LightSquared ATCt RFI Assessment: Aviation Scenario Aggregate RFI Analysis Summary (RTCA DO-327)

Briefing to PNT Advisory Board

9 June 2011

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Outline

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Introduction

- **On January 26, 2011, the FCC conditionally granted a waiver of its rules, permitting LightSquared to use terrestrial-only devices on its ATCt network.**
  - **Due to GPS community RFI concerns, the FCC conditioned the grant on LightSquared organizing and participating in a technical working group (TWG) along with GPS manufacturers, federal and non-federal GPS user representatives.**
  - **TWG is to complete the following tasks and report by 15 June:**
    - **analyze ATCt RFI overload susceptibility of various GPS devices;**
    - **identify near-term tech. and operational measures to reduce RFI risk;**
    - **recommend coexistence measures for GPS and L-Band MSS/ATC**
- **The FAA formally requested that RTCA study ATCt RFI to aviation GPS receivers and GPS-based operations.**
  - **RTCA PMC formally accepted the request (17 Mar. 2011)**
  - **SC-159 (WG-6) performed the study and prepared the report**
  - **The study and its results are documented in RTCA/DO-327**

RTCA SC-159 GNSS RFI Analysis Method

- **Classic Source-Path-Receiver Method**
  - **RFI Source Parameters:**
    - **Transmit Power**
    - **Antenna Gain Pattern Factors**
    - **Modulation Type & Spectrum**
    - **Number of Sources & Source-Source Spacing**
  - **Propagation Path Parameters:**
    - **Distance & Direction**
    - **Path Characteristics (free-space or other type)**
  - **Receiver Parameters (per RTCA/DO-235B model)**
    - **Antenna Gain to RFI Source**
    - **GNSS Signal Power**
    - **Performance Criteria (op. mode-dependent)**
    - **Baseline RFI (if applicable)**

RTCA SC-159 RFI Analysis Scenarios

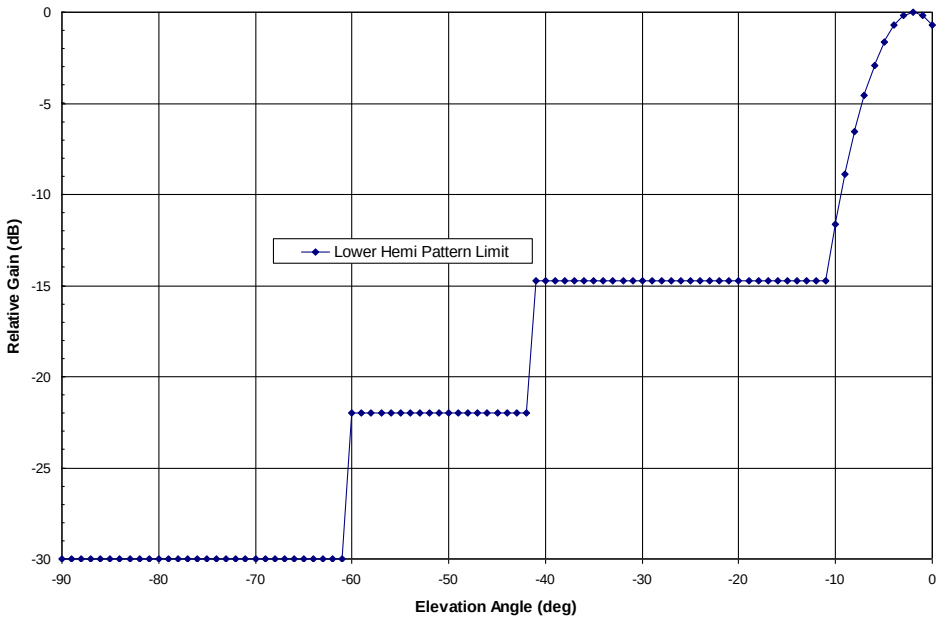
- **Low Altitude Enroute / Terminal Area Case (FAF WP)**
  - **GNSS a/c antenna height = 535.2 m (above touchdown surf.)**
  - **3 glideslope approach (nom.), distance to touchdown 10.46 km**
  - **Other low altitude operations assume level flight**
  - **GNSS receiver modes: signal tracking, acquisition**
- **Final Approach Cases (Cat. I DH, Cat. II DH)**
  - **GNSS antenna height: 53.34 m (Cat. I), 25.94 m (Cat. II)**
  - **3 Glide (nom.), Touchdown dist. 1163 m (Cat. I), 582 m (Cat. II)**
  - **GNSS receiver mode: signal tracking**
- **Airport Surface Case (taxiway)**
  - **GNSS antenna height: 4 m (nom., regional or business jet)**
  - **A/C stopped or slow taxi; Receiver modes: tracking, acquisition**
- **High Altitude Enroute Case**
  - **GNSS antenna height: 5.49 km**
  - **A/C in level hi-speed flight; Receiver modes: tracking, acquisition**

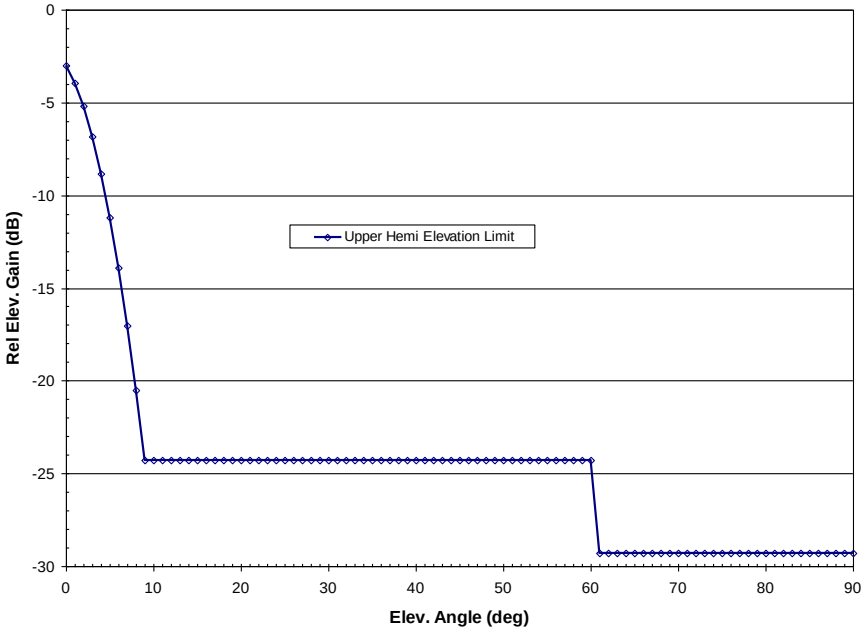
ATCt Basic RFI Source Parameters

- **ATCt Base Station**
  - **Max. fundamental EIRP: 32* dBW (total in occupied bw)**
  - **Max. unwanted EIRP: -100 dBW/MHz (1559-1610 MHz)**
  - **Modulation: LTE (OFDM), 5 MHz & 10 MHz occupied bw**
  - **Lowest center freq.: 1552.7 (Ph0), 1528.8 MHz (Ph1)**
  - **Antenna height: 30 m; Tx polarization: linear vertical**
- **ATCt Mobile Terminal**
  - **Max . fundamental EIRP: -7 dBW**
  - **Max. unwanted EIRP: -90 dBW/MHz (1559-1605 MHz)**
  - **Modulation: LTE (OFDM), 5 MHz & 10 MHz occupied bw**
  - **Lowest center freq.: 1654.2 (Ph0), 1630.3 MHz (Ph1)**
  - **Antenna height: 1.8 m (est.)**

*** FCC authorized max. total = 42 dBW**

ATCt Base Station Transmit Antenna Patterns





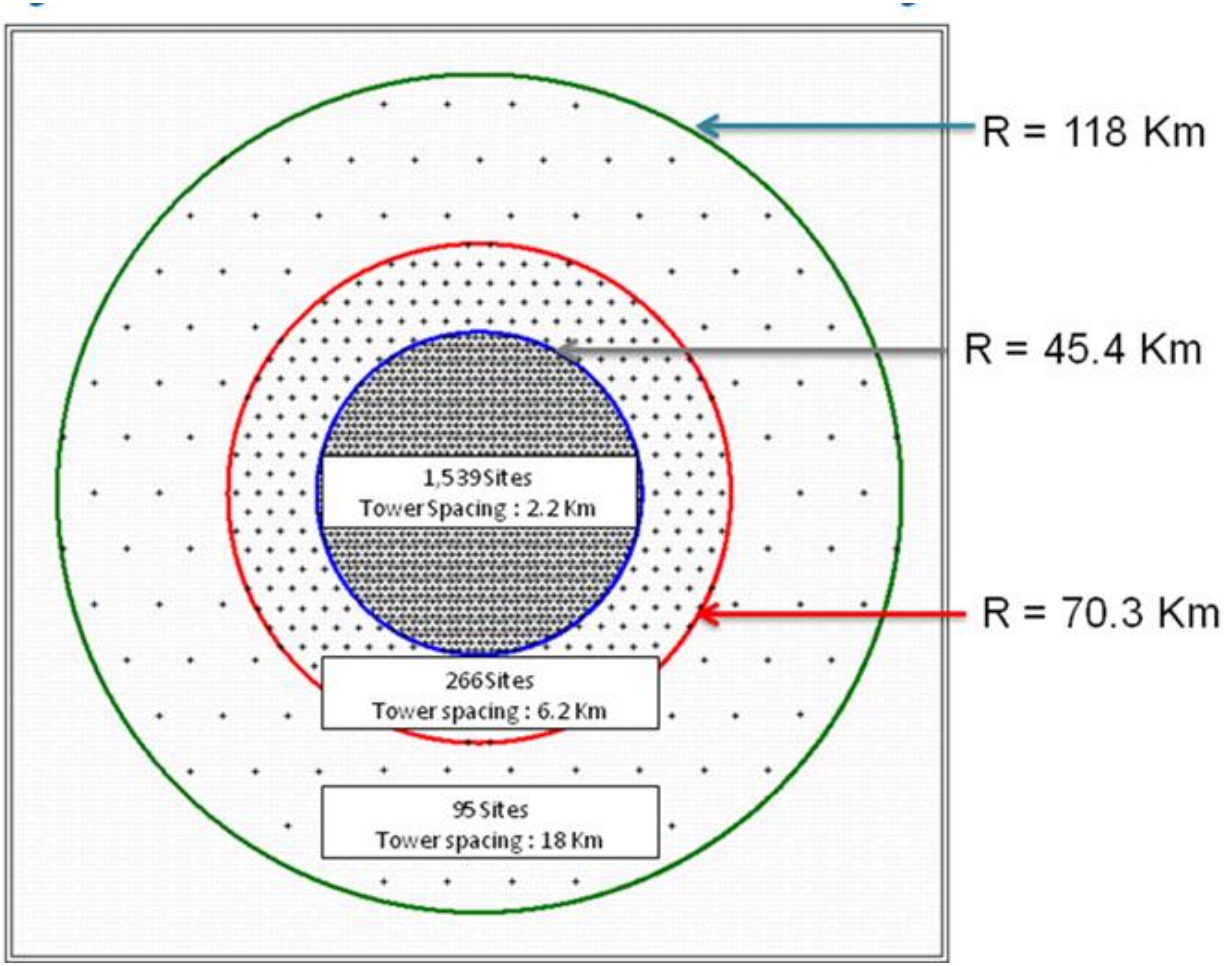
Relative Lower Hemisphere Elev. Pattern

Rel. Upper Hemi. Elev. Pattern

(~ 8 dB half-power beamwidth)

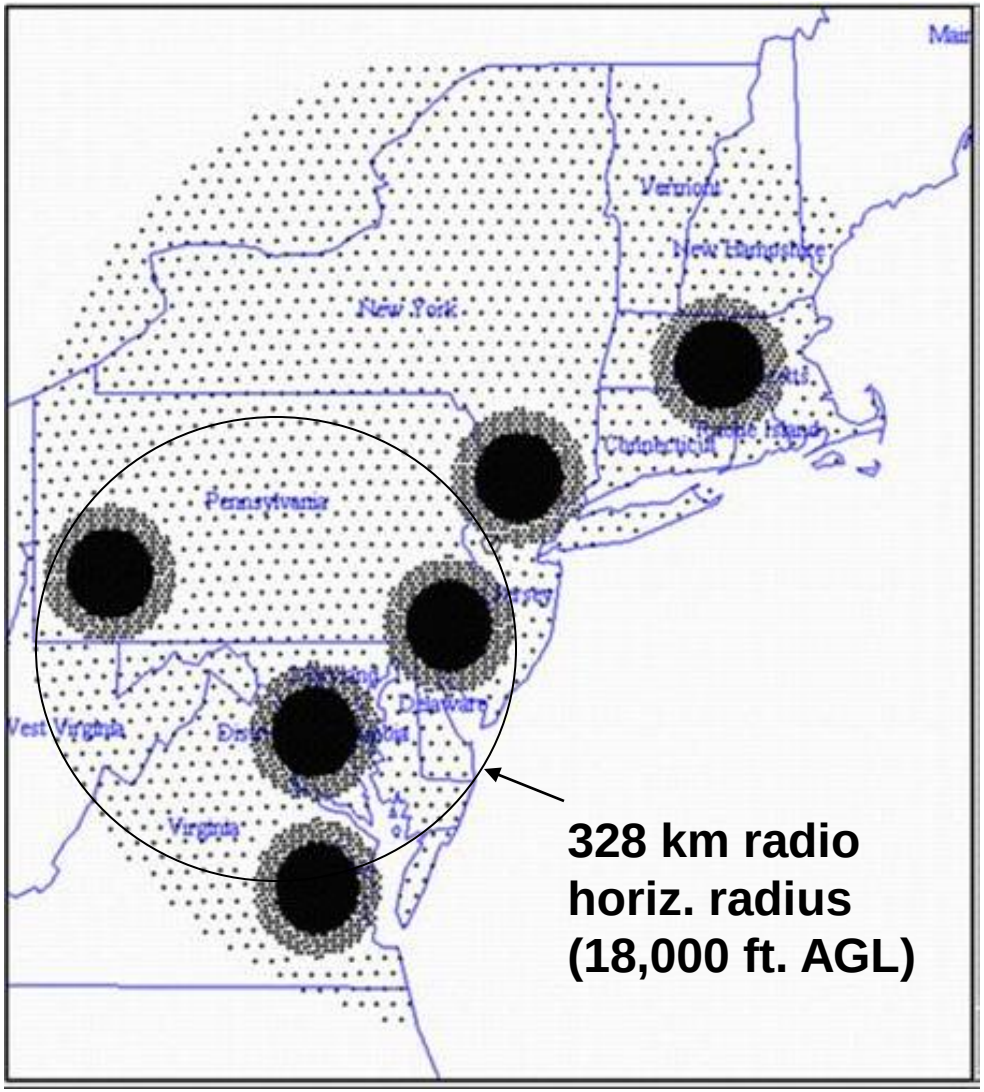
Main beam rel. gain (dB): $0.181818(2+el)^2$; $-11° \leq el < 9$
Assymetric pattern in lower hemisphere (2 deg down-tilt)
Upper hemi. gain reduced 2.3 dB for sector az. pattern scalloping effect

Generic ATCt Base Station Deployment Plan - Single Metropolitan Distribution

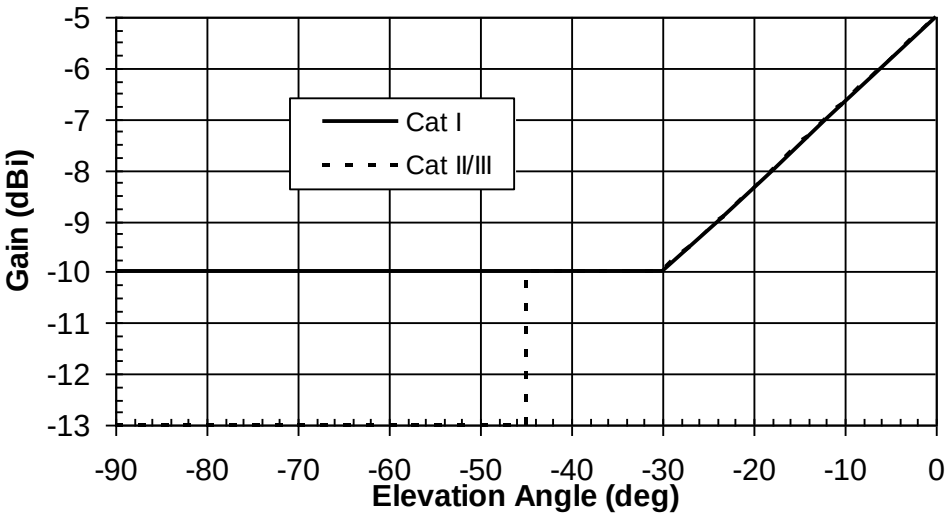


Ave. central metro zone tower spacing = 2.2 km

Generic ATCt Base Station Deployment Plan –
Multi-city Distribution (US East Coast)

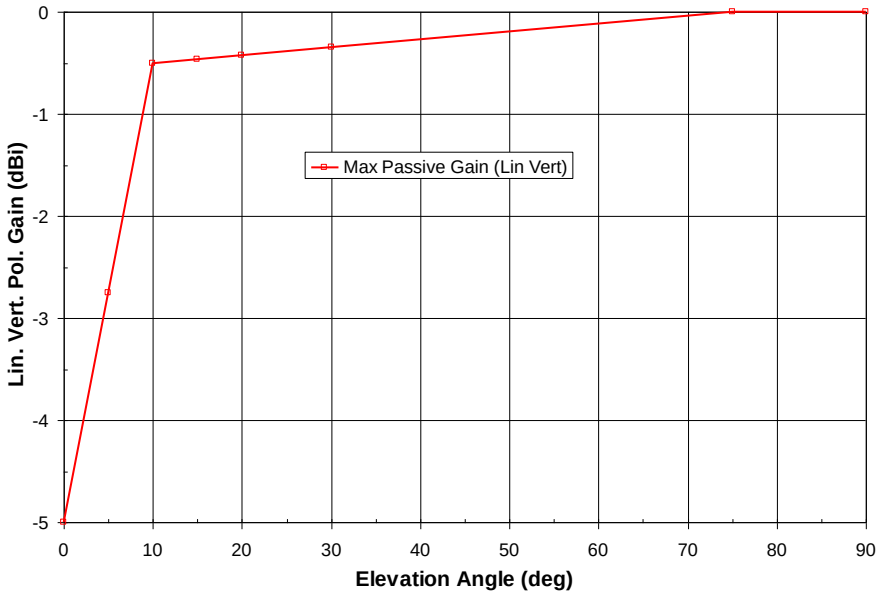


Aircraft GPS Receive Antenna Elevation Patterns



Lower Hemisphere
(Lin. Vert Pol.)

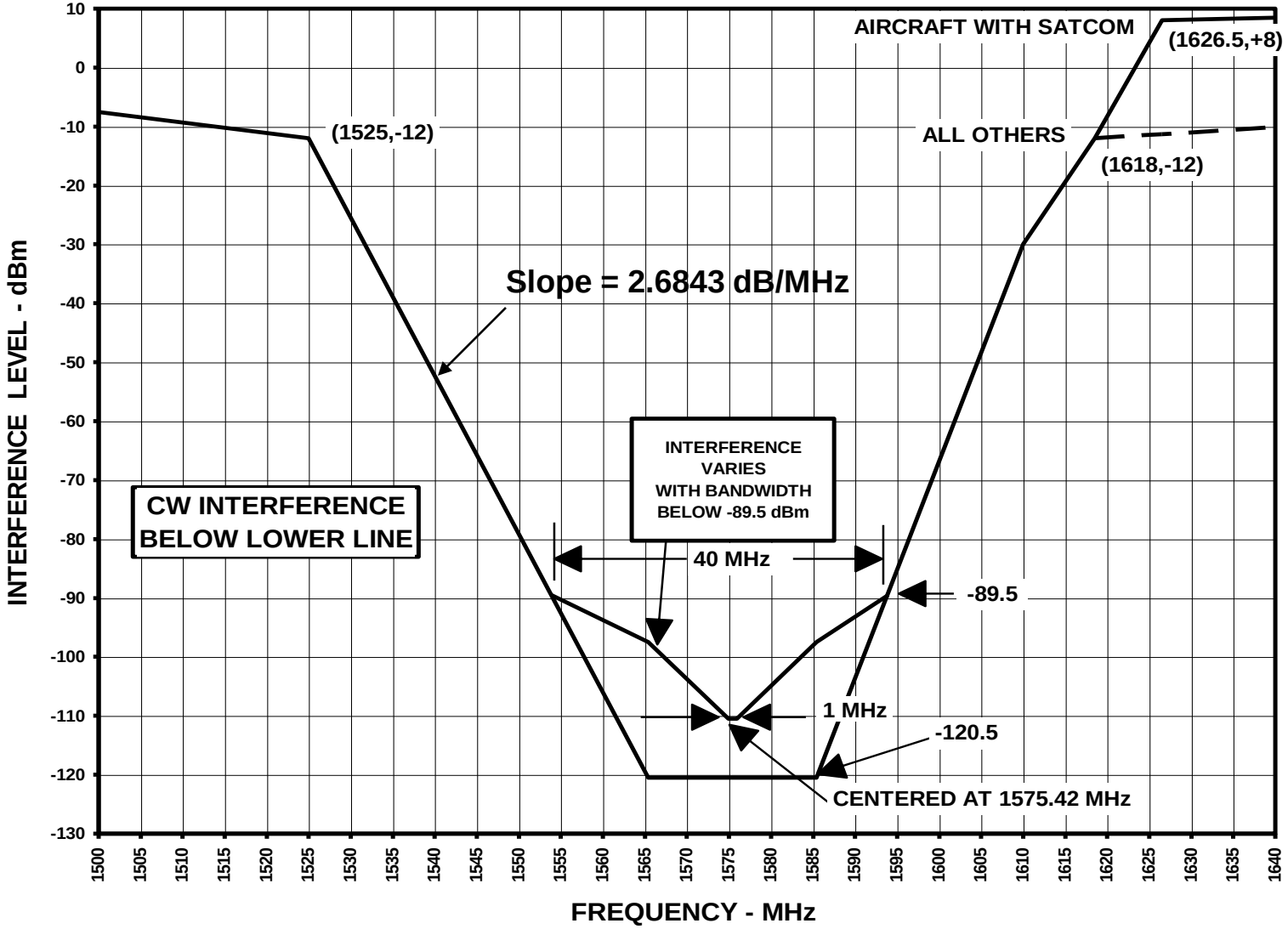
G_{RCV1} = -10 dBi for -90º ≤ elev < -30º
= -10+(5 + elev/6) dBi
for -30º ≤ elev ≤ 0º
G_{RCV2} = -13 dBi, -90º ≤ elev < -45
= G_{RCV1}, -45º ≤ elev ≤ 0º



Upper Hemisphere
(Lin. Vert Pol.)

G_{Max} = 0.0 dBi for 75º ≤ elev ≤ 90º
= -0.5 + 0.0077•(elev-10) (dBi)
for 10º < elev < 75º
= -5.0 + 4.5•elev (dBi)
for 0º ≤ elev ≤ 10º

GPS Receiver MOPS RFI Susceptibility (Track Mode)



Relative Receiver RFI Attenuation: = 34.1 dB at 1552.7 MHz, 103.7 dB at 1528.8 MHz

Overload effect assumed to be based on total power referenced to channel center.

Aviation GPS RFI Scenario Details

4/3 Earth Radius Estimate

Case	A/C Ant. Ht. (m)	ATCt Base Ant Ht. (m)	ATCt Mobile Ant. Ht.(m)	Radio Horiz. - Base (km)	Radio Horiz. - Mobile (km)
Surface	4.0	30	1.8	30.84	13.78
Cat. II DH	25.94	30	1.8	43.59	26.54
Cat.I DH	53.34	30	1.8	52.71	35.65
FAF WP	535.2	30	1.8	118.00	100.94
High Alt.*	5490	30	1.8	328.16	311.10

***** Aircraft location: 39.819 N, 77.573 W (118 km NNW of Washington, DC)

- **ATCt base locations; average spacing = 2.2 km***
- **100 / 300 / 1000 ATCt mobiles per base cell (est. range)**
- **10,000 ft. bi-directional runway (Surface – Cat. I cases)**
- **GPS satellite signal levels at min. specified value**
- **Wideband aero. baseline RFI level per MOPS**
- **6 dB safety margin applied to ATCt RFI**

***within 45.4 km radius of metro center (per slide 8)**

Aviation GPS RFI Scenario Aggregate RFI Results

ATCt Base Station Fundamental Emission Effect (mean values)
Tx EIRPsd = 25 dBW/MHz (32 dBW EIRP Tot.), 1552.7 MHz f_C

Case	A/C Ant. Ht. (m)	Random Rcv PSD (dBW/MHz)	Random Method Agg. PL (dB)	Discrete Rcv PSD (dBW/MHz)	Discrete Method Agg. PL (dB)
Surface	4.0	-86.52	111.52	-88.76	113.77
Cat. II DH	25.94	-76.03	101.03	-79.09	104.10
Cat.I DH	53.34	-75.92	100.92	-77.63	102.64
FAF WP	535.2	-73.55	98.55	-73.60	98.61
High Alt.	5490	-86.60	111.6	-87.01	112.01

- **Two analysis methods – "Random" & "Discrete"**
  - **Random: ATCt base station tower spacing = 2.2 km (ave., uniform dist.)**
  - **Discrete: Towers centered in hexagonal cells, 2.2 km fixed spacing**
- **Propagation models:**
  - **Flat Earth, Blended 2-Ray / Hata Okumura (all except high altitude case)**
  - **High Altitude Case: Flat Earth, r^{-2} (free-space)**
- **RTCA MOPS received power limit at 1552.7 MHz:**
  - **$Pr_{tot}(f_c)$ = -126.5 dBm + 2.6843·(1565.42-f_c) with 6 dB safety margin**
  - **Pr_{tot}(1552.7) = -92.36 dBm (-122.36 dBW) = -129.35 dBW/MHz over 5 MHz**

Aviation GPS RFI Scenario Aggregate RFI Results

ATCt Mobile Station Unwanted Emission Effect (mean values)
Tx unwanted EIRPsd = -90 dBW/MHz, f_C = 1575.42 MHz

Case	A/C Ant. Ht. (m)	100 / cell Rcv PSD (dBW/MHz)	300 / cell Rcv PSD (dBW/MHz)	1000 / cell Rcv PSD (dBW/MHz)	Gnd Source Agg PSD w/o ATC mobiles
Surface	4.0	-	-	-	-
Cat. II DH	25.94	-164.98	-160.21	-154.98	-149.86
Cat.I DH	53.34	-166.23	-161.46	-156.23	-151.11
FAF WP	535.2	-166.16	-161.39	-156.16	-151.04
High Alt.	5490	-	-	-	-

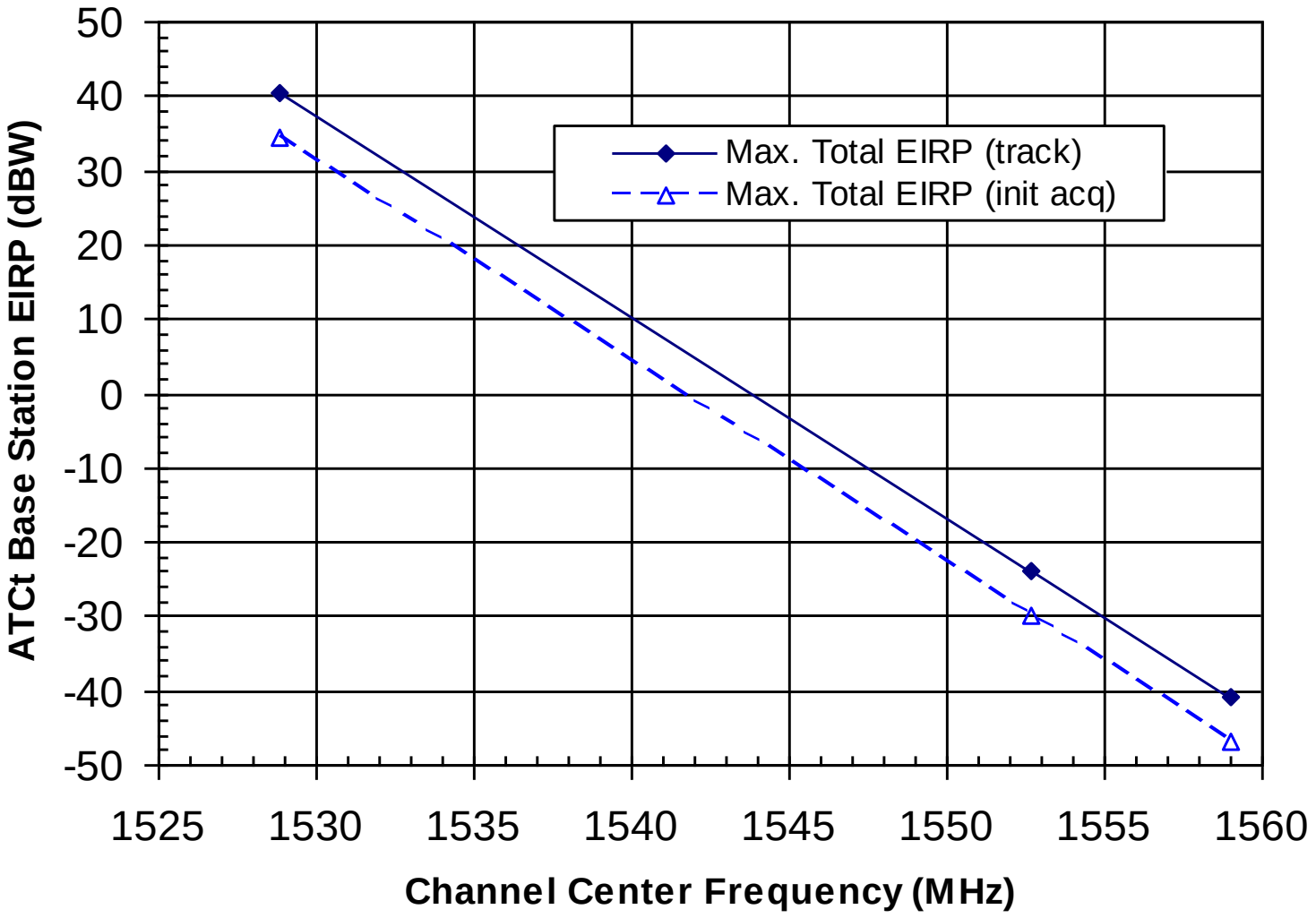
- **Random analysis method:**
  - **ATCt base stations cell area = 3.8 km^2, mobiles uniform distrib. in cell**
  - **Gnd source aggregate used 100 sources / km^2 at -81.1 dBW/MHz EIRP**
- **Propagation model:**
  - **Flat Earth, Blended 2-Ray / Hata Okumura (all except high altitude case)**
  - **High Altitude case uses free-space propagation (r^{-2})**
- **RTCA MOPS received PSD limit at 1575.42 +/- 10 MHz:**
  - **$PSDr_{tot}(f_c)$ = -116.5 dBm/MHz (-146.5 dBW/MHz) with 6 dB safety margin**
  - **Long baseline high-side CDF tail uses most or all of the safety margin**

Aviation GPS RFI Scenario Aggregate RFI Results

- **Base 1552.7 MHz fundamental mean aggregate RFI PSD exceeds MOPS limit by 42.7 to 55.8 dB for key scenarios**
  - **Complete loss of GPS receiver function expected at those levels**
  - **Highest RFI case: Low Alt. Enroute (535.2 m or 1756 feet AGL)***
  - **Rural background aggregate RFI exceeds MOPS limit by 24 dB in US East Coast high altitude enroute case**
    - **(a component of the High Altitude figure on slide 13)**
  - **Principal driver is close proximity of ATCt carrier center freq. relative to aviation GPS receiver selectivity below 1565.42 MHz**
- **Mobile unwanted aggregate mean RFI adds 9% to 31% to estimated aggregate ground RFI source baseline PSD**
  - **Principal driver is average number of mobile units per cell**
  - **Risk is RFI high-side probability distribution tail may exceed operational limits**

*** a preliminary check showed that this altitude may not have the absolute maximum mean RFI value but it should be within 2 dB of the maximum**

ATCt Base Station Total Power versus Frequency Limit



EIRP curves derived from MOPS-related environment limits and FAF WP case aggregate path loss

RTCA DO-327 Conclusions

- **Impact of LightSquared Phase 0 Spectrum Plan (single 5 MHz wide base channel, 1552.7 MHz channel center):**
  - **Due to the size of the single-city base station deployment, GPS-based operations below about 2000 feet will be unavailable over a large radius from the metro deployment center.**
  - **Given the situation in the high altitude U.S. East Coast scenario, GPS-based operations will likely be unavailable over a whole region at any normal aircraft altitude.**
- **Study results indicate terrestrial base station operation at only the lower 5 MHz channel (1528.8 MHz channel center) is compatible with aviation GPS operations.**
  - **For both signal tracking and initial acquisition receiver modes**
  - **For all 5 representative operational scenarios**
- **Study indicates base station operation* at lower 10 MHz channel (1531.0 MHz center) is compatible with aviation GPS receiver signal tracking but not initial acquisition.**

*** (Max. total channel power 32 dBW)**

RTCA DO-327 Recommendations

- **From an aviation perspective, LightSquared upper channel operation should not be allowed.**
- **Further study is recommended to more carefully determine a refined terrestrial base station power versus frequency limit considering:**
  - **determination of the lowest path loss for the low altitude enroute scenario;**
  - **confirmation of acceptable receiver susceptibility for GPS initial acquisition and signal tracking in the presence of the 10 MHz bandwidth terrestrial network interference;**
  - **computation of the cumulative probability distribution function for the mean aggregate path loss.**

DO-327

- **Web site for Executive Summary of RTCA DO-327:**

  Assessment of the LightSquared Ancillary Terrestrial Component Radio Frequency Interference Impact on GNSS L1 Band Airborne Receiver Operations

- http://www.rtca.org/CMS_DOC/LightSquared%20Article%20-%20website.pdf

- **Full document for purchase at:**

http://www.rtca.org/onlinecart/allproducts.cfm