U.S. Department of Transportation

Office of the Assistant Secretary for Research and Technology

GPS ADJACENT-BAND COMPATIBILITY ASSESSMENT PLAN

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1. INTRODUCTION

In the January 13, 2012 National Space-Based Positioning, Navigation, and Timing (PNT) Executive Committee (EXCOM) letter to the National Telecommunications and Information Administration (NTIA), Deputy Secretary of Transportation John D. Porcari and Deputy Secretary of Defense Ashton B. Carter proposed to develop new Global Positioning System (GPS) spectrum interference standards to inform future proposals for non-space, commercial uses in the bands adjacent to the GPS signals[1]. Further, adherence to these standards would ensure that any such future proposals are implemented without compromising existing and evolving uses of space-based PNT services vital to economic, public safety, scientific, and national security needs. The Department of Transportation's (DOT) proposed approach to accomplish this task is to develop GPS adjacent-band transmitter[2] power limit criteria. These criteria could then be used to define new adjacent-band applications that would be compatible with GPS, and could form the basis for GPS spectrum interference standards.

The Federal Aviation Administration (FAA) and the Research and Innovative Technology Administration (RITA), both operating Administrations of the DOT, developed this Plan to provide the framework for definition of the processes and assumptions that will form the basis for development of the GPS adjacent-band compatibility for GPS civil applications[3].

This Plan identifies the processes to (a) derive adjacent-band transmitter power limit criteria for assumed new applications necessary to ensure continued operation of GPS services, and (b) determine similar levels for future GPS receivers utilizing modernized GPS and interoperable Global Navigation Satellite System (GNSS) signals. These processes will be used to develop and specify adjacent-band transmitter power limits necessary for the protection of GPS and other space-based GNSS signals for civil applications.

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[1] GPS signals are operated, or planned for operation, in the radionavigation satellite service (RNSS) bands at 1164-1215 MHz (GPS L5); 1215-1300 MHz (GPS L2); and 1559-1610 MHz (GPS L1).

[2] For the purposes of this document, "transmitter power" equates to effective isotropic radiated power (EIRP), and includes maximum transmitter antenna gain.

[3] Compatibility assessment/criteria for military usage will be developed in a separate process managed by the Department of Defense.

It should be noted that NTIA is developing in parallel a "Plan to Determine the Feasibility of Accommodating Terrestrial Broadband Systems in the Spectrum Adjacent to the Global Positioning System L1 Signal". The analysis approach for that plan is similar to that contained in this DOT Plan; however there are two distinct differences. The NTIA plan considers only a postulated terrestrial broadband system adjacent to the GPS L1 band, and the NTIA plan would result in GPS receiver requirements necessary to tolerate assumed broadband characteristics. In contrast, this DOT Plan considers a multitude of possible adjacent-band systems, and uses GPS characteristics to determine the requirements for those postulated transmitters.

2. POLICY FRAMEWORK

2.1 GPS

Over the past three decades, GPS has grown into a global utility providing multi-use service integral to United States (U.S.) national security, economic growth, transportation safety, and homeland security, and as an essential element of the worldwide economic infrastructure. In the *Statement by the President Regarding the United States' Decision to Stop Degrading Global Positioning System Accuracy* of May 1, 2000 (Ref. 1), the U.S. recognized the increasing importance of GPS to civil and commercial users by discontinuing the deliberate degradation of accuracy for non-military signals (known as Selective Availability (SA)). Since that time, the range of commercial and civil applications of GPS has continued to expand and the importance of many GPS applications has significantly increased. Services dependent on GPS information are now an engine for economic growth, enhancing economic development, and improving safety of life. GPS is now a key component of multiple sectors of U.S. critical infrastructure.

Private sector innovations in the use of GPS greatly exceed any originally envisioned or imagined applications. However, unlike communication systems where performance improvements are enabled by coordinated changes to both the transmitting and receiving systems, GPS has shown that GPS user processing innovations can significantly improve performance *without* changing the transmitted GPS signals. These innovations have enabled the civil community to develop and implement new GPS antenna/receiver technologies and applications, with minimal dependency on government actions. As the economic and security importance of PNT gained international recognition, other countries have initiated or renewed their commitments to provide comparable systems, fueling further development of new user-based technologies.

The framework for GPS policy is defined by Presidential Policy. Title 10 United States Code, Section 2281 (b) states that the GPS Standard Positioning Service shall be provided for peaceful civil, commercial and scientific uses on a continuous worldwide basis. Further, the Federal

Radionavigation Plan (FRP), published every two years in accordance with 10 USC § 2281 (c) (Ref. 2), provides extensive details on the role of GPS and the Presidential policy that supports GPS. On June 28, 2010, the President issued National Space Policy providing high-level guidance regarding space-based PNT. The National Space Policy calls for continued U.S. leadership in the service, provision, and use of GNSS. It reaffirms existing U.S. commitments to: provide continuous, worldwide access to civil GPS, free of direct user fees; pursue international GNSS cooperation including use of foreign PNT to augment and strengthen the resiliency of GPS; operate and maintain GPS to meet published standards; and take steps to detect and mitigate GPS interference. The National Space Policy reaffirms the National Security Presidential Directive-39, *U.S. Space-Based Position, Navigation, and Timing Policy* (15 December 2004) including the following guidance and implementation actions.

> The U.S. will continue to maintain space-based Position, Navigation, Timing (PNT) services, and augmentation, backup, and service denial capabilities that: (1) provide uninterrupted availability of PNT services; (2) meet growing national, homeland, and economic security requirements, civil requirements, and commercial and scientific demands; (3) remain the pre-eminent military space-based PNT service; (4) continue to provide civil services that exceed or are competitive with foreign civil space-based PNT services and augmentation systems; (5) retain essential components of internationally accepted PNT services; and (6) promote U.S. technological leadership in applications involving space-based PNT services.

2.2 Spectrum Efficiency

Radio spectrum is a limited resource and valuable commodity, and efficient use of spectrum must be assured so that spectrum limitations do not unduly constrain economic growth and innovation. Recognizing the importance of broadband communication and the severe constraints on the growth of broadband incurred by current frequency assignments, the President has initiated a review of existing frequency allocations in the radio spectrum to identify new opportunities for the introduction of broadband communication systems to support the "Wireless Innovation and Infrastructure Initiative" (Ref. 3).

Given the importance of expanding broadband communications, the U.S. Government (USG) will continue to identify candidate frequency bands in the radio spectrum for wireless broadband communication while taking into account the need to ensure no loss of critical existing and planned Federal, State, local, and tribal government capabilities, or where current use may be addressed with alternate technologies or frequency bands. One candidate under consideration is the spectrum adjacent to the 1559-1610 MHz band utilized by GPS L1 signals. That spectrum is currently used by mobile satellite service (MSS) systems, and has been authorized by the Federal Communications Commission (FCC) for ancillary terrestrial components (ATCt) for those systems (1525-1559 MHz for base stations and 1626.5-1660.5 MHz for handsets) although no such ATCt are currently allowed to operate.

2.3 GPS Adjacent-Band Compatibility Assessment Plan

In order to develop an appropriate plan for the protection of GPS applications, the potential value of GPS services as well as the potential value of communications (or other) services in the adjacent bands must be considered. Ideally, both needs could be satisfied simultaneously, but recent analysis and testing has indicated that such confluence is not generally realizable. For example, References 4 and 5 report on efforts showing that GPS receivers used for aviation, general navigation, high-precision, timing, and scientific applications were not compatible with a ground-based broadband network operating in the lower 10 MHz of the 1525-1559 MHz band. The USG must provide market stability and predictability, both for GPS and for new systems approved for operation in the adjacent bands. The current ongoing review of the spectrum adjacent to GPS creates uncertainty for the marketplace where GPS equipment manufacturers cannot reliably predict the lifecycle of their products. Broadband communication companies have similarly expressed the desire for predictability in their spectrum requirements, which can have a significant impact on the viability of any potential new application.

Time scales are also significantly different for the broadband and GPS communities; while most broadband users are accustomed to telecom service providers periodically providing new handsets with enhanced capabilities, GPS satellite-based service changes take decades to deploy. As a result, even if future GPS receivers can be developed that will be compatible with broadband signal emissions while still satisfying their performance requirements including working with modernized GNSS signals, NTIA has acknowledged (February 14, 2012 letter to the FCC), that for some users changing existing standards "...will take many years..." and "...retro-fitting or replacing the GPS receivers to be compliant with the new standards once they are adopted will take many more years." As a result, a Plan for the assessment of GPS compatibility with adjacent-band applications, within which technical and economic analysis can be conducted, needs to be established.

In implementing the Plan, GPS elements used to derive the adjacent-band transmitter power limits should be documented in the Federal Radionavigation Plan (FRP). Due to the number of different GPS applications and the time required to complete the analysis contained in this Plan, updates should be included in the FRP on an incremental basis. As technical attributes (see Section 3 below) are developed and agreed upon, they should be introduced into the FRP. This will allow for wide dissemination of information in a timely manner and provide the current status of the GPS adjacent-band compatibility assessment Plan’s progress. It should be noted that inclusion of these elements in the FRP would not make then make these elements “mandatory”, rather they would catalog the *representative* GPS receiver performance characteristics utilized to derive the adjacent-band transmitter power limits. To avoid installed equipment performance problems, final limits to ensure compatible operation with new GPS signals should be developed well in advance of the new signal's entry into operational service.

3. DEVELOPMENT OF ADJACENT-BAND TRANSMITTER POWER LIMITS

This Plan will initially deal with the frequency bands adjacent to that utilized by GPS L1 (i.e., bands adjacent to 1559-1610 MHz). It should be noted, however, that once the initial GPS L1 task is complete the Plan can then be iterated as necessary to address the other GPS civil signals as well as to address signals broadcast from future GNSS constellations.

Two separate sets of allowable adjacent-band transmitter power limits will be developed. The first set (Set 1) will protect existing GPS receivers based on current GPS receiver standards (for example, those for certified avionics) or, in cases where such standards are not available, based on measured GPS receiver performance. The second set (Set 2) will protect future GPS receivers designed to utilize modernized GPS signals and interoperable signals from other GNSS signals, as well as potentially to provide new application capabilities. It should be noted that there are elements that are common to both Sets, and their development need not be done sequentially.

Given the widespread utilization of GPS across multiple government/non-government entities, it is critical that these adjacent-band transmitter power limits be developed in a public/transparent process. This approach should include members of both the GPS and wireless telecommunications communities to allow vetting of key assumptions and facilitate acceptance of the eventual output criteria. For example, it is expected that RTCA, Inc. will be utilized to validate aviation assumptions and degradation effects associated with these power criteria.

<u>*Expected issue:*</u>

a) *Identifying the appropriate public forum or forums for each of the various receiver types to vet the analysis inputs and results*.

3.1 Methodology

For both Sets of limit cases (i.e., current receivers and future receivers), the general methodology will be the same. Figure 1 illustrates the four categories of technical attributes that must be defined in order to complete the adjacent-band compatibility assessment analyses.

GPS/GNSS Antenna/Receiver Susceptibility Defines the tolerable aggregate interference levels for an assumed type of adjacent-band signal, considering performance requirements, antenna/receiver architectures, and technology availability	**Adjacent-band Antenna/Transmitter** Defines the transmission characteristics, including modulation characteristics of the signal and type of antenna
GPS/GNSS Use Cases Defines the operational regions and applications of GPS/GNSS	**Adjacent-band Use Cases** Defines the operational locations, density and orientation of transmitters, considering the operational objectives for the use of the adjacent-band

Figure 1: Technical Attribute Categories

3.1.1 Defining the type of application planned for deployment in the adjacent-band

Provided by the U.S. spectrum regulator(s) (i.e., the FCC and/or NTIA[4]), this definition comprises the right-hand column of Figure 1 and is essential in that it forms the basis for specifying both the GPS receiver susceptibility and the interaction scenario(s). Of particular importance are the adjacent-band signal attributes (modulation type; transmit bandwidth; etc.); deployment scenarios (indoor or outdoor; tower-based or on the ground; mobile or fixed emitters; etc.); transmitter antenna characteristics; and all other details which could impact interference to GPS. It must be stressed that the derived adjacent-band transmitter power limits are completely dependent on the details, and type, of the proposed application. If alternative or even multiple applications are proposed in the future (e.g., on different frequencies), then aggregate effects and possible intermodulation issues would need to be considered, and the adjacent-band transmitter power criteria re-assessed and possibly adjusted accordingly.

NTIA has stated that only terrestrial broadband (15-20 MHz) signals in the 1525-1540 (or 1545) MHz band and somewhere in the 1626.5-1660.5 MHz band need be analyzed, so priority will be given to assessing that application. NTIA has also stated that in the current domestic spectrum management process there is no way to stop someone from making a proposal to operate in a

[4] For example, as a result of the ongoing work in the Commerce Spectrum Management Advisory Committee.

given band, so alternate applications to broadband may also need to be considered as part of the adjacent-band compatibility assessment.

Expected issue:

a) *The definition of the type of application planned for deployment in the adjacent-band(s) is not under the control of DOT; however, since the analysis work cannot start without this input, it becomes a driver to the overall criteria definition completion schedule.*

3.1.2 Determining GPS receiver interference tolerance masks and use cases

These elements comprise the left-hand column of Figure 1. Some existing GPS receivers, such as those used for certified avionics, already include interference rejection masks as a part of their defined standards. For those receivers the antenna characteristics and rejection masks will serve to define the allowed tolerable levels of *aggregate* interference at the GPS receiver.

Other GPS receivers do not have established receiver standards that include interference rejection masks and definition of the metrics for determining what constitutes interference. For those receivers, testing performed as a function of frequency offset and characteristics of the interfering signal, will be required to develop an interference mask. This effort will be required for each "type" of GPS receiver (e.g., high precision, timing, etc.). In order to minimize the required time and resources, the approach will leverage, to the extent feasible, the work already done by the FCC-mandated LightSquared Technical Working Group (TWG). Specifically, this Plan will use the TWG definition of different receiver types and catalog of representative receiver models for each of those types. Unfortunately, the testing accomplished by the TWG focused on a very specific planned application at very specific frequencies, so additional data collection will likely be required based upon the definition(s) developed in Section 3.1.1.

The GPS use cases define the operations and regions where the interference rejection mask is to be respected. These use cases also define orientation characteristics for the GPS antenna.

Expected issues:

a) Obtaining public comment/agreement on the receivers to be tested for each GPS receiver type.
b) Getting sufficient test or analysis results to define a "representative receiver performance" for each type of GPS receiver that does not have established interference mask standards.
c) Obtaining public comment/agreement on representative GPS antenna/receiver characteristics.
d) Obtaining public comment/agreement on GPS use cases.
e) Defining the metrics for what constitutes interference for each type of GPS receiver.

3.1.3 Determining interaction scenario(s)

The efforts outlined in Section 3.1.2 should establish the maximum aggregate power levels allowable at, and the GPS use case(s) for, each particular GPS receiver to ensure its protection. For the GPS adjacent-band compatibility assessment however, the parameter of interest is the allowed interfering-transmitter power. In order to derive that limit an interaction scenario must be defined. The interaction scenario is directly dependent on the type of adjacent-band application envisioned (Section 3.1.1), the type of GPS receiver under consideration, and the GPS use case (Section 3.1.2).

As an example of how these factors could be used in the analysis, consider the case of base stations for a terrestrial broadband application in the adjacent band, where evaluation of the effects on the GPS use case of an aircraft in final approach may result in an interaction scenario composed of hundreds of emitters located at varying relative distances and aspect angles. Conversely, the same adjacent-band system assumption may result in an interaction scenario for the GPS use case of surveying applications that is composed of fewer than 10 emitters. Ground-based applications must consider the effects of actual terrain and terrain contours (hills, overpasses, on/inside buildings, etc.), which can greatly increase the number of interfering sources relative to a flat earth perspective and can often place the GPS receiver in the main beam of one or more source transmitters.

Determination of representative GPS antenna/receiver characteristics is a second key consideration for this effort. Antenna gains/patterns, line losses, and other parameters will directly impact the acceptable adjacent-band transmitter power levels.

A final consideration is the determination of how to include other sources of potential interference in calculating the maximum aggregate power levels. One approach could assess how much of the total allowed aggregate interference budget will be allocated to a “new” adjacent-band application. This apportionment might vary for different receiver types depending on other sources of interference present in the specific interaction scenario. It is important to distinguish this factor addressing how much of the interference budget can be allocated to a single application, from the aggregate effects of multiple applications discussed in 3.1.1. The former will be included in the derivation of the adjacent-band transmitter power limits while, as noted, the latter would result in the derivation of completely new limits.

Expected issues:

a) *Obtaining public comment/agreement on interaction scenarios.*
b) *Obtaining public comment/agreement on propagation model(s).*
c) *Obtaining public comment/agreement on aggregation approach(es).*

d) *Obtaining public comment/agreement on addressing other potential sources of interference.*

3.1.4 Specifying the adjacent-band application transmitter power limits

Once the GPS receiver interference tolerance (Section 3.1.2) *and* interaction scenario(s) (Section 3.1.3) are developed, the acceptable adjacent-band transmitter power for that application, at a given frequency and for a given GPS receiver type, can be determined. This calculation would include pertinent safety margins[5] and would then be repeated for different frequencies, resulting in a matrix of allowable transmitter power versus offset frequency. That matrix would be developed for each GPS receiver type. At a given frequency, the largest allowable transmitter power that protects <u>all</u> defined GPS applications will then form the reported adjacent-band transmitter power limit criteria.

<u>*Expected issues:*</u>

a) *Agreement on size of safety margins and to which applications they are applicable.*
b) *Agreement to protect <u>all</u> GPS applications*.

3.2 Current GPS Receivers (Set 1 limits)

For current GPS receivers the interference tolerance (Section 3.1.2) masks will be predicated on ensuring operation of GPS L1 C/A, GPS L1 P(Y) (for authorized U.S. government applications or other civil functions that utilize semi-codeless techniques), and GPS Satellite-Based Augmentation Services (SBAS; in the U.S. also known as the Wide-Area Augmentation System (WAAS)).

[5] For example, for certified aviation GPS receivers this would include a 6 dB safety margin.

3.3 Modernized GPS/GNSS Receivers (Set 2 limits)

Although the majority of fielded civil satellite PNT receivers process only GPS L1 C/A-code signals, some current equipment, and the majority of future equipment, are expected to track many other GNSS signals broadcast from constellations including the following:

- Russia's GLONASS – this system is currently fully operational with 24 operational medium Earth orbit (MEO) satellites broadcasting in two bands: (1) the 1559 – 1610 MHz band; and (2) the 1215 – 1300 MHz band. One operational GLONASS satellite and future GLONASS K satellites are planned to also transmit in the 1164 – 1215 MHz band.
- Europe's Galileo – Two satellites are currently deployed and transmitting a useable set of signals. This system is planned as a 27 MEO satellite constellation (plus three spares). Dual- and quadruple-launches are planned to enable a rapid deployment of Galileo so initial operational capability could be provided not later than the end of 2015.
- China's COMPASS – this system is planned to consist of 27 MEO satellites, 5 geostationary orbit (GEO) satellites, and 3-5 satellites in highly-inclined geostationary orbits (IGSO). Five GEOs, five IGSOs, and 3 MEOs have been launched to date, and the system is expected to be fully operational globally within the next decade.
- India's IRNSS – India is planning for a seven-satellite constellation in IGSO and GEO orbits.
- Japan's QZSS – this system is planned to ultimately include 7 satellites in IGSO and GEO orbits. One satellite has been launched to date.
- Multiple foreign SBAS – including the European GNSS Navigation Overlay Service (EGNOS), the Multifunctional Transport Satellite (MTSAT)-Based Augmentation System (MSAS) in Japan, the GPS and GEO Augmented Navigation (GAGAN) system in India, the System of Differential Correction and Monitoring (SDCM) in Russia, and a Chinese SBAS now in development.

In addition to the foreign systems described above, the GPS modernization program continues to populate the U.S. constellation with new civilian (L2C, L5, and L1C) and military (M-code) signals. The Block IIR-M satellites launched from 2005 to 2009 were the first to broadcast L2C and M-code. The first IIF satellite was launched in 2010 and introduced the L5 signal. Beginning with the first Block III satellite anticipated to launch in 2014, all future GPS satellites will additionally broadcast the L1C signal.

Overall, there are more than 80 GNSS satellites in orbit today and a total of over 150 satellites on orbit are anticipated within a decade. The current signal plans for the set of systems described above is shown in Figure 2.

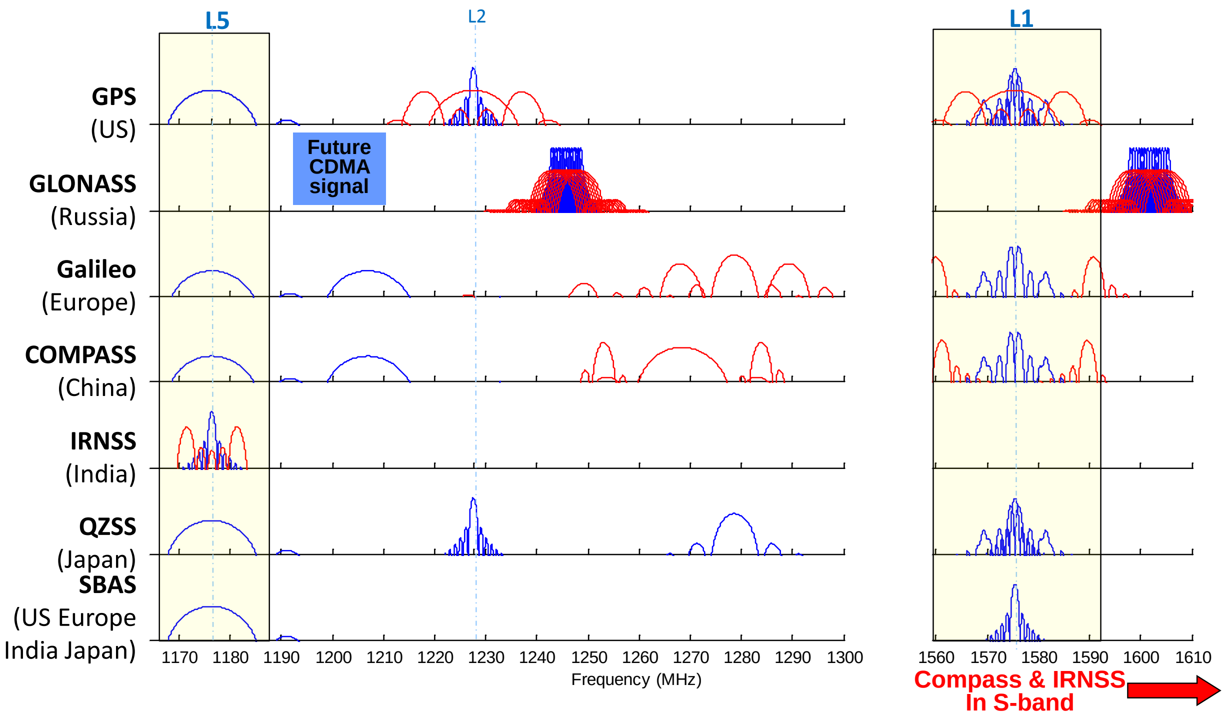

Figure 2. GNSS Signal Plans

The GPS Adjacent-Band Compatibility Assessment Plan execution should iterate the process used to protect current receivers to additionally protect future receivers developed to utilize the much larger suite of GNSS signals that are deployed over the next decade, while also taking into account advances in signal processing and filter technology.

4. SUMMARY

The FAA and RITA drafted this Plan to provide the framework for definition of the processes and assumptions that will form the basis for development of GPS adjacent-band transmitter power limits that ensure compatibility with GPS civil applications. Adherence to these criteria will ensure that such proposals are implemented without affecting existing and evolving uses of space-based PNT services vital to economic, public safety, scientific, and national security needs.

Key points of the Plan include the following:

a) GPS compatibility assessment analysis will be accomplished as part of an open, transparent government/public process. Participation and review by the GPS and wireless telecommunications industries will be encouraged in establishing initial adjacent-band transmitter power criteria to ensure protection of GPS applications, as well as in developing future changes to those criteria.
b) The USG should codify the adjacent-band transmitter power limit criteria resulting from the analyses defined in this Plan, as opposed to adopting new interference rejection regulations for civil GPS receivers.
    1. Receiver interference-rejection standards alone are insufficient to ensure protection of GPS receivers. Instead, in-depth analysis is required to address the combination of such GPS receiver characteristics with interference-specific and GPS use case-specific interaction scenarios in order to determine necessary transmitter power limits on interference sources.
    2. As part of the compatibility assessment analyses, performance capabilities and criteria associated with future GNSS antenna/receiver equipment for their future applications would be defined.
c) A mechanism should be adopted whereby the adjacent-band transmitter power limit criteria resulting from the analysis defined in this Plan are published as quickly as possible. Key elements used to derive those criteria would be published on an incremental/as-available basis in the Federal Radionavigation Plan.
d) A notification policy should be adopted that is consistent with commitments already stated in the FRP for any changes to the adjacent-band transmitter power limit criteria that could jeopardize the use of receivers designed in accordance with those criteria.
e) Implementation of this Plan would initially focus on frequency bands adjacent to that used by GPS L1 (i.e., bands adjacent to 1559-1610 MHz).
f) The Set 2 limits discussed in Section 3.3 would be developed well in advance of a new GNSS signal's entry into operational service.
g) If the Set 1 and/or Set 2 limits are not conducive to implementing terrestrial broadband services, the bands adjacent to GPS would be considered for alternate technologies more compatible with GPS, potentially freeing other frequency bands for broadband communication.
h) Completion of the Adjacent-Band Compatibility Assessment and development of the adjacent-band transmitter power limit criteria would require considerable time (3-5 years estimated for GPS L1 alone), and significant resources.

REFERENCES

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