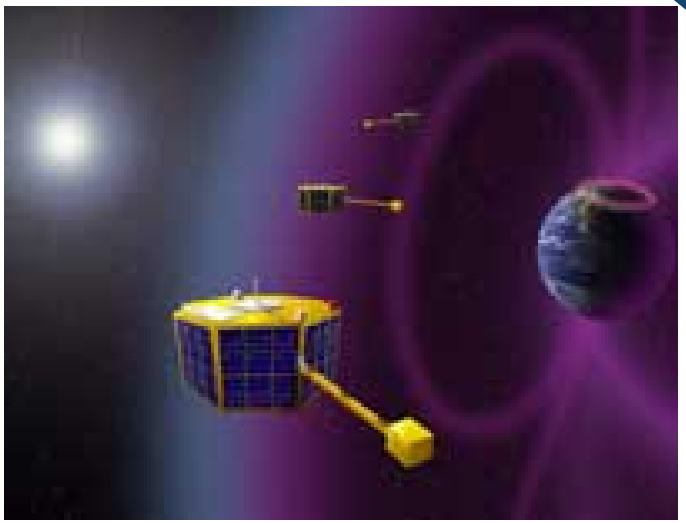
On-Orbit Maintenance of a Short Duration Mission: Space Technology 5



Alexander C. Calder
Senior Computer Scientist

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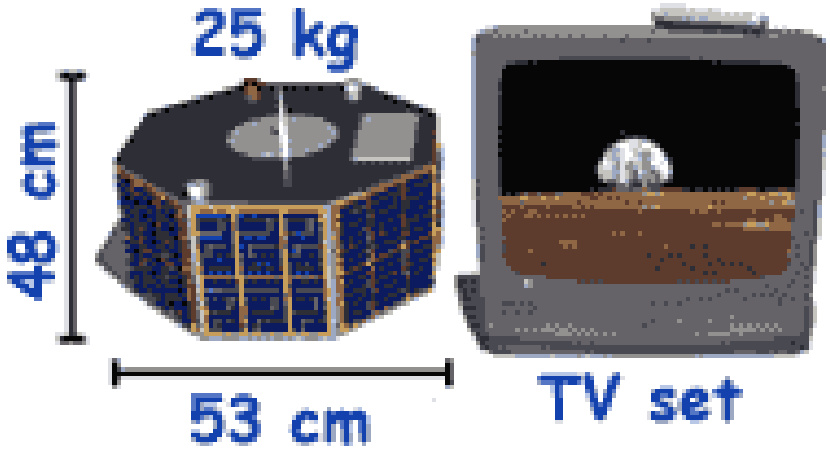
Introduction

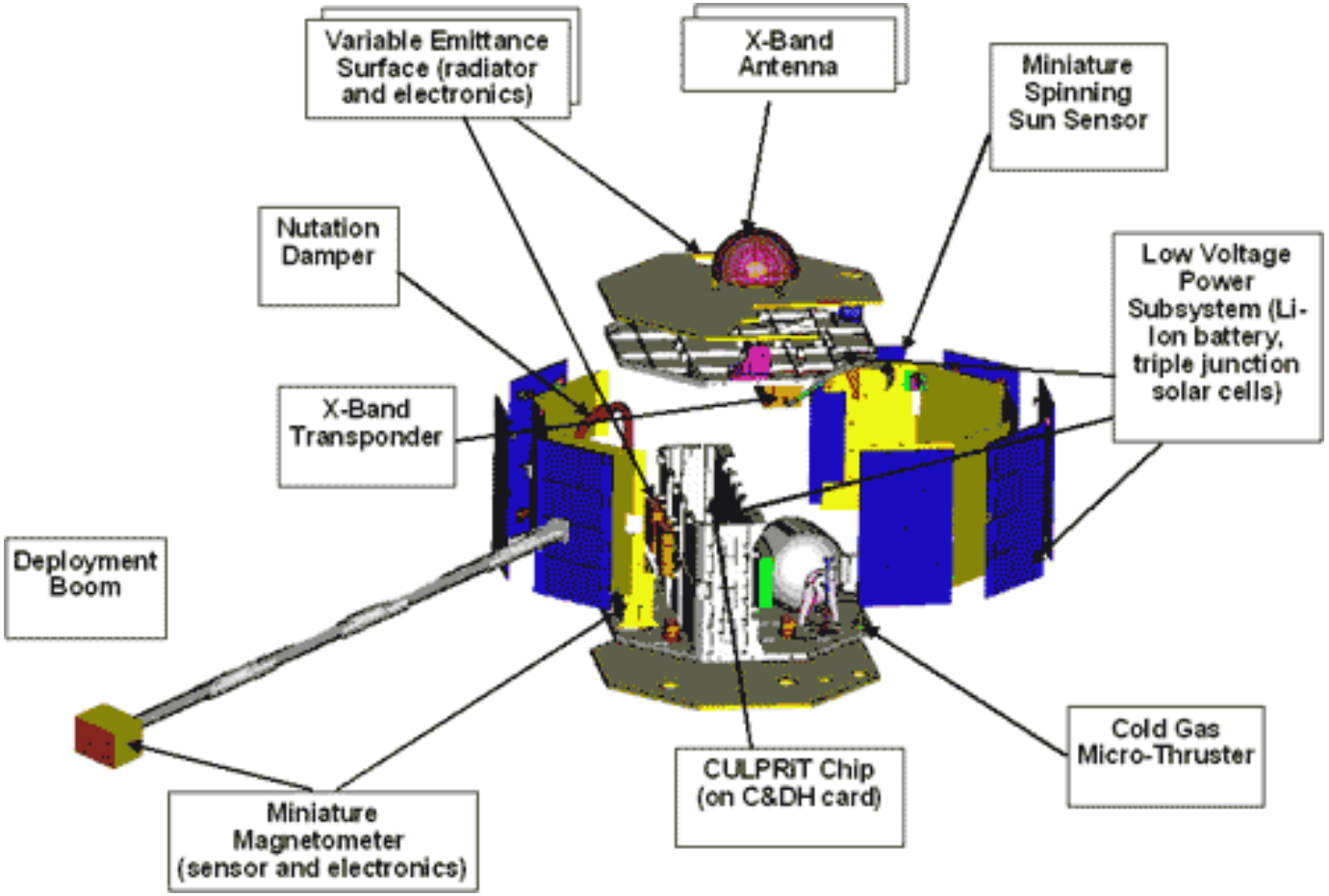
- Overview of the ST5 mission
  - Spacecraft, sensors, and orbit
  - Processor and flight software
- Post-separation anomaly
  - Symptoms
  - Preliminary diagnosis
- Patches and workarounds
  - Bus overrun error message patch
  - Software timing diagnostics patch
  - ACS parameter changes
- Multi-bit error events
  - Types of processor restarts and their consequences
  - Memory scrub parameter changes
- Conclusions



Overview of ST5 Mission (1 of 3)

- 3 spin-stabilized microsatellites
- Launched from Vandenberg AFB aboard Pegasus-XL, March 22, 2006
- Part of New Millennium Program of technology demonstration missions
  - Flight demonstration of several RF, thermal control, radiation-tolerant electronics, and ACS technologies for small satellites
  - Multipoint simultaneous measurements of geomagnetic field dynamics (precursor to MMS mission)
  - 90 day planned mission life
  - FSW developed and maintained by GSFC Code 582
- Attitude sensors and actuators:
  - Boom-mounted miniature magnetometer (also science instrument)
  - Miniature digital sun sensor (DSS)
  - Cold gas micro-thruster (for orbit and spin-axis adjustments)

Overview of ST5 Mission (2 of 3)



Overview of ST5 Mission (3 of 3)

- Orbit parameters:
  - Inclination 105.6 degrees
  - Period 136 minutes
  - Perigee altitude 300 km
  - Apogee altitude 4500 km
- Processor and flight software
  - Mongoose V processor
  - 1 bootable EEPROM FSW image, not writeable in flight
  - FSW heritage from RXTE, TRMM, WMAP
  - EDAC hardware & Memory Scrub software task for RAM integrity
    - Single bit errors detected & corrected
    - Multi-bit errors in recorder RAM detected & reported
    - Multi-bit errors in processor RAM trigger software reboot
  - Intertask communication managed by Software Bus task (e.g., sun pulse message from DSS ISR task routed to ACS task by Software Bus)

Post-Separation Anomaly

- Symptoms
  - Software bus error counter incrementing steadily
  - Flood of software bus error messages reporting bus overruns by DSS ISR message packet
  - DSS-derived spin period toggling between 0.7 and 2.7 seconds
  - Magnetometer-derived spin period steady at nominal value of 3.4 seconds
  - Same symptoms on all 3 spacecraft
- Preliminary diagnosis: Spurious sun pulses reported by DSS, due to:
  - Earth albedo, OR
  - Glint from DSS external light baffle

Patches and Workarounds (1 of 5)

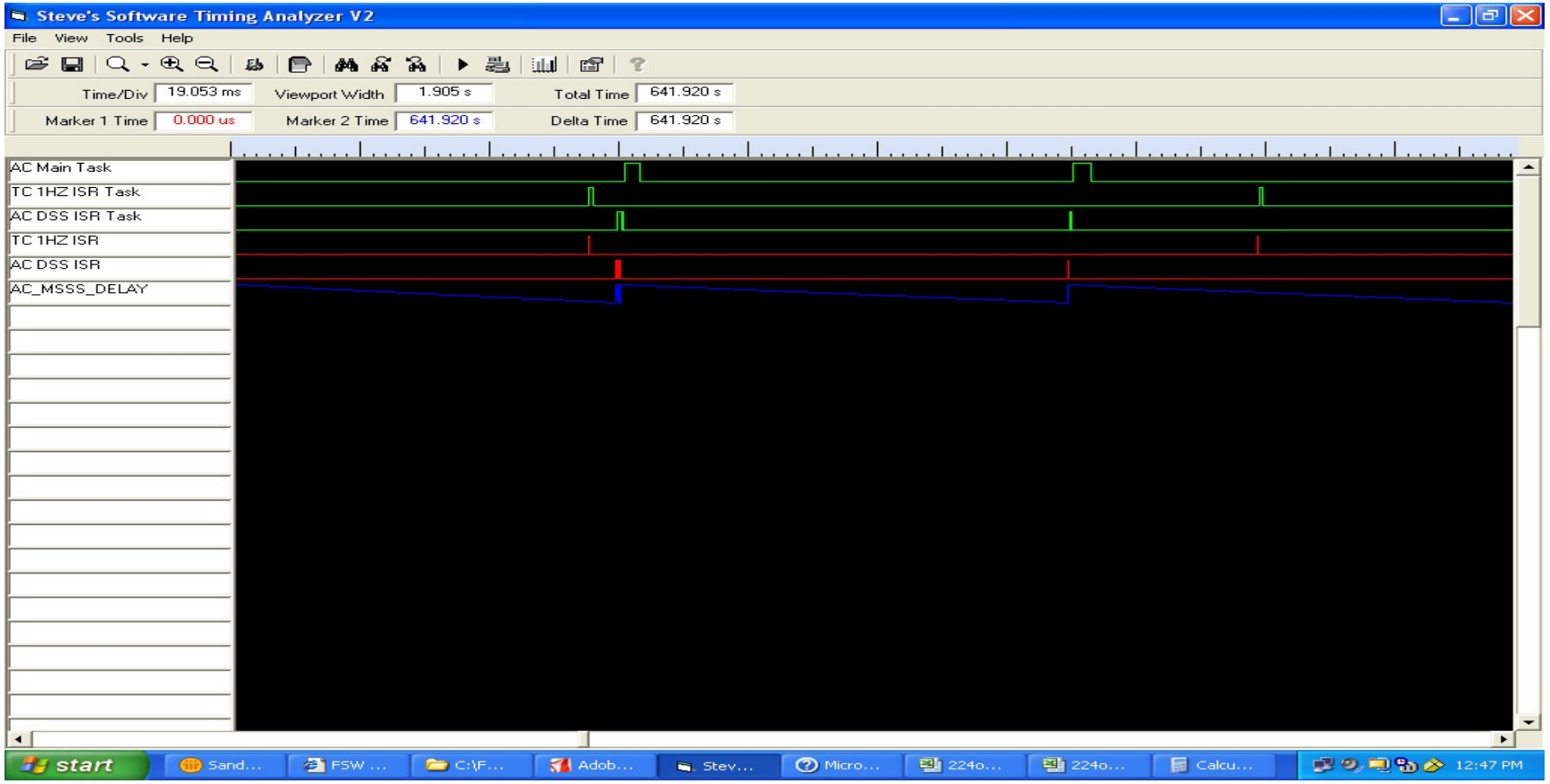
- Bus overrun error message patch
  - Flood of software bus error messages overflowing event message virtual recorder and obscuring other messages
  - At L+1 day, FSW team was tasked to patch software to silence the problematic error message
  - FSW team developed a one-word patch to NOOP the branch instruction calling the error message utility for this particular error
    - Other event messages unaffected
    - Bus overflow errors still counted
  - Patch successfully uplinked to all 3 spacecraft by end of day L+2

Patches and Workarounds (2 of 5)

- Software timing analyzer patch
  - Suspected that each spurious sun pulse actually consisted of multiple pulses
  - Available telemetry had insufficient time resolution to confirm or refute
  - FSW was instrumented for software timing analysis diagnostics during development and testing
    - On entry and exit, each task and ISR called a utility function to write a time tick to an output port
    - This utility function and calls to it left in place for flight
      - No impact on FSW performance in flight
  - FSW team developed a replacement utility function to collect timing data in memory, which could then be dumped via ground command
  - Patch successfully uplinked on L+13
  - First timing data collected on L+14

Patches and Workarounds (3 of 5)

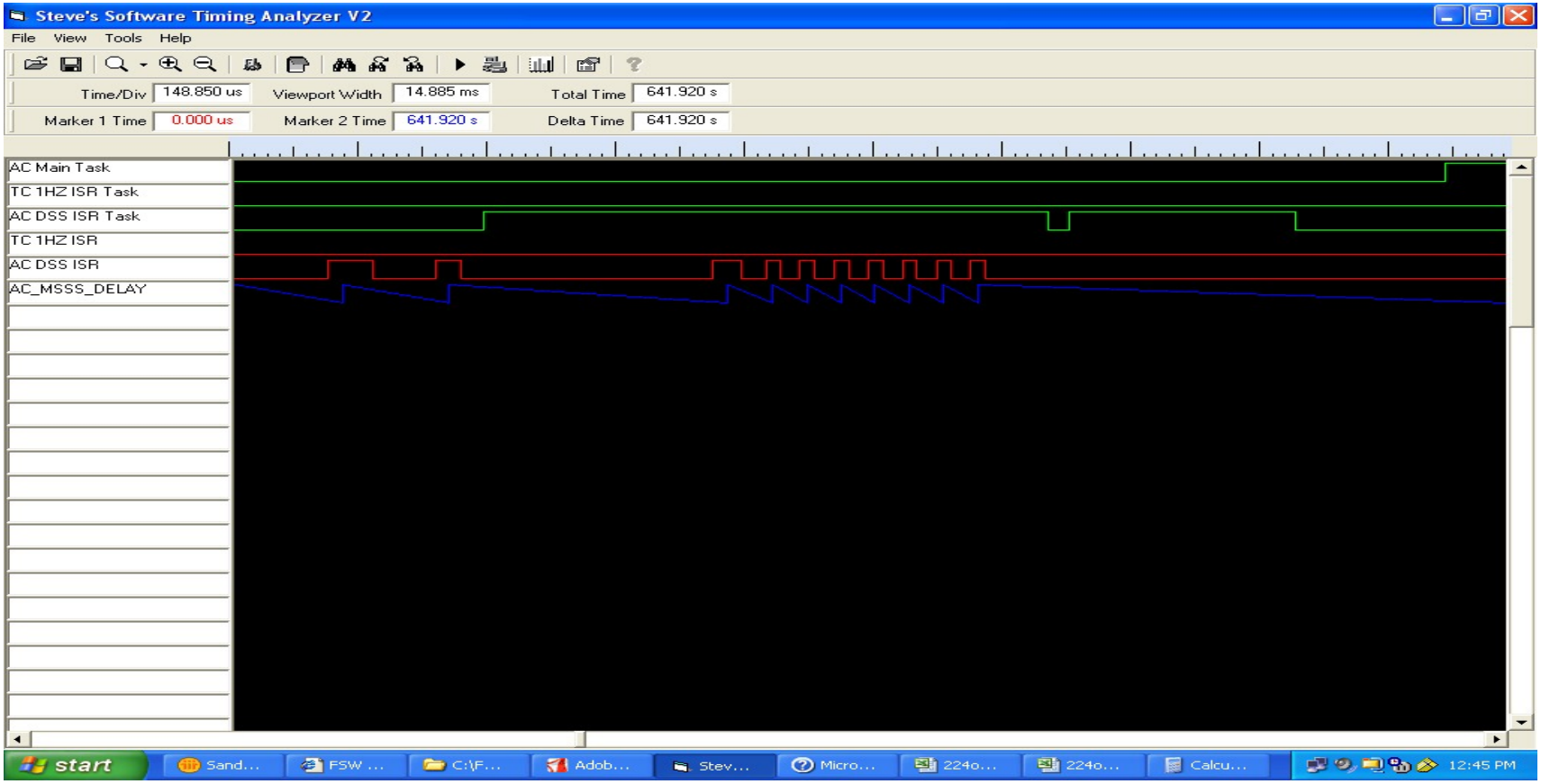
Timing Data Example



Spurious pulse precedes real pulse by about 0.66 seconds

Patches and Workarounds (4 of 5)

Zoom View of Spurious Pulse from Previous Plot



This spurious pulse consists of 10 separate flashes over 7.9 msec

Patches and Workarounds (5 of 5)

- GN&C team derived changes to ACS sensor and control parameter values to work around DSS malfunction
- FSW team generated table loads to implement the parameter changes
- The parameter changes worked well enough to allow normal mission operations to continue
- FSW team also developed a replacement DSS ISR task to filter out spurious sun pulses
  - New DSS ISR task was successfully installed and tested in FSW lab
  - Since ACS parameter changes were successful, mission management elected not to uplink the new task to the spacecraft

Multi-bit Error Events (1 of 6)

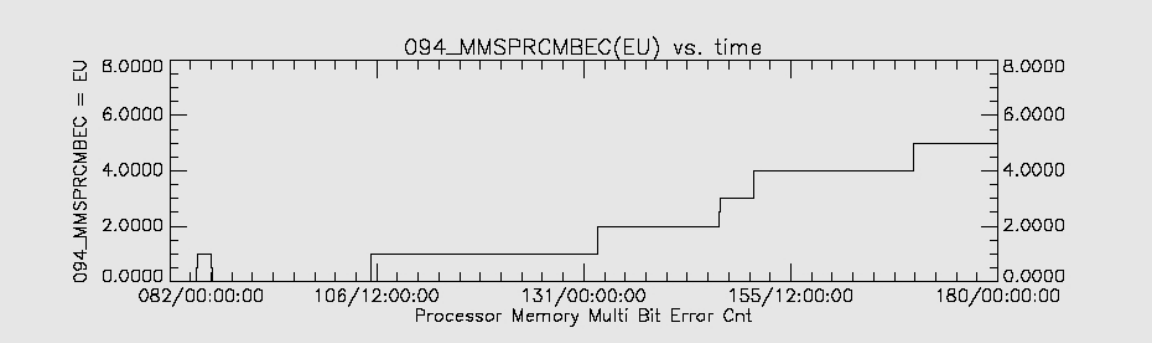
- ST5 supported 3 types of software/processor restarts
  - Warm restart
    - Code copied from EEPROM to processor RAM
    - Data in processor RAM not affected
    - Warm restart does not interrupt spacecraft operations
    - Warm restart wipes out any code patches in RAM
    - Warm restart triggered in response to MBE in processor RAM
    - 5 warm restarts force a cold restart
  - Cold restart
    - Code and data copied from EEPROM to processor RAM
    - Operations interrupted, but recorder memory not affected
    - 5 cold restarts force a soft power-on restart
  - Soft power-on restart
    - Same as hitting reset button on processor board

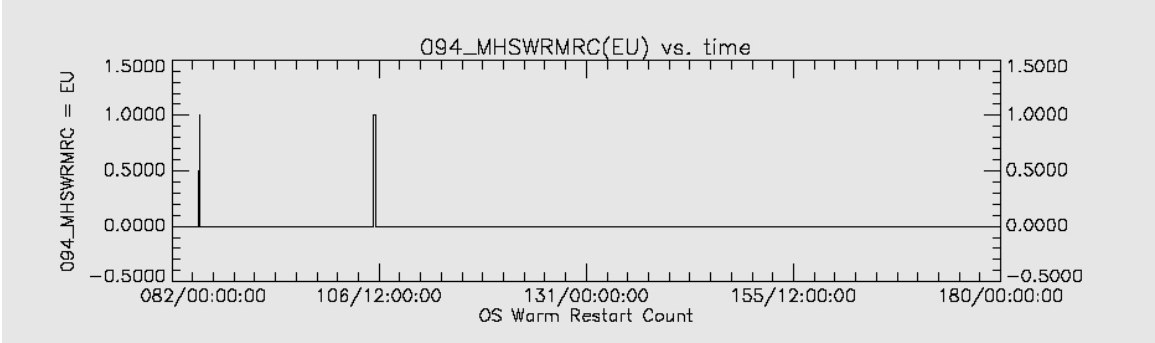
Multi-bit Error Events (2 of 6)

- ST5 spacecraft orbited through Van Allen belt
  - MBEs in recorder and processor RAM were frequent
  - Warm restarts required reloading of FSW patches
- Memory Scrub task response to MBE specified by a parameter table
  - Address ranges identified as “processor” or “recorder”
  - MBE action specified as “restart” or “no restart”
- FSW code and data occupied only 21% of processor memory
- FSW team suggested modifying MS table to flag unused processor memory as “no restart”
  - Should reduce occurrence of warm restarts by factor of 5
  - Table change uplinked to spacecraft on L+34

Multi-bit Error Events (3 of 6)

Processor MBE and warm restart counts, spacecraft 094

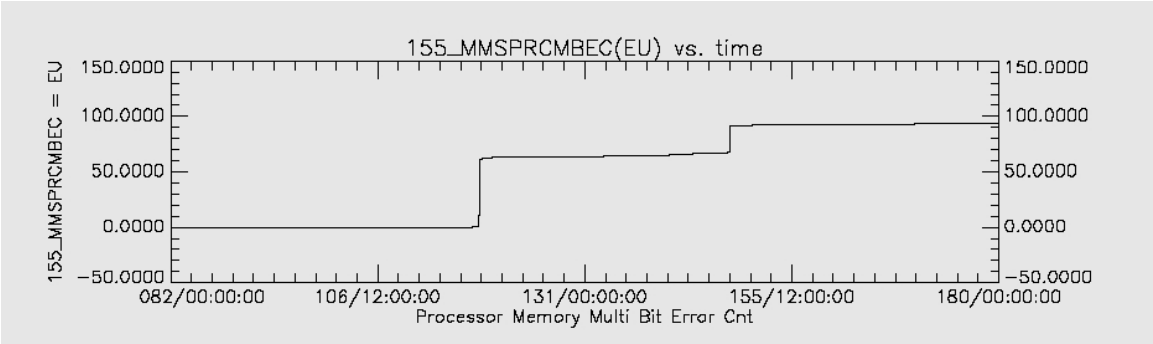


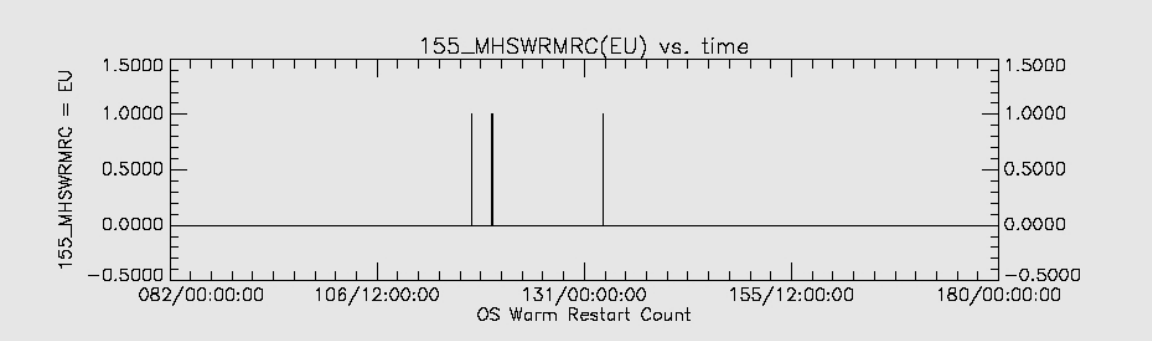


Spacecraft 094 experience soft power-on on DOY 89; MS table was updated on DOY 117

Multi-bit Error Events (4 of 6)

Processor MBE and warm restart counts, spacecraft 155

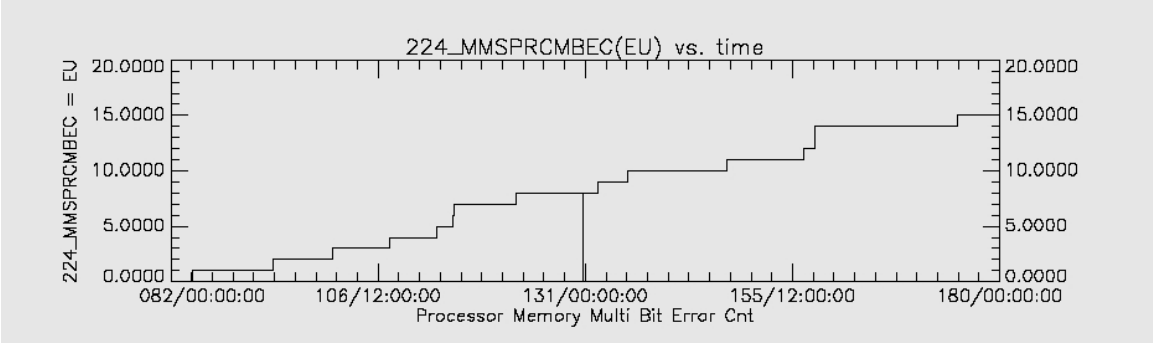


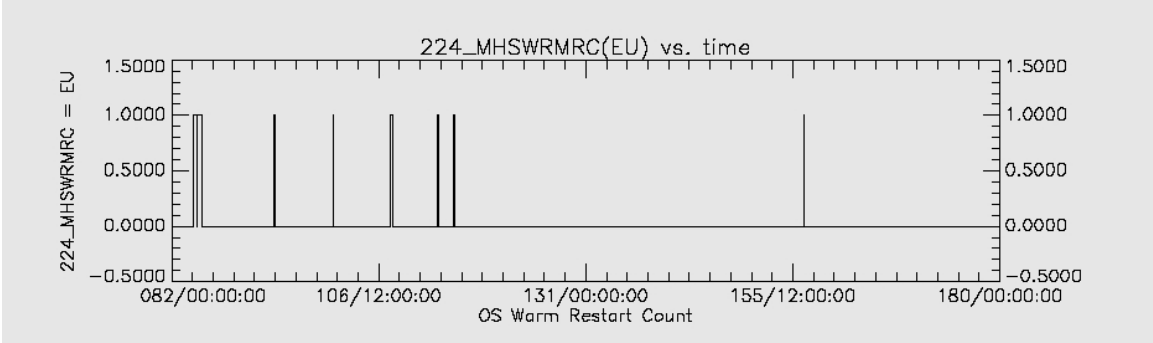


MS table was updated on DOY 117

Multi-bit Error Events (5 of 6)

Processor MBE and warm restart counts, spacecraft 224





MS table was updated on DOY 117

Multi-bit Error Events (6 of 6)

- Table below summarizes MBE and warm start counts after uplink of MS table change
  - Note: GSCID was an arbitrary ID number assigned to each spacecraft by the ground system
- None of the 3 spacecraft experienced a cold start or soft power-on after the MS table change

GSCID	# Processor MBEs	#Warm Starts
94	4	0
155	92	3
224	8	1

Conclusion

- ST5 mission operations terminated on June 30, 2006
- All science and engineering test objectives were met
- On-orbit maintenance of FSW contributed significantly to mission success

Even a 90-day mission can benefit from FSW maintenance