



SPACE-BASED POSITIONING
NAVIGATION & TIMING
NATIONAL ADVISORY BOARD

Protecting, Toughening, and Augmenting GPS for Critical Infrastructure

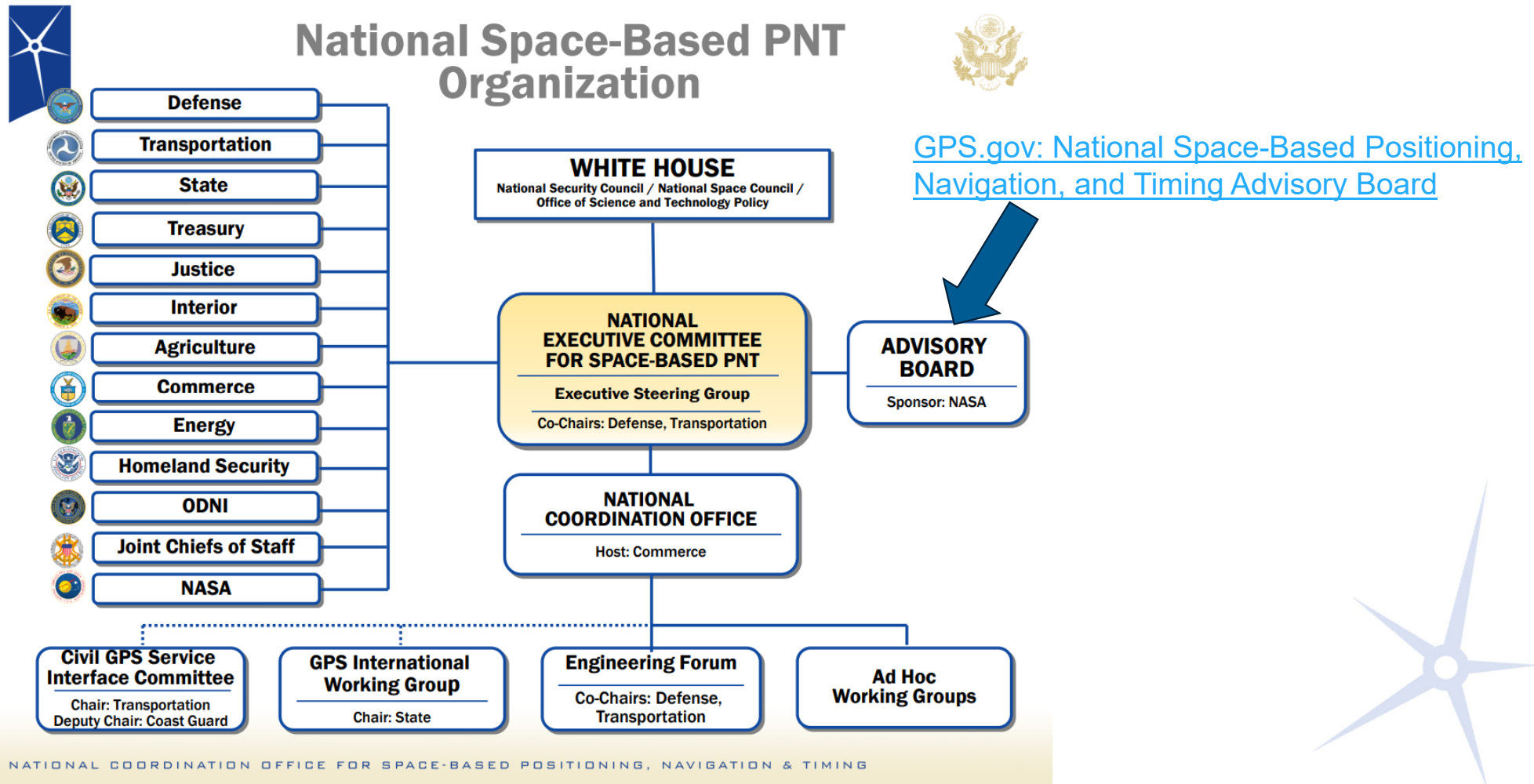
John W. Betz, PhD

Member, National Space-Based PNT Advisory Board

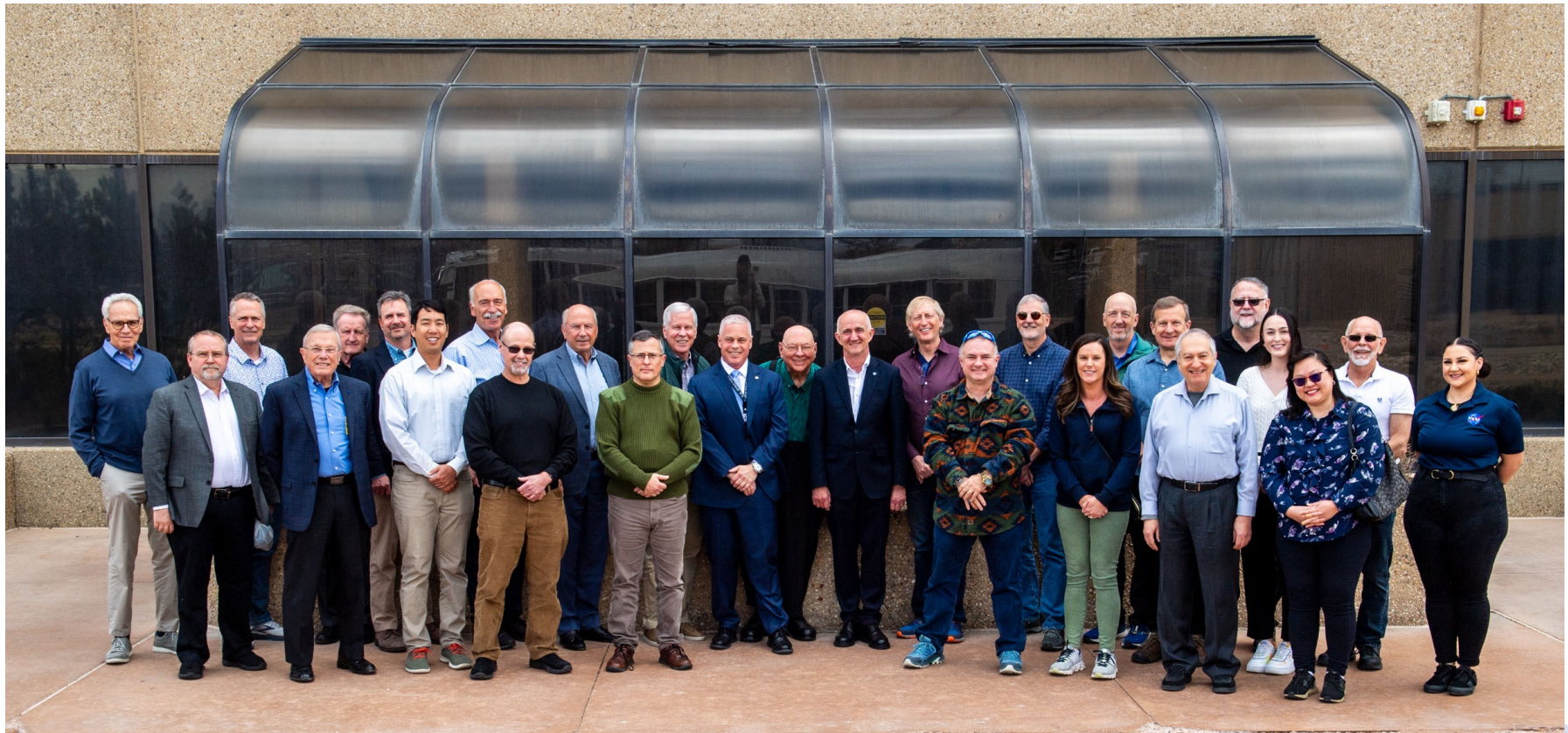
29 May 2024



National Space-Based PNT Advisory Board



30th PNTAB Meeting, April 2024



[GPS.gov: 30th Meeting of the National Space-Based Positioning, Navigation, and Timing Advisory Board - April 2024](#)

[PNT Advisory Board at 20: Still serving up big ideas - GPS World](#)

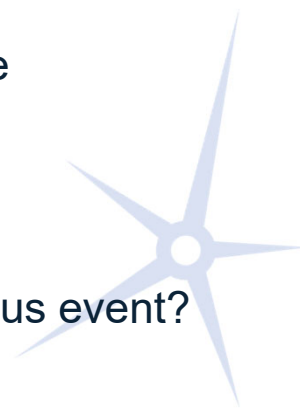


GPS Provides Unmatched Positioning, Navigation, and Timing (PNT) to Our Nation and the World



Current Issues with Civil Use of GPS

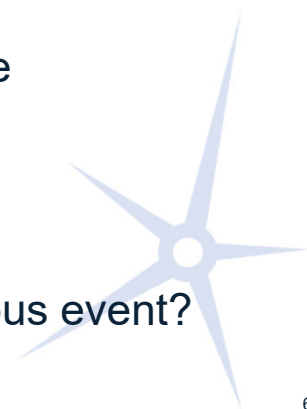
- GPS/GNSS receiver interference and spoofing
 - Accidental or malicious interference sources in GPS/GNSS frequency bands
 - Other L band systems allowed to transmit at power levels that cause interference to some high-accuracy and safety-of-life uses of GPS/GNSS
 - Receivers on more than 100 vessels report location as Beirut airport on 4 April 2024
- Some GPS/GNSS user devices lack robustness and competence
 - Some GPS civil user devices have been developed and tested assuming clean spectrum and no malevolent actors
 - Export controls limit technologies available to make civil user devices robust
 - GPS Modernization has been slow and expensive
- Widespread dependence on GPS makes its vulnerabilities a risk in critical infrastructure
- Critical infrastructure users lack needed information for risk management
 - How long will significant interference events last?
 - Which user devices are robust and competent?
 - Likelihood that GPS will not provide useful signals due to natural/accidental/malicious event?



How to Address Current Issues with GPS Use

- GPS/GNSS receiver interference and spoofing
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PROTECT
TOUGHEN
AUGMENT



Protecting, Toughening, Augmenting GPS for Critical Infrastructure

 Protect

- Toughen
- Augment
- Wrapup



Protecting Civil Use of GPS

- Protect: Measures that prevent or remove conditions that degrade, distort, or deny GPS use
 - Spectrum management
 - Deter interference and spoofing through education, policies, laws, and enforcement
 - Promptly detect, characterize, remove sources of significant interference or spoofing
 - Ensure the GPS Space and Control Segments meet the GPS Performance Standard in the presence of challenges (natural/accidental/malicious events)

U.S. Government Responsible for Protecting GPS Use



National PNT Advisory Board Protect, Toughen, Augment Subcommittee Recommendation 4 May 2023

Title of Recommendation: Commitment to Prompt Removal of Significant Interference to GPS Reception

Finding:

Significant events of terrestrial-based interference to GPS reception continue to occur. Although most to date have been accidental, intentional ones are possible. Despite decades of concern, there is no nationwide capability to detect and remove such significant interference sources, and an insufficient sense of urgency to field such a capability. Removing interference is a complicated interagency problem, and the removal process needs to be streamlined.

Recommendation:

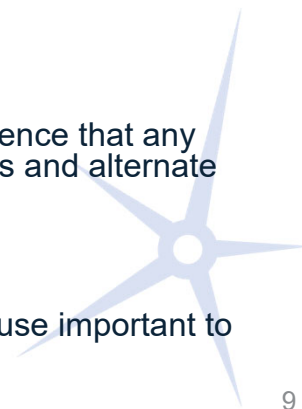
EXCOM publish a commitment this year, stating that by 2026 no significant terrestrial-based interference event affecting GPS reception in the United States will persist for more than **one day**, because the DoT-led interference detection process, combined with a streamlined removal process instituted under EXCOM leadership, will have stopped the interference.

Reasons for Recommendation:

Critical infrastructure users of GPS are being encouraged to toughen and augment in case of GPS interference. Confidence that any interference events will be of limited duration will encourage and enable adoption of practical and cost-effective backups and alternate procedures.

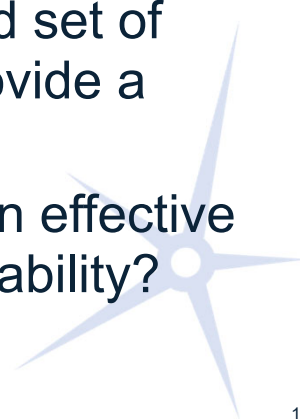
Consequences of No Action on the Recommendation:

The U.S. will continue to be subjected to significant, long-lasting terrestrial-based interference events that disrupt GPS use important to economic activity and safety of life.



What If...

- There were a single agency and lead official responsible for end-to-end prompt detection, characterization, and removal of significant sources of interference to GNSS in all U.S. territories?
- This agency/individual leads an interagency team in defining a national GNSS Interference Monitoring and Mitigation Program and operational organization/capability to effectively detect, characterize, locate, and remove GNSS interference?
- This team identifies current technical, legal, organizational, operational, and other obstacles to rapid removal of significant interference sources, develops a clear plan to overcome these obstacles, and reports to the EXCOM on an integrated set of actions, funding requirements, and legal authorities needed to rapidly provide a critical capability that has been sought since NSPD-39 in 2004?
- The result is prompt acquisition, fielding, sustainment, and operation of an effective and integrated nationwide GNSS interference detection and removal capability?



Protecting, Toughening, Augmenting GPS for Critical Infrastructure

- Protect

 Toughen

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Toughen Civil Use of GPS

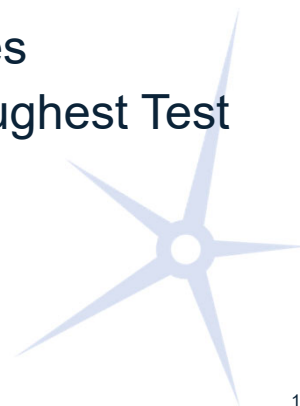
- Toughen: Measures making GPS use more robust/competent against challenges and threats
 - Make GPS Modernization operational
 - User devices that robustly and competently employ GPS signals and enhancements
- Competent receivers defend against spoofing
 - <https://www.dhs.gov/science-and-technology/publication/resilient-pnt-reference-architecture>
 - [Approaches to Toughen GPS for Critical Infrastructure](#)
- How do users know how robust and competent user devices are?

**U.S. Government, Receiver Industry, Users
Share Responsibility for Protecting GPS Use**



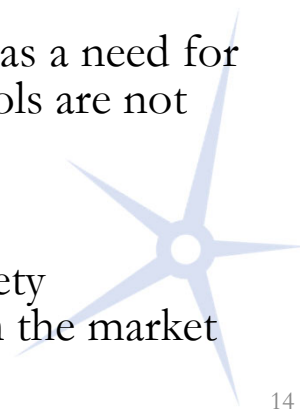
What If

- Simulator manufacturers offered a Toughness Toolkit of standard tests to assess and report the robustness and competence of different GPS civil user devices:
 - Full compliance with Interface Specifications and other relevant GPS documentation
 - Ability to tolerate in-band and out-of-band interference
 - Ability to recognize, reject, resist, report, recover from spoofing
 - Ability to replace PNT from GPS with PNT from another source when needed
- Not exhaustive or instructive, but representative of common stresses and attacks
- Civil user device manufacturers could report results (e.g., “passed X% of ABC Simulator Corporation’s Toughness Tests”)
- Federal CIOs could employ as a criterion for Federal acquisition of user devices
- Critical infrastructure owners/operators could select user devices based on Toughest Test results and use by Federal agencies
- “Raises the bar”; discourages attacks

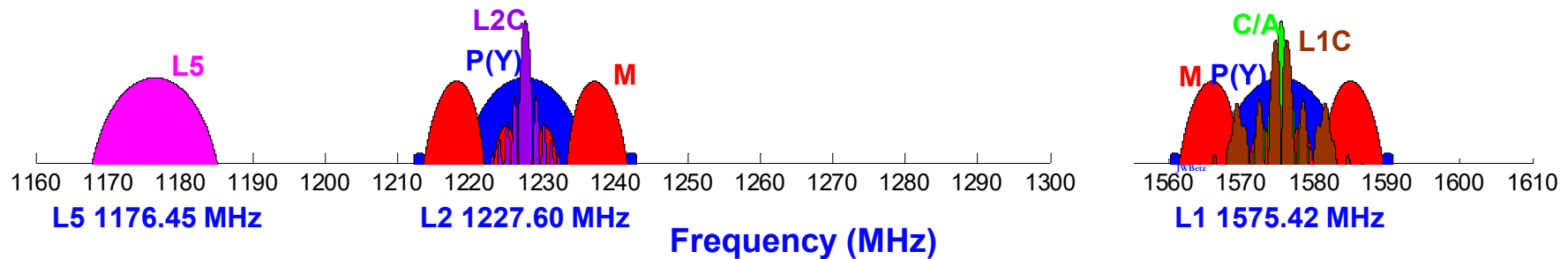


Recommendation# PNT27-08 (Protect, Toughen, Augment) National PNT Advisory Board – 27th Meeting, Nov. 2022

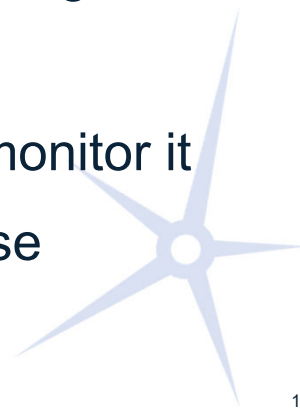
- **Identifier:** PNT27-08-PTA
- **Finding:**
 - Current export control regimes are outdated, ineffective at limiting availability of Adaptive Antennas (AA) technology outside the US and are unduly hampering development of AA products of potentially great benefit in toughening GNSS.
- **Recommendation:**
 - The USG should modify export control regulations that are restricting use of adaptive anti-jam antenna systems from protecting civil GNSS receivers.
- **Rationale for Recommendation:**
 - Current controls are hampering civil applications of the technology. Civil community has a need for AA technology to protect Critical Infrastructure and Safety applications. Current controls are not meaningfully preventing the proliferation of the technology outside the US.
- **Consequences of No Action on the Recommendation:**
 - U.S. risks losing any lead we had in this technology. Civil Critical Infrastructure and Safety Applications will remain vulnerable. US companies will continue to be disadvantaged in the market and hence will be reticent to invest in needed product developments.



Using the GPS L5 Signal

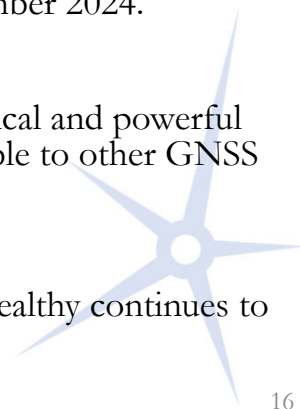


- Avoids accidental interference in L1 band
- Increases jamming resistance by more than factor of 30 over using C/A signal
- Transmitted by 17 satellites today, more next year
- Not “set healthy” since Modernized GPS Control Segment cannot yet monitor it
- New receivers designed to use it, but must violate GPS standards to use a signal not set healthy



National PNT Advisory Board Protect, Toughen, Augment Subcommittee Recommendation 24 April 2024

- **Title of Recommendation:** Setting the L5 Signal Healthy for Non Safety-of-Life Civil Use
- **Finding:**
 - The GPS L5 signal, currently transmitted from 15 satellites, is set unhealthy because OCX cannot yet monitor it. Thus, receivers that comply with GPS ICDs cannot use it. The L5 signal is highly interoperable with the Galileo E5a signal; receivers that use both have more than enough satellites in view. Using these signals provides frequency diversity to avoid accidental interference events, and more than a factor of 30 in interference resistance compared to today's GPS C/A signal. While safety of life considerations prohibit L5 use until OCX can fully support it, there currently are no certified safety of life receivers that use L5. Setting L5 healthy enables DHS and DOT to advocate its use in many critical infrastructure applications.
- **Recommendation:**
 - EXCOM direct USSF to establish a way for “good enough” monitoring of L5 signals using existing capabilities and set L5 signals healthy subject to a “use at your own risk” caveat, just as is done with L2C today. Establish a deadline of September 2024.
- **Reasons for Recommendation:**
 - Critical infrastructure users of GPS are being encouraged to toughen use of GPS. Using the L5 signal is a practical and powerful way to accomplish that. Setting L5 healthy also helps advance the international perception that GPS is comparable to other GNSS that already provide comparable signals at that frequency.
- **Consequences of No Action on the Recommendation:**
 - Non safety-of-life civil users will be deprived of a far more capable signal, while the delay in setting L5 signals healthy continues to be used as evidence that GPS is falling behind other systems.



Protecting, Toughening, Augmenting GPS for Critical Infrastructure

- Protect

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 Augment

- Wrapup



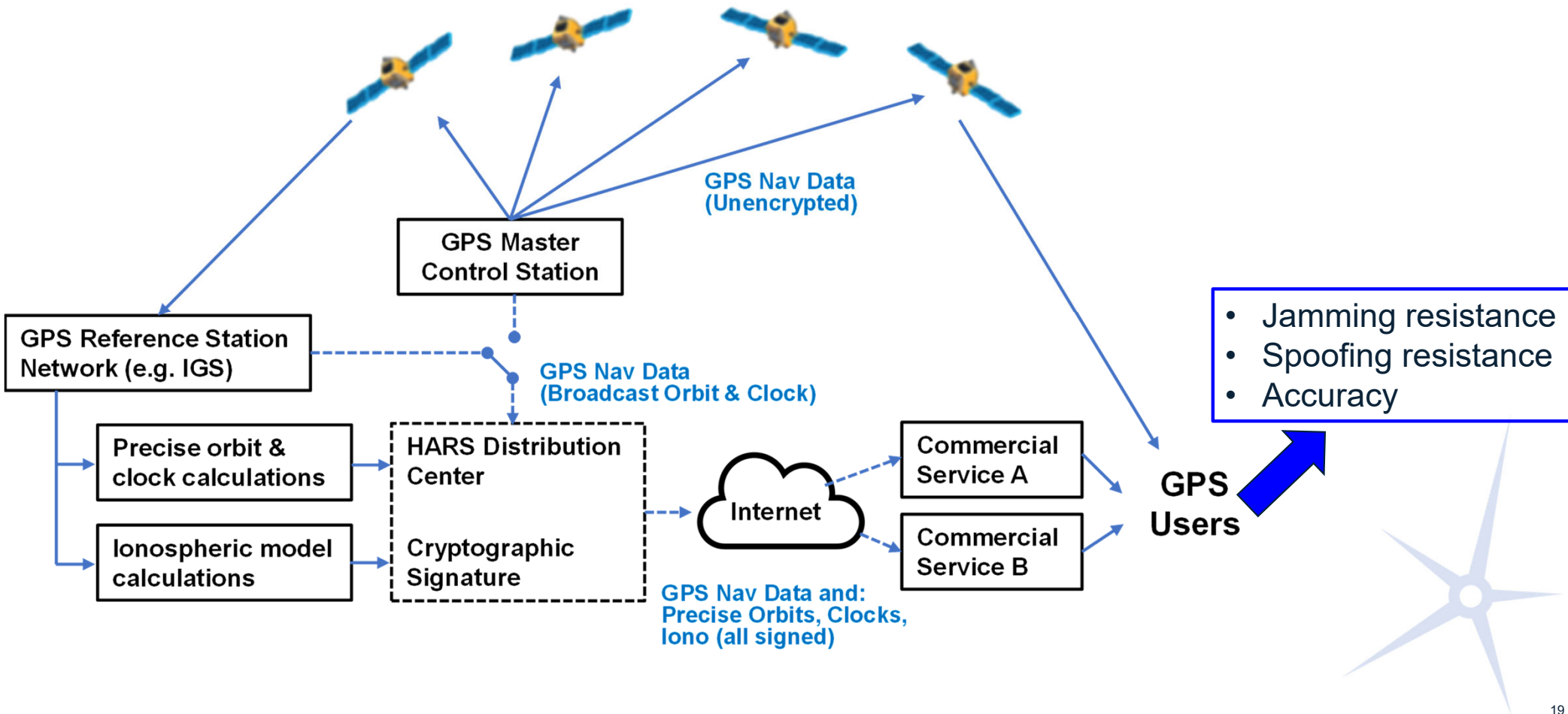
Augment Civil Use of GPS

- Augment: Provision of GPS enhancements as well as provision and use of alternate Positioning, Navigation, and Timing sources that complement, back up, or replace (partly or entirely) use of GPS

**U.S. Government, PNT Device Industry, Users
Share Responsibility for Augmenting GPS Use**



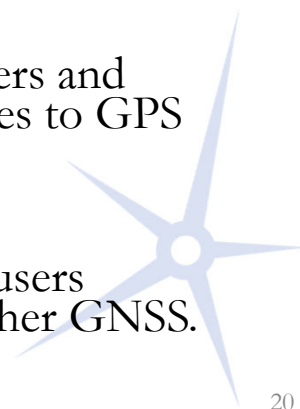
GPS High Accuracy and Robustness Service (HARS)



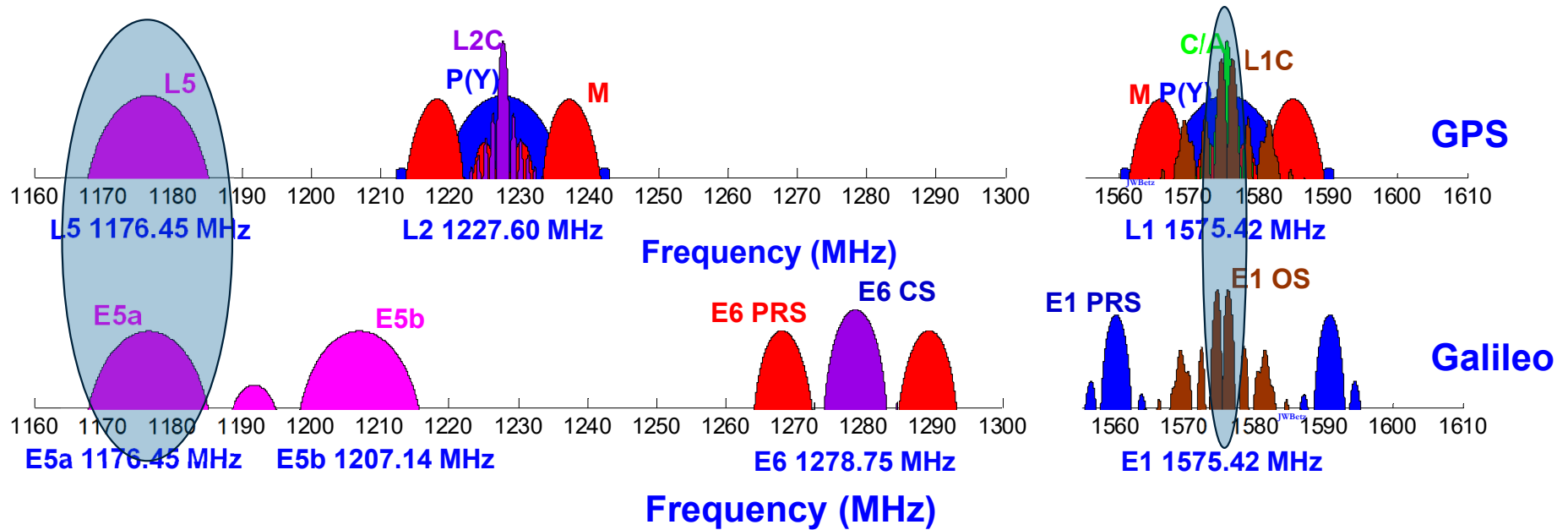
Recommendation PNT27-04 (Emerging Capabilities, Applications & Sectors)

National PNT Advisory Board – 27th Meeting, Nov. 2022

- **Identifier:** PNT27-04-ECAS
- **Finding:**
 - GPS is falling behind Galileo & BeiDou by not providing high accuracy and authentication services. Risks GPS losing current status as the primary GNSS in most GNSS chips. There are U.S. agencies/orgs already generating the data products needed and assisted GPS services that deliver similar types of data to users via the internet.
- **Recommendation:**
 - USG to develop and implement a GPS high accuracy and resilience service (HARS) delivered to users on the internet with performance initially comparable to that of other constellations. The service should provide both corrections to support PNT at the <1m level and satellite NAV data bits.
- **Rationale for Recommendation:**
 - Action will rapidly improve quality of GPS real-time performance and resilience for users and enhance GPS-based applications, based on existing U.S. capabilities, and without changes to GPS satellite operations.
- **Consequences of No Action on the Recommendation:**
 - GPS is likely to lose its relevance in the hierarchy of satellite navigation systems. GPS users will suffer from lower quality data and be more vulnerable to spoofing than users of other GNSS.



Augmenting GPS with Multifrequency GPS/Galileo Receivers



- Galileo E1OS and E5a highly interoperable with GPS
- Many receivers designed to use them
- Augments GPS with independent constellation
- As many as 30 satellites in view



National PNT Advisory Board Protect, Toughen, Augment Subcommittee Recommendation 24 April 2024

Title of Recommendation: Adopting Civil Use of Multi-Frequency GPS/Galileo Receivers

Finding:

While DoT and DHS pursue alternative sources of PNT to complement GPS, Galileo signals are already available and approved for use at the same frequencies as GPS L1 and L5. Civil receivers that use GPS and Galileo signals at multiple frequencies can continue to provide PNT during a GPS outage, avoid accidental interference events that typically affect only one frequency band, obtain a factor of more than 30 in increased interference resistance, and benefit from antispoof capabilities provided in the Galileo signals. These benefits are available now to federal users of GPS and critical infrastructure users of GPS that are not certified safety of life applications.

Recommendation:

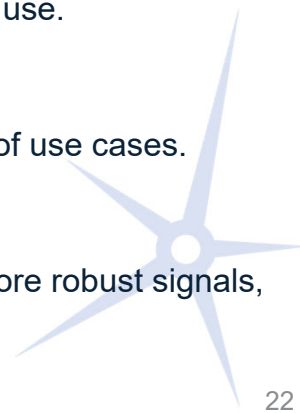
EXCOM direct Federal CIOs to acquire and install multifrequency GPS/Galileo receivers to complement GPS use. DoT and DHS should also actively encourage critical infrastructure users to adopt multifrequency GPS/Galileo receivers to complement GPS use.

Reasons for Recommendation:

Implementing this recommendation provides near-term improvements in resilience and robustness over a wide variety of use cases.

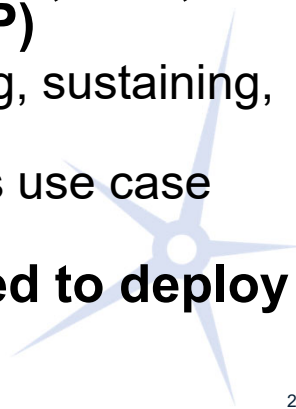
Consequences of No Action on the Recommendation:

Civil GPS users will have no suitable backup to a GPS failure, miss the opportunity for frequency diversity, access to more robust signals, and advanced antispoof features.



Evaluating Alternate PNT Sources—Having PNT Is Not Binary

- **Functions**
 - Positioning
 - Navigation
 - Timing
- **Measurement accuracy**
 - In service region with PNT infrastructure deployed
 - When a use case has varying measurement accuracy needs, the most stringent is reported
- **Operating region**
 - Satisfy service region of use case
- **Operating conditions and limitations**
 - Operate in conditions needed for use case
- **Availability and continuity—is augmentation there for needed duration in service region**
 - Augmentations can introduce new attack surfaces and vulnerabilities
 - Toughness of PNT infrastructure and user device
 - Account for augmentation dependencies (power, GNSS, Internet, etc.)
- **Infrastructure cost to Government**
- **Acceptable user device cost, size, weight, and power (CSWaP)**
 - Includes purchasing, installing, sustaining, replacing
 - User device CSWaP matches use case needs
- **Operational maturity—speed to deploy**



Critical Infrastructure Use Cases for Positioning and Timing

Positioning

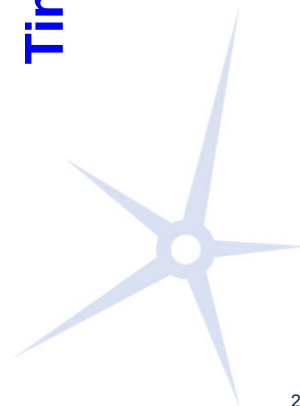
- Positive train control
- Precision agriculture, other precision commercial
- Driving: route navigation
- Driving: lane navigation
- Driving: autonomous vehicles
- Space launch
- Space operations
- Maritime: oceans/seas
- Maritime: harbors
- Maritime: inland waterways

- UAS en route
- UAS sensing
- E911
- Automated facilities
- Cellular base station: intercell interference
- Cellular base station: carrier aggregation
- Phasor measurement unit
- Financial trading

Positioning

Timing

Reference: [Canonical Use Cases for Critical Infrastructure \(gps.gov\)](https://www.gps.gov/infrastructure/critical-infrastructure-use-cases/)



What If

- DOT and DHS were to define important critical infrastructure use cases with their associated needs for PNT: accuracy, service region, availability, ...?
- Evaluate candidate alternative sources of positioning and timing—current and potential ability to meet the needs?
- Focus effort on alternative sources with the greatest potential?
- Likely results:
 - Multifrequency GPS/Galileo receivers provide near-term benefits
 - Multiple potential alternative sources for timing
 - Meeting positioning needs is a challenge



Protecting, Toughening, Augmenting GPS for Critical Infrastructure

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 Wrapup



Recommendation# PNT27-06 (Protect, Toughen, Augment) National PNT Advisory Board – 27th Meeting, Nov. 2022

- **Identifier:** PNT27-06-PTA
- **Finding:**
 - There are no authoritative assessments of the likelihood & extent that GPS infrastructure could fail in different time frames due to any cause.
- **Recommendation:**
 - USG to establish, publish, and maintain estimates of the likelihood that GPS would not provide sufficient useful civil signals, from any cause—natural, accidental, malicious. Estimates would describe likelihood of GPS infrastructure failure for different durations in different time frames.
- **Rationale for Recommendation:**
 - There currently are wildly diverse opinions concerning the likelihood and extent that the GPS infrastructure could fail in different time frames. Those making risk management decisions, and those investing in PTA lack the information needed to select the right approaches and how urgent it is to implement them.
- **Consequences of No Action on the Recommendation:**
 - U.S. risks inconsistent development and fielding of PTA. Some may be investing in Protect & Toughen, when Augment would more appropriate, or vice versa. Some may be undertaking greater expense & disruption than needed, while others risk experiencing a problem before they are ready.

Integrated PTA Strategy for Critical Infrastructure

- Protect GNSS use
 - Field national capability with commitment for rapid detection, characterization, removal of accidental or malicious interference
- Toughen user devices
 - Industry establish simulator toolboxes that evaluate robustness and competence against common interference and jamming threats
 - Remove export control obstacles to fielding of antijam antennas
 - Set GPS L5 signal healthy for use in non safety-of-life applications
- Augment GPS use
 - Implement GPS High Accuracy and Robustness Service
 - Encourage adoption of multifrequency GPS/Galileo receivers, with clocks for timing backup
 - DOT/DHS focus on alternate PNT sources with potential to meet critical infrastructure needs
- Inform users so they can properly manage risk
 - Commitment for Government to stop significant interference events?
 - Which user devices are robust and competent?
 - Likelihood that GPS will not provide useful signals due to natural/accidental/malicious event?

