RTCA

THE GOLD STANDARD FOR AVIATION SINCE 1935

Approved by the Tactical Operations Committee December 2016

Operational Review of Ligado Networks Proposal for Standoff Cylinders

Report of the Tactical Operations Committee in Response to Tasking from

The Federal Aviation Administration

December 2016

Operational Review of Ligado Networks Proposal for Standoff Cylinders

Contents

Introduction

The RTCA Tactical Operations Committee was requested by the Federal Aviation Administration (FAA) to review the operational impacts of a proposal by Ligado Networks to utilize spectrum on the GPS adjacent band (tasking letter included in Appendix A). Ligado Networks proposes to augment its existing satellite communications services with terrestrial transmitters, with the closest terrestrial downlink channel located 23 MHz away from the GNSS band. Transmissions on the GPS adjacent band may create interference for GPS receivers that are in proximity of the transmitter. Ligado's proposal calls for *Standoff Cylinders,* defined as a cylinder 250 feet in radius around and 30 feet above a Ligado transmitter within which GPS receivers should expect harmful interference due to Ligado's emissions. The cylinder goes down to ground level. Outside of the cylinder, Ligado's transmission would have no impact on GPS reception.

With support from Ligado Networks, a Task Group of the Tactical Operations Committee evaluated the Standoff Cylinder concept (participants included in Appendix B) and compiled comments. These comments identify a set of concerns that the aviation operational community has concerning Standoff Cylinders. This report provides the full set of comments (See Appendix C) as well as an Executive Summary. Briefing materials used during the Task Group meeting are included in Appendix D. All technical statements made by participants in their comments and/or briefing materials are subject to validation by RTCA Special Committee (SC) 159 and/or the FAA.

Assumptions

Comments in this report are based on the following set of assumptions:

1. A standoff cylinder around a Ligado transmitter is 250 feet in radius and 30 feet above the transmitter. The cylinder extends down to ground level.
2. There will be no interference to GPS from Ligado's transmitters outside of the standoff cylinders. Inside the cylinder, GPS may be degraded.
3. The proposal does not address cold start acquisition of GPS signal.
4. Operators should assume that GPS is unavailable inside a standoff cylinder.
5. The minimum distance between towers is 433 meters/.27 Statute Miles (SM). Ligado has stated that actual separation distances will typically be much larger.
6. There is no minimum or maximum height for a tower on which a Ligado transmitter is placed. However, towers are generally expected to be between 50 and 150 feet in height.
7. Standoff Cylinders will not interfere with Part 77 airport Obstacle Clearance Surfaces (OCS), Instrument Approach Procedures (IAPs) or One Engine Inoperative (OEI) procedures.

8. If the Part 77 surface changes in the future, due to new or amended IAPs, runway modifications/additions, or other changes, Ligado Networks will adjust its transmitter(s) to not interfere.
9. Standoff Cylinders will not be charted, either on paper or electronically, for aircraft operators. However, Ligado has agreed to provide a database of their transmitter locations to the operational community.
10. Certified aviation GPS receivers are used during VFR and IFR operations including en route, terminal, precision/non-precision navigation and airport ground movement
11. Certified aviation GPS receivers are used in urban, suburban, rural, and offshore environments.
12. Certified aviation GPS receivers provide position information to support TAWS/HTAWS and ADS-B Out/In functionality.

Executive Summary

The TOC commends Ligado for undertaking detailed coordination with the FAA in an effort to ensure its proposal conforms to FAA standards. Operators in the National Airspace System (NAS) are primarily concerned with operational safety, and review of the Ligado proposal was conducted through this lens.

After review, there are remaining concerns expressed by several, but not all, operators about the proposal and its impacts to aviation operations and safety. The full set of comments is included in Appendix C, and a summation is provided below. This task was conducted in a short time frame, so this report simply compiles and summarizes operator concerns about the proposal but does not seek to validate, identify resolution or prioritize them. The FAA is requested to consider the comments in this report as it deliberates the Ligado Networks proposal. This group expects that the FAA will work to validate all of the comments and determine resolutions, if possible. This should be done with the support and review of NAS operators.

The summary of operator comments follows:

Real-World Operational Test Data

Ligado's analysis approach to-date has been a model-based approach. For the operational community, a model-based approach is not sufficient and actual real-world testing of interference impacts and operational scenarios is necessary. Testing would require one or more prototype Ligado transmitters operating on the specified frequency combined with actual aircraft (helicopter, UAS, other) operating in the vicinity of the tower(s).[1] Without this testing it is impossible to fully determine the expected extent of the interference. Ligado's operating parameters should be further adjusted by the FAA based on the results of such field testing.

Before authorized use of the spectrum is granted, the FAA (and FCC) should identify a program for evaluating the impact and building the proof data ahead of deployment. Operators would like to have input and review results of this process.

Some specific issues the TOC suggests for consideration of real-world tests include:

- Impact of potential interference on different GPS receivers, including uncertified aviation GPS devices[2]
- Verification that GPS degradation from Ligado transmitters does not extend outside the cylinder
- Technical and human factors issues associated with re-initialization of GPS after losing the signal or if the signal goes in and out
- Workload and human factors impacts on pilots to monitor and track standoff cylinder locations and the possibility that pilot workload, confusion, or error could lead to aircraft inadvertently entering a standoff cylinder and losing needed GPS functionality
- Impact to onboard and ground systems that are dependent upon GPS, such as ADS B/C, GBAS or TAWS/HTAWS including obstacle alerting
- Possible interference interactions from multiple Ligado transmitters
- Testing on multiple operator types, not just helicopters.

Helicopter Operations

Helicopter Association International (HAI), an international helicopter industry association, remains concerned about the impact of Standoff Cylinders on all scenarios and for the reasons previously identified in the July 2015 TOC GPS Adjacent Band Compatibility report. Some new operational scenarios are also identified. Additionally, helicopter operators intend to develop a NextGen low altitude PBN route structure that could be negatively impacted by up to 20,000 Standoff Cylinders.

HAI also asserts that it is not aware of any permanently deployed networks that have known or intentional disruptive transmission properties related to GPS.

---

[1] The TOC assumes this testing would include all envisioned operational scenarios from low desntiy rural to high density urban

[2] Due to the terms of its settlement agreement with Ligado, Garmin did not participate in development of any discussion of uncertified GPS devices

North Flight Data Systems / Metro Aviation, a helicopter operator, stated that within 250 feet of an obstacle or 30 feet above, helicopter pilots would require visual reference to conduct safe operations, and the Standoff Cylinder may not have significant impact.

Unmanned Operations

UAS operations with certified GPS receivers are likely to be affected by the Ligado proposal due to the anticipated operational altitudes and locations. While it is true that sUAS can tolerate some short-term GPS outages, it is unknown to what extent UAS can tolerate short GPS outages and how they can recover from GPS outages. Testing is required to define the limits of GPS loss.

Location of Standoff Cylinders

Operators remain concerned that 10,000-20,000 Standoff Cylinders may be in the NAS and pilots may not know where they are. There is interest in understanding how operators may know where these cylinders are, and operators should be engaged to provide input into how this information would be made available to aviation stakeholders. If such information is provided in a database to the operational community, and the obstacle data was incorporated into equipment performing TAWS/HTAWS function, this would begin to help to ensure safety.

Compliance Monitoring

Operators understand that Ligado's proposal intends to bound interference within a defined cylinder and not impact current or future OCSs. However, operators would like additional detail on how Ligado will ensure compliance with these intentions. How, for example, will Ligado ensure every transmitter does not violate the Standoff Cylinder? How will Ligado monitor changes to Part 77 surfaces or IAPs to ensure its transmitter network does not interfere? How will Ligado ensure its transmitters do not interfere with use of aircraft-based certified GPS during ground movement operations?

ADS-B Position Reporting

Operators have concern that Ligado's Standoff Cylinders could impact and potentially degrade ADS-B Out transmissions and safety due to the inability of equipment to broadcast valid GPS-based data. This may impact a controller's situational awareness or ADS-B In systems on nearby aircraft that ingest this position information. These potential impacts should be considered.

Uncertified Avionics[3]

There is high interest to understand the impacts of Standoff Cylinders on all GPS receivers, including those that are uncertified. Given the proliferation of s-UAS in the past year since the

[3] Due to the terms of its settlement agreement with Ligado, Garmin did not participate in development of any discussion of uncertified GPS

TOC last looked at the former LightSquared (now Ligado) proposal, the workgroup believes it is important to comment on non-certified GPS receivers. The reality is that non-certified GPS are the dominant receivers on the hundreds of thousands of s-UAS in the NAS. Given that FAA has asserted jurisdiction over regulating the operation of s-UAS under Part 107, it is incumbent on the FAA to provide safe and reliable GPS based navigable airspace for those s-UAS. The workgroup therefore recommends the FAA take this into consideration before taking any final action on the Ligado proposal. This concern was also echoed by General Aviation operators, many of whom utilize uncertified devices for navigation of VFR flights. Also, uncertified GPS receivers are used by some avionics manufacturers for different operational design, or safety reasons required by aircraft systems. Examples include some variants of INS, EFBs and ELTs.

Safety Assessment

The FAA should consider implementation of the Ligado Networks proposal as a significant change to the NAS and conduct the corresponding thorough safety analysis.

Conditions for License

License conditions are important for current and future license holders and to help guide enforcement, when needed. Ligado may not be the license holder of the GPS adjacent band spectrum in perpetuity. Aviation operations should be protected in the case that the license transfers to another proponent in the future. Ligado has made commitments to maintaining aviation safety (for example, not penetrate OCS, move transmitter that conflicts with OCS, provide information on transmitter locations). The FAA should consider whether these commitments should be conditions for any current and future license holder. Additionally, the FAA should consider the impact on private airport or special IAPs and whether these should also be incorporated into license conditions.

Appendix A: FAA Tasking Letter

U.S. Department
of Transportation
**Federal Aviation
Administration**

October 19, 2016

Margaret Jenny
President
RTCA Inc
1150 18th St. NW, Suite 910
Washington, DC 20036

Dear Ms. Jenny,

The FAA continues to support the Department of Transportation's (DOT) activities to develop Global Positioning System (GPS) spectrum interference protection criteria to guide future proposals for non-space, commercial uses in the bands adjacent to the GPS signals. Ligado Networks has provided an analysis of the compatibility between their proposed handsets and certified GPS receivers (enclosed). We have also received a proposal from Ligado Networks concerning the compatibility of their downlink with certified GPS receivers (enclosed). Their proposal is based, in large part, on the FAA assessment of the original LightSquared proposal, and proposes to determine a site-by-site peak power output that will ensure GPS reception for aircraft using certified avionics when they are operating 250 feet or more laterally, or 30 feet or more above a Ligado transmitter antenna.

The FAA requests that RTCA review these documents and provide comments. Should the committees have any questions, please contact Ken Alexander, Chief Scientific and Technical Advisor for Satellite Navigation Systems, (202) 236-9794, ken.alexander@faa.gov.

The FAA activities are part of the ongoing DOT-led activity to understand power levels that can be tolerated in the adjacent radiofrequency bands for all civil global navigation satellite system receivers, including non-certified aviation receivers which are of interest to the FAA, but are outside the scope of the enclosed analyses and this request for comment. The FAA will continue to review for potential impacts to noncertified equipment and their effect on aviation, in the context of other noncertified receivers across many other civil applications. We appreciate your consideration of this matter and look forward to your response.

Sincerely,

Margaret Gilligan

Margaret Gilligan
Associate Administrator for Aviation Safety

Enclosures

Appendix B: Members of the TOC Ligado Proposal Review Task Group

Darrell Pennington, Air Line Pilots Association

Rune Duke, Aircraft Owners and Pilots Association

Robert Ireland, Airlines for America

Jeff Miller, Airlines for America

Mark Aitken, Association for Unmanned Vehicle Systems International (AUVSI)

Andrew Roy, Aviation Spectrum Resources, Inc.

Jim Williams, Dentons

Steve Robinson, Department of Defense (DoD)

Larry Hills, FedEx Express

Clay Barber, Garmin Ltd.

John Foley, Garmin Ltd.

Chris Martino, Helicopter Association International (HAI)

Paul McDuffee, Insitu Inc.

Rob Eagles, International Air Transport Association

Kieran O'Carroll, International Air Transport Association

Noppadol Pringvanich, International Air Transport Association

Tamara Casey, Ligado Networks

Santanu Dutta, Ligado Networks

Geoff Stearn, Ligado Networks

Louis Glabb, NASA

Robert Kerczewski, NASA

Parimal Kopardekar, NASA

Sreeja Nag, NASA

Denise Ponchak, NASA

William L Geoghagan, National Air Traffic Controllers Association (NATCA)

Bob Lamond Jr, National Business Aviation Association

Jim Arthur, North Flight Data Systems / Metro Aviation

Sai Kalyanaraman, Rockwell Collins, Inc.

Trin Mitra, RTCA, Inc.

Perry Clausen, Southwest Airlines

Appendix C: Comments from Task Group Participants

Organization	Category	Safety or Efficiency?	Comment
AOPA	GA operations	Both Safety & Efficiency	The impact of a 250' X 30' standoff cylinder will have minimal impact on fixed-wing general aviation operations should the mitigations proposed by Ligado (remaining clear of Part 77 surface, not impacting current or future IAPs, etc.) be implemented. General aviation aircraft rarely operate within 250' of a known obstruction and, if intentional and not part of an emergency situation, it is likely a VFR operation that is being conducted.
AOPA	Uncertified GPS	Both Safety & Efficiency	AOPA is concerned for the impacts of Ligado operations on uncertified avionics. Thousands of general aviation pilots rely on GPS navigation while flying VFR. These uncertified devices are the predominant form of navigation for VFR flights. They are even more relied upon as the FAA removes legacy NAVAIDs (VOR/NDB) from the NAS and define large airspace, primarily Class B, on lat/long versus VOR radial/DME. Ligado operations should be evaluated for impact on uncertified devices given the impact on safety and efficiency they could have on VFR operations.
AOPA	GA operations	Both Safety & Efficiency	The FAA must ensure there is a mechanism to protect private or special IAPs from interference by Ligado operations. Given these approaches are all known, and Ligado transmitters should be known, there is a pathway to ensuring the protection of current and future special IAPs. Pilots flying these approaches in IFR may have no way of knowing that GPS interference is expected and it could lead to an accident given loss of navigation capability at low altitude.
AOPA	GA operations	Both Safety & Efficiency	The FAA must understand the impact of Ligado operations on ADS-B Out devices and nearby radio stations. The position source for the aircraft must not be impacted outside of the proposed standoff cylinder.
ASRI	General comment	Both Safety & Efficiency	GPS signal acquisition not accounted for. Cold start acquisition of the GPS signal requires greater protection from interference than tracking. If an aircraft lands within the Ligado standoff cylinder and shuts down, it will require greater signal protection levels to reacquire a GPS signal from cold start at ground level than the predictions presented by Ligado in the TOC meeting. This should be accounted for once the appropriate technical model has been agreed at SC-159.
ASRI	General comment	Both Safety & Efficiency	GPS signal acquisition not accounted for. An aircraft that loses GPS within the Ligado standoff cylinder will then need to fly further outside the area specified by the Ligado standoff cylinder to reacquire GPS. Any agreed SC-159 model would be needed to confirm the signal levels beyond the Ligado standoff cylinder, with the appropriate GPS receiver sensitivity levels for reacquisition, to verify the impact of such a scenario. This would be especially applicable to the cold start comment previously, when aircraft are flying out of the Ligado standoff cylinder and are transitioning between VFR and IFR ops.
ASRI	General comment	Both Safety & Efficiency	Coordination of Ligado sites and aviation airspace. Aviation IFR routes are subject to change, and can include IFR flight to the ground level for certain specialist rotorcraft operations (e.g. hospital roof landing pads). Ligado stated that they will take this into account when planning new sites, but clarification is needed on how air route changes will be monitored for existing Ligado sites to ensure they do not present a risk to future navigational route changes.
ASRI	General comment	Both Safety & Efficiency	Coordination of Ligado sites and aviation airspace. How are Ligado site locations expected to be coordinated and informed to those aviation users likely to be affected by loss of GPS within the Ligado standoff cylinder?
ASRI	General comment	N/A	Compliance testing of Ligado sites once deployed. Theoretical and lab testing are being used to assess the expected Ligado emission limits at the edge of the proposed standoff cylinders. Given the Ligado tower properties are expected to be different for each basestation (dependent on the site and local user requirements), how are the compliance of these different configurations going to be physically verified once towers are deployed in a real RF environment?
ASRI	General comment	Safety of life focus	Effect on GPS dependent systems onboard aircraft. ADS-B/C and TAWS use GPS as a important data source in their operation. What is the impact on these systems for aircraft expecting to be operating within the Ligado standoff cylinder long enough to lose their GPS signal, especially if multiple aircraft are within close proximity and are coordinating separation within the same airspace.
ASRI	Uncertified GPS	N/A	Uncertified GPS use onboard aircraft needs to be protected. Uncertified GPS receivers are used by some aircraft avionics/manufacturers for operational or safety reasons (e.g. INS, ELTs, etc.). Given that the DoT testing has shown that certain uncertified GPS receivers are more susceptible to out of band RF interference than certified receivers, how will existing and future aircraft equipage of uncertified GPS be protected from harmful interference?
Garmin	General comment	N/A	Garmin's settlement agreement with Ligado provides that nothing in that agreement constitutes an endorsement of Ligado's proposed network. The agreement, however, does include restrictions on Garmin's ability to object to certain matters. Accordingly, Garmin's submission with respect to this TOC Ligado Proposal Comments matrix relates solely to interference issues regarding certified Garmin GNSS aviation equipment caused by Ligado's use of the 1526-1536 MHz spectrum. A short statement noting this point is included in Garmin's matrix entries.

Organization	Category	Safety or Efficiency?	Comment
Garmin	General comment	Safety of life focus	The submission relates solely to certified Garmin GNSS aviation equipment: FAA currently publishes NOTAMs providing specific information for locations and altitudes where temporary GPS interference can be expected (e.g., from DOD tests). Operators are expected to review and be aware of such NOTAMs when operating in these areas. Ligado's proposed network could cause permanent locations where GPS interference can be expected. The July 2015 TOC GPS ABC report made the following observation "There is no existing mechanism to notify operators of the location of all exclusion zones where GPS will be unreliable; nor is an effective notification method anticipated to be in place in the future." (pg. 7) The TOC GPS ABC TG should determine whether this observation is still a cause for concern and advise the FAA on operator expectations for NOTAM publication as it relates to Ligado's proposed network.
Garmin	Helicopter operations	Both Safety & Efficiency	The submission relates solely to certified Garmin GNSS aviation equipment: 14 CFR 135.605(a) requires that "After April 24, 2017, no person may operate a helicopter in helicopter air ambulance operations unless that helicopter is equipped with a helicopter terrain awareness and warning system (HTAWS) that meets the requirements in TSO-C194 and Section 2 of RTCA DO-309." The 14 CFR 135.605(a) applies regardless of whether the operation is conducted as a VFR or IFR operation. Several Garmin TSO-certified GNSS aviation equipment models also support TSO-C194 HTAWS functionality. TSO-C194 via RTCA DO-309 specifies requirements for obstacle data depiction (section 2.2.1.1), and aural and visual obstacle alerts (sections 2.2.2.1 and 2.2.2.2, respectively). Additionally, RTCA DO-309 specifies requirements for obstacle database processing (section 2.2.4). While RTCA DO-309 does not specify minimum requirements for which obstacles should be included in an obstacle database, publicly available Ligado cell site location information would assist equipment performing the HTAWS function with meeting the TSO-C194 and RTCA DO-309 requirements for obstacle data depiction and alerting. Publicly available Ligado cell site location information would also assist applications used to meet the 14 CFR 135.615(a)(1) and (a)(2) requirements for Helicopter Air Ambulance Operations VFR pre-flight planning with respect to "evaluating ... obstacles along the planned route of flight" and identifying and documenting "the highest obstacle along the planned route of flight". Ligado noted a willingness to make its cell site location information publicly available during the Nov 29, 2016 TOC GPS ABC TG meeting. While this cooperative spirit was acknowledged during the meeting, there is no guarantee that Ligado will remain the license holder in perpetuity. Consequently, the Dec 2016 TOC GPS ABC report should recommend a license condition that ensures Ligado, or its successor, makes a database of all its cell site locations publicly available.
Garmin	Helicopter operations	Safety of life focus	The submission relates solely to certified Garmin GNSS aviation equipment: The July 2015 TOC GPS ABC report concluded that the previously proposed 500-foot radius exclusion zones had "negative impacts to both flight safety and operations for multiple operational scenarios and multiple types of operators. This includes negatively impacting GPS-based TAWS/HTAWS alerts. Additionally, the exclusion zones are defined to go as low as 100 feet AGL, but there are some operational scenarios with negative impacts below 100 feet AGL." (pg. 4) Several Garmin TSO-certified GNSS aviation equipment models also support TAWS & HTAWS functionality including obstacle alerting. While Ligado's latest proposed method includes a reduced size standoff cylinder when compared to the previous exclusion zone, Ligado's proposed network still could result in permanent locations where GPS interference can be expected that could lead to loss of GPS, which in turn will lead to loss of GPS-based TAWS/HTAWS alerts. Some of these Garmin TSO-certified GNSS aviation equipment models also support safety-enhancing powerline alerting. Powerlines are not easily seen even in daylight VFR conditions. Some powerlines could transect a Ligado standoff cylinder where loss of GPS also would lead to loss of powerline alerting. In August 2011, the U.S. Joint Helicopter Safety Analysis Team (JHSAT) published "The Compendium Report: The U.S. JHSAT Baseline of Helicopter Accident Analysis". This report "analyzed 523 accidents and completed extensive reports on each of the respective years, 2000, 2001 and 2006". (Executive Summary, Vol I, pg. 1) This report categorized: - 21 accidents as "STRIKE-HTOL" (object strike while in the take-off/landing phase) - 29 accidents as "STRIKE-LALT/M" (object strike while in low altitude missions or accident caused by having too little altitude to recover due to the mission) -38 accidents as "STRIKE-Obj" (object strike (wire, tree, antenna, etc) while in other than the take-off/landing phase or low altitude mission operations) (Appendix B, Vol II, pg. 3) This represents 16.8% of the analyzed accidents.

Organization	Category	Safety or Efficiency?	Comment
Garmin	Helicopter operations	Safety of life focus	(Continuation of previous comment) Additionally, when FAA published the 14 CFR 135.605(a) rule requiring helicopter air ambulance operations to equip with (HTAWS), it concluded "that the use of HTAWS would create a safer environment for emergency medical services flight operations by preventing controlled flight into terrain at night or during bad weather." (FR Vol 79, No 35, Feb 21, 2014, pg. 9953) FAA based this conclusion in part on a January 2006 NTSB "Special Investigation Report on Emergency Medical Services Operations" which noted that "17 of 55 accidents [analyzed] may have been prevented with TAWS" (http://www.ntsb.gov/news/events/documents/sir_06_01-intro.pdf, pg. 30) The TOC GPS ABC TG should determine whether the July 2015 TOC GPS ABC conclusion is still a cause for concern based on operator use of TAWS & HTAWS functionality including 14 CFR 135.605(a) HTAWS requirements.
Garmin	Helicopter operations	Safety of life focus	The submission relates solely to certified Garmin GNSS aviation equipment: While not noted in the July 2015 TOC GPS ABC report, interference when flying within a Ligado standoff cylinder could lead to degradation or loss of GPS that could have downstream impacts on TSO-C166b and TSO-C154c ADS-B Out equipment. ADS-B Out equipment is required when flying in airspace defined by 14 CFR 91.225. 14 CFR 91.227 defines specific requirements for broadcast of parameters for ADS-B Out equipment. Several Garmin TSO-certified GNSS aviation equipment models are used as position sources for the ADS-B Out broadcast parameters. If GPS accuracy and integrity are degraded, it will lead to corresponding degradation of the ADS-B Out Navigation Accuracy Category (NAC) and Navigation Integrity Category (NIC) parameters. If GPS is lost, it will lead to the inability of ADS-B Out equipment to broadcast valid GPS-based position, velocity, altitude, NAC, and NIC parameters. A further downstream effect would be the inability of nearby aircraft equipped with TSO-C195 ADS-B In equipment to display a target aircraft symbol for aircraft that are no longer broadcasting valid ADS-B Out parameters or whose broadcast ADS-B Out NAC and NIC parameters have been degraded to the point that the information is considered unusable. The TOC GPS ABC TG also should determine whether degradation or loss of other certified aviation equipment functions such as ADS-B Out and ADS-B In is a cause for concern based on operator use of that equipment.
Garmin	General comment	Safety of life focus	The submission relates solely to certified Garmin GNSS aviation equipment: The Sep 19, 2016 Ligado method section 6.2 includes "In order to ensure that Ligado's operations will not interfere with aircraft IFR operations on approach and departure routes at airports and heliports and other navigable airspace governed by Part 77, Ligado will not locate sites where any portion of the standoff cylinder would pierce the plane of a defined obstacle clearance surface. This will ensure that Ligado's EIRP will be within conformance limits at all points on, and above, the OCS." (pg. 17) Most Garmin TSO-certified GNSS aviation equipment models support GNSS-based instrument approach operations that could be adversely affected if a standoff cylnder was located such that it pierced an instrument approach obstacle clearance surface plane. Ligado's cooperative spirit in making the Part 77 committment is duly noted, especially since this committment appears to exceed the 14 CFR 77.9 "Construction or alteration requiring notice" requirements. However, there is no guarantee that Ligado will remain the license holder in perpetuity. Consequently, the Dec 2016 TOC GPS ABC report should recommend a license condition that ensures Ligado, or its successor, will adhere to this committment. Additionally, the license condition should include provisions for the measures Ligado must take when one or more of its cell sites already exist where the standoff cylinder would pierce the plane of a defined obstacle clearance surface at an airport or heliport that could be constructed at a future date. e.g., a new hospital could be built where a heliport is constructed. Ligado's license should be conditioned such that it would be required to relocate such cell sites.
Garmin	General comment	N/A	The submission relates solely to certified Garmin GNSS aviation equipment: In its presentation to the TOC, Ligado provided a number of slides visualizing its assessment of the impact to a certified GPS receiver operating on the ground within a standoff cylinder (Appendix D, slides 9-19). It is important to note that this information is not representative of any consensus agreement reached during the RTCA SC-159 WG6 review of the Ligado proposal. In particular, Ligado bases its assertions regarding the GPS receiver susceptibility upon measurements from a single receiver that performs better than the GPS Minimum Operational Performance Standards (MOPS). It also eliminates any aviation safety margin intended to account for un-modeled interference effects. Ligado's visualization assumes an aircraft on the ground which does not represent the point where the most interference would be observed in each scenario shown. Finally, Ligado fails to specify the base station transmit power and antenna down-tilt used to generate the visualizations. As a result, the depictions do not allow for any conclusions to be made about real-world impacts to certified GPS receivers operating within a Ligado standoff cylinder.

Organization	Category	Safety or Efficiency?	Comment
Garmin	General comment	N/A	The submission relates solely to certified Garmin GNSS aviation equipment: Testing would require multiple prototype Ligado transmitters at the maximum planned network density operating on the specified frequency combined with actual aircraft (helicopter, UAS, other) operating in the vicinity of the tower(s). Without this testing it is impossible to fully determine the expected extent of the interference.
HAI	General comment	N/A	HAI appreciates the opportunity to participate in this important working group and the FAA's steadfast diligence to ensure the appropriate level of safety risk management is included in all decisions.
HAI	General comment	N/A	HAI also appreciates Ligado's willingness to engage in the important discussions focused on safety of aircraft in the NAS. There are two points of contention related to the Ligado presentation that necessitate clarifying comment:
HAI	General comment	N/A	1. During their presentation, Ligado spokesmen repeatedly referenced a point that all transmitting towers have the potential to disrupt GPS reception when in close proximity, implying that the addition of their towers was not introducing anything that was not already present in the NAS. HAI disagrees with this point. HAI is not aware of any permanently deployed networks that have known/intentional disruption transmission properties related to aviation GPS.
HAI	Helicopter operations	N/A	2. With regard to antenna deployments, Ligado spokesmen also provided an assessment that in urban areas helicopters were less likely to be present and, therefore, would be less likely to be affected by areas of GPS signal disruption. This assessment is incorrect. The fact is that urban areas (cities, critical infrastructure, etc) have some of the most prevalent concentrations of helicopter operations (law enforcement, fire-rescue, tours). To assume helicopters would not be affected in urban areas is incorrect. This also does not take into account the highly varying signal propagation environment due to building reflections.
HAI	General comment	N/A	At the macro level, HAI remains concerned that initiatives are still being considered that include designed/known fielding of networks that would allow the degradation of GPS signals in the aviation environment. HAI does not oppose advanced terrestrial network development and implementation, but does strongly believe that such advancements should be held to the high standards in place to protect the accuracy and reliability of aviation GPS systems.
HAI	Helicopter operations	Safety of life focus	Review of July 2015 Report – HAI understands that Ligado's previous proposal remains intact with the exception of a reduced "Standoff Cylinder" - from the original 500' radius and 100' above, to the newly proposed 250' radius and 30' above dimension. HAI remains concerned about a proposed deployment plan that would create as many as 20,000 standoff cylinders across the continental U.S. As such, all previous concerns documented in the July 2015 report related to impacts remain valid.
HAI			In addition, some areas of impact that were not previously considered should be provided the appropriate level of study:
HAI	Helicopter operations	Both Safety & Efficiency	Aerial surveying, mapping and photography – Helicopters are employed to validate fixed-point sites and to conduct a variety of surveying tasks. As an example, along the navigable waters of the U.S., GPS is often employed to verify the location of navigational aids. The presence of Ligado standoff cylinders could have negative impacts on the accuracy of such validations.
HAI	Helicopter operations	Both Safety & Efficiency	Aerial Agriculture Applications – A variety of agricultural applications require precision deployment. Standoff cylinders could negatively impact this accuracy.
HAI	Helicopter operations	Both Safety & Efficiency	News Gathering and Emergency Response Operations: Separation of aircraft is critical in those situations where multiple aircraft are involved in a large scale response. National disasters and other news worthy events are typical examples of situations where multiple aircraft congregate (including UAS). Accurate and reliable GPS is an essential element of aircraft separation. Standoff cylinders could negatively impact aircraft separation.
HAI	Helicopter operations	Both Safety & Efficiency	Next Gen Low Altitude Performance Based Navigation – The FAA is fully engaged in the development of the next generation of low altitude performance based navigation capabilities that will enable helicopters to operate under Instrument Flight Rules (IFR) with greater frequency and with far more accuracy. The presence of as many as 20,000 uncharted, GPS disrupting, standoff cylinders across the U.S. could have a detrimental impact to these operations.
HAI			Additional Comments:
HAI	Helicopter operations	N/A	The "interference level" charts presented by Ligado at the 29 November 2016 meeting provide little clarity on the impacts of operating a helicopter within, or near, a proposed standoff cylinder; particularly considering the fact that no testing data related to interference impacts have been presented.
HAI	Helicopter operations	Both Safety & Efficiency	HAI remains concerned with the particular impacts associated with GPS "re-initialization" of an aircraft GPS system in the event it is affected by interference produced by a Ligado tower.
HAI	Helicopter operations	Safety of life focus	HAI remains concerned that the position of as many as 20,000 proposed Ligado antenna locations will not be readily available to aircrews; particularly when in flight. Not enough is known about the density of the deployments, locations and altitudes of the sites. Even if published, it is not clear how aircrews would be able to monitor and track the locations of these towers.
HAI	Helicopter operations	Both Safety & Efficiency	HAI remains concerned about the lack of information on the known impacts to certified (and non-certified) GPS receivers and the subsequent impacts to safety of flight.
HAI	General comment	Safety of life focus	HAI remains concerned with the apparent lack of rigor related to actual testing of interference impacts. We understand the concept of "model-based" approaches to study the impacts, but do not feel they adequately capture the actual impact to safe flight operations.

Organization	Category	Safety or Efficiency?	Comment
HAI	Helicopter operations	Safety of life focus	HAI believes the proposed deployment of as many as 20,000 sites that will negatively impact aviation certified GPS receivers represents a significant change to the NAS that should be considered under section 3.1.2 of the FAA's Safety Management System Manual (version 4.0, exerpt below). HAI is unaware of any safety analysis completed related to the proposed Ligado network.
HAI			3.1.2 When to Perform a Safety Analysis: A safety analysis must be performed using SRM to assess safety hazards and risks and to determine appropriate mitigations. Safety analyses are most frequently performed in response to a NAS change. NAS changes may be proposed and initiated as part of implementation plans for new/modified air traffic procedures, operations, or NAS equipment, or in response to identified safety issues currently in the NAS (i.e., existing hazards). For the ATO, a NAS change is a modification to any element of the NAS that pertains to or could affect the provision of air traffic management and communication, navigation, and surveillance services. Air traffic controllers and technicians, their training, and their certification are elements of the NAS and directly relate to the provision of air traffic services.
HAI	Helicopter operations	Safety of life focus	From an operational standpoint, HAI is concerned with the potential for additional pilot workloads that would result from a deployed network of as many as 20,000 uncharted GPS-disrupting antennas. In low level flight, helicopters are already at a disadvantage with regard to navigation reception, while simultaneously being more exposed to obstacles. Adding in the challenges associated with the proposed network, would unnecessarily increase the complexity of the low level environment and subsequently increase pilot workload to mitigate the additional risks.
HAI	Helicopter operations	Safety of life focus	HAI remains concerned with the effect that the proposed network will have on ADS-B implementation and utilization.
IATA	General comment	Safety of life focus	How can we ensure that the interference to GPS will always be contained with in stand-off cylinder? Monitoring and reactive measures need to be established.
IATA	General comment	Safety of life focus	Have the case of cumulative interference from multiple Ligado transmitters be tested and addressed?
IATA	General comment	Safety of life focus	An empirical trail and suitable measurement programs are needed before full authorization. This trail needs to include both single and multiple (for highest possible density) Ligado transmitters and needs to be supervised by both the FCC and the FAA.
IATA	General comment	Safety of life focus	Due to aircraft ground movement at airports, an appropriate separation distance from airport air-side area needed to be established in addition to separation distance from flight paths.
IATA	General comment	Safety of life focus	While we appreciate the helicopter use case being defined as "challenging" , we wish to highlight that developments in the fixed wing civil aviation domain, including more extensive use of GBAS installations in the near to mid-term, means that empirical RF interference studies should not be based solely on the helicopter RF interference case and further, decisions derived therefrom reflect the far greater potential impact on air carrier operations and ground infrastructures which are using both certified and non-certified GPS receivers.
Metro Aviation / North Flight Data Systems	Helicopter operations	Safety of life focus	FAA regulations appropriately recognize that any operation closer than 500 feet from a person or object should be conducted with extreme care. The generally applicable rule, under 14 C.F.R. § 91.119, provides that an "aircraft may not be operated closer than 500 feet to any person, vessel, vehicle, or structure." The regulations provide an exception for helicopter operations, but only if "the operation is conducted without hazard to persons or property on the surface." In our view, and under Visual Flight Rules (VFR), it would be extremely hazardous to operate closer than 500 feet from an object (such as an antenna tower) while relying solely on a certified aviation GPS device to provide navigation guidance to avoid that object. Safe operations in such a situation therefore necessarily requires a helicopter to be flown soley by outside visual reference. Because such flight would require visual reference to be conducted safely, the potential degradation of the GPS signal within 250 feet of a tower does not present safety of flight issues.
Metro Aviation / North Flight Data Systems	Helicopter operations	Safety of life focus	Specific to Helicopter Air Ambulance (HAA) operations, Metro Aviation also considered 14 CFR § 135.615 (b) (1) & (2). This regulation requires the pilot-in-command of an HAA operation, while en route, to ensure all terrain and obstacles along the planned route of flight are cleared vertically by 300 ft during day operations and 500 ft during night operations. This regulation is applicable to the approximately 1,100 HAA aircraft currently operating in the United States. These requirements are fully consistent with the use of a 250' cylinder for interference analysis.
Metro Aviation / North Flight Data Systems	Helicopter operations	Safety of life focus	Ligado's proposal addresses one of the most problematic aspects of the "exclusion zone" assessed by RTCA in 2014, namely the 100-foot vertical exclusion above the top of the tower. During certain operations, helicopters could conceivably operate safely by overflying towers and other obstructions with less than 100 feet of obstruction clearance (particularly when flying offset laterally from the top of tower). In our view, it would be impractical for all helicopters to be required to operate more than 100 feet above towers. As an additional complication, a pilot will likely not know whether a particular tower contains a Ligado antenna, thus requiring all towers to be over flown with a 100-foot vertical separation. Ligado's proposal addresses this problem in two important ways. First, the cylinder extends 30 feet above the antenna, rather than the tower. This change will increase the protected area for an overflying helicopter whenever the antenna is not deployed at the top of the tower. According to Ligado, antenna deployments will often not be at the top of a tower. Second, the cylinder extends only 30 feet above the antenna, so even if the antenna is located at the top of a tower, a helicopter operating safely should be further than 30 feet above such an obstruction.

Organization	Category	Safety or Efficiency?	Comment
Metro Aviation / North Flight Data Systems	Helicopter operations	Safety of life focus	Ligado has committed to ensuring that no site will be deployed in a location where the antenna's cylinder would encroach upon areas defined in 14 C.F.R. Part 77, Subpart C. As you know, Part 77 addresses the safe, efficient use, and preservation of navigable airspace. This commitment from Ligado ensures instrument approach procedures, including Special Instrument Approach Procedures (SIAP) widely used during HAA operations, will not be affected by a Ligado antenna. Ligado has also informed us that it will avoid installing antennas in close proximity to hospitals, even hospitals that do not currently have an SIAP in use.
Metro Aviation / North Flight Data Systems	Helicopter operations	Both Safety & Efficiency	Metro Aviation has a longstanding relationship with Ligado Networks. Metro uses Ligado's satellite network to provide IRIS, an innovative two-way communication, data link, and flight data monitoring system. IRIS delivers an uninterrupted connection with constant flight data monitoring, push-to-talk communications, real-time flight tracking, and in-flight vehicle condition data and alerts. Through IRIS, Ligado is part of Metro's unending efforts to improve aviation safety. By transmitting real-time flight data to ground support staff, IRIS can help prevent accidents and identify maintenance issues before they become problems. Ubiquitous push-to-talk communications beyond the range of traditional VHF radios can dramatically improve pilots' access to critical information such as developing weather conditions. Ligado has briefed Metro regarding its future product offerings which will be enabled by deployment of terrestrial transmitters. Metro believes that the higher bandwidth capabilities of such services will enhance aviation safety, patient safety and operational efficiency.
Metro Aviation / North Flight Data Systems	Helicopter operations	Safety of life focus	Metro Aviation notes that the focus of the TOC has been on the use of Ligado's downlink channel from 1526-1536 MHz. Metro also notes that in it's current use of Ligaod's satellite network, it has experienced no interference to GPS operations resulting from the transmissions on Ligado's uplink frequencies (that are generally in the spectrum range of 1626.5-1660.5 MHz). Because Ligaod's terrestrial uplink channels would operate at even lower power than its satellite uplinks, Metro would does not foresee any potential interference resulting from such operation either.
Metro Aviation / North Flight Data Systems	Helicopter operations	Safety of life focus	Metro Aviation notes that Ligado's analysis includes assumptions regarding helicopters operating in a 25 degree banked or pitched attitude at altitudes very close to ground level and within 250 feet of physical obstructions. While we understand the utility of utilizing such parameters for the purposes of identifying "worst case" scenarios for interference analysis, we would also point out that such maneuvers would be extremely rare and would not rely on gps due to the criticality of the pilot maintaining visual reference to the ground and nearby obstructions.
NASA	UAS operations	Both Safety & Efficiency	The analysis performed to date is based on a combination of anlaytical work and some lab testing. The lab testing seems to have accomplished an initial estimate of how much RF energy is required to make GPS receivers begin to malfunction. Other testing may have been peformed to validate the amount of RF energy that bleeds into other off-frequency bands. Together, the results indicate a small area where GPS recievers may, or may not, work. However, uncertainties associated with: 1) The amount of RF interference required to disable GPS receivers (especially those in use for UTM-type vehicles), 2) The transmission of RF interference to the UTM aircraft, and 3) The actual amount of RF interference being emitted from the Ligado transmitters require comprehensive, real world testing. In order to really know the extent of the GPS interfence more complete and comprehensive testing is absolutely required. This testing would require a prototype Ligado transmitter operating on the specified frequency combined with actual prototype UTM-type aircraft operating in the vicinity of the tower. Without this testing it is impossible to fully determine the expected extent of the interference.
NASA	UAS operations	Both Safety & Efficiency	UAS operations are likely to be the most affected by the Ligado proposal due to the antiticipated operational altitudes and locations. While it is true that sUAS can tolerate some short-term GPS outages, it is unknown to what extent UAS to tolerate short GPS outages and how they can recover from GPS outages. Testing is required to define the limits of GPS loss.
NASA	UAS operations	Efficiency focus	Ligado has projected to need higher density of towers in urban and densely populated areas, which significantly impacts UAS operations for several use cases which serve population centers. A minimum tower separation of 433 m indicates that the clearance between towers in urban areas may be as low as 2/3rds of the distance. While Ligado promises the public availability (please ensure this) of all tower location and information for UTM contingency management plans, these clearances will affect the time and fuel efficiency of trajectory planning, thereby impacting cost and delay.
NASA	UAS operations	Both Safety & Efficiency	MOPS for UAS will need to be modified to include the need for non-GPS navigation within cylinders, especially for use cases where the start or end point of the UAS trajectory is within the cylinder therefore no way of going around. There is currently no established way for BVLOS UAS ops without GPS, therefore a significant impact on UAS due to outage.
NASA	UAS operations	Safety of life focus	Overall, there will likely be a UAS traffic increase around the cylinders** and more robust collision avoidance strategies will be needed causing impact on UAS ops. Even so, a UAS may fly into the cylinder and spend more than 30s w/o navigation increasing the risk of collision with another UAS or the tower itself, causing damage to people or property below. **Since the Ligado towers will be 200 ft high on average, the UAS may fly above the standoff cylinder instead of around it in the denser regions.
NASA	UAS operations	Both Safety & Efficiency	Many UAS may have Uncertified GPS and the field testing done so far, especially with the lack of any fully set up transmitting towers, creates concern for UAS outside the standoff cylinder. If GPS outage is experienced close to but outside the cylinder, the UAS has higher liklelihood of entering the cylinder in error.
NASA	UAS operations	Both Safety & Efficiency	Information on the expected maximum density of Ligado transmitters is required in order to better understand impact on UAS operations that may require avoidance of standoff cylinders or require other procedures if encountering a cylinder.

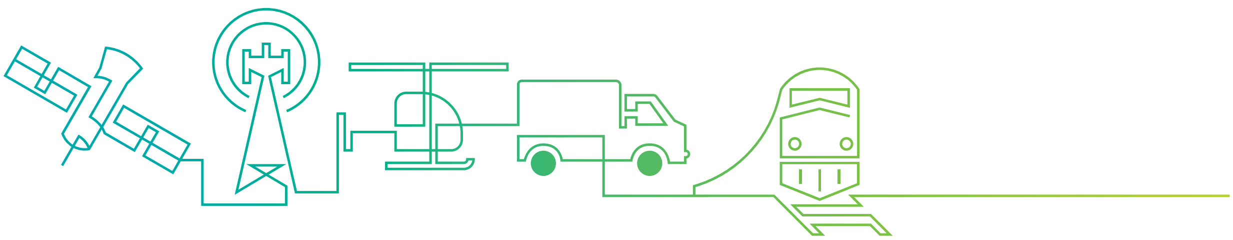
Organization	Category	Safety or Efficiency?	Comment
NASA	UAS operations	Both Safety & Efficiency	The presence of a 250 ft wide GPS outage zone in densely populated areas presents significant risk to people and property from UAS required to operate within that zone or UAS that erroneously entered, especially in the absence of any operating standards using alternative position-navigation-timing technologies. A more detailed plan of Ligado transmitter deployment that is more sensitive to population density and geography is required for further assessment.
SC-159 WG-6	Helicopter operations	Safety of life focus	Original SC-159 WG-6 comment 4: The submission relates solely to certified Garmin GNSS aviation equipment: Ligado asserts that rotorcraft operators do not use certified GPS equipment when operating in close proximity to structures of any kind. This assertion is used as a justification for a 250 foot radius standoff cylinder around a Ligado base station. This assertion ignores the presence of power lines that are within a base station's 250 foot radius standoff cylinder. These power lines are not easily seen in daylight VFR conditions. Some HTAWS equipment provides additional GPS-based safety-enhancing power-line alerting to warn pilots of such obstacles. Suggested Resolution: The assessment of the suitability of a 250 foot radius standoff cylinder around a Ligado base station should consider risks imposed by power lines and other hard-to-see obstacles that are within the standoff cylinder and for which Garmin certified equipment provides warnings. WG-6 Resolution: This is an operational concern and is expected to be addressed by the TOC
SC-159 WG-6	General comment	Both Safety & Efficiency	Original SC-159 WG-6 comment 5: The submission relates solely to certified Garmin GNSS aviation equipment: The proposed 250 foot radius standoff cylinder around a Ligado base station is very similar to the 500 foot radius exclusion zones originally proposed in the FAA Adjacent Band Compatibility Methodology. The 500 foot radius exclusion zones were evaluated by RTCA's Tactical Operations Comittee and were found insufficient to avoid adverse safety and operational impacts to aviation. Suggested Resolution: The 250 foot radius standoff cylinders should be evaluated for safety and operational impacts by the Tactical Operations Committee. WG-6 Resolution: TOC will be reviewing this proposal. TOC plans to follow the WG6 timeline (Dec 15 feedback to FAA). This comment will be forwarded to the TOC for discussion. Consensus has not been achieved on this item.
SC-159 WG-6	General comment	Safety of life focus	Original SC-159 WG-6 comment 7: The submission relates solely to certified Garmin GNSS aviation equipment: Ligado is proposing an additional 0.9 dB reduction in the base station EIRP to account for the estimated maximum aggregate power received from other base stations. This 0.9 dB reduction is proposed to be applied to all base stations regardless of the actual network deployment in the area. This blanket assumption only works if the analysis actually determines a worst case aggregate power that holds throughout the evolution of Ligado's network. While Ligado does propose a license condition to limit its intersite distance to >= 433 meters, it does not similarly propose to limit other network parameters such as antenna patterns and downtilt, limitations that are necessary. Suggested Resolution: Need additional confirmation that the 0.9 dB reduction for aggregate power effects actually overbounds the future aggregate power acounting for variations in deployment pattern and antenna characteristics. WG-6 Resolution: Ligado: Using a conditional probability approach to address the 1e-6/hr case. WG6: The conditional probability approach does not apply in this case. The conditional probability assumption is not supported.

Organization	Category	Safety or Efficiency?	Comment
SC-159 WG-6	General comment	Both Safety & Efficiency	Original SC-159 WG-6 comment 22: How is the 250 ft. standoff cylinder minimum radius justified? It seems that the RTCA TOC did not recommend any min. radius Suggested Resolution: Provide detailed technical justification WG-6 Resolution: Consensus has not been achieved on this item. Ligado perspective: Evidence suggests that emissions into the GNSS band from other sources are in excess of the RTCA criteria. WG6 perspective: There is no conclusive evidence from the data presented that we have these higher levels of OOBE from PCS and other sources in the GNSS band.
SC-159 WG-6	General comment	Safety of life focus	Original SC-159 WG-6 comment 32: Emissions correlate to frequency response of spectrum analyzer and/or amplifier. For Radio #3 and Radio #4, the displayed power on the spectrum analyzer in the spurious region of the remote radio head, as well as the displayed power in the GPS L1 band, appears to be noise generated from the test equipment. Suggested Resolution: Clarify the OOBE emission tests provided by Ligado are not related to the test equipment WG-6 Resolution: Consensus not achieved. Ligado perspective: Evidence suggests that emissions into the GNSS band from other sources are in excess of the RTCA criteria. WG6 perspective: There is no conclusive evidence from the data presented that we have these higher levels of unwanted emissions (including OOBE and spurious emissions) from PCS and other sources in the GNSS band.
SC-159 WG-6	General comment	Both Safety & Efficiency	Original SC-159 WG-6 comment 33: As applicable to civil certified GPS receivers, how does the 1e-3 threshold for the acquisition case at 6 dB below the tracking threshold get addressed in this proposal. Suggested Resolution: Please clarify how GPS acquisition cases are addressed by this proposal. WG-6 Resolution: Consensus not achieved. Ligado Response: GPS Acquisition was not stated as a requirement per the original FAA tasking letter (2014 letter and RTCA response in 2015).
SC-159 WG-6	Helicopter operations	Both Safety & Efficiency	Original SC-159 WG-6 comment 34: Should scenarios related to receiver initialization/power-up/satellite acquisition be assessed that correspond to EMS helicopter operations to/from pick-up scenes (in addition to IAPs)? The scenario would define (a) if the receiver is generally powered up through the pick-up or if it must be assumed the receiver can be powered up and initialized at the scene, (b) what the receiver operating state is required to be before departing the pick-up scene, and (c) the need for the helicopter to support IFR operations at a specific time, altitude or distance from the pick-up scene and/or destination. EMS: emergency medical services, IAP: instrument approach procedure, IFR: instrument flight rules Suggested Resolution: Either (1) In concert with the RTCA TOC, define appropriate scenarios and assess compatibility with existing MOPS requirements and test procedures. –or– (2) Submit the comment to the FAA for their consideration. WG-6 Resolution: Consensus not achieved, item not fully resolved. Do both items 1 and 2

Appendix D: Briefing Materials Used During Task Group Meeting

Ligado Presentation to TOC

November 29, 2016



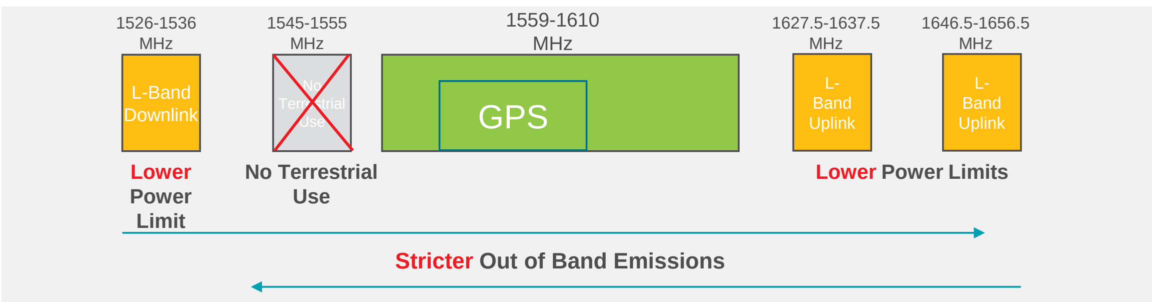
ligado NETWORKS | Making Stronger Connections

Background

- Company emerged from bankruptcy in December 2015
- Ligado Networks introduced in early 2016
- New ownership, board of directors and senior management
- New approach to problem solving – collaborating with key stakeholders to find good solutions
- Filed new applications with the FCC on December 31, 2015 to modify key operating parameters
- Central to the FCC application is the commitment to comply with all existing and future FAA standards regarding aviation GPS receivers
- Ligado created a standards-based and safety-driven analytical structure to determine appropriate operating parameters
- Met regularly with FAA engineers throughout 2016 to ensure that our analyses properly conform to FAA standards
- Completed work with FAA in September; FAA forwarded this work product to RTCA in October for review and comment
- SC-159 has been evaluating the technical piece since late October; some areas of disagreement have been noted which they will share with the FAA
- We are here today to explain our overall methodology and how we have ensured there are no operational impediments to aviators as a result of our network

Major Changes to Ligado's Key Operating Parameters

- Transmitter Noise (Out of Band Emissions)
  - Ligado has further reduced its out of band emissions to levels that are well below those of any other wireless operator
- Radio Spectrum
  - Ligado has withdrawn its request to use, for its terrestrial network, the piece of radio spectrum that is closest to the GPS band
  - This provides a large buffer zone between Ligado's operating spectrum and the GPS band
- Transmitter Power
  - Transmitter power levels have been reduced, *and will be reduced further* in order to protect aviation safety and conform to FAA standards

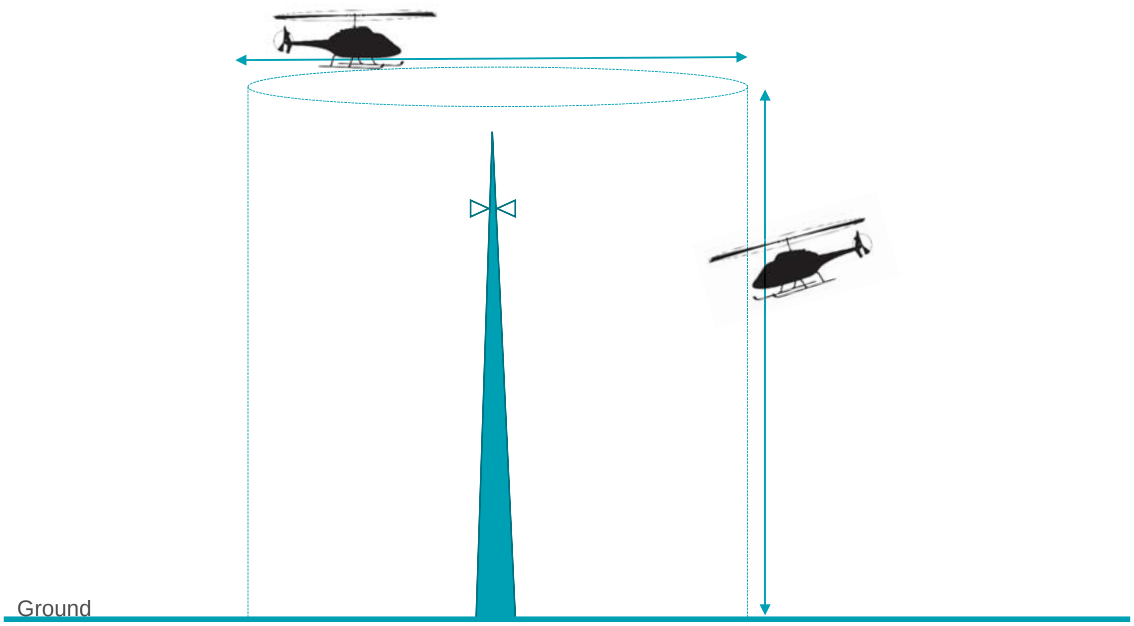


Assessment of Aviation Operations

- Helicopter Use Case is the Base Case
  - Chosen for evaluation based on input by FAA and RTCA
  - Provides for the most challenging use case of aviation operations that widely utilize certified GPS receivers
- Fixed Wing Aircraft
  - Prohibited from operating within 500' of obstructions
  - Power levels which will protect helicopter operations provide fully protect fixed wing operations using certified GPS receivers as well
- Uncertified Aviation GPS Receivers
  - Ligado power levels necessary to achieve compatibility with certified receivers will be at least **63 times lower** than previously authorized
  - This will further protect all classes of GNSS devices, including uncertified aviation
- UAS
  - UAS using certified GPS receivers will be protected on same basis as helicopters
  - Uncertified GPS receivers benefit from lower power levels as well

Assessment Process

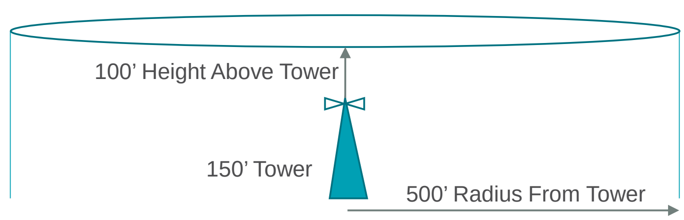
Ligado's operating parameters are assessed at a fixed distance from its radio towers to ensure no interruption to certified GPS receivers as a result of Ligado's operations



Measurement Cylinder

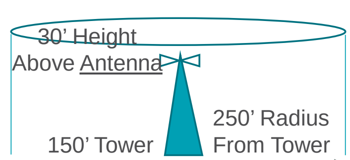
In 2015, a 500' radius measurement cylinder was evaluated by the TOC

2015 Measurement Cylinder



As a result of feedback from the TOC, the cylinder is now significantly smaller

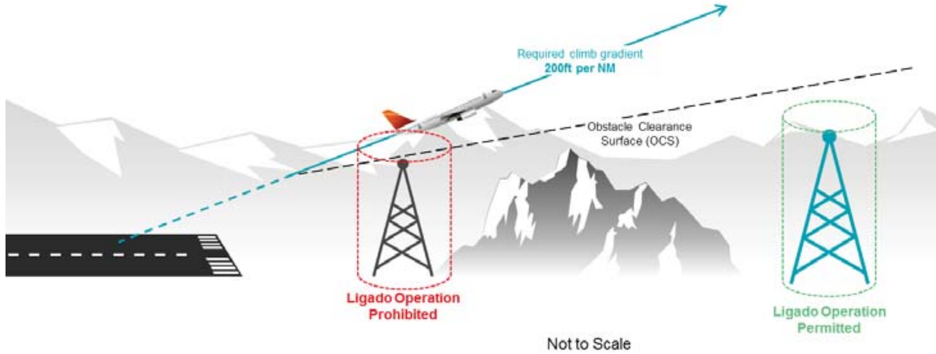
Ligado Improved Measurement Cylinder



New Cylinder is 5X Smaller Than Original
(or, more precisely, is 18% of the volume of the original)

Additional Protection of Obstacle Clearance Surfaces

- Additionally, in order to ensure compatibility with Part 77 obstacle clearance criteria, no tower can be located such that the 250’ cylinder would pierce the obstacle clearance surface



- Any subsequent modification to any Ligado site will require that the analysis be re-run for that site and the power adjusted accordingly

How Were Dimensions of Cylinder Determined?

- Close consultation with aviation services company -- Metro Aviation
  - Leading provider of air ambulance services nationwide
  - Helicopter outfitter
  - Communications and data services provider
- Evaluation of safe operating practices that rely on GPS
  - Reliance on GPS for safety functions near ground level
  - Operation of aircraft in close proximity to physical obstructions
  - VFR/IFR operations and regulations
- Evaluation of interference potential from other sources
  - Existing radio environment is noisy
  - Other RTCA documentation

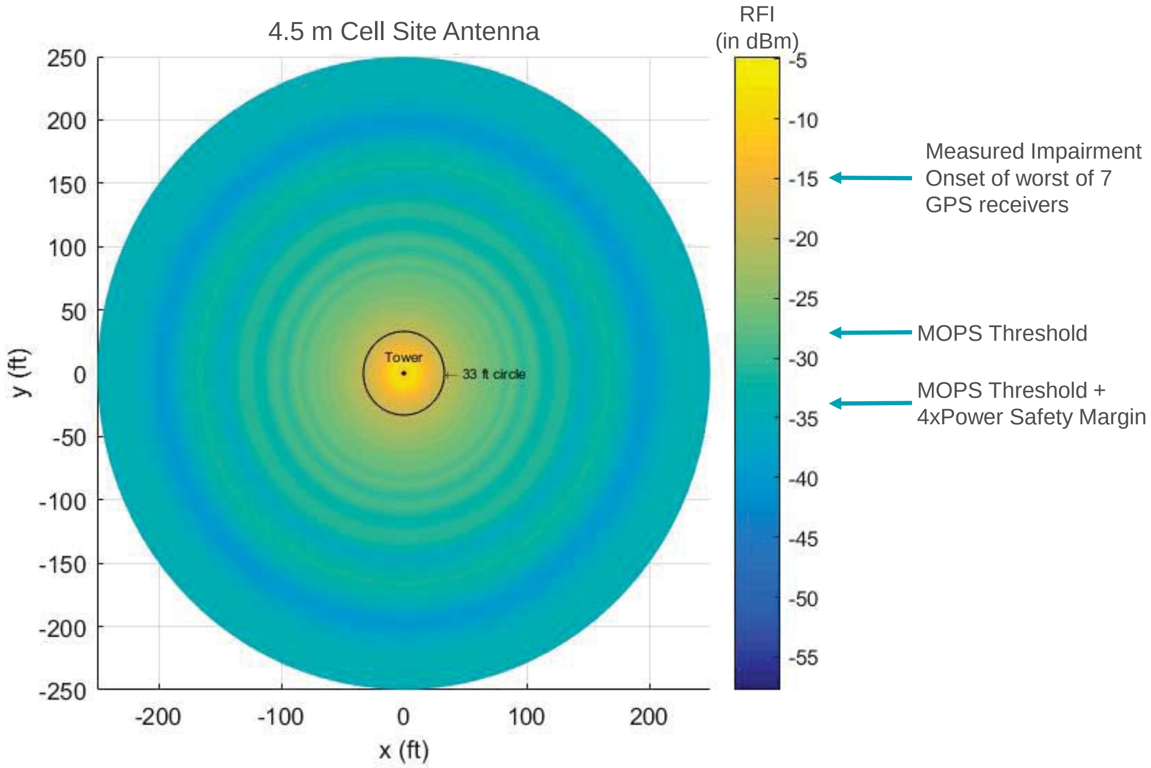
Will GPS be Available within the Cylinder?

- Analytical Versus Operational Assessment
  - Ligado has performed extensive analysis as part of its work with Working Group 6 of Special Committee 159
  - SC 159 modeling is designed to assess the worst case for *potential* interference; it does not attempt to model *actual* interference
  - This inherent conservatism is designed to overstate the potential for interference, meaning that GPS operations are likely to be unaffected within significant parts of the 250' cylinder—especially at ground level
  - Factors contributing to this additional area of availability include:
    - Aviation Safety Margin
    - Enhanced resiliency of fielded certified GPS receivers beyond the minimum MOPS compliance thresholds
    - Higher power GPS signal than is assumed in RTCA analyses
    - Ligado transmit power set at low levels to account for extreme use cases which are not typically experienced
  - As the following charts demonstrate, it is very likely that GPS will remain fully available at ground level throughout the entire 250' cylinder
- What does this mean for operators?
  - Within 250 feet of any radio antenna structure, there is the potential for reduction in GPS availability *due to a variety of radio emitters today*—and Ligado in the future
  - Outside of the 250' radius, and 30' above towers, there would be no potential impact to GPS reception as a result of Ligado's operations

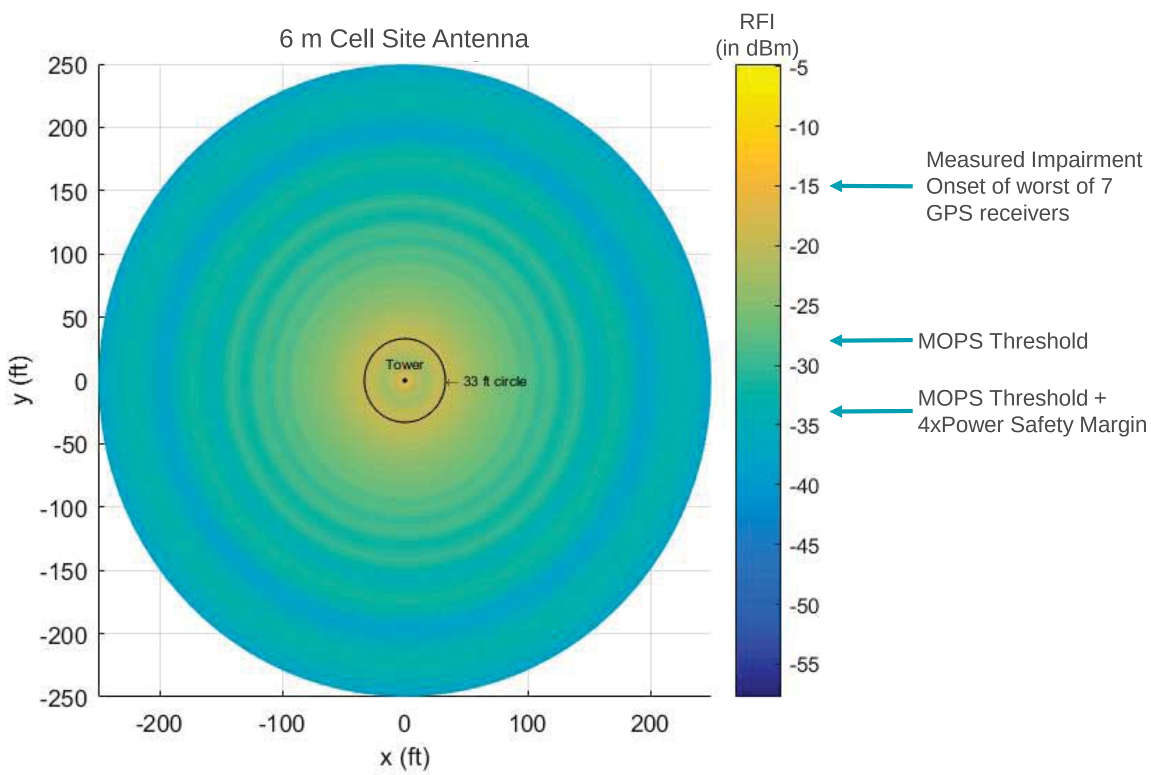
Visualization of GPS Availability

- Ligado used the power levels it has presented to SC-159 as a baseline
- We then accounted for other factors which would serve to improve GPS signal availability in real-world conditions
  - Safety Margin
  - Actual performance of least resilient certified GPS receiver tested by RTCA/Zeta and Bell Labs in 2011
- The following charts use the above data to depict what operators could expect if it were necessary for a helicopter to take off from within the 250' cylinder

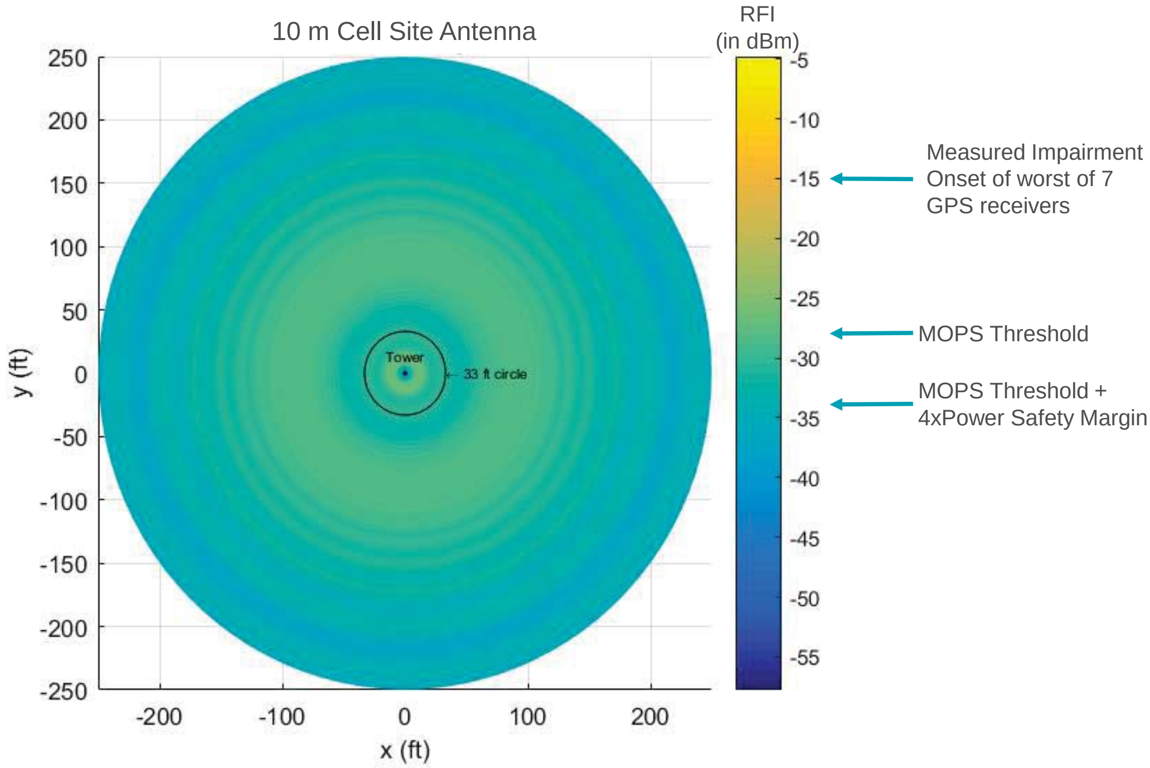
Dense Urban Deployment 1



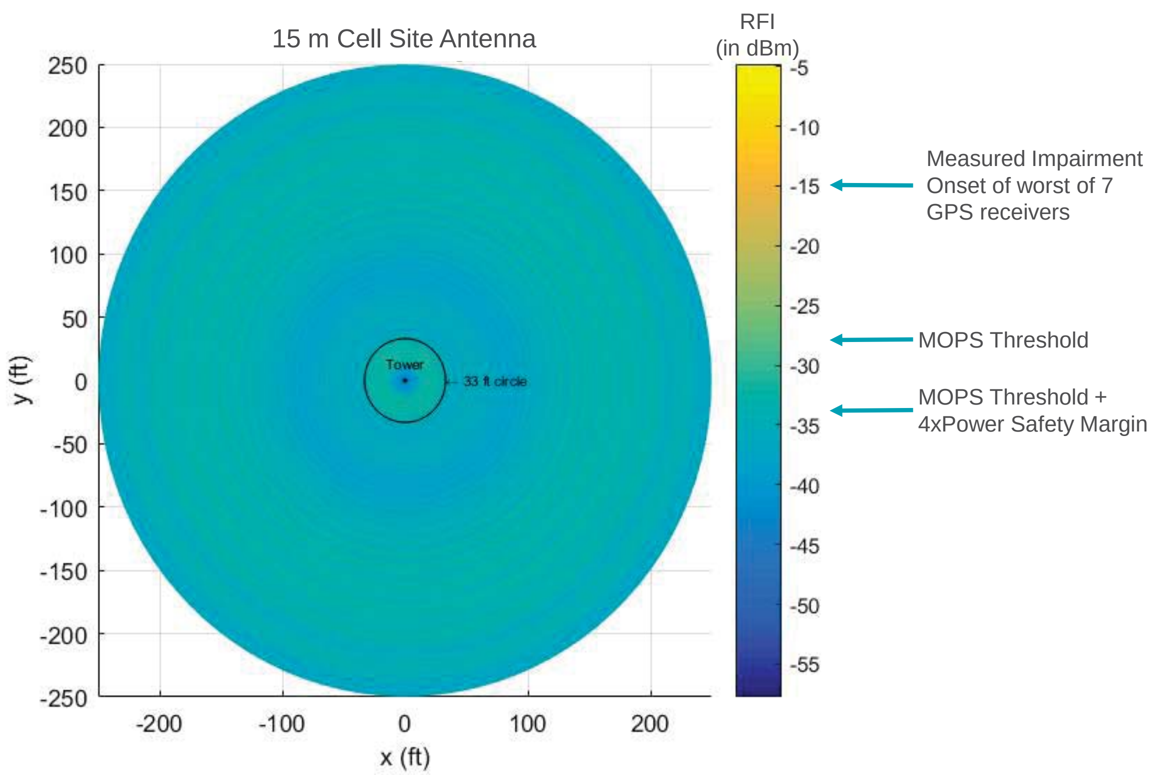
Dense Urban Deployment 2



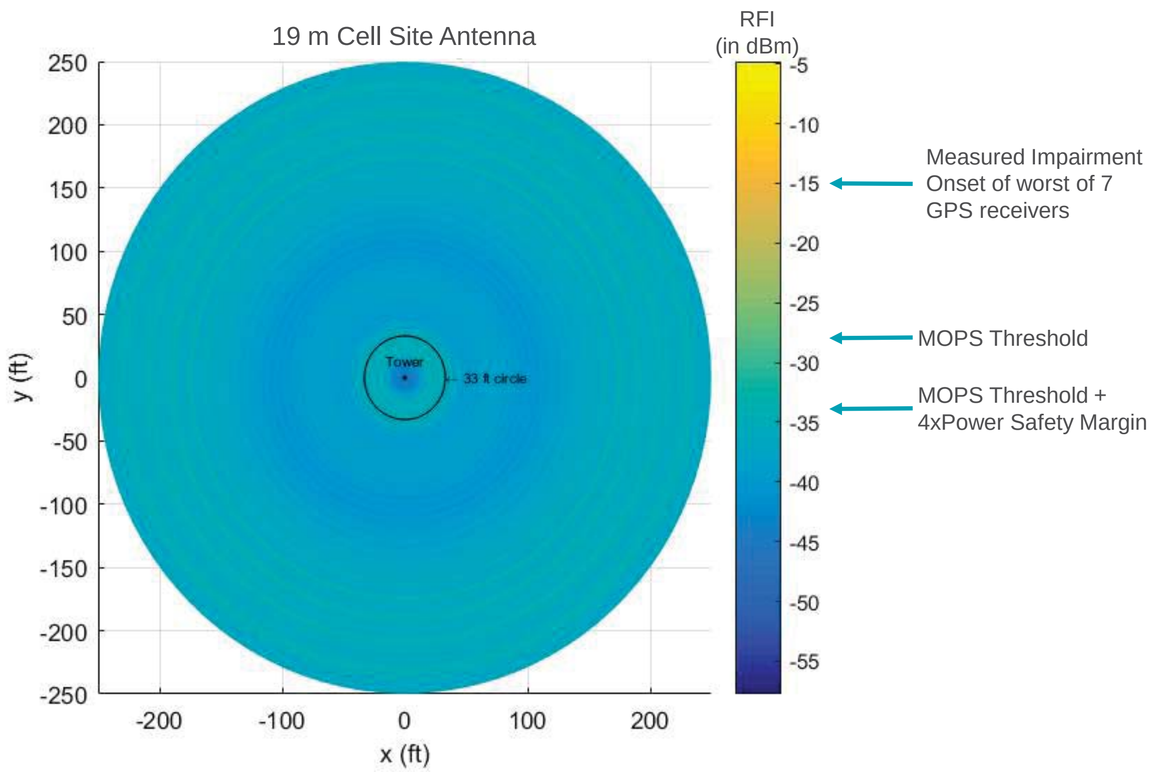
Dense Urban Deployment 3



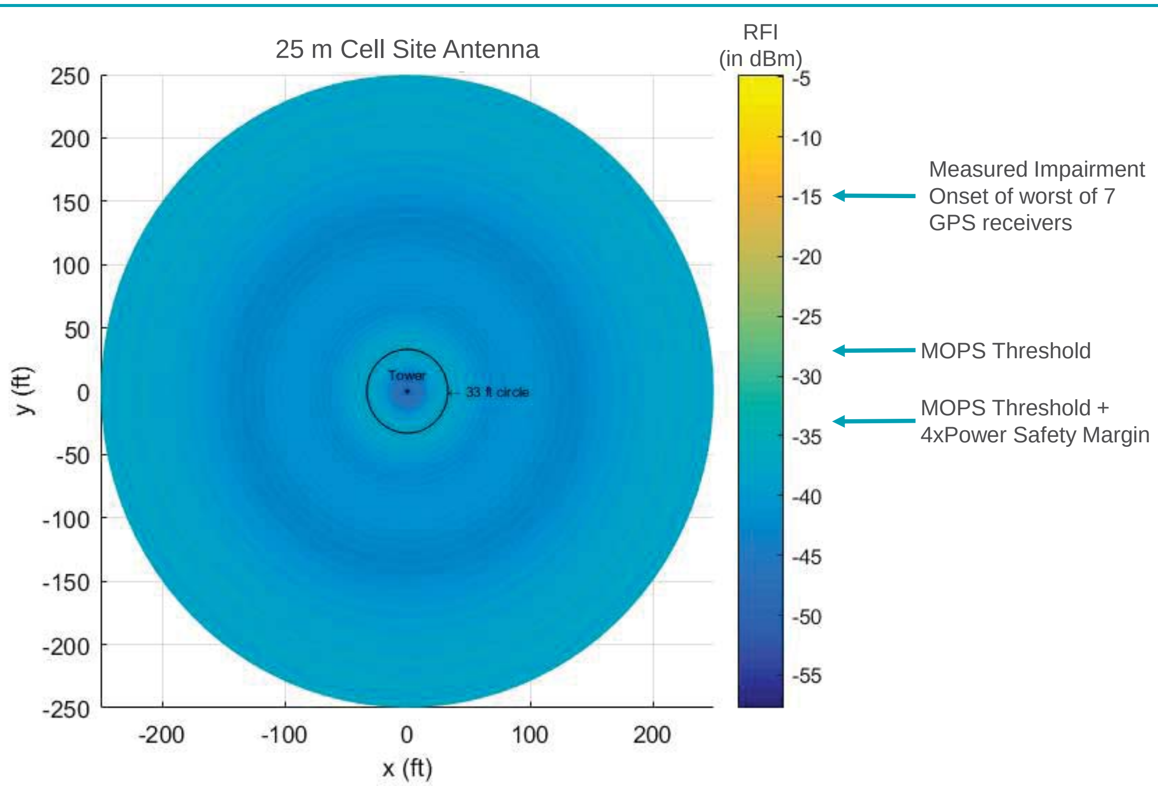
Typical Deployment 1



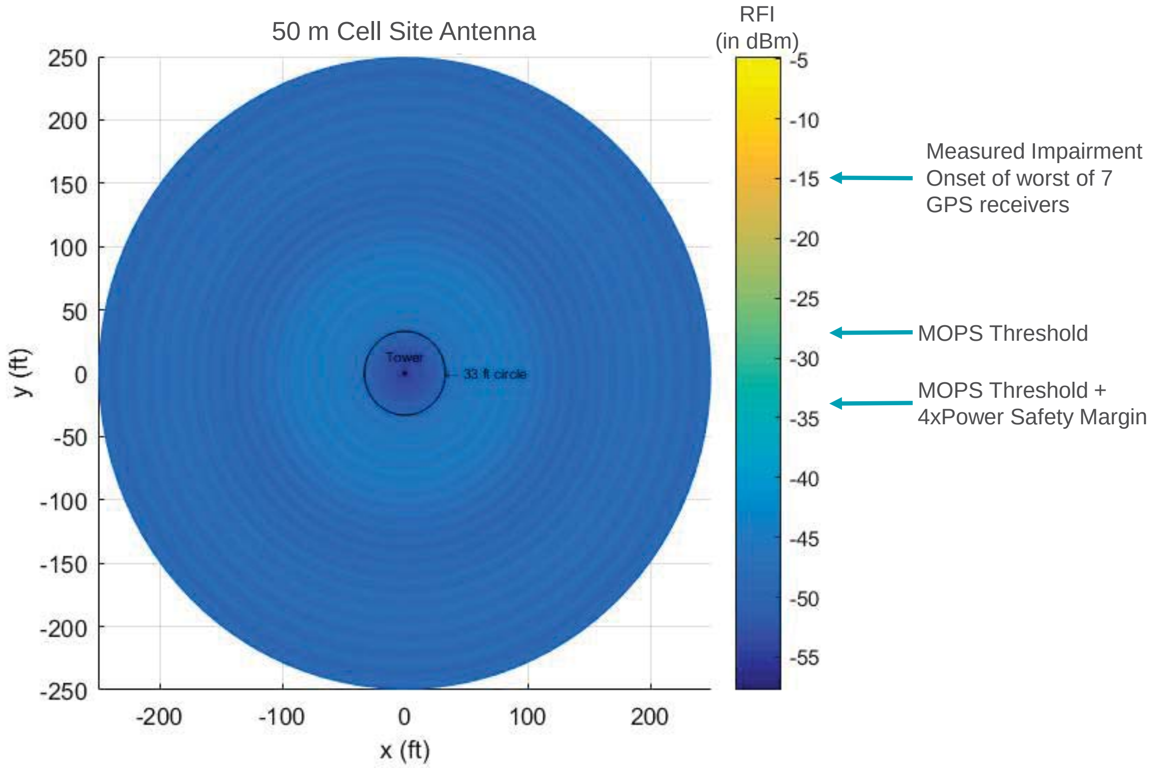
Typical Deployment 2



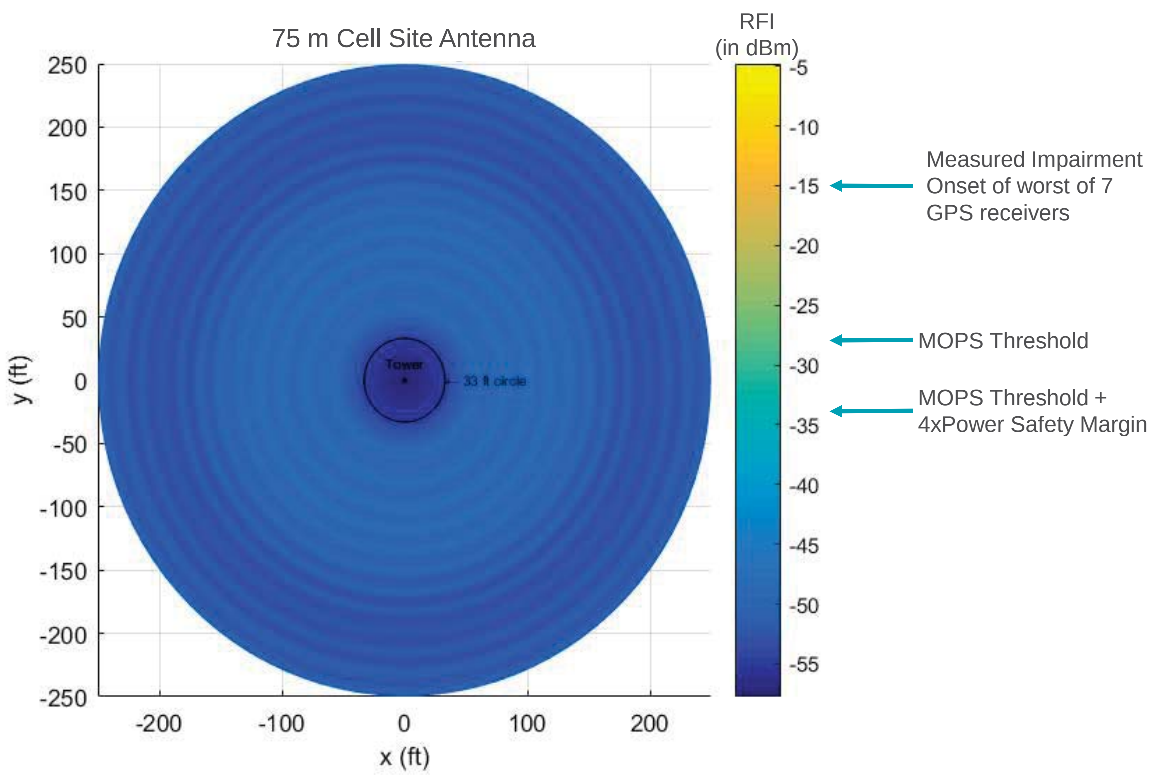
Typical Deployment 3



Typical Deployment 4



Rural High Site Deployment



Conclusion

- Ligado is committed to ensuring its network is fully compatible with aviation safety requirements
- The 250' cylinder was developed after careful review of aviation operations, including consultations with helicopter operators
- There will be no impact to certified aviation operations outside of 250' zone
- Highly unlikely there would be any impact to operations within the zone
- Ligado looks forward to continued engagement with aviation industry to further promote safe and efficient operations

Q&A

AOPA

Fixed-wing General Aviation Perspective

Rune Duke
Director of Government Affairs, Airspace & Air Traffic
Aircraft Owners & Pilots Association

General aviation relies on GPS

- Navigation
  - Instrument approaches
  - Enroute
  - VFR and IFR
- Surveillance
  - ADS-B

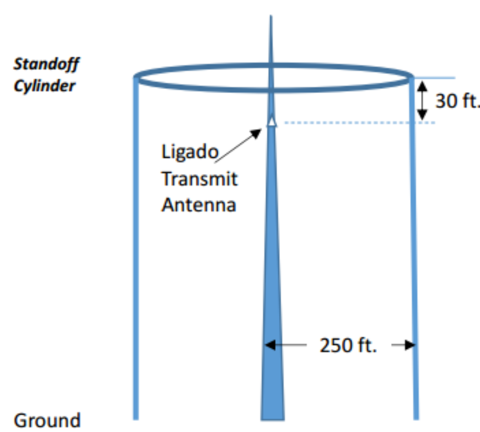
Previous proposal: 500’ X 100’ exclusion area

Impacted

- Agriculture operations
- Ultra Light and Light-Sport Aircraft (LSA) Operations
- General aviation operations in and out of public airports
- General aviation operations in and out of private airports

Operational impact of 250’ X 30’ Exclusion Zone

- Operations within 250’ laterally and 30’ vertically of an antenna are rare
- If interference is limited to this defined area, impact is minimal to fixed-wing general aviation



Ligado Networks

§91.119 Minimum safe altitudes: General.

Except when necessary for takeoff or landing, no person may operate an aircraft below the following altitudes:

(a) *Anywhere.* An altitude allowing, if a power unit fails, an emergency landing without undue hazard to persons or property on the surface.

(b) *Over congested areas.* Over any congested area of a city, town, or settlement, or over any open air assembly of persons, an altitude of 1,000 feet above the highest obstacle within a horizontal radius of 2,000 feet of the aircraft.

(c) *Over other than congested areas.* An altitude of 500 feet above the surface, except over open water or sparsely populated areas. In those cases, the **aircraft may not be operated closer than 500 feet to any person, vessel, vehicle, or structure**.

Concerns

- Impact to uncertified avionics – Utilized by thousands of pilots
- Defer to spectrum experts on the testing parameters validity
- Instrument approaches, current and future, must be protected
- Private airports – Protect instrument approaches

Conformance with Part 77 Operations

In order to ensure that Ligado's operations will not interfere with aircraft IFR operations on approach and departure routes at airports and heliports and other navigable airspace governed by Part 77, Ligado will not locate sites where any portion of the standoff cylinder would pierce the plane of a defined obstacle clearance surface. This will ensure that Ligado's EIRP will be within conformance limits at all points on, and above, the OCS.

AOPA

Air Traffic Services
202-509-9515

Rune.duke@aopa.org

Thank you!

§137.49 Operations over other than congested areas.

Notwithstanding part 91 of this chapter, during the actual dispensing operation, including approaches, departures, and turnarounds reasonably necessary for the operation, an aircraft may be operated over other than congested areas below 500 feet above the surface and closer than 500 feet to persons, vessels, vehicles, and structures, if the operations are conducted without creating a hazard to persons or property on the surface.

Helicopter Operational Scenarios Overview

RTCA TOC Task: Operational Comments on Ligado Proposal

Chris Martino
Helicopter Association International

Helicopter Association International

HAI Established 1948

The Professional Trade Association for the International Helicopter Community

~ 3,900 Members in 81 Countries

~ 90 Affiliate Members in 73 Countries

HAI Members:

- Operate over 6,000 Helicopters
- Fly nearly 3 million hours each year

U.S. Helicopter Industry

FAA: Nearly 10K Registered Helicopters Today*

Diversity Across Industry

Fleets: Functions & Capabilities

Operational Areas: All States, All Conditions

Missions: Routine to Urgent

Regulations: Variety of FARs (FAR 91, 135, …)

Certifications: Aircraft & Operators (Part 27/29)

*Estimate

U.S. Helicopter Industry

- **Helicopter Industry Operations Occur Predominantly in LowAlt Environments (LT 5K')**
- **Many Missions Conducted in First 500' of Airspace**
  - **(Air Ambulance, Agriculture, Firefighting & Utility as examples)**
  - **Fewer Options for Navigation (Decreased LOS)**
  - **Greater Exposure to Obstructions**
  - **Critical Reliance on GPS Navigation Systems**

Flight Training

Agriculture


Tours & Charters
Helicopter Association International
7


Offshore & Gas Industry
Helicopter Association International
8

Helicopter Air Ambulance Services

9

Electronic News Gathering

10


Corporate & VIP
(On Demand)
11


Fire Fighting
12

Law Enforcement

Federal Agency Support

Utility – Power & Energy

15

Utility - Logging & Construction



16

Search & Rescue

Disaster Relief

Entertainment

19

Military

20

Next Gen
(R&D)

2015 RTCA Evaluation

Review: Findings of July 2015 RTCA Report Remain Valid & Applicable

Helicopter Air Ambulance (HAA)
- Critical Reliance of GPS
- All Operating Areas: Highways, Parking Lots, Urban, etc
- All Conditions: Day, Night, Weather
- Time Critical Missions – Often Life Saving

Law Enforcement
- Accurate Positioning Essential
- Provide Coordinates to/from Ground Units
- All Conditions
- All Operating Areas: Particularly Urban Environments

Aerial Fire Fighting
- Accurate GPS Essential to Aerial Mapping & Aerial Deployment

Helicopter On-Demand Operations
- Safety of Passengers & Operations

22

Rotorcraft Missions Review

Additional Rotorcraft Missions Not Previously Addressed:

Aerial Surveying & Photography
- i.e. Validation of Fixed Point Sites (Navigation Aids, etc)
- Accuracy of GPS Essential

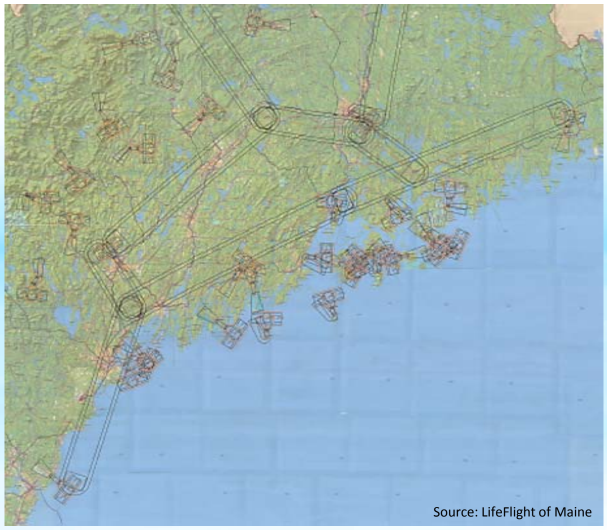
Aerial Agriculture Applications
- Certain Operations Require Precision Deployment

News Gathering Operations – Aircraft Separation
- Law Enforcement, Emergency Responders, U.S. Agencies' Aircraft

NextGen Performance Based Navigation
- Reduced Separation RNAV Routes
- Point in Space Approaches
- Concept of Operations to Support LowAlt IFR Flights

Rotorcraft PBN

Maine Low-Alt Nav Routes



Summary

Safety is First and Foremost

Helicopters Operate Coast to Coast in LowAlt Structure & Require Systemic Navigational Support to Safely Operate

- **Accurate GPS Essential to Safety of Flight – At All Altitudes**
- **Low Alt Navigation System Free of Unnecessary Complexities**
- **Low Alt Navigation System Free of Designed "?-Accuracy" Areas**

Solution Must Fully Consider NextGen Performance Based Navigation

Questions

ligado NETWORKS | Making Stronger Connections

August 30, 2016

Mr. Bruce DeCleene
Manager, Flight Technologies and Procedures Division
Flight Standards Services
Federal Aviation Administration
470 L'Enfant Plaza, Suite 4102
Washington, DC 20024

Via Email

Dear Bruce,

Further to your request, Ligado is formally transmitting to the FAA the report that Ligado included in its filing to the FCC on June 6, 2016. This report, which was authored by Ligado, assessed Ligado's operations in the uplink bands at the reduced power levels and OOBE limits that were part of the modification applications that Ligado submitted to the FCC on December 31, 2015.

Ligado undertook this analysis using the proposed FAA work plan that was submitted to RTCA in a letter dated October 7, 2014 and approved by the Plenary Session of SC-159 on March 20, 2015. Specifically, Ligado assessed the impacts of the following use cases as called for in the RTCA response: (i) numerous Ligado devices operating at ground level on aircraft in flight overhead, (ii) passengers using Ligado devices inside an aircraft that is taxiing, (iii) operation of a Ligado device at the top of the stairs leading from the tarmac to an aircraft, (iv) numerous Ligado devices operating simultaneously near an aircraft parked at the gate, and (v) numerous Ligado devices operating at ground level on low-flying aircraft utilizing terrain awareness and warning systems. In each use case, even using worst-case assumptions, the attached analyses confirm that emissions from Ligado's proposed handheld devices would not affect certified aviation GPS operations, using compatibility criteria specified in the FAA letter to RTCA. Thus, Ligado's proposed uplink operations are fully compatible with existing standards for the protection of certified aviation GPS operations.

We understand that you are ready to forward this report (as well as this cover letter) to RTCA for their feedback at their next meeting as part of your process to finalize your assessment of these conclusions. As always, please do not hesitate to contact me with any questions.

Sincerely,

/s/ Geoff Stearn

Geoff Stearn
Vice President, Spectrum Development

Ligado Report on Compatibility of Ligado Networks' Uplink Emissions with FAA Requirements for Certified Aviation GPS Receivers

June 6, 2016

1.0 Background and Summary

On October 7, 2014, the FAA, in a letter to RTCA ("FAA Letter"), submitted questions to elicit input to the FAA's analysis of commercial spectrum bands adjacent to spectrum used by GPS. The FAA Letter proposed use cases and compliance methods that would be used to determine if uplink emissions from handsets (referred to here as "User Equipment", or "UE") using bands such as those licensed to Ligado Networks, would cause harm to the operation of certified aviation GPS receivers.

On March 19, 2015 the summary response to the FAA questions, as well as new edits to the proposed FAA work plan (together, the "WG-6 Response"), were presented to WG-6 which approved the documents. The WG-6 Response was then approved by the Plenary Session of SC-159 on March 20, 2015.[1]

This report analyzes the compatibility of Ligado's proposed uplinks in accordance with the recommendations in the WG-6 Response.

The only exceptions are with respect to certain propagation models where Ligado has made simplifying assumptions that make the models *more conservative*. The need for this simplification arose because a certain input parameter (the mean out of band emissions ("OOBE") power spectral density ("PSD") of legacy UEs at the GPS receiver, for use cases where the aircraft is on the ground) is required to run the new interference models defined by the FAA. That information is controlled by the FAA and thus was not available to Ligado as it developed the analysis, and so a more conservative assumption was used instead.[2] Ligado has shared the models described below with the FAA in the process of developing the present work.

This report concludes that Ligado's operations in the uplink bands (1627.5-1637.5 and 1646.5-1656.5) are compliant with applicable FAA requirements for each of the use cases identified by the FAA – while utilizing highly conservative assumptions that further assure aviation safety is not compromised in any way.

[1] Ligado Networks (then LightSquared) had reservations about certain aspects of the RTCA's recommendations in the WG-6 Response, and proposed alternatives in a companion report filed on April 3, 2015.

[2] FAA is the owner of the aggregate legacy UE PSD model and provided the subject information for heights other than ground level in DO-327 and in the Letter.

2.0 Use Cases[3]

2.1 Inflight Aircraft / Ground-based Handset Cases

This use case is designed to demonstrate the potential effects of thousands of ground-based handsets on an aircraft that is flying overhead.

Excerpt from FAA Letter[4]:

> The FAF WP case is also used to represent airborne terminal area operations, while the other 2 cases represent limiting cases on aircraft precision approaches. The ground-based handsets in these cases are assumed to have a 1.8 meter antenna height. Their random locations are assumed to be uniformly distributed to the radio horizon except where excluded, as noted, from annular sector zones. Besides the basic parameters for the aircraft receive antenna height, radio horizon, and exclusion zone, Table 1 also lists important breakpoint radii for the blended path loss model. For example, the "Mid-range Inner Radius" is the breakpoint between the 2-Ray short range path loss model and the mid-range model.

Table 1 Key Geometric Parameters for the Inflight Aircraft / Ground-based Handset Source Cases

Parameter	FAF WP Case	Cat. I DH Case	Cat. II DH Case
Receive Antenna. Ht. (m)	535.2	53.34	25.94
Std. Dev. Inner Radius, r_S (m)	533.4	51.54	24.14
Mid-range Inner Rad. R_1 (m)	1054.237	111.149	99.3811
Mid-range Outer Rad. R_2 (m)	7502.3	11227.6	2475.381
Excl. Zone Half-angle (deg)	0.0	17	25
Excl. Zone Inner Rad. (m)	N/A	488.0	44.93
Excl. Zone Outer Rad. (m)	N/A	5830.0	2842
Radio Horizon Radius (km)	100.941	35.653	26.537

Assumptions

In the past, the FAA had evaluated the compliance of the uplink Out Of Band Emissions (OOBE) from UEs using a new band, such as Ligado's, by comparing the composite power spectral density (PSD) of the emissions from UEs in the new band with the existing emitters[5], to a maximum mean threshold of -146.5 dBW/MHz. This is also referred to as the Environmental Limit.[6]

The Environmental Limit was derived by adding 6 dB of safety margin to the absolute maximum threshold of tolerable RFI of -140.5 dBW/MHz. This threshold is the testing threshold for the RTCA Minimum Operational Performance Standards ("MOPS") (referred to herein as the "MOPS Threshold").

The FAA Letter set forth a new methodology which it described as follows: [7]

> Recent studies ([3], [5]) have shown that an existing baseline environment[8] results in an aggregate received RFI whose probability distribution tail essentially comes up to the operational probability limit for precision

[3] These use cases have been defined by the FAA and thus form the focus of this report.

[4] FAA Letter, Section 3.1.1.

[5] Model defined in RTCA DO-235B

[6] RTCA DO-327, Section 6.2.3.3

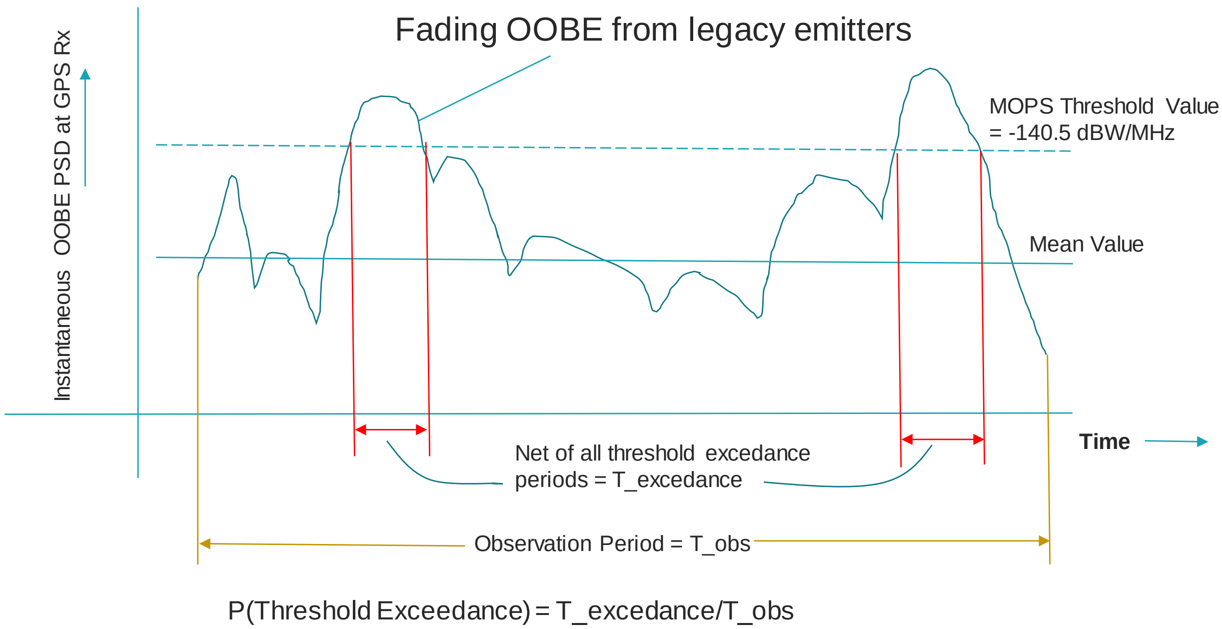
[7] Id. Section 2.1.1.2

approach. As such any additional aggregate impact from new broadband wireless source unwanted emission will need to be kept well below that of the baseline environment. The limit for the short duration study is the aggregate effect from additional in-band RFI shall not increase the exceedance probability by more than 6%.

The FAA adopted this new approach because it acknowledged that certain variations of the environmental OOBE level exist currently due to the randomness in the clustering of legacy UEs on the ground and normal variations in propagation paths between UEs and GPS receivers.

A theoretical example of the physical implication of this new methodology is illustrated in Figure 1. This demonstrates the types of random variation cited above that exist today, which at times exceed the MOPS threshold value of -140.5 dBW/MHz.

Figure 1 Description of OOBE compliance requirement introduced by FAA Letter



The FAA's methodology requires the creation of probability distribution of the OOBE from legacy UEs in the current environment. The FAA has specified in [1], [2] the method it wishes to apply to determine the probability distribution function (PDF) of the legacy UEs for all aircraft heights in Table 1 and, from them, to calculate the exceedance probability, shown as P(Threshold Exceedance) in Figure 1. The addition of Ligado devices is not permitted to increase the Exceedance Probability by more than 6%.[9] Ligado has used the FAA's methodology to obtain the results below.

---

[8] Accumulation of unwanted emissions from cellular mobile handsets, unlicensed wireless network interface infrastructure (U-NII) emitters and unintentional emissions from FCC Part 15 Class B digital devices.

[9] As mentioned, this model is not specified for the case of the aircraft on the ground but the "6% exceedance requirement" applies only to aircraft when they are airborne – specifically at the heights in Table 1 in the FAA Letter. Therefore the lack of this data was not a barrier to performing the present calculations.

2.1.1 Results and Discussion

The calculations by RTCA [1] show that the worst case mean aggregate PSD of -152.67 dBW/MHz from the legacy devices on the ground is generated at the GPS receiver at an altitude of 25.9 m AGL (which is the Category II Decision Height for a landing aircraft). The statistical behavior of the aggregate RFI is shown in table 4 of [1] and is represented in Figure 2 as a plot of cumulative probability distribution of the mean RFI PSD versus the probability of Threshold Crossing.

Here, the threshold value is the MOPS Threshold of -140.5 dBW/MHz and is referred to as 0 dB reference on the X axis. The probability of crossing this threshold is shown on the Y axis as a function of mean RFI level relative to the MOPS Threshold.

As an example, for a mean RFI PSD level of -152.67 dBW/MHz, the analysis is as follows:

1) Calculate the level relative to the reference line, which is: -140.5 - (-152.67 dBW/MHz) = 12.17 dB.
2) Read the probability of exceeding threshold on Y axis as 3.0 x10^-4.

With an equal number of Ligado devices as legacy devices in the same area and with the same user densities, the calculation shows (Table 3) that the new aggregate RFI PSD will be -152.65 dBW/MHz, an increase in noise floor of 0.02 dB. (Level relative to 0 dB reference line: 12.15 dB).

Note that the probability of exceeding the threshold is increased to 3.1 x10^-4. The increase in the exceedance probability is calculated as:

(3.1 x10^-4) – (3.0 x10^-4) / (3.0 x10^-4) = 3.33%

Figure 2 Cumulative Probability Distribution of RFI PSD versus Probability of Threshold Crossing

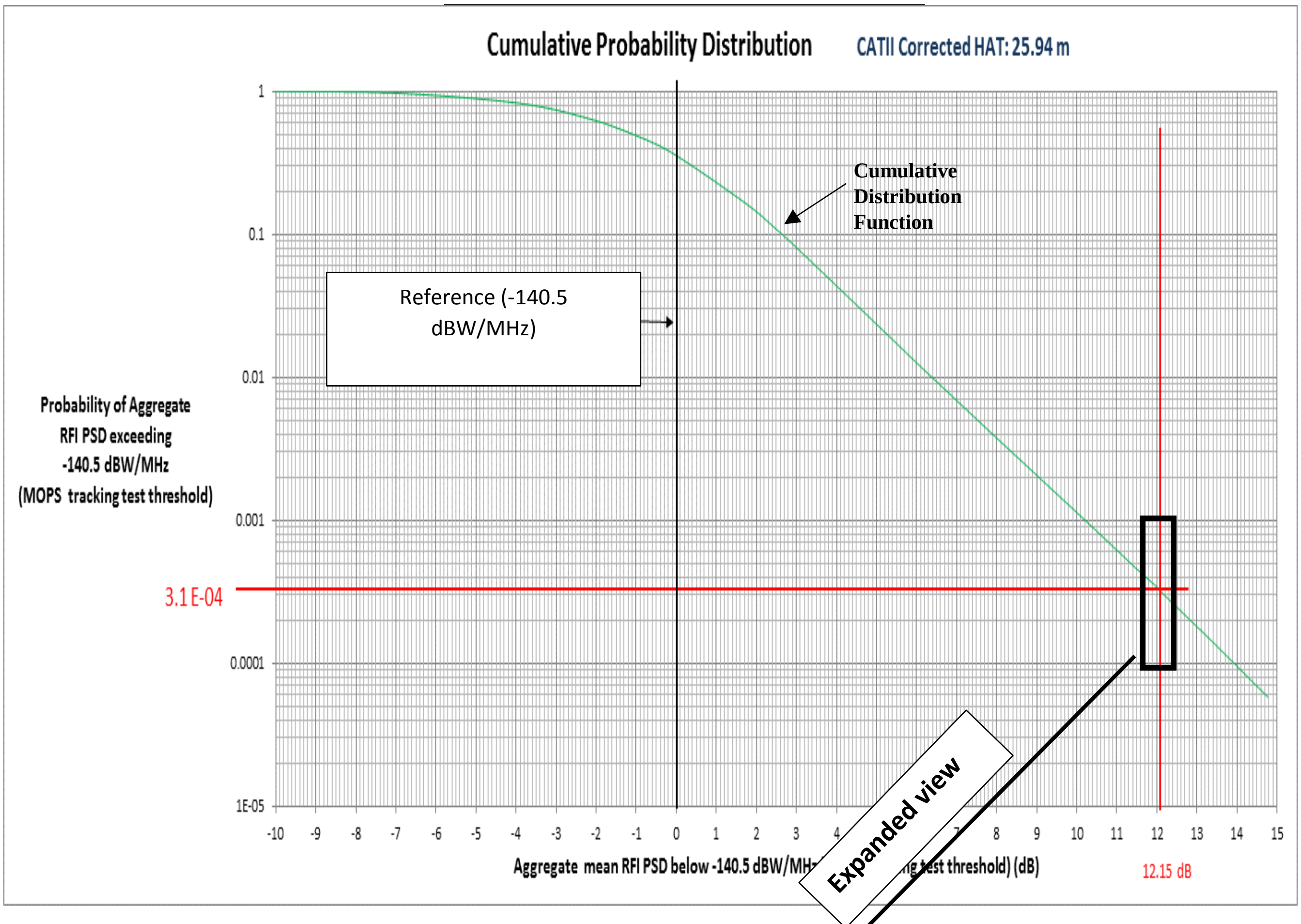


Figure 3 – Magnified view at Aggregate mean RFI PSD below -140.5 dBW/MHz at 12 dB

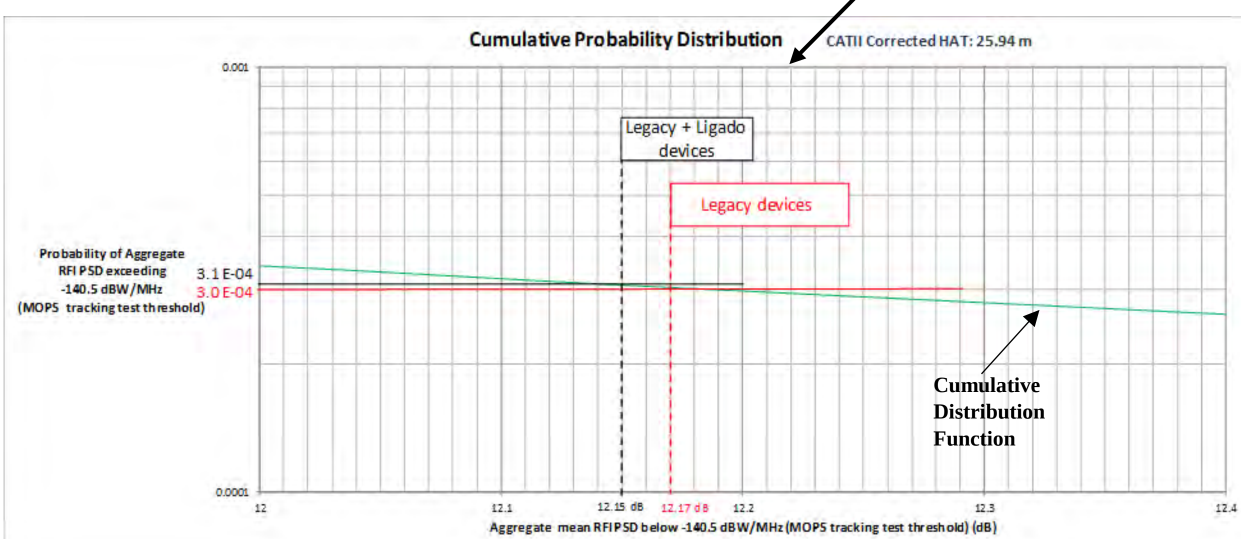


Table 2 Calculations of Exceedance Probability with Legacy UEs' OOBE

	In-Flight Aircraft/Ground Based Handset Case - Baseline			Comments
1	**Parameter**	**Value**	**Unit**	
2	Aircraft Altitude	CAT II DH		Worst case received RFI at 25.94 m height (Ref 1, Table 3)
3	Legacy UE OOBE Tx EIRP	-81.1	dBW/MHz	Surface density ρ_E = 10^-4 per sqm, (100/Sq Km), Height of handset ,H_E = 1.8 m, (Ref 1, Para 2.1)
4	Mean Aggregate received RFI Power density	-152.67	dBW/MHz	Ref 1, Table 3
5	Receiver MOPS test threshold	-140.50	dBW/MHz	Reference 1, Paragraph 4.3.2
6	Ratio of MOPS test threshold to mean aggregate received RFI	12.17	dB	Line 5 - Line 4
7	Ratio of MOPS test threshold to mean aggregate received RFI	16.5	Linear term	Linear term for line 6
8	Probability of Aggregate received RFI exceeding test threshold	3.0E-04	#	Reference 1, Table 5 (generalized model)

Table 3 Calculations of Exceedance Probability with Legacy + Ligado UEs' OOBE

	In-Flight Aircraft/Ground Based Handset Case - RFI Analysis			Comments
1	RFI from legacy devices located outside aircraft on ground	-152.67	dBW/MHz	Reference - 1, Table - 3 for CATII DH (new model Aggr mean)
2	Baseline/Environmental RFI PSD	-152.67	dBW/MHz	Line # 1
3	Aggregate Mean Path loss	71.57	dB	Calculated [-81.1 dBW/MHz-line # 1]
4	RFI from Ligado devices on ground (1 UE/10^4 Sqm)	-176.57	dBW/MHz	Calculated [-105 dBW/MHz - Line # 3]
5	Aggregate RFI	-152.65	dBW/MHz	linear sum of Line # 3 and line # 4)
6	Receiver MOPS test threshold	-140.50	dBW/MHz	Reference 1, Paragraph 4.3.2
7	Ratio of MOPS test threshold to mean aggregate received RFI	12.15	dB	Line # 6 - line # 5
8	Ratio of MOPS test threshold to mean aggregate received RFI	16.4	Linear term	Linear term for line # 7
9	Probability of Aggregate received RFI exceeding test threshold	3.1E-04	#	See chart below (chart is plot of Ref 1, table 4)
10	**Exceedance probability due to additional in-band RFI**	**3.33%**	**#**	**Objective: < 6 %**

2.1.2 Conclusion:

As the FAA requirement is that the increase in exceedance probability caused by OOBE from the new band be less than 6%, Ligado's uplinks comply with this requirement.

2.2 Aircraft on Ground / Onboard Handset Cases

This use case is designed to demonstrate the potential effects of multiple Ligado handsets operating onboard an aircraft which is taxiing.

The relevant excerpt from the FAA Letter, marked by RTCA's SC-159 WG-6[10], is provided below:[11]

> Unlike the inflight scenario above, when the aircraft is on the ground and taxiing toward the gate, the onboard broadband handsets will be assumed to communicate through a standard ground base station outside the aircraft. Because of the partial shielding of the aircraft fuselage, the handsets will be assumed to operate at full transmit power for their necessary emission. The aircraft antenna height is assumed to be 4 m above ground and at a representative location at the start of the taxiway. As in the Sec. 3.1 scenarios, the aircraft GPS receiver is assumed to be in the signal tracking mode. Propagation of both necessary and unwanted handset emissions to the aircraft GPS antenna will be characterized by the same model as in RTCA/DO-235 Appendix E.6.2. For unwanted emission analyses, the GPS receiver is assumed to operate in the presence of a baseline level of unwanted RFI from other randomly-distributed sources outside the aircraft. See Table 4 and [5] for baseline RFI calculation details. Handsets will be distributed in a random assortment of discrete locations throughout the passenger cabin for a few representative values of total handset count. Path loss values at possible locations are to be taken from DO-235 Appendix E, Table E-10.

Table 4 Key Geometric Parameters for the Ground Aircraft - Baseline Unwanted RFI

Parameter	Taxiway Case
Receive Antenna. Ht. (m)	4.0
Std. Dev. Inner Radius, r_s (m)	15.529
Mid-range Inner Rad. R_1 (m)	= r_s
Mid-range Outer Rad. R_2 (m)	1000
Excl. Zone Half-angle (deg)	25
Excl. Zone Inner Rad. (m)	60*
Excl. Zone Outer Rad. (m)	2800
Radio Horizon Radius (km)	13.7813

* Total RFI source exclusion within this radius

Assumptions

<u>UE Power</u>

Ligado, in its December 31, 2015 filing has proposed to reduce the EIRP on uplink channels from 0 dBW to -7 dBW (23 dBm). This is also the maximum power of a device according to the 3GPP standard for LTE. This is an extremely conservative assumption for the *operational power*, which will be further reduced from the above maximum value due to uplink power control. For example, the CSMAC [2] simulations have shown that, in suburban environments, the UE power is less than 10 dBm with a probability greater than 95% for an individual device. However, as a conservative assumption, Ligado has

[10] In its response to the FAA Letter, RTCA SC159 WG 6 provided suggested edits and changes to the FAA's methodology as a markup to the original FAA Letter (the "RTCA Markup")
[11] RTCA Markup, Section 3.2.2.

not factored this 13 dB average reduction in the analysis and the analysis has been done with maximum UE power of 23dBm.

UE antenna coupling loss

A device antenna coupling loss of 0 dB, relative to an isotropic radiator, was used. This value is extremely conservative. For example, in its 2011 assessment, the Cellular subgroup of Technical Working Group tasked by the FCC to study the GPS interference issue assumed a higher antenna coupling loss of 5 dB for a transmit antenna on a cellphone for the use cases that it studied.

Number of simultaneously transmitting devices

All 64 window seats of a Boeing 737-200[12] are assumed to be occupied with simultaneously transmitting users. It should be recognized that this is an implausible scenario that is more conservative than required by the FAA Letter, which requires, "handsets will be distributed in a random assortment of discrete locations throughout the passenger cabin for a few representative values of total handset count". This is an extremely conservative scenario in which 1/3 of all aircraft seats are occupied by a user with a Ligado UE operating at full power with the minimal possible path loss to the aircraft GPS antenna. It is presented here as a way to demonstrate the positive margin inherent in the use case in general, and avoid debate about the number and seat choices of the handsets.

The "baseline level of unwanted RFI from other randomly-distributed sources outside the aircraft",[13] comprised an equal number of legacy and Ligado UEs. As mentioned above, the PSD of baseline RFI was determined by a simplified model of 2-ray propagation to all UEs up to the radio horizon. This model results in less propagation loss than that recommended by the FAA and RTCA. It therefore created a higher baseline RFI than would have resulted from the FAA model had it been calculated at ground level. The model used by Ligado reduced the margin between the composite (from all UEs) mean RFI PSD and the Environmental Limit of -146.5 dBW/MHz. As the compatibility metric specified by the FAA is the positive margin between the Environmental Limit and the composite mean PSD, the approach used by Ligado is more conservative than that recommended by the FAA and RTCA.

OOBE PSD from UE

The Ligado limit of -105 dBW/MHz for OOBE PSD is used instead of the -95 dBW/MHz limit specified in the FAA Letter, which is no longer current based on Ligado's December 31, 2015 FCC filing.

[12] This is the aircraft type specified in the FAA Letter.
[13] RTCA Markup, Section 3.2.2.

OOBE threshold at the GPS receiver

The OOBE threshold used is -206.5 dBW/Hz, as per RTCA DO-229D.

Overload threshold at the GPS receiver

The overload threshold used is -16.7 dBm, as per RTCA DO-229D for a CW signal at 1632.5 MHz.

2.2.1 Result and Discussion

Table 5 Calculations for Aircraft on Ground / Onboard Handset Cases

	Aircraft on ground / Onboard Handset case (64 Users) Use case 3.2.2			
	Item	Value	Unit	Comment
1	Combined received RFI Power density @ 4 m A/C height from legacy and Ligado devices	-149.5	dBW/MHz	Environmental RFI (total) at @ 4 m Aircraft height (sum of legacy and Ligado devices on ground)
2	Total received OOBE	-157.4	dBW/MHz	64 users in all cabin window seat - Calcuated
3	Aggregate RFI	-148.8	dBW/MHz	Linear sum Line # 1 and line # 2
4	dB aviation margin	-146.5	dBW/MHz	Reference 3, Figure C-1
5	**OOBE Margin**	**2.3**	**dB**	**Calculated**
6	Aggregate path Loss (dB)	52.4	dB	(-105 dBW/MHz) - Line # 2
7	Total received fundamental power	-29.4	dBm	(23 dBm) - Line # 6
8	Overload threshold with 6 dB aviation margin	-16.7	dBm	Reference 3, Figure C-1
9	**Overload margin**	**12.7**	**dB**	**Line # 8 - Line # 7**
10	Overload threshold with 6 dB aviation margin (GLONASS)	-22.7	dBm	At 1632.5 MHz ICAO MOPS
11	**Overload Margin for GLONASS Rx**	**6.7**	**dB**	**Line # 10 - line # 7**

As mentioned above, the composite PSD of baseline RFI from legacy and Ligado devices was calculated using a conservative, line-of-sight two-ray model from each source within the radio horizon of receiver (~14 Km radius). With the total count of ~120,000 sources, the PSD value is -149.5 dBW/MHz. The calculations in Table 5 show that the aggregate RFI is below the tracking threshold of receiver with an OOBE margin of 2.3 dB and overload margin of 12.7 dB for GPS receivers and 6.7 dB for GLONASS receivers[14].

[14] The OOBE limits for GLONASS are identical to those for GPS, so the OOBE margin for GLONASS is not separately stated in this document.

2.2.2 Conclusions

The Ligado uplinks meet the requirements of this use case.

It is noteworthy that the total RFI level is dominated by legacy devices outside the aircraft. Without any Ligado devices in cabin, the in-band tracking margin would have been 3 dB. The 64 Ligado devices inside the aircraft only consumed 0.7 dB of the available margin.

2.3 Aircraft at Gate / Single Handset Source on or near Boarding Stairs or Jetway

This scenario is designed to assess the potential impact of a single user that is boarding a regional jet using a stairway, and is positioned at the top of the stairway, outside of the aircraft.

Excerpt from the RTCA Markup[15]:

> This scenario has a single broadband wireless handset operating potentially at up to full necessary emission power at the center frequencies listed in Section 2.3.1. The propagation is assumed to be free-space ($1/r^2$). Handset location relative to the GPS aircraft antenna is assumed to be such that the receive antenna gain is -5 dBi. Given the propagation conditions and single source, the result is assumed to be deterministic. In this case for a single handset with 0 dBW (30 dBm) EIRP operating at 1616 MHz, the minimum handset antenna separation distance for compatibility[16] is 3.5 m. This separation might be assured by aircraft fuselage size and geometry. Some further verification should be undertaken in the short duration study. Unwanted handset RFI analysis should also include the baseline RFI effect as in Sec. 3.2.2 and also include the effect of unwanted RFI from a concentration of general sources inside the airport terminal.

The scenario assumptions and link calculations are given below.

Maximum UE Power

As a conservative assumption, the maximum operational UE power was assumed to be 23 dBm at a transmit frequency of 1632.5 MHz. In actual use cases, the transmit EIRP will typically be much lower due to uplink power control and a UE transmit antenna coupling loss (antenna gain less than 0 dBi in the direction of transmission).

GPS antenna gain towards UE

As recommended by the FAA, GPS antenna gain of -5 dBi is assumed towards UE.

Number of simultaneously transmitting devices

This scenario involves a single user at the top of the aircraft stairs. It does not appear possible to have more than a single user at this particular location.

[15] RTCA Markup, Section 3.3.

16 With respect to 1616 MHz susceptibility (Fig. 1) with 6 dB safety margin (-22.5 dBm)

Separation distance from UE to GPS receiver

As recommended by FAA, the separation distance was assumed to be 3.5 m.

OOBE PSD from UE

The Ligado limit of -105 dBW/MHz for OOBE PSD is used instead of the -95 dBW/MHz limit specified in the FAA Letter, which is no longer current based on Ligado's December 31, 2015 FCC filing.

OOBE threshold at the GPS receiver

The OOBE threshold used is -206.5 dBW/Hz (-146.5 dBW/MHz), as per RTCA DO-229D.

Overload threshold at the GPS receiver

The overload threshold used is -16.7 dBm, as per RTCA DO-229D for a CW signal at 1632.5 MHz.

Link Calculations

Table 6 shows the link calculations for the single user case.

The analysis is performed without any changes to the recommended parameters for the scenario in the FAA Letter. The baseline noise is assumed to be sourced from legacy devices and Ligado devices on ground as described in Section 2.3 of this document.

Table 6 Calculations for Aircraft at Gate / Single Handset Source on or near Boarding Stairs or Jet-way

1	**Single Ligado User near Boarding Stairs or Jet way - Baseline RFI calculations**			
2	**Parameter**	**Value**	**Unit**	**Comment**
3	Mean Aggregate received RFI Power density @ 4 m A/C antenna height from legacy devices on the ground	-149.5	dBW/MHz	Calculated in "Baseline RFI @ 4 m" tab assuming worst case, two ray path loss assumptions. Device OOBE = -81.1 dBW/MHz (Ref -1)
4	Mean Aggregate received RFI Power density @ 4 m A/C antenna height from Ligado devices	-173.4	dBW/MHz	Calculated in "Baseline RFI @ 4 m" tab assuming worst case, two ray path loss assumptions. Device OOBE = -105 dBW/MHz
5	Combined received RFI Power density @ 4 m A/C antenna height from legacy and Ligado devices	-149.5	dBW/MHz	Environmental RFI (total) at @ 4 m Aircraft height (linear sum of line # 3 and line # 4)
6	Mean Aggregate received RFI Power density	-154.0	dBW/MHz	30 legacy devices randomly distributed in terminal (10 trials)
7	Mean Aggregate received RFI Power density	-177.6	dBW/MHz	30 Ligado devices randomly distributed in terminal (10 trials)
8	Baseline/Environmental RFI PSD	-148.2	dBW/MHz	Linear sum of line # 5, # 6 and # 7
9	**Single Ligado User near Boarding Stairs or Jet way - RFI analysis**			
10	Max UE Tx EIRP	23	dBm	
11	UE Maximum OOBE PSD (select)	-105	dBW/MHz	
12	Uplink power control factor (user location: outdoor)	0	dB	
13	Rx Antenna Coupling loss	5	dB	-5 dBi gain of GPS antenna (Reference 2, para 3.3
14	Tx/Rx Distance	3.5	Meters	Minimum plausible distance for use case (Reference 2, para 3.3)
15	Path loss to GPS antenna	47.3	dB	Free Space @ 1575 MHz
16	OOBE received by GPS antenna	-157.3	dBW/MHz	line # 11- # 12 - line # 13 - line # 15
17	Baseline/Environmental RFI PSD	-148.2	dBW/MHz	Line # 8
18	Aggregate RFI	-147.7	dBW/MHz	Linear Sum of Line # 16 and # 17
19	Receiver MOPS test threshold with 6 dB aviation margin	-146.50	dBW/MHz	Reference 3, Figure C-1
20	**OOBE Margin**	**1.2**	**dB**	**Line # 19- line # 18**
21	Fundamental signal power	-29.3	dBm	line # 10 - # 12 - # 13 - # 15
22	Overload threshold with 6 dB aviation margin for GPS	-16.7	dBm	At 1632.5 MHz, Reference 3, Figure C-1
23	**Overload margin for GPS Rx**	**12.6**	**dB**	**Line # 22 - line # 21**
24	Overload threshold with 6 dB aviation margin GL	-22.7	dBm	At 1632.5 MHz ICAO MOPS
25	**Overload Margin for GLONASS Rx**	**6.6**	**dB**	**Line # 23 - line # 21**

2.3.1 Result and Discussion

In addition to baseline noise PSD from legacy and Ligado sources within the radio horizon outside the aircraft, additional RFI sources within the terminal building are also considered contributing the base line noise. Ligado has assumed 30 legacy and 30 Ligado users randomly distributed inside the terminal building where the aircraft is parked, and has used recommendations from the FAA Letter to calculate path loss to the receiver. Even with contribution from background in-band noise, the analysis shows positive 1.2 dB margin for in-band, overload margin of 12.6 dB for GPS receiver and 6.6 dB for GLONASS receiver.

2.3.2 Conclusions

Ligado uplinks comply with this use case for both OOBE and Overload.

2.4 Aircraft at Gate/30 Users Inside Airport

This use case is designed to simulate the effects of multiple users dispersed around the gate area of an airport with an aircraft parked at the gate.

Excerpt from the RTCA Markup[17]:

> The following are proposed features for this new scenario with 30 wireless broadband handsets operating in an airport terminal gate area that generate RFI to a GPS receiver on an aircraft parked outside the terminal in front of the gate area. Unwanted handset RFI analysis should also include the baseline RFI effect as in Sec. 3.3. The choice of the ratio of baseline sources inside the terminal to wireless broadband sources should be justified.
>
> 1. The aircraft GPS antenna height is assumed to be 4 meters above ground and 34 meters from front edge of terminal area.
> 2. The handset antenna heights are all 3 m above the aircraft antenna level (2 m above terminal floor)
> 3. Terminal area is assumed to be symmetrically spaced in front of the aircraft with a 20 meters average depth and 50 meters width
> 4. 30 handsets are assumed to be uniformly distributed throughout the 1000 sq. m. area.
> 5. Handsets are assumed to be operating in the 1610-1656.5 MHz band with -95 dBW/MHz unwanted EIRP in the GPS L1 band.
> 6. Due to the relatively few handsets and the large minimum separation distance, the aggregate unwanted RFI in-band to the GPS receiver is expected to be the dominant effect (c.f. §3.3).
> 7. The median path loss model to be used would be free-space at these distances but with additional building loss incorporated as per the July, 2014 NTIA document. That is, 20% of handsets incur an additional 20 dB loss, 60% an additional 15 dB loss, and 20% an additional 10 dB loss. (excess loss assigned relative to decreasing distance from front terminal wall)
> 8. A Monte Carlo method is suggested for analysis.

Assumptions

Maximum UE Power

As a conservative assumption, the maximum operational UE power was assumed to be 23 dBm. In actual use cases, the transmit EIRP will typically be much lower due to uplink power control and a UE transmit antenna coupling loss (antenna gain less than 0 dBi in the direction of transmission).

[17] RTCA Markup, Section 3.4.

GPS antenna gain towards UE

Using the pattern of an aviation GPS antenna provided in RTCA DO-235B, Fig. G-13, an antenna gain of -2.75 dBi is used for elevation angles +5 degrees for the nearest user device to Aircraft Antenna. This is a conservative, worst case assumption.

Number of simultaneously transmitting devices

It is assumed that all thirty Ligado users are transmitting simultaneously at constant power (as detailed above) at varying distances from an aircraft parked at the gate and that their powers add at the GPS receiver as specified in the FAA Letter and RTCA Markup. Specifically, six users are operating in the front glass of the terminal building at a distance of 0 - 6 meters facing the aircraft, 18 users are in middle section of the terminal at a distance of and 6 – 14 meters, and 6 users are in backside of the terminal at a distance of 14 – 20 meters. These are extremely conservative assumptions, both in terms of the number of active users within the separation distances and in terms of the likelihood of power addition at the GPS receiver. The latter likelihood is low because the TDMA component of the LTE protocol will, with very high probability, assign non-overlapping transmit-time epochs to the users. Indeed, the CSMAC working groups assumed six simultaneous users per cell sector for its modeling assumptions.

The high number of users in this instance demonstrates the substantial margin that exists overall for this type of use case.

Separation distance from UE to GPS receiver

As recommended by FAA, the separation distances vary from 34-60 meters from the aircraft GPS receive antenna.

OOBE PSD from UE

The Ligado limit of -105 dBW/MHz for OOBE PSD is used instead of the -95 dBW/MHz limit specified in the FAA Letter, which is no longer current based on Ligado’s December 31, 2015 FCC filing.

OOBE threshold at the GPS receiver

The OOBE threshold used is -206.5 dBW/Hz (-146.5 dBW/MHz), as per RTCA DO-229D.

Overload threshold at the GPS receiver

The overload threshold used is -16.7 dBm, as per RTCA DO-229D for a CW signal at 1632.5 MHz.

2.4.1 Results and Discussion

The analysis in Table 7 was conducted using Monte Carlo method by simulating the 30 Ligado users in the airport terminal as discussed above. Hundreds of trials were performed (ten trails per each calculation epoch) to determine the median RFI. The environmental RFI PSD for background noise was considered to originate from an equal number of legacy and Ligado devices distributed within the radio horizon. The in-band aggregate RFI was compared with the receive threshold of -146.5 dBW/MHz. The analysis shows positive margin of 1.7 dB for OOBE and 31.2 dB for overload RFI. Overload margin of 25.2 dB is available for GLONASS receiver.

Table 7 Calculations for Aircraft at Gate/30 Users Inside Airport

	Aircraft at Gate, 30 users inside terminal - Baseline RFI calculations			
	Parameter	Value	Unit	Note
1	Combined received RFI Power density @ 4 m A/C height from legacy and Ligado devices	-149.5	dBW/MHz	Environmental RFI (total) at @ 4 m Aircraft height (sum of legacy and Ligado devices on ground)
2	Mean Aggregate received RFI Power density	-154.0	dBW/MHz	30 legacy devices randomly distributed in terminal (10 trials)
3	Baseline/Environmental RFI PSD	-148.2	dBW/MHz	Linear sum of line # 1 + line # 2
4	**30 Ligado Users inside terminal - RFI analysis**			
5	Mean Aggregate received RFI Power density	-175.9	dBW/MHz	30 Ligado devices randomly distributed in terminal (10 trials)
6	Aggregate OOBE received by GPS antenna	-148.2	dBW/MHz	Linear sum of line # 3 and # 5
7	Receiver MOPS test threshold with 6 dB aviation margin	-146.50	dBW/MHz	Reference 3, Figure C-1
8	OOBE Margin	**1.7**	dB	Line # 7 - line # 6
9	Aggregate path Loss (dB)	70.9	dB	Calculated, (-105 dBW/MHz) - line # 5
10	Total received fundamental power	-47.9	dBm	(23 dBm) - line 9
11	Overload threshold with 6 dB aviation margin	-16.7	dBm	DO-229D At 1632.5 MHz, Reference 3, Figure C-1
12	Overload margin (GPS) Rx	**31.2**	dB	Line # 11-line # 10
13	Overload threshold with 6 dB aviation margin GLONASS	-22.7	dBm	At 1632.5 MHz ICAO MOPS
14	Overload Margin for GLONASS Rx	**25.2**	dB	Line # 13 - line # 10

2.4.2 Conclusions

Compatibility is demonstrated for both OOBE and Overload, with the use of highly conservative assumptions.

2.5 TAWS / HTAWS and Pos/Nav Scenarios with Ground-based Mobile Broadband Handsets

This scenario was constructed to assess the potential impact of Ligado UEs located on the ground on aircraft that are using GPS with terrain awareness systems (TAWS for fixed wing aircraft and HTAWS for helicopters) as well as other positioning and navigation systems that rely on receivers certified to the RTCA DO-229D and related MOPS.

Excerpt from RTCA Markup[18]:

> The RTCA results [3] for mobile broadband handset aggregate unwanted emissions were largest for the Cat II DH scenario where the aircraft antenna was 25.94 m above the ground. For this scenario, exclusion zones were assumed where mobile handsets could NOT be (e.g., within the airport runway object-free area, obstacle clearance zone, etc. - see Table B-3 in [3]). This exclusion zone was a rather substantial annular wedge (~50 degrees). The handset interference results would be worse for the (TAWS/HTAWS) scenarios developed during the base station studies performed by the FAA with LightSquared during late 2011/early 2012 [4]. In those scenarios, the airborne user would be roughly the same height above ground but without exclusion zones for mobiles beneath the aircraft.
>
> In this study, the mobile broadband handsets are assumed to be randomly distributed at one of 3 different surface concentrations (30, 75, 180 per sq. km). Their assumed unwanted emission is -95 dBW/MHz in the GPS L1 receiver passband. At these surface concentration values, the fundamental emission effects will be insignificant by comparison. The two different aircraft antenna height cases to be analyzed are: 25.94 and 53.34 m. Comparison can then be made with the final approach cases from Sec. 3.1.1 which contain source exclusion zones.

Assumptions

Maximum UE Power

As a conservative assumption, the maximum operational UE power was assumed to be 23 dBm.

Uplink power control

No Uplink power control is assumed.

Antenna coupling loss

UE transmit antenna coupling loss is assumed to be 0 dB.

[18] RTCA Markup, Section 3.5.1

GPS antenna gain towards UE

Using the pattern of an aviation GPS antenna provided in RTCA DO-235B, Fig. G-13, varying GPS receive antenna gain are considered, based on the angle of arrival of the RFI signal from randomly located user device.

Number of simultaneously transmitting devices

Device concertation of 30, 75 and 180 per Sq. Km. in the radio horizon.

Height of GPS receiver

As suggested by FAA, the 25.94 meters and 53.34 meters are considered

OOBE PSD from UE

The Ligado limit of -105 dBW/MHz for OOBE PSD is used instead of the -95 dBW/MHz limit specified in the FAA Letter, which is no longer current based on Ligado's December 31, 2015 FCC filing.

OOBE threshold at the GPS receiver

The OOBE threshold used is -146.5 dBW/Hz, as per RTCA DO-229D.

Overload threshold at the GPS receiver

The overload threshold used is -16.7 dBm, as per RTCA DO-229D for a CW signal at 1632.5 MHz.

Exclusion Zone

For uplink use cases, the term "Exclusion Zone" refers to potential restrictions on the placement of Ligado base stations, which would then eliminate UEs from those areas as well. In the case of the current analysis, no exclusion zones have been assumed.

Propagation Model

Two-Ray Line of Sight

2.5.1 Results and Discussion

The RFI analysis in Table 8 shows that significant margin exists (more than 23 dB) for OOBE and more than 25 dB exists for the overload conditions for all aircraft heights, and device concentrations considered. Considering the fact that tracking threshold (Environmental Limit) for in-band (OOBE) was at -146.5 dBW/MHz, even for the calculating the increase in exceedance probability, the mean RFI would be approximately 29 dB (23 + 6) below the -140.5 dBW/MHz reference threshold. This also would result in an extremely small increase (less than 1 %) in exceedance probability.

Table 8

Calculations for TAWS / HTAWS and Pos/Nav Scenarios with Ground-based Mobile Broadband Handsets

Ground Based Handsets for TAWS/HTAWS				
UE Concentration (per Sq Km)	Aircraft height = 25.94 m		Aircraft height = 53.34 m	
	OOBE Margin (dB) (Threshold -146.5 dBW/MHz)	O/L Margin (dB) at 1632.5 MHz	OOBE Margin (dB) (Threshold -146.5 dBW/MHz)	O/L Margin (dB) at 1632.5 MHz
30	**31.4**	**33.2**	**31.8**	**33.6**
75	**27.4**	**29.2**	**27.8**	**29.6**
180	**23.6**	**25.4**	**24.0**	**25.8**

2.5. 2 Conclusions

The calculations use the Ligado limit of -105 dBW/MHz for OOBE PSD instead of the -95 dBW/MHz limit specified in the FAA Letter, which is no longer current.

Reference

[1] Frazier, R., Erlandson, R. J. and Peterson, K. M. "Final Report: A Generalized Statistical Model for Aggregate Radio Frequency Interference to Airborne GPS Receivers from Ground Based Emitters", DOT/FAA/TC-14/30, RTCA Paper No. 267-14/SC159-1023, September 30, 2014.

[2] Peterson, K. M. and Erlandson, R. J., "Analytic Statistical Model for Aggregate Radio Frequency Interference to Airborne GPS Receivers from Ground-Based Emitters", NAVIGATION: Journal of the Institute of Navigation, Vol. 59, No. 1, Spring 2012.

A method for calculating adjacent band RF interference power received by a certified aviation GPS receiver from proximate terrestrial base stations

09/19/2016

Introduction and Executive Summary

Background

Ligado Networks has an application pending with the FCC, which was filed on December 31, 2015, seeking to modify Ligado's terrestrial authorization to use certain radio frequencies. A key part of this application is a provision whereby the FCC would modify Ligado's licenses such that it would be required to operate in a manner so that the Effective Isotropic Radiated Power (EIRP) of Ligado's cell sites operating from 1526-1536 MHz would be restricted to assure compatibility with all standards incorporated into active and any future FAA Technical Standards Orders (TSOs) for certified aviation GPS devices. This license condition ensures that Ligado's operations would be compliant with applicable FAA requirements.

During the past nine months, Ligado has worked diligently with the FAA to determine the methods by which compatibility with these aviation standards can be assured, consistent with FAA and RTCA methodologies. This document details the methods, formulas and values by which this will be accomplished.

Selection of Helicopter Use Cases

The assessment of aviation compatibility is based on use cases involving helicopters rather than fixed wing aircraft since rotorcrafts present the most difficult use cases because they are less constrained in their operations and, as a result, can operate in much closer proximity to structures with cellular antennas. For example, fixed-wing aircraft are required by the FAA to operate at least 500 feet from any obstruction (such as a radio tower), and often farther.[1] Rotorcraft in general have no minimum distance requirement, provided that the operator ensures there is no hazard to persons or property. Because they may operate in closer proximity to Ligado's cell sites, focusing on rotorcraft use cases will result in the maximum reduction of Ligado EIRP from its 1526-1536 downlink channel in order to ensure compatibility with aviation standards.

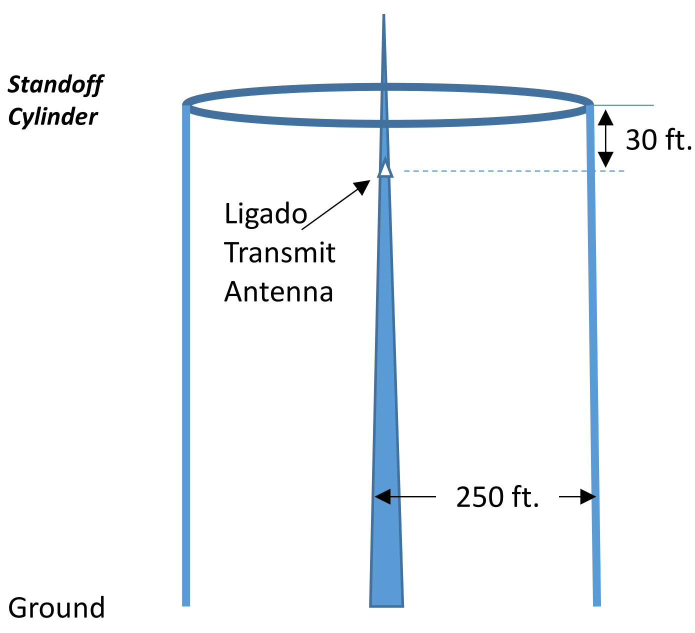
[1] 14 C.F.R. § 91.119 (requiring that aircraft operate at least 1,000 feet above the highest obstacle within 2,000 feet horizontally when over a congested area, 500 feet above the surface when not over a congested area, and not closer than 500 feet to any person, vessel or structure.

Minimum Offset Distance and Standoff Cylinder Approach

In order to assess compatibility between Ligado operations and certified aviation GPS devices, it is critical to establish the minimum distance from a Ligado transmit antenna that a helicopter is expected to operate safely, based on the TSO guarantee of performance of certified GPS equipment. Ligado studied this issue intensively, consulting with the FAA and a major operator of air ambulance helicopter services. Ligado also performed a technical analysis of the authorized out of band emissions of other FCC-licensed wireless services that are widely deployed (such as Cellular, Personal Communications Services and Advanced Wireless Services licenses that are held by all of the major wireless carriers).

As a result of this analysis, Ligado determined that: 1) a rotorcraft operating at a distance closer than 250' from a cell site, would experience authorized emissions from the commercial wireless services mentioned above that exceed the compatibility limits for certified GPS devices and thus are capable of interfering with GPS devices, and 2) in order to ensure safe operations, rotorcraft operators utilize visual flight rules when operating in such close proximity to structures of any kind and do not rely on certified GPS equipment for their rotorcraft operations at these close distances. Given these two important considerations, Ligado has used a lateral offset distance of 250' from its transmit antennas for the purpose of the calculations contained in this analysis.

To assess compliance, the model uses a cylinder around a tower with a radius for the cylinder that extends 250' laterally from the antenna with a vertical component that extends to 30' above the antenna all the way to the ground ("Standoff Cylinder"). Under this proposal, Ligado's EIRP from its 1526-1536 MHz channel cannot exceed the FAA's limits at any point on the surface of the Standoff Cylinder and outside it in order to assure compatibility.



Additionally, rotorcraft and fixed wing aircraft rely on certified GPS equipment for instrument approaches to airports and heliports and could operate within 250' of cellular transmitters while on these approaches. In order to ensure that compatibility limits are not exceeded within the obstacle clearance areas of the approach, Ligado will ensure its network fully meets FAA conformance standards in these areas.

Methodology

In the analysis that follows, Ligado uses for the most part the analytical methods, formulas and values previously endorsed by the FAA and RTCA, which are cited within the document. Any instances in which Ligado has varied from that methodology are identified within the analysis.

For elements that were not previously addressed by the FAA, or where assumptions have needed to be updated due to the evolution of wireless network architectures, Ligado has utilized highly conservative values as well, described in detail below. For instance, Ligado's assessment of the aggregate power that is received at a particular location utilizes a worst-case assumption that all cell sites are equally spaced at a minimum distance from each other. This produces the highest possible interference power level (which must be subtracted from Ligado's operating power) even though such an interference power is nearly impossible to attain because Ligado will ensure that the deployed cells sites will, in fact, be farther apart than the minimum allowable distance in real-world deployments and actual radio signals typically do not comport to a free space propagation model all the way to the radio horizon. The result of this conservative approach is a lower EIRP. The purpose of these conservative assumptions is to ensure compatibility in all possible situations.

As explained below, Ligado proposes a model analysis that would determine the maximum safe level of operation for each Ligado cell site. In order to determine the appropriate maximum power for each cell site in Ligado's network, the following two steps are performed:

> *Step 1* – Determine the Baseline Reference Power for an Individual Cell Site
>
> As detailed in Section 3.1 below, Ligado will use the model to assess the appropriate power level for each individual site within its network—prior to commencement of operation—in order to ensure that its power does not exceed the established thresholds (with applicable safety margin) on the surface of and outside the Standoff Cylinder. The power for each site is modeled, using calculations previously endorsed by the FAA and RTCA, using the unique attributes of such site including antenna height, pattern and downtilt. The maximum EIRP is determined by evaluating a helicopter along the surface of the Standoff Cylinder and determining the point and orientation (i.e. bank angle) at which the aircraft would be capable of receiving the strongest signal from Ligado's transmit antenna. Ligado's EIRP is then reduced to the point at which compatibility is achieved at this "worst case" aircraft position and orientation.

Step 2 – Further Reduce EIRP to Account for Power from Surrounding Sites

Since a helicopter's antenna can receive signal from multiple sources simultaneously, it is important to account for the effects of surrounding Ligado cell sites as well. As detailed in Section 3, Ligado has constructed and evaluated two types of models. One model emulates a macro cellular network and evaluates a variety of surrounding cell sites of different antenna heights and orientations at a fixed distance of 693 meters (which produces a cell density of 2.4 base stations/sq. km) from the central site being assessed. A different model emulated an urban small cell network and used cell sites of identical height and antenna orientations, with at a fixed distance of 433 meters from the central site being assessed. This produces a density of 6.2 cell sites/sq. km.

The results of both the macro cell and small cell analyses converged on a common value of approximately 0.9 dB of additional power that can potentially be received by a certified aviation GPS antenna. This 0.9 dB will be subtracted from the Step 1 EIRP determined above to arrive at the cell site's final maximum EIRP. Furthermore, Ligado will propose that its license be conditioned to limit deployment of sites only where the inter-site distance is 433 meters or greater in order to ensure that its actual deployment is not denser than that assumed in this analysis.

Ligado has carefully defined this analytical approach in order to ensure the safe operation of certified GPS equipment is maintained in all use cases. It has utilized existing FAA and RTCA methodology wherever possible and has utilized highly conservative assumptions, consistent with this methodology, where none had previously been established. Ligado looks forward to working with the aviation community to further vet this conformance assessment to ensure that stakeholders have full input into its adoption and implementation.

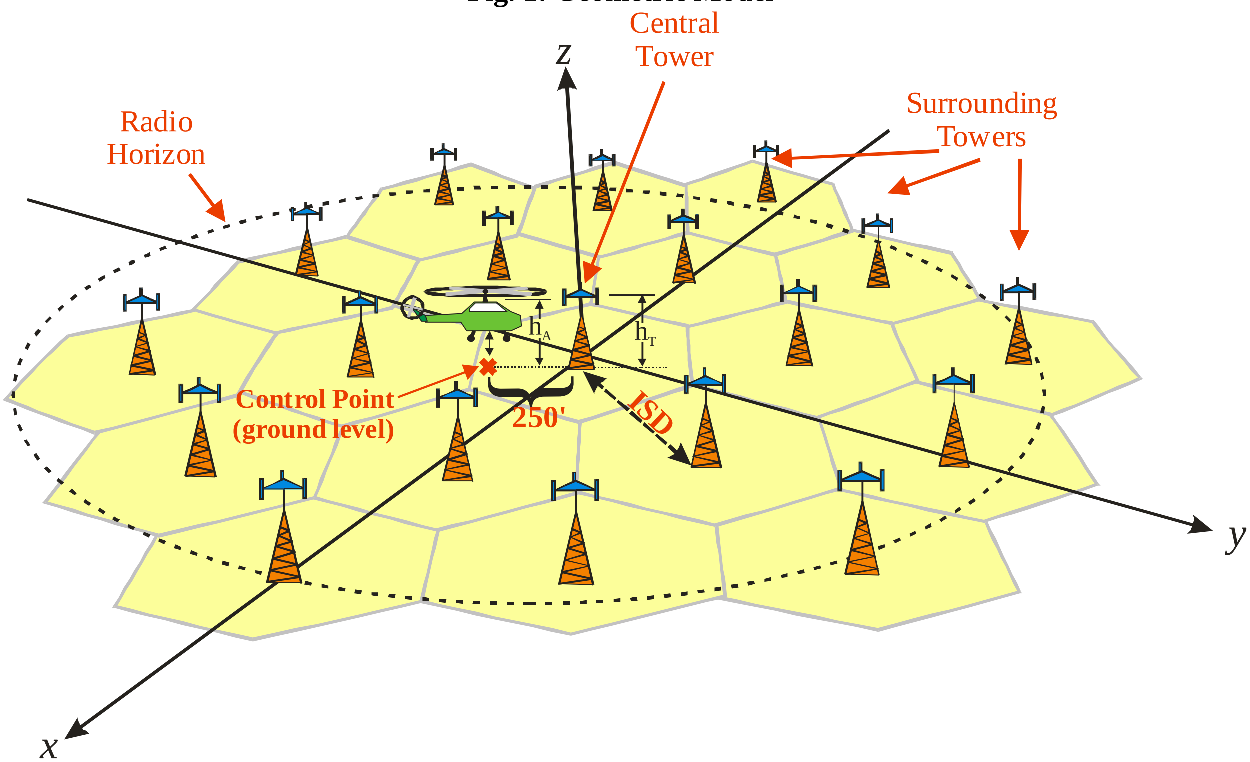
1.0 Objectives

This document provides the detailed calculation steps and methodology to predict the aggregate RFI toward a low-altitude (e.g., helicopter) aircraft GPS receiver due to combined RF emissions from surrounding base station towers using the MSS L-band (downlink) for terrestrial operations. It also proposes a method for determining the safe operating power level of a base station, with defined deployment parameters, so as to meet the certified aviation MOPS with FAA mandated safety margins.

2.0 Geometric Overview

Fig. 1 shows the geometric flat-earth model for the RFI calculation:

Fig. 1: Geometric Model[2]



A hexagonal cell pattern is defined in Cartesian coordinates out to the radio horizon, with a base station tower located at the center of each cell. The inter-site distance (ISD – i.e., the distance between adjacent towers) is determined from the given base station density D (towers per sq.km.) as follows:

ISD (m) = 1000*SQRT[2/{SQRT(3)*D}]

(1)

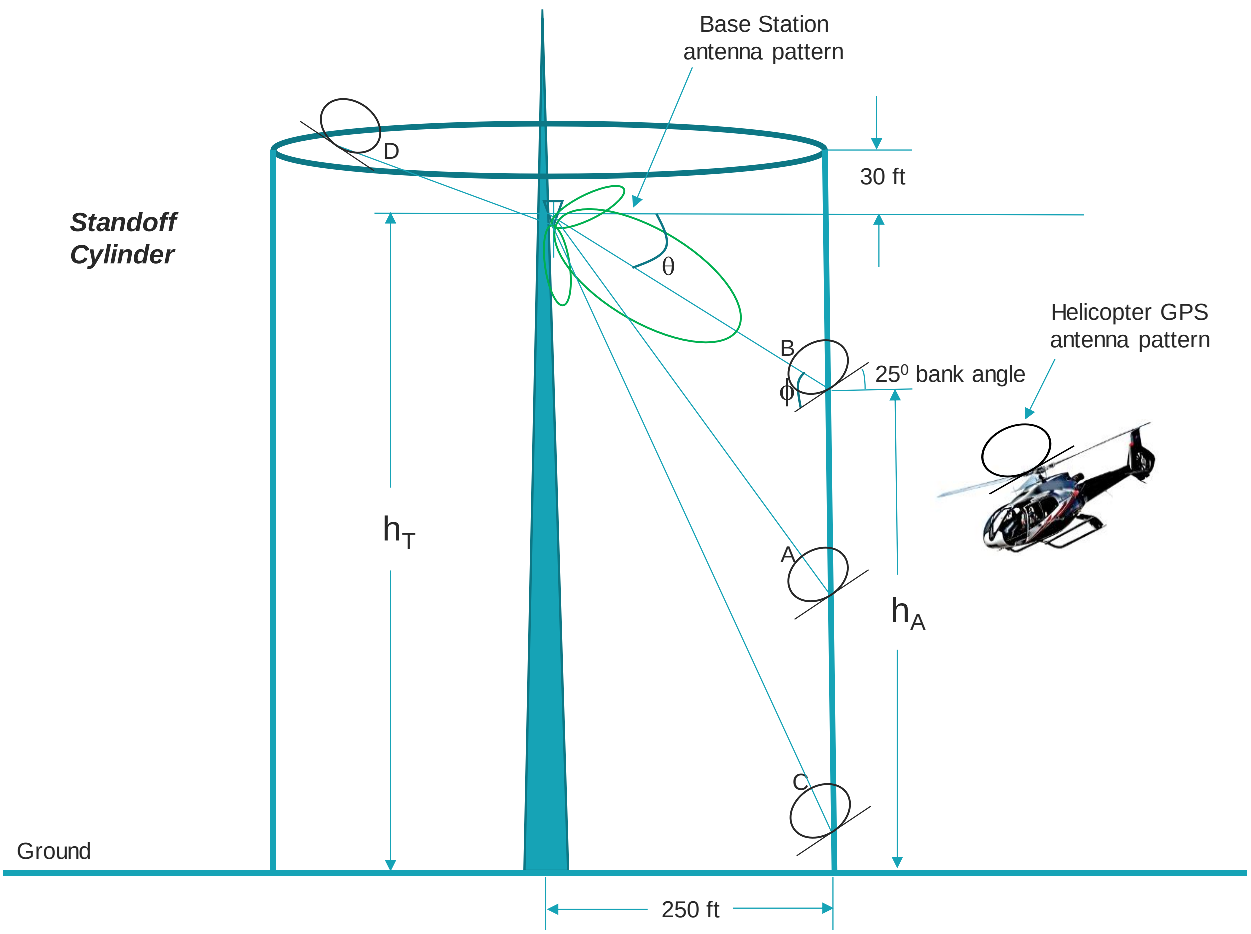
As described in Fig. 2, the aircraft is constrained to maintain a minimum standoff distance from any tower, defined by a cylinder that extends 250' radially and from ground level to 30' above the top of the Central Tower transmit antenna. The RFI power at any point on and outside the surface[3] of the cylinder must be less than a threshold value that depends on the interference mask in RTCA DO-229D [3] and

[2] Note: figures depicted in this document are for illustrative purposes and are not drawn to scale

[3] The RFI calculations extend to distances beyond the surface of the cylinder to a point where the potential RFI reaches its maximum level.

FAA mandated safety margins defined in the FAA's compatibility study methodology and assumptions [1].

Fig. 2: Aircraft Standoff Cylinder (25 Degree Banking Use Case)
Note: Both 25° and 0° bank angles are examined in the calculation method



Referring to Fig. 1, the aircraft is located a lateral distance of 250' from the Central Tower located at the origin. The aircraft receive antenna height and tower transmit antenna height, relative to ground level, are denoted h_A and h_T, respectively. The aircraft "Control Point" is defined in *x*-*y* coordinates at ground level directly beneath the aircraft antenna.

In addition to its location coordinates (*x*, *y*, and h_T), each tower is characterized by its antenna pattern, down-tilt angle and sector peak transmit EIRP. The aircraft is specified to be in one of two banking states[4]; 1) non-banking (i.e., level flight), or 2) 25° banking toward the Central Tower.[5] For purposes of

[4] Restriction of the bank angle to 2 values follows the FAA directions for such analysis, based on the FAA's compatibility study methodology and assumptions [1], where two different interference thresholds were specified, one for each bank angle.
[5] In some documents referenced herein, the Central Tower is referenced as the "Control Tower."

calculating propagation loss, the interference carrier frequency for all towers is specified to be 1531 MHz, which is the center point of a 10 MHz channel from 1526-1536 MHz.

For a given aircraft antenna height h_A and tower antenna height h_T, the radio horizon distance R_0, which includes a 4/3-earth radius factor to account for refraction, is given by the FAA's compatibility study methodology and assumptions [1]:

$$R_0\,(\text{m}) = 4124 * (\sqrt{h_A(\text{m})} + \sqrt{h_T(\text{m})}) \qquad (2)$$

Any tower whose lateral separation from the aircraft Control Point exceeds R_0 is excluded from the aggregate RFI calculation as it would be beyond the radio horizon.

3.0 RFI Calculation Approach

For a given banking scenario (no-banking or 25^o banking) and tower configuration (defined by height h_T and antenna down-tilt), the calculation of received RFI at the aircraft antenna and the corresponding maximum allowable sector EIRP proceeds in two steps:

1. **Single Tower RFI calculation:**
   a. Starting at an aircraft antenna height h_A = 4 m (or 10 m for aircraft banking), the RFI received from the Central Tower only (all other surrounding towers disabled) is calculated for some initial sector EIRP value[6], with lateral separation distance between aircraft and tower equal to 76.2 m (250'). The path loss is determined using the 2-Ray model considering the directional (in elevation) TX and RX antenna patterns[7]:
      i. To produce the most conservative 2-ray model result for the Central Tower RFI, the calculation algorithm finds the peak RFI level at or beyond the 76.2 m (250') lateral separation where the direct and reflected rays add constructively.
      ii. For conservatism, it is assumed that the aircraft bearing as viewed from the Central Tower corresponds to the azimuth of maximum sector antenna gain (i.e., boresight azimuth).
   b. With the lateral separation fixed at 76.2 m, the above RFI calculation is repeated as the receive antenna height h_A is incrementally raised from 4 m (or 10 m for aircraft banking) to a level where any further increase would result in a lower received RFI level. It is not necessary to check all the way up to full height of the standoff cylinder (30' above the height of the base station antenna) as the power reduces monotonically above the helicopter height corresponding to the maximum RFI. The value of h_A that corresponds to the highest received RFI level is denoted the "critical" receive antenna height for the single tower case.

   c. The "**Maximum Allowed Single Tower EIRP**" is referenced to the point of maximum TX antenna pattern gain, and is determined as follows:

      $$\text{Max\_allowed\_single\_tower\_EIRP (dBW)}$$

      $$= \text{Initial\_EIRP} - (RFI_{critical} - RFI_{limit}) \qquad (3)$$

      where:

[6] For this study, an initial sector EIRP of 13 dBW was used, although the actual initial value is not critical.
[7] The antenna pattern is an input to the model. The examples for which results are produced in this report, used an antenna whose pattern in provided in Appendix 1. The antenna is specified by its manufacturer as a small cell antenna.

Initial_EIRP ≡ the initial sector EIRP (dBW) described in step 1.a.

$RFI_{critical}$ ≡ max. RFI (dBm) calculated at critical antenna height.

RFI_{limit} ≡ allowed RFI limit (dBm) at RX antenna output.

The threshold RFI limit values used for this study are derived in Table 1:

Table 1: Received RFI limits at the RX Antenna Output (dBm)

Parameter	Reference	No banking	25º Banking
GPS tracking threshold:	RTCA DO-229D [3], Fig. C-1	-28.1 dBm	-28.1 dBm
Aviation safety margin:	RTCA DO-229D [3], Sec. 2.1.1.1, FAA methodology and assumptions [1], App. C	6 dB	2 dB
RFI limits:		**-34.1 dBm**	**-30.1 dBm**

The calculation of step 1 is repeated for both non-banking and banking conditions, and the more restrictive of the two conditions, in terms of defining the maximum allowed single tower EIRP, which then becomes an input into the aggregate multi-channel RFI calculation (step 2) below.

2. **Aggregate Multi-Tower RFI Calculation:**
   a. For this step, the aircraft antenna is placed at the critical antenna height for the single tower case determined in step 1.b., for the most restrictive of banking or no-banking conditions as determined in step 1. All surrounding towers (also referred to as Adjacent Towers) are enabled with transmit EIRPs equal to the Maximum Allowed Single Tower EIRP (for the applicable banking or non-banking condition) calculated in step 1c.[8] The propagation loss and received RFI from each surrounding tower is calculated separately, and the RFI contributions from the Central Tower (determined in step 1) and all surrounding towers are then summed power-wise to produce the aggregate multi-tower RFI:
      i. Unlike the Central Tower path loss calculation that uses the 2-Ray model exclusively, the path loss model for each surrounding tower is selected based on its lateral separation distance from the aircraft. The 2-Ray model is used up to a breakpoint distance r_1, where the vertically polarized component is at its minimum magnitude (Brewster angle distance). This is consistent with the definition of the r_1 breakpoint for the FAA propagation model in the FAA's compatibility study methodology and assumptions [1]. Between the r_1 breakpoint and radio horizon R_0, free-space loss (FSL) is used.
      ii. For the purpose of calculating aggregate RFI, the surrounding tower antenna gains for the specified down-tilt are reduced by 1.8 dB[9] from the peak sector gain over

[8] One exception to this rule was in Scenario 1, where the Adjacent Towers were analyzed in two ways – (i) the Adjacent Towers were identical to the Control Tower and (ii) the Adjacent Towers, while being identical to each other, were deployed with a Central Tower that was different from the Adjacent Towers.

[9] Averaging the 3-sector gain pattern used in this study over 360º in azimuth produced an average gain that is 1.8 dB below the peak azimuth gain. If the deployment has fewer than 3 sectors with random sector orientations, the aggregate power reduction is greater: 3.6 dB for 2 sectors and 6.6 dB for 1 sector. This 1.8 dB reduction of the antenna gain below the peak azimuthal value, is appropriate as the aggregate RFI is assumed to come from all azimuths *with equal probability*. The *mean* antenna gain over a 120^0 azimuth sector (with the elevation angle corresponding to boresight) is 1.8 dB below the *peak* gain over the same 120^0 azimuth sector. Only 3-sectored sites were assumed for this aggregate analysis.

azimuth, to reflect the <u>average</u> antenna gain over all possible sector azimuth orientations as viewed from the aircraft. This approach for discounting the peak antenna gain owing to azimuthal selectivity in the case of a 3-sector base station antenna, for a random azimuthal angle of departure, was used in the FAA's compatibility study methodology and assumptions [1].

b. The "**Multi-Tower EIRP Back-off**" is defined as the amount that the Maximum Allowed Single Tower EIRP from step 1 would need to be reduced to comply with the maximum RFI limits of Table 1 with the additional RFI contribution from the surrounding towers. The Multi-Tower EIRP Back-off is applied equally to the Central Tower and all surrounding towers, and is calculated as follows:

$$\text{Multi-Tower\_EIRP\_Back-off (dB)} = RFI_{agg} - RFI_{limit} \quad (4)$$

where:

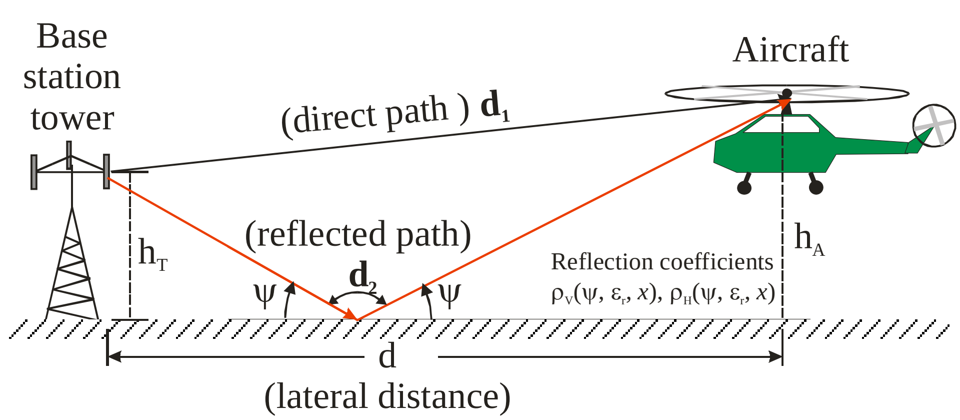
RFI_{agg} ≡ aggregate RFI (dBm) from Central Tower and all surrounding towers determined in step 2a.

RFI_{limit} ≡ maximum received RFI limit as shown in Table 1.

3.1 Detailed Calculation of Propagation Loss and Received RFI from an Individual Tower:

Fig. 3 shows the 2-Ray model geometry for RFI emissions from a single tower toward the aircraft. For cases where FSL propagation is used instead of the 2-Ray model (i.e., surrounding towers where the lateral distance d exceeds the r_1 breakpoint distance), only the direct path d_1 propagation in Fig. 3 is applied.

Fig. 3: 2-Ray Model Geometry for RFI Emissions from One Tower



Referring to Fig. 3, given tower antenna h_T, aircraft antenna height h_A, and lateral separation distance d, then the following path lengths and angles are given by:

$\mathbf{d_1}$ (direct path) $= \sqrt{[d^2 + (h_A - h_T)^2]}$

$\mathbf{d_2}$ (reflected path) $= \sqrt{[d^2 + (h_A + h_T)^2]}$

$\boldsymbol{\psi}$ (2-Ray reflection angle) $= \mathrm{ATAN}[(h_T + h_A)/d]$

For the propagation model used in this study, the base station transmits dual orthogonal linear polarizations, where each orthogonal polarization is rotated 45° (i.e., diagonally oriented) with respect to vertical. The RFI calculation resolves the diagonally polarized transmit signals into their vertically polarized (v-pol) and horizontally polarized (h-pol) vector components. It is assumed that the signals transmitted in each diagonal polarization are mutually uncorrelated and of equal transmit EIRP. Therefore, it is numerically equivalent (and computationally simpler) to calculate the RFI as if all the EIRP were transmitted from only one of the two diagonal polarizations[10].

The detailed RFI calculation steps for an individual tower are described below:

Antenna Models: Note: All terms in linear units unless otherwise indicated.

TX linear polarized antenna has h-pol and v-pol components, with antenna input power split equally between v-pol and h-pol. The TX antenna pattern is modeled to be constant over all azimuth angles[11], but varies over elevation angles. For elevation angles-of-departure corresponding to direct and reflected paths, we define:

$G_{dvTX} \equiv$ direct path TX antenna gain for v-pol, normalized to peak gain

$G_{dhTX} \equiv$ direct path TX antenna gain for h-pol, normalized to peak gain

$G_{rvTX} \equiv$ reflected path TX antenna gain for v-pol, normalized to peak gain

$G_{rhTX} \equiv$ reflected path TX antenna gain for h-pol, normalized to peak gain

RX elliptically polarized antenna is characterized by its gains with respect to v-pol and h-pol transmitted carriers. For elevation angles-of-arrival corresponding to direct and reflected paths, we define:

$G_{dvRX} \equiv$ direct path RX antenna gain for a v-pol transmitted carrier

$G_{dhRX} \equiv$ direct path RX antenna gain for an h-pol transmitted carrier

$G_{rvRX} \equiv$ reflected path RX antenna gain for a v-pol transmitted carrier

$G_{rhRX} \equiv$ reflected path RX antenna gain for an h-pol transmitted carrier

For this analysis, it is assumed that the v-pol direction coincides with the ellipse major axis, and that the h-pol direction coincides with the ellipse minor axis. Then the RX antenna voltage axial ratios for direct and reflected paths are given by:

r_d = direct path voltage axial ratio = $(G_{dvRX} / G_{dhRX})^{1/2}$

r_{refl} = reflected path voltage axial ratio = $(G_{rvRX} / G_{rhRX})^{1/2}$

[10] This yields the same result as transmitting half the total EIRP over each of 2 orthogonal polarizations, where the signals transmitted on each polarization are mutually uncorrelated, so as to combine power-wise at the receive antenna output.

[11] As previously noted, the TX antenna gain for the Central Tower assumes the maximum gain over azimuth is directed toward the aircraft, whereas for the surrounding towers, the TX antenna gain over azimuth is reduced by 1.8 dB from peak azimuth gain to account for a random sector orientation in azimuth toward the aircraft.

To create an elliptical RX antenna polarization, the h-pol received signal voltage is phase shifted by +90° (for RHCP) and vector-added to the v-pol received signal voltage to produce the composite signal voltage at the antenna output. This phase shift step is included in the calculations that follow.

Definition of Terms:

- G_{dv} ≡ $G_{dvTX}\,G_{dvRX}$ (consolidation of terms)
- G_{dh} ≡ $G_{dhTX}\,G_{dhRX}$ (consolidation of terms)
- G_{rv} ≡ $G_{rvTX}\,G_{rvRX}$ (consolidation of terms)
- G_{rh} ≡ $G_{rhTX}\,G_{rhRX}$ (consolidation of terms)
- P ≡ total sector peak EIRP
- L ≡ direct path free space loss = $[\lambda/(4\pi d_1)]^2$, where λ is the carrier wavelength and d_1 = direct path distance shown in Fig. 3
- $\Delta\phi$ ≡ phase difference between received direct and reflected carriers at RX antenna
- ρ_v ≡ v-pol reflection coefficient, $\rho_v = |\rho_v| \exp(j\theta_v)$
- ρ_h ≡ h-pol reflection coefficient, $\rho_h = |\rho_h| \exp(j\theta_h)$
- Δd ≡ ratio of direct path to reflected path distances (<1)
- ω ≡ carrier radian freq. = 2π[f(Hz)]
- $V_d(t)$ ≡ direct path received signal voltage (v + h-pol) at RX antenna output
- $V_r(t)$ ≡ reflected path received signal voltage (v + h-pol) at RX ant. output
- $V_{2ray}(t)$ ≡ combined direct + reflected path signal voltage at RX ant. output
- P_d ≡ direct path mean envelope power at RX antenna output
- P_{2ray} ≡ composite direct + reflected path mean envelope power at RX antenna output

The 2-Ray vertically and horizontally polarized reflection coefficients ρ_v and ρ_h are given by Parsons [2]:

$$\rho_v = \frac{(\varepsilon_r - jx)\sin\psi - \sqrt{[(\varepsilon_r - jx) - \cos^2\psi]}}{(\varepsilon_r - jx)\sin\psi + \sqrt{[(\varepsilon_r - jx) - \cos^2\psi]}}$$

$$\rho_h = \frac{\sin\psi - \sqrt{[(\varepsilon_r - jx) - \cos^2\psi]}}{\sin\psi + \sqrt{[(\varepsilon_r - jx) - \cos^2\psi]}}$$

where $x = \sigma/\omega\varepsilon_0 \quad = 17975\sigma / [f(MHz)]$

For the derivation that follows, it is more convenient to express ρ_v and ρ_h in complex polar form:

$\rho = |\rho| \exp(j\theta)$, where $\theta = \mathrm{ATAN}[\mathbf{Im}\{\rho\} / \mathbf{Re}\{\rho\}]$

Direct & Reflected Path RFI : The following derivation assumes that identical c.w. signals are applied to both the h-pol. and v-pol. TX antenna inputs:

Direct Path (FSL Solution):

Note: for RX antenna h-pol phase shift, $\cos(\omega t + 90^o) = -\sin(\omega t)$.

$$V_d(t) = [PG_{dv} L]^{1/2}\cos(\omega t) - [PG_{dh} L]^{1/2}\sin(\omega t) \qquad (5)$$

$$\boxed{P_d = \lim_{T\to\infty} 1/T \int_0^T V_d^2(t)\, dt = (P\,L/2)\,[G_{dv} + G_{dh}] \qquad (6)}$$

Reflected Path:

$$V_r(t) = [PG_{rv} L]^{1/2}\,\Delta d|\rho_v|\cos(\omega t+\theta_v-\Delta\phi) - [P\,G_{rh} L]^{1/2}\Delta d|\rho_h|\sin(\omega t+\theta_h-\Delta\phi)$$

$$= \cos(\omega t)\{[PL]^{1/2}\,[G_{rv}^{1/2}\Delta d|\rho_v|\cos(\theta_v-\Delta\phi) - G_{rh}^{1/2}\Delta d|\rho_h|\sin(\theta_h-\Delta\phi)]\}$$

$$- \sin(\omega t)\{[PL]^{1/2}\,[G_{rv}^{1/2}\Delta d|\rho_v|\sin(\theta_v-\Delta\phi) + G_{rh}^{1/2}\Delta d|\rho_h|\cos(\theta_h-\Delta\phi)]\} \qquad (7)$$

Direct + Reflected Path (2-Ray Model Solution):

$$V_{2ray}(t) = \cos(\omega t)\{[PL]^{1/2}\,[G_{dv}^{1/2} + G_{rv}^{1/2}\Delta d|\rho_v|\cos(\theta_v-\Delta\phi) - G_{rh}^{1/2}\Delta d|\rho_h|\sin(\theta_h-\Delta\phi)]\}$$

$$- \sin(\omega t)\{[PL]^{1/2}\,[G_{dh}^{1/2} + G_{rv}^{1/2}\Delta d|\rho_v|\sin(\theta_v-\Delta\phi) + G_{rh}^{1/2}\Delta d\rho_h|\cos(\theta_h-\Delta\phi)]\} \quad (8)$$

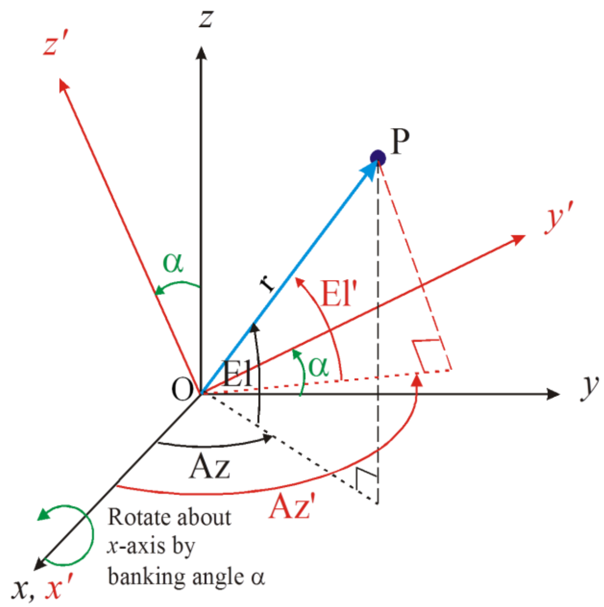
$$\boxed{\begin{aligned} P_{2ray} &= \lim_{T\to\infty} 1/T \int_0^T V_{2ray}^2(t)\, dt \\ &= (PL/2)\{G_{dv} + G_{dh} + G_{rv}\Delta d^2|\rho_v|^2 + G_{rh}\Delta d^2|\rho_h|^2 + 2[G_{rv}\,G_{rh}]^{1/2}\Delta d^2|\rho_v|\,|\rho_h|\,\sin(\theta_v-\theta_h) \\ &+ 2[G_{dv}\,G_{rv}]^{1/2}\Delta d|\rho_v|\,\cos(\theta_v-\Delta\phi) - 2[G_{dv}\,G_{rh}]^{1/2}\Delta d|\rho_h|\,\sin(\theta_h-\Delta\phi) \\ &+ 2[G_{dh}\,G_{rv}]^{1/2}\Delta d|\rho_v|\,\sin(\theta_v-\Delta\phi) + 2[G_{dh}\,G_{rh}]^{1/2}\Delta d|\rho_h|\,\cos(\theta_h-\Delta\phi) \quad \} \qquad (9) \end{aligned}}$$

Received Angle-of-Arrival Correction for Aircraft Banking:

Similar to the TX antenna, the RX antenna gain is modeled to be omni-directional in azimuth but variable over elevation. So for an aircraft in level flight, the received RFI from any given tower does not depend on the tower's azimuth direction relative to the aircraft, but only on the elevation angle-of-arrival (AOA).

When the aircraft is banking, the AOA from the Central Tower and those surrounding towers in the same azimuth direction increase, while the AOA from towers on the opposite side of the aircraft decrease. So for the banking case, the elevation AOA (and hence received RFI level) becomes dependent on the azimuth direction of the tower from the aircraft as well as its elevation. This effect is illustrated in Fig. 4, where the banking is represented by a rotation of coordinates about the *x*-axis by a banking angle denoted α:

Fig. 4: Effect of Banking on Receive Antenna Az/El Coordinates



The banking rotation changes the coordinates of fixed vector <u>OP</u> in Fig. 4 from (Az, El, r) in the original coordinate system to (Az', El', r) in the rotated coordinate system. Conversion of (Az, El, r) to (Az', El', r) is performed using a 3-step approach:

1. Convert non-banked (Az, El, r) spherical antenna coordinates to Cartesian (x, y, z) coordinates.
2. Perform coordinate system rotation about the x-axis by angle α, and determine rotated Cartesian coordinates (x', y', z').
3. Convert rotated Cartesian coordinates (x', y', z') to corresponding rotated antenna coordinates (Az', El', r). From inspection, it is clear that the vector length r is unchanged (that is, r' = r).

Using the above approach, it can be shown that the elevation AOA for the banked case is given by:

$$\text{El'(deg.)} = 90^{o} - \text{ACOS}[\,\sin \text{El} \cos \alpha - \cos \text{El} \sin \text{Az} \sin \alpha\,] \qquad (10)$$

The above elevation angle transformation is used to determine the received RFI contributions from the surrounding towers.

4.0 Example Scenarios

RFI calculations are provided in this section for two example scenarios.

4.1 Scenario Definitions

Some of the parameters determining RFI power at the GPS receiver were common to both scenarios. These are defined below.

1. Base Station Towers:
    a. Tower density D: Scenario dependent
    b. ISD: Scenario dependent
    c. Antenna height h_T: Scenario dependent
    d. Antenna down-tilt: Scenario dependent
    e. Radio horizon radius R_0: ~17 km to ~71 km (dependent on h_A, h_T)
    f. Antenna polarization: 45^0 dual-linear orthogonal pol.[12]
    g. TX antenna pattern: Andrew V65-1 XR_00DT (small cell)
2. Aircraft:
    a. Min. antenna height h_A: 4 m (no banking), 10 m (w/ banking)
    b. Banking angles: 0^o and 25^o
    c. Antenna polarization: Right-hand circular pol.
    d. RX antenna pattern: source: RTCA/DO-301
3. Propagation parameters:
    a. RFI carrier frequency: 1531 MHz
    b. 2-Ray dielectric const.: $\varepsilon_r = 7$ (ground)
    c. 2-Ray conductivity: $\sigma = 0.15$ (ground)
    d. 2-Ray/FSL breakpt. r_1: 22.5 m to 437 m (dependent on h_A, h_T)

4.1.1 Example 1: 2.4 base stations/sq. km, different deployment configurations

Example 1 comprises a geographically uniform deployment of base stations with 2.4 base stations/square km, which was the density suggested by the FAA and is a 4X increase in density from the macrocell density of 0.6 base stations/square km used in earlier FAA and RTCA analyses. With an arrangement of the base stations in hexagonal cells, the above deployment results in a uniform inter-site distance (ISD) of 693 m. This density was suitable for urban macrocells; therefore, the scenario was analyzed with a variety of (net 18) macrocell type deployment configurations,[13] referred to as use cases. Both the base station power limit considering a single site, and the power increase due to aggregate RFI (delta-RFI) were examined.

[12] Carriers transmitted on the 2 orthogonal polarizations are assumed to be uncorrelated, so they are power-additive at the receive antenna output.

[13] A "deployment configuration" refers to a particular set of the following parameters related to a given base station [antenna pattern, antenna height, antenna polarization, EIRP].

Furthermore, the aggregate RFI effect was analyzed in two ways while keeping the ISD fixed at 693 m: (i) the Adjacent Towers were identical to the Central Tower and (ii) the Adjacent Towers, while being identical to each other, were deployed with a Central Tower that was different from the Adjacent Towers. The motivation of this analysis was to determine if a low EIRP Central Tower would encounter greater delta-RFI when surrounded by higher power Adjacent Towers.

The network was assumed to extend to the radio horizon.

4.1.2 Example 2: 6.2 base stations/sq. km [ITU-R M.2292]

Example 2 comprises a denser, small cell deployment conforming to ITU-R M.2292. It is also laid out in hexagonal cells but with an ISD of 433 m (6.2 base stations/square km).

Unlike Example 1, the small cell deployment configuration was kept fixed at the ITU recommendation as these deployments are typically uniform with little variation in site height, antenna type and downtilt angles.[14]

As in Example 1 for the macrocell networks, here also the network was assumed to extend to the radio horizon, although this is almost impossible for a small cell network. The practical upper limit for the coverage of such networks is a circular area with a radius of 2.5 km relative to the Central Tower. Results for this constrained coverage case are also provided.

5.0 Results and Discussion

5.1 Example 1

The results for Example 1 are provided below.

[14] The case of increasing the antenna height from 6 m to 9 m (same antenna and downtilt) was examined but produced very similar results as the 6 m case.

Down Link Center frequency: 1531 MHz, Carrier BW: 10 MHz (BS density: 2.4 BS/Sq.Km)									
Use Case No	Base Station Antenna height (m)	Base Station Antenna down tilt (deg)	Helicopter bank angle (deg)	GPS Rx antenna height at Max EIRP (m)	Max Tx EIRP (Single Tower) for a given Threshold (dBW)	EIRP backoff required considering Multiple Towers (Same as Control Tower) (dB)	Max Tx EIRP (Multiple Towers) for a given Threshold (dBW)	EIRP backoff with use case # 14 as Control Tower and with indicated type of Adjacent Multiple Towers (all same) (dB)	Max Tx EIRP for Use case # 14 for indicated type of Adjacent Towers (dBW)
1	4.5	0	25	10	13.5	0.30	13.20	0.35	12.15
2		2	25	10	13.6	0.30	13.30	0.34	12.16
3	10	0	0	5	14.1	0.50	13.60	0.58	11.93
4		2	0	5	13.5	0.40	13.10	0.49	12.02
5	15	0	0	4	14.5	0.60	13.90	0.69	11.82
6		2	0	4	13.5	0.50	13.00	0.53	11.97
7		4	0	4	12.7	0.40	12.30	0.41	12.10
8	19	0	0	8	15.0	0.70	14.30	0.79	11.72
9		2	0	6	13.9	0.50	13.40	0.59	11.91
10		4	0	4	12.8	0.40	12.40	0.42	12.08
11	25	0	25	23	15.0	0.49	14.51	**0.55**	11.96
12		2	0	14	14.2	0.57	13.60	0.67	11.84
13		4	0	11	13.2	0.44	12.80	0.50	12.01
14		6	0	11	12.5	0.34	12.17	0.34	12.17
15	75	0	25	74	15.1	0.57	14.55	0.61	11.90
16		2	0	64	14.3	0.67	13.62	0.85	11.65
17		4	0	61	13.3	0.52	12.81	0.65	11.85
18		6	0	61	12.6	0.39	12.22	0.50	12.00

It is clear from the results, spanning a large multiplicity of use case, that the maximum delta-RFI is 0.85 dB.[15] This parameter cannot be tied to a single base station configuration (use case) if the market has a variety of base station configurations. Therefore, the most conservative approach is to apply a base station EIRP backoff corresponding to the maximum delta-RFI.

5.2 Example 2

The results for Example 2 are provided below.

Down Link Center frequency: 1531 MHz, Carrier BW: 10 MHz (BS density: 6.2 BS/Sq.Km)									
Use Case No	Base Station Antenna height (m)	Base Station Antenna down tilt (deg)	Helicopter bank angle (deg)	GPS Rx antenna height at Max EIRP (m)	Max Tx EIRP (Single Tower) for a given Threshold (dBW)	EIRP backoff required considering Multiple Towers (Same as Control Tower) Service Coverage up to Radio Horizon (dB)	Max Tx EIRP (Multiple Towers) for a given Threshold (dBW) Service Coverage up to radio Hoizon	EIRP backoff required considering Multiple Towers (Same as Control Tower) Service Coverage up to 2.5 km radius (dB)	Max Tx EIRP (Multiple Towers) for a given Threshold (dBW) Service Coverage up to 2.5 km radius (dBW)
1	6	0	25	10	13.60	0.857	12.70	0.442	13.16
2	9	0	25	10	13.80	0.904	12.90	0.459	13.34

[15] The 0.9 dB delta-RFI occurs when the Central Tower corresponds to use case #14 and the Adjacent Towers correspond to use case #16.

This example also shows that, in the case where the network extends to the radio horizon, the delta-RFI is approximately 0.9 dB. In a more likely scenario of the coverage being less than a circle of 5 km diameter, the delta-RFI is approximately 0.4 dB.

6.0 Implementation

The analytical process described above will ensure that Ligado's terrestrial base station deployments produce power levels, both individually or in the aggregate, that are fully compliant with the standards adopted (with applicable safety margins) by the FAA and RTCA for certified aviation receivers.

6.1 Inter-Site Distance and Aggregate Effects

As explained in Section 3, for each individual cell site the first step establishes the maximum power level for that cell site based on the transmit antenna height, pattern and down-tilt that complies with the FAA and RTCA standards for a helicopter operating at a lateral distance of 250' and a worst-case (*i.e.*, lowest path loss) height and bank angle.

As detailed in Section 5.2, an additional power reduction of 0.9 dB would be made to each cell site's operating parameters calculated above to account for the *maximum potential contribution* of power from adjacent sites to the aggregate power received by the certified aviation GPS antenna. This 0.9 dB power reduction assumes an inter-site distance that is never less than 433 meters, a constraint which Ligado to which Ligado would adhere in its network design and deployment.

6.2 Conformance with Part 77 Operations

In order to ensure that Ligado's operations will not interfere with aircraft IFR operations on approach and departure routes at airports and heliports and other navigable airspace governed by Part 77, Ligado will not locate sites where any portion of the standoff cylinder would pierce the plane of a defined obstacle clearance surface. This will ensure that Ligado's EIRP will be within conformance limits at all points on, and above, the OCS.

Figure 5: Part 77 Conformance

Deriving the maximum cell site power based both on the contributions from the primary site and surrounding sites, will ensure that Ligado's operations are fully consistent with all applicable RTCA and FAA standards, including the required safety margins.

References:

[1] FAA Document "FAA GPS Adjacent-Band Compatibility Study Methodology and Assumptions" (RTCA Paper No. 025-15/SC159-1025), October 3, 2014.

[2] Parsons, J.D., *The Mobile Radio Propagation Channel* (2ed.), Wiley & Sons, Chichester UK, 2000.

[3] RTCA DO-229D, *Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment*, 2006.

[4] Report ITU-R M.2292-0, "Characteristics of terrestrial IMT-Advanced systems for frequency sharing/interference analysis, 12/2013.

Appendix 1

Derivation of Small Cell Inter-Station Distance (ISD) from ITU Recommendation [4]

The subject ITU recommendation provides the following table of deployment parameters.

TABLE 3

Deployment-related parameters for bands between 1 and 3 GHz

	Macro rural	**Macro suburban**	**Macro urban**	**Small cell outdoor/ Micro urban**	**Small cell indoor/Indoor urban**
Base station characteristics/Cell structure					
Cell radius/ Deployment density (for bands between 1 and 2 GHz)	> 3 km (typical figure to be used in sharing studies 5 km)	0.5-3 km (typical figure to be used in sharing studies 1 km)	0.25-1 km (typical figure to be used in sharing studies 0.5 km)	1-3 per urban macro cell <1 per suburban macro site	Depending on indoor coverage/ capacity demand
Cell radius/ Deployment density (for bands between 2 and 3 GHz)	> 2 km (typical figure to be used in sharing studies 4 km)	0.4-2.5 km (typical figure to be used in sharing studies 0.8 km)	0.2-0.8 km (typical figure to be used in sharing studies 0.4 km)	1-3 per urban macro cell <1 per suburban macro site	Depending on indoor coverage/ capacity demand
Antenna height	30 m	30 m (1-2 GHz) 25 m (2-3 GHz)	25 m (1-2 GHz) 20 m (2-3 GHz)	6 m	3 m

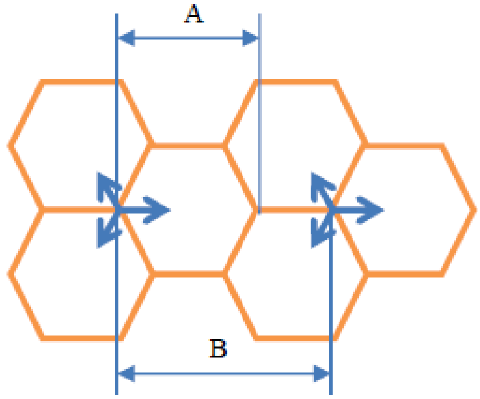
We assume that there will be 3 Small Cells per 1 Macro Urban cell, which has a cell radius (A) =0.5 km, and a derived Cell density of **2.2 BS/Sq. km.**, as shown in Table 3.

We then derive a small cell base station density of **6.02 base stations/square km**, leading to an **ISD of 433 m** as follows.

The 6.2 cells/square km base station density leads to an **ISD of 433 m**, as shown below.

FIGURE 1

Macro cell geometry



- Let "r" = length of each hexagon (i.e., small cell) side.
- Then each cell is made up of 6 equilateral triangles of length "r" on each side.
- The area of each equilateral triangle = 1/2 bh = 1/2 * r * sqrt(3) /2 * r = sqrt(3) / 4 * r^2.
- So the area of each cell = 3 * sqrt(3) /2 * r^2.
- Let D be the cell density (cells / sq. km.). So the area served by 1 tower = 1/D.
- Solving for r in terms of D: r = sqrt[2 / (3 * sqrt(3) * D)]
- ISD in Fig. 1 = sqrt(3)*r: So ISD = sqrt[2 /(sqrt(3)* D)].

EXAMPLE:	D:	6.2	cells per sq. km. (1 tower per cell)
Solution:	r:	0.25	km
	ISD:	0.43	km

Appendix – 2

TX Antenna Specifications

Note: The Commscope V65S-1XR antenna is specified for small cell deployments in the 1695 – 2690 MHz band. To Ligado's knowledge, there are no small cell antennas that are commercially available for the 1526-1536 MHz band as of yet. However, there would be no material difference in the horizontal and vertical gain patterns of the same small cell antenna modified for use in the 1526-1536 spectrum band.

This antenna was selected because it has a broad vertical and horizontal beamwidth. These attributes produce higher levels of RFI in the analytical models that were utilized in the analyses in the document than other antennas which were evaluated. This is consistent with the overall conservatism of these analyses.

Product Specifications

COMMSCOPE®

V65S-1XR

Single Band MetroCell Antenna, 1695–2690 MHz, 65° horizontal beamwidth, internal RET with manual override.

- Provides a future-ready antenna solution with flexibility to reassign antenna, for example GSM 1800 service to 2.6GHz LTE at a later date
- Employs state-of-the-art ultra wideband technology providing excellent RF performance in all bands
- RF technology flexible—suitable for LTE, UMTS, CDMA, GSM, AWS, WiMAX, and other applications from 1.7–2.7 GHz
- Excellent RF pattern control over the full operating band and tilt range for desired coverage and interference containment
- Remote beam tilt management is an optional feature using Andrew's Teletilt® system
- Integrated Internal Remote Electrical Tilt (RET), with independent control of electrical tilt with manual override on all arrays

Electrical Specifications

<table>
<tr><th>Frequency Band, MHz</th><th>1695–1880</th><th>1850–1990</th><th>1920–2200</th><th>2300–2500</th><th>2500–2690</th></tr>
<tr><td>Gain, dBi</td><td>13.4</td><td>13.7</td><td>13.9</td><td>14.6</td><td>14.5</td></tr>
<tr><td>Beamwidth, Horizontal, degrees</td><td>70</td><td>69</td><td>69</td><td>63</td><td>61</td></tr>
<tr><td>Beamwidth, Vertical, degrees</td><td>18.6</td><td>17.2</td><td>16.4</td><td>14.4</td><td>13.7</td></tr>
<tr><td>Beam Tilt, degrees</td><td>0–20</td><td>0–20</td><td>0–20</td><td>0–20</td><td>0–20</td></tr>
<tr><td>USLS (First Lobe), dB</td><td>20</td><td>21</td><td>26</td><td>19</td><td>20</td></tr>
<tr><td>Front-to-Back Ratio at 180°, dB</td><td>29</td><td>27</td><td>28</td><td>29</td><td>27</td></tr>
<tr><td>Isolation, dB</td><td>25</td><td>25</td><td>25</td><td>25</td><td>25</td></tr>
<tr><td>VSWR | Return Loss, dB</td><td>1.5 | 14.0</td><td>1.5 | 14.0</td><td>1.5 | 14.0</td><td>1.5 | 14.0</td><td>1.5 | 14.0</td></tr>
<tr><td>PIM, 3rd Order, 2 x 20 W, dBc</td><td>-153</td><td>-153</td><td>-153</td><td>-153</td><td>-153</td></tr>
<tr><td>Input Power per Port, maximum, watts</td><td>300</td><td>300</td><td>300</td><td>250</td><td>250</td></tr>
<tr><td>Polarization</td><td>±45°</td><td>±45°</td><td>±45°</td><td>±45°</td><td>±45°</td></tr>
<tr><td>Impedance</td><td>50 ohm</td><td>50 ohm</td><td>50 ohm</td><td>50 ohm</td><td>50 ohm</td></tr>
</table>

Electrical Specifications, BASTA*

<table>
<tr><th>Frequency Band, MHz</th><th>1695–1880</th><th>1850–1990</th><th>1920–2200</th><th>2300–2500</th><th>2500–2690</th></tr>
<tr><td>Gain by all Beam Tilts, average, dBi</td><td>13.1</td><td>13.4</td><td>13.5</td><td>14.0</td><td>14.1</td></tr>
<tr><td>Gain by all Beam Tilts Tolerance, dB</td><td>±0.5</td><td>±0.4</td><td>±0.6</td><td>±0.7</td><td>±0.6</td></tr>
<tr><td></td><td>0 ° | 13.0</td><td>0 ° | 13.5</td><td>0 ° | 13.5</td><td>0 ° | 14.1</td><td>0 ° | 14.2</td></tr>
<tr><td>Gain by Beam Tilt, average, dBi</td><td>10 ° | 13.2</td><td>10 ° | 13.5</td><td>10 ° | 13.5</td><td>10 ° | 14.2</td><td>10 ° | 14.2</td></tr>
<tr><td></td><td>20 ° | 13.1</td><td>20 ° | 13.3</td><td>20 ° | 13.3</td><td>20 ° | 13.3</td><td>20 ° | 13.4</td></tr>
<tr><td>Beamwidth, Horizontal Tolerance, degrees</td><td>±3.3</td><td>±2.8</td><td>±3.7</td><td>±4</td><td>±4.8</td></tr>
<tr><td>Beamwidth, Vertical Tolerance, degrees</td><td>±1.5</td><td>±0.9</td><td>±1.3</td><td>±1.1</td><td>±1.1</td></tr>
<tr><td>USLS, beampeak to 20° above beampeak, dB</td><td>13</td><td>17</td><td>17</td><td>17</td><td>20</td></tr>
<tr><td>Front-to-Back Total Power at 180° ± 30°, dB</td><td>24</td><td>24</td><td>24</td><td>25</td><td>23</td></tr>
<tr><td>CPR at Boresight, dB</td><td>18</td><td>20</td><td>20</td><td>16</td><td>15</td></tr>
<tr><td>CPR at Sector, dB</td><td>15</td><td>14</td><td>13</td><td>4</td><td>7</td></tr>
</table>

* CommScope® supports NGMN recommendations on Base Station Antenna Standards (BASTA). To learn more about the benefits of BASTA, download the whitepaper Time to Raise the Bar on BSAs.

General Specifications

Antenna Type	Metro Cell

COMMSCOPE®

V65S-1XR

Single Band MetroCell Antenna, 1695–2690 MHz, 65° horizontal beamwidth, internal RET with manual override.

- Provides a future-ready antenna solution with flexibility to reassign antenna, for example GSM 1800 service to 2.6GHz LTE at a later date
- Employs state-of-the-art ultra wideband technology providing excellent RF performance in all bands
- RF technology flexible—suitable for LTE, UMTS, CDMA, GSM, AWS, WiMAX, and other applications from 1.7–2.7 GHz
- Excellent RF pattern control over the full operating band and tilt range for desired coverage and interference containment
- Remote beam tilt management is an optional feature using Andrew's Teletilt® system
- Integrated Internal Remote Electrical Tilt (RET), with independent control of electrical tilt with manual override on all arrays

Electrical Specifications

Frequency Band, MHz	1695–1880	1850–1990	1920–2200	2300–2500	2500–2690
Gain, dBi	13.4	13.7	13.9	14.6	14.5
Beamwidth, Horizontal, degrees	70	69	69	63	61
Beamwidth, Vertical, degrees	18.6	17.2	16.4	14.4	13.7
Beam Tilt, degrees	0–20	0–20	0–20	0–20	0–20
USLS (First Lobe), dB	20	21	26	19	20
Front-to-Back Ratio at 180°, dB	29	27	28	29	27
Isolation, dB	25	25	25	25	25
VSWR | Return Loss, dB	1.5 | 14.0	1.5 | 14.0	1.5 | 14.0	1.5 | 14.0	1.5 | 14.0
PIM, 3rd Order, 2 x 20 W, dBc	-153	-153	-153	-153	-153
Input Power per Port, maximum, watts	300	300	300	250	250
Polarization	±45°	±45°	±45°	±45°	±45°
Impedance	50 ohm	50 ohm	50 ohm	50 ohm	50 ohm

Electrical Specifications, BASTA*

Frequency Band, MHz	1695–1880	1850–1990	1920–2200	2300–2500	2500–2690
Gain by all Beam Tilts, average, dBi	13.1	13.4	13.5	14.0	14.1
Gain by all Beam Tilts Tolerance, dB	±0.5	±0.4	±0.6	±0.7	±0.6
	0 ° | 13.0	0 ° | 13.5	0 ° | 13.5	0 ° | 14.1	0 ° | 14.2
Gain by Beam Tilt, average, dBi	10 ° | 13.2	10 ° | 13.5	10 ° | 13.5	10 ° | 14.2	10 ° | 14.2
	20 ° | 13.1	20 ° | 13.3	20 ° | 13.3	20 ° | 13.3	20 ° | 13.4
Beamwidth, Horizontal Tolerance, degrees	±3.3	±2.8	±3.7	±4	±4.8
Beamwidth, Vertical Tolerance, degrees	±1.5	±0.9	±1.3	±1.1	±1.1
USLS, beampeak to 20° above beampeak, dB	13	17	17	17	20
Front-to-Back Total Power at 180° ± 30°, dB	24	24	24	25	23
CPR at Boresight, dB	18	20	20	16	15
CPR at Sector, dB	15	14	13	4	7

* CommScope® supports NGMN recommendations on Base Station Antenna Standards (BASTA). To learn more about the benefits of BASTA, download the whitepaper Time to Raise the Bar on BSAs.

General Specifications

Antenna Type	Metro Cell

Product Specifications

COMMSCOPE®

V65S-1XR

Band	Single band
Brand	DualPol®
Operating Frequency Band	1695 – 2690 MHz
Performance Note	Outdoor usage

Mechanical Specifications

Color	Light gray
Lightning Protection	dc Ground
Radiator Material	Low loss circuit board
Radome Material	PVC, UV resistant
Reflector Material	Aluminum
RF Connector Interface	4.1-9.5 DIN Female
RF Connector Location	Bottom
RF Connector Quantity, total	2
Wind Loading, frontal	118.0 N @ 150 km/h 26.5 lbf @ 150 km/h
Wind Loading, lateral	48.0 N @ 150 km/h 10.8 lbf @ 150 km/h
Wind Loading, rear	151.0 N @ 150 km/h 33.9 lbf @ 150 km/h
Wind Speed, maximum	241 km/h | 150 mph

Dimensions

Depth	105.0 mm | 4.1 in
Length	600.0 mm | 23.6 in
Width	170.0 mm | 6.7 in
Net Weight, without mounting kit	3.8 kg | 8.4 lb

Remote Electrical Tilt (RET) Information

Input Voltage	10–30 Vdc
Power Consumption, idle state, maximum	2.0 W
Power Consumption, normal conditions, maximum	13.0 W
Protocol	3GPP/AISG 2.0 (Single RET)
RET Interface	8-pin DIN Female | 8-pin DIN Male
RET Interface, quantity	1 female | 1 male

Packed Dimensions

Depth	212.0 mm | 8.3 in
Length	726.0 mm | 28.6 in
Width	302.0 mm | 11.9 in
Shipping Weight	8.9 kg | 19.6 lb

Regulatory Compliance/Certifications

Agency	Classification
RoHS 2011/65/EU	Compliant by Exemption
China RoHS SJ/T 11364-2006	Above Maximum Concentration Value (MCV)

Product Specifications

COMMSCOPE®

V65S-1XR

ISO 9001:2008 — Designed, manufactured and/or distributed under this quality management system

Included Products

DB390 — Pipe Mounting Kit for 2.4 - 4.5 in (60 - 115 mm) OD round members. Use for narrow panel antennas. Includes two pipe mounts.

DB5098 — Downtilt Mounting Kit for 2.4 - 4.5 in (60 - 115 mm) OD round members

* Footnotes

Performance Note	Severe environmental conditions may degrade optimum performance

Antenna Pattern

Legend

Description	Port	Frequency	Tilt	Cut	Color
Dual Polarization	Port 1 +45	1695	0	A	
Dual Polarization	Port 1 +45	1695	0	V