Plan for Development of an Enhanced Global Positioning System:

A Report To Congress

July 1999

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1 Report Requirements

Section 218 of the National Defense Authorizations Act for Fiscal Year (FY) 1999 (Public Law 105-261) requires the Secretary of Defense to submit to Congress a plan for carrying out the development of an enhanced Global Positioning System (GPS) as an urgent national security priority. As stated in the Public Law, the enhanced Global Positioning System is to include the following elements:

- An evolved satellite system that includes increased signal power and other improvements such as regional-level directional signal enhancements.
- Enhanced receivers and user equipment that are capable of providing military users with direct access to encrypted Global Positioning System signals.
- To the extent funded by the Secretary of Transportation, additional civil frequencies and other enhancements for civil users.

This report constitutes the plan of the Department of Defense required by Section 218(d).

2 Overview

GPS continues to grow in importance as a critical information system within both the military and civil sectors. Many civil and military applications have come to rely on GPS, and new demands on its performance and reliability are continually emerging.

As a result of the widespread use of GPS, the Department of Defense (DoD) is addressing the evolving and dynamic threat situation in which adversaries will have free and open access to highly accurate GPS signals. Although Selective Availability (SA) represents the Department's primary means of preventing adversaries access to the full accuracy of GPS, technologies for circumventing SA are becoming available. The Department must develop, test, and integrate new capabilities to ensure success on the battlefield and support Presidential Decision Directive NSTC-6 decision to discontinue SA by 2006 and prepare for military operations without it.

In addition to the threat of adversary use of GPS, the threat of enemy jamming is projected to significantly reduce the operational utility of the current GPS system unless improvements are developed and deployed over the next decade. As a result, the Department of Defense will enhance GPS with modifications to the satellites, improvements in military user equipment technology, and an improved electronic crypto key management and distribution architecture.

Satellite and ground control segment upgrades coupled with the next generation user equipment will establish the foundation for US military optimization of GPS well into the next century. The DoD's Navigation Warfare (Navwar) effort is the focal point for addressing this threat situation. The DoD is in the final stages of defining the future operational requirements for both the next generation space segment and user equipment. The DoD is also carrying out a Navwar Advanced Concept Technology Demonstration (ACTD) that is evaluating prototype prevention and protection equipment in military exercises. The DoD's Joint Requirements Oversight Council (JROC) met to review and validate these new requirements in June 1999. In summer of 1999, the DoD plans to review the acquisition strategy for the enhanced GPS, including Navwar.

Concurrently with the DoD's Navwar efforts, the Department of Transportation (DOT) has conducted studies to clarify the utility of GPS to civilian users and help define civil GPS requirements.

The DoD and DOT clearly recognize evolving requirements and the need to enhance GPS and have been conducting studies and analyses as well as identifying solutions to meet those requirements. The primary military needs identified to date include: protection of the GPS signal for use by US and allied forces in an electronic warfare environment, prevention of adversary exploitation of GPS in hostile actions against the US and our allies, implementation of an improved electronic crypto key management and distribution architecture, and minimizing the impact of GPS signal protection and prevention efforts on peaceful civil users outside the area of operations. The primary civil needs are improvements to both the accuracy and availability of the GPS service. The planned enhancements to GPS will foster new civil applications, further expanding the rapidly growing market for GPS equipment and services worldwide and strengthen US leadership in this industry. Additional detail on civil plans, costs, and benefits is available in the report to the House and Senate Committees on Appropriations recently submitted by the Department of Transportation.

3 Military Satellite Enhancements

3.1 Introduction

A DoD assessment of the 2005 – 2010 threat has indicated that the current secure military P(Y)-code service needs to be improved to support a broad spectrum of operational missions in support of *Joint Vision 2010*. The GPS signal architecture and electronic crypto key infrastructure must be enhanced to provide the US military with a reliable, robust signal in the future threat environment and to provide GPS system military managers with the necessary flexibility and timely response options when crypto keys are lost or otherwise compromised.

The current GPS signal architecture has four fundamental shortcomings:

- low signal power
- the need for military receivers to first acquire the civil signal before locking on to the secure military code
- sharing of spectrum between encrypted and unencrypted signals
- relatively unsophisticated cryptographic protection of the secure military code.

The current GPS crypto key infrastructure is based primarily on paper tape keys. Superseding lost or otherwise compromised GPS paper tape crypto keys represents an operational logistics challenge. The long time required to distribute the large number of GPS crypto keys used worldwide to support many different user applications in the various crypto key subgroups also contributes to the complexities.

The proposed modernization program described in this plan will address all of these shortcomings.

3.2 Approach

Planned satellite improvements include power enhancements, a new military signal that is spectrally separate from civil signals although still within the international radionavigation satellite service (RNSS) spectrum allocations, elimination of the dependence on the coarse/acquisition (C/A) signal for military signal acquisition, and modernized cryptography.

Power Enhancements

The low power of the GPS signals makes them susceptible to intentional and unintentional interference. Increasing the power of GPS signals from space has two key advantages. First, the stronger signal increases anti-jam performance, necessitating significant increases in adversary emitter power to disrupt or prevent US military use of GPS. Second, increased power provides the first layer of separation from the civil signals. This separation allows the military to effectively electronically attack that portion of the GPS spectrum that adversaries have access to while ensuring continued US use of the military signal.

The relative benefits of various means of increasing the strength of the GPS signal are currently being evaluated. Increasing the power of the earth coverage signal is possible, but due to limitations in producing and managing power on a satellite, this approach provides only minimal benefit. However, a high gain antenna can produce significantly greater signal strength in a smaller area by concentrating the energy in the area of conflict. Therefore, several high gain antenna concepts that provide various power levels are being considered. The DoD will select a solution this year. A lower signal strength was funded in the President's Budget. During the next months, the Department will consider the relative benefits of alternative signal strengths and will address the funding issues associated with potential changes to the program.

New Military Signal Architecture

The current military encrypted signal, the P(Y) code, is located in the same spectrum as existing and planned civil codes; effectively, the signals overlap. Consequently, denying the civil signals to adversaries could impact the use of the military service by US and allies. To enable a militarily useful means to deny the civil signals in the same area, the military and civil signals must be spectrally separated and redesigned so the overlap of signals is reduced or eliminated. Further, additional spectral separation of the new signals is needed to preserve the continued use of existing C/A and P(Y) receivers. A means has been developed to host a new military signal, the "M" code and the existing military signal, P(Y) code, as well as civil signals within the existing GPS spectrum.

The M-code and civil signals are being designed to:

- Provide a significant increase in robustness for US military use,
- Increase spectral separation between military and civil signals,

- Improve the ability to evolve with changing threats through the use of a flexible data message in the military signal structure,
- Protect the current investment in military GPS receivers by providing backward compatibility with legacy systems remaining in the DoD inventory,
- Incorporate the NSA's improved cryptographic technologies, and
- Enhance civil GPS accuracy, availability, and robustness.

The operational requirement for spectral separation and enhanced security were documented in the GPS Operational Requirements Document (ORD), which was reviewed by the JROC in June 1999. The signal design is being refined and acquisition plans are being developed to put the new M-code on GPS satellites that are currently scheduled to launch beginning in 2005.

The Department is assessing a number of split spectrum modulations as candidates for the M-code. The DoD is also considering a new security control architecture. Data from analyses, simulation, and brassboard testing will be used to select the best signal.

Based on the current constellation replenishment strategy, the GPS constellation will not be fully M-code capable until approximately 2013; however, significant warfighting utility will be realized by 2009 when 12 M-code satellites are on-orbit, by supporting a direct P(Y) signal acquisition capability anywhere in the world. That is, a single in-view M-code satellite could enable an updated M-code GPS receiver to better exploit older satellites' P(Y) code in a "direct acquisition" mode without depending on the civil signals.

Updated Cryptography

The advanced military signals will incorporate the National Security Agency's latest cryptographic and electronic key management technologies. This advanced cryptography coupled with an electronic key management will ensure security from intentional introduction of false information into the military service while protecting the codes and algorithms from compromise.

An updated GPS electronic crypto key management and distribution architecture used in conjunction with the latest cryptographic and anti-reverse engineering technologies will substantially improve the security, utility, and flexibility of the U.S. military's employment of GPS and allow controlled usage within military coalition environments.

GPS Ground Control Segment

The GPS ground control segment will also require upgrades to assure its continued command and control compatibility with the enhanced satellites.

3.3 Implementation Timeline

The schedule in Figure 1 illustrates a projected timeline for developing and implementing the satellite and ground system enhancements.

These satellite and ground control changes required to enhance GPS are in the final stages of system definition. Once system definition is complete, the Department will begin the signal validation and test and evaluation (T&E) processes to ensure that the designed advancements meet operational requirements. Fielding of the advanced capabilities will begin with the seventh Block IIF satellite, currently planned for launch in 2005. Initial Operational Capability (IOC) is anticipated in 2011. The IOC date is predicated upon having on orbit the requisite number of advanced IIF satellites to provide continuous, worldwide coverage. Analysis to date has shown that a minimum of 18 satellites is needed to satisfy this requirement. This timeline is based upon current launch schedules and funding. If GPS satellites last longer than currently anticipated, timelines may change.

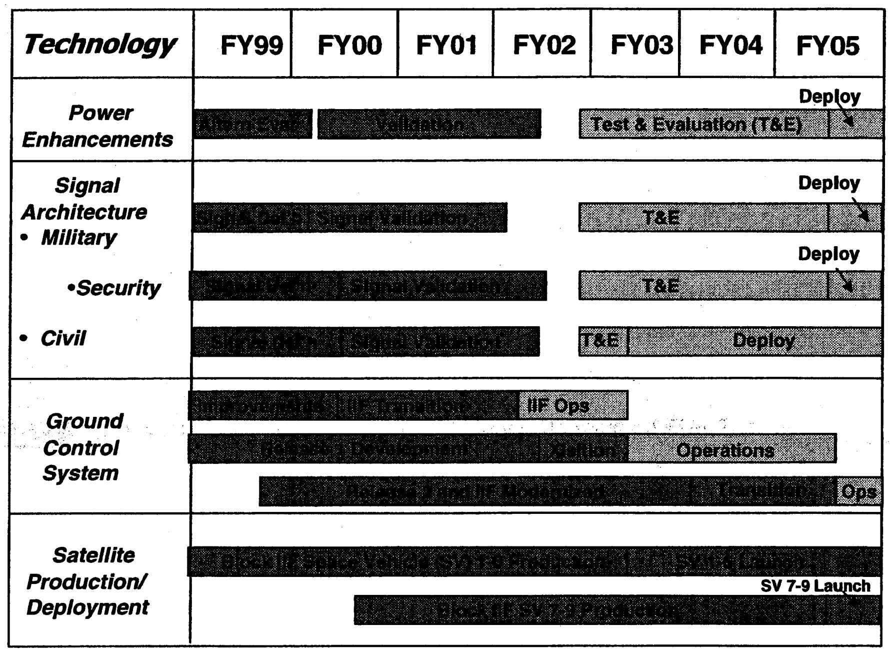

Figure 1. Modernization Schedule

4 Military User Equipment (UE)

4.1 Introduction

Advances in user equipment technology will also contribute significantly to restoring mission effectiveness in a hostile electronic environment. The DoD's plan for enhanced GPS UE is founded on four objectives. The first is a set of specific applied technologies that contribute to anti-jam performance. These include direct access to the encrypted signals, adaptive antennas that "null" jammers, and advanced signal processing techniques. All of these features are drawn from industry and government investments in basic communications, signal processing, and electronic warfare technology. The second objective is to employ anti-reverse engineering technology to enable military receivers employing cryptographic algorithms and keys to be manufactured on the same production lines as commercial GPS receivers and deployed with coalition partners without high risk of compromise to cryptographic techniques. The third major objective is to design and employ an improved electronic crypto key management and distribution architecture throughout the GPS infrastructure. This architecture will allow crypto keys to be securely wrapped and distributed electronically in a timely manner to overcome usage changes and crypto key compromises. The forth major objective is the transition to an open systems receiver architecture. The open system architecture will enable use of commercial technology that will foster competition to drive down the cost of incorporating new capabilities into DoD systems.

4.2 Approach

A comprehensive solution to both offensive and defensive Navwar (prevention and protection) drives modernization of user equipment as well as the satellites. The single most effective technology for achieving anti-jam performance is adaptive nulling antennas on the receivers, providing from 20-30 dB of jammer rejection depending on scenario. This technology, and other A/J technologies, will operate within the current GPS signal structure. An additional 10-20 dB of anti-jam margin, which can be delivered from stronger signals from the spacecraft, will benefit all users, including those who cannot afford the size or cost of adaptive antennas. Deficiencies of the current GPS signal, as noted earlier, cannot be addressed without changing the satellite design. There is not a space-UE design tradeoff in Navwar. We must start by fielding anti-jam technology operating with the current signals now, buying a partial Navwar solution for the upcoming decade, and then complete the solution with satellite changes that become operational in the second decade of the next century. The combined performance gleaned from both space and UE modernization is needed, and an open systems architecture evolutionary path for UE makes the transition affordable.

The DoD's UE investment plan is designed to facilitate the rapid integration of maturing receiver technologies and provide a cost-effective path for inserting advanced capabilities as they become available. The three key objectives of this investment plan are to 1) significantly increase the anti-jam performance of receivers over the next five years, 2) significantly increase protection and flexibility of cryptology, and 3) transition to an "open systems" receiver architecture for the long term.

Technologies that contribute to anti-jam performance include direct access to the encrypted signals, adaptive antennas that "null" jammers, and advanced processing techniques to further exploit the natural synergy between GPS and Inertial Measurement Units (Ultra-tight Coupling). The DoD plans to evolve the military UE through the GPS Receiver Applications Module (GRAM) and Selective Availability, Anti-Spoof Module (SAASM) programs.

The GRAM program will produce a standardized receiver interface control document for incorporating the GPS capability on a single card. GRAM is the means to reach an open systems architecture for DoD GPS receivers. Prototypes of the GRAM have been developed and are being evaluated in the Navwar ACTD. Initially developed for aircraft applications, GRAM will provide the functional requirements and form factor interface specifications for handheld receivers, ship, and precision guided munitions. GRAM will allow for flexibility in selecting contractors to upgrade the family of GPS cards since the interface is standard for all manufacturers. GRAM will also allow for cost-effective replacement and upgrade of military receivers in the future.

SAASM is the foundation for the future military GPS security architecture. SAASM provides three key advances. First, SAASM is compatible with the NSA's new key management system facilitating quicker and more secure distribution of keys to the user. The SAASM cryptologic architecture will offer over-the-air rekeying (OTAR) capability, enhancing authorized user flexibility and simplifying operations. Second, it enables the proliferation of Direct P(Y)-code acquisition receivers using unclassified keys. Third, it minimizes the risk of classified information compromise through the application of tamper resistant coating to the SAASM portion of the receiver. Any attempt at tampering with the SAASM module to determine the code structure leads to irrecoverable damage to the module and denies an adversary the ability to determine classified codes and algorithms. An upgrade to the SAASM to process the new military signals (M-code) is planned beginning in FY00 to enable its availability in concert with the signal's availability on the satellite. Future Department funding decisions will determine the pace of that development.

This evolutionary approach will ensure that the DoD realizes the benefits of the rapid advances in microelectronics and enable the Department to economically replace aging UE while keeping pace with the threat environment and avoiding obsolescence.

To complement the upgrades and improvements to military GPS user equipment, the Department is in the process of determining what modifications to its electronic warfare capabilities may be required to address the GPS threats. Also, the Department intends to evaluate alternative future systems to counter the projected threat situation beyond the next decade. As additional civil signals become available, we expect upgrades to electronic warfare systems to address enemy use of any/all of the three civil signals in a theater of conflict. In the near term, this capability will be fielded through upgrades and modifications to current EW platforms within the inventory. Also, the Department is in the final stages of evaluating alternatives for future advanced systems development to counter the projected threat situation over the next decade.

4.3 Implementation Timeline

Most military GPS receiver types are dual frequency and operate on military signals at both L1 and L2 (1575.42 and 1227.60 MHz, respectively). However, the single most widely fielded military receiver is the handheld Precision Lightweight GPS Receiver (PLGR). The PLGR is a single frequency (L1) receiver and is vulnerable to jamming and interference. Over 80,000 of these receivers are in the US inventory. The DoD is planning to upgrade the handheld inventory with a projected acquisition of over 100,000 dual frequency handheld receivers within a decade starting in 2002. These receivers will include a direct P(Y) code acquisition capability.

A dual frequency PLGR has been developed and demonstrated in the Navwar ACTD. Features of this PLGR upgrade will be incorporated in future handheld procurements.

The Services have identified "high priority" systems that should have GPS receiver upgrades between 2000 and 2010. Other DoD systems are expected to be upgraded as the obsolescence of the existing GPS UE or of the entire system dictates the need for replacement.

Major changes are occurring across the DoD in the planning and definition of future smart-cards, tokens, and crypto key management and distribution architectures. The enhanced GPS will be fully compatible with the overall DoD "positive user identification" thrust.

Figure 2 outlines the GPS user equipment research investment plan. The plan highlights the technologies to be integrated into weapon systems to ensure that GPS operational capability is maintained in the stressed electronic warfare environment.

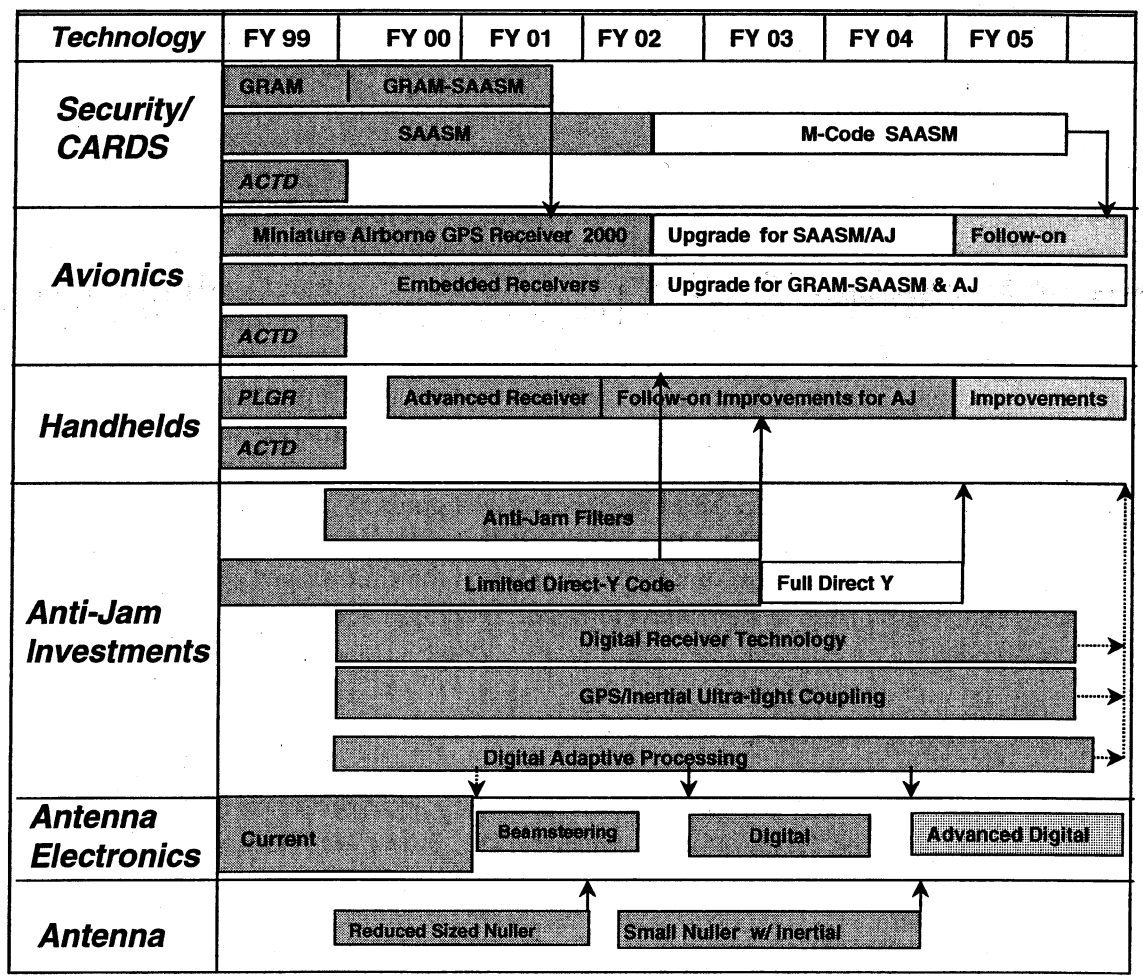

Figure 2. GPS User Equipment Investment Plan

5 Civil Enhancements

5.1 Introduction

The civil community is increasing its use of GPS to support a variety of governmental, scientific, commercial, and academic applications. Today, GPS information is being used to enhance productivity, efficiency, and safety. As is the case with the military, civil users have come to recognize the need to enhance GPS to ensure that the system can continue to meet demanding civil requirements.

5.2 Approach

Civil enhancements to the GPS satellites are designed to provide increased accuracy, availability, and continuity of service. The key to achieving this higher level of service is the addition of two more civil signals. The DOT has committed to FY00 funding for the second and third civil signals.

The DoD and DOT have agreed to add a second civil signal at 1227.60 MHz to complement the military signal already located there. The second civil signal is expected to satisfy the needs of many civil users. Certain users, civil aviation for example, require very high confidence of GPS service availability. In order to meet the demanding levels of service to civil aviation, the GPS signal needs to operate within spectrum protected for "Aeronautical Radionavigation Service" (ARNS). The GPS "L2" spectrum at 1227.60 MHz does not have an ARNS allocation. As announced by the Vice President, 1176.45 MHz has been selected for implementation of a third civil signal in an ARNS band.

The Interagency GPS Executive Board (IGEB) is working to reduces or eliminate cost and operational impacts to systems that currently operate in the 1176 MHz band. Efforts are underway to identify technical and procedural solutions to allow existing authorized military systems to operate in the 1176 MHz band and coexist with the third civil signal without causing harmful interference to civil aviation and other transportation safety users. Analysis to determine if any modifications are required to existing systems and any other nearby systems is planned to be complete by the end of August 1999. The addition of the third civil signal and the introduction of the military code will lessen the impact of military training and exercises on civil use of GPS.

5.3 Implementation Timeline

The second civil signal at 1227.60 MHz is programmed to be added to all Block IIF satellites which are currently scheduled for launch in 2003 and beyond. The third civil signal at 1176.45 will be introduced on the 7th Block IIF satellite, which is currently scheduled for launch in 2005. Availability will depend upon actual launch schedules, which will be determined by on orbit experience.

6 Future Activities

Incorporation of these GPS enhancements is critical to the effective execution of the battlespace "Ops Tempo" as stated in *Joint Vision 2010*. Therefore, the Department is committed to ensuring that this effort is accomplished in a timely manner. The Department is planning a program review of GPS/Navwar in the summer of 1999. The review will approve the Services' strategy to upgrade or replace all segments (space, control, and user equipment) of the GPS program. Prior to the program review, the JROC will validate the GPS/Navwar operational requirements.

7 Summary

This report outlines the Department's approach to enhancing GPS as an urgent national security priority. The GPS space segment and ground control system will be upgraded to ensure the future robustness of the GPS constellation in support of worldwide military operations. Concurrent with these enhancements, military user equipment upgrades are planned to leverage off maturing receiver and antenna technologies to counter the growing threat environment. These individual efforts, synergistically linked together, will provide the DoD with the continued ability to use GPS effectively for military operations globally.

At the same time, the DoD and DOT are continuing to cooperate to define and incorporate features to accommodate the civil and commercial sector's future requirements for GPS. Although plans are not yet complete, they are well underway. Both the requirements and acquisition strategies are expected to solidify in the fall of 1999.

The planned addition of a second civil signal will provide non-aeronautical and non-safety of life users the benefits of added service robustness, interference mitigation, and atmospheric error reduction. The third civil signal in an ARNS protected band will form the cornerstone for the migration to worldwide satellite navigation with attendant increases in overall system capacity and safety of aviation operations throughout the world.

GPS remains a relatively new system, in contrast to other radionavigation aids and timing systems. The enhancements being planned now are the most significant changes since the system's inception in the early 1980's.