where $\overline{g_i(\theta, \varphi)}$ is the average aircraft roll-off toward the satellite for the i-th bin whose elevation angle toward the satellite is θ and its median azimuth angle toward the satellite is φ, N_b is the number of GS beams over the CONUS (600 with 150 GSs and 4 beams per GS), and P is the peak EIRP of the aircraft transmitter averaged over all GSs, *i.e.*:

$$P = \frac{\sum_{i=1}^{N_{GS}} P_i}{N_{GS}} \qquad (2)$$

where P_i is the allowed peak aircraft EIRP of the i-th GS, and N_{GS} is the number of GSs. The peak aircraft EIRP is allowed to be different in different GSs to allow power control to mitigate rain fade in rain affected sites; but the maximum P_i may not exceed P by more than 6 dB.

P is the peak EIRP of the aircraft transmitter. The condition in Equation (8) was derived assuming aircraft peak EIRP of 3 dBW/2 MHz and average antenna roll-off over the CONUS toward the satellite of -15 dB. The rule as stated in (8) does not explicitly assume EIRP of 3 dBW and leaves it to the operator/system developer to adjust the antenna design and EIRP to ensure Equation (8) holds; this rule will be included in the proposed rules for the Next-Gen AG service in Appendix B. The baseline antenna in Section 1.1 and peak EIRP of 3 dBW showed one means of meeting Equation (8). Based on the above calculations, the condition in Equation (8) meets the $\leq 1\%$ RoT threshold with at least 3 dB of margin for the satellites located at the far sides of the CONUS.

The satellites located at the far east of the CONUS orbital arc (~ 60° longitude) see similar potential interference as the one at 140°. Note that another potential source of overestimation of RoT is that the average G/T over CONUS was also applied to the bins with low elevation angle (*i.e.*, the bins in the east). However, the G/T of the satellite will likely be much smaller for those bins with low elevation angles of 5°.

The satellite beams that cover Canada will have their G/T focused on Canada, and the Canadian beams' G/T will roll off over the CONUS. The Canadian beams' G/T could have -5 dB/K or lower over CONUS, so the RoT caused to the Canadian beams from Next-Gen AG aircraft or GSs over the CONUS will be even smaller than that seen by the CONUS beams.

Moreover, this Petition focuses exclusively on Next-Gen-AG service to aircraft over CONUS. If the service is also provided over Canada, two rows of GSs will be needed within Canada to cover the southern part of that country. The elevation angles from aircraft or GSs in Canada to the Canadian GEO beams will be a few degrees less than the values over CONUS, and the discrimination from aircraft transmitters or GSs over Canada to the Canadian GEO beams will be several dB lower than for the CONUS example. However, there will be fewer GSs deployed over Canada, and there also will be fewer aircraft over Canada. Therefore, it can be shown that the RoT limits can also be met if it is desired to provide the Next-Gen-AG service over Canada.

Also, a $\pm 5°$ aircraft roll during normal cruise was accounted for in the above RoT calculation. Qualcomm recognizes, however, that aircraft occasionally make rolls of larger angles. Many aircraft fly routes are direct lines between waypoints, usually VOR ground stations. Charts (maps), air traffic control procedures and electronic navigation aids are well developed to work with this waypoint-to-waypoint routing. This results in the vast majority of cruise flight being straight and level, with brief changes in direction via a standard rate turn. According to FAA rules, aircraft flying faster than 250 knots make a 360 degree turn in four minutes. All turns during flights under instrument rules shall be made at standard turn rate but with no more than 15° of bank. Below, the fraction of time a plane may make a 15° roll and the impact of such a roll on the RoT to GEO-arc are considered.

Consider a flight route from San Diego to New York which potentially is the worst case in terms of number of turns as the flight goes from southwest to northeast. Flight data during the cruise portion of this flight shows that about 2 minutes of the 237 minutes flight is spent in turns. That is approximately 0.82% of the flight time. However, only the north turns expose the antenna toward the GEO-arc. Therefore, on average 0.4% of the flight time for this route is spent in a 15° roll toward the GEO-arc. However, most flights (such as north-south and straight east-west routes) spend much less time turning in general. For all flights over the CONUS, perhaps at most 0.2% of the flight time sees a roll of 15° toward the GEO-arc. Given a maximum of 600 planes on a given piece of spectrum and 0.2% average roll of 15°, on average there may be about 1.2 planes making a 15° roll toward the GEO-arc. Then, even if these planes introduce as much as 20 dB (worst case) additional potential interference into the GEO-arc, they only tend to increase the RoT computed above for the satellite at 140 longitude to $\sim 0.26\%$ from $\sim 0.21\%$.

While this straightforward calculation did not account for the standard deviation of number of flights making 15° rolls simultaneously, it did consider the worst case interference increase of 20 dB. Accordingly, the margin of at least 3 dB built in the RoT before reaching 1% would comfortably accommodate the 15° rolls. And, in any event, it certainly is possible to turn the aircraft transmitter off during 15° rolls or design an antenna that steers the beam down during 15° rolls to completely avoid any potential interference.

The above calculation involved a single CONUS beam. As discussed earlier in this Appendix, the analysis readily extends to multi-beam satellites. As the number of beams is increased, the G/T of each beam is nominally increased by the number of beams; however, the number of GSs or aircraft that are covered by the smaller satellite beams is reduced proportionately because of the smaller coverage area of each beam. For instance, in going from 1 to 2 beams, the G/T is nominally increased by 3 dB but the number of planes or GSs each beam sees is halved, *i.e.*, reduced by 3 dB. This results in the same RoT that was computed for one CONUS beam.

3.3.2 Next-Gen AG Potential Interference into NGSO Satellites (Planes and GS Cases)

3.3.2.1 GS to NGSO Interference Protection Calculation

As explained above, the GS antenna uses an isoflux gain profile in elevation, wherein the antenna gain is reduced according to the distance between the airplane and the GS. When taking into account the curvature of the earth, the elevation of an airplane at a 10 km altitude is ~ 1° at a distance of 300 km from the GS and ~ 15° at ~ 37.4 km from the GS. Due to the isoflux antenna pattern in elevation of the GS, the antenna gain at 15° elevation is about 17 dB less than the antenna gain at 1° elevation. Hence, the EIRP effectively drops by the path loss change at the higher elevations so that the GS to aircraft link performance remains essentially the same for all elevations and distances. When this effect is factored into the interference cases for the sample NGSO system described above, the potential interference impact is reduced by at least 17 dB at elevation angles ≥ 15°.[54] With the assumed NGSO satellite orbit of 1000 km altitude, the distance from the GS to the satellite at 15° elevation angle is ~ 2410 km, which results in a path loss of approximately 183.0 dB at 14 GHz. As shown in Table A.13, with a Next-Gen AG GS

[54] Aircraft communications handoffs to another GS will typically occur at GS-to-aircraft elevation angles of 10°. In some cases, such as when aircraft is flying close to the southern U.S. border, aircraft may be served by a GS at an elevation angle as high as 20°.

EIRP of 39.5 dBW (aimed at 1° elevation), and an NGSO system whose satellites serve terminals at elevation angle of 15° or higher and satellite G/T of -7 dB/K, the I/N at the NGSO satellite receiver is approximately -21 dB and the resulting RoT is 0.81%.

GS EIRP per Beam Per Polarization	39.50	dBW
GS Antenna Roll-off at 15° Elevation	-17.00	dB
Atmospheric Loss at Ku Band	0.00	dB
Satellite G/T	-7.00	dB/K
Beam Gain Roll-off at 15° Elevation Compared to Center of Beam	-2.00	dB
1/BW (BW = 50 MHz)	-76.99	-dB-Hz
1/Boltzmann	228.60	-dB/K-Hz
Path Loss (2410 km from BTS to NGSO Satellite at 15° Elevation, at 14 GHz)	-183.00	dB
Polarization Discrimination (GNSO Circular, GS Linear)	-3.00	dB
I/N at Satellite Receiver	**-20.89**	**dB**
RoT	**0.81**	**%**

Table A.13. I/N at NGSO satellite receiver from Next-Gen AG GS transmitters

The above calculation shows that the NGSO system may be protected even if the Next-Gen AG GS beam is pointing directly at the NSGO satellite. Using ephemeris data on the NGSO system, it is also possible to lower the Next-Gen AG GS beam's transmit power to further mitigate interference into the NGSO satellite when the GS, the aircraft and the satellite line up. If the GS antenna is designed to follow an isoflux property in elevation as described in Section 1, then it is not necessary to use NGSO orbital ephemeris information to turn down the GS power when the GS, the aircraft and NGSO satellite align. The use of ephemeris information is mentioned here to demonstrate that there are alternative approaches to avoiding interference to NGSO satellites. Accordingly, the proposed Next-Gen AG system design will protect future NGSO systems and the system has several degrees of freedom if needed to further limit any potential interference.

3.3.2.2 Aircraft to NGSO Satellite

Based on the NGSO system assumptions in Section 3.2, one NSGO beam (with a diameter of 300 km) will at most cover some portion of three Next Gen GS service areas on the ground. Based on the design of the proposed Next-Gen AG system (*see* Section 1, *supra*), each piece of spectrum is at most used 4 times in each service area. And, since one NGSO beam covers 3

Next-Gen AG sites, each piece of spectrum is at most used 12 times by the Next-Gen AG system within one NGSO spot beam.

For the case where the aircraft is at 15° elevation with respect to the satellite (*i.e.*, a distance of 2410 km from the aircraft to the satellite and path loss of -183 dB at 14 GHz), and assuming an off-axis aircraft antenna roll-off of 15 dB accounting for 5° worst case roll during normal flight, the I/N and RoT are provided in Table A.14.

Plane EIRP	3.00	dBW
Plane Antenna Roll-off Toward NGSO Satellite at 15o Elevation to GNSO Satellite	-15.00	dB
Atmospheric Loss at Ku Band	0.00	dB
Satellite G/T	-7.00	dB/K
Beam Gain Roll-off at 15o Elevation Compared to Center of Beam	-2.00	dB
1/BW (BW = 2 MHz)	-63.01	-dB-Hz
1/Boltzmann	228.60	-dB/K-Hz
Path Loss (2410 km from Plane to NGSO Satellite at 15o Elevation, at 14 GHz)	-183.00	dB
Polarization Discrimination (NGSO Satellite Circular and GS Linear)	-3.00	dB
12 Reuses of 2 MHz Carrier in NGSO Beam Coverage Area	10.79	dB
I/N at Satellite Receiver	**-30.62**	**dB**
RoT	**0.09**	**%**

Table A.14. I/N at NGSO satellite receiver from Next-Gen AG aircraft transmitters at 15° elevation angle from satellite

For the case where aircraft are under the satellite (and within the boresight of the satellite antenna), the path loss to the satellite will correspond to -175.5 dB and the satellite beam roll-off will be 0 dB; however, the aircraft off-axis roll-off toward the satellite will be at least 20 dB (90° elevation angle from the aircraft antenna toward the satellite). By making these adjustments in values of Table A.14, RoT for this case is no greater than 0.24%; it is in fact much smaller as the antenna roll-off at a 90° elevation is much larger than the assumed 20 dB.

The calculations thus show that there is negligible interference impact from the Next-Gen AG GSs or airplanes to the assumed NGSO satellite system. Even if the NGSO beamwidths are increased to capture more interfering elements, that would be offset by the G/T reduction that

would accompany the beam widening. Each dB increase in area captured by widening the beam would result an equivalent dB reduction in G/T, leaving the interference protection calculation essentially unchanged.

3.3.3 VSAT Interference into Next-Gen AG Equipped Aircraft

The calculations performed herein assume that the aircraft is at an altitude of approximately 10 km (~ 33,000 feet) even though the aircraft altitude does not materially impact the interference protection calculations into GSO and NGSO satellites. Next-Gen AG equipped aircraft may operate at altitudes as low as 3 km if passenger electronic devices are allowed to remain operational.

The potential interference impact from VSAT terminals is derived by dividing the VSAT terminals within the viewable footprint of the airplane into two groups: the VSAT terminals to the north of the aircraft and the VSAT terminals to the south of the aircraft. This approach is used because the antenna patterns of the VSAT and aircraft antennas to the north of the plane have a common interference behavior as do the ones from the south. The VSATs to the north have their antenna pointing more directly toward the airplane, although typically these point up to the GEO-arc which lies many tens of degrees up and over the top of the airplane at about a nominal 40° elevation angle from the VSAT ground locations in CONUS. Only in extremely rare cases will there be aircraft within the line-of-sight of VSAT and GSO satellites in which case this geometry does not hold; this case is considered separately in a later section as a "harm" case that is quite small in effect.

The north half portion of the VSAT terminals in a 300 km radius area from the airplane which project their beam power toward the GEO-arc, and the Next-Gen AG airplane is outside 2° from the VSAT center-of-beam. Once outside that cone of harm, Monte Carlo simulation shows that the average combined VSAT and aircraft antenna off-axis gain roll-off from a community of VSATs within 300 km radius footprint is at least 32 dB from peak of the VSAT main beam gain based on antenna type B in Table A.7, which is assumed for VSAT terminals. The second commonality for these "north-side" VSATs is that the airplane RX antenna points southward also, away from those same VSATs to the north, and toward the GS at the south end of the service area. So, for that condition, the airplane antenna front-to-back ratio provides, as

mentioned above in Section 1.1, 15 dB of loss. These two effects produce a total VSAT power from the northern half of the footprint that is diminished by - 32 - 15 = - 47 dB from the VSAT EIRP boresight power.

Although the southern group of VSATs has their backlobes toward the airplanes, they also have a small amount of power bleeding out northward toward the airplane which has a clear line-of-sight to those VSATs to the south. But many VSAT installations will provide full shadowing depending on structural blockage, for VSAT terminals often are installed on the southern side of buildings with clear view to the GEO-arc to the south – a necessary condition for their intended use. These structures thus typically will block the VSAT radiated power toward the north. Qualcomm nonetheless estimates that 25% of those VSATs have a full unblocked view to the airplane. That is, 25% of the VSATs toward the south of the airplane have an antenna backlobe of -40 dB toward the airplane, and the remaining 75% of the southerly VSATs have an additional 20 dB of attenuation due to blocking.

Also, the aircraft receive antenna's average gain throughout its forward looking space, is 180° in azimuth and elevation angles of -3 to -15° below horizon, and thus is about -7 dB relative to the peak gain. Overall, the southern VSAT terminal's power is reduced by 40 dB for VSAT backlobe, 7 dB for airplane average forward gain for those VSATs the plane sees, and 6 dB for the reduction in the number of 25% unblocked VSATs causing harm, for a total reduction of 53 dB. Accordingly, the average attenuation factor over the whole region is the average of the northern and southern factors computed above, which is ~ -49 dB.

Next the total number of VSATs seen by the aircraft footprint is computed, adjusting for the reductions from peak VSAT EIRP, as discussed above. An estimate of the number of active VSAT terminals is derived from a consideration of the available Ku band uplink bandwidth, the number of GEO-arc locations with Ku band service at 14.0 to 14.5 GHz, and the nominal saturation transmit power levels for Ku band transponders in orbit.

The computation begins with an estimate of the Saturation Flux Density EIRP required to drive a satellite transponder to full power. While this number may vary, the typical number, based on systems Qualcomm has designed and satellites used in the Ku band, is 70 dBW for the earth station uplinks. For multi-carrier use of the transponder, that value must be reduced by 6 dB for

the nominal aggregate EIRP operating point of the transponder. From that aggregate EIRP backoff point, the uplink power per transponder is then divided by typical VSAT power EIRP capability used for its links, 40 dBW, to determine a maximum number of VSATs that may simultaneously use the transponder at any one instant. Since the Next-Gen AG FL calculations are performed for 50 MHz bandwidth, that amount needs to be multiplied by 1.1, for the number of transponders (average width of 45.5 MHz per transponder, considering transponder bandwidth mixes of 36 MHz, 48 MHz, etc.) in 50 MHz of bandwidth, and then by the number of same-band transponders across the GEO-arc width of 80°, *i.e.*, 1 satellite per 2°, a total of 40 orbital slots. Qualcomm estimates that, in practice, 50% of these transponders are in service for VSAT business. This gives about 5500 VSATs accessing the GEO-arc simultaneously. Assuming that these VSATs are all within the CONUS boundary (when in actuality Mexico and Canada share this same use), then the relative percentage area of a 300 km radius circle that the aircraft sees compared to CONUS area is about 1:28.6 (*i.e.*, ~ 3.5% or -14.5 dB) which produces about 193 active VSATs that viewable by the airplane (based upon a uniform distribution assumption). It is worth noting that the number of VSATs over the CONUS is overestimated because the number of VSATs that could be supported on the GEO-arc by the U.S., Canada, and Mexico is assumed to be operating over only the CONUS. In the calculations that follow, Qualcomm accounts for a 2 fold increase in the VSAT density in high population areas of CONUS.

The average path loss from VSATs, uniformly distributed in the 300 km radius field of view of the aircraft, to the location of the aircraft is equivalent to placing the VSATs at approximately 114 km from the aircraft. Then, the C/I seen at the aircraft, where C is the GS received signal power and I is the VSAT terminal aggregate received interference power at the aircraft, is computed in Table A.15.

GS EIRP per Beam	39.50	dBW
Path Loss from BTS to Aircraft (at 300 km, 14 GHz)	-164.90	dB
Received BTS Signal Power at Aircraft	-125.40	dBW
One VSAT Terminal EIRP	40.00	dBW
VSAT Terminal Antenna Discrimination Relative to Aircraft Antenna	-49.00	dBi
Number of VSAT in Field of View of Aircraft (193)	22.86	dB
Path Loss from Average Location of VSAT Terminals (114 km, 14 GHz)	-156.50	dB
Polarization Mismatch	0.00	dB
Received VSAT Terminal Interference Power at Aircraft	**-139.64**	**dBW**
C/I_{VSAT} at the Aircraft	**17.24**	**dB**

Table A.15. C/I received at the aircraft, where I is the VSAT terminal aggregate interference

Then, $C/(I_{VSAT}+N)$, where C/N (from Table A.1) is 10.2 dB, is given by $1/(N/C+I_{VSAT}/C)$, *i.e.*, ~ 9.4 dB; thus, the C/N is reduced by ~ 0.8 dB due to VSAT terminal interference. For the case where the aircraft is flying over an area with 2 times the number of VSAT terminals due to non-uniformity of VSAT distribution across the CONUS, C/I_{VSAT} is reduced to 11.24 dB, and $C/(I_{VSAT}+N)$ is reduced to ~ 8.8 dB.

3.3.4 NGSO Terminals into Next-Gen AG Aircraft

NGSO terminals on the ground can be seen by the aircraft flying within the NGSO terminal's footprint, a 300 km radius circle. The NGSO terminals are seen as potentially interfering signals from both the front of airplane's antenna and behind it through the backlobe gain. Overall, the average gain of the aircraft's antenna roll-off relative to peak amounts to approximately -7 dB from all azimuth directions covered by the 300 km radius footprint.

The 300 km radius airplane footprint covers about 4 NGSO spot beams. Since the NGSO system is assumed to have a frequency reuse of 3, each piece of spectrum is at most used twice by the NGSO system within the footprint of the aircraft. Further, the NGSO system design assumes that two NGSO satellites may provide coverage for the same area. In that case, each piece of spectrum may be used twice more by the two satellites resulting in a conservative increase in interference to aircraft on a given piece of spectrum of 6 dB.

The average path loss from NSGO terminals to the airplane, for the full 300 km radius footprint area, corresponds to 114 km from the aircraft. So the potential interference can be computed simply by assuming that all NGSO terminals are located at approximately 114 km from the aircraft. The NGSO terminals are not, based upon reasonable system design assumptions, served above 15° elevation; then the combined antenna roll-off of the NGSO terminal and aircraft antennas is at least -33 dB based on the antenna pattern of Type A antenna in Table A.7 and elevation roll-off of the aircraft antenna. (The harm case where an NGSO terminal points directly at an aircraft is separately analyzed below.)

Combining these factors, the link interference calculation uses 40 dBW EIRP for a reasonable high data rate NGSO system in a 5 MHz bandwidth, a path loss of 156.5 dB at 14 GHz to the aircraft from the average location of 114 km (as discussed above), an average off-axis combined elevation NGSO terminal/aircraft antenna roll-off -33 dB, a 6 dB increase from double spectrum usage plus two NGSO satellite beams on the ground, and the average azimuthal spatial gain of the aircraft's antenna off axis directivity of -7 dB relative to the main lobe G/T performance (-13 dB/K). *I/N* is calculated as shown in Table A.16.

NGSO Terminal EIRP per 5 MHz	40.00	dBW
Average Roll-off of Aircraft Antenna in Azimuth	-7.00	dB
Average Combined Elevation Roll-off of NGSO Terminal and Aircraft Antenna	-33.00	dB
Average Atmospheric (Oxygen and Water Vapor) Loss at Ku Band	-2.00	dB
Plane G/T	-13.00	dB/K
1/BW (BW = 5 MHz)	-66.99	-dB-Hz
1/Boltzmann	228.60	-dB/K-Hz
Path Loss (at Average NGSO Location of 114 km relative to Aircraft, at 14 GHz)	-156.50	dB
NGSO Satellite Circular and GS Linear, but NGSO Uses both Polarizations	0.00	dB
4 Reuses of 5 MHz Carrier in Aircraft Field of View	6.00	dB
I_{NGSO}/N at Aircraft Receiver	**-3.89**	**dB**

Table A.16. I/N at aircraft receiver from NGSO terminal transmitters

The $C/(I_{VSAT}+I_{NSGO}+N)$, where I_{VSAT} is interference from VSAT terminals and I_{NGSO} is interference from NGSO terminals may be computed as follows:

$$\frac{C}{I_{VSAT}+I_{NGSO}+N} = \frac{1}{\frac{I_{VSAT}}{C}+\frac{I_{NGSO}}{C}+\frac{N}{C}} = \frac{1}{\frac{I_{VSAT}}{C}+\frac{I_{NGSO}/N}{C/N}+\frac{N}{C}},$$

Where I_{VSAT}/C is given in Table A.15, I_{NGSO}/N is given in Table A.16 and C/N is given in Table A.1. Thus, $C/(I_{VSAT}+I_{NSGO}+N)$ is ~ 8.1 dB.

3.3.5 Direct Harm Cases, Probability of Occurrence

3.3.5.1 GEO Hubs into Next-Gen AG-Equipped Aircraft

While this potential interference source can be large enough to completely knock out the GS to aircraft link, it is short lived – on the order of seconds – because the aircraft flies quickly through the beam at altitude. Such interference may cause some packet retransmissions but it would hardly be noticed. Moreover, the probability of occurrence is quite low, less than 1/10,000th of 1% (9.3e-7).

Considering the 100 or so estimated GEO hubs with thin pencil beams radiating up from GEO hub stations, these pencil beams intersect a CONUS sized sheet at altitude of 10 km, and the aircraft would have a random chance of flying through the total area of intersection of these pencil beams within that elevated CONUS sheet. The aerial calculation reveals the total area from the pencil beams is 3 square miles (.03 square miles per hub) sprinkled throughout the total CONUS area of 3 million square miles. Hence the probability of GSO satellite interference turns out to be less than 1/10,000 of 1%. If the aircraft happens to run into a pencil beam, the maximum duration of harm may last as long as 3 seconds if the aircraft flies down an elongated elliptical intersection from a low elevation hub contact to GEO satellite, but the more likely duration is 0.8 seconds duration and the even more likely higher elevation intersection is 0.25 seconds – each of which can be handled by the Next-Gen AG system.

3.3.5.2 VSATs into Next-Gen AG Equipped Aircraft

As shown in Section 3.3.3, nominally VSATs only cause a general background drop in C/N to the aircraft on the order of 0.8 dB (*i.e.*, a small RoT effect), as long as the aircraft is not directly in the beam of a VSAT terminal. This was shown in the first analysis case for VSAT interference into aircraft. For the direct harm case where the aircraft antenna is directly within the VSAT beam boresight, the harm affects only a small fraction (1/50 for VSAT signal bandwidth of 1 MHz) of the bandwidth and may erase the symbols sent in that portion of the

band. Overall this is expected to be a small effect and is mitigated through interleaving of symbols over frequency tones and error correction coding. Given that this occurs in a beam diameter that is as much as 25 times the area of the GEO hub case, and with approximately 100 times as many transmitters as the GEO hub harm case, the probability that aircraft will fly directly into a VSAT beam is only a few tenths of one percent.

3.3.5.3 VSAT Hubs into Next-Gen AG-Equipped Aircraft

Considering that these terminals are smaller than GEO hubs and fewer in number than the VSAT terminals, the previous two analyses effectively encompass this case, and it is reasonable to conclude that VSAT hubs pose no harm case of interest for the interference into aircraft either.

3.3.5.4 NGSO Terminals Looking Directly into Next-Gen AG-Equipped Aircraft

NGSO terminals are assumed to transmit within a 5 MHz block of spectrum. If an NGSO terminal looks directly at the aircraft, it only knocks out 5 MHz out of the 50 MHz channel used by the GS to aircraft transmission. This represents an erasure of only 10% of the symbols being sent within the 50 MHz channel, which could be addressed through error correction coding and interleaving. If the NGSO terminals are allocated wider bandwidth, then the terminals will use the allocated bandwidth in a TDM fashion, and, at worst, some of the packets of Next-Gen-AG will be lost when the NGSO terminal antenna boresight points directly at the aircraft, which, as explained above, is a very low probability event.

3.3.5.5 NGSO Hubs into Next-Gen AG-Equipped Aircraft

While this is a more complicated case, the probability calculation demonstrates that it is an exceedingly low probability event that the Next-GEN AG system can easily tolerate.

This section shows the probability that the aircraft will receive an excessive amount of interference from the NGSO hubs is very small. The potential interference may be further mitigated by reassigning the aircraft to a piece of spectrum not used by the NGSO hub that is temporarily causing interference to the aircraft. Note that the NGSO system is presumed to divide the spectrum among the terminals of 3 adjacent satellite beams that operate on a frequency reuse of 3 basis and the hub that serves those 3 beams. Thus, the hub only uses a portion of the available spectrum. So, if the aircraft receives excessive interference on a given

piece of spectrum that it is using, the aircraft may be reassigned to receive signals on another piece of spectrum that the hub is not using. The GS does the frequency reassignment based on the aircraft's received SINR (Signal to Interference plus Noise Ratio) estimate. The aircraft sends the SINR estimates of the FL connections to the GS, and the GS will reassign the aircraft to a different piece of spectrum on the FL if the SINR falls below a certain threshold, *e.g.*, 0 dB.

NGSO hubs radiate enough power to produce interference when an aircraft flies through the pencil beam path between the NGSO hub and its target satellite. Although the number of hubs is much less dense over CONUS than their partner terminals, the NGSO model suggests that the hubs occasionally may interfere with the GS-to-plane link, but with a very low probability.

The NGSO candidate model assumes approximately 55 to 60 hubs spaced uniformly across the CONUS. That is a reasonable number of hubs to serve 3 spot beam areas (3:1 reuse scheme) out of approximately 150 to 160 beam areas covering CONUS by an NGSO satellite network. The aircraft with its 300 km radius field of view potentially sees up to 3 NGSO hubs simultaneously when equidistant from each of them at 211 km. The spacing between NGSO hubs is on the order of 365 km. At the equidistant location from the aircraft to 3 NGSO hubs, the elevation angle from the aircraft to the NGSO hubs is well below the hub pointing elevation angle of 15° above the horizon. Then, the off-axis roll-off of the NGSO hub antenna gain is high enough to avoid harm to the aircraft's receiver even if all three hubs were to point in the direction of the aircraft. Thus, this particular case produces no harm until the aircraft gets close enough to one of them (while further from the others) where because of the path loss adjustments from all three hubs and the elevation angles, only the NGSO hub closest to the aircraft could cause excessive interference to the aircraft's receiver. This scenario is covered further below.

At a 100 kilometer distance from the hub, the elevation angle from the aircraft to hub is 5.6° resulting in hub antenna off-axis angle of 15° - 5.6° = 9.4°. At this angle, the hub antenna rolls off by ~ 27 dB according to antenna type A of Table A.7. The I/N of the aircraft's receiver due to hub interference is given in Table A.17.

The calculations in Table A.17 assume 58.5 dBW EIRP for the NGSO hub as opposed to 62.5 dBW EIRP in Table A.6, because 4 dB of the power was allocated for rain fade. Because of the power control assumption in the NGSO hub, only 58.5 dBW of the EIRP is transmitted

during clear sky conditions. Since this calculation considers the case where hub antenna points at the aircraft, if there is rain fade, it also will impact the propagation from the hub to the aircraft. In other words, the increased hub EIRP to combat rain fade is attenuated by the same amount before it reaches the aircraft. Thus, only the hub EIRP needs to be considered in a clear sky condition as shown in Table A.17.

NGSO Hub EIRP	58.50	dBW
Plane Antenna Roll-off from Peak at 5.6° Below Horizon	-2.00	dB
NGSO Antenna Roll-off at 9.4°	-27.00	dB
Average Atmospheric Loss at Ku Band	-1.50	dB
Plane G/T	-13.00	dB/K
1/BW (BW = 100 MHz)	-80.00	-dB-Hz
1/Boltzmann	228.60	-dB/K-Hz
Path Loss (100 km from aircraft to NGSO Hub, at 14 GHz)	-155.40	dB
Polarization Discrimination (NGSO Satellite Circular and BTS Linear, But NGSO HUB Uses Both Polarizations)	0	dB
I/N at Aircraft Receiver	**8.2**	**dB**

Table A.17. I/N at the aircraft receiver from NGSO hub transmitters

Recall from Section 3.3.4 that the aggregate interference from NGSO and VSAT terminals reduces the 10.2 dB *C/N* dB of Table A.1 to ~ 8.1 dB. This leaves ~ 4 dB of margin to mitigate interference from NGSO hubs before the C/(I+N) falls below the 4 dB level needed to maintain a spectral efficiency of 1 bps/Hz. The probability of receiving interference from NGSO hubs described in Table A.17 is particularly low. In order to compute the probability of getting excessive interference from the hubs, Monte Carlo simulation is used to integrate the probability of impact as a function of distance from the hub. These simulations show that the probability of an airplane being impacted by hubs is less than 0.1%. In any case, as mentioned above, this effect can be mitigated by reassigning the impacted aircraft to a different piece of spectrum not used by the hub. Moreover, note that the interference seen from the NGSO hubs is only present for very limited amount of time. Thus, at most, one beam from the Next-Gen AG GSs located throughout the CONUS will need to use the additional available GS EIRP to mitigate the interference from a hub to an aircraft. Since the Next-Gen AG system will employ power control, the 4 dB margin provisioned for the NGSO hub only will be used when an aircraft is being interfered with by a hub. Since the probability of more than one aircraft requiring

additional power to mitigate interference form an NGSO hub is very small, even if 10 dB more power were allocated on 6 beams out of the total of 600 co-frequency beams to overcome the potential interference from an NGSO hub, the total power averaged over all beams would only increase by 0.4 dB. Therefore, even in the presence of an NGSO system, most of the 4 dB margin allocated to mitigate NGSO hubs could be used to compensate for other artifacts such as rain fade. As mentioned in Section 1.1, the total EIRP of the Next-Gen AG system over the CONUS from all 600 beams (4 beams per 150 GSs) is still kept below 67.3 dBW even while adjusting the power of different beams in response to interference or rain fade.

3.3.6 GS and Aircraft Interference into the TDRSS

The impact of the Next-Gen AG system upon the NASA Tracking and Data Relay Satellite System ("TDRSS") is covered in this section.

3.3.6.1 Aircraft to TDRSS Case

Consider first the WSC site whose location and antenna characteristics were described in Section 3.1.2. To compute the nominal upper limit power that a TDRSS site might capture at its antenna output, the azimuth space of the TDRSS site is divided into 4 quadrants, one of which is forward, toward its main beam receive direction (WSW or ESE directions) and the other 3 quadrants are off to the side or behind the antenna at the backlobe gain levels. Three quadrants are beyond ± 45° off-axis from the TDRSS pencil beam. According to the TDRSS antenna characteristic provided in Section 3.1.2, the TDRSS beam antenna gain is less than -9.3 dB at ±45° from boresight. For aircraft in that space, the average off-axis reduction from the aircraft's antenna gain averages about -7 dB or less. Because there may be 4 beams on the same frequency at each site, and the aircraft use 3 dBW on 2 MHz of bandwidth, there may be as many as 700 aircraft transmissions at 3 dBW on 350 MHz of spectrum. If there are two systems deployed then the aircraft combined power on 350 MHz must meet the 350 aircraft limit, with each system supporting the number of aircraft in proportion to its share of the 350 MHz spectrum where TDRSS limits are specified.

Plane EIRP	3.00	dBW
Average aircraft Antenna Roll-off	-7.00	dB
TDRSS Off-Axis Antenna Gain (±45° from Peak)	-9.30	dB
Atmospheric Loss at Ku Band	0	dB
Number of Aircraft in Three Quadrant (525)	27.20	dB
Path Loss (average 114 km from Aircraft to TDRSS Site, at 14 GHz)	-156.70	dB
Total Received Power by TDRSS Receiver from Aircraft in the Three Off-Axis Quadrants	**-142.80**	**dBW**

Table A.18. Power received by TDRSS from aircraft in the three quadrants off of main beam of TDRSS, but outside the 0.1° boresight

For aircraft in the forward quadrant, the off-axis gain is a mix between the full backlobe (for aircraft further south in that quadrant) and 45° to 90° off-axis for aircraft further east or west of the TDRSS site depending on which direction the TDRSS is pointed. The overall azimuthal off-axis aircraft antenna gain is -15 dB behind the aircraft antenna as described in Section 1.1. There also is at least 2 dB of roll-off in elevation. The azimuthal plus elevation antenna roll-off behind the aircraft is at least -17 dB. Given the TDRSS antenna characteristics described in Section 3.1.2, the average TDRSS antenna gain in the forward quadrant outside of 0.1° beamwidth is about 27.7 dBi. Thus, while the forward quadrant produces a much higher interference input, per Table A.19 below, it is still substantially below the required threshold.

Plane EIRP	3.00	dBW
Plane Off-Axis Gain (Front to Back) Roll-off	-17.00	dB
TDRSS Antenna Gain at 0.1° from Peak	27.70	dB
Atmospheric Loss at Ku Band	0	dB
Number of Aircraft in Forward Quadrant (175)	22.43	dB
Path Loss (average 114 km from Aircraft to TDRSS Site, at 14 GHz)	-156.70	dB
Total Received Power by TDRSS Receiver from Aircraft in the Front Quadrant	**-120.57**	**dBW**

Table A.19. Power received by TDRSS from aircraft in the forward quadrant of space in front of TDRSS beam, but outside the 0.1° boresight

The total power from all quadrants is ~ -120 dBW – well below the -100 dBW threshold specified in Table A.4 for the 14.05 to 15 GHz band. Note that if this power is spread over the

350 MHz band than per MHz, the limit specified for the 14 to 14.05 MHz band of -146 dBW/MHz can be met.

The above cases for the average distribution computation are all outside 0.1° of the main lobe of the TDRSS antenna. For the case of an aircraft inside the pencil beam, which has a closest possible distance of about 22 km when the WSC site points to its highest elevation angle direction, is a space that is approximately equal to the dimensions of an aircraft, that is, a ~ 70 m wide pencil at 22 km. The other WSC azimuth directions have lower elevations and therefore further distances to the aircraft. The probability of the aircraft appearing within the pencil beam (half-angle = 0.1°) is very small, approximately 1.5e-6, and the aircraft would be in the beam for about 0.25 seconds at nominal cruising speed. Table A.20 shows the power received by TDRSS site from an aircraft in its pencil beam.

Plane EIRP	3.00	dBW
Plane Off-Axis Gain (Front to Back) Azimuth Plus Elevation Roll-off	-30.00	dB
TDRSS Peak Antenna Gain	66.40	dB
Atmospheric Loss at Ku Band	0	dB
Number of aircraft in Forward Quadrant	0.00	dB
Path Loss (Plane 22 km from TDRSS Site 14 GHz)	-142.40	dB
Received Power by TDRSS Receiver from an aircraft in the Boresight of TDRSS Beam	**-103.00**	**dBW**

Table A.20. Power received by boresight of TDRSS beam from a close aircraft

Therefore, the Next-Gen AG system will avoid operating at 14 to 14.05 GHz in the very small area around the TDRSS sites. Outside this area, all the spectrum in the 14.0 to 14.5 GHz band can be used while meeting the limits set out in Table A.4 above.

3.3.6.2 GS to TDRSS Case

The following discussion focuses on the location of Next-Gen AG GS that is close to the WSC TDRSS site location. Since the BP site in Maryland has 15 dB less protection requirement at -85 dBW total power rather than the -100 dBW level required at WSC, if the conditions at WSC are satisfied, then it will be easier to meet the less stringent conditions at BP using the same Next-Gen AG site location strategy. While there is one GEO-arc location for BP that is nearly

due south of that site (79° West GEO-arc position), an advantageous GS location can be employed to ensure significant off-axis reduction in gain to the TDRSS antenna to easily handle that one rare case. Furthermore, all of the other pointing directions from the BP site to TDRSS satellites are out over the Atlantic making it easy to position the GS sites for the service areas in the Maryland area in a manner that avoids exceeding the power density requirements for the BP site.

The GS site near the WSC TDRSS location must be chosen so that the GS beam received power at the TDRSS antenna output does not exceed -100 dBW total power in 350 MHz and is below -146 dBW/MHz power density in the lowest 50 MHz of the 14 GHz spectrum. This can be accomplished easily for separation distances of 40 km or more. Because the WSC location is likely to be at least 70 km due north of Next-Gen AG system GS locations on the southern border of New Mexico (near El Paso TX), it is likely that the protection level from the GS will be at least 10 to 20 dB better than what is shown in the accompanying computation of Table A.21 below, which assumes only 40 km of separation. Not only is there increased path loss of 5 dB at 70 km distance, but there also is likely to be shadowing losses from the terrain in between the two locations.

The most disadvantaged location for the GS is ESE (60° away in azimuth) or WSW (300° away in azimuth) relative to the WSC location. At these azimuth angles, the off axis antenna roll-off of the TDRSS is the least with respect to the GS location. To meet the power limits, the GS is located such that the azimuth angles to the TDRSS location is within 55° to 295°. At these locations, the GS antenna would have -2 dB roll-off at 0° elevation relative to its peak at 1°. Moreover, the GS antenna has an azimuthal scan loss of ~ -4.75 dB at ~ 60°, both east and west of due north. Thus, the GS antenna discrimination relative to the TDRSS sites at WNW or ENE is ~ -6.75 dB. The lowest angle from the TDRSS beam to the Next-Gen AG GS is 24°. At 24° off boresight, the TDRSS antenna gain is ~ -2 dB.

Because 45.5 dBW of power is allocated to 50 MHz of spectrum on the FL in the baseline system, an increase in power to cover 350 MHz, 5.4 dB (relative to 50 MHz power level) is included if the GS puts all of its capability into one beam. In this case, the total received power by TDRSS in 350 MHz is calculated by Table A.21.

GS EIRP on 4 Beams in 50 MHz	45.50	dBW
GS Antenna Roll-off (azimuth angle from BTS to TDRSS 55°)	-6.75	dB
TDRSS Antenna Gain at 24° off Boresight	-2.00	dB
Atmospheric Loss at Ku Band	0.00	dB
Power in 350 MHz vs. 50 MHz	8.45	dB
Path Loss, BTS to TDRSS Distance of 40 km, at 14 GHz)	-147.40	dB
Received Power by TDRSS Receiver from an Aircraft in the Boresight of TDRSS Beam	**-102.20**	**dBW**

Table A.21. Received power by TDRSS receiver from GS

If the Next-Gen AG GS is directly south of the TDRSS site, then the off-axis gain of the WSC antenna drops to the backlobe level (-10 dBi), in combination with no scan loss from the GS, providing ~ 1 dB more protection than that shown in the Table A.21 computation. Note that Table A.21 depicts an extreme case since it is much more likely that the total power would be split between four beam directions, reducing the total interference in the example computed by 6 dB. In addition, the computation does not assume any shadowing effect from the mountain range terrain that is close to the WSC location. The directional relationship between GS and WSC could be such that these mountains would likely provide 10, 20, or 30 dB or more protection from the GS radiation beams coming from the south on account of a shadowing effect. Table A.21 also assumes free space path loss between the GS site and the TDRSS site which is particularly conservative. Thus, given the most likely desired GS locations, nearby El Paso Texas, the GS power levels will be well below the power requirement level of -100 dBW.

Although the total power level of -100 dBW is met, the power density requirement would not be met if the GS were to operate at 14.0 to 14.05 GHz with the above conservative power approach. At 14.0 to 14.05 GHz, where the power density must not exceed -146 dBW/MHz, the above computed power (for 50 MHz) is equivalent to 18.4 dB more than allowed. Given that terrain shadowing and a distance of 70 km rather than 40 km likely will be in play, the power density will be below -146 dBW/MHz. Even if shadowing and path loss reductions were not available, the GS could simply restrict use of that lower portion of the spectrum for the single narrow beam that points toward WSC and still be able to use that spectrum for all the other beam directions.

3.3.7 Radio Astronomy

Protection of the Radio Astronomy Service in the U.S. will be in accordance with US203 and US342 of 47 C.F.R. § 2.106. The 30 MHz band from 14.47 to 15.0 GHz will not be used in an exclusion zone around the Radio Astronomy ("RA") sites when radio astronomy systems are operating. The exclusion zone needed between GSs and RA sites will depend on the terrain and propagation characteristics near each site and will be determined during Next-Gen AG system deployment. Next-Gen AG aircraft, however, will most likely have a free space propagation toward the RA sites and will need an exclusion zone of as much as 500 km from the RA sites.

4. Conclusion

The foregoing analysis considered all potential interference conditions from/to the proposed Next-Gen AG system to/from all services that operate (or, may operate) in the 14.0 to 14.5 GHz band. The analysis shows that the Next-Gen AG system will present an RoT ($\Delta T/T$) of less than 1% (in fact, less than 0.5% for the parameters set forth above) into the GSO satellite uplink. Note that since the aircraft and GSs transmit in a TDD (Time Division Duplex) fashion, at any given instant of time on a given GS-aircraft link, only the GS or the aircraft will be transmitting; thus, the RoT into the satellite uplink is not the sum of all aircraft and GS transmissions but rather the sum of only those GSs and aircraft that are transmitting at a given instant of time.

For the NGSO systems, an RoT of 6% was used because NGSO systems do not exist in Ku band today, and they can be designed in the future to cope with 6% RoT that existing systems are required to meet. Nonetheless, even in this case, baseline system assumptions of the Next Gen AG system led to an RoT below 1% from Next-Gen AG-equipped aircraft into NGSO system and below 1% from Next-Gen AG GS to NGSO satellites.

It also was shown that the proposed system will protect NASA's TDRSS service and meet the interference thresholds that NASA has required in similar circumstances. It may be necessary to restrict GSs from using the 14.0 to 14.05 GHz band in small areas or in particular directions near the three TDRSS sites, but it will not materially impact the Next-Gen AG system performance.

Potential interference from GSO satellite terminals and potential future NGSO systems into the Next-Gen AG system were examined too. The proposed system design copes well with these sources of interference while supporting a combined throughput of 300 Gb/s over the CONUS.

Appendix B

Proposed Next-Generation Air-Ground Service Rules

Title 47 of the U.S. Code of Federal Regulations shall be amended by adding the following rules.

Section 2.106, the Table of Frequency Allocations, is amended by adding a mobile allocation as secondary within the 14.0 to 14.5 GHz band for the Next Generation Air-Ground mobile broadband communications service.

§ __.___. Definitions Associated With Next-Gen Air Ground Service.

Next-Gen Air-Ground Service. A next-generation mobile broadband communications service that operates in the 14.0 to 14.5 GHz band and provides high-data-rate connectivity between terrestrial Ground Stations and aircraft flying above the Continental United States ("CONUS").

Next-Gen Air-Ground Equipped Aircraft. Aircraft equipped with Next-Gen Air-Ground Service mobile broadband communications technology.

Ground Stations. Fixed terrestrial-based communications stations that provide Next-Gen Air-Ground Service to Next-Gen Air-Ground Equipped Aircraft.

§ __.___. Next-Gen Air Ground System Protection of GSO Satellites. The aggregate Rise over Thermal ($\Delta T/T$) from all Next-Gen Air-Ground-Equipped Aircraft and Ground Stations into the uplink of GSO satellites shall not exceed 1%. This 1% $\Delta T/T$ limit may be met by complying with subsection (a) and (b) below:

a) For a baseline Next-Gen Air-Ground system consisting of 600 beams (*e.g.,* 150 Ground Station sites and 4 beams per site) operating on a given band of spectrum, the transmit power spectral density from a single Ground Station beam into the GEO-arc must be less than -74.5 dBW/Hz. If the number of Ground Station beams is increased beyond 600 or reduced below 600, then the total transmit power toward the GEO-arc must be adjusted accordingly, such that the total transmit power toward the GEO-arc from all beams is not greater than -46.7 dBW/Hz. The Next-Gen Air-Ground system may allocate different amounts of power to different Ground Stations for communications with Next-Gen Air-Ground Equipped Aircraft, so long as the sum of the emissions into the GEO-arc does not exceed -46.7 dBW/Hz. Furthermore, the transmit power from any one beam into the GEO-arc shall not exceed -68.5 dBW/Hz.

b) Where the Continental United States ("CONUS") coverage area is divided into bins of 2.5° latitude and 5° longitude, which results in 89 bins, the Next-Gen Air-Ground Equipped aircraft emission into the GEO-arc shall be limited in accordance with Equation (1) below:

$$\left(\frac{N_b P}{89B \times 10^6}\sum_{i=1}^{89}\overline{g_i(\theta,\varphi)}\right)_{dB} \leq -47\ dBW/Hz, \qquad (1)$$

where $\overline{g_i(\theta,\varphi)}$ is the average aircraft roll-off toward the GSO satellite for the i-th bin whose elevation angle toward the satellite is θ, whose median azimuth angle toward the satellite is φ, where N_b is the number of Ground Station beams over the CONUS, B is channel bandwidth in MHz, and P is the peak EIRP of the aircraft transmitter averaged over all GSs, *i.e.*,

$$P = \frac{\sum_{i=1}^{N_{GS}} P_i}{N_{GS}} \qquad (2)$$

where P_i is the allowed peak aircraft EIRP of the i-th GS, and N_{GS} is the number of GSs, P_i may not exceed P by more than 6 dB. The azimuth angle of a bin is defined as the angle between the line connecting the Next-Gen Air-Ground Equipped Aircraft antenna to the GSO satellite and the line connecting the aircraft antenna to the Ground Station antenna serving that aircraft. In computing Equation (1) above, the aircraft cruise level roll of ±5° in elevation must be taken into account. By way of example, the condition in Equation (1) is met assuming aircraft transmitter peak EIRP of 3 W, channel bandwidth of 2 MHz, 600 beams over the CONUS, and average antenna roll-off over the CONUS toward the satellite of -15 dB. Note that the condition in Equation (1) does not explicitly assume an aircraft transmitter peak EIRP of 3 W and in this way allows the Next-Gen Air-Ground system operator to adjust the antenna and its associated EIRP so long as each of the other requirements in this Rule Part and the condition in Equation (1) are met.

§ __.___. Out of Band Emissions (OOBE) Requirement For Two Separate Next-Generation Air-Ground Systems. If two separate licensees deploy Next-Gen Air Ground systems within distinct portions of the 14.0 to 14.5 GHz band, the power level of any emission outside a Next-Gen Air-Ground licensee's frequency band of operation shall be attenuated below

the transmitter power of P watts (with averaging performed only during periods of transmission) within the licensee's band of operation by at least 43 + 10 log (P) dB. Compliance with this rule shall be measured via use of instrumentation employing a resolution bandwidth of 1 MHz or greater, except that in the 1 MHz bands immediately adjacent to the licensee's frequency band of operation, a resolution bandwidth of at least 1 percent of the emission bandwidth of the fundamental emission of the transmitter may be employed. A narrower resolution bandwidth is permitted in all cases to improve measurement accuracy provided the measured power is integrated over the full required measurement bandwidth (that is, 1 MHz or 1 percent of the emission bandwidth, as specified). The emission bandwidth is defined as the width of the signal between two points, one below the carrier center frequency and one above the carrier center frequency, outside of which all emissions are attenuated by at least 26 dB below the transmit power level.