Ku-band Open Loop Performance Assessment at Higher TDRS Eccentricities

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March 30, 2011

DI22/Communications and Tracking Group (CATO)

Questions for the Analysis:

- Can the TDRS network allow the orbits of the TDRS satellites go to a higher eccentricity of 0.0035 without impacting Open Loop operations at 150 Mbps?
  - Conclusion is “No”, not 0.0035 and supporting data analysis is provided.
  - Briefing recommends one-half that figure, 0.00175, to maintain 100% reliability for Open Loop at 150 Mbps.
- Can TOPO get some down-track accuracy relief to update their flight rule currently indicating that we can accept only 90 Km of down track error?
  - Conclusion is “Yes” because the original flight rule was written with Open Loop performance in-mind and today’s standard operating mode is autotrack, which offers a 2^0 search radius (~ 1234.8 Km).
  - Flight rule will be re-written to address the error budget for the unlikely case of Open Loop operations with a proposed error budget that indicates we can allow as much as 0.5 degrees of system (not Ku-band and not attitude) error.
    - Roughly 308.7 Km when supporting 150 Mbps.

Questions for the Analysis:

•Can the present system errors support Open Loop operations at a return link data rate of 300 Mbps?

- Conclusion is that some successful Open Loop passes could occur provided consideration of certain aspects of the system error budget;
  - The current return link at 150 Mbps affords approximately 10 dB of operational margin.
  - Upon increasing the data rate to 300 Mbps, expect a 5 dB drop in the return link signal level attributable to the standard link margin equation for the signal-to-noise (Eb/N_0) ratio, TRC design and TDRS filtering.
  - Testing to support this brief indicates that the carrier signal drops off by 3 dB at an average off-boresight angle of 0.4^0. (Assume this is representative of the return link.)
  - Currently, while studying TDRS 171 tracking for this report, the system would keep the Ku-band boresight within 0.4^0 of TDRS 100% of the time.

Questions for the Analysis:

•Can the present system errors support Open Loop operations at a return link data rate of 300 Mbps? (continued)

- Conclusion (continued)

  •Currently, TDRS 171 tracking accuracy is at 0.39^0, 3-sigma.

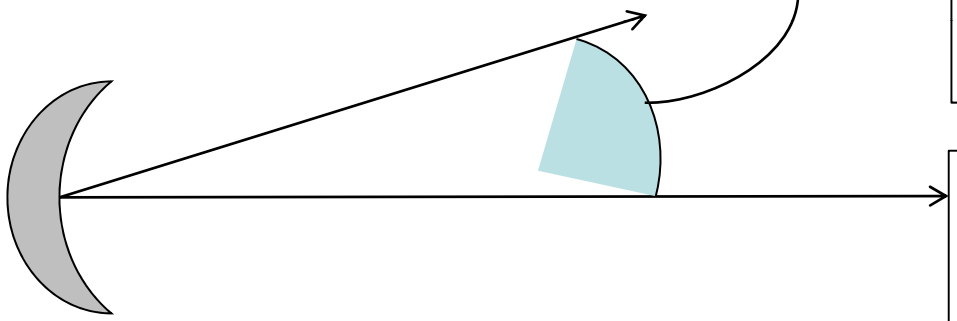
  •Resulting margin computation: 10 dBm – (5 dB for data rate increase) – (3 dBm for Open Loop pointing performance) = ~ 2 dBm margin.

  •Conclusion, based on performance using TDRS constellation last summer, during optimal conditions, some successful Open Loop events could occur at 300 Mbps on the return link.

Questions for the Analysis:

- What is CATO's mitigation plan for bandwidth management should Ku-band autotrack fail and we are forced to use Open Loop to support higher data rates?
  - CATO will develop a protocol for choosing a lower data rate based on system pointing performance at the time that Open Loop execution is mandated.
  - CATO will ask the team to attempt to improve the system's pointing performance
    - Possibly updating TDRS orbital parameters through state vector updates.
    - Possibly updating attitude filters to improve attitude estimates.
- This briefing recommends not increasing TDRS eccentricity at all beyond current values.
  - TDRS 171 current analytical value is 0.0023552, and we will show that this is very near the maximum we can tolerate.

Geometry and Definitions:



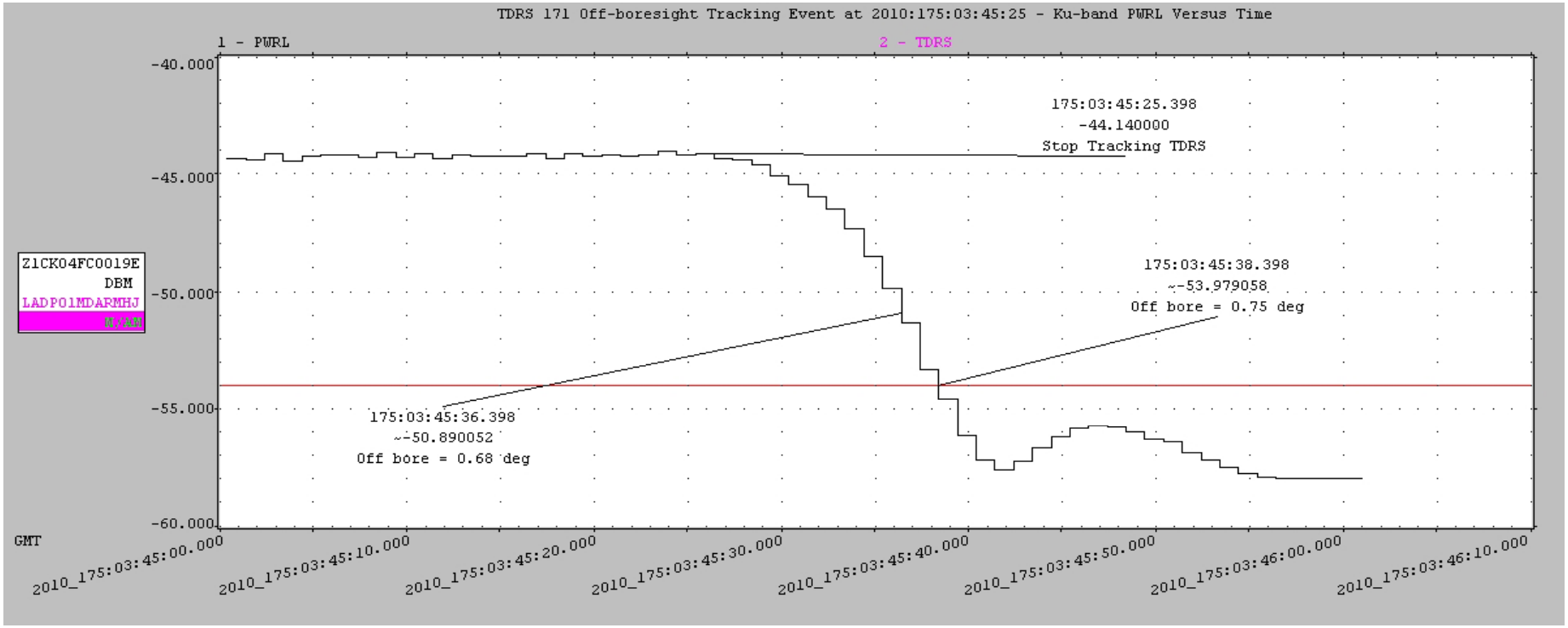
Ku-band Antenna

Half-cone angle – represents the performance tolerance of the Ku-band system, in degrees. Ultimately, the sum of the total system pointing error must “fit” into this value to support successful return link operations.

The boresight – unit vector representing specific direction of the focus of the parabola represented by the Ku-band parabolic dish

Example Analysis: TDRS 171 @ 2010:175:03:40

- Stopped Autotracking @ 2010:175:03:45:25 and studied signal performance until the forward PWRL equaled -54 dBm.
- This plot of PWRL vs. Time indicates that the Ku-band maintained a useful return link until TDRS was 0.75 degrees off-boresight



Resulting Ku-band Half-Cone Angle Based on the off-boresight testing:

•The rest of the graphs of each TDRS event are in the back-up data section of this brief. Raw data supporting these results will be provide on the CATO SharePoint site:

TDRS Event	Off-boresight @ -54 dBm (degrees)	Off-boresight @ -51 dBm (degrees)
TDRS 171 @ 175:03:40	0.75	0.68
TDRS 171 @ 182:03:34	0.75	0.68
TDRS 174 @ 175:21:23	0.68	0.59
TDRS 174 @ 176:02:27	0.59	0.56
TDRS 046 @ 174:21:38	0.66	0.55
TDRS 046 @ 182:05:49	0.53	0.49
TDRS 041 @ 174:23:11	0.76	0.72
TDRS 041 @ 175:00:49	0.72	0.68
TDRS 275 @ 175:01:39	0.74	0.57
TDRS 275 @ 176:00:18	0.71	0.66
Mean Off-boresight Angle	0.689	0.618
Standard Deviation of the Off-Boresight Angle	0.076368987	0.075395255

Geometry and Definitions (cont):

•Ku-band minimum signal strength (PWRL): -54 dBm. This value was established from operations experience during the first two years of Ku-band operations.

- •The CATOs learned that, anytime the forward link signal strength (the PWRL) drops below -54 dBm, we start experiencing Payload data dropouts in the return link.
- •Autotrack has been pre-programmed to stop transmitting anytime the forward link PWRL drops below -54 dBm.
- •Open Loop performance in this briefing will be evaluated on the basis of this same threshold.
- •This study depends on the strong correlation between the forward link received signal strength and the performance of the return link during off-boresight pointing conditions.

Geometry and Definitions (cont):

•Link Margin equation:

- •Reference: “Space Mission Analysis and Design”, James R Wertz and Wiley J. Larson (editors), ISBN 0-7923-0971, Chapter 13.3, “Link Design”, page 458.
- • The signal-to-noise ratio (Eb/N_0) equation includes the data rate in the denominator of the equation.
- •By theory, if we double the return link data rate from 150 Mbps to 300 Mbps, we can expect a 3 dBm decrease in the return link Eb/N_0 ratio (link margin).
- •In practical experience, due to Ku-band transmitter-receiver controller (TRC) design and TDRS carrier filtering, the return link can expect a 5 dBm drop in the Eb/N_0 ratio.

Geometry and Definitions (cont):

- Link Margin equation:
  - This off-boresight testing shows that we have 5 dBm in the return link to give up to the increased return link data rate.
  - The increased TDRS eccentricity will diminish our probability of success at 300 Mbps, but would not completely nullify service at this data rate.
  - Key mitigation steps should include lowering the return link data rate to assure the reliability we experienced during these Open Loop tests that were conduced for this report.
    - For example, should we lose autotrack while the attitude control system is healthy and was producing good line-of-sight vectors before Ku-band autotrack went bad, then we could elect to drop the return link rate to 200 or 250 Mbps.
    - If attitude was not healthy and it had been trending outside of 0.4^0, we may elect 150 Mbps or less for the sake of link reliability.

TDRS Eccentricity and ISS Downrange Error:

- A table of data depicting the impact of TDRS eccentricity on Ku-band Open Loop pointing performance can be calculated using the following process/assumptions:
  - For the results depicted in the following table, TOPO provided an ISS State Vector to represent ISS state during the post ULF 6 timeframe -- ~400 Km altitude.
  - Assume perfect LVLH attitude (0,0,0) and perfect Ku-band performance.
  - Use the GNC to provide a calculated TDRS inertial state that closely approximates zero eccentricity and use it as a baseline reference.
    - GNC provided a state vector with an eccentricity of 0.000177.
  - Use the same ISS State Vector in each simulation, but each time, increase the TDRS eccentricity by 0.0005, starting at 0.0005.
    - Each simulation covers three days (~45 orbits) to ensure statistical significance.

TDRS Eccentricity and ISS Downrange Error:

- Post-process the data by comparing the TDRS pointing vectors from each elevated eccentricity back to the baseline TDRS state that the GNC provided.
  - Only above-the-horizon (unblocked) data was used to compute the statistics.
    - At each unblocked data point, compute the relative state vector from the ISS to the TDRS target by subtracting the ISS inertial state from the TDRS inertial state.
    - At each unblocked data point, compute the angle between the relative state vector for the TDRS at higher eccentricities and the baseline relative state.
    - Compute the statistics on the angles over three days.
    - Compute the apparent down-range error in Km using the average value for the error angle and the minimum distance between ISS and TDRS.
      - Using the TOPO-provided ISS state and the GNC calculated TDRS state (the baseline), the minimum distance between ISS and TDRS is 35,380.459 Km.

TDRS Eccentricity and ISS Downrange Error:

- TOPO provided a history of the TDRS eccentricity over the past year:

TOPO Name	GC Name	e @ 3/18/2010	e @ 3/25/2011	% change
T046W	TDS	0.0007659	0.0009034	15%
T171W	TD171	0.0018587	0.0023552	21%
T174W	TDW	0.0010608	0.0015389	31%
T275W	TDZ	0.0033974	0.0032673	-4%
T041W	TDE	0.0004462	0.0004102	-9%

TDRS Eccentricity and ISS Downrange Error:

TDRS Eccentricity and Resulting Pointing Error

Eccentricity	Down Range Error (Km)	Average Angular Error (degrees)	Standard Deviation (degrees)	Maximum Error (degrees)	Minimum Error (degrees)
0.0005	21.1	0.0342	0.0121	0.0425	0.0005
0.0010	53.8	0.0871	0.0309	0.1082	0.0013
0.0015	86.5	0.1401	0.0497	0.1740	0.0021
0.0020	119.2	0.1931	0.0685	0.2397	0.0028
0.0025	152.0	0.2462	0.0873	0.3054	0.0036
0.0030	184.8	0.2993	0.1061	0.3712	0.0044
0.0035	217.7	0.3525	0.1249	0.4369	0.0052

System Error Budget:

- Ku-band's 3-sigma pointing accuracy value is 0.1 degree (established by Boeing during Ku-band CDR)
- Attitude control system's pointing accuracy is 0.1 degree.
  - The following data describes the attitude control system's performance over a one-day period (GMT 2011:083-084):
    - All values are degrees

Average Variance	0.0337032
Std Deviation	0.0003486
Min Variance	0.0327831
Max Variance	0.0351140

System Error Budget:

• Since the Ku-band pointing system and the attitude control system are independent systems, their error sources are considered uncorrelated, and hence, to compute measurement uncertainty, their accuracy performance figures must be added.

- Hence, 0.2 degrees are reserved for the combined pointing performance of the Ku-band and Attitude control systems

- The rest of the Ku-band half-cone angle can be allotted to the rest of the system (i.e TDRS eccentricity impacts)

  - Since the Ku-band half-cone angle is 0.7 degrees, then 0.5 degrees can be allotted to the TDRS eccentricity problems.

  - At typical distances between ISS and TDRS expected after ULF 6, this margin equates to approximately 308.7 Km (35380.459Km * sin(0.5 degrees)).

    - This value is a greater tolerance over the present 90 Km tolerance.

How Are We Doing Today?
Ku-band versus the Rest of the System:

- Used the Ku-band autotrack pointing vector as the “truth” and compared the GNC line-of-sight (LOS) vector to it.
  - The GNC LOS vector represents the attitude control system and the rest of the total system error.

TDRS 171 Tracking Performance

GMT (All times in 2011)	Average Angular Diff (degrees)	Standard Deviation (degrees)	Maximum Angular Difference	Minimum Angular Difference
083:13:09:33 – 083:13:58:	0.1592	0.0447	0.5505	0.0785
083:14:51:12 – 083:15:29:40	0.2670	0.0316	0.3065	0.2067
083:16:18:30 – 083:17:04:41	0.3273	0.0284	0.3714	0.2649
083:18:01:37 – 083:18:39:41	0.3312	0.0087	0.3551	0.3099

How Are We Doing Today?
Ku-band versus the Rest of the System:

TDRS 171 Tracking Performance (continued)

GMT (All times in 2011)	Average Angular Diff (degrees)	Standard Deviation (degrees)	Maximum Angular Difference (degrees)	Minimum Angular Difference (degrees)
084:00:35:31 – 084:01:23:16	0.2717	0.0598	0.6647	0.0661
084:02:11:10 – 084:02:54:40	0.3046	0.0574	0.3765	0.0720

- Note the good agreement between theory and practical experience:
  - The TDRS 171 eccentricity is up to 0.0023552 and the table on slide 15 indicates that an eccentricity of 0.0025 provides an average angular error of 0.2562^0 and a one-sigma value of 0.0873 degrees.
  - Add a 0.1 degree of attitude uncertainty to the theoretical value and theoretical values fairly agree with what we are seeing in operations.

Conclusion:

•Currently, TDRS 171's eccentricity represents as much error as we can accept and still assure 100% reliability for Ku-band Open Loop at 150 Mbps.

•If the Program truly expects Ku-band Open Loop to support a return link data rate of 300 Mbps, then we cannot increase TDRS eccentricity and we should pursue capping TDRS eccentricity at 0.00175.

- •This requested eccentricity cap applies only until late 2012, when we update the on-board GNC to support elliptical orbits.

•TOPO can write their flight rule predominantly addressing autotrack performance and addressing Open Loop as a contingency.

•CATO will develop a bandwidth determination plan to mitigate the remote possibility that only Open Loop operations are available to support data rates greater than 150 Mbps.

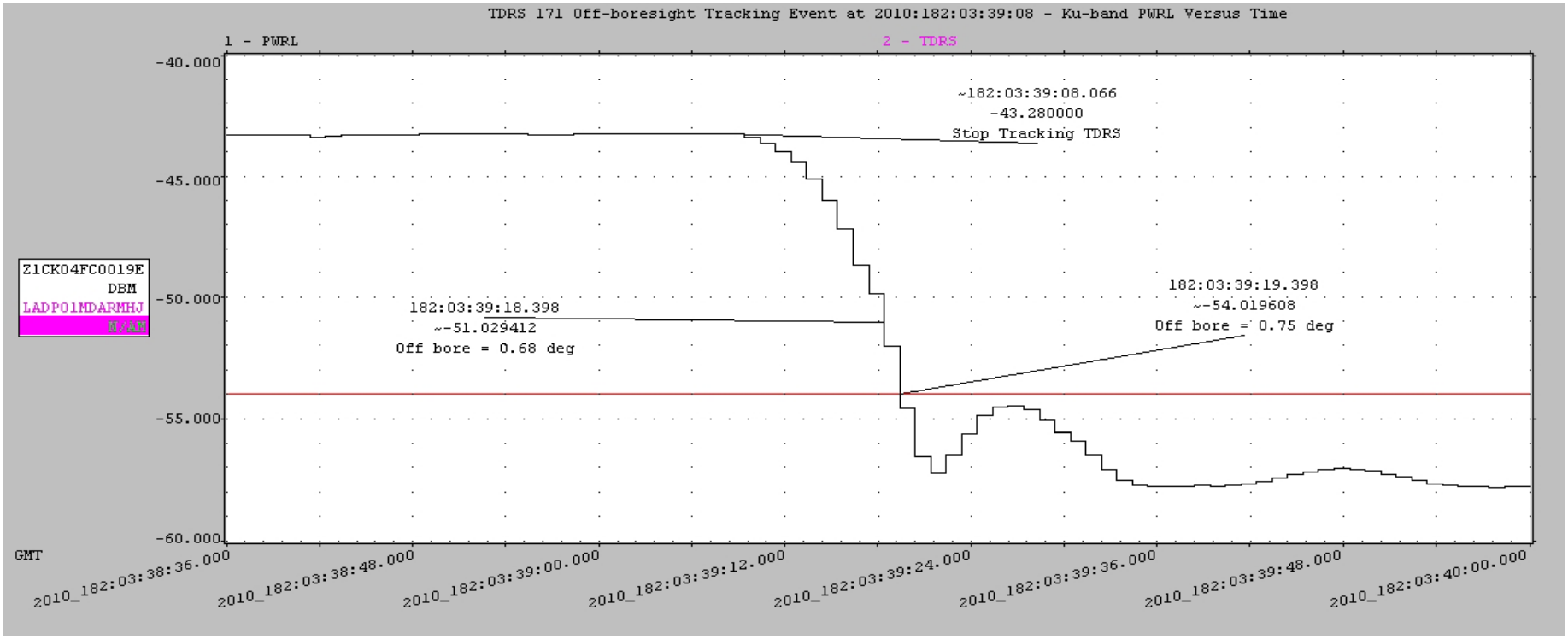
- •Some automation can aid in quick assessment – statistical system performance can be electronically related to a recommended data rate.

BACKUP CHARTS

- Plots of the forward link study data.
- The briefing from September 13, 2010 follows.
- Raw data supporting all this analysis will be located on the CATO SharePoint site at this link.

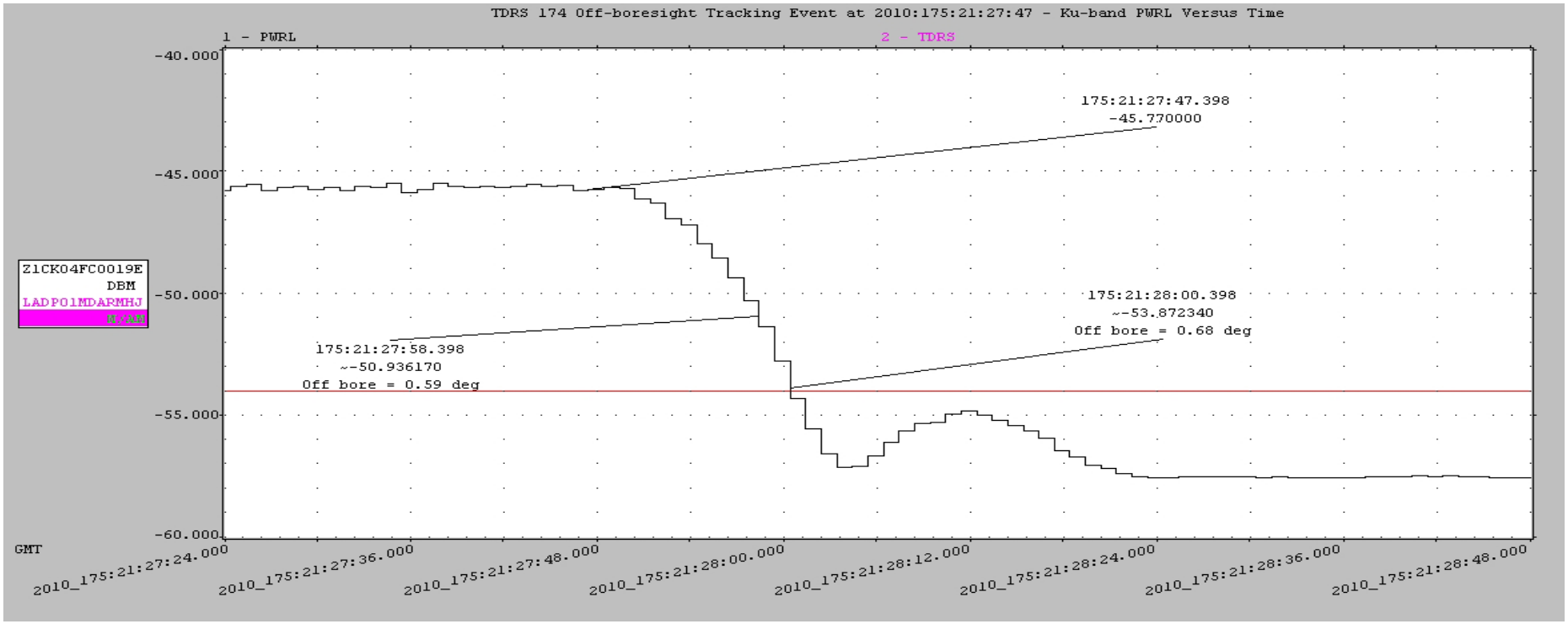
TDRS 171 @ 2010:182:03:34

- Stopped Autotracking @ 2010:182:03:39:08 and studied signal performance until the forward PWRL equaled -54 dBm.
- This plot of PWRL vs. Time indicates that the Ku-band maintained a useful return link until TDRS was 0.75 degrees off-boresight



TDRS 174 @ 2010:175:21:23

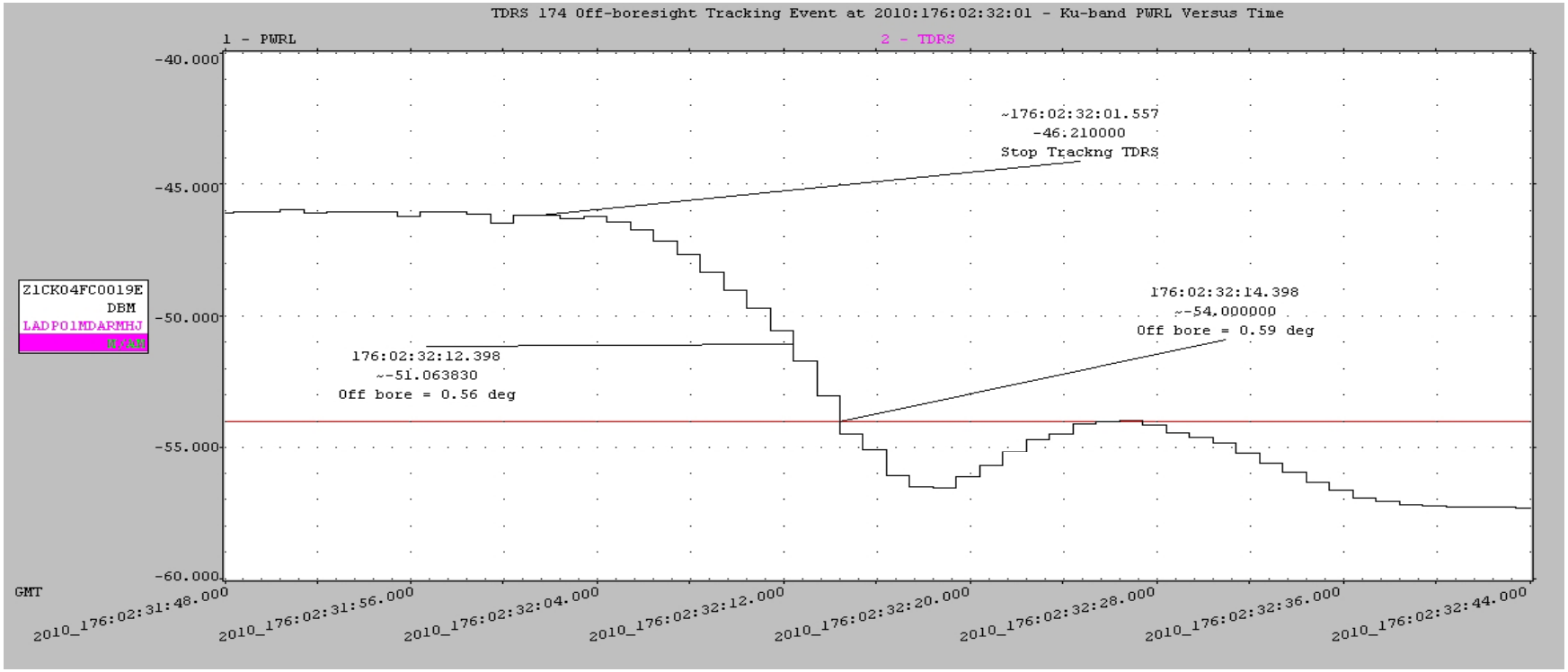
- Stopped Autotracking @ 2010:175:21:27:47 and studied signal performance until the forward PWRL equaled -54 dBm.
- This plot of PWRL vs. Time indicates that the Ku-band maintained a useful return link until TDRS was 0.68 degrees off-boresight



TDRS 174 @ 2010:176:02:27

•Stopped Autotracking @ 2010:176:02:32:01: and studied signal performance until the forward PWRL equaled -54 dBm.

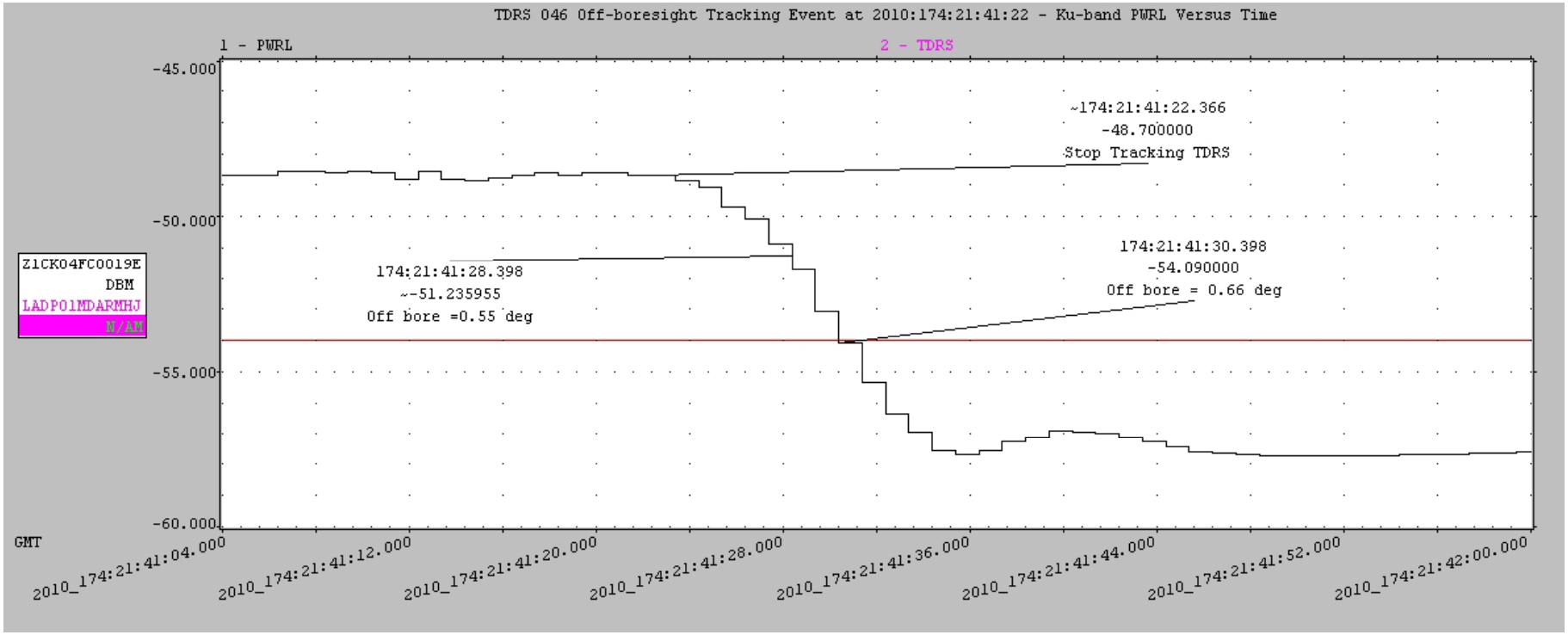
•This plot of PWRL vs. Time indicates that the Ku-band maintained a useful return link until TDRS was 0.59 degrees off-boresight



TDRS 046 @ 2010:174:21:38

•Stopped Autotracking @ 2010:174:21:41:22 and studied signal performance until the forward PWRL equaled -54 dBm.

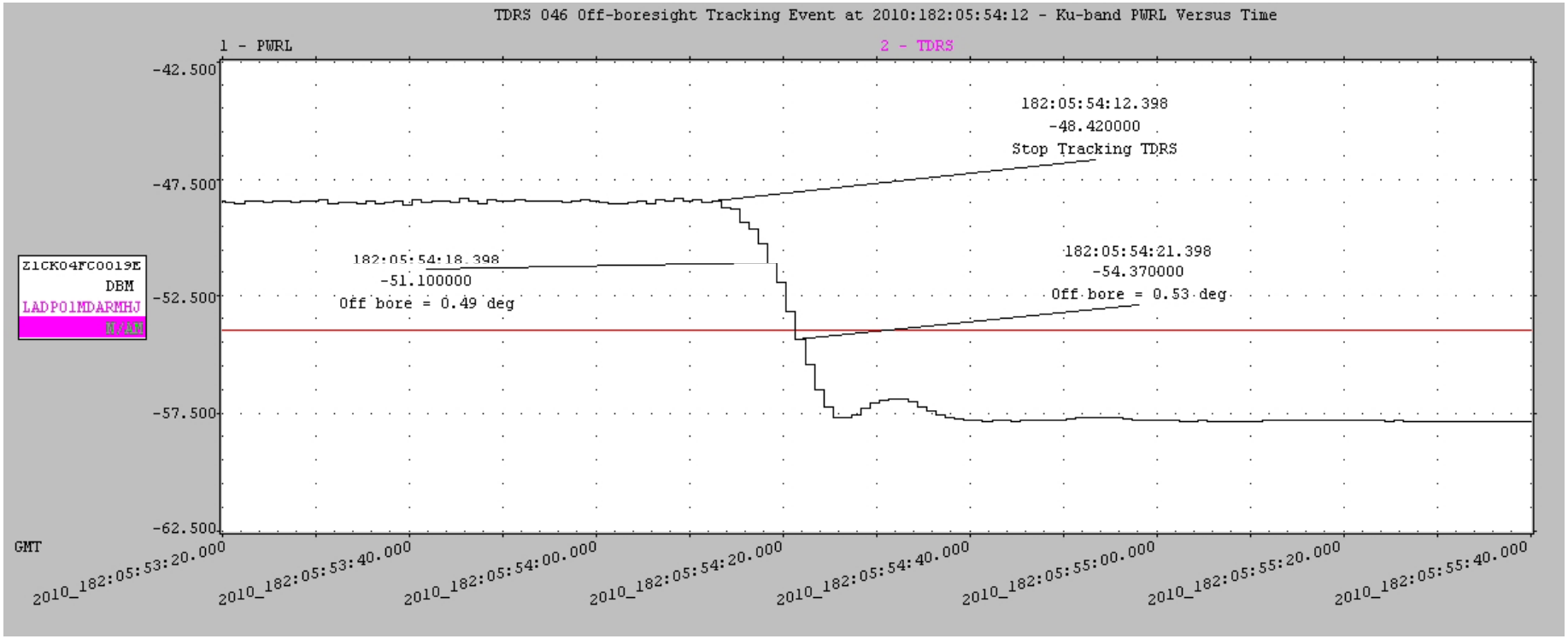
•This plot of PWRL vs. Time indicates that the Ku-band maintained a useful return link until TDRS was 0.66 degrees off-boresight



TDRS 046 @ 2010:182:05:49

•Stopped Autotracking @ 2010:182:05:54:12 and studied signal performance until the forward PWRL equaled -54 dBm.

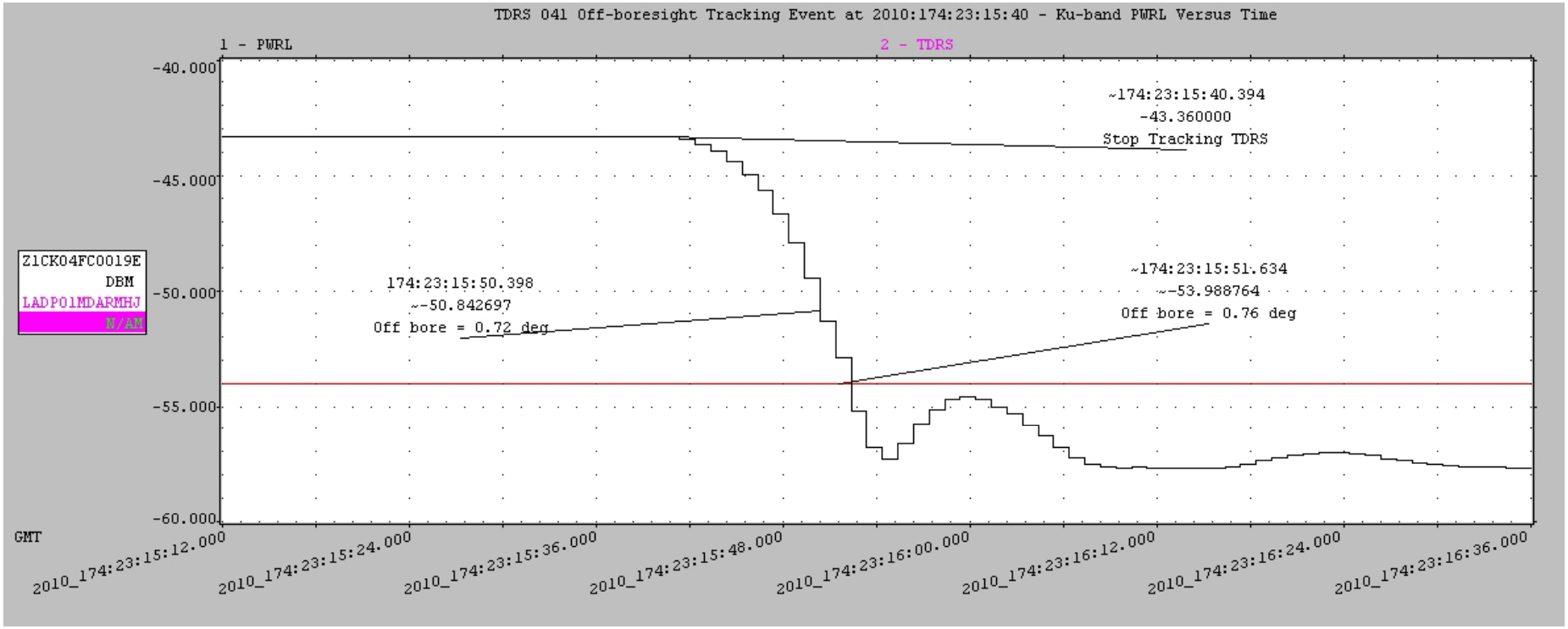
•This plot of PWRL vs. Time indicates that the Ku-band maintained a useful return link until TDRS was 0.53 degrees off-boresight



TDRS 041 @ 2010:174:23:11

•Stopped Autotracking @ 2010:174:23:15:40 and studied signal performance until the forward PWRL equaled -54 dBm.

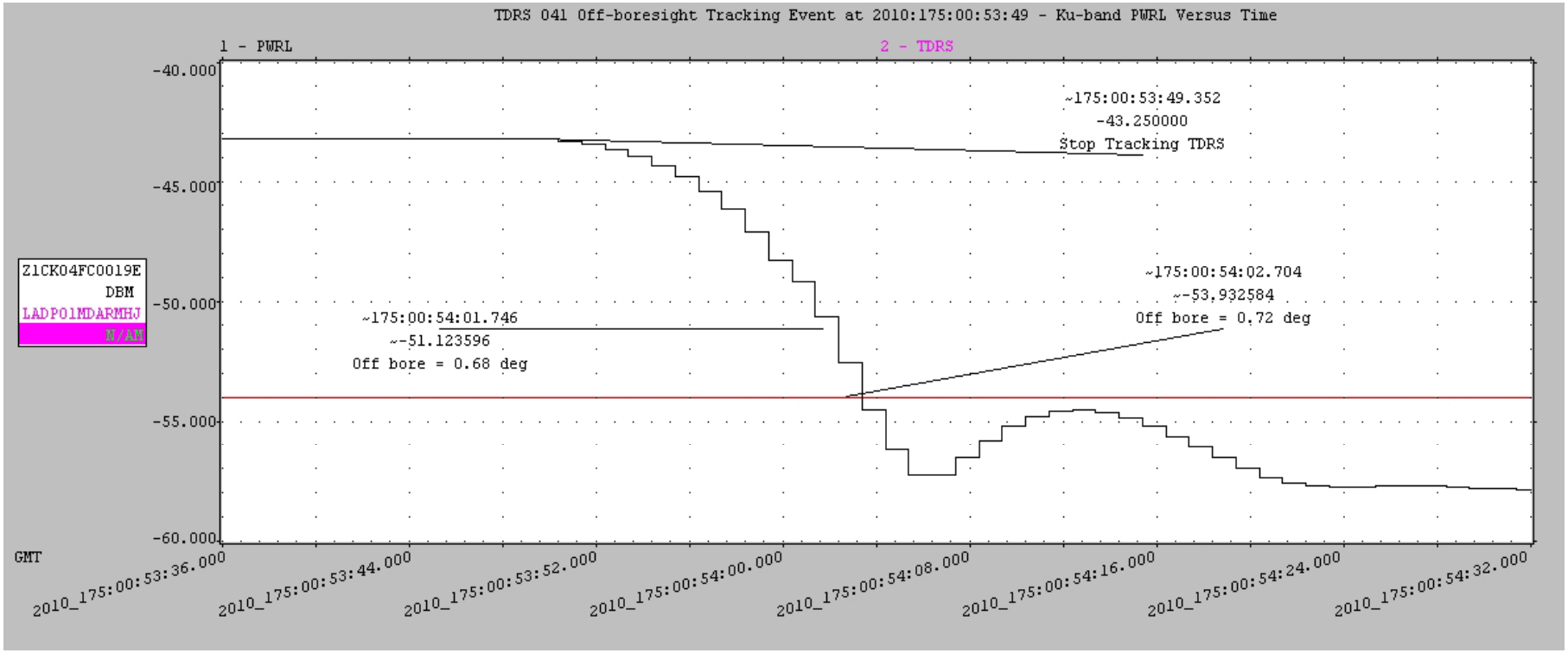
•This plot of PWRL vs. Time indicates that the Ku-band maintained a useful return link until TDRS was 0.76 degrees off-boresight



TDRS 041 @ 2010:175:00:49

•Stopped Autotracking @ 2010:175:00:53:49 and studied signal performance until the forward PWRL equaled -54 dBm.

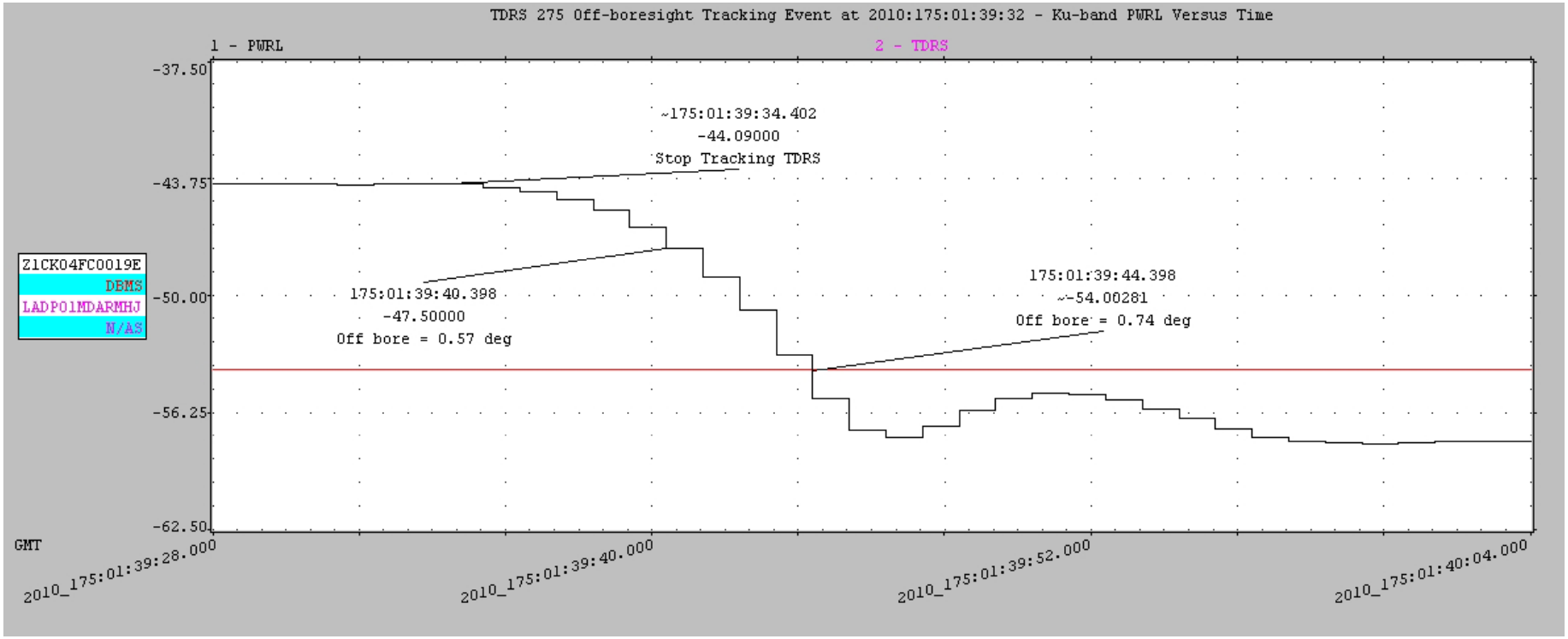
•This plot of PWRL vs. Time indicates that the Ku-band maintained a useful return link until TDRS was 0.72 degrees off-boresight



TDRS 275 @ 2010:175:01:39

•Stopped Autotracking @ 2010:175:01:39:34 and studied signal performance until the forward PWRL equaled -54 dBm.

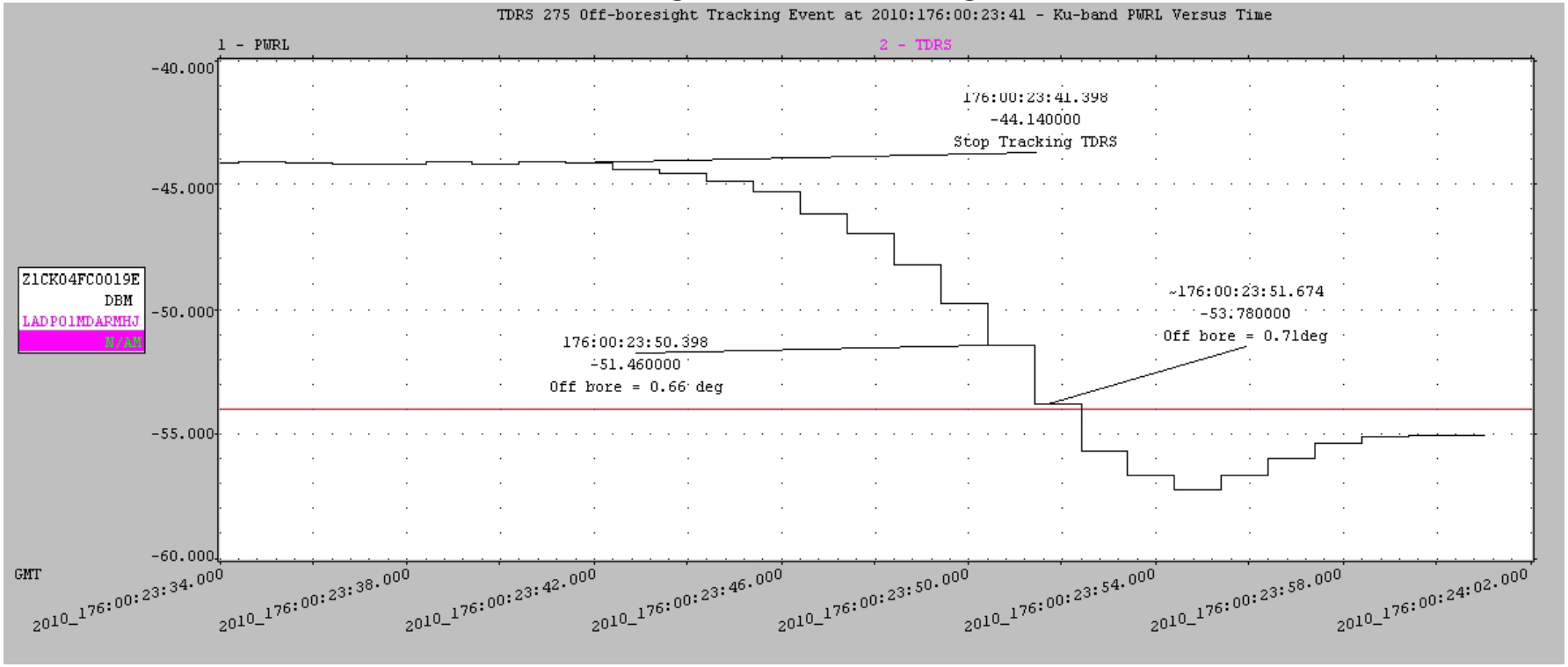
•This plot of PWRL vs. Time indicates that the Ku-band maintained a useful return link until TDRS was 0.74 degrees off-boresight



TDRS 275 @ 2010:176:00:18

•Stopped Autotracking @ 2010:176:00:23:41 and studied signal performance until the forward PWRL equaled -54 dBm.

•This plot of PWRL vs. Time indicates that the Ku-band maintained a useful return link until TDRS was 0.71 degrees off-boresight



Ku-band Open Loop Performance Assessment at Higher TDRS Eccentricities

Prepared by: Dan Jackson

September 13, 2010

DI22/Communications and Tracking Group (CATO)

Questions for the Analysis:

- Can the TDRS network allow the orbits of the TDRS satellites go to a higher eccentricity of 0.0035 without impacting Open Loop operations?
    - TDRS 275 is already at the higher eccentricity
- Can TOPO get some down-track accuracy relief to update their flight rule currently indicating that we can accept only 90 Km of down track error?

Notes on Analysis Method:

- Compared the mean and the standard deviation of the PWRL during the autotrack portion of each event to the Open Loop part of the event.
  - The effect of range can be seen in the results – the Open Loop portions all contained the shortest TDRS ranges.
- Assessed the GNC pointing vector accuracy with respect to the Ku-band, after applying the static bias in PPL #27.
  - Computed the total angle between the Ku-band and the GNC pointing solution from the beginning and end of Autotrack mode just before the start of Open Loop operations.

Ku-band Forward Link Analysis Results:

TDRS ID	Autotrack PWRL (dBm)	Open Loop PWRL	GNC Pointing Accuracy (degrees)
046	Median = -48.6 Std Dev = .0998	Median = -48.0 Std Dev = .7220	Median = .1777 Std Dev = .0044
041	Median = -43.4 Std Dev = .0428	Median = -43.22 Std Dev = .2427	Median = .2192 Std Dev = .0255
041	Median = -43.3 Std Dev = .1462	Median = -42.91 Std Dev = .3220	Median = .1793 Std Dev = .0048
275	Median = -44.22 Std Dev = .0772	Median = -46.74 Std Dev = .5435	Median = .2701 Std Dev = .0047
171	Median = -45.1 Std Dev = .3432	Median = -43.88 Std Dev = .7597	Median = .2926 Std Dev = .0116

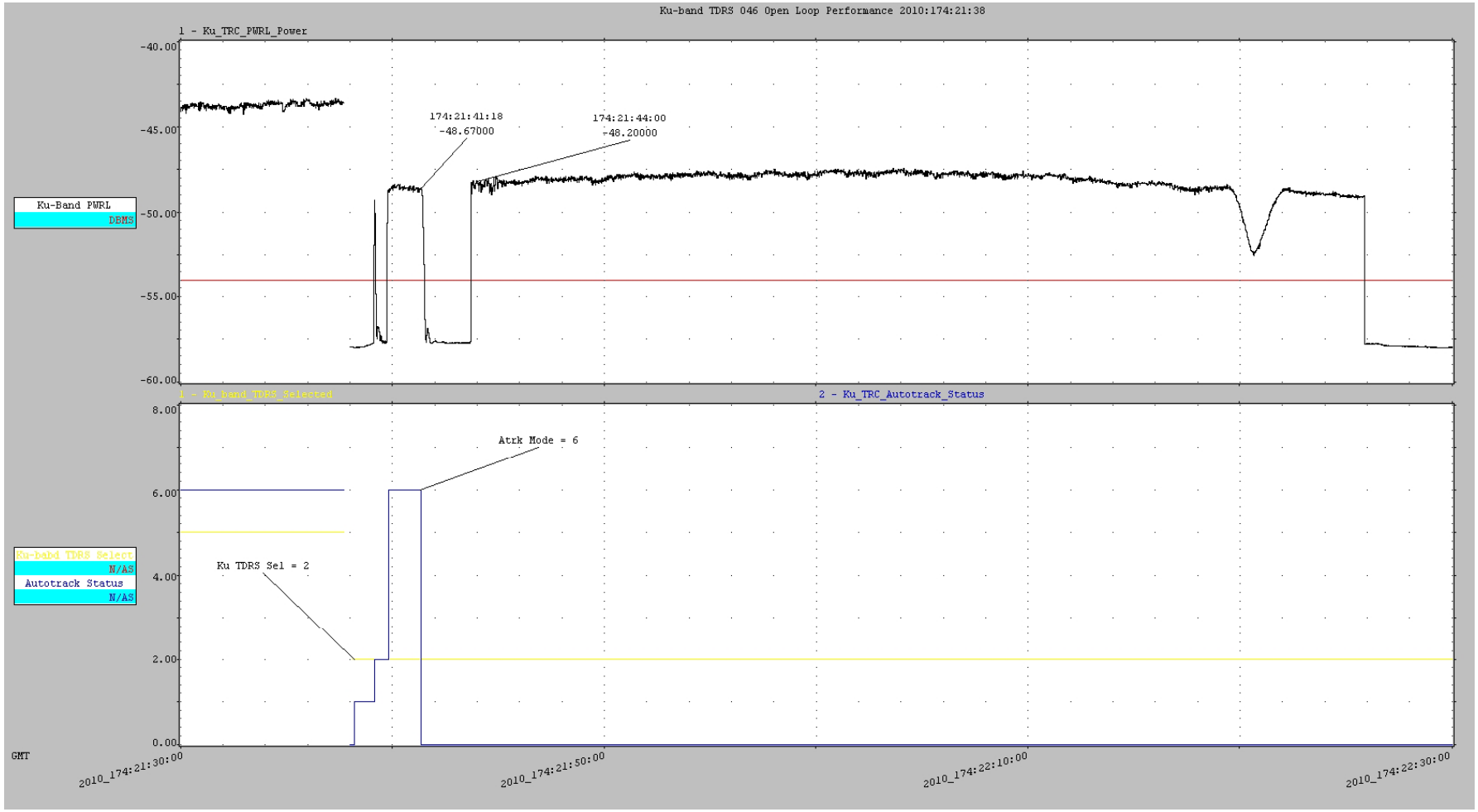
Ku-band Forward Link Analysis Results:

TDRS ID	Autotrack PWRL (dBm)	Open Loop PWRL	GNC Pointing Accuracy (degrees)
174	Median = -45.77 Std Dev = .2151	Median = -43.96 Std Dev = .5081	Median = .1626 Std Dev = .0104
275	Median = -44.27 Std Dev = .0737	Median = -47.3 Std Dev = .4949	Median = .3324 Std Dev = .0072
174	Median = -46.38 Std Dev = .3541	Median = -44.56 Std Dev = .3518	Median = .2353 Std Dev = .0126
046	Median = -48.47 Std Dev = ..0664	Median = -48.18 Std Dev = .1270	Median = .1161 Std Dev = .0048
171	Median = -43.41 Std Dev = .1146	Median = -43.07 Std Dev = .6741	Median = .1559 Std Dev = .0044

Two Answers Based On Ku-band Forward Link Performance:

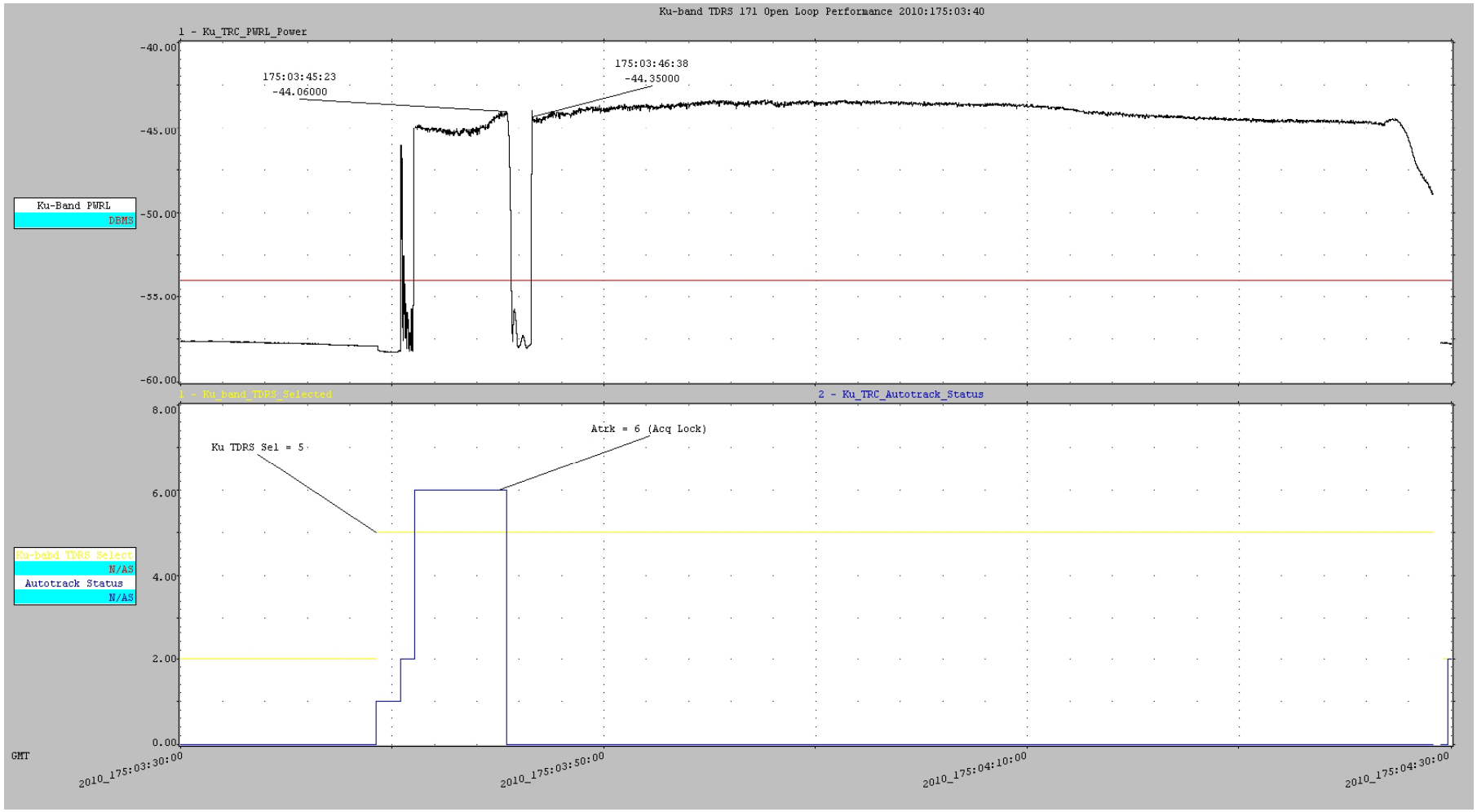
- Can the TDRS network allow the orbits of the TDRS satellites go to a higher eccentricity of 0.0035 without impacting Open Loop operations?
  - Yes, the Ku-band maintained forward link lock on TDRS 275 and the on-board state vector was 203 days old.
- Can TOPO get some down-track accuracy relief to update their flight rule indicating that we can accept only 90 Km of down track error?
  - Yes, testing indicates that the Ku-band half-angle value is in excess of 0.4 degrees.
  - Recommend allowing CATO to retain some forward link margin and allowing for a Ku-band half-cone angle of 0.3 degrees.
  - Equates to 219 Km of acceptable down track error assuming TDRS 42,000 Km semi-major axis.

TDRS 046 Open Loop Performance 2010:174:21:38

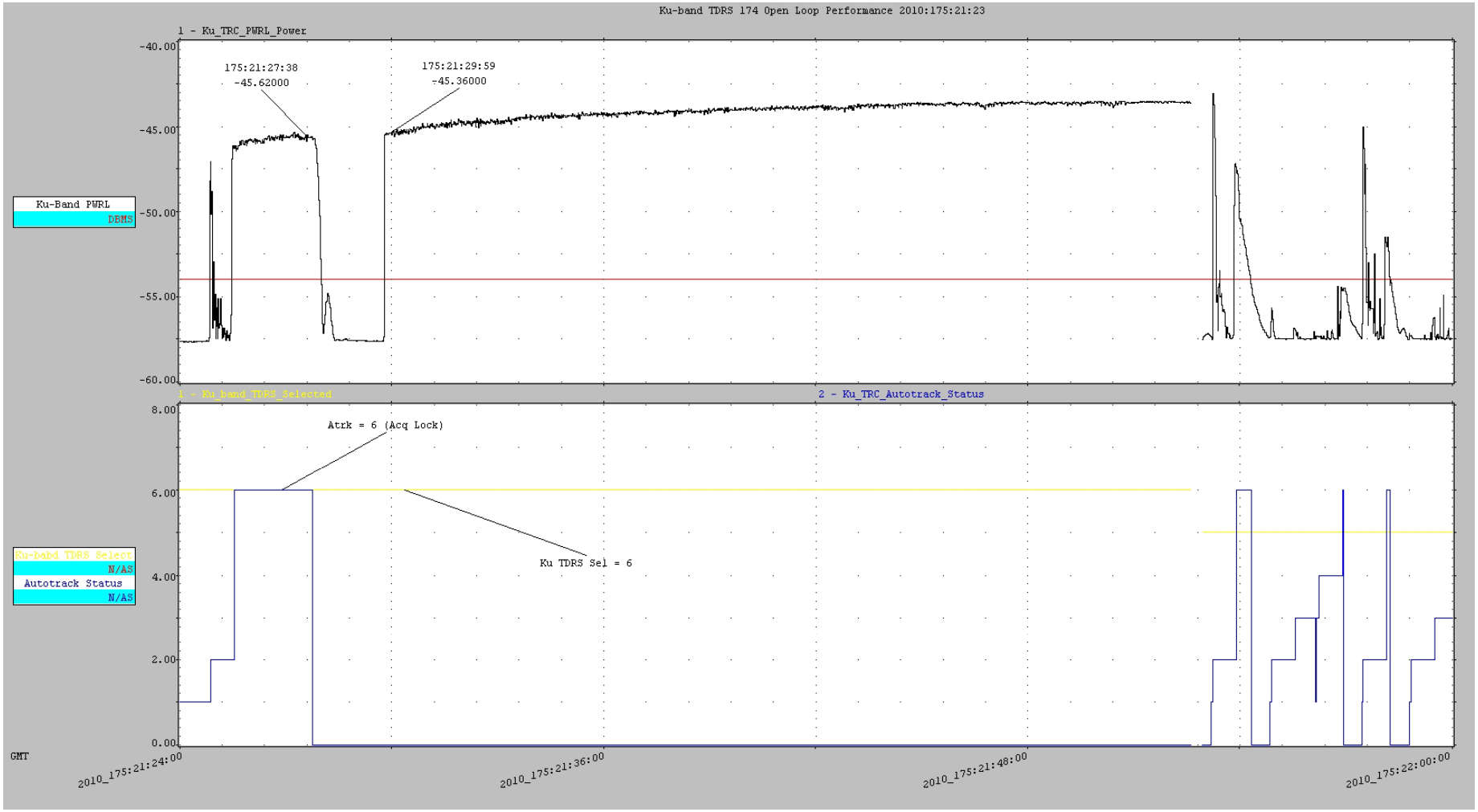


TDRS 046 Open Loop Performance 2010:177:00:05

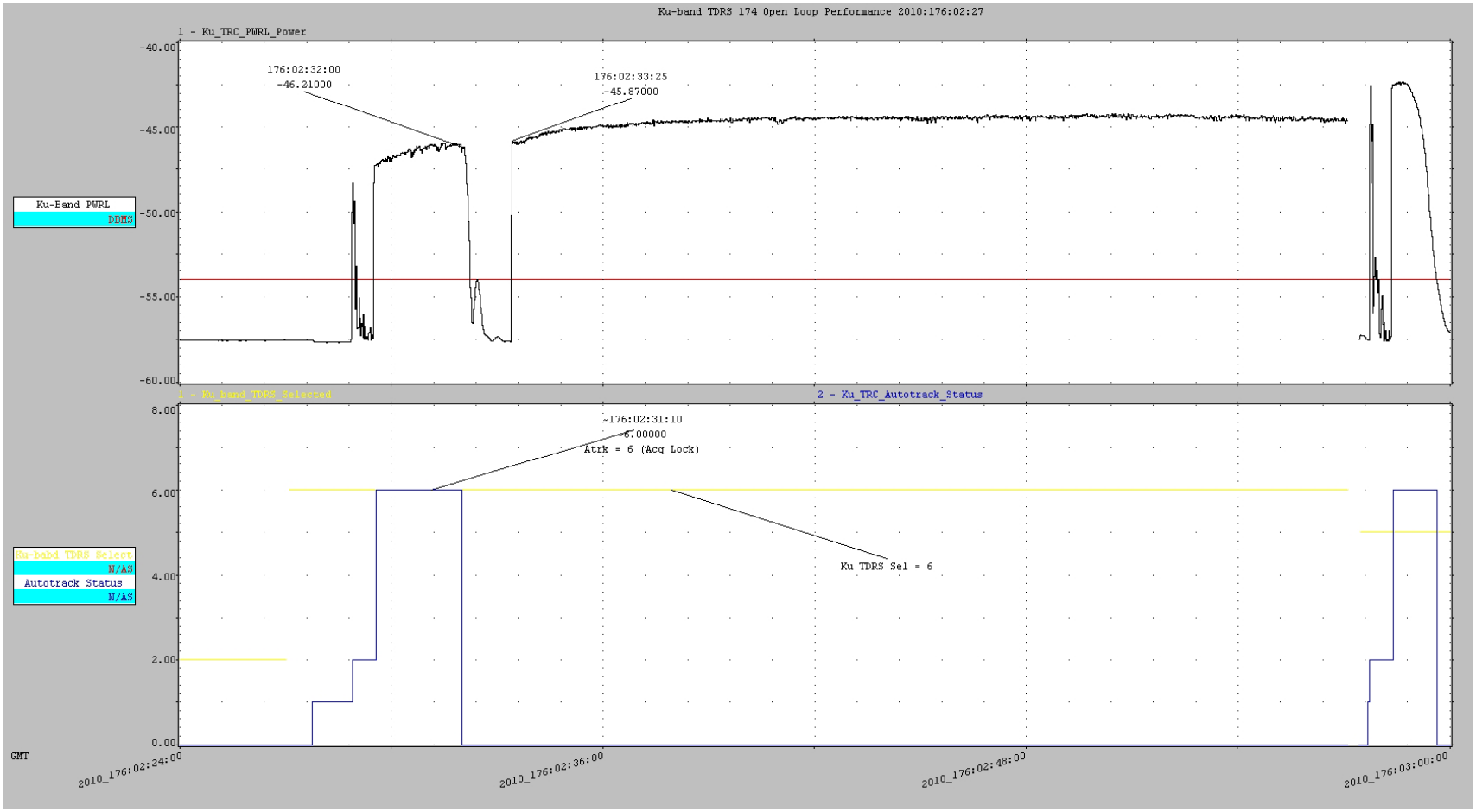
TDRS 171 Open Loop Performance 2010:175:03:40



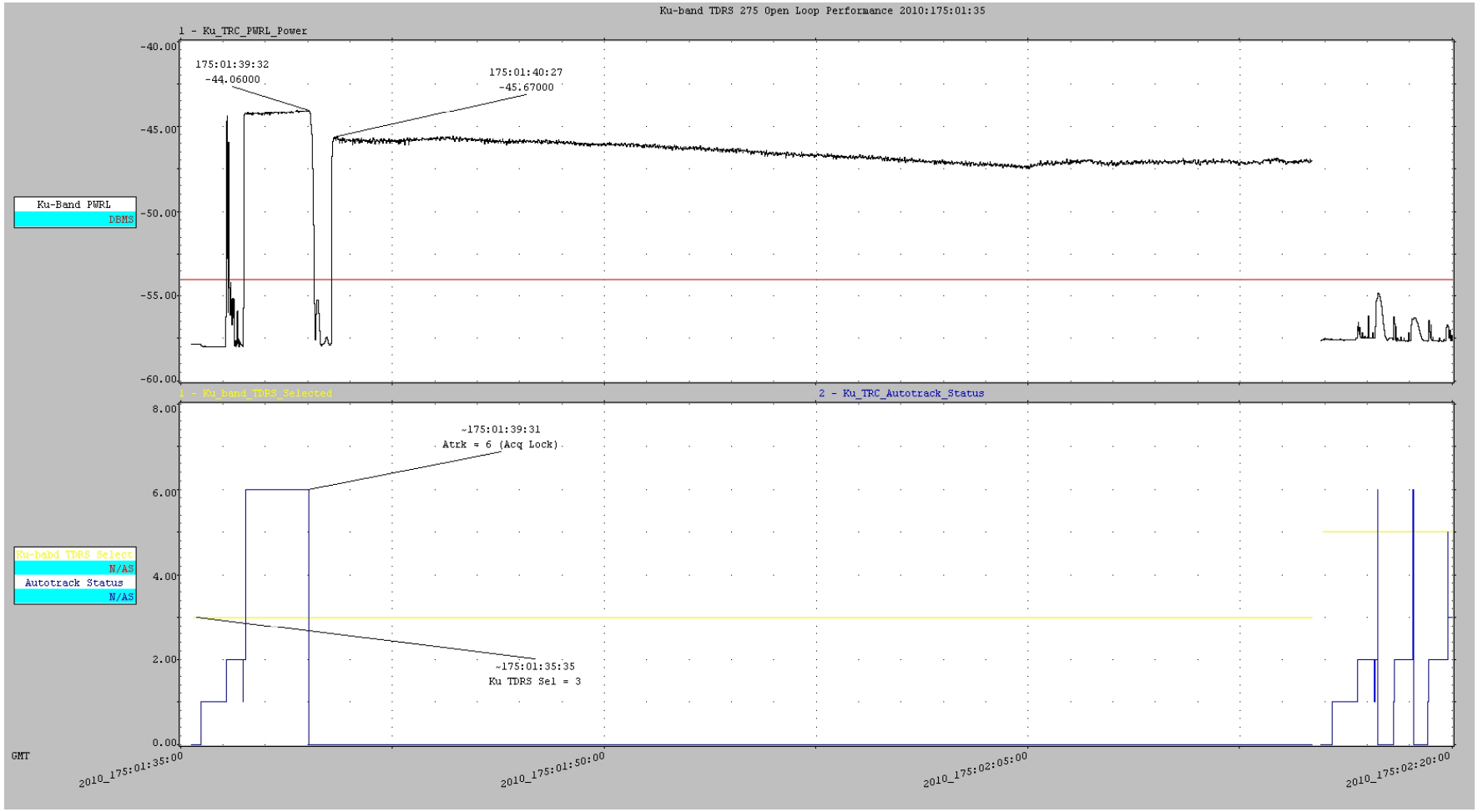
TDRS 174 Open Loop Performance 2010:175:21:23



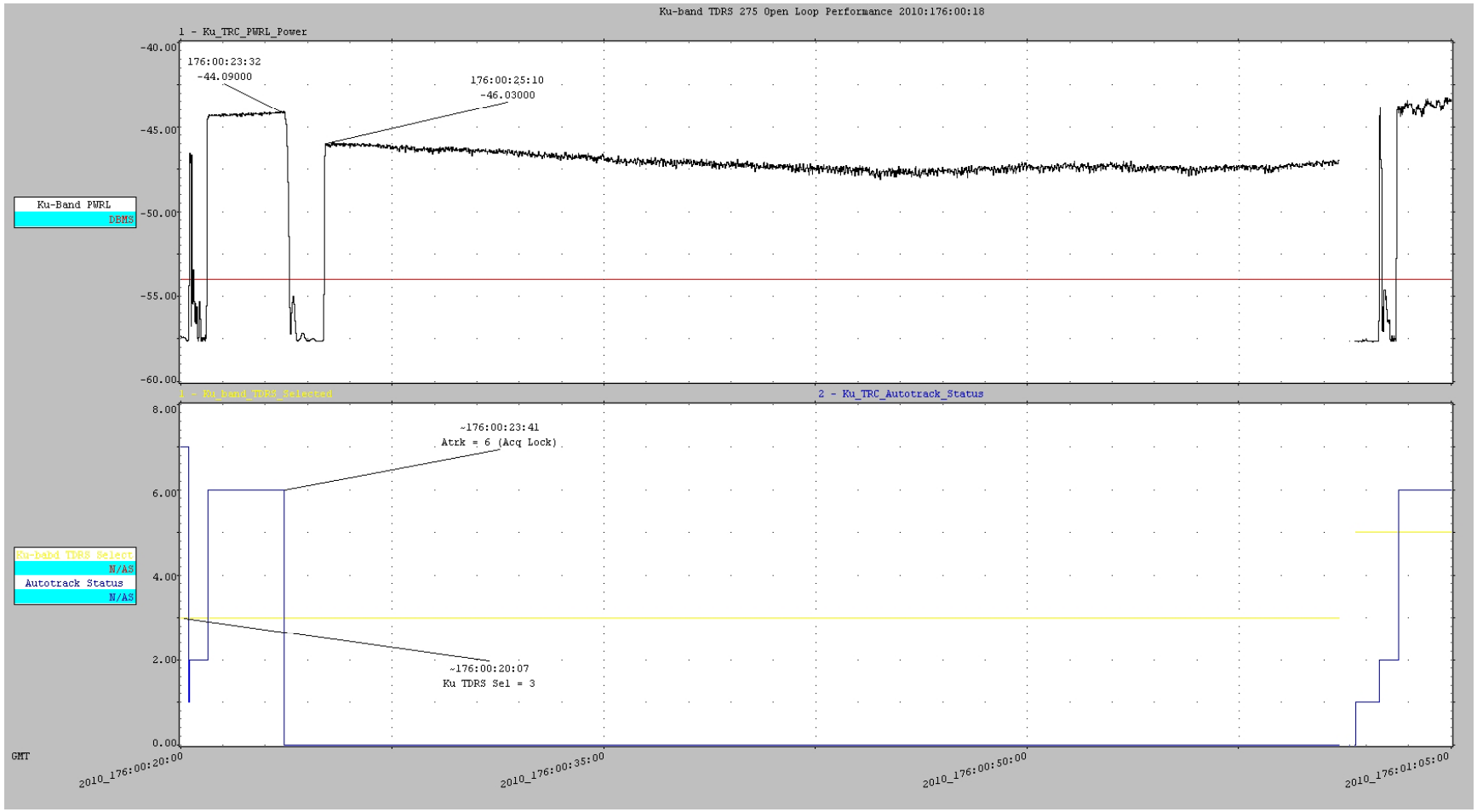
TDRS 174 Open Loop Performance 2010:176:02:27



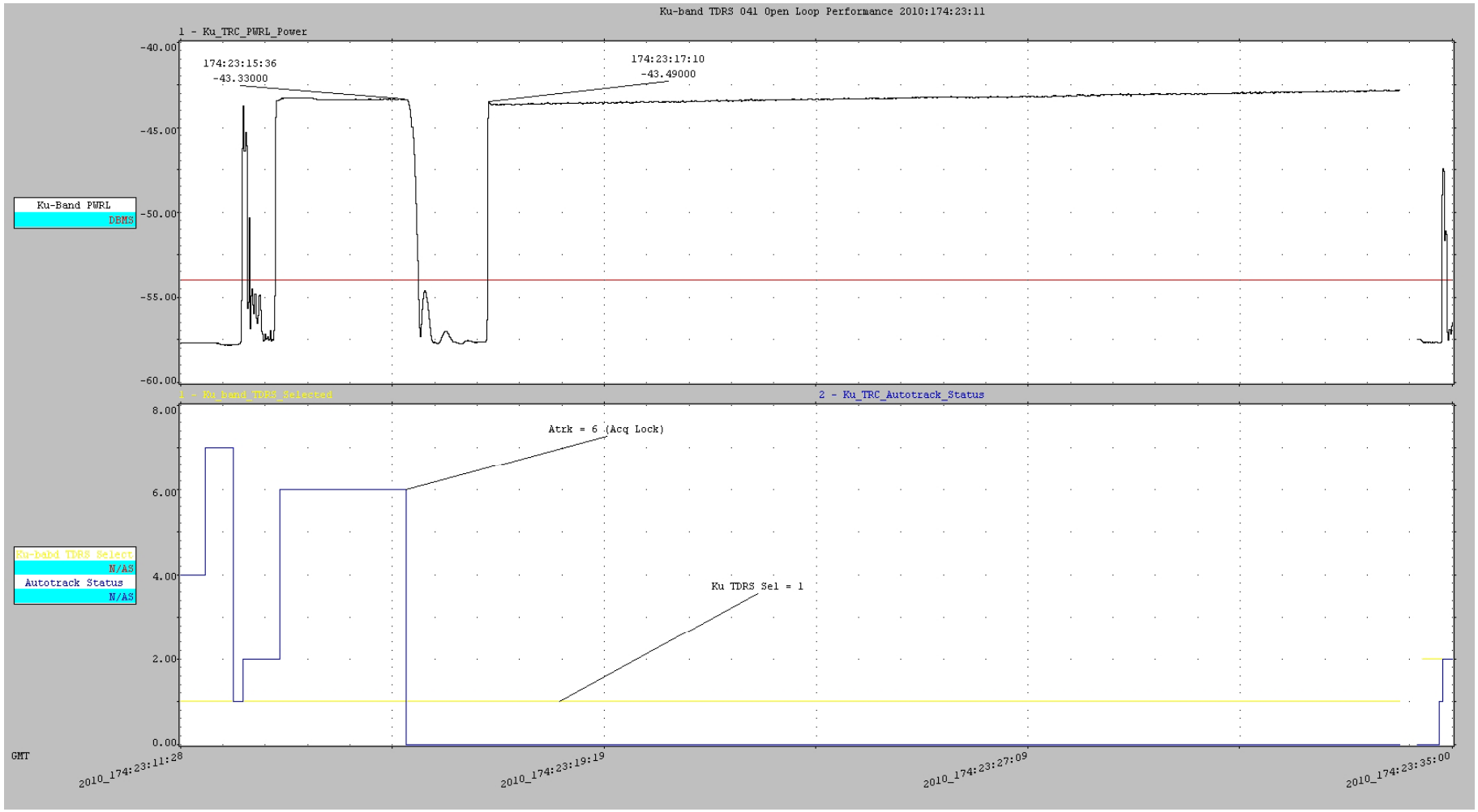
TDRS 275 Open Loop Performance 2010:175:01:35



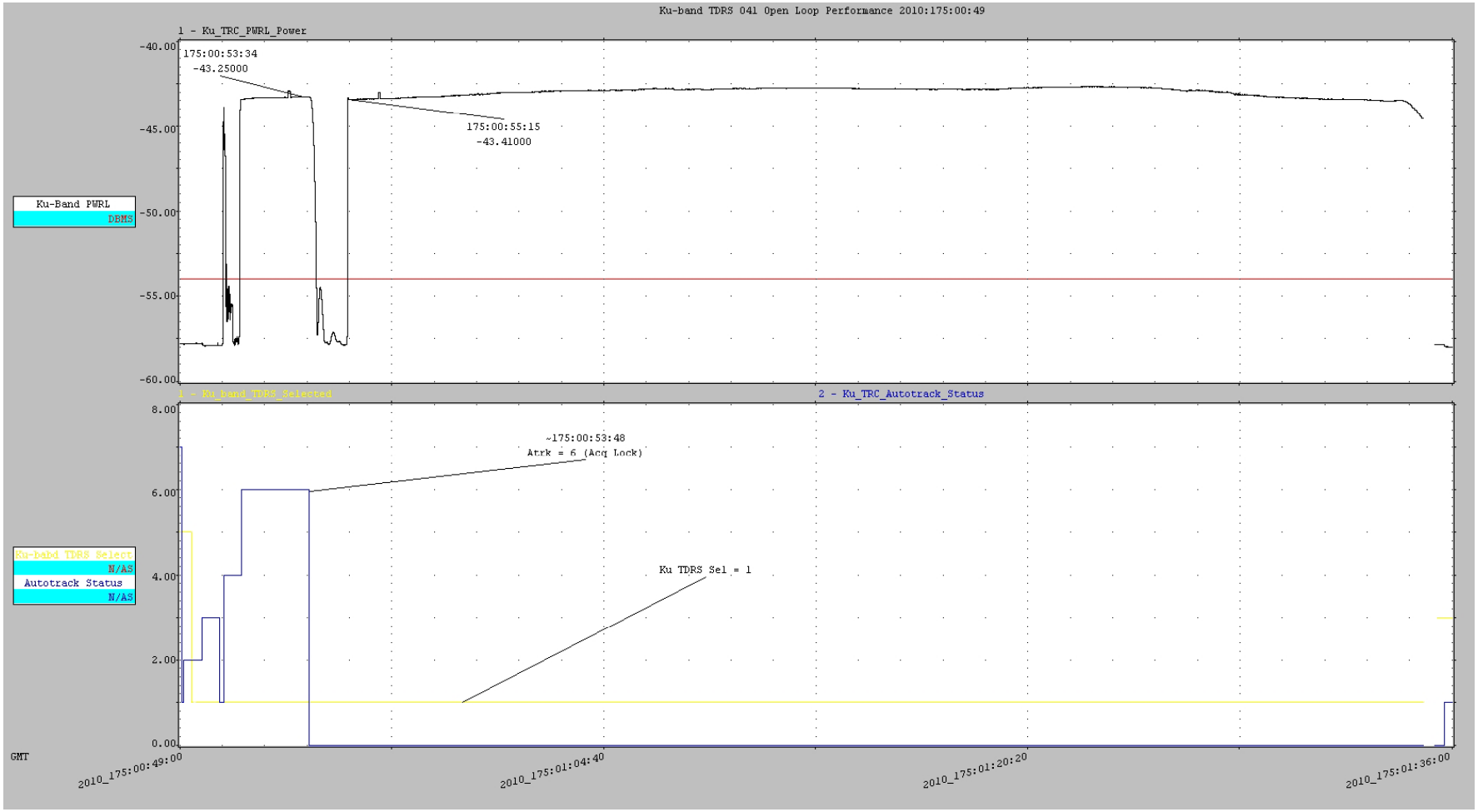
TDRS 275 Open Loop Performance 2010:176:00:18



TDRS 041 Open Loop Performance 2010:174:23:11



TDRS 041 Open Loop Performance 2010:175:00:49



Conclusion

- The test results indicate that the Ku-band link margin can provide the Open Loop capability using TDRS at higher eccentricities.
- TOPO can allow for greater down track error, thereby decreasing the frequency of TDRS state vector uplinks.
  - Acceptable down track error up to 219 Km.

TDRS Event Data Supporting Ku-band Open Loop Performance Study

- TDRS 041 event times for this study: 2010:174/23:11 and 2010:175/00:49

T041 State Vector Time: 2010:125:15:00	
Command Parameter	**Value Uplinked**
Slot Number:	5
Satellite ID:	1
Semi-Major Axis	42162335.286948
Inclination	0.006405865
RA of the Asc. Node Time, Coarse	957084451
RA of the Asc. Node Time, Fine	0.0150000
Asc. Node Longitude	5.478852
Mean Motion	0.000072921900
Uplink ID	04112

- Uplink time-tag for this state vector: 2010:125/22:59:35.355
- Means this state vector was approximately 49 days old when we used it for this test.
- Corresponding Cartesian Coordinates for the uplinked state vector:
  - X = 28571043.835546
  - Y = 31009596.079659
  - Z = 269624.461998
  - XDOT = -2261.27667666
  - YDOT = 2083.09333400
  - ZDOT = -1.1795754
  - Longitude = 40.90

TDRS Event Data Supporting Ku-band Open Loop Performance Study

- TDRS 046 event times for this study: 2010:174/21:38 and 2010:182/05:49

T046 State Vector Time: 2010:169:12:00	
Command Parameter	**Value Uplinked**
Slot Number:	2
Satellite ID:	2
Semi-Major Axis	42164862.994569
Inclination	0.197985342
RA of the Asc. Node Time, Coarse	960813137
RA of the Asc. Node Time, Fine	0.010000
Asc. Node Longitude	0.831452
Mean Motion	0.000072917700
Uplink ID	04631

- Uplink time-tag for this state vector: 2010:169/20:50:23.478
- Means this state vector was approximately 5 days old when we first used it.
- Corresponding Cartesian Coordinates for the uplinked state vector:
  - X = 31922369.314769
  - Y = 27488774.152275
  - Z = -1016254.299451
  - XDOT = -1958.30988760
  - YDOT = 2295.56090067
  - ZDOT = 600.59110958
  - Longitude = 45.75

TDRS Event Data Supporting Ku-band Open Loop Performance Study

- TDRS 275 event times for this study: 2010:175/01:35 and 2010:176/00:18

T275 State Vector Time: 2009:336:12:00	
Command Parameter	**Value Uplinked**
Slot Number:	3
Satellite ID:	3
Semi-Major Axis	42161746.628170 m
Inclination	0.199707806^0
RA of the Asc. Node Time, Coarse	943720998
RA of the Asc. Node Time, Fine	0.470000
Asc. Node Longitude	.808583
Mean Motion	0.000072921500
Uplink ID	27562

- Uplink time-tag for this state vector: 2009:336:19:44:46.811
- Means this state vector was approximately 203 days old when we first used it.
- Corresponding Cartesian Coordinates for the uplinked state vector:
  - X = 37856452.203369 m
  - Y = -16536146.011744 m
  - Z = -7853454.334670 m
  - XDOT = 1264.31824289 m/sec
  - YDOT = 2804.14202032 m/sec
  - ZDOT = 206.82545842 m/sec
  - Longitude = 274.93^0

TDRS Event Data Supporting Ku-band Open Loop Performance Study

- TDRS 171 event time for the first event in this study: 2010:175/03:40

T171 State Vector Time: 2010:158:12:00	
Command Parameter	**Value Uplinked**
Slot Number:	1
Satellite ID:	5
Semi-Major Axis	42165880.989196 m
Inclination	0.186804542^0
RA of the Asc. Node Time, Coarse	959895297
RA of the Asc. Node Time, Fine	0.610000
Asc. Node Longitude	.896312
Mean Motion	0.0000729916600
Uplink ID	17129

- Uplink time-tag for this state vector: 2010:159:04:38:38.701
- Means this state vector was almost 16 days old when we first used it.
- Corresponding Cartesian Coordinates for the uplinked state vector:
  - X = -1858951.870836 m
  - Y = -41905183.335015 m
  - Z = -4671842.188735 m
  - XDOT = 3036.49792363 m/sec
  - YDOT = -77.82566208 m/sec
  - ZDOT = -457.43671240 m/sec
  - Longitude = 168.18^0

TDRS Event Data Supporting Ku-band Open Loop Performance Study

- TDRS 171 event time for the second event in this study: 2010:182/03:34

T171 State Vector Time: 2010:174:12:00	
Command Parameter	**Value Uplinked**
Slot Number:	1
Satellite ID:	5
Semi-Major Axis	42164715.406202 m
Inclination	0.187589732^0
RA of the Asc. Node Time, Coarse	961273944
RA of the Asc. Node Time, Fine	0.360000
Asc. Node Longitude	0.893467
Mean Motion	0.000072922300
Uplink ID	17132

- Uplink time-tag for this state vector: 2010:175:17:43:21.029
- Means this state vector was a little more than 6 days old when we used it.
- Corresponding Cartesian Coordinates for the uplinked state vector:
  - X = 9368015.770042 m
  - Y = =40657262.509054 m
  - Z = -6222446.457793 m
  - XDOT = 2961.70165343 m/sec
  - YDOT = 742.34074529 m/sec
  - ZDOT = -349.77818014 m/sec
  - Longitude = 168.43^0

TDRS Event Data Supporting Ku-band Open Loop Performance Study

- TDRS 174 event times for this study: 2010:175/21:23 and 2010:176/02:27

T171 State Vector Time: 2010:158:12:00	
Command Parameter	**Value Uplinked**
Slot Number:	6
Satellite ID:	6
Semi-Major Axis	42165354.819927 m
Inclination	0.175781171^0
RA of the Asc. Node Time, Coarse	959896931
RA of the Asc. Node Time, Fine	0.590000
Asc. Node Longitude	0.947961
Mean Motion	0.000072920300
Uplink ID	17430

- Uplink time-tag for this state vector: 2010:159:04:36:05.386.
- Means this state vector was a more than 16 days old when we first used it.
- Corresponding Cartesian Coordinates for the uplinked state vector:
  - X = -4479333.812307 m
  - Y = -41803153.308742 m
  - Z = -3685005.297722 m
  - XDOT = 3023.49225545 m/sec
  - YDOT = -280.23221061 m/sec
  - ZDOT = -465.21366213 m/sec
  - Longitude = 171.75^0