GPS AND ITS APPLICATIONS

UNIT I

GPS:HISTORY-ADVANTAGES AND LIMITATIONS-SEGMENTS:CONTROL-SPACE AND USER-GEOPOSITIONING:POINT-RELATIVE-STATIC-KINEMATICS-USES OF GPS

The GPS project was launched in the United States in 1973 to overcome the limitations of previous navigation systems,[15] integrating ideas from several predecessors, including classified engineering design studies from the 1960s. The U.S. Department of Defense developed the system, which originally used 24 satellites. It was initially developed for use by the United States military and became fully operational in 1995. Civilian use was allowed from the 1980s. Roger L. Easton of the Naval Research Laboratory, Ivan A. Getting of The Aerospace Corporation, and Bradford Parkinson of the Applied Physics Laboratory are credited with inventing it.[16] The work of Gladys West is credited as instrumental in the development of computational techniques for detecting satellite positions with the precision needed for GPS.[17]

The design of GPS is based partly on similar ground-based radio-navigation systems, such as LORAN and the Decca Navigator, developed in the early 1940s.

In 1955, Friedwardt Winterberg proposed a test of general relativity – detecting time slowing in a strong gravitational field using accurate atomic clocks placed in orbit inside artificial satellites. Special and general relativity predict that the clocks on the GPS satellites would be seen by the Earth's observers to run 38 microseconds faster per day than the clocks on the Earth. The GPS calculated positions would quickly drift into error, accumulating to 10 kilometers per day (6 mi/d). This was corrected for in the design of GPS

Predecessors

When the Soviet Union launched the first artificial satellite (Sputnik 1) in 1957, two American physicists, William Guier and George Weiffenbach, at Johns Hopkins University's Applied Physics Laboratory (APL) decided to monitor its radio transmissions.[19] Within hours they realized that, because of the Doppler effect, they could pinpoint where the satellite was along its orbit. The Director of the APL gave them access to their UNIVAC to do the heavy calculations required.

Early the next year, Frank McClure, the deputy director of the APL, asked Guier and Weiffenbach to investigate the inverse problem—pinpointing the user's location, given the satellite's. (At the time, the Navy was developing the submarine-launched Polaris missile, which required them to know the submarine's location.) This led them and APL to develop the TRANSIT system. In 1959, ARPA (renamed DARPA in 1972) also played a role in TRANSIT

TRANSIT was first successfully tested in 1960.[24] It used a constellation of five satellites and could provide a navigational fix approximately once per hour.

In 1967, the U.S. Navy developed the Timation satellite, which proved the feasibility of placing accurate clocks in space, a technology required for GPS.

In the 1970s, the ground-based OMEGA navigation system, based on phase comparison of signal transmission from pairs of stations,[25] became the first worldwide radio navigation system. Limitations of these systems drove the need for a more universal navigation solution with greater accuracy.

Although there were wide needs for accurate navigation in military and civilian sectors, almost none of those was seen as justification for the billions of dollars it would cost in research, development, deployment, and operation of a constellation of navigation satellites. During the Cold War arms race, the nuclear threat to the existence of the United States was the one need that did justify this cost in the view of the United States Congress. This deterrent effect is why GPS was funded. It is also the reason for the ultra-secrecy at that time. The nuclear triad consisted of the United States Navy's submarine-launched ballistic missiles (SLBMs) along with United States Air Force (USAF) strategic bombers and intercontinental ballistic missiles (ICBMs). Considered vital to the nuclear deterrence posture, accurate determination of the SLBM launch position was a force multiplier.

Precise navigation would enable United States ballistic missile submarines to get an accurate fix of their positions before they launched their SLBMs.[26] The USAF, with two thirds of the nuclear triad, also had requirements for a more accurate and reliable navigation system. The U.S. Navy and U.S. Air Force were developing their own technologies in parallel to solve what was essentially the same problem.

To increase the survivability of ICBMs, there was a proposal to use mobile launch platforms (comparable to the Soviet SS-24 and SS-25) and so the need to fix the launch position had similarity to the SLBM situation.

In 1960, the Air Force proposed a radio-navigation system called MOSAIC (MObile System for Accurate ICBM Control) that was essentially a 3-D LORAN. A follow-on study, Project 57, was worked in 1963 and it was "in this study that the GPS concept was born". That same year, the concept was pursued as Project 621B, which had "many of the attributes that you now see in GPS"[27] and promised increased accuracy for Air Force bombers as well as ICBMs.

Updates from the Navy TRANSIT system were too slow for the high speeds of Air Force operation. The Naval Research Laboratory (NRL) continued making advances with their Timation (Time Navigation) satellites, first launched in 1967, second launched in 1969, with the third in 1974 carrying the first atomic clock into orbit and the fourth launched in 1977.[28]

Another important predecessor to GPS came from a different branch of the United States military. In 1964, the United States Army orbited its first Sequential Collation of Range (SECOR) satellite used for geodetic surveying.[29] The SECOR system included three ground-based transmitters at known locations that would send signals to the satellite transponder in orbit. A fourth ground-based station, at an undetermined position, could then use those signals to fix its location precisely. The last SECOR satellite was launched in 1969.[30]

Development

With these parallel developments in the 1960s, it was realized that a superior system could be developed by synthesizing the best technologies from 621B, Transit, Timation, and SECOR in a multi-service program. Satellite orbital position errors, induced by variations in the gravity field and radar refraction among others, had to be resolved. A team led by Harold L Jury of Pan Am

Aerospace Division in Florida from 1970–1973, used real-time data assimilation and recursive estimation to do so, reducing systematic and residual errors to a manageable level to permit accurate navigation.[31]

During Labor Day weekend in 1973, a meeting of about twelve military officers at the Pentagon discussed the creation of a *Defense Navigation Satellite System (DNSS)*. It was at this meeting that the real synthesis that became GPS was created. Later that year, the DNSS program was named *Navstar*.[32] Navstar is often erroneously considered an acronym for "NAVigation System Using Timing and Ranging" but was never considered as such by the GPS Joint Program Office (TRW may have once advocated for a different navigational system that used that acronym).[33] With the individual satellites being associated with the name Navstar (as with the predecessors Transit and Timation), a more fully encompassing name was used to identify the constellation of Navstar satellites, *Navstar-GPS*.[34] Ten "Block I" prototype satellites were launched between 1978 and 1985 (an additional unit was destroyed in a launch failure).[35]

The effect of the ionosphere on radio transmission was investigated in a geophysics laboratory of Air Force Cambridge Research Laboratory, renamed to Air Force Geophysical Research Lab (AFGRL) in 1974. AFGRL developed the Klobuchar model for computing ionospheric corrections to GPS location.[36] Of note is work done by Australian space scientist Elizabeth Essex-Cohen at AFGRL in 1974. She was concerned with the curving of the paths of radio waves (atmospheric refraction) traversing the ionosphere from NavSTAR satellites.[37]

After Korean Air Lines Flight 007, a Boeing 747 carrying 269 people, was shot down in 1983 after straying into the USSR's prohibited airspace,[38] in the vicinity of Sakhalin and Moneron Islands, President Ronald Reagan issued a directive making GPS freely available for civilian use, once it was sufficiently developed, as a common good.[39] The first Block II satellite was launched on February 14, 1989,[40] and the 24th satellite was launched in 1994. The GPS program cost at this point, not including the cost of the user equipment but including the costs of the satellite launches, has been estimated at US$5 billion (then-year dollars).[41]

Initially, the highest-quality signal was reserved for military use, and the signal available for civilian use was intentionally degraded, in a policy known as Selective Availability. This changed with President Bill Clinton signing on May 1, 2000 a policy directive to turn off Selective Availability to provide the same accuracy to civilians that was afforded to the military. The directive was proposed by the U.S. Secretary of Defense, William Perry, in view of the widespread growth of differential GPS services by private industry to improve civilian accuracy. Moreover, the U.S. military was actively developing technologies to deny GPS service to potential adversaries on a regional basis.[42]

Since its deployment, the U.S. has implemented several improvements to the GPS service, including new signals for civil use and increased accuracy and integrity for all users, all the while maintaining compatibility with existing GPS equipment. Modernization of the satellite system has been an ongoing initiative by the U.S. Department of Defense through a series of satellite acquisitions to meet the growing needs of the military, civilians, and the commercial market.

As of early 2015, high-quality, FAA grade, Standard Positioning Service (SPS) GPS receivers provided horizontal accuracy of better than 3.5 meters (11 ft),[43] although many factors such as receiver quality and atmospheric issues can affect this accuracy.

GPS is owned and operated by the United States government as a national resource. The Department of Defense is the steward of GPS. The *Interagency GPS Executive Board (IGEB)* oversaw GPS policy matters from 1996 to 2004. After that, the National Space-Based Positioning, Navigation and Timing Executive Committee was established by presidential directive in 2004 to advise and coordinate federal departments and agencies on matters concerning the GPS and related systems.[44] The executive committee is chaired jointly by the Deputy Secretaries of Defense and Transportation. Its membership includes equivalent-level officials from the Departments of State, Commerce, and Homeland Security, the Joint Chiefs of Staff and NASA. Components of the executive office of the president participate as observers to the executive committee, and the FCC chairman participates as a liaison.

The U.S. Department of Defense is required by law to "maintain a Standard Positioning Service (as defined in the federal radio navigation plan and the standard positioning service signal specification) that will be available on a continuous, worldwide basis," and "develop measures to prevent hostile use of GPS and its augmentations without unduly disrupting or degrading civilian uses."

Timeline and modernization

Summary of satellites[45][46][47]

Block	Launch period	Satellite launches				Currently in orbit and healthy
		Suc-cess	Fail-ure	In prep-aration	Plan-ned	
I	1978–1985	10	1	0	0	0
II	1989–1990	9	0	0	0	0
IIA	1990–1997	19	0	0	0	0
IIR	1997–2004	12	1	0	0	12
IIR-M	2005–2009	8	0	0	0	7
IIF	2010–2016	12	0	0	0	12
IIIA	2018–	4	0	4	10	4

IIIF	—	0	0	0	22	0
Total		73	2	5	24	34
(Last update: July 12, 2020) 8 satellites from Block IIA are placed in reserve USA-203 from Block IIR-M is unhealthy [48] For a more complete list, see *list of GPS satellite launches*						

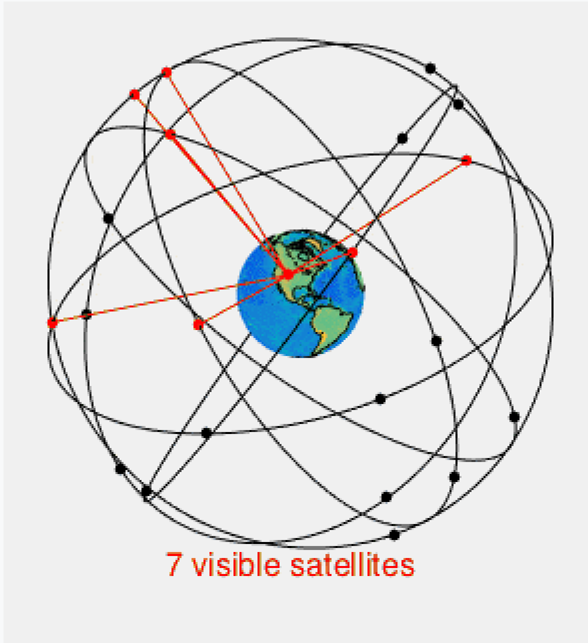
- In 1972, the USAF Central Inertial Guidance Test Facility (Holloman AFB) conducted developmental flight tests of four prototype GPS receivers in a Y configuration over White Sands Missile Range, using ground-based pseudo-satellites.[49]
- In 1978, the first experimental Block-I GPS satellite was launched.[35]
- In 1983, after Soviet interceptor aircraft shot down the civilian airliner KAL 007 that strayed into prohibited airspace because of navigational errors, killing all 269 people on board, U.S. President Ronald Reagan announced that GPS would be made available for civilian uses once it was completed,[50][51] although it had been previously published [in Navigation magazine], and that the CA code (Coarse/Acquisition code) would be available to civilian users.[*citation needed*]
- By 1985, ten more experimental Block-I satellites had been launched to validate the concept.
- Beginning in 1988, command and control of these satellites was moved from Onizuka AFS, California to the 2nd Satellite Control Squadron (2SCS) located at Falcon Air Force Station in Colorado Springs, Colorado.[52][53]
- On February 14, 1989, the first modern Block-II satellite was launched.
- The Gulf War from 1990 to 1991 was the first conflict in which the military widely used GPS.[54]
- In 1991, a project to create a miniature GPS receiver successfully ended, replacing the previous 16 kg (35 lb) military receivers with a 1.25 kg (2.8 lb) handheld receiver.[22]
- In 1992, the 2nd Space Wing, which originally managed the system, was inactivated and replaced by the 50th Space Wing.

Emblem of the 50th Space Wing

- By December 1993, GPS achieved initial operational capability (IOC), with a full constellation (24 satellites) available and providing the Standard Positioning Service (SPS).[55]
- Full Operational Capability (FOC) was declared by Air Force Space Command (AFSPC) in April 1995, signifying full availability of the military's secure Precise Positioning Service (PPS).[55]
- In 1996, recognizing the importance of GPS to civilian users as well as military users, U.S. President Bill Clinton issued a policy directive[56] declaring GPS a dual-use system and establishing an Interagency GPS Executive Board to manage it as a national asset.
- In 1998, United States Vice President Al Gore announced plans to upgrade GPS with two new civilian signals for enhanced user accuracy and reliability, particularly with respect to aviation safety, and in 2000 the United States Congress authorized the effort, referring to it as *GPS III*.
- On May 2, 2000 "Selective Availability" was discontinued as a result of the 1996 executive order, allowing civilian users to receive a non-degraded signal globally.
- In 2004, the United States government signed an agreement with the European Community establishing cooperation related to GPS and Europe's Galileo system.
- In 2004, United States President George W. Bush updated the national policy and replaced the executive board with the National Executive Committee for Space-Based Positioning, Navigation, and Timing.[57]
- November 2004, Qualcomm announced successful tests of assisted GPS for mobile phones.[58]
- In 2005, the first modernized GPS satellite was launched and began transmitting a second civilian signal (L2C) for enhanced user performance.[59]
- On September 14, 2007, the aging mainframe-based Ground Segment Control System was transferred to the new Architecture Evolution Plan.[60]
- On May 19, 2009, the United States Government Accountability Office issued a report warning that some GPS satellites could fail as soon as 2010.[61]
- On May 21, 2009, the Air Force Space Command allayed fears of GPS failure, saying "There's only a small risk we will not continue to exceed our performance standard."[62]
- On January 11, 2010, an update of ground control systems caused a software incompatibility with 8,000 to 10,000 military receivers manufactured by a division of Trimble Navigation Limited of Sunnyvale, Calif.[63]
- On February 25, 2010,[64] the U.S. Air Force awarded the contract to develop the GPS Next Generation Operational Control System (OCX) to improve accuracy and availability of GPS navigation signals, and serve as a critical part of GPS modernization.

Space segment

Unlaunched GPS block II-A satellite on display at the San Diego Air & Space Museum



A visual example of a 24 satellite GPS constellation in motion with the Earth rotating. Notice how the number of *satellites in view* from a given point on the Earth's surface changes with time. The point in this example is in Golden, Colorado, USA (39.7469°N 105.2108°W).

The space segment (SS) is composed of 24 to 32 satellites, or Space Vehicles (SV), in medium Earth orbit, and also includes the payload adapters to the boosters required to launch them into orbit. The GPS design originally called for 24 SVs, eight each in three approximately circular orbits,[78] but this was modified to six orbital planes with four satellites each.[79] The six orbit planes have approximately 55° inclination (tilt relative to the Earth's equator) and are separated by 60° right ascension of the ascending node (angle along the equator from a reference point to the orbit's intersection).[80] The orbital period is one-half a sidereal day, i.e., 11 hours and 58 minutes so that the satellites pass over the same locations[81] or almost the same locations[82] every day. The orbits are arranged so that at least six satellites are always within line of sight from everywhere on the Earth's surface (see animation at right).[83] The result of this objective is that the four satellites are not evenly spaced (90°) apart within each orbit. In general terms, the angular difference between satellites in each orbit is 30°, 105°, 120°, and 105° apart, which sum to 360°.[84]

Orbiting at an altitude of approximately 20,200 km (12,600 mi); orbital radius of approximately 26,600 km (16,500 mi),[85] each SV makes two complete orbits each sidereal day, repeating the same ground track each day.[86] This was very helpful during development because even with only four satellites, correct alignment means all four are visible from one spot for a few hours each day. For military operations, the ground track repeat can be used to ensure good coverage in combat zones.

As of February 2019,[87] there are 31 satellites in the GPS constellation, 27 of which are in use at a given time with the rest allocated as stand-bys. A 32nd was launched in 2018, but as of July

2019 is still in evaluation. More decommissioned satellites are in orbit and available as spares. The additional satellites improve the precision of GPS receiver calculations by providing redundant measurements. With the increased number of satellites, the constellation was changed to a nonuniform arrangement. Such an arrangement was shown to improve accuracy but also improves reliability and availability of the system, relative to a uniform system, when multiple satellites fail.[88] With the expanded constellation, nine satellites are usually visible from any point on the ground at any time, ensuring considerable redundancy over the minimum four satellites needed for a position.

Control segment

Ground monitor station used from 1984 to 2007, on display at the Air Force Space and Missile Museum.

The control segment (CS) is composed of:

1. a master control station (MCS),
2. an alternative master control station,
3. four dedicated ground antennas, and
4. six dedicated monitor stations.

The MCS can also access U.S. Air Force Satellite Control Network (AFSCN) ground antennas (for additional command and control capability) and NGA (National Geospatial-Intelligence Agency) monitor stations. The flight paths of the satellites are tracked by dedicated U.S. Space Force monitoring stations in Hawaii, Kwajalein Atoll, Ascension Island, Diego Garcia, Colorado Springs, Colorado and Cape Canaveral, along with shared NGA monitor stations operated in England, Argentina, Ecuador, Bahrain, Australia and Washington DC.[89] The tracking information is sent to the MCS at Schriever Air Force Base 25 km (16 mi) ESE of Colorado Springs, which is operated by the 2nd Space Operations Squadron (2 SOPS) of the U.S. Space Force. Then 2 SOPS contacts each GPS satellite regularly with a navigational update using dedicated or shared (AFSCN) ground antennas (GPS dedicated ground antennas are located at Kwajalein, Ascension Island, Diego Garcia, and Cape Canaveral). These updates synchronize the atomic clocks on board the satellites to within a few nanoseconds of each other, and adjust the ephemeris of each satellite's internal orbital model. The updates are created by a Kalman filter that uses inputs from the ground monitoring stations, space weather information, and various other inputs.[90]

Satellite maneuvers are not precise by GPS standards—so to change a satellite's orbit, the satellite must be marked *unhealthy*, so receivers don't use it. After the satellite maneuver, engineers track the new orbit from the ground, upload the new ephemeris, and mark the satellite healthy again.

The operation control segment (OCS) currently serves as the control segment of record. It provides the operational capability that supports GPS users and keeps the GPS operational and performing within specification.

OCS successfully replaced the legacy 1970s-era mainframe computer at Schriever Air Force Base in September 2007. After installation, the system helped enable upgrades and provide a foundation for a new security architecture that supported U.S. armed forces.

OCS will continue to be the ground control system of record until the new segment, Next Generation GPS Operation Control System[6] (OCX), is fully developed and functional. The new capabilities provided by OCX will be the cornerstone for revolutionizing GPS's mission capabilities, enabling[91] U.S. Space Force to greatly enhance GPS operational services to U.S. combat forces, civil partners and myriad domestic and international users. The GPS OCX program also will reduce cost, schedule and technical risk. It is designed to provide 50%[92] sustainment cost savings through efficient software architecture and Performance-Based Logistics. In addition, GPS OCX is expected to cost millions less than the cost to upgrade OCS while providing four times the capability.

The GPS OCX program represents a critical part of GPS modernization and provides significant information assurance improvements over the current GPS OCS program.

- OCX will have the ability to control and manage GPS legacy satellites as well as the next generation of GPS III satellites, while enabling the full array of military signals.
- Built on a flexible architecture that can rapidly adapt to the changing needs of today's and future GPS users allowing immediate access to GPS data and constellation status through secure, accurate and reliable information.
- Provides the warfighter with more secure, actionable and predictive information to enhance situational awareness.
- Enables new modernized signals (L1C, L2C, and L5) and has M-code capability, which the legacy system is unable to do.
- Provides significant information assurance improvements over the current program including detecting and preventing cyber attacks, while isolating, containing and operating during such attacks.
- Supports higher volume near real-time command and control capabilities and abilities.

On September 14, 2011,[93] the U.S. Air Force announced the completion of GPS OCX Preliminary Design Review and confirmed that the OCX program is ready for the next phase of development.

The GPS OCX program has missed major milestones and is pushing its launch into 2021, 5 years past the original deadline. According to the Government Accounting Office, even this new deadline looks shaky.