Three Wishes

and

an elaboration

For Reception of

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 high-payoff areas
- Add eLoran differential capability where justified
Wish 2: 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*

<table>
<thead>
<tr>
<th>Technique</th>
<th>Improvement</th>
<th>Resulting Jammer Area as % of Original</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wider Spreading GNSS Signal (e.g. L1C)</td>
<td>5 dB</td>
<td>32%</td>
</tr>
<tr>
<td>Digital Beam Forming Antenna</td>
<td>20-30 dB</td>
<td>1.0% - 0.1%</td>
</tr>
<tr>
<td>Aircraft Shading (commercial Aircraft)</td>
<td>5-10 dB</td>
<td>32% - 10%</td>
</tr>
<tr>
<td>“Spilker” Vector Receiver (A powerful form of frequency diversity)</td>
<td>Up to 10 dB</td>
<td>10%</td>
</tr>
<tr>
<td>Potential Total Improvement</td>
<td>48–67 dB</td>
<td>0.0016% - 0.00002%</td>
</tr>
</tbody>
</table>

Require > 60,000 Jammers to cover Original Area
Toughening GPS Receivers

- Basic Hi Quality Receiver
- + Wider Spread Signal (L1C)
- + Inertial Aiding
- + Digital Beam Forming Antenna
- + A/C shading Range 1/6th Mile

Effective Areas of 1KW Jammer Against GPS A/J “Nibbles”

Line of Sight Distances

Assured Availability of PNT “PTA”

Example: Jammer at Capital

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

- Particularly Beam-steering digital antennas - 17 Elements large base preferred
- 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 Communications:
  o Incoming message is not known – finding it is the whole point
  o Must determine whether each signal “bit” is a one or a zero
  o Use sophisticated methods to correct errors

• Digital Radio Navigation:
  o Incoming signal sequence (ones and zeros) is totally known by user
  o 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 accuracy 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
  o US (L1C and Lm)
  o 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
  o 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 \(\frac{1}{\text{Bandwidth}}\) for Position/timing applications
• Susceptibility of newer GNSS signal receivers must be included (e.g. consider new Qualcomm 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.

ICD Min. Power

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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

Low Elevation

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Typical Urban Antenna Power Pattern

Plotted around 360 degrees of Azimuth

**Minimum** Power and Most Challenging Communication Link Problem

99\(^{th}\) Percentile – only exceeded 1% of the full azimuth circle – Prudent for a *Navigation Interference* Model

**Maximum** Power - Maximum Interference Levels Most Challenging for Navigation Systems

5\(^{th}\) Percentile – Less signal in only 5% of the full azimuth circle Useful as a *Com* model

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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

~ 15 dB

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:
  o Does not fall off as $1/r^2$ (free-space) would suggest
  o 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
  o Must insure connectivity - use largest attenuation
  o Tend to model as “worst case” (Perhaps the 5 percentile low “tail”)

• As Interference to a Navigation Signal
  o Must consider “least attenuation” (An envelope of the highest signal)
  o 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

<table>
<thead>
<tr>
<th>Category</th>
<th>ITM at 1530 MHz (dBm)</th>
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<tbody>
<tr>
<td>GAV - General Aviation</td>
<td>-61.0</td>
</tr>
<tr>
<td>(non certified)</td>
<td></td>
</tr>
<tr>
<td>GLN - General Location/Navigation</td>
<td>-60.5</td>
</tr>
<tr>
<td>HPR - High Precision &amp; Networks</td>
<td>-73.0</td>
</tr>
<tr>
<td>TIM - Timing</td>
<td>-59.4</td>
</tr>
<tr>
<td>SPB - Space Based</td>
<td>-73.5</td>
</tr>
<tr>
<td>CEL - Cellular</td>
<td>-15.3</td>
</tr>
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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**

Transmitter Power is **16.6 Watts**
- Most Sensitive Receiver Tested
Consider the *Median* High Precision GPS L1 C/A receiver with transmitter at 16.6 Watts (1/100th of Proposed) and proposed laydown (1420")

Affected Area at 1/100th the proposed power for Median result
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

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

- Channel Capacity
- Power in Comm Signal
- 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 1/2 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?