

Delfi-C3 Preliminary Mission Results

Robbert J. Hamann, Jasper Bouwmeester, Geert F. Brouwer



Delft University of Technology, The Netherlands
Faculty of Aerospace Engineering
Chair of Space Systems Engineering

Presented by Geert F. Brouwer

SSC08-X-7

23rd Annual AIAA/USU Conference on Small Satellites

Content

- Delfi-C³ Objectives, characteristics and operations
- Delfi-C³ Payloads
- Delfi-C³ Subsystems performance
- Delfi-C³ Ground segment
- Conclusions

Delfi-C³ Objectives

- Main objective
Give students hands-on experience of a real life satellite project
- Secondary objective
Provide a means for fast and (relatively) cheap in-orbit technology demonstration

Delfi-C³ Key Mission Characteristics

- 635 km sun-synchronous orbit
- 3-unit CubeSat of 2.2kg
- Thin Film Solar Cells payload (Dutch Space)
- Autonomous Wireless Sun Sensor payload (TNO)
- Transceiver doubles as Radio Amateur transponder
- No battery
- Passive ADCS, UHF uplink, VHF downlink
- 3 years development time
- ~60 students involved, 4 FTE staff (man hour ratio ~ 6:1)
- 314 registered radio amateurs around the world

Delfi-C³ Operations

28 April 2008, 03:53 UTC	Launch
06:39:08 UTC	First ground contact (radio amateur in California, USA)
11:49:51 UTC	First contact Delft Ground Station
30 April 2008, 10:50:42 UTC	Delfi-C ³ CDHS set to Read-Only mode to prevent early flash memory failure
29 July 2008, 10:00 UTC	Switch from Science Mode to Transponder Mode
End of September 2008	First signs of transponder degradation
14 October 2008, 11:00 UTC	Switch to Basic Mode to investigate problem
29 January 2009, 09:33:17 UTC	Switch to Science Mode

- Operations continuing
- Tumbling of satellite almost stopped (Summer 2009)

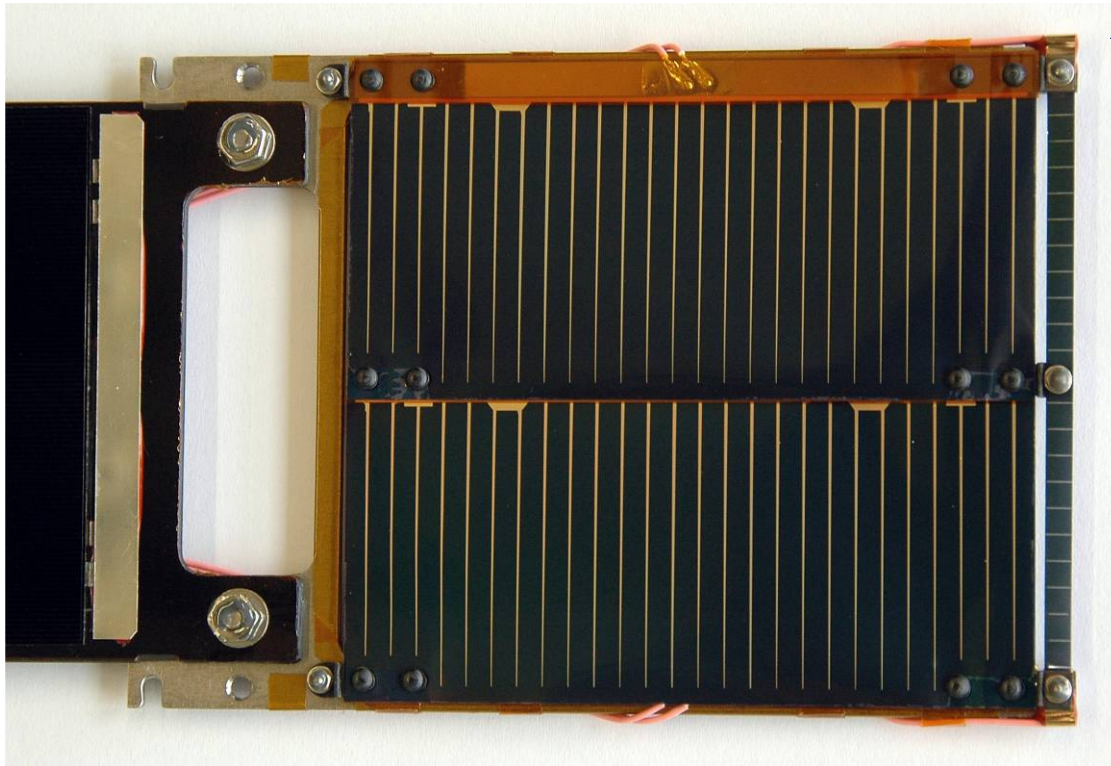
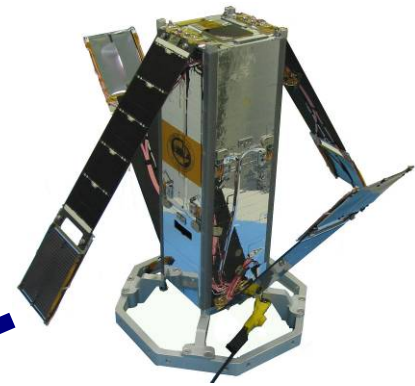
Results

Telemetry analyzed for period
April 28th until July 12th 2008 only

for two payloads:

Thin Film Solar Cells
Autonomous Wireless Sun Sensor

Thin Film Solar Cell payload

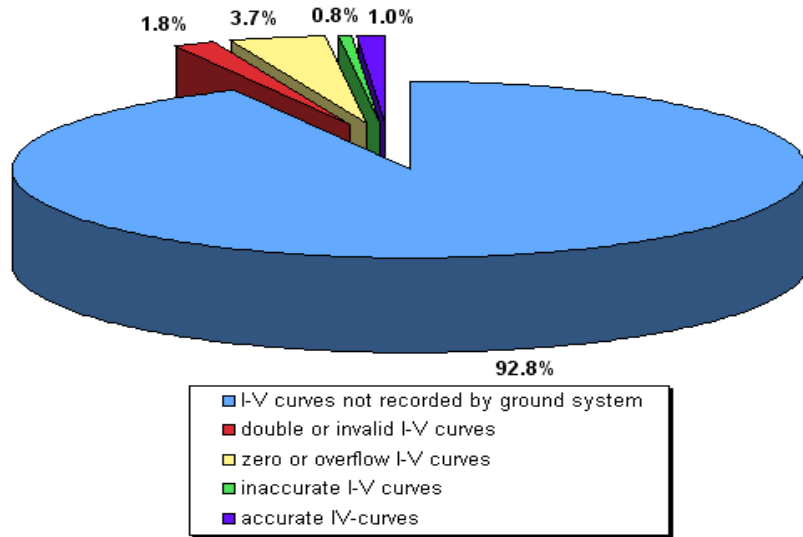


Copper-Indium-Gallium-diSelenide deposited on 25 μm Titanium foil

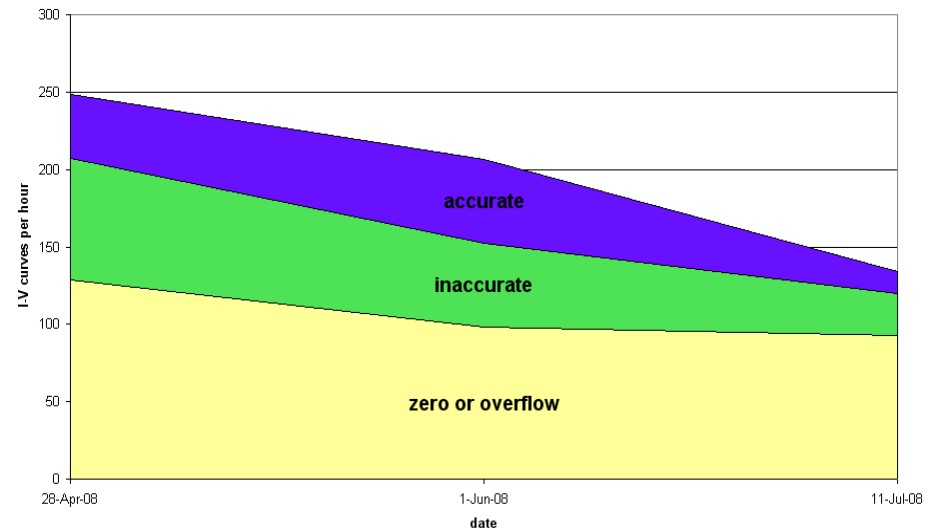
Thin Film Solar Cell payload (2)

In 3 months Science Mode more than 53000 accurate I-V curves have been harvested

TFSC I-V curves harvested

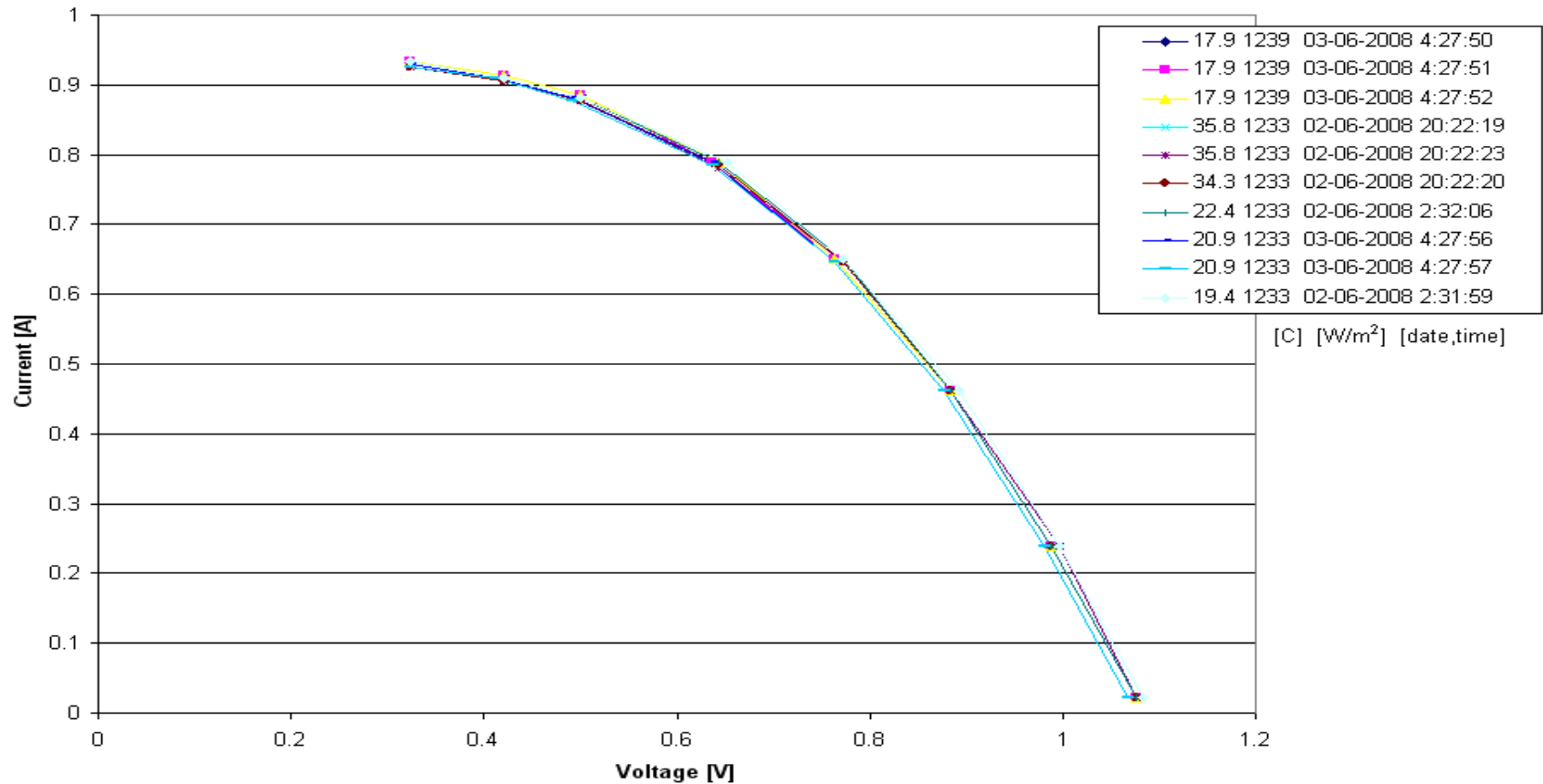


I-V curves harvested in time



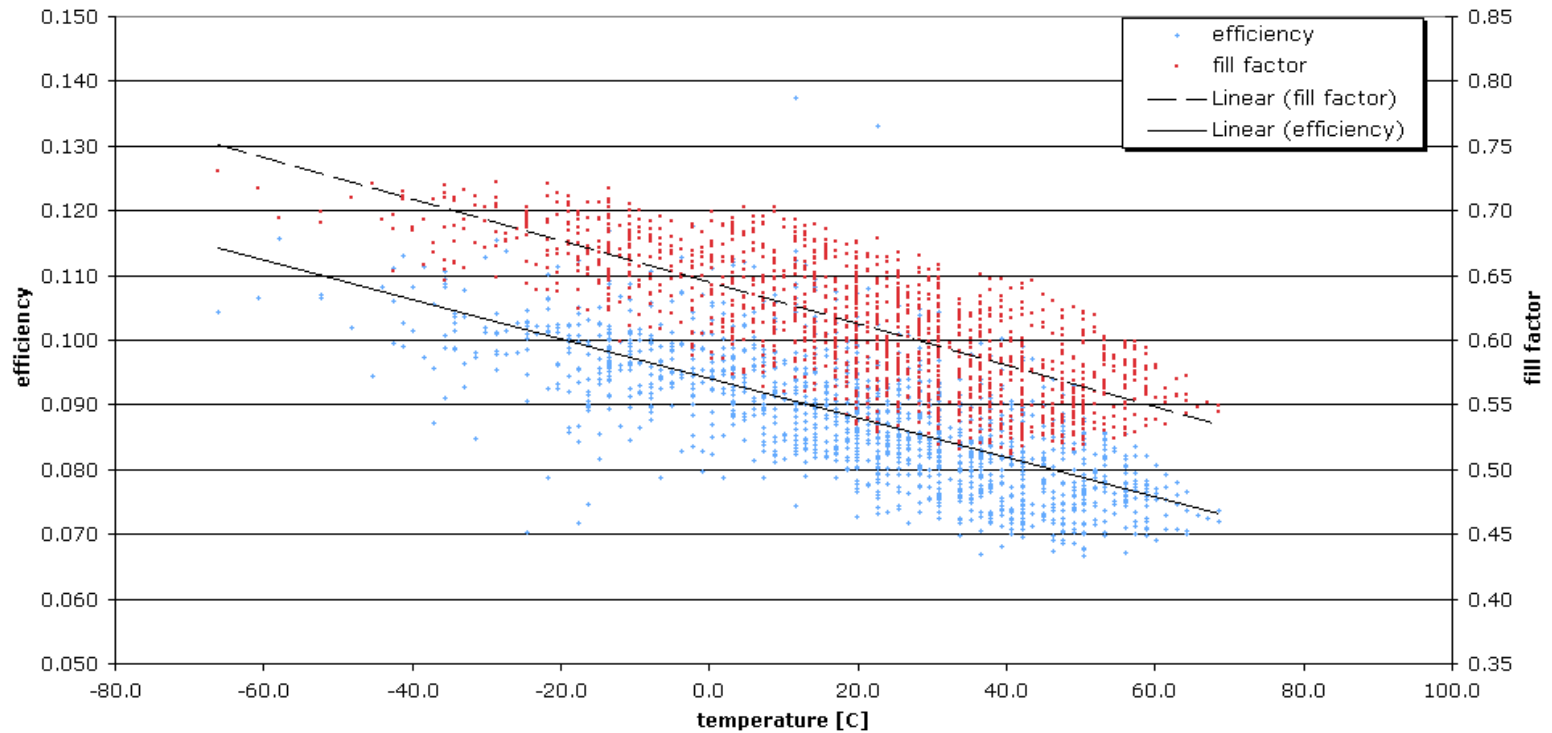
Typical TFSC data

I-V Curve Panel -X



Typical TFSC data (2)

Efficiency +X TFSC assy



Efficiency is the ratio between delivered power on maximum power point in I-V curve to incoming sunlight

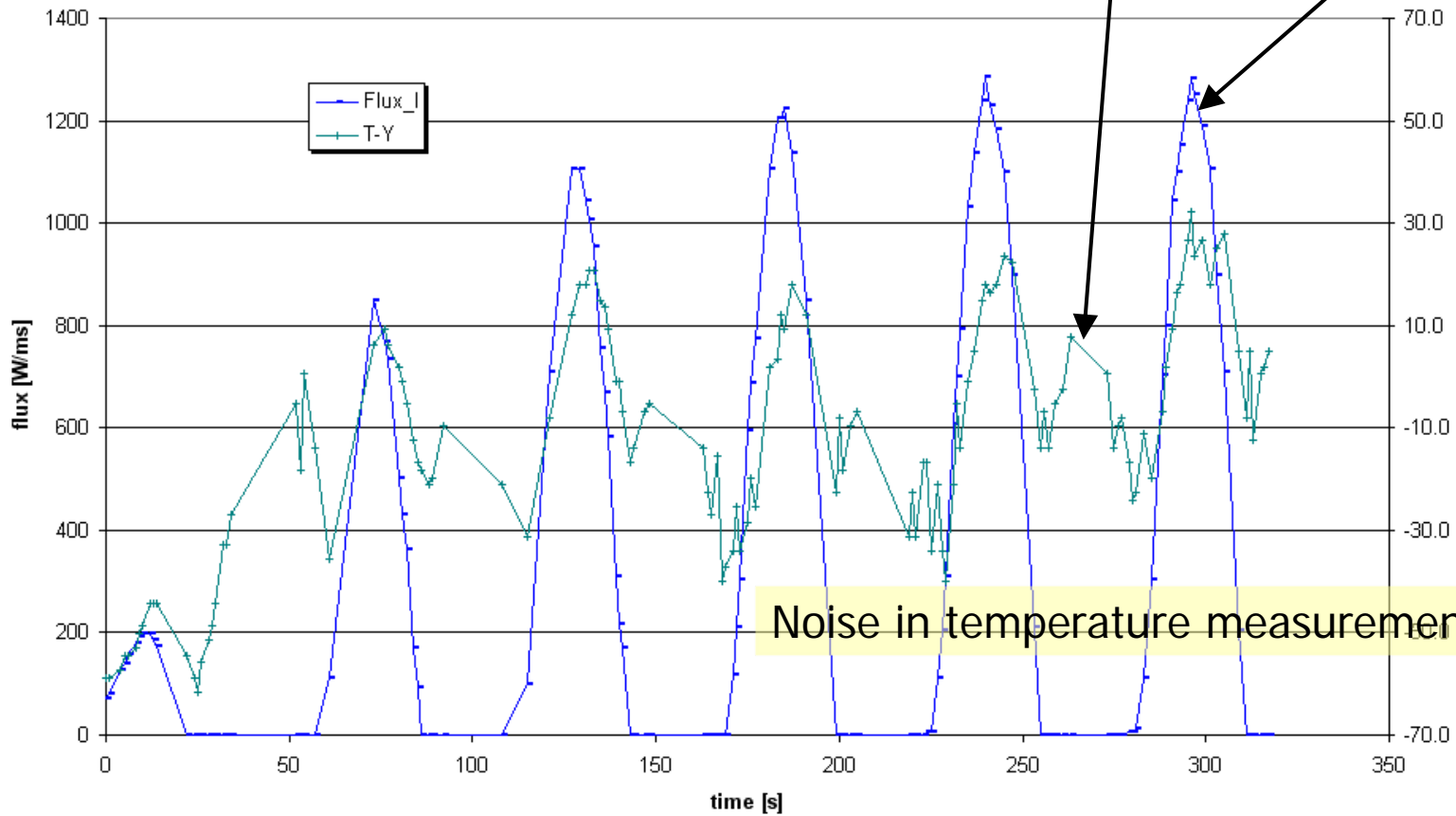
Fill factor is defined as ratio under I-V curve divided by rectangle composed from max I and Max Voltage on previous sheet.

TFSC analysis

Temperature measurements on strips near cells

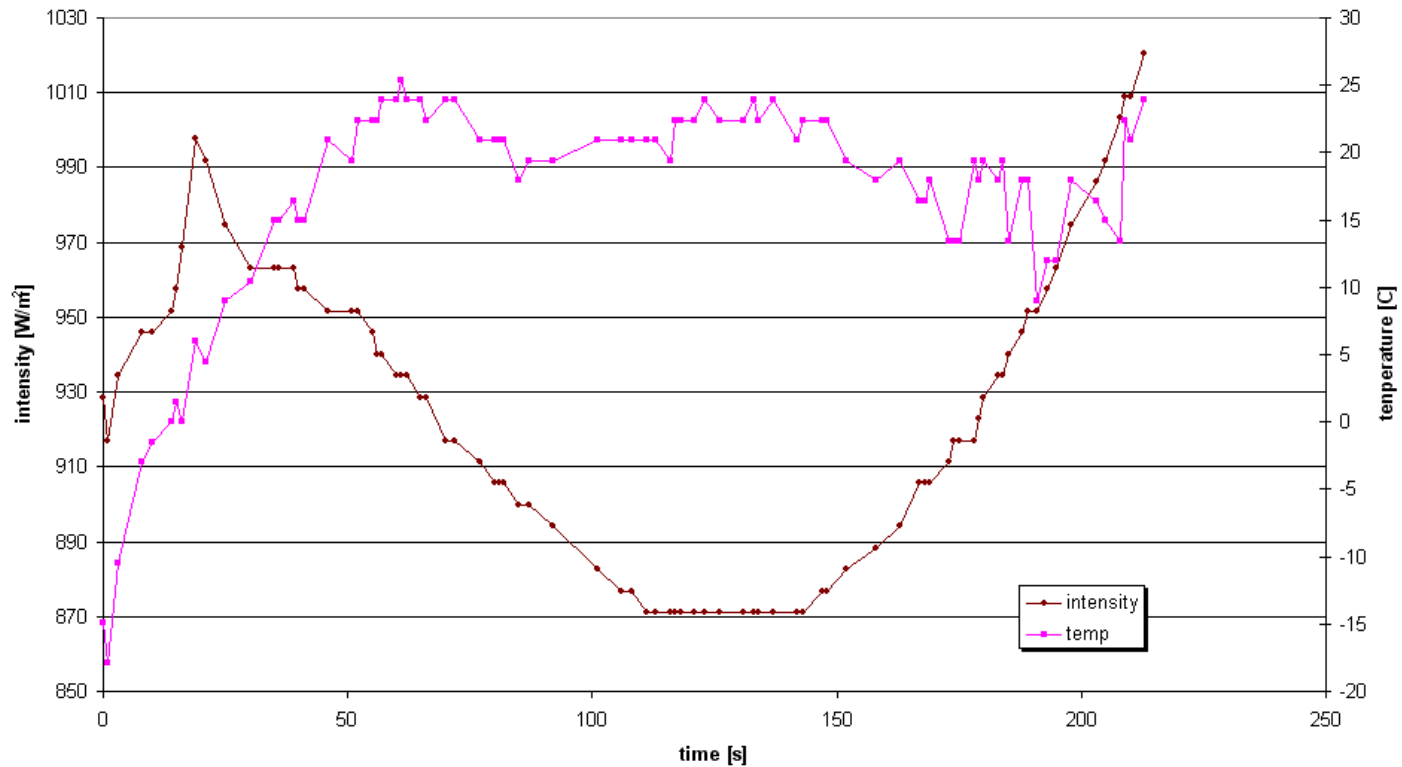
Incoming flux on cells

Temperature & intensity -Y panel



TFSC analysis (2)

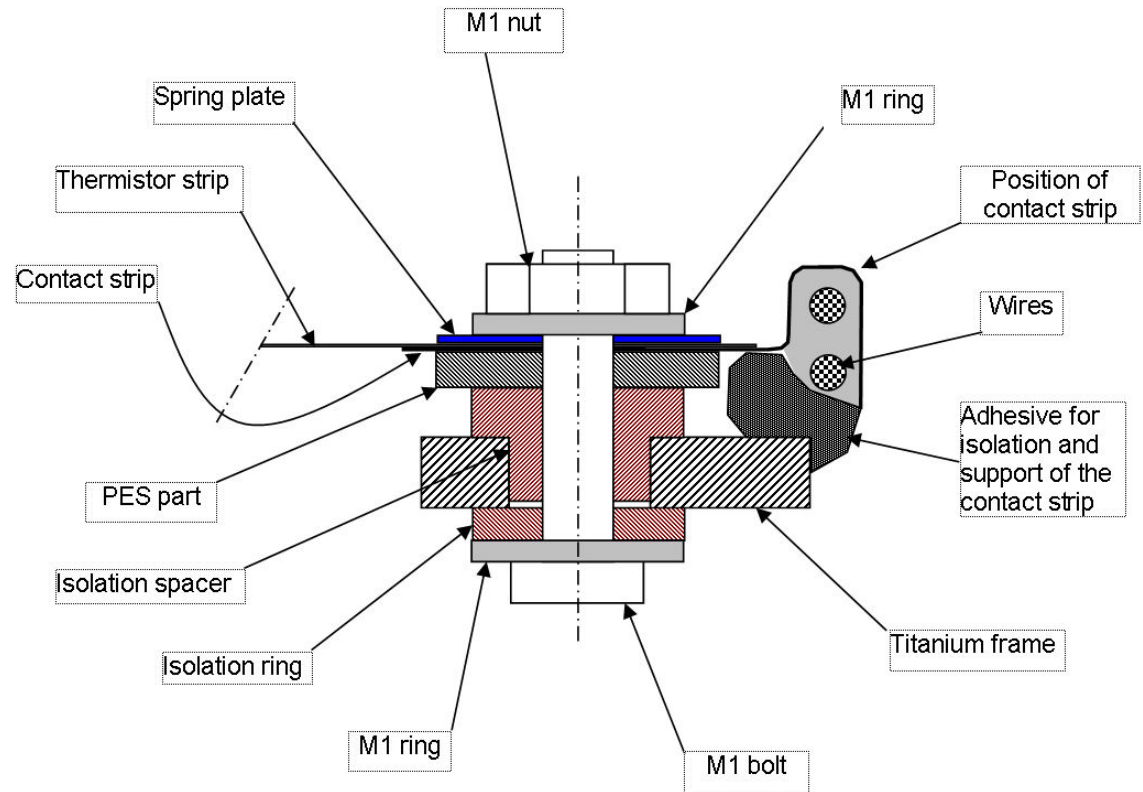
Intensity & temperature -X TFSC panel



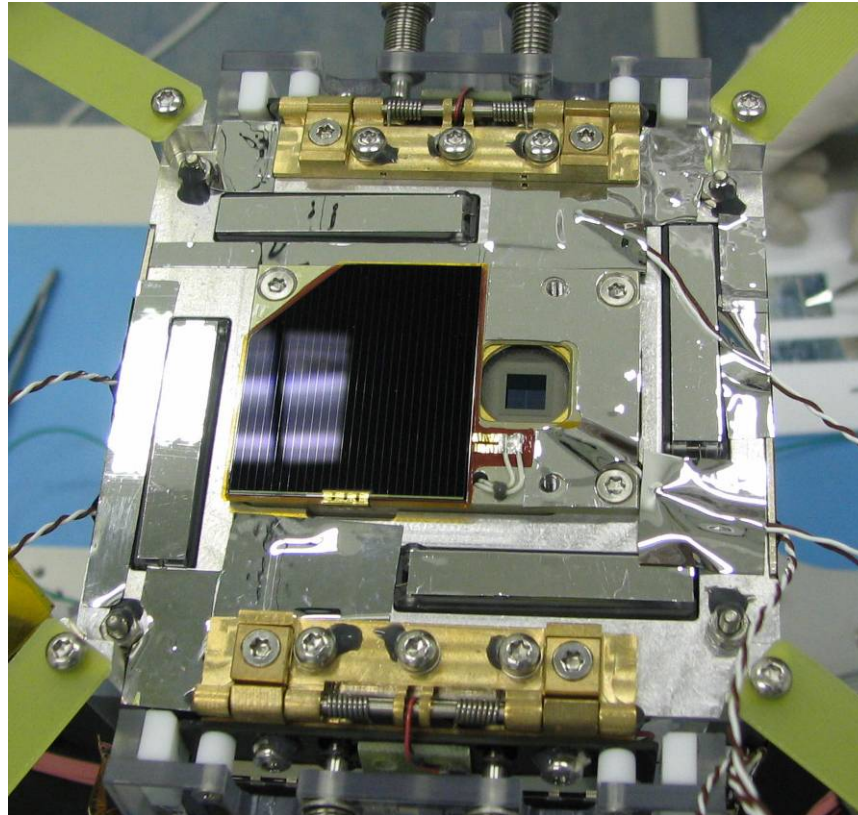
TFSC analysis (3)



- Probable cause
 - Rapidly changing electrical resistance in temperature strip due to temperature transients in mounting structure
 - Only steady state measurements were done on the sensor on ground



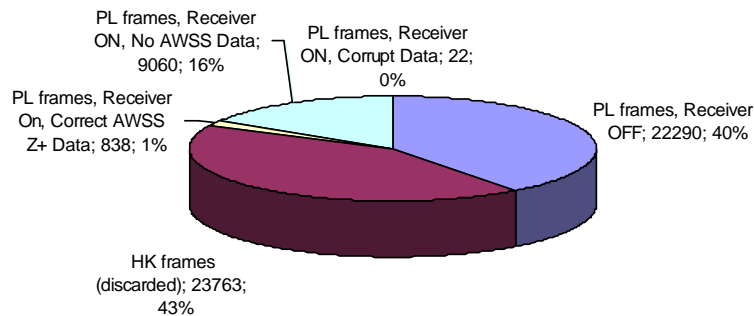
Autonomous Wireless Sun Sensor



Solar cell for power provision, radio transmitter for data transfer to OBC

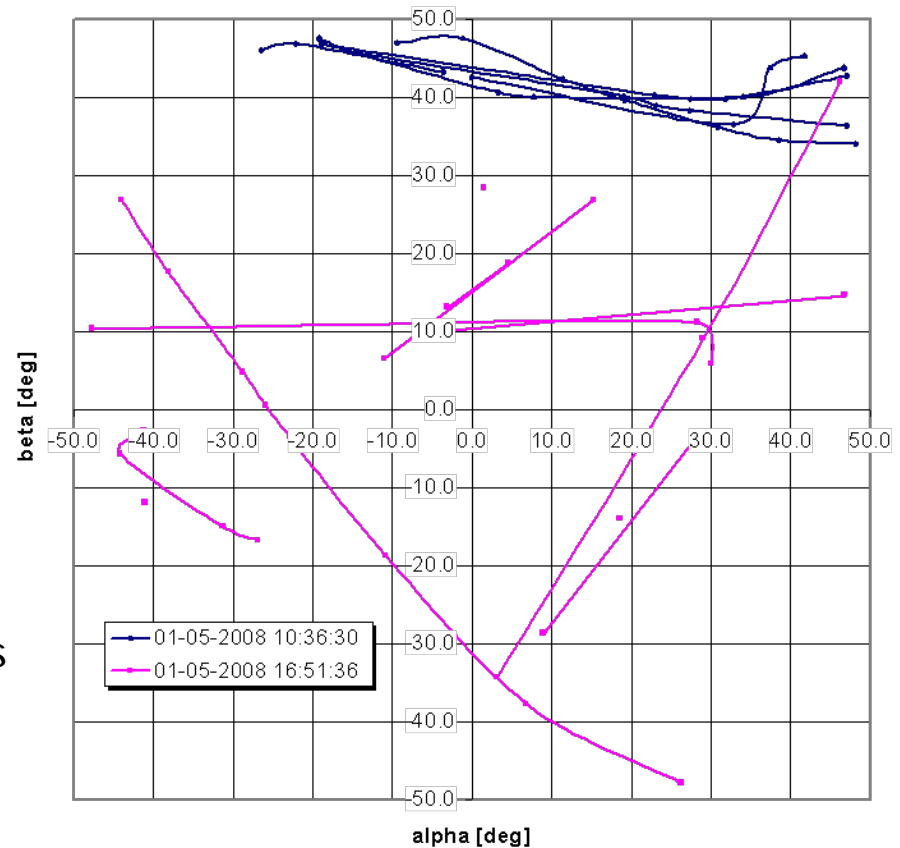
AWSS data

Period April 28th until May 11th 2008

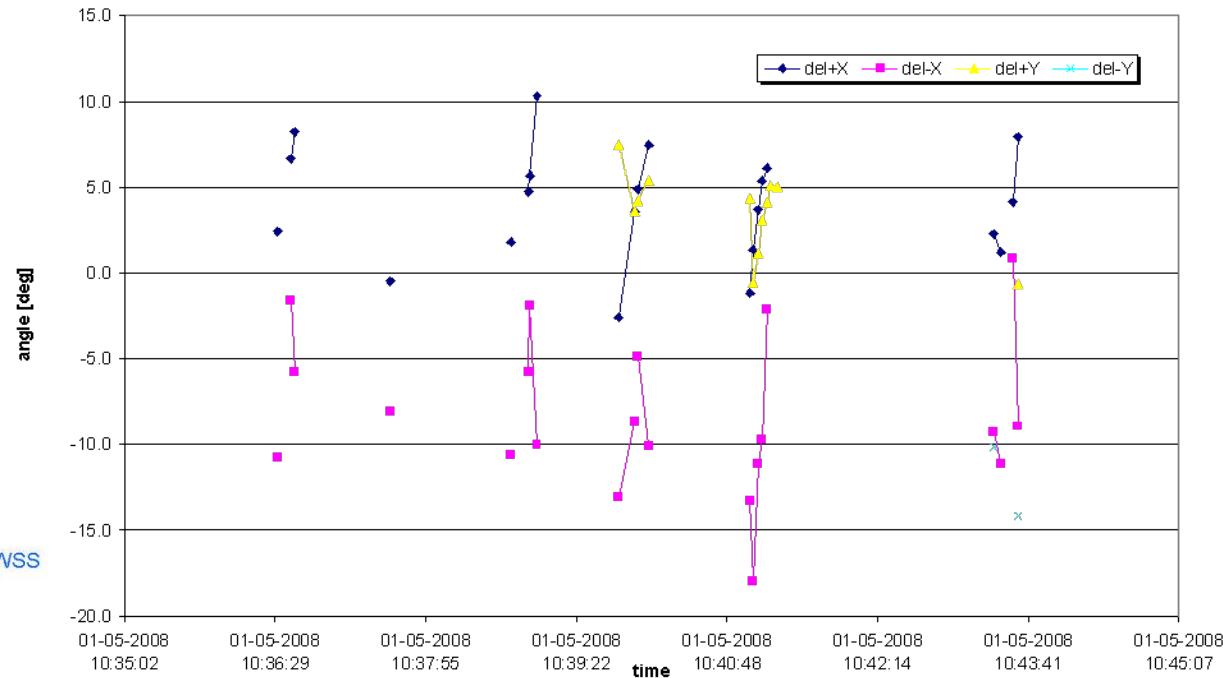
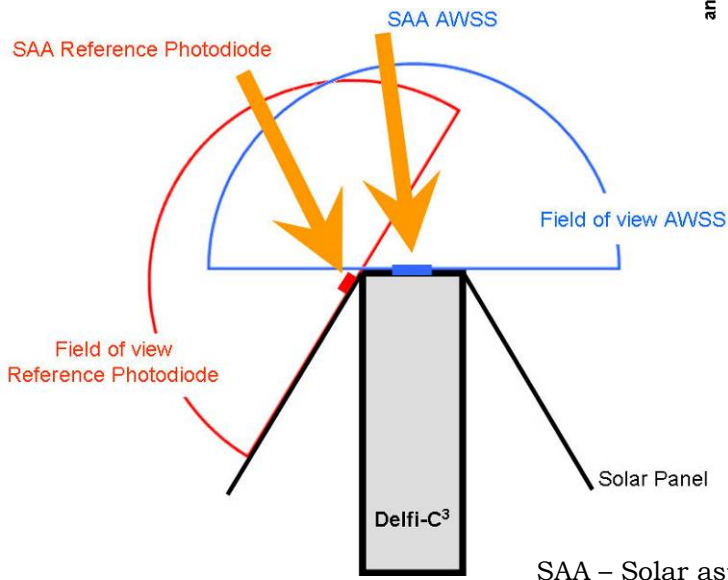


Total estimated number of AWSS data points
3,500 to 5,800

- Bit shift in data-cutting
- Reversed status byte (MSB <> LSB)
- AWSS Z+ working
- AWSS Z- very little data, maybe spurious
- Data still useful enough to draw conclusions, but much work still to be done



Sun position according to AWSS & Reference Photodiodes on solar panels



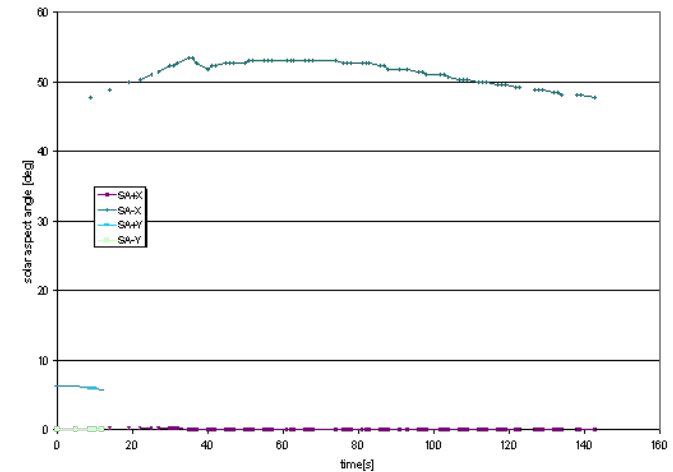
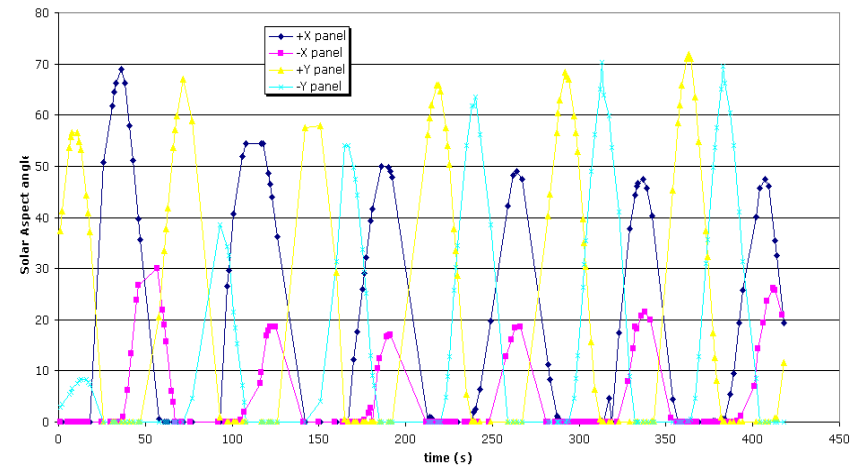
Attitude Determination & Control Subsystem

- Predicted performance of design: Rotation rate decreases by magnetic hysteresis material within a few orbits from a maximum of $10^\circ/\text{s}$ after ejection from X-POD to $0.2\text{-}2^\circ/\text{s}$
- Actual performance rotation rate:
From ***5.06 °/s at separation***
 - ⇒ ***4.95 °/s on May 5th (top picture)***
 - ⇒ ***4.50 °/s on May 12th***
 - ⇒ ***0 - 0.7 °/s on July 11th***
(bottom figure)

(Year 2008)

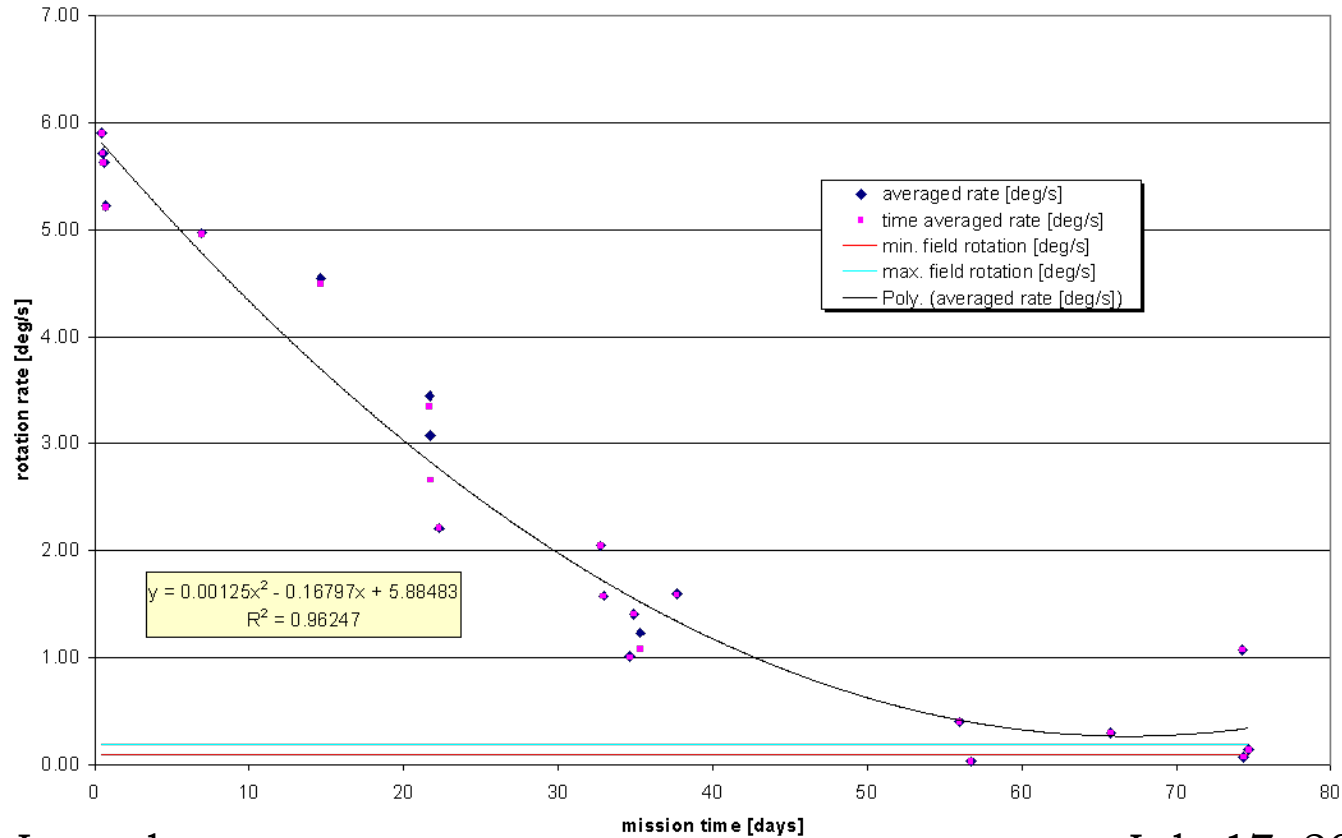
(rotation rate magnetic field $\sim 0.13^\circ/\text{s}$)

Solar Aspect angle 080505032246



ADCS – details (2)

Rotation rate on basis on reference diode measurements

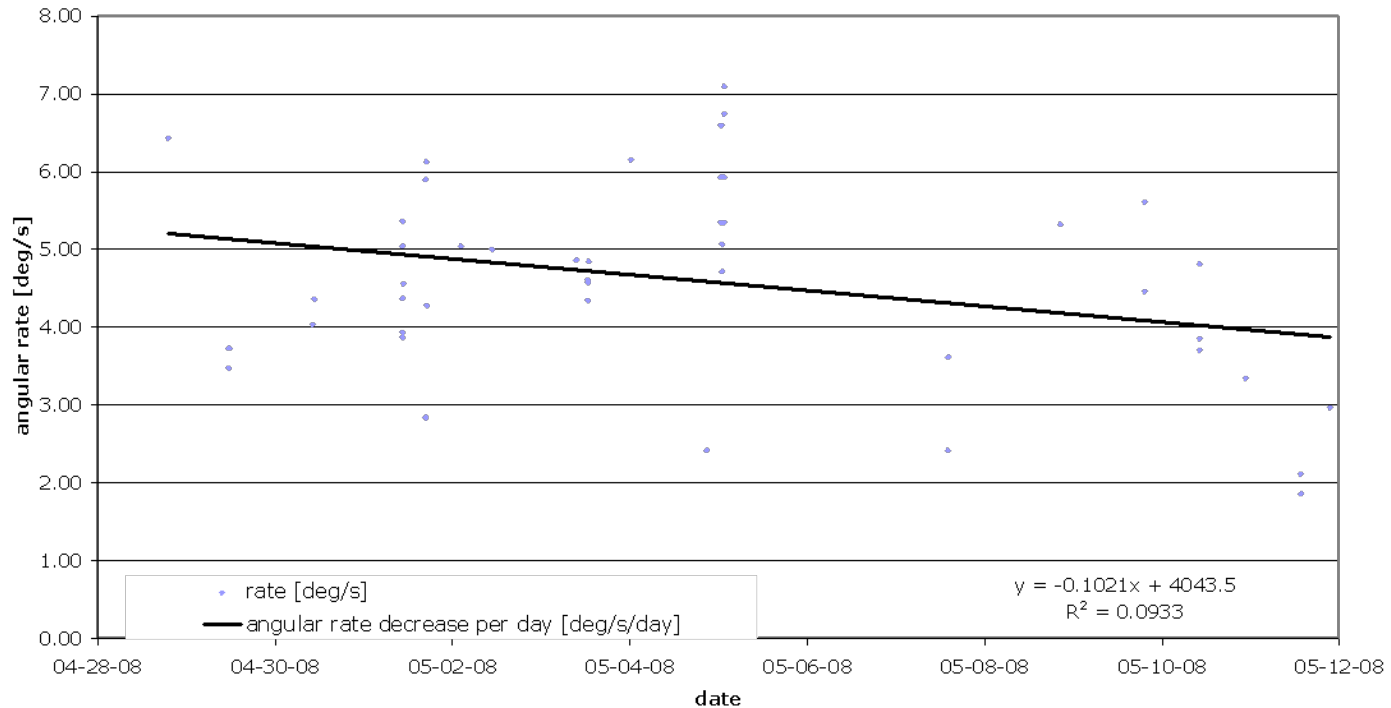


Launch

July 17, 2008

ADCS – details (3)

Rotation rate on basis on AWSS measurements

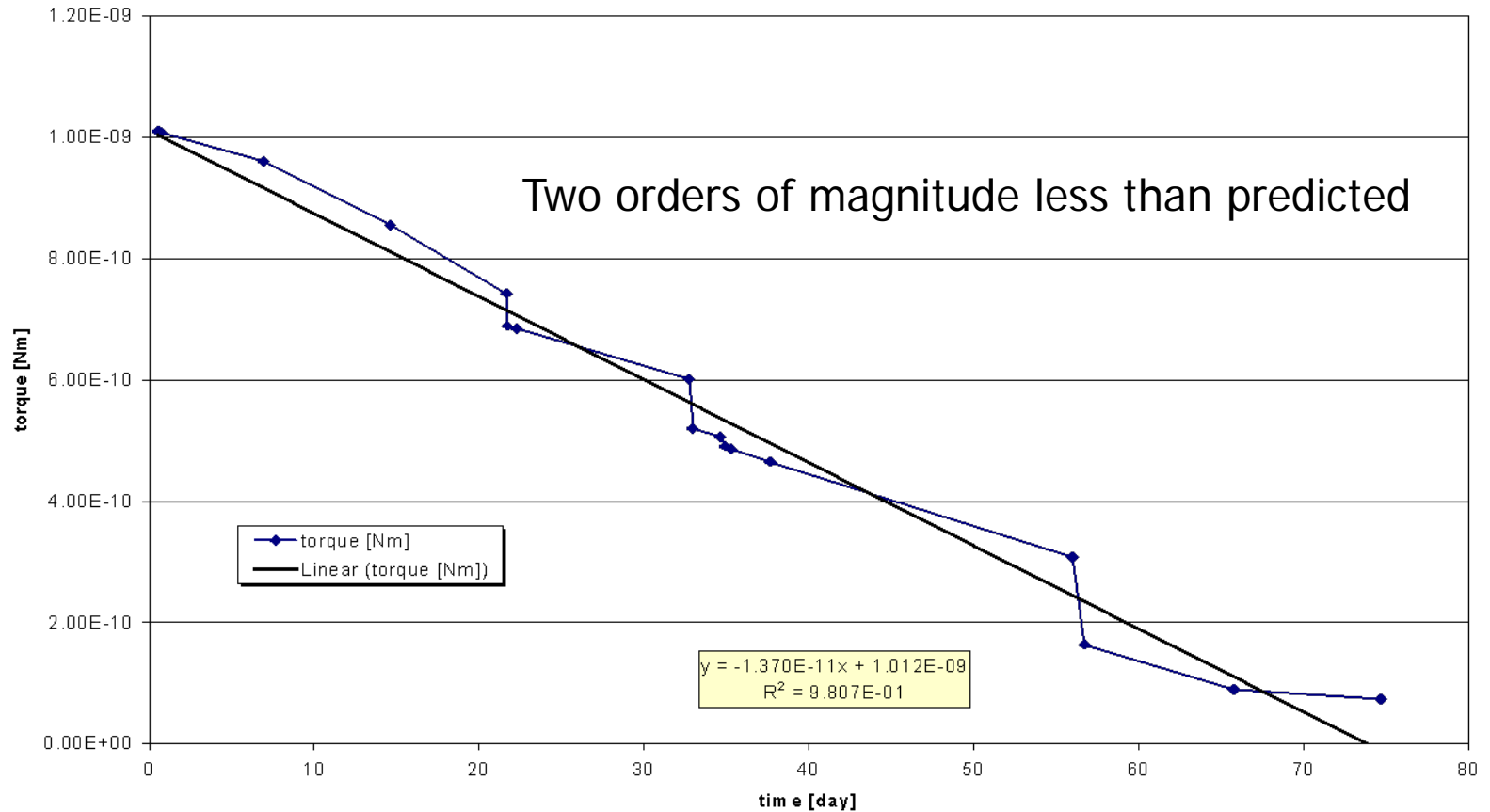


Launch April 28, 2008

May 12, 2008

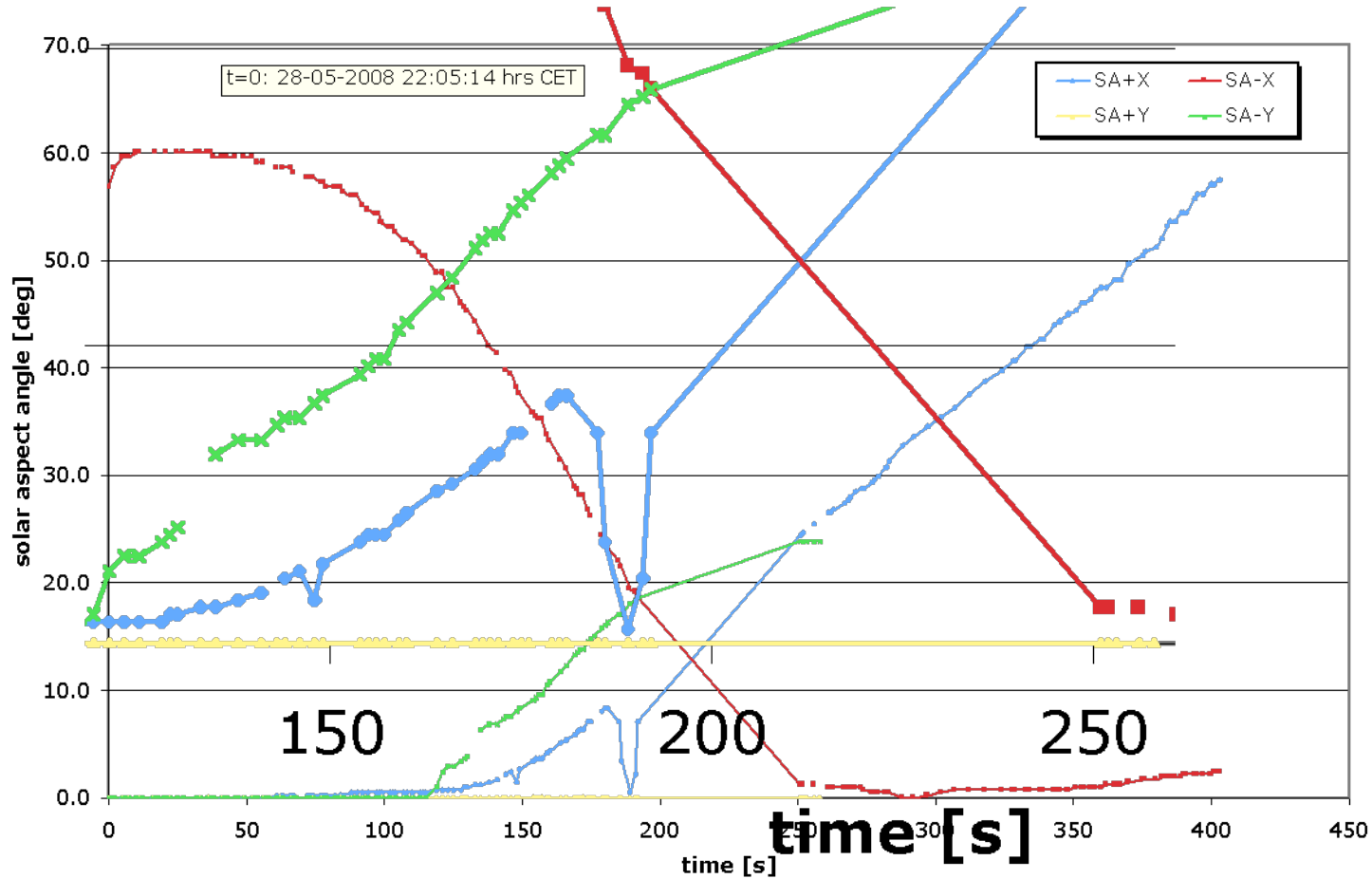
ADCS - details (4)

Decelerating torque



Sometimes a surprise

reference diode output



Command & Data Handling Subsystem

Findings on CDHS

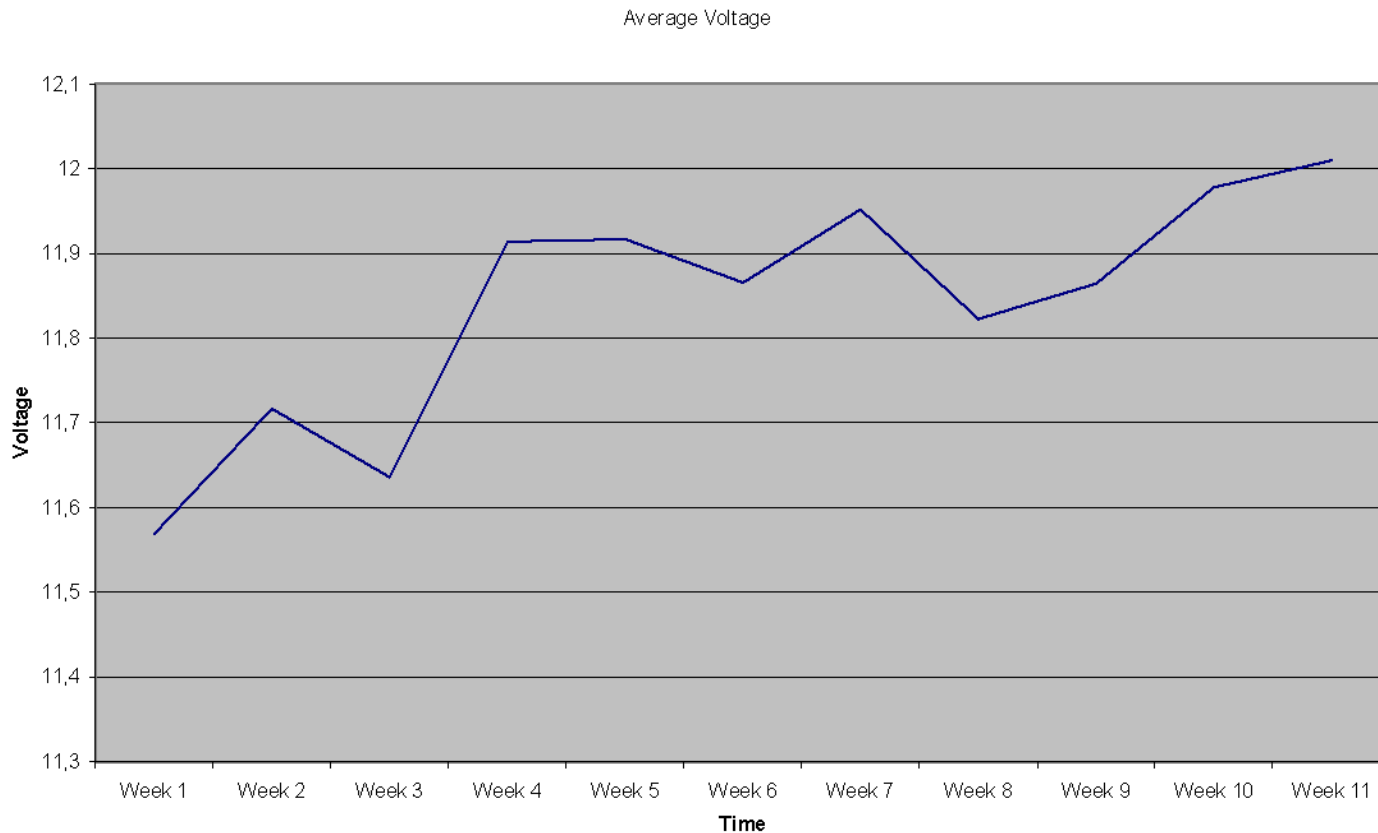
- Subsystems switch off arbitrarily due to CDHS instability
- Data missing even for subsystems which are on
- A rapid increase of the number of computer resets (consumption of flash memory cycles) forced switch-off of auto-reconfiguration function (loss of unique frame identification)

Main causes:

- I²C clock speed must be < 10% of clock speed of slowest node; in Delfi-C³ this was ~50%
- Bad node protection and watch-dog functionality
- No structured testing methods applied

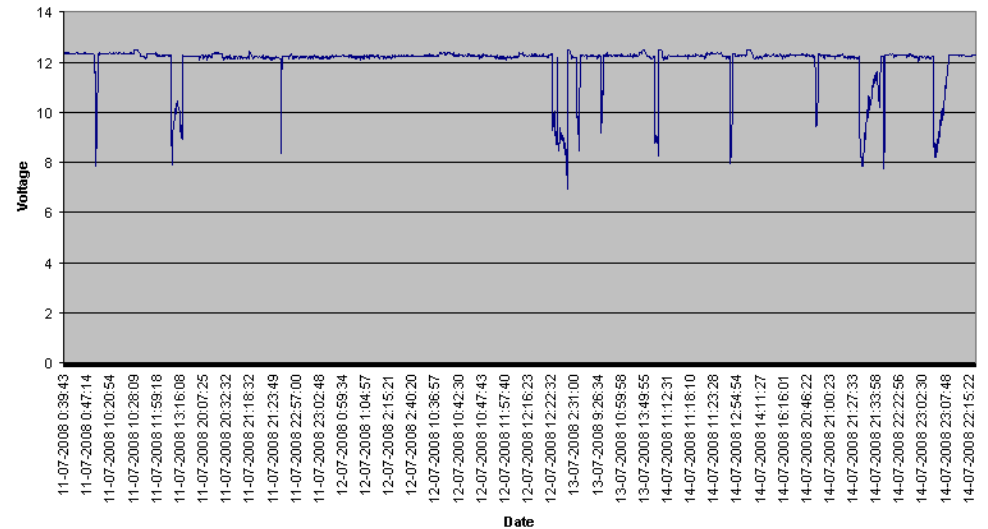
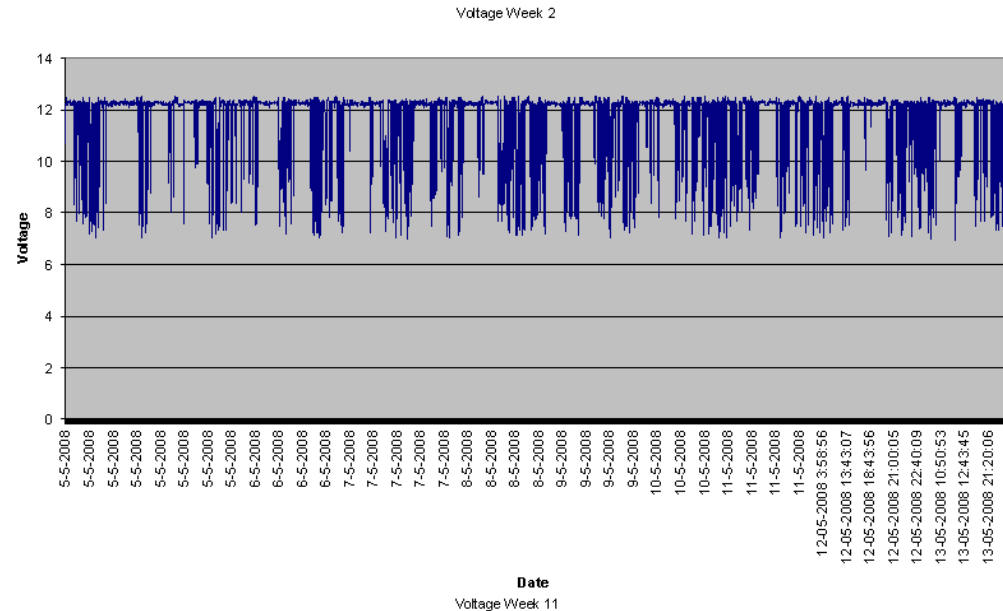
Electrical Power Subsystem (EPS)

Power performance increasing over time of solar panels



EPS (2)

- Decrease of voltage drops owing to decreasing rotation rate
- Dips cause temporary loss of transmitter
- No proven relation to subsystem switch off



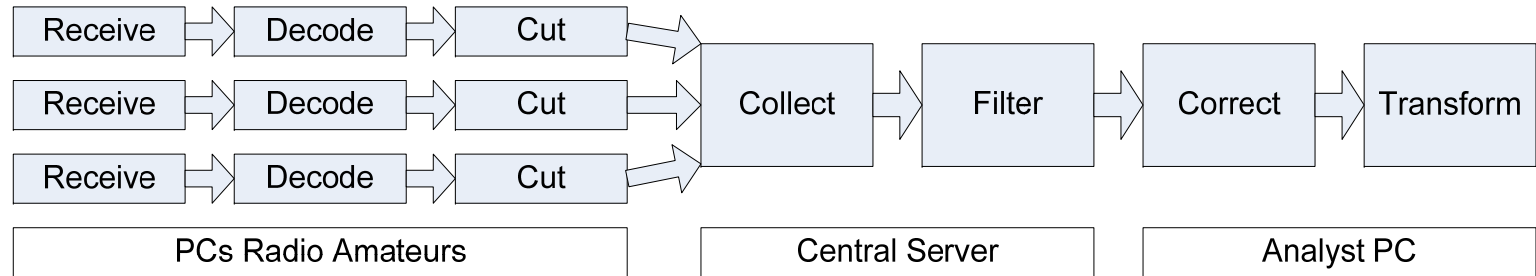
Ground Segment (1)

- 314 registered radio amateurs
- 150 actively participating
- Radio amateurs are very helpful in collecting data
- Return favor:
Transponder function + software package to see real time satellite data
- Although reasonable global distribution, never coming close to full coverage
- Also caused by frequent switch-off of transmitter (every eclipse and at low power levels, because of tumbling)



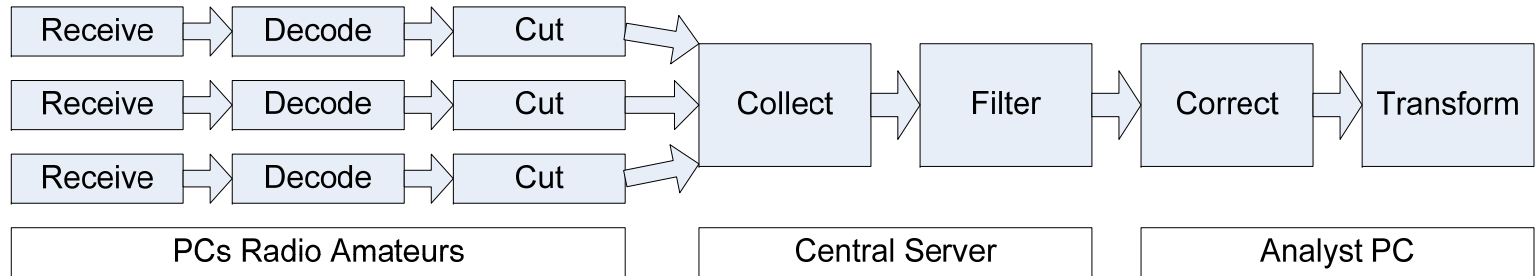
Ground Segment (2)

Currently

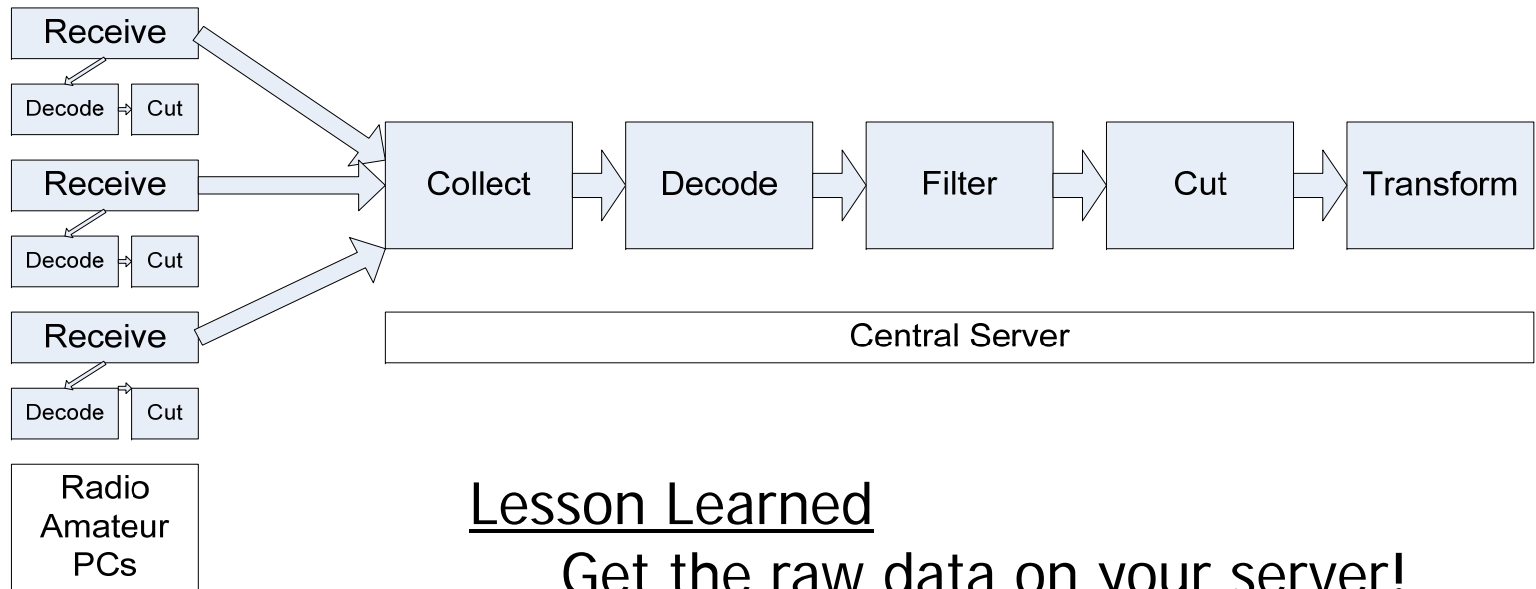


Ground Segment (2)

Currently



Better Solution



Lesson Learned

Get the raw data on your server!

Ground Segment (3)

Evaluation:

- The radio amateur community is very helpful
- Modular and easily adaptable ground segment essential
- Include non-nominal performance of satellite also in ground segment design
- Ground segment is just as important as the space segment

Conclusions

- In a number of areas incomplete and lack of end-to-end testing has been identified
- In some areas design has been limited to nominal satellite behavior only
- Rigorous project documentation, effective project management, reliable satellite operations and satellite data post-processing are functions difficult to realize in an academic and educational environment
- Radio amateur ground segment is a useful “amplification” for the mission yield
- Sufficient data can be delivered to our “customers”
- **Delfi-C³ mission is a full success**

