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**Source:** LightSquared  
**Title** Preliminary results on Overload Characteristics of GPS Receivers in Proximity to LightSquared's L-band Terrestrial Base Stations (BTS) and User Equipment (UE)  
**Agenda Item:** 5.1  
**Document for:** Discussion and Informative

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## 1 Executive Summary

This interim report documents progress on a study undertaken by LightSquared on the overload vulnerability of GPS receivers in proximity to base stations transmitting in L-band (3GPP Band 24). Future reports will document the results of investigations into overload caused by proximate UE's. A field trial was undertaken by LightSquared to test the operational behaviour of cell-phones equipped with GPS receivers in an open parking lot with some tree shadowing. The criterion of GPS service failure was defined to be the point where either the number of satellites tracked simultaneously fell below 4, or a positioning application on the UE declared that it was switching from using GPS to cellular triangulation. Based on this criterion and LightSquared's deployment plans regarding spectrum occupancy and base station EIRP, it was concluded (from analytical/geometric link calculation) that, for one (1) out of the three (3) phones tested, the maximum exclusion zone (where GPS service would be affected as defined above) would be approximately 20m around the base of the tower. For two (2) phones, there were no exclusion zones at all. Interpreting the outdoor test results with a cellular planning tool, incorporating market specific morphologies, suggested that (for the one phone) the exclusion zone would be 1.1 – 2.5 % of the coverage area. Owing to the small sample size (3), no definitive conclusion can be drawn at this stage about the generality of this trend. LightSquared intends to test at least 10 more devices, both in the field and in a certified test laboratory (AT4 Wireless). The lab tests are expected to offer more granular insight on the performance of various parameters of the GPS engine, at different levels of adjacent band interference and desired signal strength. The results of these tests will be reported in subsequent reports. In addition to the work on mobile GPS receivers, this document also reports on the work done by LightSquared over the past several years to analyze the overload effect of L-band base stations antennas on proximate, timing unit GPS antennas. A GPS antenna preselector, sufficient to allow deployments as close as 3 m, was specified and caused by LightSquared to be developed and made commercially available by more than one GPS timing unit vendor. The new, robust GPS antenna has been independently tested and approved for co-site deployment by one major cellular infrastructure vendor.

## 2 Introduction

The L-band work item in RAN-4, as defined in the Scope of the Technical Report (TR), was deemed completed in the Xian Plenary meeting [1,2,3] except for one remaining item related to potential GPS interference [4] where it was stated:

*A study will be initiated on the blocking vulnerability of legacy mobile GPS receivers, wherein LightSquared will provide RAN4 with measurement data and conclusions from a test campaign it is currently undertaking. This is expected to take 2 – 3 months. Support may be required from device-supplier members to supply devices and device data. The L-Band WI TR 36.813 will be kept open to enable the study to be completed. All the current CRs should be technically endorsed.*

Pursuant to this requirement, LightSquared is filing this document as an interim progress report. Additionally, based on inputs from some RAN-4 members, LightSquared is voluntarily increasing the scope of the study beyond *mobile GPS receivers* to include *fixed timing units*, such as those used by CMRS operators for deriving network timing.

This work started years before the study request was made by 3GPP. The initial focus was on timing units, as LightSquared was specifically obligated by the ATC Order to “coordinate with CMRS operators” in deploying its base stations. The work on analyzing mobile GPS receivers (built into cellphones) with respect to overload potential (where no specific obligation exists as part of LightSquared ATC license) is more recent but also started proactively by LightSquared well before the 3GPP request. Owing to the more recent origin of the cellphone GPS work, results are only available for a small sample (3) of devices. It is planned to test many more mobile devices in the coming months.

Although some preliminary analytical work has been performed on UE – GPS overload vulnerability, the results have not been reported here as they need to be backed up with experimental data.

## Report Organization

Section 2.0 describes in-house field testing of cellphone GPS receivers and the preliminary conclusions thereof from the currently limited sample of devices.

Section 3.0 describes the test plan for testing cellphone GPS receivers by a commercial testing laboratory (AT4 Wireless).

Section 4.0 describes the work undertaken by LightSquared to evaluate potential overload interference that might be caused to fixed (timing unit) GPS receivers by proximate L-band base stations, and the mitigations thereof that have been developed.

## 2.1. L-band ATC Frequency Plans GPS

Figure 1 describes the LightSquared's present ATC frequency plans by deployment phase. These plans are subject to coordination with other satellite operators and may change in the future. However, a change in the frequency plans would not change LightSquared's obligations to protect other services in adjacent bands, such as GPS.



\*Only upper 5-MHz LTE carrier is used in Phase-0. Both 5-MHz carriers are used in Phase-1

Figure 1: Lightsquared Downlink LTE L-Band and GPS Band

## 3 Field Testing of Cell-phone GPS Receivers

### 3.1 Test Objectives

Outdoor tests were conducted by LightSquared to test the operational behaviour of three (3) static cellphone GPS receivers when subjected to adjacent channel signals, of different power levels, corresponding to the frequency plans shown in Figure 1. The cell-phones were located in an open parking lot with a clear view of the sky from some look angles, tree shadowing from some angles and a two story building blockage in others. The location could be categorized as a typical suburban location.

Applications running on the phones were used to determine the following information about the GPS receiver. Not all parameters were available on all phones.

1. GPS position in lat/long coordinates
2. Position on Google map
3. Number of satellites being tracked
4. Reported position measurement accuracy
5. RSSI (received GPS signal strength)
6. Whether GPS was being used in position determination or whether the latter was based on cellular triangulation

While logs were kept of all of the above parameters, the criterion used to decide whether GPS had been degraded as a service was:

Either

(A) when less than 4 satellites could be tracked simultaneously as per parameter 3

Or

(B) the application declared that a GPS signal of sufficient quality was unavailable and it was switching to cellular triangulation as per parameter 6

Whichever occurred earlier.

Unfortunately, a common criterion could not be used for all phones as the same applications were not available on all phones.

It was observed that the above events (A and B) usually coincided with the position error (parameter 4) increasing above 47m. It is noteworthy that exactly the same application behaviour could be induced by taking the phone from outdoor to deep inside a building.

### 3.2 Test Setup

The test set up is shown in Figure 2. The objective of the test was to create a known power flux density (PFD) at the location of the cellphone, so that the PFD could be mapped to a received power level in the phone (assuming a 0 dBi antenna gain). This was done by means of a calibrated receive antenna connected to a spectrum analyzer. The characteristics of the transmit antenna and its calibration are irrelevant to the present testing approach.

The LTE signals were emulated by noise modulated broadband signals of the same bandwidth as LTE signals. A key challenge was to ensure that the OOB of the signals sources do not degrade the sensitivity of the GPS receiver. For this, highly frequency-selective, custom filters, tuned to the ATC channels (originally developed as prototype, L-band BTS filters) were used. It is noteworthy that without such filters, it would be impossible to conduct meaningful overload sensitivity tests.

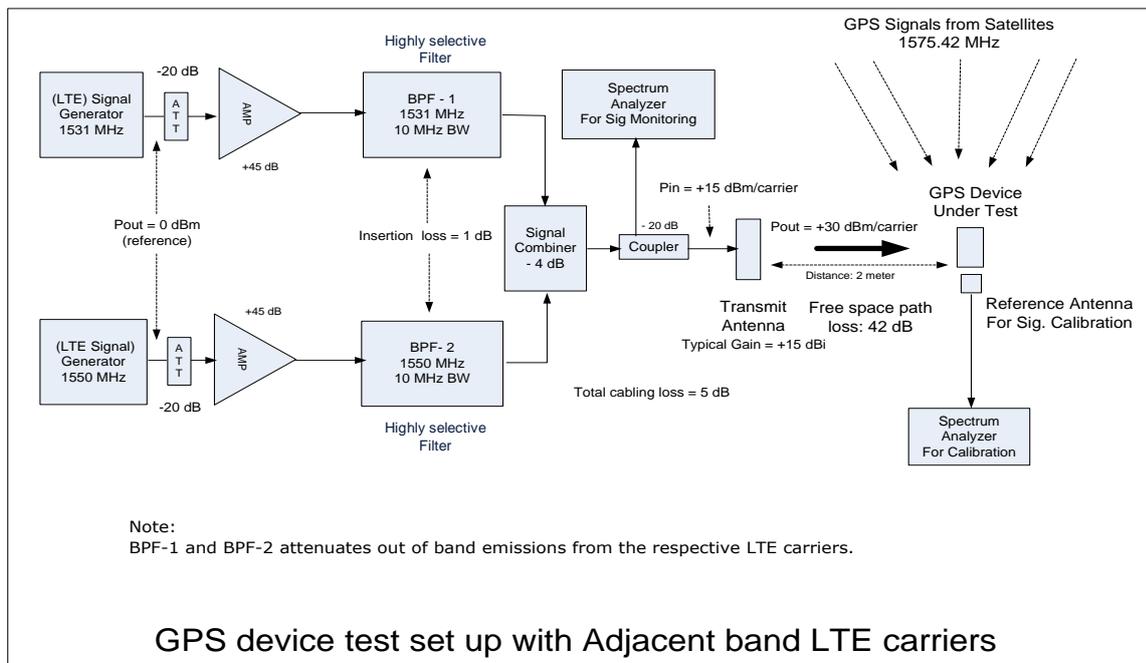


Figure 2: Outdoor Measurement Test Set Up

### 3.3 Results

The results are summarized in Table 1.

Table 1 Per Carrier LTE Power Thresholds for GPS Receivers

Cell Phone GPS Test Results (Interferer Threshold Level at which device switches to AGPS)			
	One 5MHz carrier @ 1552.5MHz	One 10MHz carrier @ 1550.5MHz	Two 10MHz carriers @ 1550.5MHz & 1531MHz
Device 1	-15dBm	-16dBm	-17dBm
Device 2	-29dBm	-32dBm	-34dBm
Device 3	>-10dBm	>-10dBm	>-10dBm

#### 3.3.1 Results Interpretation

While the overload threshold level is interesting, it provides no information on how LightSquared’s deployment plans will affect existing GPS services. The most appropriate performance metric is considered to be the following:

*What percentage reduction of the currently available GPS service area would be caused by deployment of LightSquared’s planned L-band network?*

In order to predict the latter, given an overload threshold level, two alternative approaches were used:

##### 3.3.1.1 Analytical Method

Analytical calculations have been made, using the planned deployment parameters, to predict the zone around the foot of a 30 ft tower where the given threshold level would be exceeded. The actual base station antenna pattern was used to predict propagation in the “underbelly” of the antenna. The pattern is shown in Figure 3. It is acknowledged that, close to the base of the tower, owing to multipath clutter, it may not be feasible to achieve the discrimination promised in Figure 3, which was recorded in an anechoic chamber. Therefore the maximum discrimination was capped at a value of 20 dB. To validate the 20 dB value, an independent trial was conducted to measure high elevation angle discrimination with a sample L-band base station antenna. This is reported in Appendix 1.

The following parameters were used in the analysis.

- Base Station Antenna height: 30 meters
- Antenna pattern (elevation) : as shown in Figure 3
- Device antenna gain towards Base station antenna: -3 dBi
- Body blockage loss: 5 dB
- eNodeB Tx EIRP: 35 dBW (Two carriers, MIMO configuration)
- Propagation model used: Walfisch Ikegami line of sight (WI LOS)
- Horizontal distance: 10 meter to 1 Km.
- Tx Antenna gain towards device (Antenna discrimination): Variable based on distance. Capped at -20 dB from direction of maximum gain due to possible multipath scattering.

The signal level on the ground was calculated for varying separation distances from the base of the tower. The results are shown in Figure 4. An example link calculation for a specific distance (100 m) is shown below.

Link Budget (Handheld device)			
Parameters	Value	Unit	Note
eNodeB antenna elevation (Hb)	30	Meter	Nominal
Device elevation (Ht)	1.5	Meter	Nominal
Device horizontal distance from eNodeB (H)	100	Meter	Variable
eNodeB Antenna Discrimination towards device	-18.5	dB	Calculated for horizontal dist. (Capped at -20 dB)
Device antenna gain towards eNodeB Antenna	-3	dBi	Assume-Fixed
Blocking loss (average)	-5	dB	local clutter, body etc.
eNodeB EIRP	32.0	dBW	Per carrier
Slant path Loss	81	dB	WI LOS - Calculated
Rx Signal level by device	-45	dBm	Per carrier

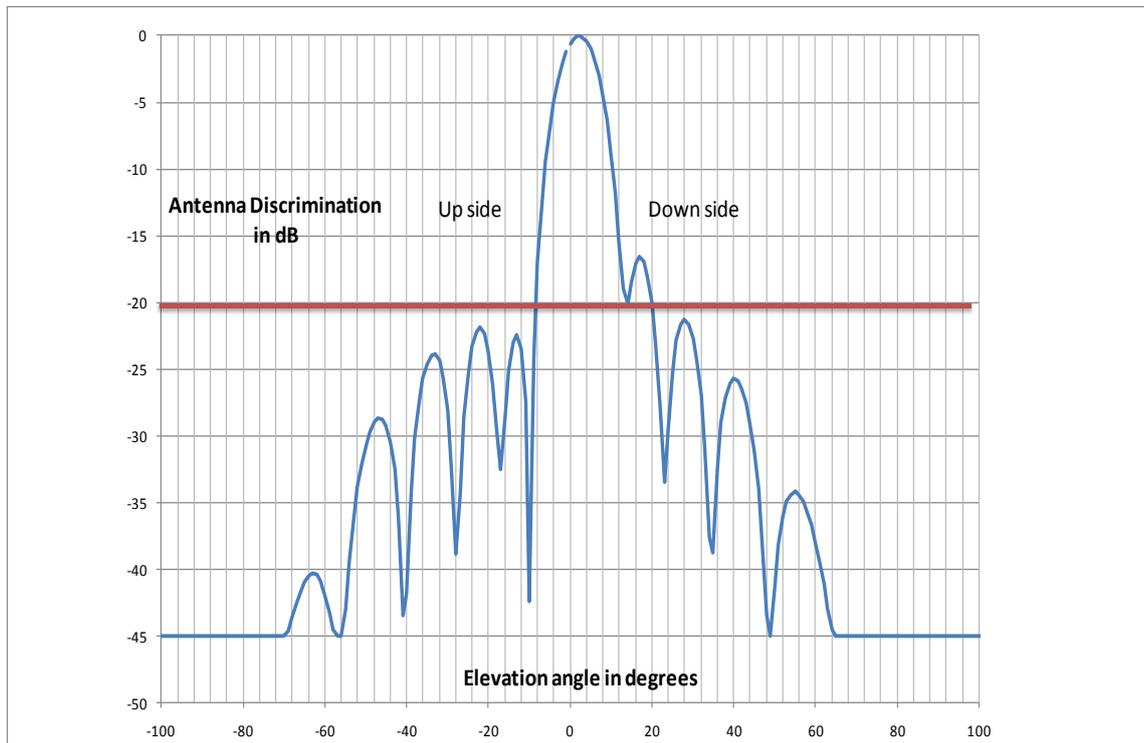


Figure 3: L-band base station antenna elevation pattern

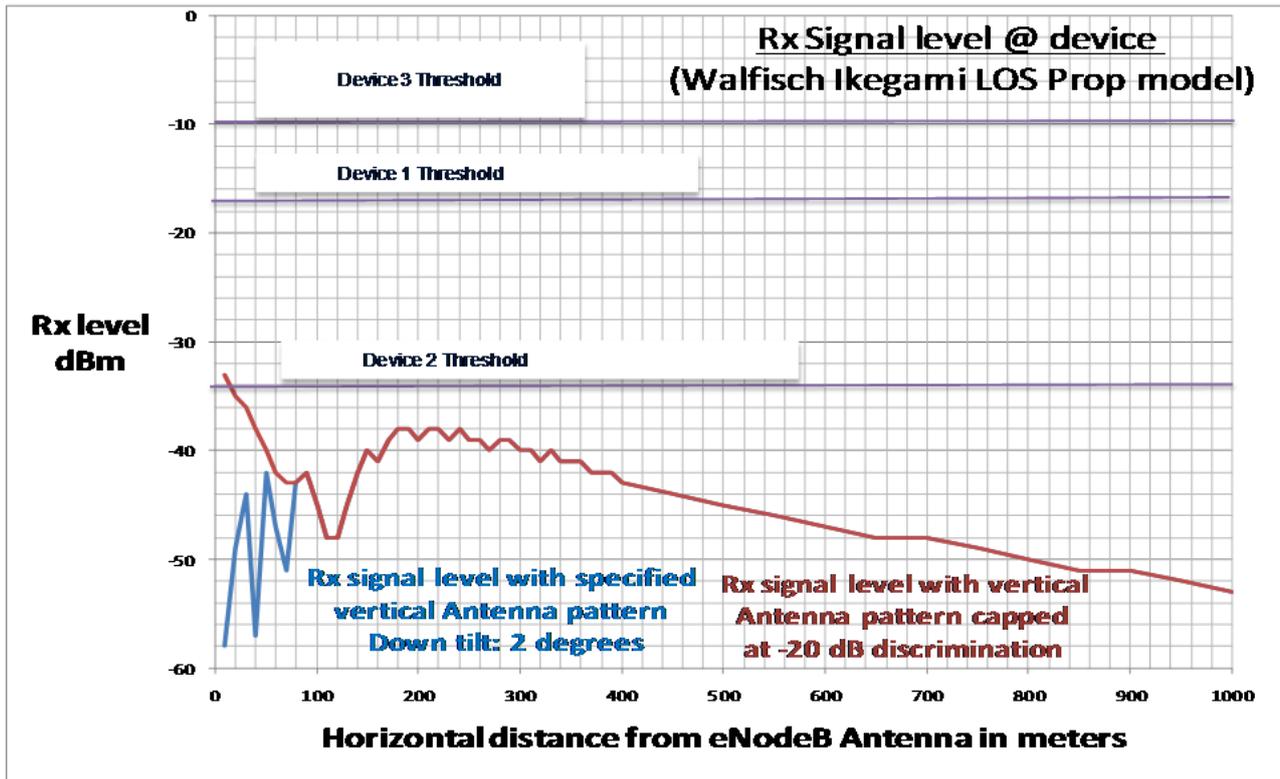


Figure 4: Results: received signal level on the ground near the base of BTS tower

### 3.3.1.1.1 Conclusions

It is apparent from Figure 4 that, of the three phones tested, two would never face service disruption due to overload (as defined here) at any distance, right up to the base of the tower. The third phone would face disruption only if it were closer than approximately 20 m from the base of the tower.

### 3.3.1.2 Exclusion Distance Prediction based on commercial cellular planning tools

In addition to the analytical method, the cellular planning tool used by LightSquared for deployment planning was used to predict contours of received signal strength around the bases of the planned cell sites. This approach has the advantage over the analytical/geometric method that actual morphologies in a given market are factored in – the results are of course market specific. Appendix 2 shows results of this study for the Baltimore-Washington (BaWa) and Phoenix markets.

### 3.3.1.2.1 Conclusions

The followings are the key conclusions, bearing in mind, that for the limited sample of cellphones tested, the lowest overload threshold level encountered was -35 dBm and this applied to only one (1) out of three (3) phones.

- In the BaWa market, 1.1% of the coverage area will have a received signal level greater than -35 dBm.
- In the Phoenix market, 2.5% of the coverage area will have a received signal level greater than -35 dBm.

## 4 Test Plans for Lab Testing of Mobile GPS Receivers

Laboratory testing by a certified laboratory has the following benefits:

- Testing is performed by an impartial and reputable third party
- More fine grain observation of various parameters of the GPS engine are feasible than in the field trial, where the observables were limited to those provided by commercially available cellphone applications

The details of the test plan are provided in Appendix 3. The highlights are noted below.

- Different levels of GPS signal strength will be used down to the specified minimum of -130 dBm
- Both tracking and acquisition performance (time to first fix) will be measured
- The effect of cellular assist (as in AGPS) will be emulated
- The position measurement uncertainty, if reported by the GPS engine, will be logged if diagnostic tools are available from the device manufacturer.

## 5 Characterization and Mitigation of Overload Vulnerability of Fixed GPS Receivers in proximity to LightSquared's L-band Base Station Antennas

### 5.1 Introduction

LightSquared has investigated and addressed potential issues associated with the close proximity of its spectrum allocation to that of the GPS band. In performing assessments of commercially available fixed GPS receiver antennas (used to derive precision timing), LightSquared has learned that many GPS antennas lack front-end filtering, which will make them prone to continuous receiver signal overload when they are located in close proximity to LightSquared's transmit antennas. This level of vulnerability depends on the receiver/antenna model and its position relative to a BTS transmit antenna. The receiver overload will result in loss of signal to GPS receivers operating in very close proximity to LightSquared's transmit antennas; GPS receivers operating further from LightSquared's antennas may experience inconsistent performance. The nature of the disruption will vary not only with distance, but with the model and manufacturer of the GPS device<sup>1</sup>. This receiver overload issue cannot be ameliorated through modifications to LightSquared's transmit equipment; the solution relies upon the design and/or placement of the GPS receive antennas.

### 5.2 Scope of the Problem

Table 2 and Table 3 are examples of an ATC base station-GPS timing receiver link budget. This link budget utilizes a receiver sensitivity-to-broadband interference (-145 dBW/MHz) that is typical for the technology currently used in GPS timing receivers, which insures that the BTS OOB interference does not dominate the thermal noise floor for which the receivers were designed to operate. For the limiting case scenario, it is assumed that a BTS transmit antenna is 2 meters (~ 6 feet) away from a GPS receiver/antenna within a clear line of sight. This link budget results in a transmit OOB EIRP requirement of -100 dBW/MHz, which is consistent with the technical parameters of LightSquared's agreement with the GPSIC. The link budget concludes with calculations to determine minimum required separation distance for receive overload protection with typical GPS antenna models currently in use and, the required receive overload

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<sup>1</sup> The maximum distance from LightSquared's transmit antennas where this issue is expected to occur is approximately 308 meters and is detailed later in this document.

protection threshold for 2 meter separation for one ATC carrier per sector, and 3 meter separation for two ATC carriers per sector.

Table 1. ATC Base Station-GPS Rx Link Budget (One ATC carrier per sector)

Parameter	Value	Unit	Note
<b><u>Minimum Required Distance for Tx OOBE:</u></b>			
GPS Receiver Interference Susceptibility (Broadband Noise)	-144.5	dBW/MHz	Typical Specifications for GPS Timing Rx
Maximum allowable Tx OOBE EIRP	-100	dBW/MHz	Specs - GPS IC agreement
GPS Receive Antenna Gain Towards Tx Antenna	0	dBi	Assumption
Polarization Loss	3	dB	Linear to RHCP
Required Propagation Loss	41.5	dB	Calculations
Required Minimum Distance to meet OOBE Interference Susceptibility	2	meter	Calculations - Assume Free Space Line of Sight
<b><u>Minimum Required Distance for typical GPS Rx (One ATC carrier):</u></b>			
BTS Tx EIRP (LS is authorized to transmit up to 42 dBW/sector)	62	dBm	32 dBW Nominal (2X2 MIMO)
Average Overload Rx Susceptibility Threshold	-21	dBm	Measured - One carrier
GPS Receive Antenna Gain Towards Tx Antenna	0	dBi	Assumption
Antenna Coupling Loss	5	dB	Assumption
Polarization Loss	3	dB	Linear to RHCP
Required BTS Tx to GPS Rx Antenna Isolation	75	dB	Calculations
Required Rx Antenna Separation Distance in Front of BTS Antenna (Propagation model A)	87	meter	Calculations - Assume Free Space Line of Sight (LOS)
Required Rx Antenna Separation Distance in Front of BTS Antenna (Propagation model B)	62	meter	Calculations - Assume Walfisch Ikegami LOS
Required Rx Antenna Separation Distance in Back of BTS Antenna (Front - Back gain ratio : 30 dB)	3	meter	Calculations - Assume Free Space Line of Sight
<b><u>Required Rx overload Susceptibility calculations (One ATC Carrier):</u></b>			
Required Rx overload Susceptibility Threshold for Minimum Distance of 2 meter	12	dBm	62 dBm - 42 dB (LOS path loss for 2 m distance) - 8 dB

LightSquared has tested a limited number of GPS receivers and found that the average overload threshold is approximately -21 dBm at the input of an antenna with a high degree of variability among manufacturers (-18 dBm to -25 dBm) for one interfering carrier, and -29 dBm (average) with variability of -23 dBm to -41 dBm for two interfering carriers. With maximum BTS EIRP of 32 dBW per carrier (one ATC carrier in 2X2 MIMO configuration), and using a receive overload susceptibility value of -21 dBm, typical antennas operating within 75 to 87 meters in front (max gain direction) of the BTS antenna, and up to 3 meters in back of the BTS antenna (assuming 30 dB front to back gain ratio) may be subject to RF signal overload. With two ATC carriers in the same configuration (35 dBW EIRP) and using a receive overload susceptibility value of -29 dBm, typical interference radius is 165 to 308 meters in front, and 10 meters in back of the BTS antenna. In those situations, wireless network operators would need to replace their GPS receive antennas with models having better front-end rejection capabilities when they are located within the main beam of a LightSquared transmitting antenna.

Various factors impact the ability of a receive antenna to reject adjacent-band emissions including:

- (1) Overload susceptibility rating
- (2) Distance and azimuth from transmitter
- (3) Any external objects that may obstruct or attenuate the interference signal.

A combination of all “worst case” factors, while believed to be rare, would require a separation distance of up to 308 meters.

Table 2. ATC Base Station-GPS Rx Link Budget (Two ATC carriers per sector)

Parameter	Value	Unit	Note
<b><u>Minimum Required Distance for Tx OOBE:</u></b>			
GPS Receiver Interference Susceptibility (Broadband Noise)	-144.5	dBW/MHz	Typical Specifications for GPS Timing Rx
Maximum allowable Tx OOBE EIRP	-100	dBW/MHz	Specs - GPS IC agreement
GPS Receive Antenna Gain Towards Tx Antenna	0	dBi	Assumption
Polarization Loss	3	dB	Linear to RHCP
Required Propagation Loss	41.5	dB	Calculations
Required Minimum Distance to meet OOBE Interference Susceptibility	2	meter	Calculations - Assume Free Space Line of Sight
<b><u>Minimum Required Distance for typical GPS Rx (Two ATC carrier):</u></b>			
BTS Tx EIRP (LS is authorized to transmit up to 42 dBW/sector)	65	dBm	35 dBW Nominal (2X2 MIMO)
Average Overload Rx Susceptibility Threshold	-29	dBm	Measured - Two carriers
GPS Receive Antenna Gain Towards Tx Antenna	0	dBi	Assumption
Antenna Coupling Loss	5	dB	Assumption
Polarization Loss	3	dB	Linear to RHCP
Required BTS Tx to GPS Rx Antenna Isolation	86	dB	Calculations
Required Rx Antenna Separation Distance in Front of BTS Antenna (Propagation model A)	308	meter	Calculations - Assume Free Space Line of Sight (LOS)
Required Rx Antenna Separation Distance in Front of BTS Antenna (Propagation model B)	165	meter	Calculations - Assume Walfisch Ikegami LOS
Required Rx Antenna Separation Distance in Back of BTS Antenna (Front - Back gain ratio : 30 dB)	10	meter	Calculations - Assume Free Space Line of Sight
<b><u>Required Rx overload Susceptibility calculations (Two ATC Carriers):</u></b>			
Required Rx overload Susceptibility Threshold for Minimum Distance of 3 meter	11	dBm	65 dBm - 50 dB (LOS path loss for 3 m distance) - 8 dB

### 5.3 Solution

GPS timing receivers / antennas with either an unknown resilience to overload or a known resilience that may be insufficient to operate near a BTS must either be replaced with models having a higher overload threshold value (suggested value of +20dBm at frequency offset of -20 MHz or more from 1575.42 MHz) or with an alternate method of synchronization (e.g. timing over packet). As detailed in Appendix 4 a GPS antenna will need to attenuate the incoming signal by 65 dB or more at frequencies less than 1560 MHz so that it can operate at a distance as close as two/five meters from a BTS transmit antenna. There is at least one manufacturer of GPS timing devices for the wireless industry, Panasonic, that produces an antenna meeting the necessary specifications (Model VIC 100 – enhanced). This antenna utilizes receive filters which produce a signal attenuation of 65 dB at 1575.42 MHz ±50 MHz. See Appendix 5 for additional specifications. This antenna is currently available for order at prices of about \$100 per antenna.

## 6 References

- [1] RP-101117; Status report for WI core part: Adding L-Band LTE for ATC of MSS in North America, rapporteur. LightSquared
- [2] RP-101285; TR 36.813 “Adding L-Band LTE for ATC of MSS in North America”, version 2.0.0, LightSquared,
- [3] RP-101361; CRs for Adding L-Band LTE for ATC of MSS in North America, core part
- [4] R4-104678; Band 24 (L band) impact on legacy devices using GPS for location. Sprint

## Appendix 1

### A.1 Experimental Verification of Base Station Antenna Discrimination close to Tower Base

#### Objective:

- To measure the amount of signal suppression that can be achieved near the base of a BTS transmitter due to antenna side lobe discrimination, which is partially mitigated by signal contributions from local multipath reflections.

#### Test Approach:

- Place BTS TX antenna at 2 different outdoor locations:
  - Building roof above loading dock (Part 1). See Figure A.1.1.
  - Ground level in front of loading dock (Part 2). See Figure A.1.2.
- Measure receive signal level at HNS prototype H/S antenna as horizontal distance between antennas is increased in 3' steps.
- Compare predicted signal levels (based on antenna gains w/o multipath) to measured levels for Parts 1 & 2.

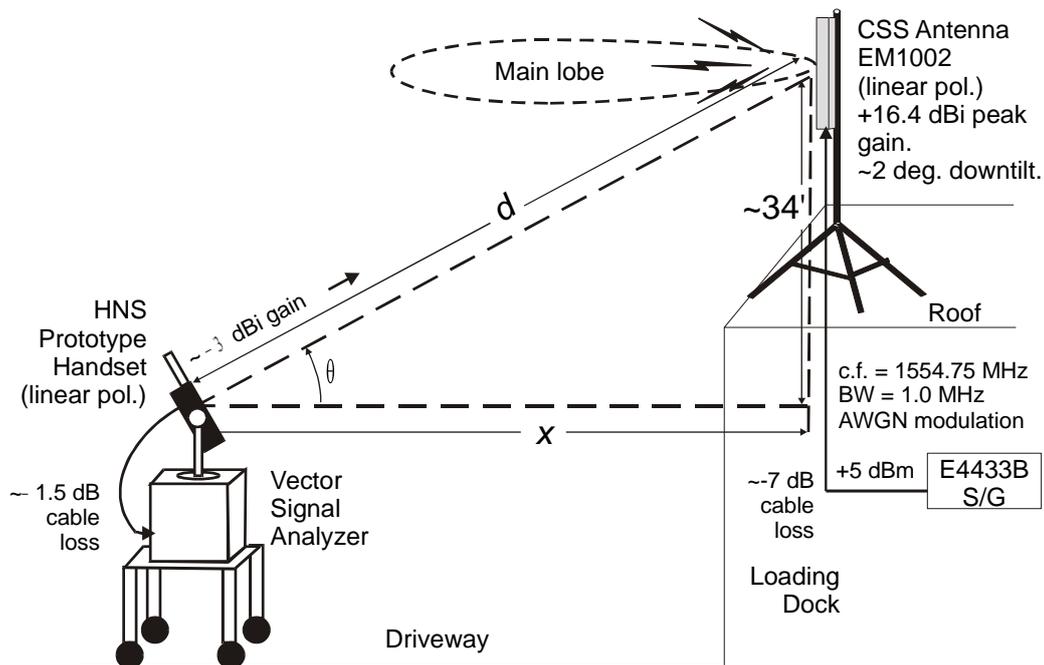
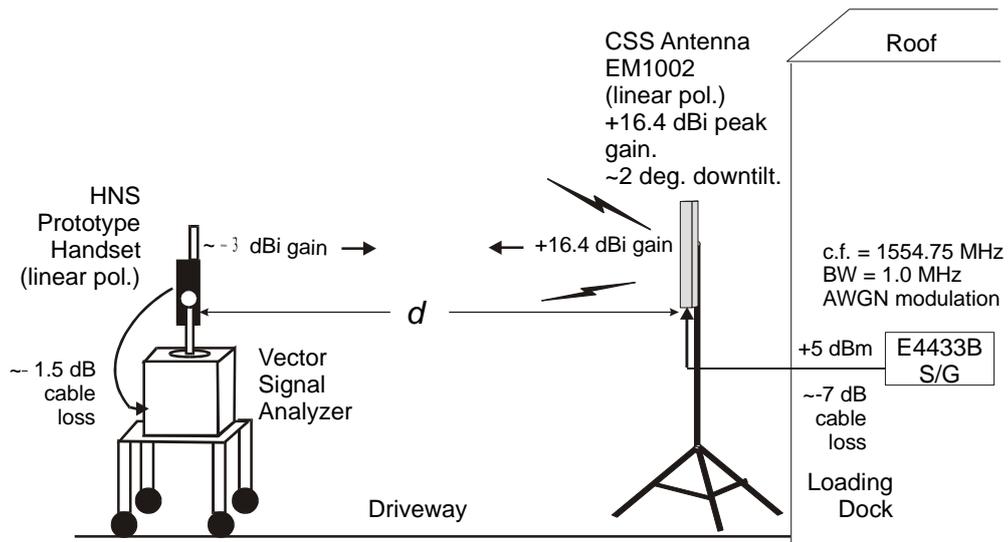
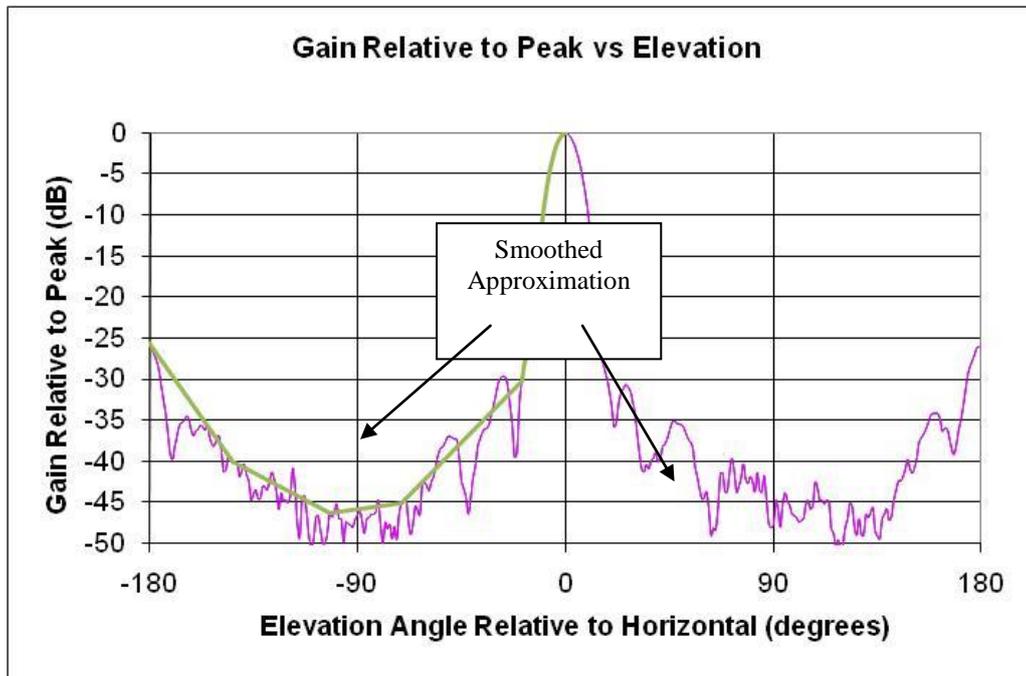


Figure. A.1.1: Test Set-up for Part 1 – Rooftop Transmission

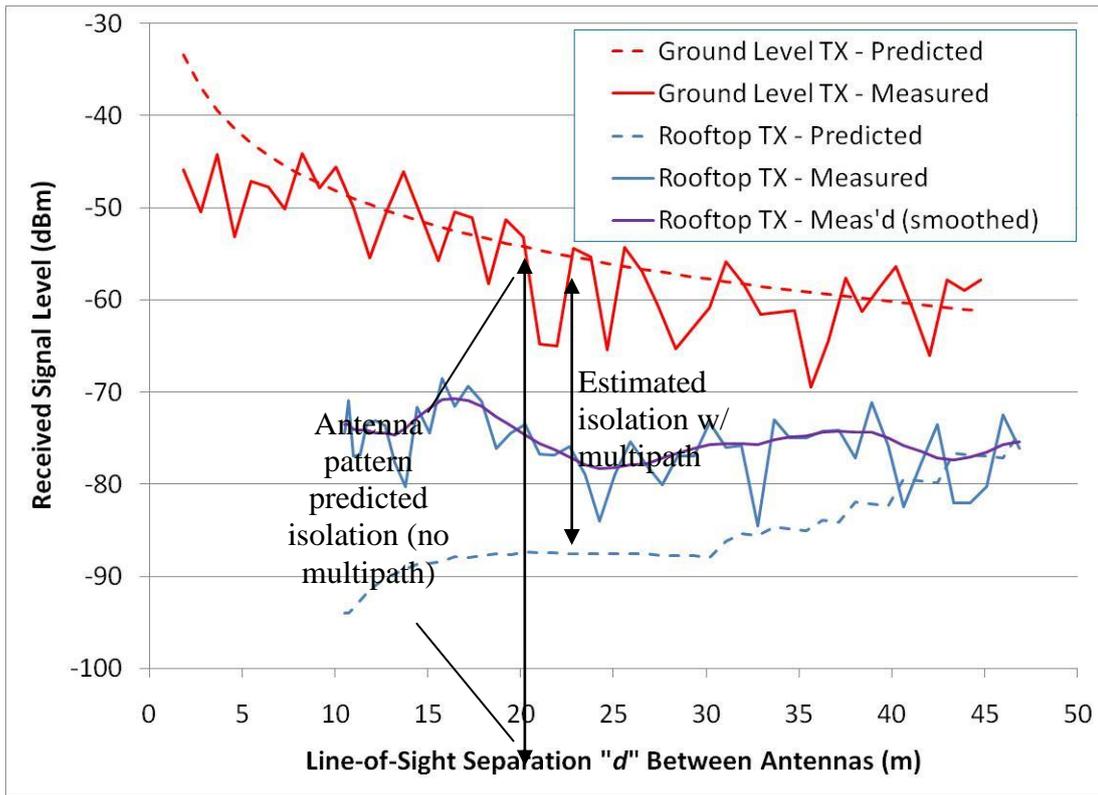


**Figure A.1.2: Test Set-up For Part 2 – Ground Level Transmission**

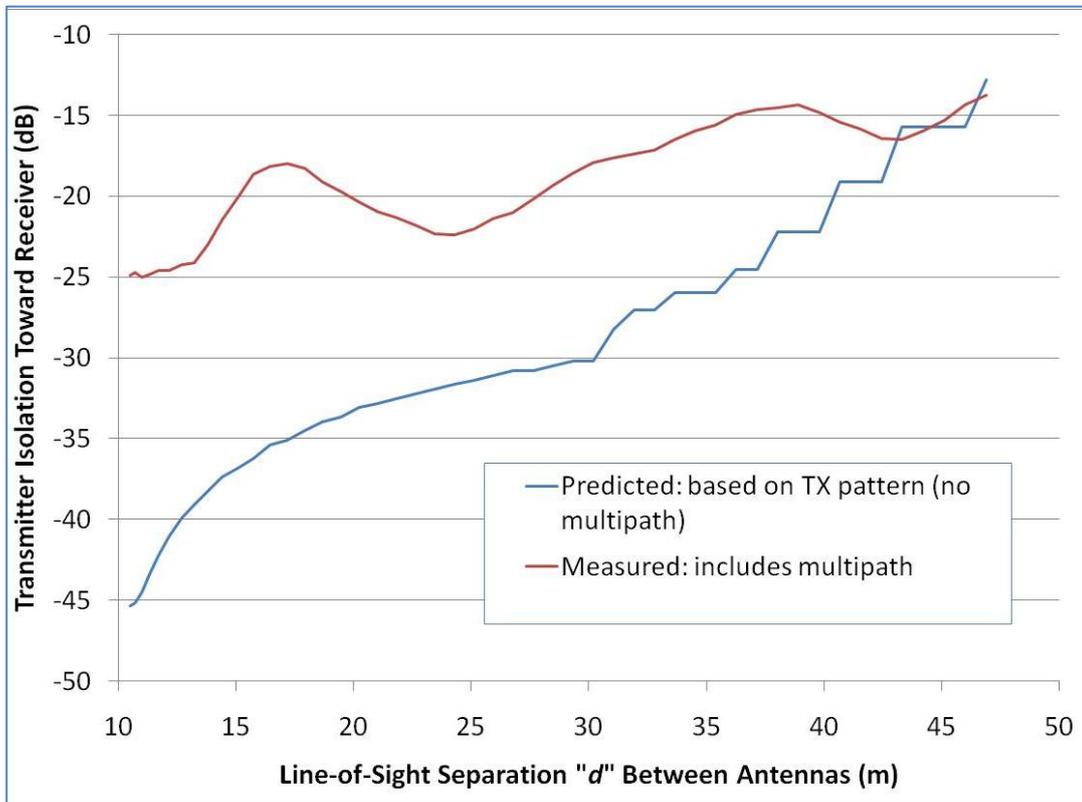


**Figure A.1.3: CSS Base Station Antenna Gain Model**

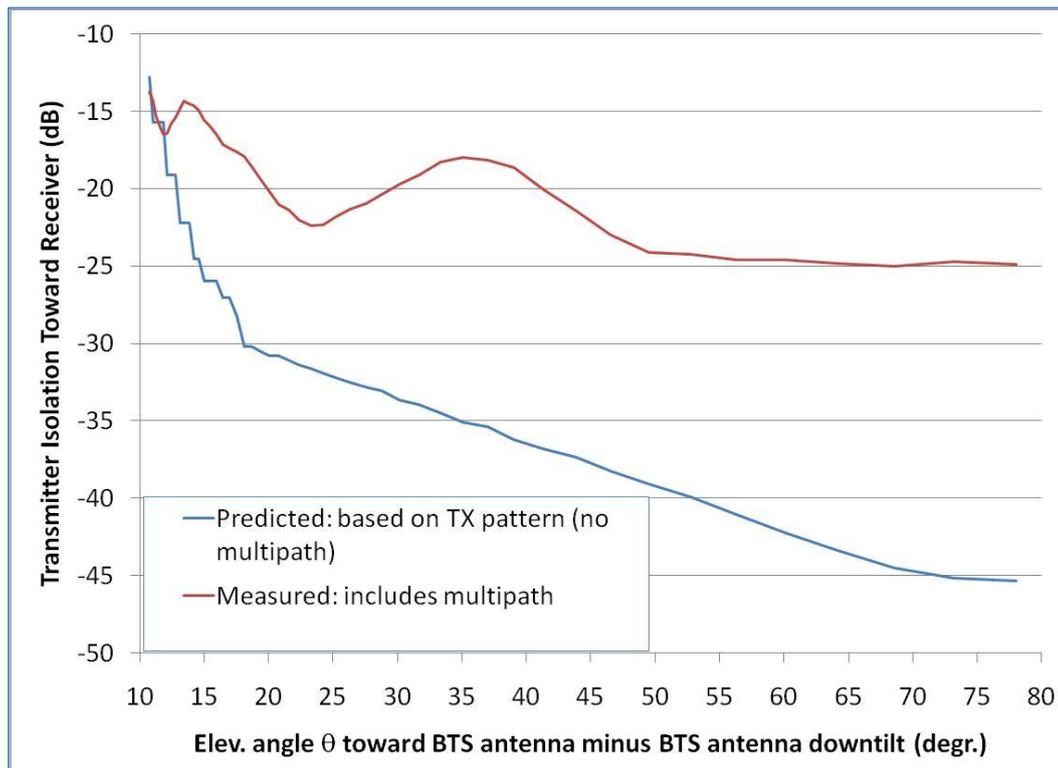
- The above contour corresponds to CSS antenna EM1000. The outdoor measurements were performed using EM1002, which has non-identical ripples in low level side lobes. Therefore a smoothed side lobe curve (shown above) was used to estimate the predicted suppression.



**Figure A.1.4: Comparison of Measured and Predicted RX Signal Levels For Rooftop (Part 1) and Ground Level (Part 2) Transmitters**



**Figure A.1.5: TX Antenna Isolation Toward Receiver vs. Distance**



**Figure A.1.6: TX Antenna Isolation Toward Receiver vs. Elevation Angle**

#### **Comments and Conclusions Referring to Figure A.1.4:**

- The predicted signal levels (dashed lines) are based on the antenna patterns without any multipath effects.
- The measured levels (solid lines) include all effects including multipath.
- For the ground level TX case (red curves), the RX antenna is always in the main beam of the TX antenna, so there is no TX antenna isolation.
- For the rooftop TX case (blue curves), where the ground-level receiver is closest to the TX antenna, the reflected signal component dominates the direct LOS component, which is suppressed by the TX antenna pattern. However, as the separation distance becomes larger, the direct LOS component increases, so that the predicted and measured levels tend to merge, as shown in Figure A.1.5.
- The abrupt changes in measured signal levels shown in Fig. A.1.4 are caused by local reflections, which would be different for each test location. To minimize the effects of a specific test location, the measured levels have been averaged over a short distance (purple line) to show the general trend.
- The estimated average BTS antenna isolation, including the effect of multipath reflections, is shown as the difference between averaged measured values (purple line) and the predicted receive level with no multipath fading (dashed red line). Using this definition, the antenna isolation was found to vary between about 15 dB and 25 dB over the range of separation distances and elevation angles. See Figures A.1.5 and A.1.6.

## Appendix 2

### A.2 Results of Exclusion Zone Analysis using Cellular Planning Tool

#### A.2.1 Assumptions

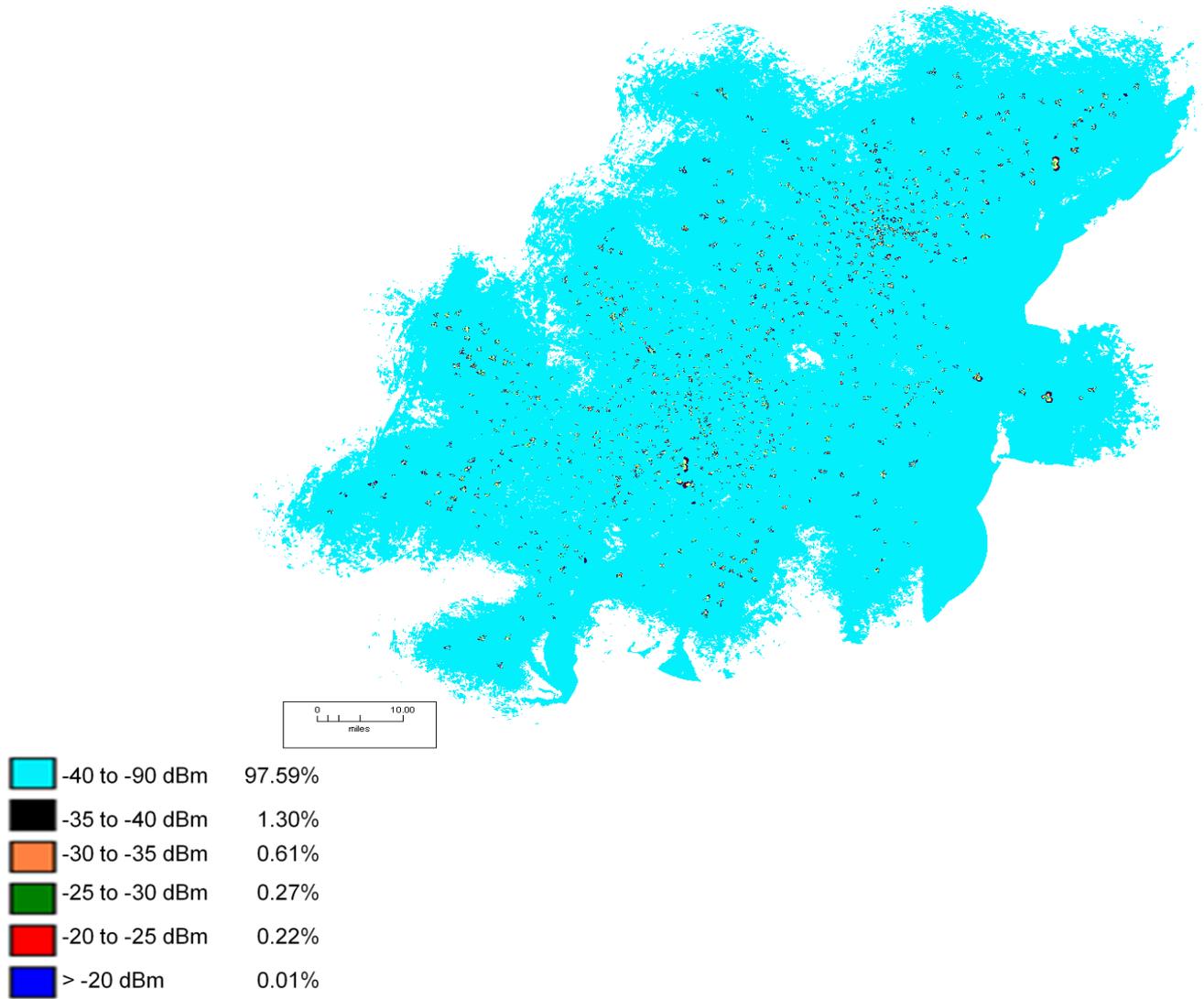
- ▶ EIRP : 64 dBm EIRP
- ▶ Worst Case Analysis- 100% Network loading
- ▶ No Polarization Discrimination assumed
- ▶ Tuned Propagation Model Used
- ▶ Baltimore –Washington Market
  - 784 sites in coverage area
  - Total coverage area is 14,527 sq. km
- Phoenix Market
  - 474 sites in coverage area
  - Total coverage area is 3,557 sq. km

#### A.2.2 Summary

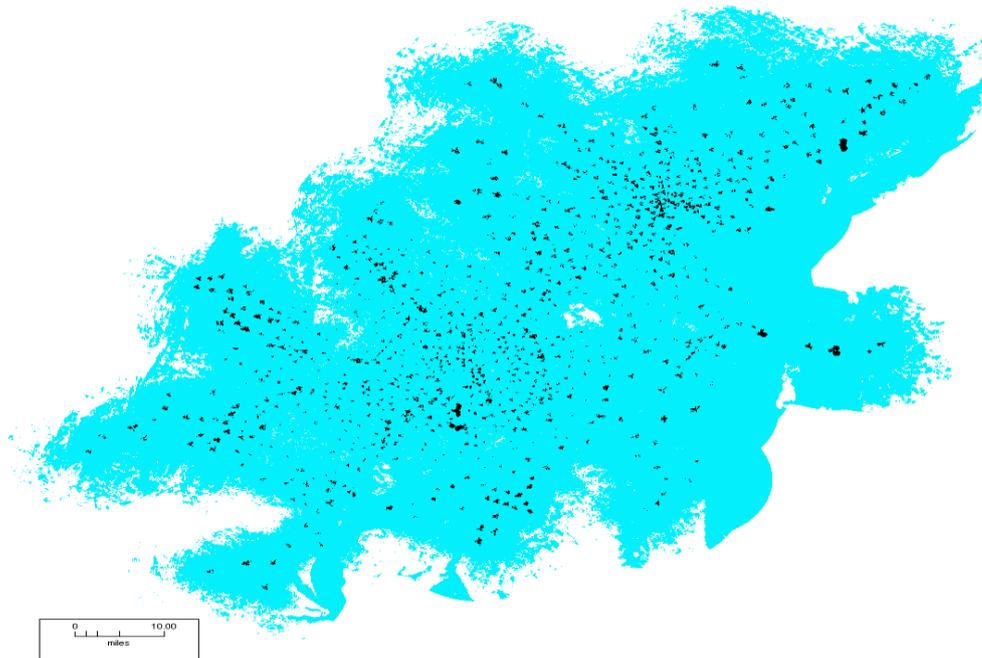
Market	Total Coverage Area	Total Sites	Signal Threshold	%age Area
BaWa	14,527 sq. km	784	-40 to -90 dBm	97.59%
			-35 to -40 dBm	1.30%
			-30 to -35 dBm	0.61%
			-25 to -30 dBm	0.27%
			-20 to -25 dBm	0.22%
			> -20 dBm	0.01%
Phoenix	3,557 sq. km	474	-40 to -90 dBm	94.84%
			-35 to -40 dBm	2.68%
			-30 to -35 dBm	1.39%
			-25 to -30 dBm	0.7%
			-20 to -25 dBm	0.3%
			> -20 dBm	0.09%

### A.2.3 Baltimore Washington Coverage Plot

97.6% of the covered area will have signal strength weaker than -40dBm

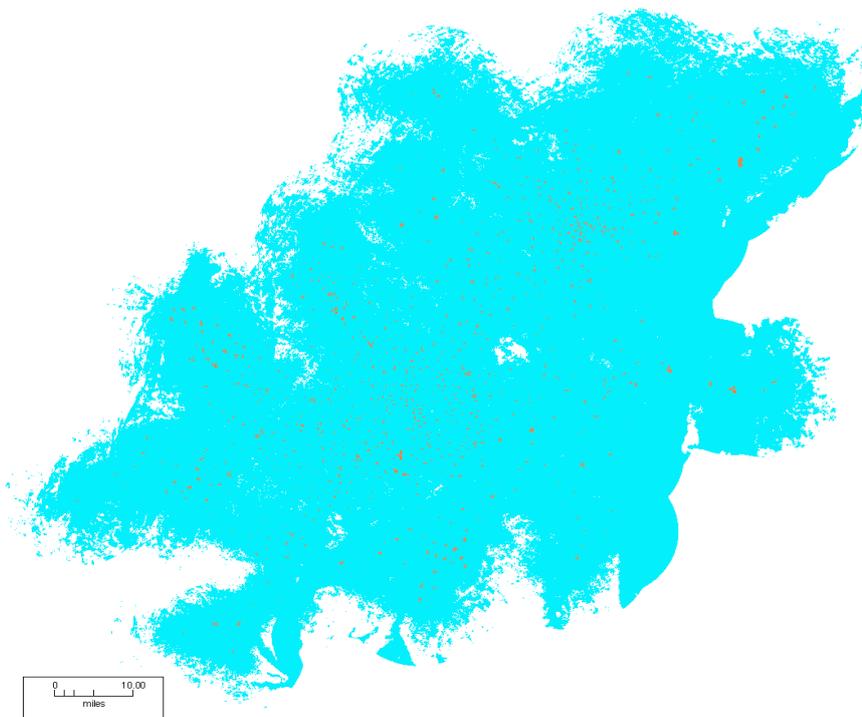


Only 2.4% of the covered area will have signal strength stronger than -40dBm



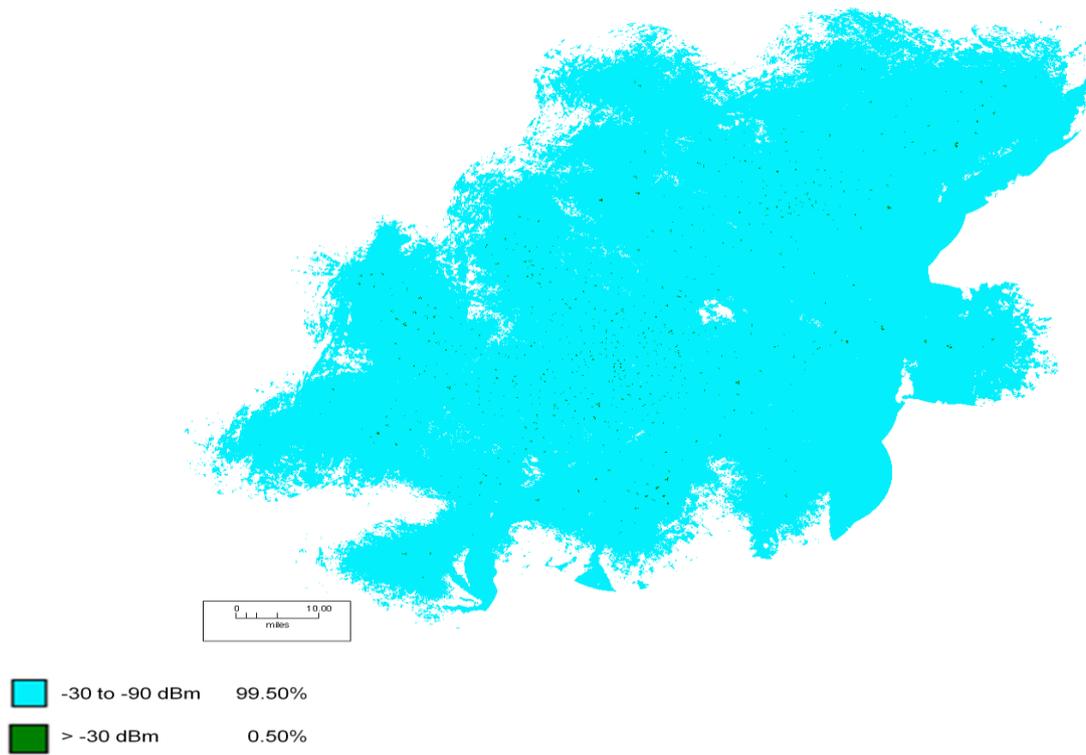
	-40 to -90 dBm	97.59%
	> -40 dBm	2.41%

Only 1.1 % of the covered area will have signal strength stronger than -35dBm

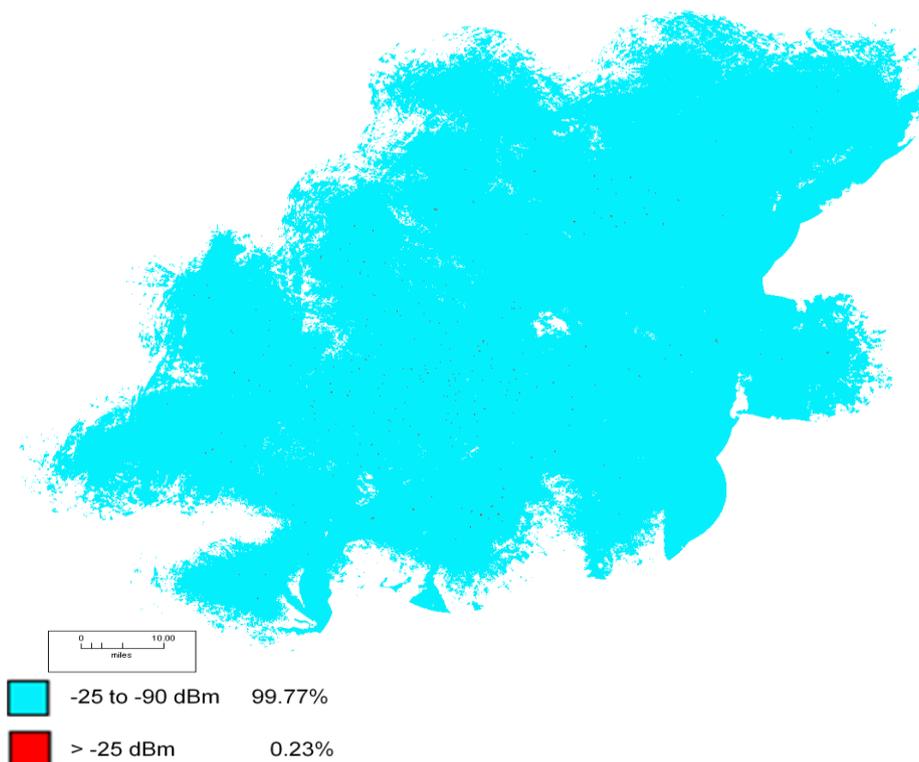


	-35 to -90 dBm	98.89%
	> -35 dBm	1.11%

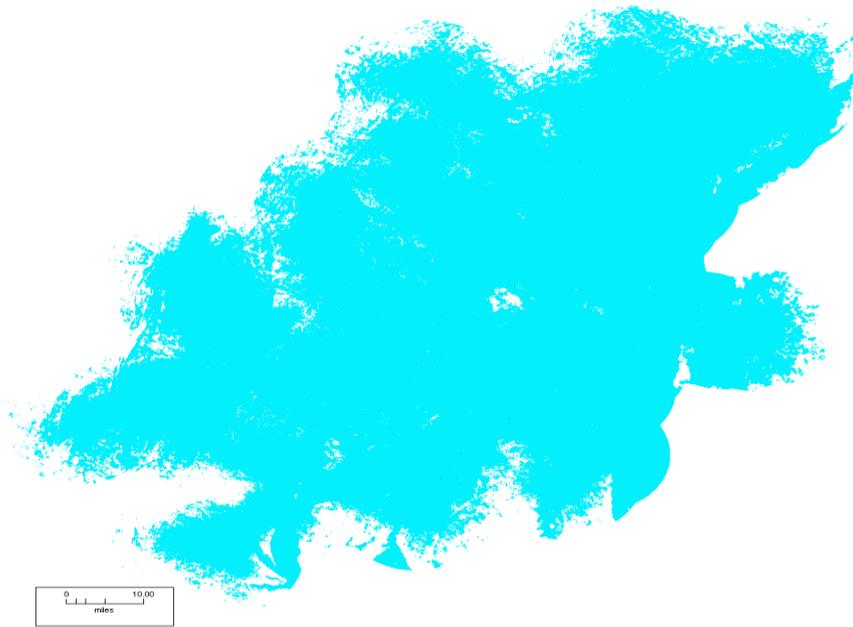
Only 0.5 % of the covered area will have signal strength stronger than -30dBm



Only 0.2 % of the covered area will have signal strength stronger than -25dBm



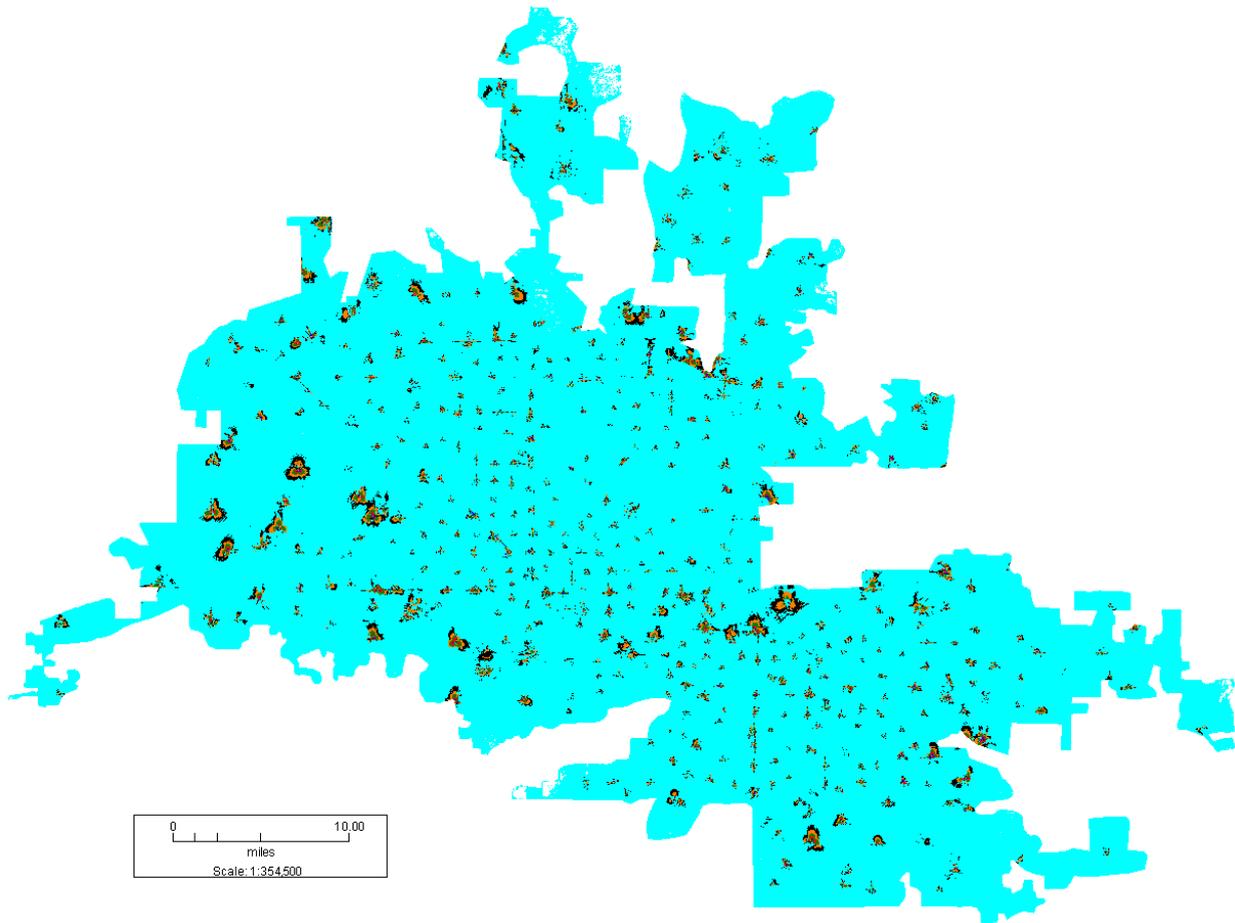
Only 0.01% of the covered area will have signal strength stronger than -20dBm



	-20 to -90 dBm	99.99%
	> -20 dBm	0.01%

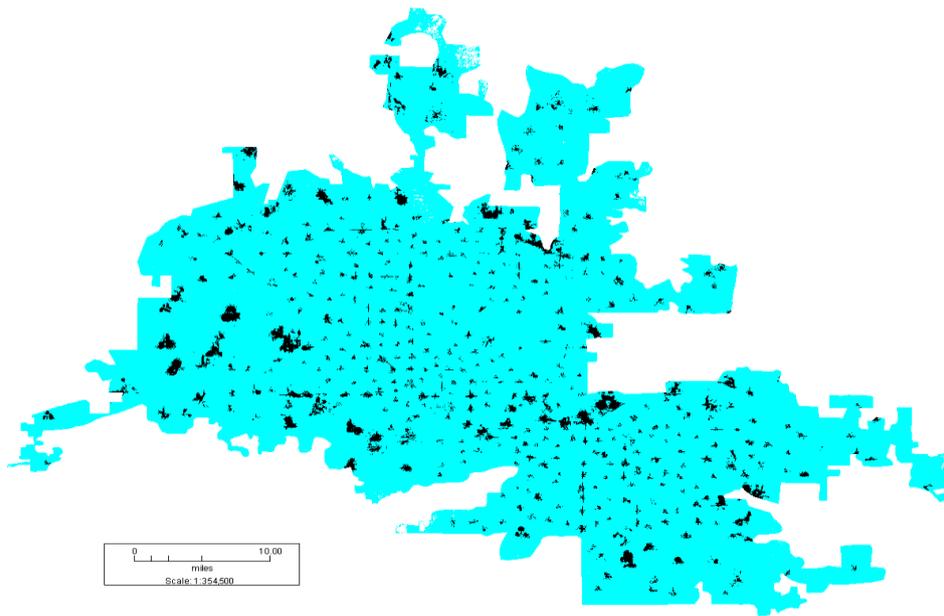
## A.2.4 Phoenix Coverage Plot

94.8% of the covered area will have signal strength weaker than -40dBm

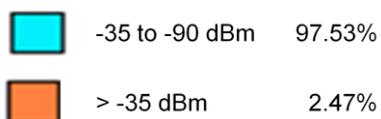
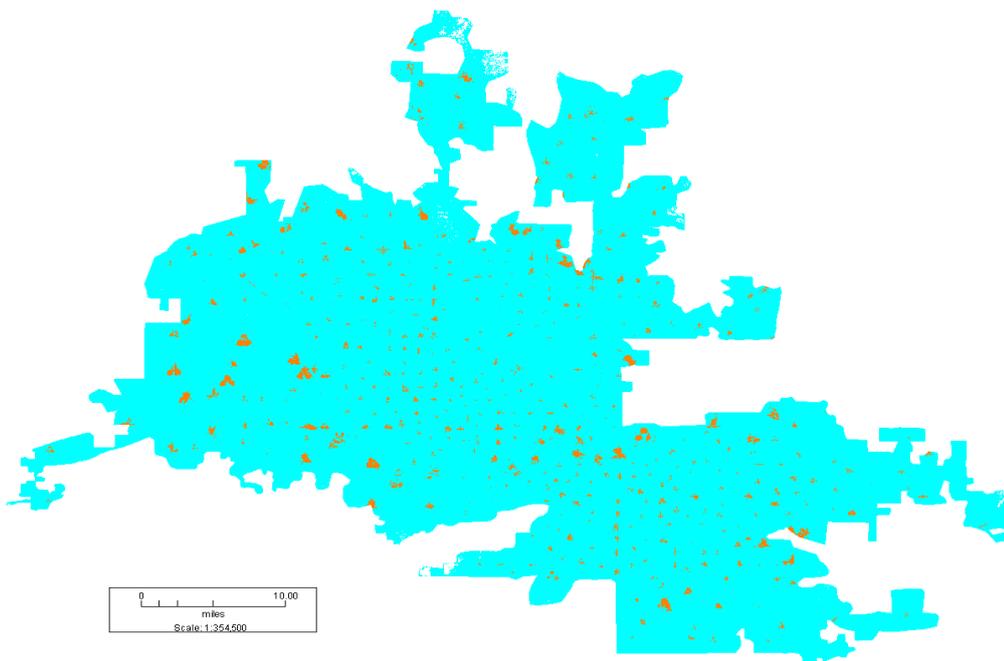


	-40 to -90 dBm	94.84%
	-35 to -40 dBm	2.68%
	-30 to -35 dBm	1.39%
	-25 to -30 dBm	0.7%
	-20 to -25 dBm	0.3%
	> -20 dBm	0.09%

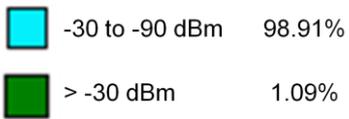
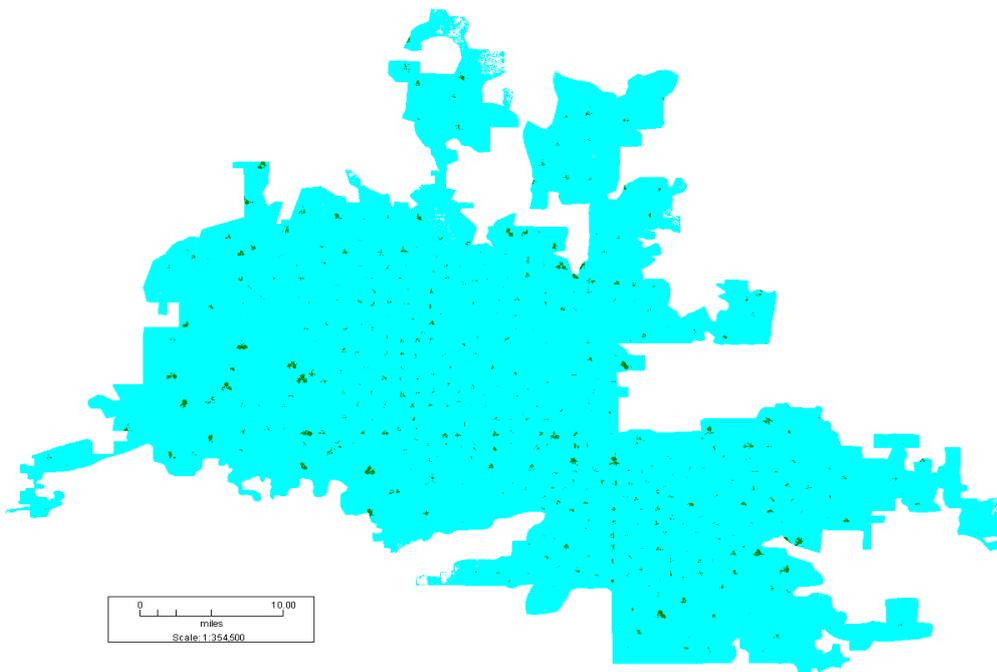
Only 5.2% of the covered area will have signal strength stronger than -40dBm



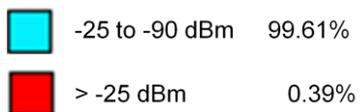
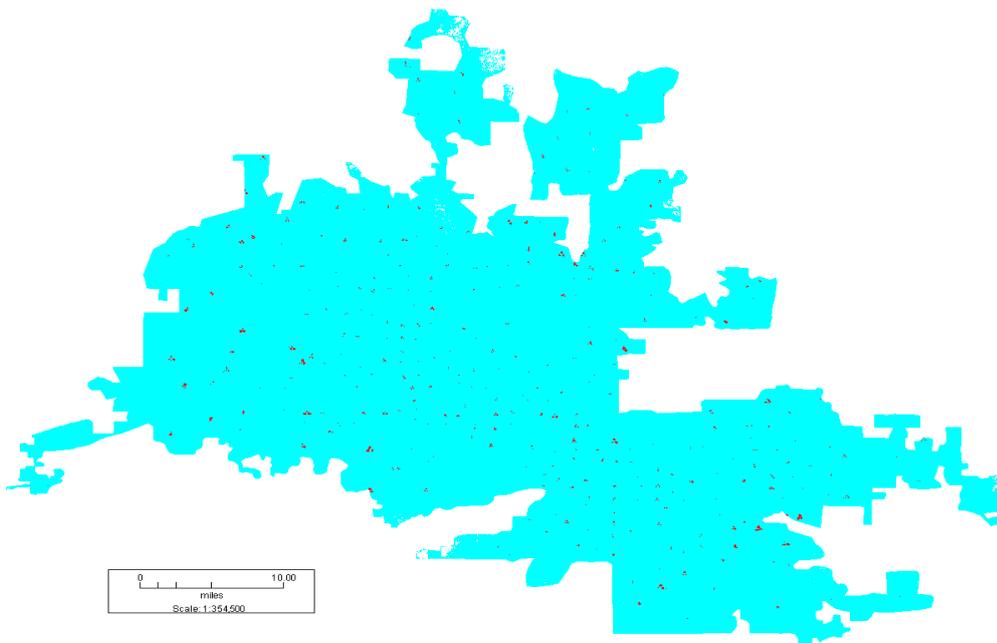
Only 2.47% of the covered area will have signal strength stronger than -35dBm



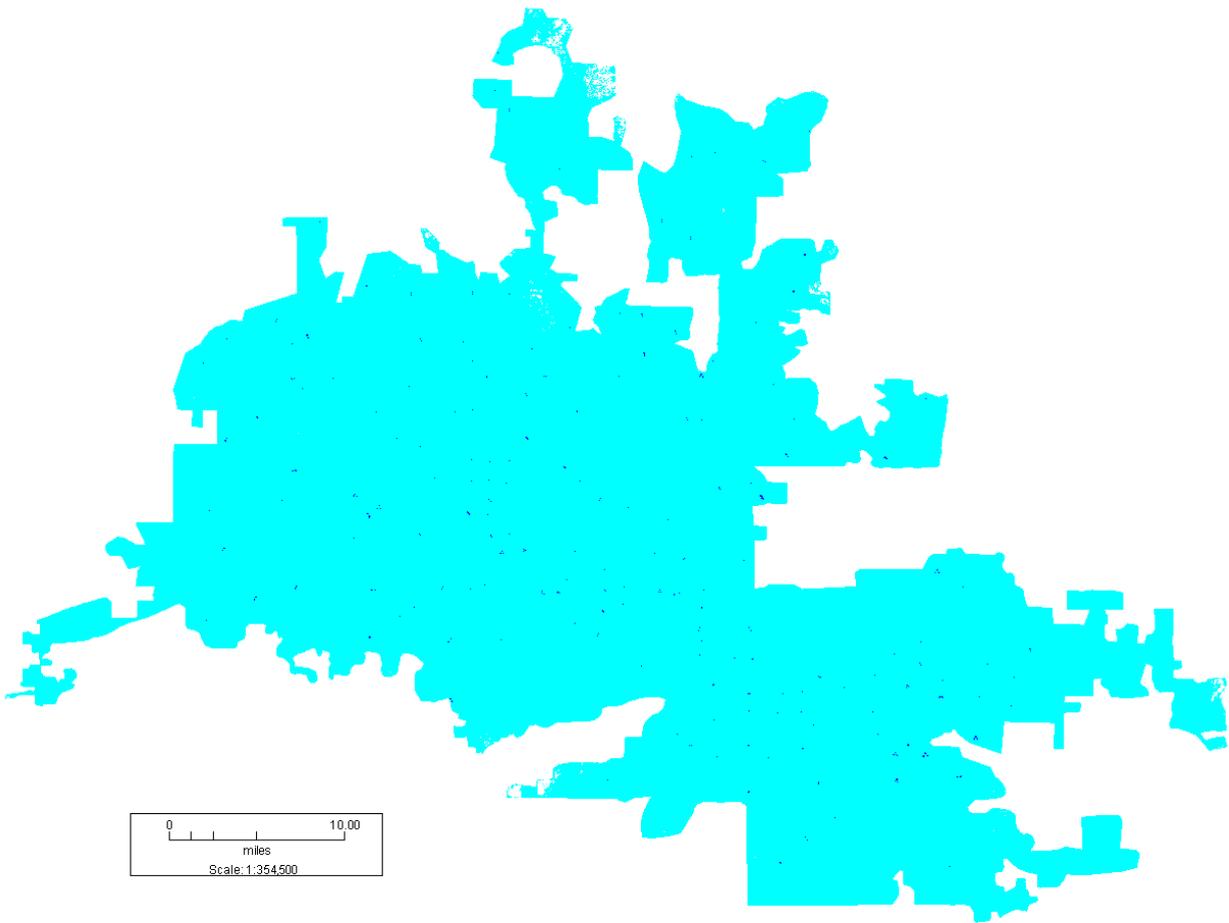
Only 1.1% of the covered area will have signal strength stronger than -30dBm



Only 0.39% of the covered area will have signal strength stronger than -25dBm



Only 0.09% of the covered area will have signal strength stronger than -20dBm



	-20 to -90 dBm	99.91%
	> -20 dBm	0.09%

## Appendix 3

### A.3 Test Plan for Laboratory Testing of Mobile GPS Receivers by AT4 Wireless

#### A.3.1 Introduction

This document describes the methodology to be used by AT4 Wireless, under contract to LightSquared, for evaluating the blocking performance of GPS receivers embedded in cellular phones when strong L-band<sup>2</sup> ATC signals are present. Such strong, adjacent-band signals may be present owing to physical proximity of the cellular phone to either a LightSquared base station or User Equipment (UE).

The end goal of the tests is to create a database of the blocking performance of a number of commercially available cellular phones with internal GPS receiver in presence of L-band LTE strong signals.

#### A.3.2 Abbreviations

- DUT - Device under test
- LP - Linear polarized
- LTE - Long term evolution
- OFDM - Orthogonal frequency-division multiplexing
- RHCP - Right hand circularly polarized
- RSE - Radiated spurious emission
- SV - Space vehicle

#### A.3.3 Test Objectives

### Objective 1: Determine base station to GPS Overload Susceptibility

Determine overload susceptibility of the GPS device (embedded in a cellular phone) for adjacent band downlink LTE carriers as shown in the following spectrum plan.

Either one or both carriers may be present in a given sector, depending on LightSquared's deployment phase. This applies to both 5 MHz and 10 MHz channels, except that 5 and 10 MHz carriers will not be mixed in a given sector. In other words, a sector may have one of the following combinations of carriers:

- a) one (the upper) 5 MHz carrier
- b) two 5 MHz carriers
- c) one (the upper) 10 MHz carrier
- d) two 10 MHz carriers

It is assumed that only one base station sector is visible to the GPS receiver – this is a valid assumption as it can be shown that the levels of signals from other sectors and cell sites will be too small to trigger blocking.

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<sup>2</sup> In the present document, L-band refers to the MSS L-band, which consists of the 1525 – 1559 MHz in the downlink and 1626.5 – 1660.6 MHz in the uplink.

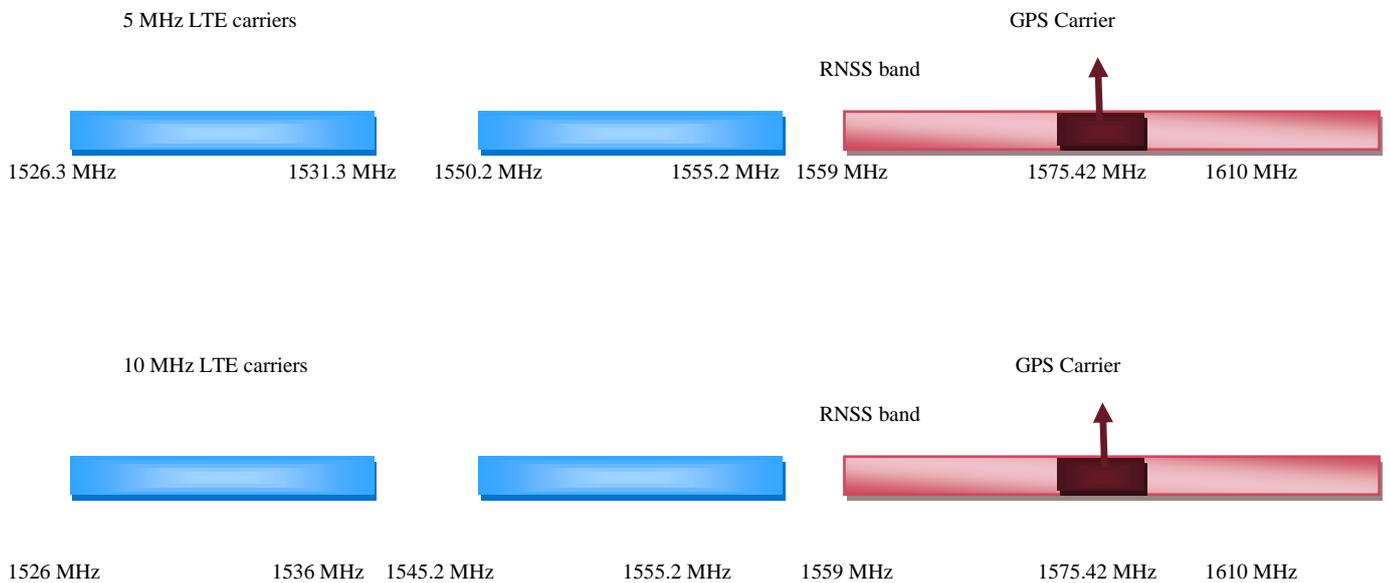


Figure A.3.1: Lightsquared LTE Downlink and GPS/RNSS Spectrum Layout

## Objective 2 Determine UE to GPS Overload Susceptibility

Determine overload susceptibility of the GPS device (embedded in a cellular phone) for adjacent-band uplink LTE carriers as shown in the following spectrum plan.

The following are assumed:

- a) only one (lower), transmitting 5 MHz LighSquared UE sufficiently close to the GPS receiver to potentially cause blocking;
- b) only one (upper), transmitting 5 MHz LighSquared UE sufficiently close to the GPS receiver to potentially cause blocking;
- c) only one (lower), transmitting 10 MHz LighSquared UE sufficiently close to the GPS receiver to potentially cause blocking;
- d) only one (upper), transmitting 10 MHz LighSquared UE sufficiently close to the GPS receiver to potentially cause blocking;

The UE condition transmitting on both channels simultaneously would require uplink carrier aggregation, which is not currently on LightSquared product roadmap and, in any case, will not be available as a standard for several years.

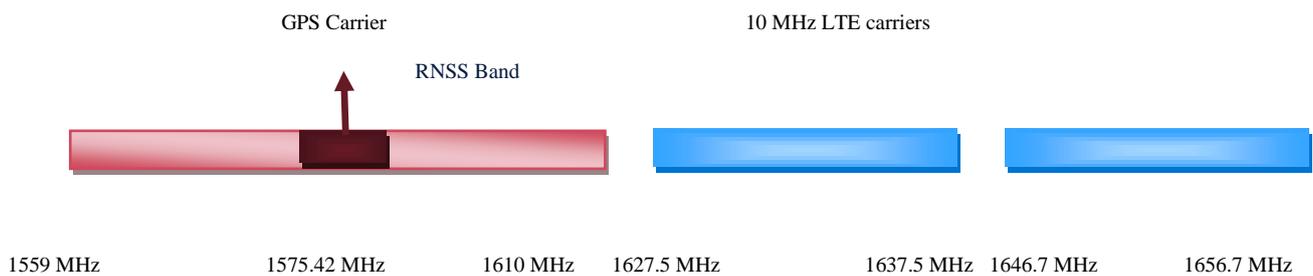
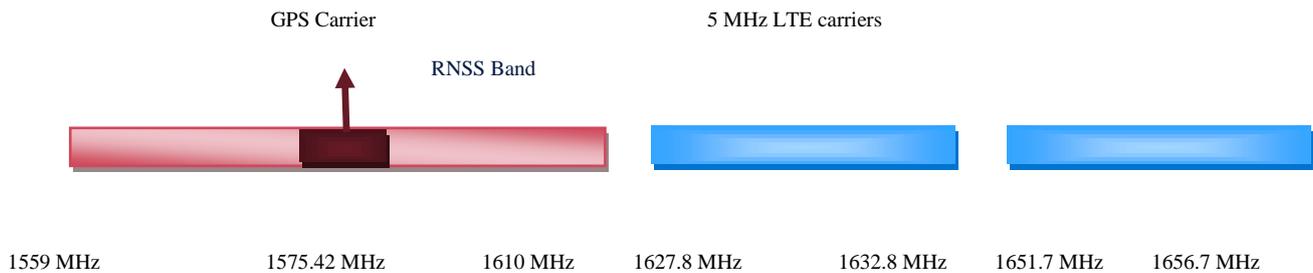


Figure A.3.2: Lightsquared LTE Uplink and GPS/RNSS Spectrum Layout

### A.3.4 Test Requirements

## Tests and test conditions

### Tests

- Characterize the performance of each device under test receiver (DUT) in the presence of simulated adjacent-band LTE downlink and uplink signals with simulated GPS satellite signals from a signal generator.
- Perform the following tests
  - TC\_DL\_01: One (the upper) 5 MHz LTE eNB carrier
  - TC\_DL\_02: Two 5 MHz LTE eNB carriers
  - TC\_DL\_03: One (the upper) LTE eNB 10 MHz carrier
  - TC\_DL\_04: Two 10 MHz LTE eNB carriers
  - TC\_UL\_01: One (lower) 5 MHz UE carrier
  - TC\_UL\_02: One (upper) 5 MHz UE carrier
  - TC\_UL\_03: One (lower) 10 MHz UE carrier
  - TC\_UL\_04: One (upper) 10 MHz UE carrier
- In each test repeat measurement with two GPS signal power conditions.
- For each test characterize:
  - Acquisition performance.
  - Tracking performance.

### Test conditions

- GPS signal generator characteristics:

- GPS constellation with all 8 SVs at the signal power specified for each case.
- GPS Signal power cases:
  - Case GPS1: -125 dBm, desired signal at DUT input antenna
  - Case GPS2: -130 dBm, desired signal at DUT input antenna

Note: GPS signal generator power is set such that the output of an isotropic (0 dBi) antenna located at the position of the DUT would see the specified level.

- Cellular signal (generator) for the communication link
  - Cellular GSM 1900 MHz band
  - Cellular signal level at the DUT position will be [-75 dBm].
- LTE downlink signal characteristics (4 cases):
  - LTE Carrier @ 1552.7 MHz, BW:5 MHz
  - LTE Carriers @ 1552.7 MHz and @ 1528.8 MHz, BW:5 MHz, each
  - LTE Carriers @ 1531 MHz, BW: 10 MHz
  - LTE Carriers @ 1531 MHz and @ 1550.2 MHz , BW:10 MHz, each
  - LTE signal power at the DUT position will be [-10 dBm to -50 dBm]
- LTE uplink signal characteristics (4 cases):
  - LTE Carrier @ 1654.2 MHz, BW:5 MHz
  - LTE Carriers @ 1630.3 MHz, BW:5 MHz
  - LTE Carriers @ 1632.5 MHz, BW:10 MHz
  - LTE Carriers @ 1651.7 MHz, BW:10 MHz
  - LTE signal power at the DUT position will be [+13 dBm to -25 dBm]

### A.3.5 Deliverables

The deliverables to be provided are:

D1: Test methodology and test plan

D2.x: Test report for each DUT

D3: Summary report with all aggregated results

### A.3.6 Test Setup

Figure A.3.3 shows the proposed test setup to cover all test cases and test conditions.

The testing is carried out in an anechoic chamber. The GPS, Cellular and LTE signals are radiated within the anechoic chamber, over-the-air, as shown. The cellular signals are used to create an in-situ environment for the Handset/GPS device to assist in finding its initial position fix (triangulation/AGPS functionality).

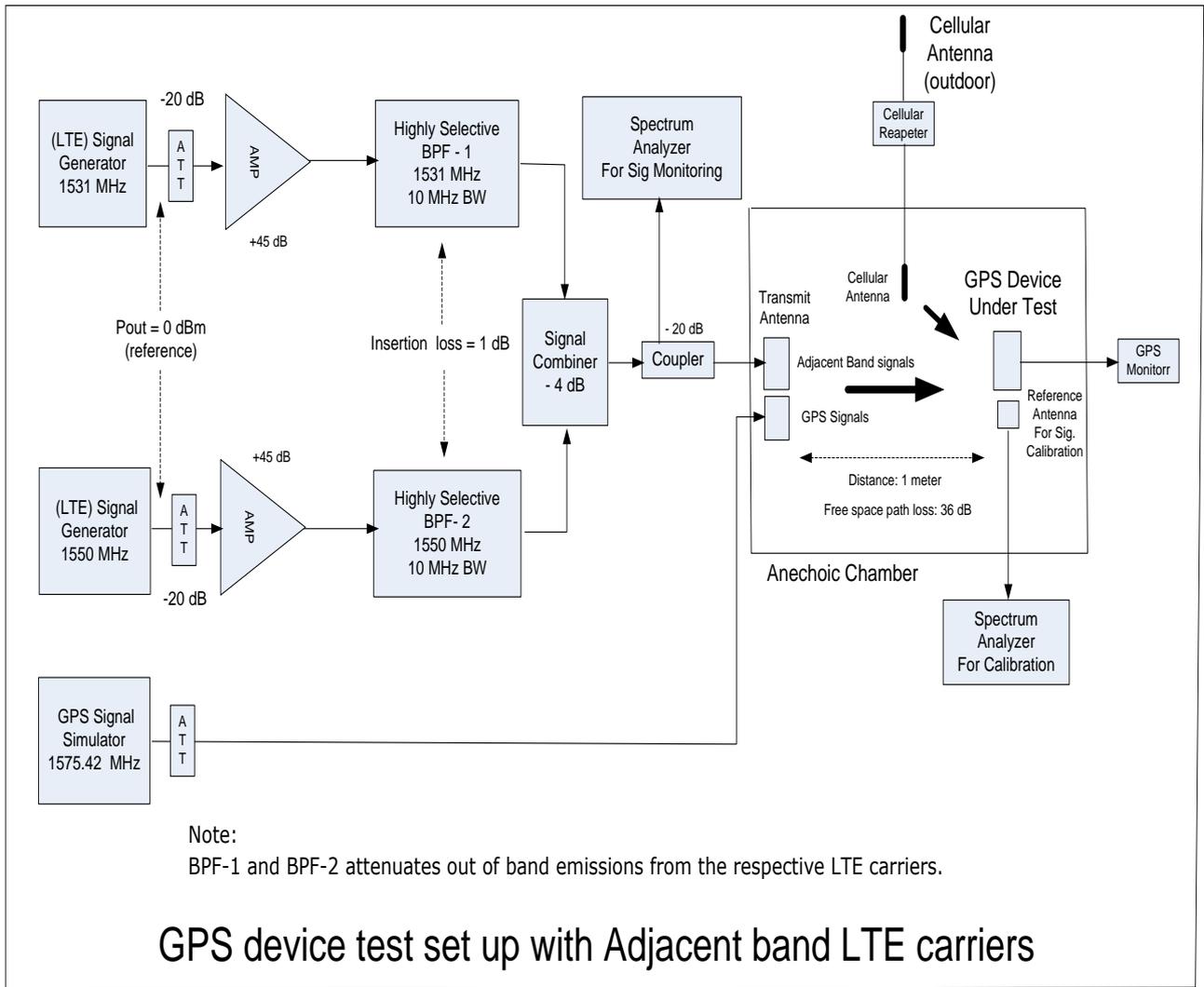


Figure A.3.3: Test Setup

Note: The attenuator at the output port of the LTE generator is not needed if the output power of the generator can be controlled in the desired range.

The cellular outdoor antenna plus repeater could be replaced by a cellular communication test equipment.

3 different links need to be established: LTE DL, LTE UL and GPS.

## Link budget and assumptions for the LTE UL

The setup is shown in the Figure A.3.4 . Two LTE generators are in the setup to use the same setup as when two carriers have to be generated.

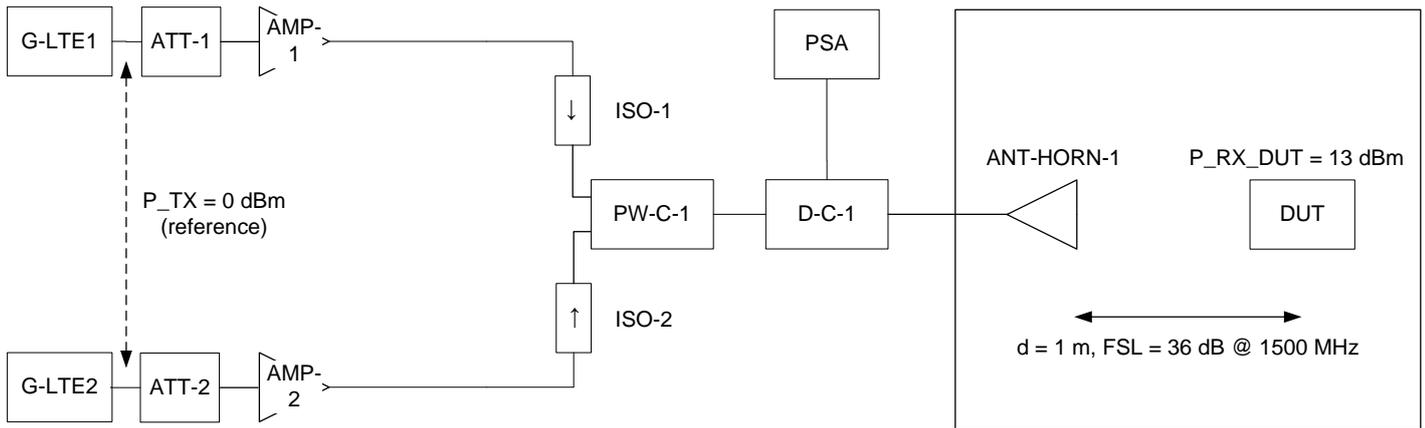


Figure A.3.4: test Setup

Provisional link budget for LTE generator 1 signal

	f (MHz)	1500,00	1500,00
	d (m)	1,00	1,00
		Option 1	Option 2
G-LTE1	VSG Output power (dBm)	<b>-4,83</b>	<b>0,00</b>
ATT-1	Attenuator (dB)	0,00	-1,00
AMP-1	Amplifier Gain (dB)	40,00	45,00
ISO-1	RF Isolator Insertion Loss (dB)	-0,10	-0,10
PW-C-1	Power Combiner Insertion Loss (dB)	-0,30	-0,30
D-C-1	Directional Coupler Insertion Loss (dB)	-0,40	-0,40
Cables	Cable Loss (dB)	-1,40	-1,40
ANT-HORN-1	Transmission Antenna Gain (dBi)	16,00	8,00
FSL(1m)	Free-Space Loss (dB)	-35,97	-35,97
ANT-DUT	DUT Reception Antenna Gain (dBi)	0,00	0,00
	Power Received at DUT (dBm)	13,00	13,83

Assumptions:

- The maximum interference power at the position of the DUT is 13 dBm. Reasoning: Maximum output power of an LTE UE is +23 dBm. LTE UE antenna to GPS antenna coupling loss assumption is [10 dB].
- Antenna used to transmit the LTE generator 1 signal is a horn antenna. Gain between 8 and 16 dB at 1500 MHz
- LTE generator 1 antenna and DUT distance: 1 m
- The LTE generator 1 (VSG) maximum output power: 17 dBm
- Amplifier characteristics: Maximum input signal: 0 dBm; Gain: [40 or 45 dB]
- Cable (TBD) loss at 1500 MHz: 14.1 dB/100 m. Maximum cable length: 10 m.

# Link budget and assumptions for the LTE DL

The setup is shown below:

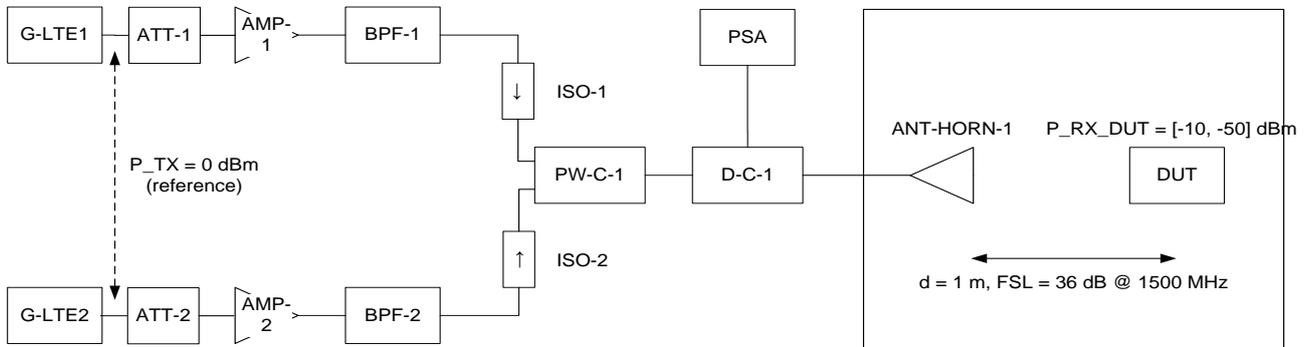


Figure A.3.5: Test Setup

## Provisional link budget

		1500,00	1500,00	1500,00	1500,00
		Option 1	Option 2	Option 1	Option 2
	f (MHz)	1500,00	1500,00	1500,00	1500,00
	d (m)	1,00	1,00	1,00	1,00
G-LTE1	VSG Output power (dBm)	<b>-6,83</b>	<b>0,00</b>	<b>-6,83</b>	<b>0,00</b>
ATT-1	Attenuator (dB)	-20,00	-24,00	-60,00	-64,00
AMP-1	Amplifier Gain (dB)	40,00	45,00	40,00	45,00
BPF-1	Band Pass Filter Insertion Loss (dB)	-1,00	-1,00	-1,00	-1,00
ISO-1	RF Isolator Insertion Loss (dB)	-0,10	-0,10	-0,10	-0,10
PW-C-1	Power Combiner Insertion Loss (dB)	-0,30	-0,30	-0,30	-0,30
D-C-1	Directional Coupler Insertion Loss (dB)	-0,40	-0,40	-0,40	-0,40
Cables	Cable Loss (dB)	-1,40	-1,40	-1,40	-1,40
ANT-HORN-1	Transmission Antenna Gain (dBi)	16,00	8,00	16,00	8,00
FSL(1m)	Free-Space Loss (dB)	-35,97	-35,97	-35,97	-35,97
ANT-DUT	DUT Reception Antenna Gain (dBi)	0,00	0,00	0,00	0,00
	Power Received at DUT (dBm)	-10,00	-10,17	-50,00	-50,17

### Assumptions

- Interference power levels at the position of the DUT fall in the range of [-10 to -50] dBm.
- Antenna used to transmit the LTE generator 1 signal is a horn antenna. Gain between 8 and 16 dB at 1500 MHz
- Cable loss at 1500 MHz is 14.1 dB/100 m. 10 meters of cable are foreseen to be needed.
- LTE generator 1 antenna and DUT distance: 1 m
- The LTE generator 1 (VSG) maximum output power: 17 dBm
- Amplifier characteristics: Maximum input signal: 0 dBm; Gain: [40 or 45 dB]
- Cable (TBD) loss at 1500 MHz: 14.1 dB/100 m. Maximum cable length: 10 m.

## Link budget and assumptions for the GPS link

The setup is provided below

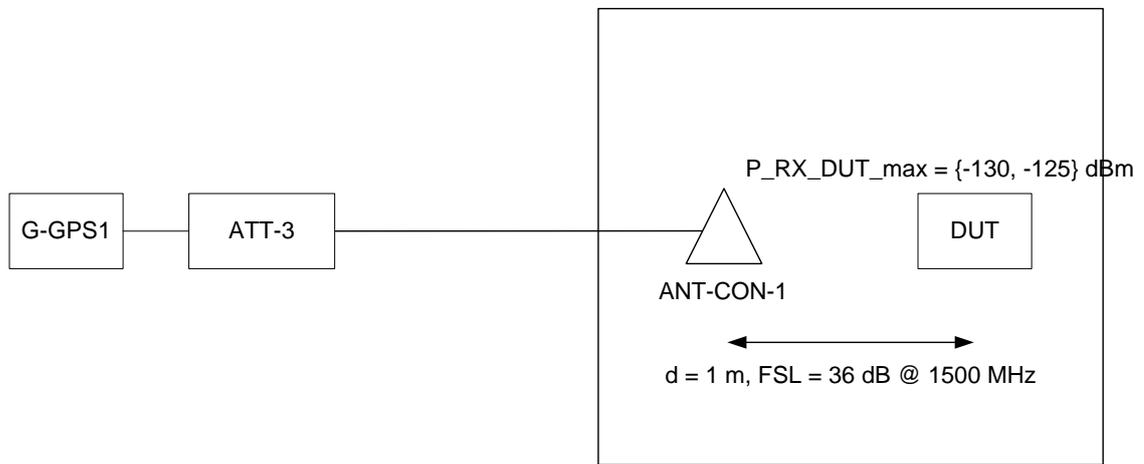


Figure A.3.6: Test Setup

### Provisional link budget

	f (MHz)	1500,00	1500,00
	d (m)	1,00	1,00
		GPS Case 1	GPS Case 2
G-GPS1	VSG Output power (dBm)	-10,00	-10,00
ATT-3	Attenuator (dB)	85,13	81,13
Cables	Cable Loss (dB)	-1,40	-1,40
ANT-CON-1	Transmission Antenna Gain (dBi)	2,50	2,50
FSL(1m)	Free-Space Loss (dB)	-35,97	-35,97
ANT-DUT	DUT Reception Antenna Gain (dBi)	0,00	1,00
	Power Received at DUT (dBm)	-130,00	-125,00

#### Assumptions:

- In the paper “GPS Receiver Architectures and Measurements”, the authors calculate the satellite-to-receiver link budget and determine the minimum expected received signal power as -157.6 dBW (-127.6 dBm). The two proposed GPS power levels at the position of the DUT are -125 dBm (2.6 dB above the minimum level) and -130 dBm (2.4 dB below the minimum level).
- Antenna used to transmit the GPS signal is a conical antenna. Gain is around 2.5 dB at 1500 MHz
- Cable loss at 1500 MHz is 14.1 dB/100 m. 10 meters of cable are foreseen to be needed.
- GPS generator 1 antenna and DUT distance: 1 m
- The LTE generator 1 (VSG) minimum output power: -136 dBm

## Signal description

### GPS Signal

Name	Setting	Comment
Center frequency	1575.42 MHz	
RF Band	L1	
Filter	Rectangular	
Scenario	TBD	Pre-set
Location	TBD	
	TBD	
Altitude	1.5 m	
Almanac file	SEM464.txt	
GPS Week xxxx	TBD	
Start time	TBD	
Spreading	Enabled	
Initial HDOP	TBD	
Initial PDOP	TBD	
Power per SV	-125 dBm/-130 dBm	

## LTE Signals

Name	Setting	Comment
Carrier frequency	As shown in section - 3	
Release	3GPP R8 Stage 1	
Duplexing	FDD	
Modulation	OFDMA	
Frame Duration	10 ms	
Sub frame Duration	0.5 ms	
Channel Bandwidth	5/10 MHz	According to test
PRB Bandwidth	0.375 MHz	
Sampling Rate	15.36 MHz	
FFT Size	1024	
Dummy Data	PRN9	

## Range calibration

With the exception of the cellular path, all paths are required to be calibrated.

Path calibration will be carried out using a substitution method. In this method, a test antenna is used as the transmitting device and a measuring antenna is used to enable a measurement of the transmitted signal strength in the vicinity of the DUT. Signal strength (e.g. power level) is measured using a spectrum analyzer (SA) connected to the measuring antenna. The test and measuring antennas, the spectrum analyzer and the cable used to connect the measuring antenna with the spectrum analyzer shall be calibrated along the measurement frequency range. For the frequency ranges considered in this work, waveguide horns are recommended for both the test and measuring antennas. A tuned dipole may also be used for the measuring antenna.

The substitution method is as follows:

1. The test antenna shall be located at the position of the intended transmitter.
2. The measuring antenna shall be located at the intended position of the DUT and shall be connected to a spectrum analyzer.
3. The transmitter shall be switched on, [if possible without modulation], and the spectrum analyzer shall be tuned to the frequency of the transmitter.
4. The orientation and height of the test antenna shall be varied until a maximum signal level is detected by the spectrum analyzer.
5. The output power of the signal generator feeding the test antenna shall be varied until the desired signal level (see section 6 for details on these levels) is received by the spectrum analyzer. This output power shall be recorded.

This procedure shall be repeated for all relevant signal levels to be received at the position of the DUT (see section 6 for details on these levels).

During tests, the measuring antenna is substituted by the DUT and the output power of the signal generator is set to the value that achieved the desired receive signal level in the substitution method.

The list of paths to be calibrated is listed in the table below.

Path ID	From	To	Frequency (MHz)	Comment
1	G-LTE1	DUT	1528.8	
2	G-LTE2	DUT	1552.7	
3	G-LTE1	DUT	1531	
4	G-LTE2	DUT	1550.2	
5	G-LTE1	DUT	1630.3	
6	G-LTE1	DUT	1654.2	
7	G-LTE1	DUT	1632.5	
8	G-LTE1	DUT	1651.7	
9	G-GPS1	DUT	1575.42	
10	Meas. Ant.	SA	1 GHz-3 GHz	

## Measurement Uncertainties

TBD

## GPS Satellite Scenario

The scenario will be a fixed receiver scenario based in TBD City. (Signal generator is pre-configured). All satellites shall have the same power level. Auto SV handover is enabled.

### A.3.6 Test Procedure:

Parameters to be characterized during the tests:

- Acquisition threshold: Characterize acquisition performance of receiver by varying the LTE signal power to determine the “Acquisition threshold” defined as the LTE signal power at which the DUT just acquires minimum 4 satellites.
- Tracking threshold: Characterize GPS Rx tracking performance in presence of LTE signals by monitoring the receiver S/N degradation. Determine the “Tracking threshold -3 dB” defined as LTE signal power at which the Rx S/N is degraded by 3 dB, and “Loss of lock threshold” defined as LTE signal power at which the DUT receiver loses all satellite lock.

## Test position determination

1. Tests shall be performed at the intended DUT normal orientation relative to the zenith.
2. If there are two normal orientations in the DUT, tests should be run for the worst case.
3. If the normal orientation is not clear, a suitable orientation shall be determined or if not possible the orientation used in the test must be reported in the test report.

Method to determine a suitable orientation

- a. Turn on the GPS simulator and set the output power to match the -130 dBm at the DUT.
- b. Get a reading of the GPS S/N levels.
- c. Obtain max S/N level by rotating turntable slightly to a different position. ( on  $\theta$  axis,)
- d. Rotate turntable ( $\varphi$  axis or horizontal plane) searching for maximum S/N.
- e. Iterate through (d) and (f ) until the maximum can be identified.

## Test procedure

For each test the following measurements shall be performed following the next steps

1. Set the GPS signal simulator power at the desired power level (such that signal level at the DUT input is -125 dBm or -130 dBm).
2. Set the LTE signal OFF and record the number of GPS satellites acquired (should be 8) and the average S/N reported by the DUT
3. Set the desired LTE signal configuration to the minimum in the range to be tested and record the number of GPS satellites acquired (should be 8) and the average S/N reported by DUT.
4. Increase the LTE signal generator power in 1 dB increment
5. Record the number of satellites acquired and the average S/N reported by DUT
6. Continue steps 4 and 5 until
  - a. 4 satellites loose acquisition (loss of acquisition). 4 satellites are still being tracked. Record the signal power level. This is “Acquisition threshold” value.
  - b. The average S/N is 3 dB below the value reported in step 2. Record the LTE signal power level. This value is “Tracking threshold -3 dB”.
7. Continue steps 4 and 5 until all (8) satellites loose lock. Record the signal level. This is defined as “Loss of lock threshold” value.
8. Decrease the LTE signal generator power in 1 dB decrement, and record the acquisition status of each satellite. Record the number of satellites being tracked at each power level.
9. Continue step 8 until 4 satellites are acquired. Rerecord the signal level. This should correspond to “Acquisition threshold” value.
10. Continue step 8 until all (8) satellites are acquired. Record the signal level. This is the interference free value.

Repeat steps 1 through 10 for each GPS signal power level, and LTE configuration.

### A.3.7 Test report requirements

Each test report or calibration certificate shall include at least the following information:

- a) a title (e.g. “Test Report”);
- b) the name and address of the laboratory, and the location where the tests were carried out, if different from the address of the laboratory;
- c) unique identification of the test report (such as the serial number), and on each page an identification in order to ensure that the page is recognized as a part of the test report, and a clear identification of the end of the test report;
- d) the name and address of the customer;
- e) identification of the method used;
- f) a description of, the condition of, and unambiguous identification of the item(s) tested;
- g) the date of receipt of the test item(s) where this is critical to the validity and application of the results, and the date(s) of performance of the test;

- h) reference to the sampling plan and procedures used by the laboratory or other bodies where these are relevant to the validity or application of the results;
- i) the test results with, where appropriate, the units of measurement;
- j) the name(s), function(s) and signature(s) or equivalent identification of person(s) authorizing the test report;
- k) where relevant, a statement to the effect that the results relate only to the items tested or calibrated.

NOTE 1: Hard copies of test reports should also include the page number and total number of pages.

NOTE 2: It is recommended that laboratories include a statement specifying that the test report shall not be reproduced except in full, without written approval of the laboratory.

Following is suggested template for such reporting. **TBD**

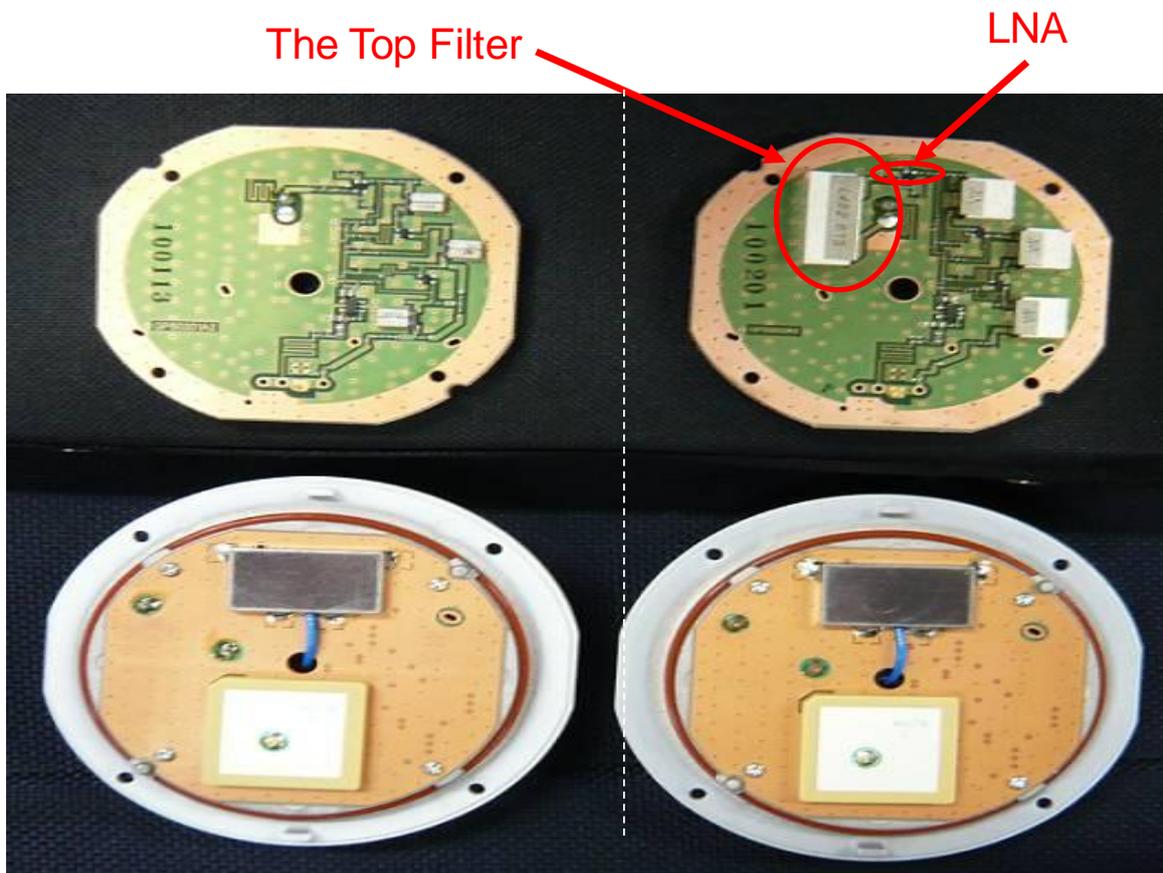
## Appendix 4

### A.4 Timing GPS RX Unit

Figure A.4.1 shows modifications applied to a Panasonic GPS antenna (prior to the introduction of the new model VIC - 100 enhanced) described in Appendix 5. The pre-select filter (labeled as “Top Filter”) is installed between the GPS patch antenna element and LNA. The dimension of the pre-select filter is 20x8x6 mm.

Figure A.4.2 shows the measured frequency response of a modified and an unmodified antenna from 1530 MHz to 1630 MHz. Note that the relative attenuation in MSS L-band (1525 to 1559 MHz) is improved by more than 65 dB due to modifications applied, resulting in an additional rejection of BTS carriers in the band. This rejection improves the overload performance of the GPS receiver.

Figure A.4.3 shows the proposed specification of the GPS Antenna (Filter and LNA) for the GPS receiver that identifies the most critical rejection specification for the filter. (-65 dB at frequencies less than 1560 MHz)



Normal GPS timing antenna

Enhanced GPS timing antenna with Top Filter for High Jamming Rejection

*Figure A.4.1*

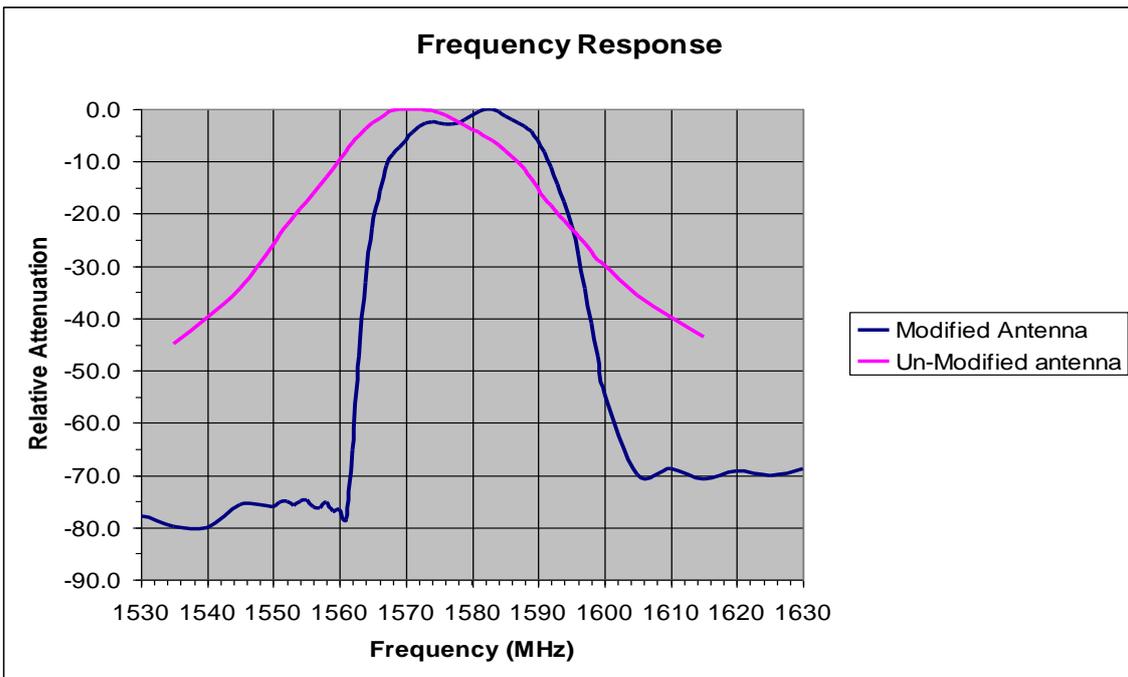


Figure A.4.2

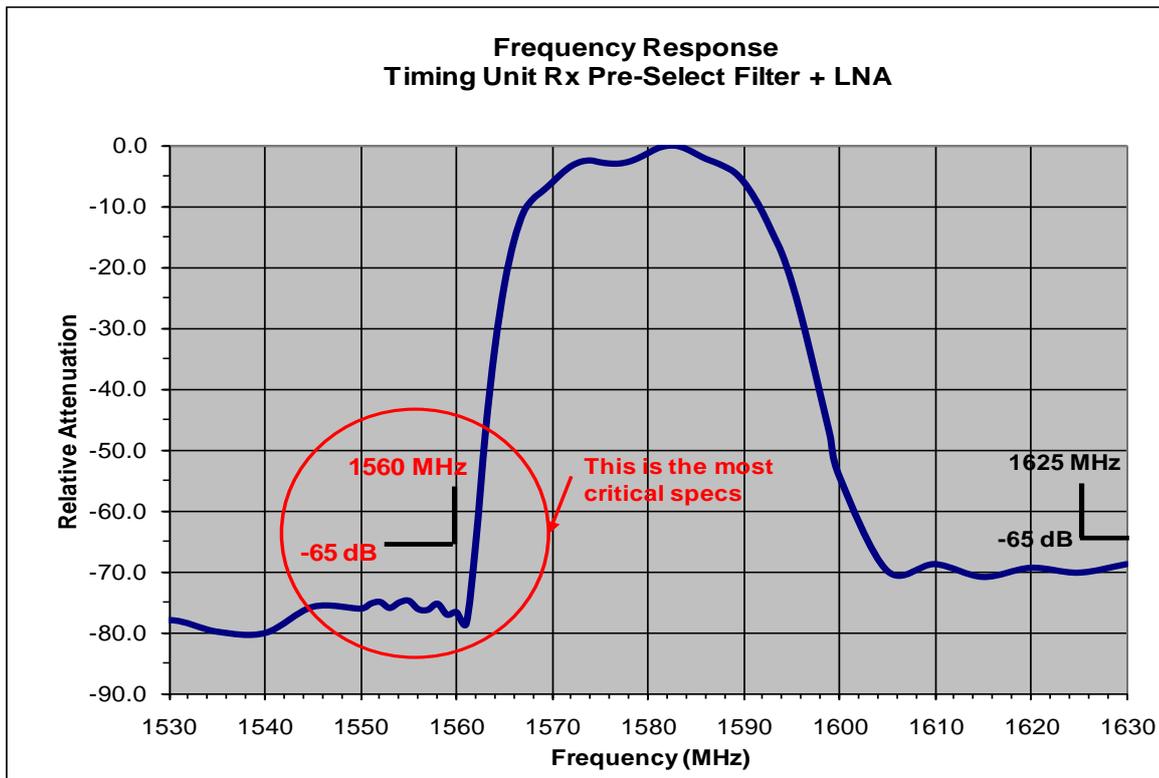


Figure A.4.3 – 3 Pre-select Filter + LNA Specifications

# Appendix 5

## A.5 Timing GPS Rx Unit Antenna Specification

Panasonic Data Sheet for Model No. CCAH32NT21

Panasonic Data Sheet for Model No. VIC100

Material extracted from:

<http://pewa.panasonic.com/lighting/gps/VIC100-enhanced/>

For the application which requires superior noise performance ...

### Immunity to noise and interference

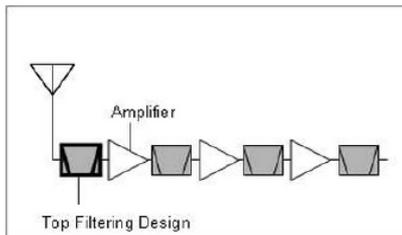
Secure performance by attenuating noise and interference near GPS L1 frequency through the special filtering design.

### Durability to severe environment

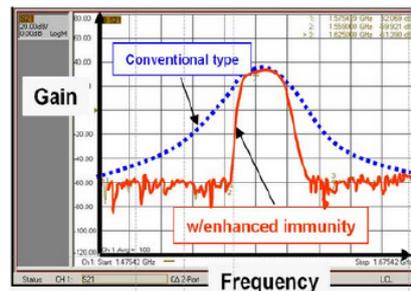
Excellent performance under severe environment (rain, snow, etc.) with application conscious design.



### Special filtering design



### Immunity to noise and interference



Item	Specifications
Frequency range	1575.42 MHz $\pm$ 1.023 MHz
Polarization	Right-hand circular
Total gain	30 dBi Minimum
Attenuation	65 dB c typical @ 1559MHz, @ 1625 MHz
Noise figure	4.5dB Typical
VSWR	2.5 Maximum
Operating Voltage	DC 5V $\pm$ 0.5V
Operating Current	23mA Typical 30mA Maximum
Dimension	98.4 mm H x 90.0 mm D (without connector)
Weight	295g Typical
Connector	TNC or N Connector
Operating Temp.	-40 to 85°C
Storage Temp.	-40 to 90°C
RoHS Compliant	

Specifications are subject to change without notice