L-Band Interferer Test Report and Mitigation

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Abstract

This report summarizes the results of testing performed by Qualcomm to assess the potential impact of LightSquared's LTE base stations operating on BC24 (L band) on GPS receivers in mobile phones. This report will also suggest some methods and techniques for mitigation for future devices.

1. Introduction

The Qualcomm GNSS test engineering group has tested multiple Qualcomm reference designs for their resilience to LightSquared terrestrial (LTE) base station blockers. Each reference design is a mobile phone designed for Qualcomm internal test and integration. Each such phone uses a different Qualcomm chipset. The selected chipsets comprise several different generations of the GPS signal processing engine, deployed over more than 100 million mobile phones.

Observed performance differences may be due not only to chipset differences but also front-end component differences. Qualcomm does not manufacture the front-end components.

While testing efforts are still in progress, the purpose of this report is to provide a preliminary snapshot of test results along with the associated test methodology. At this time, testing has been restricted to GPS only and Glonass testing may be implemented at a future date. The term GNSS is used in this report generically for any GPS or GPS/Glonass receiver.

2. MSS/ATC blockers

LightSquared's planned frequency plan for each phase of their deployment is identified in Table 1.

Table 1 LightSquared frequency plan

Phase	Channel bandwidth	Channel #1			Channel #2		
		$EARFCN_{DL}$	Center frequency (MHz)		$EARFCN_{DL}$	Center frequency (MHz)	
			DL	UL		DL	UL
0	5 MHz	7977	1552.7	1654.2	N/A		
1	5 MHz	7977	1552.7	1654.2	7738	1528.8	1630.3
2	10 MHz	7952	1550.2	1651.7	7760	1531.0	1632.5

With sufficient filtering at the LightSquared BS and UE, emission in the GNSS band can be controlled without compromising performance of the MSS/ATC data service. That emission will not be considered further here.

However, from the perspective of the established GNSS user base, the LightSquared terrestrial base stations represent a new interferer. Assessing the impact of that on GPS receiver performance is the subject of the next two sections of this report.

Interference from the base station downlink carriers in the LightSquared phase 2 deployment has been tested. Each of the two carriers is presently being modeled as AWGN with 9 MHz bandwidth. One signal generator with arbitrary waveform generation capability is used to generate both carriers, as shown in the standalone test set-up of Figure 1. To filter out any local oscillator feed thru and emission in the GNSS band, the signal generator output is passed through high-Q base station filters provided by LightSquared.

Future test plans include replacing the AWGN carriers with OFDM waveforms and adding coverage of uplink bands and other deployment phases.

3. Standalone GPS tests

Using the set-up shown in Figure 1, position-level sensitivity as a function of LightSquared jammer power was measured. With the same set-up, it is also possible to investigate other key performance indicators such as time-to-fix and fix accuracy. The tests were performed at room temperature.

These standalone GPS tests are performed with the mobile's cellular (wireless wide-area network, or WWAN) communications function disabled. No time or frequency aiding is available from the network.

A full constellation of GPS satellites is simulated, such that typically 8 satellites are in view at any instant of time. All satellites have the same power and the user location is fixed throughout the test. The jammer power is swept from −80 dBm to −30 dBm in 10 dB increments, and the following steps are repeated for each jammer power:

1. Ephemeris, almanac, position, and time are deleted.
2. The satellite power is set to −120 dBm and a tracking session is initiated. The mobile is allowed 13 minutes to decode almanac and ephemeris with no jammer present.
3. The LightSquared base station jammer is turned on.
4. A GPS tracking session is re-initiated (hot start) with fixes generated once per second.
5. The satellite power is decreased in 1 dB steps with a 2 minute dwell at each power level. The satellite power is stepped down in this way from −120 dBm to −160 dBm.

The results are shown in Figure 2 and Figure 3, using two different definitions of sensitivity. Each of the 4 curves shows the performance of a different phone reference platform, and each reference platform uses a different chipset.

In Figure 2, sensitivity is defined as the lowest satellite power that gives 100% fix yield for the 2 minute dwell. This definition is relaxed in Figure 3 to allow 50% fix yield for the dwell.

The addition of a fix accuracy requirement is being considered, to ensure that fixes at sensitivity are not corrupted by large errors. However, no such constraint is applied in the results reported here, although the mobile is configured to not report a fix if the estimated standard deviation of horizontal error exceeds 250 m.

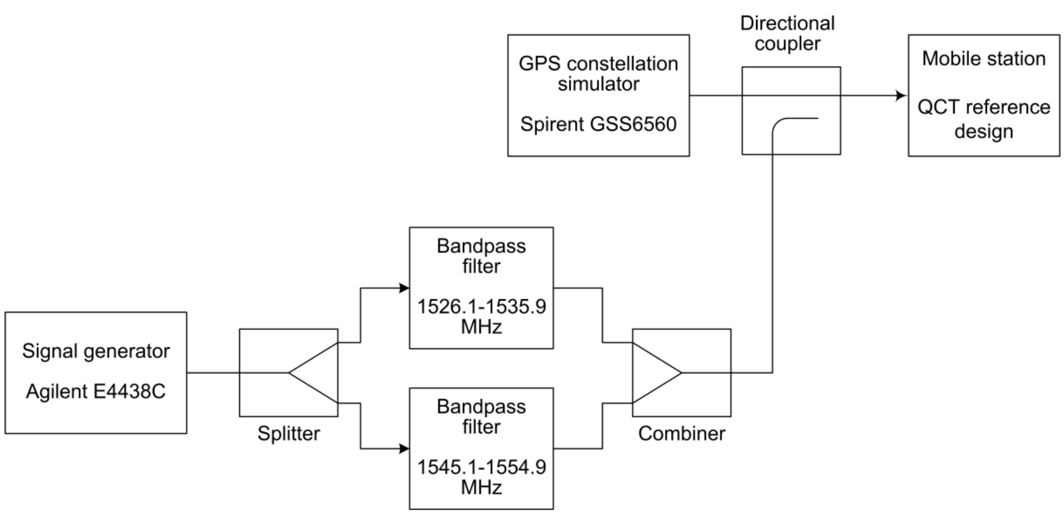

Figure 1 Equipment set-up for standalone sensitivity tests

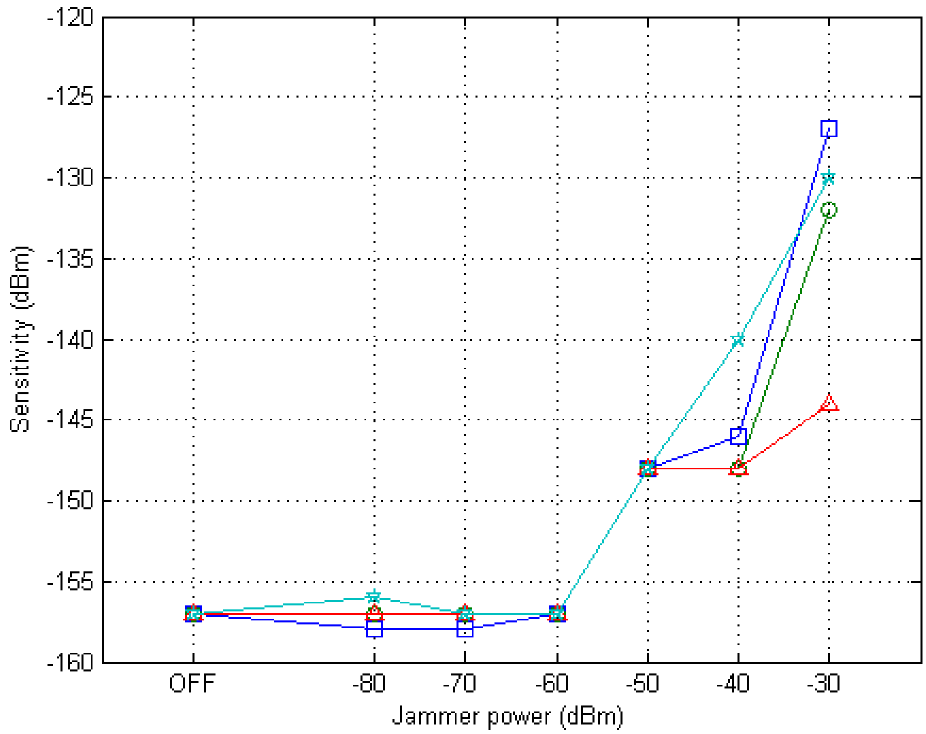

Figure 2 Standalone GPS sensitivity as a function of MSS/ATC power for 4 different platforms

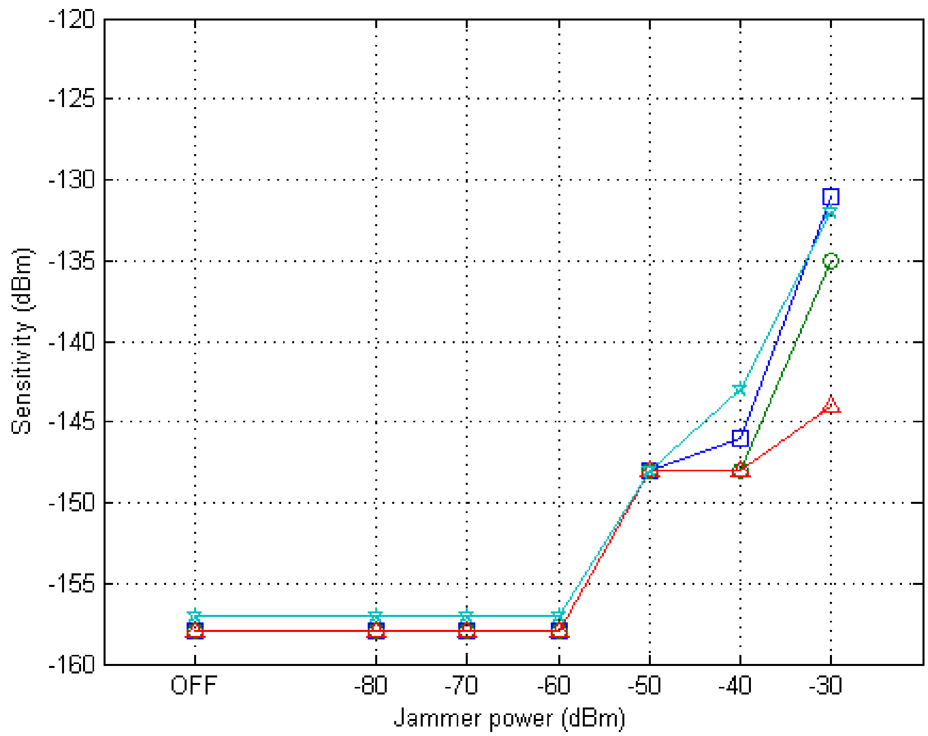

Figure 3 Sensitivity with yield requirement relaxed to 50% for 4 different platforms

Notes:

1. As mentioned at the beginning of this report, the testing is preliminary, and validation of the test setup and methodology, especially at high jammer powers, is still ongoing.
2. It is also important to note that while the above tests sweep jammer power over a range of values, which is a generally-accepted way to characterize any receiver's susceptibility to a jammer, the actual received power distribution in a cellular network is statistical. Specficially, the probability of a mobile user seeing -30 dBm jammer power may be a very small percentage, especially when operating close to GPS sensitivity level.

4. A-GPS tests

To characterize assisted GPS performance, the standard TIA-916/3GPP2 C.S0036-0 MS-assisted GPS sensitivity test in a CDMA network was performed, while injecting the LightSquared base station jammer.

This is a conducted test that simulates 4 satellites at equal power. The position server provides assistance data for these satellites and an additional 5 satellites that are not simulated. A sequence of voice calls is established. During each call, an MS-assisted session is initiated, and the mobile is allowed 16 s to execute its satellite search and transmit the measurement results to the position server. The measurement results—code phase, Doppler frequency, and satellite power—must pass prescribed accuracy checks.

The standard test was modified as follows:

- The LightSquared jammer was coupled into the GPS receiver. This is the same jammer used in the standalone testing.
- A portion of the cellular reverse link was also coupled into the GPS receiver, simulating 10 dB antenna isolation. This is standard procedure in Qualcomm testing. It predicts performance in the CTIA certification test which uses a radiated version of the TIA-916 test.
- The voice call is carried out at maximum reverse link power. The standard does not specify this power.
- A maximum of 40 sessions were allowed in which to satisfy the required statistical bounds on measurement accuracy. The standard itself does not impose an upper limit on the number of sessions attempted.

The jammer power was swept from −50 dBm to −30 dBm in 5 dB steps. For each jammer power, the simulated satellite power was adjusted (with 1 dB resolution) until the breaking point was discovered. The maximum satellite power attempted was −125 dBm.

The line markers in Figure 4 give the weakest satellite power for which the test passes. That power is effectively the TIA-916 sensitivity of the mobile.

The standard does not call for finding the threshold of failure in this way. Rather, it just requires a passing result when the satellite power is −147 dBm. This requirement has been tightened to −149 dBm, as shown by the limit line in Figure 4. The markers intersecting that limit line were determined by setting satellite power to −149 dBm and adjusting jammer power (with 1 dB resolution) until the breaking point was found.

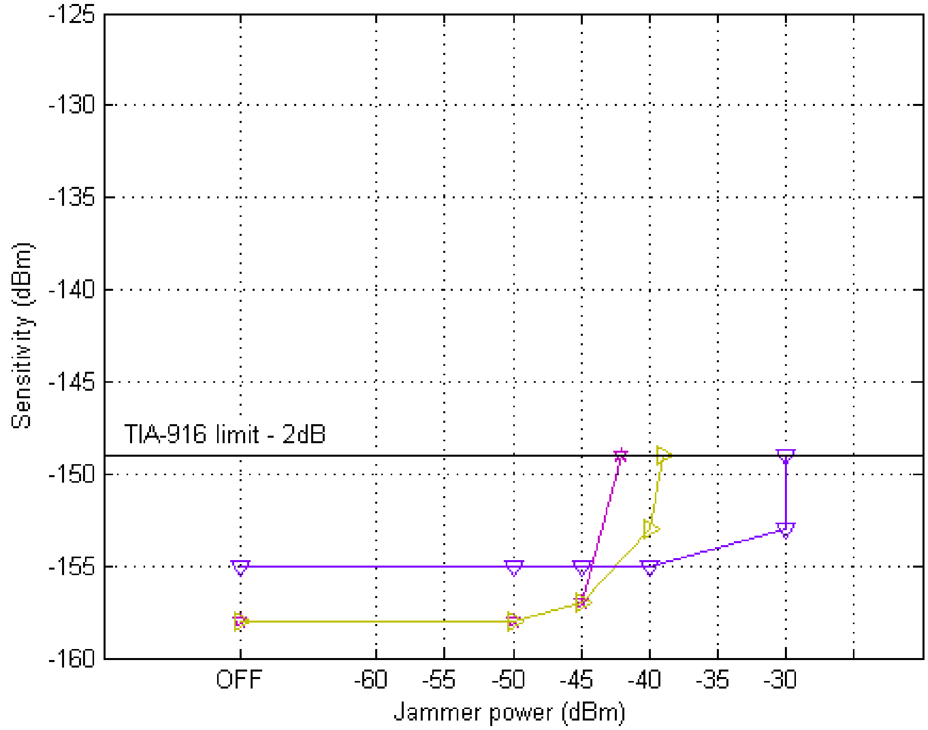

Figure 4 CDMA MS-assisted GPS sensitivity as a function of MSS/ATC power

Notes:

1. As mentioned earlier, the testing is preliminary, and validation of the test setup and methodology, especially at high jammer powers, is still ongoing.
2. The same point about the statistical distribution of jammer power applies here too. In addition, in an indoor environment, at low GPS received signal levels, the jammer power would also be less.

5. Strategies for Mitigation – Framework

For future devices, there are a number of approaches to be considered to improve performance and robustness of a GPS/GNSS receiver in the presence of this L-Band terrestrial downlink.

The proposed requirements could be summarize as follows.

- Downlink (DL) jammer level: up to -30 dBm in band 1525 – 1555MHz (see Table 1 "LightSquared frequency plan" for exact frequencies)
- DL only present, no L-band uplink on the phone – those can be considered separately
- Requirement for GPS+Glonass support
- Consideration of both External LNA (two filter) and no External LNA (one filter) RF front end scenarios
- GPS RX degradation through (1) high level of Jammer (saturation, reciprocal mixing, etc) and (2) phase 1 and 2 of deployment considers 2 simultaneous channels which could generate IM3 falling into GPS L1 band
- No requirement for or account taken of (a) wideband GPS receivers that use +/-10 MHz or (b) Compass B1 centered at 1561 MHz – which may be deployed in China in 2013-2014 time-frame.

Preliminary measurement results on various representative Qualcomm platforms (see Figures 2 and 3 of earlier section) indicate that typically up to -60dBm jammer power in this band can be tolerated without violating sensitivity requirements.
As a first approach, these results suggest that an additional rejection of 30dB may be required to support up to -30dBm jammer at the antenna connector. This does not take into account any relaxation or adjustment for the statistical distribution of received power, as mentioned above.

6. Possible Solutions – Front End (FE) Filter Considerations for L-Band Downlink

There are some possibilities that can be considered based on the preliminary test results that have been obtained.

6.1. Configuration without eLNA:

The following figure illustrates the typical configuration without an off chip LNA (external LNA, eLNA). Only one external band-pass filter is used in this low cost configuration. Typically, SAW technology is used for the external band-pass filter.

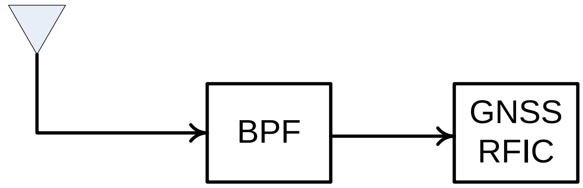

Figure 5 FE configuration without eLNA

Two options are possible.

- Option 1: Stay with SAW technology typically used in current GPS FE solutions
    - Current GPS FE filters typically provide only a few dB (e.g. 3dB) rejection at 1555MHz while featuring ~1dB insertion loss in the GPS band. Significant rejection (>40dB) is achieved below ~1543MHz (at room temp)
    - Due to process and temperature variation in SAW filters a guard band (between pass-band and stop-band) of at least 20 - 25MHz is required to guarantee low insertion loss.
    - The gap between GPS L1 band and 1555MHz is only ~19MHz. Guaranteeing >30dB below 1555MHz would likely cause the insertion loss in the GPS band to increase by a few tenths of a dB (e.g. 0.3-0.5dB). For low-cost devices without eLNA, higher insertion loss is typically acceptable.
    - If insertion loss is too big, the out of band rejection spec could be iterated or relaxed – potentially taking into account received jammer power distributions as mentioned above.
- Option 2: Switch to different filter technology that provides steeper stop band rejection (e.g. FBAR or BAW)
    - For example, FBAR/BAW is known to achieve low insertion loss while providing very steep stop-band rejection, e.g. insertion loss could be less than 1.2dB while achieving >45dB rejection at ~1% of the pass band frequency over process and temperature. 1555MHz is 19MHz below passband which corresponds to ~1.2% and seems feasible.
    - FBAR or BAW technology is typically more expensive than SAW. The cost impact could be on the order of 5 cents, depending on volume.

6.2. Configuration with eLNA:

To achieve best sensitivity or combat insertion losses due to long traces, an off chip LNA (external LNA, eLNA) is commonly used in Smartphones, as shown in the configuration below:

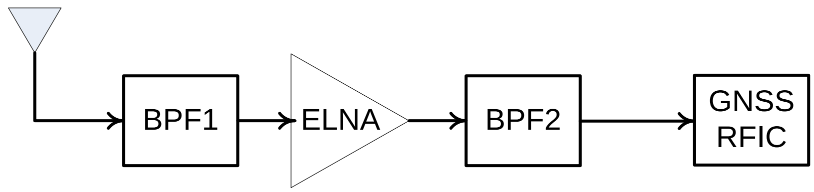

Figure 6 FE configuration with eLNA

An eLNA configuration typically uses one filter prior to eLNA and another filter post eLNA. The required attenuation of >30dB below 1555MHz can be distributed between BPF1 and BPF2 while keeping in mind:

- BPF1 needs to provide sufficient rejection to eliminate the risk IM3 in the eLNA (simultaneous presence of LightSquared channel 1 and channel 2 can cause the IM3 product to fall into the GPS band)
- Maintaining low insertion loss prior to the eLNA will ensure optimum GPS sensitivity

Since the filtering load is distributed across two filters, it is expected this could be achieved using SAW filters, while maintaining minimal overall system noise figure impact. Alternatively, using FBAR/BAW (or similar) with low insertion loss and high stop-band rejection as BPF1 while leaving BPF2 as is would represent a possible solution.

6.3. Summary of Mitigation Approaches

As stated above, although the testing initiatives have not been concluded, the preliminary results suggest that additional 30dB attenuation is needed compared to a typical existing solution (applies to both eLNA and no eLNA). This does not take into account any relaxation or adjustment for the statistical distribution of received power. The stopband is very close to the pass-band with a frequency offset of only ~1.2% of passband. Very likely, for a single filter front end topology, SAW technology may not be enough of a robust solution over process and temperature. FBAR/BAW based filters may be a potential candidate due to their low insertion loss and high stopband rejection. Going with FBAR/BAW may add cost to the GPS solution, possibly on the order of ~5 cents more than SAW. Filter vendors should be able to assess the feasibility of such solutions and provide a better estimate on the associated cost.