This presentation is a variation on the webinar held April 21, 2011.
http://www.gpsworld.com/wireless/market-insights-webinars-8423

Comments on LightSquared Ancillary Terrestrial Component (ATC) Interference Potential
Figure 1: Lightsquared Downlink LTE L-Band and GPS Band

Figure From: LightSquared, "Preliminary results on Overload Characteristics of GPS Receivers in Proximity to LightSquared's L-band Terrestrial Base Stations (BTS) and User Equipment (UE)" 3GPP TSG-RAN4 #57AH R4-110470 Austin, TX, US 17 -21 Jan, 2011

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

- In Band Interference
  - Light Squared Transmits Sidelobe Energy Into GPS Frequency Band

- Out of Band Interference
  - GPS Receiver Frontend Saturation (Blocking)
  - Two Tone Intermodulation Converts Out of Band Interference Into In Band Interference
In Band Interference Effects
LightSquared Plans to Use 4G LTE Orthogonal Frequency Division Multiplex (OFDM) Signal Format
Situation at 500 meters Without Any Filtering

Spectrum at Antenna Output
1500 Watt EIRP Interferer at 0.5 km, $G_J=0$ dBi, $G_{sv}=0$ dBiC

Unfiltered OFDM Signal centered at 1552.5 MHz

1559-1610 MHz Radio Navigation Band (US)

-204 dBW/ Hz Thermal Noise Floor

C/A Code Signal

P(Y) Code Signal

M Code Signal

source_spectra_lightsquared.m

10 May 2011 LS Consulting / loganscott53@gmail.com
Situation at 500 meters With 66 dB Out of Band LTE Filtering

66 dB Filtered OFDM Signal centered at 1552.5 MHz

1559-1610 MHz Radio Navigation Band (US)

-204 dBW/Hz Thermal Noise Floor

C/A Code Signal

P(Y) Code Signal

M Code Signal

source_spectra_lightsquared.m
Effective Baseband $C/N_0$ (numeric)

$$\left[ \frac{C}{N_0} \right]_{\text{effective}} = \frac{C}{N + I}$$

$$= \frac{C_s \left[ \beta_r / 2 \int G_s(f) df \right]}{\beta_r / 2 \int G_s(f) df + C_t \int G_t(f) G_s(f) df}$$

In Band Interference Is Not The Problem
66 dB Filtered OFDM(5) ATC All Cases

Effective $C/N_0$ (dB-Hz) vs Range (km)

- M-Code
- C/A-Code (24 MHz Passband)
- C/A-Code (1.7 MHz Passband)
- Y-Code

28 dB Conventional Track Threshold

All Cases: $T_{ant.} = 130K$, NF=2 dB, L=1 dB
Free Space, $G_{sig} = 0 \text{dBIC}$, $G_{jam} = 0 \text{dBIC}$
Out of Band Interference Effects

GPS Front End Saturation (Blocking)
Nonlinearity Effects (Two Tone Intermodulation)
LightSquared Forward Link Frequency Plan
Each LTE Carrier Up to 1500 Watts EIRP

1552.5 MHz Center

Phase 0/1* Plan

LS1
LTE Carrier
1526.3 M 1531.3 M

LS2
LTE Carrier
1550.2 M 1555.2 M

Phase 2 Plan

1575.42 MHz L1

1575.42 MHz L1

1610 M

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

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GPS Antenna May Offer Limited Rejection of LightSquared Signals
Narrowband Patch Antennas Are More Selective

- **Wider Bandwidth Needed for:**
  - Military Signals
  - Anti-Multipath
  - Survey Receivers

- **PIFA Found In Cellular Phones**
  - ~ 10dB Rejection at LS2 Center

![Graphs showing gain at L2 and L1 bands]

*Figure 19 - Simulation results for the broadside gain across both L2 and L1 bands.*

*Figure from: HOLLAND “MINIATURIZATION OF MICROSTRIP PATCH ANTENNAS FOR GPS APPLICATIONS”, May 2008 Thesis, University of Massachusetts Amherst*
GPS Frontend PreFilter Often Has Modest Selectivity
Insertion Loss vs. Selectivity

- Limited Filtering At L1
  - LightSquared Center Frequency 1.45% Lower than L1 Center Frequency
  - GPS Receiver Selectivity Developed Further Down-line

![Graphs showing insertion loss and passband response for TriQuint 856756 and 856039 SAW filters.](image)
GPS Front-End May See High LightSquared Powers
Wide Range of Saturation Characteristics

- Maxim MAX2654 Preamp
  - 15 dB Gain
  - 1.5 dB Noise Figure
  - -7.2 dBm IP3 (Input Third Order Intercept Point)
  - -18 dBm 1-dB Compression

- Maxim MAX2741 Integrated L1 Receiver Frontend
  - 80 dB Cascaded Gain / 21 dB First Stage
  - 4.7 dB Noise Figure
  - -30 dBm IP3 (Input Third Order Intercept Point)
  - -40 dBm 1-dB Compression (Inferred from IP3, A Guess on My Part)
LightSquared Experimental Results
Focused Mainly On Cell Phone Desensitization

Table 1 Per Carrier LTE Power Thresholds for GPS Receivers

<table>
<thead>
<tr>
<th>Cell Phone GPS Test Results (Interferer Threshold Level at which device switches to AGPS)</th>
<th>One 5MHz carrier @ 1552.5MHz</th>
<th>One 10MHz carrier @ 1550.5MHz</th>
<th>Two 10MHz carriers @ 1550.5MHz &amp; 1531MHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Device 1</td>
<td>-15dBm</td>
<td>-16dBm</td>
<td>-17dBm</td>
</tr>
<tr>
<td>Device 2</td>
<td>-29dBm</td>
<td>-32dBm</td>
<td>-34dBm</td>
</tr>
<tr>
<td>Device 3</td>
<td>&gt;=-10dBm</td>
<td>&gt;=-10dBm</td>
<td>&gt;=-10dBm</td>
</tr>
</tbody>
</table>

- Note That Threshold Is Defined As “Switches to AGPS”
  - Corresponds to ~ 15 dB GPS Desensitization (45 db-Hz -> 30 dB-Hz)
- Cell Phones Have a 2 Year Life Cycle

Extract From: LightSquared, “Preliminary results on Overload Characteristics of GPS Receivers in Proximity to LightSquared’s L-band Terrestrial Base Stations (BTS) and User Equipment (UE)” 3GPP TSG-RAN4 #57AH R4-110470 Austin, TX, US 17 -21 Jan, 2011
Strong Out Of Band Interference From LightSquared Is Possible

1500 Watt EIRP Jammer at 50 feet AGL, Victim Receiver at 5 feet AGL

-17 dBm Blocking (Device 1)

-34 dBm Blocking (Device 2)

Free Space Propagation

-40 dBm

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Free Space Model Under Estimates LightSquared Signal Strength: Simple Ground Reflection Can Cause +6dB Relative to Free Space Out to 10 Miles Tx at 100’ AGL, Rx at 100’ AGL
LightSquared Exclusion Analysis
Presumes Ground Based GPS Users
-8 dBiC GPS Gain Towards Interference?

5% Of Phoenix Above -40 dBm

2.4% Of Baltimore Washington Above -40 dBm

Extract From: LightSquared, “Preliminary results on Overload Characteristics of GPS Receivers in Proximity to LightSquared’s L-band Terrestrial Base Stations (BTS) and User Equipment (UE)” 3GPP TSG-RAN4 #57AH R4-110470 Austin, TX, US 17 -21 Jan, 2011
Third Order Intermodulation Product Hits Close to GPS Center Frequency But Causes Little Effect

Maxim 2654 Parameters (Preamp)

LS1 Center at -80 dBm (40 dB Additional GPS Receiver Filtering)

LS2 at -40 dBm

Two Tone OFDM Input Spectrum (-80 dBm at 1528.8 MHz / -40 dBm at 1552.7 MHz)

Intermodulation Product
-90 dBm /
J / S ~ -10 dB for P(Y)
J / S ~ -20 dB for C/A

Output Spectrum (G=15 dB, IP3=-7.2 dBm)
Third Order Intermodulation Product Hits Close to GPS Center Frequency And Jams the GPS Receiver
Maxim 2741 Parameters (Integrated L1 Front-End)

Two Tone OFDM Input Spectrum (-80 dBm at 1528.8 MHz / -40 dBm at 1552.7 MHz)

LS1 Center at -80 dBm (40 dB Additional GPS Receiver Filtering)

LS2 at -40 dBm

Output Spectrum (G=21 dB, IP3=-30 dBm)

Intermodulation Product -90 dBm /
J / S~40 dB for P(Y)
J / S ~30 dB for C/ A

twotone.m
What Happens If LightSquared Is Deployed? Absent J/N Meters, Situation Will Be Confusing

- Conventional C/A Code
  - Probable Outages / Less Tolerance of Foliage
  - Effects are Very Type and Location Dependent
    - Front-End Linearity, Antenna Bandwidth

- Civil Aviation
  - Seven 9’s Issues (Black Swan Territory)
  - Hotspots Due to Reflections / Approach Vectors
  - LightSquared Hazardous Emissions Monitoring Reliability
  - Wider Front-Ends for Anti Multipath Raise Blocking Exposure

- Military
  - Vulnerabilities Similar to Civil Plus Anti-Jam Interaction Issues
Summary

- Are Current GPS Receivers Universally Compatible with LightSquared Signals?
  - NO

- Can GPS Receivers Be Designed So They Are Compatible with LightSquared Signals?
  - YES†

† Barring Unforeseen Black Swans
Propagation Models

(Backup Material)
Free Space Propagation Model

- Appropriate under "Line Of Sight" Conditions (1\textsuperscript{st} Fresnel Zone)
- Rarely Appropriate in Ground Mobile Analysis

\[ S_{\text{received}} = S_{\text{transmitted}} + G_t + G_r + 20 \log_{10}(\lambda/4\pi d) \]

where:

- \( S_{\text{received}} \) is received signal power (dBm)
- \( S_{\text{transmitted}} \) is transmitted signal power (dBm)
- \( G_t \) is transmitter antenna gain in the direction of the receiver (dBiC)
- \( G_r \) is receiver antenna gain in the direction of the transmitter (dBiC)
- \( \lambda \) is the signal’s wavelength (19 cm @ L1, 24 cm @ L2)
- \( d \) is spatial Tx/Rx separation in same units as wavelength
Free Space Propagation Model Is Often Inappropriate, Especially for Jamming Signals

- Reflected Path Can Add to Direct Path Either Destructively or Constructively Depending on Geometry
- At Longer Ranges, Signal Strength Falls Off at $R^4$ Rate
- Can Also Apply In Ground Jammer to Airborne Receiver Cases
Ground Reflection Can Cause +6dB Relative to Free Space Out to 10 Miles
Tx at 100’ AGL, Rx at 100’ AGL

Two Ray Model

Frequency = 1.5754 GHz, h1 = 100’, h2 = 100’, Fresnel Breakpoint at 12.126 miles, Link Pt*Gt*Gr of 1500 Watts
Ground Reflection Can Cause +6dB Relative to Free Space Out to 1 Mile
Tx at 100’ AGL, Rx at 5’ AGL

Frequency = 1.5754 GHz, h1 = 100’, h2 = 5’, Fresnel Breakpoint at 0.6063 miles, Link Pt*Gt*Gr of 1500 Watts
The Ground Mobile Channel

From: Siwiak, *Radiowave Propagation and Antennas for Personal Communications*, Artech 1995