The Radiation Qualification of the Taiwanese CMOS Image Sensor for the Remote Sensing Satellite

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National Space Organization (NSPO)

- The National Space Organization is the civilian space agency of Taiwan under the support of National Science Council. NSPO is involved in the development of:
  - Space exploration
  - Satellite construction and development
  - Related technologies and infrastructure
  - Related research in aerospace engineering, remote sensing, astrophysics, atmospheric science, information science.

- NSPO headquarters and the main ground control station are in Hsinchu, Taiwan.
FORMOSA Satellite No.5 (FS-5) Program

• Missions:
  – To build up Taiwan’s self-reliant space technology on the remote sensing payload and spacecraft bus
  – To develop the key components of the Earth Observation type remote sensing instrument and spacecraft bus by integrating the domestic resources
  – To continue to serve the global imagery users’ community of FS-2
  – To promote the space science experiment & research

http://www.nspo.org.tw/2008c/projects/project5t/cooperation.htm
System Architecture

Space Segment

Remote Sensing Instrument

Spacecraft Bus

S/S Band

X Band

(Science Instrument)

(Falcon-9)

Launch Segment

TT&C Tainan

TT&C Chung-Li

Remote Sensing

Image Processing Center

CSRSR (Back-up)

X Band

XAS

Hsin-Chu

720km
Sun-Sync. Orbit

GT T&C Stations

RTS

XAS

SOCC

Products

Users

Ground Segment

Galileo Satellite

TSBAC

Galileo T/D Package

Space Segment
Acquisition Strategy

Ground Segment
- Mission Operations
- Ground Stations
- IPS

Spacecraft
- Design
- Assembly
- Integration
- Test

Components
- Domestic
- STI/CGS
- Out-Sourcing

RSI
- Telescope
- FPA (CMOS)
- EU

NSPO

Program Management
- Schedule
- Cost
- Contract
- Risk

System Engineering
- Specification
- Verification
- Integration
- I/F Control

Contractor

Launch
- Commercial Launch Service

FORMOSAT-5

NSPO/ITRC
Mission Orbit (SSO@ 720km/98.28°)

Two-day Revisit

Day 1, 3, ...

Day 2, 4, ...

Swath=24km

Global Coverage

福衛五號運作成功後，預估短時間內即可再佈署第二枚遙測衛星於第二條軌道，達到每日再訪週期且全球涵蓋之目標。
Deployed Configuration Overview
Component Layout

- Gyro
- Star Camera
- OSS
- RSI
- OSS
- S-Band
- X-Band
- OSS
- OSS
- OSS
- Solar Panel
- GPS
Component Layout (cont’d)

- SPEU
- PCDU
- Battery
- X-Band Transmitter
- Torquer-X
- Torquer-Y
- Torquer-Z
- DDPU
- GPSR
- MAG
- RFEA
- Reaction Wheel
- Star Camera

Component Layout (cont’d)
RSI Domestic Partners

Remote Sensing Instrument (RSI)
- NARL (PM)
- NSPO/ITRC
  (System Design, Integration & Test)

Focal Plane Assembly/CMOS Sensor
- CMOS Sensor Inc. (FPA/CMOS)
- ITRC (Filter)
- CIC (CMOS Verification)

Telescope
- ITRC (Optical Design/Mirror/Lens)
- NSPO (Structure/Thermal Design)
- ITRC/NSPO (Assembly/Calibration)

Electronic Unit
- NSPO (System Design)
- CSIST (Unit Design/Manuf.)
- Camels VT (SSR Design)

Structure
- NSPO (Design)
- AIDC (Manufacturing)
# RSI System Specification

<table>
<thead>
<tr>
<th>System Parameter</th>
<th>System Design Spec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orbit</td>
<td>720 km</td>
</tr>
<tr>
<td>Mass</td>
<td>≤ 95 kg</td>
</tr>
<tr>
<td>Power</td>
<td>≤ 75 W (Average)</td>
</tr>
<tr>
<td>Spectral Band</td>
<td>PAN+4MS</td>
</tr>
<tr>
<td>Ground Sampling Distance (GSD)</td>
<td>2m (PAN)</td>
</tr>
<tr>
<td></td>
<td>4m (MS)</td>
</tr>
<tr>
<td>Swath</td>
<td>24km</td>
</tr>
<tr>
<td>Contrast Transfer Function (CTF)</td>
<td>≥ 0.1 (PAN)</td>
</tr>
<tr>
<td></td>
<td>≥ 0.2/0.2/0.2/0.16 (MS)</td>
</tr>
<tr>
<td>Signal to Noise Ratio (SNR)</td>
<td>≥ 92 (PAN)</td>
</tr>
<tr>
<td></td>
<td>≥ 100 (MS)</td>
</tr>
<tr>
<td>Entrance Pupil Diameter</td>
<td>450 mm</td>
</tr>
<tr>
<td>Image Sensor Type</td>
<td>CMOS</td>
</tr>
</tbody>
</table>
Image Quality Simulation (MS, Color)

MS 8m, CTF \approx 0.37

MS 4m, CTF \approx 0.18
RSI Structure

Top View

Front View

Side View

次鏡片 (Mirror 2)
主鏡片 (Mirror 1)
修正透鏡組 (Correct Lens)
次鏡遮光罩 (M2 Baffle)
主鏡遮光罩 (M1 Baffle)
聚焦面組合 (FPA/CMOS)
Remote Sensing Instrument (RSI)

Telescope

FPA

EU

Structure Analysis

Optical Design

Cassegrain

Mirrors & Lens
Telescope Experimental Model (ExM)

- **ExM Polished Mirrors**
- **Secondary Structures**
  - Strut
  - Main plate
- **CFRP Parts**
  - Primary Baffle
  - Top Panel
- **Brackets**
- **Main Plate Int. Fitting**
M1 Baffle Assembly Design

Main Plate

M1 Baffle

Corrector Lens

Fitting
Focal Plan Assembly

5 bands, 12,000 pixels, TDI CMOS Sensor

Test chip

MS1

MS2

PAN

MS3

MS4

RSI

FPA
TDI CMOS Image Sensor (CIS)

Chip size: 120 mm x 24 mm
Question: How much total radiation dose will the CIS get in 5 years service in space?
RSI Cutout View
Illustration of the Optical Lens Coating Area

Source of Light

Main Plate

Coating

M1

M2

CMOS Image Sensor
The Total Ionizing Dose as Function of Aluminum Thickness for FS-5

4 pi Dose at Center of Al Spheres

- **Total**
- **Trapped Proton**
- **Trapped Electron**
- **Solar Proton**
- **Bremsstrahlung**

Dose in Si (rad)

Aluminium Thickness (mm)
## Analysis and Estimation of the Total Radiation Dose

<table>
<thead>
<tr>
<th>Total Ionizing Dose (Krad)</th>
<th>No any Protection</th>
<th>270° ~ 360°</th>
<th>Covered Area (70%)</th>
<th>Un-Covered Area (30%)</th>
<th>Total</th>
<th>100% Safety Margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>See Figure “Total Dose vs. Aluminum Thickness”</td>
<td>300</td>
<td>75</td>
<td>30</td>
<td>22.5</td>
<td>52.5</td>
<td>105</td>
</tr>
<tr>
<td></td>
<td>= 300 * 1/4</td>
<td>= 75 * 70% * 2/3</td>
<td>= 75 * 30%</td>
<td>= 30 + 22.5</td>
<td>= 52.5 * 2</td>
<td></td>
</tr>
</tbody>
</table>
## Estimated value

<table>
<thead>
<tr>
<th>Radiation</th>
<th>FS-2 Test Spec</th>
<th>FS-5 Estimated Test Spec</th>
<th>FS-5 Recommended Test Spec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Dose</td>
<td>100 Krad</td>
<td>105 Krad</td>
<td>100 Krad</td>
</tr>
</tbody>
</table>
Method to Measurement Radiation Dose in Test Field

• **Step 1:**
  Freshly prepared Fricke (ferrous sulfate dosimeter), packed into sealed container, put in Co-60 radiation field for a certain distance.

• **Step 2:**
  Removed Fricke after a certain time after irradiation.

• **Step 3:**
  Measured O.D. (Optical Density, or Absorbance) by using spectrophotometer at 304nm.
Method to Measure Radiation Dose in Test Field

Total Absorbed Dose, \( D = 2.74 \times 10^4 \times O.D. \) (rad)

- Example:
  Location: **25 cm** from radiation source
  Exposure Time: 3 hours
  O.D. Measured: 0.162
  Calculated absorbed dose in 3 hours:

  \[
  D = 2.74 \times 10^4 \times 0.162 = 4438 \text{ (rad)}
  \]
  Dose rate: \( \frac{4438}{3} = 1479 \text{ rad / h} = 1.479 \text{ Krad / h} \)

For radiation test of CIS for FS-5, the actual distance from radiation source was **26 cm**, and the corresponding dose rate was **1.38 Krad / h**
Test Configuration
The distances from here to each sensors are 1 m

PAN#1 +3.3V
PAN#2 +3.3V
PAN#3 +3.3V
MS#1 +3.3V
MS#2 +3.3V
MS#3 +3.3V

Power Supply

打開電源供應器,調整電壓為3.5V,然後逐下去量測每個Sensor是否有3.3V,若有一顆sensor低於3.3V,就將電源供應器往上調整到3.6V~4V,直到每一顆Sensor的電源有+3.3V以上
## Test Condition

Room Temperature: 24 °C  
Humidity: 60%  
Distance: 26 cm  

<table>
<thead>
<tr>
<th></th>
<th>30 Krad</th>
<th>60 Krad</th>
<th>100 Krad</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>3 PAN</strong></td>
<td>Function Test</td>
<td>Function Test</td>
<td>Function Test</td>
</tr>
<tr>
<td><strong>3 MS</strong></td>
<td>Function Test</td>
<td>Function Test</td>
<td>Function Test</td>
</tr>
<tr>
<td><strong>Dose Rate</strong> (Krad/ h)</td>
<td>1.38</td>
<td>1.38</td>
<td>5.8</td>
</tr>
<tr>
<td><strong>Total Time</strong> (hour)</td>
<td>21.74</td>
<td>43.48</td>
<td>72.46</td>
</tr>
</tbody>
</table>
FS-5 RSI CIS Chip  
1st Radiation Test Result

• After 30 Krad radiation test, all of 6 chips passed function test. (0 failed)

• After 60 Krad radiation test, only 3 chips passed function test. (3 failed)

• After 100 Krad radiation test, none of the 6 chips passed function test. (6 failed)
Failure Analysis (Circuit Design)

- Problems:
  - no close loop to hold trigged data

Add resistors to simulate the effect of leakage current.
Failure Analysis (Simulation)

mux<2>

mux<1>
n4
n3
n2
n1
d1
Improvement (Circuit Design)

- By mask change

mux<1>

mux<2>
Improvement (Simulation)
## Test Schedule

<table>
<thead>
<tr>
<th>Item</th>
<th>Task Description</th>
<th>Time Begin</th>
<th>Time End</th>
<th>Time Duration</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Test Setting up</td>
<td>2011/08/01 09:00</td>
<td>2011/08/01 09:40</td>
<td></td>
<td>THOR (*Note)</td>
</tr>
<tr>
<td>1.1</td>
<td>0 ~ 30K Radiation Exposure</td>
<td>2011/08/01 10:00</td>
<td>2011/08/02 08:00</td>
<td>22 hour</td>
<td>THOR</td>
</tr>
<tr>
<td>1.2</td>
<td>Function Test</td>
<td>2011/08/02 08:20</td>
<td>2011/08/02 09:40</td>
<td></td>
<td>NSPO</td>
</tr>
<tr>
<td>2.1</td>
<td>30 K ~ 45 K Radiation Exposure</td>
<td>2011/08/02 10:00</td>
<td>2011/08/02 21:00</td>
<td>11 hour</td>
<td>THOR</td>
</tr>
<tr>
<td>2.2</td>
<td>Function Test</td>
<td>2011/08/02 21:20</td>
<td>2011/08/02 22:40</td>
<td></td>
<td>NSPO</td>
</tr>
<tr>
<td>3.1</td>
<td>45 K ~ 60 K Radiation Exposure</td>
<td>2011/08/02 23:00</td>
<td>2011/08/03 10:00</td>
<td>11 hour</td>
<td>THOR</td>
</tr>
<tr>
<td>3.2</td>
<td>Function Test</td>
<td>2011/08/03 10:20</td>
<td>2011/08/03 11:40</td>
<td></td>
<td>NSPO</td>
</tr>
<tr>
<td>4.1</td>
<td>60 K ~ 100 K Radiation Exposure</td>
<td>2011/08/03 12:00</td>
<td>2011/08/04 17:00</td>
<td>29 hour</td>
<td>THOR</td>
</tr>
<tr>
<td>4.2</td>
<td>Function Test</td>
<td>2011/08/04 17:20</td>
<td>2011/08/04 18:40</td>
<td></td>
<td>NSPO</td>
</tr>
</tbody>
</table>

*Note: THOR, Radioisotope Laboratory of National Tsing Hua University*
FS-5 RSI CIS Chip
2nd Radiation Test Result

- After 30 Krad radiation test, all of 6 chips passed function test. (0 failed)
- After 45 Krad radiation test, all of 6 chips passed function test. (0 failed)
- After 60 Krad radiation test, all of 6 chips passed function test. (0 failed)
- After 100 Krad radiation test, all of 6 chips passed function test. (0 failed)
SNR

After comparing the SNR between pre-radiation-test and post-radiation-test, we found that there is no apparent difference, just as expected.
Packaged CMOS Image Sensor for FormoSat-5
Conclusion and Future Work

- We successfully demonstrated the CMOS Image Sensor is capable of anti-radiation dose for five years.

- We will keep improving the circuit design to meet the specification of Taiwan’s FORMOSAT 5, and to improve the signal to noise ratio (SNR), making the image quality as expected.
Your Comments are Welcome

Thank You