Draft Test Plan to Develop Interference Tolerance Masks for GNSS Receivers in the L1 Band

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Objective

- 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.

- These ITMs will be used to assess the adjacent band interference power levels that can be tolerated by these GNSS receivers.

- The implementation (signal generation, filtering, amplification…) of the test plan is currently under development. ←More on that in a later presentation

Interference Tolerance Masks (ITM)

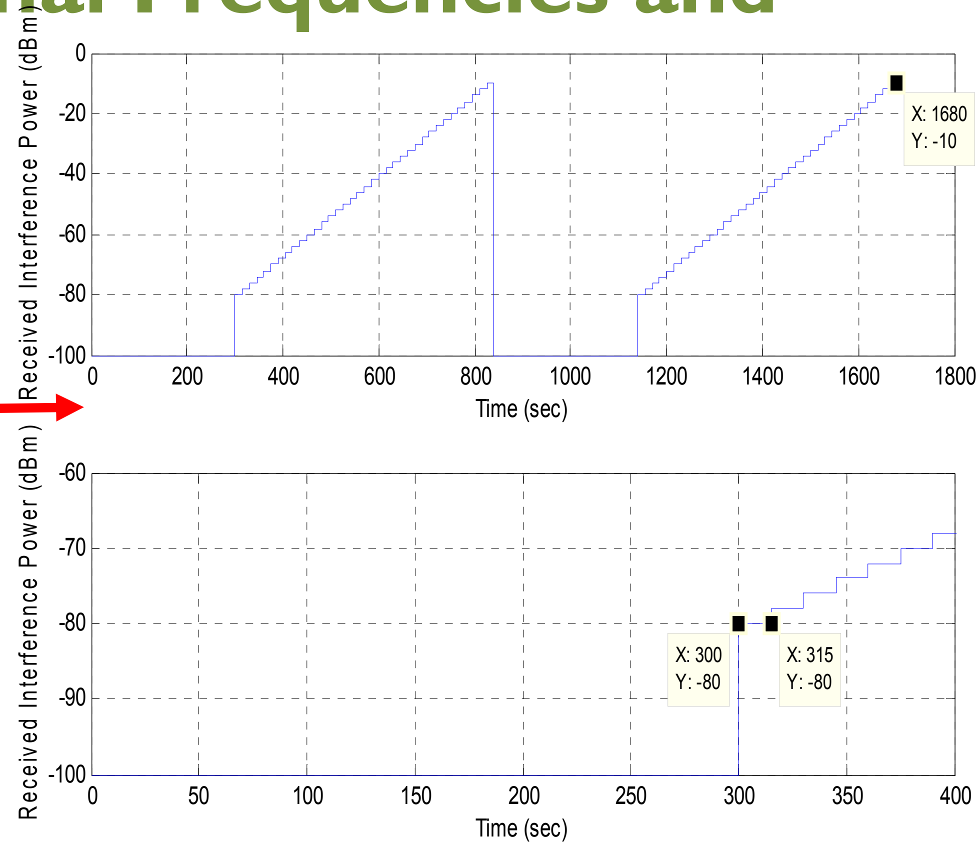
- $P_I = 0$ (Baseline): $CNR_{BL} = 10\ log_{10}\left(\frac{C}{N_o}\right)\ dB\ Hz$

- $P_I \neq 0$: $CNR_I = 10\ log_{10}\left(\frac{C-\delta c}{N_o+I_0}\right)\ dB\ Hz$

- ITM: The value of $P_I(f)$ that results in CNR_{BL}-CNR_I=1dB

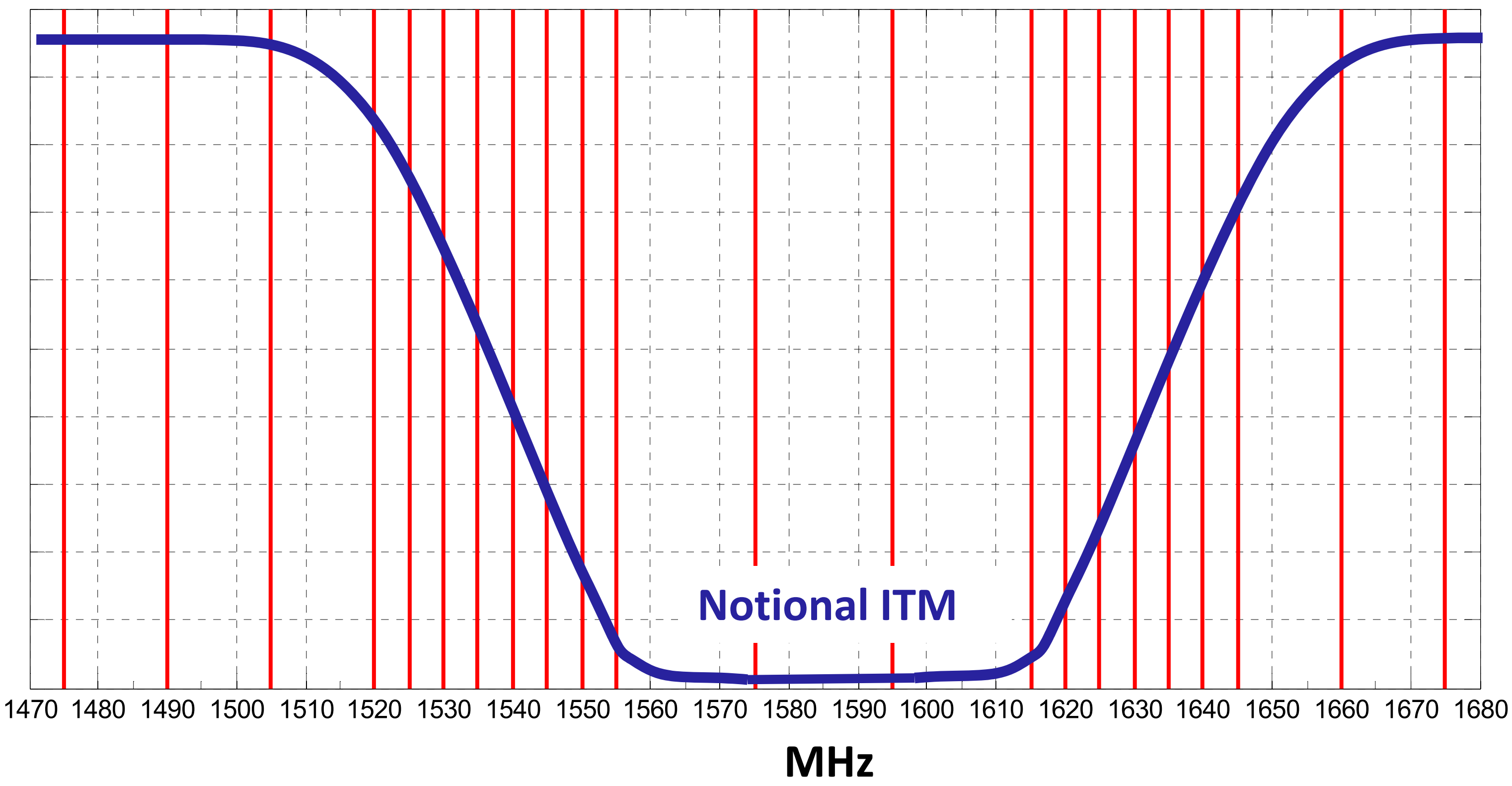
Interference Test Signal Frequencies and Power Profiles

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



Nominal receive interference power profiles at GNSS antenna location for the (1520 to 1555 MHz) and (1645 to 1675 MHz) frequency ranges.

Illustration of ITM



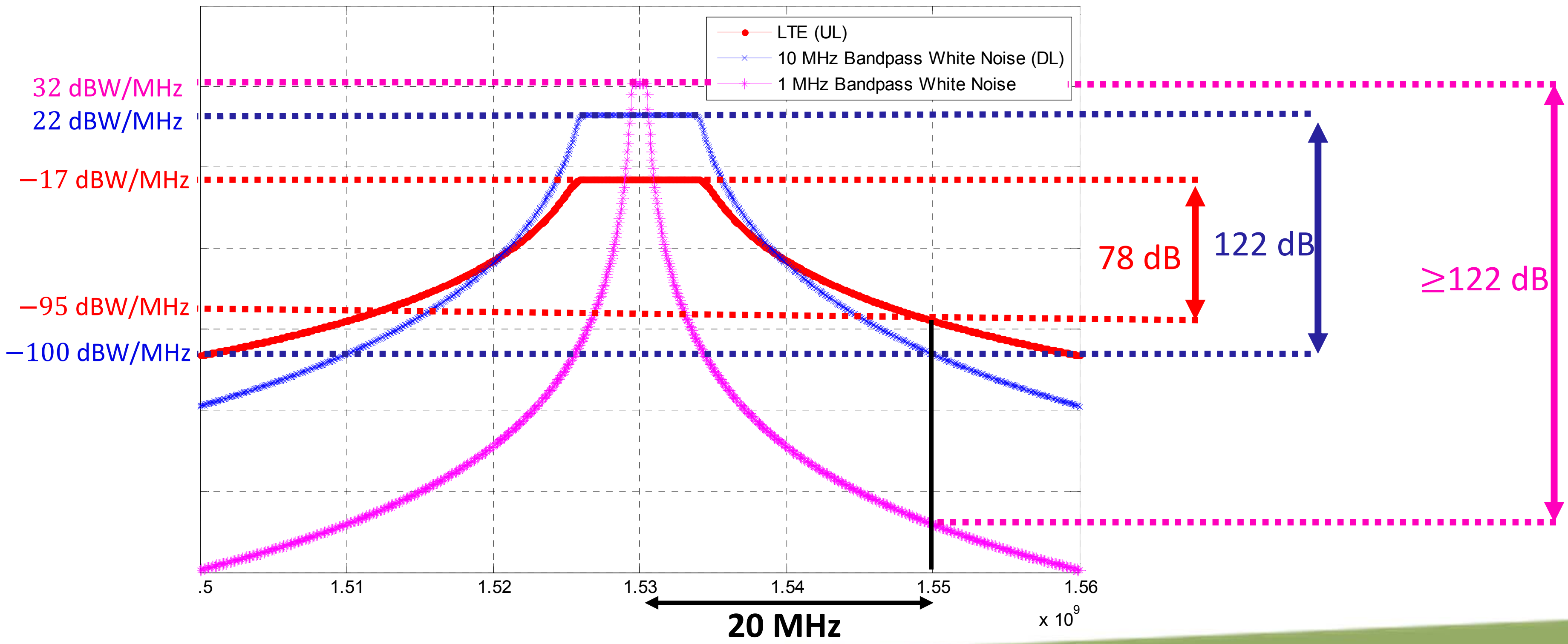
Interference Signal Types

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

- Signal Type-2:
  A. Bandpass white noise with a bandwidth B = 10 MHz (For the Downlink emulation)
  B. LTE emulation of the Uplink (SC-FDMA)

Desired Interference Test Signals

- The actual signal characteristics will be finalized after the design and implementation of the signal generation is complete (more details in a later presentation).



Out of Band Emissions (OOBE) Specifications for Interference Test Signals

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)

Augmenting ITM's with Data to Assess 3rd Order Intermodulation Effects

- When two or more signals are operating at different center frequencies, 3rd order intermodulation product(s) can be generated by nonlinearities in the front end of a GNSS receiver.

- The impact of such spurious emissions are not captured by ITMs .

- Therefore 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.

- For this test 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 the table on slide 4. Also, the second of the two signals will be radiated from the same antenna or using an identical linearly polarized antenna illuminating the GNSS receivers' antennas from approximately the same look angle.

3rd Order Intermodulation Effects (Cont'd)

- Whether to use one or two transmitter chains to simultaneously radiate the two signals will be determined upon completion of the test design

- 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.

GNSS Receivers to be Tested

- Existing GPS/GNSS receivers that are currently fielded in each of the seven categories: aviation (non-certified), cellular, general location/navigation, high precision, timing, networks, and space-based receivers

- The rational for receiver selection is expected to be a combination of factors such as:

  - To what level the applications associated with a particular receiver are vital to economic, public safety, scientific, and/or national security needs. And,

  - The adaptability for testing from technical perspective, and level of support available from the associated manufacturer(s) or other entity providing the GNSS receiver to be tested.

Desired Test Data Reported from Each Receiver

- Data Needed to Develop an ITM for each receiver:
  - $CNR(s, i, t_j)$ (here, *s* identifies the GNSS, *i* the SV and t_j is the time at increment *j*).
  - Reporting time t_j
- To the extent possible, additional data to report the state of the receiver at each time step
  - 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)

Additional Requested Data

- 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:
  - Radiofrequency filter selectivity over the frequency range 1575 ± 100 MHz for the different stages
  - Gain and noise figure of the low noise amplifier (LNA);
  - 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
  - Third-order intercept point of the LNA.

Test Modes

A. <u>Radiated Emissions Test</u>:

- Employs the least number of assumptions about the receiver-antenna system and is therefore the primary focus of this Test Plan

B. <u>Conducted Emissions Test</u>:

- Less resource intensive and can be conducted simultaneously at multiple facilities and is intended for:
  i. Sensitivity analysis of ITMs generated from the Radiated Emissions Test to different signal types and Out of Band Emission (OOBE) levels .
  ii. Producing masks after the radiated tests are complete if/when additional receivers need to be tested.
  iii. Studying the interference effects on acquisition if needed

Radiated Test Setup

- Four main elements:
  1. A transmitter and antenna system radiating the interference test signals previously described.
     - Signal generation hardware and control software will be discussed in a later presentation
  2. A GNSS simulator and antenna system radiating the GNSS signals
  3. A precise layout of receivers' antennas
  4. Data Logging System(s)
     - To be worked out with receiver manufacturers

GNSS Simulator and Antenna System

- Live sky environment with a minimum of 12 satellites in-view (per GNSS service).

- Satellites #1-10 will be set to transmit at the same power level C_{High} to produce GNSS received power levels commensurate with specified minimums (e.g., -128.5 dBm for the GPS C/A-code signal)

- Satellite #11 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.

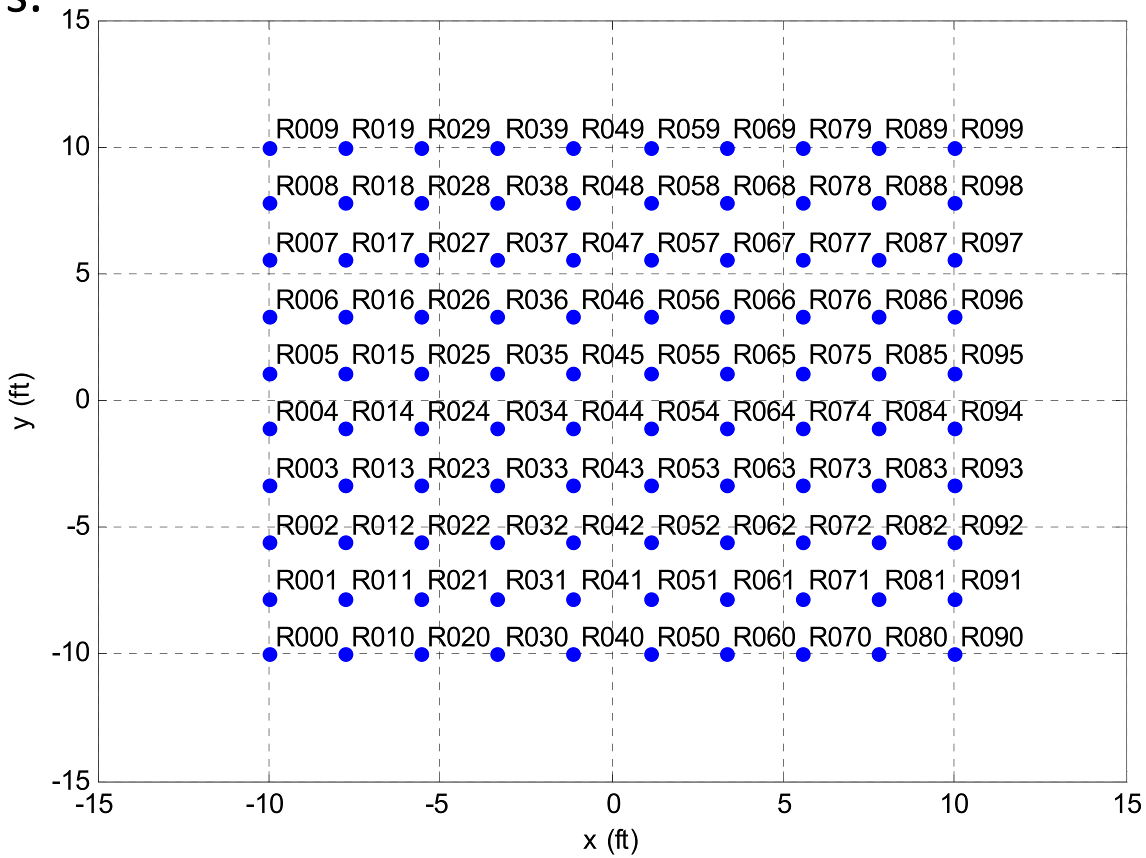
- Satellite #12 power level set to $C_{Low2} = C_{Low1} - 10dB$ in order to partially investigate interference effects under foliage or other line of site blockage conditions for satellites at these low elevations.

- 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

- To the extent practicable, all GNSS signals processed by the receivers under test will be generated. For 1559 – 1610 MHz, this includes:
  - GPS C/A-code and P(Y)-code
  - Satellite-based augmentation system (SBAS) C/A-code,
  - GLONASS L1
  - BeiDou B1
  - Galileo E1 open service
  - QZSS L1 signals.

Precise Layout of Receivers' Antennas

- In order to apply to the appropriate calibration for the receive powers.



Sample layout of codified 100 GNSS receivers

Anechoic Chamber Considerations

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

- Criteria used to estimate adequate chamber dimensions:
  - The lateral dimensions of the chamber are chosen to accommodate approximately 100 receivers on a 2 ft by 2 ft rectangular grid (spacing between receivers) as well as additional test equipment and personnel.
  - Vertical dimension chosen so that the elevated transmit antennas can illuminate the receiver antenna farm within the 3-dB beam width on the order of 45^o
  - 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.

Pre-Tests

- Test the operation of the signal generation, and automation

- Produce two calibration maps for the receive power over the area encompassing all GNSS receivers' Locations and spot check for repeatability.
  - One for the radiated interference signals, and
  - One for the radiated GNSS signals.

- Perform a linearity test on the CNR estimators for all receivers for satellite signal power settings used for this test.
  - Collected data will be used in post-processing to assist in forming the ITM for each receiver.

Approximate Test Duration

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)**

- The on-site commitment and support from manufacturers and other entities providing GNSS receivers for testing is expected to be limited to one work-week