International Committee on Global Navigation Satellite Systems

GNSS, How it Works and Applications

Historic Navigation

- Reference points in the sky used for navigation
  - The Sun
  - The Pole Star / North Star
  - Southern Cross

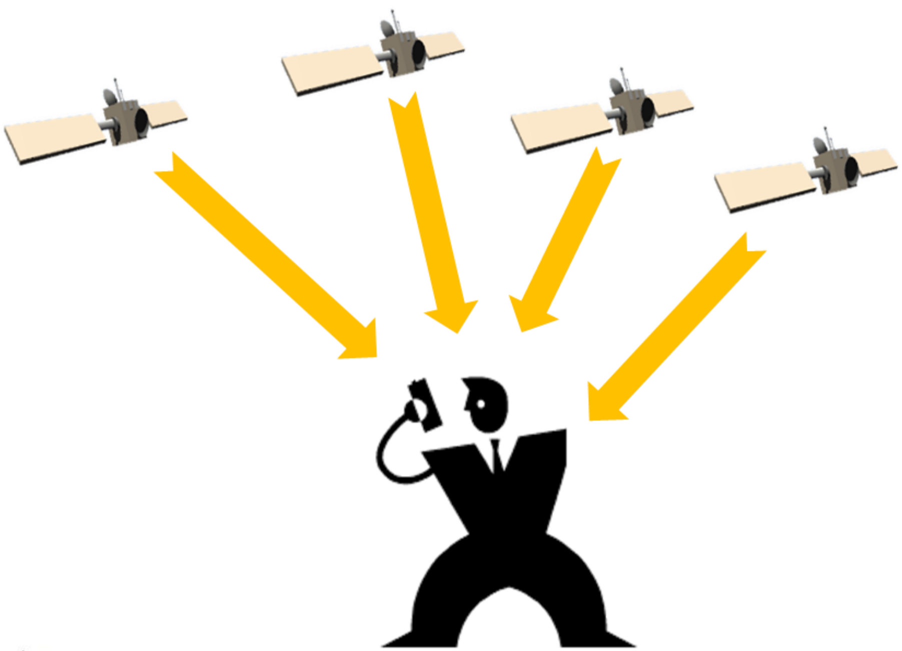
- Gives Direction, but not position

- Add a sextant to give latitude

- And a clock to give longitude

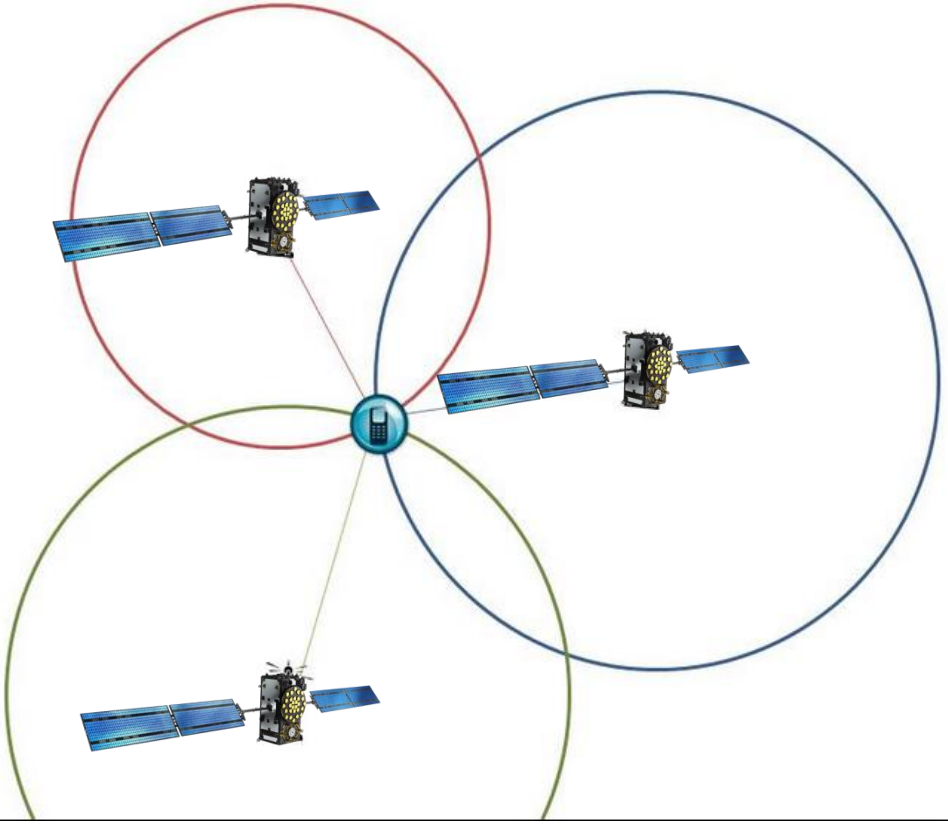
GNSS Principles

- GNSS satellites in the sky are the new reference points
- If my GNSS receiver "sees" 4 or more satellites, it can compute my position
  - "see" means track and process navigation signals



Satellites as Accurate Reference Points

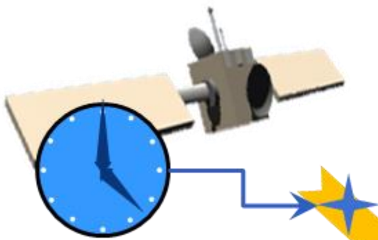
- GNSS signals contain information about the satellites' positions
  - very accurate reference points
- Measure the distance from the satellites to the receiver
- Knowing at least three distances from three reference points gives position

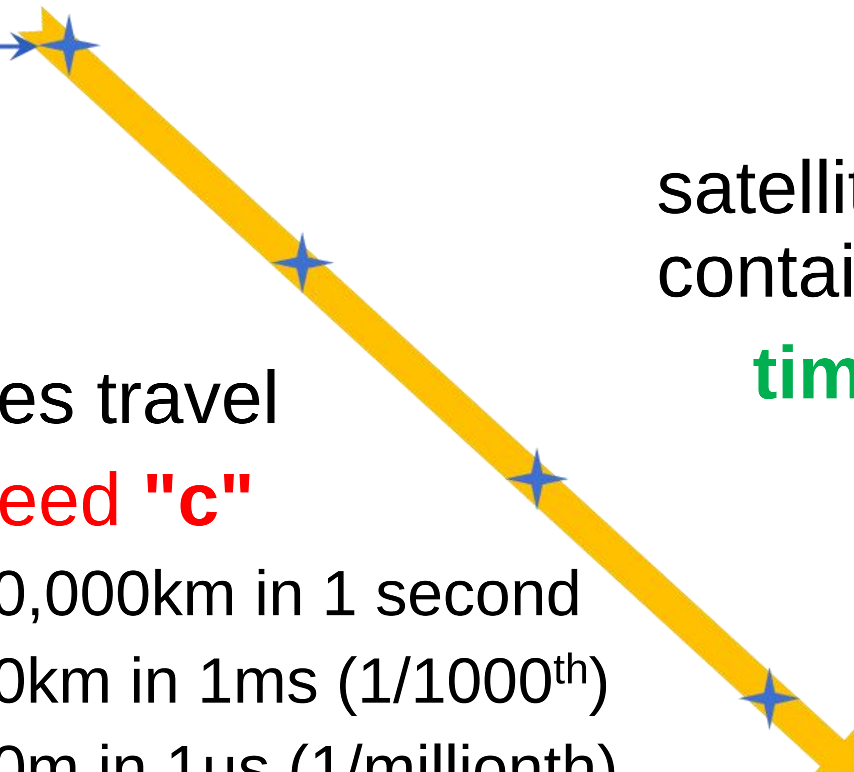


How do you measure distance?

speed = distance / time

⇨ **distance = speed x time**





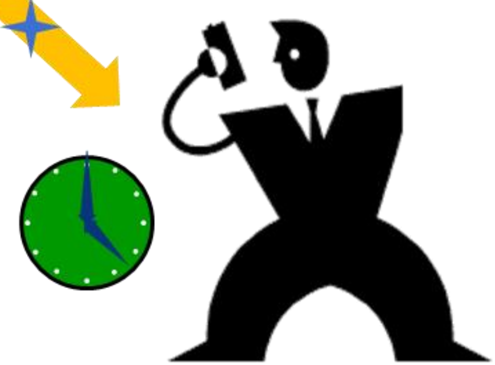
satellite signals contain 'time stamps'

time = $t_{sent} - t_{received}$

radio waves travel

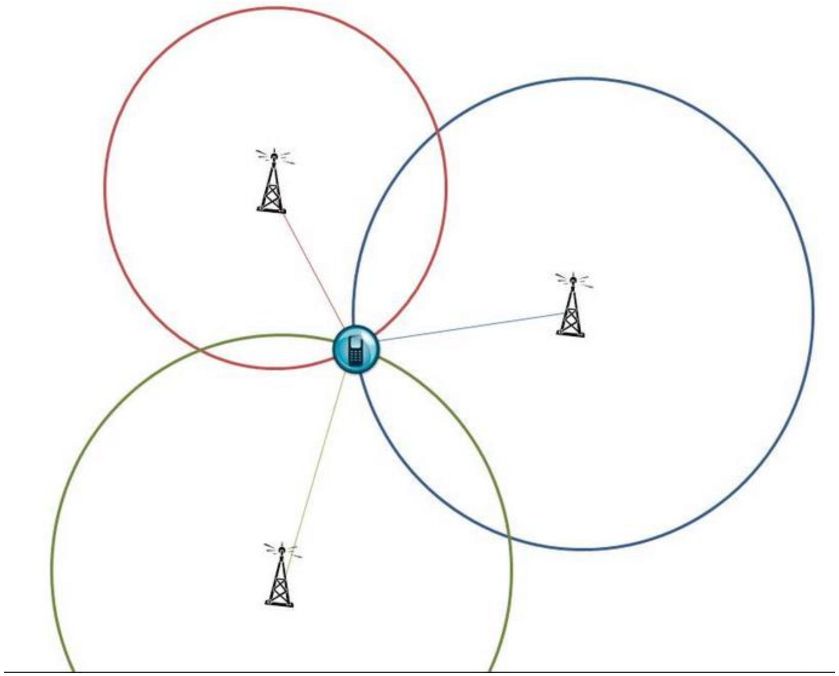
at light speed **"c"**

- 300,000km in 1 second
- 300km in 1ms (1/1000th)
- 300m in 1μs (1/millionth)
- 300mm in 1ns



Compute position

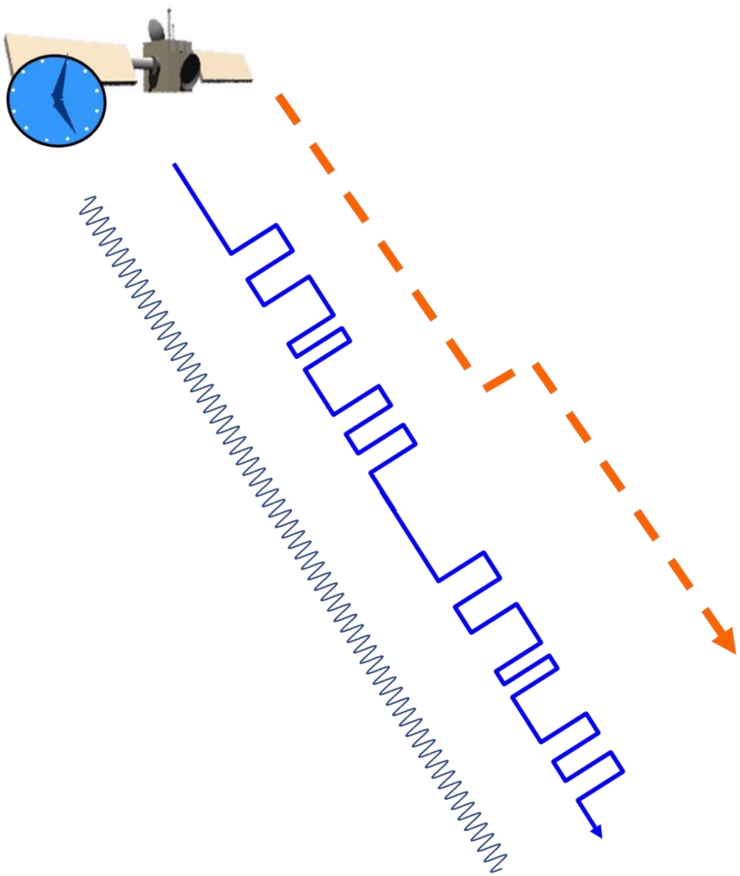
distance = speed x time



- **speed** = 3×10^8 m/s
- **time** = $t_{sent} - t_{received}$

- but, receiver time not accurately known
- so the time stamp from a fourth satellite is measured
- compensates for the missing receiver time

Example GNSS Signal



- radio frequency at "L-band"
  - typically 1575MHz
- at satellite: signal energy spread by a code
- at receiver: spread signal energy is unlocked and refocused
  - "code gain"
- allows simple antennas to receive low power signals

- and to share the frequency with other satellites/systems

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Position relative to?

- A position is pointless without having a ground reference
- A world reference is used, eg WGS84
  - World Geodetic System 1984
- Allows position fix to be placed on a World grid
- Maps can be referenced to the same grid
- you can determine where you are on a map

What is GNSS used for?

PNT

- Positioning… surveying and mapping
  - – location based services
  - – air traffic management
  - – search and rescue
- Navigation… a given. cars, ships, cranes
  - – remember GNSS gives position, you still need reliable/up-to-date maps and routing software
- Timing?... most large networks synchronised
  - – telecoms
  - – electricity distribution
  - – banking… microseconds matter for transactions!

What about?

- Monitoring sea/lake/snow levels
  - uses GNSS reflections seen into a fixed receiver
- Atmospheric measurements
  - GNSS signals change as they pass through atmosphere: air quality, gaseous content, etc
- Space weather monitoring
  - measuring changes in the ionosphere
- Soil and vegetation moisture measurements
- Volcanic plume density measurements
  - atmospheric ash uncertainty after eruptions
- Sea surface roughness, wind direction and more
- Earthquake/tsunami monitoring….

etc, etc……

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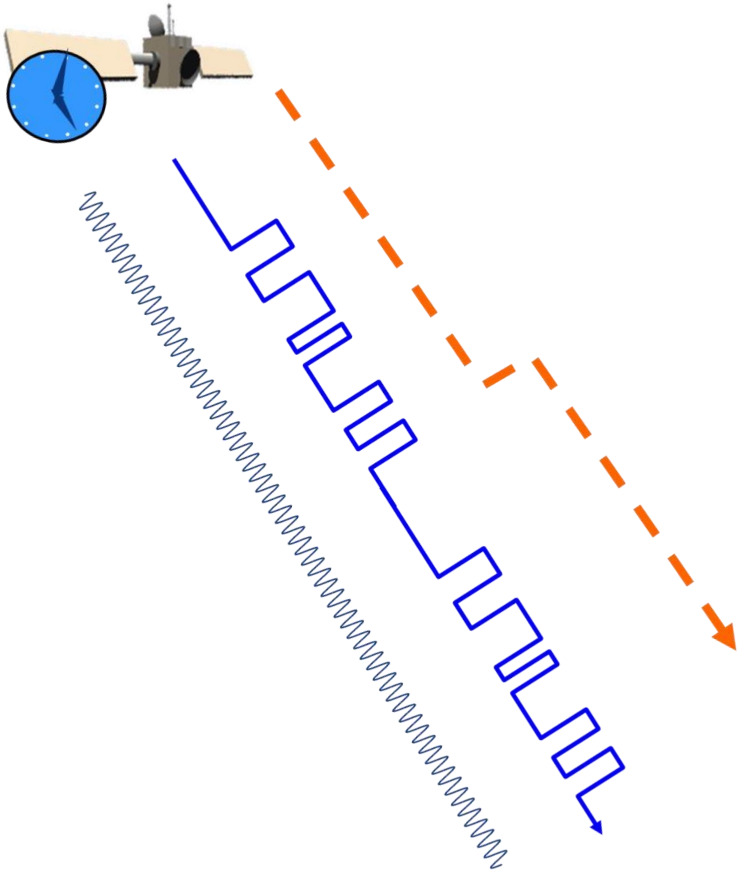
GNSS compared to terrestrial signals (why GNSS is vulnerable)

GNSS signal power



- radio waves disperse energy as they propagate
- satellites are 23,000km away
- signal emitted at about 30W
- signal strength proportional to: $^{1}/_{distance^2}$
- at 23,000 km, GNSS signal reduced by a factor of about 10^{18} !
- Imagine trying to see a lightbulb 23,000km away

- signal levels are below the natural background radiation

Terrestrial signal powers

- mobile phone base station
  - typical transmit power,10-100W
  - signal power reduction depends on range
  - at 10km, signal power reduced by factor of 10^{11}
  - at 1km, reduced by 10^{9}

  compared to the GNSS signal (10^{18} reduction) it is over billion times stronger
- mobile phone, typical transmit power, 0.1-1W connected to a cell tower at 1km
  - typical signal reduction 10^{9}

  still over a million times stronger than the GNSS signal!

Expected receiver signal power levels

- GNSS receivers expect to receive and can operate at signal levels even below the natural background radiation level, the "noise floor"
- **GNSS receivers** need a minimum power level "−130dBm"
  – GNSS receivers designed to work at these low levels
  – provided they are not overloaded by other signals
  – modern GNSS receivers can use even lower levels!

- **Mobile phones** (eg GSM) expect a minimum "−104dBm"
  – around a thousand times higher than GNSS

Consequences of the different levels

- The large difference between GNSS and mobile signal levels make GNSS receivers comparatively more susceptible to interference
    - mobile network devices also have the luxury of being able to raise their power levels in steps to cope with obstructions and poor radio environments - GNSS cannot, the low power level is fixed
- If GNSS signals shared frequencies with mobile systems, they would be swamped by interference
- GNSS reception would not be possible

How do you avoid interference?

- To avoid such interference, the **Radio Regulations*** separate different types of services (eg terrestrial mobile, satcoms, TV) into different frequency bands
  - eg mobile at 900MHz
  - TV at 600MHz
  - satcoms at 1650MHz
  - GNSS at 1575MHz
- However, when high power services operate in nearby frequencies, interference to GNSS is still possible (covered later)

* the Radio Regulations is treaty text agreed between the 195 member states of the International Telecommunication Union