Basic GPS

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References

- My presentation is mainly based on the tutorial of U-blox company in Switzerland.
- This company is one of the best company in the field of high-sensitivity GNSS receiver.
- http://www.u-blox.com/

What is GNSS ?

- **Global Navigation Satellite Systems** (**GNSS**) is the standard generic term for satellite navigation systems that provide autonomous geo-spatial positioning with global coverage. GNSS allows small receivers to determine their location to within a few meters.
- As of 2009, the United States NAVSTAR Global Positioning System (GPS) is the only fully operational GNSS. The Russian GLONASS is a GNSS in the process of being restored to full operation. The European Union's Galileo positioning system is a GNSS in initial deployment phase, scheduled to be operational in 2014.

From Wikipedia

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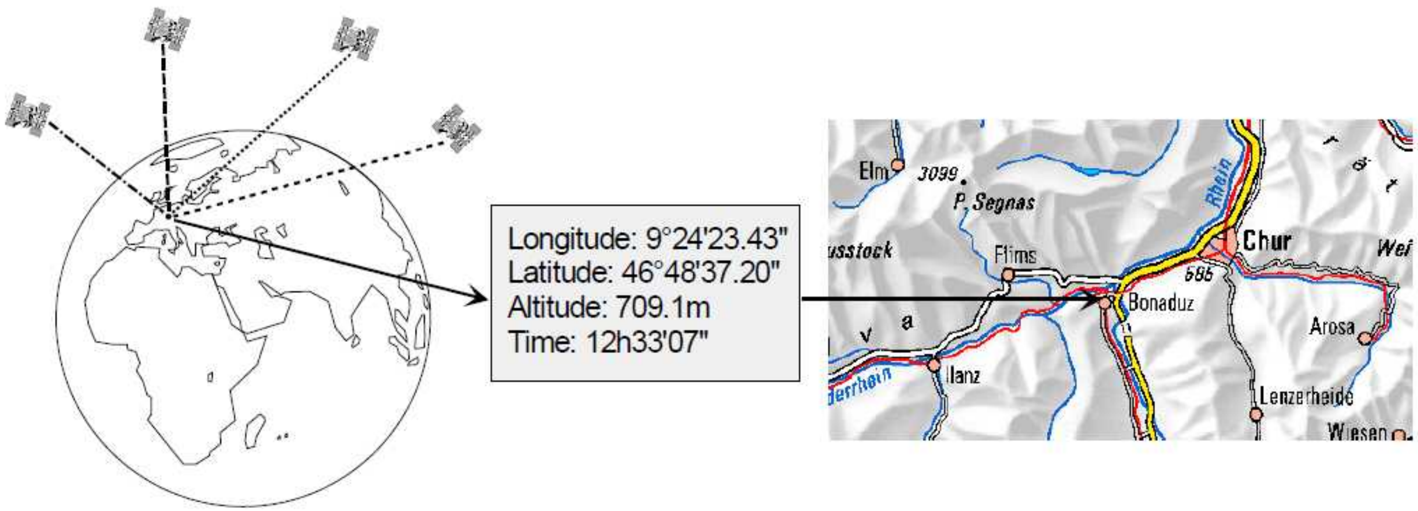
Where on Earth am I ?

Your position on earth is of vital importance.

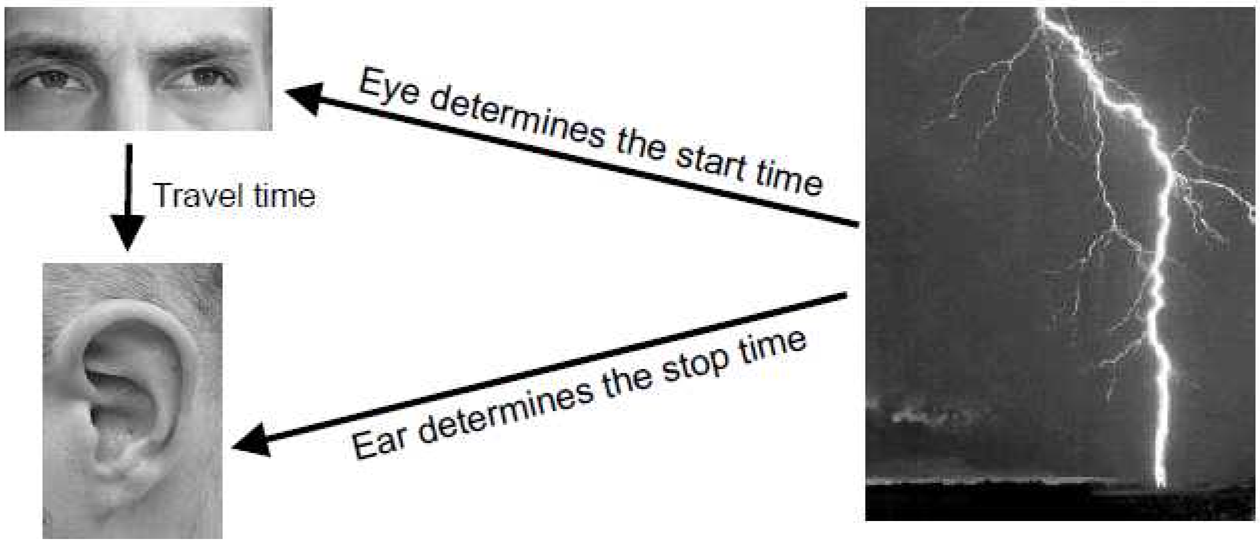
Introduction



The following values can accurately be determined anywhere on the globe.

- Exact position (longitude, latitude and altitude) accurate to within **<u>20m to approx. 1mm</u>**
- Exact time (UTC) accurate to within **<u>60ns to approx. 5ns</u>**

Measuring signal transit time

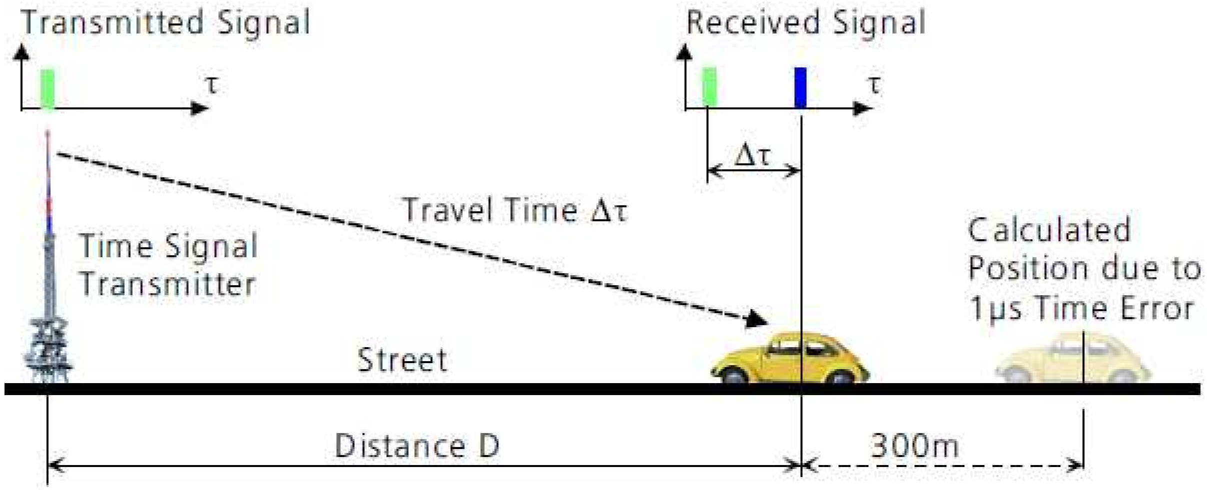


The distance can be established quite easily:

- Distance = travel time * speed of sound

Satellite Navigation functions by the <u>same principle.</u> In this case, the distance is calculated from the travel time of **<u>radio waves</u>** transmitted from the satellites.

Basic principles of satellite navigation

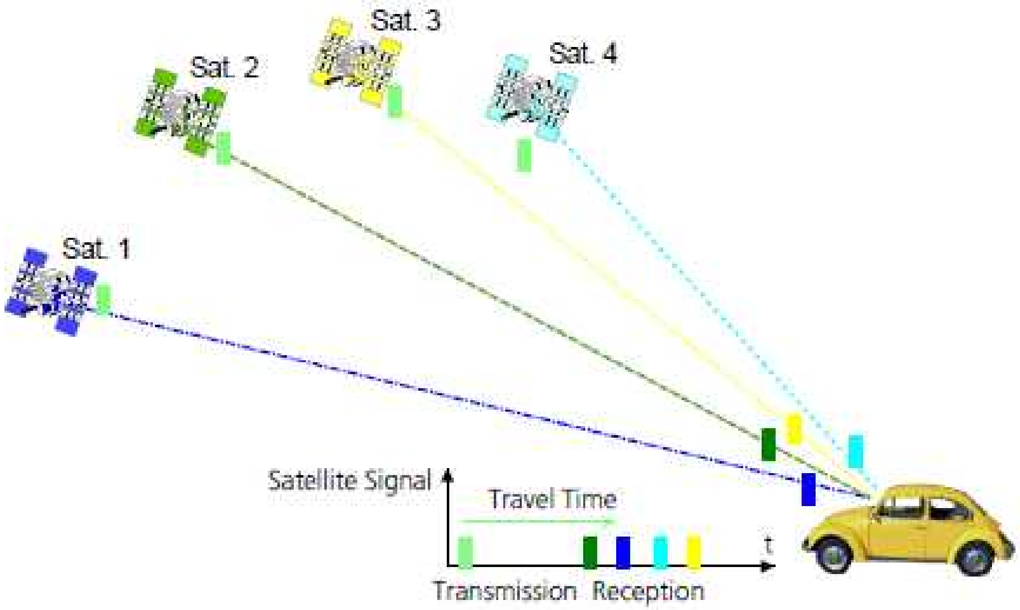


- D = travel time * c

Because the time of the clock onboard our car may not be exactly synchronized with the clock at the transmitter, there can be a discrepancy between the calculated and actual distance traveled. One microsecond error generates a 300m error.

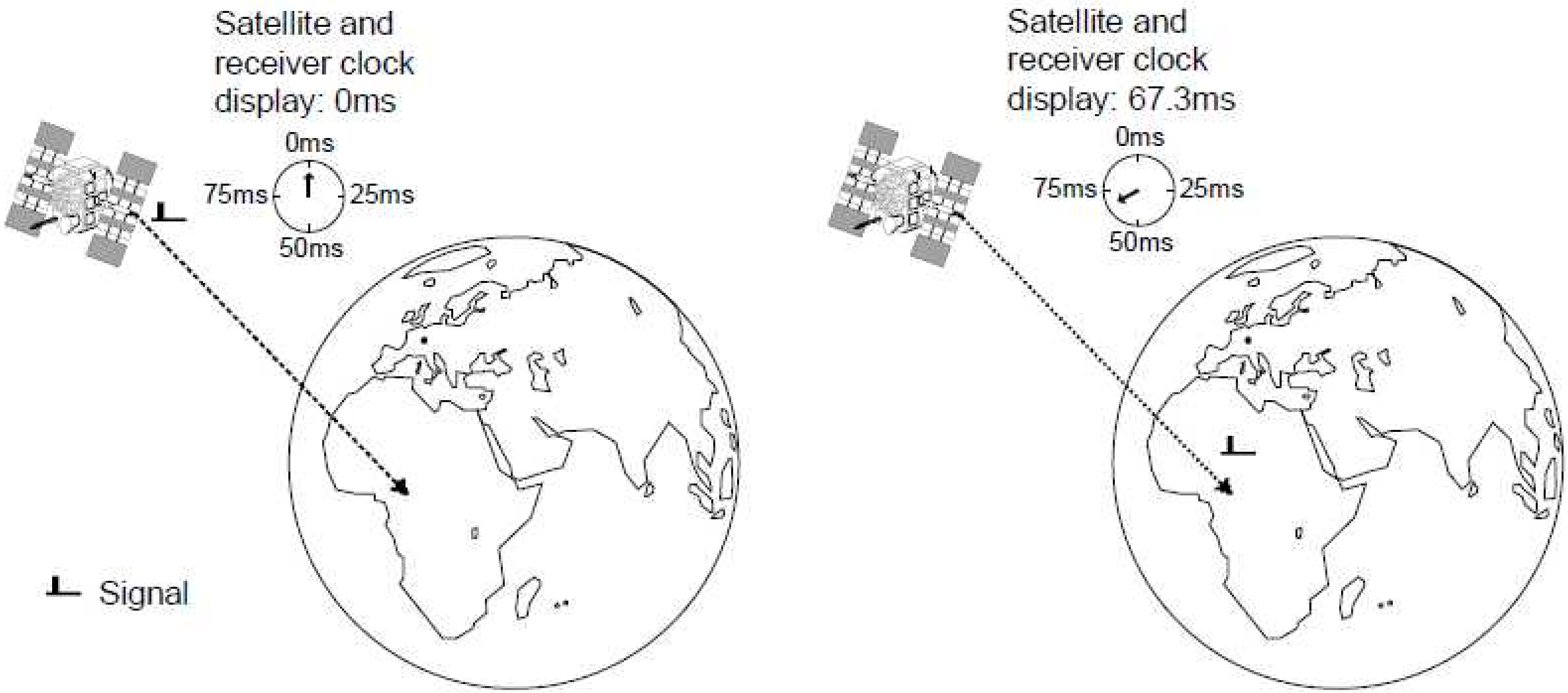
We could solve a problem by adding another unknown parameter of the clock onboard error.

Four satellites are needed



Satellite Navigation Systems use satellites as time-signal transmitters. Contact to at least four satellites is necessary in order to determine the three desired coordinates (Longitude, Latitude, Altitude) as well as the exact time. I explain this in more detail later.

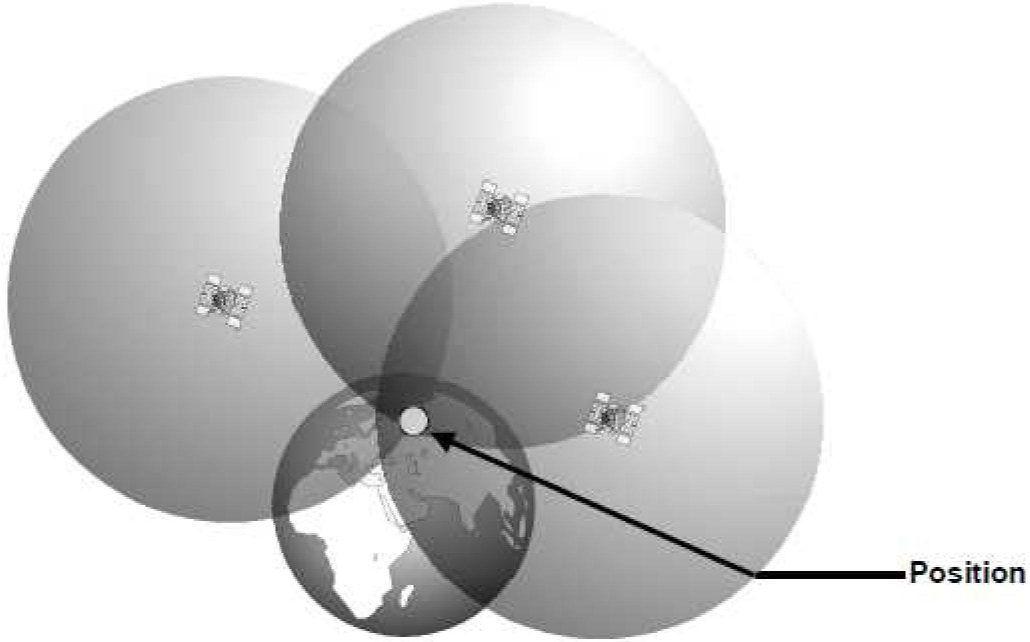
Signal travel time



Signal transmission (start time) **Signal reception (stop time)**

GNSS satellites transmit their exact position and onboard clock time to Earth. These signals are transmitted at the speed of light (300,000km/s) and therefore require approx. 67ms to reach a position on the Earth's surface.

Determining position

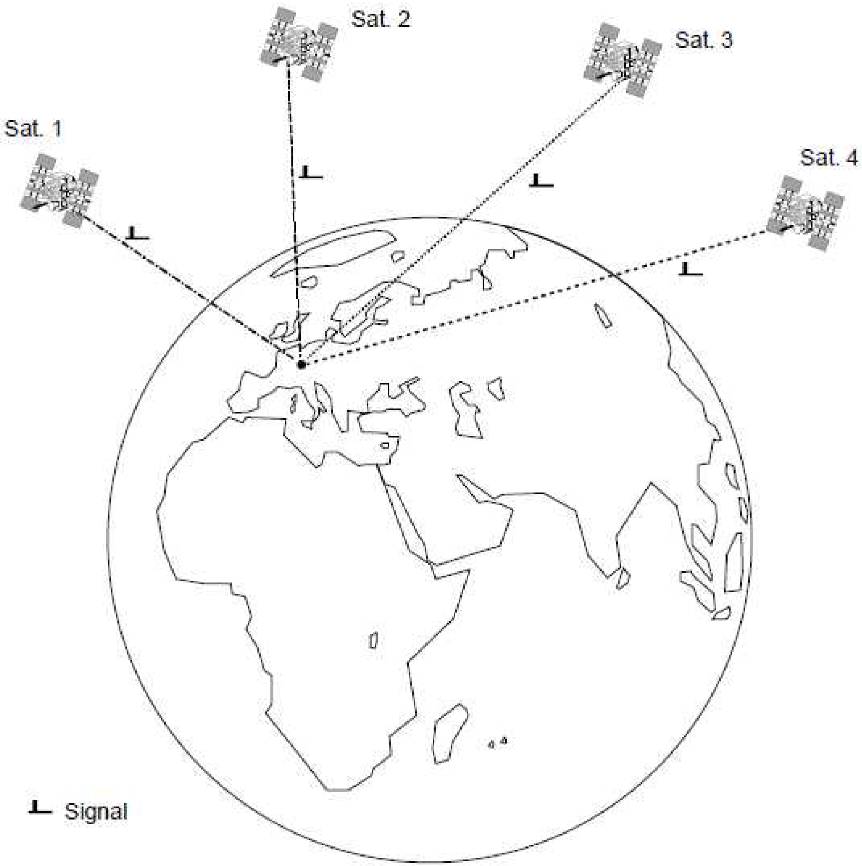


In the real world, a position has to be determined in three-dimensional space.
If the distance to the three satellites is known, all possible positions are located on the surface of three spheres whose radii correspond to the distance calculated.

This fact is only valid if the clock at the receiver and the atomic clocks onboard the satellites are synchronized. If the measured travel time between the satellites and a receiver is incorrectly by just 1micro-second, a position error of 300m is produced.

Correction of time error

longitude
latitude
Height
time error



Mathematics can help us in this situation.
N variables are unknown → we need N independent equations
The error produced from the receiver clock is same for all satellites !!!

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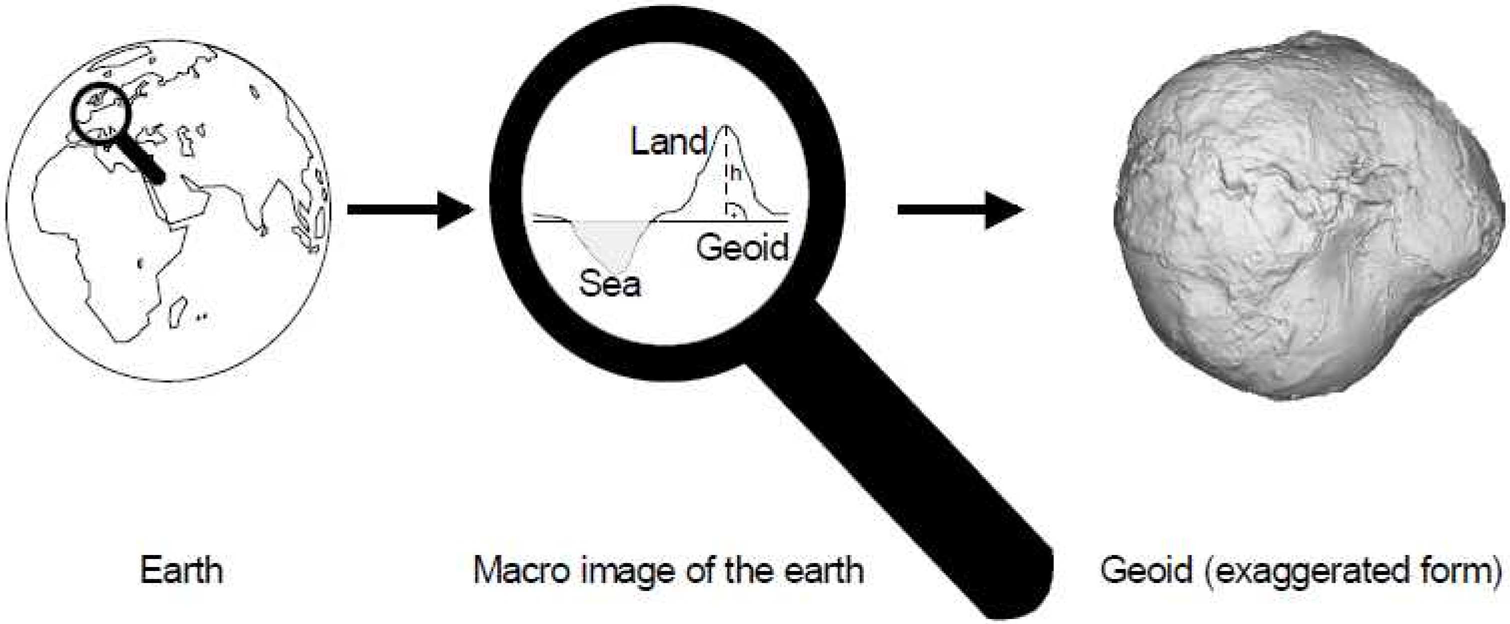
Coordinate systems

- A significant problem to overcome when using a GNSS system is the fact that there are a great number of differing coordinate systems worldwide.
- As a result, the position measured and calculated does not always correspond with one's supposed position.
- In order to understand how GNSS systems function, it is necessary to examine some of the basics of geodesy.

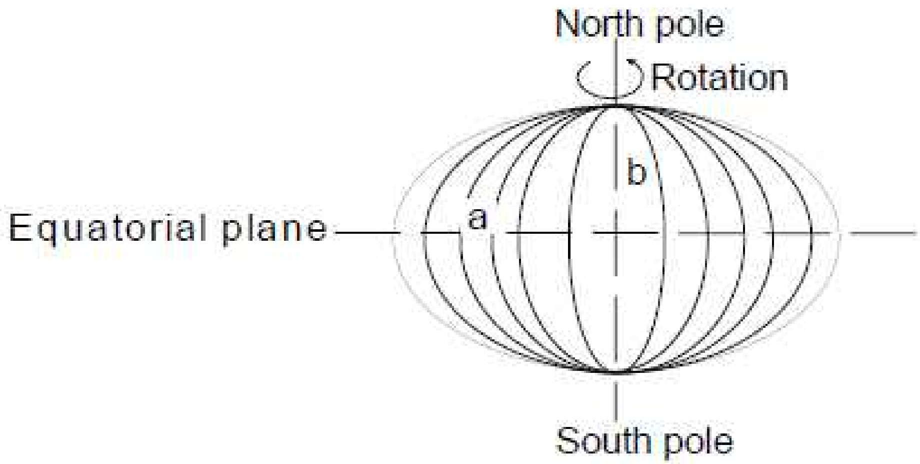
What is Geoid ?



- The geoid represents the true shape of the earth; defined as the surface, where the mean sea level is zero. However, a geoid is a difficult shape to manipulate when conducting calculations.

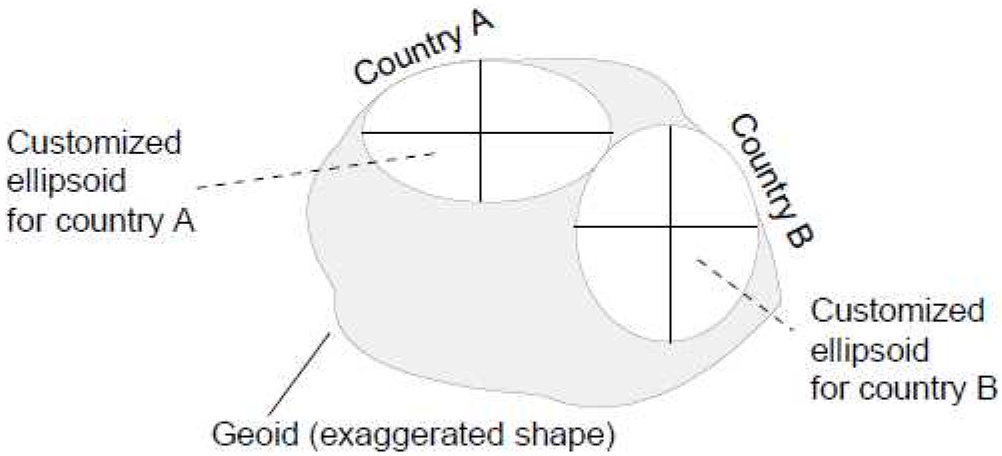
What is Ellipsoid ?

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

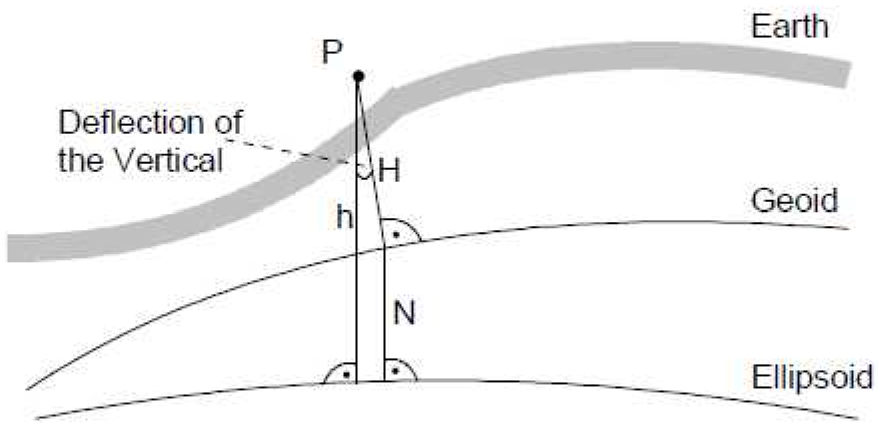


- A simpler, more definable shape is needed when carrying out daily surveying operations. Such a substitute surface is known as an ellipsoid. A spheroid is obtained like the above figure.

Datum, map reference system



Each country has developed its own customized non-geocentric ellipsoid as a reference surface for carrying out surveying operations.

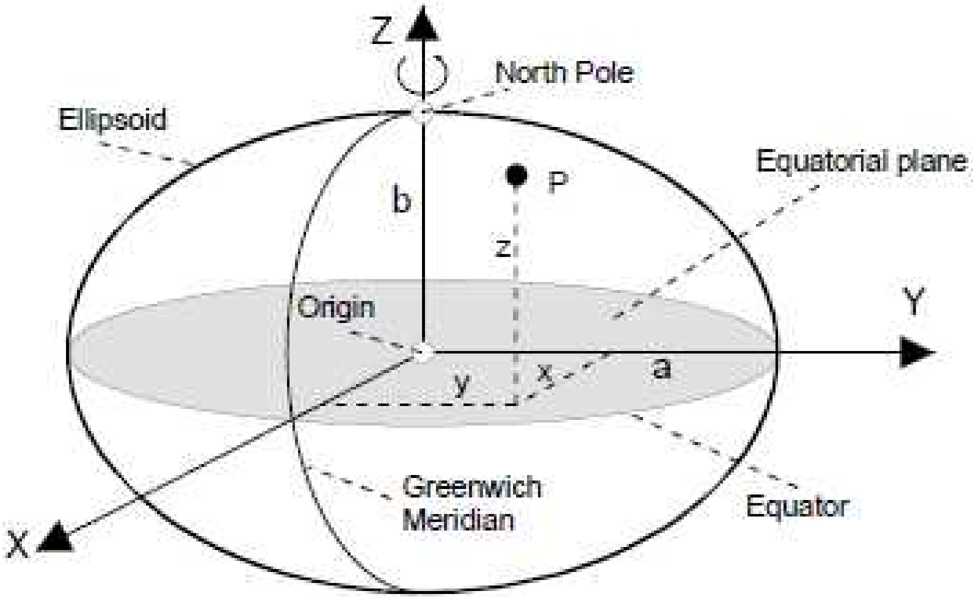


Ellipisodal Height = Undulation N + Geoid Height

An ellipsoid is well suited for describing the positional coordinates of a point in degrees of longitude and latitude.

My lab is on the 5th floor (20m MSL). But GPS height is 60m. Why ?

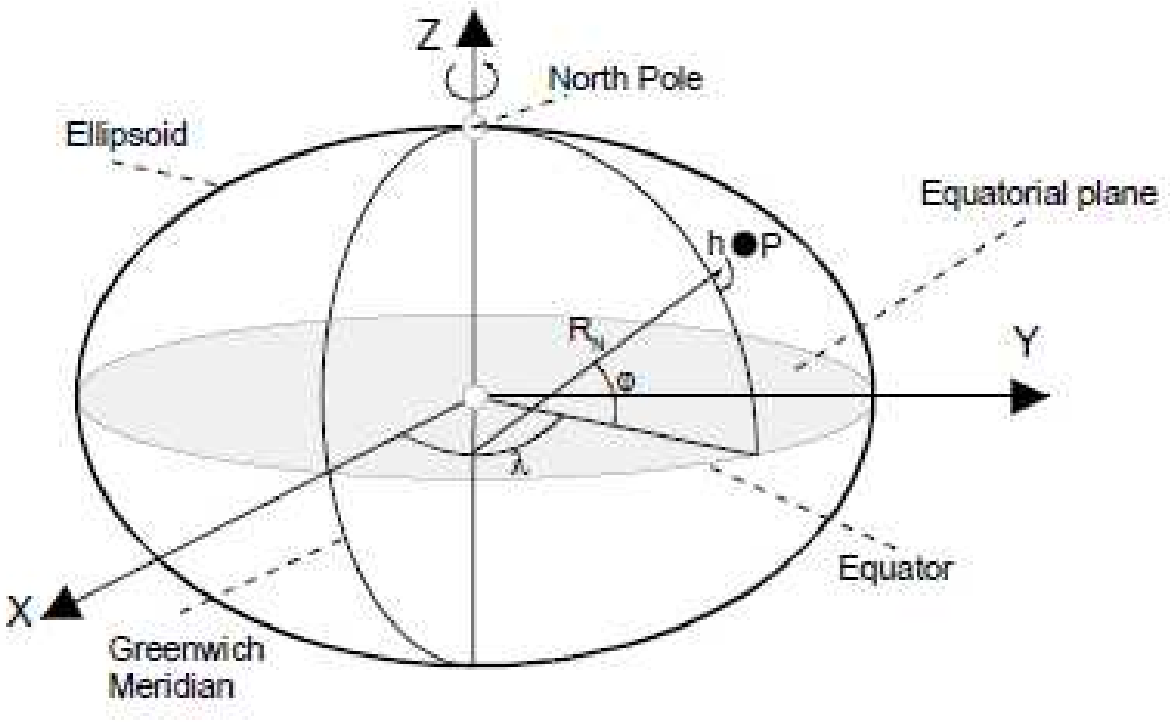
Worldwide reference ellipsoid WGS-84 (World Geodetic System 1984)



Parameter of WGS-84 Reference Ellipsoids		
Semi major axis a (m)	Semi minor axis b (m)	Flattening (1: ....)
6,378,137.00	6,356,752.31	298,257223563

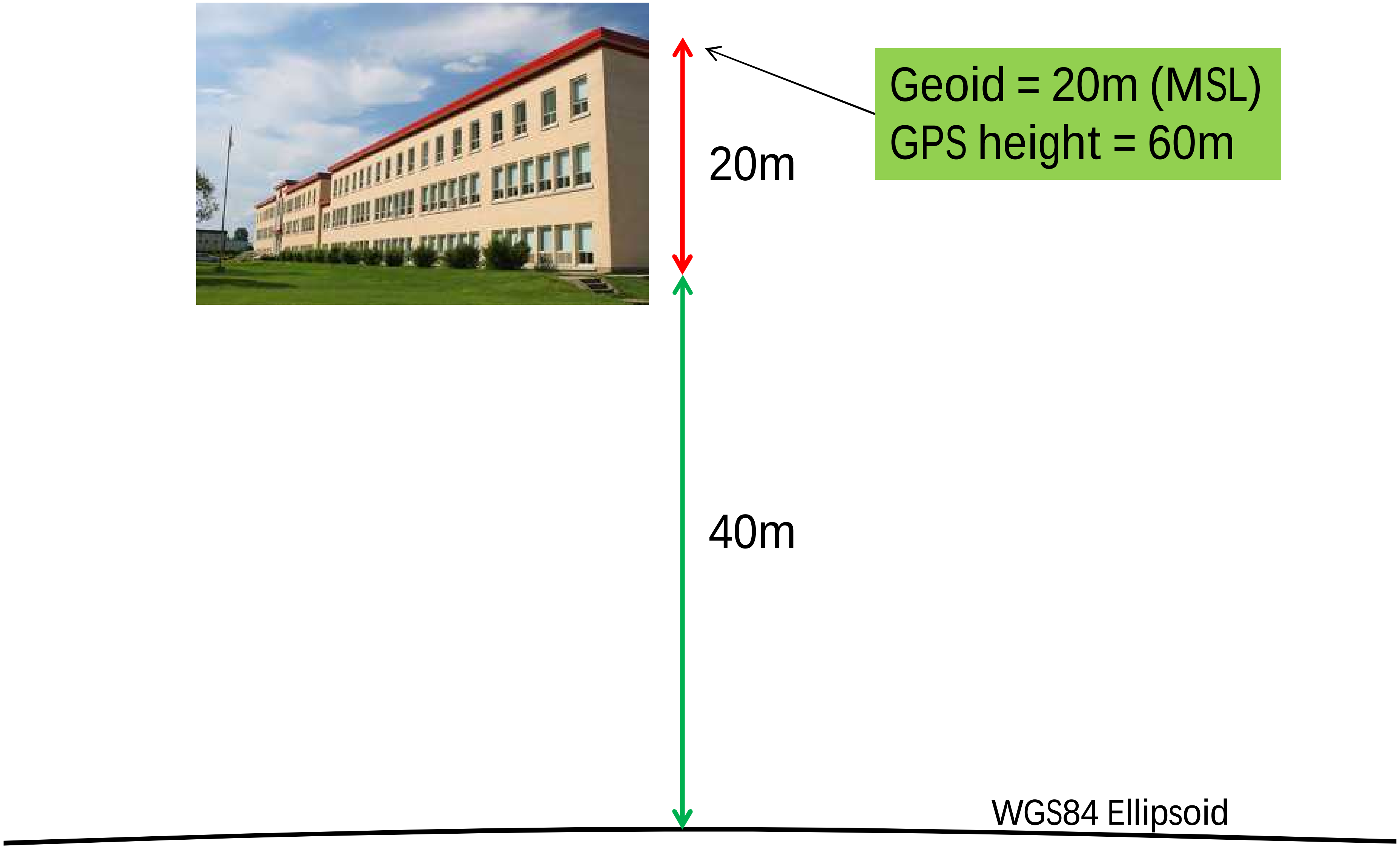
- The WGS-84 coordinate system is geocentrically positioned with respect to the center of the Earth. Such a system is called ECEF (Earth Centered, Earth Fixed)
- The WGS-84 is a three-dimensional, right-handed, Cartesian coordinate system with its original coordinate point at the center of mass of an ellipsoid.

Ellipsoidal Coordinates



Ellipsoidal coordinates (Φ, λ, h), rather than Cartesian coordinates (X, Y, Z) are generally used for further processing. Φ corresponds to latitude, λ corresponds to longitude and h to the Ellipsoidal height.

Example



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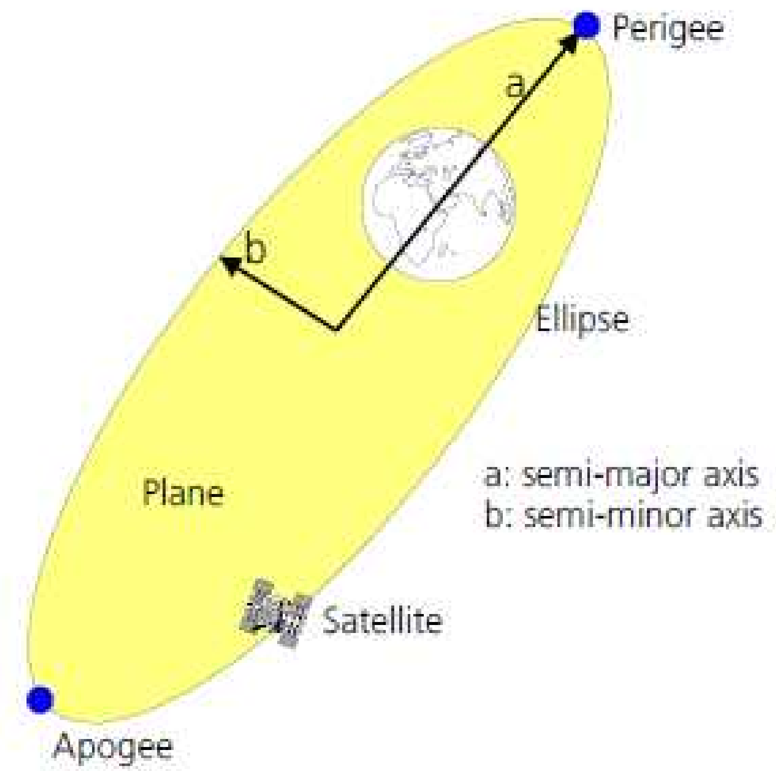
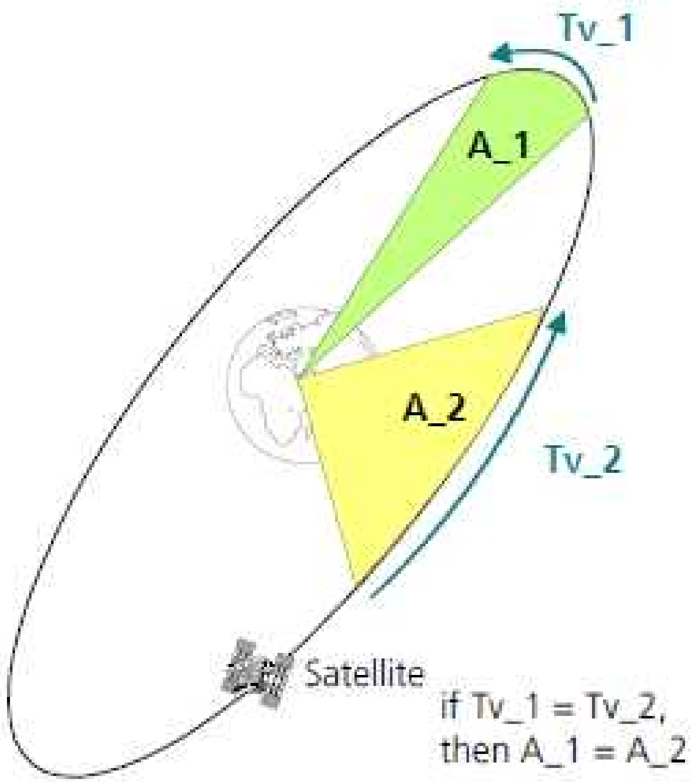
Kepler's first law



- The Apogee expresses the furthest point of an elliptical orbit from the canter of the Earth.
- The Perigee is the closest point of the orbital ellipse to the Earth.

Kepler's second law



- The second law states that: "A line joining a planet and the sun sweeps out equal areas during equal intervals of time"
- For satellites this means left figure.

Kepler's third law

$\frac{P^2}{a^3}$ is constant for all planets.

P = orbital Period, a = semi-major axis of the orbital ellipse

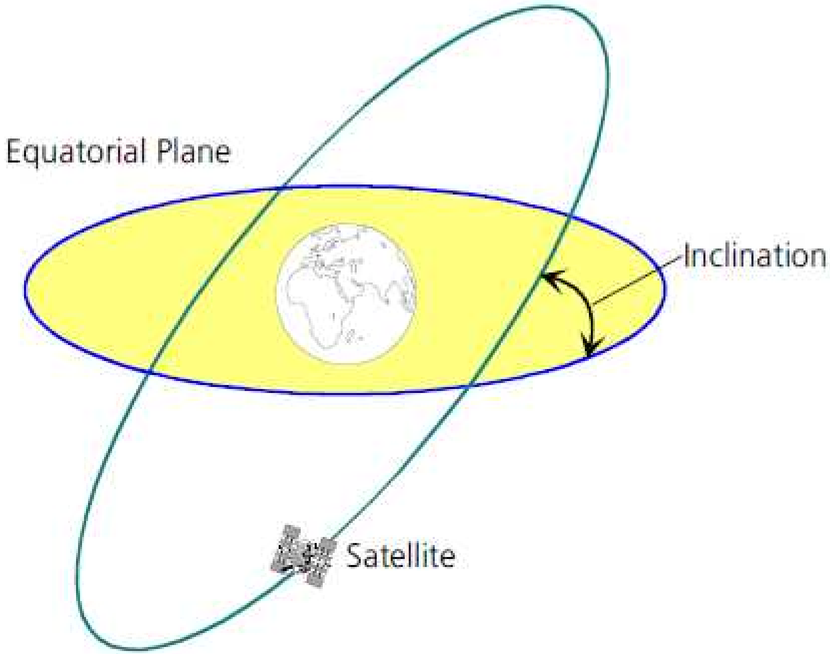
$$h = \sqrt[3]{3.9860042 \bullet 10^{14} \frac{m^3}{s^2} \bullet \left(\frac{P}{2\pi}\right)^2} - R_e \qquad [m]$$

R_e: Radius of the Earth (6378.137km)

P: orbital period of the satellite around the Earth

- This law states that the squares of the orbital periods of planets are directly proportional to the cubes of the semi-major axis of the orbits.

Satellite orbits



The spatial orientation:
Orbital inclination, excentricity, length, altitude

The parameters of motion:
Orbital period

The **Ephemeris** of a satellite is a mathematical description of its orbit. The high precision satellite orbital data is necessary for a receiver to calculate the satellite's exact position in space at any given time.
Orbital data with reduced exactness is referred to as an **Almanac.**

Almanac

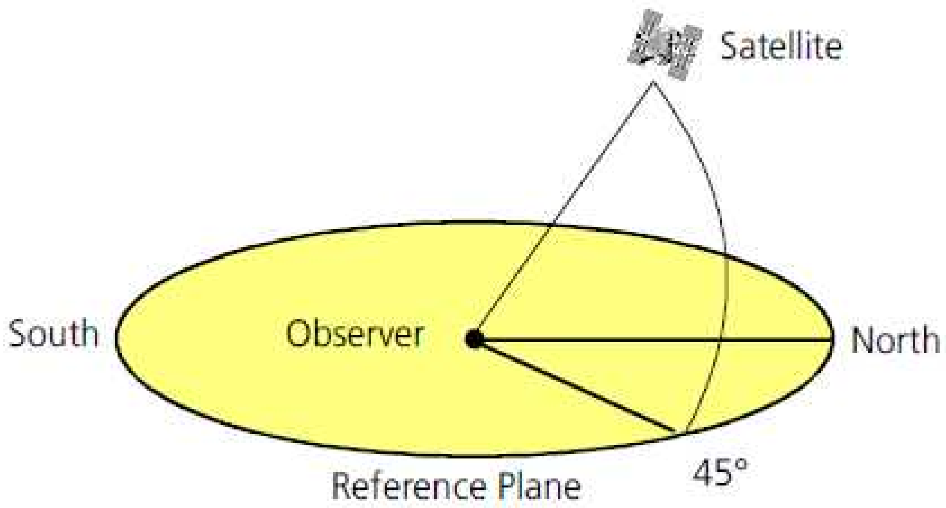
```
******** Week 424 almanac for PRN-01 ********
ID:                           01
Health:                       000
Eccentricity:                 0.6912231445E-002
Time of Applicability(s):     405504.0000
Orbital Inclination(rad):     0.9911766052
Rate of Right Ascen(r/s):    -0.7417838788E-008
SQRT(A)  (m 1/2):             5153.549316
Right Ascen at Week(rad):    -0.1640348434E+000
Argument of Perigee(rad):    -1.812852621
Mean Anom(rad):              -0.1197433472E+000
Af0(s):                       0.1583099365E-003
Af1(s/s):                     0.3637978807E-011
week:                         424
```

- The current Almanac Data can also be viewed over the internet.
- <u>Accuracy</u>

Almanac: 100-1000m 1week

Ephemeris: 1-2m 2hours

Elevation, Azimuth



- The **Elevation** describes the angle of a satellite relative to the horizontal plane.
- The **Azimuth** is the angle between the satellite and true North.

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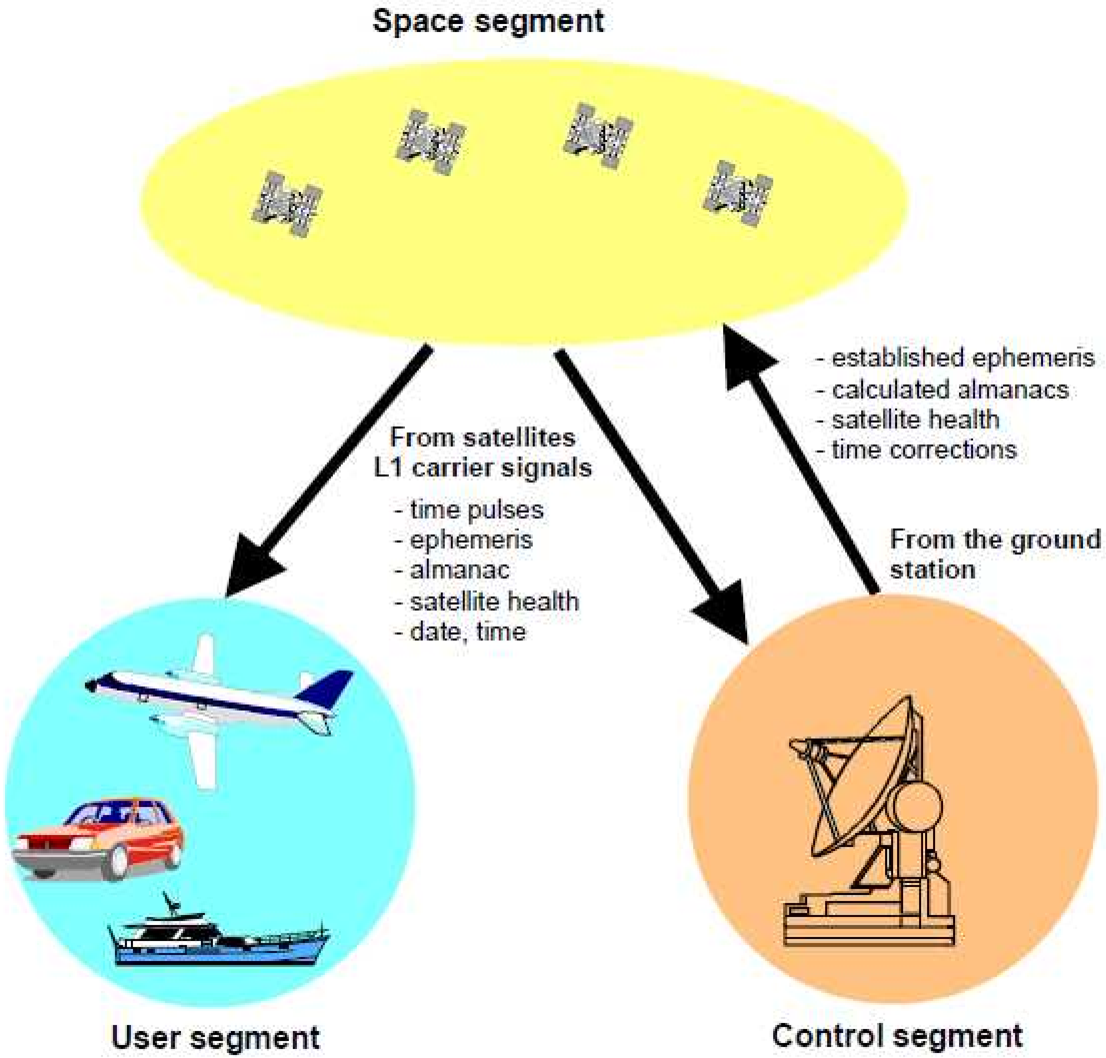
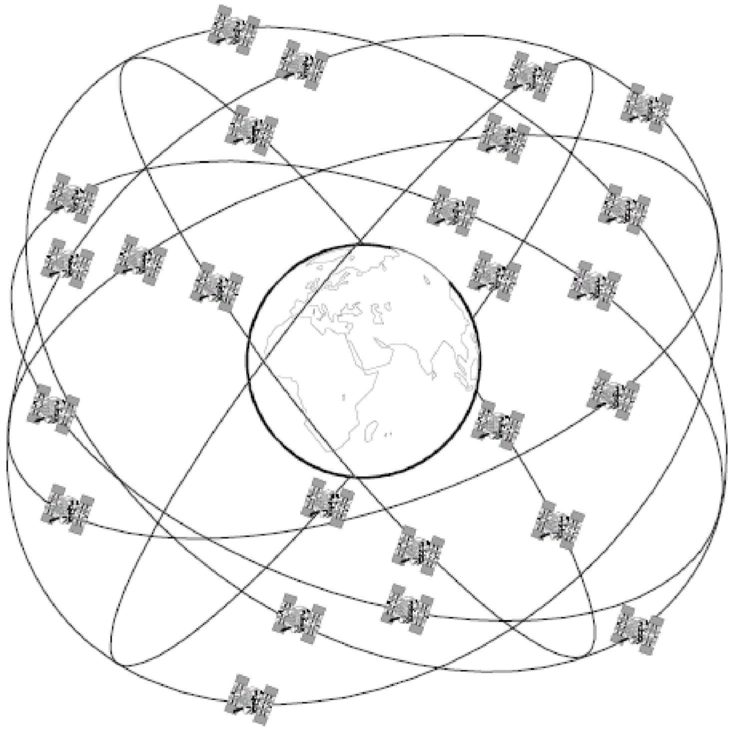
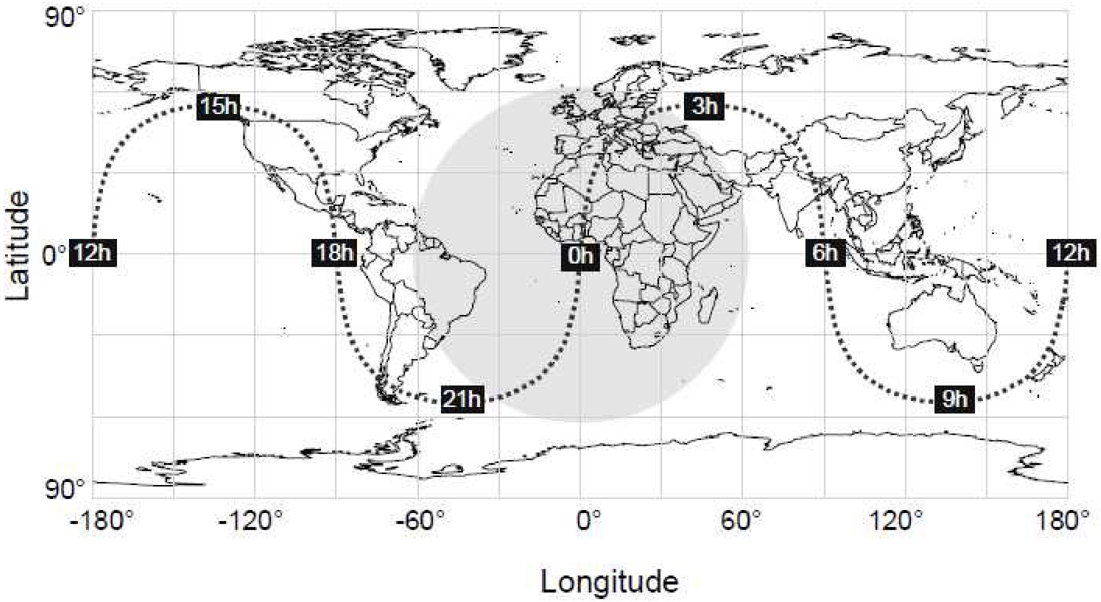
Three GPS Segments

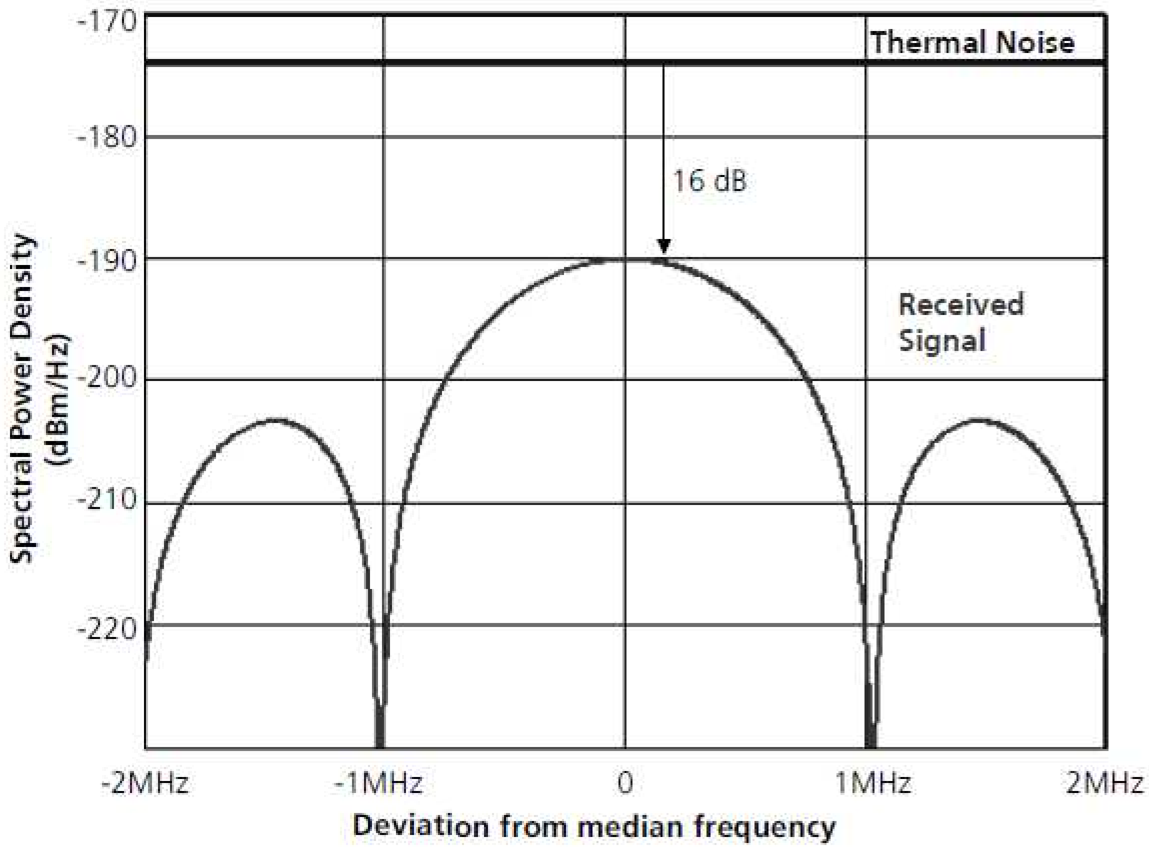


GPS satellites orbit





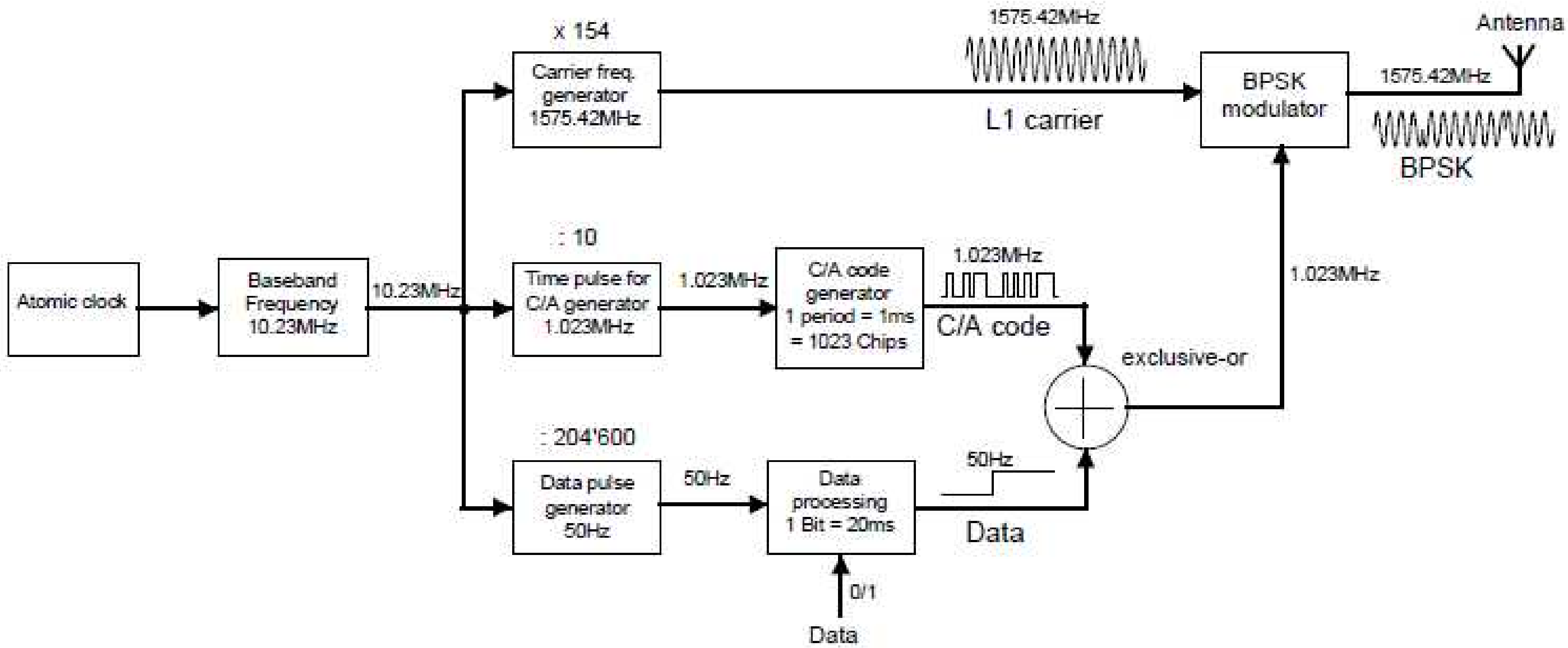
Spectral Power Density



Power of the Received GPS signal = 10^{-16}W

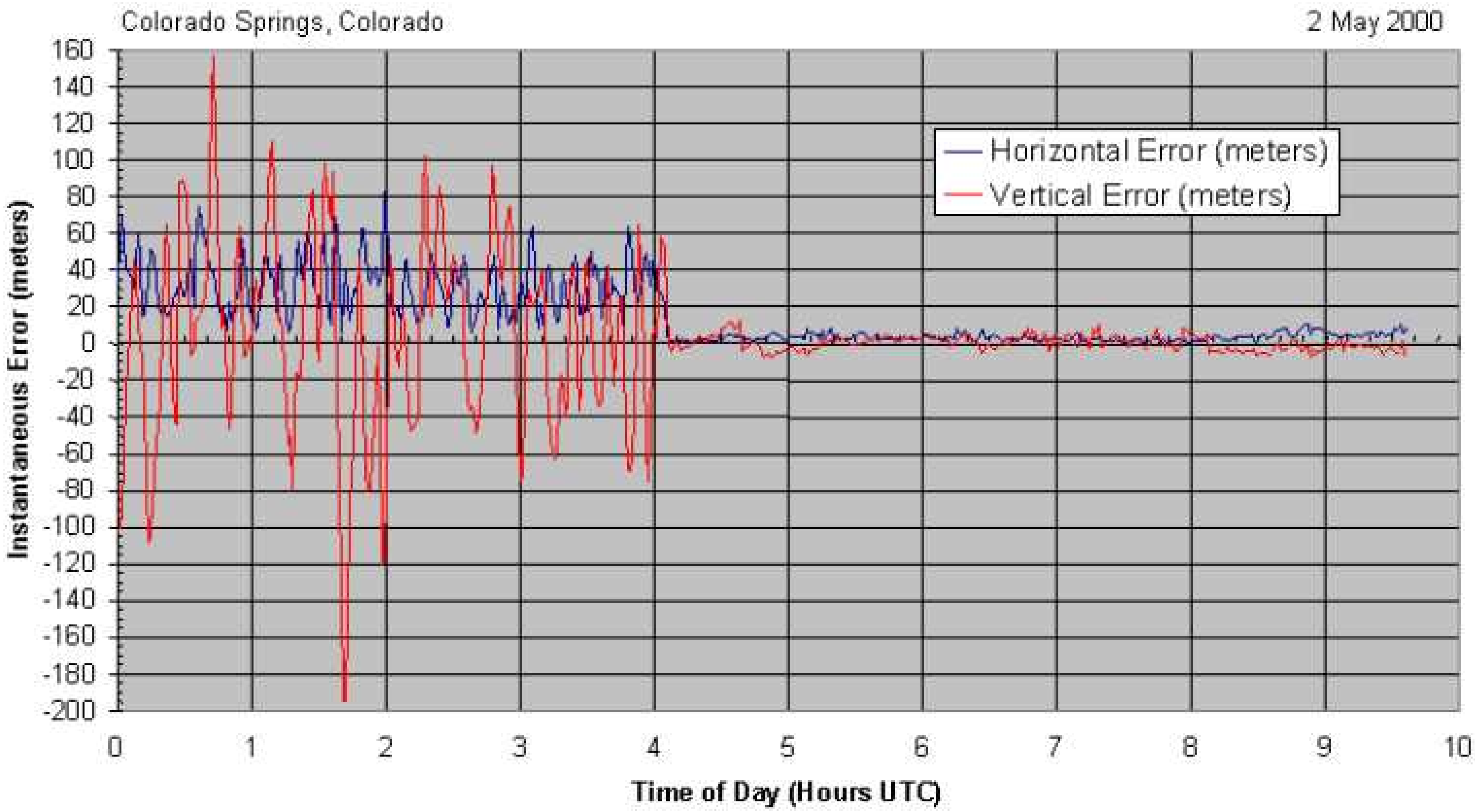
Received signal power is approximately 16dB below the thermal background noise level.

Satellite block diagram



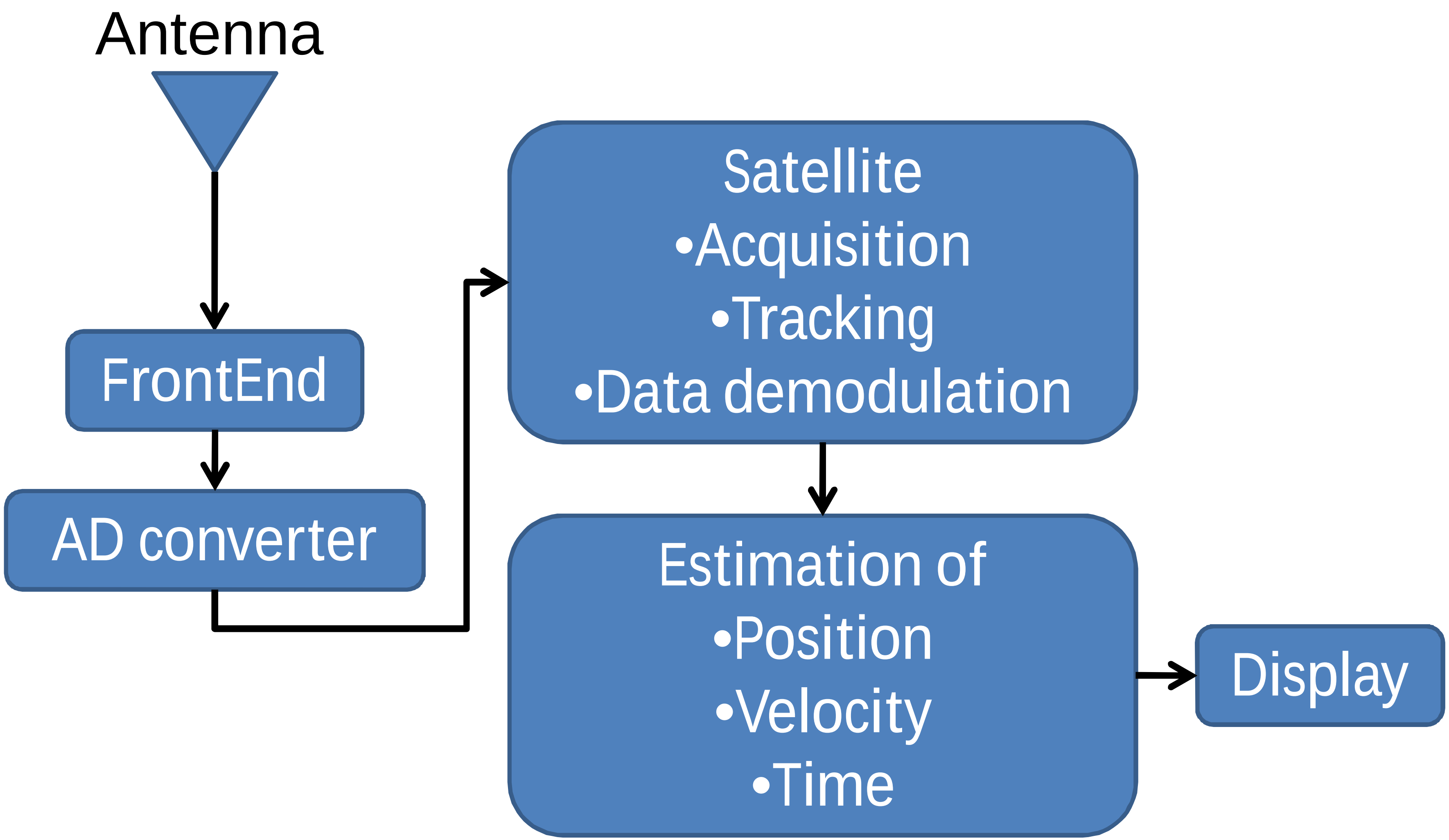
The C/A code plays an important role in the multiplexing and modulation.

Deactivation the artificial distortion of the signal

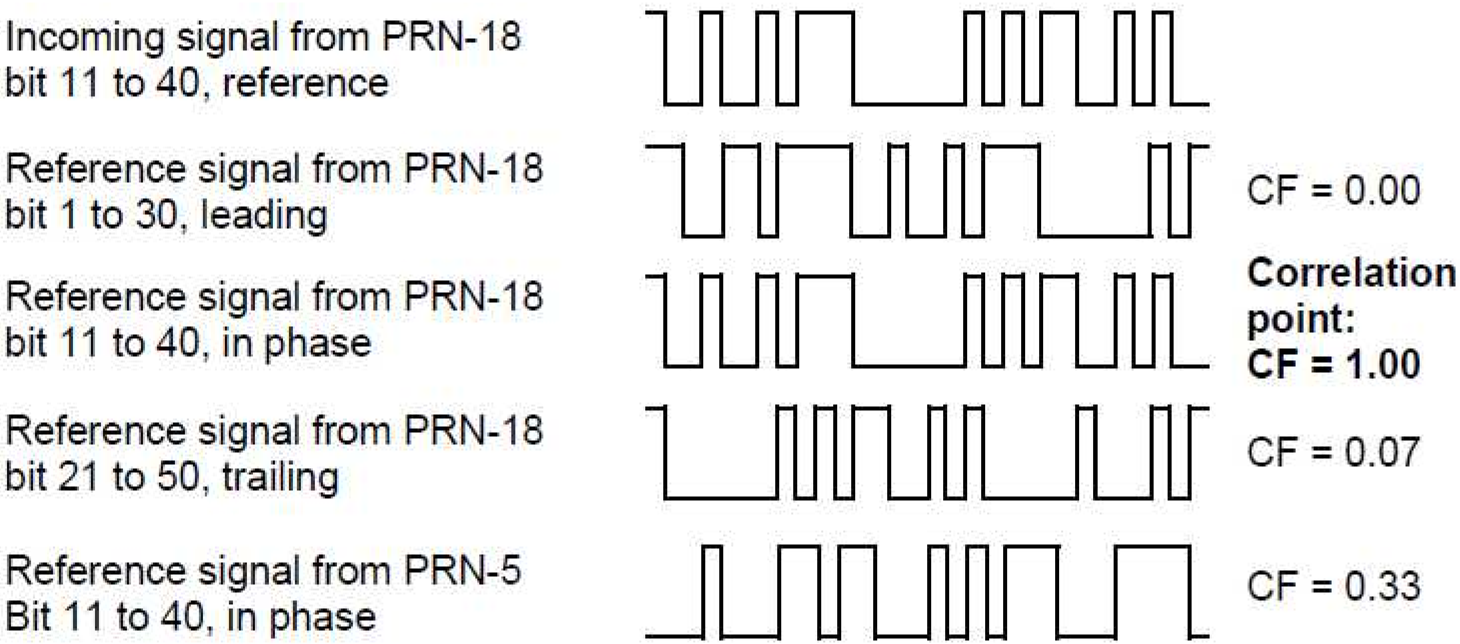


On September 18, 2007, the US DoD reported that with the next generation of GPS satellites (GPS III), satellite navigation signals can no longer be artificially distorted

Receiver block diagram

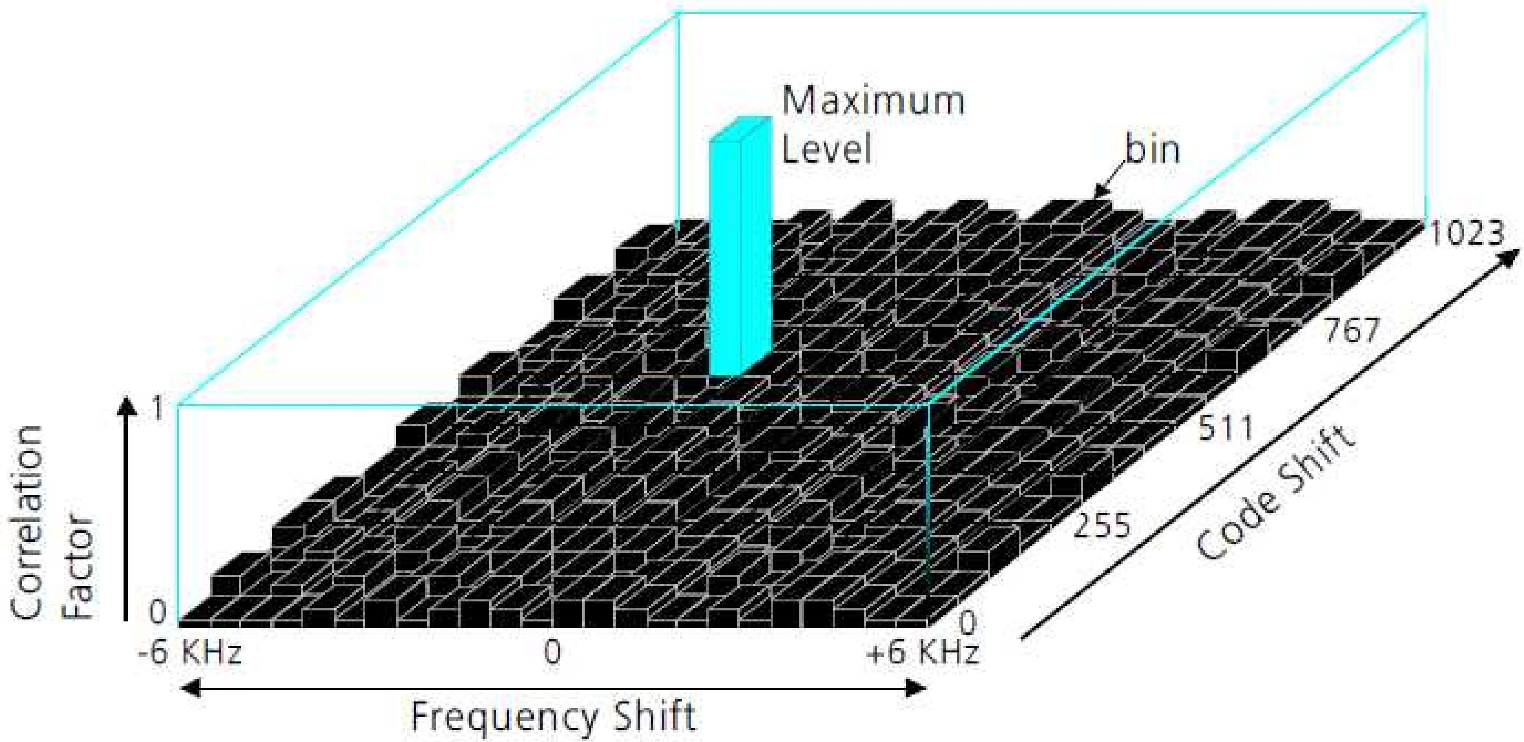


Correlation process across 30 bits



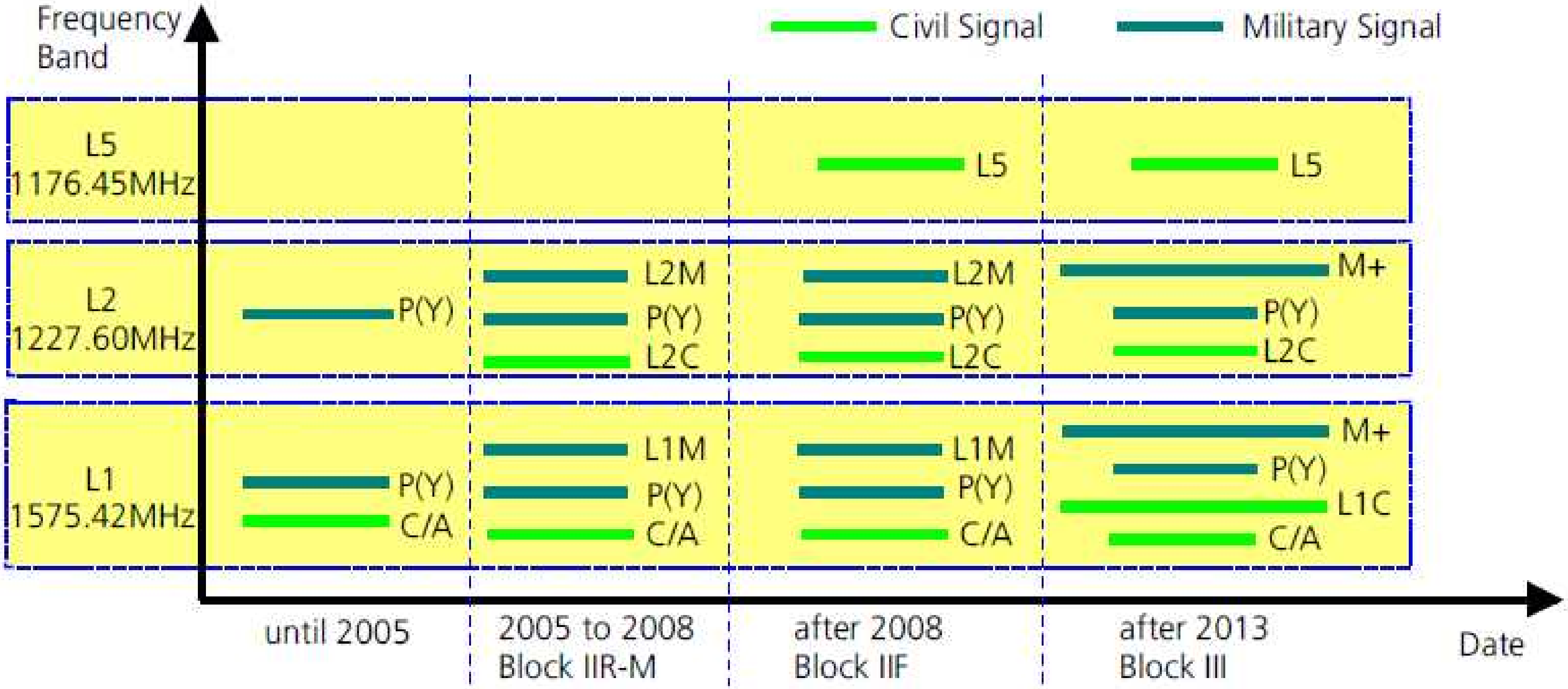
The quality of the correlation is expressed here as a CF (correlation factor). The value range of the CF lies between -1 and +1 and is only +1 when the signals completely match .

Search for the maximum correlation in code and carrier frequency domains



After de-spreading, the power density of the usable signal is greater than that of the thermal or background signal noise.

Modernization



With modernization the number of available GPS frequencies will be increased

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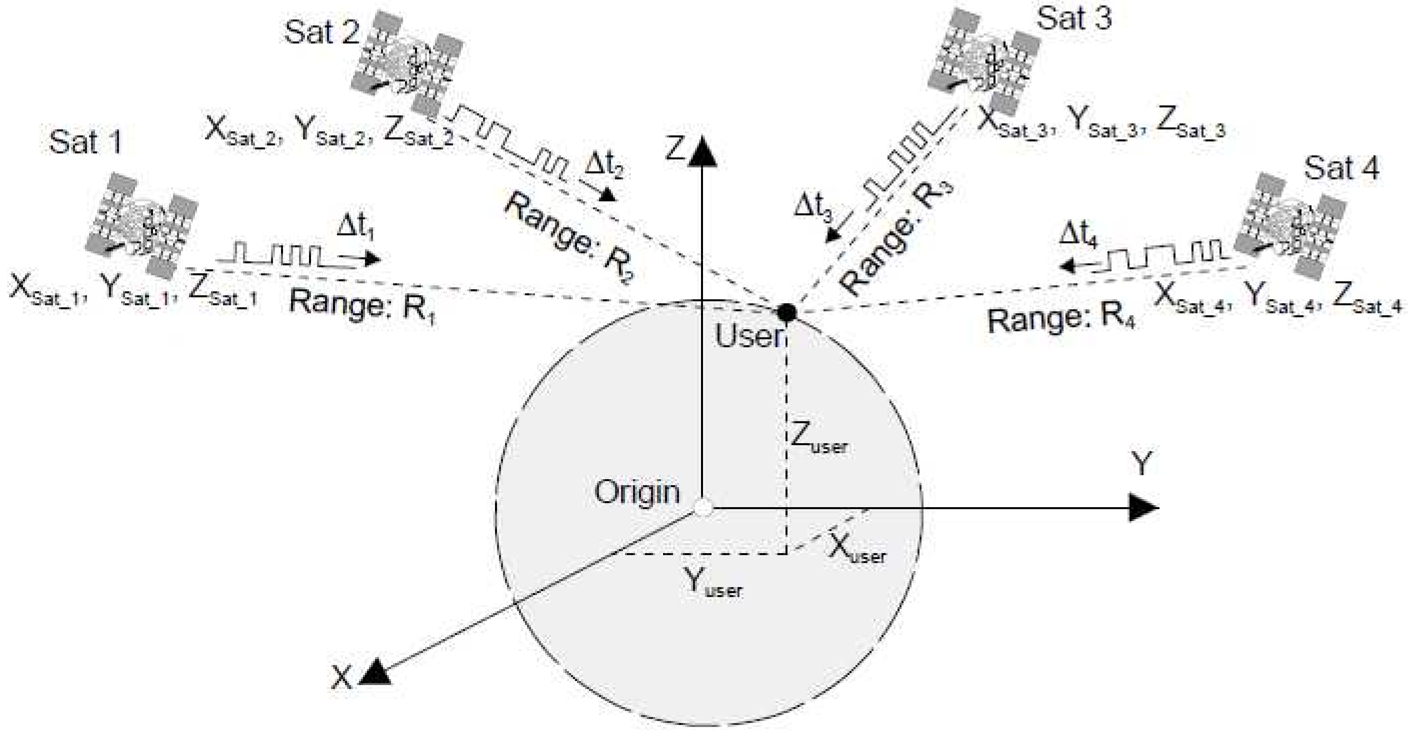
Three-dimensional coordinate system



Pseudo-range

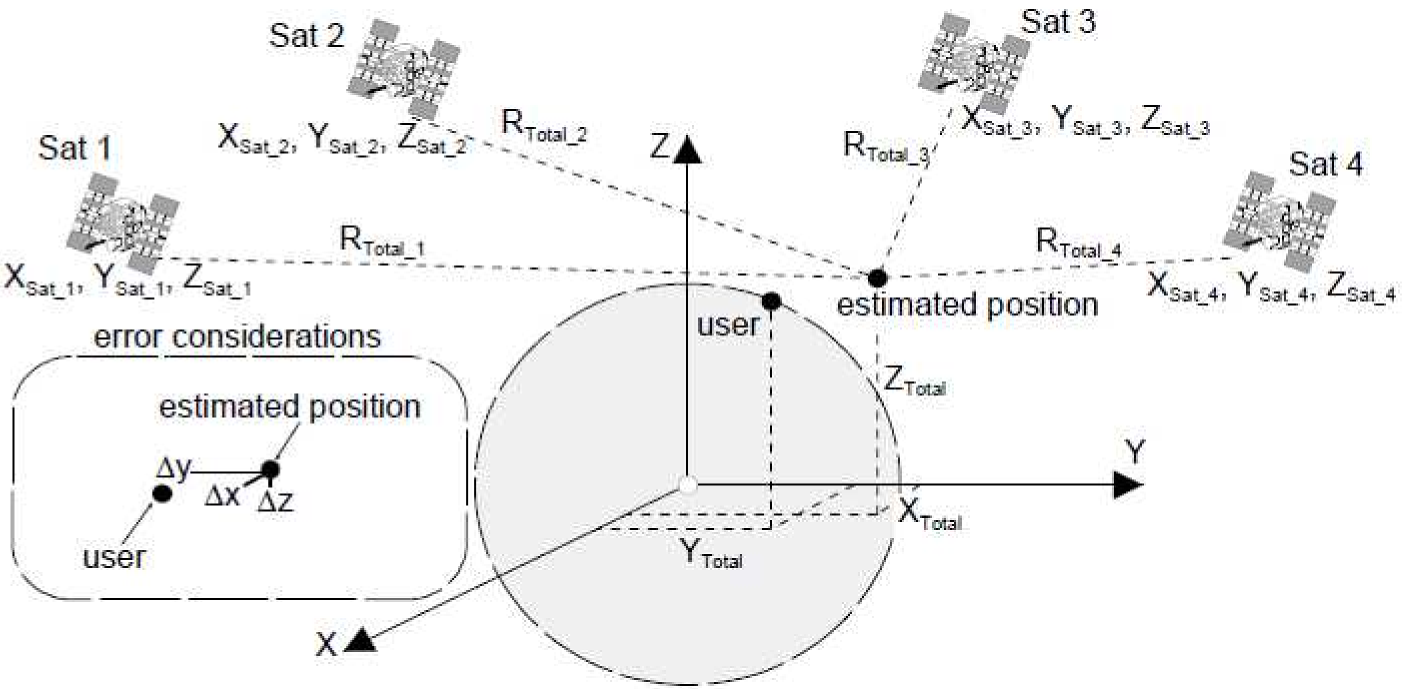
$$\Delta t_{measured} = \Delta t + \Delta t_0$$

$$PSR = \Delta t_{measured} \cdot c = (\Delta t + \Delta t_0) \cdot c$$

$$\mathrm{PSR} = \mathrm{R} + \Delta t_0 \cdot \mathrm{c}$$

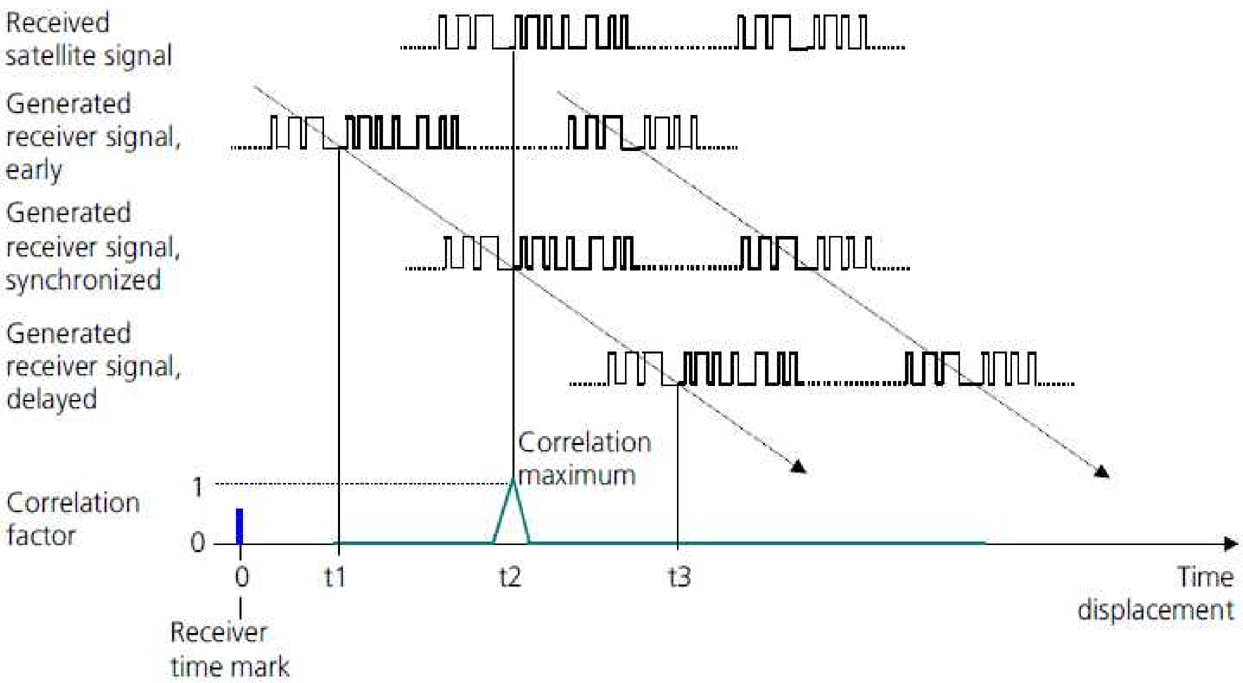
R:	true range of the satellite from the user
c:	speed of light
Δt:	signal travel time from the satellite to the user
Δt_0:	difference between the satellite clock and the user clock
PSR:	pseudorange

Estimating a position



Least Square Method is used to calculate position

Determination of travel time



Correlation maximum achieved by shifting time t2

$$t_{measured} = \Delta t + \Delta t_0 = \text{Arrival Time}_{\text{Receiver Time}} - \text{Transmission Time}_{\text{GPS Time}}$$

Δt: true signal travel time: Satellite to Receiver

t_0: Difference between Receiver Time and GPS Time

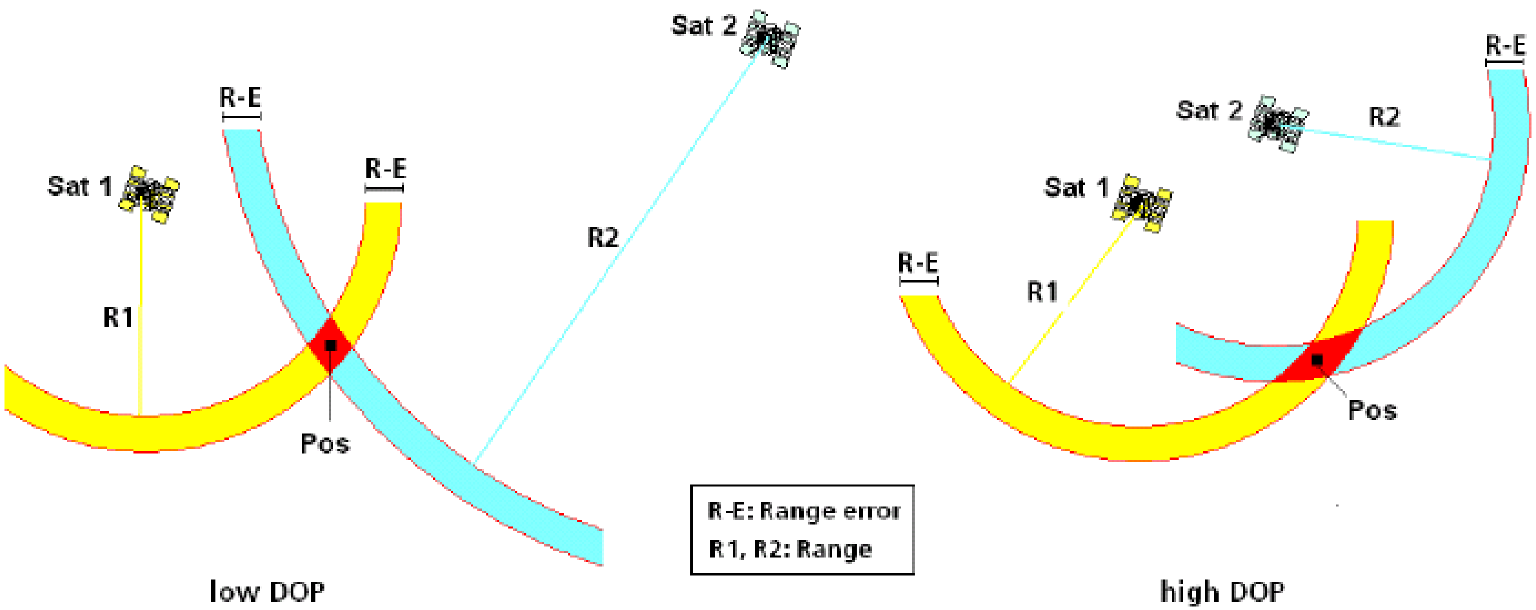
Additional travel time error

Error cause	**Error without DGPS**
Ephemeris data	1.5m
Satellite clocks	1.5m
Effect of the ionosphere	3.0m
Effect of the troposphere	0.7m
Multipath reception	1.0m
Effect of the receiver	0.5m
Total RMS value	**4.0m**

These are typical values.

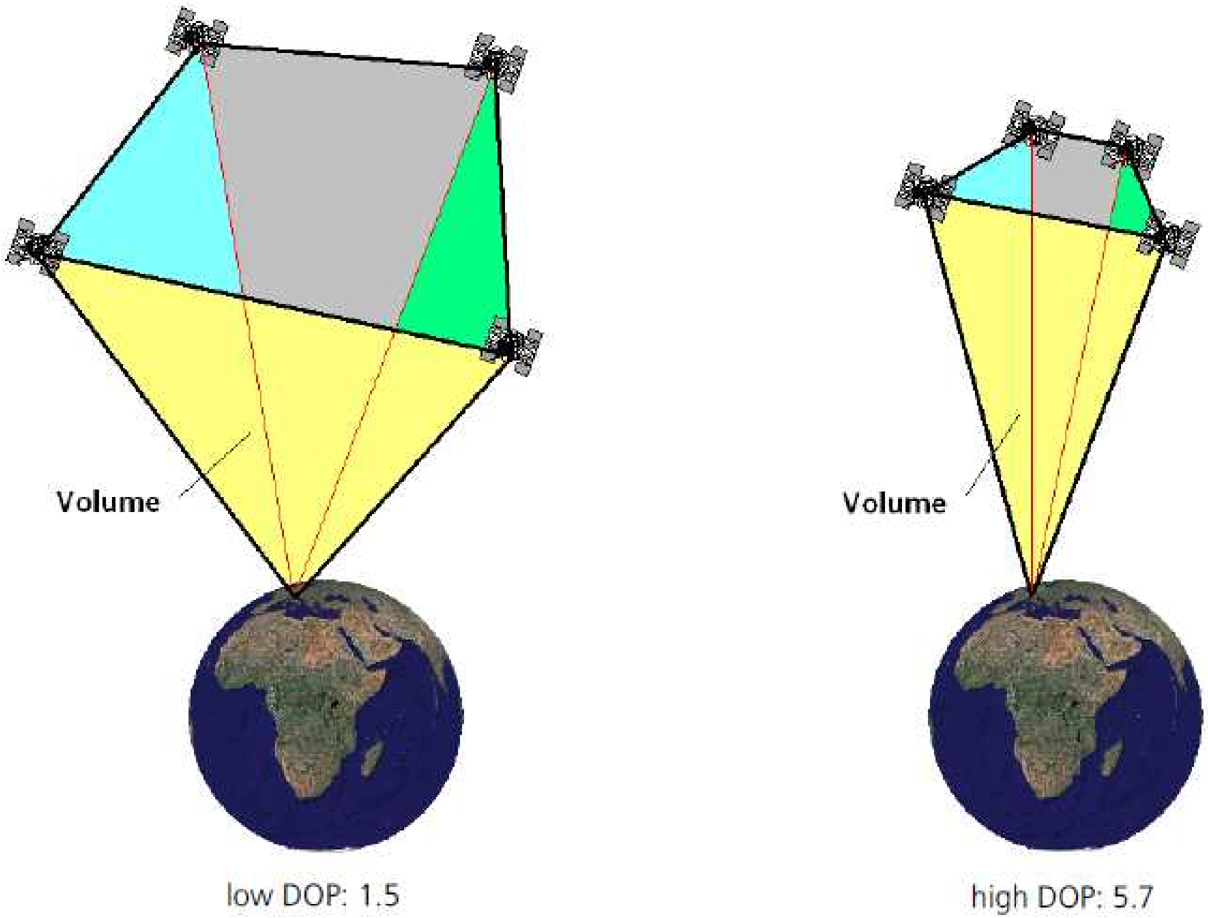
The influence of satellite geometry

- The precision of positioning with GPS navigation depends on the one h and on the precision of the individual pseudorange measurements and on the other hand on the geometric configuration of the satellites used . This configuration is expressed in terms of a scalar value, which is ref erred to in navigation literature as DOP (Dilution of Precision).



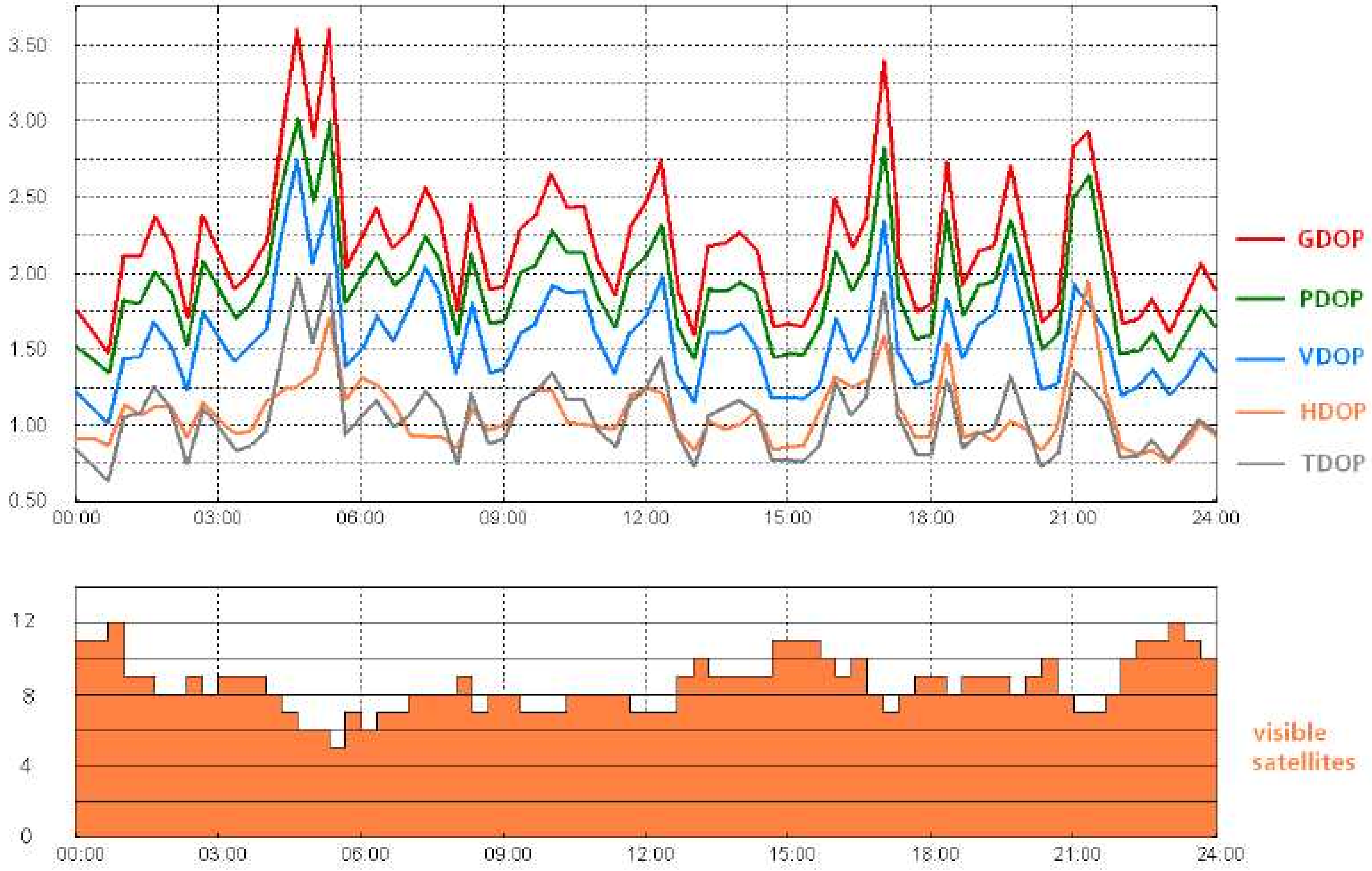
Total Error = Total RMS Error * DOP

Illustration of the DOP-value



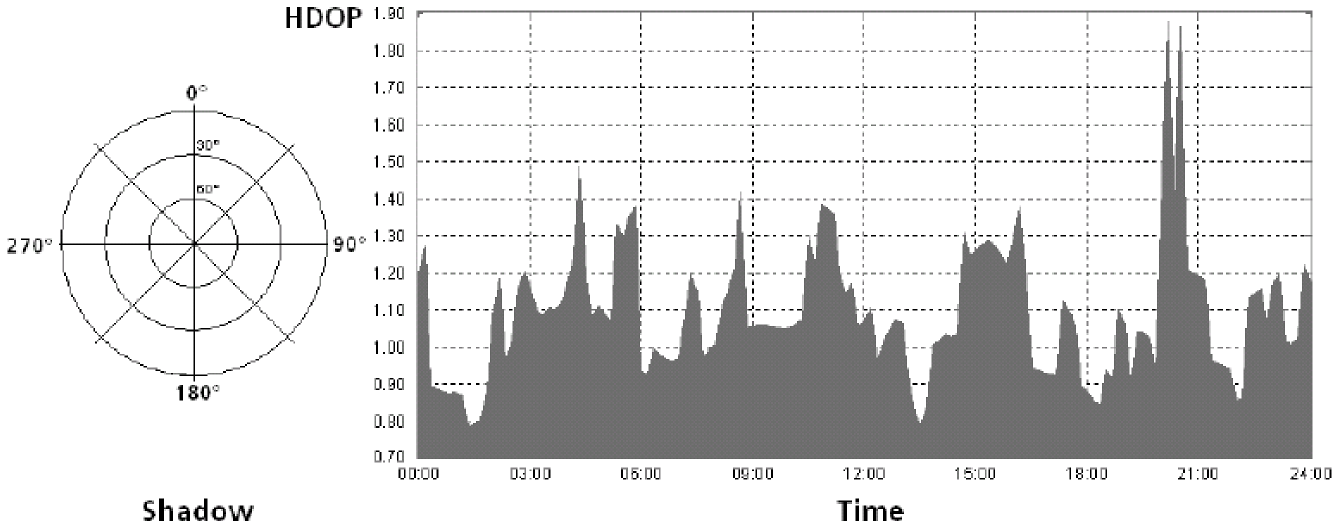
Total position error = (Position error through other influences) * (DOP value)

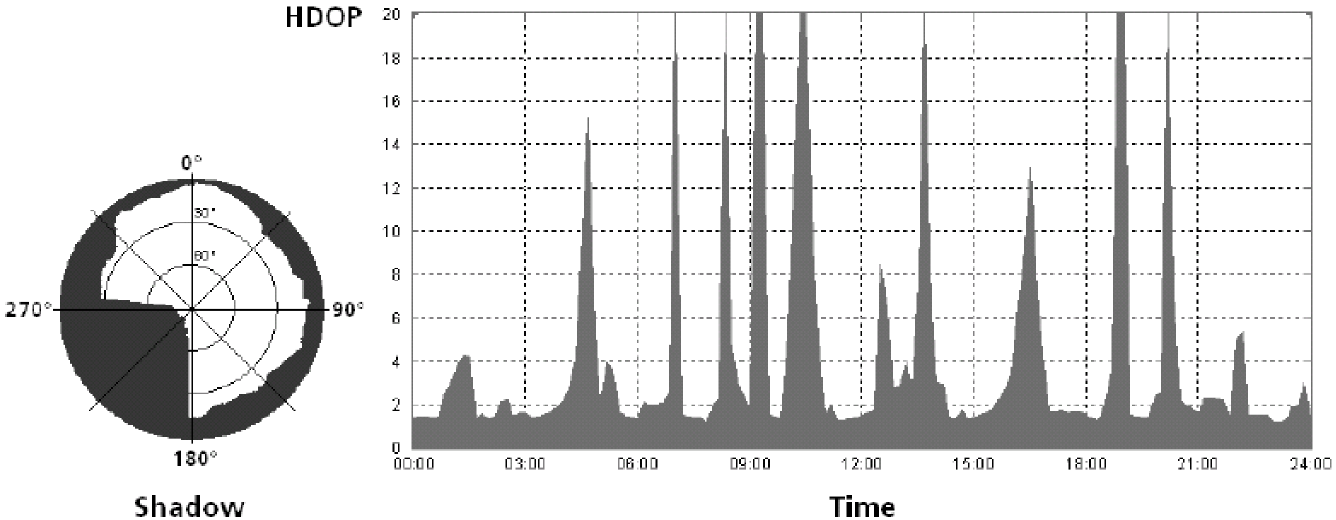
Practical implications of DOP values



DOP values and the number of satellites over an open area during a 24-hour period

24-hour HDOP values (no obstruction/with obstruction)





Total error

- Measurement accuracy is proportionally dependent on the DOP value. This means that when the DOP value doubles, the positioning error is also twice as large.
- Total RMS value: **4.0m**
- Horizontal error (1sigma HDOP=1.5): **6.0m**
- Horizontal error (2sigma HDOP=1.5): **12.0m**

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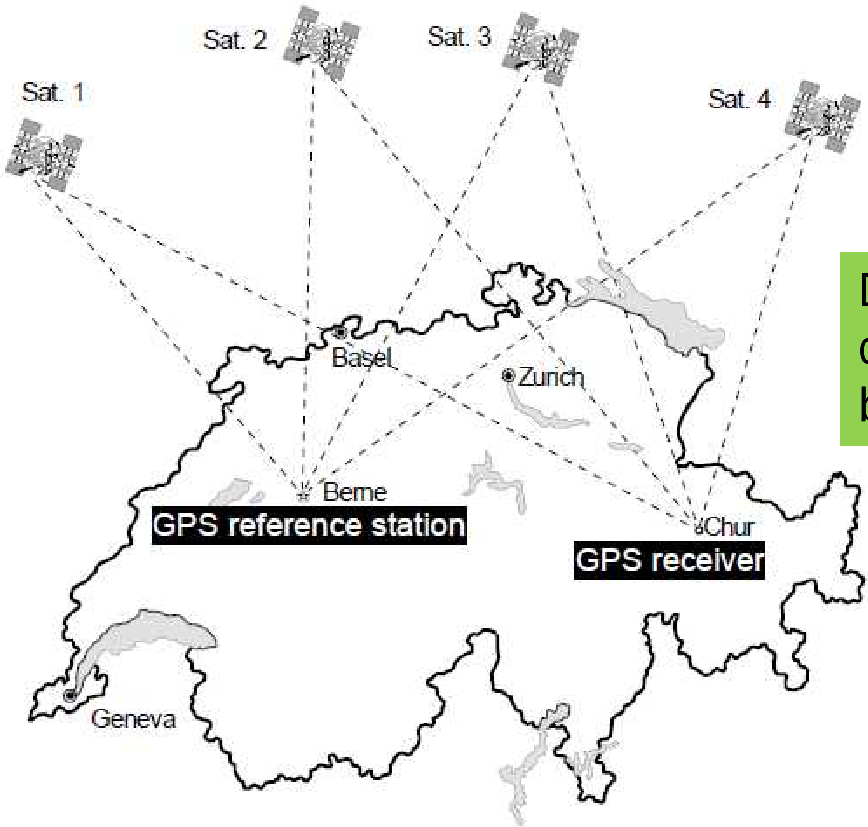
Sources of GPS error

Error cause	Error without DGPS
Ephemeris data	1.5m
Satellite clocks	1.5m
Effect of the ionosphere	3.0m
Effect of the troposphere	0.7m
Multipath reception	1.0m
Effect of the receiver	0.5m
Total RMS value	**4.0m**

- Multipath and receiver noise is relatively difficult to reduce.

DGPS



DGPS uses the fact that the most of error sources change slowly in the time domain if the distance between ref and user is approx. within 100km.

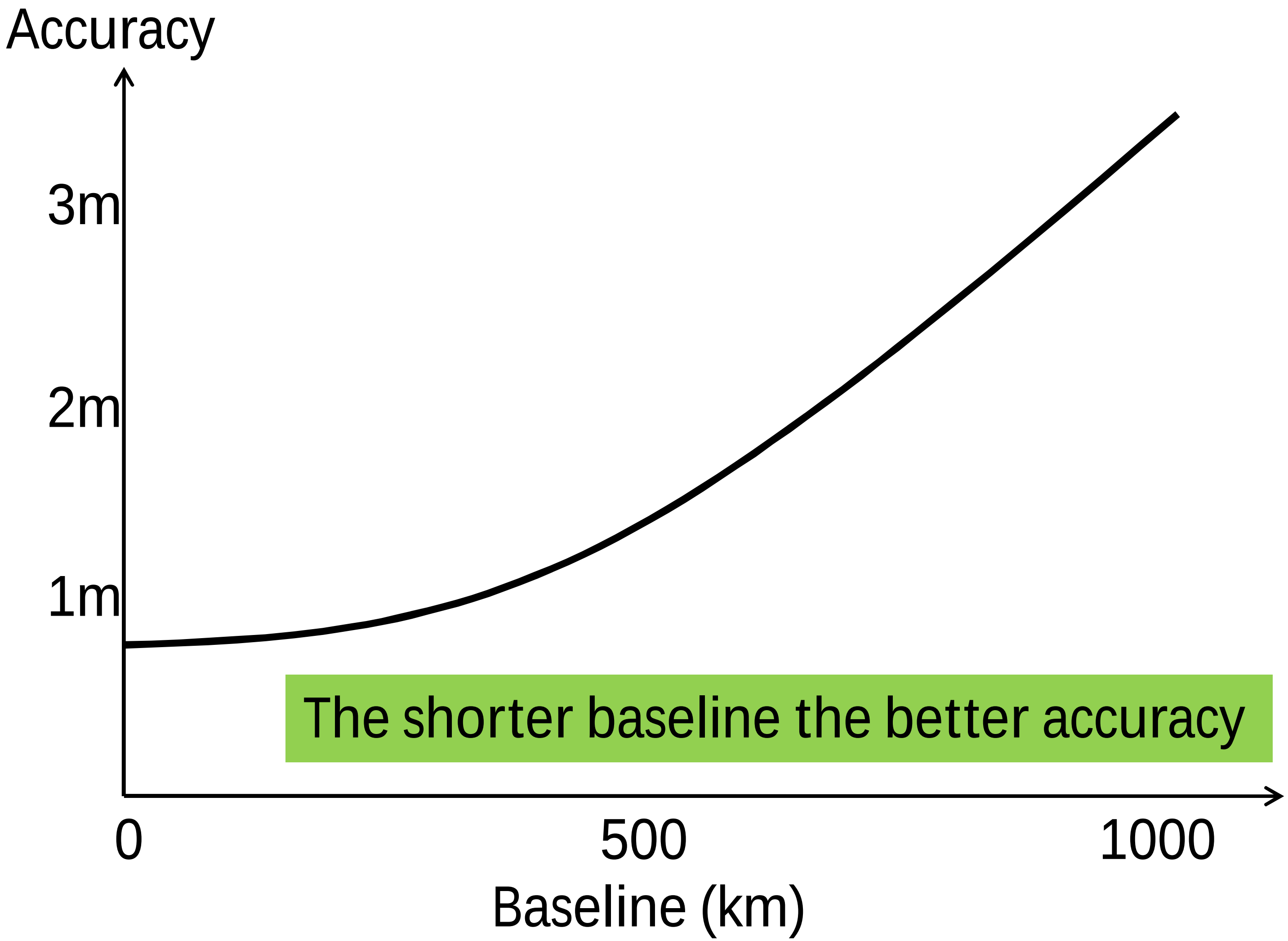
- Determination of the correction values at the reference station
- Transmission of the correction values from the reference station to the G PS user
- Compensation for the determined pseudoranges to correct the calculated position of the GPS user

Achievable accuracy with DGPS

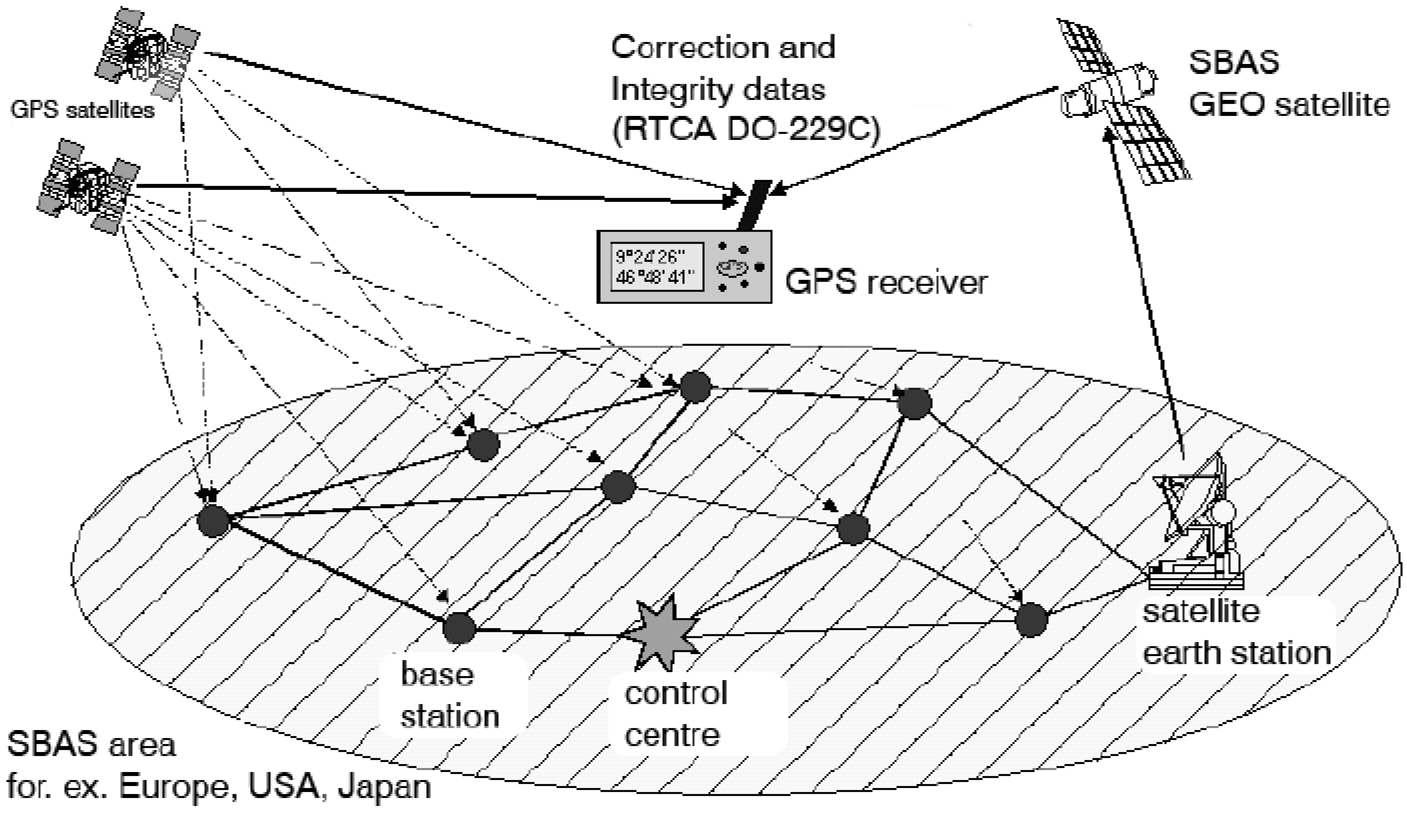
Error cause and type	Error without DGPS/SBAS	Error with DGPS/SBAS
Ephemeris data	1.5m	0.1m
Satellite clocks	1.5m	0.1m
Effect of the ionosphere	3.0m	0.2m
Effect of the troposphere	0.7m	0.2m
Multipath reception	1.0m	1.4m
Effect of the receiver	0.5m	0.5m
Total RMS value	4.0m	1.2m
Horizontal error (1-Sigma (68%) HDOP=1.3)	6.0m	1.8m
Horizontal error (2-Sigma (95%) HDOP=1.3)	**12.0m**	**3.6m**

Most of error sources can be reduced by using DGPS correction data

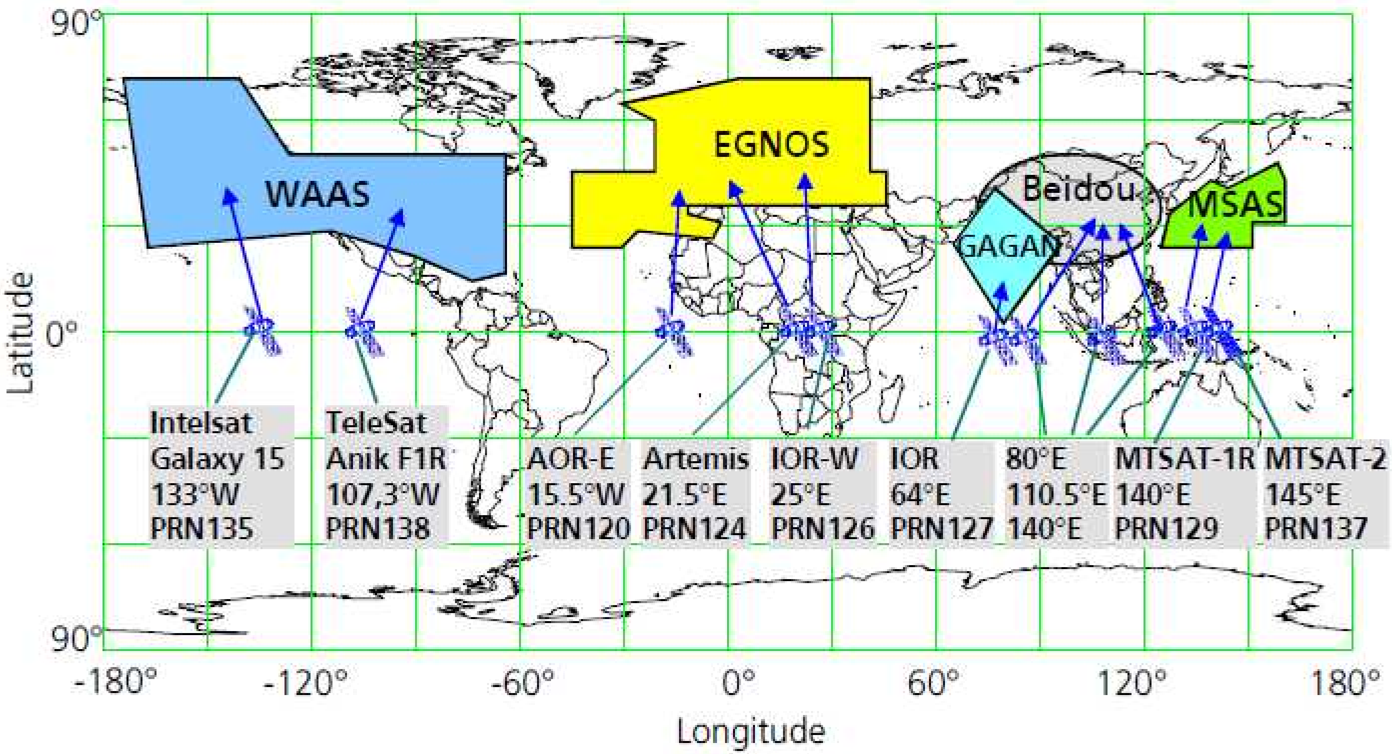
Limitations of DGPS



Wide Area DGPS



SBAS

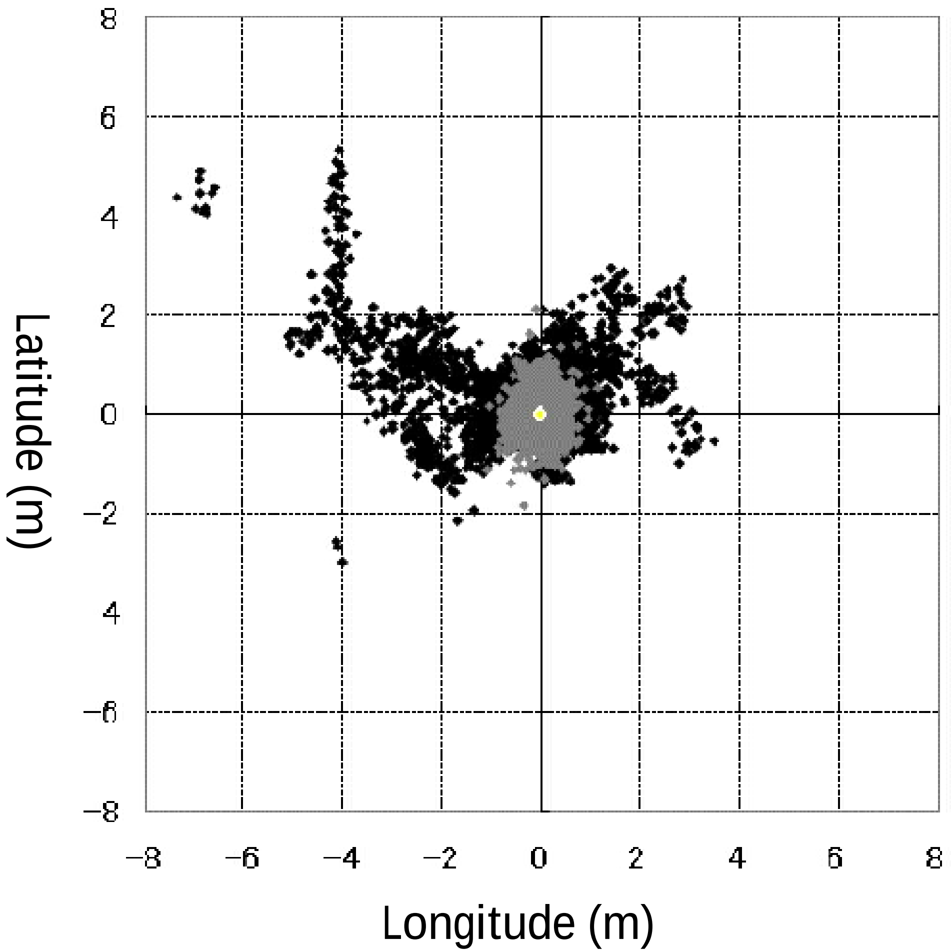


90°
0°
90°
Latitude
-180°
-120°
-60°
0°
60°
120°
180°
Longitude
WAAS
EGNOS
Beidou
GAGAN
MSAS
Intelsat Galaxy 15 133°W PRN135
TeleSat Anik F1R 107,3°W PRN138
AOR-E 15.5°W PRN120
Artemis 21.5°E PRN124
IOR-W 25°E PRN126
IOR 64°E PRN127
80°E 110.5°E 140°E
MTSAT-1R 140°E PRN129
MTSAT-2 145°E PRN137

RTK (Real Time Kinematic)

- The concept of RTK is same as DGPS.
- The only difference is that RTK uses carrier phase measurements. DGPS uses pseudo-range measurements.
- GPS receiver is able to measure 1/100 of wavelength of L1 frequency.
- If you have high-end receiver, you know your position within 1cm accuracy as long as you are in open sky condition.

RTK example (1hour data)



Single Positioning
DGPS
RTK

Rooftop (Lab.)

High Sensitivity Receiver

- Modern GNSS receivers typically possess a sensitivity of approximately -160dBm (standard: -145dBm).Given that the GPS operator (US) guarantees signal strength of -130dBm(45dB-Hz), GNSS receivers can therefore function in buildings that weaken the signal by up to 15-30dB.

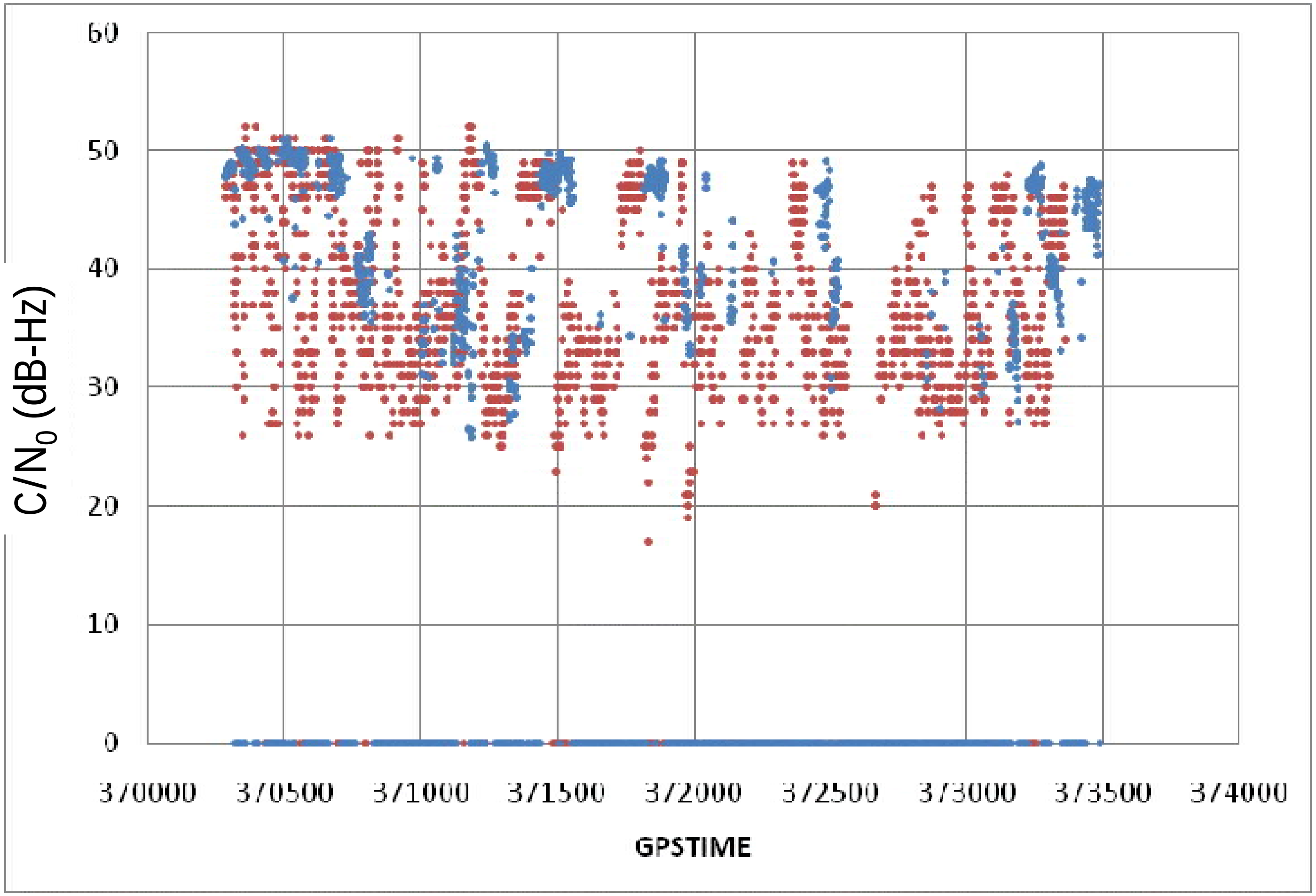
Focuses of efforts:

*Increased signal sensitivity
*Quicker acquisition upon activation of the receiver
*Reduced sensitivity to interference

Technical aspects:

*Improved Oscillator Stability
*Antennas
*Noise Figure considerations
*Increasing the correlators and the correlation time

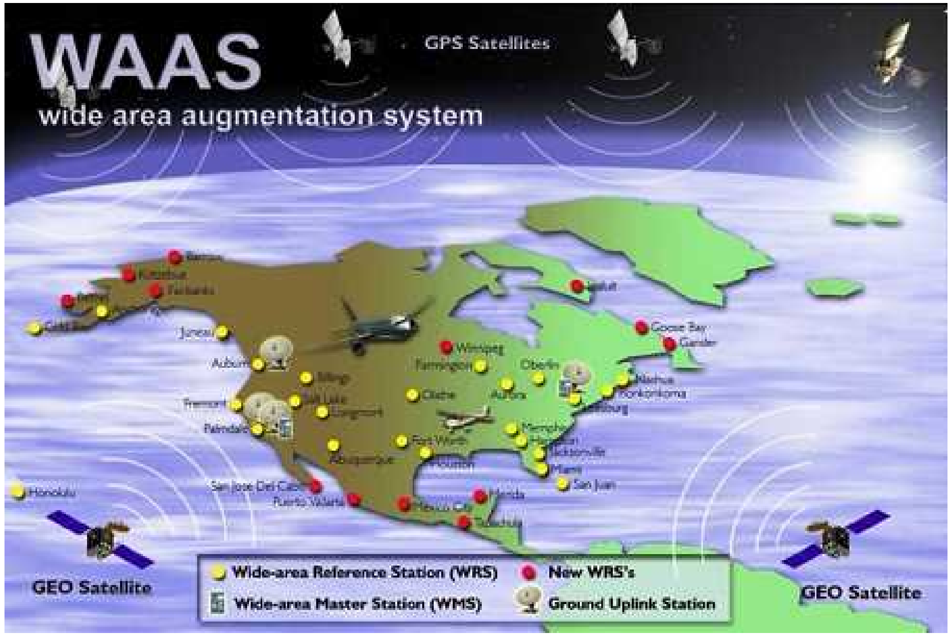
Signal Strength in Urban Area



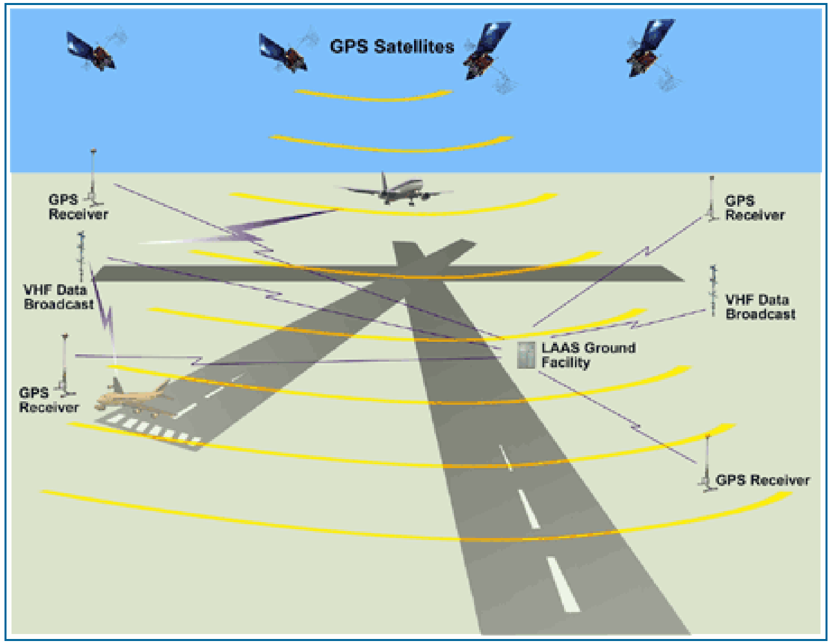
Red: High Sensitivity Receiver Blue: Standard Receiver

Contents

Air Traffic Control

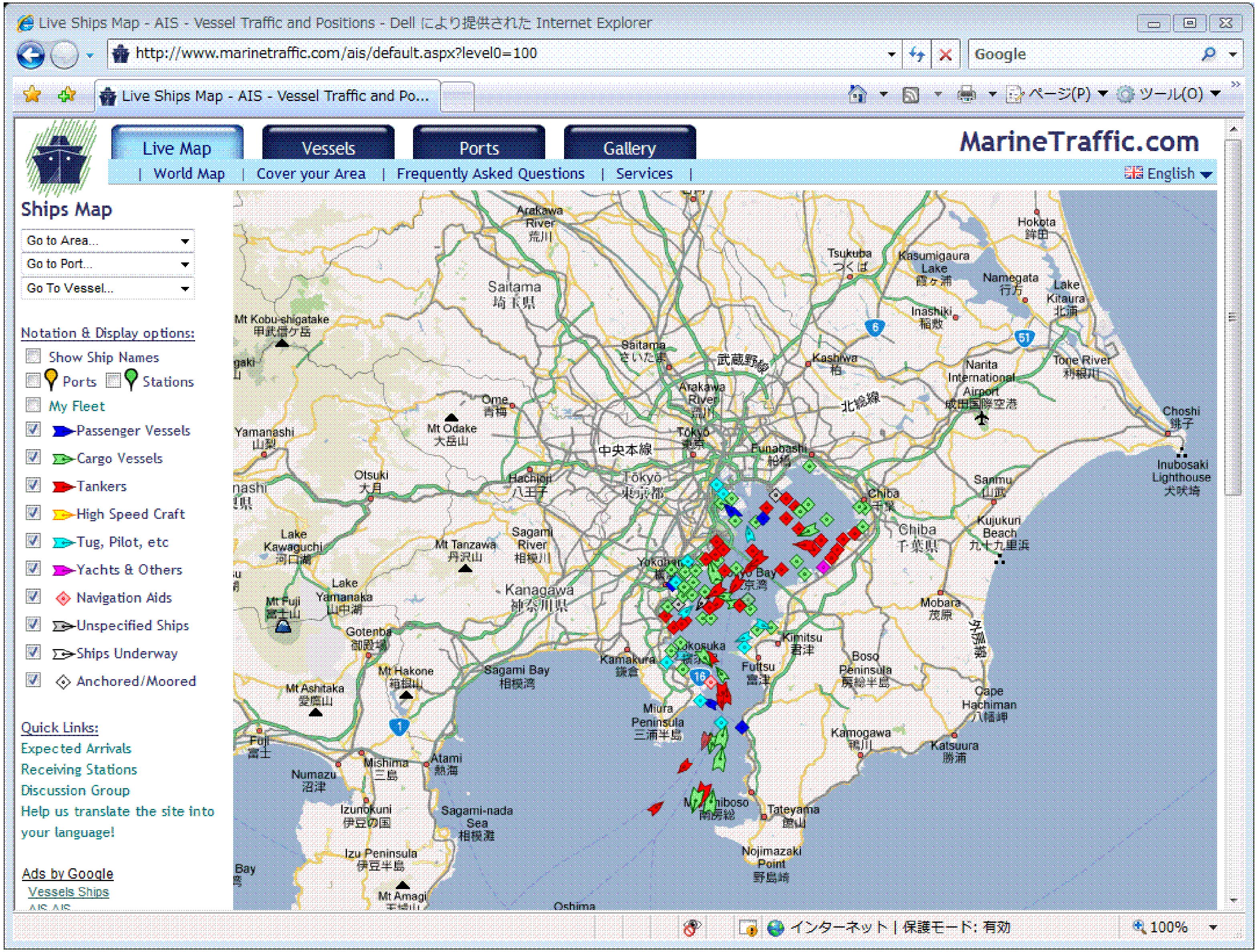


Satellite Based Augmentation System



Ground Based Augmentation System

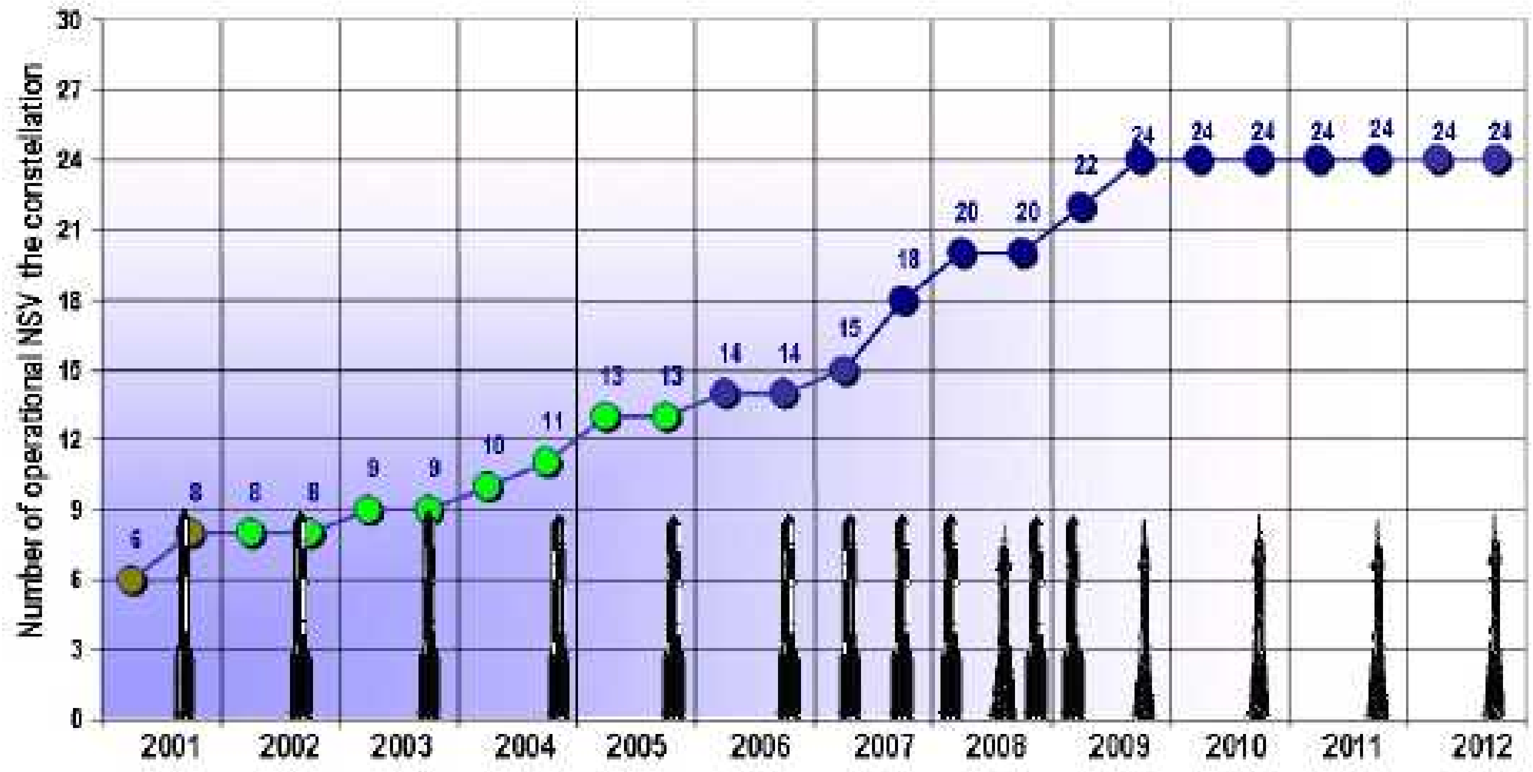
Ship Navigation (AIS)



Car Navigation

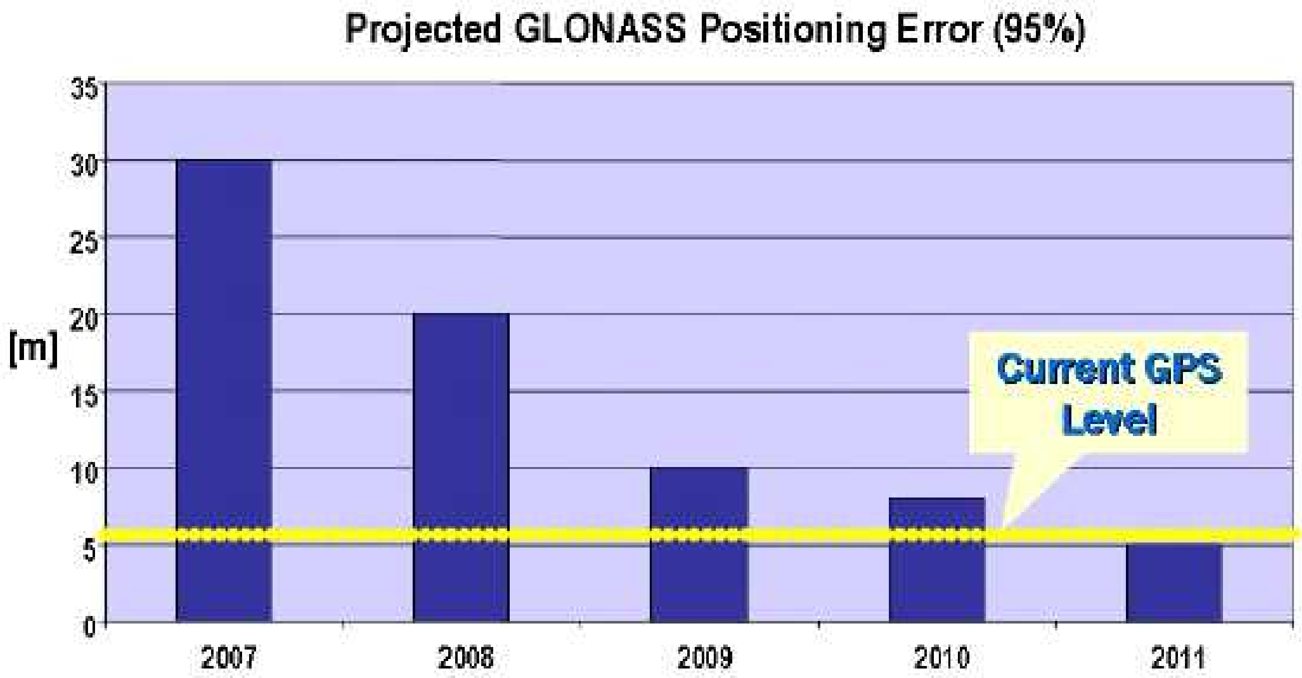
Contents

GLONASS development plan



GLONASS is an abbreviation for a GNSS system currently operated by the Russian Defense Ministry.
The first three test-satellites were launched into orbit on October 12, 1982.

GLONASS positioning error



The measured position accuracy of GLONASS should gradually approach that of GPS.

Galileo

Galileo is a global navigation satellite system (GNSS) currently being built by the European Union (EU) and European Space Agency (ESA). The €3.4 billion project is an alternative and complementary to the U.S. Global Positioning System (GPS) and the Russian GLONASS. On 30 November 2007 the 27 EU transportation ministers involved reached an agreement that it should be operational by 2013.[1]

- 28 spacecraft
- orbital altitude: 23,222 km (MEO)
- 3 orbital planes, 56° inclination, ascending nodes separated by 120° longitude (9 operational satellites and one active spare per orbital plane)
- satellite lifetime: >12 years
- satellite mass: 675 kg
- satellite body dimensions: 2.7 m x 1.2 m x 1.1 m
- span of solar arrays: 18.7 m
- power of solar arrays: 1,500 W (end of life)

From Wikipedia

QZSS

- The **Quasi-Zenith Satellite System** (QZSS), is a proposed three-satellite regional time transfer system and enhancement for the Global Positioning System, that would be receivable within Japan. The first satellite is currently scheduled to be launched in 2010. Full operational status is expected by 2013.[1][2]

From Wikipedia

Beidou

- **The Beidou Navigation System** or **Beidou Satellite Navigation and Positioning System** is a project by China to develop an independent satellite navigation system. The current Beidou-1 system (made up of 4 satellites) is experimental and has limited coverage and application. However, China has planned to develop a truly global satellite navigation system consisting of 35 satellites (known as Compass or Beidou-2).

From Wikipedia

GPS textbook

- http://www.u-blox.com/

I used this tutorial today.

- http://www.gpstextbook.com/

Global Positioning System: Signals, Measurements, and Performance Second Edition (2006)

By Pratap Misra and Per Enge

There are many GPS textbooks in English.
You can choose one which is suitable for you.
If you can’t, I recommend the above one. Firstly, you should read u-blox tutorial and if you would like to know more in details, you can read the above one.

Conclusion

- What is Geoid ? or What is WGS84 ?
- What is CDMA ?
- Total Error = Total RMS Error * DOP

Questions ?