Test Plan to Develop Interference Tolerance Masks for GNSS Receivers in the L1 Radiofrequency Band (1559-1610 MHz)

I. Background

In December 2012 the U.S. Department of Transportation (DOT) developed its Global Positioning System (GPS) Adjacent Band Compatibility Assessment Plan [1] that identifies the processes to: (a) derive adjacent-band transmitter power limit criteria for assumed new applications necessary to ensure continued operation of GPS services, and (b) determine similar levels for future GPS receivers utilizing modernized GPS and interoperable Global Navigation Satellite System (GNSS) signals.

II. Objective

The objective of this test is to collect data to determine Interference Tolerance Masks (ITM) for categories of GPS and GNSS receivers processing signals in the 1559-1610 MHz Radionavigation Satellite Service (RNSS) frequency band, as well as receivers that process Mobile Satellite Service (MSS) signals to receive differential corrections. DOT is neither developing standards for GPS receivers, nor is it developing standards for transmitters operating in the adjacent radiofrequency bands. These ITMs will be used to assess the adjacent band interference power levels that can be tolerated by GNSS receivers processing desired signals in the RNSS band. This document outlines the requirements, the overall test plan, and the associated output data needed to successfully perform this component of the GPS Adjacent Band Compatibility assessment. This document is not intended to provide the detailed test procedure currently being developed by the DOT team.

III. GPS/GNSS Receivers to be Tested

The first phase of this study will focus on existing GPS/GNSS receivers that are currently fielded. Seven categories of receivers will be included in this testing: aviation (non-certified), cellular, general location/navigation, high precision, timing, networks, and space-based receivers. While the primary focus of this phase of the effort is on GPS receivers, it is recognized that there are fielded multi-GNSS receivers and they will also be included in this first phase of testing.

Each receiver should be accompanied by use cases defining its regions of operation (dense urban, urban, suburban, and/or rural). The use cases also will identify applications that are vital to economic, public safety, scientific, and/or national security needs and any other factors supporting why this particular receiver model is important to be tested (e.g., quantity in use, economic impact, etc.). The information required for the development of ITMs for GNSS receivers operating in the 1559 – 1610 MHz band will be requested in conjunction with a Non-Disclosure Agreement (NDA).

Additional technical data on the GNSS receivers' front-end designs will also be requested and covered by the NDA. Such data includes the number of amplification and filtering stages, and the following information for each stage:

A. Radiofrequency filter selectivity over the frequency range 1575 ± 100 MHz for the different stages
B. Gain and noise figure of the low noise amplifier (LNA);
C. 1 dB gain compression point for the LNA, including the reference point (e.g., power referenced to the input or output of the LNA); and
D. Third-order intercept point of the LNA.

In the case of integrated receiver/antenna systems, information about antenna characteristics will be requested and covered by the NDA. The antenna characteristics for a typical antenna/receiver pairing will be requested for receivers that use external antennas. Antenna characteristics include:

A. Same information requested on the GNSS receiver front-end design (only for the case of an active antenna)
B. Frequency-dependent antenna gain
C. Gain offset (in dB) between right-hand circularly polarized (RHCP) and linearly polarized incident waves; and
D. Normalized antenna gain pattern.

IV. Test Frequency Range

The first phase of the study will address the compatibility of adjacent-band systems with GNSS receivers processing desired signals in the 1559 – 1610 MHz band. A test frequency range of ±100 MHz from the GPS Link 1 (L1) center frequency of 1575.42 MHz was selected. This range is anticipated to include the passbands and transition bands of the filtering for most GNSS receivers processing signals in the 1559 – 1610 MHz band, as well as the MSS signals used to receive differential corrections for some receivers. This results in a test frequency range of [f_{min}, f_{max}] = [1475, 1675] MHz.

V. Interference Tolerance Mask (ITM)

In the absence of interference, the carrier-to-noise density ratio (CNR) is the ratio of the received GNSS signal carrier power C, in watts, to the receiver noise power density. The receiver noise power spectral density (PSD) (N_o, in W/Hz) is given by following expression

$$N_o = kT \qquad \text{Eq 1}$$

where k is Boltzmann's constant, $1.38 \cdot 10^{-23}$, in joules (equivalent to W/Hz) per kelvin and T is the receiver system noise temperature (in K). Using a decibel scale the baseline CNR with no interference present is

$$CNR_{BL} = 10\, log_{10}\left(\frac{C}{N_o}\right)\ dB\, Hz \qquad \text{Eq 2}$$

When interference is present, a reduction in CNR can occur that is equivalent to an addition of I_o W/Hz in the noise floor and in some cases a reduction in signal power δc to the received satellite signal. The CNR expression under Interference conditions becomes

$$CNR_I = 10\, log_{10}\left(\frac{C - \delta c}{N_o + I_0}\right)\, dB\, Hz \qquad \text{Eq 3}$$

Where δc = 0 except for the case when the interference power is large enough to drive the receiver front end to a non-linear regime.

The received interference test signal power level that causes a 1-dB CNR degradation (change from Eq 2 to Eq 3, as reported by the receiver) as a function of interfering signal center frequency is referred to as the interference tolerance mask (ITM). The uncertainty on the CNR measurements will be a consideration in forming the ITM for each receiver. Additional GPS and GNSS receiver performance parameters will be used to monitor receiver state during the post processing of the CNR data. This test plan only addresses receivers processing GNSS signals in the 1559 – 1610 MHz RNSS band. Later tests will address GNSS signals in other RNSS bands.

VI. Interference Test Signals

To the extent possible, the ITM will be developed for interference test signals having characteristics representative of the planned signals for the application proposed to operate in adjacent bands. Since it is impossible to predict signal characteristics for all future proposals, the following approach is used in selecting test signals:

- Select an easily generated interference test signal type with a PSD shape comparable with known proposed applications. The currently known proposals are for Long Term Evolution (LTE) signals. A bandpass white noise signal that matches the bandwidth and roll-off characteristics of the LTE signal is expected to produce similar masks as exemplified by previous testing (at least for the downlink or base-station transmitted signal). This is because the equivalent increase in the noise floor at the output of a GNSS receiver correlator due to a bandpass white noise up-converted to the operating frequency of the interferer is comparable to the equivalent increase in receiver noise floor given an Orthogonal Frequency Division Multiplexing (OFDM) signal possessing the same power spectrum at the receiver front end. In addition, the level at which the non-linearity of a GNSS receiver frontend is triggered depends primarily on the power spectrum characteristics and not the modulation details as long as the modulation is fast enough relative to the time constants in the amplifier and filtering front ends. As such the test will employ bandpass white noise signals to derive ITMs.

- An ITM for a narrowband signal value at a frequency on the edge of a future proposed band (the edge closer to the center of the GNSS band) provides a conservative measure of the interference tolerance levels for some receivers. The bandwidth of this signal is also selected to be large enough so that the ITM results are not compromised for receivers that employ continuous wave (CW) jamming suppression capabilities.

As discussed above, ITMs corresponding to the following two types of signals will be generated:

- Signal Type-1: Bandpass white noise with a bandwidth B = 1 MHz.
- Signal Type-2: Bandpass white noise with a bandwidth B = 10 MHz.

The result is a mask surface $ITM(B, f)$ representing the power of an interference test signal having a bandwidth *B*, and a center frequency *f* that causes a measured CNR degradation of 1-dB taking into account the variations in the estimated CNR as reported by the GPS/GNSS receiver. A depiction of the mask surface is shown below.

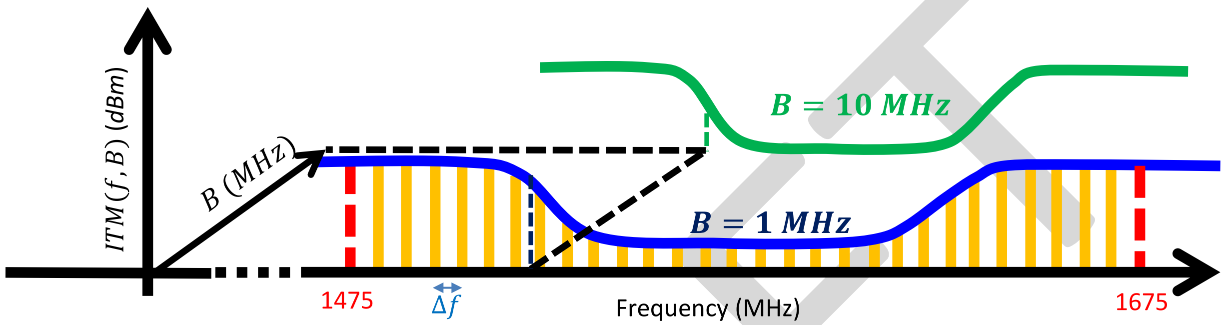

Figure-1: Notional illustration of an interference tolerance mask surface

VII. Test Modes

There are two test methods to generate ITMs:

A. Radiated Emissions Test
B. Conducted Emissions Test

The Radiated Emissions Test employs the least number of assumptions about the receiver-antenna system and is therefore the primary focus of this Test Plan. The Conducted Emissions Test is less resource intensive and is easier to repeat at a larger number of facilities. Therefore, it can be used for sensitivity analysis of ITMs generated from the Radiated Emissions Test to different signal types and Out of Band Emission (OOBE) levels . It is also more suitable to evaluate the interference impact on GNSS receivers during the signal acquisition phase (cold or warm start) for a select set of receivers. Conducted Emissions Tests are therefore reserved for special investigations, including studying the interference effects on acquisition if/when needed, as well as producing masks after the radiated tests are complete if/when additional receivers need to be tested.

Antenna pattern characteristics can either be obtained from manufacturers or other sources. However, this might not preclude the anechoic chamber antenna pattern measurements to characterize one or more antennas. At a minimum, a standardized antenna pattern will be defined for each receiver category. Description of antenna pattern calibration will be reflected in a separate test procedures document.

The rest of this document focuses on the Radiated Emission Test since it is expected to be the primary source of data used to construct the $ITM(B, f)$ for each GNSS receiver. The interference effects on GNSS receivers during signal acquisition/re-acquisition is not covered by this test plan.

VIII. Radiated Emissions Test Setup and Approach

The Radiated Emissions Test is to be conducted in an anechoic chamber. The details of the anechoic chamber specifications are outlined in a later section. The test set-up will be calibrated to confirm that each receiver is exposed to the same radio frequency (RF) environment and that the test results are reproducible. Special care will be taken to minimize multipath effects caused by reflection of ranging and interference test signals by covering scattering and reflective surfaces with absorbing foam. The test setup has the following three main elements:

i- **A transmitter and antenna system radiating the interference test signal**. The signal generation mechanism will be capable of producing the two types of interference test signals previously described with a selectable center frequency within the test frequency range. It will also ensure that emissions outside the intended transmission band are kept to a low level (see Section IX). The signal output will have the additional characteristics listed in Table-1.

Table-1: Interference Transmitter Signal Specifications

Name	Value	Unit
Range of selectable center frequencies	[1475, 1675]	MHz
Min step size in center frequency	≤5	MHz
Number of selectable bandwidths	2	N/A
3 dB bandwidth (Signal Type-1)	1	MHz
3 dB bandwidth (Signal Type-2)	10	MHz

ii- **A GNSS simulator and antenna system radiating the GNSS signals**. The test will employ a simulated live sky environment starting with a minimum of 12 satellites in-view (per GNSS service). The first 10 satellites will be set to transmit at the same power level C_{High}. The value C_{High} will be set to produce nominal GNSS received power levels commensurate with specified minimums (e.g., -128.5 dBm out of an isotropic receive antenna for the GPS C/A-code signal as specified by IS-GPS-200H [2]). One of the two remaining satellites will be set to a reduced power level C_{Low1} (nominally $C_{Low1} = C_{High} - 10dB$) in order to emulate the reduced GNSS receiver antenna gain at low elevations. The remaining satellite will employ additional reduction resulting in a power level C_{Low2} (nominally $C_{Low2} = C_{Low1} - 10dB$) in order to partially investigate interference effects under foliage or other line of site blockage conditions for satellites at these low elevations. The GNSS receivers' CNR estimators are expected to be operating in the linear region for all three power levels (C_{High}, C_{Low1}, C_{Low2}). However, the linearity of the CNR estimators at the test GNSS signal levels will be verified as discussed later in this document. To the extent practicable, all GNSS signals processed by the receivers under test will be generated. For 1559 – 1610 MHz, this includes the GPS C/A-code and P(Y)-code, satellite-based augmentation system (SBAS) C/A-code, GLONASS L1, BeiDou B1, Galileo E1 open service, and QZSS L1 signals.

iii- **A precise layout of receivers' antennas**. The GNSS receiver antennas (or receivers in the case of integrated antenna) will be laid out on a pre-defined location grid designed to minimize the total combined footprint. All the receiver antennas will be oriented so that the maximum directivity of the antenna pattern from each receiver is directed towards the interference transmit antenna. A chamber mapping procedure will be performed to generate calibration surfaces for both the interference and GNSS emissions that cover the location grid for accurate calculations of the ITMs. The following is a sample layout with associated receiver and location codes. Once a specific test facility has been selected, an illustrative diagram will be created with relative position and directivity of GNSS signals and test signals. Also, position/orientation of various receivers will be described (particularly the antenna orientation with respect to the GNSS and test signal transmitters).

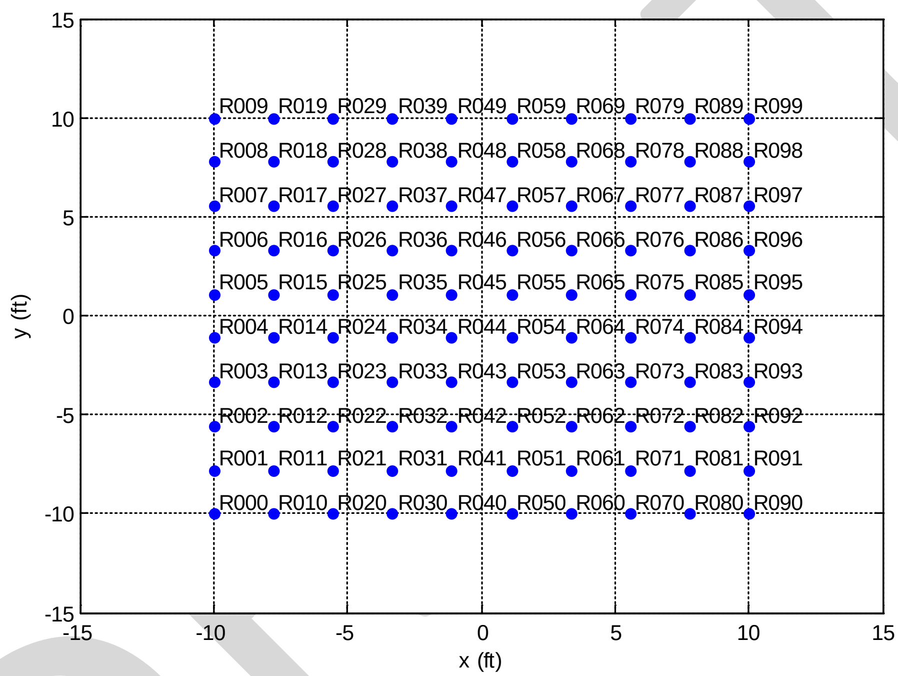

Figure-2: Sample layout of codified 100 GNSS receivers (receiver antennas)

The transmit antennas should be elevated so as to illuminate the GNSS receiver antennas from above. This will reduce the difference in received power across the location grid. It will also minimize any multipath effects from horizontal surfaces on the mounting tables, as well as the forward scattering from mounting elements and cables in the direction of the receive antennas. The key specifications of the interference transmit antenna are:

- Bandwidth to support testing over [1475, 1675] MHz.
- Linear polarization (perpendicular to line-of-sight to receivers under test).

The GNSS transmitter will drive a RHCP antenna. It will also employ appropriate frontend isolation to prevent any significant coupling of the high power radiated interference test signal which can distort the radiated GNSS signals.

The antennas for the receivers under test will utilize (to the extent possible) ground planes that emulate what each of these receivers experience in field operations.

The test configuration described above is designed to have both the linearly polarized interference and the GNSS RHCP electromagnetic waves impinge on the boresight of the receiver antenna (i.e. in the direction of maximum gain). Consequently, knowledge of receiver antenna patterns is not critical to carry out the test. However, when utilizing the test results to assess a proposed new system, the normalized antenna gain patterns for the satellites (RHCP waves) and proposed service (linearly polarized waves) must be taken into account.

The test sequence for each type of signal under consideration Type-1 (1 MHz), and Type-2 (10 MHz) will be carried out as follows:

- Load the appropriate ephemerides into the GNSS simulator. (Performed only once at the beginning of the test)

- With the GNSS signals radiating and the interference transmitter off, power up all GNSS receivers and wait a time T_{Start} for all receivers to acquire the GNSS signals and enter into steady-state tracking mode. (Performed only once at the beginning of the test.)

- The following sequence will be repeated for each frequency step Δf (which is not necessarily uniform across the test range – see Table-2 for details). As these steps are carried out and repeated, all GNSS receivers are on and operating in continuous data collection mode.
    - With the interference transmitter off, collect data for duration of T_{BL} to establish a baseline CNR. This data will also be used to establish a confidence limit on the estimated mean CNR for each receiver
    - The interference power is then set to provide a minimum received power of p_{min} (as seen at the output of an isotropic antenna at the center of the receiver location grid and as determined via a chamber power mapping calibration process), and then increase it by ΔP (dB) increment till p_{max} is reached. The duration of each power step is T_{step}.
    - The interference power cycle just described will be repeated N_{cycle} times to allow for the reduction of measurement uncertainty and facilitate data screening.

- Minimum integration time T_{Step} for CNR measurements will be chosen so that:
    - The uncertainty on the estimate of mean CNR $< CNR_m >_{T_{step}}$ is small relative to one dB. That is, for stable GNSS and interference radiated signal powers (i.e. near constant received power levels at the GNSS receive antenna), T_{Step} is chosen to meet the following two criteria:
        i. T_{Step} is equal to or exceeds the largest time needed by any of the receivers under test to perform and report a CNR estimate.
        ii. $T_{Avg} = N_{SV} \cdot N_{Cycle} \cdot T_{Step}$ is large enough for the uncertainty on the CNR estimate to be on the order of 8% or less of the true average noise floor (about 1/3 of the power needed to raise the noise floor by 1 dB) for all receivers (or equivalently for the receiver having the lowest noise floor). Recall that, when the error forms a stationary white noise random process,

the longer equivalent averaging time (T_{Avg}), the smaller is the uncertainty on the estimated mean.

- The following is the tabulated values for the parameters described so far. The values are nominal and might be adjusted by the time of the test.

Table-2: Test Parameter Values

Name	Value	Unit
f_{start}	1475	MHz
f_{end}	1675	MHz
$[p_{min_1}, p_{max_1}]$ **(1475 to 1505 MHz)**	[-75,-5]	dBm
$[p_{min_2}, p_{max_2}]$ **(1520 to 1555 MHz)**	[-80,-10]	dBm
$[p_{min_3}, p_{max_3}]$ **(1575 and 1595 MHz)**	[-130,-60]	dBm
$[p_{min_4}, p_{max_4}]$ **(1615 to 1640 MHz)**	[-80,-10]	dBm
$[p_{min_5}, p_{max_5}]$ **(1645 to 1675 MHz)**	[-75,-5]	dBm
Δf_1**(1475 to 1505 MHz)**	15	MHz
Δf_2**(1520 to 1555 MHz)**	5	MHz
Δf_3**(1575 and 1595 MHz)**	N/A	MHz
Δf_4**(1615 to 1640 MHz)**	5	MHz
Δf_5**(1645 to 1675 MHz)**	15	MHz
ΔP	2	dB
Startup Time	15	min
T_{BL}	5	min
T_{step}	15	s
N_{cycle}	2	N/A

The tabulated frequency limits and spacing parameters result in the following 22 center frequency values (in MHz) for each type of interference test signals: 1475, 1490, 1505, 1520, 1525, 1530, 1535, 1540, 1545, 1550, 1555, 1575, 1595, 1615, 1620, 1625, 1630, 1635, 1640, 1645, 1660, 1675.

The following plot shows the received interference power time series based on the tabulated parameters for one frequency step. This figure uses only one of the tabulated power ranges [-80,-10] dBm. The resulting duration is the same for all other interference power ranges since they all span equal size intervals.

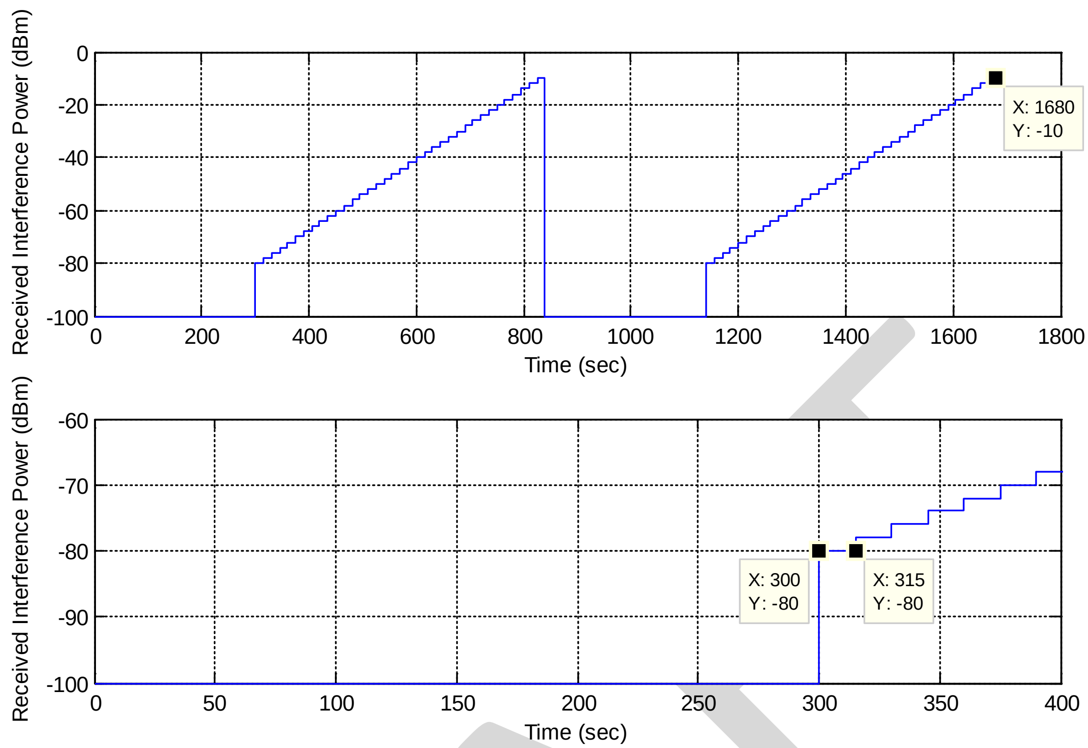

Figure-3: Time series of interference power at the furthest receiver location from transmitter antenna (Top). Same data plotted with only the first 400 seconds shown (Bottom). Time zero signifies the start of data collection after all receivers have acquired all the GNSS signals and are in tracking mode.

Therefore the current choice of parameters corresponds to test duration of approximately 28 minutes per frequency step. The non-uniform frequency spacing outlined in Table-2 results in 22 frequency steps. The associated minimum total test duration is therefore 22 x 28 minutes or approximately 10.3 hours per signal type. This duration is in addition to setup, chamber mapping (or receive power calibration), as well as GPS linearity tests. The following table is a breakdown of estimated duration for various components of the test:

Table-3: Time allocation for each test component and calculated total duration of the test.

Event	**Duration (hours)**
Installation and test of signal generation and radiation equipment	16
Chamber mapping	16
Setup and configuration of GNSS receivers	8
Linearity Test	1
Mask test for Signal Type-1 (1 MHz)	10.3
Setup for new signal Type-2 (10 MHz)	3
Mask test for Signal Type-2 (10 MHz)	10.3
Total duration	**8.08 x 8 (8 to 9 work days)**

These approximate durations will be regarded as rough estimates for initial planning purposes and will be revised as needed as the start time of the test approaches. The actual time of the test excluding chamber preparation and setup of the receivers is on the order of three work days. It is also worth noting that for the case of automated power and frequency stepping of the interference test signal, data collection might be carried out unattended outside work hours; potentially further reducing the actual test time from three to two days.

To the extent possible the following receiver outputs will be recorded at a rate equal to or greater than 1 Hz (or reporting time interval of $\Delta t = 1\ second$).

- $CNR(s, i, t_j)$ (here, *s* identifies the GNSS, *i* the SV and t_j is the time at increment *j*).
- Reporting time t_j
- Number of satellites tracked for each GNSS service: $N_{SV}(s, t_j)$
- Location: $Lat_s(j.\Delta t)$, $Lon_s(j.\Delta t)$, $h_s(j.\Delta t)$ (relative to WGS84 or other Datum)
- Pseudorange: $R_{s,i}(j.\Delta t)$
- Carrier phase
- Cycle slip or loss of carrier phase lock indicator (per satellite)
- Loss of code and carrier tracking indicator, or inferred loss of tracking in the case when it is not reported by the receiver (per satellite)

Some of this data might not be part of the standard output messages for many receivers. Therefore it is expected that not all of the data listed above will be reported by all receivers. This data is collected to provide information on the receiver state during the post processing of the CNR data.

As part of initial test preparation, a linearity check test will be conducted on the CNR estimator by turning the interference test signal off and varying the signal power level on one of the satellites (using the same time-step parameters but for only 1 cycle including an upward and downward power progression). The following is an example result from White Sands testing.

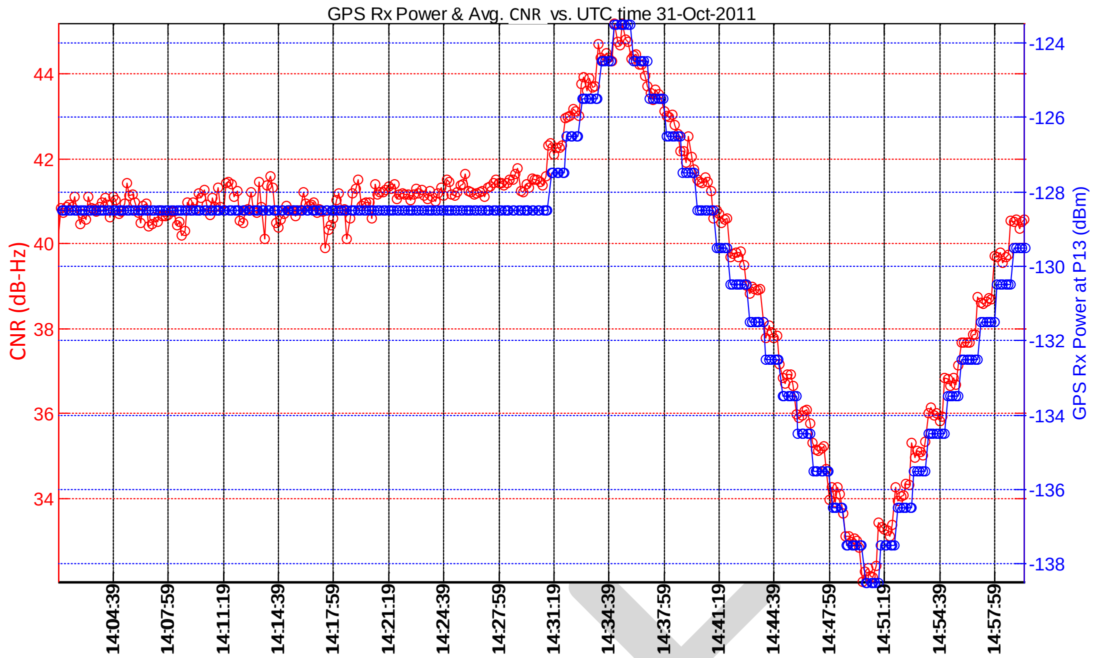

Figure-4: Overlaid plot of GNSS signal power and output SNR for one of the receivers tested at White Sands. This test is described in the NPEF 2011 test report [3].

IX. Out-of-Band Emissions

The OOBE for the case of the Type-2 (10 MHz) signal must be consistent with what is expected for an LTE type signal. Since the downlink (base station) and uplink (user equipment) may have different specifications, the OOBE level could be different depending on the center frequency of the Type-2 interference test signal. Since specifications and service rules for LTE do not exist for all frequencies in the [1475,1675 MHz] range, the following approach will be used:

- To the extent practicable, the radiated emissions test will generate Type-2 (10 MHz) signals with OOBE emissions that are at or below the lowest proposed levels for LTE signals in adjacent bands to 1559 – 1610 MHz. These levels are expressed in terms of an equivalent isotropically radiated power (EIRP) density of: (1) -100 dBW/MHz in 1559 – 1610 MHz for downlinks, referenced to a downlink peak EIRP of 32 dBW, and (2) -95 dBW/MHz in 1559-1610 MHz for uplinks, referenced to an uplink peak EIRP of -7 dBW.

For the case of the 1 MHz interference signal used to develop a general ITM, the OOBE will be set to the lowest practicable level (maximum OOBE rejection). This level will be determined after completing the design and implementation of the interference test signal generation setup. The following table provides a guideline for the OOBE levels at each signal frequency for the Type-1 and Type-2 Signals.

Table-4: OOBE levels as a function of center frequency for each interference signal type. Downlink OOBE is referenced to 32 dBW peak EIRP. Uplink OOBE is referenced to -7 dBW peak EIRP.

Center Frequency (MHz)	Type-1 (1 MHz) OOBE Level	Type-2 (10 MHz) OOBE Level
1475	Max rejection	Downlink (-100 dBW/MHz)
1490	Max rejection	Downlink (-100 dBW/MHz)
1505	Max rejection	Downlink (-100 dBW/MHz)
1520	Max rejection	Downlink (-100 dBW/MHz)
1525	Max rejection	Downlink (-100 dBW/MHz)
1530	Max rejection	Downlink (-100 dBW/MHz)
1535	Max rejection	Downlink (-100 dBW/MHz)
1540	Max rejection	Downlink (-100 dBW/MHz)
1545	Max rejection	Downlink (-100 dBW/MHz)
1550	Max rejection	Downlink (-100 dBW/MHz)
1555	Max rejection	N/A (Eliminated for Type-2 signal)
1575	Max rejection	N/A (Frequency is inside L1 Band)
1595	Max rejection	N/A (Frequency is inside L1 Band)
1615	Max rejection	N/A (Eliminated for Type-2 signal)
1620	Max rejection	Uplink (-95 dBW/MHz)
1625	Max rejection	Uplink (-95 dBW/MHz)
1630	Max rejection	Uplink (-95 dBW/MHz)
1635	Max rejection	Uplink (-95 dBW/MHz)
1640	Max rejection	Uplink (-95 dBW/MHz)
1645	Max rejection	Uplink (-95 dBW/MHz)
1660	Max rejection	Uplink (-95 dBW/MHz)
1675	Max rejection	Downlink (-100 dBW/MHz)

X. Effects of 3rd Order Intermodulation Product

While the ITM provides a measure of the effect of an interfering signal on a particular GNSS receiver, it excludes the impact of spurious emissions due to two or more signals operating simultaneously at different center frequencies. This is primarily due to the 3rd order intermodulation product that is generated by nonlinearities in the front end of a GNSS receiver. Such intermodulation products are produced with much larger magnitudes if one of the interference signals drives the front end outside the linear gain region.

In order to quantify this effect on the receivers under test, the center frequencies for a pair of simultaneously transmitted Type-2 signals are chosen so that their 3rd order intermodulation product falls near the center of the L1 band. Two frequencies that satisfy this criterion are 1530 MHz and 1550 MHz. The intermodulation test will follow the same test procedure described in Section VIII. The difference is that the two interference test signals are radiated and their power levels are increased and decreased simultaneously between p_{min_2} and p_{max_2} defined in Table-2 of Section VIII. Also, the second of the two signals will be radiated using an identical linearly polarized antenna illuminating the GNSS receivers' antennas from approximately the same look angle. This is primarily to ensure that the electromagnetic waves associated with both signals are exposed to the same path loss and antenna gains characteristics before they are coupled into the input of each receiver.

In order to not significantly increase the test duration, two of the 22 center test frequencies for the Type-2 (10 MHz) signal will be eliminated to offset some of the time needed for the just described intermodulation test. The eliminated frequencies are 1555 MHz and 1615 MHz which are the closest to the edge of the L1 band.

XI. Anechoic Chamber Specifications

The primary specifications required for the anechoic chamber are: Dimensions, frequency range of the absorption foam, and equipage. These specifications will be considered approximate guidelines and might be changed depending on several unknown factors such as the finalized number of receivers to be tested. Also the requirements on the vertical dimension of the chamber might change depending on the mounting mechanism and final chosen locations for the transmit antennas.

The lateral dimensions of the chamber are chosen to accommodate approximately 100 receivers (number of receivers is estimated on the high side to give conservative chamber dimensions) on a 2 ft by 2 ft rectangular grid (spacing between receivers) as well as additional test equipment and personnel. Thus, to accommodate 100 GNSS receivers, the chamber footprint should be at least 30 ft by 30 ft. The vertical dimension is chosen so that the elevated transmit antennas can illuminate the receiver antenna farm within the 3-dB beam width of the main lobe at small angles from the vertical (as previously described). For a main lobe 3-dB width of 45^{o} (for both interference and GNSS transmitters), and if the receivers are mounted on 1-meter high tables, the minimum height required is approximately 25 ft. This assumes that the transmit antenna(s) are mounted near the ceiling with a vertical boresight direction aligned laterally with the origin (or center) of the receiver antennas location grid. The absorption foam will attenuate the waves reflected from the chamber surfaces by at least 10 dB for the test frequency range [f_{min}, f_{max}]. This information is summarized in the table below:

Table-5: Anechoic chamber initial specifications

Name	Value	Unit
Chamber Length	40	*ft*
Chamber Width	40	*ft*
Chamber Height	25	*ft*
Attenuation frequency band of absorbing foam	[1475, 1675]	*MHz*
Minimum attenuation of reflected waves within the band	10	*dB*

As stated before, these specifications are to be used as guidelines for chamber selection rather than hard requirements.

XII. References

[1] DOT, *GPS Adjacent-Band Compatibility Assessment Plan*, U.S. Department of Transportation, Washington, D.C., December 2012.

[2] GPSD, Navstar GPS Space Segment/Navigation User Interfaces, IS-GPS-200H, GPS Directorate, El Segundo, California, March 2014.

[3] NPEF test report, Follow-on Assessment of LightSquared Ancillary Terrestrial Component Effects on GPS Receivers, http://www.gps.gov/news/2012/02/lightsquared/NPEF-report.pdf

List of Acronyms and Symbols

B: 3-dB bandwidth of the transmitted signal
C: Received GNSS signal carrier power
C_{High}: Received GNSS signal carrier power from 10 of the 12 simulated satellites
C_{Low1} C_{Low2} : Received GNSS signal carrier power for one of the remaining two of the 12 simulated satellites
CNR: Carrier-to-Noise density Ratio
CNR_m : Measured CNR or CNR reported by the receiver
CW: Continuous Wave
EIRP: Effective Isotropically Radiated Power
f_{start}: Lower edge of the testing frequency band
f_{end}: Upper edge of the testing frequency band
GNSS: Global Navigation Satellite System
GPS: Global Positioning System
I_o: Equivalent rise in N_o in the presence of interference
ITM: Interference Tolerance Mask
LTE: Long Term Evolution
MSS: Mobile Satellite Services
N_{cycle}: Number of interference power cycles corresponding to each frequency point
N_o: Noise Power Spectral Density
NB: Narrowband
NDA: Non-Disclosure Agreement
NPEF: **N**ational Space-Based **P**NT Systems **E**ngineering **F**orum
N_{SV}: Number of satellites in view
OFDM: Orthogonal Frequency Division Multiplexing
OOBE: Out-of-band Emissions
p_{min}: Min received power at the receiver location furthest from interference antenna
p_{max}: Max received power at the receiver location furthest from interference antenna
PNT: Positioning, Navigation and Timing
PSD: Power Spectral Density
RF: Radio frequency
RNSS: Radionavigation Satellite Service
T_{BL}: Time to establish a baseline CNR
T_{start}: Startup time for all receivers to move beyond acquisition phase
T_{step}: Duration of each power step
Δf : Interference frequency increment between measurements
ΔP : Interference power increment between measurements
Δt : Data reporting time interval for GNSS receivers under test.
$<.>_T$: The average of the bracketed quantity over a time duration T