DESCRIPTION OF PROPOSED MODIFICATION

Planet Labs Inc. (Planet) respectfully requests authority to modify the authorization for the Planet Earth Exploration Satellite Service (EESS) system (FCC Call Sign S2912, a.k.a. "Flock").[1] Specifically, Planet requests authority to:

- Remove Condition 2 from the Planet Authorization. Planet is no longer pursuing the launch of 56 satellites on the SpaceX Formosat-5/Sherpa mission and has no plans to replace that launch with another launch to a similar elliptical orbit.[2]

- Increase the orbit apogee altitude limit specified in Condition 5 of the Planet Authorization from 500 km to 550 km, thereby allowing up to 120 satellites of the 600 authorized to exceed an orbit apogee altitude of 550 km.[3] Planet has increased its target deployment altitude from 475 km to 500 km and requests greater flexibility for its orbit apogee altitude limit in light of its secondary payload status on launches.

- Revise Condition 8 of the Planet Authorization to state:

  "Transmissions of remote-sensing and telemetry data in the 8025-8400 MHz frequency band may only be made to earth stations coordinated with the National Aeronautics and Space Administration (NASA). Planet shall provide the FCC the list of coordinated earth stations."

  Planet has executed a written coordination agreement with NASA identifying the earth stations with which Planet may communicate and specifying a process by which to remove and add earth stations.[4] The revised condition eliminates the administrative complication of having to modify the satellite license for changes in earth station operations while still ensuring that Planet's earth stations will not cause harmful interference to NASA operations in the 8025-8400 MHz frequencies.

- Change data downlink frequencies and necessary bandwidth from two (2) single polarization carriers to three (3) selectable dual polarization capable carriers

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[1] *See* Stamp Grant, Application, File No. SAT-MOD-20150802-00053 (granted Sep. 15, 2016) ("Planet Authorization").
[2] *See* Letter from Mike Safyan to Marlene H. Dortch, File No. SAT-MOD-20150802-00053 (filed Nov. 8, 2016).
[3] *See infra* Section I.A.
[4] *See infra* Section I.C. The same coordination agreement executed with NASA satisfies Condition 9 of the Planet Authorization.

(one, two, or all three carriers per polarization may be used at any one time per satellite with a maximum of six (6) carriers in dual polarization mode) within the X-band (8025-8400 MHz).[5] The proposed changes increase Planet's ability to communicate with its satellites, have no material impact on the coordination agreement executed with NASA and comply with relevant technical requirements. The additional channels would also facilitate coordination with other operators in this band.

- Change the high-speed telecommand uplink frequency from one (1) carrier to three (3) selectable carriers (only one carrier will be used at any one time per satellite) within the S-band (2025-2110 MHz).[6] The additional channels would facilitate coordination with other operators in this band.
- Update the Schedule S to reflect the changes discussed above and the use of a new X-band downlink antenna.
- Update the ownership information of Planet to reflect a new board member and minor changes in the ownership percentages of shareholders.[7]

For completeness and to facilitate coordination with federal agencies, Planet is submitting in this application a complete set of information regarding the radio communications parameters of the Flock system, including an updated Schedule S form, identifying all relevant technical specifications.[8] Except for those items stated above, Planet is not requesting any other change to the Planet Authorization.

I. Overview

Planet operates a constellation of commercial non-geostationary orbit (NGSO) remote-sensing satellites. Transmissions to and from the satellites in Planet's network use standard communications protocols typical of other satellites operating in the EESS frequency bands.

In September 2016, the Commission authorized the launch and operation of up to 600 satellites in the Flock constellation, not to exceed 200 operational satellites at any one time.[9] Planet is currently operating on-orbit 132 Flock satellites and has

[5] *See infra* Section I.C. and Table 2b.
[6] *See infra* Section I.C. and Table 1.
[7] *See* attached Exhibit 40, Ownership Information.
[8] Planet is not including in this application details pertaining to the approved orbital debris plan, which is not changed by this application. *See* Application, File No. SAT-MOD-20150802-00053 at 6-7 (granted Sep. 15, 2016).
[9] *See* Condition 4, Planet Authorization.

manifested an additional number of launches in the coming months, consistent with its authorization.

A. General Description of Overall Facilities, Operations, and Services

The Flock satellite system consists of a remote sensing space segment together with a ground segment comprised of earth stations listed in Table 4. Mission operations and the control point for Flock satellites are conducted from Planet's Mission Operations Center at its headquarters in San Francisco, California. Each satellite is authorized and designed to receive commands in the S-band frequencies (2025-2110 MHz) and to downlink imaging data in the X-band frequencies (8025-8400 MHz).[10] The Flock satellites also use the UHF bands (401-402 MHz (space-to-Earth) and 449.75-450.25 MHz (Earth-to-space)) for TT&C links (downlink and uplink, respectively) for the early commissioning phase, emergency back-up communications, and to perform ranging and orbit determination on a regular basis throughout the mission lifetime.[11] Planet is not seeking in this modification application any changes to its authorized UHF operations.

The Flock satellites will operate generally in sun-synchronous orbit (SSO) within an altitude range between 350 km and 660 km above sea level. Some satellites may be deployed from the International Space Station and operate in that orbit. The minimum inclination for any Flock satellite will be 30 degrees.

Planet has revised its target primary orbit for satellites from 475 km circular to 500 km circular.[12] Because Planet's satellites are launched as secondary payloads and the exact orbital deployment altitudes will vary considerably depending on the launch vehicle selected, Planet requests additional flexibility in the orbit apogee altitude limit specified in Condition 5 of the Planet Authorization and requests to increase that limit from 500 km to 550 km. This new limit would allow up to 20% of the Flock constellation, or 120 satellites, to exceed an orbit apogee altitude of 550 km. As discussed below in Section I.G., this proposed modification has no material impact to the orbital debris assessment or mitigation plan previously submitted by Planet.[13]

B. Description of Types of Services and Areas to be Served

The Flock satellites provide satellite imagery and derived information products on a non-common carrier basis to commercial customers, nonprofits, and governments

[10] *See generally* Planet Authorization.
[11] *See generally* Planet Authorization.
[12] *See* Application, File No. SAT-MOD-20150802-00053, at 2-3 (granted Sep. 15, 2016).
[13] *See* Application, File No. SAT-MOD-20150802-00053, at 2-3 (granted Sep. 15, 2016).

worldwide. Planet serves industries such as agriculture, scientific research, environmental monitoring, disaster response, natural resources, news media, and online mapping industries.

C. Technical Description

As noted above, the communications system onboard the satellites is designed to receive commands from the associated earth stations and to downlink the data that is collected by the imaging sensor and stored onboard the satellites.

Table 1 lists the currently authorized and proposed additional S-band frequency channels to be used for the satellite tasking and commanding uplink. Flock satellite operations will choose one of the three frequencies as optimum for each contact. All Flock satellites, including those currently orbiting and yet to be launched, can be updated to use any of the three proposed S-band frequencies.

Planet requests the authorization of these additional S-band channels as proposed in Table 1 in order to facilitate coordination with other satellite missions with overlapping S-band uplink frequencies. In the event a Flock satellite could cause interference with another satellite operator, Planet could choose an alternate uplink frequency that avoids the interference and continue its operations uninterrupted.

Tables 2a and 2b list the currently authorized and proposed X-band frequency channels, respectively, to be used for the imaging payload data downlink. In this modification, we request to change the current authorization from two frequencies (8133 and 8200 MHz) to just one wider bandwidth frequency at 8150 MHz applicable to currently orbiting satellites. This is a reduction in total bandwidth authorized for the current satellites and a slight reduction in transmit power resulting in a lower PFD at Earth's surface. These revisions are shown for Beam ID XDLH in Form 312 Schedule of S associated with this modification application.

Planet has also developed a higher gain and dual-polarization capable satellite data downlink antenna as well as improved radio transmitters resulting in a capability of three channels per polarization (six channels total in dual-polarization mode). Planet requests authorization for additional channels and dual polarization operations as shown in table 3 and as new Beam ID's XDLR and XDLL in the Form 312 Schedule S associated with this modification application. Planet can select between the above referenced single channel or three simultaneous channels in single or dual polarization mode. Satellites currently being constructed may have this new capability but will operate consistent with existing authorized parameters until this application is approved.

Planet requests authorization for these additional channels proposed in Table 2b in order to facilitate higher data downlink throughput and demonstrate future capabilities. This capability allows Planet to optimize its data downlink efficiency at its current and proposed earth stations, as well as improve the Flock mission service to its customers with higher imagery collection and downlink capacity.

For completeness, Table 3 lists the currently authorized UHF-band frequencies used for commissioning, backup TTC, and regular satellite ranging operations. There are no proposed changes to Planet's authorized UHF operations.

Channel ID	Center Frequency	Assigned Bandwidth
SCH2 (proposed)	2054.69 MHz	1.310 MHz
SCH1 (authorized)	2056 MHz	1.310 MHz
SCH3 (proposed)	2057.31 MHz	1.310 MHz

Table 1: Currently Authorized and Proposed S-band Earth-to-Space Channels

Channel ID	Center Frequency	Assigned Bandwidth	Polarization	Tx Power	EIRP
XCH1	8133 MHz	66.8 MHz	RHCP	2.9 W	15.9 dBW
XCH2	8200 MHz	66.8 MHz	RHCP	2.9 W	15.9 dBW

Table 2a: Currently Authorized X-band Space-to-Earth Channels

Channel ID	Center Frequency	Assigned Bandwidth	Polarization	Tx Power	EIRP
XCH1 (existing satellites)	8150 MHz	96.3 MHz	RHCP	2.0 W	15 dBW
XCH2 (new antenna)	8150 MHz	96.3 MHz	RHCP	2.0 W	18 dBW

XCH1R XCH2R XCH3R	8087.5 MHz 8212.5 MHz 8337.5 MHz	96.3 MHz each channel	RHCP	2 W total (each polarization)	18 dBW total (each polarization)
XCH1L XCH2L XCH3L	8087.5 MHz 8212.5 MHz 8337.5 MHz	96.3 MHz each channel	LHCP	2 W total (each polarization)	18 dBW total (each polarization)

Table 2b: Proposed X-band Space-to-Earth Channels

Channel ID	Direction	Center Frequency	Assigned Bandwidth	Tx Power	EIRP
UDCH1	Space-to-Earth	401.3 MHz	60 kHz	0.7 W	0.19 dBW
UUCH1	Earth-to-Space	450 MHz	60 kHz		

Table 3: Currently Authorized UHF-band frequencies

The Flock ground segment listed in Table 4 is currently authorized for X-band and S-band earth stations[14] and have been coordinated formally with NASA. Planet expects to coordinate with NASA the operations of the additional earth station listed in Table 5.

Station Location	**Lat, Long, Alt**
Maddock, ND, USA	47.8442, -99.4694, 474m
Brewster, WA, USA	48.1468, -119.6999, 384m

[14] Communications with the earth stations located in Troll, Antarctica, and Punta Arenas, Chile are pursuant to special temporary authority. *See, e.g.*, Application, SAT-STA-20170407-00059 (granted June 1, 2017).

Goonhilly, UK	50.0519, -5.1818, 107m
Chilbolton, UK	51.1450, -1.4384, 83m
Awarua, New Zealand	-46.5291, 168.3815, 10m
Usingen, Germany	50.3315, 8.4696, 380m
Ningi, Australia	-27.0561, 153.0642, 9m
Keflavik, Iceland	63.9581, -22.5812, 32m

Table 4: Authorized X/S-band earth stations

Station Location	Lat, Long, Alt
Prudhoe Bay, AK, USA	70.20, -148.45, TBD[15]
Fairbanks, AK, USA	64.7936, -147.5363, 142m
Inuvik, Canada	68.3258, -133.6093, 33m
Svalbard, Norway	78.2269, 15.4166, 498m
Troll, Antarctica	-72.0112, 2.5536, 1458m
Punta Arenas, Chile	-52.9381, -70.8572, 16m

Table 5: Proposed additional X/S-band earth stations

[15] The exact location in Prudhoe Bay has not yet been determined.

The FCC Form 312, Schedule S describes in detail the technical characteristics of the system. The associated link budgets and space station antenna patterns are included as Attachment A and B respectively. Attachment C shows the predicted gain contours required by Section 25.114(d)(3) of the Commission's rules at each of the earth station sites from a 90° elevation angle.

D. Power Flux Density Calculation

1. Power Flux Density at the Surface of the Earth in the 8025–8400 MHz band

Commission Rule 25.208 does not contain limits on power flux density (PFD) at the Earth's surface produced by emissions from NGSO EESS space stations operating in the 8025–8400 MHz band.[16] However, Table 21-4 of the ITU Radio Regulations states that the PFD at the Earth's surface produced by emissions from an EESS space station in the 8025–8400 MHz band, including emissions from a reflecting satellite, for all conditions and for all methods of modulation, must not exceed the following values:

- -150 dB(W/m²) in any 4 kHz band for angles of arrival between 0° and 5° above the horizontal plane;
- -150 + 0.5(d – 5) dB(W/m²) in any 4 kHz band for angles of arrival d (in degrees) between 5° and 25° above the horizontal plane; and
- -140 dB(W/m²) in any 4 kHz band for angles of arrival between 25° and 90° above the horizontal plane.

These limits relate to the PFD that would be obtained under free-space propagation conditions. As shown in Figures 1 through 3 below, the PFDs at the Earth's surface produced by the Flock satellites data transmissions satisfy the PFD limits in the ITU Radio Regulations for all angles of arrival with at least 6 to over 10 dB of margin. In addition, the transmit power for the payload data transmitters is adjustable on orbit. This capability supports Planet's ability to manage the satellites' PFD levels during all phases of the mission, *i.e.*, for all operational altitudes.

[16] 47 C.F.R. § 25.208.

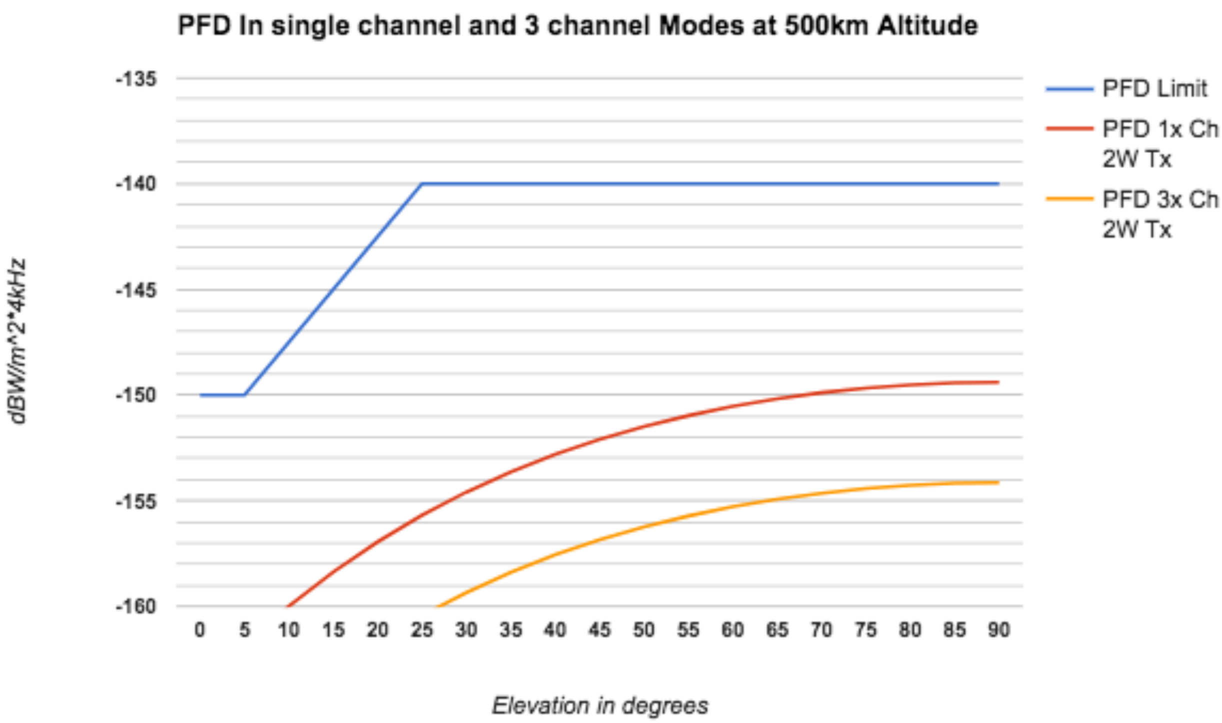

Figure 1. PFD at Earth's surface produced by the payload data downlink (shown for baseline 500 km orbit altitude)

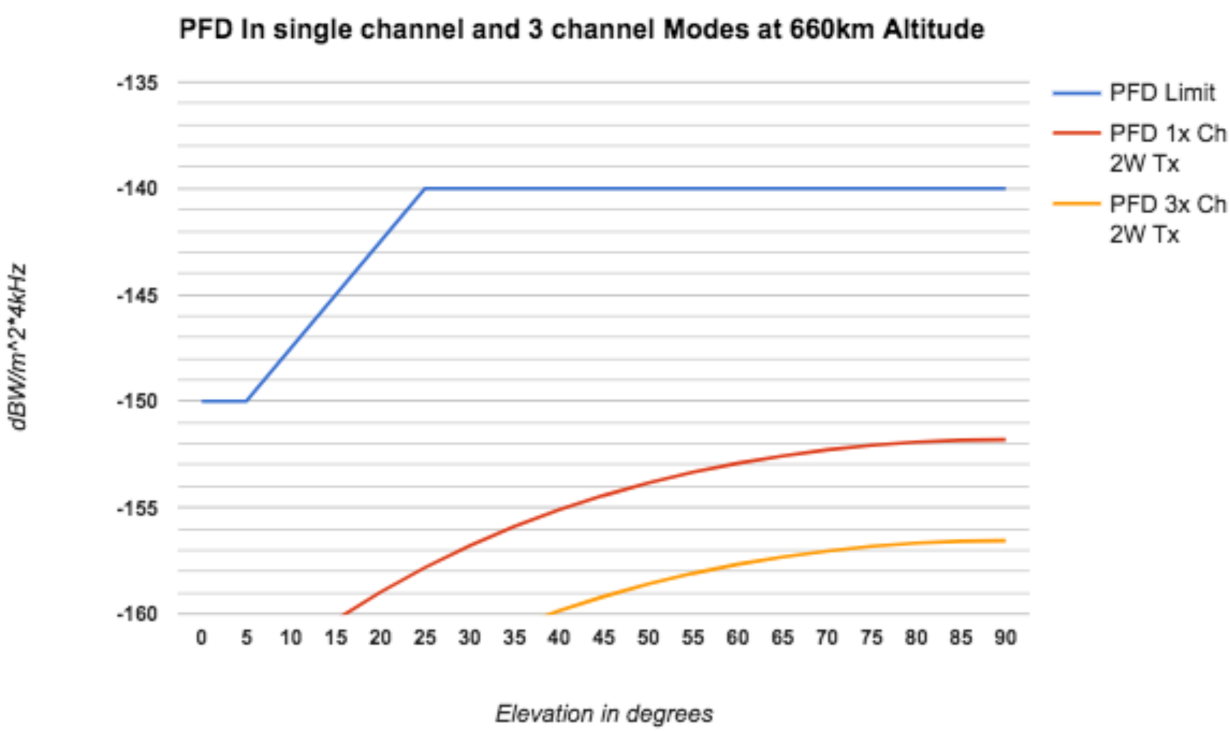

Figure 2. PFD at Earth's surface produced by the payload data downlink (shown for maximum 660 km orbit altitude)

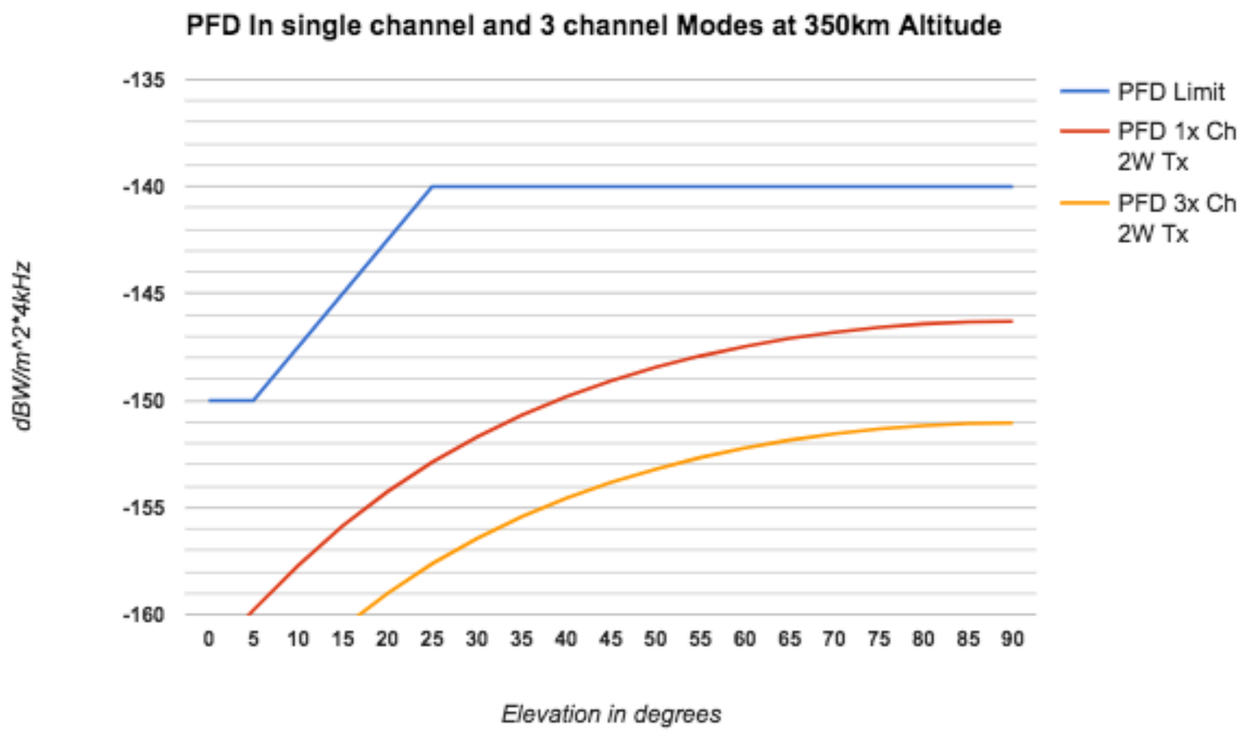

Figure 3. PFD at Earth's surface produced by the payload data downlink (shown for minimum 350 km orbit altitude)

2. Power Flux Density at the Surface of the Earth in the 8400–8450 MHz band

Recommendation ITU-R SA-1157 specifies a maximum allowable interference power spectral flux-density level at the Earth's surface of -255.1 dB(W/(m²Hz)) to protect ground receivers in the deep-space research band of 8400–8450 MHz. Planet Labs uses a combination of baseband digital filtering (using an alpha roll-off factor of 0.35) and RF layer bandpass filtering to achieve the ITU recommended protection level for the 8400-8450 MHz band for the payload channels with center frequency at 8150 MHz (the proposed single channel cases in Table 2). Payload transmissions at center frequency 8212.5 MHz and 8337.5 MHz would slightly exceed the allowable PFD at Earth's surface and therefore when in line of site of a DSN site, as identified in ITU-R SA.1014-2, Planet will cease transmissions on these channels, thereby protecting the deep-space research earth station.

3. Power Flux Density at the Geostationary Satellite Orbit

ITU Radio Regulation No. 22.5 specifies that in the 8025–8400 MHz frequency band, which the EESS using non-geostationary satellites shares with the fixed-satellite service (Earth-to-space) or the meteorological-satellite service (Earth-to-space), the maximum PFD produced at the geostationary satellite orbit (GSO) by any EESS space station shall not exceed -174 dB(W/m²) in any 4 kHz band. The calculation below shows that the PFD produced by transmissions from the proposed Flock EESS satellites does not exceed ITU limits even in a worst-case, hypothetical analysis.

The PFD at the GSO produced by the Flock transmission is:

$$\text{PFD}\ [\text{dB}(\text{W/m}^2\ /\ 4\ \text{kHz})] = \text{EIRP}\ (\text{dBW}) - 71 - 20\log10(D) - 10\log10(BW) - 24$$

Where:

- EIRP is the maximum EIRP of the transmission, in dBW;
- D is distance between the Flock satellite and the GSO, in km; and
- BW is the symbol bandwidth of the transmission, in MHz.

The minimum possible distance between a Flock satellite and the GSO is 35786 – 660 = 35126 km for the highest possible Flock satellite orbit altitude of 660 km. Under a hypothetical assumption that the Flock satellite antenna is radiating at its peak EIRP directly toward the GSO, the data downlink transmission with a peak EIRP = 18.01 dBW and BW = 70 MHz produces a PFD at the GSO of -186.35 dB(W/m²) in any 4 kHz band.

E. Interference Analysis

1. Interference between EESS systems operating in the 8025–8400 MHz band

Interference between the Flock satellite downlinks and those of other EESS systems is very infrequent because EESS systems operating in the 8025–8400 MHz band normally transmit only in short periods of time while visible from the dedicated receiving earth stations. For interference to happen, satellites belonging to different systems would have to travel through the antenna beam of the receiving earth station and transmit at the same time. In the event of a precise alignment, interference can be avoided by coordinating the satellite transmissions so that they do not occur simultaneously.

In addition, Planet maintains a coordination agreement with NASA that protects governmental space missions against harmful interference from Flock operations in this band. Planet also maintains coordination agreements for foreign earth stations if required by the responsible foreign administration or local authorized users of the frequency bands. The proposed changes in this application have no material impact to the coordinated operations. In any event, Planet will apprise NASA of this application and coordinate the proposed operations.

2. Interference with the Fixed Service and the FSS in the 8025–8400 MHz band

Sections I.D.1 and I.D.3 in the above section D demonstrate that the Flock satellite transmissions will meet the limits specified by the ITU for protection of the Fixed Service in the 8025–8400 MHz band, as well as the geostationary FSS satellites using this band for their uplinks.

3. Protection of deep-space research in the 8400-8450 MHz band

Section I.D.2 in the above section D demonstrates that the protection criterion recommended by the ITU for deep-space research in the 8400-8450 MHz band is met.

F. Public Interest Considerations

The Commission's grant of this application will serve the public interest by permitting Planet to more effectively cooperate with other users in these frequency bands while improving the efficiency of Flock satellite operations, which will increase the cadence of imagery collection and dissemination, which will enhance Planet's ability to meet the growing market demand for commercial remote sensing data.

G. Orbital Debris Mitigation

Planet previously considered a worst-case scenario of a circular 660 km altitude deployment for its satellites and determined that its proposed operations would be within NASA guidelines.[17] There is no change to this worse case orbit scenario or any other material specification that would impact the orbit debris analysis or mitigation strategies previously proposed and currently authorized by the Commission.

Planet Labs has updated the Orbital Debris Assessment Report ("ODAR") for the Flock satellites with a target orbital altitude of 500 km, and the constellation is in compliance with NASA-STD-8719.14, which is attached as a separate exhibit. In an abundance of caution, Planet also conducted an ODAR for the Flock satellites at an orbital altitude of 550 km altitude, and the constellation is also in compliance with NASA-STD-8719.14. Accordingly, the Flock satellite systems are compliant with all

[17] *See* Application, File No. SAT-MOD-20150802-00053 at 6-7 (granted Sep. 15, 2016).

applicable orbital debris requirements as listed in Section 25.114(d)(14).

The expected orbital lifetime of the satellites at the maximum of the target orbit range, 550 km, and assuming expected solar activity conditions over the next few years, would be at most 8.3 years, which is well within NASA guidelines.[18] At the 500 km target orbit, the longest expected lifetime is 5.6 years. Assuming no mitigating collision avoidance maneuvers, and analyzed as risk to the NORAD catalog of space objects, the probability of collision is 7.4E-5. In the case of satellites launched at the maximum desired orbit of 550 km, the probability of collision is 2.9E-4, which is still compliant with NASA standards.

Planet works closely with the Joint Space Operations Center (JSpOC) for space situational awareness and the mitigation of potential conjunction events, and can perform limited collision avoidance maneuvers using the same differential drag techniques it uses for satellite orbit phasing, thereby reducing considerably the potential for a collision.

II. Additional/General Considerations

A. Waiver Request of Modified Processing Round Rules

Planet requests that this application be processed pursuant to the first-come, first-served procedure adopted for "GSO-like satellite systems" under Section 25.158 of the Commission's rules.[19] To the extent necessary to allow for such processing, Planet also requests waiver of Sections 25.156 and 25.157 of the Commission's rules, which stipulate the processing of "NGSO-like satellite systems" under a modified processing round framework.[20]

The Commission previously granted waiver of the modified processing round requirement with respect to the existing Flock satellites.[21] The Commission concluded that authorizing Planet to operate in its requested EESS frequency bands would not preclude other NGSO operators from operating in those bands.[22] Even though this modification requests additional spectrum bandwidth within the allocated bands, other operators are not precluded from using the bands under the same sharing and

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[18] *See* NASA-STD-8719.14.
[19] 47 C.F.R. § 25.158.
[20] 47 C.F.R. §§ 25.156 and 25.157.
[21] *See* IBFS File Nos. SAT-LOA-20120322-00058, SAT-MOD-20150408-00019, and SAT-MOD-20150802-00053.
[22] *See id.*; *see also Space Imaging, LLC*, 20 FCC Rcd. 11964, 11968 (2005) (determining such authorization does not cause harmful interference to other EESS systems currently operating in band).

coordination conditions as with the current authorization, and therefore, the Commission should similarly grant Planet a waiver of Sections 25.156 and 25.157 for the modifications proposed herein.

B. Waiver Request of Default Service Rules

Planet requests a waiver of the default service rules under Section 25.217(b) of the Commission's rules.[23]

The Commission previously granted a waiver of the default service rules contained in Section 25.217(b) for the Flock Satellites based on the requirement that EESS operators in the 8025–8400 MHz band are required to comply with technical requirements in Part 2 of the Commission's rules and applicable ITU regulations.[24] With respect to the Flock Satellites, the Commission concluded that because the technical requirements specified in Part 2 are sufficient to prevent harmful interference in the 8025–8400 MHz band, there was no need to impose additional technical requirements on operations in that band, and therefore granted the waiver request.[25] Given that the proposed changes in this modification do not materially deviate in design from the Flock satellites currently authorized, nor increase the number of satellites, the Commission should similarly grant Planet a waiver of the default service rules contained in Section 25.217(b) for the proposed modification.

C. Form 312, Schedule S

As required by the Commission's rules and policies, Planet has completed, to the best of its ability and the limitations of the Commission's software, the FCC Form 312, Schedule S submission that reflects the orbital and physical/electrical characteristics of the satellites proposed in this application. Planet also refers the Commission to the link budgets in Attachment A to this Exhibit 43 for additional information regarding the performance of Flock satellite links.

To the best of Planet's understanding, the information in Form 312, Schedule S is complete. Any additional information used to complete the application process is identified in this Exhibit.

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[23] 47 C.F.R. § 25.217.

[24] *See e.g.*, Conditions 10 and 13, Planet Authorization.

[25] *See id.; see also DigitalGlobe, Inc.*, 20 FCC Rcd. 15696, 15701 (2005) (determining that compliance with Part 2 and applicable ITU service rules provides adequate interference protection to other spectrum users from space-to-Earth emissions from EESS satellites with X-band (8025–8400 MHz) feeder links).

D. Implementation Milestones

Planet has a fully operational constellation, and accordingly, there are no applicable implementation milestones.[26]

E. ITU Advance Publication Materials and Cost Recovery

Planet has prepared the ITU submission for the proposed modification of its non-geostationary EESS system, and will provide an electronic file with this information to the Satellite Engineering Branch of the Satellite Division of the Commission's International Bureau.

* * * * *

For the reasons set out above, Planet respectfully requests approval of this modification application.

[26] *See* Conditions 14 and 15, Planet Authorization.

<u>ATTACHMENT A</u>
LINK BUDGETS

Figure 1 through 3 of this Attachment A depict the link budgets for the Flock satellite payload downlink (X-band), Telemetry downlink (UHF), and command uplink (S-band and UHF) respectively at their intended altitude of 500 km.

Section 25.114(c)(4)(v) of the Commission's rules requests the beam peak flux density at the command threshold for command beams. Schedule S includes a similar but not identical parameter. For completeness, -99.5 dBW/m^2 and -117.5 dBW/m^2 has been entered as the minimum power required to achieve reliable S-band and UHF command receiver lock respectively.

X-band Payload Downlink	Channel 1	Channel 2	Channel 3	Single	Flock 2p, 3P (1)	
General						
Orbit Altitude	500	500	500	500	500	km
Elevation Angle	5	5	5	5	5	deg
Slant range	2078	2078	2078	2078	2078	km
Transmission (Space Station)						
Frequency	8.0875	8.2125	8.3375	8.150	8.150	GHz
Symbol rate	70	70	70	70	70	msps
Occupied Bandwidth	94.5	94.5	94.5	94.5	94.5	MHz
PA Output Power	0.67	0.67	0.67	2.00	2.00	W
Circuit Loss	1	1	1	1	1	dB
Antenna Peak Gain	16	16	16	16	13	dBi
Antenna HPBW	18	18	18	18	41	deg
EIRP of Spacecraft	13.3	13.3	13.3	18.0	15.0	dBW
EIRP Total for 3 channels		18.0				dBW
EIRP Density	-65.2	-65.2	-65.2	-60.4	-63.4	dBW/Hz
Reception (Ground Station)						
Free Space Loss	176.9	177.0	177.2	177.0	177.0	dB
Pointing Loss	0.2	0.2	0.2	0.2	0.2	dB
Polarization Loss	0.3	0.3	0.3	0.3	0.3	dB
Atmospheric Loss, clear sky	0.8	0.8	0.8	0.8	0.8	dB
Ground antenna gain	49	49	49	49	49	dBi
Antenna HPBW	0.55	0.55	0.55	0.55	0.55	deg
Received power at LNA input	-85.9	-86.1	-86.2	-81.3	-84.3	dBm
Ground System G/T (at 5 deg)	29	29	29	29	29	dB/K
Received C/No	92.7	92.5	92.4	97.3	94.3	dB-Hz
Received Es/No	14.2	14.1	13.9	18.9	15.9	dB
Demodulator (Ground Station)						
Modulation (2)	16 APSK	16 APSK	16 APSK	16 APSK	16 APSK	
Symbol rate	70	70	70	70	70	msps
Composite Code rate (2)	0.75	0.75	0.75	0.89	0.75	
Uncoded data rate	202	202	202	240	202	mbps
Target BER	1E-10	1E-10	1E-10	1E-10	0.0	
Demod. Implementation loss	0.5	0.5	0.5	0.5	0.5	dB
Required Es/No at target BER	11.8	11.8	11.8	14.5	11.8	dB
Link Margin	**2.4**	**2.3**	**2.1**	**4.4**	**4.1**	**dB**

(1) Flock 2p, 3p represent the current design capability of on-orbit satellites
(2) Adaptive codiing and Modulation (ACM) is used on all channels to optimize link margin

Figure 1: Flock Payload downlink (X-band) link budget for 500 km (nominal) altitude

UHF Telemetry Downlink		
General		
Orbit Altitude	500	km
Elevation Angle	5	deg
Slant range	2078	km
Transmission (Space Station)		
Frequency	0.4013	GHz
Symbol rate	4.8	ksps
Channel Bandwidth	17.5	kHz
PA Output Power	0.70	W
Circuit Loss	0.45	dB
Antenna Peak Gain	2.19	dBi
Antenna HPBW	70	deg
EIRP of Spacecraft	0.19	dBW
Reception (Ground Station)		
Free Space Loss	150.8	dB
Pointing Loss	0.4	dB
Polarization Loss	3.3	dB
Atmospheric Loss, clear sky	0.4	dB
Ground antenna gain	16.5	dBi
Antenna HPBW	30	deg
Received power at LNA input	-108.2	dBm
Ground System G/T (at 5 deg)	-8.8	dB/K
Received C/No	65.1	dB-Hz
Received Es/No	28.3	dB
Demodulator (Ground Station)		
Modulation	GFSK	
Symbol rate	4.8	ksps
Composite Code rate	0.50	
Uncoded data rate	2.4	kbps
Target BER	1.00E-07	
Required Es/No at target BER	11.0	dB
Demod. Implementation loss	4.0	dB
Link Margin	**13.3**	**dB**

Figure 2: Flock Telemetry downlink (UHF) link budget for 500 km (nominal), 350 km (minimum), and 660 km (maximum) altitude

Command Uplink	S-band	UHF	
General			
Orbit Altitude	500	500	km
Ground Elevation Angle	5	5	deg
Slant range	2078	2078	km
Transmission (Ground Station)			
Frequency	2.056	0.450	GHz
(one of 2.0547, 2.056, 2.0573 MHz)			
Symbol rate	500	4.8	ksps
Channel Bandwidth	1310	17.5	kHz
PA Output Power (Watts)	50.0	25.0	W
PA Output Power (dBW)	17.0	14.0	dBW
Circuit Loss	3	1	dB
Antenna Peak Gain	35	16.5	dBi
Antenna HPBW	2.2	30	deg
EIRP of Ground Antenna	49.0	29.5	dBW
Reception (Space Station)			
Atmospheric Loss, clear sky	0.4	0.4	dB
Free Space Loss	165.0	151.8	dB
Pointing Loss	0.5	0	dB
Polarization Loss	1.5	3.3	dB
Antenna HPBW	80	80	deg
Antenna Gain	-1	-2.5	dBi
Circuit Loss	0	0	dB
Received power at LNA input	-89.4	-98.5	dBm
Demodulator (Space Station)			
Modulation	MSK	GFSK	
Symbol rate	500	4.8	ksps
Composite code rate	0.50	0.50	
Uncoded data rate	250	2.4	kbps
Target BER	5E-08	5E-08	
Required Signal at Target BER	-99.6	-111.2	dBm
Received Signal Level	-89.4	-98.5	dBm
Link Margin	**10.2**	**12.7**	**dB**

Figure 3: Flock Command uplink (S-band and UHF) link budget for 500 km (nominal) altitude

ATTACHMENT B
FLOCK SYSTEM ANTENNA PATTERNS

The currently orbiting and soon to be launched Flock satellites employ the X-band Helical antenna has shown in Figure 1 and applicable to Beam ID XDLH in Schedule S.

The next generation higher gain X-band antenna is a Quad Helical offering 3 dB more gain and dual polarization and applicable to Beam ID XDLR and XDLL in Schedule S and its antenna pattern is shown in Figure 2.

All Flock satellites employ an S-band patch with the pattern shown in Figure 3 applicable to Beam ID SUL in Schedule S.

All Flock satellites employ a UHF antenna with the pattern shown in Figures 4 and 5 applicable to Beam ID's UDL and UUL in Schedule S.

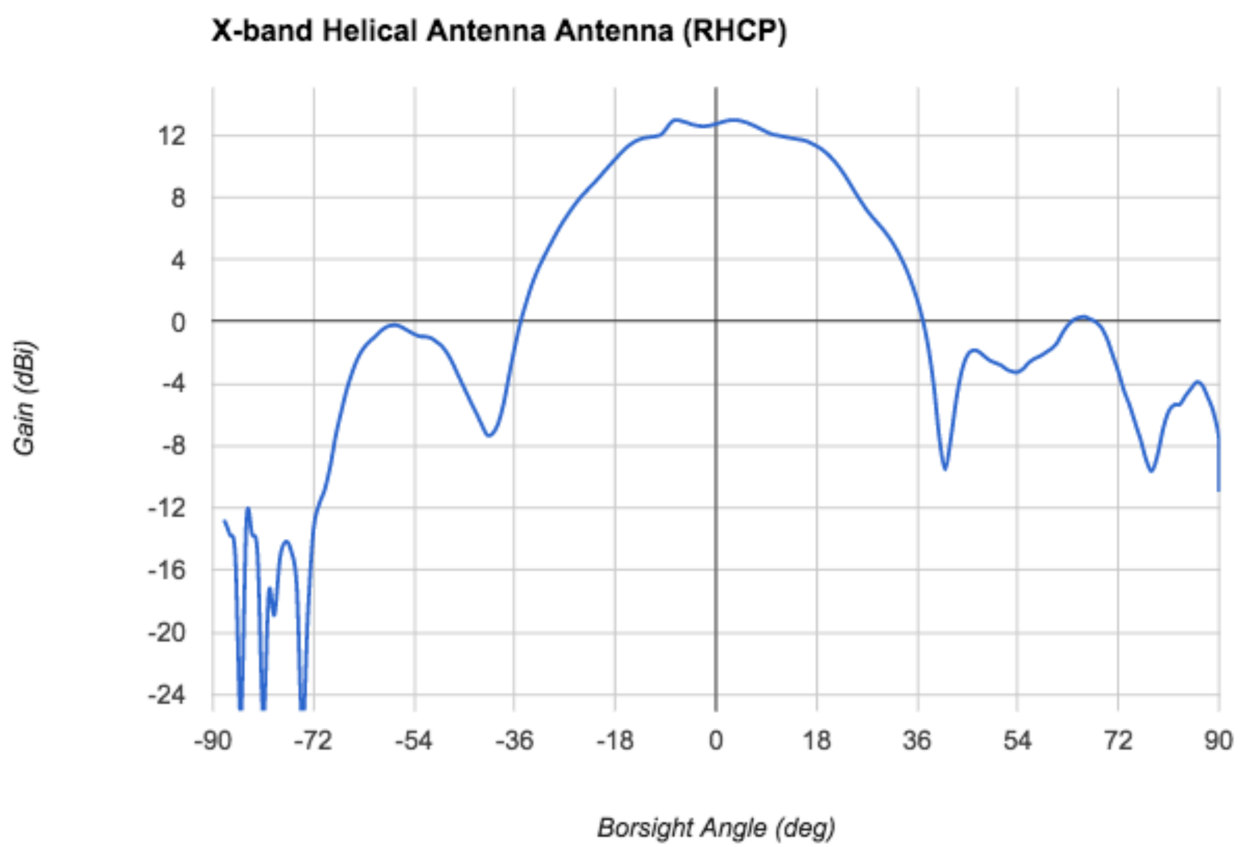


Figure 1: X-band Helical for all current generation Flock Satellites using Beam XDLH.

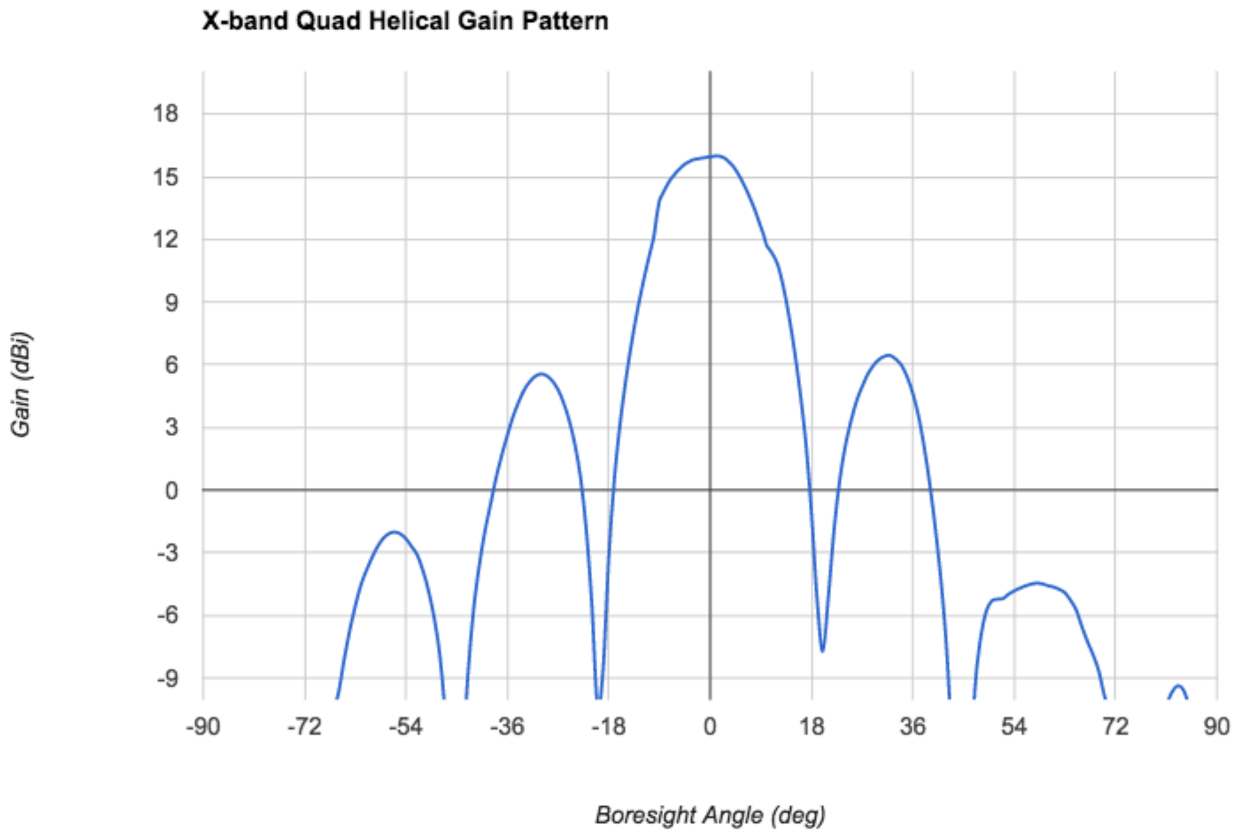


Figure 2: X-band Quad Helical for next generation Flock Satellites using Beam XDLR and XDLL.

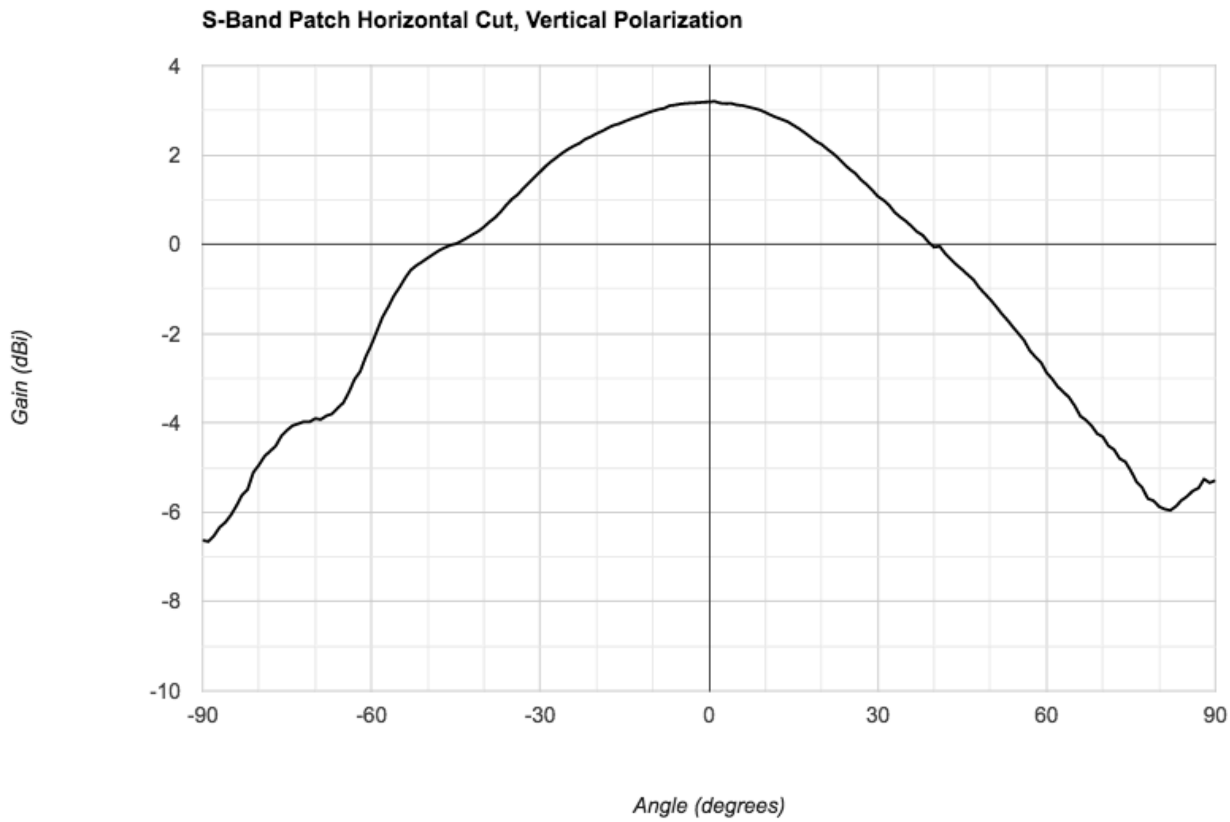
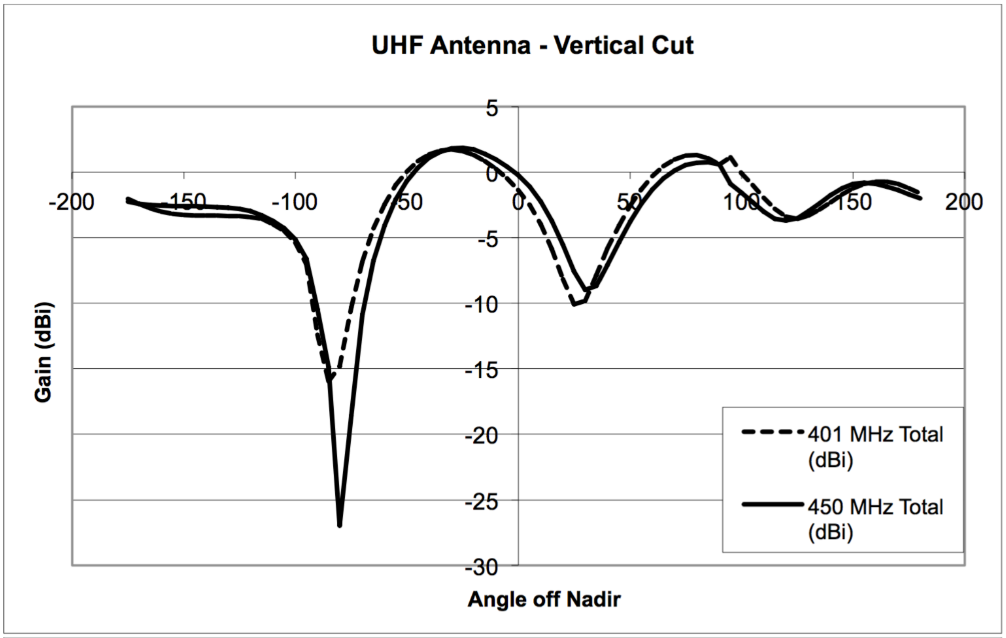


Figure 3: S-band Patch for all Flock Satellites applicable to Beam SUL.



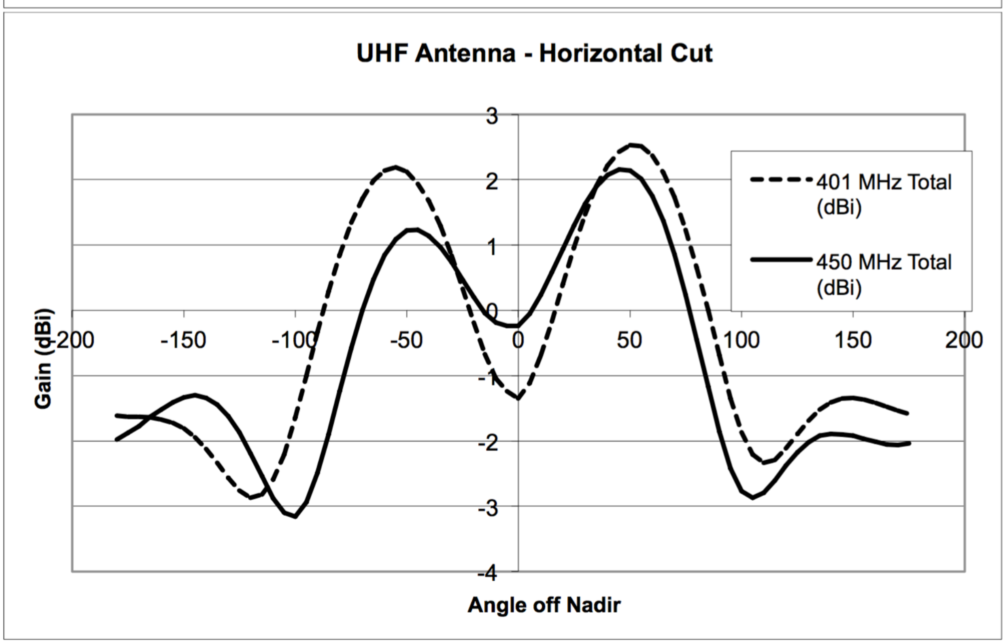


Figure 4: UHF antenna for all Flock Satellites applicable to Beam's UDL and UUL.

ATTACHMENT C
PREDICTED GAIN CONTOURS

Figures 1 through 14 in this Attachment depict the Helical antenna (currently authorized antenna) gain contours over the Flock earth stations for the X-band Flock payload data downlink for the nominal altitude of 500 km.

Figures 15 through 28 in this Attachment depict the Quad Helical antenna (proposed new antenna) gain contours over the Flock earth stations for the X-band Flock payload data downlink for the nominal altitude of 500 km.

The UHF telemetry, tracking and command (TT&C) links are excluded since there are no changes from the previously approved application and current authorization.[27]

[27] *See* Attachment C, Application, File No. SAT-MOD-20150802-00053 (granted Sep. 15, 2016).

The first 13 Figures depict the existing Helical antenna contour for all ground stations.

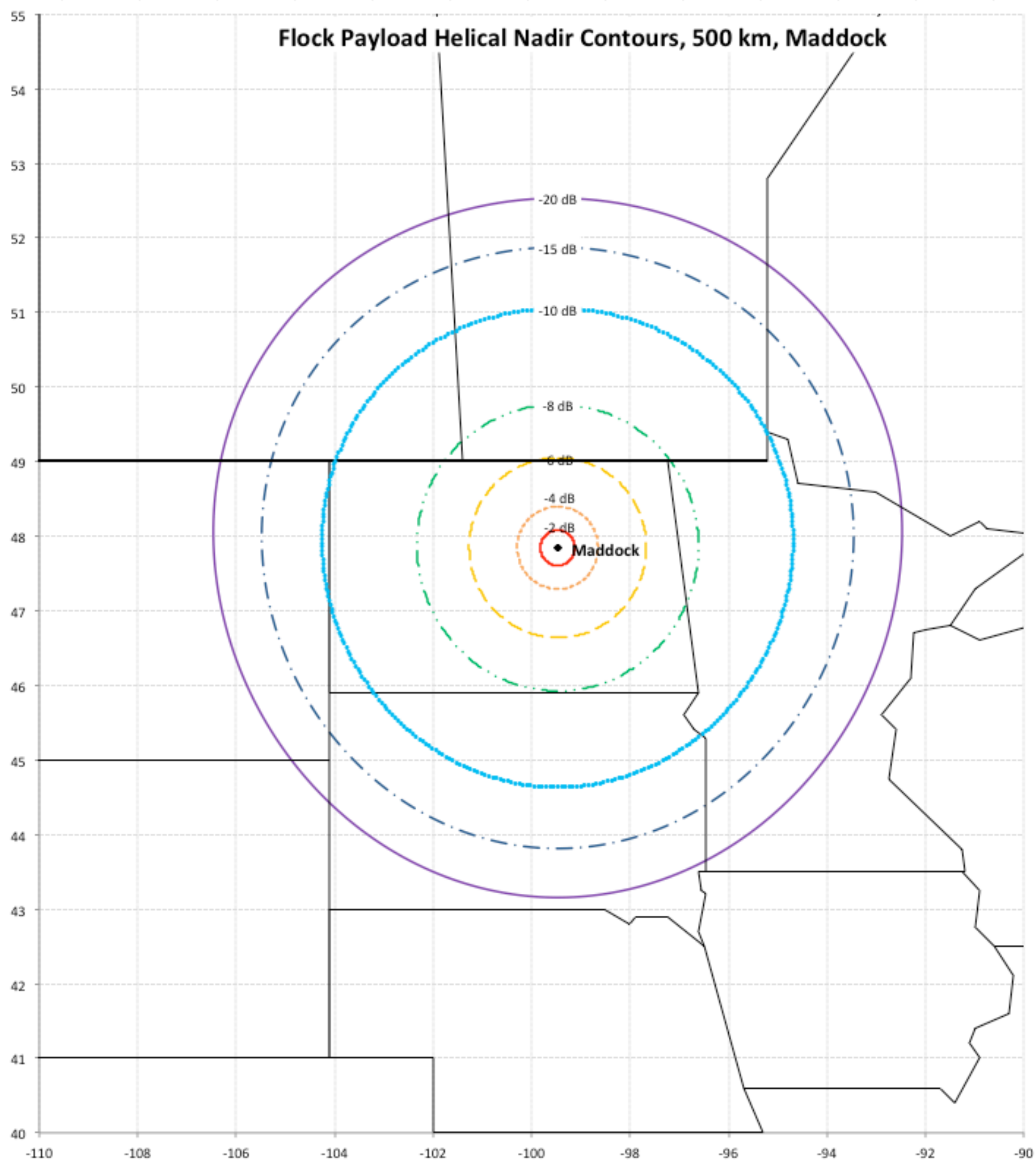


FIGURE 1

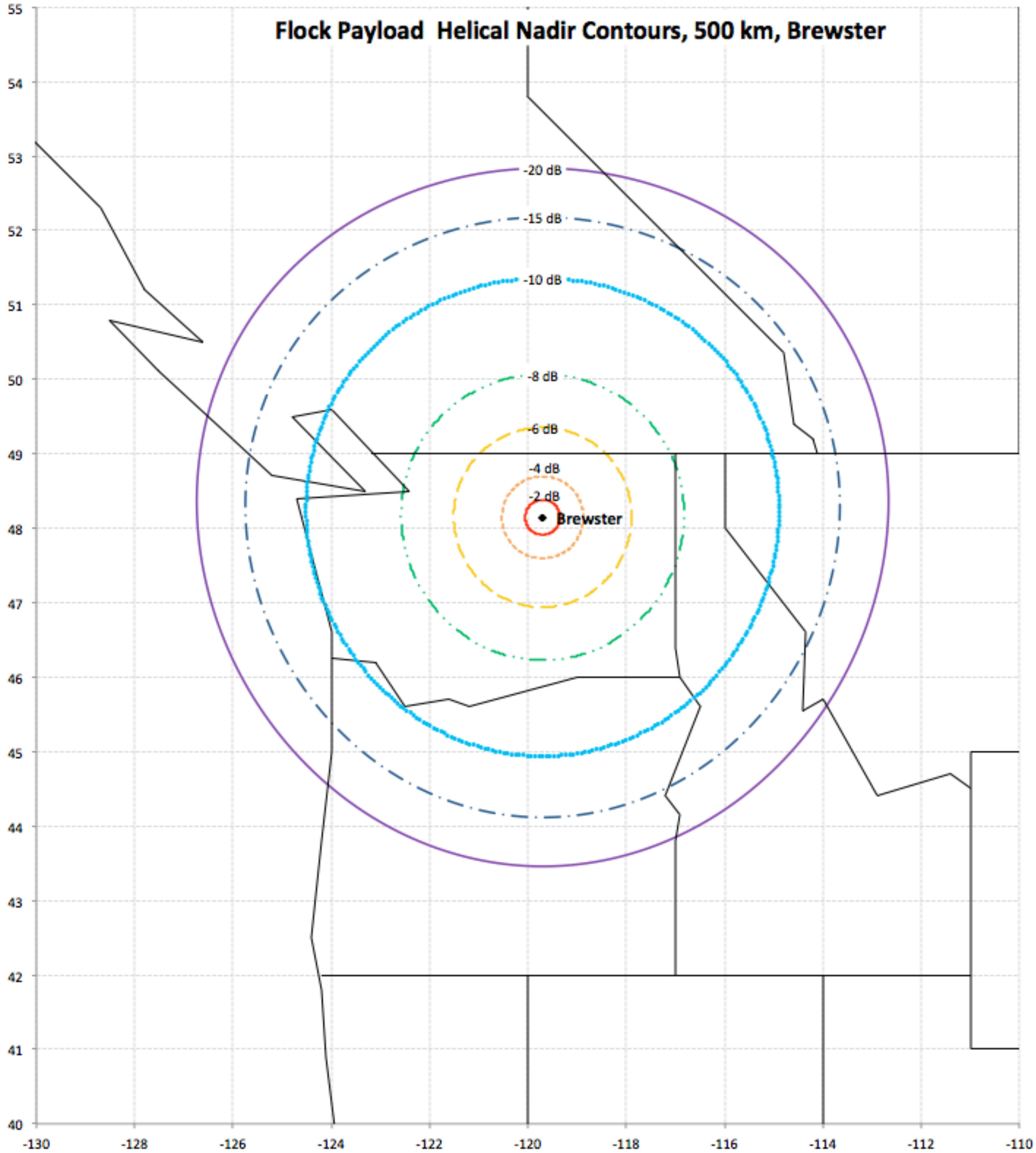

Flock Payload Helical Nadir Contours, 500 km, Brewster
-20 dB
-15 dB
-10 dB
-8 dB
-6 dB
-4 dB
-2 dB
Brewster
55
54
53
52
51
50
49
48
47
46
45
44
43
42
41
40
-130
-128
-126
-124
-122
-120
-118
-116
-114
-112
-110

FIGURE 2

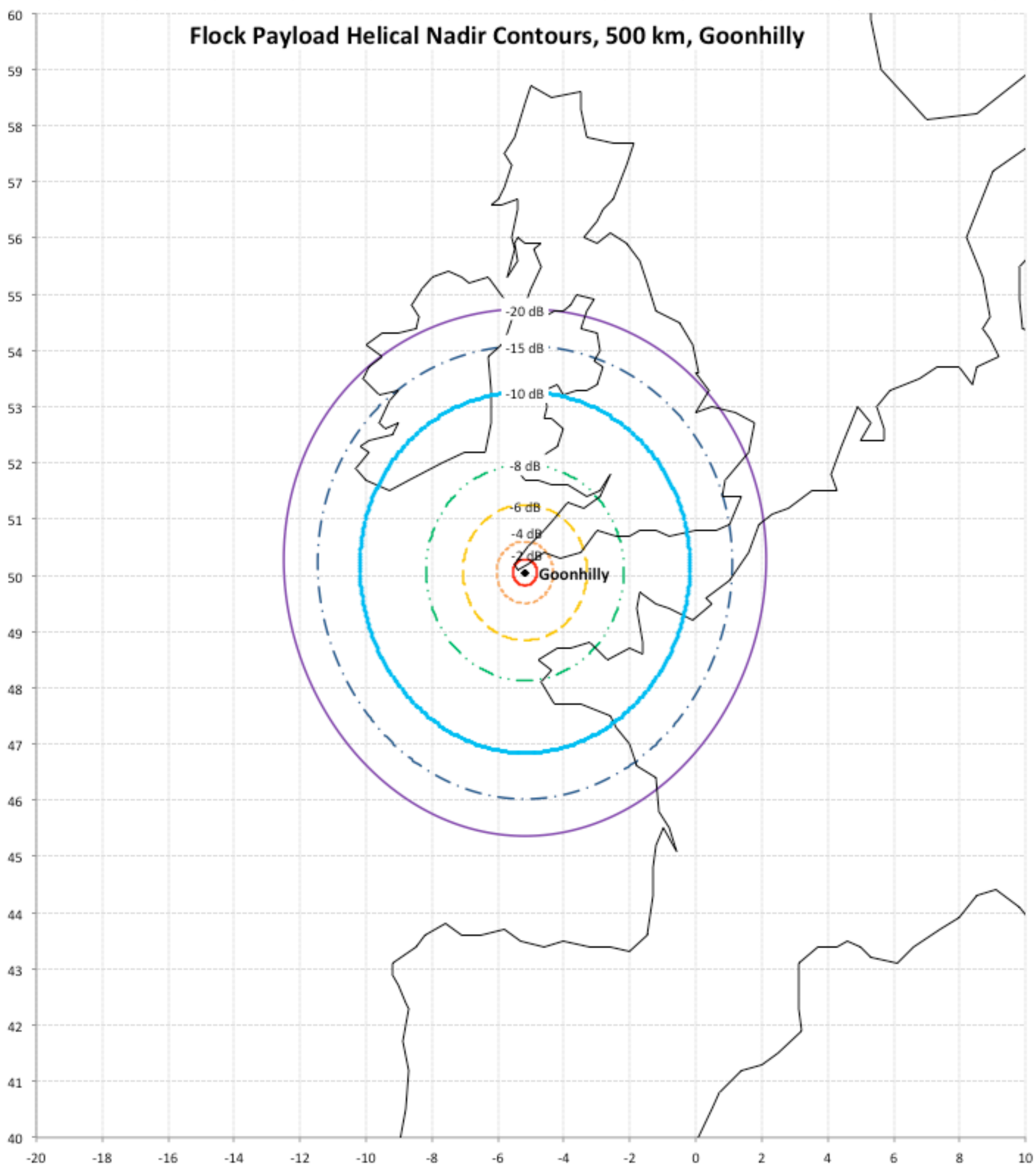

Flock Payload Helical Nadir Contours, 500 km, Goonhilly
-20 dB
-15 dB
-10 dB
-8 dB
-6 dB
-4 dB
-2 dB
Goonhilly
60
59
58
57
56
55
54
53
52
51
50
49
48
47
46
45
44
43
42
41
40
-20
-18
-16
-14
-12
-10
-8
-6
-4
-2
0
2
4
6
8
10

FIGURE 3

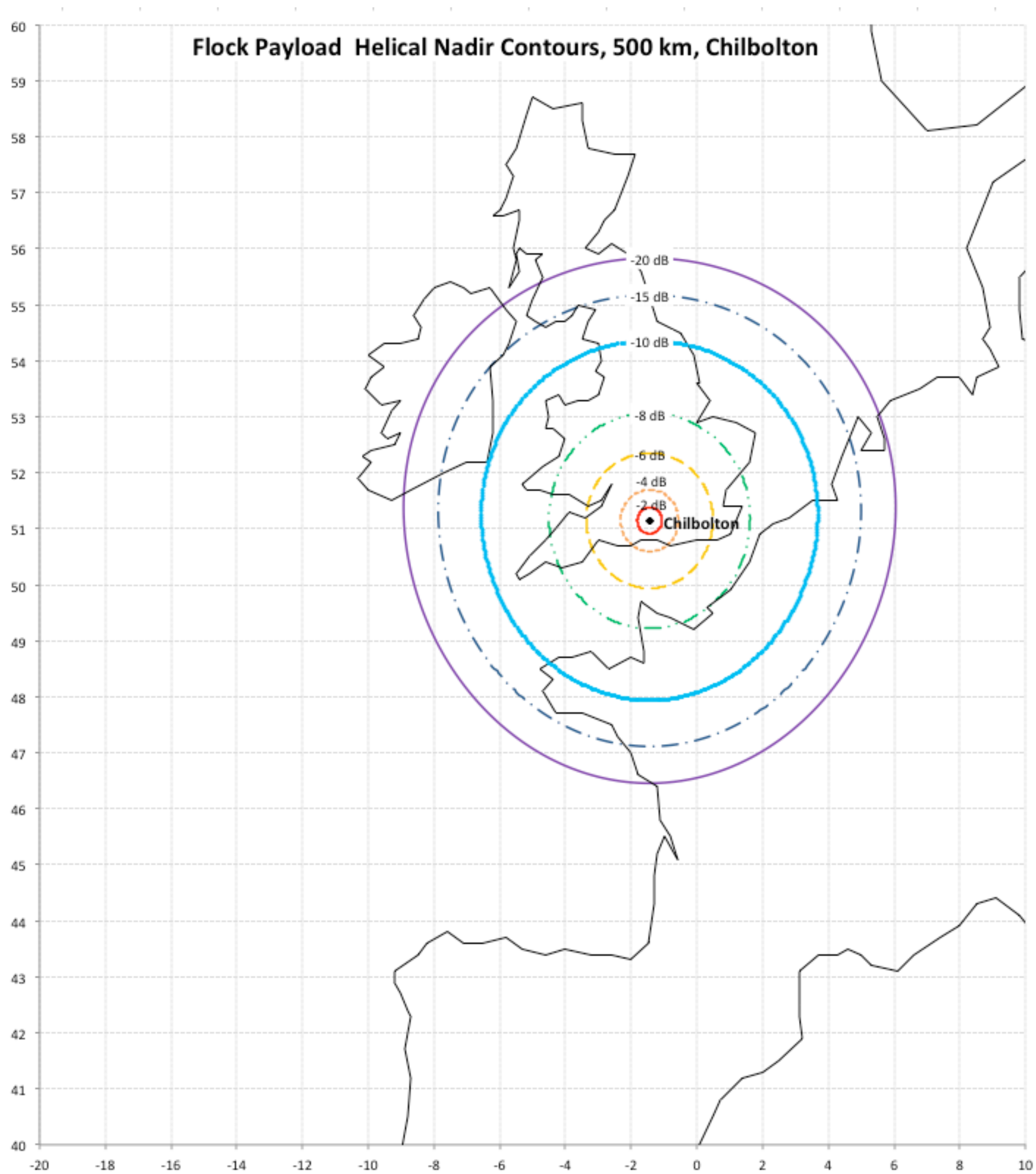

Flock Payload Helical Nadir Contours, 500 km, Chilbolton
-20 dB
-15 dB
-10 dB
-8 dB
-6 dB
-4 dB
-2 dB
Chilbolton
60
59
58
57
56
55
54
53
52
51
50
49
48
47
46
45
44
43
42
41
40
-20
-18
-16
-14
-12
-10
-8
-6
-4
-2
0
2
4
6
8
10

FIGURE 4

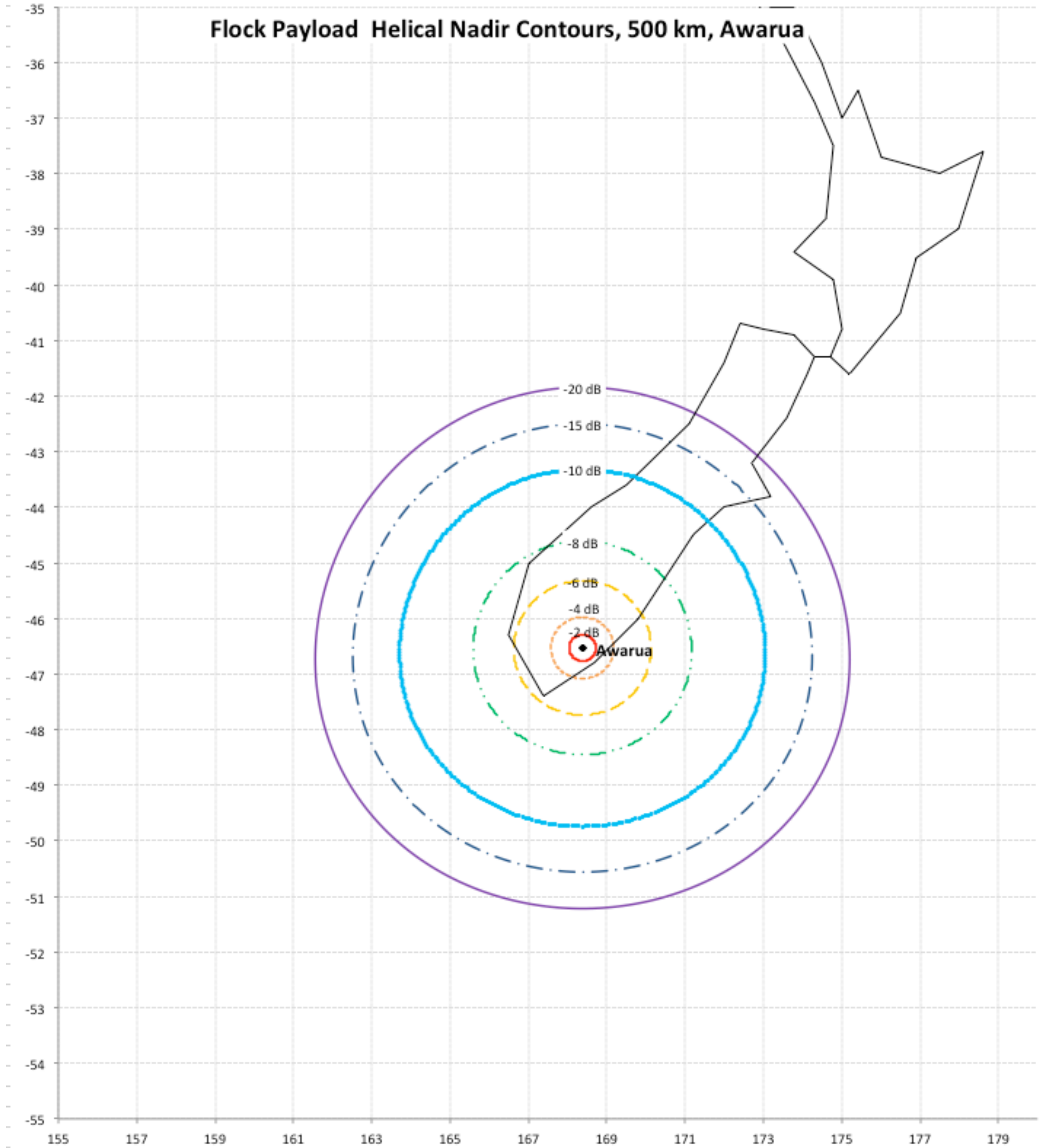

Flock Payload Helical Nadir Contours, 500 km, Awarua
-20 dB
-15 dB
-10 dB
-8 dB
-6 dB
-4 dB
-2 dB
Awarua
-35
-36
-37
-38
-39
-40
-41
-42
-43
-44
-45
-46
-47
-48
-49
-50
-51
-52
-53
-54
-55
155
157
159
161
163
165
167
169
171
173
175
177
179

FIGURE 5

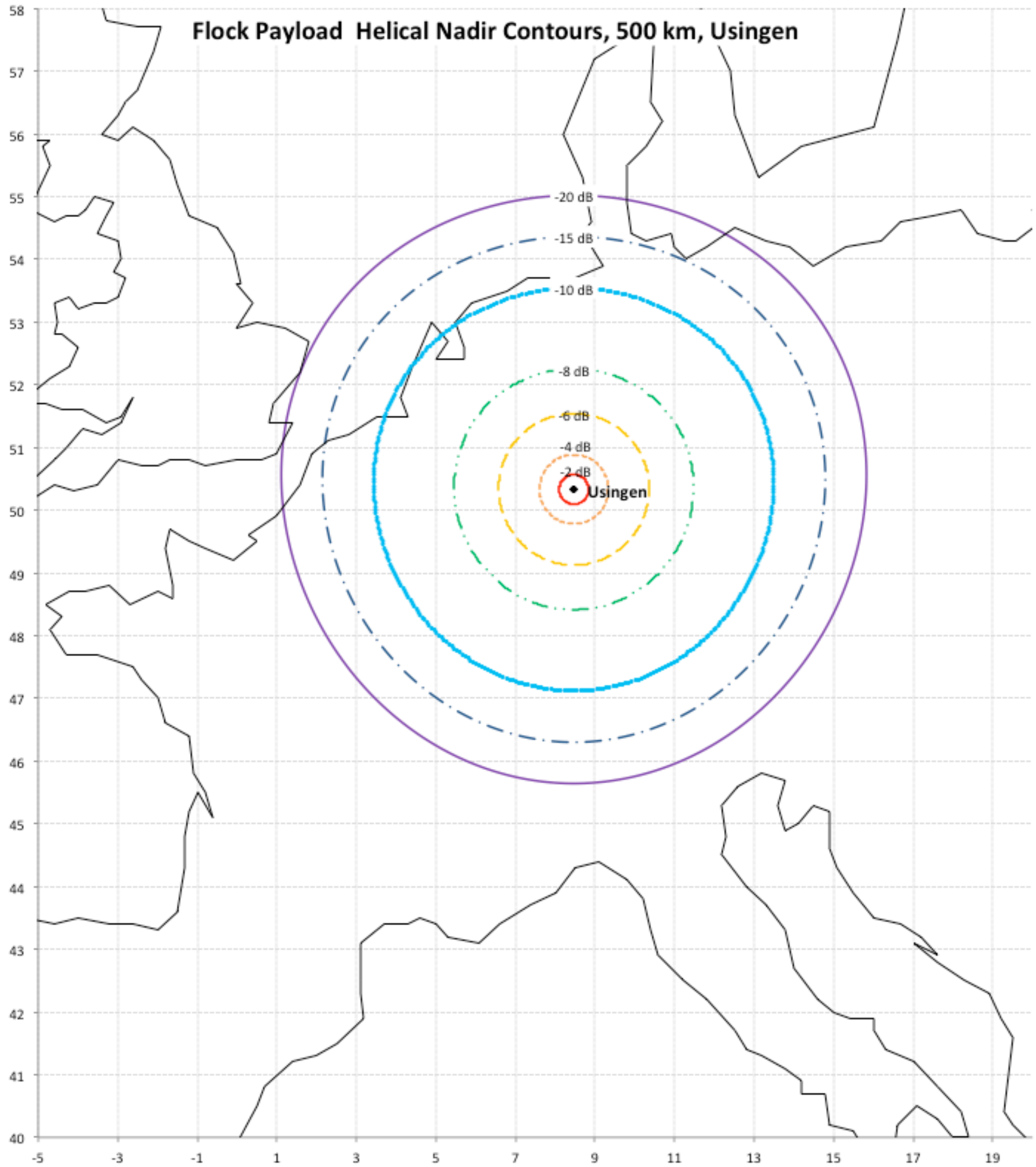

Flock Payload Helical Nadir Contours, 500 km, Usingen
-20 dB
-15 dB
-10 dB
-8 dB
-6 dB
-4 dB
-2 dB
Usingen
58
57
56
55
54
53
52
51
50
49
48
47
46
45
44
43
42
41
40
-5
-3
-1
1
3
5
7
9
11
13
15
17
19

FIGURE 6

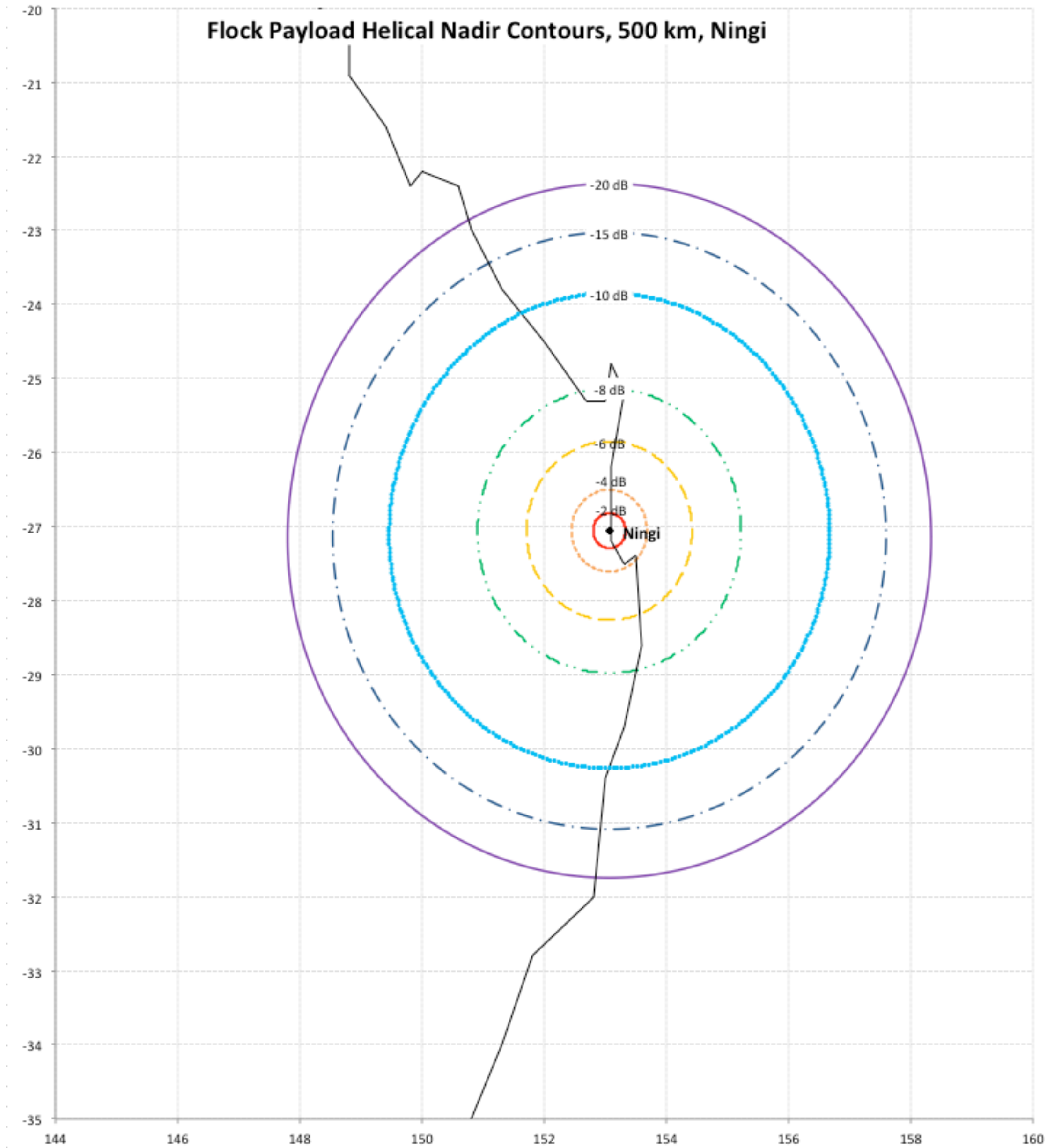

Flock Payload Helical Nadir Contours, 500 km, Ningi
-20 dB
-15 dB
-10 dB
-8 dB
-6 dB
-4 dB
-2 dB
Ningi
-20
-21
-22
-23
-24
-25
-26
-27
-28
-29
-30
-31
-32
-33
-34
-35
144
146
148
150
152
154
156
158
160

FIGURE 7

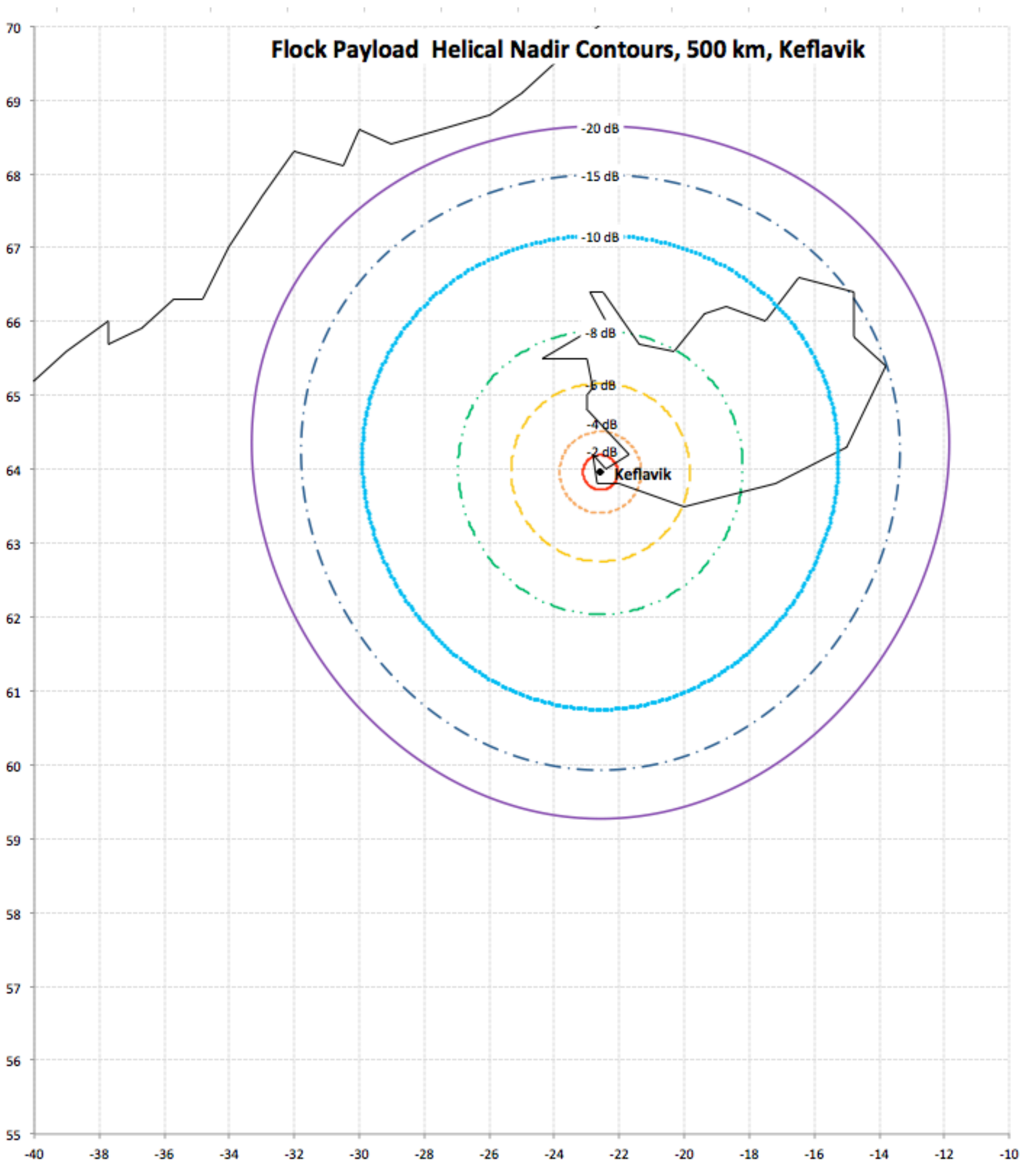

Flock Payload Helical Nadir Contours, 500 km, Keflavik
-20 dB
-15 dB
-10 dB
-8 dB
-6 dB
-4 dB
-2 dB
Keflavik
70
69
68
67
66
65
64
63
62
61
60
59
58
57
56
55
-40
-38
-36
-34
-32
-30
-28
-26
-24
-22
-20
-18
-16
-14
-12
-10

FIGURE 8

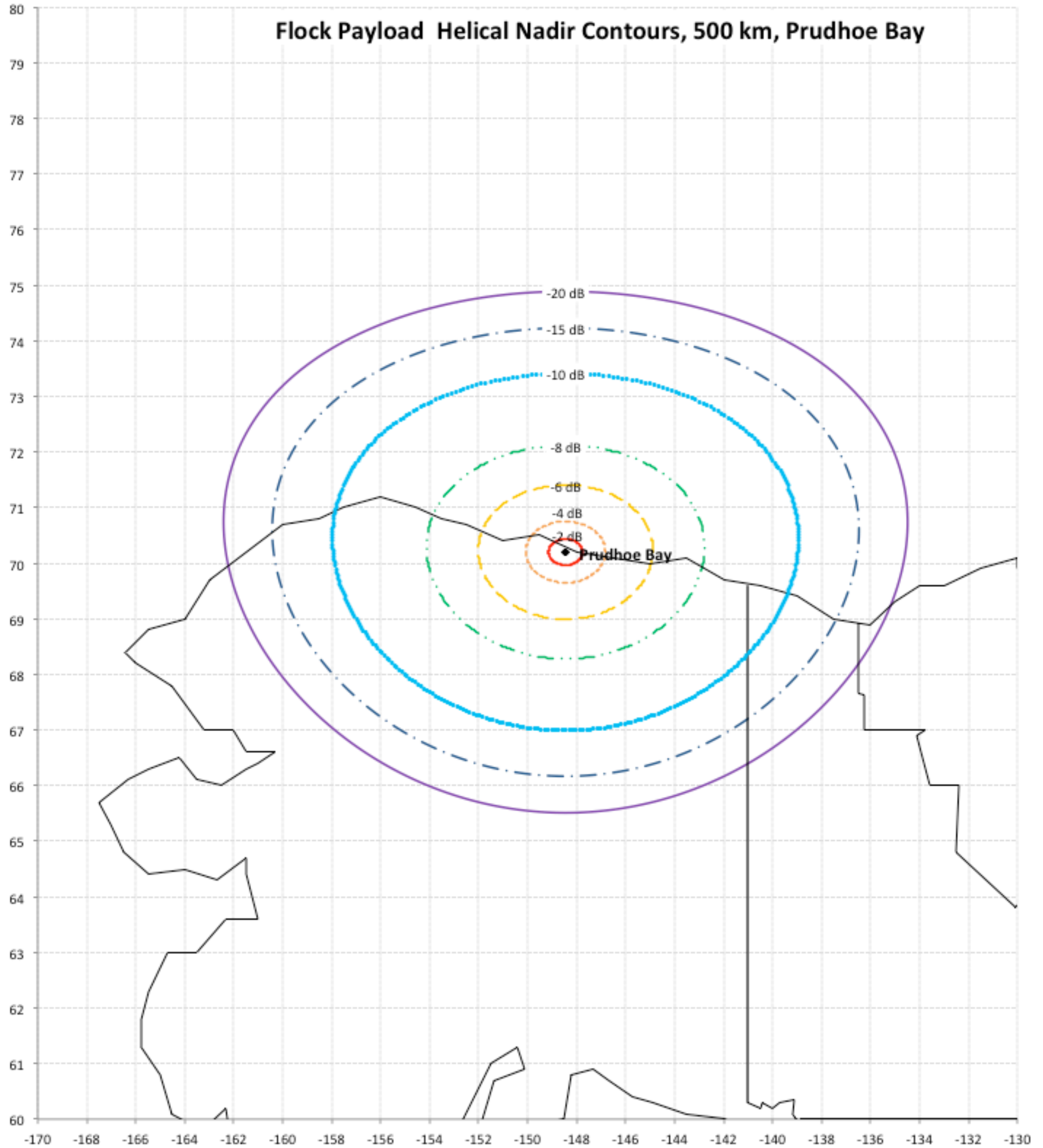

Flock Payload Helical Nadir Contours, 500 km, Prudhoe Bay
-20 dB
-15 dB
-10 dB
-8 dB
-6 dB
-4 dB
-2 dB
Prudhoe Bay
80
79
78
77
76
75
74
73
72
71
70
69
68
67
66
65
64
63
62
61
60
-170
-168
-166
-164
-162
-160
-158
-156
-154
-152
-150
-148
-146
-144
-142
-140
-138
-136
-134
-132
-130

FIGURE 9

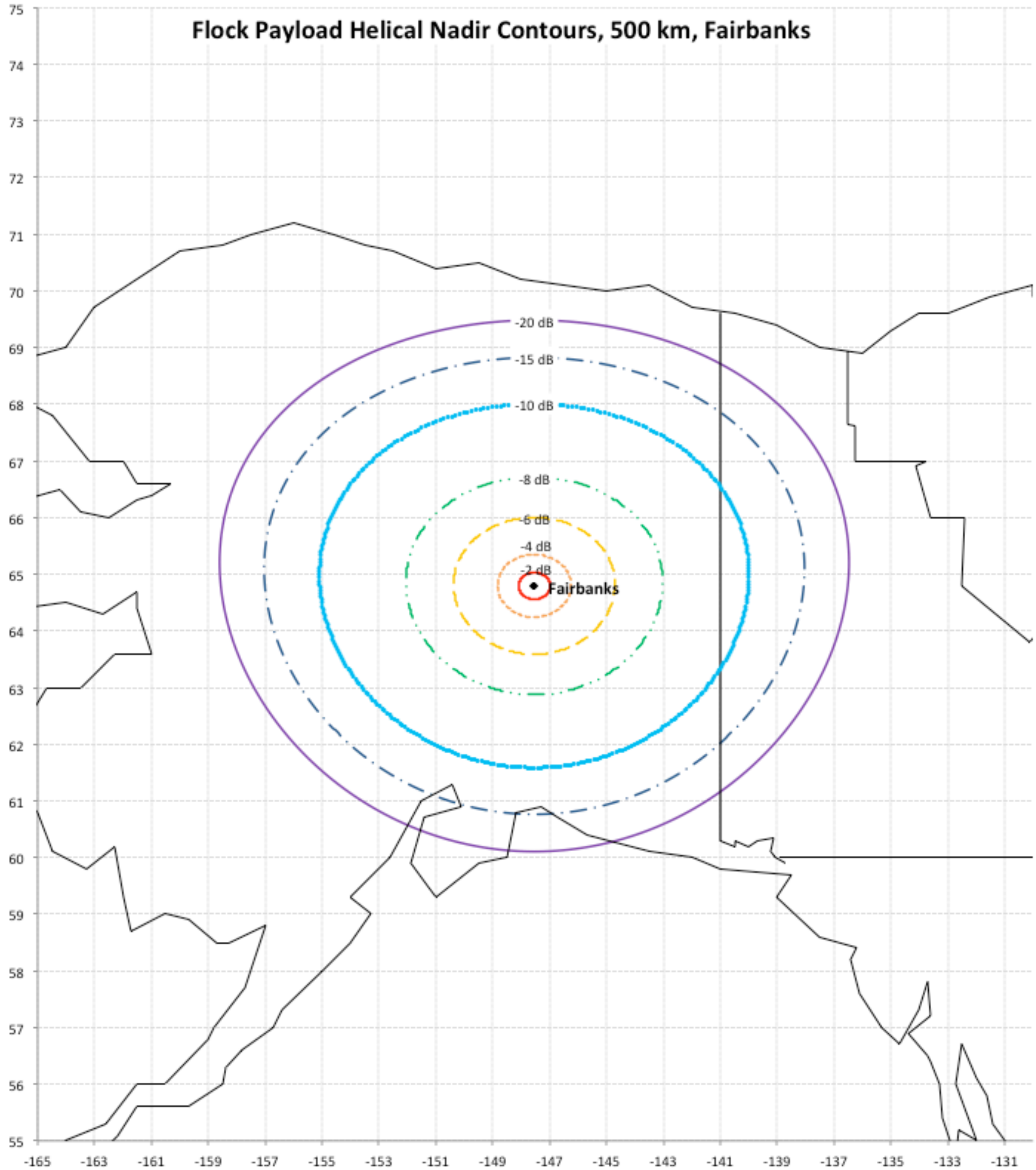

Flock Payload Helical Nadir Contours, 500 km, Fairbanks
-20 dB
-15 dB
-10 dB
-8 dB
-6 dB
-4 dB
-2 dB
Fairbanks
75
74
73
72
71
70
69
68
67
66
65
64
63
62
61
60
59
58
57
56
55
-165
-163
-161
-159
-157
-155
-153
-151
-149
-147
-145
-143
-141
-139
-137
-135
-133
-131

Figure 10

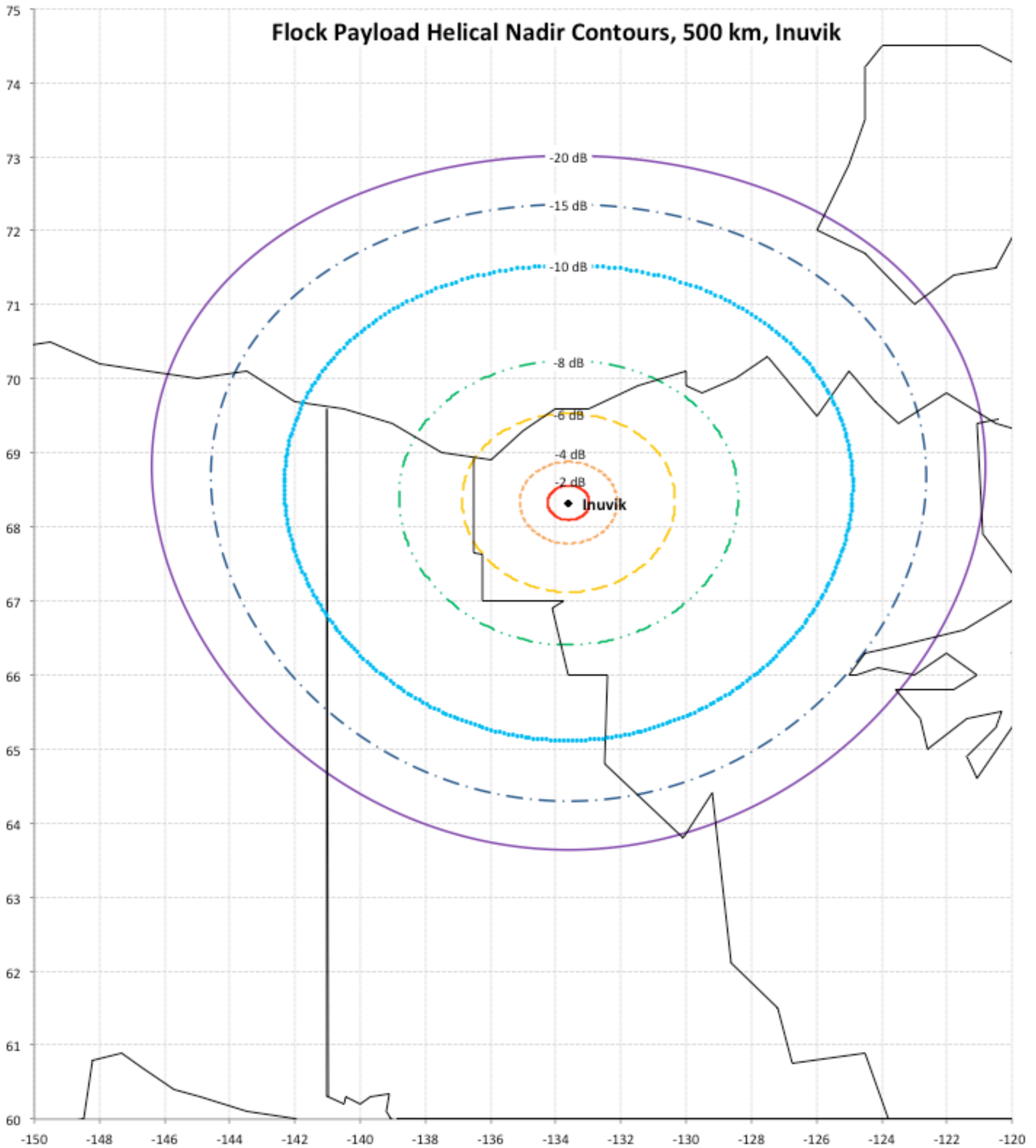

Flock Payload Helical Nadir Contours, 500 km, Inuvik
-20 dB
-15 dB
-10 dB
-8 dB
-6 dB
-4 dB
-2 dB
Inuvik
75
74
73
72
71
70
69
68
67
66
65
64
63
62
61
60
-150
-148
-146
-144
-142
-140
-138
-136
-134
-132
-130
-128
-126
-124
-122
-120

FIGURE 11

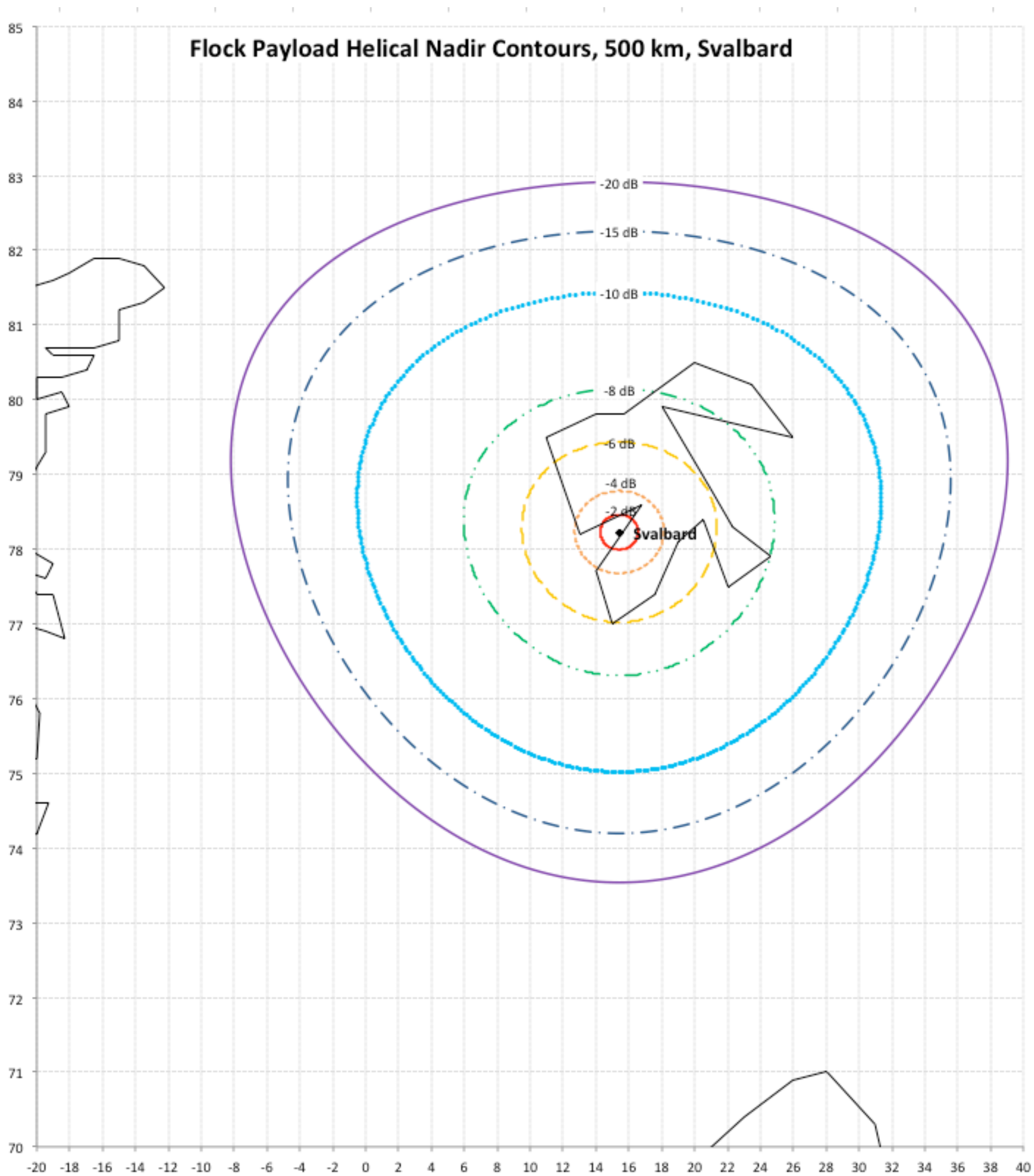

Flock Payload Helical Nadir Contours, 500 km, Svalbard
-20 dB
-15 dB
-10 dB
-8 dB
-6 dB
-4 dB
-2 dB
Svalbard
85
84
83
82
81
80
79
78
77
76
75
74
73
72
71
70
-20 -18 -16 -14 -12 -10 -8 -6 -4 -2 0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40

FIGURE 12

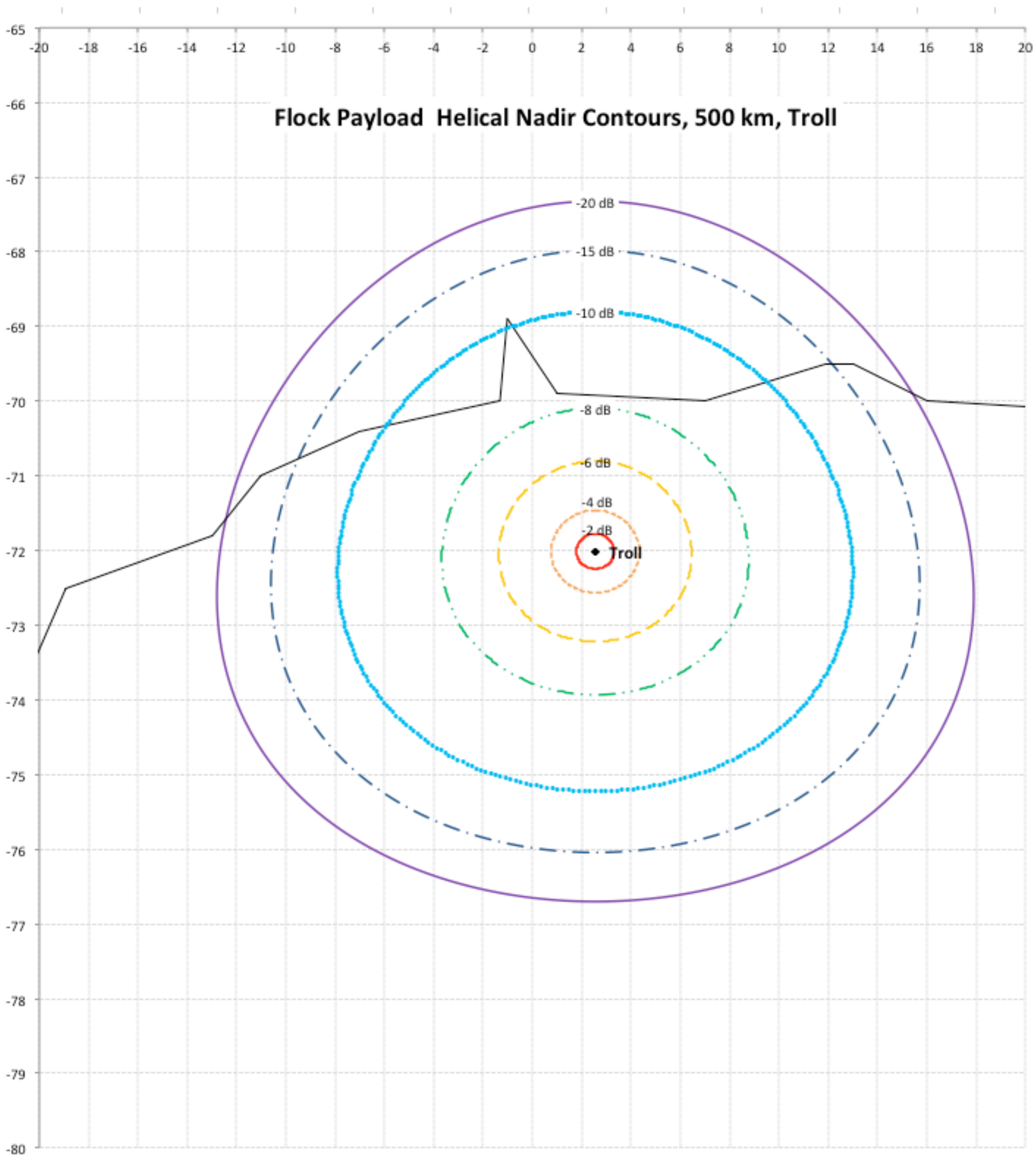

Flock Payload Helical Nadir Contours, 500 km, Troll
-20 dB
-15 dB
-10 dB
-8 dB
-6 dB
-4 dB
-2 dB
Troll
-65
-66
-67
-68
-69
-70
-71
-72
-73
-74
-75
-76
-77
-78
-79
-80
-20
-18
-16
-14
-12
-10
-8
-6
-4
-2
0
2
4
6
8
10
12
14
16
18
20

FIGURE 13

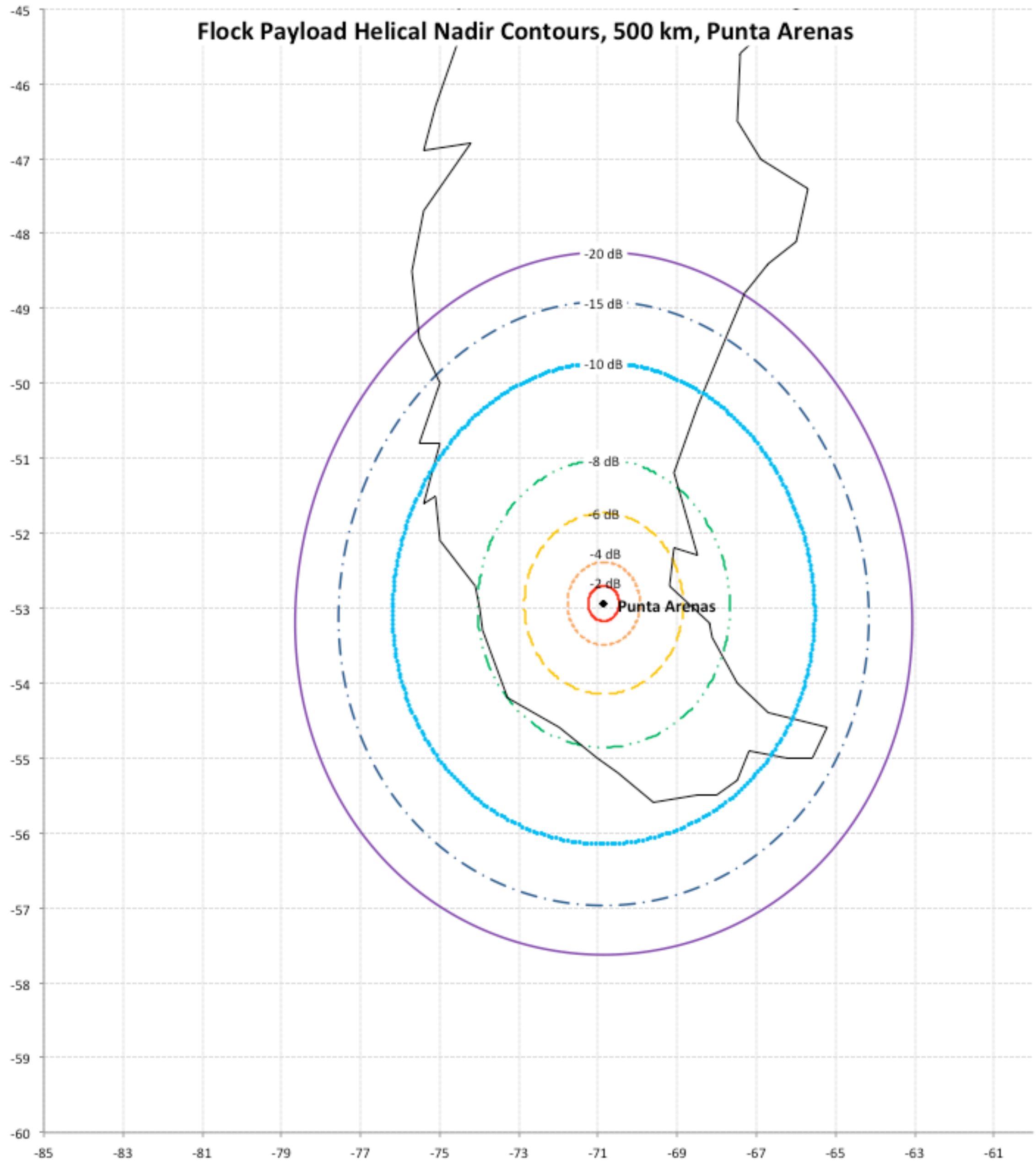

Flock Payload Helical Nadir Contours, 500 km, Punta Arenas
-20 dB
-15 dB
-10 dB
-8 dB
-6 dB
-4 dB
-2 dB
Punta Arenas
-45
-46
-47
-48
-49
-50
-51
-52
-53
-54
-55
-56
-57
-58
-59
-60
-85
-83
-81
-79
-77
-75
-73
-71
-69
-67
-65
-63
-61

FIGURE 14

The next 13 Figures depict the new Quad Helical antenna contour for all ground stations.

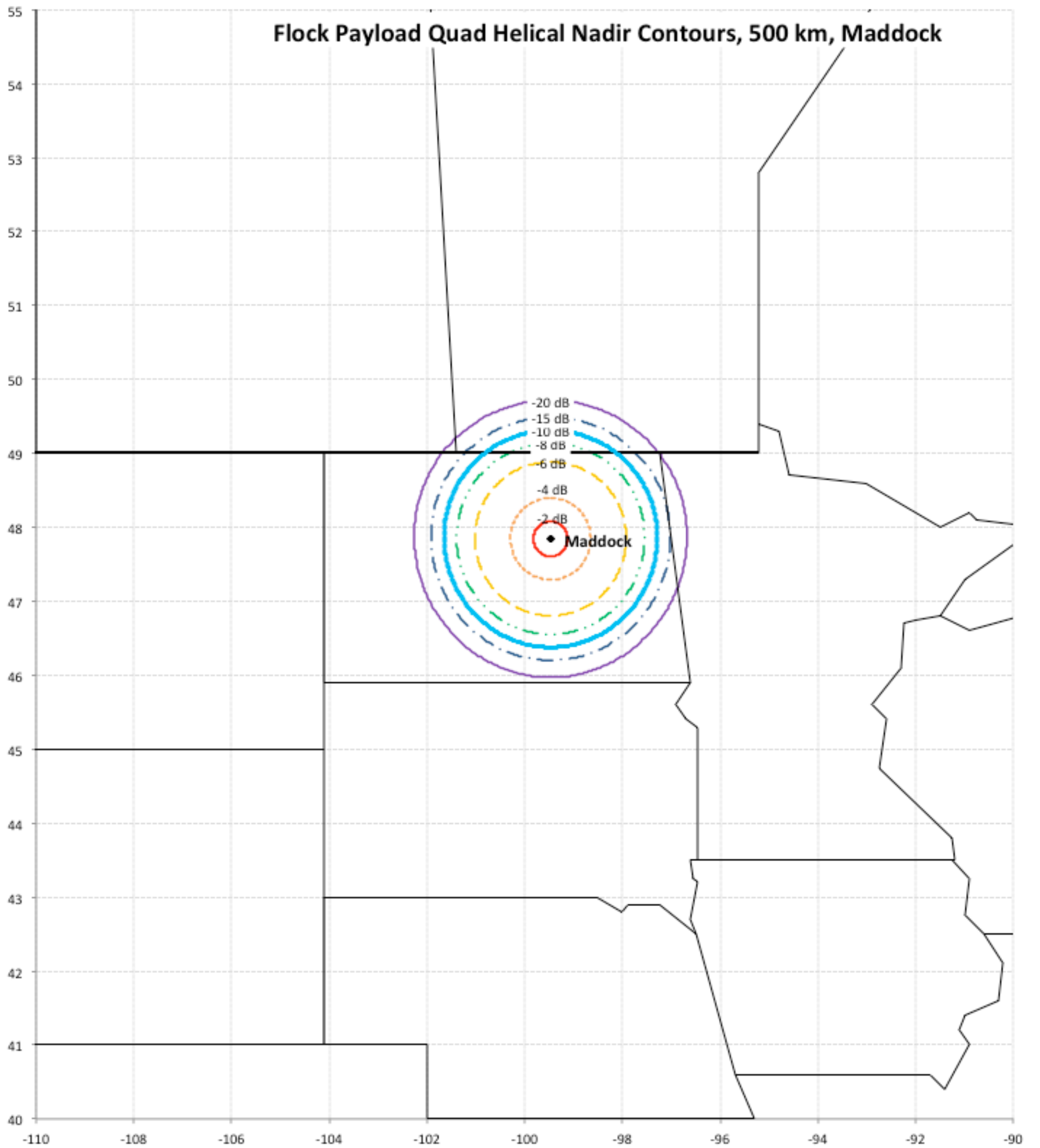


FIGURE 15

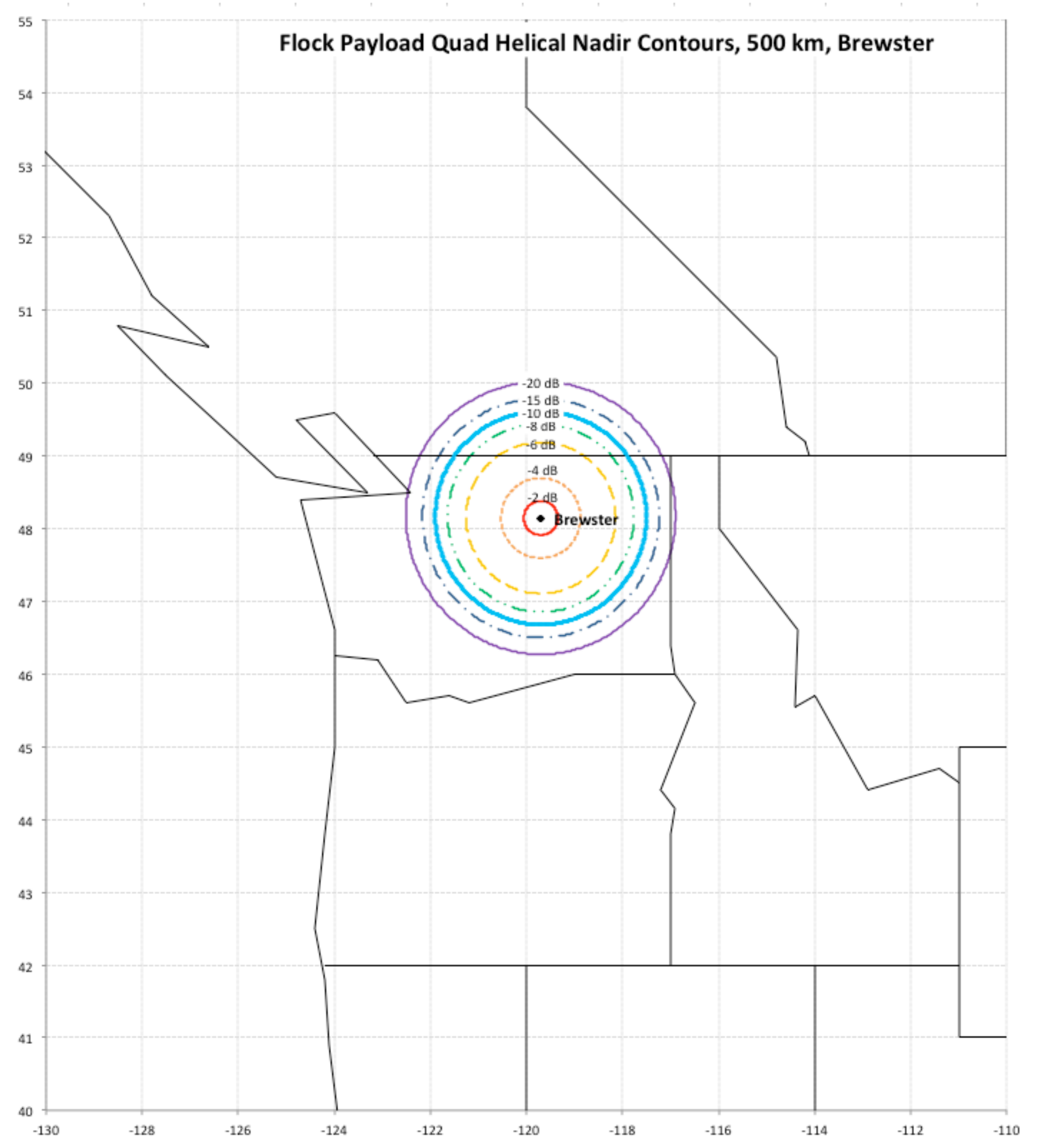

Flock Payload Quad Helical Nadir Contours, 500 km, Brewster
-20 dB
-15 dB
-10 dB
-8 dB
-6 dB
-4 dB
-2 dB
Brewster
55
54
53
52
51
50
49
48
47
46
45
44
43
42
41
40
-130
-128
-126
-124
-122
-120
-118
-116
-114
-112
-110

FIGURE 16

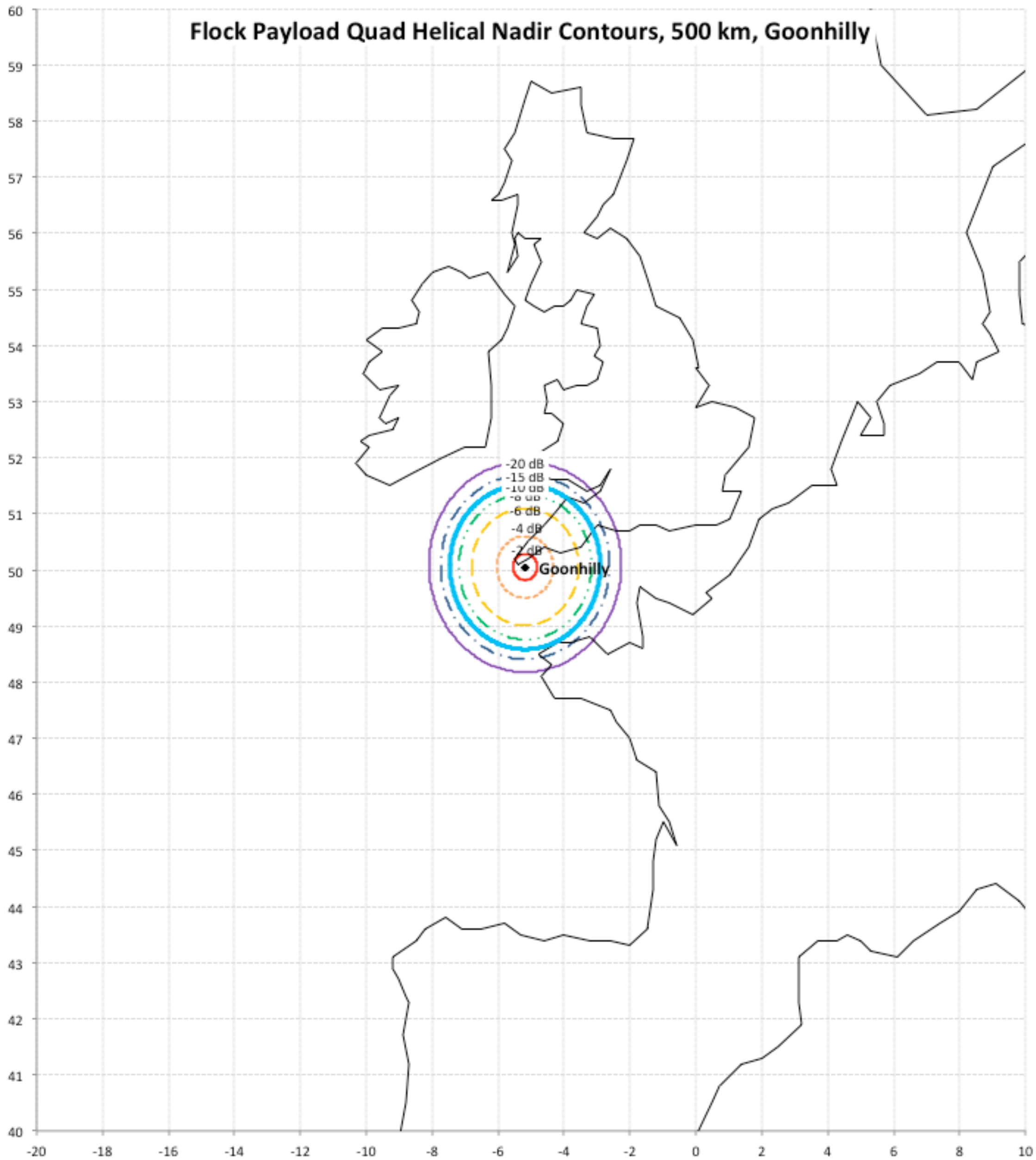

Flock Payload Quad Helical Nadir Contours, 500 km, Goonhilly
-20 dB
-15 dB
-10 dB
-8 dB
-6 dB
-4 dB
-2 dB
Goonhilly
60
59
58
57
56
55
54
53
52
51
50
49
48
47
46
45
44
43
42
41
40
-20
-18
-16
-14
-12
-10
-8
-6
-4
-2
0
2
4
6
8
10

FIGURE 17

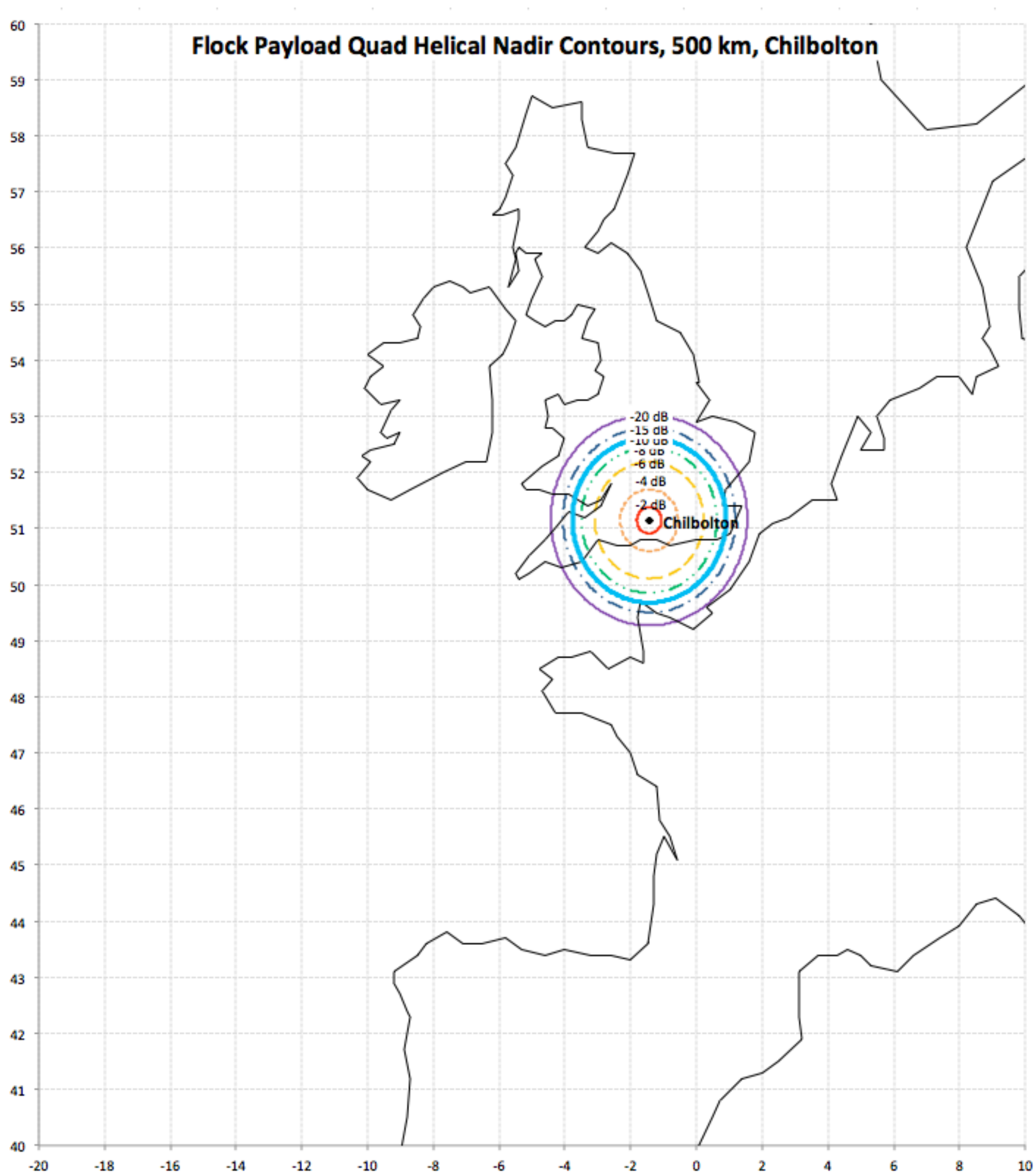

Flock Payload Quad Helical Nadir Contours, 500 km, Chilbolton
-20 dB
-15 dB
-4 dB
-2 dB
Chilbolton
60
59
58
57
56
55
54
53
52
51
50
49
48
47
46
45
44
43
42
41
40
-20
-18
-16
-14
-12
-10
-8
-6
-4
-2
0
2
4
6
8
10

FIGURE 18

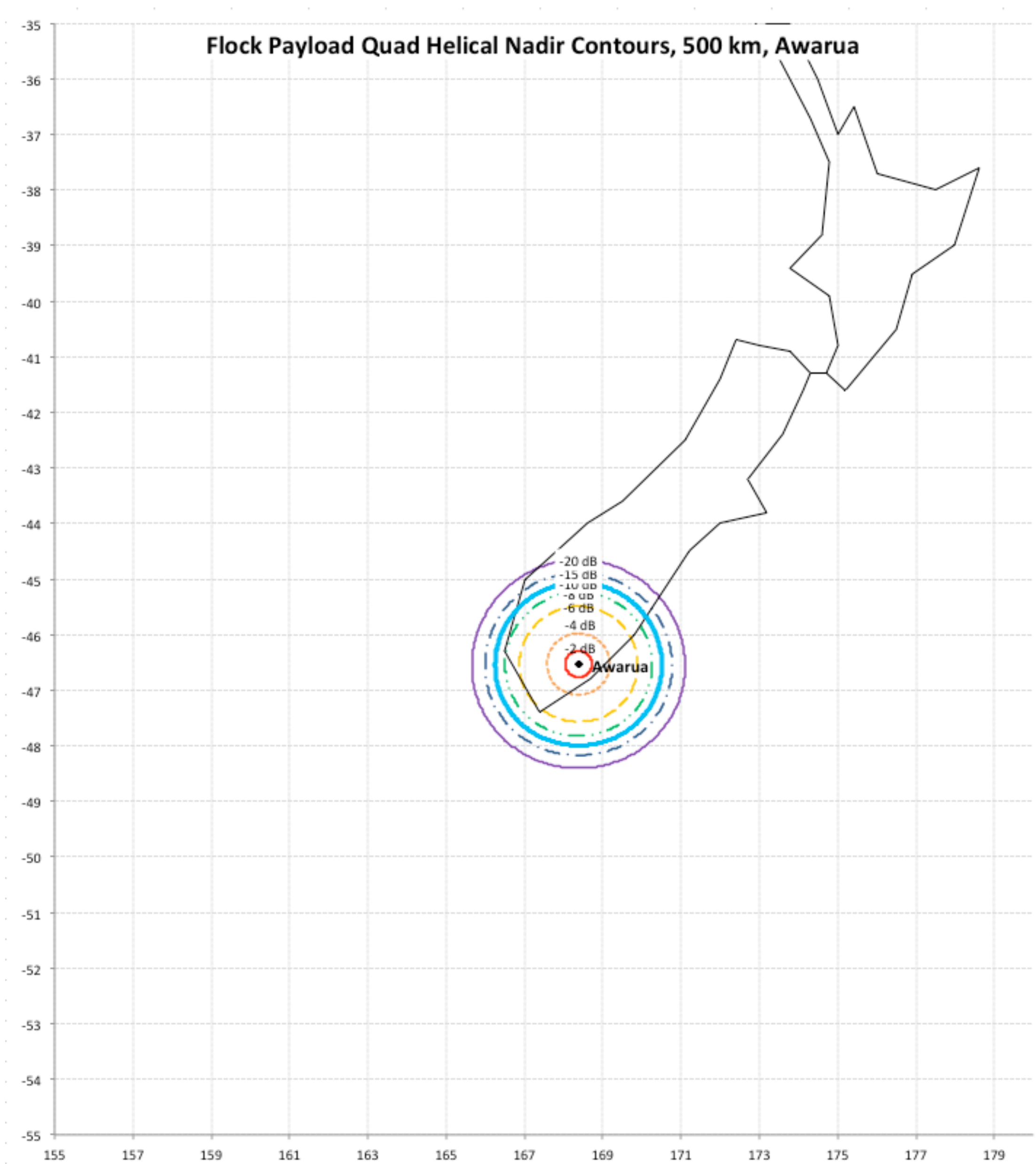

Flock Payload Quad Helical Nadir Contours, 500 km, Awarua
-20 dB
-15 dB
-10 dB
-6 dB
-4 dB
-2 dB
Awarua
-35
-36
-37
-38
-39
-40
-41
-42
-43
-44
-45
-46
-47
-48
-49
-50
-51
-52
-53
-54
-55
155
157
159
161
163
165
167
169
171
173
175
177
179

FIGURE 19

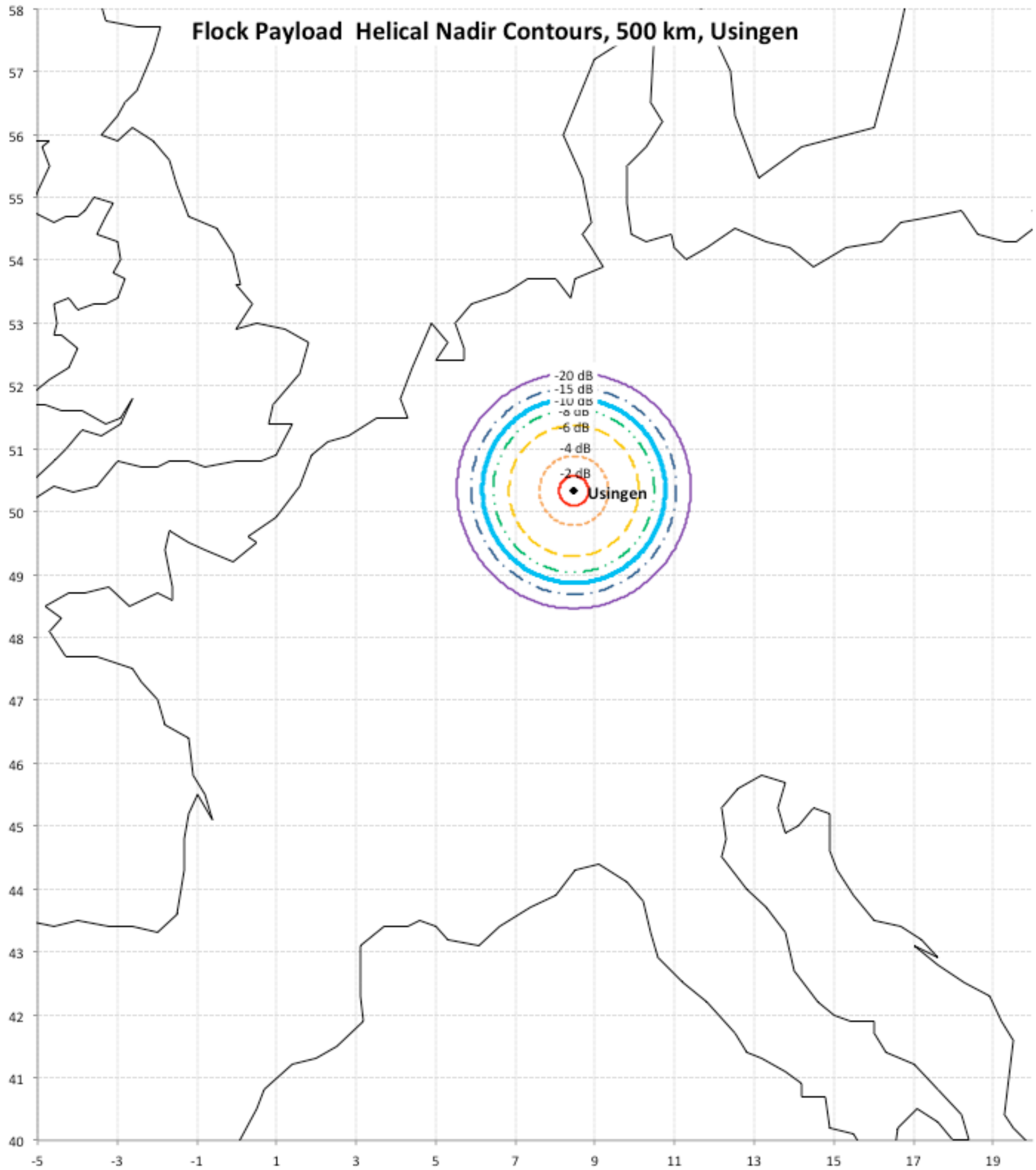

Flock Payload Helical Nadir Contours, 500 km, Usingen
-20 dB
-15 dB
-10 dB
-6 dB
-4 dB
-2 dB
Usingen
58
57
56
55
54
53
52
51
50
49
48
47
46
45
44
43
42
41
40
-5
-3
-1
1
3
5
7
9
11
13
15
17
19

FIGURE 20

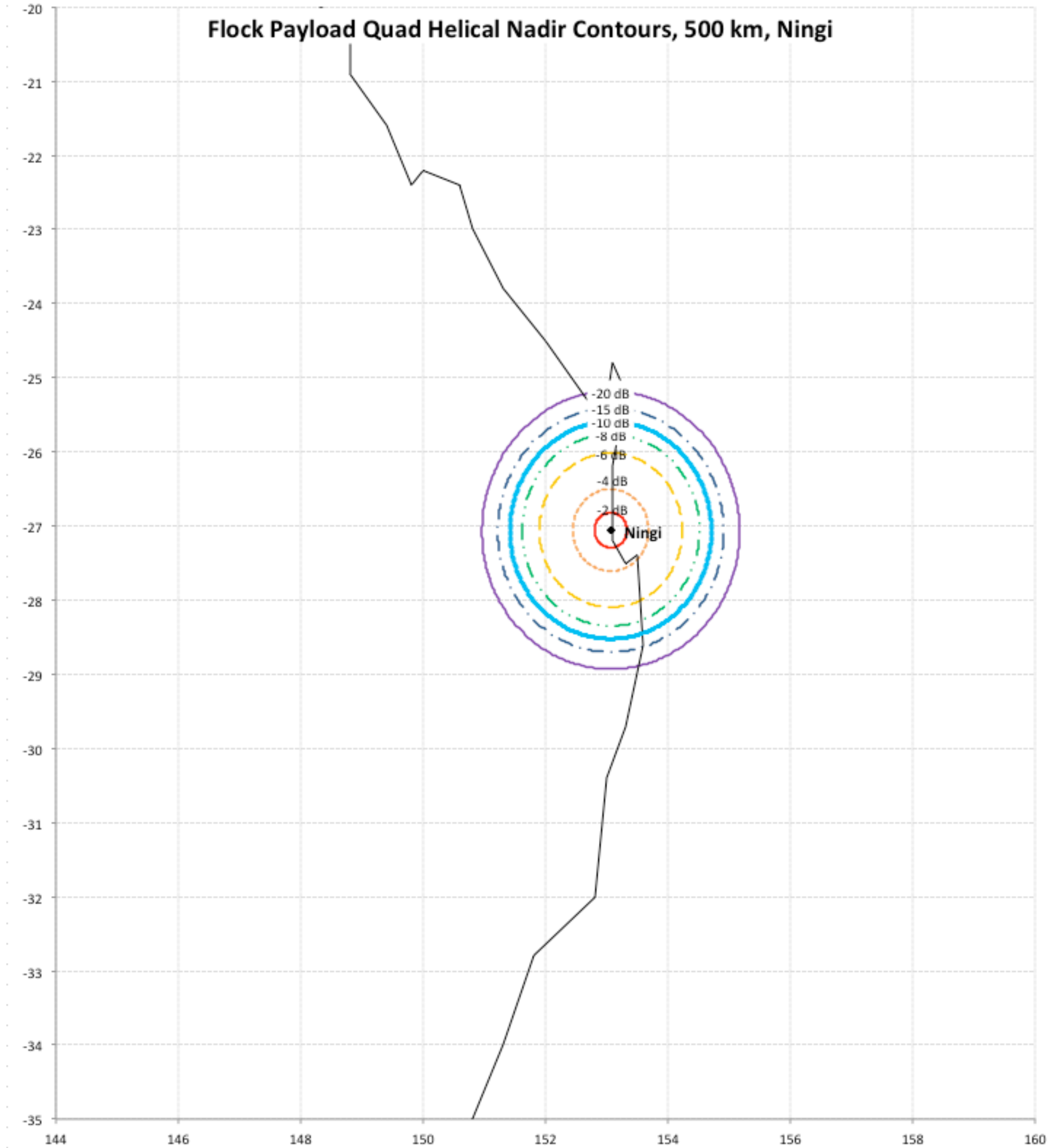

Flock Payload Quad Helical Nadir Contours, 500 km, Ningi
-20 dB
-15 dB
-10 dB
-8 dB
-6 dB
-4 dB
-2 dB
Ningi
-20
-21
-22
-23
-24
-25
-26
-27
-28
-29
-30
-31
-32
-33
-34
-35
144
146
148
150
152
154
156
158
160

FIGURE 21

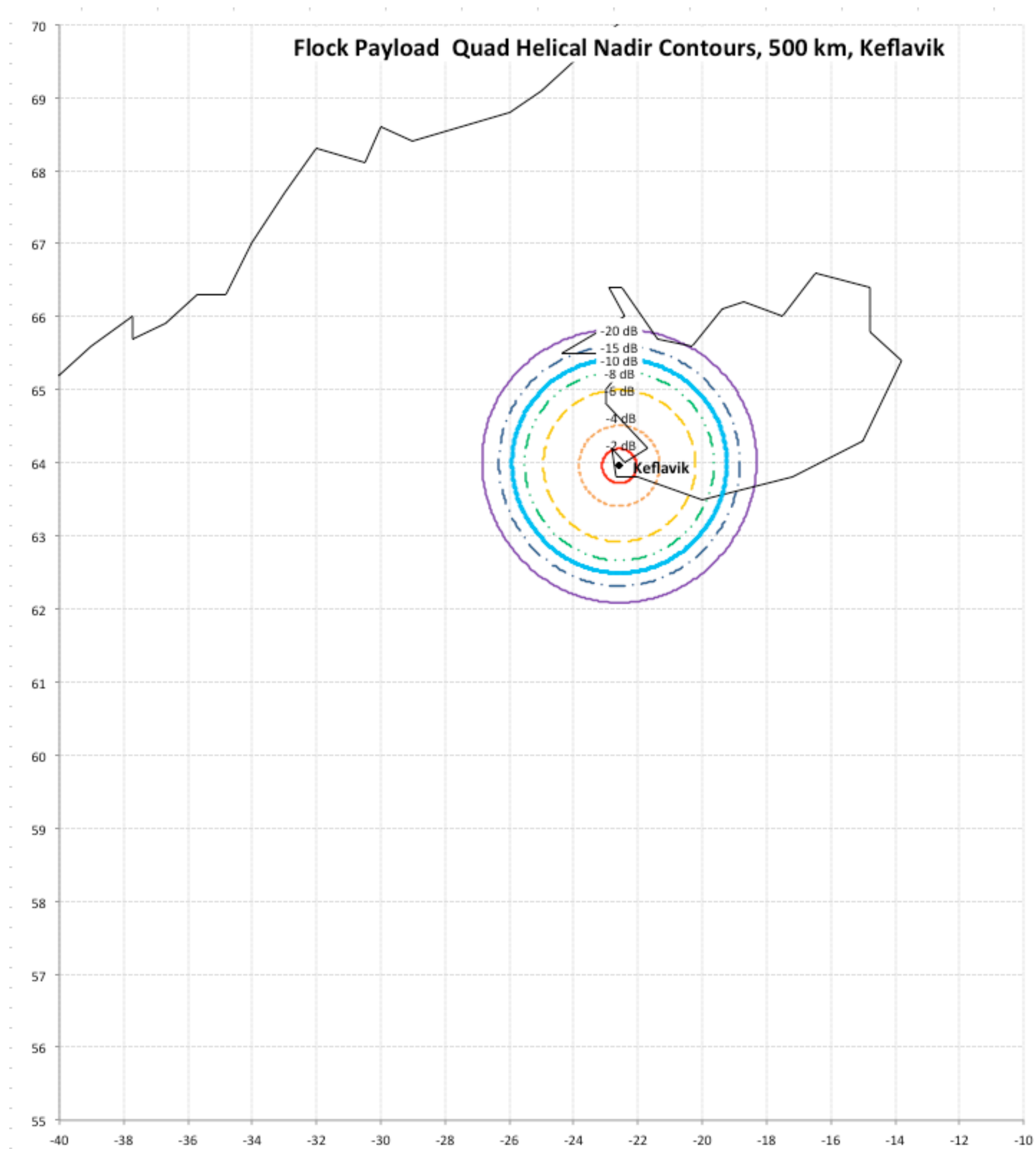

Flock Payload Quad Helical Nadir Contours, 500 km, Keflavik
-20 dB
-15 dB
-10 dB
-8 dB
-6 dB
-4 dB
-2 dB
Keflavik
70
69
68
67
66
65
64
63
62
61
60
59
58
57
56
55
-40
-38
-36
-34
-32
-30
-28
-26
-24
-22
-20
-18
-16
-14
-12
-10

FIGURE 22

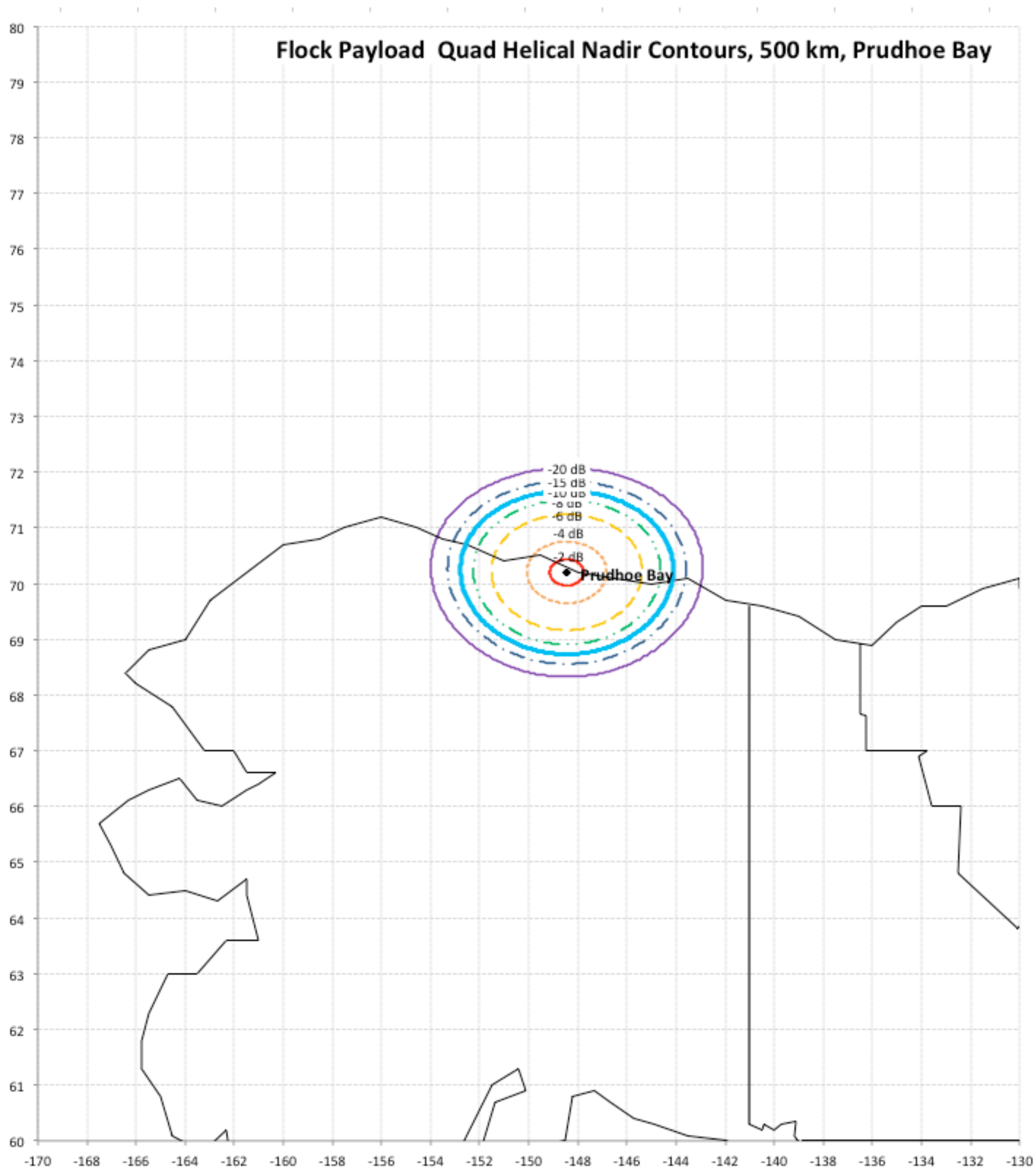
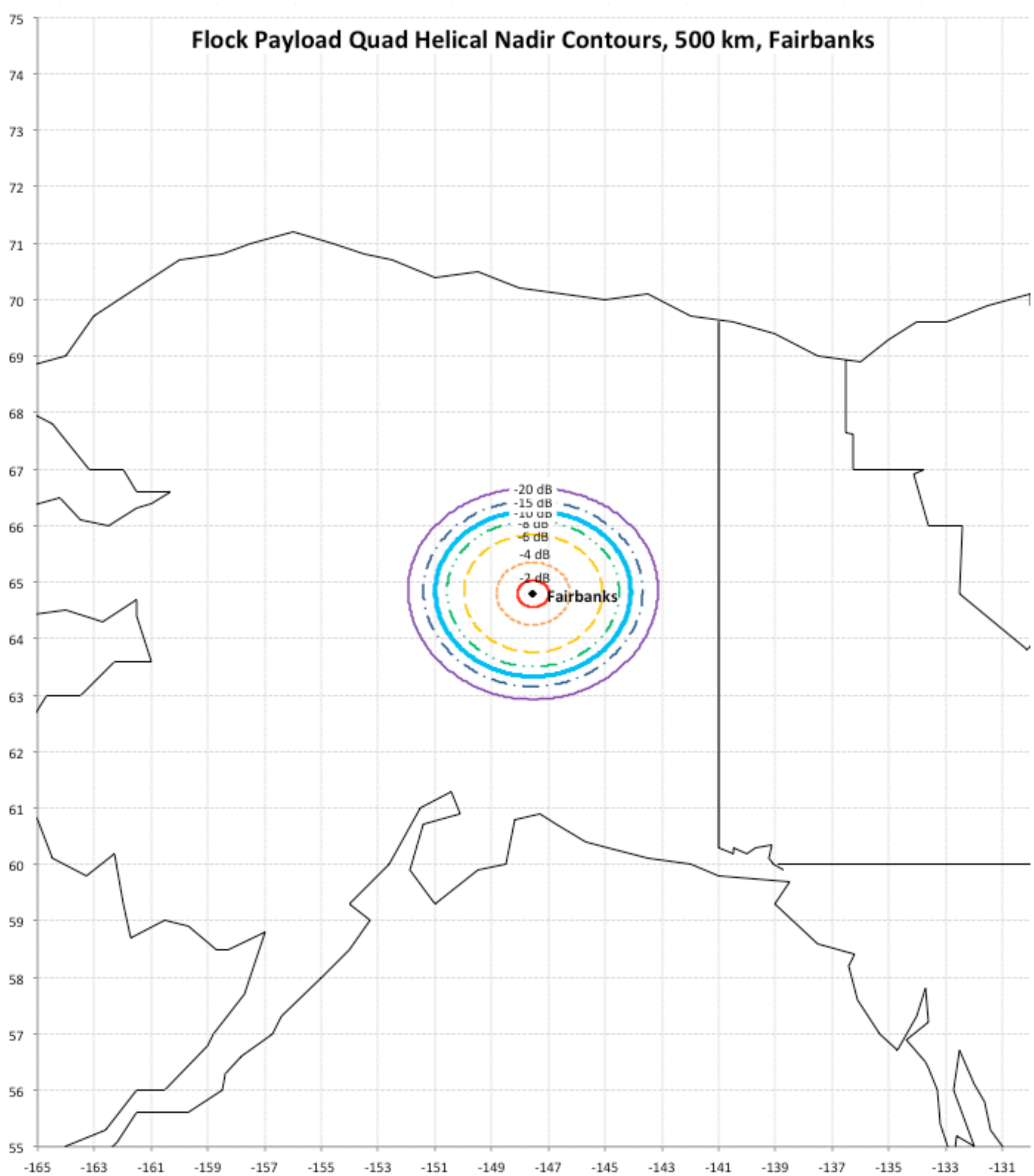

Flock Payload Quad Helical Nadir Contours, 500 km, Prudhoe Bay
-20 dB
-15 dB
-10 dB
-8 dB
-6 dB
-4 dB
-2 dB
Prudhoe Bay
80
79
78
77
76
75
74
73
72
71
70
69
68
67
66
65
64
63
62
61
60
-170
-168
-166
-164
-162
-160
-158
-156
-154
-152
-150
-148
-146
-144
-142
-140
-138
-136
-134
-132
-130

FIGURE 23


Flock Payload Quad Helical Nadir Contours, 500 km, Fairbanks
-20 dB
-15 dB
-10 dB
-8 dB
-6 dB
-4 dB
-2 dB
Fairbanks
75
74
73
72
71
70
69
68
67
66
65
64
63
62
61
60
59
58
57
56
55
-165
-163
-161
-159
-157
-155
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-151
-149
-147
-145
-143
-141
-139
-137
-135
-133
-131

Figure 24

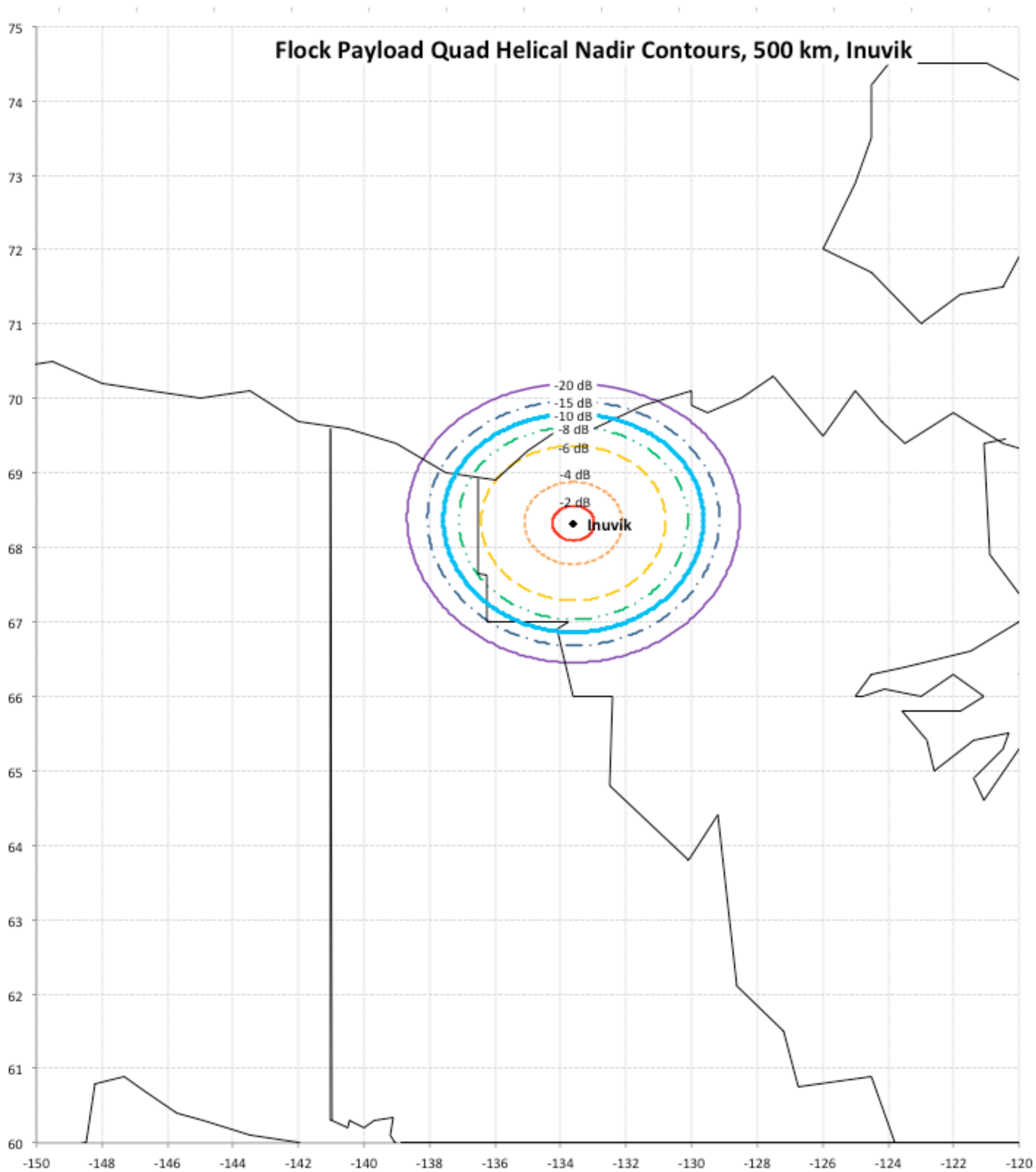
Flock Payload Quad Helical Nadir Contours, 500 km, Inuvik
-20 dB
-15 dB
-10 dB
-8 dB
-6 dB
-4 dB
-2 dB
Inuvik
75
74
73
72
71
70
69
68
67
66
65
64
63
62
61
60
-150
-148
-146
-144
-142
-140
-138
-136
-134
-132
-130
-128
-126
-124
-122
-120

FIGURE 25

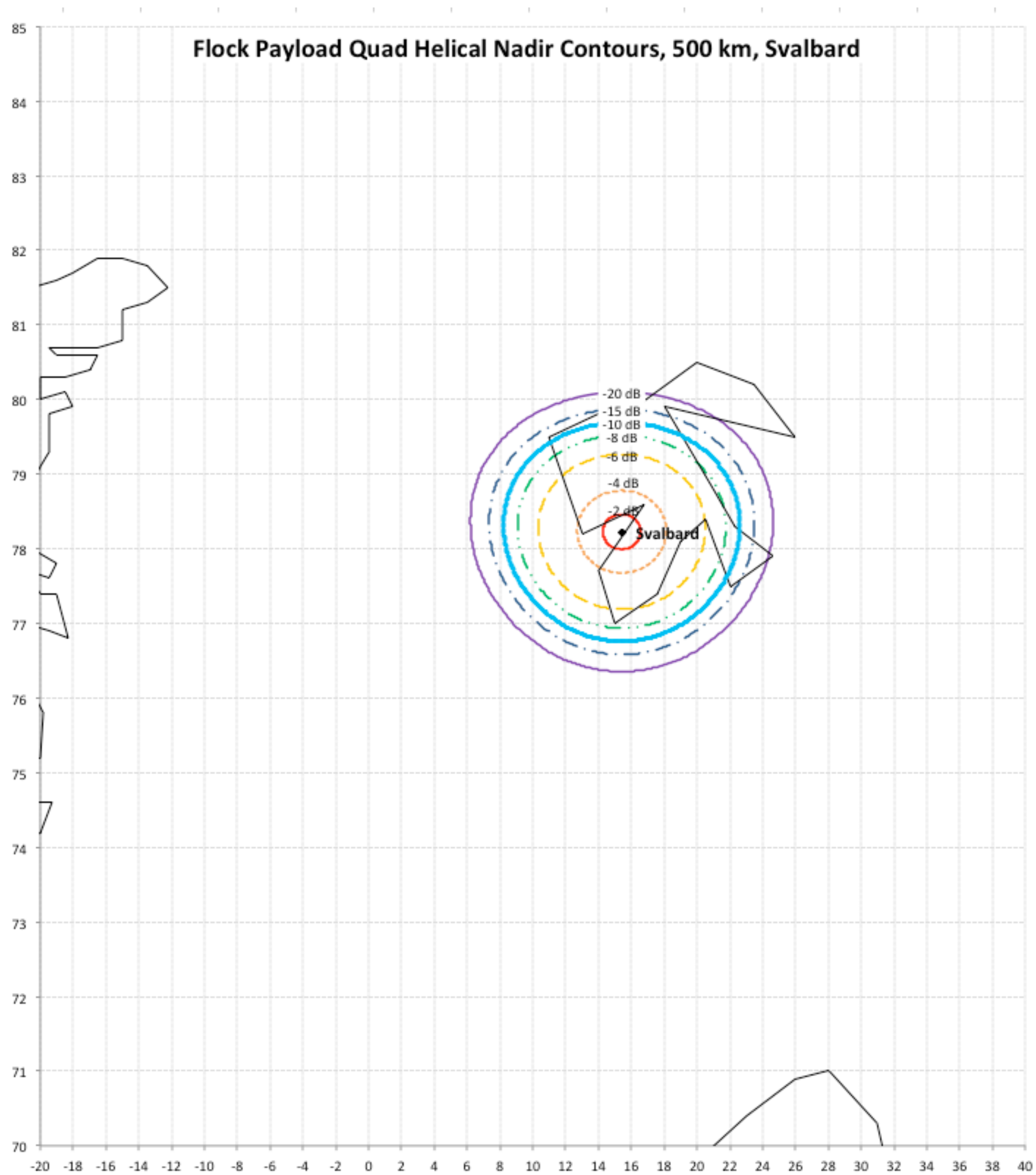
Flock Payload Quad Helical Nadir Contours, 500 km, Svalbard
-20 dB
-15 dB
-10 dB
-8 dB
-6 dB
-4 dB
-2 dB
Svalbard
85
84
83
82
81
80
79
78
77
76
75
74
73
72
71
70
-20 -18 -16 -14 -12 -10 -8 -6 -4 -2 0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40

FIGURE 26

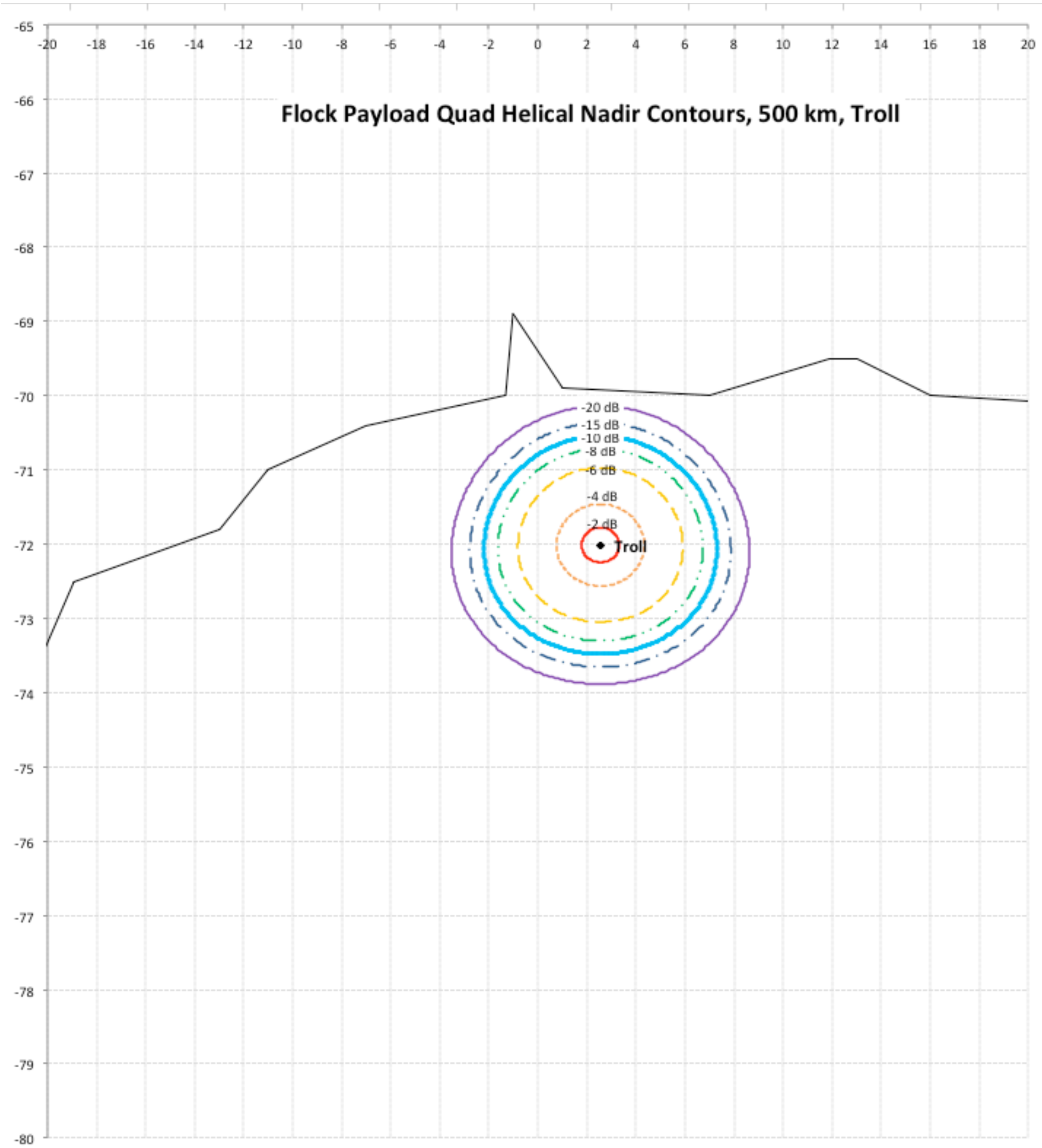
Flock Payload Quad Helical Nadir Contours, 500 km, Troll
-65
-66
-67
-68
-69
-70
-71
-72
-73
-74
-75
-76
-77
-78
-79
-80
-20
-18
-16
-14
-12
-10
-8
-6
-4
-2
0
2
4
6
8
10
12
14
16
18
20
-20 dB
-15 dB
-10 dB
-8 dB
-6 dB
-4 dB
-2 dB
Troll

FIGURE 27

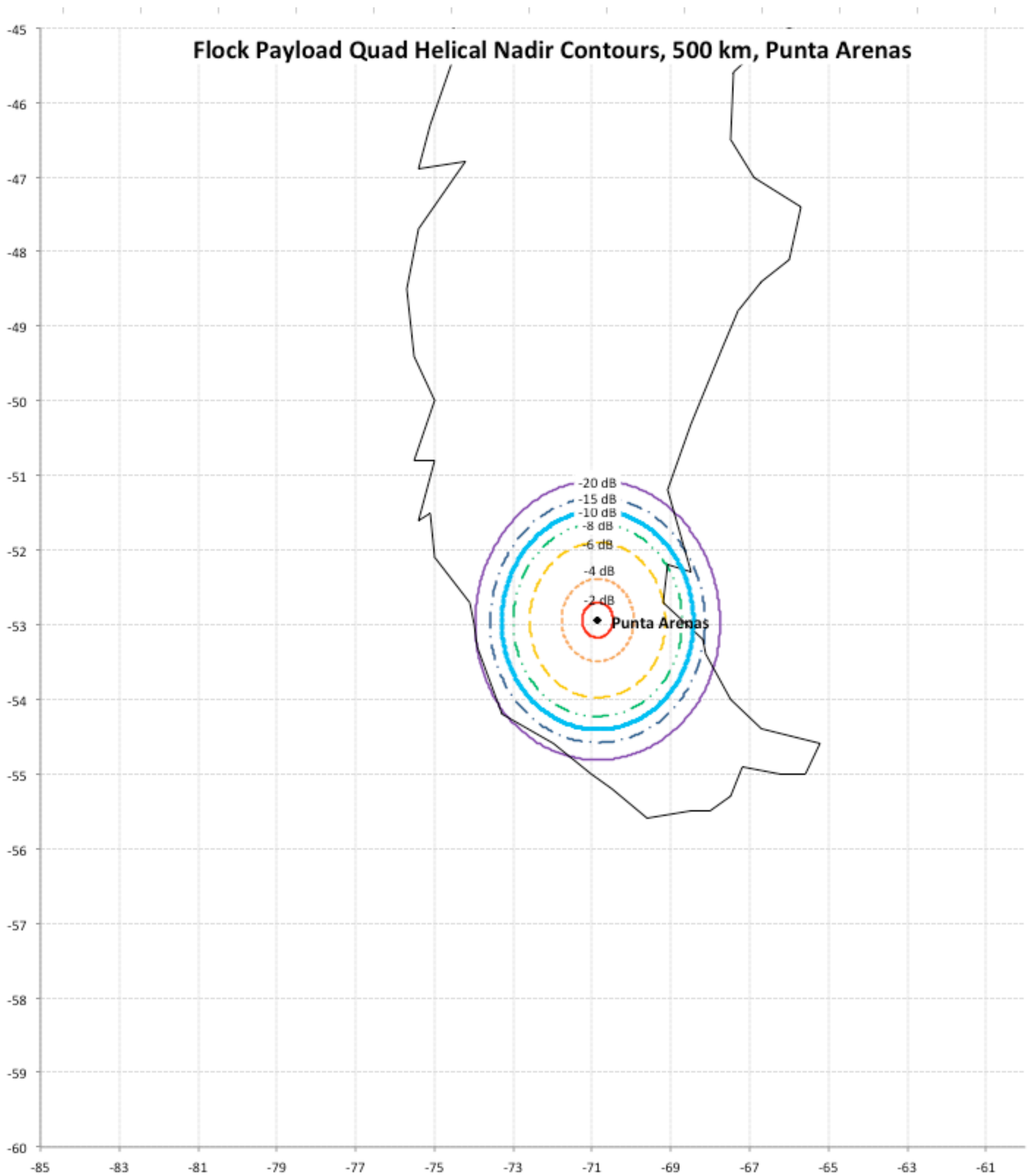
Flock Payload Quad Helical Nadir Contours, 500 km, Punta Arenas
-20 dB
-15 dB
-10 dB
-8 dB
-6 dB
-4 dB
-2 dB
Punta Arenas
-45
-46
-47
-48
-49
-50
-51
-52
-53
-54
-55
-56
-57
-58
-59
-60
-85
-83
-81
-79
-77
-75
-73
-71
-69
-67
-65
-63
-61

FIGURE 28

TECHNICAL CERTIFICATE

I, Craig Scheffler, hereby certify, under penalty of perjury, that I am the technically qualified person responsible for the preparation of the engineering information contained in the technical portions of the foregoing application and the related attachments, that I am familiar with Part 25 of the Commission's rules, and that the technical information is complete and accurate to the best of my knowledge and belief.

Craig Scheffler
Spectrum Manager
Planet Labs Inc.