BACKGROUND PAPER

ON

USE OF A 1-dB DECREASE IN $C/N_0$ AS GPS INTERFERENCE PROTECTION CRITERION

1. **Purpose:** This paper provides extensive background regarding the use of the 1 dB decrease in the carrier-to-noise density ratio ($C/N_0$) as the appropriate interference protection criterion (IPC) for GPS and other Radionavigation Satellite Service (RNSS) receivers. The use of the 1 dB IPC has significant domestic and international precedence, is consistent with the protection afforded other radiocommunication services, and is the only reliable mechanism to ensure adequate protection for civilian and military GPS receivers. The 1 dB IPC is consistent with the National Space Policy for managing and sustaining the RF environment in which these systems operate.

2. **Explanation of Parameters:** A brief explanation of the relationship between a (post-correlation) 1 dB drop in C/N[1] and an interference to noise ratio (I/N) of – 6 dB is shown below. This relationship is pivotal to the references throughout this paper.

**Relationship of 1 dB C/N Degradation to I/N = -6 dB**

C = Carrier (Signal) Power
N = Power of Existing Noise Floor
C/N determines if signal is useful

Pre-Interference: C/N
Post-Interference: C/(N+I)
I = Power of Interference

$$\text{Degradation of C/N} = \frac{\text{Pre-interference C/N}}{\text{Post-interference C/N}} = \frac{C/N}{C/(N+I)} = \frac{N+I}{N} = 1 + \frac{I}{N} = \frac{\text{New noise}}{\text{Old noise}}$$

$\frac{I}{N}$ = Change in the Noise Floor due to the New Interference, I, relative to previous Noise Floor, N

Sample Calculation:

$$\frac{(N+I)}{N} = 1.26, \quad \frac{I}{N} = 0.26$$

$$\frac{(N+I)}{N}\ \text{(dB)} = 10\times\log(1.26) = 1\ \text{dB C/N degradation}$$

$$\frac{I}{N} = \text{(dB)} = 10\times\log(0.26) = -5.9\ \text{dB}$$

[1] Note that the difference between noise density (noise in a 1 Hz bandwidth or $N_0$) and noise in a reference bandwidth (N) is immaterial as long as the bandwidth for the noise and interference source is the same throughout the calculation.

**3. Harmful Interference versus IPC**

a. Longstanding U.S. policy, domestic and international, has been to not ascribe any values that would quantify *harmful interference*.

i. There are numerous reasons for this policy, among them being that by the time a harmful level of interference is experienced, the victim radio system is already degraded beyond normal function.

ii. In addition, the concept of *harmful interference* serves as a regulatory method to raise a concern with respect to a new service signal having a severe impact on an existing service. This is apparent from the formal definition of *harmful interference* found in the International Telecommunication Union's Radio Regulations and Constitution, which is duplicated in U.S. domestic rules (NTIA Redbook and FCC rules):

> **1.169** *harmful interference: Interference* which endangers the functioning of a *radionavigation service* or of other *safety services* or seriously degrades, obstructs, or repeatedly interrupts a *radiocommunication service* operating in accordance with Radio Regulations.

b. An interference protection criterion, on the other hand, is developed to ensure that a *harmful interference* level is prevented in the first place, so that systems operating in the same or adjacent bands do not interfere with one another.

i. Regulators should avoid the use of harmful interference levels. The appropriate measure of one radio service's impact on another is not exceeding the interference protection criterion established for the victim service, which is normally based on management of the noise environment in which the receiver operates.

ii. In this regard, the efforts of the FCC's Technological Advisory Council (TAC) to develop "harm claim thresholds" that would attempt to quantify *harmful interference* levels for different radiocommunication services, is inappropriate for GPS or RNSS receivers and is an effort which contravenes longstanding U.S. domestic and international policy, precedent, and practice.

**4. Domestic and International Precedence**

a. The use of a 1 dB decrease in carrier-to-noise density ($C/N_0$) has a long and well-established history in both the domestic and international regulatory arenas as the appropriate IPC for GPS receivers[2].

[2]As an exception, certified aviation receivers, which enable safety applications, utilize an overall interference mask that these receivers must be able to tolerate and still meet all applicable performance requirements. ITU-R M.1903 recommends that the interference environment that such equipment is exposed to is controlled so as to preserve a 6-

i. In the 2003 timeframe, the 1 dB decrease in $C/N_0$ was employed as the IPC for GPS receivers in the FCC's Rulemaking on Ultra-Wideband (UWB) devices. In that proceeding, the FCC interference criterion used in developing emission limits for UWB systems was based on a total rise in the noise floor of the GPS receiver of 1 dB (which has the same effect as decreasing $C/N_0$ by 1 dB)[3].

ii. In 2004, the same criterion of a 1 dB rise in the noise floor was used in developing the FCC's rules for limiting emissions of Low Power Television (LPTV) stations into the GPS band[4].

iii. The NTIA, in its comments to the FCC on the MSS Ancillary Terrestrial Component (ATC) proceeding, used the 1 dB increase in the GPS receiver noise floor, and the equivalent I/N metric of -6 dB as the appropriate measure of interference susceptibility for GPS receivers and establishing out-of-band emission limits for ATC base station and user equipment transmitters[5].

iv. On September 9, 2011, the NTIA's Administrator directed the Space-Based PNT Executive Committee to test LightSquared's modified proposal strictly according to the NTIA standards and methodologies, including, and in particular, a 1 dB maximum allowable degradation in $C/N_0$ for general location and navigation and cellular GPS receivers. This IPC was also referenced in the February 14, 2012 letter from the NTIA to the FCC on the results for general location and navigation and cellular GPS receivers of the Space-Based PNT EXCOM testing.

b. The 1-dB decrease in $C/N_0$ IPC is also used extensively in the international spectrum management arenas such as the International Telecommunications Union (ITU).

i. For example, the IPC of a 1 dB rise in the noise floor of radiocommunication services is well established and universally accepted for a wide array of radiocommunication service (e.g., GPS and other GNSS systems, radars, satellite systems, etc.). This is equivalent to an interference-to-noise ration (I/N) of -6 dB, and a 1 dB increase in noise,

---

dB safety margin from the mask levels. Certified aviation receivers are tested against their key performance requirements in the presence of radio frequency interference at the mask values in lieu of utilizing the simpler 1-dB *$C/N_0$* degradation.

[3] Reference FCC proceeding 98-153. For example, the FCC, in Paragraph 12 of the February 13, 2003 Memorandum Opinion and Order on UWB states: "The emission limits established for UWB operation were based on a 1 dB increase in the noise floor of the GPS receiver…" It is noted that *initially* the FCC proposed an I/N of -3 dB as the appropriate criterion, but this was revised to -6 dB and the equivalent 1-dB increase in the GPS receiver noise floor. ITU-R Recommendation SM.1757 reflected the original FCC-proposed protection criteria of - 3 dB I/N; however other RNSS systems, such as the European Galileo system, used an I/N of -20 dB for safety services and an I/N of -6 dB for non-safety applications.

[4] The FCC used the analysis and recommendations submitted by the NTIA on August 27, 2004 in docket 03-185. Page A-7 of the NTIA submission specifically refers to the I/N criterion of -6 dB used in the NTIA analysis to develop the LPTV filtering required, which the FCC adopted.

[5] Reference the NTIA Comments (Page 5 of the attachment) to the FCC on the MSS ATC proceeding (01-185) dated November 12, 2002 and received at the FCC on February 10, 2003.

which again equates to a 1 dB decrease in the $C/N_0$ ratio[6].

ii. Likewise, the ITU-R Recommendations for the radionavigation-satellite service (RNSS), which GPS operates in, use this same IPC to establish the maximum acceptable interference power level and specify that this is an *aggregate* value, taking into account the total interference power at the antenna output of an RNSS receiver due to all interfering sources other than those in the RNSS.

c. So there is significant precedence, both domestically and internationally, for using a 1 dB decrease in $C/N_0$ as the appropriate IPC to protect GPS and many other types of RNSS receivers. In particular, the recommended IPC for GPS and other RNSS receivers is a 1 dB decrease in $C/N_0$ and this is the IPC that should not be exceeded for the total interference power due to the aggregate emissions from all non-RNSS interfering sources (in–band, adjacent band and out-of-band).

## 5. GPS Use Consistent with Other Radio Services Use of the 1-dB Interference Protection Criteria

a. Allowing a 1 dB decrease in $C/N_0$ due to the aggregate interference from all non-RNSS sources equates to limiting the aggregate interfering signal power to 6 dB below the noise level of the GPS receiver. This also equals a 25% increase in the noise level of the GPS receiver, commonly referred to as $\Delta T/T$ in commercial and government satellite coordination circles.

i. This level for an IPC is consistent with that of other radio services. Not only has this measure been widely used in RNSS ITU-R Recommendations, it is used for radar, fixed and mobile services, and radio altimeters. See Appendix 1.

ii. The use of an I/N of -6 dB criterion has gained widespread acceptance in the ITU-R Study Groups as the appropriate interference protection criteria for numerous radio services.

iii. Appendix 1 shows a listing of some of the numerous ITU-R Recommendations (in numerical order) using the 1 dB $C/N_0$ or, equivalently, an I/N of –6 dB as the appropriate IPC.

iv. This IPC was proposed and supported in many cases through inputs from the U.S. that were agreed in the National Committee process and therefore, fully vetted by the federal agencies, the FCC, and all interested private sector entities.

[6] While this I/N value equates numerically to -6dB, this parameter is unrelated to the aeronautical safety margin mentioned in Annex 1 to Recommendation ITU-R M.1903.

v. Management of the noise floor through use of the 1 dB decrease in $C/N_0$ for receivers for a wide variety of radio services has been fundamental to ensuring that systems in the same or adjacent bands can be operated without degrading the RF environment for important satellite and terrestrial services. This ensures, among other things, that there is sufficient operating margin for commercial systems, safety margins for safety related applications, and jamming margins for military systems and provides a stable regulatory environment in which technological advancements can occur for these services.

vi. Management of the noise floor also accounts for degradations due to emissions from other in band or adjacent band radio services which, in the case of GPS, have included emissions from LPTV, UWB, and others as noted previously in this paper, each of which were afforded no more than the 1 dB allowance.

vii. For reception of weak signals, such as satellite downlinks (e.g., GPS) and radar receivers, management of the noise floor is the only practical means of ensuring the RF receive environment is sustained.

**6. Impracticality of Alternatives to the 1-dB IPC**

a. Other measures of interference, such as loss of signal lock for the receiver, or degradation of pseudo-range or position accuracy, would use as a basis for the metric an interference level that erodes the overall spectrum environment for GPS and/or causes disruption of the GPS receiver (i.e., *harmful interference*).

i. It should also be noted that the use of the 1-dB IPC not only avoids *harmful interference* to GPS receivers, it also, consistent with U.S. National Space Policy[7], sustains the overall radiofrequency environment in which critical U.S. space systems, such as GPS, operate.

ii. Evaluation of compatibility based on an interference level that produces undesired effects in the receiver, such as "break lock", would require evaluating all receiver types currently in use, using multiple receiver modes (acquisition, tracking, etc.), in various test cases and quantifying every possible interference source in terms of potential impacts to each receiver. This would be an enormous and impractical undertaking and is one reason why an IPC that protects the entire the service (e.g., GPS or GNSS), rather than individual receivers, is used for evaluating compatibility between radio services or applications.

[7] *see* National Space Policy, June 28, 2010, Radiofrequency Spectrum and Interference Protection.

iii. Another difficulty associated with use of an accuracy metric for an IPC is that the accuracy requirements for different applications of RNSS, and different types of RNSS receivers, differ vastly.

iv. Further, for some applications the receiver output of primary importance may not be position but rather velocity, acceleration, time, frequency, attitude, heading, or other parameters (e.g., atmospheric delay, reflected signal strength). Thus, degradation of accuracy is not a practicable interference metric for general use.

v. There does not exist one "accuracy degradation limit" that could be applied to all RNSS applications and types of receivers. Therefore, a measure for the degradation of the received RNSS signal quality such as $I/N_0$ is the most appropriate metric for an RNSS IPC.

vi. Interference masks are commonly used for certified aviation receivers. Such equipment is certified to meet all applicable performance requirements in the presence of interference at levels at or below the mask level. However, certified aviation interference masks are not extendible for other receiver types for the reasons presented above.

**7. Adjacent Band Interference Allowance**

a. While most of this paper has focused on interference caused by emissions falling into the RNSS band, which has widely been agreed should cause no more than a 1 dB rise in the RNSS receiver noise floor, some discussion is necessary to address other interference mechanisms arising from the operation of high power adjacent band services that could overwhelm the reception of the RNSS signals.

It is noted that some have asserted (or implied) that the receiver must bear nearly full responsibility for rejecting adjacent band interference. This challenge for the receiver builder would probably not be unreasonable if it weren't for the exceptionally large difference in power levels between the desired RNSS signal and potential interferers in the adjacent band. Moreover, Section 25.255 of the FCC's rules[8], which was established in a fully-vetted rulemaking, clearly places the burden of mitigating and resolving harmful interference to in- band and adjacent band services on the MSS ATC operator, so shifting the burden to receiver manufacturers is not consistent with the FCC's rules.

[8] §25.255 Procedures for resolving harmful interference related to operation of ancillary terrestrial components operating in the 1.5/1.6 GHz and 1.6/2.4 GHz bands.

If harmful interference is caused to other services by ancillary MSS ATC operations, either from ATC base stations or mobile terminals, the MSS ATC operator must resolve any such interference. If the MSS ATC operator claims to have resolved the interference and other operators claim that interference has not been resolved, then the parties to the dispute may petition the Commission for a resolution of their claims.

[68 FR 33653, June 5, 2003, as amended at 78 FR 8267, Feb. 5, 2013]

It is understood that, while receiver designs in general do strive to reject undesired (e.g., adjacent-band) signals as much as practicable, there are practical limits to what can be done with reasonably implementable technology, given cost, size, weight, and performance requirements. Thus, frequency allocations have historically been made to organize services in such a way as to maximize the sharing potential of systems having similar (homogeneous) parameters. For instance, the nominal received level of GPS satellite emissions on the ground is on the order of -158.5 dBW[9]. Similarly, the emissions received from a mobile-satellite service (MSS) downlink, allocated to the lower-adjacent frequency band, may be expected to range from about -150 to -127 dBW, depending on emission bandwidth and terminal type. On the other hand, the emissions from just one terrestrial broadband base station, located 1 km away, would result in -64 dBW at the input to the adjacent-band GPS receiver (assuming 32 dBW EIRP as proposed for adjacent band operator, mainbeam antenna gain, and no cable losses). Thus, the power discontinuity between desired GPS emissions and undesired emissions of an adjacent terrestrial base station would be on the order of 90 dB (i.e., a power difference of 1 billion times). This is in stark contrast to the relatively benign (and manageable) power difference (up to approximately 20 dB) that may be experienced with MSS operations appropriate to the allocation in the adjacent band.

As testing and analyses have shown, this large difference is greater than what can be accommodated by many GPS receivers presently in use. Moreover, tests comparing the adjacent band rejection performance of selected GPS and consumer electronics receivers have indicated that the GPS receivers reject adjacent band signals at least as well as the consumer receivers tested[10].

Evidence that regulators recognized the difficulties that could arise from implementing diverse services in adjacent bands can be seen with Radio Regulation 4.7, which reads: "The frequency assigned to a station of a given service shall be separated from the limits of the band allocated to this service in such a way that, taking account of the frequency band assigned to a station, no harmful interference is caused to services to which frequency bands immediately adjoining are allocated."

[9] Minimum signal level specified in [IS-GPS-200H], paragraph 3.3.1.6, measured at the output of a 3 dBi linearly polarized user antenna, for the C/A component of the L1 channel.

[10] See Mikhail B. Tadjikov, Esteban L. Valles, and Alan Choy, "Adjacent-Band Interference to Consumer Radio Receivers," The Aerospace Corporation, Report No. TOR-2013-00046, May 7, 2013.

Further, while the Presidential Executive Memorandum of June 14, 2013 the Middle Class Tax Relief and Jobs Creation Act of 2012 encouraged FCC and others, including manufacturers, to develop standards or others measures such that "reasonable use of adjacent bands" would not endanger the functioning of a receiver, the term "reasonable" is left undefined. However, a power differential of the magnitude discussed in this section, such as would be created by the introduction of high power terrestrial systems in bands adjacent to sensitive space service reception spectrum, could not rationally be considered "reasonable".

b. There is sufficient basis to apply the 1-dB C/N degradation limit to RNSS performance resulting from *all interference mechanisms* imposed by the adjacent band interference.

i. As a practical matter, the effects of such an interference source on the RNSS receiver must be kept at least as low as the effects caused by emissions falling in the RNSS bands or the existing criteria used for protecting the noise floor is effectively invalidated and rendered useless.

ii. Moreover, precedent in existing ITU-R recommendations (e.g., F.1094, F.758, S.1432, and SA.1743) has allowed significantly less interference from adjacent band services. In the case of satellite reception as noted in recommendation ITU-R S.1432, an interference budget is established to manage interference contributions from various sources. In that recommendation, the maximum interference allotted to all sources of interference in adjacent bands is 1% of the total system noise power. The 1% allotment referenced in that recommendation is understood to be the contribution from all sources of interference from systems operating outside the band of interest. If this limit were to be applied to the case of the RNSS, it would be significantly lower than the 1 dB CNR degradation (which is equivalent to I/N of 25%).

iii. Thus, when considering application of an interference budgeting process for the RNSS (comparable to that indicated above), contributions from various sources would need to be accounted for (i.e., co-network interference, other RNSS networks, other systems in the band, and interference from other systems outside the allocation.) It is this latter component where the 1 dB $C/N_0$ degradation is being applied as the criterion for developing the interference threshold masks in DOT's Adjacent Band Compatibility Assessment. Clearly, this generous interference allotment must include not only unwanted emissions but also the degradation resulting from other mechanisms caused by the strong adjacent signal.

c. It is also worth noting the use of the word "environment" in the National Space Policy, which mandates that the United States "…take necessary measures to sustain the radiofrequency environment in which critical U.S. space systems operate." It can be assumed that the use of this word was intentional and that the operating environment for space systems warrants particular care so that reception of weak signals is not impaired.

## 8. Conclusion

a. The 1 dB interference protection criterion is the only appropriate IPC for protecting GPS and other GNSS receivers.

i. It has been extensively and successfully used to regulate the use of spectrum, both domestically and internationally, by effectively managing the RF noise floor for a variety of radiocommunication services and is consistent with National Space Policy, which mandates that the United States "…take necessary measures to sustain the radiofrequency environment in which critical U.S. space systems operate."

ii. There are not any viable IPC alternatives for GPS and RNSS receivers that protect GPS and RNSS reception and effectively manage the RF environment in which these receivers operate.

b. Therefore, the well-established maximum allowable 1 dB decrease in $C/N_0$ protection criterion due to the aggregate interference from all non-RNSS sources should continue to be used as the IPC reference for measurements and analyses conducted in connection with GPS and RNSS receivers.

## Appendix 1

### Listing of some ITU-R Recommendations using the 1-dB IPC

| ITU-R Recommendation | Service to be Protected | Protection Criterion Statement |
|---|---|---|
| ITU-R M.1460-1 (Yr. 2006) | Radars in 2900-3100 MHz | "*recommends*…3) that an *I*/*N* ratio of -6 dB should be used as the required protection level." |
| ITU-R M.1461-1 (Yr. 2003) | Radars for Radiodetermination Service and other Services | "In general cases, a signal from another service resulting in an *I*/*N* ratio below –6 dB is acceptable by the radar users for signals from the other service with high-duty cycle (e.g. CW, BPSK, QPSK, noise-like, etc.). An *I*/*N* ratio of –6 dB results in a $(I + N)/N$ of 1.26, or approximately a 1 dB increase in the radar receiver noise power." |
| ITU-R M.1462-0 (Yr. 2000) | Radars in 420-450 MHz | "*recommends*…3) that an interfering signal power to radar receiver noise power level, *I*/*N*, ratio of –6 dB be used as the required protection level for the radiolocation systems, and that this represents the net protection level if multiple interferers are present." |
| ITU-R M.1463-2 (Yr. 2013) | Radars in 1215-1400 MHz | "*recommends*…3) that in the case of continuous (non-pulsed) single or aggregate interference, an interfering signal power to radar receiver noise power level, *I*/*N*, of –6 dB should be used as the required protection level for the radiodetermination radars." |
| ITU-R M.1465-1 (Yr. 2007) | Radars in 3100-3700 MHz | "*recommends*…3) that the criterion of interfering signal power to radar receiver noise power level, *I*/*N*, of –6 dB should be used as the required protection level for the radiolocation systems, and that this represents the net protection level if multiple interferers are present." |
| ITU-R M.1739 (Yr. 2006) | WAS/RLAN in 5 GHz | "*recommends 1)*…the *I*/*N* ratio at the WAS/RLAN receiver should not exceed –6 dB, assuring that degradation to a WAS/RLAN receiver's sensitivity will not exceed approximately 1.0 dB as described in Annex 1." |

| | | |
|---|---|---|
| ITU-R M.1767 (Yr. 2006) | Protection of land mobile systems from terrestrial digital video and audio broadcasting systems in the VHF and UHF shared bands allocated on a primary basis | "*considering* e) that an interference criterion $I/N = -6$ dB is a suitable value for the protection of LMS systems from broadcasting systems in the VHF and UHF shared bands; f) that this $I/N = -6$ dB is equivalent to a 1 dB increase of the LMS receiver system noise." |
| ITU-R M.1800 (Yr. 2007) | Protection of the fixed, mobile and radiolocation services from MSS feeder links that may operate in the bands 1390-1392 MHz and 1430-1432 MHz | "An increase of about 1 dB would constitute significant degradation, equivalent to a detection-range reduction of about 6%. Such an increase corresponds to an (I + N)/N ratio of 1.26, or an I/N ratio of about – 6 dB (see recommends 3 of Recommendation ITU-R M.1463)." |
| ITU-R M.1903 (Yr. 2012) | Protection Criteria for RNSS in 1559-1610 MHz (space-to-earth) | "Therefore, the accepted approach is to define the aggregate interference power density threshold at a level that will not raise the total noise floor by more than 1 dB above the environmental noise floor." |
| ITU-R M.1904 (Yr. 2012) | Characteristics, performance requirements and protection criteria for RNSS in 1164-1215 MHz, 1215-1300 MHz, 1559-1610 MHz (space-to-space) | "This threshold is based on an I/N ratio of −6 dB with respect to the thermal noise floor. Equivalently, this interference will result in a 1-dB increase in the thermal noise floor." |
| ITU-R M.2059 (Yr. 2014) | Operational and technical characteristics and protection criteria of radio altimeters utilizing the band 4200-4400 MHz | "The radio altimeter performance is considered degraded when the interfering signal causes a noise floor increase within the RA receiver of 1 dB. This corresponds to an I/N of –6 dB where the effective receiver thermal noise power." |
| The same protection criterion can be found in: ITU-R M.1466 (Yr. 2000, radars in 31.8-33.4 GHz); ITU-R M.1638 (Yr. 2003, radars in 5250-5850 MHz); ITU-R M.1644 (Yr. 2003, radars in 13.75-14 GHz); ITU-R M.1730-1 (Yr. 2009, radars in 15.4-17.3 GHz); ITU-R M.1796-2 (Yr. 2014, radars in 8500-10680 MHz); ITU-R M.2007 (Yr. 2012, radars in 5150-5250 MHz) . | | |