Global Positioning System

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Introduction

- GPS is funded and controlled by U. S. Department of Defense (DOD).
- GPS provides specially coded satellite signals that can be processed in a GPS receiver.
- Four GPS satellite signals - to compute positions in three dimensions and the time offset in the receiver clock.

GPS - Intro

- Space segment
- Control segment
- User segment

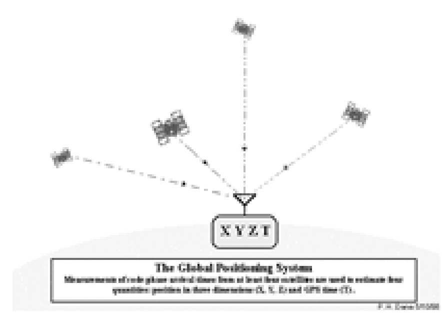
Space Segment

- GPS satellites - Space vehicles (SVs) send radio signals from space
- Nominal GPS Operational Constellation consists of 24 satellites that orbit the earth in 12 hours
- 6 orbital planes (4 SVs in each), equally spaced (60^{o} apart), and inclined at about 55^{o} to equatorial plane

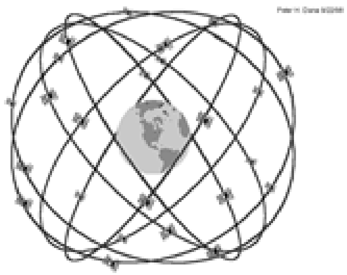
Space Segment - Contd..

- This constellation provides the user with between five and eight SVs visible from any point on the earth

GPS - Intro

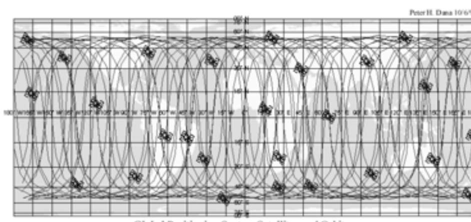


GPS Nominal Constellation



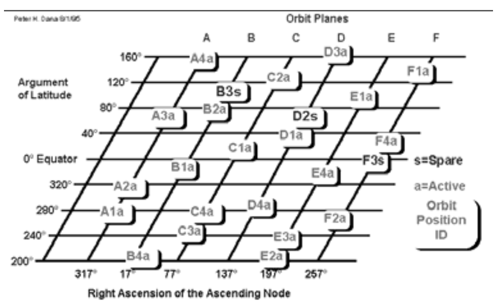
GPS Nominal Constellation
24 Satellites in 6 Orbital Planes
4 Satellites in each Plane
20,200 km Altitudes, 55 Degree Inclination

Satellite Orbits



Global Positioning System Satellites and Orbits
for 27 Operational Satellites on September 29, 1998
Satellite Positions at 00:00:00 9/29/98 with 24 hours (2 orbits) of Ground Tracks to 00:00:00 9/30/98

Simplified Representation



Simplified Representation of Nominal GPS Constellation

Control Segment

Global Positioning System (GPS) Master Control and Monitor Station Network

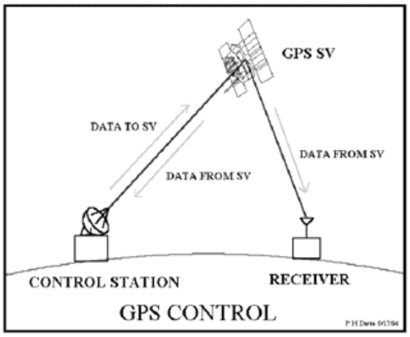
Control Segment

- The Master Control facility is located at Schriever Air Force Base (formerly Falcon AFB) in Colorado, USA
- Monitor stations measure signals from the SVs which are incorporated into orbital models for each satellite

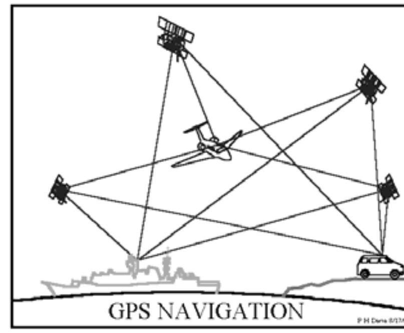
Control Segment - Contd..

- Models compute precise orbital data (ephemeris) and SV clock corrections for each satellite
- Master Control station uploads precise ephemeris and clock data to the SVs
- SVs then send subsets of the orbital ephemeris data to GPS receivers over radio signals

Control Segment



User Segment



User Segment

- GPS receivers and the user community
- GPS receivers convert SV signals into position, velocity and time estimates
- Four satellites are required to compute the four dimensions of X, Y, Z (position) and Time
- Used for Navigation, Positioning, Time Dissemination ….

User Segment - Contd..

- Navigation receivers are made for aircraft, ships, ground vehicles and for hand carrying by individuals
- Precise positioning at reference locations for Surveying, geodetic control, and plate tectonic studies ...

User Segment - Contd..

- Time and frequency dissemination (Based on Precise clocks): Astronomical Observatories, Telecommunications Facilities and Laboratory Standards can be set to Precise Time Signals

GPS Positioning Services

- Precise Positioning Service (PPS)
- Standard Positioning Service (SPS)

Precise Positioning Service

- Authorized users with cryptographic equipment and keys and specially equipped receivers
- PPS Predictable Accuracy
  - 22 meter Horizontal accuracy
  - 27.7 meter vertical accuracy
  - 200 nanosecond time (UTC) accuracy

Standard Positioning Service

- Civil users worldwide use the SPS without charge or restrictions
- SPS Predictable Accuracy
  - 100 meter horizontal accuracy
  - 156 meter vertical accuracy
  - 340 nanoseconds time accuracy

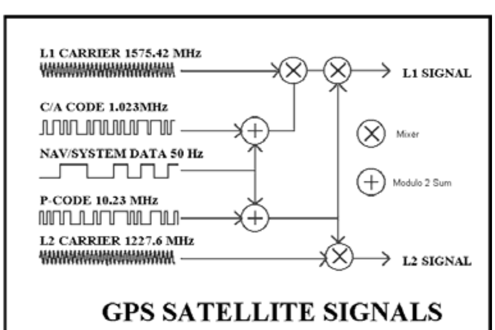
GPS is made Public

- **Tuesday May 2 2000 3:53 AM ET**
- **Clinton Acts to Make GPS Systems More Accurate**
- By Steve Holland
- WASHINGTON (Reuters) - President Clinton on Monday gave the go-ahead to let boaters, motorists and hikers use a satellite-navigation system with the same pinpoint accuracy that the military has long enjoyed. Clinton ordered the U.S. military to stop scrambling satellite signals used by civilians as of midnight GMT (8 p.m. EDT) on Monday night. The decision should mean that Global Position System receivers will be ten times more accurate.

GPS Satellite Signals

- SVs transmit two microwave carrier signals
  - L1 frequency (1575.42 MHz) - Carries the navigation message and the SPS code signals
  - L2 frequency (1227.60 MHz) is used to measure the ionospheric delay by PPS equipped receivers

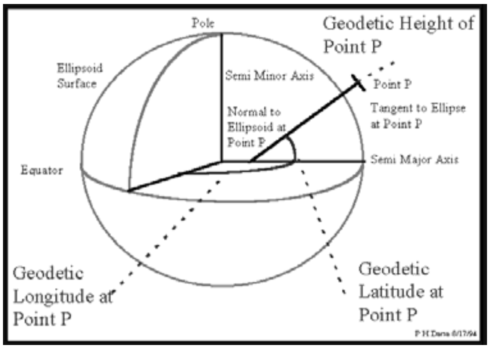
GPS Satellite Signals



Pseudo-Range Navigation

- The position of the receiver is where the pseudo-ranges from a set of SVs intersect
- Position is determined from multiple pseudo-range measurements
- Position dimensions are computed by the receiver in Earth-Centered, Earth-Fixed X, Y, Z (ECEF XYZ) coordinates

Earth-Centered, Earth-Fixed X, Y, Z



Lat, Lon & Height from X,Y,Z

Coordinate Conversion: Cartesian (ECEF X, Y, Z) and Geodetic (Latitude, Longitude, and Height)

Direct Solution for Latitude, Longitude, and Height from X, Y, Z

This conversion is not exact and provides centimeter accuracy for heights < 1,000 km (See Bowring, B. 1976. Transformation from spatial to geographical coordinates. Survey Review, XXIII: pg. 323-327)

$$\phi = \operatorname{atan}\left(\frac{Z + e'^2 b \sin^3\theta}{p - e^2 a \cos^3\theta}\right)$$

$$\lambda = \operatorname{atan2}(Y, X)$$

$$h = \frac{p}{\cos(\phi)} - N(\phi)$$

where:

ϕ, λ, h = geodetic latitude, longitude, and height above ellipsoid

X, Y, Z = Earth Centered Earth Fixed Cartesian coordinates

and:

$p = \sqrt{X^2 + Y^2}$ $\theta = \operatorname{atan}\left(\frac{Za}{pb}\right)$ $e'^2 = \frac{a^2 - b^2}{b^2}$

$N(\phi) = a / \sqrt{1 - e^2 \sin^2\phi}$ = radius of curvature in prime vertical

a = semi - major earth axis (ellipsoid equatorial radius)

b = semi - minor earth axis (ellipsoid polar radius)

$f = \frac{a - b}{a}$ = flattening

$e^2 = 2f - f^2$ = eccentricity squared

X,Y,Z from Lat, Lon & Height

Coordinate Conversion

Geodetic Latitude, Longitude, and Height to ECEF, X, Y, Z

$$X = (N + h)\cos\phi\cos\lambda$$

$$Y = (N + h)\cos\phi\sin\lambda$$

$$Z = [N(1 - e^2) + h]\sin\phi$$

where:

ϕ, λ, h = geodetic latitude, longitude, and height above ellipsoid

X, Y, Z = Earth Centered Earth Fixed Cartesian Coordinates

and:

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Peter H. Dana 8/3/96

Velocity and Time

- Velocity is computed from change in position over time, the SV Doppler frequencies, or both
- Time is computed in SV Time, GPS Time and UTC
- SV Time is the time maintained by each satellite (Each SV contains four atomic clocks)

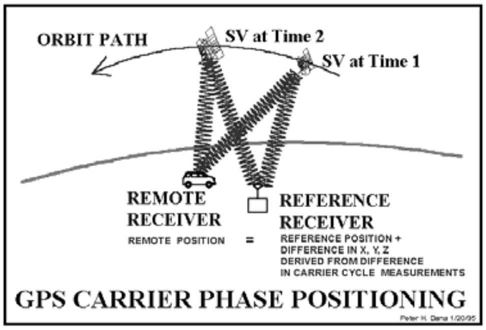
Velocity and Time - Contd..

- GPS Time is a "paper clock" ensemble of the Master Control Clock and the SV clocks
- Time in Universal Coordinated Time (UTC) is computed from GPS Time using the UTC correction parameters sent as part of the navigation data bits

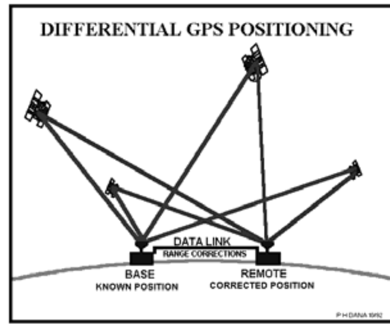
Carrier Phase Tracking (Surveying)

- A line of sight along the ground is no longer necessary for precise positioning
- Positions can be measured up to 30 km from reference point without intermediate points
- Carrier phase is tracked at both receivers and the changes in tracked phase are recorded over time in both receivers.

Carrier Phase Tracking



Differential GPS (DGPS)



GPS Error Sources

GPS ERROR SOURCES

ERROR SOURCE	TYPICAL RANGE ERROR	DGPS (CODE) RANGE ERROR <100 KM REF-REMOTE
SV CLOCK	1 M	
SV EPHEMERIS	1 M	
SELECTIVE AVAILABILITY	10 M	
TROPOSPHERE	1 M	
IONOSPHERE	10 M	
PSEUDO-RANGE NOISE	1 M	1 M
RECEIVER NOISE	1 M	1 M
MULTIPATH	0.5 M	0.5 M
RMS ERROR	15 M	1.6 M
ERROR * PDOP=4	60 M	6 M

PDOP=Position Dilution of Precision (3-D) 4.0 is typical

Handheld GPS

Garmin EMap ($200) & ETrex

Garmin12 & GPS 12XL

GPS 300 & GPS 312

GPS 320 & GPS II Plus