

Assuring PNT
for Humanity -
an Essential Element of
National Power:
Strategy and Status

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PNTAB Overarching Goal: "Assured PNT for All Users"

- "Assured" implies that users PNT needs will be satisfied.
 - But needs vary by Application.
- Fundamental is 1, 2, or 3 Dimensions.
- Will use a "Needs 2 Pack" (Perhaps top discriminators):
 - Accuracy
 - Interference Resistance (Maximum range of 10 Watt GPS Jammer)
- Define 5 Broad PNT *User Categories*
 - To help understand value of "Assurance" methods ...

The Five PNT User Categories

	A	B	C	S	T
User Category	<u>A</u> dvanced Ultra-Precise 3D	<u>B</u> asic Precision 3D	<u>C</u> ommon or Generic At Least 2D	<u>S</u> urvey and <u>S</u> cientific 3D	<u>T</u> ime Sync & Transfer T
Method	RTK	WAAS Integ. & Correct.	"Raw" GPS	Base Station	Trace to Master
Accuracy (95 th %)	0.1 Meters. <i>Dynamic</i>	2.5 Meters <i>Dynamic</i>	0-25 Meters <i>Dynamic.</i>	cm- 0.1mm <i>Static</i>	Static microsec to nanosecond
Examples	Auto Farming, Machine control	Aircraft precision approach	Cell Phones, Watches, Autos	3 Dimensional Surveying, Plate Tectonics	Banking, Power Grid
Dynamic Users			Static Users		

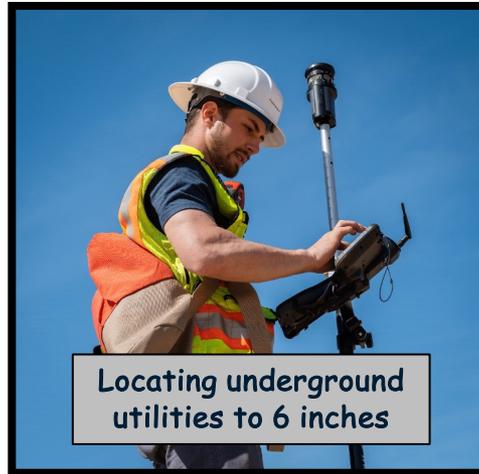
High Payoff Applications - Examples of PNT Categories A, and B

(dynamic/mobile users):

Most require 3 dimensions-Accuracy down to 2 inches



Machine Control to 2 inches



Locating underground utilities to 6 inches



Land and Maneuver BVLOS 3D and a few feet



Autofarming - 2 inches



Positive Train Location (PTL) a Train Positioning System better than 4 feet, integrity of 99.999999997% (10 nines), Defining train length and track discrimination.



Automatic unloading of Container ships - 3D inches



Over 4,476 LPV (GPS Based) approaches, Old 1,550 Cat I ILS approaches -

PNTAB Assurance Strategy - PTA -

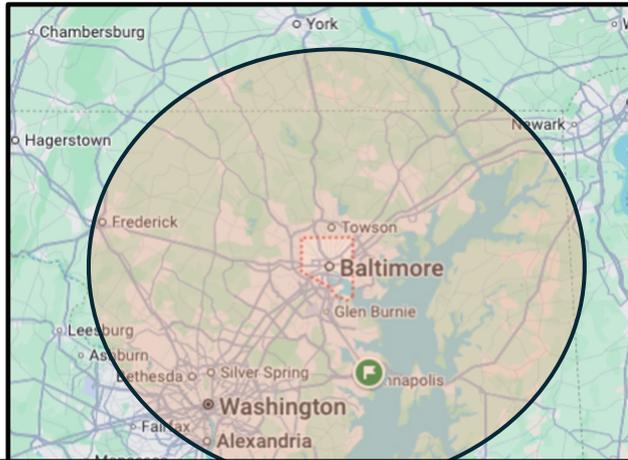
Protect, Toughen, and Augment GPS
to ensure that it

continues to provide Economic and Societal Benefits

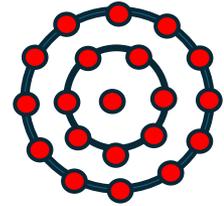
- Protect the Clear and Truthful Reception -7 steps
 - 3 Pre-actions - Legal/Law Enforcement/FCC
 - 4 Re-actions when interference/spoofing occurs
- Toughen User's Receivers
 - Diversify - Use All US GPS signals - particularly L5
(with WAAS to attain acceptable integrity)
 - Increase Jam resistance - use well established techniques
- particularly multi-element antennas (CRPAs)
- Augment or substitute PNT sources
 - Densify and Diversify satellites with Foreign/Regional GNSS-
 - With adequate integrity verification
 - Use LEO sources (Comsats or Dedicated LEO sats and signals)
 - eLORAN
 - Cell or TV towers - particularly for Time Synchronization

Toughening EXAMPLE: Combining GPS Techniques: L5, Inertial aiding, and Digital Beam/Null-steering Antennas

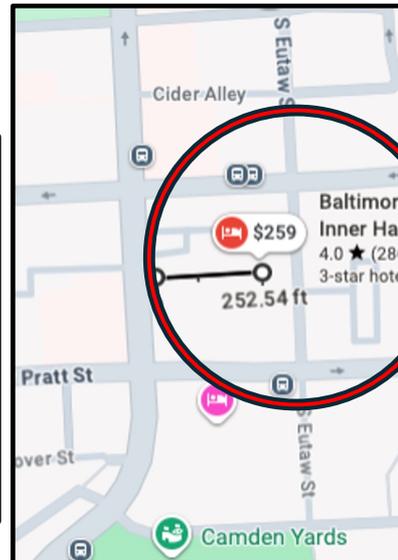
Denial Range of a 10 Watt GPS Jammer - Located in downtown Baltimore



19 Element -
48 cm
diameter - ~20"



Today: Commercial Aircraft L1 C/A Receiver with Single Element GPS Antenna-
10W Jammer Located at Baltimore Marriott
Denies PNT out to Washington
56 Km- 35 miles (LOS)



Aircraft with 19 Element GPS Antenna, L5 and inertial aiding.

Jammer - Effects reduced to about 75 meters (~250 feet).
Aircraft at 2000 foot altitude would be unaffected

Important Note: This antenna capability is available and was first demonstrated for GPS in 1978! USG has prohibited use up to now...

Category Key Needs - Dynamic Users

K
E
Y

Needs
2-Pack

Horiz. Accuracy 95 th Perc.
Range to 10 W Jammer

	<h2 style="text-align: center;">A</h2> <p style="text-align: center;"><u>A</u>dvanced Ultraprecise (0.1 meters 3D)</p>	<h2 style="text-align: center;">B</h2> <p style="text-align: center;"><u>B</u>asic Precision (2.5 meters 3D)</p>	<h2 style="text-align: center;">C</h2> <p style="text-align: center;"><u>C</u>ommon (25 meters 2D)</p>
User Category	0.1 m	2.5 m	25 m
Needs	<1 Km	<1 Km	<15 Km

Following Charts:
Evaluation Color
Keys

**Meets
Requirement**

**Does not meet
Requirement**

GPS Toughening Score Table

2 P K E Y	Horiz. Accuracy 95 th Perc. <hr/> Range to 10 W Jammer	A <u>A</u> dvanced or Ultraprecise (0.1 meters 3D)	B <u>B</u> asic Precision (2.5 meters 3D)	C <u>C</u> ommon (25 meters 2D)
	User Category Requirements	0.1 m	2.5 m	25 m
		<1 Km	<1 Km	<15 Km
0	Untoughened GPS	0.1 m	2.5 m	6 m
		56 Km	56 Km	56 Km

GPS Toughening Score Table

2
P
K
E
Y
C
A
C
K

Horiz. Accuracy 95 th Perc.
Range to 10 W Jammer

	A	B	C
	<u>A</u> dvanced or Ultraprecise (0.1 meters 3D)	<u>B</u> asic Precision (2.5 meters 3D)	<u>C</u> ommon (25 meters 2D)
User Category	0.1 m	2.5 m	25 m
Needs	<1 Km	<1 Km	<15 Km
Untoughened GPS	0.1 m	2.5 m	6 m
	56 Km	56 Km	56 Km

Toughened GPS

1	GPS with L5	0.1 m	2.5 m	2.5 m
		12 Km	12 Km	12 Km
2	GPS + L5 + CRPA + Inertial	0.1 m	2.5 m	6 m
		75 meters	75 meters	75 meters

LEO and Terrestrial Augmentation Score Table

2

KEY

Horiz. Accuracy 95 th Perc.
Range to 10 W Jammer

	A	B	C
	<u>A</u> dvanced or Ultraprecise (0.1 meters 3D)	<u>B</u> asic Precision (2.5 meters 3D)	<u>C</u> ommon (25 meters 2D)
User Category	0.1 m	2.5 m	25 m
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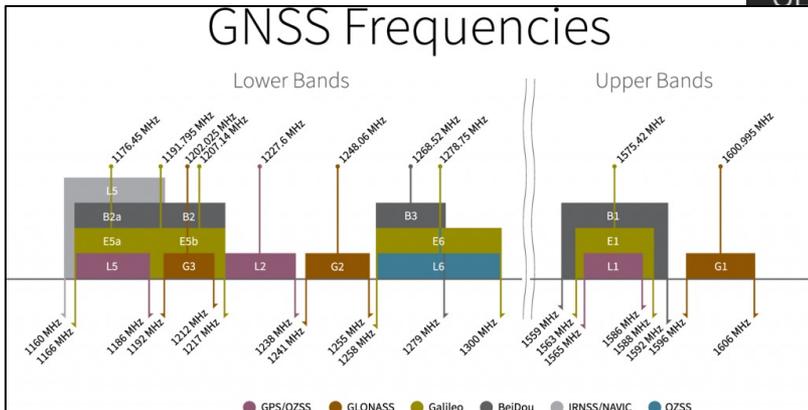
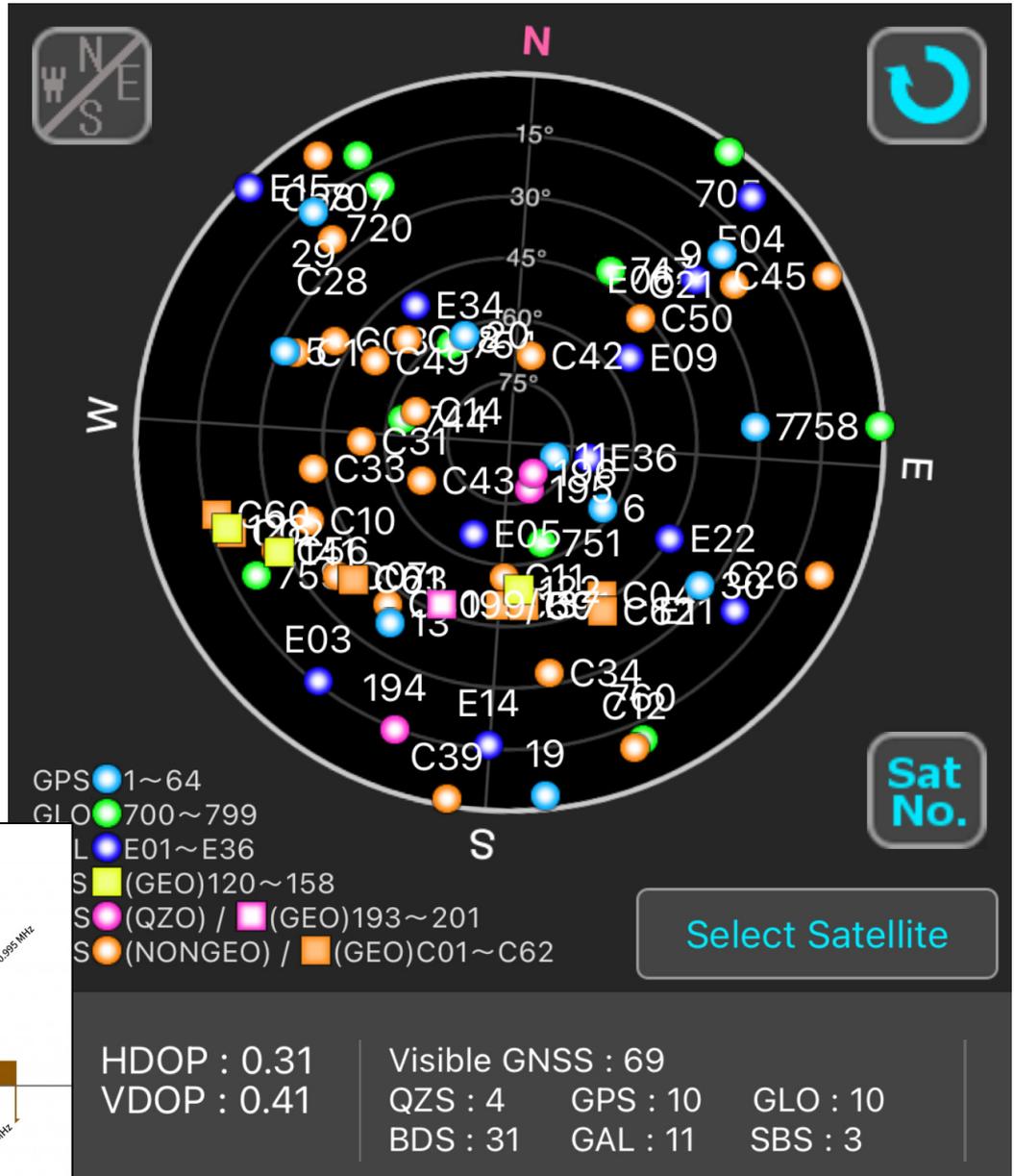
System - Demonstrated Augmentation Capability

1	ComSat of Opportunity	40 m	40 m	40 m
		20 Km (?)	20 Km (?)	20 Km (?)
2	Cooperative LEO	20 m	20 m	20 m
		1 Km ?	1 Km ?	1 Km ?
3	eLORAN	15 m	15 m	15 m
		~0 Km	~0 Km	~0 Km
4	TV or Cell Towers	40 m	40 m	40 m
		1 Km ?	1 Km ?	1 Km ?

San Luis Obispo GNSS Snapshot

Visible GNSS : 69		
QZS : 4	GPS : 10	GLO : 10
BDS : 31	GAL : 11	SBS : 3

- Probably ~ 200 ranging Signals
- My cell phone is already using most of the signals
- To Certify integrity there is a technique called **ARAIM**.



Conclusions

Current pursuit of Augmentation techniques is valuable, but full implementation may take many years. Partial is already being done by some.

Toughening GNSS receivers with CRPA and L5 is probably the quickest route to significantly improving Interference resistance.

None of the demonstrated, non-GNSS augmentations can meet the assurance needs of Categories A, B, and S. Most fail in accuracy, dimensions, and probably integrity for these PNT categories.

All Augmentation proposals should be scrutinized (independently tested and verified) in the same way as GPS, e.g.-

Accuracy	Dimensionality (1,2,3 or Time)	24/7 availability
Geographic Coverage	Integrity	Continuity
Toughness/ Vulnerability	User Affordability	Time to Field Capability
Operational Management Structure	Commitment for multiple-decade Operations	

A few recommendations

Three Urgent steps that can help assure PNT in the near term:

- L5: Set healthy, complete 24 Satellite constellation, certify receivers, and gain Airline acceptance
- Nulling Antennas: Remove all restrictions on GNSS CRPA receivers, certify antennas and use deep Inertial integration for Aircraft. Encourage rapid introduction, particularly for aviation.
- Galileo: Enhance resilience by adding it to WAAS and certifying. Consider other GNSS.

Overarching Recommendation

Space Force has been outstanding in Operating GPS. But have been very late in modernizing Civil GPS - e.g. L5, retroreflectors, HARS, and OCX.

GPS lags well behind Galileo and Beidou according to many experts.

The national structure for overseeing National PNT needs a major overhaul - So my recommendation:

- *Establish a National Leader/Champion/Visionary who has authority, funding (power), human resources and backing to catch up and surpass Galileo and Beidou.*
 - *The National Leader's goals should highlight Assured PNT and ensure this country is second to none in the PNT Arena*

Thank You

- Questions?