Status of HGA anomaly investigations on 2003-07-01

1. The anomaly started with the on-board HGA (High Gain Antenna) monitoring triggering a communications backup on May 4. It turned out that 2 encoder pulses were missing since May 1. The antenna is driven by 2 motors: one for the azimuth (Z-axis) and one for the elevation (Y-axis). The anomaly is on the Z-axis.
   The encoder is a disk with 2 holes mounted on the motor shaft giving 2 pulses per revolution. Between the motor and the antenna there is a harmonic drive with a reduction factor of 160. One revolution of the motor shaft corresponds to 1.5 ° movement of the antenna. Each motor revolution needs 240 steps, so we expect one encoder pulse every 120 steps.

2. After missing 2 pulses on the Z axis the encoder pulses returned for a short while (two pulses were seen), but they were 7 steps too early relative to the regular 120 steps interval. Then we missed an other pulse (the third one). The pulses came back again, this time exactly in phase with the original 120 steps interval between pulses.

3. There were two possible failure scenarios: either the motor has been stepping properly and the antenna has moved, but the telemetry was wrong, or the telemetry was right and we have actually been missing steps, i.e. the antenna was falling behind.

4. On May 25 we were at the extreme of the halo orbit, meaning that the antenna Z-axis had to start moving in the opposite direction from May 25 onward. In order not to loose evidence we decided to stop the antenna movements on May 25. A test was designed to measure the position of the earth in the antenna pattern by moving the spacecraft to +2° and -2° in yaw (corresponding to +2°and -2° extra in antenna azimuth) and moving the antenna Y axis in small steps while measuring the ground and on-board received signal strength. This test was performed on June 4. Beforehand we had calculated the expected results based on the two possible failure scenarios given above.
   We had expected that the antenna pattern would be symmetric w.r.t. the antenna Y-axis. The test result showed it was not. There seems to be a systematic offset in both Z- and Y-axes. Correcting for this offset, the test result was very close to the "antenna missing steps, TM OK" case.
   Note however that we do not have a measurement of the in-flight antenna pattern. During the spacecraft commissioning this test was skipped, based on the excellent performance of the RF subsystem so far. Looking later into the antenna pattern measurements done by Ericsson in 1993 it seems that the pattern could be offset from the mechanical center by one to several degrees. This puts the conclusion of the June 4 test in doubt.

5. On June 12 we resumed the nominal antenna pointing after a nominal station keeping and momentum management maneuver on June 11. We had to catch up for the measured offsets in the June 4 test. The antenna had to be moved 120 steps in Y and 234 steps in Z. The Y-axis movement performed as expected. On the Z-axis we got the first encoder pulse exactly where we expected it (accounting for the hysteresis due to the reversal of direction). However the second pulse, which was expected during this movement, did not come. During the following 2 regular movements we should have gotten the next encoder pulse on the Z-axis, but this one never occurred.

6. Based on the above, we knew it was an intermittent problem. Due to the uncertainty about the antenna pattern we still could not say categorically if it was a telemetry or a motor/mechanical problem. Therefore we planned to do a second off-pointing test on Wednesday June 18 , which should give us a second position of the earth in the antenna pattern. Together with the June 4 results we should be able to tell if the antenna moved properly or not.

7. On June 18 the second off pointing test was done. The spacecraft was moved from 0° to +2° in yaw. At this point the antenna Y-axis was moved first in the negative direction, then in the positive direction and back to the original position. The maneuver was completed by moving the spacecraft from +2° to -2° and then back to 0° in yaw. Before we had computed the ground

received signal strength for the cases antenna did not move at all since last received encoder pulse on June 12 and for the case where the antenna had moved properly. The test showed very clearly that the antenna had not moved at all in the Z-axis since June 12. Now it was clear it was either a motor electronics problem or a motor mechanical problem.

8. After the test we decided to switch to the B-side electronics. 130 steps were commanded in the positive Z direction in order to start the catch up with of the antenna position. The received ground signal strength increased slightly at the beginning of the move, but no encoder pulse occurred. Various attempts were made to move the antenna in both low and high speed. All of them were not successful. After consultation with Moog/Schaeffer (the motor manufacturer) we decided to increase the motor temperature by switching on the redundant heater and regulating on the nominal heater (control limits between 15° and 20°) and try again the next day.

9. In the morning of June 19 various attempts were made to command the motor in both low and high speed and with and without all electronic protections enabled. All of them were unsuccessful. The thermal settings were returned to their normal values (between 0° and 10° and only the nominal heater on, resulting in the heater on continuously and the motor temperature just below 0°). Schaeffer had confirmed that using both motor windings simultaneously, effectively doubling the torque, was no problem for the motor. The only way to get both electronics working together is to command the motor in low speed (1 stepper motor pulse per 10 seconds). We commanded 150 steps in low speed and did see the ground received signal strength increase continuously. After 78 motor pulses an encoder pulse occurred. After the movement completed the signal strength had increased by approximately 1.7 dB. Based on the previous history of the encoder pulses it could be concluded that the motor had actually moved about 20 steps in the first attempt on the B side before it got stuck again on June 18.

10. It was decided to move to the so called "sweet spot" at a Z-axis angle of –17.7°. If the antenna is left at this Z position it maximizes the periods of coverage over the year. This implies a high rate telemetry outage of about 18 days and a spacecraft roll of 180° every 3 months. A second 150 step movement was commanded energizing both motor windings. This was also successful. With still 171 steps to go it was decided to try 150 steps on a single winding. We tried the A side and no movement was observed. A final 150 step movement was commanded, again with both windings, and this was successful. The encoder pulses proved that the motor had not moved at all in the previous attempt using only the A side electronics. No more movements were commanded since the antenna Z position was now very close to the "sweet spot".

11. The next step in the investigations is to investigate if this is a thermal issue, i.e. by lowering the motor temperature we can get the motor to move with a single electronics. This should give more information if the problem is caused by a temperature dependent mechanical interference or by increased friction (lubrication) issue or by ….

12. From June 19 onward we have varied the temperature of the motor between –5 and 18 degrees in various steps. First we used thermostatic control: a lower limit where the heater switches on and a high limit where the heater switches off. We used both nominal and redundant heater in parallel, since the situation before the anomaly was the nominal heater on continuously with the motor just below 0 degrees (thermostatic control with low limit at 0 degrees and high limit at 10 degrees). Later we switched to duty cycle based thermal control. This gives a much more constant heat input to the motor instead of the thermal cycling caused by the thermostatic control. The first attempt to move the motor by -30 steps on a single winding succeeded on June 20. Since then all attempts to move it back by +30 steps at various temperatures have failed. The antenna is now at a Z-angle of –18.2 degrees

13. In the meantime we have done various tests with the DSN 70m and 34m antennas. The 70m antennas can only be used for downlink, we need a separate station for commanding. With a 70m dish we can get high rate telemetry via the omnidirectional LGA This means that whenever we have a 70m antenna we can dump the on-board recorder. On the 34m antenna we are able to

acquire medium rate telemetry via the LGA. So with a 34m antenna we get real-time scientific data. Also after the 26m antenna failed to acquire high rate telemetry via the HGA, the 34m antennas were still able to give us a few extra days of high rate TM via the HGA. So with the antenna at its present Z position of –18.2 degrees we get the following scenario:

- Normal operations with high rate TM via the HGA using 26m antennas until we loose the high rate TM
- Normal/reduced operations with high rate TM via the HGA using 34m antennas for a few days depending on 34m availability .
- Reduced operations with medium rate TM via the LGA using 34m and with high rate TM via the LGA using the 70m. During this period we will have to roll the spacecraft by 180 degrees
- Normal /reduced operations with high rate TM via the HGA using 34m antennas for a few days.
- Normal operations with high rate TM via the HGA using 26m antennas until we loose the high rate TM.

For this keyhole period the predicted dates are:
June 27 - June 30: High rate via HGA on 34m (actual dates)
July 1 - July 10: Medium rate via LGA on 34m
July 10 - July 14: High rate via HGA on 34m.

The next normal period is:
July 14 – Sep 22: Normal high rate via HGA on 26m

The following keyhole and normal periods are:
Sep 22 – Sep 27: High rate via HGA on 34m
Sep 27 – Oct 12: Medium rate via LGA on 34m
Oct 12 – Oct 16: High rate via HGA on 34m

Oct 17 – Dec 23: Normal high rate via HGA on 26m

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