Space Technology

Global Positioning System

GNSS (Global Navigation Satellite Systems)

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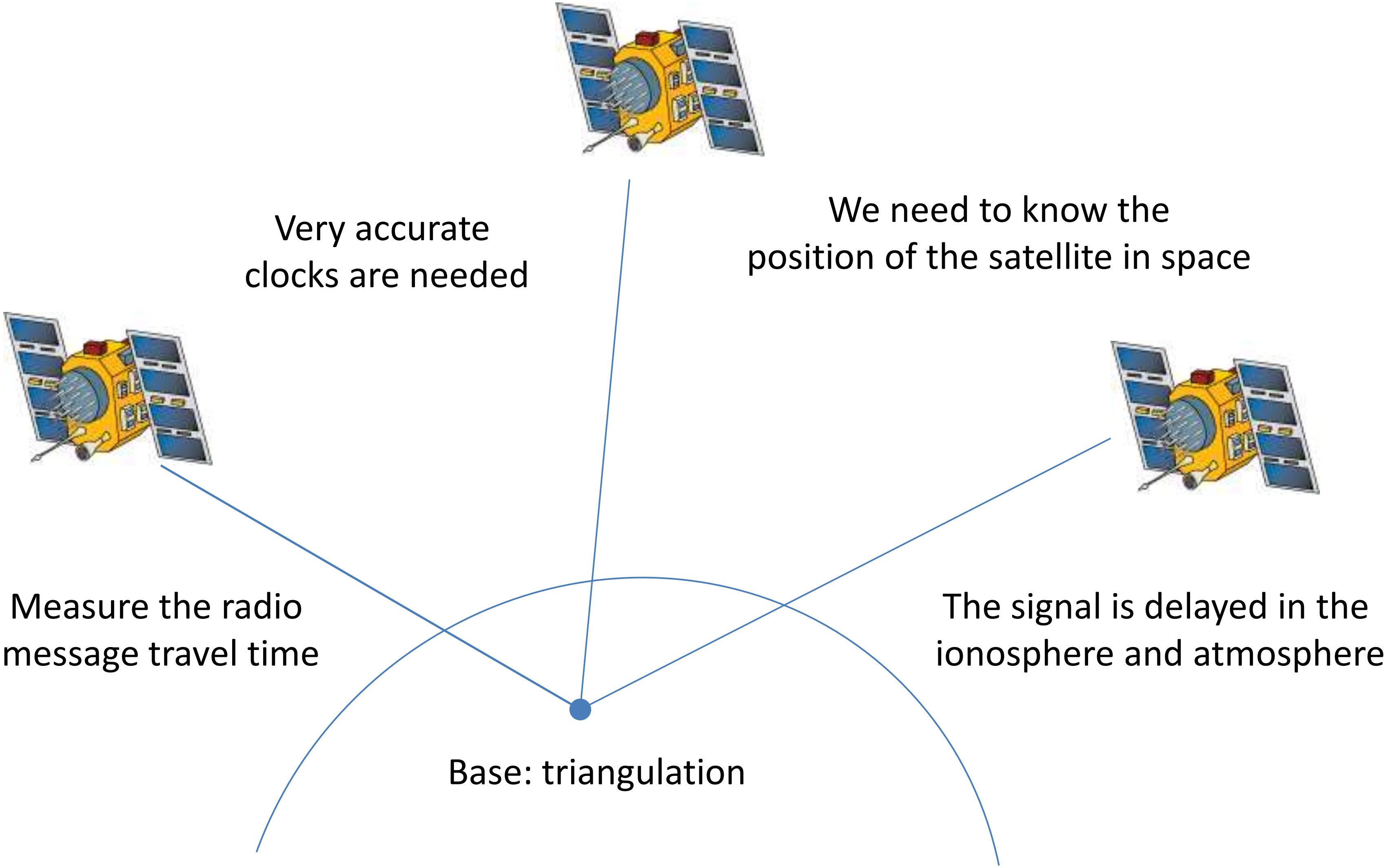
One of the most known satellite application

- Developed by the U.S. Department of Defense
- 1979/1985 (commercial)
- 24 satellites @ 20.000km height (MEO)
- 3D positioning

Other systems

- Transit (USA)
  - Based on the Doppler-effect
  - 1959-1996
- Galileo (ESA/EU)
  - 2016-
- GLONASS (RUS)
  - 1976-
- BeiDou (CHI)
  - BeiDou 1: 2000-12
  - BeiDou 2: 2012-

Principles



Very accurate
clocks are needed

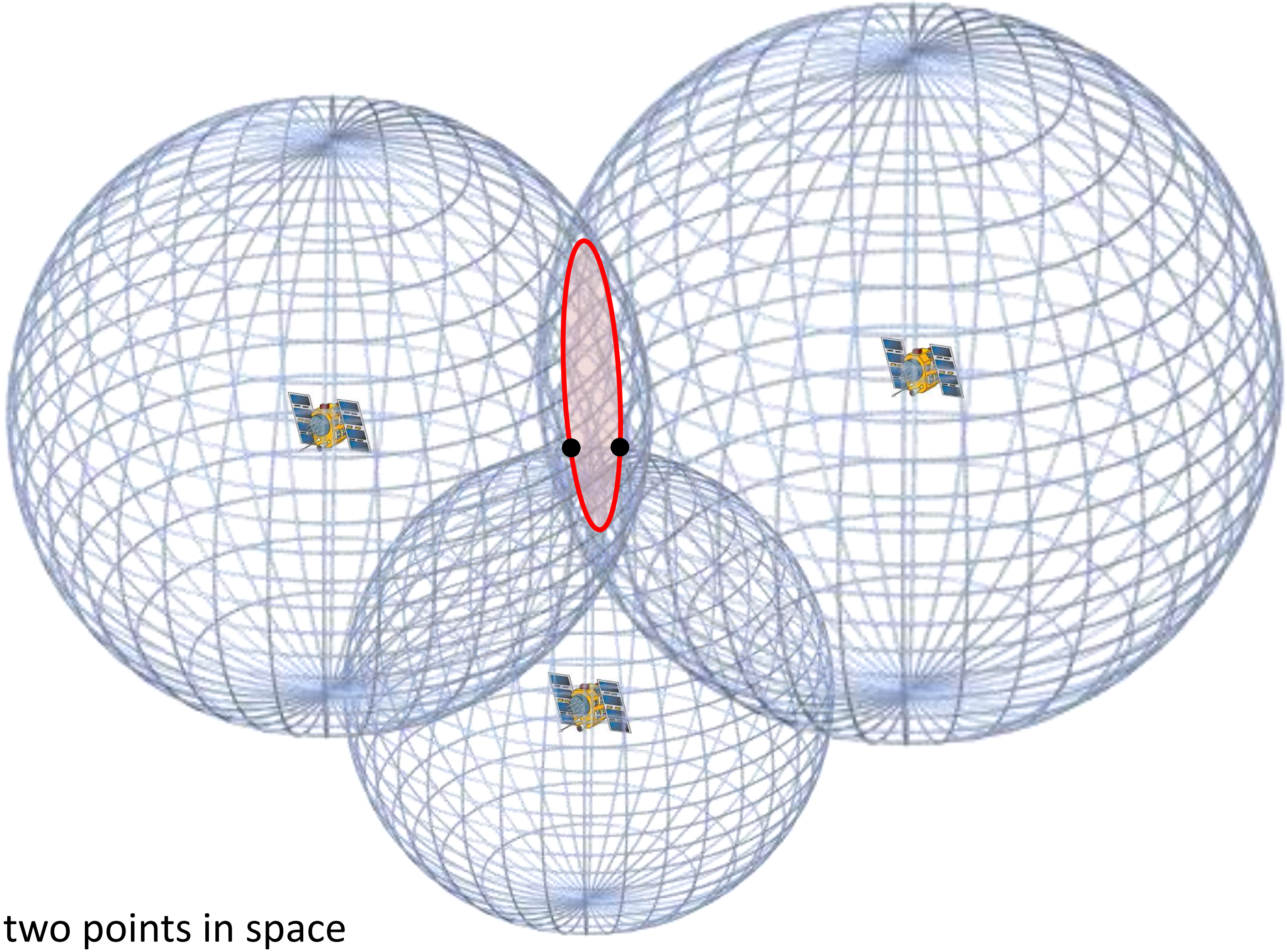
We need to know the
position of the satellite in space

Measure the radio
message travel time

The signal is delayed in the
ionosphere and atmosphere

Base: triangulation

Satellite ranging

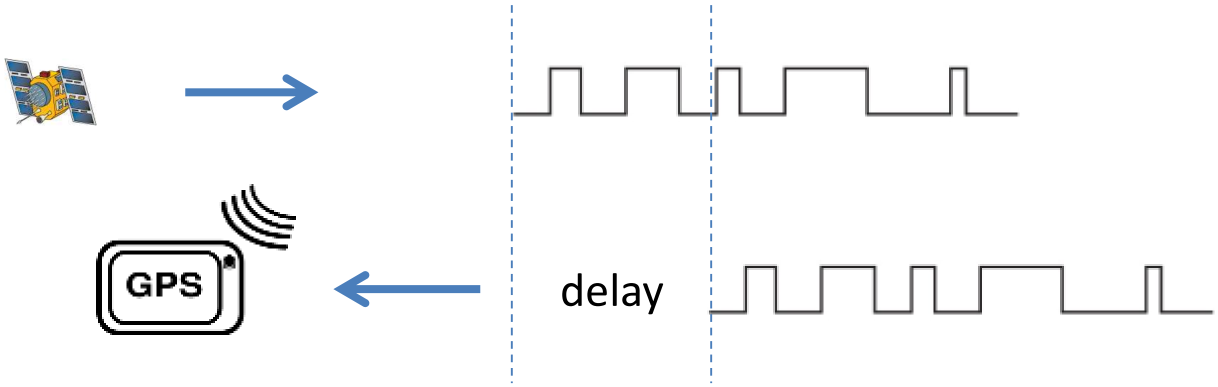


Three satellites: two points in space
- incorrect point may excluded
- or a fourth satellite needed

Satellite distance measurements

Speed of radio waves: 299.792km/sec
Distance: ~20.000km
Time: ~0.06sec

300m/µsec 0.3m/nsec



How do we know, when the signal left the satellite?

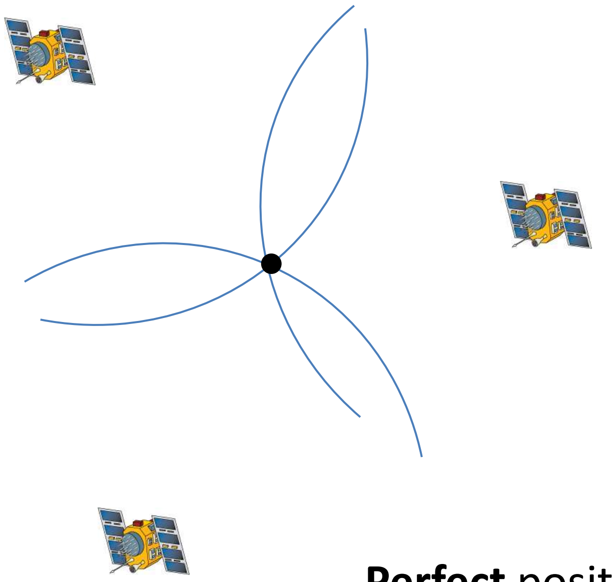
- We synchronize all the satellites and receivers.
- The satellites are transmitting pseudo-random codes.
- Nanosecond precision is required.

Perfect timing

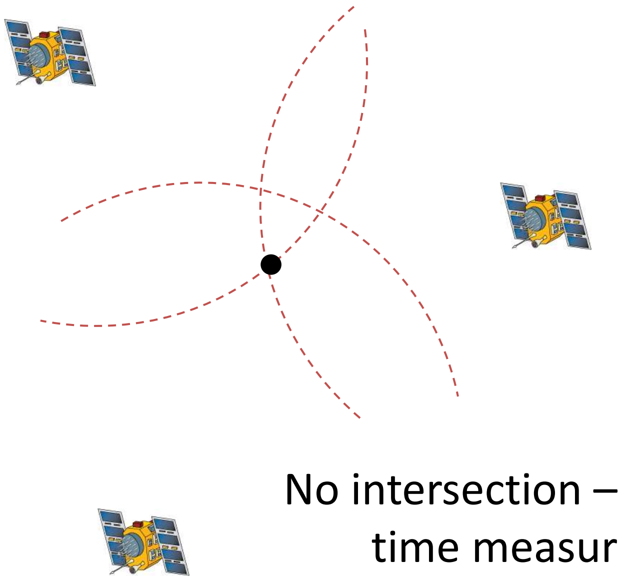
- The satellites have atomic clocks on board.
- Four clocks on each satellite → too expensive for receivers!

- Three perfect time measurements **OR** four imperfect timing measurements!

In 2D:



Perfect position



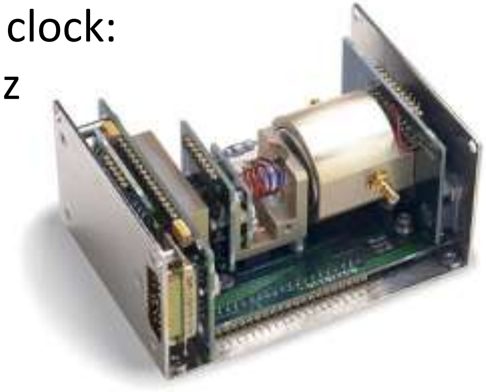
No intersection – **imperfect** time measurement
But the receiver's computer can **find the time offset**

In 3D: fourth measurement is needed
Single channel/three channel/four channel receiver

Atomic clock

Caesium-133 atomic clock for GPS satellite (1970):
9 192 631 770 Hz

Rubidium-87 atomic clock:
6 834 682 610.904 Hz



Microsemi, 2018
-20 krad
-for LEO application

Where is the satellite in space?

- The satellites are precisely injected into their orbit
- Mathematical orbit models are existing, but positions are constantly monitored
- The GPS satellites are orbiting (~12hr/round) – DoD (Department of Defense) stations are monitoring twice a day
- Ephemeris error: gravitational field variation, solar wind, etc.
- The GPS satellites are transmitting their exact positions

- NMEA: National Marine Electronics Association format:

$GPGGA,181908.00,3404.7041778,N,07044.3966270,
W,4,13,1.00,495.144,M,29.200,M,0.10,0000*40

181908.00 is the time stamp: UTC time in hours, minutes and seconds.

3404.7041778 is the latitude in the DDMM.MMMMM format.

07044.3966270 is the longitude in the DDDMM.MMMMM format.

…….

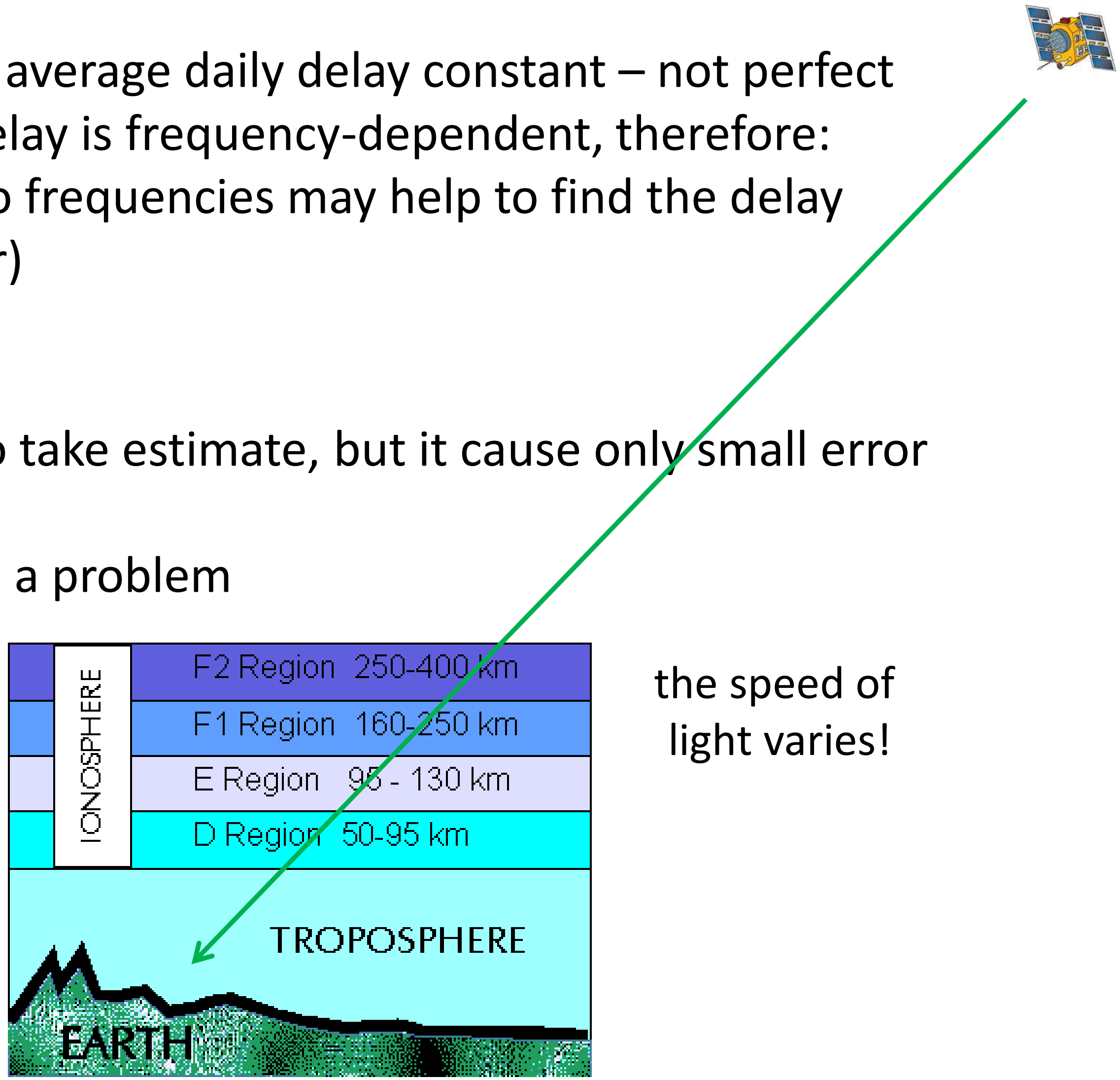
ftp://cddis.gsfc.nasa.gov/gnss/data/daily/
https://cddis.nasa.gov/

Ionospheric and atmospheric effects

- Ionospheric effects:
- delay correction using an average daily delay constant – not perfect
- high-tech solution: the delay is frequency-dependent, therefore:
  - measurement at two frequencies may help to find the delay (dual-band GPS receiver)

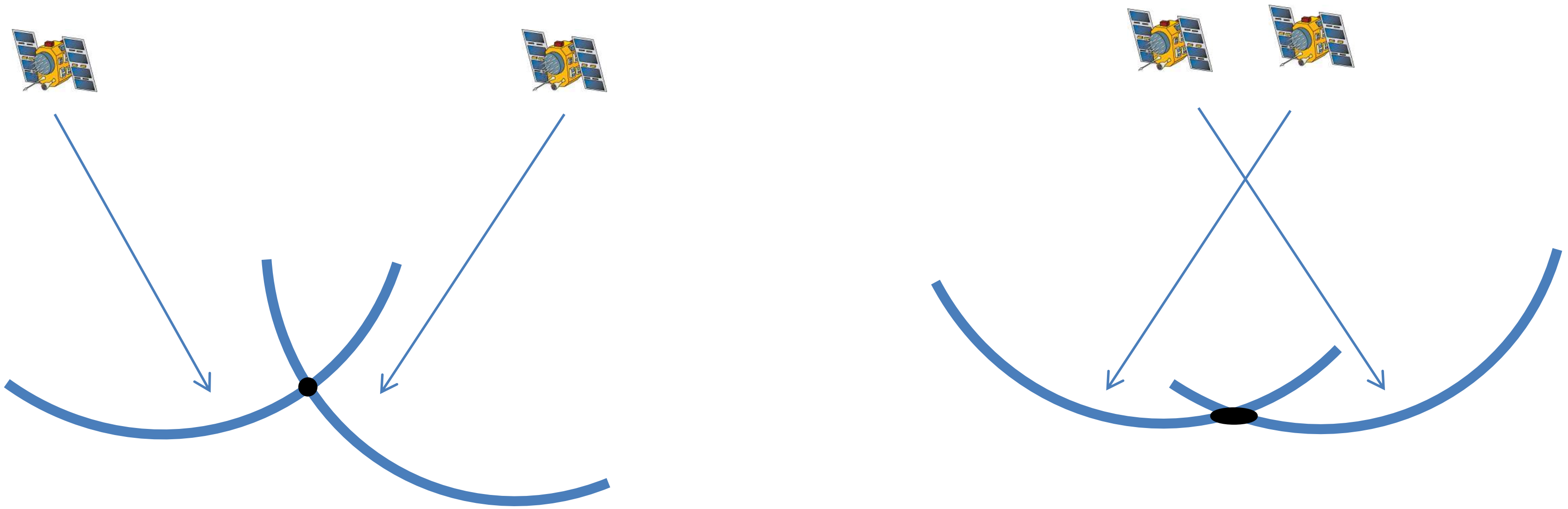
- Atmospheric effects:
  - almost impossible to take estimate, but it cause only small error

- Multipath error may also a problem



the speed of light varies!

Geometric Dilution of Precision (GDOP)



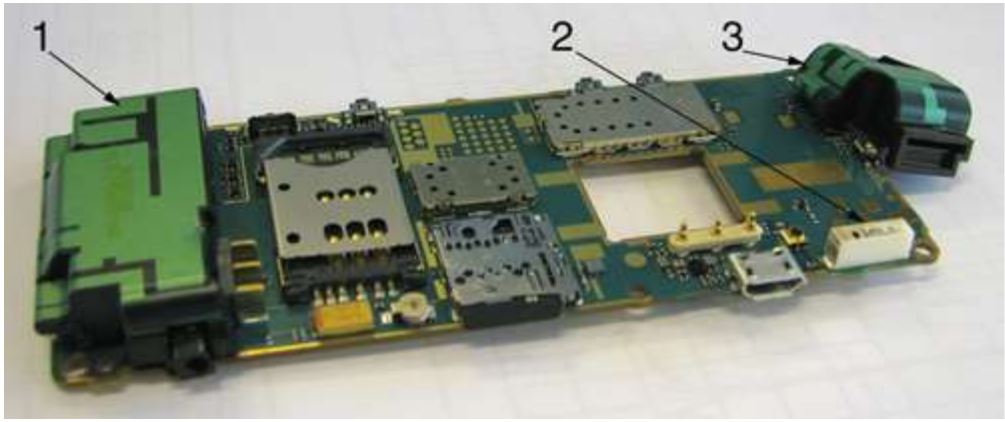
closer satellites : larger uncertainity

Receivers

- The GPS signal level is similar than the background noise
- The antennas in the reseivers are small, they have low gain
- Pseudo-random code allows to detect low-level signals
- Therefore received data speed is slow
- All satellites can use the same frequency – the difference is that each satellite has its own pseudo-random code

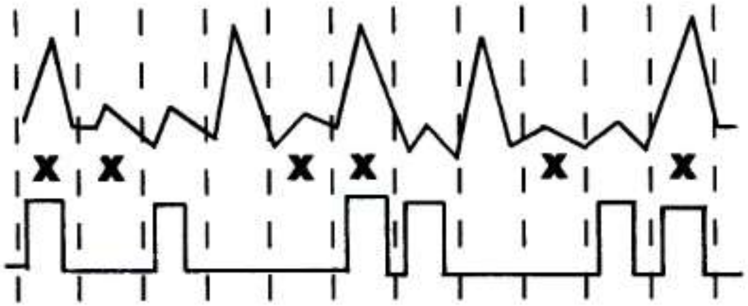
L1 band (1575.42 MHz) / L2 band (1227.60 MHz)

bi-quad antenna



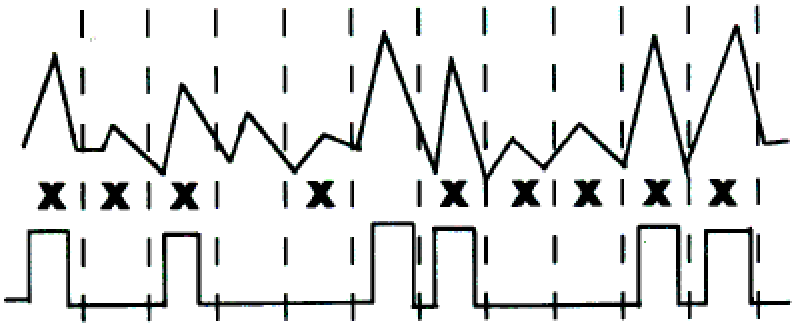
1. GSM/WCDMA antenna 2. Wi-Fi/Bluetooth combined ceramic chip antenna 3. GPS antenna

The received GPS signal



Received data (bad correlation)

Pseudo-random code (PRN)



Received data (good correlation)

Pseudo-random code (PRN)

Data XOR PRN -> BPSK modulated carrier

L1 channel, 50bit/sec, 1500 bits, 30sec to transmit