USN Support of Proba-V Antenna Pattern specification

Proba-V is an NGSO space station in an 820 Km altitude orbit at an inclination of 98.7°. Due to the NGSO type orbit its antenna pattern impinging upon the earth is dynamic. This analysis is intended to provide the space station static pattern and attempt to provide how this pattern impinges upon the ground station area in North Pole Alaska and surrounding areas.

Figure 1 below shows the total passes calculated for a typical day that are visible from USN's Alaska ground station. Note that not all 10 passes each day will be supported, typically only two each day will be taken.

Proba-V

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1 39159U 13021A   15097.16845750  .00000099  00000-0  63656-4 0  9990
2 39159 098.6652 177.8153 0004362 164.1357 195.9962 14.22868732 99540
```

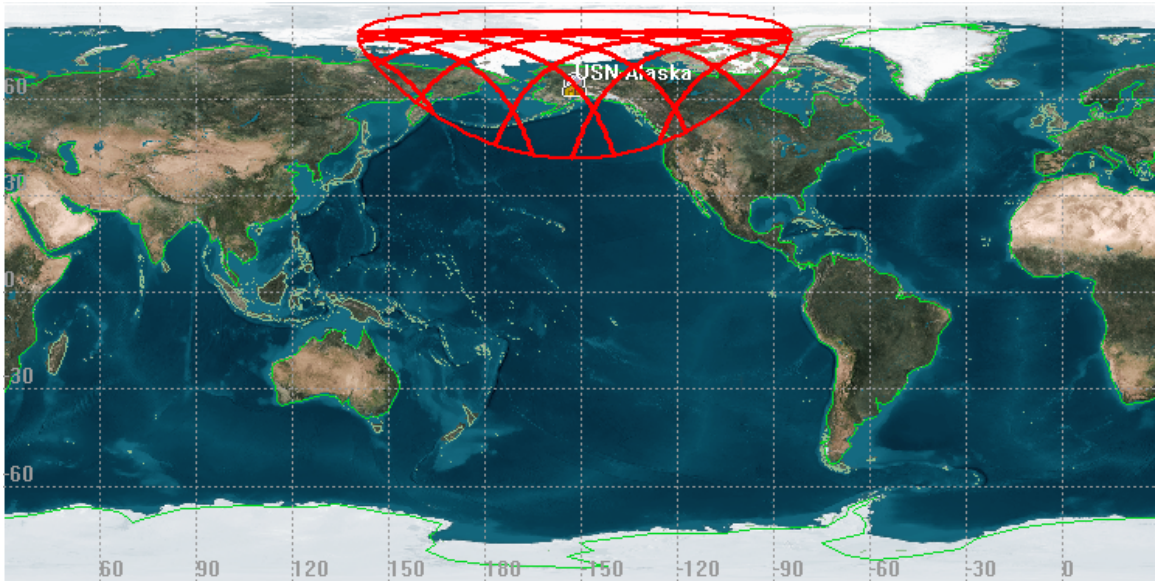

Figure 1 - USN Alaska coverage of Proba-V on a typical day 7 April 2015

USN Alaska possible passes for Proba-V on a typical day

Pass	Start Time (UTCG)	Stop Time (UTCG)
1	7 Apr 2015 01:03:26	7 Apr 2015 01:13:43
2	7 Apr 2015 02:42:29	7 Apr 2015 02:51:26
3	7 Apr 2015 04:20:21	7 Apr 2015 04:30:12
4	7 Apr 2015 05:58:09	7 Apr 2015 06:09:58
5	7 Apr 2015 07:37:15	7 Apr 2015 07:50:08
6	7 Apr 2015 09:18:33	7 Apr 2015 09:30:13
7	7 Apr 2015 11:03:30	7 Apr 2015 11:09:09
8	7 Apr 2015 19:41:24	7 Apr 2015 19:51:14
9	7 Apr 2015 21:21:14	7 Apr 2015 21:33:53
10	7 Apr 2015 23:01:25	7 Apr 2015 23:13:54

Figure 2 below represents the spacecraft transmit antenna's beam pattern. The color red indicates the dominant polarization of RHCP, while the blue indicates LHCP. Theta of 0 is the boresight of the antenna that is nadir pointing towards earth. The antenna is rated at a +3.0 dBi gain maximum and typically for any visible satellite pass the worst case gain is approximately -1.0 dBi since the edge of the antenna pattern is not visible due to the combination of orbital altitude and the earths curvature.

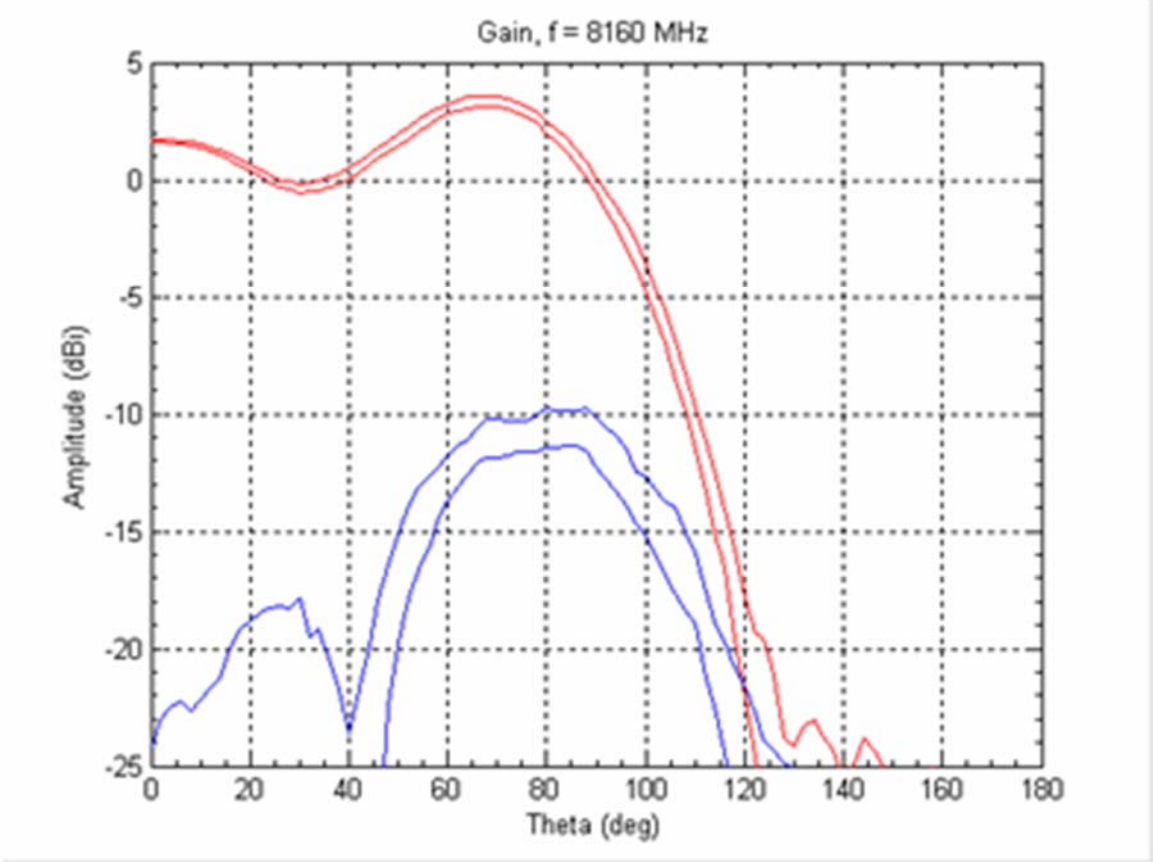

Figure 2 – Static spacecraft antenna pattern

During a direct overhead pass taken at USN Alaska, the space station impinges a dynamic pattern on the earth as shown in figure 3. Note the blue grid in the figure represents radio frequency impingement on the earth during this direct overhead pass. Figure 4 shows the nominal flux density delta power impinging in the area as the space station is directly overhead. Note that the yellow shaded area is in the 0 to +1 dBi contour of the pattern and the red shaded area is in the 0 to +3 dBi contour of the pattern.

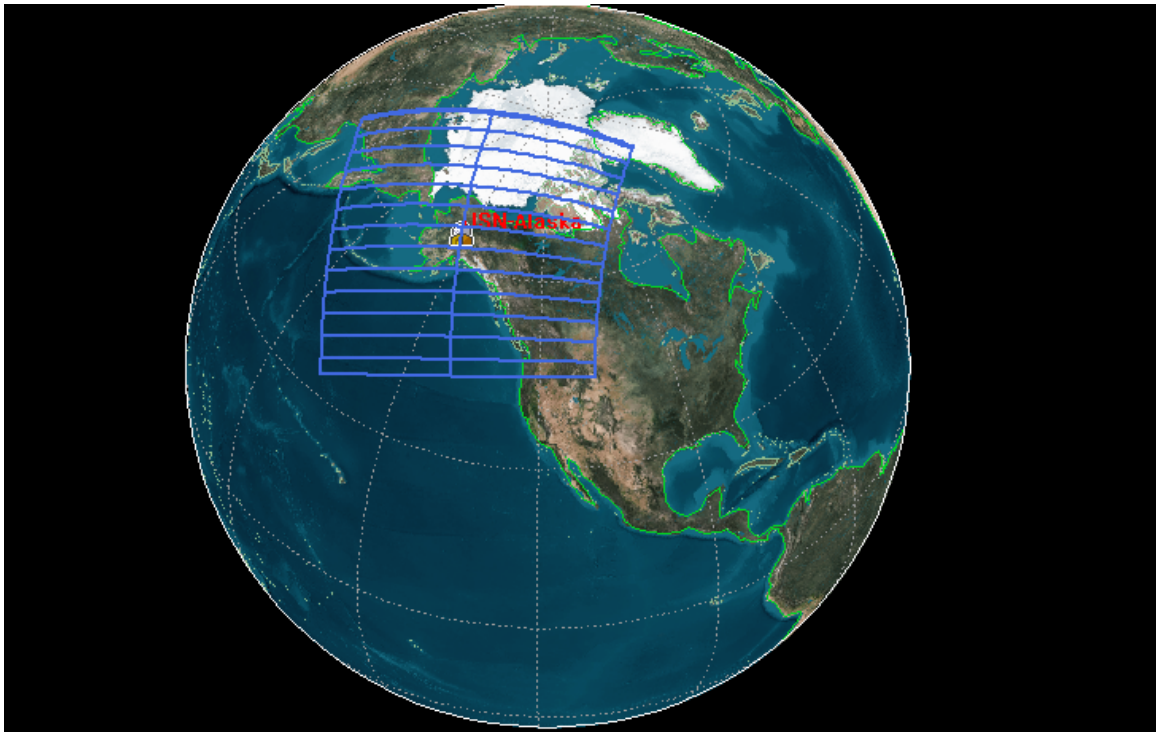

Figure 3 – Overhead pass RF impingement on earth

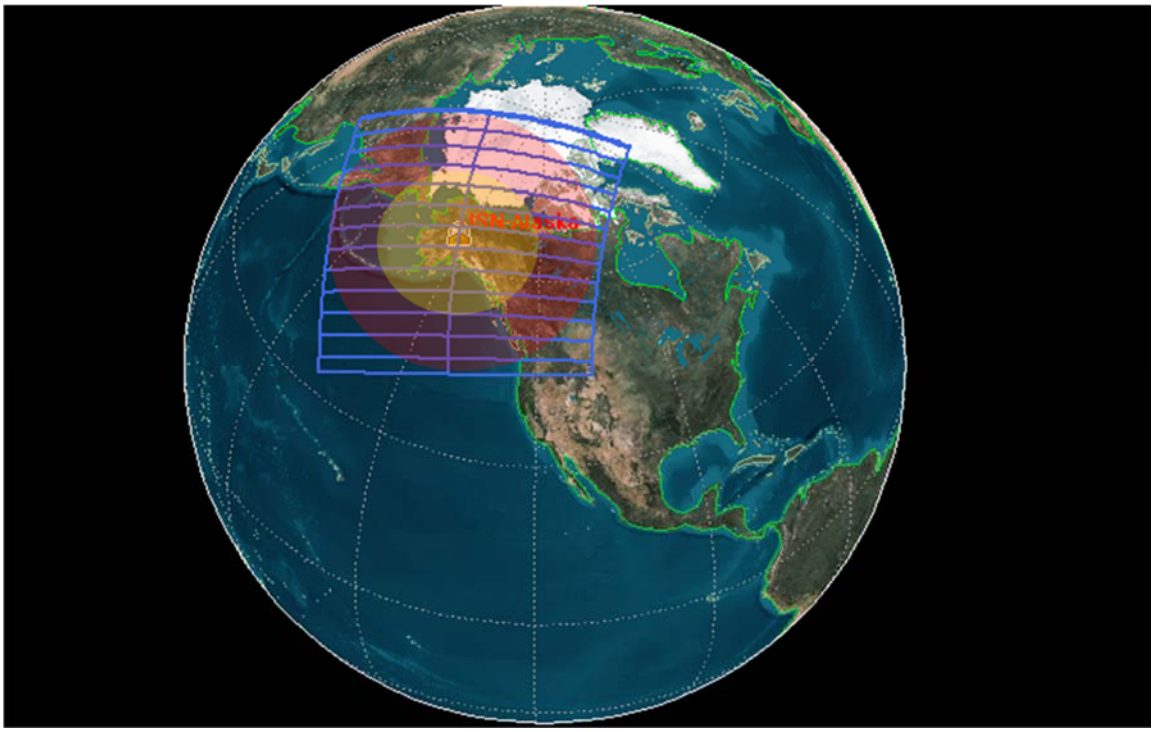

Figure 4 – RF flux density delta power at moment of overhead

Due to the dynamic nature of the NGSO space station and the antenna pattern it impinges on the earth it is difficult to show in map form the pattern impinging on the earth. Figure 5 attempts to show the cumulative pattern on the earth for the typical day. Note that this is the addition of all 10 passes for the day and does not represent a static pattern upon the earth as each of the 10 passes projects a different flux density on any particular part of the earth as it move over it.

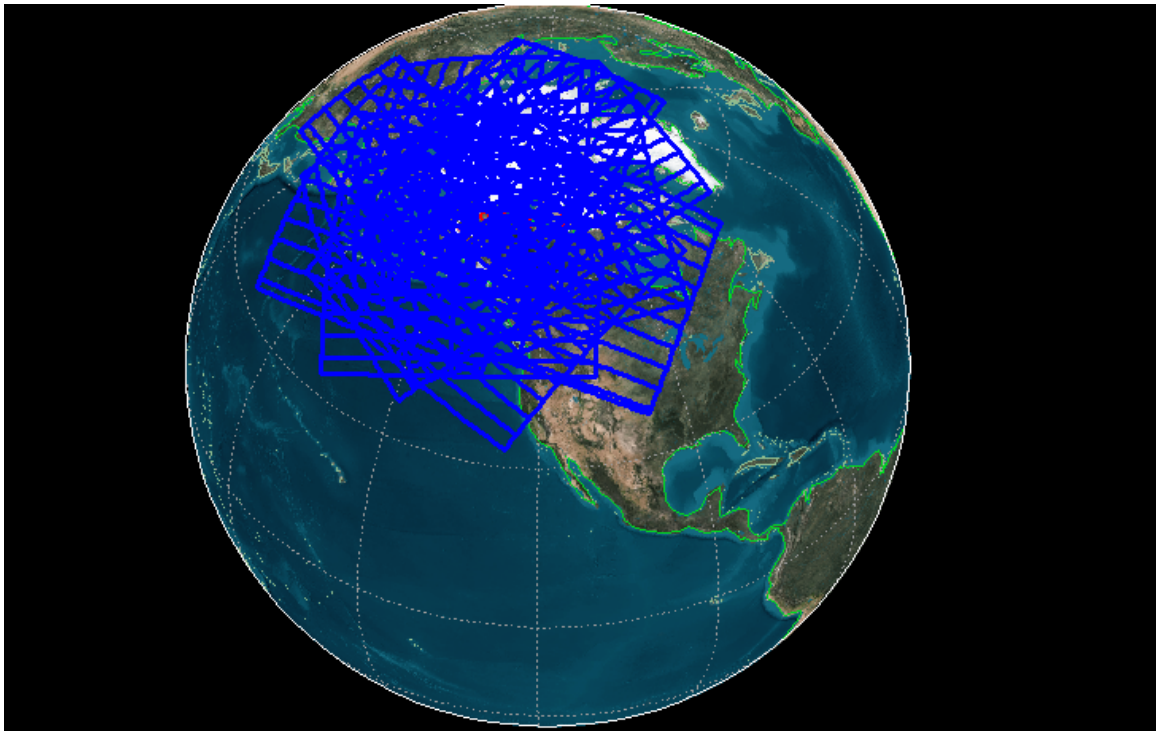

Figure 5 – Cumulative track map for a typical day over USN Alaska

Power Flux Density (PDF) impinging on the Earth
The Flux density is calculated as:

$$\boldsymbol{Flux\ density = EIRP \div (4\,\pi\, Rse^2)}$$

Where $\boldsymbol{Rse}$ is the distance from spacecraft to the ground.
Where $\boldsymbol{EIRP}$ is the Effective Isotropic Radiated Power of the Spacecraft.

Data from the spacecraft vendor indicates that the maximum EIRP of Proba-V is 13.0 dBW (10.0 effective watt transmit power into a +3 dBi antenna). The altitude (and thus the closest distance to earth during an overhead pass) is = 820 Km

Converting 13.0 dBW to scalar watts = 19.95 watts transmitted at 8090 MHz

Therefor:

$$\boldsymbol{Flux\ density = 19.95 \div (4\,\pi * 820{,}000\ meters^2)}$$

PDF = 2.361 x 10^{-12} Watts/meter^2
Or
PDF = 2.361 x 10^{-13} mW/cm^2
Or
PDF = -116.3 dBW/meter^2
Or
PDF = -160.2 dBW/meter^2/4KHz worse case (using occupied BW = 100MHz)

Table 1 shows the PDF versus the incident angle as seen from ground.

Incidence Angle	PDF (dBW/m2/4KHz)
0	-163.2
5	-161.7
10	-160.7
15	-160.5
20	-160.2
25	-160.2
30	-160.3
35	-160.7
40	-161.2
45	-162.2
50	-162.7
55	-163.1
60	-163.2
65	-163.2
70	-162.4
75	-162.2
80	-161.7
85	-161.5
90	-161.4

Figure 6 shows the compliance of PDF on the earth surface with NTIA and ITU specifications. Note this shows the worse case PDF on an overhead pass at the closest possible distance of spacecraft to ground. Most Proba-V passes will produce a lower PDF.

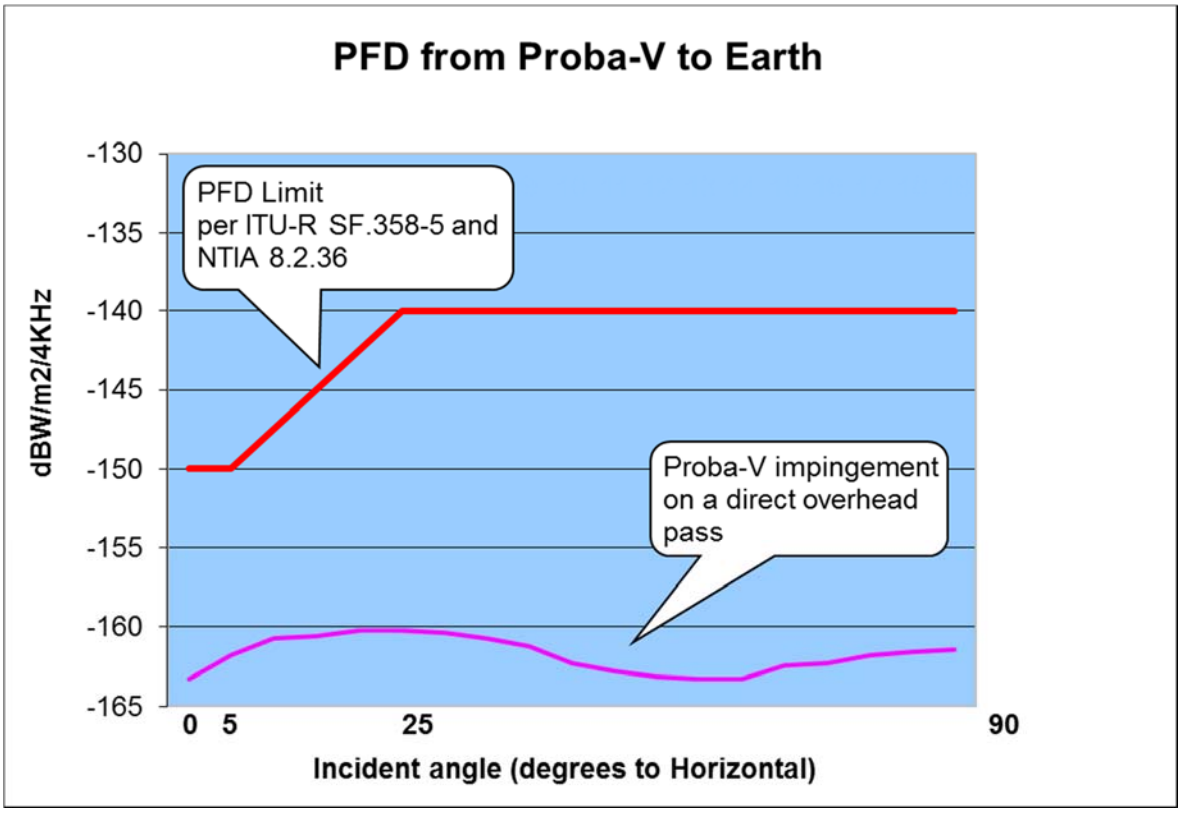

Figure 6 – Proba-V PDF incident on the earth's surface