Flight Note

FLIGHT NOTE NO.	417
SUBJECT	December 2002 DPA-A Turn Off Anomaly Report
DATE	03-25-03
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Summary

On December 19, 2002, the primary ACIS Digital Processing Assembly (DPA-A) unexpectedly powered off between science observations and not during a real-time communications pass. This is the second occurrence of this anomaly, which was first witnessed on October 26, 2000. As was discovered in 2000, the most likely cause was isolated to a Single Event Upset (SEU) to the ACIS Power Supply and Mechanisms Controller (PSMC).

Background

Detailed workings of the DPA and PSMC can be found in Flight Note 394, which first described the anomaly (Ref [5]).

Timeline

Table 1 has the timeline of the events surrounding the anomaly. At the time of the anomaly, the OCC was not in communication with Chandra. The problem was not discovered until the scheduled pass with DSS-34 (Canberra). The on-duty Operations Controllers noticed that DPA-A was off via a limit violation during the routine State of Health check. The GRETA limit exception monitor displayed the unexpected state of the DPA-A on/off status. The controllers noted the limit exception and notified the spacecraft Systems Engineer who happened to be in the control room at the time.

The SOT was contacted regarding the anomaly, and contingency plans were put in place. The OC scheduled extra communications time on DSS- 27 (Goldstone). During the pass, the SOT was able to restore ACIS to an operational state using CAP 818 and CAP 548. Based on the fact that the anomaly occurred at the beginning of a perigee passage and was immediately recognized by the on duty controller, there was no interruption to the observing schedule, which was still running in the OBC and there was no science loss due to the anomaly. Operations were resumed prior to the ascending leg CTI.

Time (GMT)	Event
2002:353:19:53	Radmon Disable
2002:353:20:20	Start maneuver to OBSID #60915
2002:353:23:18	DPA-A turns off
2002:354:00:00	AOS on DSS-34 OC/CC discover anomaly
2002:354:01:00	LOS on DSS-34
2002:354:06:00	AOS on DSS-27
2002:354:06:38	Execute CAP #818 - DPA-A commanded back on, ACIS FSW event histogram and CC 3x3 option patch rev B uplinked, DEA housekeeping loaded and started
2002:354:06:48	Execute CAP #548 - Reset ACIS Focal Plane to -121°C
2002:354:08:00	LOS on DSS-27
2002:354:11:50	Radmon Enable

Table 1 - Event Timeline

At the time of the anomaly, a typical observing schedule was running onboard. The spacecraft was in the radiation belts and had already completed the descending leg CTI, observation #60915.

Even though Chandra was in the nominally elevated radiation environment of the radiation zone, the external radiation environment was even more elevated due to recent solar activity. On Dec. 19, 2002 a long duration M2.7 X-ray event occurred and was accompanied by a full halo Coronal Mass Ejection (CME). A weak shock from the CME passed the Earth 3 days later on Dec. 22nd. Hard and soft proton levels had only started rising shortly before the DPA turned off. **Figures 1 and 2** show the electron and proton environment as measured by EPHIN during the event. Peak radiation can be seen at approximately 06:30 GMT on day 354. Although elevated, the radiation level experienced by the vehicle during the time of the turn off was not atypical, in fact EPHIN levels were at least an order of magnitude less than what is typically seen during nominal transit of the Van Allen belts. It is not believed that the slightly elevated radiation was a significant contributor to the event.

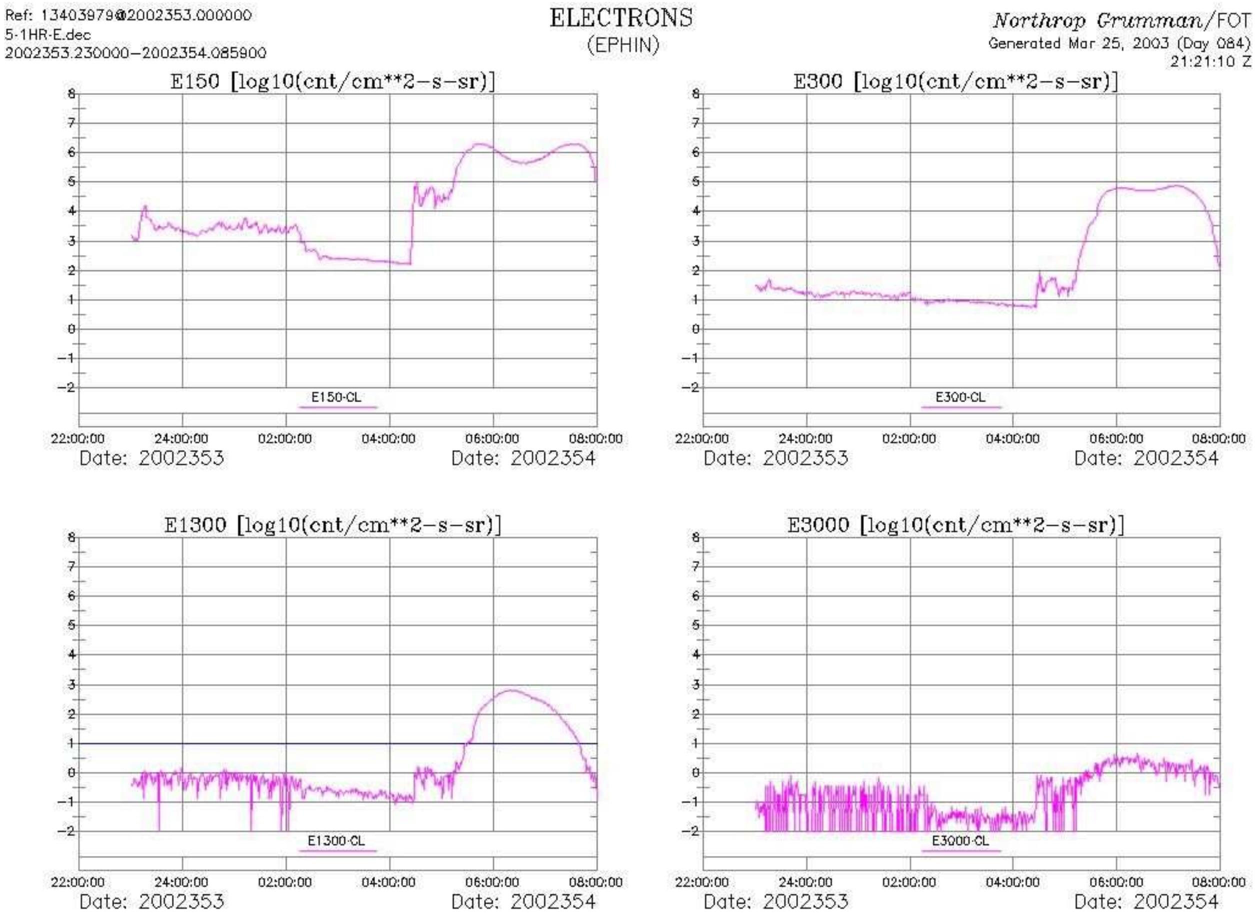

Figure 1 – EPHIN Electron Channels

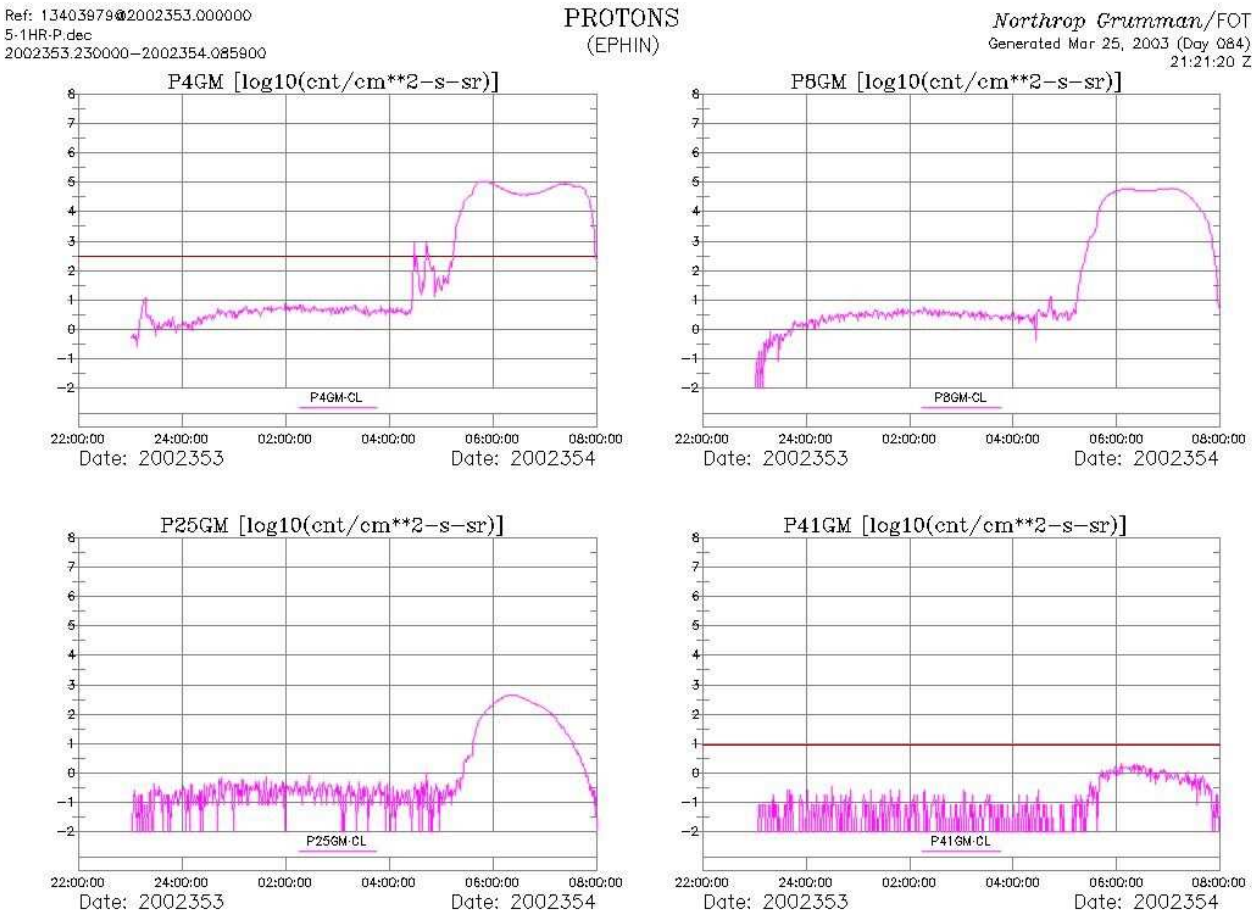

Figure 2 – EPHIN Proton Channels

Figure 3 shows the DPA-A voltage, current, and on/off indication telemetry for the day of the anomaly. The upper plot shows both the voltage (msid 1DPPOAVO) and current (msid 1DPICACU) dropping directly to 0 from their normal values. DPA-B voltage (msid 1DPPOBVO) stays at approximately the same value and DPA-B current (msid 1DPICBCU) drops to approximately 0.3A. The reason for the B-side voltage and current drop is that the Back End Processor (BEP) "in control", controls the switches that power all six Front End Processors (FEP) (it controls the power switches, not the source of the power). So if BEP A is in control, and it loses power, the power switch command for all six FEPs goes off. The upper plot also shows that the A-side current returned to its normal “thermal standby” level when CAP 818 was executed at 354:06:40, as expected. The lower plot shows that the DPA on/off status (msid 1DPPSA) goes to the "OFF" state at the same time as the voltage and current drop-off. In summary, the DPA-A turn off appeared to be a "nominal" turn off. The DPA-A acted just as it would if it received the DPA-A turn off command from the ground.

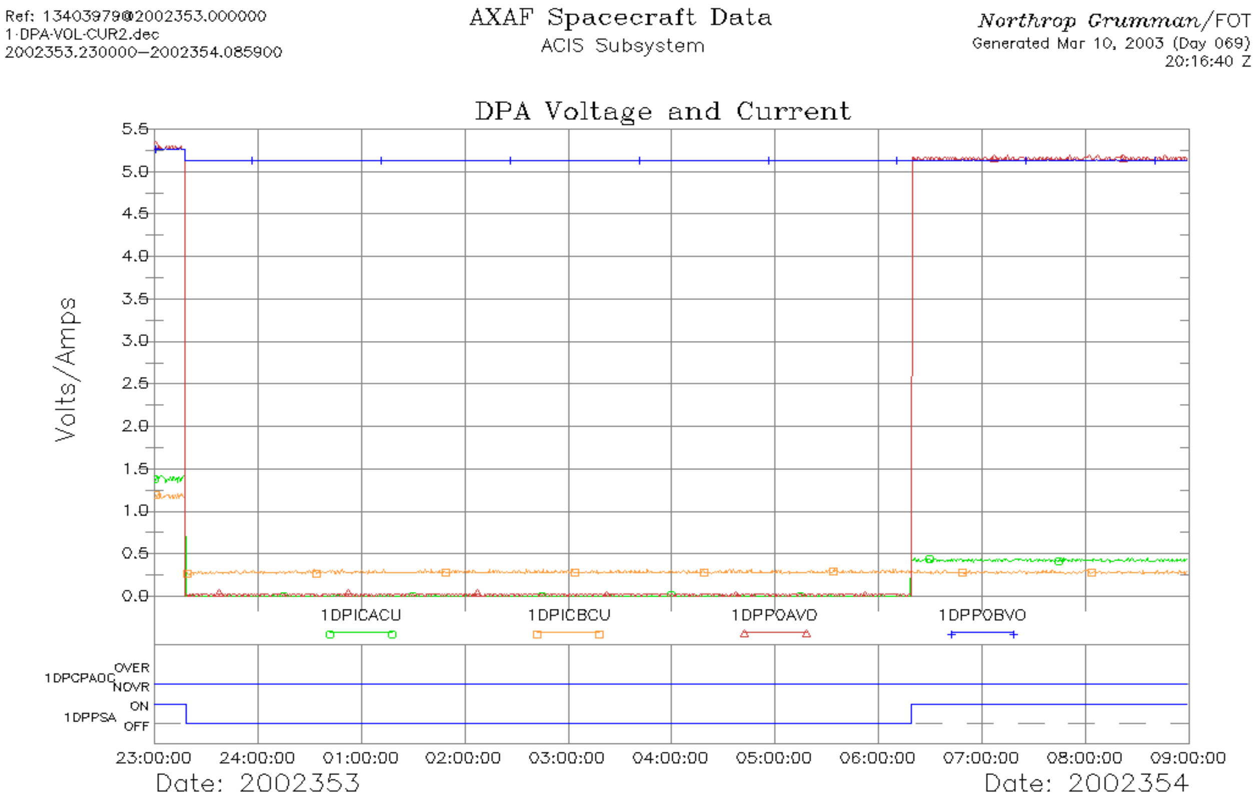

Figure 3 - DPA-A Voltage and Current

Fault Tree

The fault tree developed for this anomaly is shown in **Figure 4**. The fault tree approach is used to ensure that all possible causes of the anomaly are listed and addressed. Criteria for exonerating each possible cause are developed. Below, each box on the fault tree is addressed.

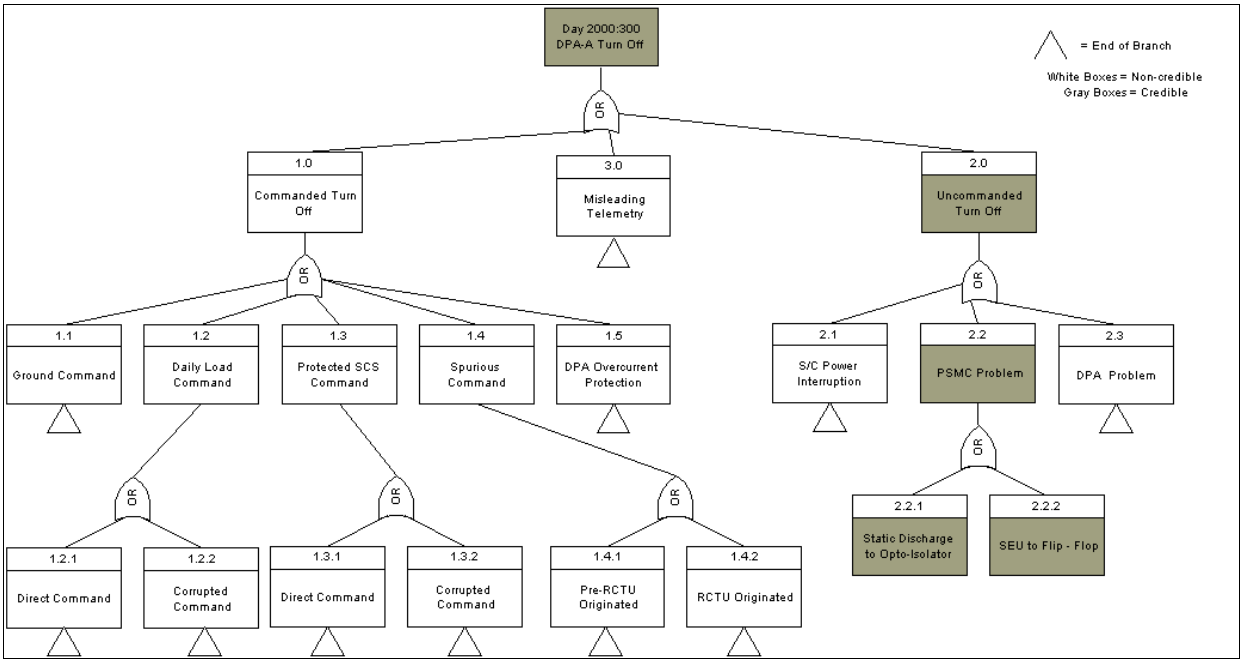

Figure 4 - Fault Tree

1.0 Commanded Turn Off - This branch lists possible causes of the DPA-A power off command being issued to the PSMC.

1.1 Ground Command - This branch represents the case of a real-time DPA-A power off command being issued to the spacecraft. This case is considered to be **non-credible** because:

The spacecraft was not in contact with a ground station at the time of the anomaly. A snapshot of the command lock telemetry in **Figure 5** shows that the receivers were not locked onto an uplink carrier (msid CRXACL=CRXBCL="NLCK").

The CTU command counter did not increment. A plot of the CTU command counter and command reject counter in **Figure 6** shows that no commands were received by the CTU at the time of the anomaly.

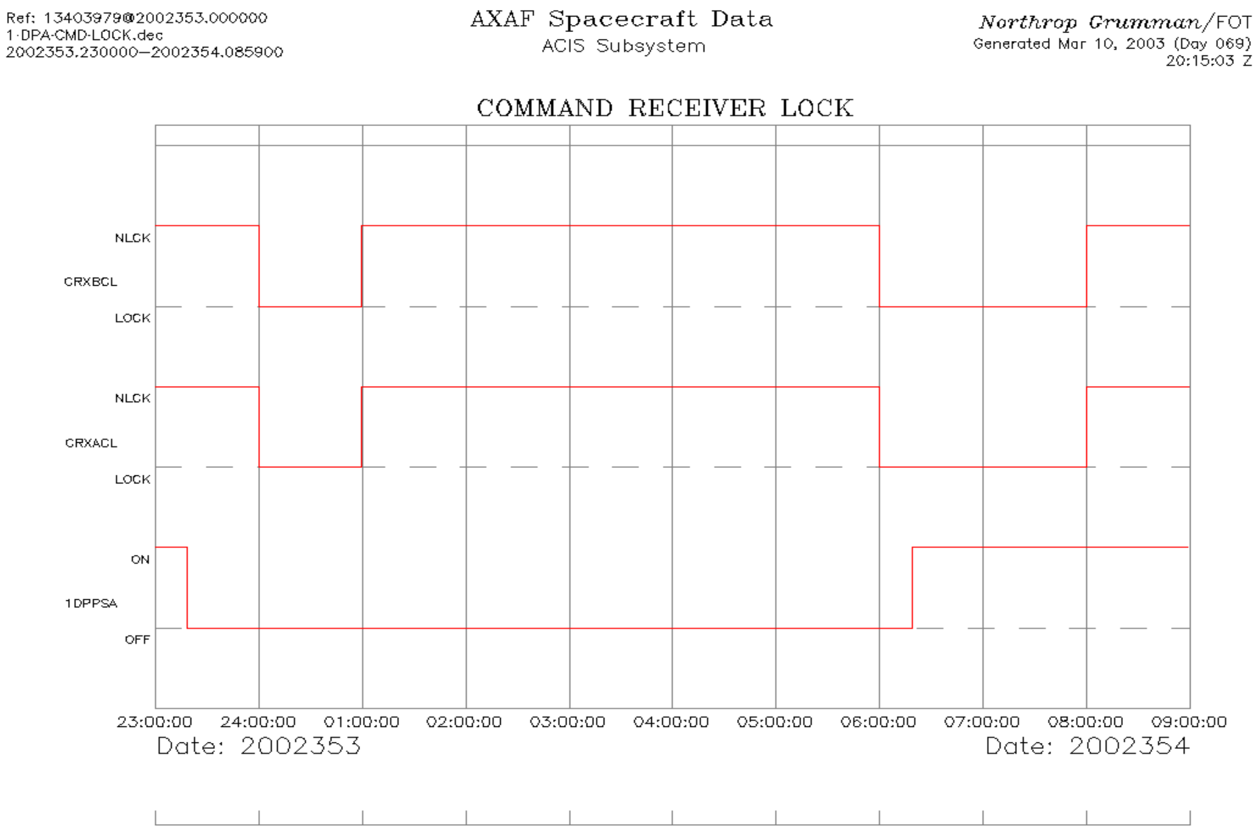

Figure 5 - Command Receiver Lock

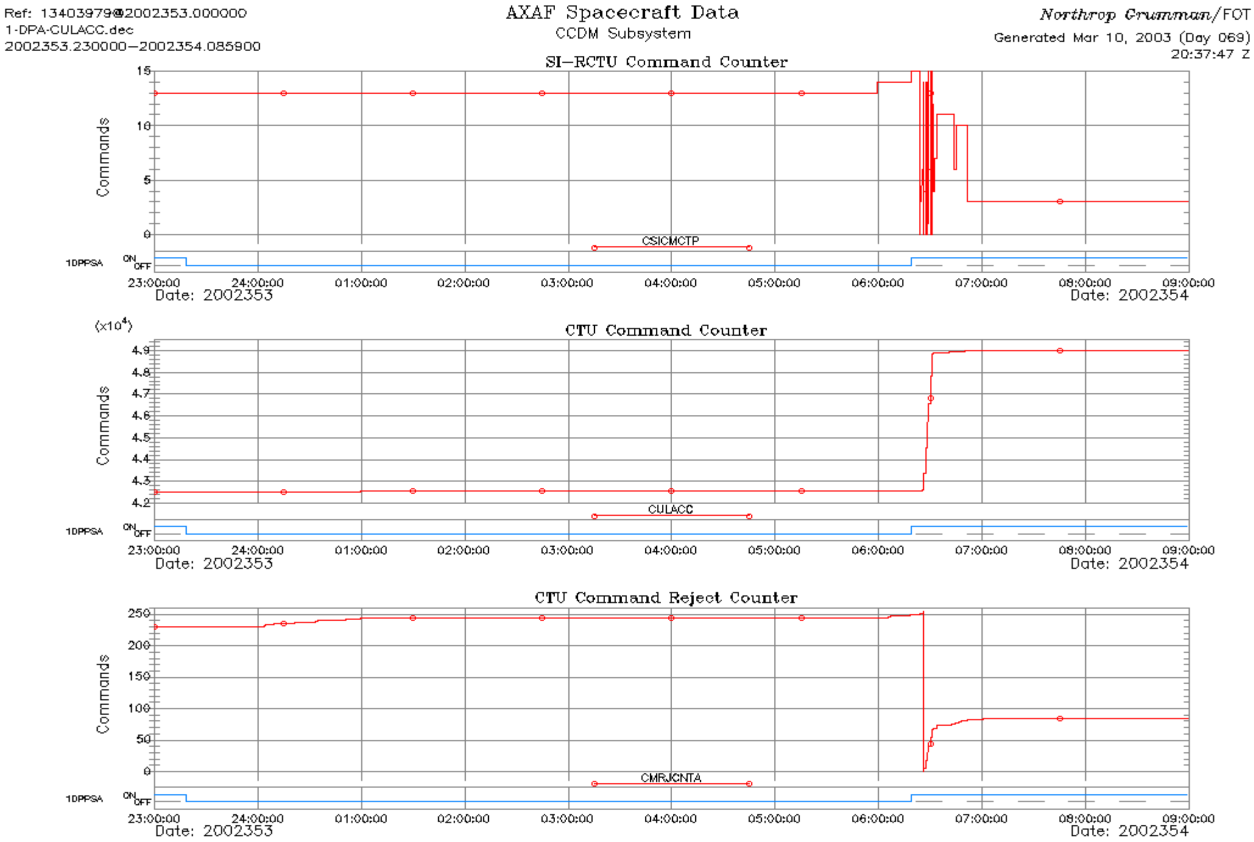

Figure 6 - CTU Command Accept and Reject Counters

1.2 Daily Load Command - This branch lists possibilities for the DPA-A off command to have come from the daily load running on-board at the time.

1.2.1 Direct Command - This branch represents the case that the DPA-A off command was actually included in the daily load running on-board. This case is **non-credible** because:

Review of the daily load shows that the command to turn off DPA-A (1DPPSAOF) was not included. **Table 2** is a listing of the commands in the daily load near the time of the anomaly. There were no commands issued from the daily load for more than 37 minutes prior to the anomaly.

Time (GMT)	Command	Description
2002:353:19:58:16	AOMANUVR	Start maneuver to OBSID #60915
2002:353:20:01:06	AOACRSTE	Set OBSID to 60915
2002:353:22:40:58	ACISPKT	Last Command of ACIS Packet
2002:353:23:18:00		DPA-A turns off
2002:354:05:28:06	AOACRSTD	ACA Reset Command

Table 2 - Daily Load Commands Surrounding the DPA-A Anomaly

1.2.2 Corrupted Command - This branch represents the case that the DPA-A off command was not included in the daily load running on-board, but that another command from the daily load was somehow corrupted into the DPA-A turn-off command. This case is **non-credible** because:

Referring again to **Table 2**, there were no commands issued from the daily load for more than 37 minutes before the anomaly. A corrupted command can not be delayed to be executed later. The commands are issued within a minor frame (128 ms) of their scheduled time.

Furthermore, if a command had been corrupted into the DPA-A turn off command, it would have been issued to the SI-RCTU. However, the SI-RCTU command accept counter did not increase at the time of the anomaly, as shown in **Figure 6**.

It should be noted that the OBC is constantly sending NO-OP commands to the SI-RCTU as part of the command wrap monitor function. The command wrap monitor is disabled when command lock with the ground is detected. The command wrap monitor sends out 1 NO-OP every minor frame or 32 NO-Ops approximately every 8 seconds. Also, the 4 bit (0-15) SI-RCTU command accept counter is inserted into the telemetry stream every 8 seconds. This means that if no other commands besides the NO-Ops are issued to the SI-RCTU, the command accept counter appears to remain constant. The counter rolls over to its previous value every 4 seconds due to the NO-Ops.

1.3 Protected SCS or FSW Command - This branch lists possibilities for the DPA-A off command to have come from a Protected SCS, which reside in checksummed OBC memory in slots 0 - 127 or from the flight software.

1.3.1 Direct Command - This branch represents the case that the DPA-A off command was issued from an protected SCS. This case is **non-credible** because:

Review of all protected SCSs and the flight software showed that the DPA-A off command is not present. Furthermore, the SI-RCTU command counter did not increment at the time of the anomaly, as shown in **Figure 6**.

1.3.2 Corrupted Command - This branch represents the case that the DPA-A off command was created by the corruption of a command from a protected SCS or the flight software. This case is **non-credible** because:

The SI-RCTU command counter showed that no commands were received at the time of the anomaly.

1.4 Spurious Command - This branch lists possibilities for the DPA-A off command to have come from a source other than the ground or the OBC.

1.4.1 Pre-RCTU originated - This branch represents the case that the DPA-A off command was issued to the SI-RCTU from a source other than the ground or the OBC. This case is **non-credible** because:

There were no unexpected commands received by the SI-RCTU. The SI-RCTU command counter did not increment at the time of the anomaly. Furthermore, the OBC would detect such spurious commands via the SI-RCTU command wrap monitor. If the SI-RCTU received a command not generated by the OBC, the command wrap monitor would have tripped, causing a swap to the redundant SI-RCTU and safing of the science instruments. Before launch, the three spurious command events resulted in increments of an RCTU command counter (Ref [3]).

1.4.2 RCTU originated - This branch represents the case that the RCTU produced the DPA-A off command by corrupting an incoming command. The RCTU vendor, BF Goodrich investigated this possibility, and the report can be found in **Appendix A** of Flight Note 394. This case is **non-credible** because:

The only commands being received at the time of the anomaly were NO-OP commands issued by the OBC as part of the command wrap monitor. For the NO-OP command to be corrupted into the DPA-A off command, three bit flips would have to occur in exactly the right locations. The report shows that although the possibility exists for SEUs in the RCTU, the likelihood of even a single bit flip is extremely low.

1.5 DPA Current Limit Monitor - The DPA has built-in overcurrent protection. If a current above the threshold is reached, the DPA will be turned off. This case is **non-credible** because:

ACIS telemetry contains an indicator of the running state of the overcurrent protection monitor as well as a flag that will be set if the overcurrent protection monitor is tripped. Neither of these telemetry values indicated an overcurrent situation. Furthermore, the DPA current telemetry was well behaved before the anomaly, as shown in **Figure 3**. The state of the overcurrent protection monitor is also shown the lower portion of **Figure 3 (**msid 1DPCPAOC).

2.0 Uncommanded Turn Off - This branch represents cases where the DPA-A turned off for any reason other than being commanded off from any source.

2.1 Spacecraft Power Interruption - This branch represents the possibility of the spacecraft not providing power to the DPA correctly. This case is **non-credible** because:

Telemetry shows that spacecraft power was constantly provided to the DPA power supply in the PSMC. Power from the spacecraft bus, at a nominal 28 volts, is gated and regulated to a 5 volt signal in the PSMC. The PSMC then provides the 5 volt power to the DPA. As shown in **Figure 7,** the power supplied to the PSMC by the spacecraft was not interrupted and the 28 volt bus had power before, during, and after the DPA-A turned off.

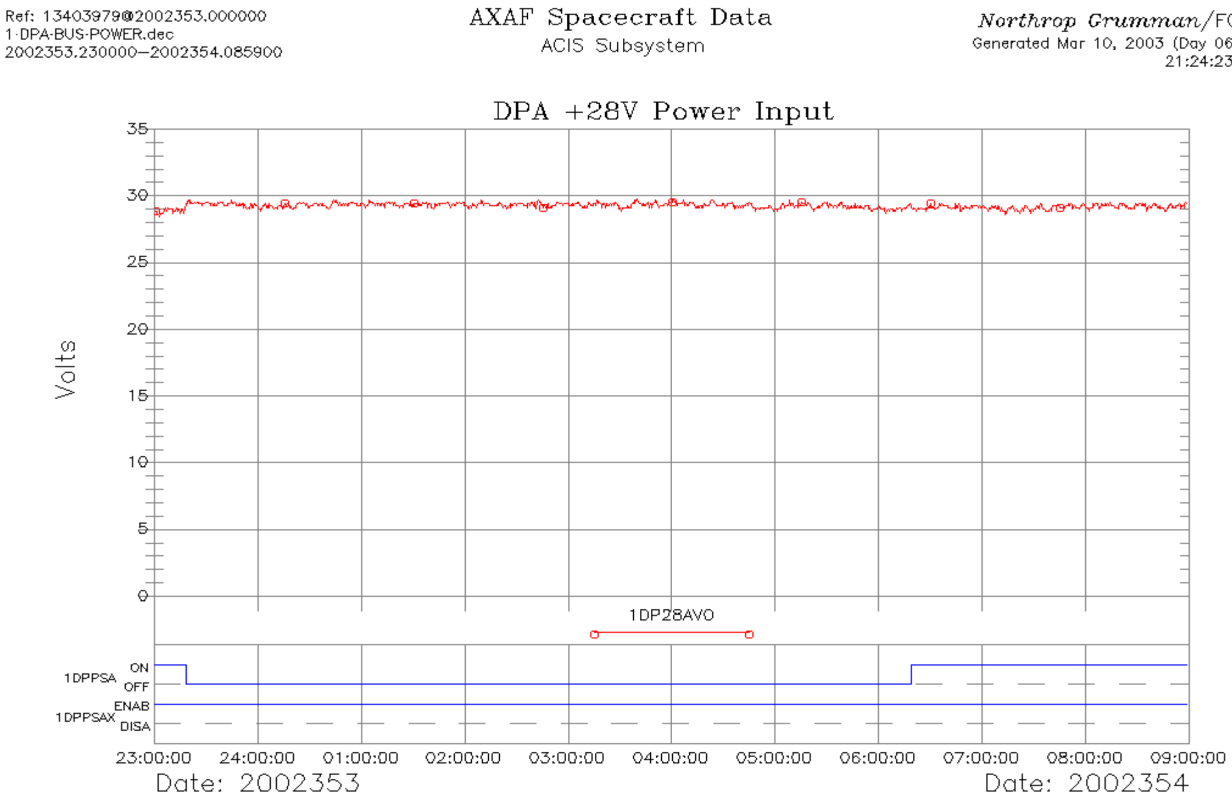

Figure 7 - Power Supply to PSMC

2.2 PSMC Problem - This branch represents the case that a problem internal to the PSMC caused the DPA-A to be turned off. As mentioned earlier, the PSMC switches power to the DPA with an opto-isolator and a flip-flop.

2.2.1 Static Discharge to the Opto-Isolator - Exposure to high energy electrons can result in significant spacecraft charging effects. Potential differences between spacecraft surfaces or between spacecraft surfaces and spacecraft ground can cause an electrostatic discharge (ESD) to occur. The transient generated by this discharge can couple into the spacecraft electronics and cause unwanted effects. This case hypothesizes that an ESD created a transient signal on the same input that would be created by a DPA-A off high level pulse command. This would trigger the opto-isolator which would send a signal to the flip-flop, turning the DPA-A off. This case is **credible** because:

It is essentially impossible to prove that this did or did not occur. However, the ACIS team believes that the PSMC is qualified to handle ESDs of the expected magnitude for our orbit. Furthermore, there have been no other ESD effects observed for the entire mission.

2.2.2 SEU to the Opto-Isolator - Energetic particles, such as cosmic rays, can produce spurious signals in electrical components. A common effect is a bit-flip, which is a reversal in the state of the silicon transistors in a flip-flop. This case hypothesizes that an energetic particle created a transient signal, which changed the state of the PSMC DPA-A power supply flip-flop, thus turning off DPA-A. This case is **credible** because:

It is essentially impossible to prove that this did or did not occur. The susceptibility of the PSMC flip-flops to energetic particles is not known from ground testing. However, using the rate of observed bit flips in bulk ACIS memory, the probability of a bit flip in a single memory element is very small.

2.3 DPA Problem - This branch represents the case that a problem internal to the DPA caused the DPA-A to be turned off. This case is **non-credible** because:

Telemetry from the PSMC indicated that the power had been removed from the DPA in the PSMC. There were no indications of an internal failure in DPA-A either before or after the anomaly.

3.0 Misleading Telemetry - This branch represents the case that the DPA was not actually off, but telemetry showed that it was. This case is **non-credible** because:

Both analog and bilevel telemetry showed that DPA-A was powered off. For example, **Figure 3** shows that the DPA-A voltage and current dropped out at the same time as the on/off status showed that the DPA-A was off.

Conclusion

The analysis conclusively showed that the DPA-A was not turned off by a command from any source. This includes commands from the ground, the daily load, the flight software, a spurious command from any source, and the DPA overcurrent protection. Furthermore, it was shown that the anomaly was not caused by an interrupt in the spacecraft power supply or by an internal DPA problem.

As it was in October of 2000, both an ESD to the Opto-Isolator and SEU to the flip-flop within the PSMC DPA power supply are considered to be credible causes of the anomaly. An SEU to the flip-flop is the more likely cause. There is supporting data to show that the PSMC would be resistant to ESD, but there is no data for the susceptibility of the flip-flop to SEUs.

As before, there are no recommended changes for mission operations. The normal FOT State of Health checks of the Limit Exception Monitor caught the reoccurrence of the anomaly. Since the DPA was powered up with no problems after this anomaly, the only mission impact of a reoccurrence is loss of science.

References

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