GPS III Bringing New Capabilities to the Global Community

The next generation of GPS satellites — GPS III — is under development to bring improved performance and new capabilities to users around the globe. In this article, authors from the company designing and building those satellites describe the technical features and operational requirements of the GPS III that will produce these benefits.

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In May 2008, Lockheed Martin Space Systems Company received a contract from the U.S. Air Force to develop a new, third generation of GPS satellites. The GPS III space vehicle (SV) has been designed (**Figure 1**) and is now being built to bring new future capabilities to both military and civil positioning, navigation, and timing (PNT) users throughout the globe.

The GPS III SV critical design review (CDR) was successfully completed in August 2010 — two months early. CDR marked the completion of the GPS III design phase, and the production phase is now well under way with integration and test to follow next year. The program remains on schedule to have the first GPS III SV available for launch in 2014.

This article will introduce the reader to the basic features of the new SV, elaborating on its advanced capabilities, and identifying similarities to and differences from earlier versions of GPS satellites. We will highlight the basic subsystems of the GPS III SVs being built by Lockheed Martin, its navigation payload subcontractor, ITT; communications payload subcontractor, General Dynamics; and numerous other subcontractors. This article will also provide an overview of the new signals and services on the GPS III SV, the SV simulators, and the assembly facility.

The Need for GPS III

GPS III is required to maintain the GPS constellation and improve PNT services to meet user demand in the future. The GPS III capabilities, with the new L1C signal, higher signal power, greater accuracy, longer SV lifetime, and higher signal availability, will maintain GPS as the "Gold Standard" for worldwide satellite navigation systems.

GPS III will be needed to sustain the constellation (**Figure 2**) in the near term, following completion of the current GPS

(left to right)
GPS III GPF thermal vacuum chamber
Completing Construction on GPS III GPF high bay
GPS III GNST core structure
GPS III GNST navigation panel with heater harness installed
GPS III GPF anechoic chamber

Block IIF launch schedule. The 10 remaining GPS IIF SVs will generally replace the 13 older IIA SVs now on orbit, as these satellites are well past their expected life. GPS III will then replace older Block IIR SVs, essential to maintaining the backbone of the constellation for years to come.

The GPS III SVs will be able to use their capability to select higher PRNs (38-63) for active SVs, allowing more than 32 GPS SVs to broadcast in the constellation. This will provide improved accuracy and greater coverage for all users.

GPS III's expandable capability and active production line will allow it to readily adapt to unforeseen and changing capability requirements to meet the needs of GPS users in the future.

The first GPS III satellites will deliver signals three times more accurate than current GPS spacecraft and provide three times more power for military users. They will also increase the SV design life to 15 years and add a new civil signal

FIGURE 1 GPS III On Orbit

FIGURE 2 GPS Constellation circa 2015

designed to be interoperable with international global navigation satellite systems (GNSS).

The new expandable GPS III design is based on the award-winning Lockheed Martin A2100 bus design and its long heritage. Important design elements have also been pulled from the GPS Block IIR and IIR-M SVs and their impressive heritage of almost 150 years of accumulated on-orbit performance.

Lockheed Martin has used the A2100 bus design for 37 successfully launched SVs over the past 17 years. Ten other A2100-based SVs currently are being built, including the first several GPS III SVs, the Advanced Extremely High Frequency (AEHF) satellites, and the Space-Based Infrared System (SBIRS) SVs. A2100 SVs currently on orbit have an accumulated operational lifetime of more than 325 years. Heritage communications satellite customers using A2100 buses include the Broadcasting Satellite System Corporation (B-SAT) for the BSat satellites, SKY Perfect JSAT Corporation for the JCSAT satellites, and Vietnam Post and Telecommunication Corporation for the VINASAT satellites.

The GPS III navigation payload is being designed and built by ITT based on its heritage of more than 30 years of GPS payloads. ITT has built all or part of the navigation payload on every GPS satellite block: I, II, IIA, IIR, IIF, and now the GPS III. GPS III is fully backward-compatible with existing GPS system capabilities, but with important improvements for the future of GPS.

The GPS III SV design itself has the capacity to accommodate new advanced capabilities as soon as they are mature and determined ready to add to the SV.

GPS III Design Overview

We can highlight the basic GPS III SV design by examining its various elements and subsystems: the navigation payload element (NPE), the network communications element (NCE), the hosted payload element (HPE), the antenna subsystem element, and the vehicle bus element with its subsystems. A brief description of each element and subsystem follows.

The NPE includes the payload computer (the mission data unit or MDU), the L-band transmitters (L1, L2, L3, L5), the atomic frequency standards (AFSs), and signal filters. The MDU incorporates the waveform generator functionality first introduced in the modernized IIR-M SV.

Each GPS III SV hosts three enhanced rubidium AFSs ("clocks"), which build upon the strong heritage from the GPS IIR/IIR-M SVs. The GPS III SV also includes a fourth slot for enhanced new or experimental frequency standard designs, such as a hydrogen maser.

Significantly, a GPS III has the capability to operate and monitor a backup AFS for stability performance measurement and characterization. This is separate from the operational AFS. Redundant time-keeping system loops allow independent operation of the accurate hardware/software control loops. This capability is not available on any of the previous generations of GPS satellites.

The NCE provides communications capability to the SV. It consists of the enhanced crosslink transponder subsystem (ECTS), the thin communications unit (TCU) to distribute commands and collect telemetry, and the S-band boxes.

The HPE hosts several government-furnished equipment (GFE) items provided to GPS III. The antenna subsystem consists of the Earth coverage L-band antenna panel, the S-band antennas, and the UHF antennas.

The vehicle bus element includes numerous subsystems: the attitude control subsystem (ACS), the electrical power subsystem (EPS), the thermal control subsystem (TCS), the telemetry, tracking and commanding (TT&C) subsystem, the propulsion subsystem (PSS), and the mechanical subsystem (MSS).

Let's take a closer look at each of these.

The ACS maintains the attitude knowledge and controls the pointing of the SV. This includes the nominal Earth pointing of the L-band antenna panel, and pointing the solar arrays at the Sun. It also controls thrust direction for propulsion subsystem maneuvers.

The ACS consists of a set of sensors and actuators: coarse sun sensors, earth sensors, the inertial measurement unit (IMU), reaction wheels, magnetic torque rods for fine maneuvers, and 0.2-lbf thrusters for more coarse maneuvers including periodic station keeping.

The EPS provides the stable electrical power for the entire satellite, including during eclipse events. It consists of the solar arrays, nickel-hydrogen batteries, and the power regulation unit. The TCS maintains the proper temperature of the various SV components within safe limits. It consists of insulation, reflectors, heaters, radiators, heat pipes, and thermistors.

The TT&C subsystem consists of the bus computer (the on-board computer or OBC), the uplink/downlink unit

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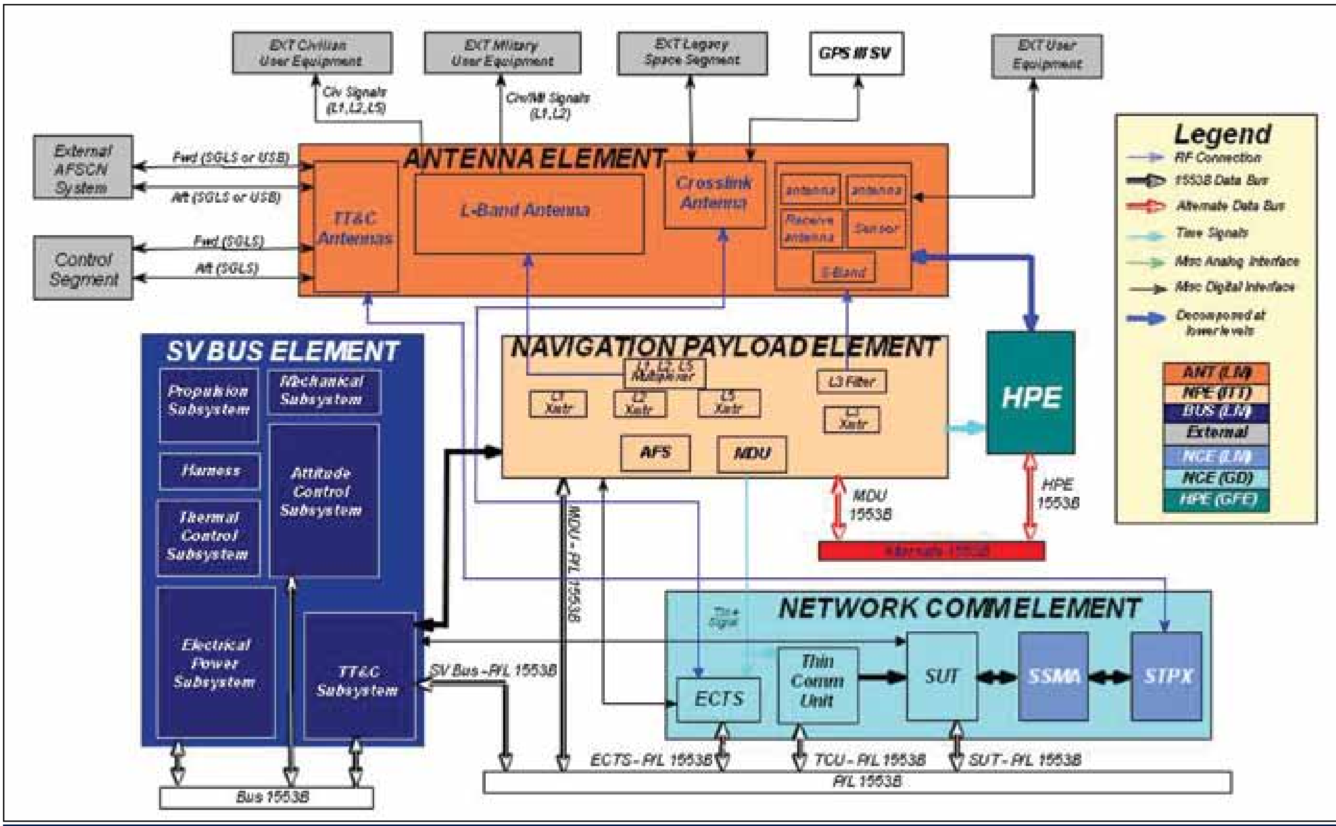

FIGURE 3 GPS III block diagram

(UDU) for commanding and telemetry communication with the GPS Operational Control Segment (OCS), remote interface units, deployment device control, and event detectors.

The PSS provides the thrust capability to alter the position and attitude of the SV. It consists of the liquid apogee engine for final orbit insertion, the 5-lbf thrusters for large on-orbit maneuvers, and the 0.2-lbf thrusters for attitude and station-keeping maneuvers. The MSS consists of the basic SV structure, hinges, and the frangibolts for deployable elements.

Figure 3 presents the GPS III SV block diagram, highlighting all the primary subsystems.

Figure 4 shows an expanded view of the GPS III SV showing its basic structure and notional component location.

Performance Requirements

The GPS III SV requirements include a 12-year mean mission duration and a 15-year design life. The GPS III L-band signals will consist of the heritage L1 C/A, L1 P(Y), and L2 P(Y); the modernized L1M, L2C, and L2M; and full support for the new L5 and L1C civilian signals.

The GPS III M-code received signal power at Earth will be at least -153 dBW at five degrees elevation, as compared to -158 dBW for IIR and IIF. This will provide for substantially improved service for military users in stressed conditions throughout theaters of operation.

Navigation accuracy is one of the primary concerns for users. The GPS Block II SV is required to meet a daily requirement of 3.5-meter user range error (URE). The IIR is required to meet 2.2 meters URE at 24 hours when operating with a rubidium atomic frequency standard (RAFS). A IIF is required to provide 3-meter URE at 24 hours. GPS III will be required to meet a 1.0-meter URE requirement at 24 hours, a three-fold improvement.

GPS III Processing Facility

To ensure the most efficient GPS III production process, Lockheed Martin has invested in the development of a new, multi-capability GPS Processing Facility (GPF) at its Waterton site near Denver. This will be the assembly, integration and test (AI&T) location for the entire GPS III fleet.

Satellite assemblies and elements will come from various locations around the country for final assembly, followed by a thorough battery of tests including thermal vacuum and electro-magnetic interference. Photos accompanying this article show the thermal vacuum (TVAC) chamber, the anechoic chamber, and the "high bay" assembly and test area at the GPF.

Construction of the GPF was completed earlier this year, and the facility checkout and validation is nearly complete.

GPS Non-Flight Satellite Testbed

The GPS Non-Flight Satellite Testbed (GNST) is the "pathfinder" unit for the program. A full-sized model of the GPS III SV populated with fully functional non-flight boxes, the

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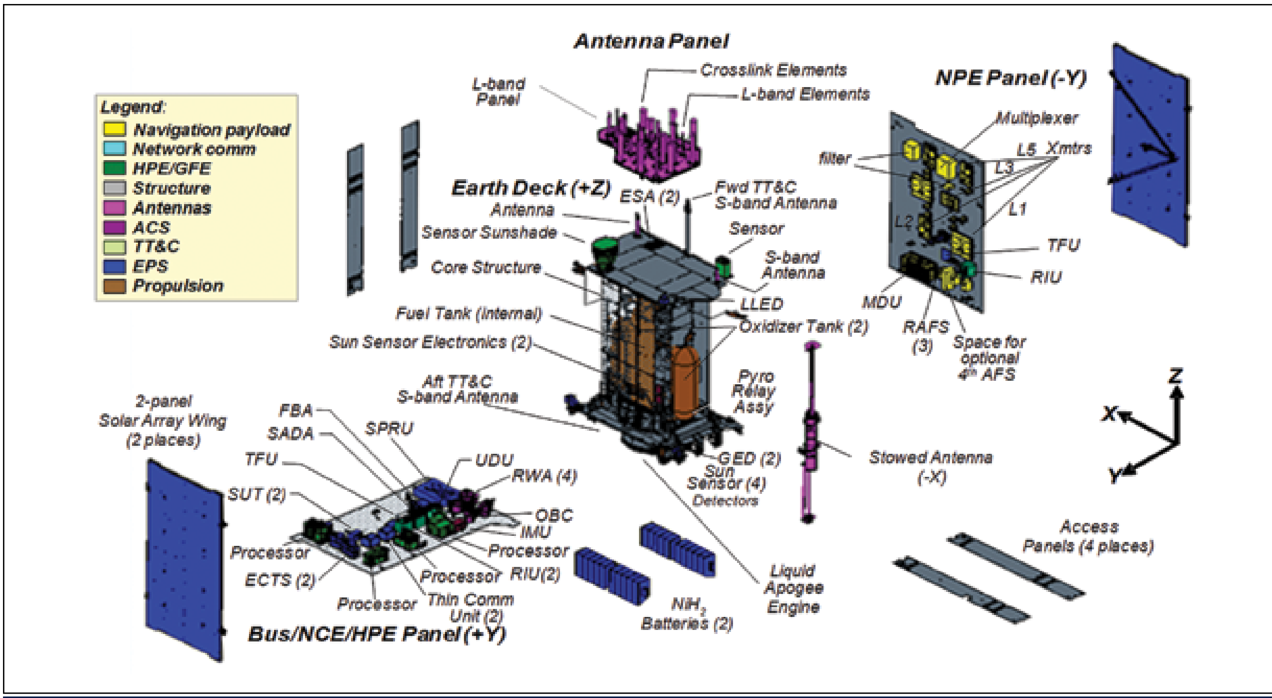

FIGURE 4 GPS III expanded view

Specifications		I	II	IIA	IIR	IIR-M	IIF	III
Accuracy (meters)	User Range Error at 1 day	-	7.6	7.6	2.2	2.2	3.0	1.0
SV Lifetime (years)	MMD Reg.	4.5	6	6	6	6	9.9	12
	Design Life	5	7.5	7.5	7.5	7.5	12	15
	Expendables	7	10	10	10	10	-	-
Signal Power (dBW)	L1C/A	-160.0	-160.0	-158.5	-158.5	-158.5	-158.5	-158.5
	L1P	-163.0	-163.0	-161.5	-161.5	-161.5	-161.5	-161.5
	L1M	-	-	-	-	-158.0	-158.0	-158.0
	L1C	-	-	-	-	-	-	-157.0
	L2C	-	-	-	-	-160.0	-160.0	-158.5
	L2P	-166.0	-166.0	-164.5	-164.5	-161.5	-161.5	-161.5
	L2M	-	-	-	-	-161.0	-161.0	-158.0
	L5	-	-	-	-	-	-157.9	-157.0
SV Availability	%	Availability specification levied on full constellation at 98% with SV goals of 95%					98.08%	99.45%

Table 1. GPS SV Specifications

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GNST will serve as a vehicle demonstrator for GPS III. It will provide for physical fit-checks at the GPF in Colorado and at the GPS launch site at Cape Canaveral Air Force Station (CCAFS). This will significantly reduce risk for SV assembly, test, pre-launch operations, and capability insertion.

Photos on the opening pages of this article show the GNST core structure and the navigation payload element panel with heater harness prior to installation of the navigation payload boxes.

The GNST will be shipped to the GPF late this year and used there for initial AI&T activities paving the way for build and test of the first flight article in 2012. The GNST will be shipped to CCAFS about a year from now for pathfinding activities at the launch site.

Following activities at CCAFS, the GNST will return to the GPF in Colorado to serve as a long-term test article for the entire life of the GPS III program. This will include retrofitting the GNST for all future capability insertions. The GNST will provide SV design level validation, early verification of ground, support, and test equipment, and early confirmation and rehearsal of transportation operations.

GPS III Advanced Capabilities

On orbit, GPS III satellites will provide longer SV life, improved accuracy, and improved availability compared to all previous GPS generations. Table 1 provides a summary of the critical performance requirements for the program. The GPS Block IIF and GPS III SVs have an SV availability requirement levied on them at the individual satellite level. Earlier GPS SVs did not. They worked with a "goal" derived from the constellation requirement. Based on current best estimates, GPS III will meet or exceed all of these critical requirements.

The new generation of satellites will also bring new capabilities to the user community beyond the current GPS generations, notably the L1C signal. A later section will discuss the details of this important capability.

GPS III is the first version of GPS satellite capable of selecting pseudo-random number (PRN) settings in the range of 38-63. This allows for more than 32 active SVs in the constellation, a limitation of the current GPS satellites and operational control segment. This capability complies with the IS-GPS-200 specification.

GPS III SVs can also host a fourth advanced technology clock. This could be used as a technology demonstrator or on-orbit performance validation for future clock designs, which will likely be critical to future advances in GPS constellation accuracy.

The ability to insert new capabilities on the GPS III SV is a key feature of the program. Capability insertion — which we will discuss in greater detail later — is enabled by a modern scalable bus design, active parts suppliers, and engaged subcontractors. Numerous important capabilities are already being pursued for near-term incorporation.

The New L1C Signal

GPS III will be the first generation of satellites to broadcast the new L1C signal. This will be the fourth civilian signal (in addition to L1 C/A, L2C, and L5) and implements the second-generation CNAV-2 modernized navigation message. This signal will be fully interoperable with other GNSSes, such as Europe's Galileo, Japan's Quasi-Zenith Satellite System (QZSS), and potentially China's Compass (BeiDou).

As with other modernized GPS signals, the L1C signal design provides for improved acquisition and tracking, faster data download, and a more accurate ranging signal. It brings the modernized GPS signal structure to the L1 frequency.

L1C benefits include improved accuracy, acquisition, and tracking. The presence of additional data bits enables greater PNT accuracy in the CNAV-2 message, including more SV orbital position data elements in the navigation message that improve the ephemeris model.

The L1C signal consists of a dataless pilot signal and a data signal. The data signal is spread with a ranging code, then combined with the data message, and modulated on the L1 carrier using a binary offset carrier (BOC) modulation technique. The pilot signal is spread with a ranging code, combined with an SV-unique overlay code, and modulated on the L1 carrier using a time-multiplexed BOC (TMBOC) modulation technique. The TMBOC technique allows for more robust acquisition by the user. The L1C PRN sequence itself provides more accuracy in the pseudorange measurement.

Overall, navigation and timing users throughout the globe will benefit significantly from having GPS broadcast the L1C signal.

Capability Insertion

Included in the fundamental GPS III program is a *capability insertion program* that will support a graceful growth to enhanced GPS III versions.

Capability insertion has shown great value in the GPS IIR program. The GPS Block IIR SVs (Figure 5) ended up coming in many "flavors." Originally, 21 total SVs were developed. Eight of these were modernized as IIR-M SVs. All eight IIR-M SVs, plus the final four original IIR SVs were retrofitted with an improved antenna panel. Unique characteristics, boxes, and capabilities were added to most SVs, such that each SV is unique: almost 20 distinct "flavors" of GPS IIR/IIR-M SVs exist.

First on the list for capability insertion to GPS III is the Distress Alerting Satellite System (DASS) payload that relays distress signals from emergency beacons to search and rescue operations. In addition, a space laser ranging capability will allow scientists to accurately measure the GPS III SV orbit, leading to more accurate modeling of the Earth's gravitational field and the effects of special relativity.

FIGURE 5 GPS IIR-M SV

A digital waveform generator will replace the analog boxes creating a fully digital navigation payload capable of generating new navigation signals on-orbit. Lithium-ion batteries will reduce SV weight and provide better EPS performance. Moreover, more M-code power will be added to provide higher power modernized signals to the military.

Another aspect of capability insertion is the effort currently being made to enable the launch of two GPS III SVs at a time. This would greatly relax constraints on booster and launch slot availability for maintaining the GPS constellation while significantly reducing launch costs.

Current Status

The first GPS III SV, simulators, and support facilities and systems are all being developed with an eye on ensuring that the first GPS III SV will be available for launch in 2014. The GNST is currently being manufactured and will be delivered to the GPF in Colorado late this year.

Additional simulators are being developed and delivered on schedule, including a bus real-time simulator, the GPS spacecraft simulator, an integrated software interface test environment (InSite), and the space vehicle subsystem models and simulation.

These simulators, in both hardware and software implementations, provide

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for support system checkout, readiness for launch, and SV on-orbit maintenance. Ground support equipment such as the *bus ground support equipment* and the *payload ground support equipment*, as well as mechanical support structures and shipping and handling devices, are nearing completion.

The flight boxes and flight panels for the first satellite are in production with long-lead parts acquisition approved for the first four SVs.

The GPS Next Generation Operational Control System (OCX) will provide for operational control of the new modernized capabilities on the GPS III SV. An early version of the OCX will provide a GPS III Launch and Checkout System (LCS) prior to OCX being ready to fully operate the GPS III SVs. This is motivated by the situation that the current OCS, operated by the Architecture Evolution Plan (AEP), is not designed to track nor fully operate any of the new modernized signals on GPS IIR-M, GPS IIF or GPS III. The LCS will begin development later this year and will undergo incremental testing as the various capabilities of the ground software are delivered for readiness testing.

The GPS III program is successfully moving forward towards a delivery of the first GPS III SV in 2013 with first launch in 2014.

Conclusion

The first GPS III space vehicle will be ready to launch within three years to begin a new era for the Global Positioning System. It will have extended and expandable capability and will provide increased performance to GPS users. GPS III will improve PNT services and provide advanced anti-jam capabilities yielding superior system security, accuracy, and reliability worldwide.

GPS III is needed to sustain the GPS constellation, replace older SVs, and deliver critical new capabilities demanded by users. All users, civilian and military, will benefit from the improved performance and advanced capabilities of GPS III for the several decades to come.

Authors


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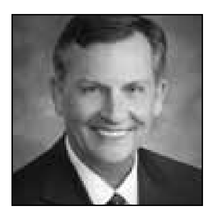
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