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March 15, 2011

ELECTRONIC FILING

Marlene H. Dortch
Secretary
Federal Communications Commission
445 12th Street, SW
Washington, DC 20554

Re: SAT-MOD-20101118-00239

Dear Ms. Dortch:

In its Order dated January 26, 2011 ("*LightSquared Order*"), the Federal Communications Commission ("Commission") required LightSquared Subsidiary LLC ("LightSquared") to submit reports on the 15th day of each month describing the progress of the Working Group ("WG") convened to study the GPS overload/desensitization issue discussed in the *LightSquared Order*, concluding in a Final Report due no later than June 15, 2011.[1] The first of these reports, due March 15, 2011, was required to include, at a minimum, "base station transmitter characteristics, categories of GPS devices and their representative performance characteristics, and test plans and procedures."[2]

A copy of the WG's first progress report ("March Progress Report"), hereby submitted to the Commission jointly by LightSquared and the United

[1] *LightSquared Subsidiary LLC; Request for Modification of its Authority for an Ancillary Terrestrial Component*, SAT-MOD-20101118-00239, DA 11-133, ¶ 43 (rel. Jan. 26, 2011).
[2] *Id*.

States Global Positioning System ("GPS") Industry Council ("USGIC") as Co-Chairs of the Working Group, is attached. As discussed in greater detail in the March Progress Report, in the short time since filing its initial report,[3] which included a work plan outlining the intended actions and governance of the WG, the Technical Working Group has been formed, has held several work sessions, and is moving forward with the items outlined in the work plan.

Please do not hesitate to contact me with any questions.

Respectfully,

Henry Goldberg

Henry Goldberg
Counsel for LightSquared Subsidiary LLC

cc: Julius Knapp, FCC
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[3] Letter from Henry Goldberg, Counsel for LightSquared Subsidiary LLC, to Marlene H. Dortch, Secretary, Federal Communications Commission, File No. SAT-MOD-20101118-00239 (Feb. 25, 2011) (attaching initial report, including work plan).

GPS Technical Working Group Progress Report #1
Submitted to the Federal Communications Commission Under DA 11-133

Introduction

On February 25, 2011, LightSquared and the United States Global Positioning System Industry Council (USGIC) submitted a Work Plan to the Commission outlining the intended actions and governance of the Working Group (WG), including the Technical Working Group (TWG) to study fully the potential for overload interference/desensitization to GPS receivers, systems, and networks. In the short time since the Work Plan was filed, the TWG has been formed, held several work sessions and is moving forward with the items outlined in the Work Plan. As directed in DA 11-133, LightSquared, along with the non-governmental members of the GPS Technical Working Group (TWG) hereby submit this progress report to the Co-Chairs of the WG for review and agreement to submit to the Commission[1].

Progress to date

According to the Work Plan, "the TWG will be comprised of GPS industry experts and will provide guidance and recommendations for the WG on critical elements of the interference study. It is expected that the TWG will be made up of individuals numbering 14-20 who will bring strong technical and/or use case expertise to the working group and represent a diversity of receiver categories and installed user groups." The TWG currently has 34 members along with two working group co-chairs and four information facilitators. TWG members represent a diverse group of interested parties including equipment and chipset manufacturers, aerospace / aviation companies, wireless providers, engineering firms, public safety and various federal agencies. Additionally, several individuals have volunteered to be advisors to the TWG. Appendix A contains more detailed information about these participants.

The TWG held its first meeting on March 3, 2011 in Arlington, VA and via a conference bridge for those members who were unable to attend in person. Additional teleconferences have been held subsequently. During these sessions, the TWG focused on the first seven items from the Work Plan, as outlined in 'First Work Plan Key Milestone for the Overall Analysis:' in the February 25, 2011 FCC filing:

1. Establish pertinent analytical and test methodologies and assumptions underlying the test regime
   - Definition of harmful interference
   - Relevant information regarding terrestrial broadband network
   - Interference analysis assumptions
   - Evaluation of potential test methodologies
2. Select categories of receivers and receivers to be tested
3. Develop operational scenarios
4. Establish methodology for analyzing test results
5. Derive test conditions based on the established operational scenarios
6. Write test plan and procedures

[1] This report was prepared with technical input from USG employees and contractors but does not necessarily represent their views.

7. Identify and engage appropriate test facilities

Monthly progress reports will be used to update the Commission on the work of the TWG to achieve the goals outlined by the Commission. In this report, the TWG presents the progress it has made to date towards the first Work Plan milestone.

Work Plan Item 1: Establish pertinent analytical and test methodologies and assumptions underlying the test regime

Analytical Approach and Underlying Assumptions

Prior to generating detailed test plans and procedures, it is necessary to determine the parameters to be used in the tests using GPS simulators and the simulation of the terrestrial broadband transmitters.

Definition of Harmful interference at the GPS/GNSS/Augmentations/L-band Receiver

The TWG members have discussed a number of receiver parameters related to the definition of harmful interference. In the FCC Rules[2], harmful interference is defined as "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 [the ITU] Radio Regulations."

Harmful interference affects different types of receivers in different ways. The key factors that pertain to the functioning of GPS receivers and/or whether service is degraded, obstructed or interrupted are accuracy (position, velocity, time), availability (ability to perform a given function), coverage (within what space can a function be performed), integrity (what is the probability that the results are correct), and continuity (what is the probability that a given function can be completed). Metrics for harmful interference are developed from an understanding of the consequential relationship between negative impacts and receiver parameters, which include effective C/N_0, PVT accuracy, time to first fix, loss of lock, cycle slips, etc. The signal conditions to be taken into account are defined in the GPS Standard Positioning Service (SPS) Performance Standard, 4th Edition[3], Interface Specifications (ISs)[4], GPS policy[5], and both the present and planned future signal environments will be considered. Environmental and field conditions in which GPS receivers operate will also be considered.

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[2] Section 2.1 of the FCC's Rules, 47 C.F.R. § 2.1: No. 1.169 of the ITU Radio Regulations.
[3] SPS Performance Standard (SPS PS) http://www.pnt.gov/public/docs/2008/spsps2008.pdf
[4] 3 IS-GPS-200E: NAVSTAR GPS Space Segment / Navigation User Interfaces.
http://www.losangeles.af.mil/shared/media/document/AFD-100813-045.pdf and
3IS-GPS-800A: NAVSTAR GPS Space Segment / User Segment L1C Interfaces.
http://www.losangeles.af.mil/shared/media/document/AFD-100813-047.pdf
[5] U.S. Space-based Positioning, Navigation, and Timing Policy (2004); National Space Policy (2010)

It should be possible to assess interference impact, up to that which includes harmful interference, using metrics in terms of receiver parameters that include measurable changes in effective C/N_0 as well as position accuracy, time to first fix, loss of lock, cycle slips, etc. Related to this discussion is whether there is any margin that could be budgeted for terrestrial broadband operation, and if so, what that amount could be. When considering systems guaranteed for safety-of-life operations, there may be very little or no margin.

There is general agreement within the TWG that the device testing protocols should include changes in effective C/N_0 and degradation of other key performance measures so as not to exclude data that might be relevant for the post-testing analytical phase using operational scenarios

Overload interference/desensitization at the GPS/GNSS/Augmentations/L-band Receiver

Desensitization/overload due to strong signals outside of the GPS band may cause the GPS receiver to operate in a non-linear mode with reduced gain (i.e., gain compression) for the desired GPS signal; there may also be other receiver impairments caused by strong signals outside the GPS band. The TWG will consider these mechanisms further after testing is underway and sufficient samples are available to adequately assess such mechanisms.

Relevant Information Regarding Terrestrial Broadband Network

LightSquared provided technical details to the TWG regarding the equipment that is planned for its terrestrial broadband deployment. The information, which is detailed in Appendix B, includes LightSquared's channelization plan, output power, OOBE characteristics and emissions mask.

Interference Analysis Assumptions

The TWG has discussed the types of assumptions that underlie the interference analysis. These discussions have included the number of GPS space vehicles available, the received signal strength of the GPS signal, whether devices would have an obstructed or clear view of the sky, the terrestrial broadband signal strength, distance of the receiver from the terrestrial broadband transmitter, and whether statistical characterization of the likelihood of interference (at different severity levels) is useful for some use cases. It was generally agreed that these assumptions will vary with specific device categories and use cases. There is also general agreement that the range of assumptions should include "worst case" conditions specific to each receiver category.

Evaluation of Potential Test Methodologies

The TWG has agreed to move forward with a combination of laboratory-based and field-based testing programs. Laboratory tests are repeatable, allow for the creation of a fully controlled environment and the ability to test multiple scenarios and many devices in an efficient, repetitive manner. Field tests expose devices to a real-world environment where measurements can be performed at various distances and morphologies from terrestrial broadband network sites in order to gauge the effects of distance and physical environments on terrestrial broadband signal strength and potential interference. One advantage of field testing is that it captures a complete, live test environment comprehensively and helps develop keener testing or analysis insights that modeling cannot offer. The major disadvantage or concern is that field testing uses the present environment, not the environment that might exist at some future or past time. Interference testing analysis has to consider worse case assumptions, and not only the current test reality.

Laboratory testing will be performed either using conducted testing, where devices are connected directly to transmission sources via 50 ohm connectors, or through radiated testing in anechoic or other radiated emissions chambers. While conducted testing is the preferred laboratory methodology, anechoic chambers will be used where conducted testing is not practical, is not recommended by the manufacturer, or where connectorized devices cannot be made available within the established test timeline.

Field testing will be performed at outdoor test locations that will utilize transmitters, filters and antennas similar to those that will be deployed by LightSquared in its commercial operations. Due to the heightened concern about interference occurring during its test operations, especially for aviation applications, LightSquared will work closely with the Federal Aviation Administration (FAA) in the test site selection process so that the FAA may issue Notices to Airmen (NOTAMs) should the agency determine it is appropriate. Furthermore, LightSquared intends to conduct field testing with the utmost caution and in compliance with any specific FAA recommendations. The company is willing to adopt safeguards such as performing initial field tests at reduced power levels and restrict testing to particular times of day and weather conditions.

LightSquared will also notify Commercial Mobile Radio Service (CMRS) carriers and public safety network operators that have transmit facilities within two kilometers of the test sites, so that they may take any necessary precautions with regard to fixed GPS timing receivers operated at their transmitter sites.

While the bulk of the testing effort will be devoted to testing use cases related to the base station proximity, some testing will also be performed for use cases related to proximity to terrestrial handsets transmitting in the 1626.5 – 1660.5 MHz bands.

For some applications/scenarios, tests are not practical, so the effects can only be determined by analysis.[6]

[6] For instance, the testing of networks of GPS receivers, aggregate interference received by GPS avionics during flight as well as aggregate interference received by other types of GPS receivers will be calculated through the use of analytical modeling as opposed to lab or field testing.

Work Plan Item 2: Select categories of receivers and receivers to be tested

The TWG has identified seven categories of receivers that are representative of the non-military use of GPS in the United States: aviation, cellular, general location/navigation, high precision, timing, space-based receivers[7] and networks. Each category includes augmented and unaugmented devices. Public safety receivers are included in precision timing and in general location/navigation. Receivers used in science are included in high precision. Commercial and global maritime distress and safety receivers are included in general location/navigation. These categories are subject to change or could be consolidated for test efficiency at the discretion of the TWG and the Working Group co-chairs.

The TWG has created seven sub-teams, each focused on one of these categories. These sub-teams are responsible for determining device selection and prioritization criteria, defining operational scenarios, listing testing conditions and test plan procedures, and recommending appropriate test facilities. Devices will be selected such that they represent an appropriate range of manufacturers and uses. They will then be prioritized for testing by criteria, including criticality of use, such as safety-of-life and public safety; the size of embedded user base; operational and economic dependency on positioning, navigation, and timing information; the availability of suitable test devices as well as others that may be developed by the sub-team.

Aviation

See Appendix C: GNSS Aviation Receivers – Performance Characteristics and Operational Scenarios

Cellular

- **Operational Modes:** Most cellular telephones can support both Assisted GPS (AGPS) and autonomous GPS operation. During typical use, the cellular telephone's GPS receiver will operate in the AGPS mode.
- **Baseline Performance Specifications:** AGPS receivers in cellular telephones designed for operation with airlink technologies covered by the specifications of the 3rd Generation Partnership Project (3GPP), are designed to comply with core performance specification 3GPP TS 25.171. *"Requirements for support of Assisted Global Positioning System (A-GPS) Frequency Division Duplex (FDD)".*
- **Baseline Conformance Specifications:** AGPS receivers designed for operation with airlink technologies covered by the specifications of 3GPP are tested for conformance to test

[7] The National Aeronautics and Space Administration (NASA) has informed the TWG that it will be conducting testing of space-based receivers at NASA's Jet Propulsion Laboratory (JPL) and will inform the TWG of the results of this testing and the methodology and procedures used to produce the test results. Accordingly, the TWG does not plan to conduct its own tests within this specific category of devices.

specification 3GPP TS 34.171 *"Terminal conformance specification; Assisted Global Positioning System (A-GPS); Frequency Division Duplex (FDD)".*

- **GPS Receiver Sensitivity, Assisted Mode:** AGPS receiver sensitivity is specified in terms of location accuracy relative to the received signal level. For example, current 3GPP TS 34.171 test requirements call for a location accuracy of 100 meters 95% of the time and a Time to First Fix (TTFF) of between 16 and 20 seconds (the TTFF is dependent upon the specific 3GPP airlink technology supported by the cellular telephone). 3GPP TS 34.171 calls for the cellular telephone to comply with the accuracy metrics listed above at a signal level of -147 dBm and will be tested down to -162 dBm. In addition to 3GPP standards, the TWG will utilize accuracy and availability standards prescribed in the FCC's rules and within OET 71[8].
- **GPS Receiver Sensitivity, Unassisted (Autonomous) Mode:** Like the assisted mode above, the sensitivity of an unassisted GPS receiver can also be specified in terms of location accuracy. However, neither the 3GPP TS 25.171 core performance specification nor the 3GPP TS 34.171 conformance test specification defines a minimum performance value for this mode. Given sufficient measurement time, an unassisted GPS receiver in a cellular telephone should be able to comply with the accuracy metrics associated with the assisted mode.

<u>General Location/Navigation</u>

Position Accuracy: Dependent upon operational scenario
Velocity: 0.2 meters / second
Acquisition and Tracking Sensitivity: Dependent upon operational scenario
Acquisition Time[9]: 1.0 seconds (Hot Start[10]); 38.0 seconds (Warm Start[11]); 45.0 seconds (Cold Start[12])

<u>High Precision</u>

Characteristics:
Acquisition signals: GPS (L1 C/A, L1C, WAASL1), (L2 semi Codeless , L2C), (L5, WAASL5), L Band (OmniStar, StarFire)

[8] Federal Communications Commission, Office of Engineering and Technology, *Guidelines for Testing and Verifying the Accuracy of Wireless E911 Location Systems,* OET Bulletin No. 71, April 12, 2000; *see also* 47 C.F.R. §20.18.
[9] Acquisition time is measured over 200 test intervals.
[10] Hot start is defined as the retention of Space Vehicle (SV) Ephemeris, User Equipment (UE) Time, UE Position, and SV Almanac data. The user equipment under test is turned off and then turned on and the time to first fix (TTFF) is measured.
[11] Warm start is defined as the deletion of SV Ephemeris, and the retention of UE Time, UE Position and SV Almanac data. The user equipment under test is turned off and then turned on and the TTFF is measured.
[12] Cold start is defined as the deletion of SV Ephemeris, UE Time, UE Position and the retention of SV Almanac data. The user equipment under test is turned off and then turned on and the TTFF is measured.

Signal acquisition time (s)
- Use case
- 1: Cold = no almanac, no PV or T
- 2: Warm= almanac + (T +/- min)
- 3: Hot = complete ephemeris + PV+(T+/- us)

Acquisition sensitivity (dBm) (Signal Power Level)
- Use case
- 1: Cold = no almanac, no PV or T
- 2: Warm= almanac + (T +/- min)
- 3: Hot = complete ephemeris + PV+(T+/- us)

Tracking
- GPS Tracking
  - Range measurement accuracy (m)
  - Range rate measurement accuracy (m/s)
  - Carrier phase measurement accuracy (cm)
  - Mean time between cycle slips (s)
  - Sky plot of measurement accuracies vs. elevation/azimuth angles
  - Sky plot of reported cycle slips vs. elevation/azimuth angles
- WAAS Tracking
  - Range measurement accuracy (m)
  - Range rate measurement accuracy (m/s)
  - Carrier phase measurement accuracy (cm)
  - Mean time between cycle slips (s)
  - Bit Error Rate
- L Band
  - Bit Error Rate
- Sensitivity (dBm)
  - GPS Point of mean time between cycle slips < 600(s) (usable for RTK)
  - GPS Point of loss of lock
  - WAAS Point of BER > 1E-6
  - WAAS Point of loss of lock
  - L Band Point of BER > 1E-6
  - L Band Point of loss of lock

<u>Timing</u>

Characteristics for use case: Single point mode, no Augmentation, Stationary
- Tracking
  - Signal Acquisition time (L1CA)
    - Cold = no almanac, no position or T
    - Warm= almanac + fixed position + (time +/- minutes)
    - Hot = complete ephemeris + fixed position and (time +/- us)
    - Sensitivity (dBm)
  - Tracking L1
    - Range measurement accuracy (cm)
    - Mean time between loss of lock (s)
    - Sky plot of measurement accuracies vs. elevation/azimuth angles

Sky plot of reported loss of lock vs. elevation/azimuth angles
Sensitivity (dBm)

Initial Setup
Time To First Fix Position + Time (s)
Cold: no almanac, time or position
Installed
Time to “Good Clock” (s)
Cold: (Position known and fixed, no almanac or time)
Warm: (Position known and fixed, almanac + (time +/- min))
Hot: (Position known and fixed, ephemeris + (time +/- us)
Steady state time accuracy ITU G.810 MTIE, TDEV
Steady state frequency accuracy ITU G.810 ADEV, MDEV
Phase noise (dBc)

Networks

The performance characteristics of networks vary greatly by network type. This information is still being gathered by the TWG.

Space-Based Receivers

Name:
BlackJack family of receivers

Manufacturers:
Jet Propulsion Laboratory, OSC (was Spectrum Astro), Broad Reach Engineering

Applications:
Precision measurements from space orbit, including vertical location of satellites with sub-cm error, use for gravity recovery with integrated K+Ka bands transmit/receive capability, measurement of atmospheric refractivity during GPS limb soundings, ionospheric science measurements of electron content and ionospheric scintillation, ground-based carrier-based frequency transfer

Users:
BlackJack-family receivers currently fly on about 18 science satellites, mostly from the USA, but including European, African, Australian, and Asian satellites.

General description of receiver:
Tracks C/A code, L2C code (some receivers), Y1 and Y2 codes using semi-codeless, L5 code (receivers being built now)
Receiver can be upgraded in orbit. New software is routinely uploaded after launch. Firmware in FPGAs is modified after launch to add new signal capability.

Observables produced:

Time-tagged pseudo-range, carrier phase, and effective C/N_0 are produced for each of the codes mentioned above. Also, the onboard solution consisting of the position, the receiver clock offset, and their time derivatives, along with the satellites used in the solution, the formal error, and the solution Chi squared are all output.

Measurement precision:
The occultation experiment requires the phase rate be measured with 0.8 mm/s accuracy. Data are output at 100 Hz. Typical 1-second measurement precisions are 0.3 mm for the ionospheric error free combination of dual carrier phase measurements. The unknown delay variation through the receiver filters must be less than 1 nanosecond over 0 to 40 degrees C.

Work Plan Item 3: Develop operational scenarios

Aviation

The following operational scenarios are extracted from an RTCA assessment document[13] ("DO-235B"). For each operational scenario, all applicable performance requirements from the relevant RTCA Minimum Operating Performance Standards [14][15]will be evaluated in the presence of both LightSquared emissions (considering constraints on the siting of the base stations near airports to protect mobile satellite services) and all known other interference sources as identified in DO-235B and all other interference sources as included within the test procedures contained within DO-229D and DO-253C.

1. Enroute/Terminal Area

For the enroute flight phase aircraft are generally constrained to be at an altitude of at least 500 feet above structures or terrain in uncongested areas and at least 1000 feet above structures or terrain in congested areas. In the terminal area on the initial approach segment the flight path is a minimum of 1000 feet above any obstacles. On the intermediate approach segment the flight path is a minimum of 500 feet above obstacles. In these phases of flight, GNSS may be used for horizontal guidance in IMC operations. For off-board sources, the minimum RFI source separation distance to the closest terrestrial source is defined as 500 feet.

   a. Enroute Acquisition

   The aircraft in this scenario is assumed to have been in normal, enroute GNSS navigation for a sufficient time to have up-to-date satellite ephemeris data, stored position, velocity, and receiver clock bias/drift information. Normal navigation is then somehow interrupted for a short time (e.g. by a momentary aircraft power failure) and the receiver must re-establish navigation by a full "warm-start" acquisition. For this scenario, the aircraft is assumed to be in level flight at a representative limiting-case altitude of 18,000 feet (5.5 km).

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[13] RTCA, *Assessment of Radio Frequency Interference Relevant to the GNSS L1 Frequency Band*, Washington, D.C., RTCA DO-235B, March 13, 2008.

[14] RTCA, *Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment*, Washington, D.C., RTCA DO-229D, Dec. 13, 2006. ("DO-229D")

[15] RTCA, *Minimum Operational Performance Standards for Global Positioning System Local Area Augmentation System Airborne Equipment*, Washington, D.C., RTCA DO-253C, December 16, 2008. ("DO-253C")

b. Enroute Tracking/Data Demodulation

For the enroute tracking / demodulation scenario, the aircraft is assumed to be in level flight at a representative limiting-case altitude of 18,000 feet (5.5 km) above ground level. Both GPS and SBAS (e.g., WAAS) satellite signals are considered. The usefulness of the SBAS signals for integrity and error correction depends on the aircraft position being within an area covered by SBAS ground reference stations. Certain components of total RFI vary as a function of location, (e.g., GNSS self-interference, terrestrial RFI). Given these two aspects, the enroute GPS and SBAS scenario link analyses may be performed at different limiting-case locations.

c. Terminal Area Tracking/Data Demodulation

For this terminal area scenario, the aircraft is assumed to be in level flight with its GNSS antenna at an intermediate value between the enroute and Category I precision approach scenarios. The airborne GPS antenna height is 1756 feet (535.2 m).

2. Non-precision Approach Tracking/Data Demodulation

   For non-precision approach operations, DO-235B recommends using a 100 foot (30.5 m) separation to a ground-based obstacle (source of interference) and the Category I airborne antenna gain pattern below the aircraft (see Figure 2).

3. Category I Precision Approach Tracking/Data Demodulation

   For category I (CAT I) precision approach, DO-235B recommends using a 96.7 foot (29.5 m) obstacle clearance surface (OCS) distance (distance to closest possible ground-based interference source) and a 175 foot (53.3 m) above-ground GNSS airborne antenna height.

4. Category II/III Precision Approach Tracking/Data Demodulation

   For a CAT II/III precision approach, DO-235B recommends using a 70 foot (21.3 m) OCS distance (distance to closest possible ground-based interference source) and a 85.1 foot (25.9 m) above-ground GNSS airborne antenna height. Such operations require a CAT II/III GBAS to be installed at the airport.

5. Surface Acquisition and Tracking/Data Demodulation

   This operational scenario encompasses surface operations where the aircraft is at the gate or taxiing. For this scenario, the GNSS aircraft antenna height is assumed to be 4 m (a nominal height for a regional or business jet). The aircraft is either stationary or in a slow taxi. GNSS receiver signal tracking and acquisition should be tested in the scenario.

6. Future Considerations

   Work is currently underway domestically and internationally towards the development of multi-frequency, multi-GNSS standards. Such standards will support additional signals in the 1559 – 1610 MHz band, including the Galileo open service and GPS L1C signals that use a multiplexed binary offset carrier modulation (MBOC). The power spectral density of MBOC is much broader than the GPS L1 C/A-code and may require wider bandwidth avionics.

Future GNSS avionics, in order to accrue the benefits of new civil signals on other frequencies (e.g., GPS L5 at 1176.45 MHz) will require new airborne multi-band antennas. These will likely be stacked patch antennas, and it is possible that their gain performance at L1 will suffer in comparison to existing antennas. Additionally, in the future, GNSS avionics may be required to meet more demanding performance requirements. These factors, together, will tighten current slim margins on interference budgets (see, e.g., DO-235B) for airborne GNSS equipment.

Cellular

Cellular Telephone AGPS Use Cases

The three primary use case examples for GPS receivers in cellular telephones are: 1) E911 Location; 2) Location-Based Services and 3) Real-Time Navigation. This is not an all-inclusive list, but the three groups above are representative of typical AGPS use in the context of cellular telephones. Each of these three use cases is associated with unique signal level and propagation aspects, driven, in part, by device orientation and proximity to the user.

- **E911 Location:** During an E911 call, the cellular telephone is expected to obtain a fix within 20 seconds to an accuracy of 50 meters 67% of the time and an accuracy of 150 meters 95% of the time. These performance criteria are in alignment with FCC E911 requirements. During an E911 call, the cellular telephone must be capable of meeting the location accuracy requirements described above while the device is held to the user's ear, which may affect the manufacturer's selection of antenna design and location.
- **Location-Based Services:** This use case provides cellular telephone users with information concerning businesses, activities, events, etc., located or taking place near the user's current location. Typically, in this use case the cellular telephone is oriented such that the display is easy to read, which may imply that the GPS antenna is facing away from the sky.
- **Real-Time Navigation:** This use case allows the user to utilize his cellular telephone as a navigation device. Like location-based services above, the cellular telephone will typically be oriented such that it does not have a direct view of the sky. In addition, the cellular telephone may be situated inside a moving vehicle where the GPS signal strength is further compromised and fading is prevalent.

Cellular Telephone Non-AGPS Use Case

- **E911 Roaming:** In instances where a cellular telephone is roaming onto another system, the telephone may not be able to receive network assist information from the roaming network. In these instances, E911 location information is determined by the cellular phone in an independent fashion using GPS in an autonomous mode.

General Location/Navigation

Operational Scenarios:

1. *PND Use Case 1: Suburban*
   Suburban, tree lined environment mounted on dash of vehicle. Frequent changes of direction, obscuration of signals by the roof of the car, signal attenuation through windscreen, mild dynamics. Unit needs the ability to lock on to the correct road and navigate turns successfully. Need to distinguish between adjacent roads and ramps.

2. *PND Use Case 2: Urban Canyon*
   Urban canyon environment mounted on dash of vehicle. Frequent changes of direction, obscuration of signals by the roof of the car, blockage of satellites in view by tall buildings, signal attenuation through windscreen, mild dynamics. Unit needs the ability to lock on to the correct road and navigate turns successfully. Need to distinguish between adjacent roads and ramps.

3. *Outdoor Use Case: Golfing*
   Open area environment. Unit is held in the hand of a user who is walking and standing. Some dynamics associated with walking with the device, partial obscuration of signals by user's body. Unit needs the ability to measure distance, track user's position, and navigate to waypoints successfully.

4. *Outdoor Use Case: Deep Forest*
   Deep forest environment. Unit is held in the hand of a moving user. Some dynamics associated with walking with the device, obscuration of signals by forest canopy and body of user. Unit needs the ability to measure distance, track user's position, and navigate to waypoints successfully.

5. *Fitness Use Case: Arm Swing Environment*
   Unit under test mounted on the arm of a user who is swinging their arms in a manner consistent with distance running. The unit will experience frequent heading changes and the signal will be obscured by the body at times. Stressful dynamics are associated with the arm swing. Unit needs the ability to measure distance, track user's position/velocity, and navigate to waypoints successfully.

High Precision

1: Single point mode (no Augmentation)
Time To First Fix (s)
Position accuracy (m)
Velocity accuracy (m/s)
Time accuracy (ns)
PVT availability (% of time, or coverage area)

2 : WAAS Augmentation Stationary
(Same TTFF, PVT as above)

3: DGPS+RTK (code and carrier)
(Same TTFF, PVT as above)

Timing

The following operation modes of devices in the category will be considered:

1) Autonomous operation in a single point mode (no augmentation), stationary
2) WAAS augmented operation, stationary

Networks

The operational scenarios of networks vary greatly by network type. This information is still being gathered by the TWG.

Space-based Receivers

Application scenarios:
1. The BlackJack family of receivers are each ground tested using rooftop antennas at the Jet Propulsion Laboratory for performance and burn-in for approximately 2000 hours before launch.
2. A "worst case" scenario after launch has the occultation antenna, with up to 18 dBi antenna gain, directed toward the earth limb at the Eastern 1/3 of the continental USA. Six satellites are planned for an orbit at 520 km altitude, 24 degrees inclination, with six more at 800 km and 72 degrees.

Work Plan Item 4: Establish methodology for analyzing test results

The TWG has discussed analytical methodologies that might be appropriate for interpreting the test results. For example, as devices are tested and the power levels at which terrestrial broadband signals impact them are determined, it will be necessary to understand the distances from a LightSquared site at which those power levels might occur. The actual distance is a function of not only LightSquared's operating parameters (power levels, antenna orientation, etc.), but also of the terrestrial broadband signal attenuation. The TWG is evaluating models to determine which ones are appropriate for specific use cases and environments. Analytical methods which are required to evaluate the test results have not yet been addressed by the TWG.

Work Plan Item 5: Derive test conditions based on the established operational scenarios

The sub-teams assigned to each category are tasked with deriving test conditions based on the identified operational scenarios. This activity is underway and will be completed as part of the process of developing test plans and procedures.

Work Plan Item 6: Write test plan and procedures

The sub-team process is being utilized to review existing, industry standard test plans that are prevalent for device certification, for categories where such plans exist. Where such test plans exist, , they will be considered for the TWG testing program and will be supplemented with additional elements to facilitate an understanding of the impact of operation of the terrestrial broadband network.

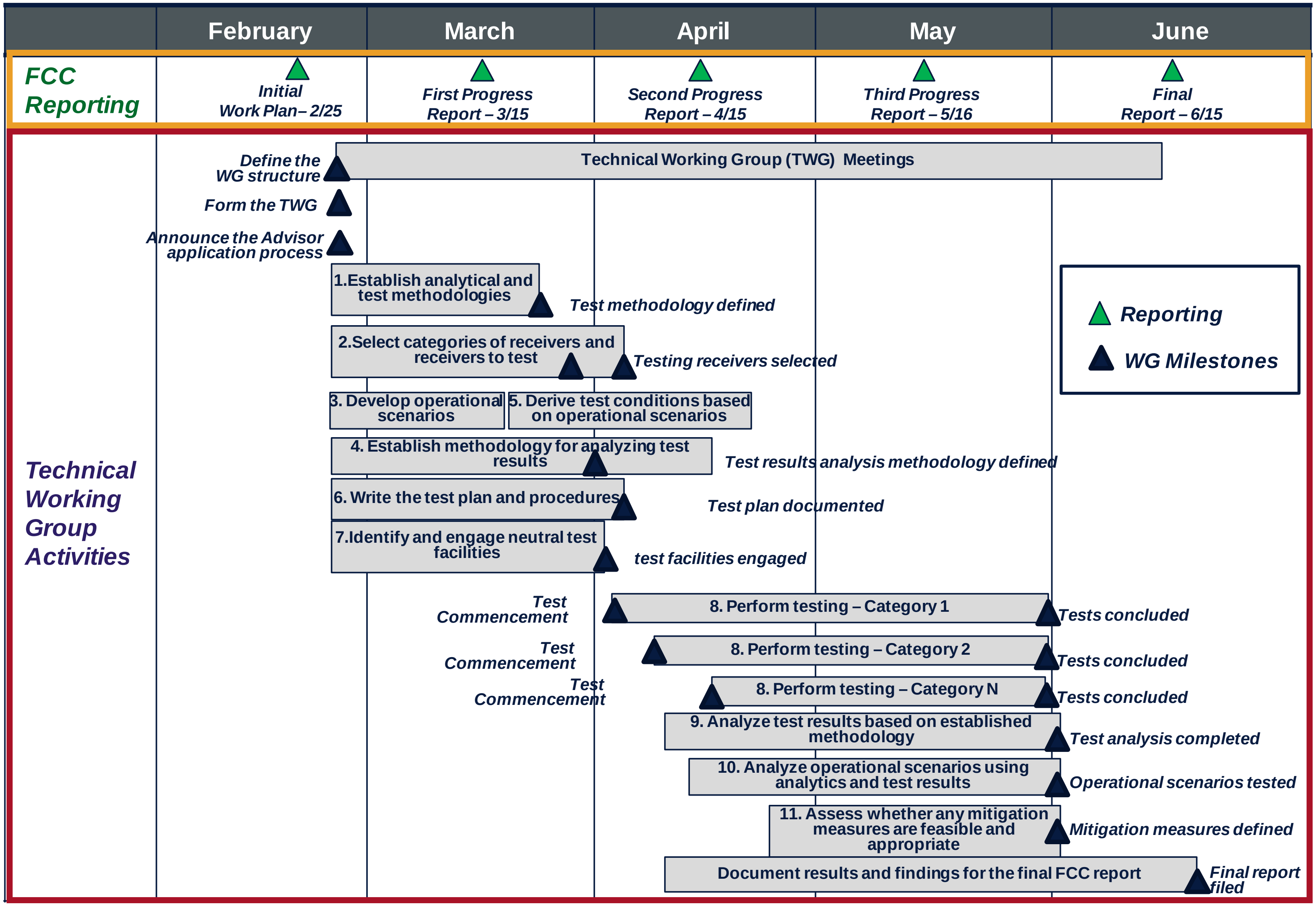
Work Plan Item 7: Identify and engage appropriate facilities

Several potential testing locations in university and industry settings have been identified by members of the TWG. TWG members have begun reaching out to test facilities to determine their available capacity and capabilities to conduct the testing that the TWG is undertaking.

Going-Forward Activities

The following timeline lays out the planned process and sequence of activities for the TWG up to and including the filing of the final report which is due to the FCC on June 15, 2011. The WG co-chairs will update the Commission on its progress in the subsequent progress reports on April 15 and May 16, 2011.

TWG Planned Process Timeline



Appendix A
FCC ORDER DA 11-133
GPS WORKING GROUP MEMBERSHIP

GPS Working Group Co-Chairs

Jeffrey Carlisle

Jeff Carlisle is Executive Vice President for Regulatory Affairs and Public Policy for LightSquared, where he is responsible for all domestic and international regulatory and policy matters. Before joining LightSquared, Jeff served as Vice President, International Public Policy and Government Relations of Lenovo, the global computer manufacturer. From 2001 to 2005, Jeff served as Deputy Chief and then Chief of the FCC's Wireline Competition Bureau. From 1995 to 2001, he practiced law at O'Melveny & Myers and independently. He received a B.A. in History, magna cum laude and with honors, from UCLA; a J.D. from Boalt Hall at the University of California, Berkeley; and an M.A. in Law and Diplomacy from The Fletcher School.

Charles R. Trimble

Charles R. Trimble was the principal founder and served as President, Chief Executive Officer, and a director of Trimble Navigation Limited from 1981 to 1998. He strategically guided Trimble to its dominant role in the GPS information technology market. Mr. Trimble has been personally responsible for many of the breakthrough innovations at Trimble. For example, the underlying patent, on which the very successful TANS products are based, is held by Mr. Trimble. Under his leadership, Trimble grew from a startup housed above a theater to the first publicly held U.S. company engaged in providing GPS solutions. Prior to founding Trimble Navigation, Mr. Trimble had already established a reputation for innovation in development at Hewlett Packard, as Manager of Integrated Circuit Research and Development at Hewlett Packard's Santa Clara division. He led important commercial advances in 4 areas, 1) the efficient quantization of noisy signals and their subsequent signal processing; 2) high speed monolithic analog to digital converters; 3) ultra high precision single shot digital time interval measurement techniques; 4) establish IEEE 488 bus standard. Mr. Trimble is a principal founder and the current Chairman of the United States GPS Industry Council (USGIC) . He is a member of the National Academy of Engineering (NAE) member of the Board of Trustees of CALTECH (California Institute of Technology); he served as a member of the Board of Governors for the National Center for Asia-Pacific Economic Cooperation (APEC), he is a member of the Council on Foreign Relations; and the NASA Advisory Council (NAC). Mr. Trimble received his B.S. degree in Engineering Physics, with honors, in 1963, his M.S. degree in Electrical Engineering in 1964, and the Distinguished Alumni Award in 1995 from the California Institute of Technology. Mr. Trimble holds four GPS-related U.S. patents and has published articles in the field of signal processing, electronics, and GPS.

Technical Working Group Members

<u>Dominic Arcuri</u>

Dominick Arcuri, P.E. is a Senior Vice President with RCC Consultants, Inc., in charge of Public Safety Radio Communications consulting in the Mid-Atlantic, Midwest and Southeast regions. Prior to joining RCC, Mr. Arcuri served as Vice President of Engineering of the Land Mobile Radio Division of Ericsson, Inc. He has been engaged in the management of engineering and product development in communications and defense electronics over a 30-year period with RCC, Ericsson and General Electric Aerospace. Dominick has been active in the Telecommunications Industry Association (TIA) and APCO P25 committees since 1994 and has previously chaired the committee responsible for Phase II 2-slot TDMA systems. Mr. Arcuri is a registered professional engineer in Virginia and a certified Project Management Professional. He holds a Bachelor of Science degree in Electrical Engineering from Renssalear Polytechnic Institute, a Master of Science degree in Electrical Engineering from Syracuse University, and a Master of Business Administration degree from the Fuqua School of Business at Duke University.

<u>Knute Berstis*</u>

Knute Berstis has been involved in GPS data acquisition and processing for some 30 years. He has been with NOAA since its inception in 1970 and has been with the National Geodetic Survey since 1984. He is also involved in GPS Modernization through participation in numerous working groups such as RTCA Working Group 6 (GPS Interference), Federal Radionavigation Plan 2008 and the current 2010 FRP update Working Groups, the National PNT Engineering Forum Working Group, the Civil Signal Monitoring Working Group, and the 2025 Architecture Development and Architecture Transition Teams. Since July 2009 he has been detailed from NGS to the National Coordination Office. Mr. Berstis received his BS in Electrical Engineering from the University of Nebraska and his MSEE from George Washington University. He is a registered Professional Engineer in Washington, DC.

<u>John Betz*</u>

John Betz is a Fellow of the MITRE Corporation. He has contributed to the design of several modernized GPS signals, made fundamental contributions to understanding interference effects on GPS receiver operation, and contributed to technical discussions concerning compatibility and interoperability between GPS and other Global Navigation Satellite Systems. He is a Fellow of the IEEE and of the Institute of Navigation. Dr. Betz received a B. S. in Electrical Engineering from the University of Rochester in 1976, a M.S. in Electrical Engineering from Northeastern University in 1979, and a Ph.D. in Electrical Engineering from Northeastern University in 1984.

<u>Michael Biggs*</u>

Michael Biggs is a senior engineer with the United States' Federal Aviation Administration's Air Traffic Organization Spectrum Engineering Services. He has over 25 years of system design and spectrum management experience, both in industry and for the Federal government. He was intimately involved in U.S. government activities to define and gain international acceptance for GPS L5, and in his current position, his duties include serving as spectrum matters expert for U.S. delegations to International Civil Aviation Organization and International Telecommunication Union fora.

Scott Burgett

Scott Burgett is a Software Engineering Manager with Garmin International. Scott oversees Garmin's consumer GPS area. He has been involved with GPS since 1991. Scott began his career in GPS working with high accuracy motion measurement systems for synthetic aperture radar. Scott was a principle contributor to Garmin's first Portable Navigation Device with turn by turn voice guidance and has worked on many other consumer GPS devices for Garmin. Scott also has worked on GPS-based avionics, contributing to Garmin's GNS 430/530 and G1000 products lines. Scott's education includes a Bachelor of Science in Electrical Engineering from Kansas State University, and a Master of Science in Electrical Engineering from the University of New Mexico.

Santanu Dutta

Santanu Dutta is the Senior Vice President of Radio Access Technology and Chief Engineer of LightSquared. He is responsible for the RF system architecture of LightSquared's hybrid network, which comprises integrated satellite and terrestrial (LTE) subnetworks. His responsibilities include developing the radio access networks (RAN) and chipset platforms for both subnetworks. Dr. Dutta is also responsible for spectrum management and standardization. He has over 33 years experience in the wireless industry where he has also held positions with Rockwell Collins and Ericsson. He holds a Bachelors Degree in Electronics and Electrical Communications Engineering from the Indian Institute of Technology, a Masters Degree in Communications Engineering from the University of Bradford and a PhD in Electrical Engineering from the University of Manchester

Richard Engelman

Richard Engelman is the Director of Spectrum Resources for Sprint Nextel. Rick is an electrical engineer with 35 years of professional experience in radio communication, both in government and industry. Prior to Sprint Nextel, Rick served at the FCC for 30 years, working in a variety of positions focusing on radio interference, radio regulation and spectrum policy matters. He was a member of Chairman Powell's Spectrum Policy Task Force and served as chair of the Spectrum Efficiency Working Group in 2002. He is a former head of the US delegation to ITU on International Mobile Telecommunications 2000. In 2005 he received the FCC's Distinguished Service/Gold Medal Award for accomplishments that had an extraordinary impact on the ability of the FCC to accomplish its mission. He is a Senior Member of IEE and recipient of the IEEE Third Millennium Award for outstanding contributions.

Pat Fenton

As the Chief Technology Officer of NovAtel Inc., Pat Fenton is responsible for the company's research division which investigates advanced technologies and their possible integration into NovAtel's Global Navigation Satellite System (GNSS) product line. Pat has been the chief system GNSS architect for the company for over twenty-five years. He has been instrumental in six generations of GNSS receiver development. These developments include receivers that track single or combinations of the GPS, GLONASS, Galileo and Compass satellite constellations, tracking their signals in the L1, L2 and L5 Radio Frequency Bands. Pat received a BSc in Survey Engineering from the University of Calgary in 1981.

John Foley

John Foley is a Software Engineering Team Leader with Garmin International. John is the Project Engineer responsible for Garmin's aviation GPS/SBAS receiver technology. He has over 18 years experience developing software for aviation and defense applications, including 11 years of experience developing GPS-based avionics. Since 2005 John has served as Garmin's representative to RTCA Special Committee 159 and was an active contributor to the development of DO-229D, the Minimum Operational Performance Standards for GPS/WAAS Airborne Equipment.

Paul Galyean

Paul Galyean is Manager of Systems Engineering at NavCom Technology (division of John Deere). His primary responsibilities include the management of development for advanced position locating systems and electronics for GNSS receivers. He has been involved in the design and development of navigation and augmentation systems for 40 years, including terrestrial radio navigation systems, Transit, and GPS, and has been part of the system engineering and management teams for all recent NavCom GNSS receivers. Paul's education includes a PhD in mathematics from UCLA.

Capt. Anil Hariharan*

Capt. Anil Hariharan is the Chief of GPS Spectrum Engineering in the GPS Directorate. The Global Positioning Systems Directorate is a joint service effort directed by the US Air Force and managed at the Space and Missile Systems Center, Air Force Space Command, Los Angeles Air Force Base, Calif. He leads all DoD analysis for GPS interoperability and compatibility; leads interference assessment teams for GPS, and leads anomaly resolution teams for GPS. Capt. Hariharan received a B.S. in Electrical Engineering from Purdue University and an M.S. in Systems Engineering from the Air Force Institute of Technology

Chris Hegarty*

Dr. Christopher J. Hegarty is the Director for CNS Engineering & Spectrum with The MITRE Corporation, where he has worked mainly on aviation applications of GNSS since 1992. He is currently the Chair of the Program Management Committee of RTCA, Inc., and co-chairs RTCA Special Committee 159 (GNSS). He served as editor of *NAVIGATION: The Journal of the Institute of Navigation* from 1997 – 2006 and as president of the Institute of Navigation (ION) in 2008. He was a recipient of the ION Early Achievement Award in 1998, the U.S. Department of State Superior Honor Award in 2005, the ION Kepler Award in 2005, and the Worcester Polytechnic Institute Hobart Newell Award in 2006. He is a Fellow of the ION, a Fellow of the IEEE, and co-editor/co-author of the textbook *Understanding GPS: Principles and Applications*, 2nd Ed.

Bronson Hokuf

Bronson Hokuf is a Design Engineering Team Leader at Garmin International. Bronson began his career at Garmin working on handheld VHF/UHF products, where he was involved in LNA, VCO, and mixer design. He has also been involved in the design, testing and qualification of L-band LNAs, front-end filters, and antennas for various products that he developed for the outdoor, Auto/OEM, and Mobile segments, before moving into the team leader role in the Automotive segment. Bronson holds a B.S.E.E. from Cedarville University with an emphasis in Communication Systems.

Sai Kalyanaraman

Sai Kalyanaraman is a Senior Systems Engineer at Rockwell Collins in Cedar Rapids, IA and is involved in airborne GNSS receiver development and its applications. He received his M.S. and Ph.D. degrees in Electrical Engineering with a specialization in Navigation Systems from Ohio University, Athens, OH. Dr. Kalyanaraman is a member of RTCA Special Committee SC-159 Working Group 6 (WG-6, which defines GPS Interference requirements for airborne solutions) and is a co-chair of WG-7 (which defines GPS Airborne Antenna requirements). He chaired development of the standalone GPS Receiver MOPS (RTCA DO-316) and is an active contributor to the other working groups in SC-159. His areas of interest include signal processing, multipath modeling, adaptive antenna arrays for interference mitigation and GNSS receiver design.

Jerry Knight

Jerry Knight is a Senior Product Design Engineer at NavCom Technology (division of John Deere). He is the architect for Deere's precision GPS receivers and has been involved in the design of GPS receiver hardware and software for over 30 years at NavCom, SiRF Technolgy, Leica and Magnavox. Previously, Jerry led teams that achieved the first DO229C certified GPS receiver, the first certified SAASM receiver and the first RTCA-104 compatible differential GPS system delivered to the US Coast Guard. Jerry's education includes a BS in Earth Sciences from California University, Hayward and MS degrees from University of Arizona with majors in Geosciences and Computer Sciences. Jerry is the author and coauthor of numerous publications and patents. Jerry is serving as an alternate member of the TWG for NavCom Technology.

John Lacey

John Lacey serves as a Systems Engineer, and in particular as the Operations Manager & Lead Systems Engineer for the Lockheed Martin RPS/GCCS Program, and has responsibility for GCCS Integration & Test Lead Engineer. However, he has been engaged in satellite communications since 1982 to present, having extensive hands-on experience with a wide variety of technical aspects of satellite and wireless communications, both analog and digital. Mr. Lacey is serving as an alternate member of the TWG for Lockheed Martin.

Farokh Latif

Farokh Latif is the Director of AFC for Spectrum Management Division of the Association of Public Safety Communications Officials International) (APCO). Mr. Latif has a Bachelor's Degree in Electrical Engineering, and has been employed by APCO since January of 2001. Prior to joining APCO, Mr. Latif was employed by the State of Florida as an Electrical Engineer where he helped local, city, and state governments with system design and implementation. Mr. Latif has been the Director of AFC since July of 2007.

Richard Lee

Richard Lee is the President of Greenwood Telecommunications which focuses on wireless, positioning, A-GPS, precise indoor location, MSS communications, WCDMA & LTE femtocell, 3G/4G RF semiconductor design, product planning comprehensive launch and economic modeling, selected regulatory/spectrum management matters and currently consults to LightSquared. Rich has been in the wireless industry for 35 years and has been involved with mobile GPS since 2000 including as co-founder in two venture backed GPS start-ups. Rich has held senior executive level positions for a variety of companies including Motorola, US WEST/AirTouch, Global Locate, plus two A-GPS start-ups, RX Network and iPosi. He received a BSEE from the University of Detroit and an MBA from the University of Chicago.

Fred Moorefield*

Fred Moorefield serves as Technical Director and Director of Strategic Planning, Air Force Spectrum Management Office, Washington, D.C. In this capacity he provides strategic and engineering advice to the AFSMO Commander, Air Force Space Command Commander, and the Secretary of the Air Force Chief Information Office on all engineering and strategic planning matters concerning National and International telecommunications policy on the use of the radio frequency spectrum. Mr. Moorefield is also the current Air Force Interdepartment Radio Advisory Committee representative.

Tim Murphy

Tim Murphy is Technical Fellow with the Boeing Commercial Airplane group where he is a member of the Electronic Systems organization. Tim has 27 years of experience in the field of radio navigation and communications systems for civil aviation. The current focus of his work is avionics for new airplane product development, and next generation CNS technologies to support Air Traffic Management. Tim's primary expertise is in navigation systems including satellite navigation systems (GPS, GPS augmentations, GPS modernization, GPS Landing Systems) as well as conventional navigation systems (VOR, DME, ILS etc.). Tim is very active in the development of domestic international standards for use of satellite navigation by commercial aviation. He is the panel member nominated by ICCAIA to the ICAO Navigation Systems Panel. He currently serves as a member of the National Space-Based PNT Advisory Board. He has been an active participant within RTCA in the areas of Satellite Navigation, Satellite Communications and Automatic Flight Guidance and Control Systems. He has published more than 30 papers and holds 10 patents. He received a BSEE and MSEE from Ohio University where he was a Stocker fellow and graduate research intern at the Ohio University Avionics Engineering Center.

Gary Pasicznyk

Gary Pasicznyk is the Manager of the Electronic Engineering Bureau of the City & County of Denver Colorado, where he is responsible for overseeing the maintenance and administration of a state of the art public safety communication system for the City and County of Denver. In this position, his responsibilities include maintenance, planning and operational aspects of communications. The systems provide emergency communications for police, fire, EMS, and many other governmental agencies and supports over 8,000 individual radio users. He is involved in planning and implementing alternatives to ensure emergency communications capabilities at all times. Mr. Pasicznyk holds an Associates of Applied Science degree from North Dakota State School of Science.

Bruce Peetz

Bruce Peetz is the Vice President of Advanced Technology at Trimble Navigation Limited. He has been involved in the development of GPS technology for over 20 years, including overseeing the design of many Trimble products. Bruce received his undergraduate degree in electrical engineering from MIT and did graduate work at UCLA.

Brian Poindexter

Brian Poindexter is the Design Engineering Manager for Consumer Automotive products at Garmin. Brian began his career designing electronic avionics systems for the general aviation market. At Garmin Brian developed Garmin's first audio system for the aviation market. Brian then transitioned to the automotive team and developed several portable navigation systems in Garmin's highly successful StreetPilot series before expanding his role to include team leadership. Brian holds a Bachelor of Science in Electrical Engineering from the University of Missouri- Columbia.

Tom Powell*

Tom Powell is a Systems Director at The Aerospace Corporation, supporting the Engineering and Technology Branch of the GPS Directorate at Los Angeles Air Force Base. He leads the GNSS Engineering and Technology Group, which provides systems engineering support on issues of GPS constellation sustainment, satellite reliability, technology development, and spectrum management. He has supported the GPS program for over 15 years at Aerospace, and was lead engineer on the DAGR program from 2001-2003. He holds a BS degree in Aeronautical and Astronautical engineering from Purdue University, an MS in Aerospace Engineering from the University of Texas at Austin, and a PhD in Aerospace Engineering from UCLA.

Brian Ramsay*

Brian Ramsay is a PNT and Spectrum Policy Specialist in NASA's Space Communications and Navigation program office. He has over 20 years of domestic and international spectrum management and regulatory experience, including participation as a delegation member and/or spokesperson at several International Telecommunication Union (ITU) World Radiocommunication Conferences (WRCs). Prior to joining NASA in 2009, Brian was a Lead Communications Engineer for The MITRE Corporation supporting the Air Force Frequency Management Agency (AFFMA) where he provided domestic and international spectrum regulatory and policy expertise in areas such as GPS policy and spectrum protection. Previous experience includes service at the U.S. State Department and the National Telecommunications and Information Administration (NTIA), where he dealt with issues such as GPS policy and spectrum protection, MSS spectrum sharing with Federal agency systems, and third-generation wireless issues. Brian also previously held positions in the private sector with commercial satellite interests, satellite system engineering consulting firms, and defense contractors, where he specialized in spectrum management, policy, and regulatory issues. Brian received his B.S. degree in Electronic Engineering Technology from Colorado Technical College in Colorado Springs. He is a past Chairman of U.S. ITU-R Working Party 8D (MSS and GPS issues) and past Vice Chairman of the Telecommunications Industry Association's Satellite Communications Division.

Pat Reddan*

Patrick Reddan is a Senior Associate at Zeta Associates who has worked with the FAA WAAS and GCCS Programs providing system engineering and design development for over fifteen years. The focus of efforts is signal processing and interference mitigation techniques as applicable to differential reference stations along with detailed design implementations intended to satisfy WAAS performance and integrity requirements. He has been involved in the development of three generations of reference station receivers for WAAS and GCCS. He joined Zeta Associates in 1986 and has provided system engineering support to several national programs as well as supporting the FAA WAAS development, National PNT Engineering Forum and the GPS Evolutionary Architecture

Study (GEAS) group. He continues to participate in RTCA Special Committee 159 Working Group 2 for WAAS and WG6 for Interference requirements for certified GPS aviation equipment. Mr. Reddan received his B.E.E.E. from Manhattan College and the Degree of Engineer (EE) as well as Master in Engineering Administration from George Washington University.

<u>Daniel Reigh</u>

Daniel Reigh has worked on RNSS spectrum issues at Lockheed Martin, including RF test licensing, for the last three years. Mr. Reigh has also addressed signal interference concerns for several years, including the SVN49 issue and the addition of the L1C signal to the GPS system. Mr. Reigh is serving as an alternate member of the TWG for Lockheed Martin.

<u>Mark Rentz</u>

Mark Rentz is a Senior Systems Engineer at NavCom Technology (division of John Deere). His primary responsibilities include the design and development of advanced position locating systems and electronics for GNSS receivers. At NavCom he was responsible for the original design of the StarFire GNSS augmentation system. For 30 years he has been doing communication systems engineering, mostly for military and commercial satellite systems and receivers. He has been part of the system engineering team for all recent NavCom GNSS receivers, and has been the principal designer of antenna/LNA systems for these receivers. Mark's education includes a BS in Engineering from Harvey Mudd College, Claremont CA and an MSEE from Stanford University.

<u>Stuart Riley</u>

Stuart Riley is the Engineering Manager for GNSS Product Development at Trimble Navigation Limited, and has been at Trimble for over 15 years. Stuart is responsible for architecture and product design of Trimble's precision GNSS products. Stuart received his PhD in Electrical Engineering from the University of Leeds in the United Kingdom.

<u>David Shively</u>

David Shively is currently a Lead Member of Technical Staff in the Radio Technology Group at AT&T. He is active in the evaluation of new wireless technologies and works in developing AT&T's strategy for wireless services including regulatory issues related to spectrum and interference. He regularly works with the CTIA, 3G Americas, ATIS, etc., on issues related to spectrum, regulations, and wireless services. In 2007, Dr. Shively received the AT&T Science and Technology Medal for his work on spectrum and wireless technologies. He has also been active in the standardization of new technologies in 3GPP including UMTS/HSPA and LTE. Previously, Dr. Shively spent several years at the NASA Langley Research Center where he developed and tested antennas and antenna systems for aircraft and spacecraft. He was also involved in antenna and radar cross section measurements. Dr. Shively is currently a senior member of the IEEE and has 10 patents.

<u>Mike Simmons</u>

Mike Simmons is a Senior RF Design Engineer at Garmin International. His primary responsibilities include RF component qualification and modeling, Ultra-Low Noise Amplifier Design, Image Reject Mixer Design, RF System Architecture and Systems analysis. Duties also include high power transmitter design and development with concomitant drive circuits and systems for Garmin's Marine Systems department. Mike has been involved with Receiver and Transmitter circuit and system analysis for over 30 years. When he was with Rockwell-Collins in the late 1970s and early 1980s, he worked on the GPS User equipment for the Air Force and General Motor GPS Receivers. During the 1990s Mike served as Honeywell International's representative to RTCA Special Committee 173 as an active contributor to DO-213 and DO-220 (Forward Looking Windshear Weather Avoidance Radar). Mike's education includes a Bachelor of Science in Physics and a Bachelor of Science in Electrical Engineering (two degrees) from Rose-Hulman Institute of Technology (Terre Haute, IN) with a strong minor in mathematics and various courses through the years from George Washington University (St. Louis, MO) distance learning, Iowa State University and Colorado State University.

William H. (Bill) Stone
Bill Stone is the Executive Director of Network Strategy for Verizon Wireless. Bill's team is responsible for advanced technology planning for Verizon Wireless including the development of network evolution plans, participation in industry standards group and spectrum planning. At present, Bill's team is heavily involved in LTE advanced technology trials and developing plans to enhance and fully utilize the capabilities of the Verizon Wireless commercial LTE network. During his 22-year career in the wireless industry Bill previously served in a variety of Network leadership positions where his responsibilities included network planning, engineering, system performance and maintenance.

Mark Sturza
Mark Sturza is President of 3C Systems Company which provides consulting expertise relating to communications and navigation systems. He is currently a consultant to LightSquared. Mark has 35 years experience in the design, development and application of GPS receiver technology including major roles with Teledyne, Magnavox, Litton, NAVSYS and SIRF. He presented a GPS short course at UCLA 7 times, and presented it 4 times for industry. Mark has authored 21 papers on GPS, two of which were published in NAVIGATION, the ION journal. He has been awarded 7 GPS technology patents, and holds 18 additional patents in related fields. Mark has a BS in Applied Mathematics from the California Institute of Technology, a MSEE from the University of Southern California, and a MBA from Pepperdine University. He is a Senior Member of the IEEE and is a Senior Member of the American Institute of Aeronautics and Astronautics.

Greg Turetzky
Greg Turetzky is the Senior Marketing Director and Distinguished engineer for location strategy at CSR, plc. He came via merger with SiRF Technology, Inc in 2009 where he had been for over 13 years since its inception. His responsibilities include defining and incorporating new GNSS and other SOP technologies as well as new applications for CSR location products. He is also responsible for strategic partnerships helping to push CSR location technology into a variety of mobile platforms. Prior to joining SiRF, he worked in GPS receiver design and applications for 16 years at Trimble Navigation, Stanford Telecommunications and the Applied Physics Laboratory at Johns Hopkins University. Mr. Turetzky holds a B.A. in Physics from Cornell University and an M.S. in Computer Science from Johns Hopkins University and several patents in GPS.

A.J. Van Dierendonck
A.J. Van Dierendonck, consultant to the USGIC, is the principal at AJ Systems and a partner of GPS Silicon Valley. He received his B.S.EE from South Dakota State and

M.S.EE and Ph.D.EE from Iowa State University. He has worked on the Global Positioning System for 37 years. Dr. Van Dierendonck has received numerous awards from the U.S. Institute of Navigation (ION) and is an ION Fellow. He is also an IEEE Fellow and is in the U.S. Air Force's GPS Hall of Fame. Dr. Van Dierendonck's current work includes ionospheric scintillation effects on GNSS, GNSS spectrum protection, and future GPS and satellite-based augmentation system civil signal structures and their compatibility with Galileo and COMPASS. Dr. Van Dierendonck is a member of the RTCA, Special Committee 159 (SC159), Working Group 6, chartered with defining interference requirements for certified GPS aviation equipment, He is also co-chair of SC159's Working Group 7, chartered with defining certified aviation GNSS antenna requirements.

Rick Walton

Rick Walton is the Lockheed Martin Navigation Services Architect/Geostationary Communications and Control Segment Program Manager responsible for day to day operations and maintenance of uplink services and engineering design management. Mr. Walton has over 30 years experience in satellite communications and navigation systems engineering, with extensive knowledge of principles and processes used in managing complex programs, including technical, schedule, cost, resources and risk management. Mr. Walton's expertise extends to frequency allocation, systems engineering and systems integration and testing. He has served as a Lockheed Martin representative of RTCA SC-159 WG 2 on GPS WAAS. Mr. Walton is serving on the TWG as Lockheed Martin's primary representative.

Larry Young*

Larry E. Young earned his B.A. (Physics) from the Johns Hopkins University in 1970 and the Ph.D. (Nuclear Physics) from the State University of New York at Stony Brook in 1975. Larry has developed radiometric systems at Caltech's Jet Propulsion Laboratory since 1978, and currently supervises a group developing high precision GNSS receivers for remote sensing from space. Larry's recent work includes calculating and measuring the effects of radar interference to GPS receivers. He chaired the technology portion of the National Research Council's Committee on the Future of GPS. He holds 4 radiometric-related US patents, is author or co-author of 34 papers in scientific journals and books; and is author or co-author of 60 papers published in conference proceedings.

Information Facilitators

<u>Ann Ciganer</u>
Ann Ciganer is Vice President, Strategic Policy, Trimble and Director, Policy, for the USGIC since its founding in 1991. She has participated in radiofrequency proceedings involving satellite navigation domestically and internationally as a member of multiple U.S. delegations to the International Telecommunications Union (ITU) Conferences on behalf of Trimble and USGIC since 1997. She was the first president of the Joint Venture: Silicon Valley Defense Space Consortium and was chair of the Bay Area Regional Technology Alliance.

<u>Martin Harriman</u>
Martin Harriman is LightSquared's Executive Vice President of Ecosystem Development and Satellite Business. Martin is responsible for satellite engineering, devices and chipset development, service applications, partner solutions, as well as IT and Back Office systems. Before joining LightSquared, Martin held a number of senior executive positions with Ericsson in Sweden including Senior Vice President of Sales, Marketing, and Business Development. Prior to Ericsson, Martin was the Chief Marketing Officer of Marconi, where he also had responsibility for Marconi's Asia Pacific and Middle East businesses. He represented Marconi on the Executive of the UK Broadband Stakeholder Group, and he was also a director of Easynet, an early broadband pioneer, which was subsequently acquired by Sky. Prior to that, he led a Corporate Sales and Marketing team at BT (previously British Telecommunications).
Martin has a degree in psychology and post-graduate degrees in History and Business Administration.

<u>Geoffrey Stearn</u>
Geoff Stearn is LightSquared's Vice President of Spectrum Development. He is a 24-year veteran of the commercial wireless industry having served previously with Sprint Nextel and McCaw Cellular Communications holding management positions in regulatory, engineering, business operations and strategy functions. At Sprint Nextel he was the executive with primary responsibility for the company's spectrum acquisition and development initiatives. He holds a Bachelor's Degree in Government and Politics from the University of Maryland and a Masters of Business Administration from the George Washington University.

<u>F. Michael Swiek</u>
Mike Swiek is the Executive Director for the USGIC since its founding in 1991. He represents the USGIC in international initiatives involving GNSS. Mr. Swiek served previously as Vice President of the Nomos Corporation, a Washington-based consulting firm specializing in high technology trade issues.

List of Advisors to GPS Working Group

The following individuals have offered to serve as advisors to the GPS Working Group:

Bob Calaff, Director, Spectrum and Technology Strategy, T-Mobile USA
Mark Cato, Senior Staff Engineer, Air Line Pilots Association
Giselle Creeser, Lockheed Martin

Charles Daniels, Senior Policy Analyst, Overlook Systems Technologies, Inc.
Walter Feller, Hemisphere GPS, Inc.
Alex Gerdenitsch, Motorola Mobility
R. Scott Harris, Florida Permanent Reference Network
Richard Kolacz, President, Global Spatial Technology Solutions
Alfred Leick, Professor, University of Maine
Charles Meyer, Principal Engineer, Alcatel Lucent, Bell Laboratories
Olav Queseth, Senior Researcher, Ericsson, Inc.
Michael E. Shaw, Lockheed Martin
Claudio Soddu, Director of Navigation and Operational Services, Inmarsat Global Limited
Mike Woodmansee, RF Engineer, Ericsson, Inc.

*Denotes GPS Working Group participants that are employees or contractors of the Federal Government. These individuals provide technical input to the GPS Working Group only. Reports and filings made by the GPS Working Group do not necessarily represent the views of these individuals.

Appendix B

Relevant Technical Characteristics of LightSquared Network

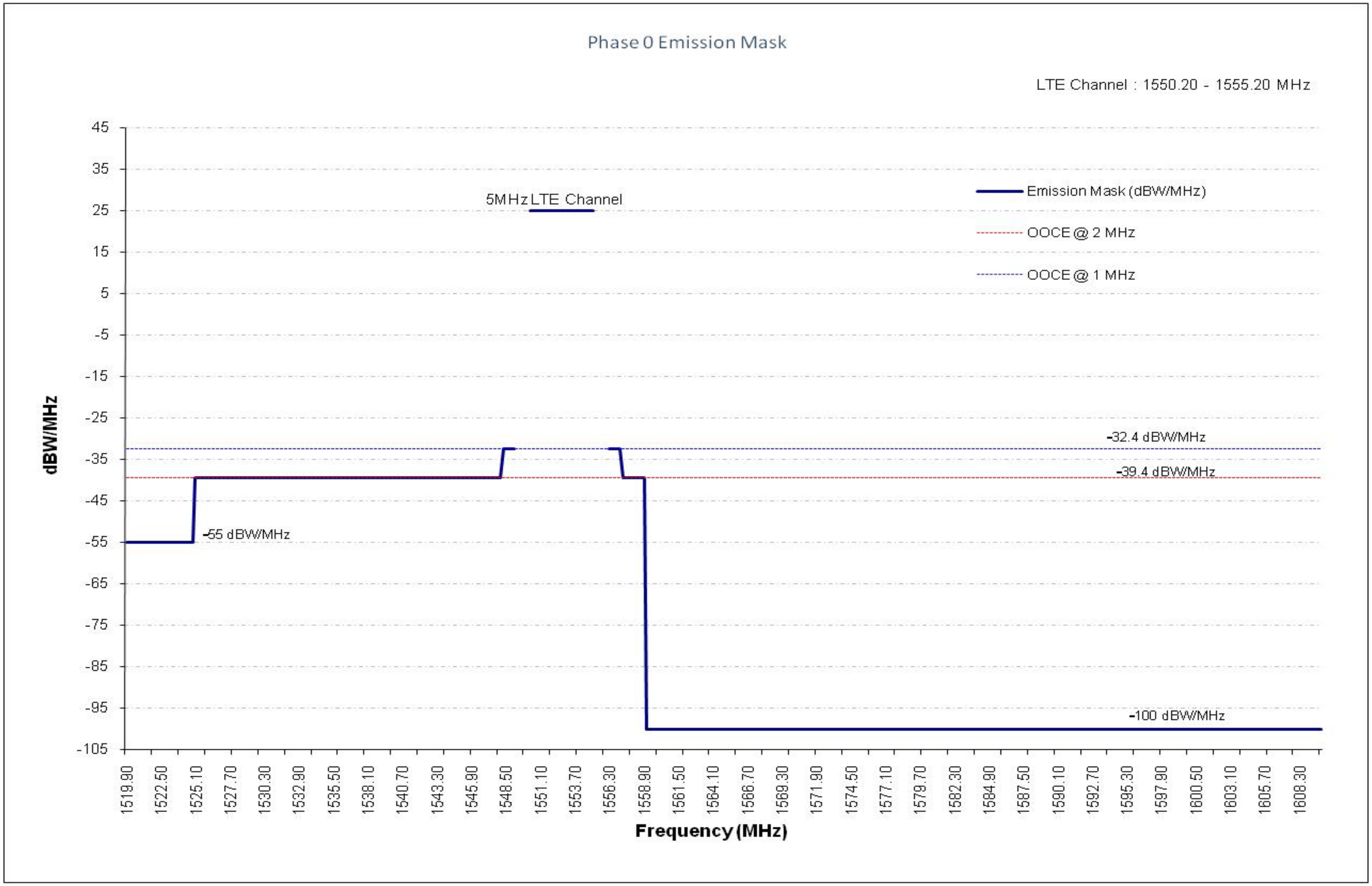
LightSquared RAN RF Characteristics

- **LTE Technology (OFDM)**
- **Three Deployment Phases. Details Below:**

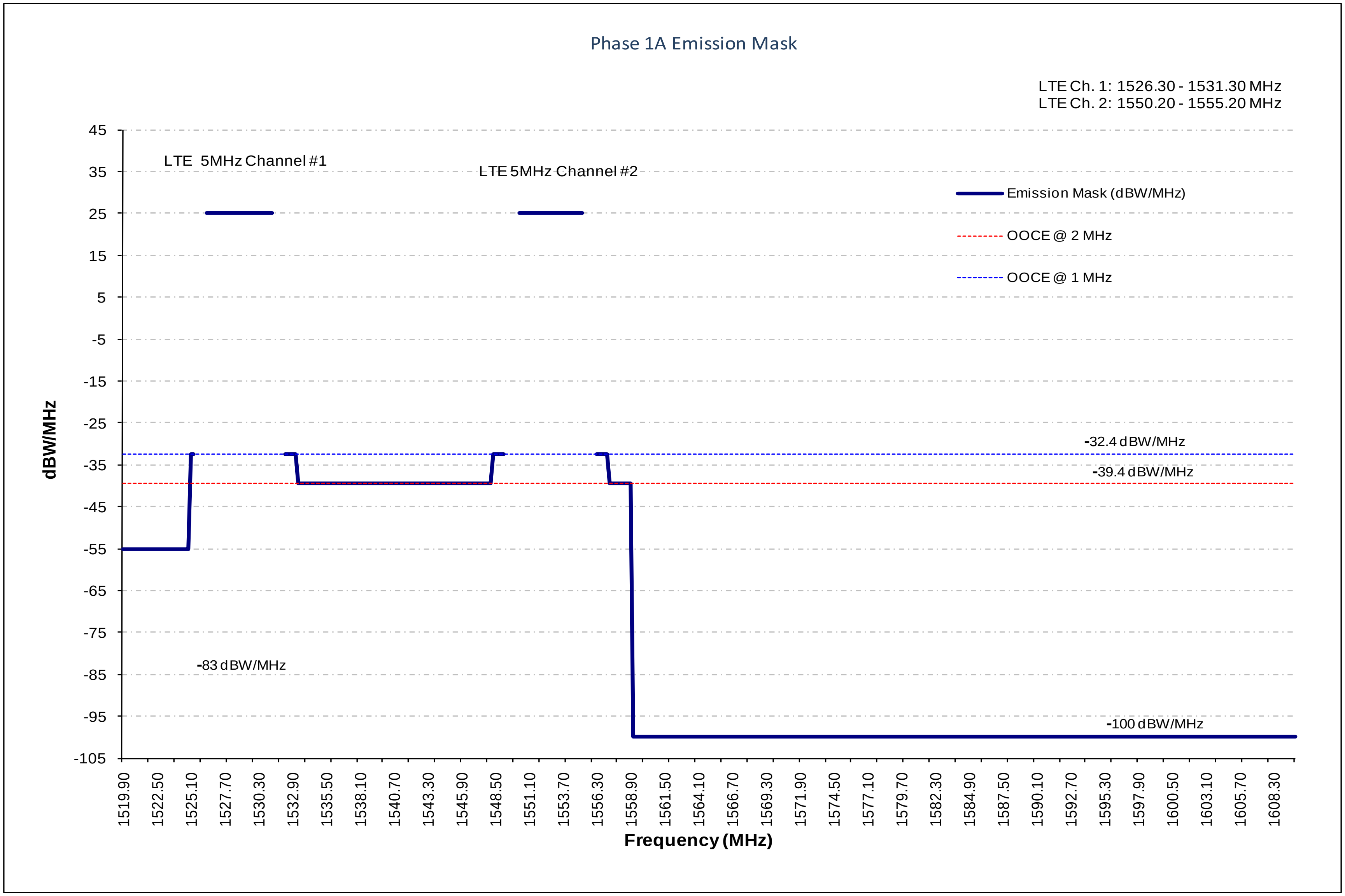
Development Phase	Channel Quantity and Size	Channel Locations	Nominal BTS Channel EIRP
Phase 0	One (1) 5MHz FDD	DL: 1550.2-1555.2MHz UL: 1651.7-1656.7 MHz	32 dBW (25 dBW/MHz)
Phase 1A	Two(2) 5MHz FDD	**Channel 1** DL: 1526.3–1531.3MHz UL: 1627.8-1632.8 MHz **Channel 2** DL: 1550.2-1555.2 MHz UL: 1651.7-1656.7 MHz	32 dBW (25 dBW/MHz)
Phase 2	Two(2) 10 MHz FDD	**Channel 1** DL: 1526-1536 MHz UL: 1627.5-1637.5 MHz **Channel 2** DL: 1545.2-1555.2 MHz UL: 1646.7-1656.7 MHz	32 dBW (22 dBW/MHz)

- **Maximum base station EIRP emissions into RNSS band (1559- 1610MHz): -100 dBW/MHz**
- **Maximum UE EIRP: -7 dBW**
- **UE OOBE at 1559 – 1605 MHz: -90 dBW/MHz**
  - **For all new mobile terminals placed in service more than five years after commencement of ATC operations, the above limit is -95dBW/MHz**

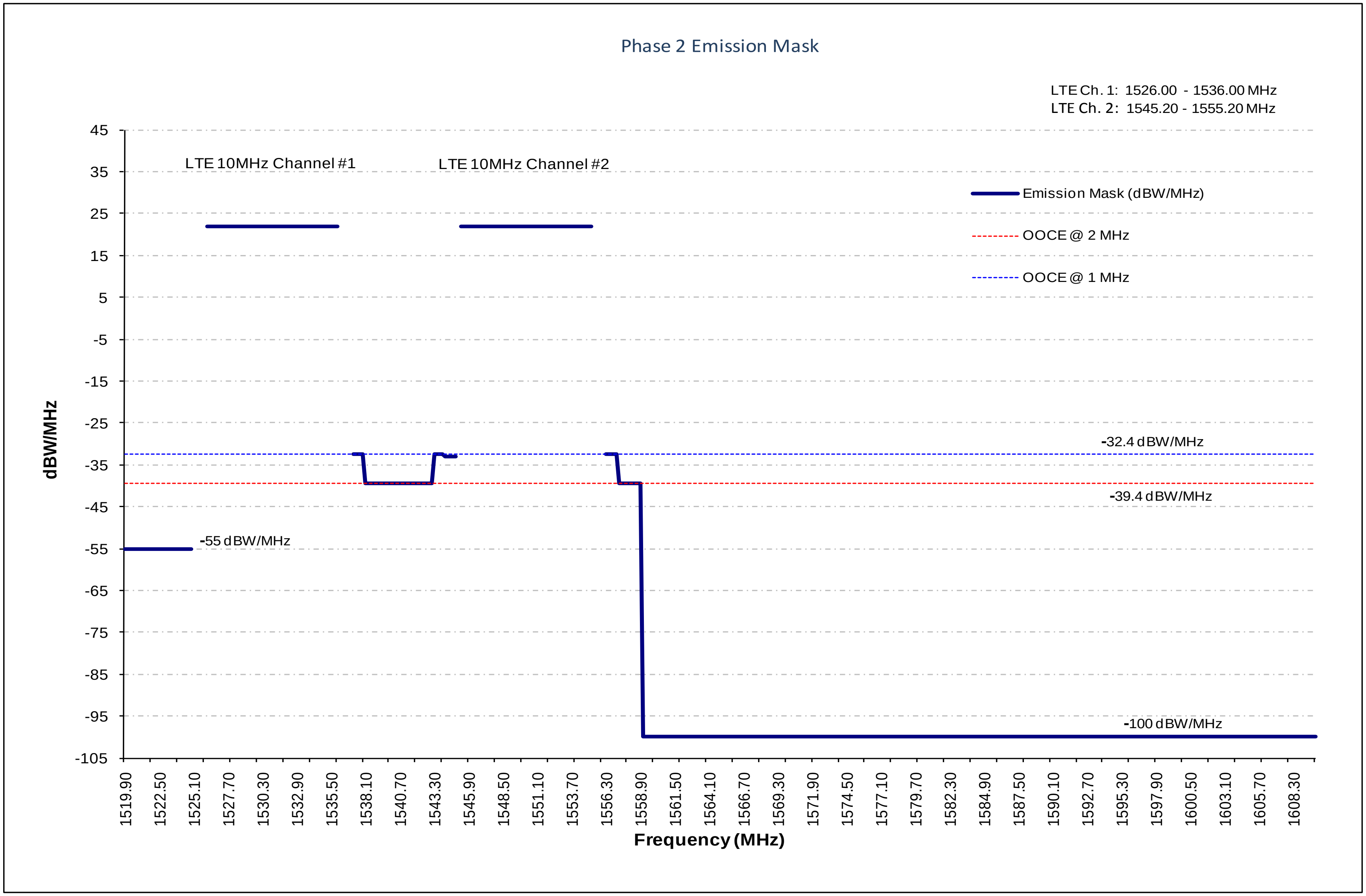
LightSquared planned Phase 0 Base Station Mask



LightSquared planned Phase 1A Base Station Mask



LightSquared planned Phase 2 Base Station Mask



Appendix C
GNSS Aviation Receivers – Performance Characteristics and Operational Scenarios

1. Overview

This document describes receiver performance characteristics and operational scenarios for civil aviation applications of GNSS. The focus is on receivers that are relied upon to allow civilian aircraft to navigate in instrument meteorological conditions (IMC)[16]. These receivers include those installed on aircraft, and those used on the ground for satellite-based or ground-based augmentation systems (SBAS/GBAS).

Currently-available airborne GPS receivers allow civilian aircraft to navigate using GPS for all phases of flight, from en route to precision approach. Over 10,000 GPS-based instrument approach procedures in the United States have been published to date.

2. Airborne Equipment

2.1 Antennas

Minimum performance standards for current-generation airborne GNSS antennas for use in the United States are provided in [1 – 4]. Harmonized requirements are included within the International Civil Aviation Organization (ICAO)'s Standards and Recommended Practices (SARPs) [5].

The majority of airborne antennas are active. Some key performance requirements include:

- Passive element gain - The minimum specified gain of the passive antenna component for elevation angles at or above 5 degrees is -5.5 dBic. RTCA recommended installed antenna gain models for minimum and maximum gain for the purposes of interference analysis are provided in [6] and summarized in Figures 1 and 2 below.
- Axial ratio - Although airborne antennas are nominally right hand circularly polarized, axial ratio is only controlled at boresight (zenith), where it is specified to be less than 3.0 dB. Like most low-profile GNSS antennas, airborne antennas tend to be approximately linearly (vertical) polarized at low elevation angles with typical axial ratios exceeding 15 dB near the horizon.
- Active antenna subassembly gain – at least 26.5 dB from the passive antenna output port to the output port of the active antenna.
- Input 1 dB compression – see Figure 3 below for minimum performance, with the level referenced to the output of the passive antenna
- Filtering requirements – see Figure 4 for minimum attenuation vs. frequency (note that the active antenna is required to provide a 3-dB bandwidth of at least 15 MHz).

[16] GPS is used on many aircraft for other purposes, including photogrammetry and flight test instrumentation. These applications are not addressed here.

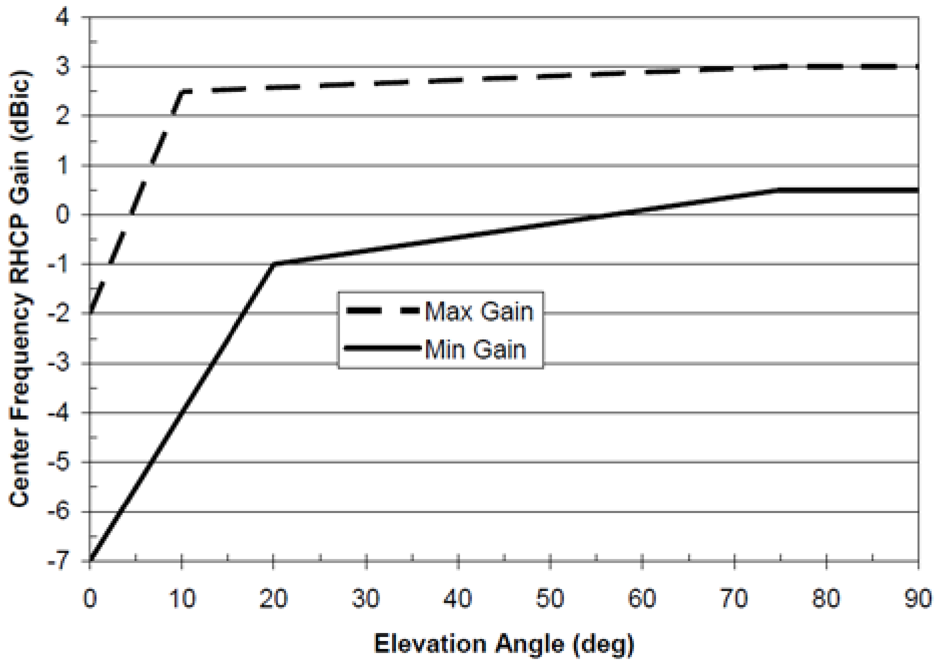


Figure 1. Minimum and Maximum Installed Airborne Antenna Gain Above the Horizon

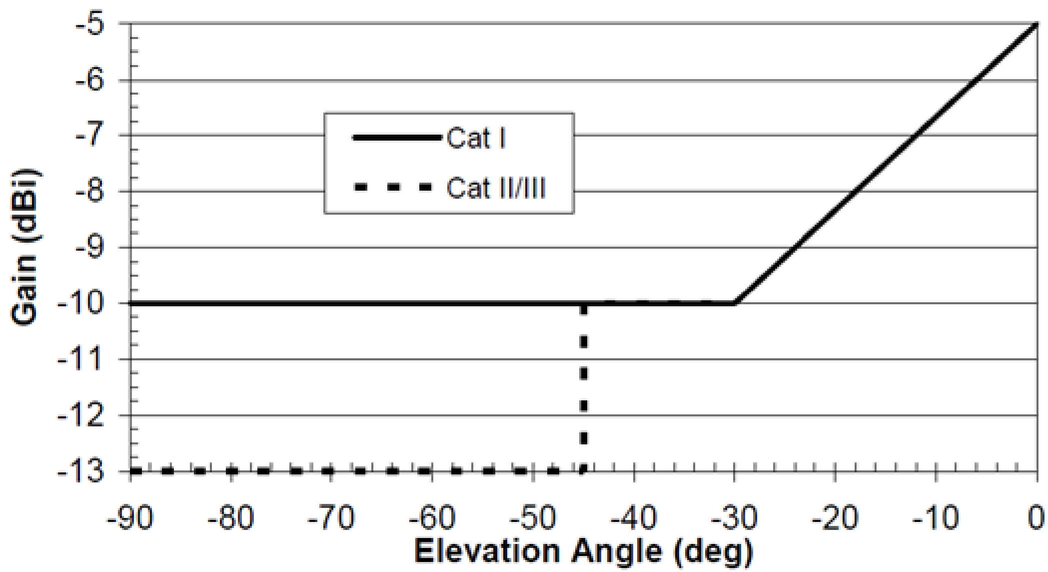


Figure 2. Maximum Installed Airborne Antenna Gain Below the Horizon

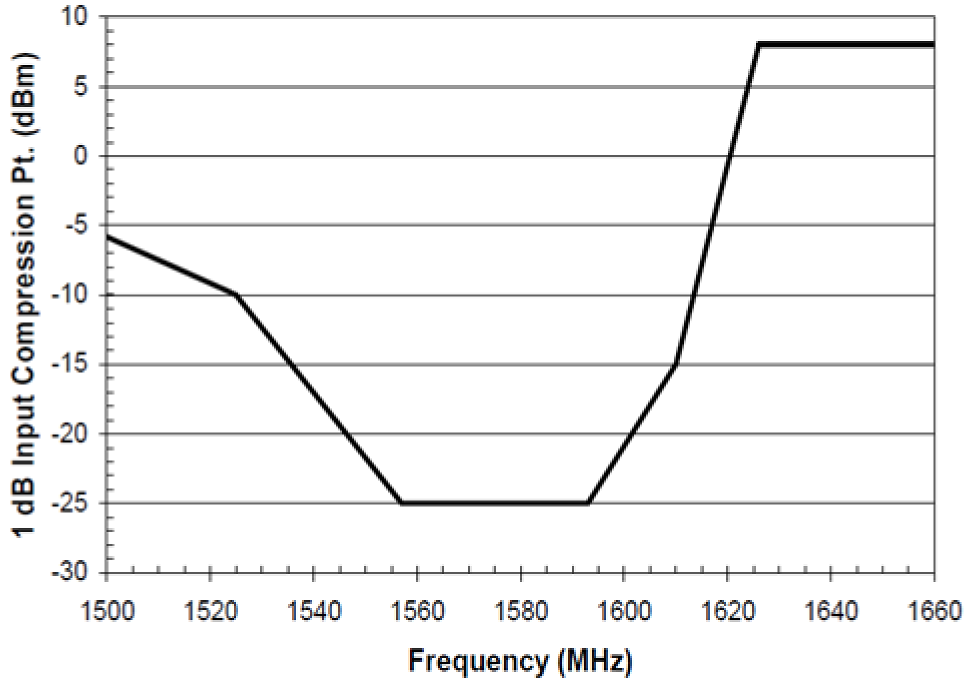


Figure 3. Input 1 dB Compression Point for Active Airborne Antenna

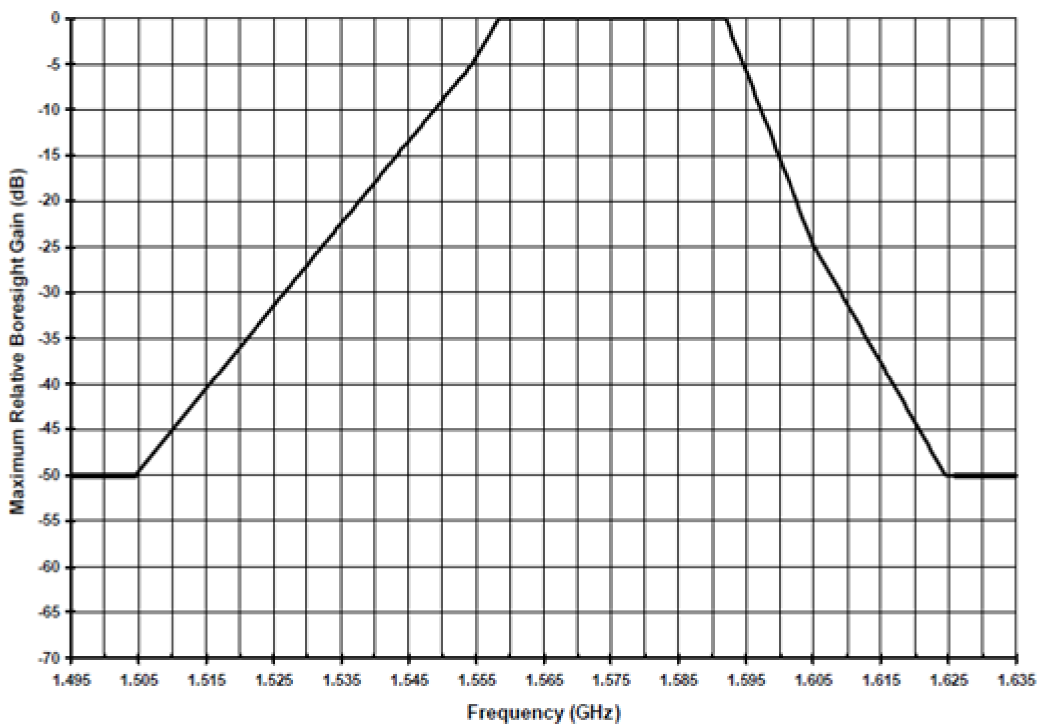


Figure 4. Antenna Frequency Selectivity Requirements

To satisfy operational performance requirements, airborne antennas must comply with many other low-level specifications that are too numerous to summarize here. See [3,4]. These include specifications on group delay differential vs. frequency, group delay differential vs. direction of signal arrival, environmental conditions, burnout protection, power supply interfaces. Airborne antennas also must be low-profile. Maximum and minimum cabling losses between the airborne antenna and the receiver would also need to be considered in light of the signal operating environment. A common form factor for airborne GPS antennas is specified in [7]. This form factor calls for a conformal antenna that is 4.7 × 2.9 × 0.75 in^3, with the height dimension (0.75 in) only accounting for the portion of the unit protruding above the fuselage.

2.2 Airborne Receivers

Current-generation civilian airborne receivers used for IMC navigation all rely on the GPS C/A-code signal broadcast at 1575.42 MHz (L1), and typical receivers have 3-dB pre-correlation bandwidths ranging from 2 to 20 MHz. WAAS-capable airborne receivers additionally rely on L1 C/A-like signals that are broadcast by geostationary satellites, which provide differential corrections and integrity data to the aircraft from a ground network. LAAS airborne receivers are provided differential corrections and integrity data from a very high frequency (VHF) datalink.

Well over 100,000 airborne GPS receivers have been sold to date in the United States. Approximately 60,000 of these include both GPS and WAAS functionality. Typical GPS equipment for large air transport aircraft are redundant (two or three) multi-mode receivers (MMRs) (see Figure 5). These receivers are referred to as multi-mode, because they also provide other navigation sensor functionality (e.g., Instrument Landing System [ILS], very high frequency omnirange [VOR], and marker beacon). They are connected via an aircraft bus to external antennas, flight displays, flight management systems, autopilot, and other avionics that require position, velocity, or timing (PVT) inputs (e.g., automatic dependent surveillance broadcast [ADS-B] equipment and terrain awareness warning systems [TAWS]).

Figure 5. Multi-Mode Receiver, approximately 7.85 in × 5 in × 14.1 in, 15 lbs (courtesy of Rockwell-Collins)

General aviation and business/regional aircraft may include distributed navigation systems similar to those employed by air transport aircraft. However, a more common configuration for general aviation aircraft is the use of a panel mount unit (see Figure 6). A typical panel-mount unit integrates GPS/SBAS with ILS/VOR, and VHF communications functionality.

Figure 6. Panel Mount General Aviation GPS Receiver, approximately 6.25 in × 4.60 in × 11.0 in, 9.5 lbs (courtesy of Garmin)

Minimum performance standards for airborne GNSS receivers are provided in [8-11] for standalone airborne equipment, in [12 - 14] for GPS/Wide Area Augmentation System (WAAS) equipment, and in [15,16] for GPS/Local Area Augmentation System equipment. Performance requirements are far too numerous to describe completely here, so the interested reader is urged to refer to the referenced standards. Some particularly challenging performance requirements include:

- Root-mean-square (RMS) pseudorange measurement error ≤ 15 centimeters at minimum GPS C/A-code signal levels (-128.5 dBm out of a reference 3 dBil user antenna as specified in [17] adjusted by the minimum airborne antenna gain of -5.5 dBic at 5 degree elevation angle as specified in [3, 4]).
- SBAS message loss rate less than 1 message per 1000 at minimum specified SBAS C/A-code signal level. (One SBAS message is 250 bits in length, and the SBAS signal data is sent at 250 bits/second as specified in [14]).

The standards also include detailed test procedures. These test procedures include laboratory testing with a signal simulator. In the acquisition-reacquisition tests [11,14], only five signals are simulated, and the tests always include one satellite (GPS or WAAS, depending on the specific test) at minimum specified power levels (minimum specified signal-in-space level adjusted by minimum airborne antenna gain at 5 degrees elevation angle). When testing receiver measurement accuracy additional satellites at the minimum satellite power are permitted. However, the measurement accuracy is tested in the pseudorange domain and is not dependent on the satellite geometry. It is not permissible to lose track of any satellite during testing, and indeed the quality of the tracking and data demodulation must meet numerous performance requirements including the RMS pseudorange error and SBAS message loss rate requirements described above. See [11,14,16] for details.

As with the airborne antennas, requirements for airborne receivers have been harmonized internationally within the ICAO SARPs [5]. A summary of the high-level performance requirements for each phase of flight supported by current generation equipment is provided in Table 1. It should be noted that the most challenging requirements are the very stringent integrity levels, which for instance only permit two or fewer occurrences out of 10 million Category I precision approach operations for the GPS sensor to provide position errors exceeding the associated horizontal and alert levels, without an alert to the pilot within 6 seconds.

Table 1. ICAO GNSS Performance Requirements

Operation	*Horizontal/ Vertical Accuracy (95%)*	*Integrity Level*	*Horizontal/ Vertical Alert Limit*	*Time-to-alert*	*Continuity*	*Availability*
En-route	3.7 km N/A	$1 - 1{\times}10^{-7}$ /h	3.7 to 7.4 km N/A	5 min	$1{-}1{\times}10^{-4}$/h to $1{-}1{\times}10^{-8}$/h	0.99 to 0.99999
Terminal	0.74 km N/A	$1 - 1{\times}10^{-7}$ /h	1.85 km N/A	15 s	$1{-}1{\times}10^{-4}$/h to $1{-}1{\times}10^{-8}$/h	0.999 to 0.99999
Non-precision approach	220 m N/A	$1 - 1{\times}10^{-7}$ /h	556 m N/A	10 s	$1{-}1{\times}10^{-4}$/h to $1{-}1{\times}10^{-8}$/h	0.99 to 0.99999
Approach with vertical guidance (APV)-I	16 m 20 m	$1 - 2{\times}10^{-7}$ /approach	40 m 50 m	10 s	$1{-}8{\times}10^{-6}$ in any 15 s	0.99 to 0.99999
Approach with vertical guidance (APV)-II	16 m 8 m	$1 - 2{\times}10^{-7}$ /approach	40 m 20 m	6 s	$1{-}8{\times}10^{-6}$ in any 15 s	0.99 to 0.99999
Category I	16 m 4 to 6 m	$1 - 2{\times}10^{-7}$ /approach	40 m 10 to 35 m	6 s	$1{-}8{\times}10^{-6}$ in any 15 s	0.99 to 0.99999

Source: [5].

Airborne equipment are required to meet all of the applicable performance specifications in the presence of interference up to those levels shown in Figure 7a for standalone GPS, GPS/WAAS, and GPS/LAAS airborne equipment and Figure 7b for older airborne supplemental navigation GPS equipment. (Note that these interference levels are system level, i.e., they must be met by the receiver/antenna combination for the installed equipment, and are referenced to the output port of the passive antenna whether the antenna is passive or active). For interference centered at frequencies within the range of 1553.8 – 1593.8 MHz, the maximum tolerable interference levels for standalone GPS, GPS/WAAS and GPS/LAAS avionics specified in [11,14,16] are a function of the bandwidth of the interference (presumed to be noiselike with a rectangular power spectral density). The bottom curve in Figure 7a over this range of frequencies is for continuous-wave (CW; i.e., tone) interference, and the top curve in this figure for interference with 1 MHz bandwidth. For interference at center frequencies outside of the range of 1553.8 – 1593.8 MHz, only CW levels are specified.

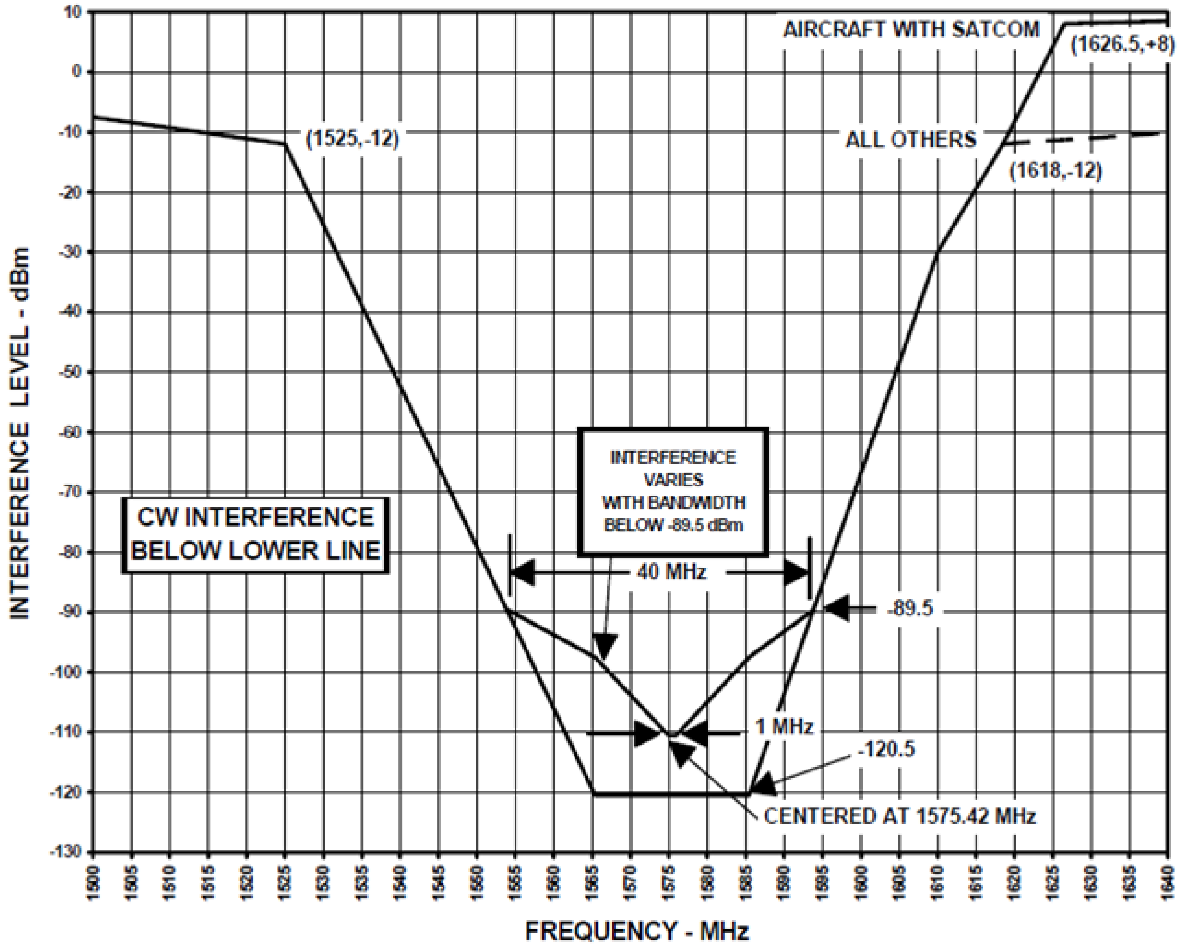


Figure 7a. Maximum Tolerable Interference Levels for Airborne GPS, GPS/WAAS and GPS/LAAS Equipment (referenced to the passive antenna output port) [11, 14, 16]

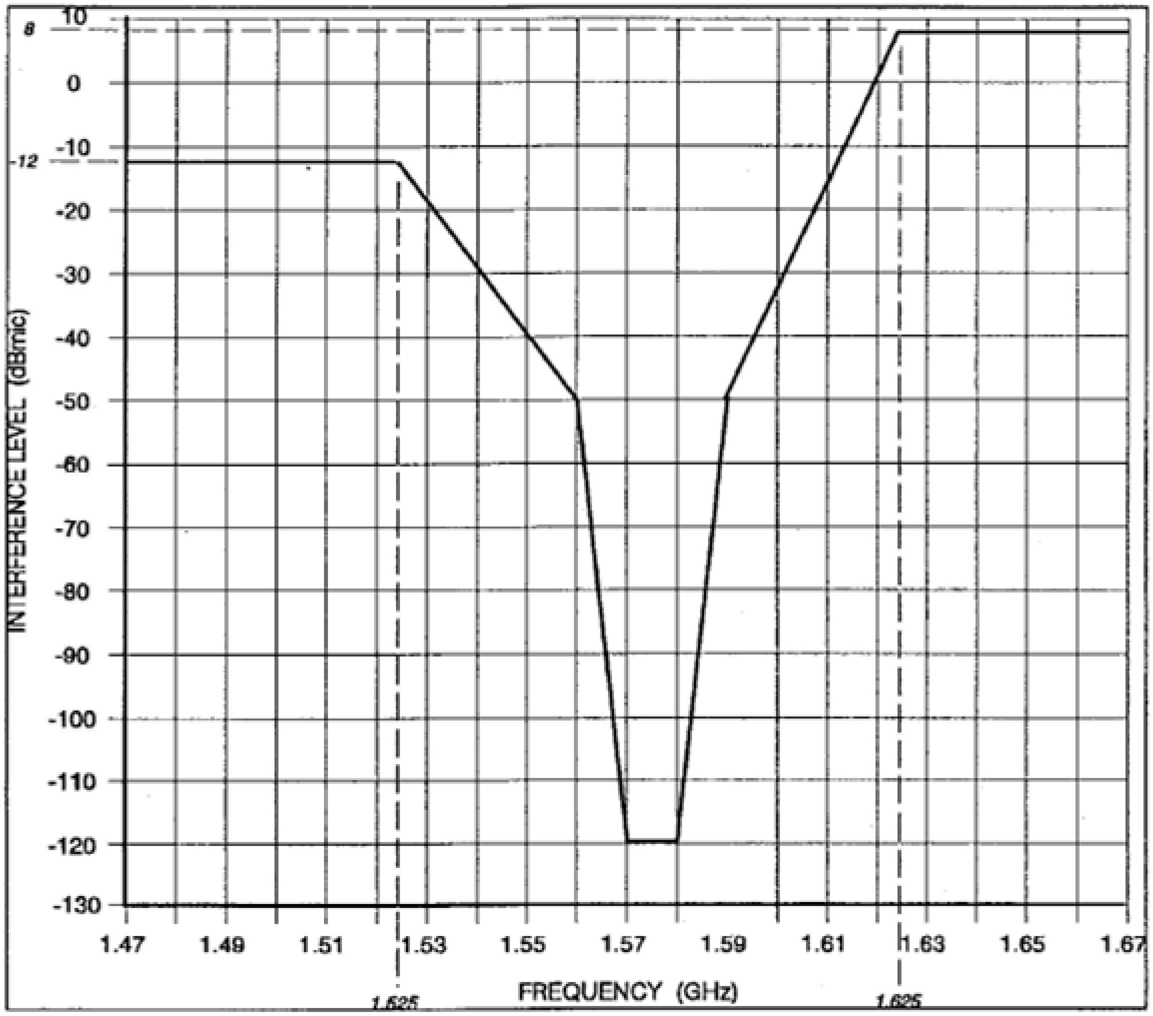


Figure 7b. Maximum Tolerable CW Interference Levels for Airborne Supplemental Navigation GPS Equipment [8]

2.3 Integrated Equipment

Airborne GPS receivers may be used to provide PVT data to other on-board equipment, including TAWS and ADS-B equipment. Such installations may place additional requirements upon the GPS receiver output.

4. Ground equipment

To meet the integrity requirements for aircraft navigation, ICAO defines several types of augmentations. Aircraft-based augmentation systems (ABAS) include methods to provide integrity using redundant GPS measurements (i.e., receiver autonomous integrity monitoring [RAIM]) or other on-board sensors (e.g., inertial, baro-altimeter). The other types of augmentation require GPS receivers on the ground in conjunction with processing facilities to generate differential corrections and integrity data to be supplied to the aircraft. Satellite-based Augmentation Systems (SBAS) provide this functionality using a ground network with GPS receivers widely dispersed over a large geographic region. Ground-based augmentation systems (GBAS) provide this functionality using redundant GPS receivers located on an airport.

GPS receivers are used also for timing purposes for critical Federal Aviation Administration systems.

4.1 WAAS Network

The U.S. SBAS program is referred to as WAAS. The WAAS is a safety critical system that augments GPS by providing additional ranging with geostationary earth orbit (GEO) satellites, improved accuracy with differential corrections, and safety with integrity monitoring. The WAAS system consists of 38 reference stations, three master stations, and six Ground uplink Subsystems supporting three L1/L5 GEO satellites. WAAS reference stations (WRSs) are located throughout the Continental United States, Hawaii, Alaska, and Puerto Rico and internationally with stations in Mexico and Canada. Reference stations are located primarily at FAA Air traffic control facilities but some are located at flight service stations, airports and for remote stations in specially constructed shelters. The WRSs utilize the Omni directional NW2225 antenna and G-II reference receiver. Each of the redundant WRS receivers includes the capability to track the GPS and SBAS L1 C/A-code signals and additionally the GPS L1 and L2 P(Y)-code signals using semi-codeless processing techniques. Further details on this equipment are provided in the next sections.

Ground uplink Subsystems used with the WAAS GEOs are located at commercial earth station terminals at Woodbine (Maryland), Brewster (Washington), Littleton (Colorado), Napa (California), Santa Paula (California) and Pamalu (Hawaii). These sites also utilize the NW2225 antenna as well as high gain/high directional antennas for L1 and L5 downlink signals. The L1 signal processing in the GUST receiver is the same as with the G-II reference receiver.

WAAS has been continuously operating since 1998, and has been supporting safety operations since 2003. The system, at present, supports en route through category I-equivalent (referred to as “LPV”) precision approach operations, see, e.g., [18,19].

4.1.1 WAAS Antenna Assemblies

4.1.1.2 Omni Directional Antenna Characteristics

WAAS reference stations and Ground uplink Subsystems both utilize the NW2225 antenna. The requirements this antenna must satisfy are documented in unit and system level WAAS documentation. Table 2 provides an excerpt from this documentation for key L1 antenna requirements useful for evaluation with interference. Additionally, Figure 8 provides actual performance of the antennas integrated Filter/LNA for frequencies near the L1 passband.

Table 2 Key L1 Antenna Characteristics for NW2225

Antenna pattern gain for RHCP signal Gain L1 Elevation = 5° Elevation = 90° (Zenith)	 ≥ -9.0 dBic ≥ 3.0 dBic
Axial ratio	4.0 dB, Max.
RF Gain	48 ± 3 dB
Maximum Input Signal w/o Damage	+20 dBm, CW
1 dB Compression Point	+10 dBm, Min,
Noise Figure*	≤ 2.0 dB @25° C
Attenuation ≥ -80 dB Attenuation near L1 -80 dB	Non operating frequencies @ ± 50 of 1575.42 MHz (Max)

* Shall be met across ±10 MHz passband for each operating frequency

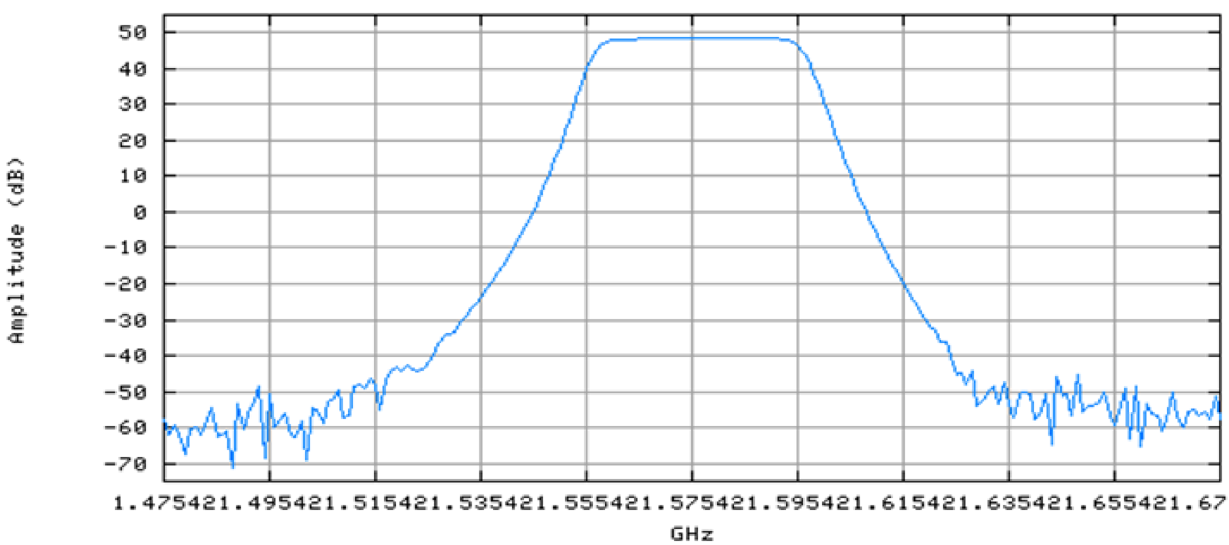


Figure 8. WAAS Antenna (NW2225) L1 Signal Conditioning Performance

4.1.1.2 Downlink Antenna Characteristics

The Ground Uplink Subsystem also uses a High Directional/High Gain antenna for receiving the L1 and L5 downlink signals from the WAAS GEO satellites. Key performance requirements for this antenna are reflected in Figure 9 where the max gain has been normalized to zero dB. The gain of the antenna at boresight is nominally 28 dB.

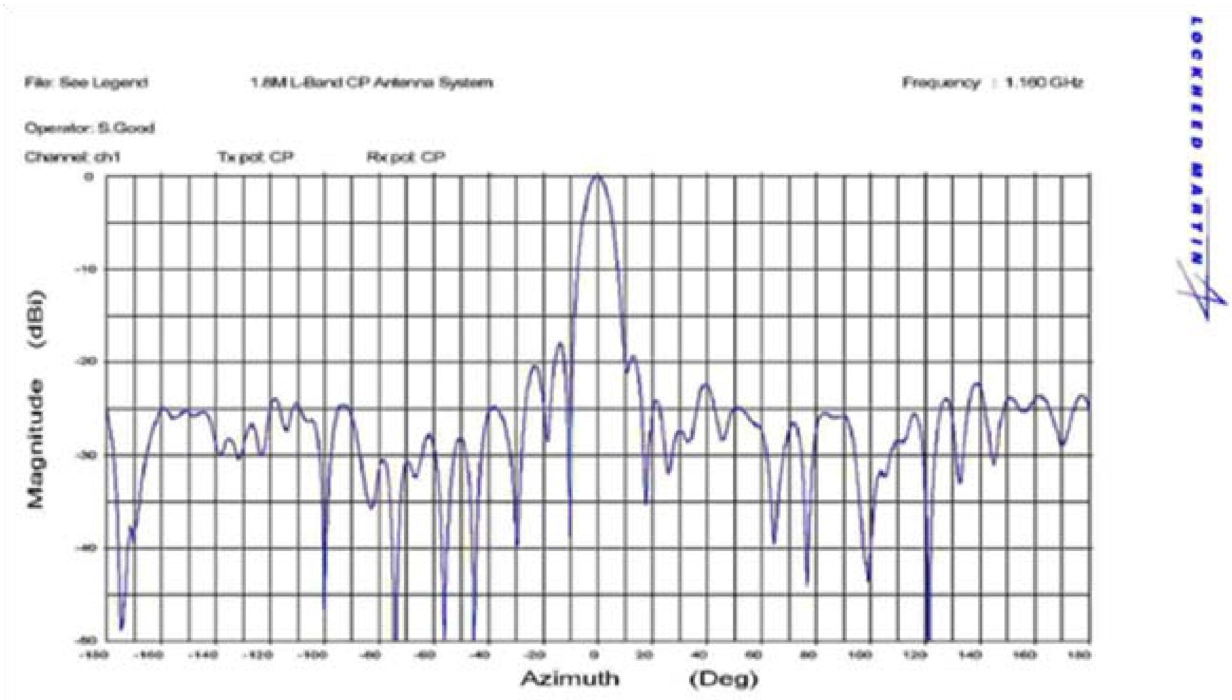


Figure 9. GUS Antenna Gain Pattern

4.1.2 WAAS Network Receivers

L1 signal processing provided by the receiver is essentially identical for reference station and ground uplink applications in WAAS. As with the WAAS antenna, signal processing requirements relevant to RF interference performance are documented in unit and system level WAAS documentation. This documentation contains other requirements too numerous to list in this document related to signal acquisition, accuracy and data demodulation performance. For receiver performance pertaining to interference, the specifications require the receiver provide filter attenuation for out-of-band emissions of 50 dB or greater. For out-of-band emissions within ± 50 MHz of the L1, L2 and L5 center frequencies, the receiver shall provide filter attenuation characteristics as specified in Figure 10. The receiver may achieve these attenuation characteristics through a combination of RF and IF filters.

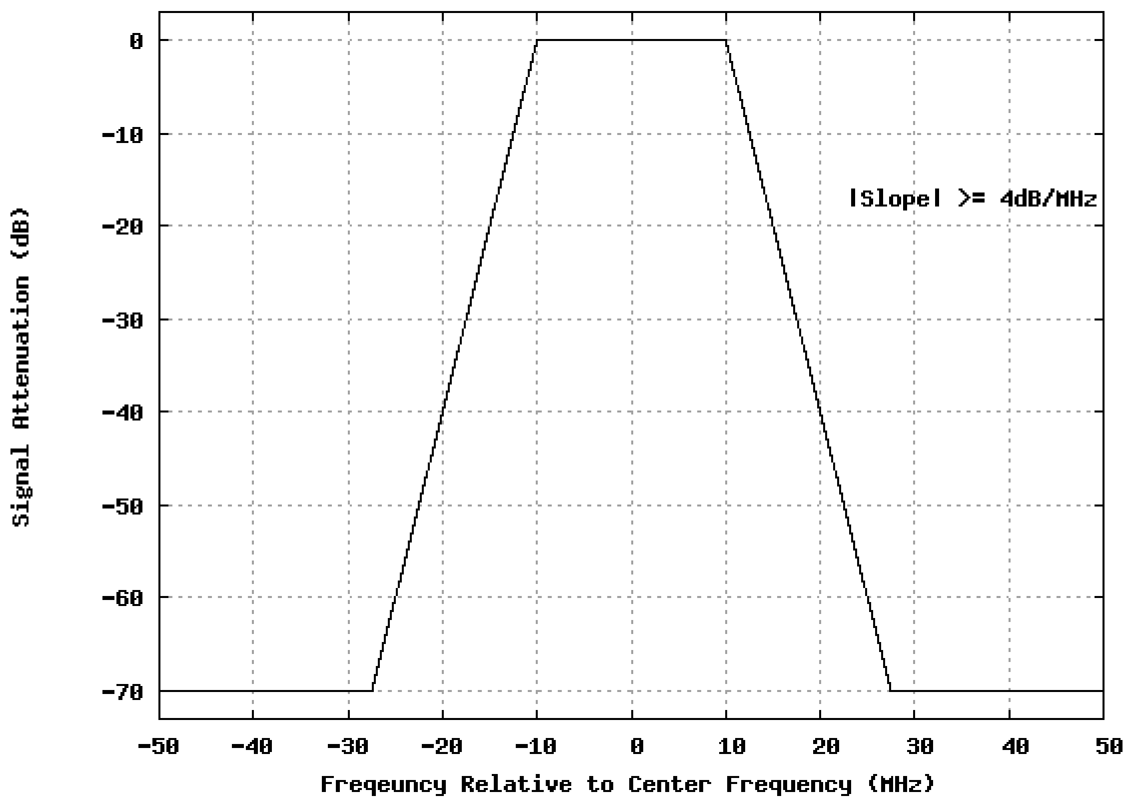


Figure 10. RF Attenuation Near L1 L2 and L5 Passbands

Out-of-band rejection characteristics are intended to be satisfied with the combination of antenna and receiver filtering and receiver processing gain. Therefore, after initial signal acquisition and steady-state operation has commenced with the receiver, a GPS/WAAS antenna/receiver shall operate in the presence of a single CW interferer that does not exceed the interference to signal power ratio by more than the levels shown in Table 3 (further illustrated in Figure 11). The interference signal shall be relative to the minimum GPS/WAAS signal levels. The signal suppression allocations are as follows: 80 dB for the antenna filter, 50 dB for receiver out of band, and 24 dB for receiver in-band processing gain. Note that CW was specified for out-of-band emissions to constrain test requirements.

Table 3. Out of Band Rejection Characteristics

Interference Frequency, f (MHz)	Interference to Signal Power Ratio (dB)
800 < f ≤ 1106.45	≥150 dB
1106.45 < f ≤ 1166.45	+150 – 2*(f-1106.45) dB
1237.6 < f ≤ 1297.6	+30 + 2*(f - 1237.6) dB
1297.6 < f ≤ 1505.42	≥150 dB
1505.42 < f ≤ 1565.42	+150 - 2*(f-1505.42) dB
1585.42 < f ≤ 1645.42	+30 + 2*(f - 1585.42) dB
1645.42 < f < 2000 for L1	≥150 dB
1645.42 < f < 1700 for L2	≥150 dB

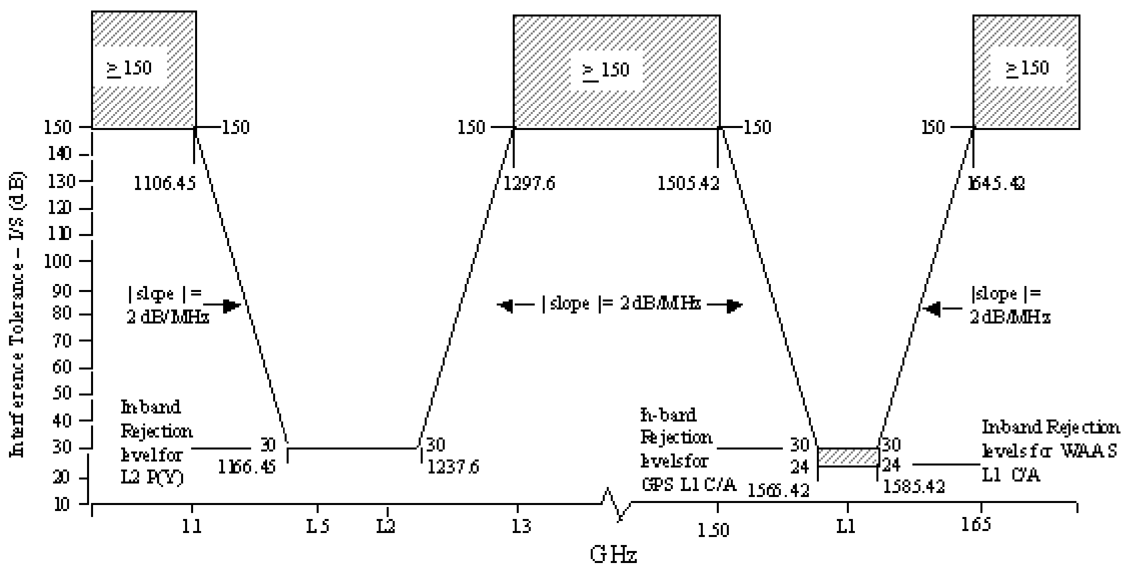


Figure 11. Out of Band Rejection Characteristics for CW Interference

4.2 GBAS

The U.S. GBAS program was currently referred to as the Local Area Augmentation System (LAAS) but recently changed in name to adhere to international terminology. A Category I (CAT I) Non-Federal GBAS built by Honeywell International received System Design Approval (SDA) from the FAA on September 3, 2009. The Port Authority of New York/New Jersey has purchased and installed the first system at Newark Liberty International Airport. This system is expected to become operational in the near future. Several different prototype systems are installed at other locations in the United States. The FAA's GBAS program office is working in conjunction with industry towards the operational validation of Category II/III GBAS standards and specifications. The FAA expects to make an investment decision by 2013 as to whether to deploy FAA-funded CAT II/III GBAS ground facilities in the United States.

Current CAT I non-Federal GBAS systems conform to the specifications in [20], which provides numerous performance requirements that must be met with identical maximum interference levels as those in use for GPS avionics described earlier in this document.

4.3 Timing

GPS timing receivers are used for critical purposes at numerous facilities in the national airspace system (NAS). These include Trimble Resolution T receivers for the ADS-B stations being deployed by ITT. TrueTime and Symmetricom GPS timing receivers are used for timing for several automation systems. These are commercial timing products that should be covered by the TWG's timing receiver category.

5 Operational Scenarios

The following operational scenarios are extracted from [6]. For each operational scenario, all applicable performance requirements from [14, 16] must be met in the presence of both LightSquared emissions (considering constraints on the siting of the base stations near airports to protect mobile satellite services) and all known other interference sources as identified in [6].

5.1 Enroute/Terminal Area

For the enroute flight phase aircraft are generally constrained to be at an altitude of at least 500 feet above structures or terrain in uncongested areas and at least 1000 feet above structures or terrain in congested areas. In the terminal area on the initial approach segment the flight path is a minimum of 1000 feet above any obstacles. On the intermediate approach segment the flight path is a minimum of 500 feet above obstacles. In these phases of flight, GNSS may be used for horizontal guidance in IMC operations. For off-board sources, the minimum RFI source separation distance to the closest terrestrial source is defined as 500 feet.

5.1.1 Enroute Acquisition

The aircraft in this scenario is assumed to have been in normal, enroute GNSS navigation for a sufficient time to have up-to-date satellite ephemeris data, stored position, velocity, and receiver clock bias/drift information. Normal navigation is then somehow interrupted for a short time (e.g. by a momentary aircraft power failure) and the receiver must re-establish navigation by a full "warm-start" acquisition. For this scenario, the aircraft is assumed to be in level flight at a representative limiting-case altitude of 18,000 feet (5.5 km).

5.1.2 Enroute Tracking/Data Demodulation

For the enroute tracking / demodulation scenario, the aircraft is assumed to be in level flight at a representative limiting-case altitude of 18,000 feet (5.5 km) above ground level. Both GPS and SBAS (e.g., WAAS) satellite signals are considered. The usefulness of the SBAS signals for integrity and error correction depends on the aircraft position being within an area covered by SBAS ground reference stations. Certain components of total RFI vary as a function of location, (e.g., GNSS self-interference, terrestrial RFI). Given these two aspects, the enroute GPS and SBAS scenario link analyses may be performed at different limiting-case locations.

5.1.3 Terminal Area Tracking/Data Demodulation

For this terminal area scenario, the aircraft is assumed to be in level flight with its GNSS antenna at an intermediate value between the enroute and Category I precision approach scenarios. The airborne GPS antenna height is 1756 feet (535.2 m).

5.2 Non-precision Approach Tracking/Data Demodulation

For non-precision approach operations, [6] recommends using a 100 foot (30.5 m) separation to a ground-based obstacle (source of interference) and the Category I airborne antenna gain pattern below the aircraft (see Figure 2).

5.3 Category I Precision Approach Tracking/Data Demodulation

For category I (CAT I) precision approach, [6] recommends using a 96.7 foot (29.5 m) obstacle clearance surface (OCS) distance (distance to closest possible ground-based interference source) and a 175 foot (53.3 m) above-ground GNSS airborne antenna height.

5.4 Category II/III Precision Approach Tracking/Data Demodulation

For a CAT II/III precision approach, [6] recommends using a 70 foot (21.3 m) OCS distance (distance to closest possible ground-based interference source) and a 85.1 foot (25.9 m) above-ground GNSS airborne antenna height. Such operations require a CAT II/III GBAS to be installed at the airport.

5.5 Surface Acquisition and Tracking/Data Demodulation

This operational scenario encompasses surface operations where the aircraft is at the gate or taxiing. For this scenario, the GNSS aircraft antenna height is assumed to be 4 m (a nominal height for a regional or business jet). The aircraft is either stationary or in a slow taxi. GNSS receiver signal tracking and acquisition should be tested in the scenario.

6 Future Considerations

Work is currently underway domestically and internationally towards the development of multi-frequency, multi-GNSS standards. Such standards will support additional signals in the 1559 – 1610 MHz band, including the Galileo open service and GPS L1C signals that use a multiplexed binary offset carrier modulation (MBOC). The power spectral density of MBOC is much broader than the GPS L1 C/A-code and may require wider bandwidth avionics.

Future GNSS avionics, in order to accrue the benefits of new civil signals on other frequencies (e.g., GPS L5 at 1176.45 MHz) will require new airborne multi-band antennas. These will likely be stacked patch antennas, and it is possible that their gain performance at L1 will suffer in comparison to existing antennas. Additionally, in the future, GNSS avionics may be required to meet more demanding performance requirements. These factors, together, will tighten current slim margins on interference budgets (see, e.g., [6]) for airborne GNSS equipment.

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