

Research on the Development Status of GPS Navigation Countermeasure Capability

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Abstract: At present, the GPS navigation, positioning and timing (PNT) capability has become the cornerstone of the US national critical infrastructure and joint warfare capability. The GPS system is further building a more resilient, redundant and secure integrated architecture. This paper analyzes the modernization process and technical characteristics of GPS, focuses on the development status and trends of navigation countermeasure capabilities in the space segment, ground segment and user segment of GPS, and finally summarizes and prospects the modernization process and navigation countermeasure capabilities of GPS.

Keywords: GPS; Navigation Countermeasure; Resilient Agility.

1. Introduction

The Global Positioning System (GPS) of the United States has become the basic guarantee for national operation. From precision-guided military strikes to power grid synchronization, communication base station timing, autonomous driving, and smart cities, GPS services have penetrated into all aspects of national security and social life.

As the first country in the world to build and operate a global satellite navigation system, the United States has long relied on GPS to build its military superiority and technological hegemony [1]. However, with the intensification of great power competition, the proliferation of navigation countermeasure capabilities, and the increasing dependence of critical infrastructure on PNT, the vulnerability of single reliance on GPS has become increasingly prominent.

In recent years, GPS jamming and spoofing operations in various military confrontations have posed a substantial impact on the overseas military deployment, civil aviation flights and maritime shipping of the US military. According to a report by the Center for Advanced Defense Studies (C4ADS), a 501(c) non-profit organization in the United States, US military drones are frequently shot down. In 2018, Iran interfered with the data transmission of US drones, causing a US MQ-9 drone to lose control and make an emergency landing[2]. On February 22, 2026, a US MQ-4C Triton drone worth 2.2 billion US dollars lost contact near the Gulf of Oman, and it is widely speculated that it was shot down by Iran. At present, most drones rely on GPS equipment and inertial navigation for navigation and positioning.

During the Russia-Ukraine conflict, Russia frequently used suppressive jamming, such as the Krasukha-4 system, which greatly reduced the hit rate of Ukrainian guided weapons and affected airborne early warning and control systems. To counter the Russian jamming threat, Ukraine used drones to prioritize destroying Russian navigation countermeasure equipment, resulting in frequent drone attack interference incidents in downtown Moscow[3].

In the confrontation between Israel and Iran from June to October 2025, the two sides launched GNSS offensive and defensive operations in the Persian Gulf and the

Mediterranean Sea[4]. Israel jammed the GPS signals of Iranian drones to deviate them from their targets, while Iran jammed the navigation of merchant ships in the Strait of Hormuz, causing the ship positioning error to soar from 3 meters to 200 meters.

Against this background, the United States is promoting the transformation of the PNT system from "GPS-dominated" to a "multi-source fusion, resilient and agile, reconfigurable" architecture. Its goal is to build a "resilient GPS ecosystem" that can maintain basic functions under navigation-restricted or failed conditions, ensuring the US military superiority, economic stability and national security worldwide. Therefore, an in-depth study of the modernization process of US GPS and the development path of navigation countermeasure technology has extremely high military and civilian value.

2. GPS III Modernization Process

GPS modernization has been a lengthy process spanning over 30 years, achieving leapfrog in GPS modernization is a long process lasting more than 30 years, which has gradually achieved a leapfrog improvement in accuracy, anti-jamming and interoperability capabilities through the comprehensive upgrading of satellites, ground systems and signal systems[5]. The following figure shows the development roadmap of GPS modernization.



Figure 1. GPS Modernization Roadmap

The United States announced the latest GPS modernization strategic roadmap in April 2022, planning various task developments by the end of fiscal year 2028. The core of GPS III modernization is "two batches of iterations in the space segment (GPS III → GPS IIIF) + synchronous upgrade of the ground segment OCX". The deployment of GPS III will be completed in 2026, and the delivery and continuous enhancement of GPS IIIF will start at the end of 2026, finally forming a new generation of PNT system with anti-jamming, high precision and multi-load[6].

GPS III navigation satellites include four types: A, B, C and F. ① The core function of GPS IIIA satellites is to improve positioning accuracy, expand signal coverage, and conduct on-orbit tests for subsequent GPS IIIB/C satellites. ② The core function of GPS IIIB satellites is to realize inter-satellite transmission of satellite injected telegrams and telemetry data, and improve the system's anti-destruction and survivability by adding inter-satellite link loads. ③ The core function of GPS IIIC satellites is to improve the M-code capability by equipping high-power, spot beam transmitting systems, which can increase the M-code power in some areas by 20dB, greatly enhancing the navigation countermeasure capability in the theater. ④ GPS IIIF satellites add spot beam power enhancement function, which can achieve about 22dB spot beam power enhancement in any two regions with a diameter of 1000 kilometers worldwide[7-9].



Figure 2. GPS-IIIA and GPS-IIIF Satellites (Power Enhancement Antennas Circled in Red)

According to the GPS III plan, it can be seen that GPS IIIC and GPS IIIF satellites have M-code spot beam capability, which can increase the transmission power by more than 20dB within a range of hundreds of kilometers, greatly enhancing the theater navigation countermeasure capability. GPS will provide users with high-precision positioning, super anti-jamming, high anti-destruction and survivability capabilities in future navigation warfare.

3. Current Status of GPS Navigation Countermeasure Capability

3.1. GPS Space Segment Countermeasure Capabilities

The GPS space segment consists of 6 orbital planes with an orbital altitude of 20,200 km and an inclination angle of 55° between the orbital planes and the equator. Each orbital plane is unevenly distributed with 4 satellites, and the entire constellation is composed of 24 MEO satellites[10]. Each satellite broadcasts navigation signals to the center of the earth through a global beam antenna, and the signals include navigation telegrams and other information for navigation, positioning and timing.

3.1.1. Power Enhancement Countermeasure Capability Status

Power enhancement counteracts interference to enemy receivers by increasing the transmission power of navigation signals. Aiming at the weaknesses of satellite navigation systems such as low signal transmission power and poor penetration capability, GPS III satellites focus the transmission power of M-code to a range of hundreds of kilometers through the equipped spot beam antennas, and the power enhancement capability is increased by more than 20dB, from -158dBW to -138dBW. This means that under the condition of using anti-jamming receiving technologies such as adaptive nulling antennas at the receiver end, the availability of GPS in wartime will be significantly improved.

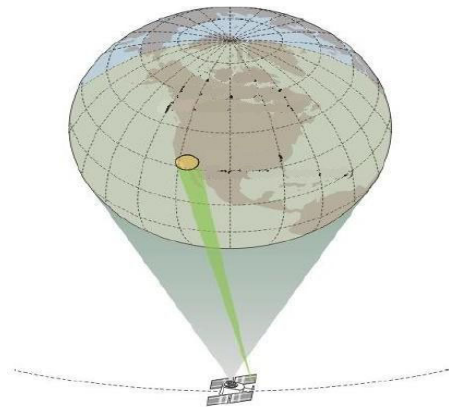


Figure 3. GPS-IIIC Satellite Spot-Beam Coverage

The United States is also developing spot beam enhancement technology using high-gain parabolic antennas, which is planned to be equipped on GPS IIIC satellites. The power enhancement capability will reach 20dB, increasing the ground receiving power of the new generation M-code signal of the GPS system from -158dBW to -138dBW, which can greatly improve the capability of the GPS system to counteract suppressive and blocking interference[11].

By design, each GPS IIIC satellite can form a spot beam coverage area with a diameter of about 1000 kilometers (see the figure below). The spot beam areas formed by 4 GPS IIIC satellites together can constitute a complete GPS military M-code signal service. The GPS system has the capability to form 2 spot beams, that is, the GPS system can use the spot beam enhancement function to support US military operations in two combat areas simultaneously. According to the current plan, around 2033, the GPS space constellation will have 16 GPS IIIC satellites with spot beam enhancement

capability, initially forming global spot beam enhancement capability.

Spot beam enhancement is realized based on the military M-code signal. The military M-code signal adopts binary offset carrier modulation. A significant difference from the P(Y) code signal is that the military M-code signal generates a power spectral density concentration area on each side of the carrier center frequency, while the P(Y) code signal only generates one power spectral density concentration area at the center frequency. Therefore, the military M-code signal on one side of the carrier center frequency can be used for spot beam enhancement, and the military M-code signal on the other side provides normal navigation services.

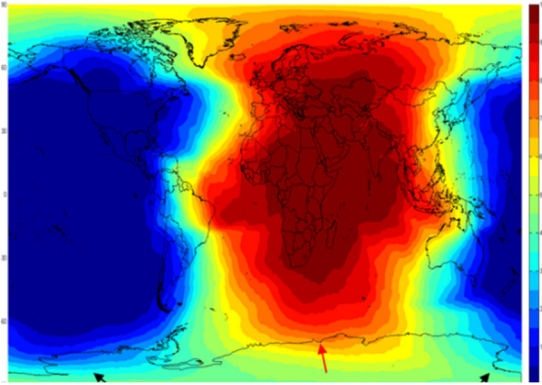


Figure 4. Simplified Diagram of Power Enhancement Technology

3.1.2. NTS-3 Satellite Countermeasure Capability Status

On August 13, 2025, in the USSF-106 mission of the US Space Force, a Vulcan rocket launched a high-orbit navigation test satellite NTS-3 (Navigation Technology Satellite-3). The satellite will verify the value of the multi-layer resilient architecture and test breakthrough technologies on orbit to address the challenges of competitive, degraded and denied positioning, navigation and timing (PNT) threats to national security. The NTS-3 Vanguard program is the first space-based integrated PNT experimental system in the United States in nearly 50 years, which will demonstrate disruptive PNT technologies in the full link of the space segment, ground control segment and user equipment segment.

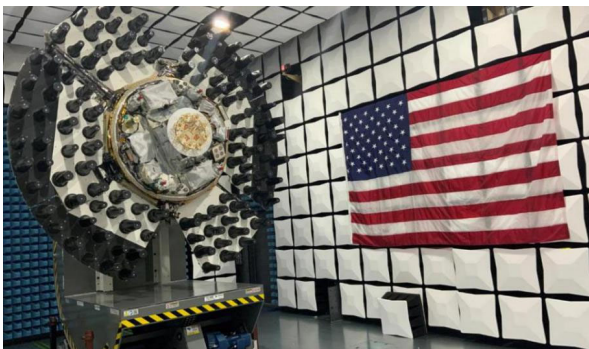


Figure 5. NTS-3 Satellite Illustration

According to research, the goal of the NTS-3 satellite is to balance technology, capability and affordability for the next generation of GPS satellites through the development of Advanced GPS Technology (AGT), while cost-effectively maturing new GPS payload technologies and concepts, and reducing the risk of applying new technologies to GPS satellites in the future. ① Complete a variety of integrated advanced technology experiments and new operational

concept development, test antennas, flexible and secure signals, enhanced automation and commercial asset utilization. ② On-orbit reprogrammable digital signal generators allow operators to quickly deploy new signals when encountering electronic threats, avoid and eliminate interference, and improve performance. ③ Equip phased array antennas or array-fed reflector antennas to support simultaneous broadcasting of multiple waveforms in earth-shaped beam and spot beam configurations. ④ Add signatures to mask original signals and prevent spoofing[12].

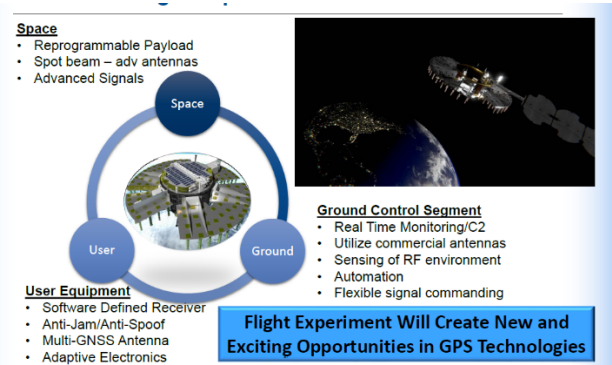


Figure 6. NTS-3 Segment Functions

3.1.3. LEO Navigation Countermeasure Capability Status

The US Space Development Agency (SDA) is studying how to provide alternative PNT services through the upcoming "Proliferated Warfighter Space Architecture (PWSA)", including cooperation between SDA and the US Army. PWSA will consist of hundreds of LEO satellites, providing critical data relay, missile warning and missile tracking capabilities. The Army is developing an alternative PNT signal received by the MGEU Increment 2 radio chipset, enabling warfighters to utilize the military M-code signals of the GPS constellation. SDA is also studying the future broadcasting of alternative PNT signals through L-band or S-band, and has issued a request for information to the industry seeking L-band LEO PNT payloads.

Xona Space Systems is currently cooperating with the US Air Force Research Laboratory and the US Space Force to accelerate the development of a LEO PNT architecture capable of utilizing the company's PULSAR service. PULSAR is a commercial satellite navigation service using LEO small satellites, which improves the security, resilience and accuracy of PNT by enhancing existing GNSS, and can also operate as an independent PNT constellation, serving as a resilient navigation alternative to GPS. XONA plans to start building a constellation of 250 to 300 small satellites in low Earth orbit in 2025 to provide encrypted, high-precision PNT services for authorized users[13].

In October 2022, *MIT Technology Review* reported that funded by the US Army, researchers from the Radio Navigation Laboratory at the University of Texas at Austin (UTA) demonstrated the potential of the Starlink LEO broadband constellation as a backup for GPS by studying the downlink signal structure of the Starlink constellation. The laboratory deeply studied the blind signal identification technology of 10.7-12.7 GHz downlink signals, and receivers can calculate their own positions by analyzing the synchronization signals of multiple satellites, with a positioning accuracy of 30 meters. This research again demonstrates the technical feasibility of LEO communication

satellites providing emerging navigation applications and their value as a backup for GNSS.

3.2. GPS Ground Segment Countermeasure Capabilities Status

The GPS ground control segment consists of a Master Control Station (MCS), alternates, monitor stations, and ground uplink antennas. The current system (Architecture Evolution Plan, AEP) has been in service for over 20 years and suffers from high maintenance costs, low automation, and cybersecurity vulnerabilities.

In its "GPS Modernization – U.S. Department of Defense Continues Development of New Anti-Jamming Capabilities," the U.S. initiated the Next-Generation Operational Control Segment (OCX) project, built by Raytheon (now RTX) and expected to be fully operational by 2028.

In July 2025, the U.S. Space Force formally took over the OCX Block 1/2 from contractor RTX, which supports GPS III launch and operations and has been fielded. OCX 3F was awarded in April 2021 (\$283 million) to adapt to new GPS IIF capabilities such as RMP and LRA, using an adaptive

architecture for future upgrades. This system is expected to be formally activated later this year.

3.3. GPS User Segment Countermeasure Capabilities Status

The research on user segment equipment focuses on improving M-code functions. To use the M-code signals broadcast by the GPS space segment and controlled by the ground segment, the US military services (Army, Navy, Air Force, Marine Corps) need to upgrade existing weapon systems with equipment supporting M-code functions. Therefore, it is necessary to develop new M-code supporting receiving cards suitable for different conditions/scenarios (the key factor is the development of application-specific integrated circuits to decode and process GPS signals) for GPS receivers, and further integrate them into various US DoD weapon platforms/systems. On this basis, improvements in component miniaturization (such as integration on missile-borne platforms) are made to further meet the application requirements of handheld GPS receiving equipment[14].

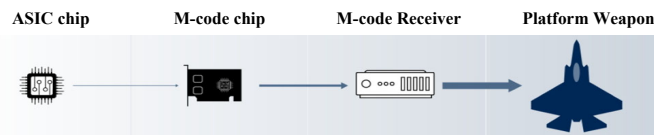


Figure 7. Simplified Description of GPS Military User Equipment Integration Process

It is reported that the US DoD plans to add M-code supporting equipment to about 700 different types of weapon systems. The US DoD has selected military enterprises such as RTX and BAE Systems to research and produce GPS receiving boards for different application scenarios, embed new GPS receivers, and carry out integration tests on representative weapon platforms such as Stryker armored vehicles, Joint Light Tactical Vehicles, B-2 bombers, and Arleigh Burke-class destroyers.

4. Summary

Through the above analysis, it can be found that the US military uses GPS modernization, NTS-3 and other projects to improve the system's countermeasure capability and security through various technical means, with the main characteristics as follows: ① Continuously promote the development of new military code signals to improve military security. ② Further improve the ground reception power and anti-jamming capability of military signals based on on-board spot beam power enhancement and other technologies. ③ Continuously develop flexible countermeasure signal systems using on-orbit programmable and software-defined technologies to improve system countermeasure capabilities.

Through the collaborative upgrading of the space segment and ground segment, US GPS has gradually realized the leap from "baseline improvement of accuracy and anti-jamming" to "global reinforcement and multi-load expansion", laying the foundation for the future hybrid PNT system. In the future, facing the volatile international situation and the rapid changes of electronic countermeasure means in modern warfare, China's Beidou system must accelerate the construction of a more agile and resilient space-based space-time countermeasure system to provide solid PNT guarantee for national security and economic and social development.

References

- [1] Wu, J., Liu, C., Zhou, Y., et al. (2021). Research on navigation technology satellite-3 (NTS-3) program. In Proceedings of the 12th China Satellite Navigation Conference (CSNC 2021) — S03 Navigation Signals and Signal Processing (pp. 35–39). Nanchang, China: Academic Exchange Center of China Satellite Navigation System Management Office.
- [2] Wu, J., Qian, K., Song, B., et al. (2024). Analysis on development of U.S. military navigation systems and technologies. In Proceedings of the 14th China Satellite Navigation Conference (CSNC 2024) — S08 PNT Architecture and Emerging Technologies (pp. 35–41). Jinan, China: Academic Exchange Center of China Satellite Navigation System Management Office.
- [3] Wu, J., Wang, Y., Zhang, Y., et al. (2025). Review on development of foreign navigation satellite systems in 2024. *International Space*, (03), 4–7.
- [4] Luccio, M. (2023, July 10). First fix: Still waiting for M-Code. *GPS World*. <https://www.gpsworld.com/first-fix-still-waiting-for-m-code/>.
- [5] <https://www.gpsworld.com/first-fix-still-waiting-for-m-code/>.
- [6] C4ISRNET. (2023, April 19). US Space Command commercial integration office draws company interest. <https://www.c4isrnet.com/battlefield-tech/2023/04/19/us-space-command-commercial-integration-office-draws-company-interest/>
- [7] Calatrava, H., Gusi-Amigó, A., Melman, F., & Closas, P. (2025). Robust interference mitigation in GNSS snapshot receivers. *NAVIGATION: Journal of the Institute of Navigation*, 72(2). <https://doi.org/10.33012/navi.699>
- [8] Atencio, A., et al. (2025). PANTHER: A power-optimized and accurate positioning, navigation, and timing with high efficiency and reliability. *IEEE Open Journal of the Communications Society*, 6, 3265–3279.

- [9] Babić, K., et al. (2025). GNSS spoofing detection based on wavelets and machine learning. *Electronics*, 14(3).
- [10] Felux, M., et al. (2024). Impacts of global navigation satellite system jamming on aviation. *Journal of the Institute of Navigation*, 71(3). <https://orbilu.uni.lu/handle/10993/66929>
- [11] Almadhor, A., et al. (2025). CTDNN-Spoof: Compact tiny deep learning architecture for detection and multi-label classification of GPS spoofing attacks in small UAVs. *Scientific Reports*, 15.
- [12] Wu, D. L., Csar, C., & Salinas, J. H. (2024). GPS jamming: A historical record from global radio occultation (RO) observations. In *Proceedings of the 37th International Technical Meeting of the Satellite Division of the Institute of Navigation (ION GNSS+ 2024)* (pp. 4197–4208).
- [13] Zeng, F., Ouyang, X., & Rui, Z. (2023). *Satellite navigation countermeasure* (in Chinese). Science Press.
- [14] GPS Spoofing WorkGroup. (2024). *GPS spoofing: Final report*. OPSGROUP.