Purpose: This memorandum is an attachment to the Northrop Grumman Systems Corporation (NGSC) FCC Special Temporary Authorization (STA) application for the Cygnus NG-21 spacecraft.

Scope: This memorandum provides a data summary in support of the FCC Office of Engineering and Technology (OET) e-File system application. The data is submitted in support of the following application:

Description	Number
FCC File Number	0881-EX-ST-2024

Results: The attached charts summarize the expected NG-21 spacecraft power flux density (PFD) during each phase of the mission on a nominal trajectory to the International Space Station (ISS). The mission phases covered in this summary are the Approach (to the ISS), Berthed (at the ISS), and Departure (from the ISS). The PFD algorithm uses the equations presented in the NASA Space Network Users' Guide (450-SNUG), Revision 11, Appendix D. The specific equation is the one used for Total Power in the Reference Bandwidth (P_{tB}) of an NRZ waveform. This equation is listed as Equation D-6. The main parameters used in these PFD calculations are the Cygnus spacecraft's expected nominal mission trajectory (azimuth, elevation, and altitude) to the ISS from the launch pad in Cape Canaveral, Florida. PFD calculations use NG-21 transmitter power levels and network losses along with comparable as-flown trajectories from recent missions (NG-20 as-flown trajectory used for Approach phase; NG-17 as-flown for Berthed phase; NG-18 as-flown for Departure phase).

Two PFD limit lines are shown on each "PFD versus Time" plot herein:

- -144 dBW/m^2/4 kHz (ITU / FCC limit)

  This is the primary and most-stringent limit. It is put forth in at least three documents, including the ITU Radio Regulations (Article 21, Provision 16), the US regulation pertaining to Telecommunications (47 CFR 2, Part 2, Subpart B, Section 2.106, Footnote US303), and the ISS-to-COTS IRD (SSP 50808 Rev F).

- -128 dBW/m^2/4 kHz (PIRN 50885-NA-0068B limit)

  This limit is specified in Preliminary Interface Revision Notice (PIRN) 50885-NA-0068B to the ISS-to-Cygnus ICD (SSP 50885 Rev C). This limit represents a NASA relaxation (16 dB) of the primary limit. The PIRN indicates that while -128 dBW/m^2/4 kHz is acceptable from a NASA requirement compliance standpoint, any exceedance of the primary requirement must be approved by the FCC via the STA process.

Attachment 2 to this application gives more details on the PFD limit exceedances identified in the data summary. The PFD results presented herein assume on-orbit Cygnus operation where the primary emitter is radiating for the duration of a scheduled communication pass which is controlled by the mission timeline and the mission phase (approach, berthed, and departure).

The NG-21 spacecraft will transmit in the Spacecraft Operations Service S-Band. This band is allocated to the US Federal Government and covers 2200 to 2290 MHz. The band allocation is

consistent with operations for the ISS cargo delivery service. The Cygnus spacecraft RF communication subsystem operates with multiple data rates and modulation modes. Table 1 below lists the primary RF communication links along with the mission phases during which they are active.

Table 1. Primary RF Communication Links

Link Operation	Carrier Frequency (MHz)	NTIA Emission Designator	NGSC Designation	Modulation Mode	Data Rate (after encoding) (kbps)	Necessary Bandwidth (MHz)	Tx Output Power (W)	ERP (W)	Frequency Tolerance (%)	Mission Phase (Active)			
										In-Orbit Test	ISS Approach	ISS Berth	ISS Departure
Space-to-Space (Cygnus-to-TDRS MA/SMA)	2287.5	6M16G1D	TDRS MA/SMA	SQPN	8	6.16	23.28	7.80	± 0.00018		√	√	√
Space-to-Space (Cygnus-to-TDRS SSA)	2287.5	6M16G1D	TDRS SSA	SQPN	42	6.16	15.00	5.02	± 0.00018	√	√	√	√
Space-to-Ground (Cygnus-to-GN)	2287.5	4M98G1D	GN at 6 Mbps	SQPSK	6000	4.98	15.00	5.02	± 0.00018		√	√	√
Space-to-Ground (Cygnus-to-GN)	2287.5	3M00G1D	GN at 3 Mbps	SQPSK	3000	3.00	15.00	5.02	± 0.00018		√	√	√
Space-to-Space (Cygnus-to-ISS)	2203.2	5M93G1D	CLS at 36 kbps	SQPN	36	5.93	14.42	7.11	± 0.00008	√	√		√

The detailed PFD results are shown below for each phase of the Cygnus NG-21 mission. Additional detail on PFD requirement exceedances is provided in Appendix A (of this attachment) and in Attachment 2. Appendix A depicts the PFD requirement exceedances as ground track plots. Attachment 2 summarizes the PFD requirement exceedances in tabular form, to include latitude, longitude, and duration.

1. Approach Phase

This mission phase starts after the Cygnus spacecraft separates from the launch vehicle. Initial spacecraft telemetry transmission will be via the TDRS SSA link. Figure 15 in Appendix A shows spacecraft altitude vs time for the approach phase.

a) Cygnus-to-TDRS SSA link at 42 kbps (emission designator 6M16G1D; 2287.5 MHz)

- Figure 1 below provides a plot of PFD vs time
- Figure 17 in Appendix A depicts PFD requirement exceedances as ground track plots
- Table 1 in Attachment 2 provides PFD requirement exceedances in tabular form

b) Cygnus-to-TDRS MA/SMA link at 8 kbps (emission designator 6M16G1D; 2287.5 MHz)

- Figure 2 below provides a plot of PFD vs time
- Figure 18 in Appendix A depicts PFD requirement exceedances as ground track plots

- Table 2 in Attachment 2 provides PFD requirement exceedances in tabular form

c) Cygnus-to-GN link at 6 Mbps (emission designator 4M98G1D; 2287.5 MHz)

- Figure 3 below provides a plot of PFD vs time
- Figure 19 in Appendix A depicts PFD requirement exceedances as ground track plots
- Table 3 in Attachment 2 provides PFD requirement exceedances in tabular form

d) Cygnus-to-GN link at 3 Mbps (emission designator 3M00G1D; 2287.5 MHz)

- Figure 4 below provides a plot of PFD vs time
- Figure 20 in Appendix A depicts PFD requirement exceedances as ground track plots
- Table 4 in Attachment 2 provides PFD requirement exceedances in tabular form

e) Cygnus-to-ISS link at 36 kbps (emission designator 5M93G1D; 2203.2 MHz)

- Figure 5 below provides a plot of PFD vs time
- Figure 21 in Appendix A depicts PFD requirement exceedances as ground track plots
- Table 5 in Attachment 2 provides PFD requirement exceedances in tabular form

2. Berthed Phase

This mission phase starts after the Cygnus vehicle is grappled by the ISS robotic arm and berthed to the ISS. The Cygnus-to-ISS link will not be active during this phase. Telemetry transmission will be via the Cygnus-to-TDRS and Cygnus-to-GN links.

a) Cygnus-to-TDRS SSA link at 42 kbps (emission designator 6M16G1D; 2287.5 MHz)

- Figure 6 below provides a plot of PFD vs time
- Figure 22 in Appendix A depicts PFD requirement exceedances as ground track plots
- Table 6 in Attachment 2 provides PFD requirement exceedances in tabular form

b) Cygnus-to-TDRS MA/SMA link at 8 kbps (emission designator 6M16G1D; 2287.5 MHz)

- Figure 7 below provides a plot of PFD vs time
- Figure 23 in Appendix A depicts PFD requirement exceedances as ground track plots

- Table 7 in Attachment 2 provides PFD requirement exceedances in tabular form

c) Cygnus-to-GN link at 6 Mbps (emission designator 4M98G1D; 2287.5 MHz)

- Figure 8 below provides a plot of PFD vs time
- Figure 24 in Appendix A depicts PFD requirement exceedances as ground track plots
- Table 8 in Attachment 2 provides PFD requirement exceedances in tabular form

d) Cygnus-to-GN link at 3 Mbps (emission designator 3M00G1D; 2287.5 MHz

- Figure 9 below provides a plot of PFD vs time
- Figure 25 in Appendix A depicts PFD requirement exceedances as ground track plots
- Table 9 in Attachment 2 provides PFD requirement exceedances in tabular form

3. Departure Phase

This mission phase starts after the Cygnus spacecraft is already unberthed from the ISS and released by the ISS robotic arm. The spacecraft then performs a series of departure burns to lower its perigee. A final reentry burn puts the spacecraft on a controlled re-entry path into the Earth's atmosphere. The Cygnus-to-ISS link is active during departure and is deactivated once the spacecraft is no longer in proximity to the ISS. The Cygnus-to-TDRS and Cygnus-to-GN links are active during the departure and reentry phases.

Figure 16 in Appendix A shows spacecraft altitude vs time for the departure phase. There are no secondary payload operations planned for NG-21.

a) Cygnus-to-TDRS SSA link at 42 kbps (emission designator 6M16G1D; 2287.5 MHz)

- Figure 10 below provides a plot of PFD vs time
- Figure 26 in Appendix A depicts PFD requirement exceedances as ground track plots
- Table 10 in Attachment 2 provides PFD requirement exceedances in tabular form

b) Cygnus-to-TDRS MA/SMA link at 8 kbps (emission designator 6M16G1D; 2287.5 MHz)

- Figure 11 below provides a plot of PFD vs time
- Figure 27 in Appendix A depicts PFD requirement exceedances as ground track plots
- Table 11 in Attachment 2 provides PFD requirement exceedances in tabular form

c) Cygnus-to-GN link at 6 Mbps (emission designator 4M98G1D; 2287.5 MHz)
   - Figure 12 below provides a plot of PFD vs time
   - Figure 28 in Appendix A depicts PFD requirement exceedances as ground track plots
   - Table 12 in Attachment 2 provides PFD requirement exceedances in tabular form

d) Cygnus-to-GN link at 3 Mbps (emission designator 3M00G1D; 2287.5 MHz)
   - Figure 13 below provides a plot of PFD vs time
   - Figure 29 in Appendix A depicts PFD requirement exceedances as ground track plots
   - Table 13 in Attachment 2 provides PFD requirement exceedances in tabular form

e) Cygnus-to-ISS link at 36 kbps (emission designator 5M93G1D; 2203.2 MHz)
   - Figure 14 below provides a plot of PFD vs time
   - Figure 30 in Appendix A depicts PFD requirement exceedances as ground track plots
   - Table 14 in Attachment 2 provides PFD requirement exceedances in tabular form

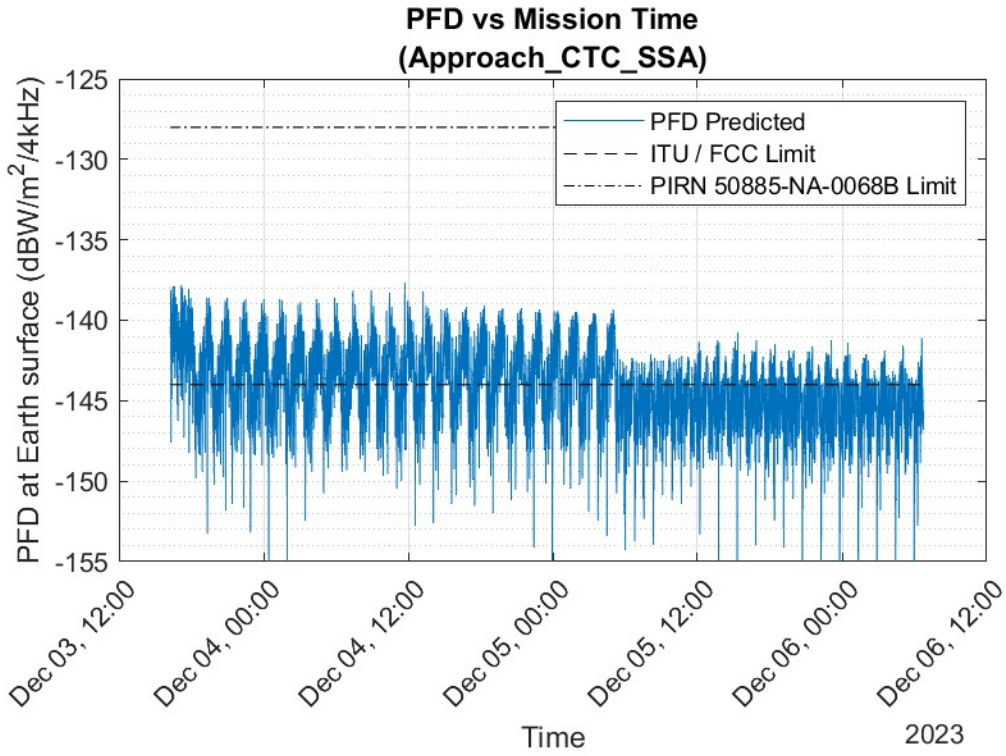

Figure 1. NG-21 PFD during Approach, TDRS SSA (6M16G1D Emitter)

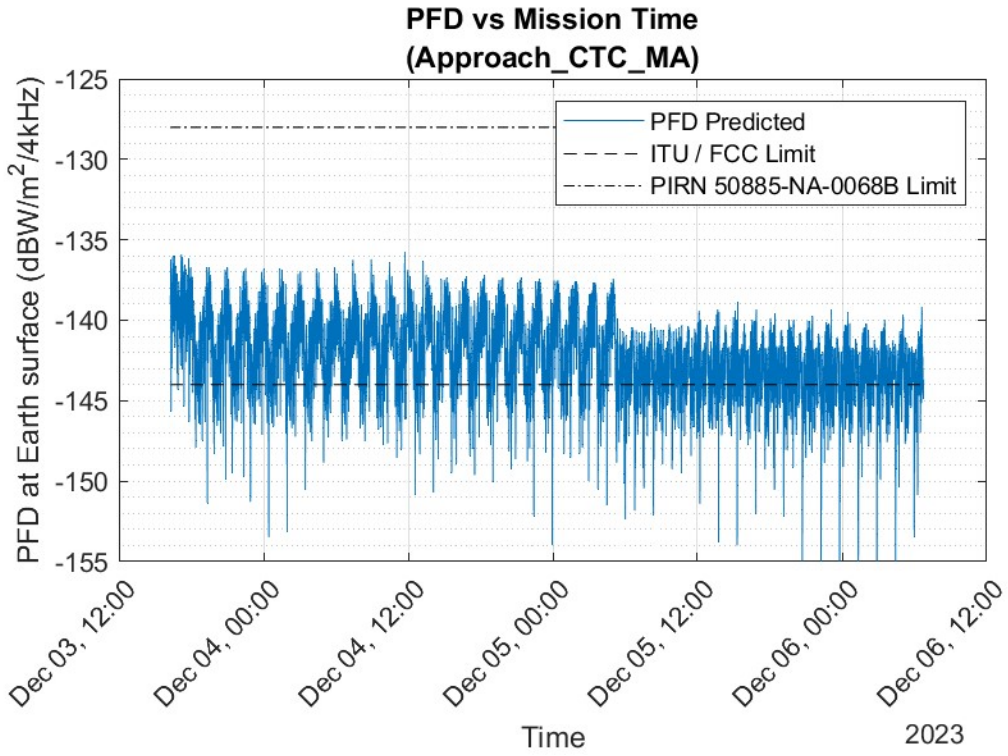

Figure 2. NG-21 PFD during Approach, TDRS MA/SMA (6M16G1D Emitter)

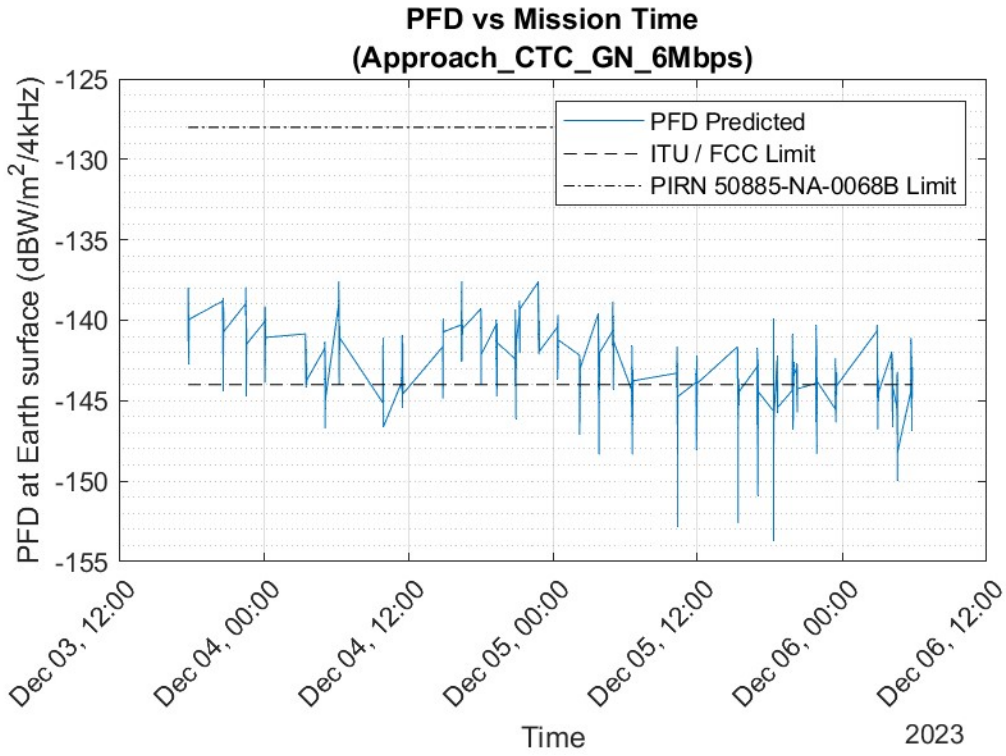

Figure 3. NG-21 PFD during Approach, GN 6 Mbps (4M98G1D Emitter)

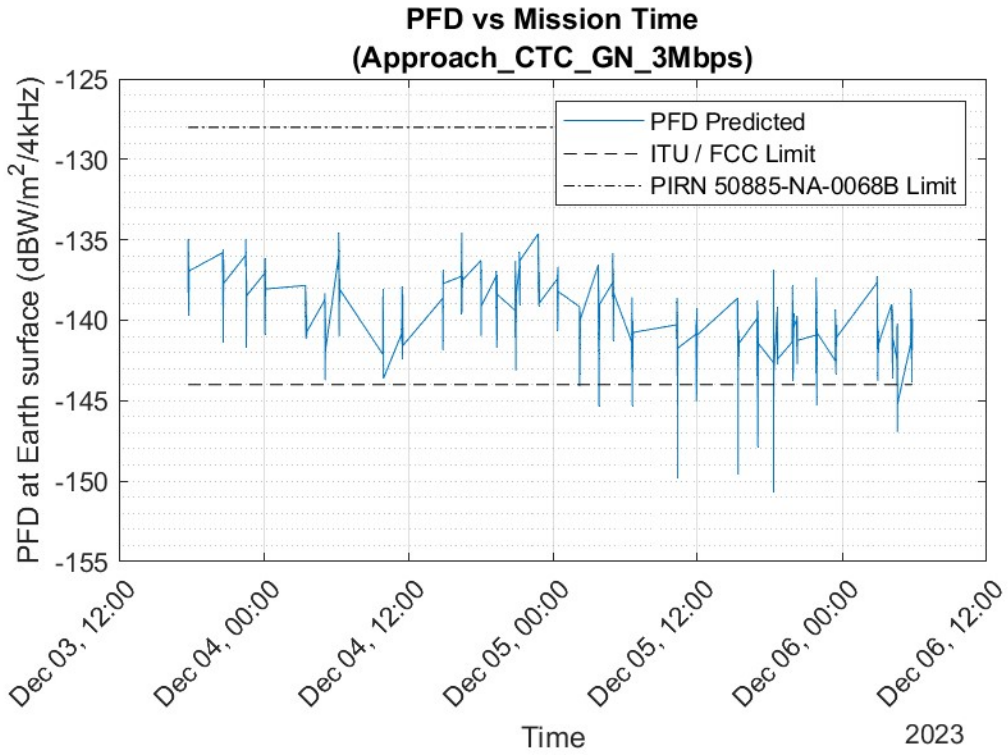

Figure 4. NG-21 PFD during Approach, GN 3Mbps (3M00G1D Emitter)

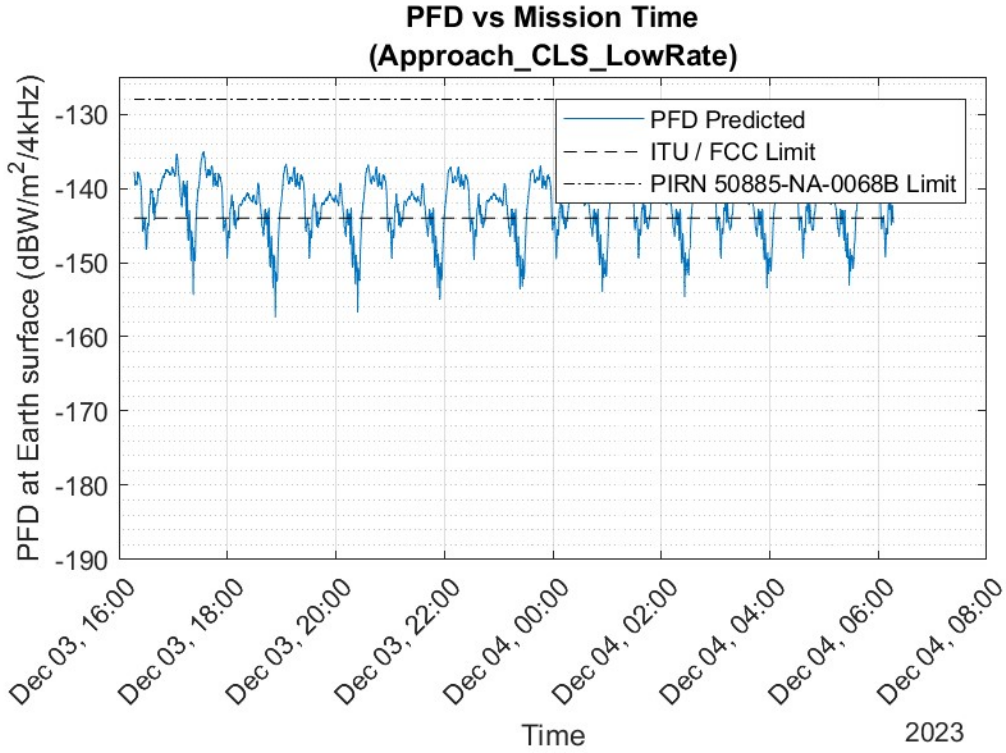

Figure 5. NG-21 PFD during Approach, CLS Low Rate (5M93G1D Emitter)

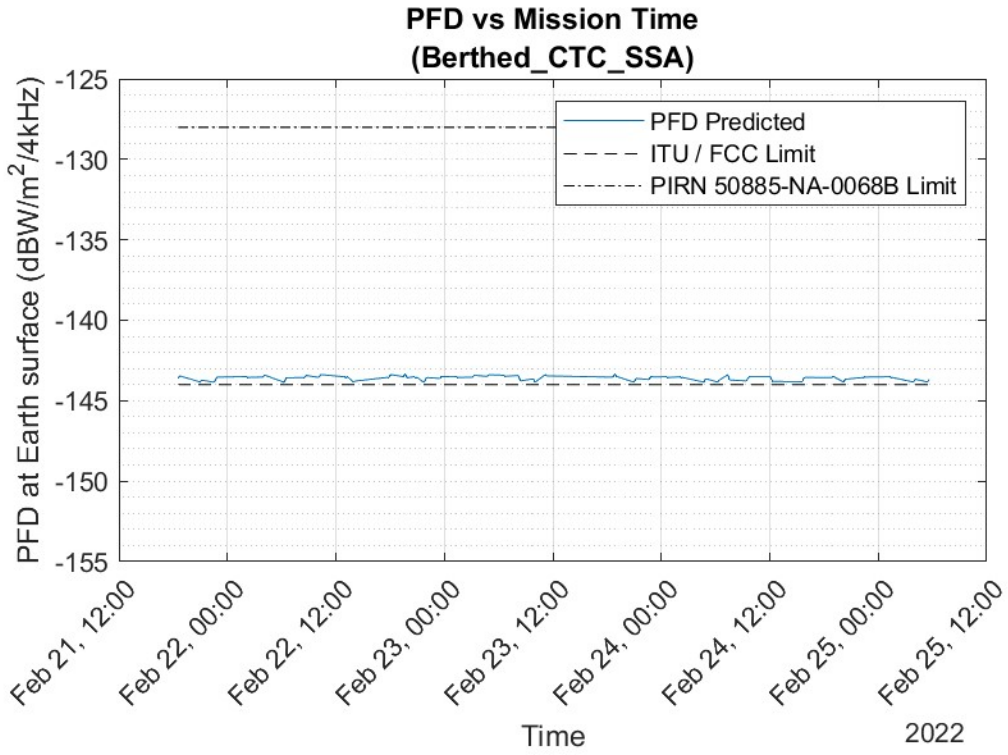

Figure 6. NG-21 PFD during Berthed Phase, TDRS SSA (6M16G1D Emitter)

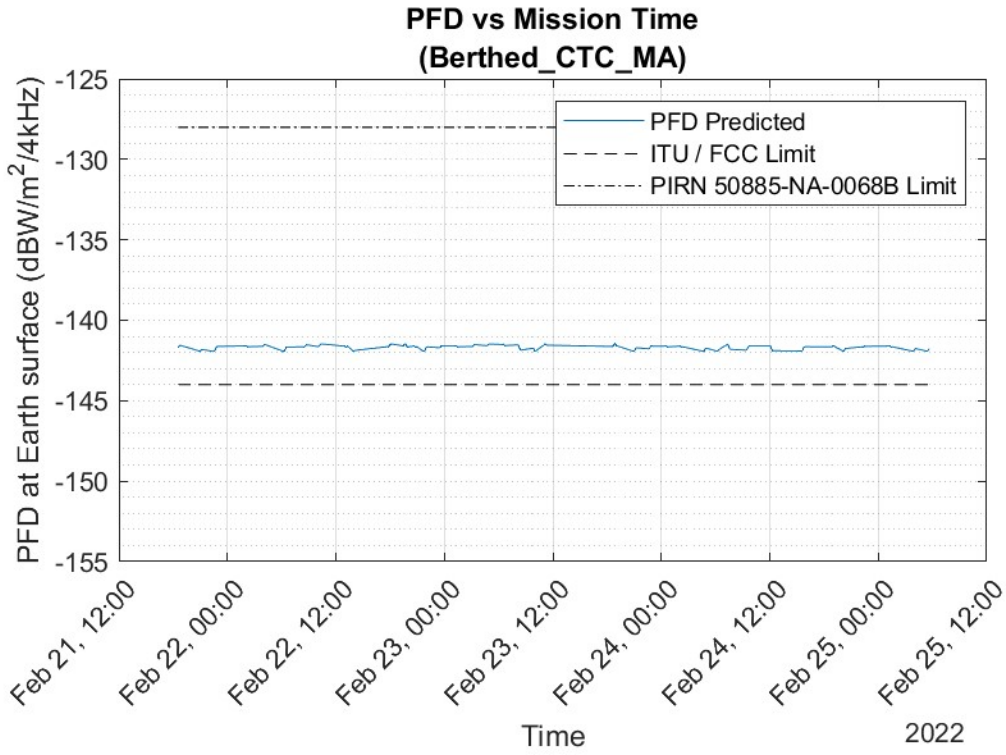

Figure 7. NG-21 PFD during Berthed Phase, TDRS MA (6M16G1D Emitter)

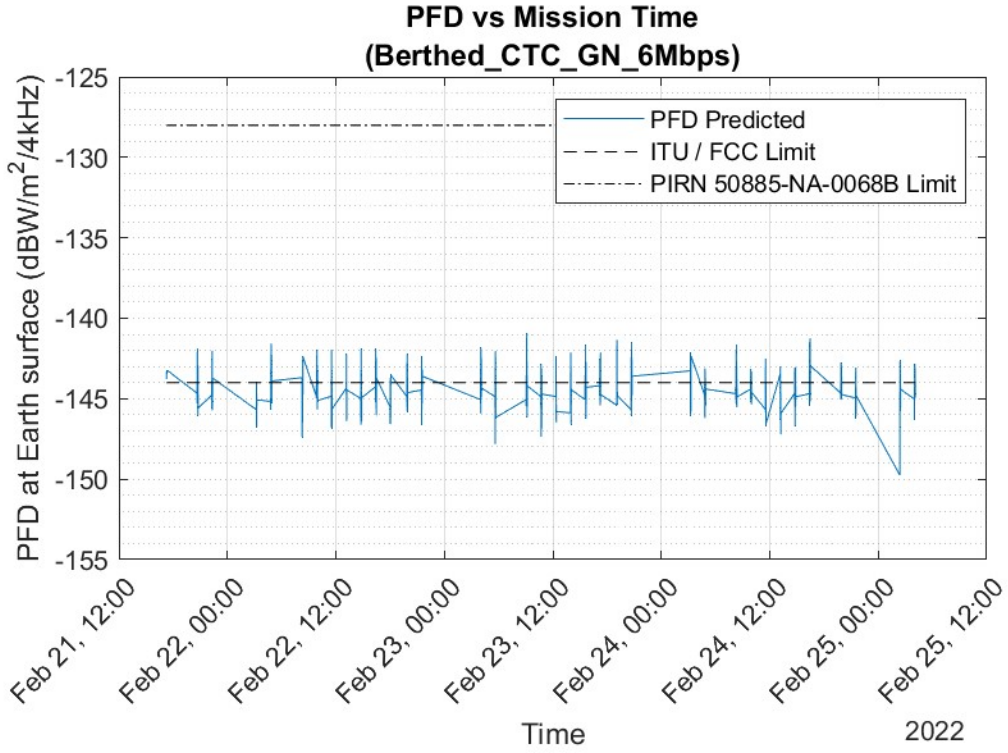

Figure 8. NG-21 PFD during Berthed Phase, GN 6 Mbps (4M98G1D Emitter)

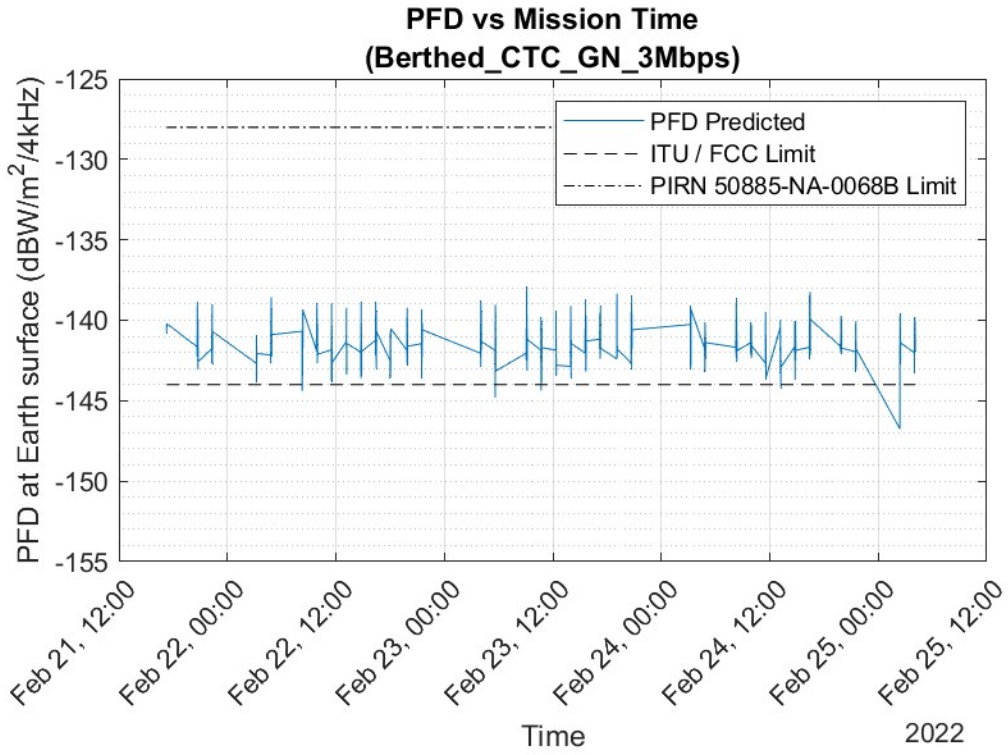

Figure 9. NG-21 PFD during Berthed Phase, GN 3Mbps (3M00G1D Emitter)

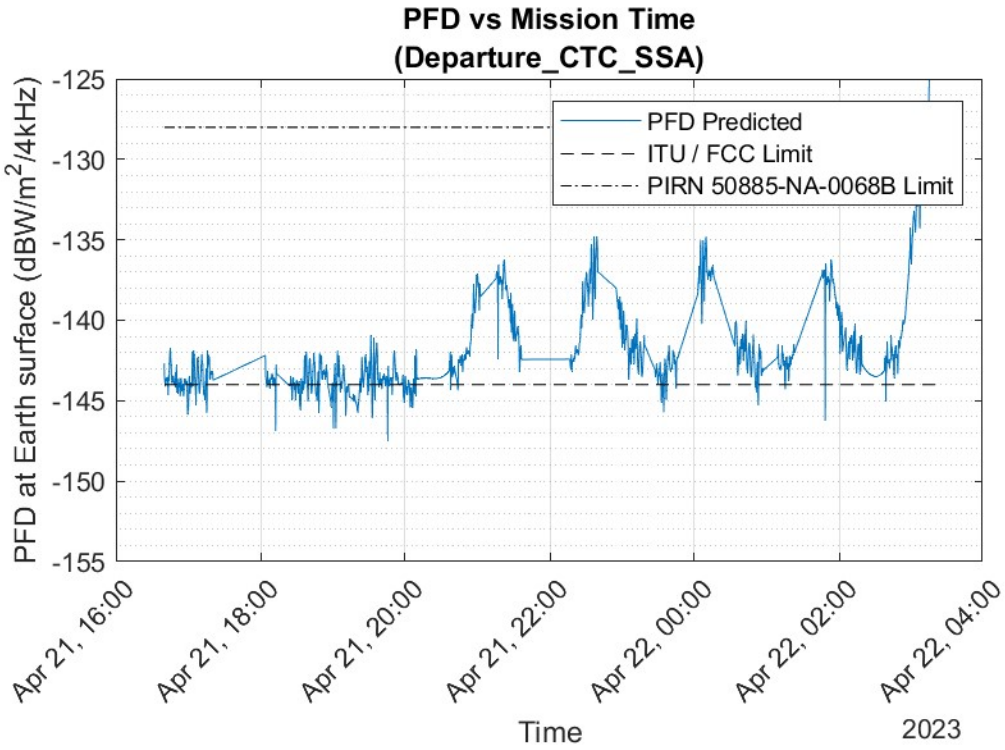

Figure 10. NG-21 PFD during Departure Phase, TDRS SSA (6M16G1D Emitter)

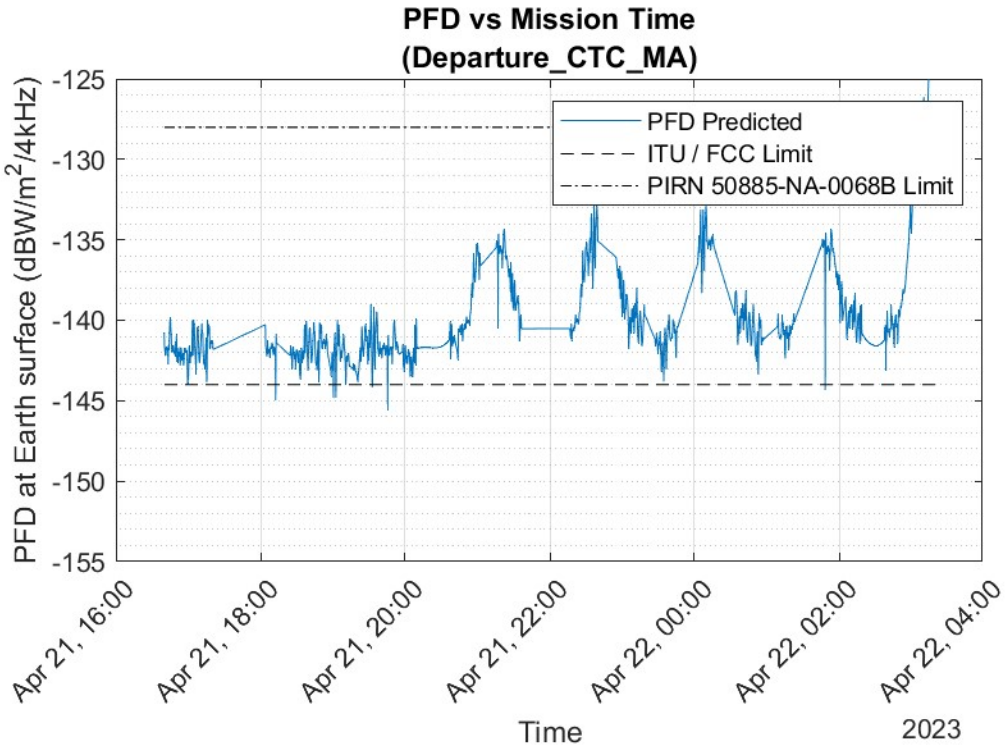

Figure 11. NG-21 PFD during Departure Phase, TDRS MA (6M16G1D Emitter)

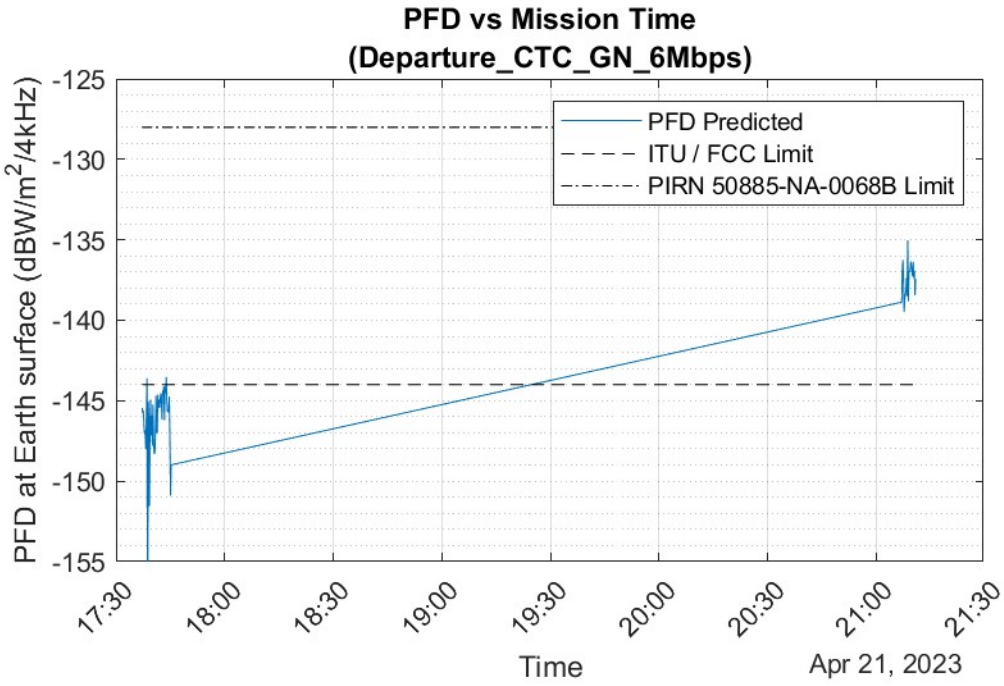

Figure 12. NG-21 PFD during Departure Phase, GN 6 Mbps (4M98G1D)

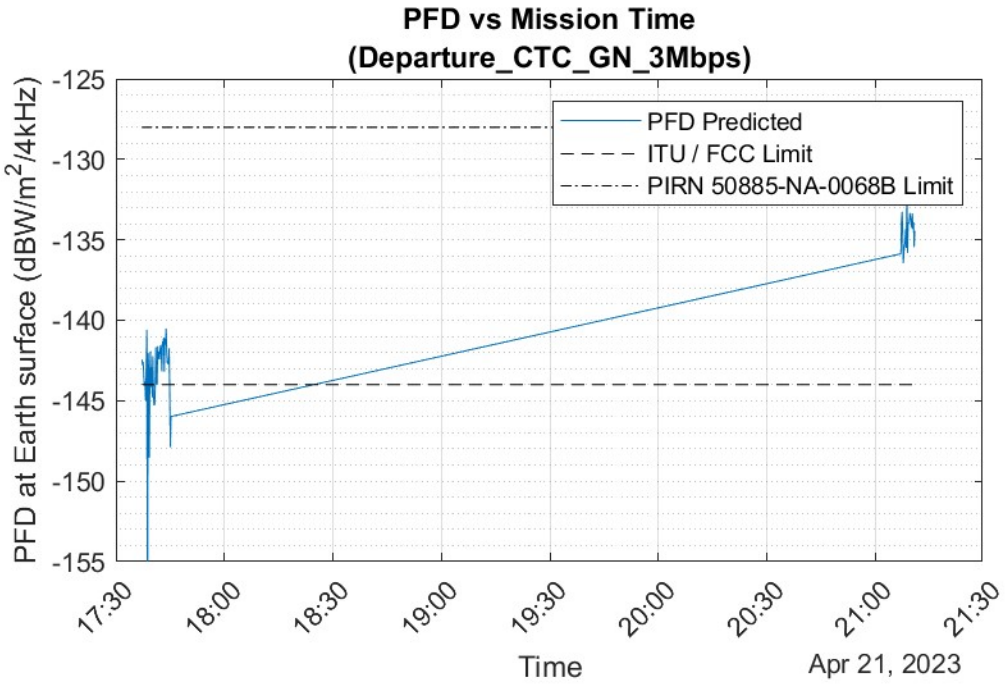

Figure 13. NG-21 PFD during Departure Phase, GN 3 Mbps (3M00G1D Emitter)

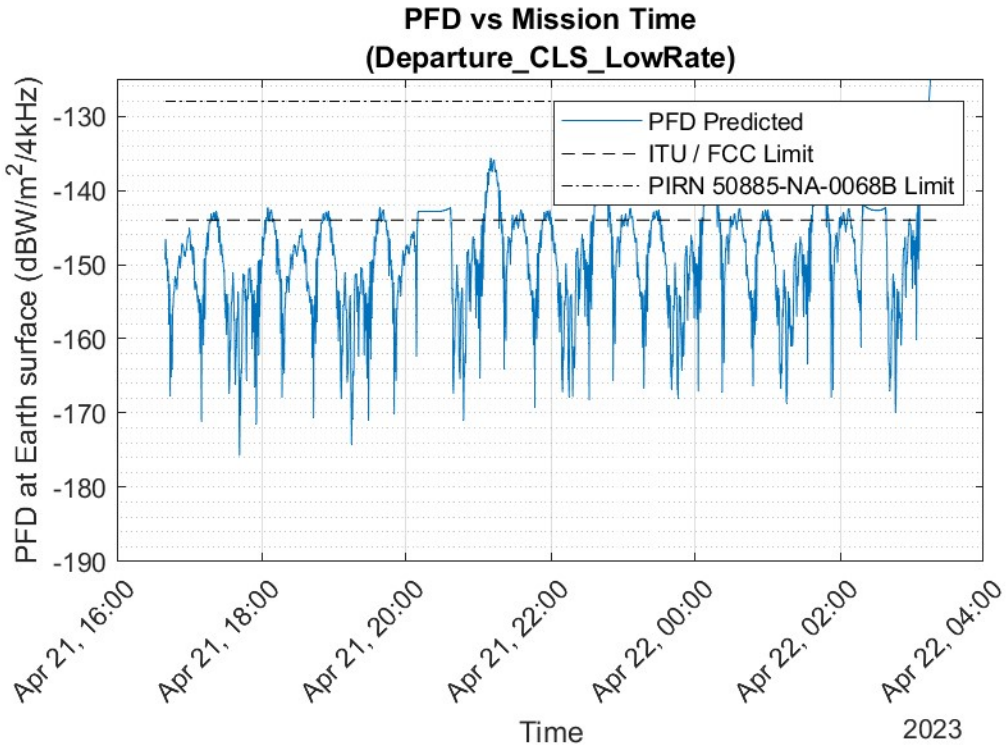

Figure 14. NG-21 PFD during Departure Phase, CLS Low Rate (5M93G1D Emitter)

Appendix A

(Altitude and Ground Track Plots of PFD Exceedances during Mission Phases)

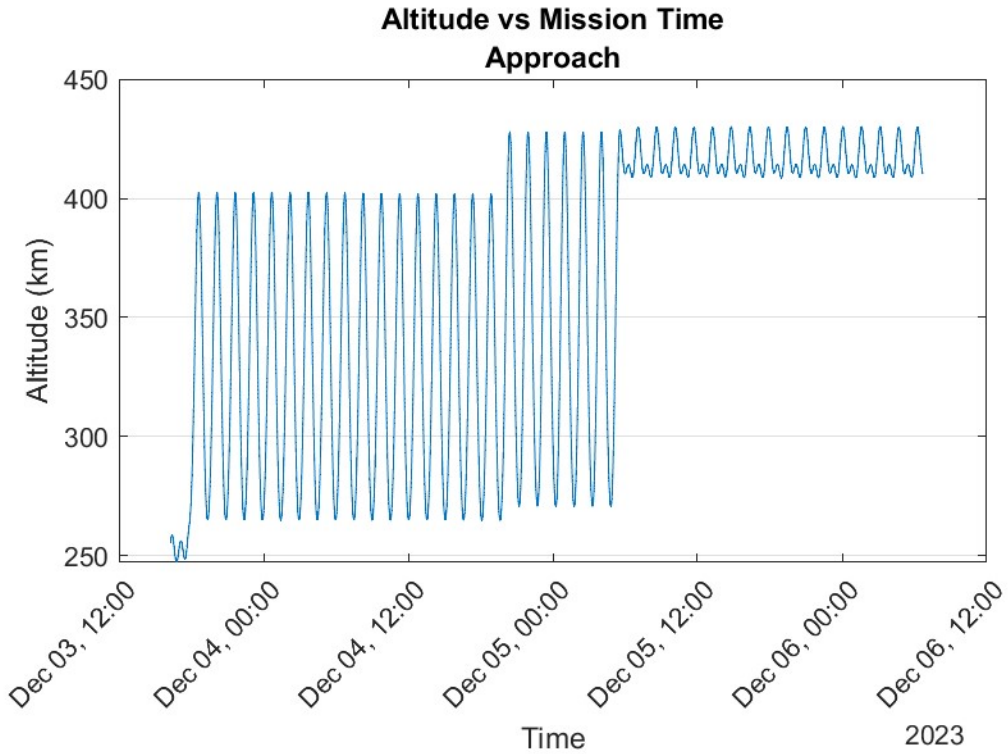

Figure 15. NG-21 Altitude vs. Mission Time (Approach)

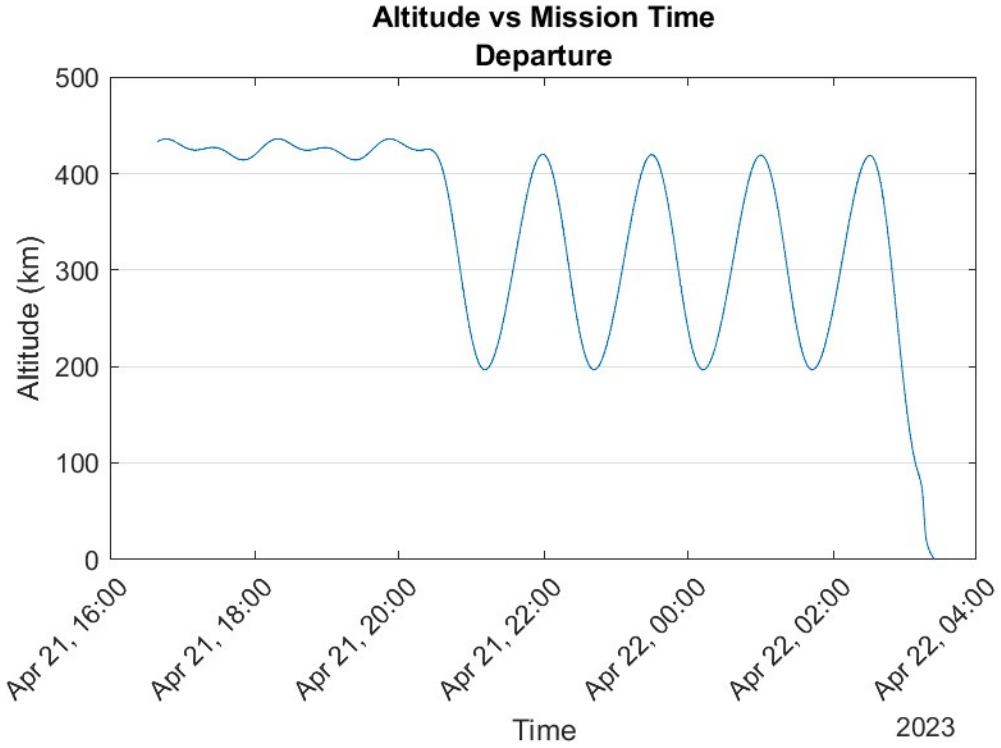

Figure 16. NG-21 Altitude vs. Mission Time (Departure)

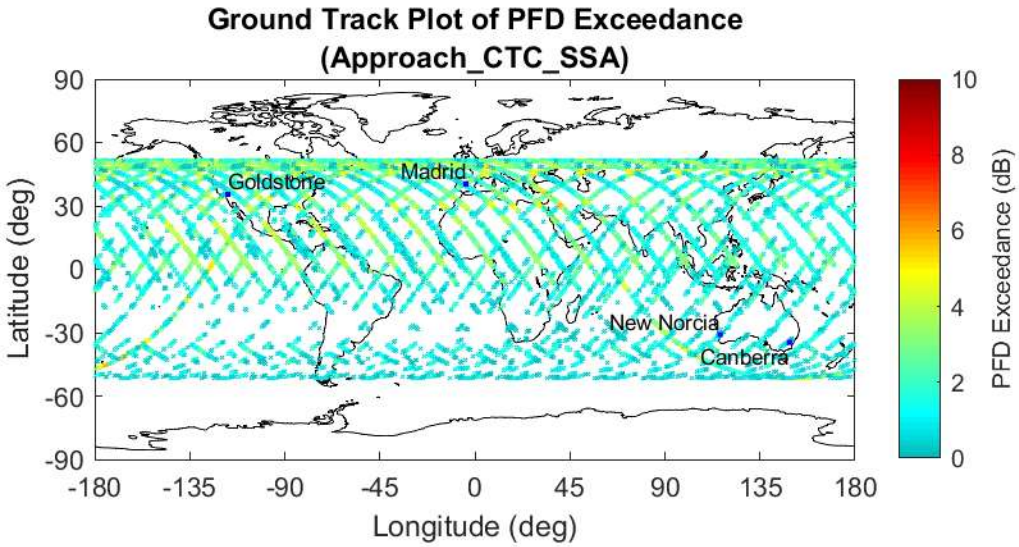

Figure 17. NG-21 PFD Limit Exceedance during Mission Approach, TDRS SSA (6M16G1D Emitter)

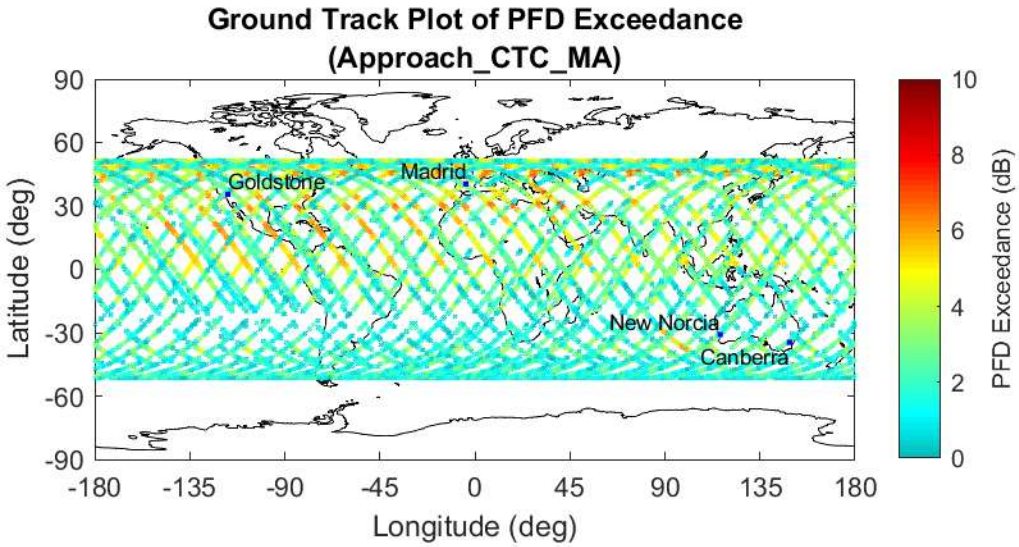

Figure 18. NG-21 PFD Limit Exceedance during Mission Approach, TDRS MA (6M16G1D Emitter)

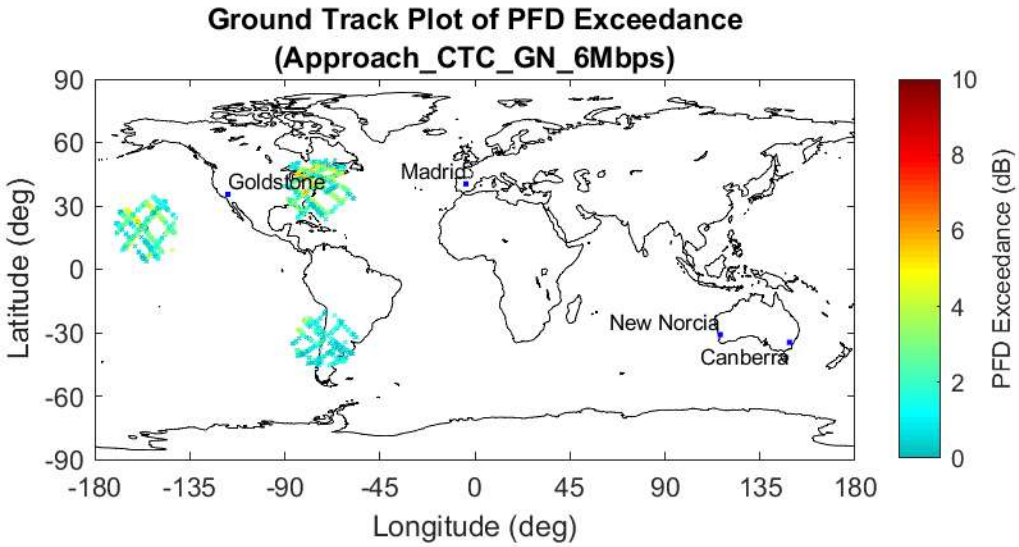

Figure 19. NG-21 PFD Limit Exceedance during Mission Approach, GN 6 Mbps (4M98G1D Emitter)

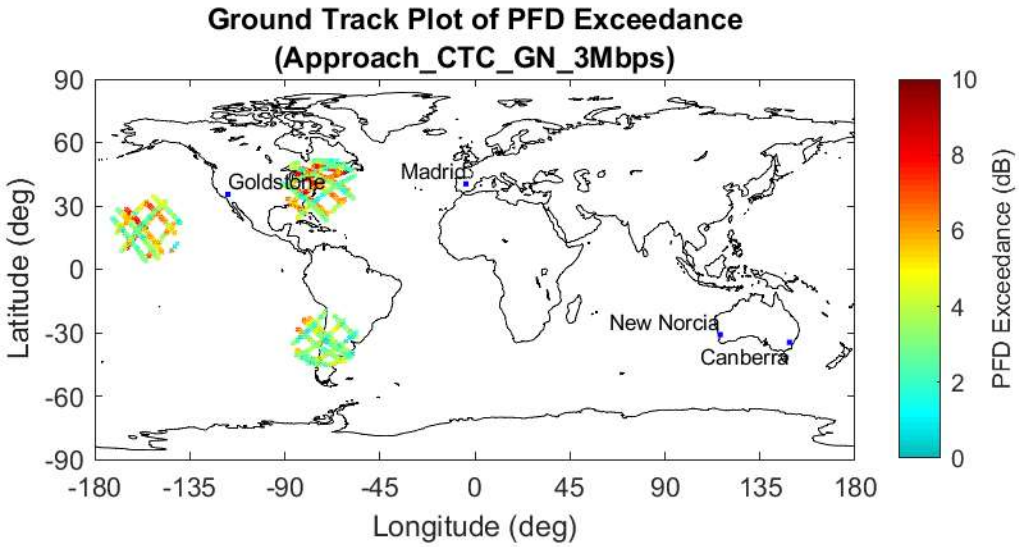

Figure 20. NG-21 PFD Limit Exceedance during Mission Approach, GN 3 Mbps (3M00G1D Emitter)

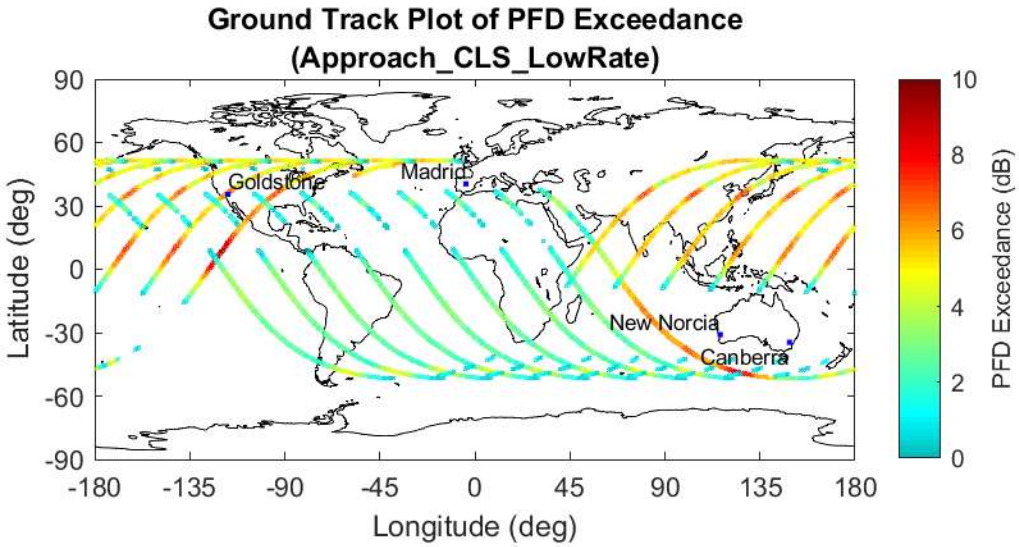

Figure 21. NG-21 PFD Limit Exceedance during Mission Approach, CLS Low Rate (5M93G1D Emitter)

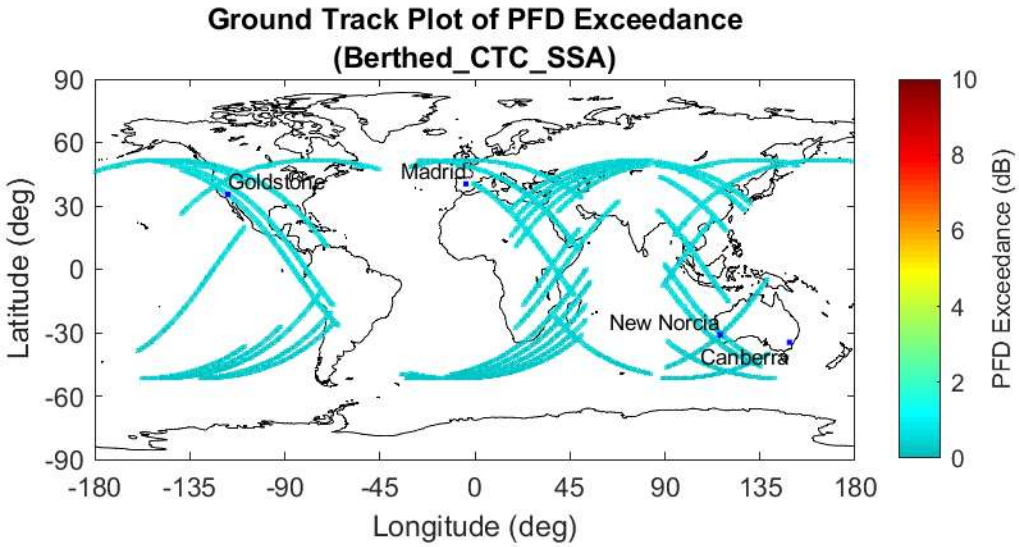

Figure 22. NG-21 PFD Limit Exceedance during Mission Berthed, TDRS SSA (6M16G1D Emitter)

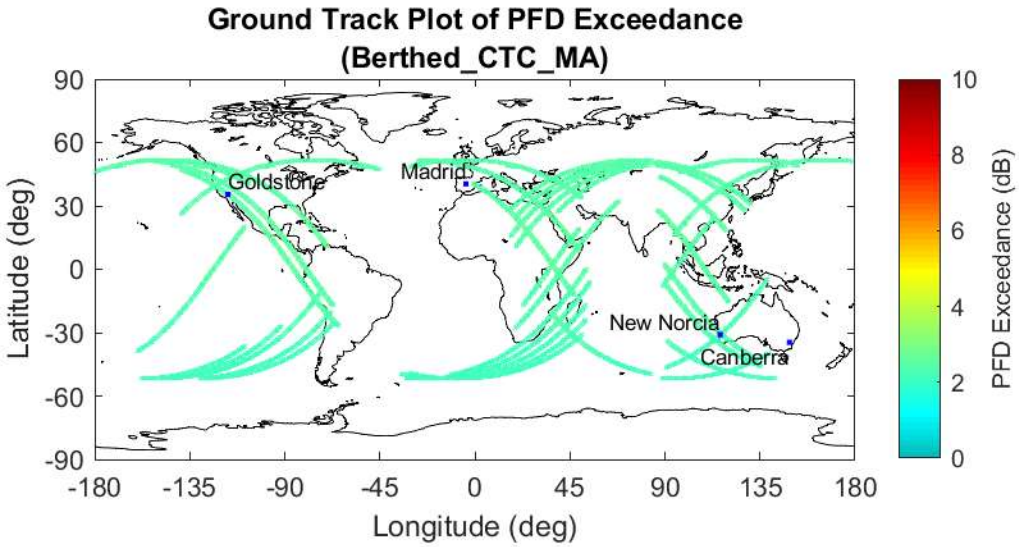

Figure 23. NG-21 PFD Limit Exceedance during Mission Berthed, TDRS MA (6M16G1D Emitter)

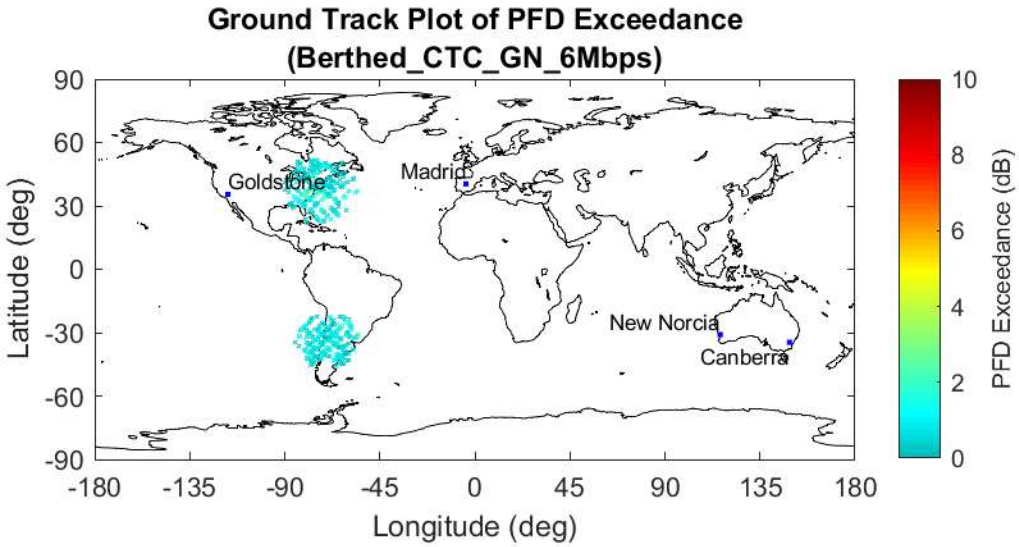

Figure 24. NG-21 PFD Limit Exceedance during Mission Berthed, GN 6 Mbps (4M98G1D Emitter)

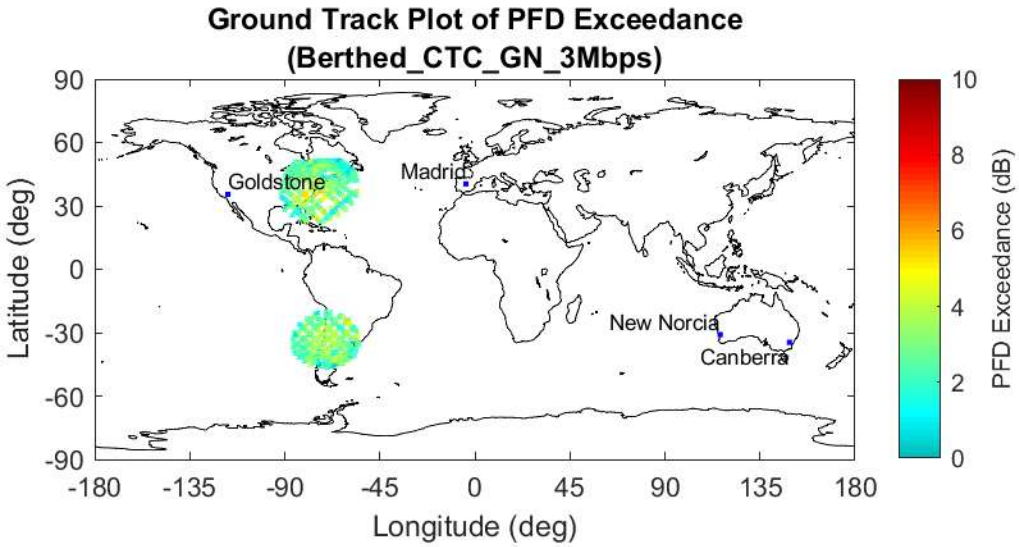

Figure 25. NG-21 PFD Limit Exceedance during Mission Berthed, GN 3 Mbps (3M00G1D Emitter)

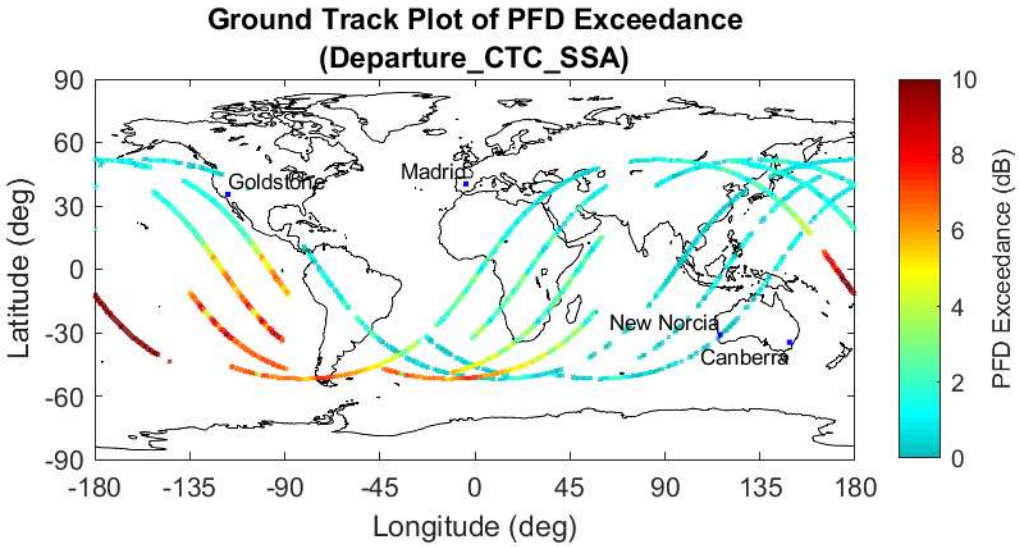

Figure 26. NG-21 PFD Limit Exceedance during Mission Departure, TDRS SSA (6M16G1D Emitter)

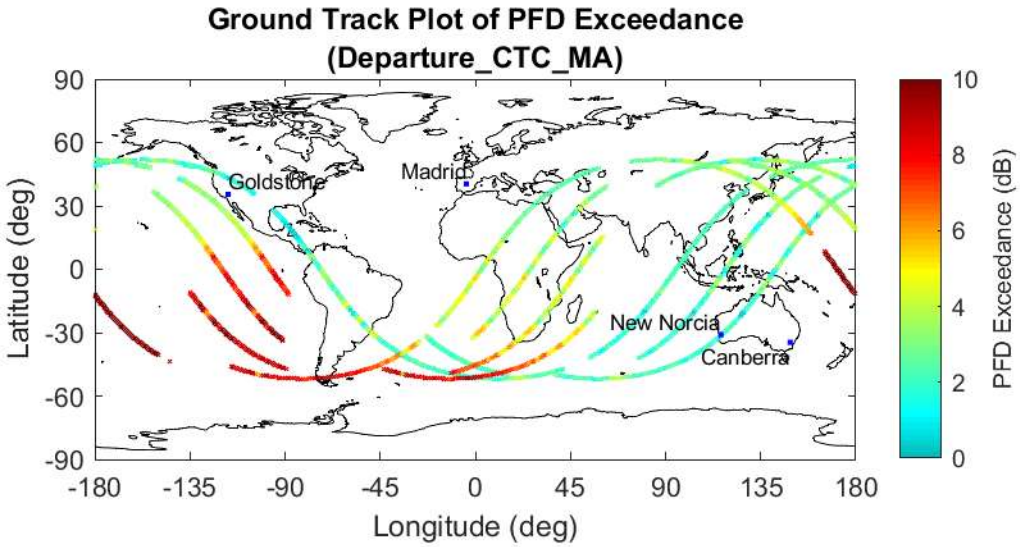

Figure 27. NG-21 PFD Limit Exceedance during Mission Departure, TDRS MA (6M16G1D Emitter)

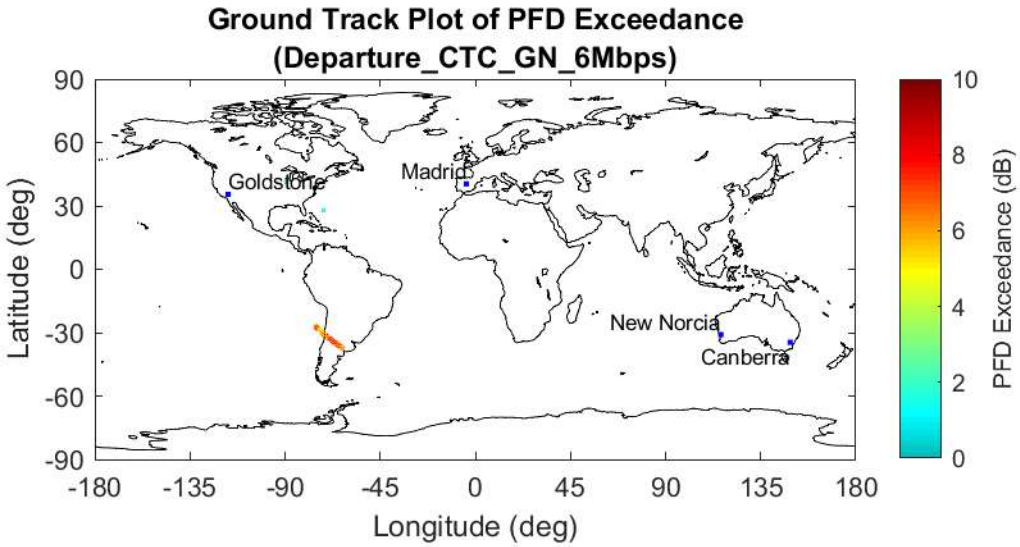

Figure 28. NG-21 PFD Limit Exceedance during Mission Departure, GN 6 Mbps (4M98G1D Emitter)

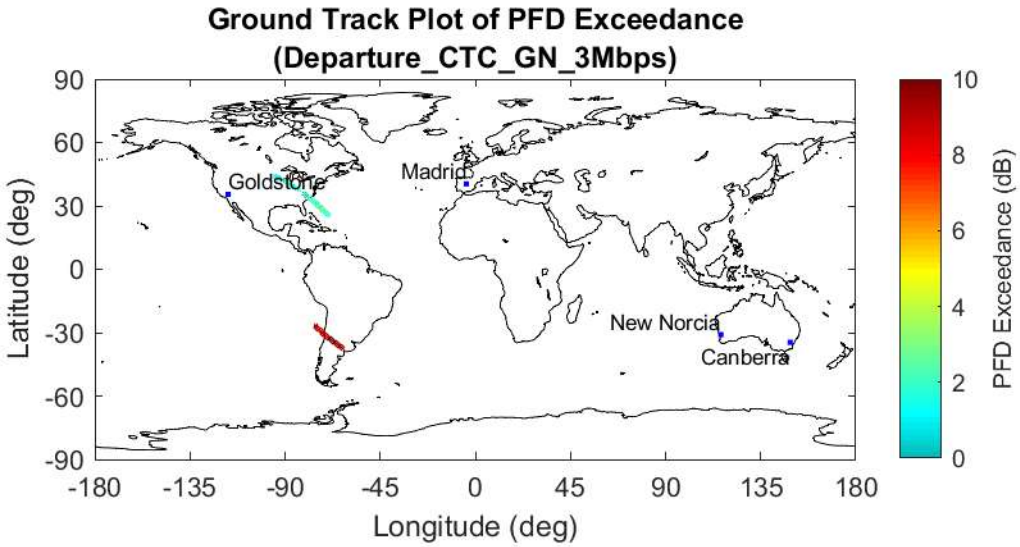

Figure 29. NG-21 PFD Limit Exceedance during Mission Departure, GN 3 Mbps (3M00G1D Emitter)

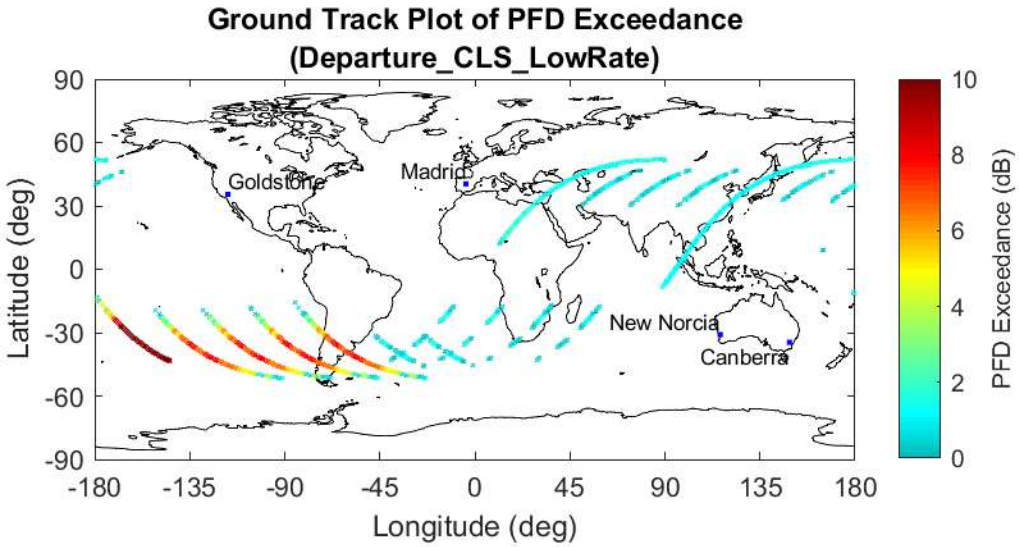

Figure 30. NG-21 PFD Limit Exceedance during Mission Departure, CLS Low Rate (5M93G1D Emitter)