The Impact of "Uninformed" RF Interference on GBAS and Potential Mitigations

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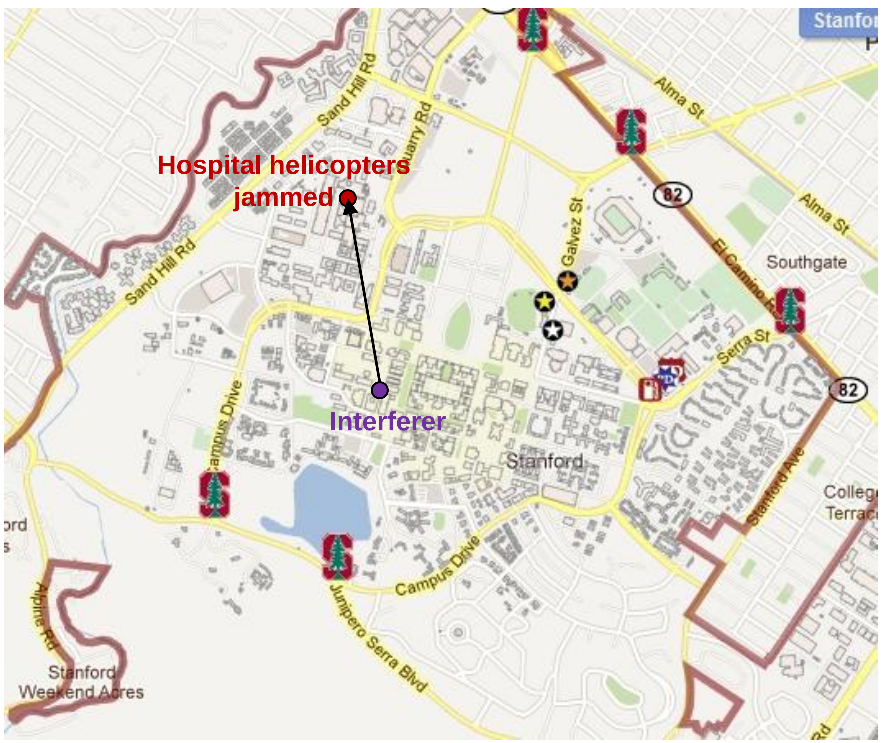
Outline

- **Examples of RF Interference to GNSS**
- **The Growing Problem of Personal Privacy Devices (PPDs)**
- **RFI Impact on GBAS and Aviation Precision Approaches**
  - **Impact of PPDs on GBAS at Newark Airport**
- **Mitigations: Short-term and Long-term**
- **Summary**

Example 1: "Uninformed" RFI at Stanford University (c. 1999)

Interfering Device

GPS Denied over Large Area



Digital camera and data transmitter to monitor construction site

Example 2: "Accidental" RFI at Moss Landing Harbor, CA (c. 2001)

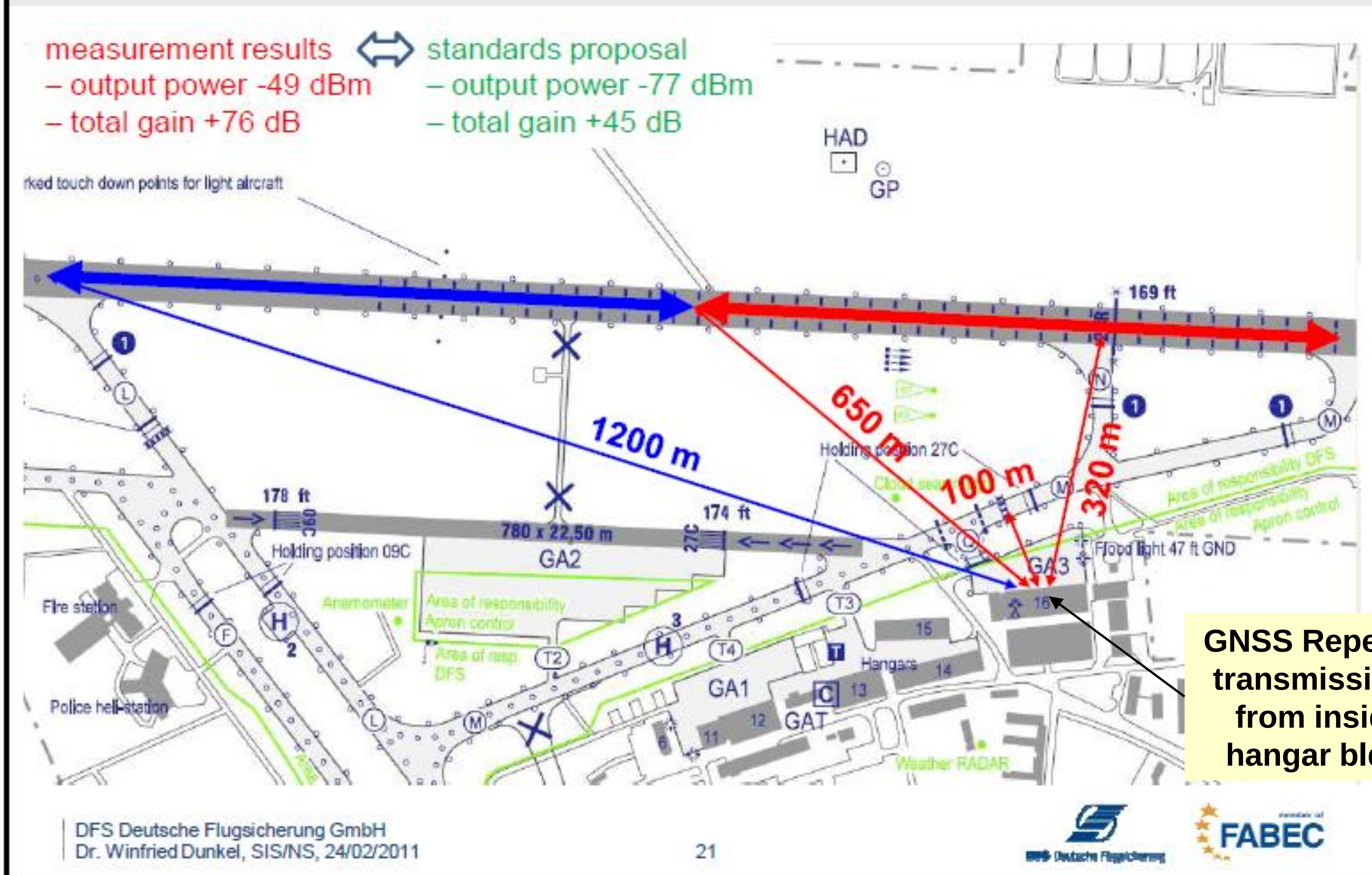
***Source*: W. Vincent, *et al*, "The Hunt for RFI," *GPS World*, Jan. 2003.**

RFI broadcast by at least 3 boats docked in harbor (*due to same equipment defect*)

Detected by MBARI

Example 3: "Uninformed" RFI at Airports in Germany (2010-11)

***Source*: Dr. Winfried Dunkel (DFS), I-GWG-11, Osaka, Feb. 2011**



GNSS Repeater transmissions from inside hangar bldg.

Personal Privacy Devices (PPDs)

- **GPS is now widely used to track trucks, service vehicles, and some passenger vehicles.**
  - **This conflicts with many peoples' expectation of privacy.**
- **GPS signals are weak and can easily be jammed.**
- **Jammers are now widely available over the Internet.**
  - **Small, inexpensive, and easy to use**
  - **Illegal in the U.S. (and elsewhere), but enforcement is difficult, and consequences are limited**
- ***When vehicles using these jammers pass close to GBAS reference receivers, weakening or loss of received GPS signal can occur.***
  - **At Newark, this occurs several times per week.**

PPDs Obtained for Testing

***Source*: T. Kraus, *et al*, “Survey of In-Car Jammers,” ION GNSS 2011**

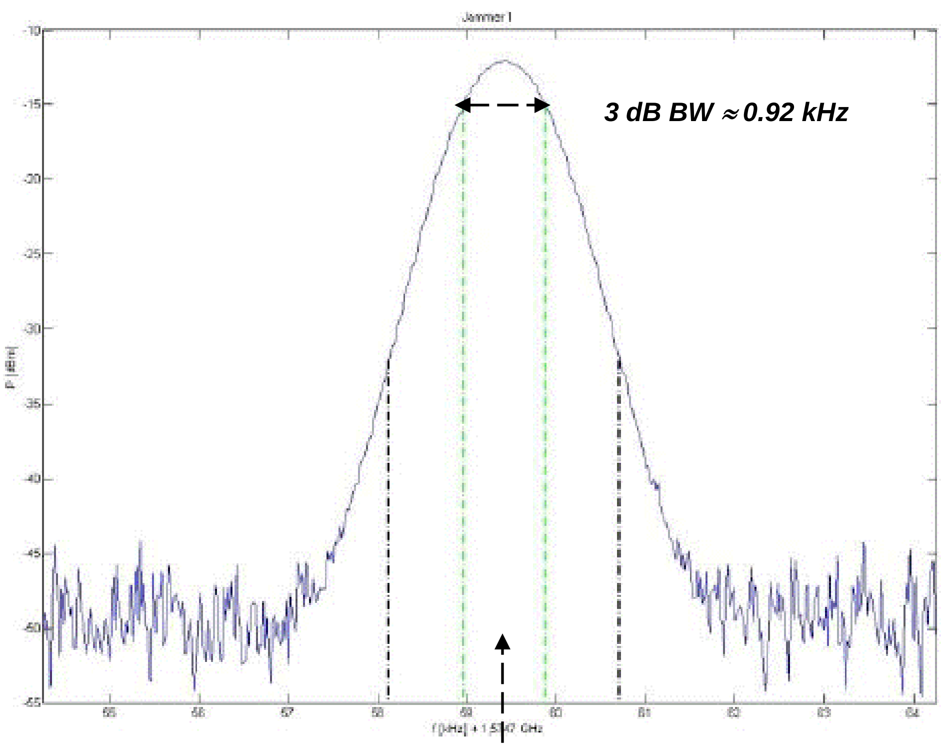
- **Labs at Univ. FAF Munich (Germany) and Cornell/UT Austin (USA) separately “acquired” PPDs online and performed controlled experiments to examine their signal characteristics.**
- **Two papers published at recent *ION GNSS 2011* conference.**

Example PPD Spectrum Plots

***Source*: T. Kraus, *et al*, “Survey of In-Car Jammers,” ION GNSS 2011**

“CW-like” Jammer Type

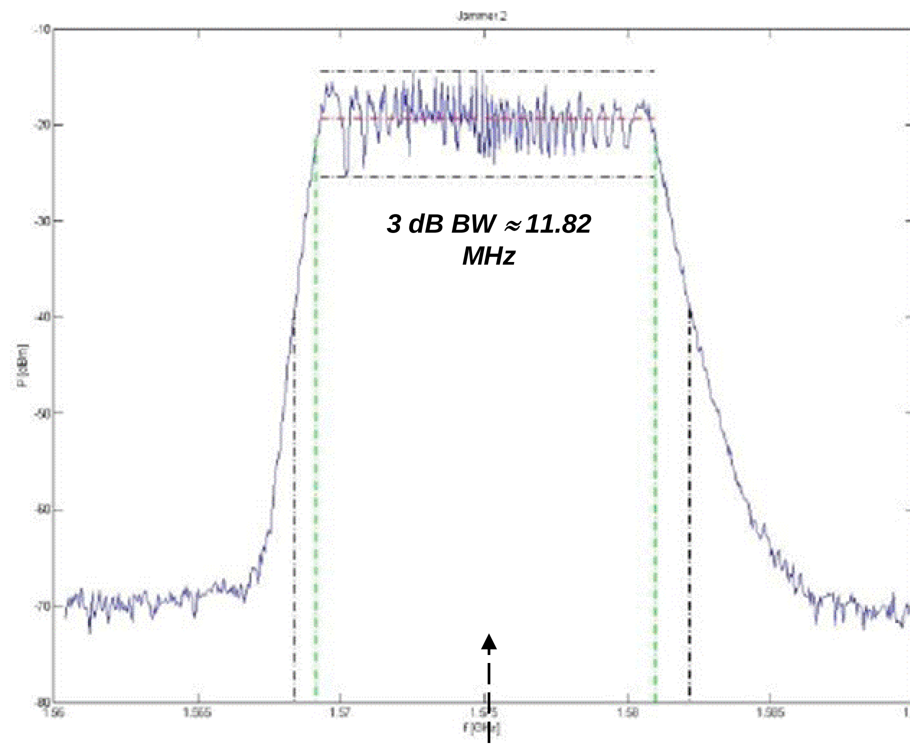
(cheap, small cigarette-lighter plug-in)



Center freq. very close to GPS L1 (varies with temperature)

“Chirp” Jammer Type

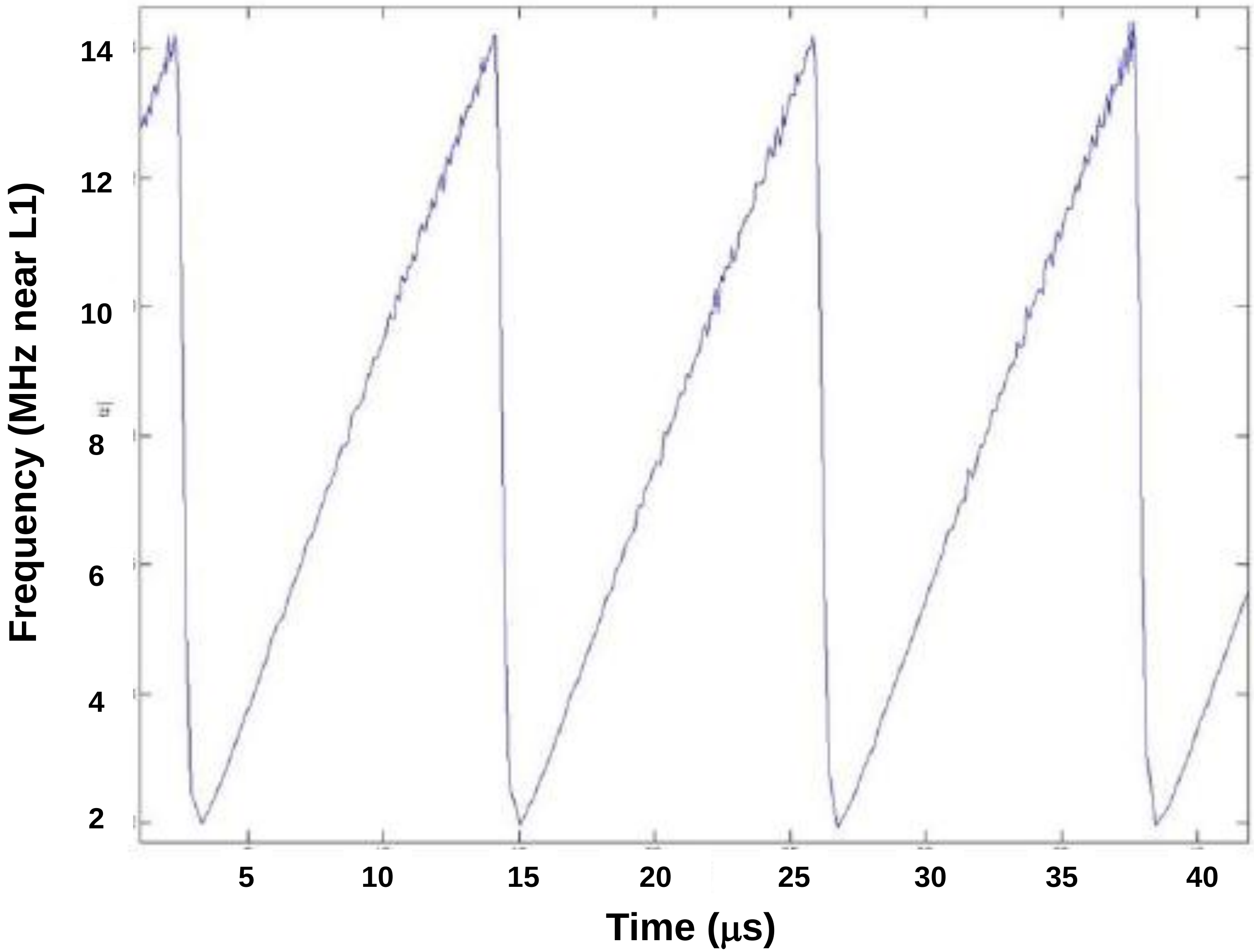
(most common behavior)



Center freq. very close to GPS L1

Frequency Sweep of "Chirp" Jammer

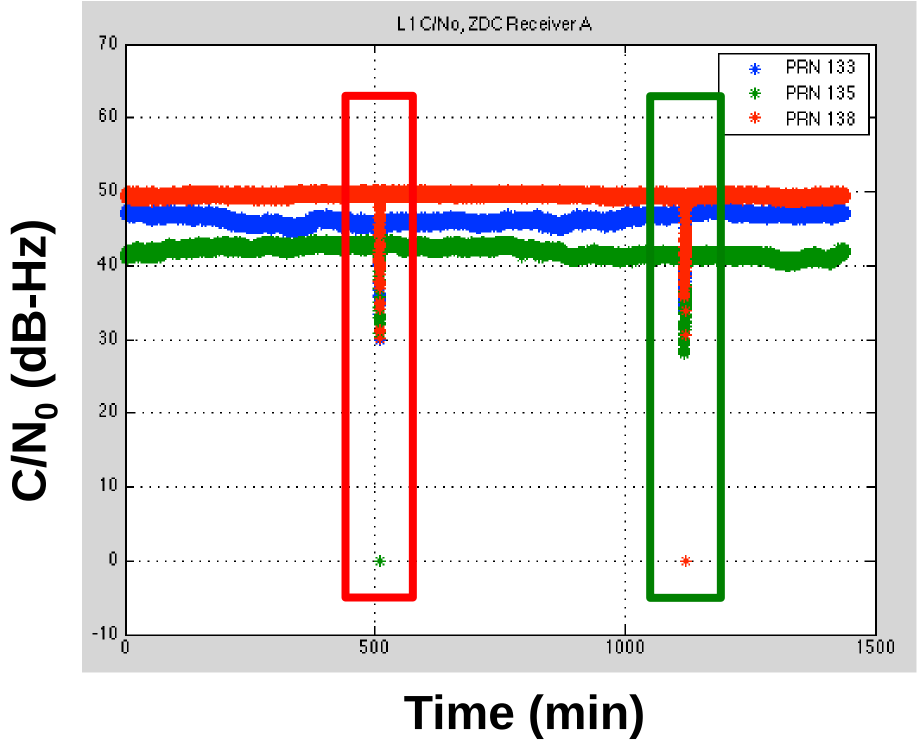
***Source*: T. Kraus, *et al*, "Survey of In-Car Jammers," ION GNSS 2011**



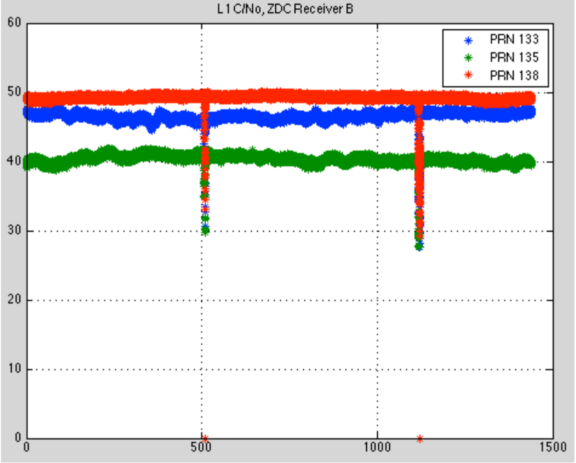
Example 4: Unknown RFI (likely from PPDs) Observed by WAAS

L1 C/N$_0$ WAAS GEO measurements at ZDC WRS (Leesburg, VA.) on 9 Apr. 2011

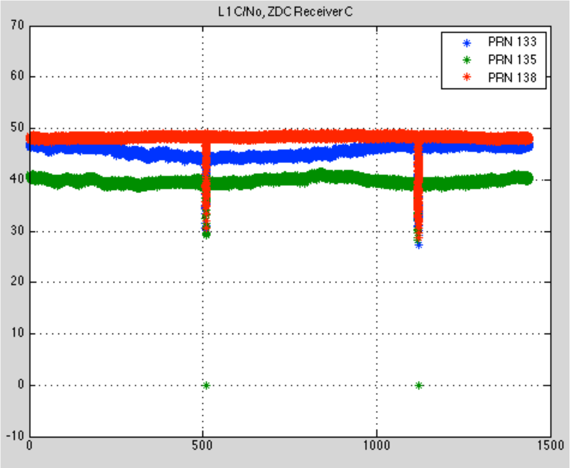
ZDC Receiver A



ZDC Receiver B



ZDC Receiver C



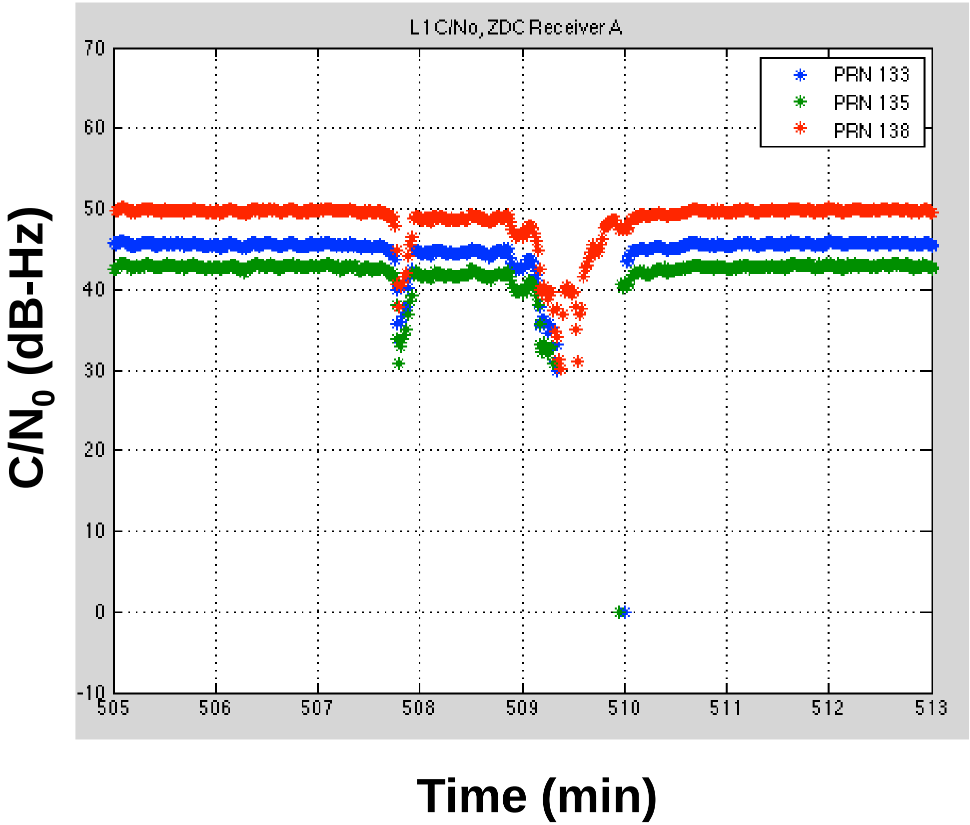
At least two RFI events happened on this one day.

Example 4: Unknown RFI Observed by WAAS (2)

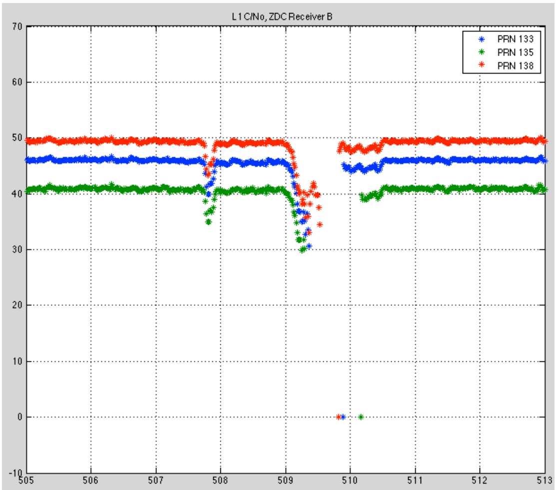
L1 C/N_0 WAAS GEO measurements at ZDC WRS (Leesburg, VA.) on 9 Apr. 2011

Zoom in on first RFI event

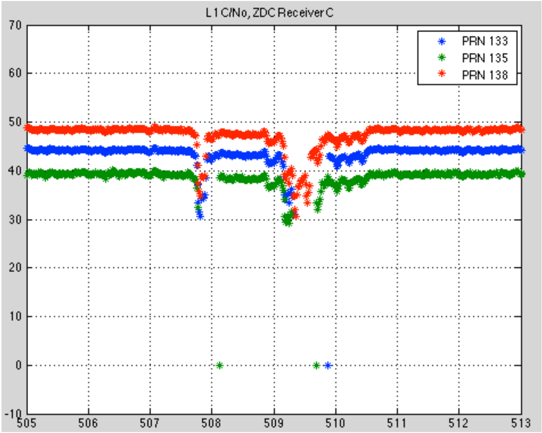
ZDC Receiver A



ZDC Receiver B

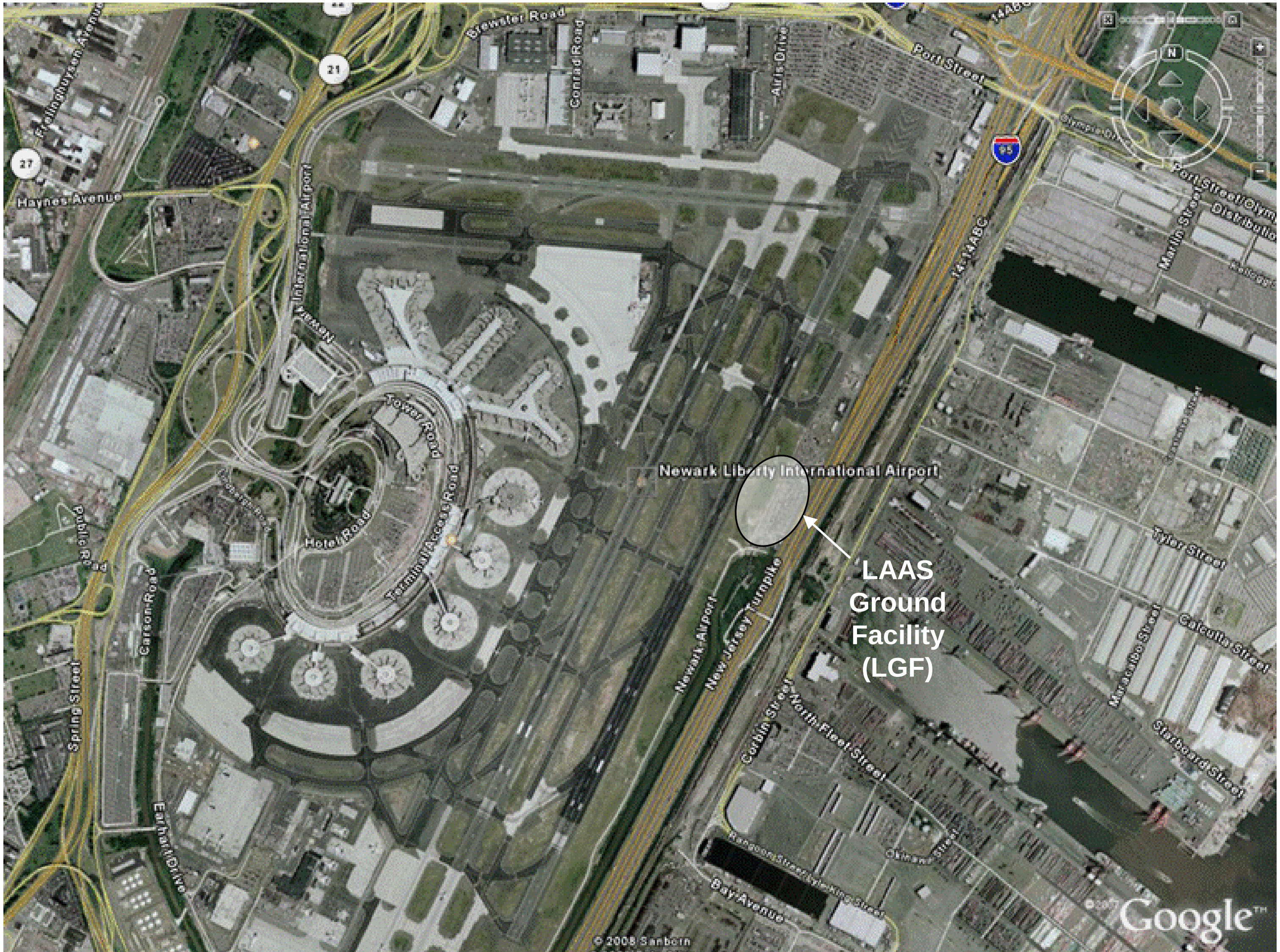


ZDC Receiver C



Area Surrounding ZDC WRS in Leesburg, VA.

Newark Airport (Newark, NJ, USA)

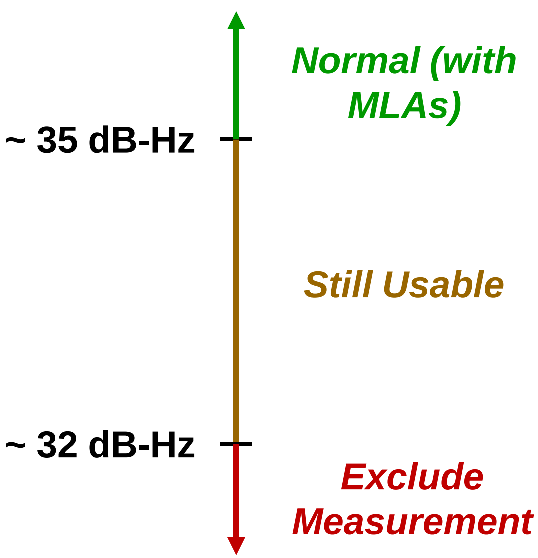


LAAS Site at Newark (Near Freeway)

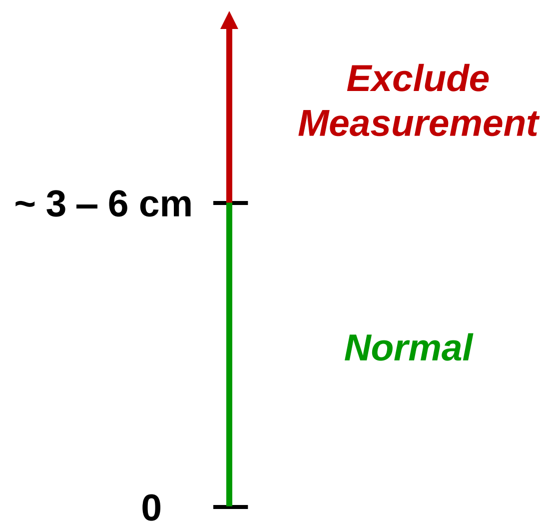
GBAS RFI Monitoring

- **C/N_0 (signal strength) monitoring detects broadband RFI that exceeds tolerable limits.**
- **Carrier phase residual monitoring detects impact of CW-like RFI on carrier tracking loop.**
  - **Receiver Automatic Gain Control (AGC) levels can be checked to distinguish RFI from other anomalies.**

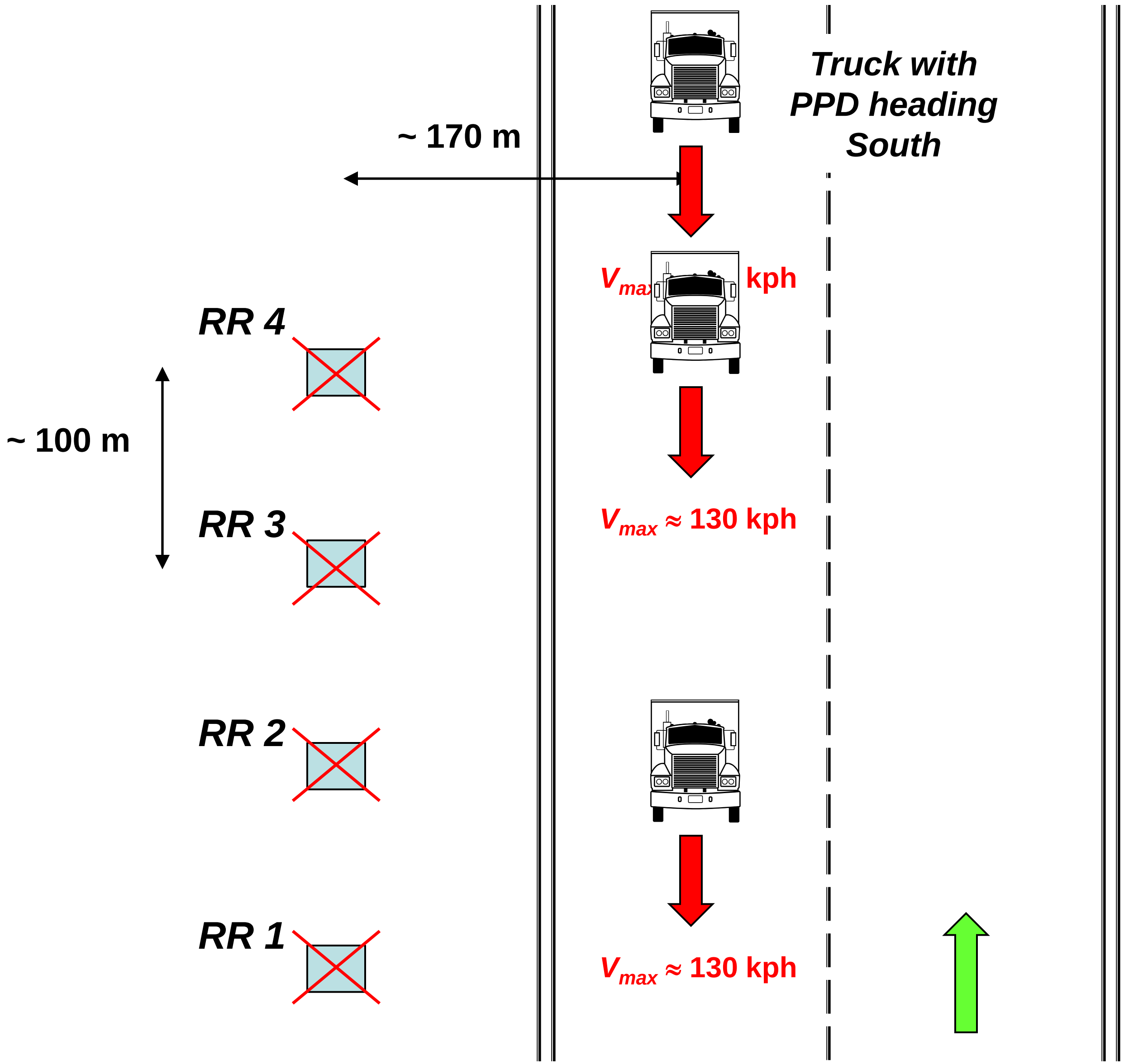
C/N_0 Monitor



ϕ_r Monitor



Newark LAAS PPD Impact Scenario



Drawing not to scale

PPD Performance Impacts

- **While GBAS monitoring protects integrity, need to exclude affected measurements causes *loss of continuity and availability***
- ***Continuity (CAT I)*: 8 × 10^{-6} per 15 sec**
  - **Equivalent to one unexpected loss of service every 521 hours, or 21.7 days ("average risk" basis)**
  - **PPD interference to Newark GBAS is much more frequent**
- ***Availability*: minimum of 0.99 (0.999 much preferred) over all causes**
  - **Outage prob. of 0.01 equivalent to 14.4 min/day or 88 hrs/yr**
  - **Outages caused by PPDs and recovery time required make this a considerable challenge**

PPD Threat Mitigations (1): *Hardware Improvements*

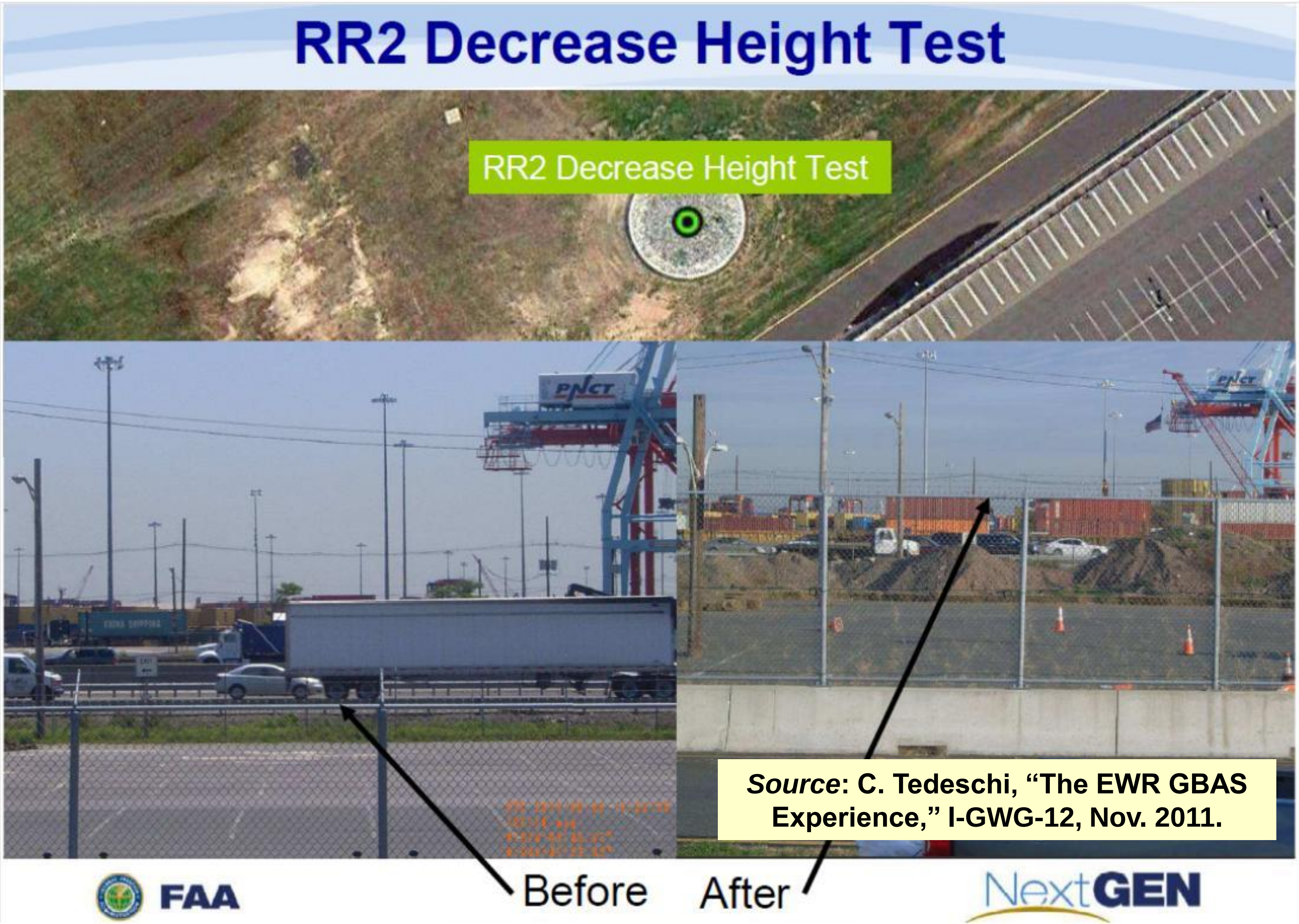
- **Where feasible, spread out receivers over a larger area (or install additional receivers) to reduce impact of a single interferer.**
  - **Increases difficulty of siting at some airports**
- **Modify antenna design and installation to attenuate low elevation angles susceptible to RFI from ground transmitters.**
  - **May restrict usage of low-elevation GNSS signals.**
- **CRPA antennas in future (R&D)?**

Newark Site Modifications (1)

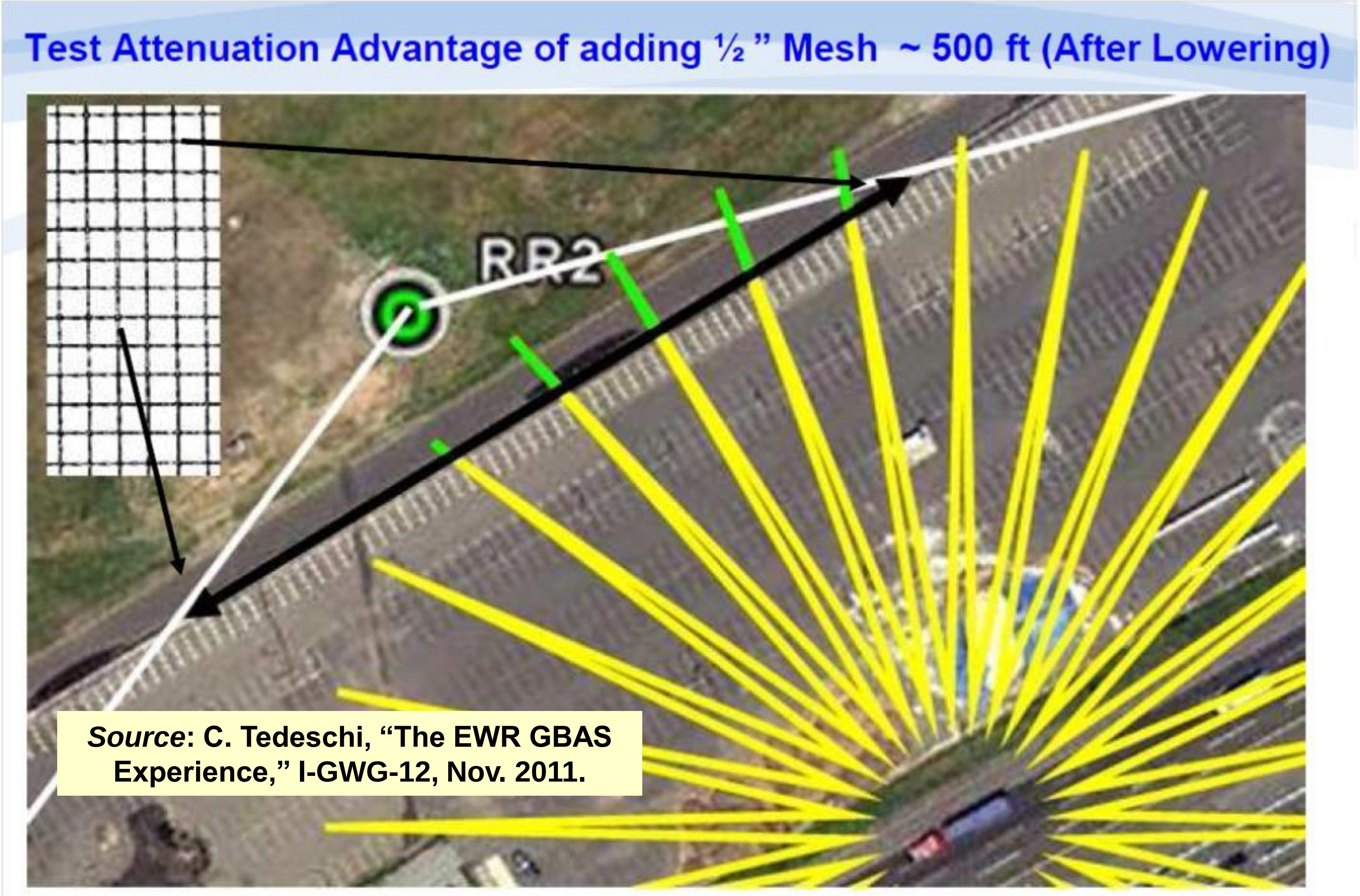
RR1 Displace South

***Source*: C. Tedeschi, "The EWR GBAS Experience," I-GWG-12, Nov. 2011.**

Newark Site Modifications (2)



Newark Site Modifications (3)



***Source*: C. Tedeschi, “The EWR GBAS Experience,” I-GWG-12, Nov. 2011.**

Example Reference Receiver Sites at Newark

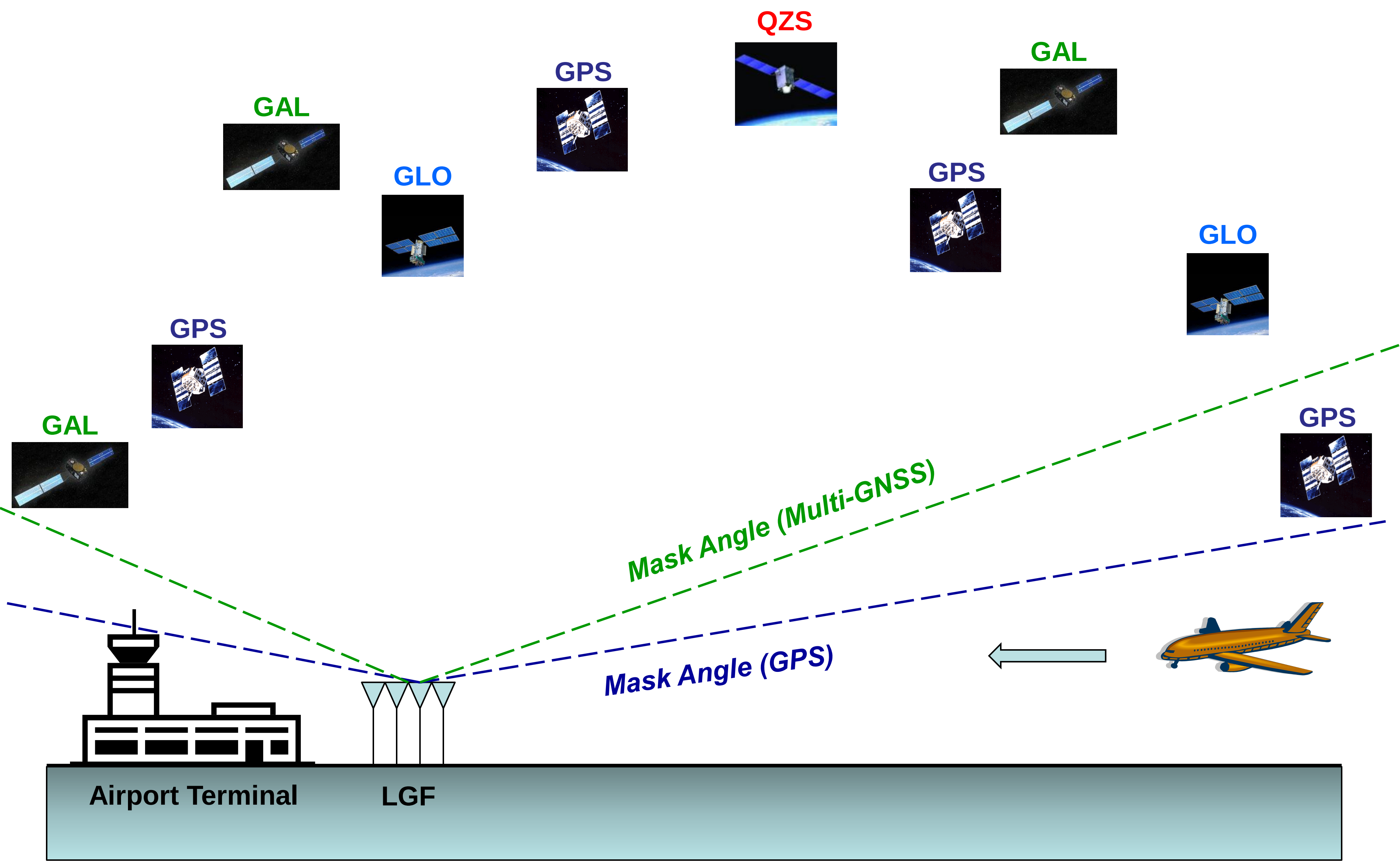
***Source*: C. Tedeschi, "The EWR GBAS Experience," I-GWG-12, Nov. 2011.**

Reference Receiver Site at Houston/George Bush Airport (IAH)

RFI Threat Mitigations (2): *Software Improvements*

- **Operate safely with fewer (2) reference receivers.**
  - **Requires improvements to integrity monitors**
- **Reduce probability and impact of system "shutdown" if RFI occurs.**
  - **Support safe precision approach capability at somewhat higher levels of RFI.**
  - **Recover all signals after jammer disappears (e.g., vehicle with PPD "moves on down the road").**
  - **Minimize outage duration if shutdown and restart is required.**

"Multi-GNSS" Protection Against RFI



Summary

- **The threat of RFI to GNSS has grown in recent years.**
  - **GNSS is now used everywhere and all the time; thus more encounters with RFI are to be expected.**
  - **Many more interferers exist now due to easy access to (illegal) "privacy protection" jammers (PPDs).**
- **Because RFI cannot be prevented, *robust* and *flexible* strategies are required for GBAS.**
  - **Where possible, reject or attenuate interference to minimize impact on reference receivers.**
  - **Support safe precision approach capability under a greater range of jamming scenarios.**
  - **Recover quickly when temporary loss-of-service cannot be prevented.**

Backup slides…

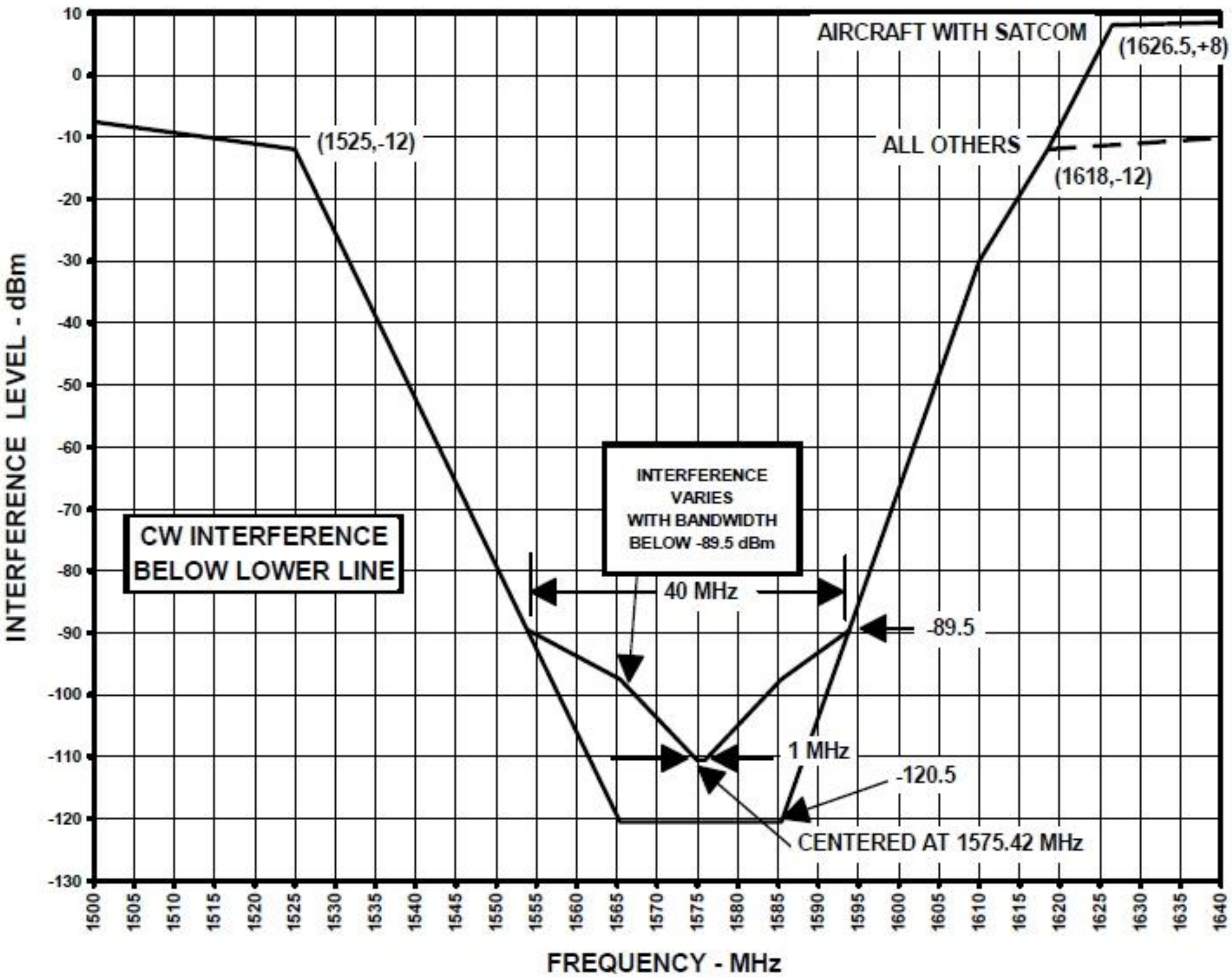
Backup slides follow…

RF Interference Signal Types

- ***CW interference*: very-narrow-band signals that impact, for example, a single C/A-code spectral line.**
  - **Can cause large jumps in carrier phase and result in receiver loss of lock on affected satellite(s)**
- ***Broadband interference*: interference that occupies a significant frequency range relative to the bandwidth of GNSS signals.**
  - **E.g., 2 MHz or more for GPS L1 C/A code**
  - **Appears as additional RF "noise" that makes tracking of all satellites more difficult**
- ***Pulsed interference*: RFI transmission switches on and off within a single C/A-code period (~ 1 ms)**

RFI "Mask" for Civil Aviation

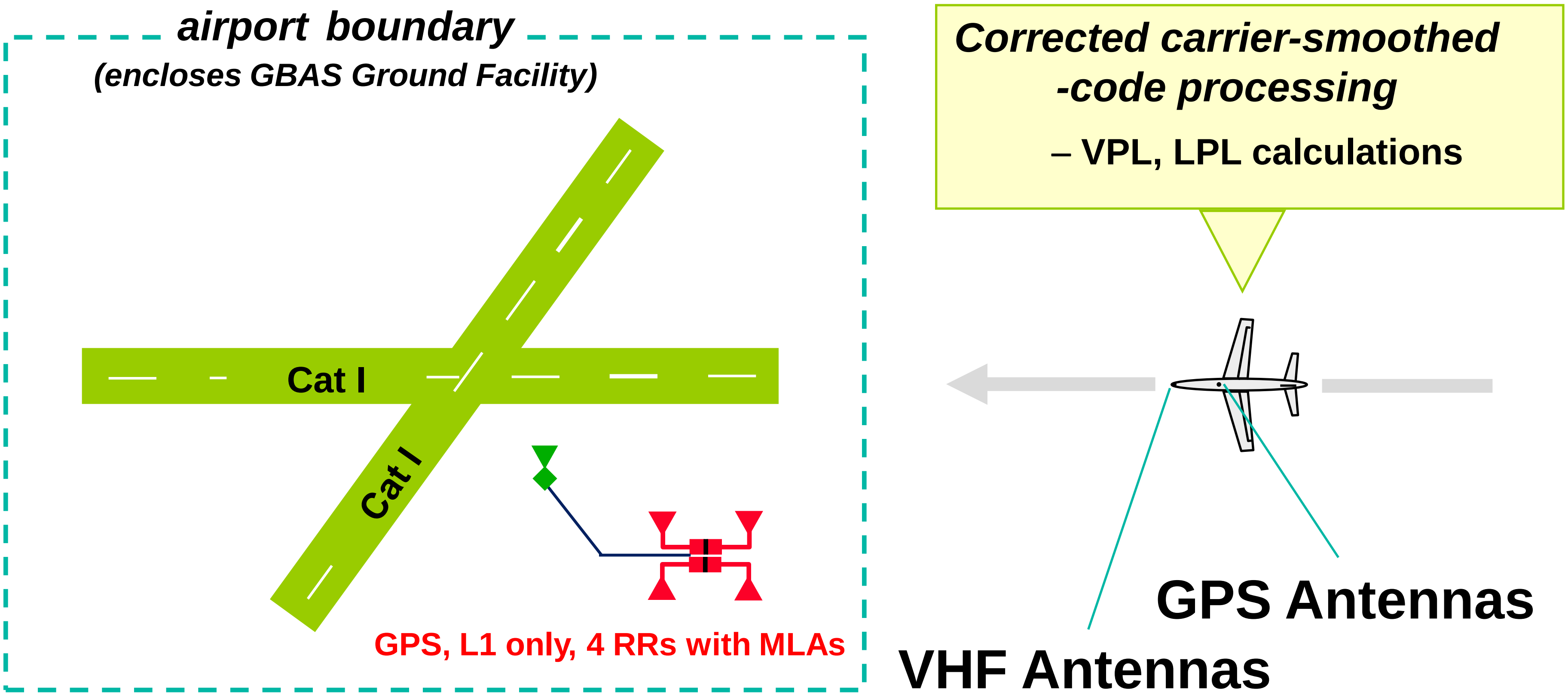
***Source*: RTCA LAAS MOPS, DO-253C, 12/16/2008**



Three Types of Interferers *(My Definitions)*

- ***Malicious Interferers*: Those who intend to cause harm to GNSS users.**
  - **E.g., people trying to shut down civil-aviation operations**
  - **May use high-power jammers to deny GNSS over large areas**
- ***Uninformed Interferers*: Those who intend to transmit near GNSS frequencies but intend no harm to users.**
  - **E.g., Personal Privacy Devices (PPDs), who want to hide from GNSS based monitoring of their movements**
  - **E.g., Miscalibrated pseudolites and GNSS repeaters**
- ***Accidental Interferers*: Those who have no intent to transmit near GNSS but do so accidentally.**
  - **E.g., mis-tuned radio transmitters, factory testing that generates broadband RF noise, etc.**

GBAS Architecture Layout (Supports CAT I Precision Approach)

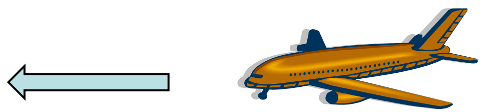


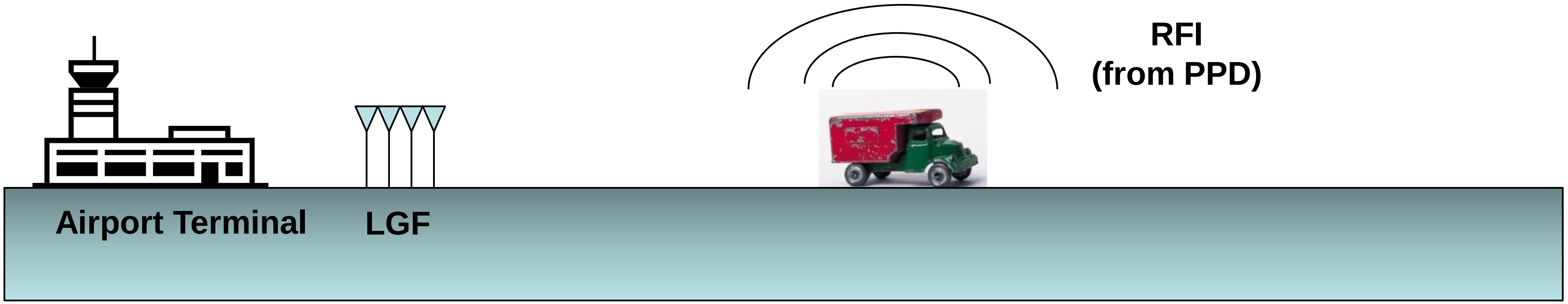
Reference Receivers and Processing

VHF Data Link

PPD Impact on Aircraft Precision Approach

- **Ground-based DGNSS reference receivers (part of GBAS) are most vulnerable to nearby RFI.**
- **Nearby aircraft taxiing to or from gate and airport vehicles are also vulnerable but are not depending on GNSS.**
- **Nearby aircraft in flight (e.g., approach phase) are better-shielded from RFI coming from the ground (top-mounted GNSS antenna).**





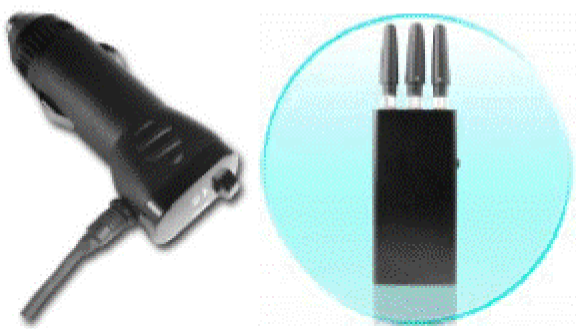
PPDs for Sale Over the Internet

***Source*: L. Eldredge, "GNSS Program Status," 51st CGSIC, Sept. 2011**

$110 Ebay

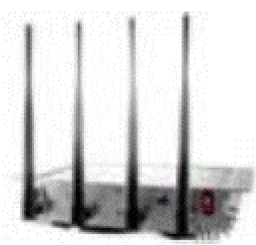
$335 Ebay

$92 Ebay



$40 GPS&GSM
www.chinavasion.com

$55 Ebay



$83 GPS&GSM
www.Tayx.co.uk

$152 Ebay

Summary of PPD Characteristics

***Source*: T. Kraus, *et al*, "Survey of In-Car Jammers," ION GNSS 2011**

No.	Class	Center frequency	Bandwidth	P_{Peak} [dBm]
1	I	1.5747594 GHz	0.92 kHz	-12.1 dBm
2	II	1.57507 GHz	11.82 MHz	-14.4 dBm
3	II	1.58824 GHz	44.9 MHz	-9.6 dBm
4	I	1.5744400 GHz	0.92 kHz	-25.6 dBm
5	III	1.57130 GHz	10.02 MHz	-19.3 dBm
6	IV	1.57317 GHz (1.57723 GHz)	11.31 MHz (– 19.43 MHz)	-9.5 dBm
7	II	1.57194 GHz	10.72 MHz	-30.8 dBm

CW Type

"Chirp" Type

Significant power variation

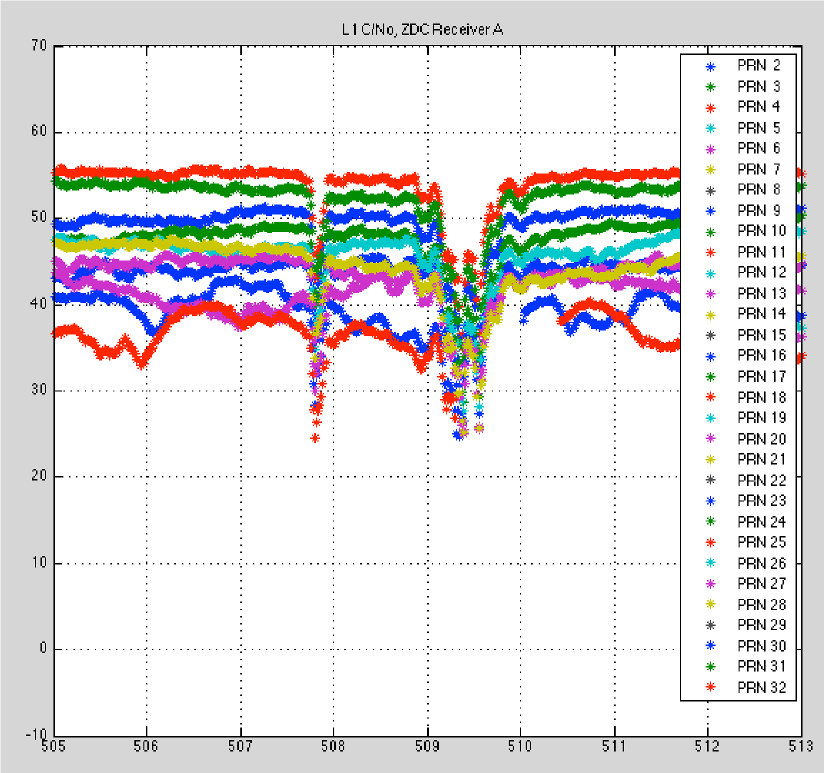
Example 4: Unknown RFI Observed by WAAS (3)

L1 C/N$_0$ GPS SV measurements at ZDC WRS (Leesburg, VA.) on 9 Apr. 2011

Zoom in on first RFI event

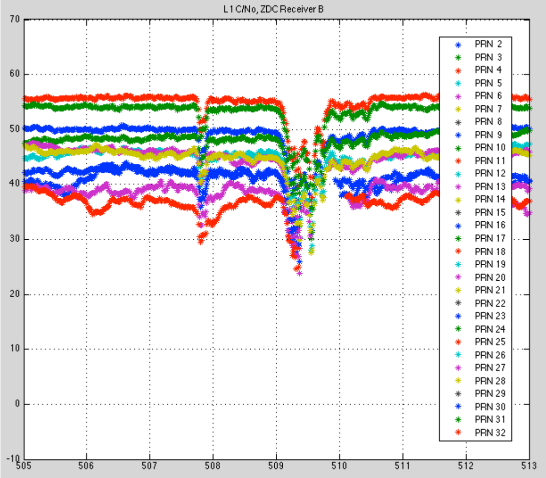
ZDC Receiver A

C/N$_0$ (dB-Hz)

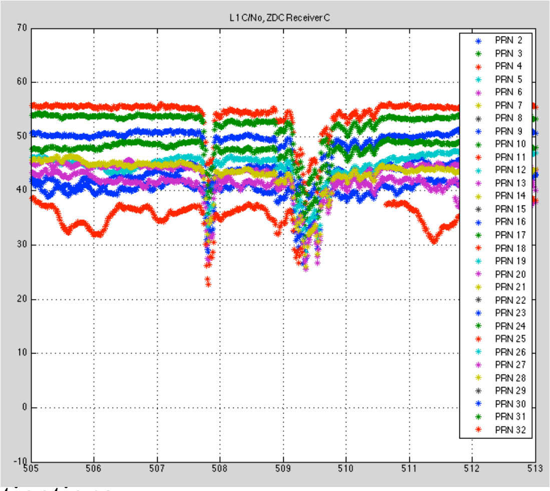


Time (min)

ZDC Receiver B



ZDC Receiver C



RFI Monitoring at Kaohsiung Airport, Taiwan (August-Sept. 2011)

***Source*: O. Isoz, D. Akos, *et al*, "GPS L1/Galileo E1 Interference Monitoring System," ION GNSS 2011, Sept. 2011.**

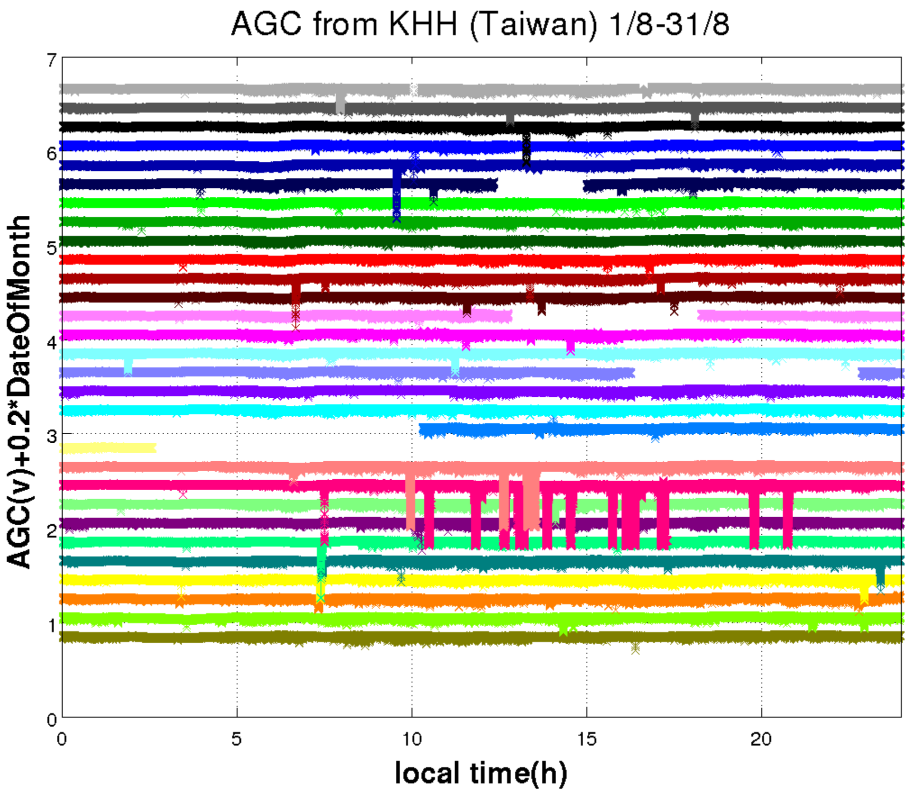
Monitor System Location Near Airport

View toward Highway and Industrial Area

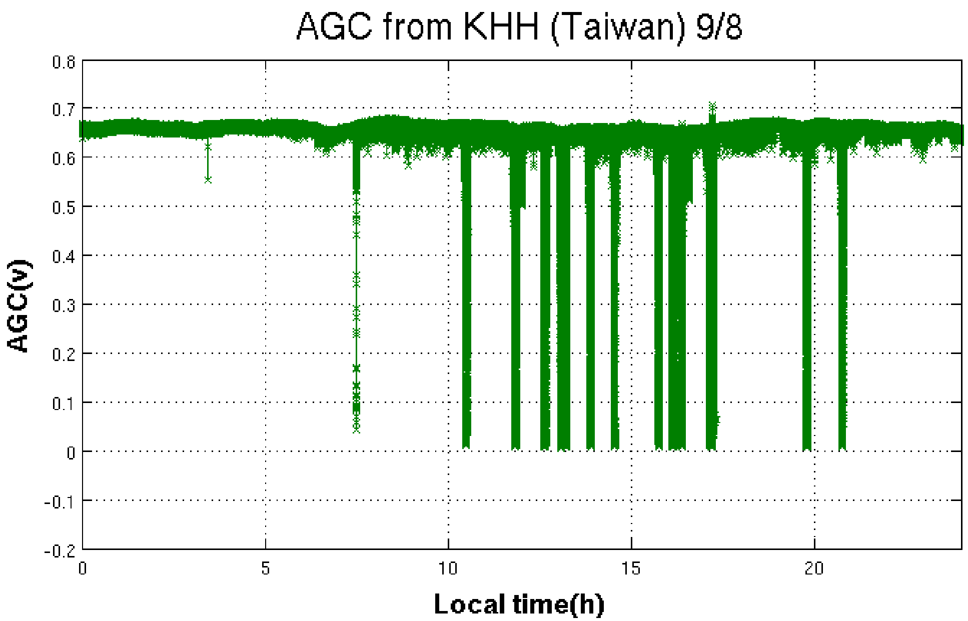
RFI Detection Using Receiver AGC During August 2011

***Source*: O. Isoz, D. Akos, *et al*, "GPS L1/Galileo E1 Interference Monitoring System," ION GNSS 2011, Sept. 2011.**

AGC over Entire Month



AGC during 9 Aug. RFI Event



Advantages from GNSS Modernization

- **New civil signals (e.g., GPS L5C) are somewhat more resistant to RFI.**

- **Civil signals on multiple frequencies add protection against *accidental* and some *uninformed* interferers.**
  - **However, future PPDs likely will begin transmitting on multiple frequencies.**

- **Satellites from multiple GNSS constellations will greatly increase the number of visible satellites.**
  - **With more than 10 – 12 satellites in view, not all satellites need to be used → *optimal sub-selection* becomes advantageous.**
  - **Benefit for mitigating RFI shown on next slide.**