Three Wishes

and

an elaboration

For Reception of RESILIENT NAVIGATION and TIMING FOUNDATION

Professor Bradford Parkinson

Stanford University

(these are my personal views)

Good News: World-wide dependency on GNSS – *PNT Taken for Granted – the "Stealth" Utility*

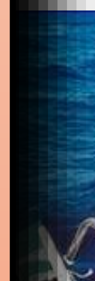


- Civil
  - Transportation
    - Aviation

The *Majority* of these Applications were not part of the original "formal definition" of GPS

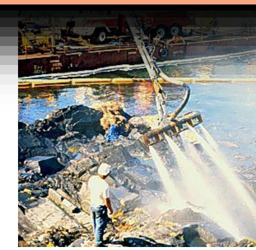
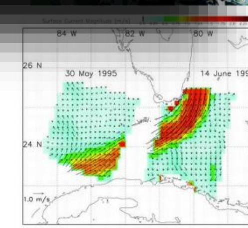
They resulted from:

- Civil Creativity
- Plummeting cost of GPS receivers
- Virtually 100% Reliability and Availability




  - Other
- Military



Primary PNTAB Objective:

Meet the ***Obligation*** of

Assured *PNT* for all Users

- Therefore Focus is ***PTA Program***
  - ***Protect*** the **radio spectrum** + identify + prosecute interferers
  - ***Toughen*** GPS receivers against natural and human interference
  - ***Augment*** with additional GNSS/PNT sources and Techniques

A

Wish 1: Begin deployment of eLoran Immediately

eLoran Characteristics

- **Unjammable** (virtually) **and adds Frequency Diversity**.
- **Regional –** Trial system in UK. Full US deployment would require 20 to 30 transmitters plus ~50 differential stations
- **Horizontal Only.** No third dimension –Baro can help
- **Accuracy over landmass adequate for backup.** Variable speed of signal – errors can be 0.1 mile (or perhaps more).
  - Issue is spatial and temporal decorrelation if differential techniques are used (ASF corrections are a form of differential and assume temporal decorrelation is negligible)
- **Can Achieve 10-15 meter accuracy in small areas** (within about 5-10 miles of calibration point) must use ~ *continuous updates* of Differential Accuracy for Integrity

eLoran is the most viable augmentation to GPS to provide PNT in times of stress and to deter deliberate jamming

Wish 1: Begin deployment of eLoran Immediately

- Consider Government Commercial partnership
- Develop and offer affordable eLoran timing and positioning receivers
- Start with US timing capability
- Add redundancy and positioning capability in hi-payoff areas
- Add eLoran differential capability where justified

<u>Wish 2:</u> *That low-cost Very Jam-resistant GNSS receivers are Commercially available*

Jam Resistance - the *"Nibbles"*

Improving Jamming Resistance Performance

Digital Technology is making beam steering and vector receivers much more affordable

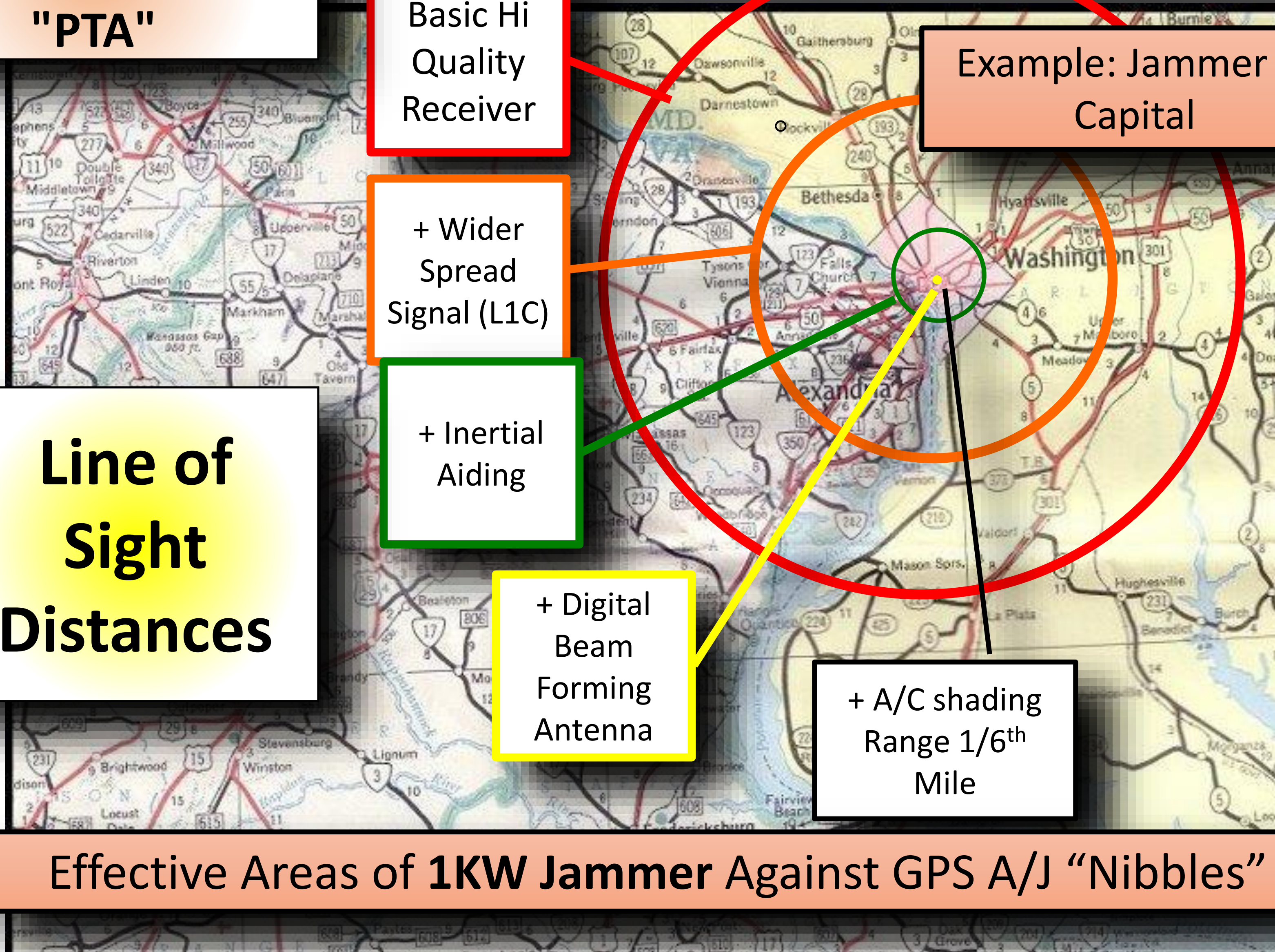
Believe This is a trend that will continue

Ine (MEN		
Wider Spreading GNSS Signal (e.g. L1C)	5 dB	32%
Digital Beam Forming Antenna	20-30 dB	1.0% - 0.1%
Aircraft Shading (commercial Aircraft)	5-10 dB	32% - 10%
"Spilker" Vector Receiver (A powerful form of frequency diversity)	Up to 10 dB	10%
Potential Total Improvement	**48 –67 dB**	**0.0016% - 0.00002%**

Require > 60,000 Jammers to cover Original Area

Toughening GPS Receivers

Assured Availability of PNT "PTA"



Basic Hi Quality Receiver

+ Wider Spread Signal (L1C)

+ Inertial Aiding

+ Digital Beam Forming Antenna

+ A/C shading Range 1/6th Mile

Example: Jammer at Capital

Line of Sight Distances

Effective Areas of **1KW Jammer** Against GPS A/J "Nibbles"

Wish 2: *That low-cost Very Jam-resistant GNSS receivers are Commercially available*

- Particularly Beam-steering digital antennas – 17 Elements large base perferred
- Specifications of Capability included in Commercial aircraft receivers
- For military remove incentive to add complex and expensive steerable arrays on satellites
  (Earliest full capability would be about 2035)

The #1 GPS/GNSS *Availability* Issue

Spectrum Interference –

Illegal jamming

and/or

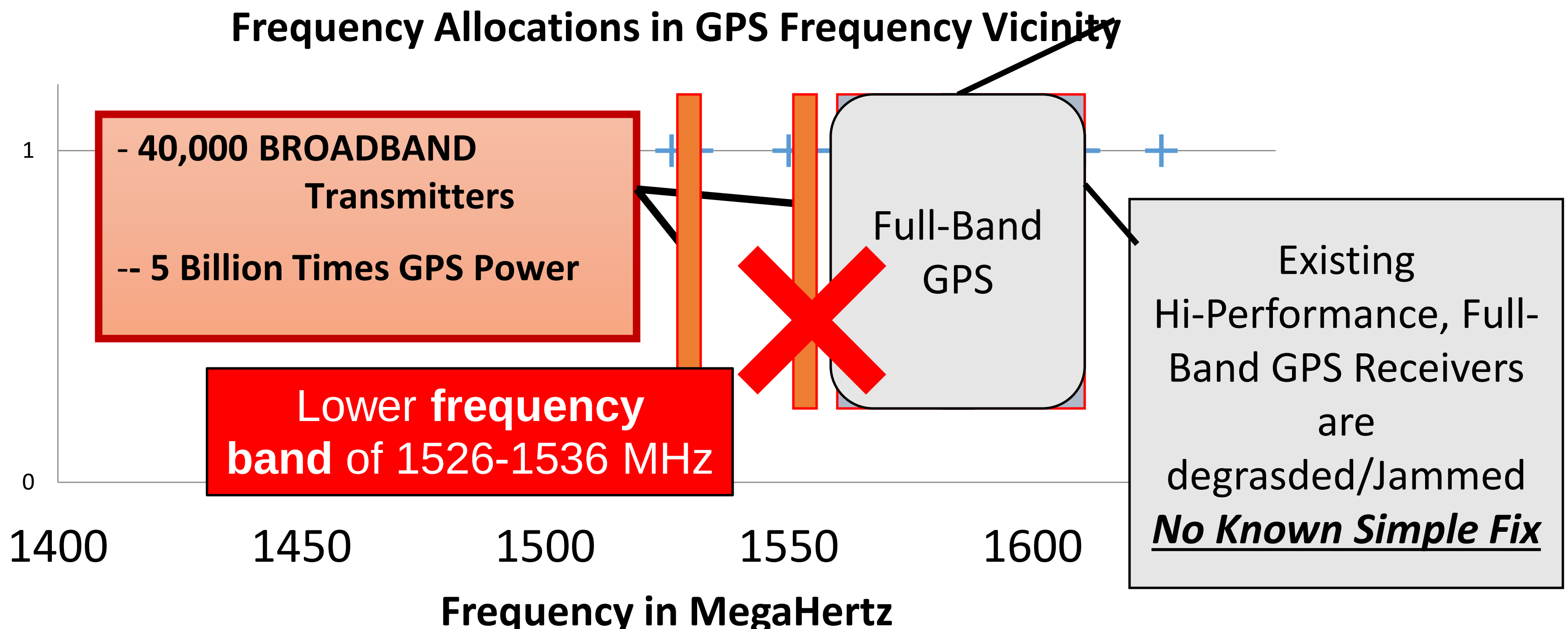
Licensed Intrusion

Adjacent band interference concern

"Upper" band is apparently off the table, but not officially rescinded

Original proposal: transmit 15 kW+ ,
Tested in 2011 - Transmit 1.58 kW – "Ligado's proposed minimum tower spacing of 1420', impacted area must be far less than 710' or else impacted area could be, e.g., city-wide " (FAA report)

Existential Threat to GPS – FCC Re-allocation of Nearby Band to Higher Power *(Ligado Proposal)*



Problems:

Proximity (geographic and RF spectrum) and ***Power***

DepSecDef Carter and DepSecTrans Pocari ExCom Letter to Asst Sec Strickling 13 Jan 2012

". . . without affecting existing and evolving uses of space-based PNT services vital to economic, public safety, scientific, and national security needs."

Wish 3: FCC does not approve repurposing of Adjacent Spectrum until/unless proposal passes realistic evaluation of all current and future GNSS signals, applications and techniques

The Fundamental Differences in Radio Communications and Radio Navigation must be Recognized

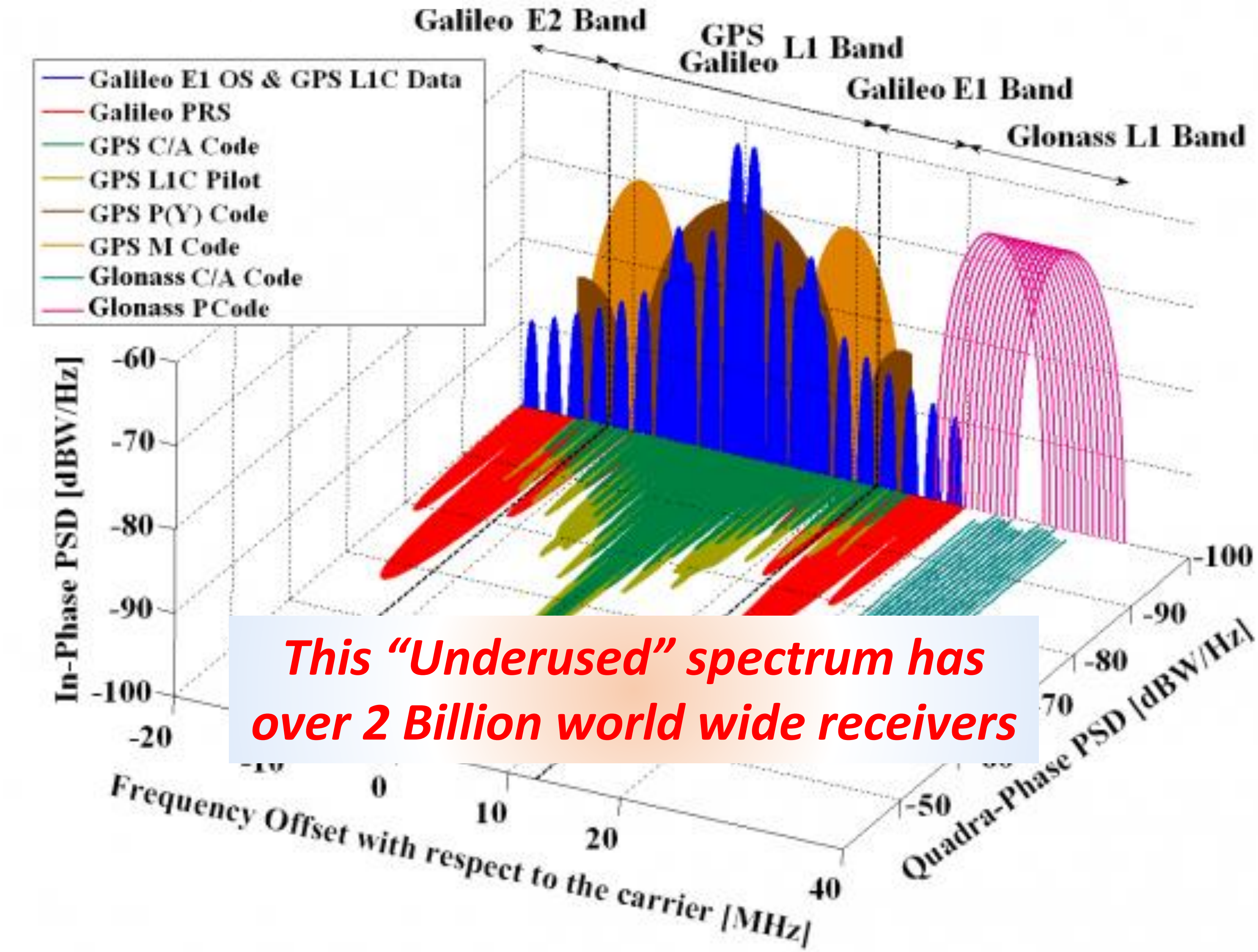
- Digital Radio <u>Communications</u>:
  - Incoming <u>message is not known</u> – finding it is the whole point
  - Must determine whether each signal "bit" is a one or a zero
  - Use sophisticated methods to correct errors
- Digital Radio <u>Navigation:</u>
  - Incoming signal sequence (ones and zeros) is totally known by user
  - The goal of the user is to precisely time the transition from one to zero (and zero to one)

In the face of interference, degradation of positioning <u>accuracy</u> occurs well before total loss of signal

Specific Issues (Near L1 C/A, P/Y, M, L1C, Galileo i.e. the 1575 mHz band)

- The New GNSS Signals
  - US (L1C and Lm)
  - Other GNSS (Galileo + Glonass and Beidou)
- Embracing the 1 dB criterion
- Antenna Patterns and Propagation Model
- Repurposed transmitter density and power
- Applications apt to be within Harms Way
  - Both Current and Emerging

Very Crowded Primary GNSS Frequency Band



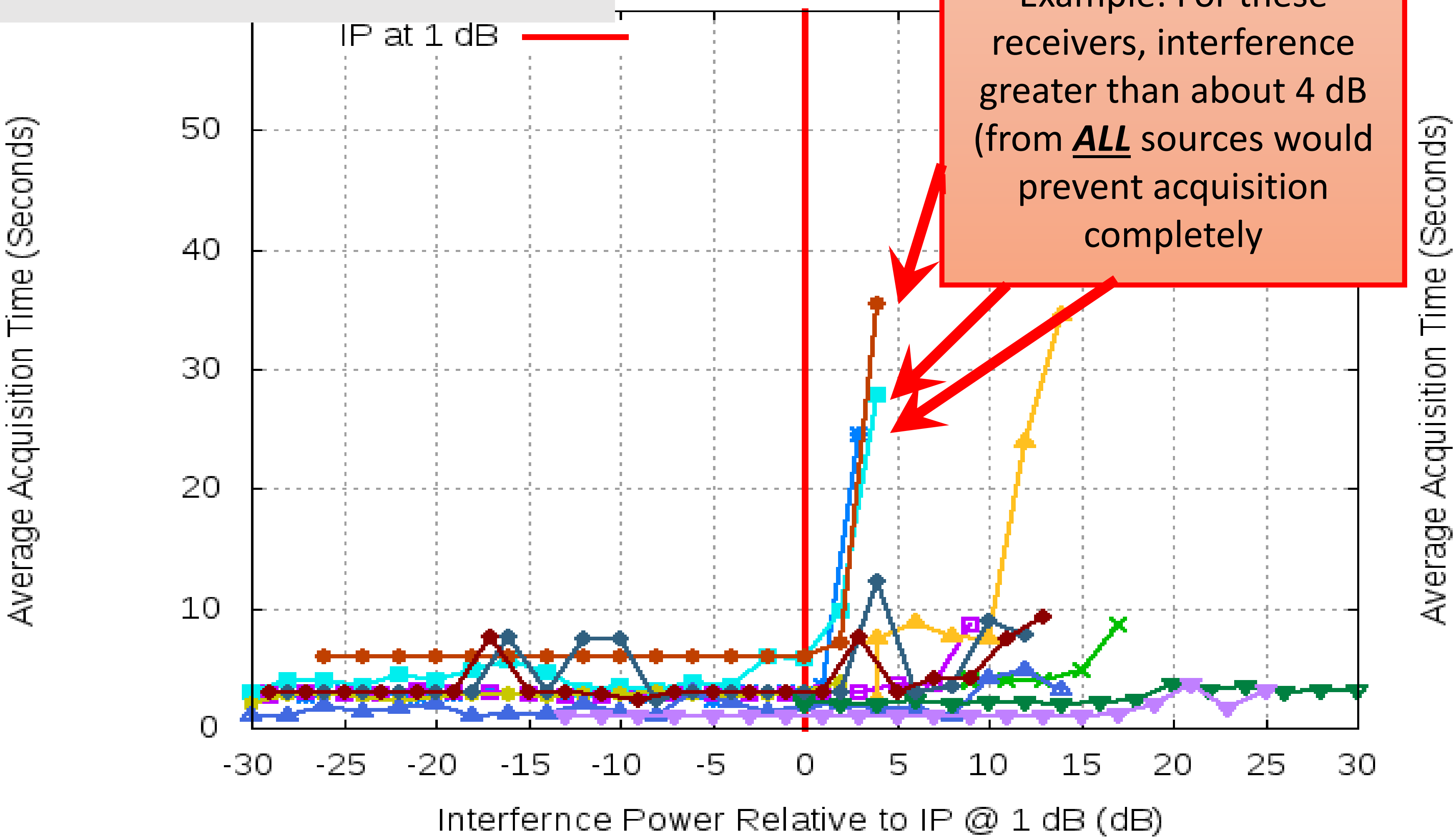
This "Underused" spectrum has over 2 Billion world wide receivers

The 1 dB Criterion:

Non-GNSS Transmitters should not raise the effective noise floor more than 1 dB (12.2%)

- Well established National and International Standard (Just reaffirmed internationally)
- Avoids having to test every application/operation
- Susceptibility varies depending on Precision of receiver - **Generally Precision is (1/Bandwidth) for Position/timing applications**
- Susceptibility of newer GNSS signal receivers must be included (e.g. consider new Qualcom chip)
- Must consider multiple transmitters, spacing, antenna patterns, and "Space Loss"

Some receivers have little acquisition margin…



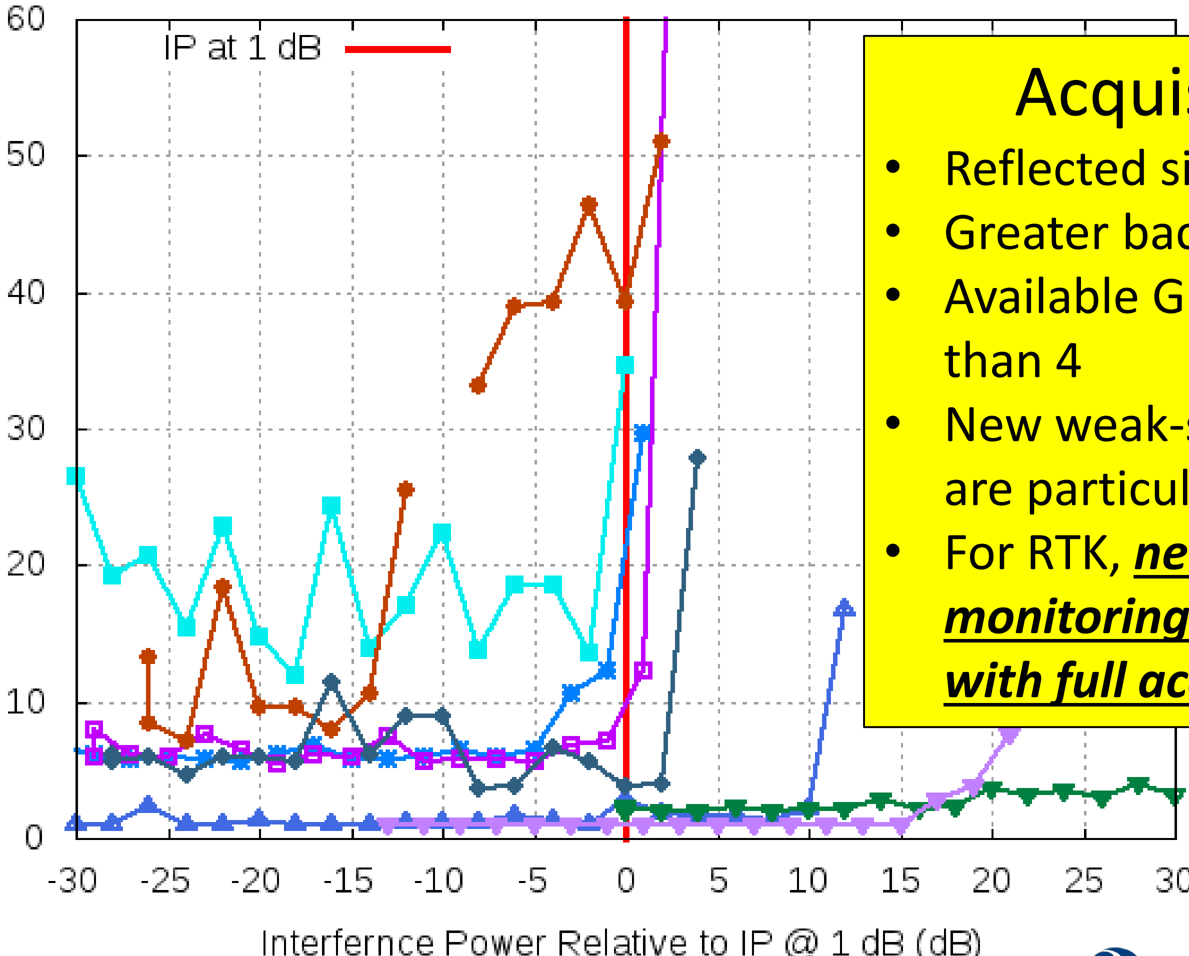
Example: For these receivers, interference greater than about 4 dB (from ***ALL*** sources would prevent acquisition completely

U.S. Department of Transportation

Office of the Assistant Secretary for Research and Technology

ICD Min. Power

Some receivers have little acquisition margin…



Acquisition in cities

- Reflected signal weaker and LHCP
- Greater background interference
- Available GPS signals frequently less than 4
- New weak-signal (indoor) receiver are particularly susceptible – (911?)
- For RTK, ***need both user and monitoring station to be operating with full accuracy***

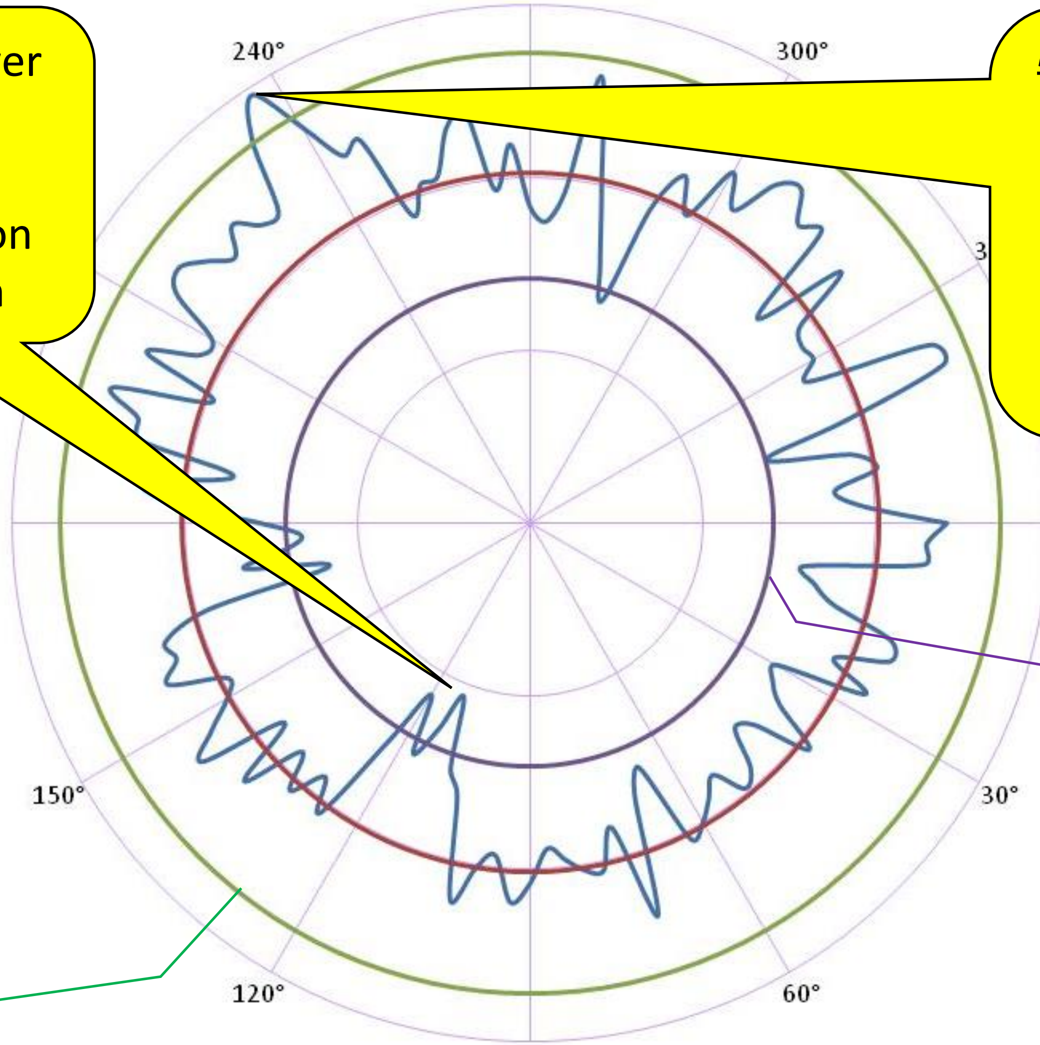
U.S. Department of Transportation

Office of the Assistant Secretary for Research and Technology

Low Elevation

Typical Urban Antenna Power Pattern

Plotted around 360 degrees of Azimuth



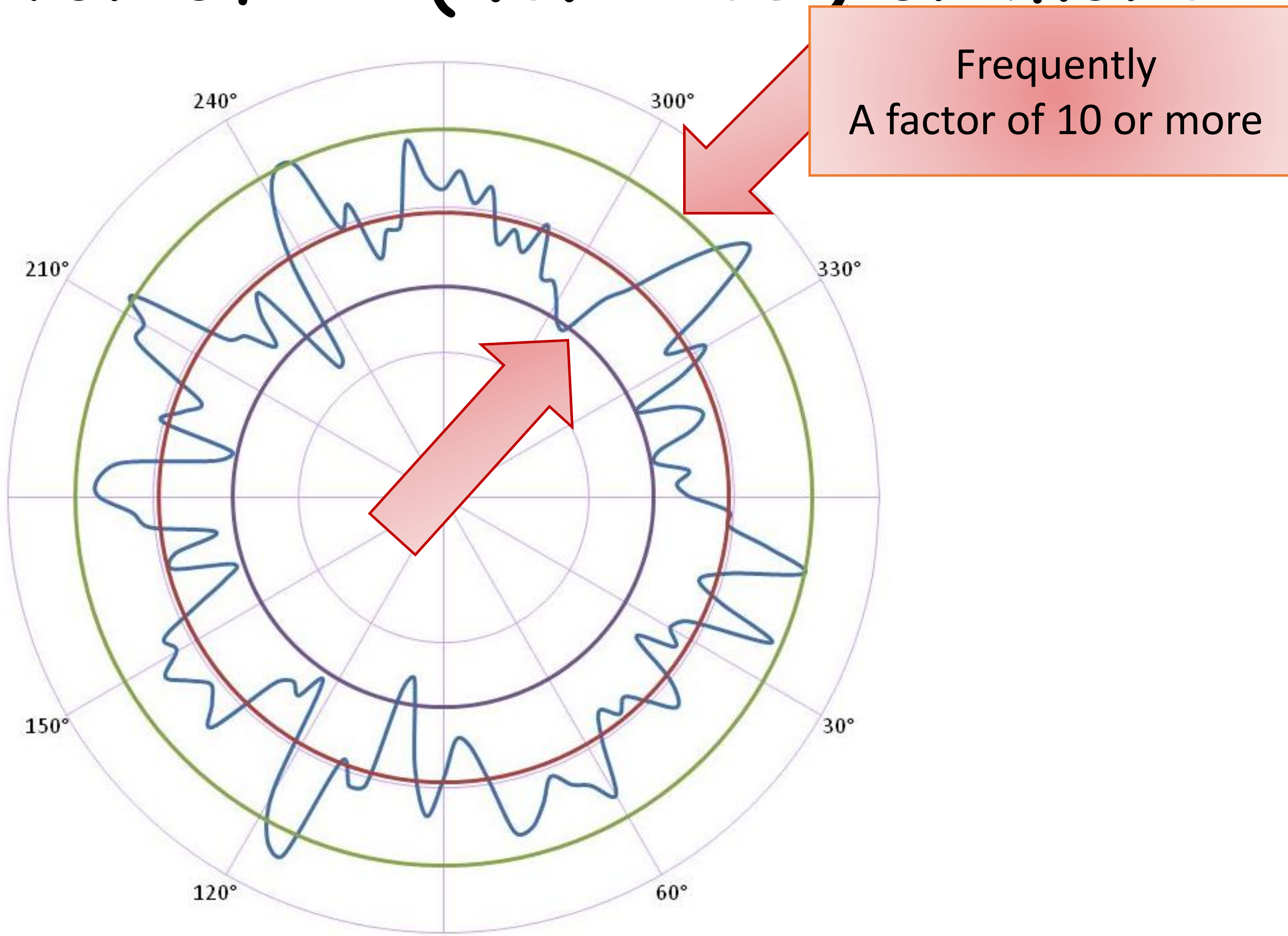
Minimum Power and Most Challenging Communication Link Problem

Maximum Power -Maximum Interference Levels Most Challenging for Navigation Systems

99th Percentile – only exceeded 1% of the full azimuth circle – Prudent for a ***Navigation Interference*** Model

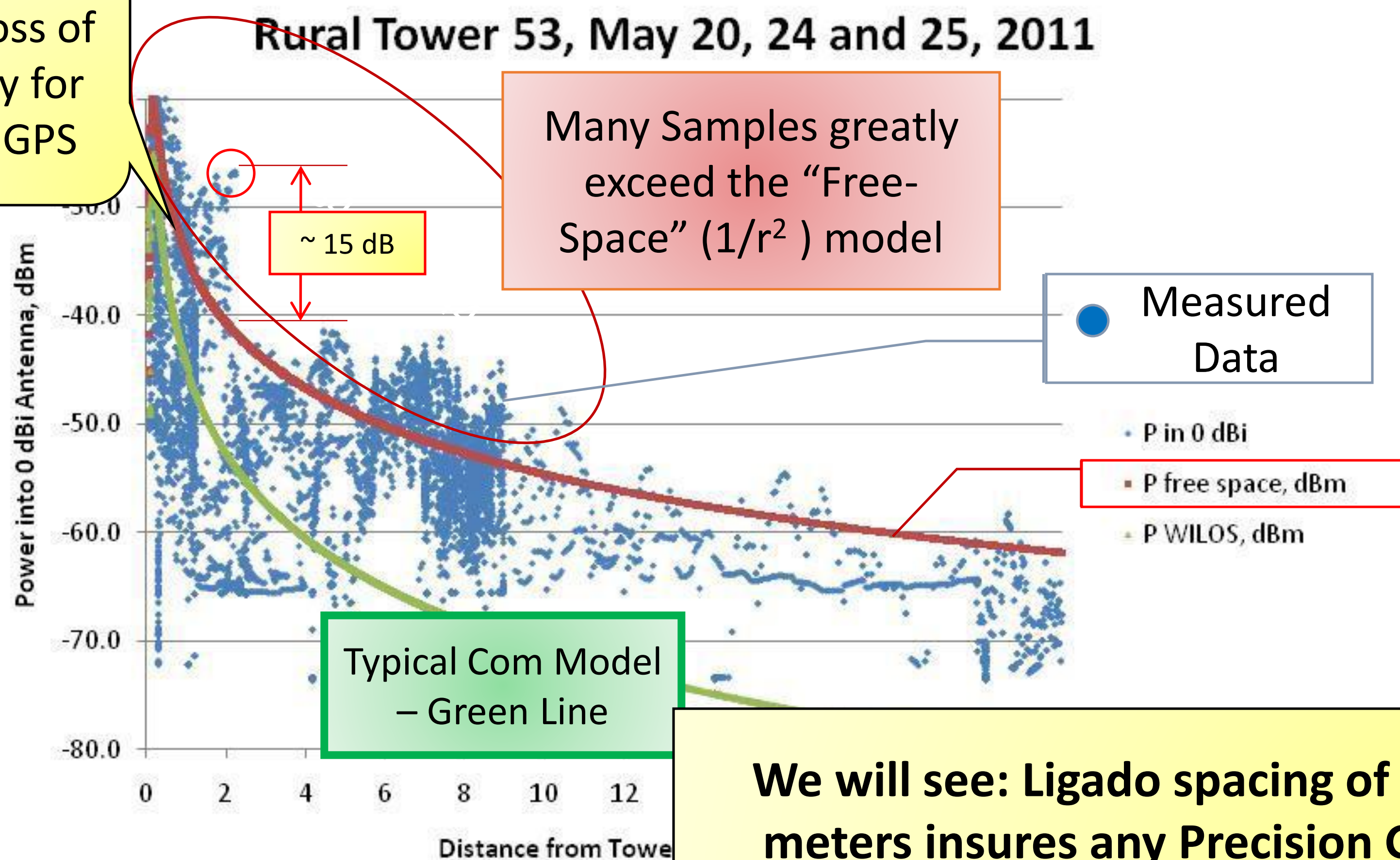
5th Percentile – Less signal in only 5% of the full azimuth circle Useful as a ***Com*** model

In urban areas the differences can be a factor of 10 (i.e. 10dB) or more



Real Data - One Azimuth in Las Vegas

Massive Loss of Availability for Precision GPS



Many Samples greatly exceed the "Free-Space" ($1/r^2$) model

Measured Data

Typical Com Model – Green Line

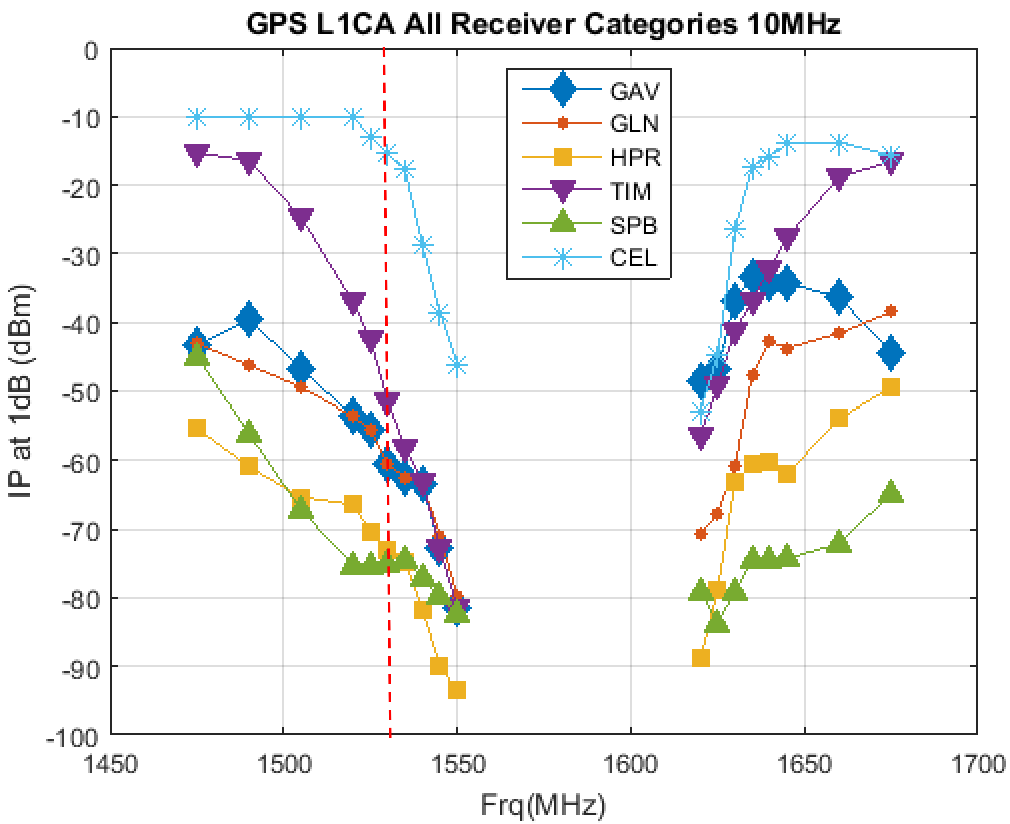
We will see: Ligado spacing of 400 meters insures any Precision GPS receiver is well within Jamming Range

Summary: Why are there Different Views of Propagation* Models?

- Propagation in the real world:
  - Does not fall off as $1/r^2$ (free-space) would suggest
  - There are peaks and valleys reflecting reinforcing reflections or attenuation – **and they change with rain, passing trucks and urban construction**
- As an ***Assured Communications System***
  - Must insure connectivity - use largest attenuation
  - Tend to model as "worst case" (Perhaps the 5 percentile low "tail")
- As ***Interference to a Navigation Signal***
  - Must consider "least attenuation" (An envelope of the highest signal)
  - In Urban areas signal can be larger than "free-space", $1/r^2$, model due to reflections (multipath)

* A **Propagation Model** is a mathematical description of how the transmitted Radio Signal varies with distance and angle to the transmitter

DOT measurement of
10 MHz Bounding Masks
Most Sensitive GPS L1 C/A Receivers



Category	ITM at 1530 MHz (dBm)
GAV - **General Aviation (non certified)**	**-61.0**
GLN - **General Location/Navigation**	**-60.5**
HPR - **High Precision & Networks**	**-73.0**
TIM - **Timing**	-59.4
SPB - **Space Based**	**-73.5**
CEL - **Cellular**	-15.3

U.S. Department of Transportation

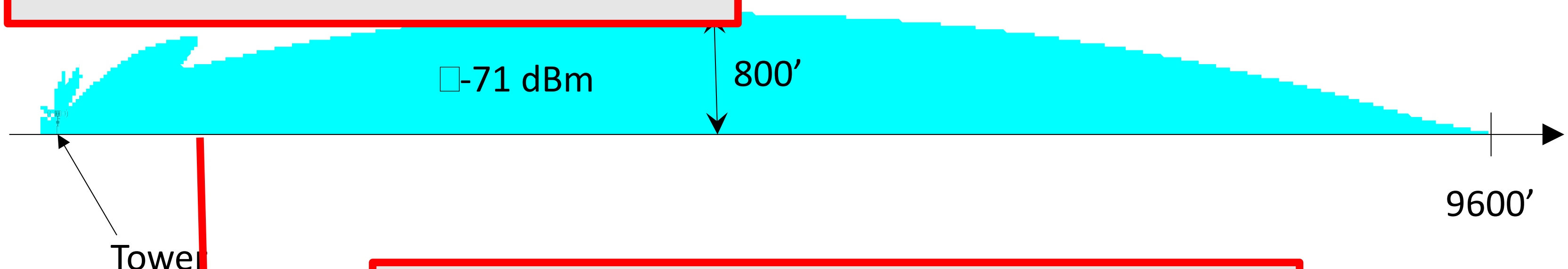
Office of the Assistant Secretary for Research and Technology

Preliminary Results

Impact of Single 12.2 dBW Tower on High Precision Receivers

Transmitter Power is
16.6 Watts
- Most Sensitive Receiver Tested

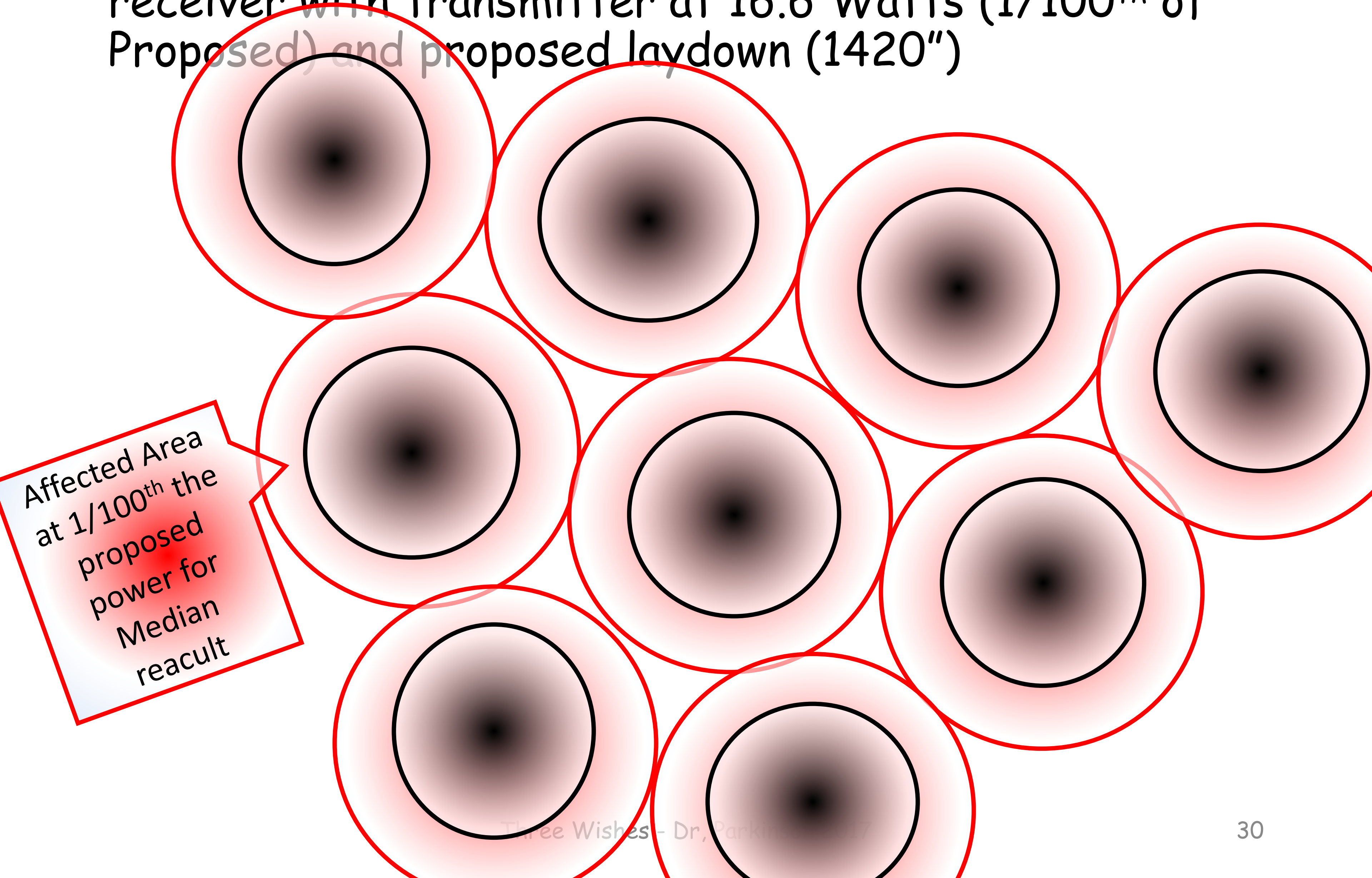
- EIRP = 12.2 dBW
- Tower height = 25 m (82’)
- Downtilt = 6 degrees
- Frequency = 1530 MHz



Median Sensitivity, Hi Performance receiver might improve by 25 dB -
Impact Radius would still be 9600/(316)^1/2
or over 525 feet for 17 Watt Transmitter

6

Consider the ***Median*** High Precision GPS L1 C/A receiver with transmitter at 16.6 Watts (1/100th of Proposed) and proposed laydown (1420")



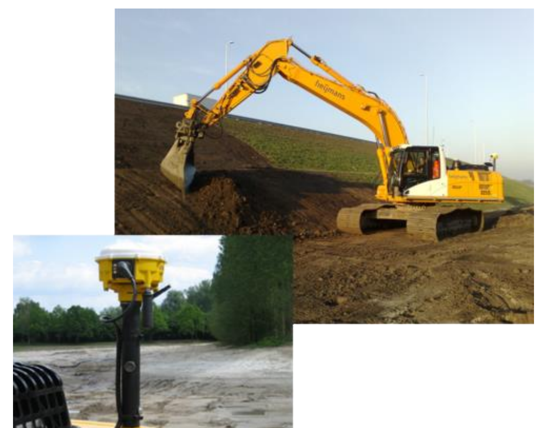
So What?

Urban Applications at Risk

Taxiway and Runway Navigation

Emergency Vehicle Control and Monitoring Plus 3D victim location

Control and Monitoring of UAVs – Delivery and Reconnaissance



Precision control of Construction Vehicles

Also Possibly in the interference pattern

GNSS Precision Survey in construction of High-Rise Buildings

Self Piloted Cargo Airplanes

Flying Car/Robotic Taxi

GNSS Track Safety Discernment

Wish 3: *FCC: Does not approve repurposing of Adjacent Spectrum until proposal passes realistic evaluation of all current and future GNSS signals, applications and techniques*

- Must honor international "1 dB" criterion
- Tests and analysis are incomplete
  - Excellent work by DOT
  - NASTCN did not explore many critical aspects
  - Critical current Applications and installed base apt to be in Harms way
  - Future Applications and techniques are in jeopardy

The Fundamental Problem: The Shannon Limit

Channel Capacity

Power in Comm Signal

$$C = B\,log_2\left(1 + \frac{S}{N}\right)$$

Transmission Bandwidth 10 mHz

Ambient Noise- Not Adjustable

Recap: The 3 Wishes

P

Wish 3: That *FCC does not approve repurposing of Adjacent Spectrum until/unless proposal passes realistic evaluation of all current and future GNSS signals, applications and techniques*

T

Wish 2: *That low-cost Very Jam-resistant GNSS receivers are Commercially available*

A

Wish 1: *Begin deployment of eLoran Immediately*

Important Takeaway: ***A Real Concern***

- A US commercial company has argued that ***"precise" GNSS applications*** should not be frequency-protected, since they were not originally "authorized"
- Tests show this is very harmful to precision GPS **At 1/100th** the current proposal power (16 W):
  - The most Sensitive receivers affected everywhere
  - Half the Receivers affected at ½ the transmitter operating radius
  - Many future applications/techniques potentially at risk…
- Let's support both existing Base and the Future

Are you our Genii?

Questions?

Third Floor in High Sierras 2017 Drought is over?