ACS VOD Tiger Team
Status Report to SMOV Meeting

June 10, 2009
ACS VOD Questions

• Does CCD Reset Drain (VOD) anomaly imply any elevated risk of ACS degradation or failure in:
  – Infinite flush (current state)?
  – Activities currently planned for 166 SMS?
  – Activities contained in remaining required ACS-R SMOV optimization?
Tiger Team

- ACS-R SMOV team
  - Edward Cheng
  - Markus Loose
  - Augustyn Waczynski
  - Kevin Boyce
  - Erin Wilson
  - Kathleen Mil
  - Linda Smith
  - David Golimowski
  - Tom Wheeler
  - Barbara Scott
  - Darryl Dye
  - Steve Arslanian
  - Olivia Lupie
  - Ed Cheung
  - Bev Serrano
  - Ike Orlowski
  - Ken Albin
  - Art Whipple
  - Roger Chiei
  - Randy Kimble
Going in Plan

✓ ACS-R SMOV team summarize VOD anomaly and other ACS SMOV results to-date

✓ Tiger team develop fault tree to identify possible causes of VOD anomaly

✓ Determine if any identified possible causes imply risk from infinite flush
  – ACS-R team summarize current state of WFC
  – Tiger team identify risks and conduct activities required to retire risks

✓ Determine if any identified possible causes imply risk from the planned 166 SMS activities
  – STScI summarize current ACS plans for 166 SMS
  – Tiger team identify risks and conduct activities required to retire risks

• Determine if any identified possible causes imply risk from the remaining required SMOV optimization
  – ACS-R team summarize remaining required SMOV optimization
  – Tiger team identify risks and conduct activities required to retire risks

• Return to ACS-R SMOV
Meetings

• **June 8**
  – 8:00 – 9:00: Kick-off and overview of anomaly
  – 10:30 – 1:00: Detailed look at Visit D data, start on fault tree
  – 2:00 – 5:00: Review of DCL test results, fault tree

• **June 9**
  – 8:00 – 10:30: Review of engineering telemetry, voltage monitor circuit model, BATC ground testing
  – 2:00 – 4:00: Review of DCL and ESTIF test results, assessment of 159 intercept and 166 SMS, write Wed SMOV status report
Observables

• **Unexpected data obtained from quadrants C and D during May 28 bias voltage optimization activity (Optimization Campaign 1, Visits D)**
  – Occurred only when CCD Reset Drain voltage (VOD) commanded to +14.1 V (-1 V from nominal +15 V)
    • CEB-R generated voltages are measured and telemetered with an accuracy and resolution of better than 0.1 V
    • All voltages were nominal
      – Note: voltages are not sampled during CCD readout to prevent noise injection into CCD data
  – **Quadrant C (bias and flats) showed:**
    • ~4X elevated counts, with no structure, in prescan region
    • ~4X elevated counts, with column structure, in image region
      – Column structure is repeatable from exposure to exposure and between bias and flats
  – **Quadrant D (bias and flats) showed:**
    • Elevated counts, with step, in prescan region
      – Step seen in other nominal images in columns closest to amp D
    • Depressed counts in image region, image is inverse of normal flat (bright features are dark and visa versa)

• **Images from quadrants A and B are nominal with VOD at 14.1 V**

• **Data is nominal in all quadrants for all other VOD settings**
  – Exception is first row read-out on all amp D and some amp A images are anomalous
Possible Causes - 1

- **Lower VOD levels alone cannot cause the column pattern in quadrant C**
  - CCD output amplifier is on serial shift, perpendicular to column structure
  - Would affect prescan region

- **Lower VOD levels can prevent the CCD output amplifier to reset properly and could cause inverted image effect seen in quadrant D**
  - However:
    - No history of similar anomalies during BATC ground testing of ACS
    - DCL test on ACS flight spare of VOD change from 15V to 10V did not produce charge injection effect observed on-orbit but did reproduce baseline shift observed in prescan of quadrant D
    - Over-saturated registers (e.g. from Charge Injection) can also cause improper CCD output amplifier reset

- **To knowledge of Tiger Team, observed column pattern is uniquely caused by Charge Injection; changing potentials of CCD Overflow Drain (VOFD) and/or Transfer Gate (TG)**
  - Included in SITe CCD design to permit rapid charge dumping during CCD flush (not used for ACS)
  - Proper function on ACS flight spare detector verified at DCL
  - Affects both halves of CCD chip
    - However, improper CCD output amplifier reset could explain lack of column structure in quadrant D
  - Charge Injection caused by changing potentials is normally repeatable from exposure to exposure, as observed on-orbit
  - Charge Injection caused by changing potentials does not affect prescan region, as observed on-orbit
    - Prescan pixels deliberately not connected to overflow drain
Possible Causes - 2

- No connection between VOD and VOFD or TG by design
- **Anomalous connections could be caused (in order of likelihood) by:**
  - Pre-existing condition(s) in CCD camera head, cabling, or CEB mother board
    - No previous instrument level ground or on-orbit variation of CCD voltages performed
  - ESD damage during EVA
    - Only 20 V required to destroy CCD, degradation due to lower levels cannot be ruled out but cannot be assessed
  - Radiation damage
    - Unlikely to change any potential by > 0.5 V which is not enough to explain on-orbit behavior
    - Unknown effects cannot be ruled out but cannot be assessed
  - Open in CEB-R or CCD camera head
    - Allowing capacitive coupling between VOD and VOFD or TG
    - However, DCL testing showed:
      - When TG is floating (but VOFD is nominal) no change is observed under normal conditions or, with VOD lowered to 10V
      - When VOFD-CD is floating (but TG is nominal -7V) image in CD is fully saturated under nominal biases
  - Short in CEB-R or CCD camera head
    - Unlikely since circuit modeling of bias voltages shows voltage at CCD should differ from sensed voltages by no more than ~2V
    - Clock voltages are not read back but CCD read-out is normal
  - **Wiring error in CEB-R**
    - DCL article (EM3) should be identical, does not show effect even when VOD varied, does show Charge Injection when TG varied
    - ESTIF article (EM2) test varied and directly measured CEB-R output voltages – all nominal
      - Test of design, not flight implementation
    - Expected effects from crossed lines still to be analyzed
  - **Coding error in SIDECAR ASIC**
    - Could cause inverted image seen in quadrant D but not Charge Injection effect seen in quadrant C
    - Very unlikely to be turned on and off by changing VOD
    - Errors would be replicated in DCL version of SIDECAR
VOD anomaly does not imply sufficiently elevated risk of ACS degradation or failure in Infinite Flush mode to warrant powering off CEB-R (unanimous finding communicated to HSTP on 6/8/09)

- **Arguments against powering off CEB-R**
  - CEB-R is currently configured to a state at which no anomalies have been seen
    - Verified by D8 visit during Iteration 1 and nominal Iteration 2
  - Monitored currents and voltages have been within limits for the ~3 weeks that ACS has been running in this state
  - Anomaly could be caused by something in CEB-R that would degrade further by power cycling

- **Arguments for powering off CEB-R**
  - Have not yet (as of 6/8/09) shown that an unsafe voltage condition on the CCD would be detected
    - Have since shown that hazardous short circuits would be detected but that open circuits might not
  - CEB-R on is not required for currently (159 SMS) executing SMOV activities
  - CEB-R is powered off for anneals and SBC power cycling
  - Cannot rule out degradation of internal CEB-R components with operating time without identifying root cause
Safety of 159 Intercept and 166 SMS ACS Activities - 1

• Assessed against identified possible causes of VOD anomaly
  – Pre-existing condition in CCD camera head, cabling, or CEB mother board
  – Open in CEB-R or CCD camera head, cabling, or CEB mother board
  – ESD damage during EVA
  – Radiation damage
  – Short in CEB-R or CCD camera head, cabling, or CEB mother board
  – Wiring error in CEB-R
  – Coding error in SIDECAR ASIC

• SMS 159 intercept:
  11510 - external CTE check (first external visit)
  11371 - external cross-talk

• SMS 166:
  11369 - CCD functional (internal)
  11465 - CCD monitor (runs every 2 days - internal)
  11379 - WFC focus + FGS alignment (external)
  11374 - Flat field stability (internal)
  11398 - SBC: Sensitivity, geometric distortion + FF verification
  11196 - SBC: GO science
  11791 - SBC: GO science

• CEB-R power cycles associated with SBC operations
Safety of 159 Intercept and 166 SMS ACS Activities - 2

• **Operation of WFC with default voltages and timing patterns appears to be safe**
  – Performance of WFC when operated with default voltage settings was identical and nominal in both Iterations 1 and 2 of Optimization Campaign (OC)
  – Indicates anomaly in amps C and D noted in Iteration 1 when VOD was lowered to 14 V had no lasting or degrading effects on WFC performance

• **Performance Summary (Visit Group A of OC) contained WFC exposures recorded with various combinations of parameters:**
  – Gain (1 or 2)
  – Correlated Double Sampler (CDS) mode (dual-slope integration and clamp & sample)
  – Readout timing patterns (4-amp full frame, single-amp subarray, and single-amp full frame Extended Pixel Edge Response (EPER))
  – Readout speeds (full and half)

• **SMOV programs remaining in SMS 159 and SMS 166 utilize only camera modes verified as safe and operational in the Performance Summaries of Iterations 1 and 2, with one exception**
  – 11369 CCD Functional Test contains exposures obtained with First-Pixel Response (FPR) timing pattern, which was not tested in Iterations 1 and 2
  – FPR exposures are recorded with same default bias and clock voltages used in OC Iterations 1 and 2, so no reason to doubt safety of FPR timing pattern

• **No concern regarding CEB-R power cycles**
  – SBC powered off if no future SBC observation within 100 minutes
  – WFC CEB-R powered off as part of subsequent SBC power-on
Conclusion

• Tiger Team unanimously recommends resumption of ACS-R SMOV
  – Real-time commanding to reset offsets to full speed readout values for supporting normal science operation
  – 159 intercept SMS to perform external CTE check and cross-talk measurements
  – Nominal 166 SMS
Backup
System Block Diagram
Clocks and Biases Defined

- **VOD** - Bias applied to CCD Reset Drain, (often called VRD)
- **VDD** - Bias applied to CCD Output Drain
- **VOS** - CCD video signal output
- **VLG** - Bias applied to CCD Last Gate
- **RG** - Reset Gate for CCD amplifier
- **SW** - Summing Well gate
- **Sx** - Serial Register Clock gates
- **Px** - Parallel Register Clock gates
- **TG** - Transfer Gate controlling CCD overflow drain
- **VOFD** - Bias applied to the CCD overflow drain
DCL Testing Reproduces Anomalous Effect

- ACS flight ‘dark’ image with VOD=14.1V

- ACS flight spare ‘dark’ image with VOFD=12V and TG=0V – DCL testing
Quadrant D Flats Are Inverted When VOD = 14.1 V

OC 1 Visit D4 (VOD = 14.1 V)  OC 1 Visit D8 (VOD = 15 V)