

GPS and Adjacent Band Co-Existence Study: Summary of Method and Results

May 18, 2016

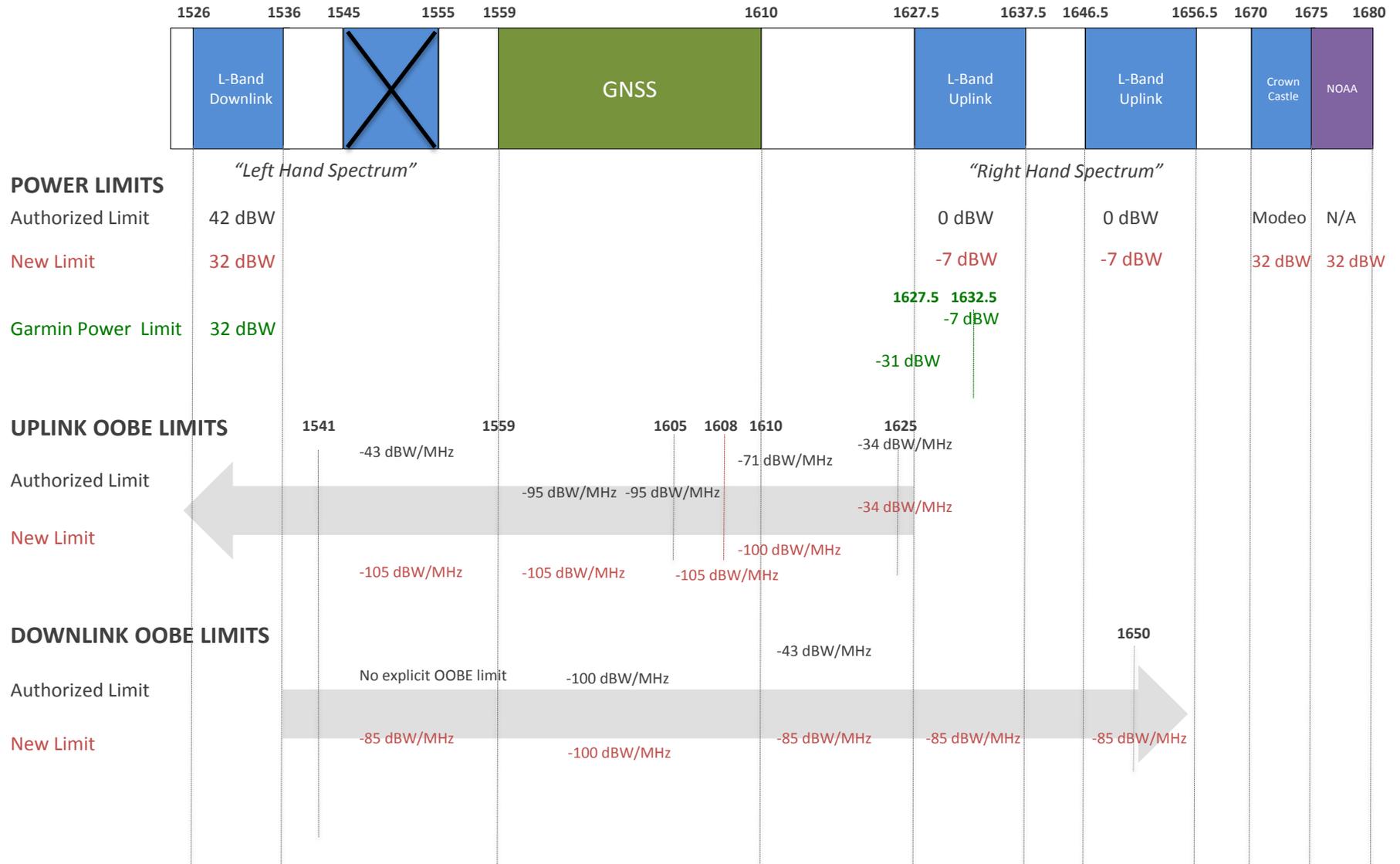


Roberson and Associates, LLC
Technology and Management Consultants

Background and Timeline

- The preliminary Roberson GPS Test Plan was filed at the FCC in August 2015 with revisions initially filed in October 2015 and subsequently in February 2016
 - Stakeholder input provided in various forums incorporated into the Roberson GPS Test Plan
- Roberson and Associates presented an initial set of preliminary test results on February 5, 2016 to representatives of the DOT and other government agencies
 - Test results of multiple devices from a single device OEM and other selected devices
 - Materials for the February 5, 2016 briefing filed at the FCC on February 24, 2016
- Final Roberson Test Plan Results filed at the FCC on May 9, 2016
 - Over 250 pages of test results for 27 devices in the Cellular, GLN, High-Precision, and Non-Certified Aviation Device categories
 - Excel file for each device with KPI measurements by band by test condition
 - Summary document that provides overview of test method, conditions, and results

Ligado's FCC Proposal Based on New GPS Agreements



Note: The Coexistence Plans also include narrowband limits not depicted here.

Five Test Procedures Used in RAA Testing

1. **Open Sky.** Spirent simulator created a moving constellation of GPS signals representative of a static location which were presented to devices along with LTE signals. This method was predominantly used for High Precision Devices.
2. **Open Sky with Motion.** Spirent simulator created a moving constellation of GPS signals representative of a moving vehicle, which were presented to devices along with LTE signals. This method was used for General Location and Navigation devices and the Samsung Tablet.
3. **Impaired GPS Signals with Motion.** Spirent simulator created a moving constellation of GPS signals at reduced GPS power levels representative of a moving vehicle which were presented to devices along with LTE signals. This method was used for General Location and Navigation devices.
4. **Live Sky.** A rooftop antenna captured GPS signals (and MSS augmentation signals in the case of some receivers) which were presented to devices along with LTE signals. This method was used for some of the High Precision devices.
5. **3GPP A-GPS Tests.** These are GPS conformance tests approved by 3GPP, the internationally recognized standards group for testing cellular devices. These methods were used for the Samsung S5 and S6.

Measurement and Assessment Approach

1. Establish performance baseline for each device

- Measure position error without LTE
- Apply GPS signal for 2 hours



2. Measure performance with LTE

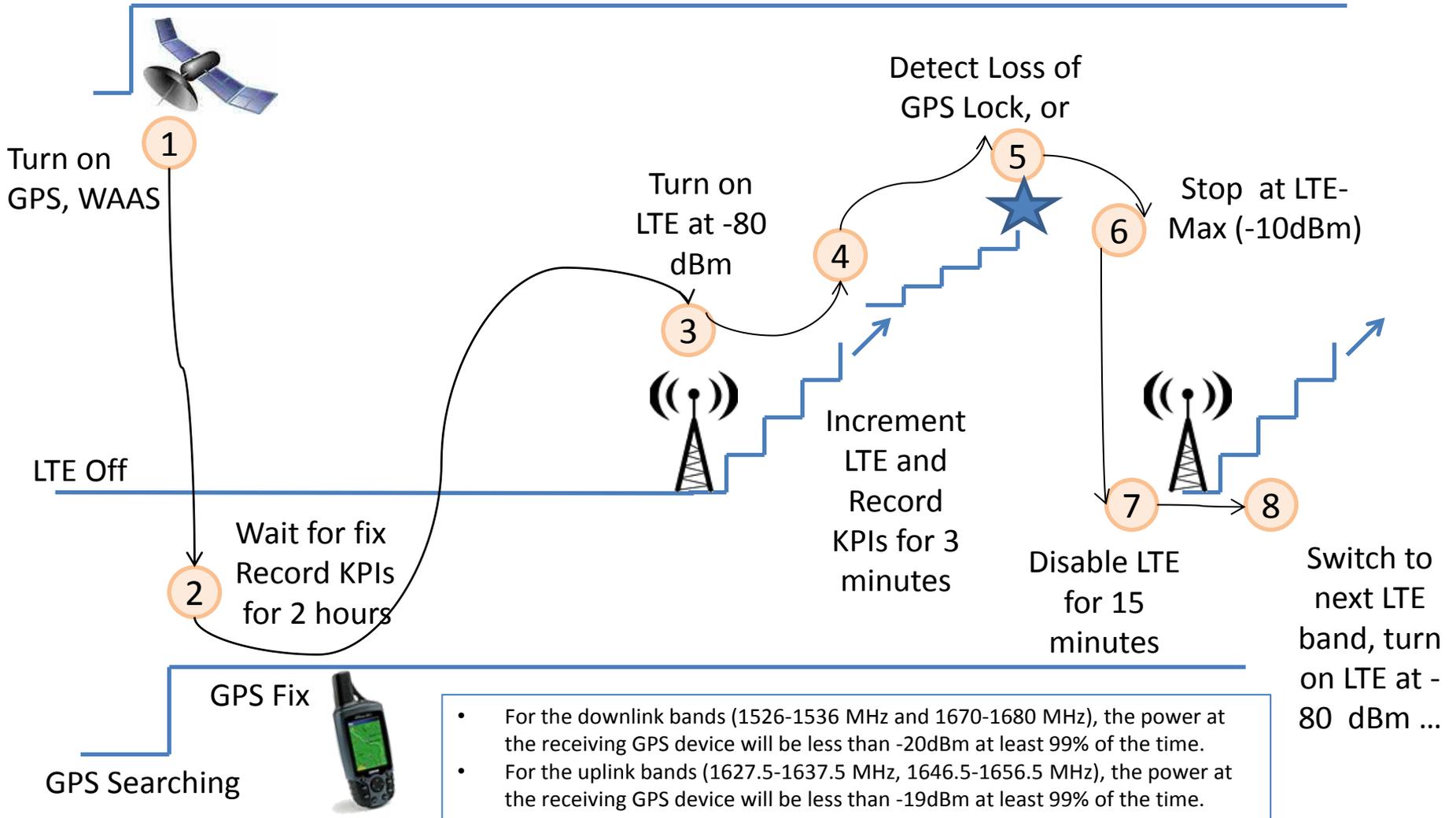
- Apply increasing LTE signal up to and beyond levels corresponding to the proposed Ligado power levels
- Test all four 10 MHz bands
- Test devices via Open Sky, Open Sky with Motion, Impaired GPS Signals with Motion, Live Sky, and 3GPP test condition methods



3. Compare device performance with and without LTE to determine the difference

4. Analyze device performance under the proposed Ligado power levels

Basic KPI (Position Error) Measurement Sequence: All Devices Except A-GPS Cellular

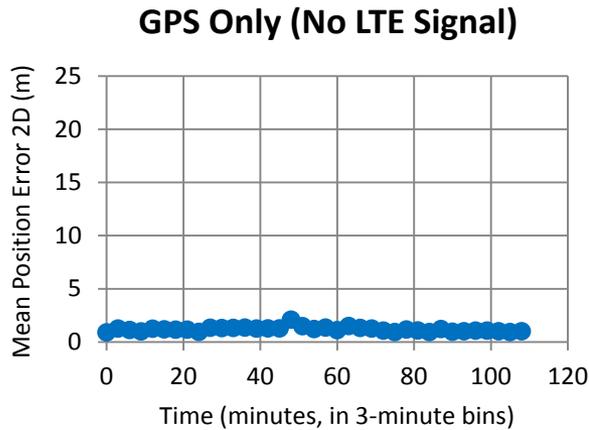




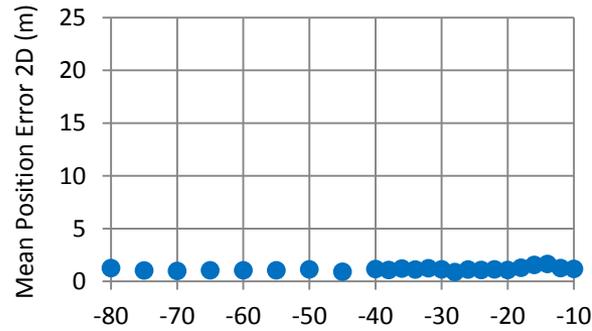
Results Example: Garmin eTrex

Condition: Open Sky with Motion

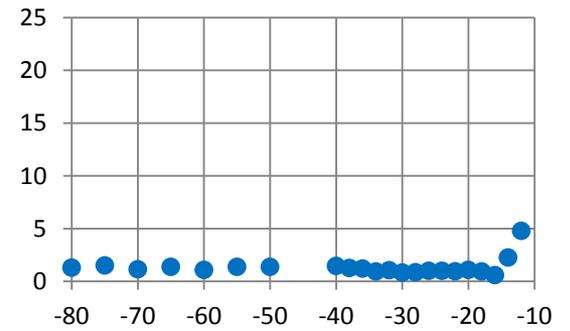
1526-1536 MHz Downlink	1627.5-1637.5 MHz Uplink	1646.5-1656.5 MHz Uplink	1670-1680 MHz Downlink
No Impact	No Impact	No Impact	No Impact



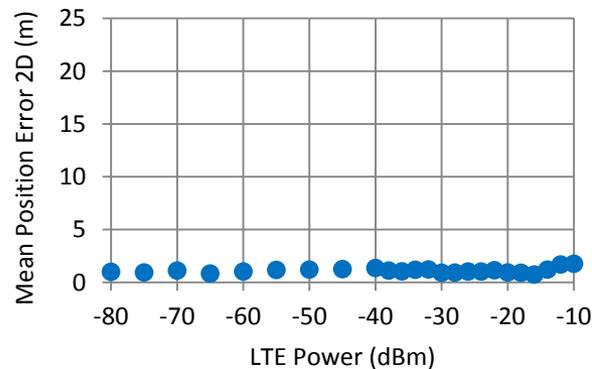
1526-1536 MHz LTE



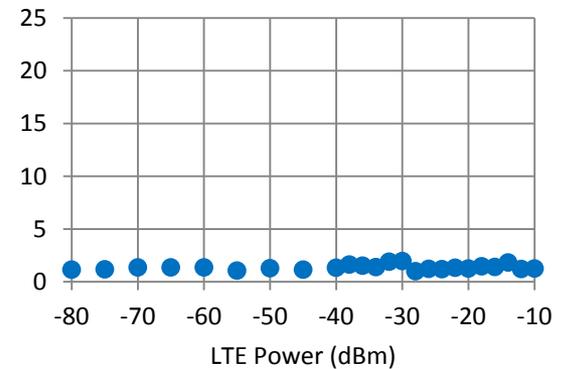
1627.5-1637.5 MHz LTE



1646.5-1656.5 MHz LTE



1670-1680 MHz LTE

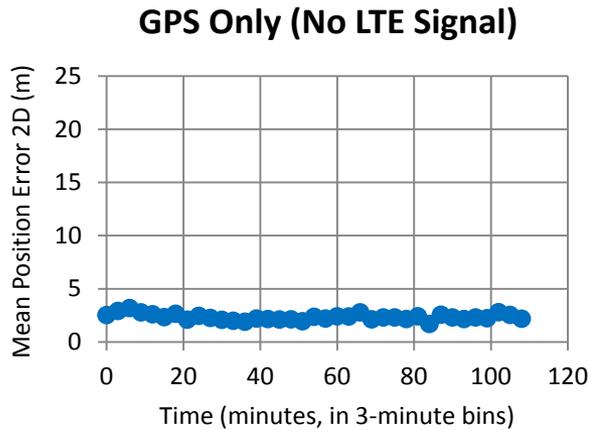




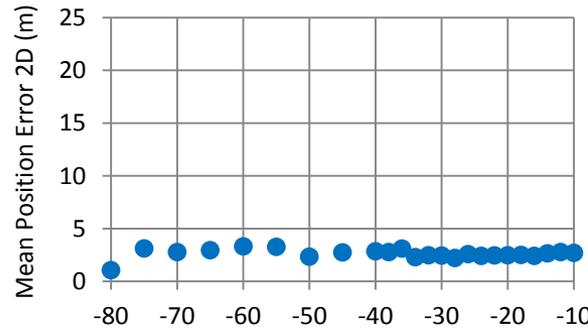
Results Example: Garmin eTrex

Condition: Impaired GPS Signal with Motion

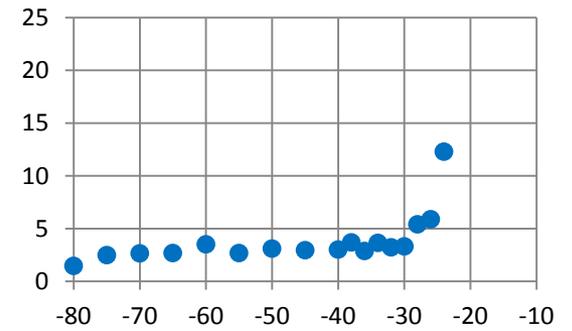
1526-1536 MHz Downlink	1627.5-1637.5 MHz Uplink	1646.5-1656.5 MHz Uplink	1670-1680 MHz Downlink
No Impact	-30 dBm*	No Impact	No Impact



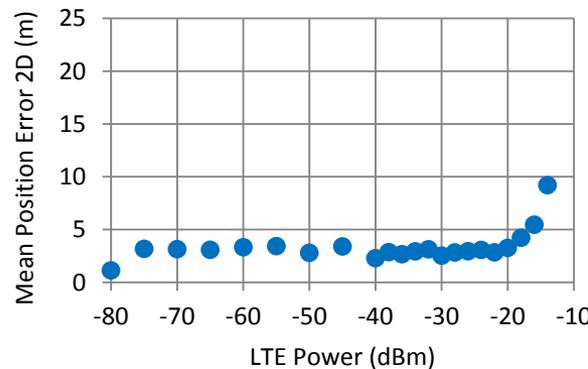
1526-1536 MHz LTE



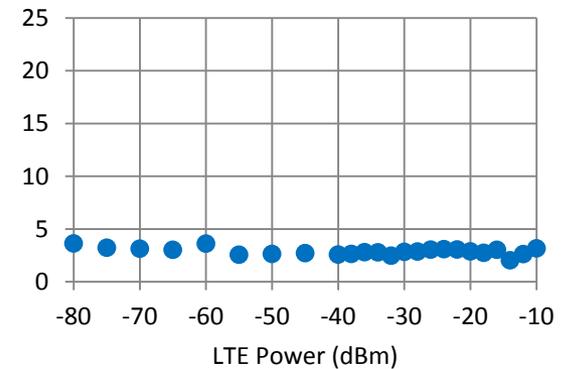
1627.5-1637.5 MHz LTE



1646.5-1656.5 MHz LTE



1670-1680 MHz LTE



* Compatible with the 1627.5-1637.5 MHz band with up to -30 dBm of LTE power when tested with an impaired GPS signal with motion.

Consumer GPS Device Conclusions Under Ligado's Deployment

- RAA successfully tested GPS user performance metrics for four 10MHz bands
 - 1526-1536 MHz, 1627.5-1637.5 MHz, 1646.5-1656.5 MHz, and 1670-1680 MHz
- Study demonstrates feasibility of using Key Performance Indicators (KPIs) for GPS Devices
 - 2D Position Errors were captured
 - Testing included static and simulated motion of the device
- 16 Devices Successfully Tested
 - Two Smartphones and One Tablet
 - Twelve General Location and Navigation (GLN) devices
 - One Non-Certified Aviation Device
- Comparing device performance with and without LTE to determine the difference, the RAA analysis demonstrates that GPS user performance shows:
 - No impact for Smartphone and Tablet devices
 - No impact for GLN devices in Open Sky conditions
 - No impact in 15 out of 16 use cases for GLN devices under Impaired GPS Signal test conditions
 - No impact for Non-Certified Aviation device
- 1 dB C/N_0 degradation does not predict impact of adjacent band signals on Consumer GPS device positioning performance

High Precision GPS Device Conclusions Under Ligado's Deployment

- RAA successfully tested GPS user performance metrics for four 10MHz bands
 - 1526-1536 MHz, 1627.5-1637.5 MHz, 1646.5-1656.5 MHz, and 1670-1680 MHz
- Study demonstrates feasibility of using Key Performance Indicators (KPIs) for GPS Devices
 - 3D Position Errors were captured
- 11 High Precision (HP) Devices Successfully Tested
- Comparing device performance with and without LTE to determine the difference, the RAA analysis demonstrates that GPS user performance shows:
 - No impact on four HP devices from two different Device OEMs
 - One Device OEM that experienced no user impacts on three of its HP devices, did show impacts on some 10 MHz bands for three other HP devices. When each of these impacted HP devices, however, were re-tested using filtered antennae, all three HP devices showed no impact to user performance from LTE
 - One HP device manufactured by a separate Device OEM also showed impacts on some 10 MHz bands
 - This device is intended for agriculture use
 - Three HP devices manufactured by another Device OEM show performance impacts on just the lower downlink 1526-1536 MHz band, for which Ligado has agreed to operate at power levels consistent with FAA requirements
- 1 dB C/N₀ degradation does not predict impact of adjacent band signals on High Precision GPS device positioning performance