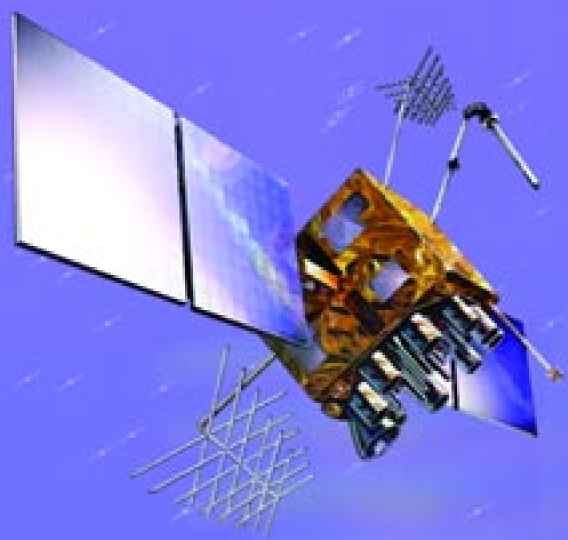

GPS Primer

A student guide to the Global Positioning System

THE AEROSPACE CORPORATION

The Sky's the Limit

The men and women who created the Global Positioning System, more commonly known as GPS, were once young people like you. Each had a special interest in the marvelous order of mathematics and the physical laws affecting all of our lives. By pursuing careers in science or engineering, they were able to develop a remarkable navigation system that can tell you exactly where you are on Earth at any time of day or night and in any type of weather.

This booklet was developed by The Aerospace Corporation to help you understand GPS and how it works. If you are interested in an exciting career in navigation or a related field, we encourage you to study mathematics and science in junior high and high school. By becoming proficient in these areas, you will lay the groundwork for an understanding of physics and astronomy—the building blocks of the science of navigation.

Cover: GPS Block IIR rendering courtesy of Lockheed Martin.

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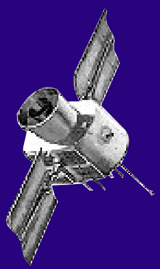
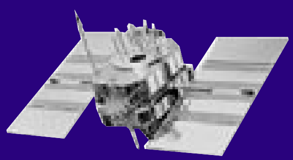


GPS Block I
First launched in 1978



GPS Block II/IIA
First launched in 1989

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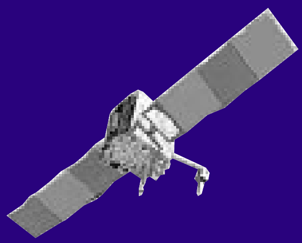
First launched in 1997



GPS Block IIF
Scheduled to be launched in late 2005

An Amazing Tool

Photo courtesy of Magellan Systems

Imagine being an archaeologist on an expedition to the Yucatan Peninsula in Mexico. After preparing for your trip for months, you are certain that somewhere close by are the ruins of villages once inhabited by Mayan Indians. The forest is dense, the sun is hot, and the air is moist and humid. The only way you can record where you have been or find your way back to civilization is by using the power of your GPS receiver.

Or let's suppose you are an oceanographer for the International Ice Patrol, responsible for finding icebergs that form in the cold waters of the northern Atlantic Ocean. Some of the icebergs are 50 miles long. More than 300 of them form every winter, and they are a major threat to the ships that travel those waters. Using a GPS receiver, you are able to help ships avoid disaster by zeroing in on the position of the icebergs and notifying ship captains of their locations, perhaps averting disaster.

Someday soon every car on the road could be equipped with a navigation and communication system. The in-dash monitor would provide a full-color display of your location and a map of nearby roads. A computer-generated voice would guide you to your destination. In the event of an accident, the car would use its built-in cell phone to call local emergency services and tell them where you are. At its heart will be a GPS receiver. Systems as advanced as this one are already available in some cars.

What is GPS?

GPS, the Global Positioning System, is the only system today able to show you your exact position on Earth at any time, any where, and in any weather. GPS satellites orbit 11,000 nautical miles above Earth. They are monitored continuously at ground stations located around the world. The satellites transmit signals that can be detected by anyone with a GPS receiver.

The first GPS satellite was launched in 1978. The first 10 satellites launched were developmental satellites, called Block I. From 1989 to 1997, 28 production satellites, called Block II, were launched; the last 19 satellites in the series were updated versions, called Block IIA. The launch of the 24th GPS satellite in 1994 completed the primary system. The third-generation satellite, Block IIR, was first launched in 1997. These satellites are being used to replace aging satellites in the GPS constellation. The next generation, Block IIF, is scheduled for its first launch in late 2005.

Before we learn more about GPS, it's important to understand something about navigation.

What is Navigation?

Since prehistoric times, people have been trying to figure out a reliable way to tell where they are and how to get to their destination—and home again. Such knowledge often meant survival and economic power in society. Early cultures probably marked trails when they set out hunting for food. They later began making maps and, by the Classical Age of Greece, developed the use of latitude (your location on Earth measured north or south from the equator) and longitude (your location on Earth measured east or west of a designated prime meridian) as a way of locating places. Today the prime meridian, used worldwide, runs through the Royal Observatory at Greenwich, England.

Early mariners followed the coast closely to keep from getting lost. When they learned to chart their course by following the stars, they could venture out into the open ocean. The ancient Phoenicians used the North Star to journey from Egypt and Crete. According to Homer, the goddess Athena told Odysseus to "keep the Great Bear on his left" during his travels from Calypso's Island. Unfortunately the stars are only visible at night—and only on clear nights. Sometimes lighthouses provided a light to guide mariners at night and warn them of nearby hazards.

Sextant

The next major developments in navigation were the magnetic compass and the sextant. The needle of a compass always points to the magnetic North Pole, so it tells you your "heading," or the direction you're going. Mariner's maps in the Age of Exploration often depicted the headings between key ports and were jealously guarded by their owners.

The sextant uses adjustable mirrors to measure the exact angle of the stars, moon, and sun above the horizon. From these angles and an "almanac" of the positions of the sun, moon and stars, you can determine your latitude in clear weather, day or night. Sailors, however, were still unable to determine their longitude. When you look at very old maps, you sometimes find that the latitudes of the coastlines are accurate, but the longitudes are off by hundreds of miles. This was such a serious problem that in the 17th century the British government formed a special Board of Longitude consisting of well-known scientists. This group offered 20,000 British pounds—equal today to about $32,000 but worth a lot more back then—to anybody who could find a way to determine a ship's longitude within 30 nautical miles.

The offer paid off. The answer lay in knowing what time it is when you make your sextant measurements. For example, say your Greenwich almanac predicts that the sun is highest at noon. Your shipboard clock, synchronized to Greenwich time when you left port, says it's 2 p.m. when your sextant measures that event. Then you must be the equivalent of two hours west of Greenwich.

In 1761 a cabinetmaker named John Harrison developed a shipboard timepiece called a chronometer, which lost or gained only about one second a day—incredibly accurate for the time. For the next two centuries, sextants and chronometers were used in combination to provide latitudes and longitudes.

In the early 20th century several radio-based navigation systems were developed and used widely during World War II. Both allied and enemy ships and airplanes used ground-based radio-navigation systems as the technology advanced.

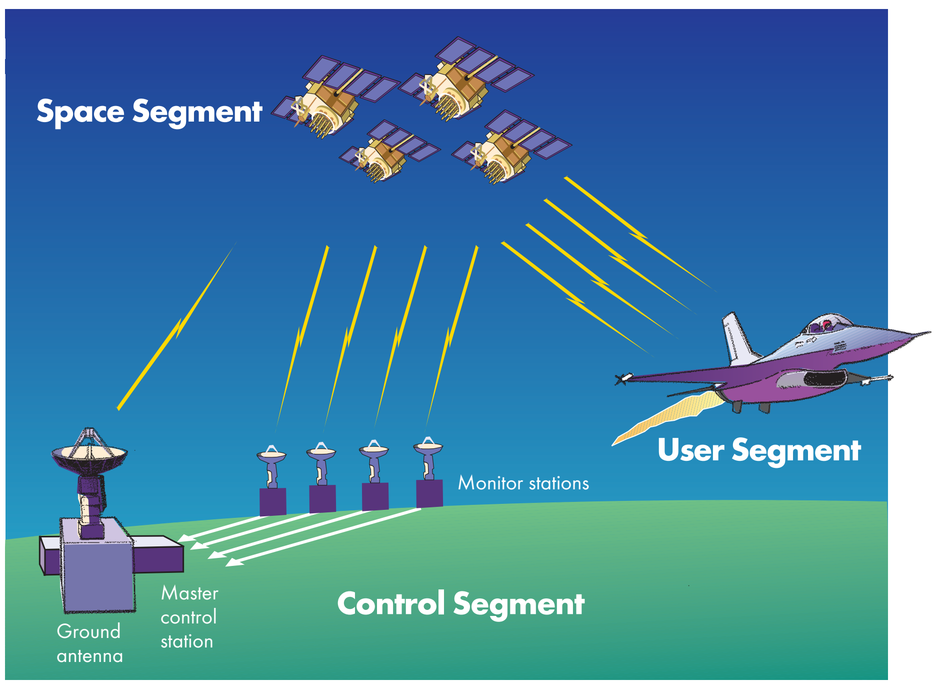
A few ground-based radio-navigation systems are still in use today. One drawback of using radio waves generated on the ground is that you have only two choices: (1) a system that is very accurate but doesn't cover a wide area or (2) a system that covers a wide area but is not very accurate. High-frequency radio waves (like satellite TV) can provide accurate position location but can only be picked up in a small, localized area. Lower-frequency radio waves (like FM radio) can cover a larger area, but are not a good yardstick to tell you exactly where you are.

Scientists, therefore, decided that the only way to provide accurate coverage for the entire world was to place high-frequency radio transmitters in space. A transmitter high above Earth would broadcast a high-frequency radio wave with a special coded signal that could cover a large area and still reach Earth far below at a useful power level. This is one of the main principles behind the GPS system. It brings together 2,000 years of advances in navigation by providing precisely located "lighthouses in space" that are all synchronized to a common time standard.

The GPS system can tell you your location anywhere on or above Earth to within about 20 to 30 feet. Even greater accuracy, usually within less than three feet, can be obtained with "differential corrections" calculated by a special GPS receiver at a known fixed location.

Elements of GPS

GPS has three parts: the space segment, the user segment, and the control segment. The space segment consists of a constellation of 24 satellites plus some spares, each in its own orbit 11,000 nautical miles above Earth. The user segment consists of receivers, which you can hold in your hand or mount in a vehicle, like your car. The control segment consists of ground stations (five of them, located around the world) that make sure the satellites are working properly. The master control station at Schriever Air Force Base, near Colorado Springs, Colorado, runs the system.



To help you understand GPS let's discuss the three parts of the system—the satellites, the receivers, and the ground stations—and then look more closely at how GPS works.

A Constellation of Satellites

An orbit is one trip in space around Earth. GPS satellites each take 12 hours to orbit Earth. Each satellite is equipped with an atomic clock so accurate that it keeps time to within three nanoseconds—that's 0.000000003, or three-billionths of a second—to let it broadcast signals that are synchronized with those from other satellites.

The signal travels to the ground at the speed of light. Even at this speed, the signal takes a measurable amount of time to reach the receiver. The difference between the time when the signal is received and the time when it was sent, multiplied by the speed of light, enables the receiver to calculate the distance to the satellite. To calculate its precise latitude, longitude, and altitude, the receiver measures the distance to four separate GPS satellites.

Receivers

GPS receivers can be carried in your hand or be installed on aircraft, ships, tanks, submarines, cars, and trucks. These receivers detect, decode, and process GPS satellite signals. More than 100 different receiver models are already in use. The typical hand-held receiver is about the size of a cellular telephone, and the newer models are even smaller. The commercial hand-held units distributed to U.S. armed forces personnel during the Persian Gulf War weighed only 28 ounces (less than two pounds). Since then, basic receiver functions have been miniaturized onto integrated circuits that weigh about one ounce.

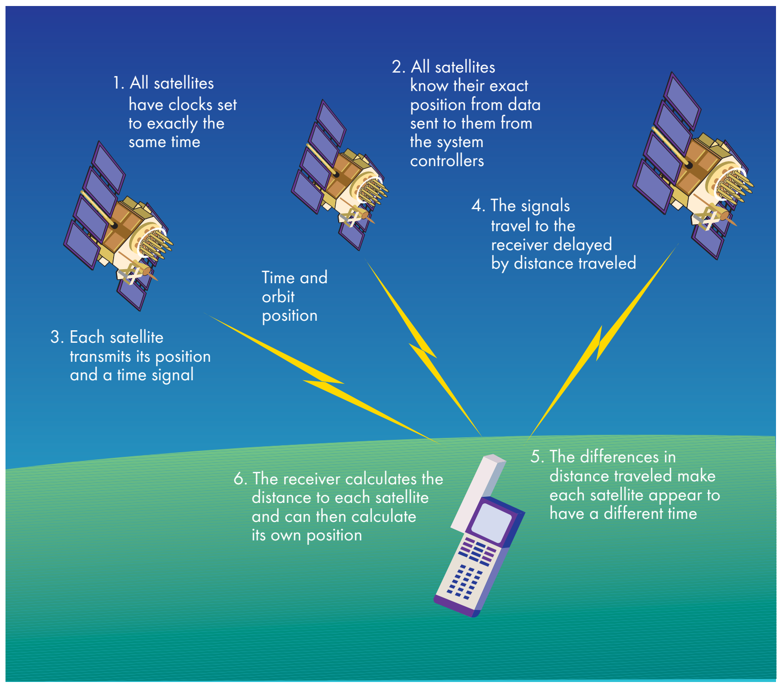
Ground Stations

The GPS control segment consists of several ground stations located around the world:

- a master control station at Schriever Air Force Base in Colorado
- five unstaffed monitor stations: Hawaii and Kwajalein in the Pacific Ocean; Diego Garcia in the Indian Ocean; Ascension Island in the Atlantic Ocean; and Colorado Springs, Colorado
- four large ground-antenna stations that send commands and data up to the satellites and collect telemetry back from them

How GPS Works

To help you understand some of the scientific principles that make GPS work, let's discuss the basic features of the system.



The principle behind GPS is the measurement of distance (or "range") between the satellites and the receiver. The satellites tell us exactly where they are in their orbits. It works something like this: If we know our exact distance from a satellite in space, we know we are somewhere on the surface of an imaginary sphere with a radius equal to the distance to the satellite radius. If we know our exact distance from two satellites, we know that we are located somewhere on the line where the two spheres intersect. And, if we take a third and a fourth measurement from two more satellites, we can find our location. The GPS receiver processes the satellite range measurements and produces its position.

GPS uses a system of coordinates called WGS 84, which stands for World Geodetic System 1984. It produces maps like the ones you see in school, all with a common reference frame for the lines of latitude and longitude that locate places and things. Likewise, it uses time from the United States Naval Observatory in Washington, D.C., to synchronize all the timing elements of the system, much like Harrison's chronometer was synchronized to the time at Greenwich.

You should now have a fairly clear picture of the GPS system. You know that it consists of satellites whose paths are monitored by ground stations. Each satellite generates radio signals that allow a receiver to estimate the satellite location and distance between the satellite and the receiver. The receiver uses the measurements to calculate where on or above Earth the user is located.

Now that you have an idea about how GPS functions, let's see how we can put it to work for us. As you might imagine, GPS has many uses in both military and civilian life.

Military Uses for GPS

Although the GPS system was completed only a few years ago, it has already proved to be a valuable aid to U.S. military forces. Picture the desert, with its wide, featureless expanses of sand. The terrain looks much the same for miles. Without a reliable navigation system, U.S. forces could not have performed the maneuvers of Operation Desert Storm and Operation Iraqi Freedom. With GPS the soldiers were able to go places and maneuver in sandstorms or at night when even the Iraqi troops who lived there couldn't. More than 1,000 portable commercial receivers were initially purchased for their use. The demand was so great that before the end of the conflict, more than 9,000 commercial receivers were in use in the Gulf region. They were carried by soldiers on the ground and were attached to vehicles, helicopters, and aircraft instrument panels. GPS receivers were used in several aircraft, including F-16 fighters, KC-135 aerial tankers, and B-52 bombers. Navy ships used them for rendezvous, minesweeping, and aircraft operations.

GPS has become important for nearly all military operations and weapons systems. It is also used on satellites to obtain highly accurate orbit data and to control spacecraft orientation.

GPS in Everyday Life

The GPS system was developed to meet military needs, but new ways to use its capabilities for everyday life are continually being found.

GPS is helping to save lives and property across the nation. Many police, fire, and emergency medical-service units use GPS receivers to determine the police car, fire truck, or ambulance nearest to an emergency, enabling the quickest possible response in life-or-death situations. GPS-equipped aircraft can quickly plot the perimeter of a forest fire so fire supervisors can produce updated maps in the field and send firefighters safely to key hot spots.

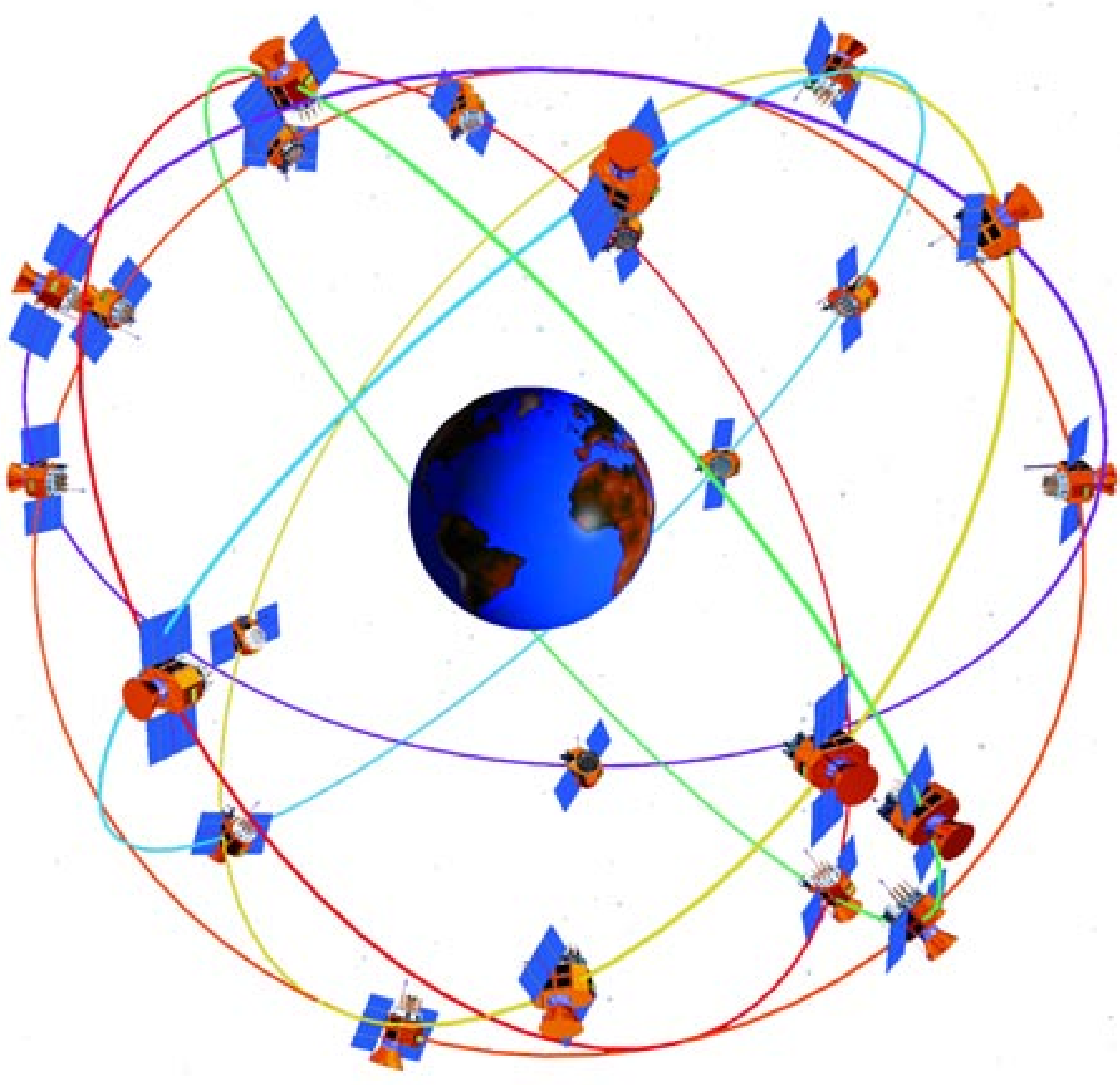
Mapping, construction, and surveying companies use GPS extensively. During construction of the tunnel under the English Channel, British and French crews started digging from opposite ends: one from Dover, England, and one from Calais, France. They relied on GPS receivers outside the tunnel to check their positions along the way and to make sure they met exactly in the middle. Otherwise, the tunnel might have been crooked. GPS allows mine operators to navigate mining equipment safely, even when visibility is obscured.

Remember the example of the car with a video display in the dashboard? Vehicle tracking is one of the fastest-growing GPS applications today. GPS-equipped fleet vehicles, public transportation systems, delivery trucks, and courier services use receivers to monitor their locations at all times.

Automobile manufacturers are offering moving map displays guided by GPS receivers as an option on new vehicles. The displays can be removed and taken into a home to plan a trip. Several Florida rental car companies have GPS-equipped vehicles that give directions to drivers on display screens and through synthesized voice instructions. Imagine never again getting lost on vacation, no matter where you are.

GPS-equipped balloons monitor holes in the ozone layer over the polar regions as well as air quality across the nation. Buoys tracking major oil spills transmit data using GPS to guide cleanup operations. Archaeologists, biologists, and explorers are using the system to locate ancient ruins, migrating animal herds, and endangered species such as manatees, snow leopards, and giant pandas. GPS is also an important tool used by farmers in agriculture and herding.

The future of GPS is as unlimited as your imagination. New applications will continue to be created as technology evolves. GPS satellites, like stars in the sky, will be guiding us well into the 21st century.



Twenty-four GPS satellites orbit 11,000 nautical miles above Earth to serve military and civilian users around the clock. This network of satellites forms the core of the most precise navigation system ever invented.

The Aerospace Corporation

The Aerospace Corporation is a private, nonprofit company established in 1960 to serve and support U.S. national-security space projects and programs. We operate a federally funded research and development center specializing in space systems and technologies. Aerospace provides systems engineering, architecture, and development support to the U.S. government, principally the United States Air Force. We also perform national-security work for other agencies in the national interest.

Our primary resource is people. Technical and scientific professionals of the highest caliber are responsible for a corporate tradition of excellence. Nearly half of our employees are members of the technical staff. Two-thirds of the technical staff hold advanced degrees in a broad range of disciplines, and about one-fourth of those staff members hold doctoral degrees.

Our corporate headquarters is located in El Segundo, California, next to Los Angeles Air Force Base. Regional offices exist at Air Force launch sites on the East and West coasts; at Johnson Space Center in Texas; at satellite operations and technology centers in California, Colorado, and New Mexico; and in the Washington, D.C., area.

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