 5Y total dose 1kRad (half in low energy protons), design for 5kRad
- **Heat management**
  operate SSD at 25°C max
- **Launch- weight, vibrations-**
  Footprint of SSD
  Strength of SSD wafers (<100>)
  Strength of glue joints

Predictability of Performance

- Poly-silicon biasing
- Oxide-Nitride combination for coupling cap dielectric
- Low leakage current
- Low depletion voltage
- Silicon dioxide passivation
- Large Aluminum overhang
- Balance strip width effects: capacitance vs. field
- Accurate mask alignment
- No voltage across saw-cut

Ease of Testing

- AC coupling
- Large, redundant bonding/probing pads
- N-sub contact on top

Ease of Assembly

- Separate fiducials for alignment, bonding and metrology
- Accurate control of saw-cut

- **Numbers: GLAST is modular:**
  16 flight (+ 2 calibration towers) with 18 x-y SSD planes each
  4 x 4 SSD per plane (4 ladders with 4 SSD each)
  Number of SSD needed:
  10368 (+ 5% spares + 5% wastage) => 11,500
- **Total SSD Area: 83m², ~1M channels, ~ 5M wire bonds**
- **Simple mechanical assembly method:**
  Butt-join and wire-bond 4 SSD to "ladders"
  Glue 4 Ladders onto both sides of 3cm thick panels ("trays")
  Attach MCM on the side of the panel via 90° interconnect
  Stack trays into towers
- **QA:**
  Tight specification increase reliability of SSD
  Charge manufacturer with all detailed testing
  Test important parameters before further integration step

Science Requirements Document (SRD)

- **Derives the GLAST LAT instrument performance requirements from the GLAST science objectives.**
- **Sets requirements and goals for several instrument parameters, e.g.**

Effective Area = (Active area * conversion probability * reconstruction efficiency)
Point Spread Function = Resolution in the photon direction
Cosmic Ray rejection

The science requirements flow down into the TKR and SSD specifications.

GLAST LAT Committees on TKR issues:

- **SSD Configuration : April/May 2000 ("GLSSDWG") LAT-TD-00070**
- **Converter Optimization: June/Nov 2000 ("GTOCC") LAT-TD-00029-01**

These Committees specified the footprint of the instrument, the size of the trays, and the layout and size of the SSD, taking into account the SRD and the IRD (see next)

The following issues were addressed in the GLAST SSD design ("GLSSDWG") and are reflected in the specification

Issue	Action	Reason
Leakage Current	Minimize	Power, Noise, μ-Discharge
Depletion Voltage	Minimize	Power, Safety, Efficiency
Detector Thickness	Optimize	Signal vs. Depletion Voltage
Saw-cut dimensions	Control	Mechanical assembly
Number of bad strips	Minimize	Efficiency, C.R. rejection
Strip geometry	Optimize	Capacitance vs. μ-Discharge
Mask Alignment	Control	μ-Discharge, Testing
Dielectric of Caps	Oxide+Nitride	Pinholes, Bondability
Radiation Effects	Measure	Leakage current, Capacitance, Strip isolation, Bias resistor
Guard ring/Edge design	Narrow	Leakage current, active area
Bonding/probe pads	Redundant	Repairs, Automatic Test
Fiducials	Dedicated	Ease & QC of assembly

Leakage Current: (av)<240nA , max<800nA

- The low detector leakage current is an indication of a mature manufacturing process.
- A low detector leakage current specification allows us to eliminate the time consuming leakage current measurement on every strip and measure instead the entire current on the detector only.
- The leakage current has to be kept low to reduce shot noise (35cm long strips!)
- Single detector strip with ~20nA has increased noise level.
- One of the major limitation for the GLAST LAT is the available power. The power assigned to the detector biasing is 4W at end of mission, mainly due to radiation damage.
- At 150V, this is 2.6uA/SSD, and the initial detector current should be a small fraction of this number.
- Because we observe a factor 2 increase of the leakage current from production testing to finished ladders, our specs mean actually an initial current of about 500nA/SSD, about 20% of the end of mission limit.

Detector Thickness: 400um

- The TKR has sufficient S/N as specified. The signal is proportional to the path length. For normal incidence, it's the thickness (400um), for large angles it's the pitch (228um). So if S/N is a problem, the pitch has to be increased as well, which hurts the science.
- The depletion voltage has to be kept low to reduce power and noise. We set an upper limit of 150V, but would like to operate at 100V (like in the BTEM).
- The depletion voltage depends on the square of the detector thickness and the inverse of the resistivity. Thus changing the thickness from 400um to 500um requires an increase in resistivity of 56%, from 4kΩ-cm to more than 6kΩ-cm. We are told that the wafer manufacturers can't guarantee a stable supply of 6" wafers with resistivity higher than 4kΩ-cm on our time scale.
- We see now depletion voltages at 120V, which would increase to 188V with 500um thickness at the same resistivity. This is too high.
- Our principle supplier prefers 400um detectors and fabricates (exclusively?) in that thickness. Mixing different thickness sounds like an assembly nightmare.

Prototypes of GLAST SSD with Hamamatsu Photonics (HPK)

	GLAST 1996	GLAST 1997	GLAST 1998	GLAST 1999	GLAST 2000
Wafer Size	4"	4"	6"	6"	6"
Sensor Size[cmxcm]	6x6	6.4×6.4	6.4×10.7	9.5×9.5	8.95x8.95
Pitch [um]	236	194	194	208	228
Implant Width[um]	57	50	50	52	56
Thickness [um]	500	400	400	400	400
Biasing	Punch Through	Poly-Si	Poly-Si	Poly-Si	Poly-Si
Bias Voltage [V]	140	100	100	100	100
Current [nA/cm^2]		~2.5	~2.5	~1.8	~1.8
% bad strips		0.02	0.04	0.04	0.03
# delivered	~20	296	256	35	35
Use	BT'97	BTEM	BTEM	<100> Wafer	Acceptance

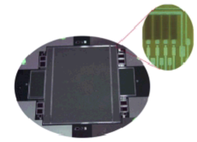
We have gained experience with a large number of SSD (~5%of the GLAST needs)

Additional Prototypes:
Micron (UK), STM (Italy), CSEM (Switzerland) (?)

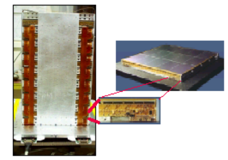
4 Step Procurement Process

1998: Market survey (RFI), contact 12 manufacturers
-> 6" wafers
-> Identify cost-drivers in fabrication and testing

1996-2000: Prototyping with 3 manufacturers, involve them in writing of specs



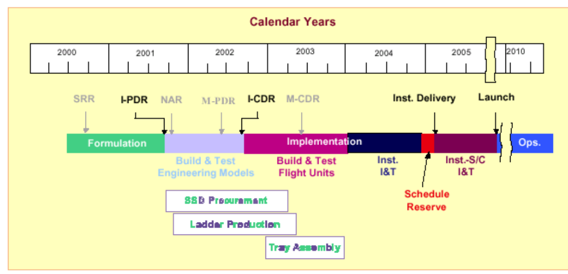
1998-1999: Purchase large number (>500) of SSD, build BTEM, 2 month beam test at SLAC



Fabrication and Test Plan of Flight Sensors:

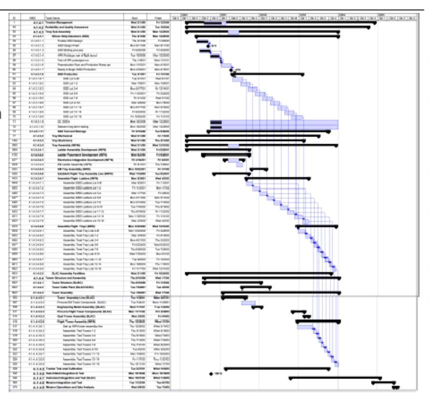
prototyping	(Jun 2000 -- Dec 2000),
evaluation	(Dec 2000 – Jan 2001),
ramp-up	(Feb 2001 – Aug 2001),
production	(Aug 2001 – Mar 2003).

Tray Production is embedded in the GLAST LAT Schedule



Testing is a large part of the SSD / tray manufacturing process

Procurement of SSD is part of the GLAST tray construction
2001: 500 SSD/month
2002: 1000 SSD/month



Acceptance QC: flight sensors

- Order high quality SSD → testing of detectors is done by vendor:
  I-V, C-V, bad Channels, Process Parameters. NO single channel current!
- Measurement of parameters crucial for assembly by GLAST assembly institution:
  i-V (and possibly of dimensions)

Process Control: test structures

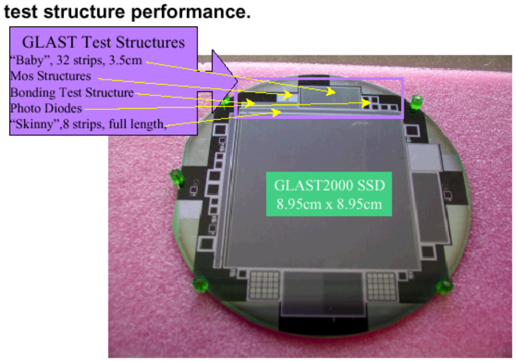
- Thorough test on test structures, one out of every lot (48) by Hiroshima U. & INFN:
  Measure all detector parameters specified in specifications
- Test wire bonding on test structures

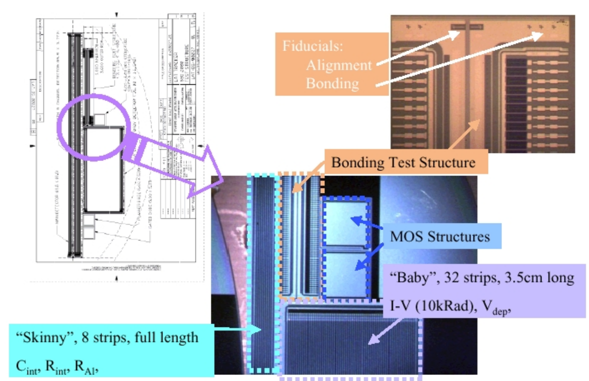
Assembly QA: flight sensors / ladders

- Testing after bonding and encapsulation by GLAST assembly institution:
  "Vital" parameters (I-V of ladders and coupling caps on every strip)
- Test before tray assembly:
  i-V on ladders

This program is based on our experience with the >500 HPK SSD in the Beam Test Engineering Module (BTEM, SLAC-8471).

Each wafer has a GLAST2000 SSD and a GLAST cut-off.
We are now establishing the correlation between SSD and test structure performance.





b. Mechanical Tests: A. Brez (INFN-Pisa)

GLAST SSD mechanical measurements

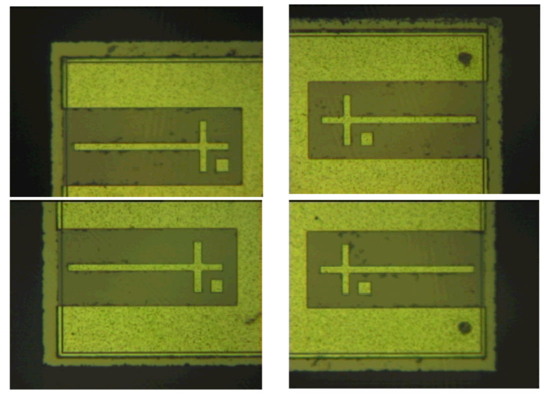
Instruments and methods:

15cm X 30cm micrometric computer assisted table with 5μm resolution over the whole range
Microscope with a computerized CCD camera with 768 X 576 pixels
pixel size = 0.64μm
view area = 500 μm X 370 μm

Dimensional check: distance from strip 1 to strip 384
Nominal distance = 87324 μm
Measured distance = 87329 ± 5 μm
Measured pitch = 228.01 ± 0.01 μm

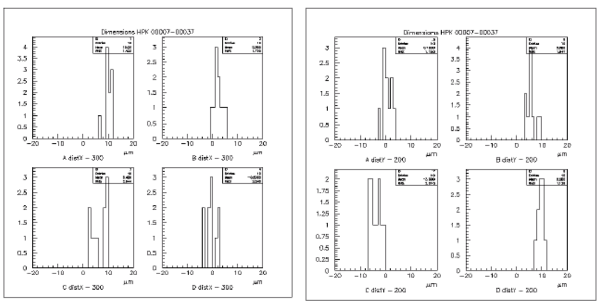
DICING MEASUREMENTS

d a

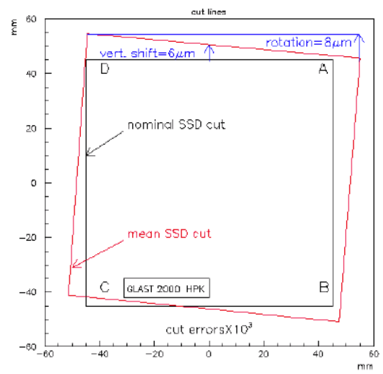


c b

STATISTICS OF THE DICING ERRORS



Front cut orthogonal to the strips Side cut parallel to the strips



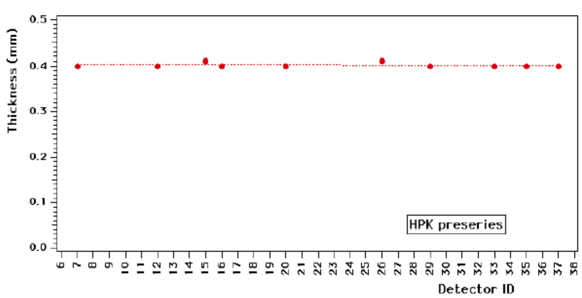
levant measurements for
lder's assembly:

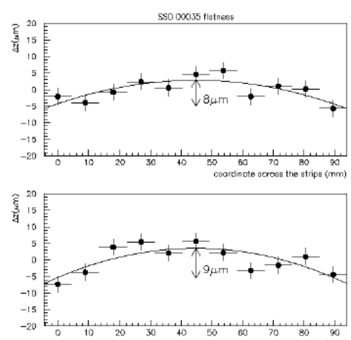
= marker_edge dist.-300μm
= marker_edge dist.-200μm

quirement :
0μm < Δx, Δy < 20μm

lection parameters
ift = $(\Delta y_a+\Delta y_d)/2$
tation = $\Delta y_d-\Delta y_a$

WAFER THICKNESS
(10μm sensitivity measurement)





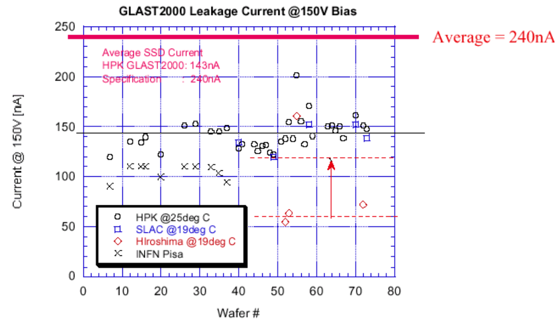
A moderate bending (<10μm) has been measured on a wafer

c. Electrical Tests: T. Ohsugi (Hiroshima U.)

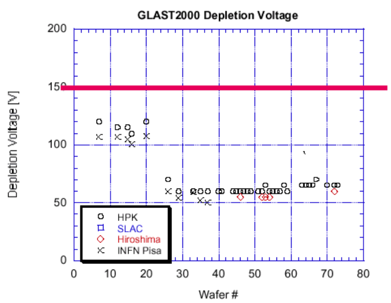
Electrical Tests on GLAST2000 Prototypes
Takashi Ohsugi
Hiroshima University

35 SSD delivered:
Measurements at Hiroshima U.(20), INFN Pisa(10), SLAC(5)
Comparison between HPK and GLAST Results
Comparisons between Full-size SSD and Test Structures

- **Leakage Current depends on Temperature, Humidity, Time**
- **Use HPK measurement, below specs.**



- **Depletion Voltage agrees well among different measurements**
- **Capacitances at depletion indicate good thickness uniformity**



Bad strips are shorted coupling capacitors, open connections or strips shorted together.

- **A total of 4 bad strips were found by HPK: 0.03% (Spec <0.2%)**
- **Hiroshima found the shorted capacitor,**
- **Hiroshima had 3 disconnected Bias resistors**
- **SLAC checked 2 SSD and found no bad strips**
- **INFN Pisa measured ALL capacitors on 10 detectors and found NO bad channels.**

The bad channel rate is 10x better than specified.
The measurements at HPK are confirmed by GLAST

- **Don't expect variation of inter-strip capacitance wafer-to-wafer.**
- **Expect variation of body capacitance wafer-to-wafer only due to thickness variations.**

- **Strip capacitance**
  - **Backplane (Body) Capacitance:**
  - **1860pF/384Strips/8.75cm = 0.55pF/cm**
  - **Inter-strip Capacitance:**
  - **5.5pF/0.82/8.75 = 0.77pF/cm**
  - **Total strip capacitance = 1.3pF/cm (Spec <1.5pF)**

- **Coupling capacitance varies with thickness of dielectric**
  - **Measure between 550 and 600pF, (Spec >500pF).**

- **Bias Resistance**
  - **Spec: Polysilicon , 20MΩ <R <80MΩ, wafer uniform to 10MΩ**
  - **Observed ~35-40MΩ, very uniform, agrees with HPK**

- **Al Trace Resistance**
  - **Spec: R < 50Ω**
  - **Observed R=25-30Ω, very uniform, agrees with HPK**

- **Interstrip Isolation**
  - **Spec: >1GΩ,**
  - **Observed >1TΩ**

- **The 35 HPK GLAST2000 SSD exceed the specifications.**
- **The measurements at HPK and GLAST correlate very well.**

- **The bad channel count continues to be 10x lower than specified**
- **The leakage current is very low, below the specifications. We plan to rely on the HPK measurements.**
- **No u-discharge observed up to 200V bias**
- **Depletion voltages are low (~60V) except for a batch of 5 SSD.**
- **Radiation damage is well in hand and understood.**
- **Based on the measurements, we see no obvious need to change the parameter values at which we reject SSD's.**
- **Measurements of the correlation between full SSD and test structures are being finished to allow the QA plan to be finalized.**

d. Irradiation Tests: T. Handa (SLAC)

Validation of the GLAST Pre-production SSD
-- Radiation Damage --

Takanobu Handa SLAC
Jan.30,2001
Review of the GLAST SSD Specifications

- Radiation dose expected : 1 krad / 5years
- x5 engineering margin : 5 krad
- Our tests(x2 over requirement) : 10 krad

- ^{60}Co gamma-ray irradiation at UCSC : 10 krad
- ^{60}Co gamma-ray irradiation at Hiroshima : 8 krad

* 150V bias voltage
* Temperature correction to 25 °C

Specs

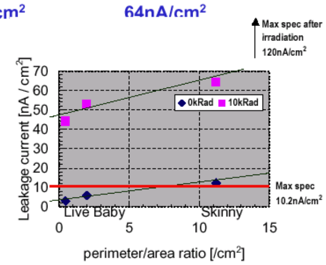
0 krad : average < 240nA (3.13nA/cm^2)
max < 800nA (10.4nA/cm^2)
10 krad : < 9200nA (120nA/cm^2)

Results

0 krad : average ~ 230nA, max = 251nA
10 krad : 3360 nA

Leakage current at 150V bias (corrected to 25 °C)

	0 krad	10krad
Live(76.7cm^2)	3.0nA/cm^2	44nA/cm^2
Baby(4.82cm^2)	5.9nA/cm^2	53nA/cm^2
Skinny(1.60cm^2)	12.4nA/cm^2	64nA/cm^2



Smaller total strip capacitance (C_total) is favorable for lower readout noise

C_total = C_inter-strip(all neighbor) + C_back-plane

C_inter-strip(all neighboring pair)
= C_inter-strip(one neighboring pair) / 0.83

C_back-plane = 0.53 pF/cm

We measured C_inter-strip(one neighboring pair)

Specs

0krad : < 1.5 pF/cm
10krad : < 1.6 pF/cm

Results

0krad : 1.3 ~ 1.5 pF/cm (5.5~7.5 pF)
10krad : 1.2 ~ 1.3 pF/cm (4.7~5.8 pF)
( ) measured C_inter-strip (one neighboring pair)

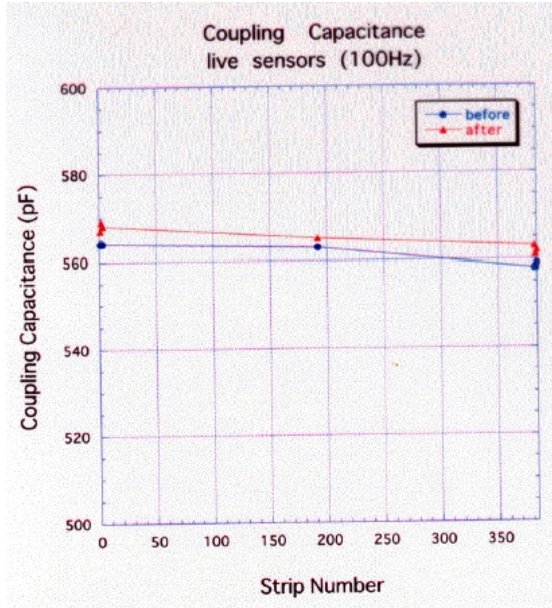
Strip isolation

Specs

0 krad : > 1 GΩ
10 krad : > 1 GΩ

Results

0 krad : ~ 1000 GΩ
10 krad : ~ 1000 GΩ



Bigger C coupling is better not to lose the signal charge

Specs

0krad : > 500 pF
10krad : > 500 pF

Results

0krad : ~ 560 pF
10krad : ~ 565 pF

GLAST HPK pre-production detectors meet our specifications after 10krad gamma-ray irradiation on these parameters:

- **Leakage current**
- **Inter-strip capacitance**
- **Inter-strip resistance**
- **Coupling capacitance**