

# Satellite Navigation segments

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- ❑ Global Navigation Satellite Systems
- ❑ Horizontal positioning accuracy up to 5m, anywhere in the world in open sky conditions
- ❑ Nano-second timing
- ❑ Sovereign capability
- ❑ Multiple use
- ❑ Free to use signals
- ❑ Driver for economic activity
- ❑ Critical Infrastructure

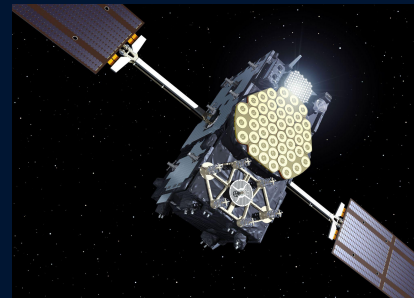
**GPS III** 



**BEIDOU** 



**GALILEO** 



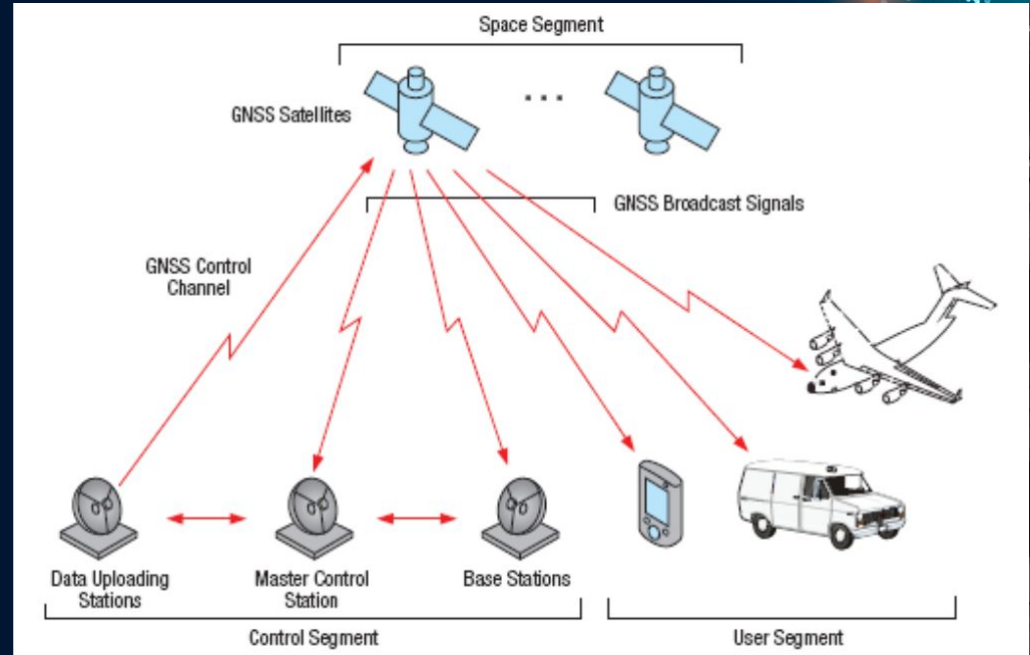
**GLONASS** 



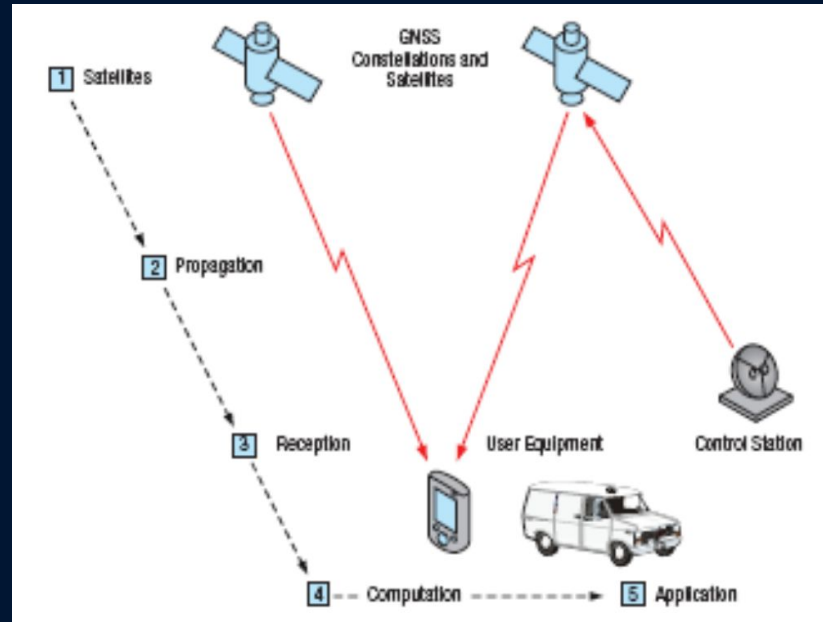
# Architecture

GNSS satellite systems consists of three major components or “segments”:

- Space Segment
- Control Segment
- User Segment



# Basic GNSS Concepts

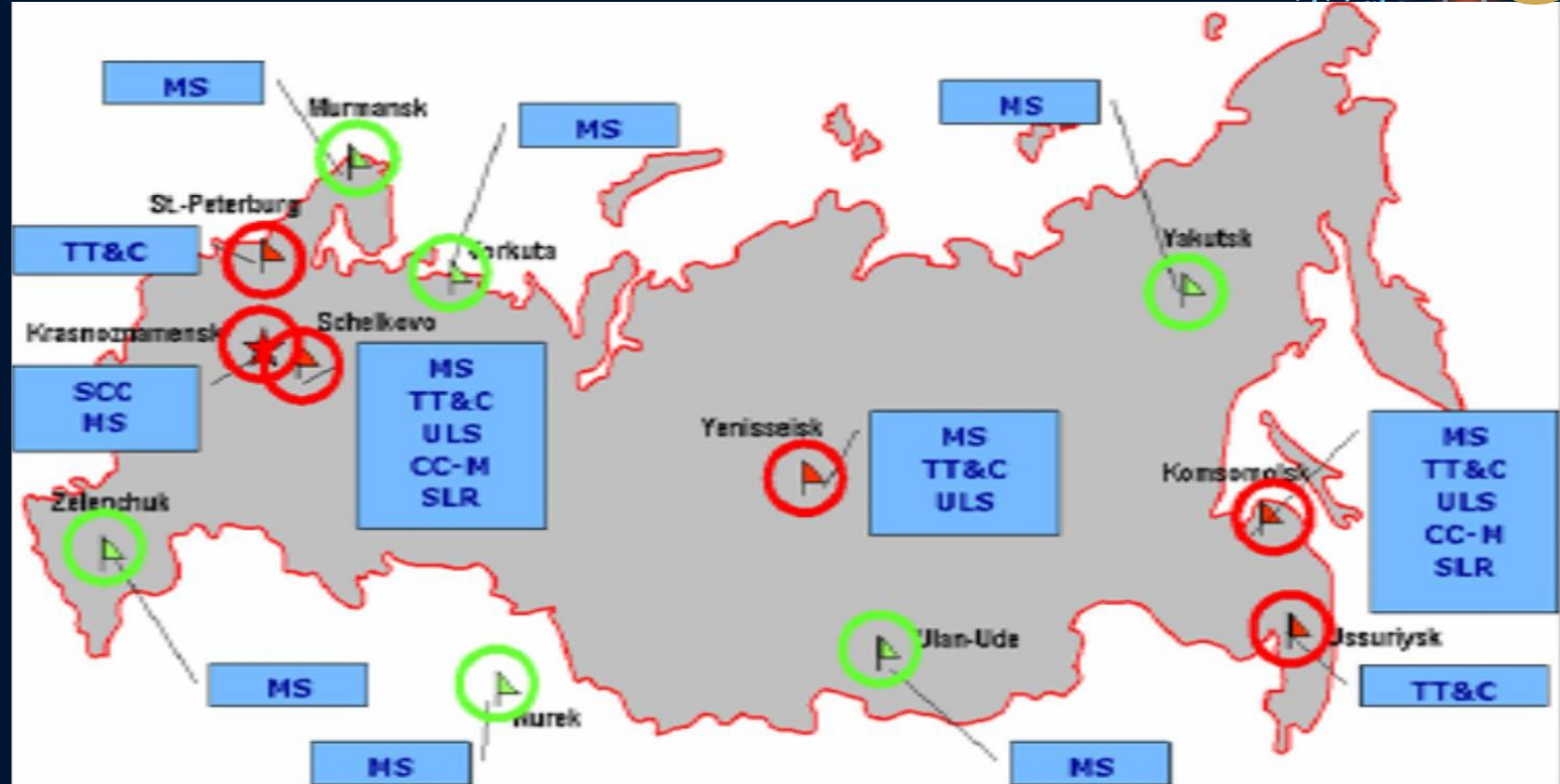


The above figure shows the steps involved in using GNSS to determine time and position then applying the information.

# GPS Control Segment



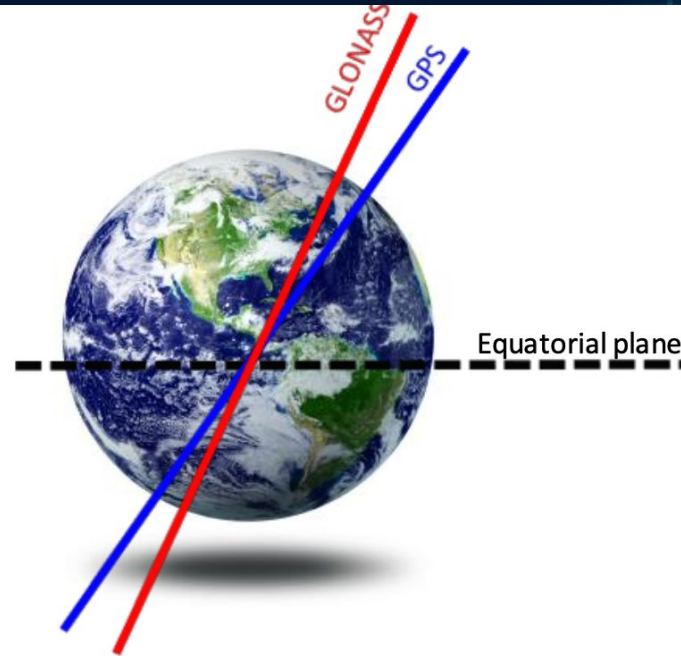
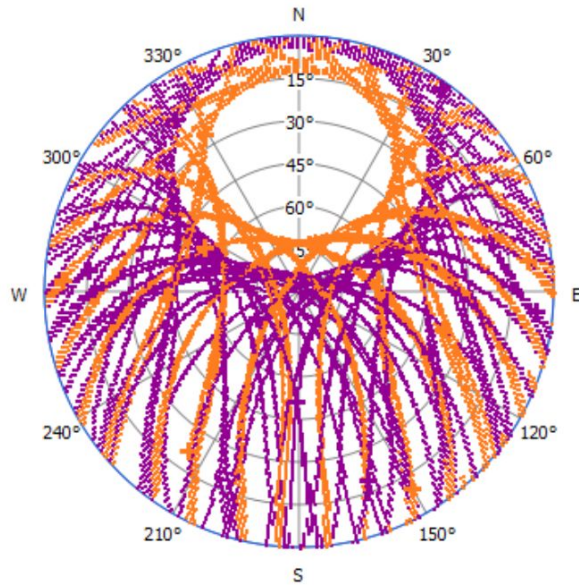
- ❑ Master Control Station (MCS): satellite control, system operations
- ❑ Alternate Master Control Station (AMCS, Vandenberg AFB, 2004)
- ❑ Monitor Station (MS): Collect range data, monitor navigation signal
- ❑ NIMA Tracking Station (TS): Collect range data, monitor nav signal
- Ground Antenna (GA): Transmit data/commands, collect telemetry



# GLONASS Satellite Coverage



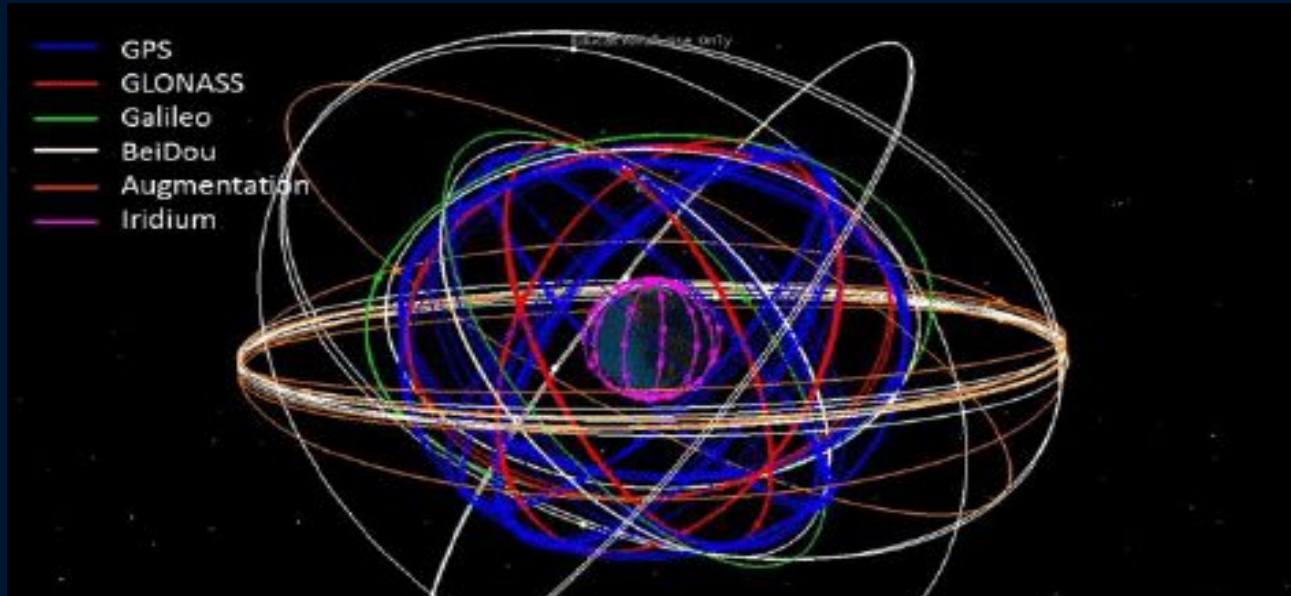
GLONASS improves satellite coverage over GPS at higher latitudes due to the different inclination.



<https://igs.org/>



- ❑ Provide world-wide coverage, 24 or more MEO satellites
- ❑ Rely on timing synchronisation; and ranging
- ❑ Should be interoperable
- ❑ Main systems are GPS, GLONASS, BEIDOU & GALILEO
- ❑ Consist of MEO, GEO, GSO & IGSO





### ➤ Low Earth Orbit (LEO)

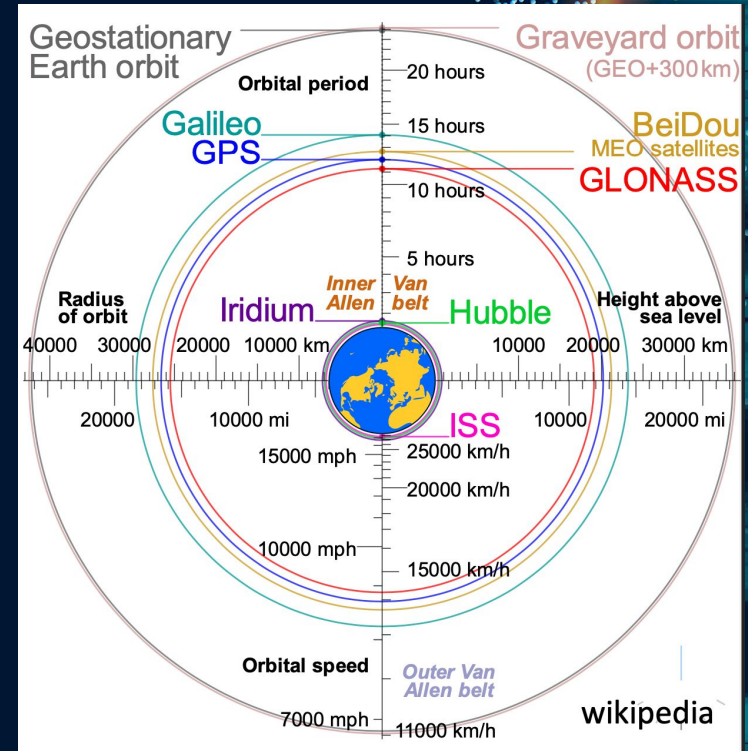
- Altitude of less than 2000 km, ISS, space shuttle, cube-sats, EO, mega-constellations, StarLink etc
- Fast ground repeats

### ➤ Medium Earth Orbit (MEO)

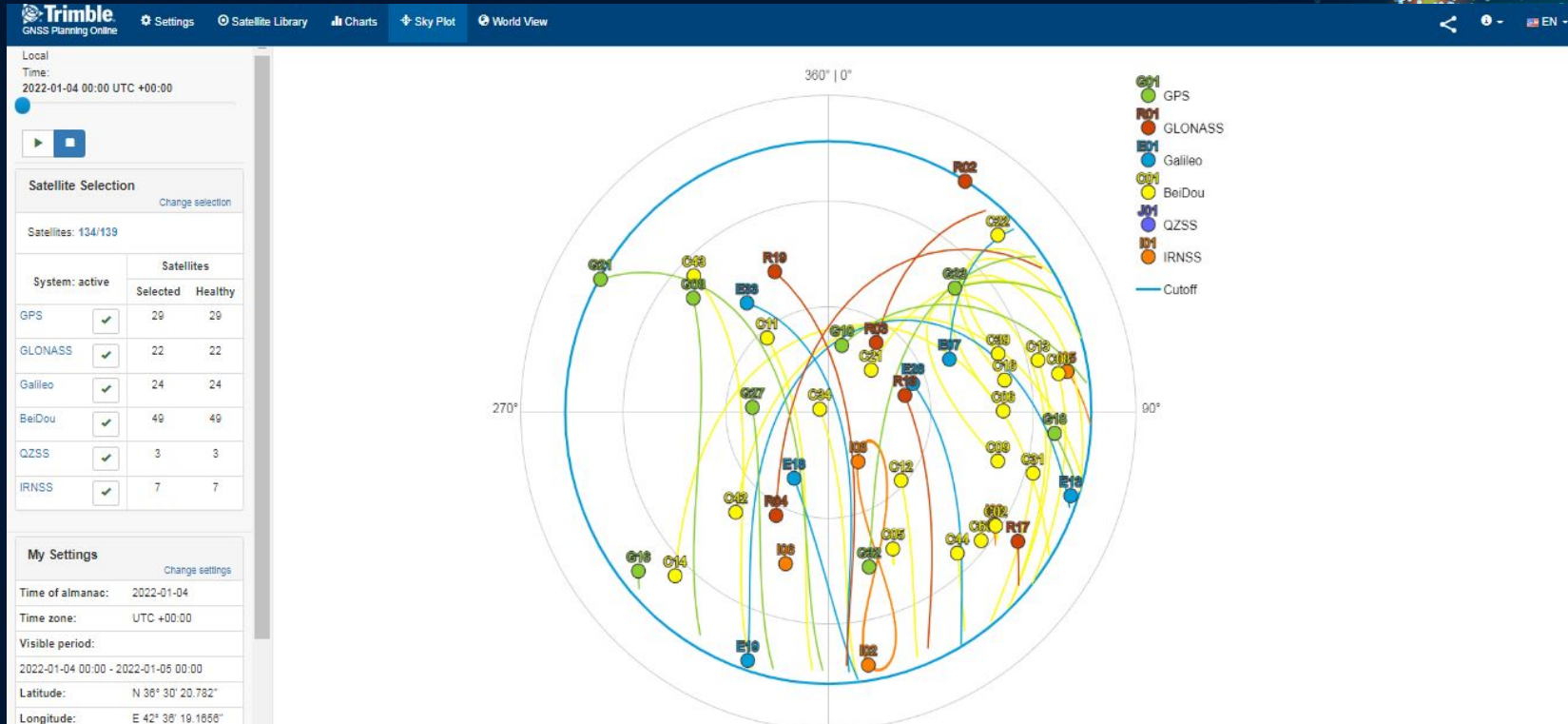
- Altitude above 2000km,
- Typically, navigation
- GPS (20,000km), Galileo (23,000km)
- Global coverage

### ➤ Geostationary Earth Orbit (GEO)

- Altitude of 32,000km
- Typically Comms, Navigation and EO
- Uninterrupted coverage



# www.gnssplanningonline.com

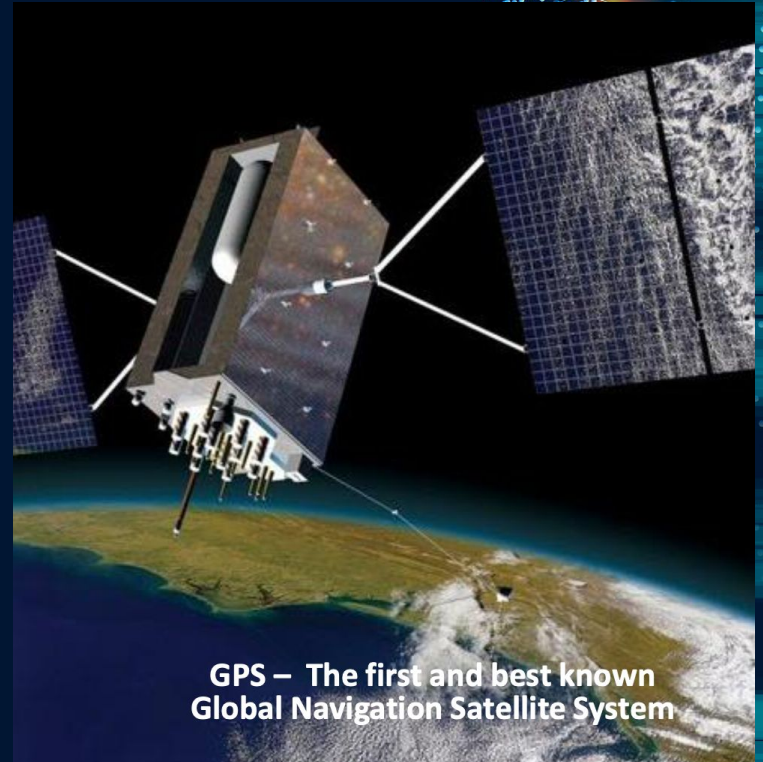


# GNSS



## Position, Navigation & TIMING

- ★ Atomic clocks on board GPS satellites are stable to within 1 part in  $10^{12}$
- ★ An observer would have to watch a GPS clock for  $10^{12}$  seconds (32,000 years) to see it gain or lose a single second.



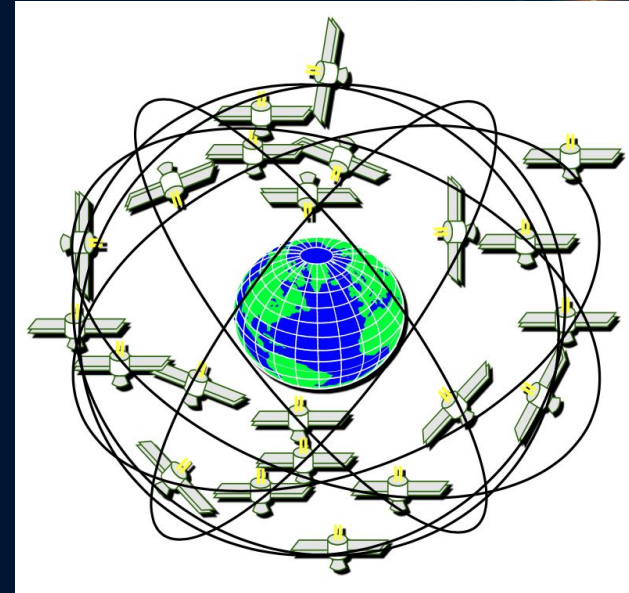
# Satellites - Timing



- ❑ Multiple GNSS constellations
- ❑ GNSS satellites know their time and orbit ephemerides very accurately
- ❑ Timing accuracy is very important. The time it takes a GNSS signal to travel from satellites to receiver is used to determine distances (range) to satellites
- ❑ 1 microsecond = 300m, 1 nanosecond = 30 cm.
- ❑ Small deviations in time can result in large position errors

# Global Positioning System

- 24 Satellites
- 6 Orbital planes
- 55° Inclination
- 20200 km above the Earth
- 12 hour orbits



# User segments

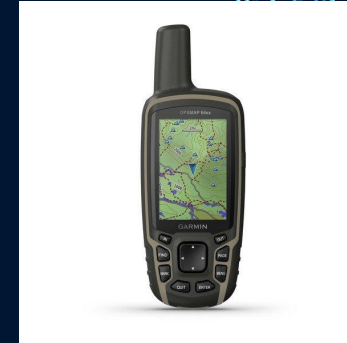
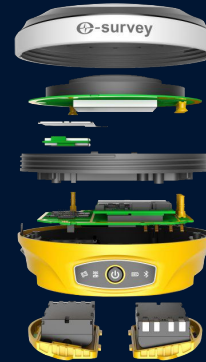
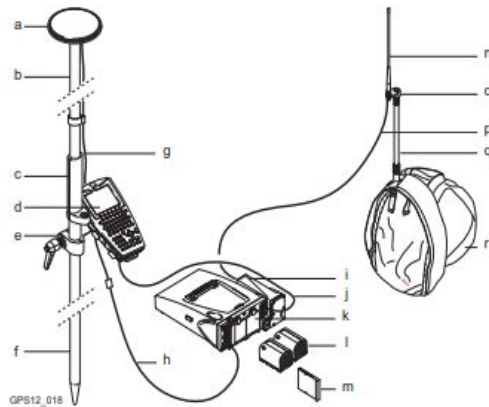


## 2.6 Real-Time Rover, Pole and Minipack

### Use

The equipment setup described below is to be used for a real-time rover with extended periods of use in the field. Raw observation data may also be collected for post-processing.

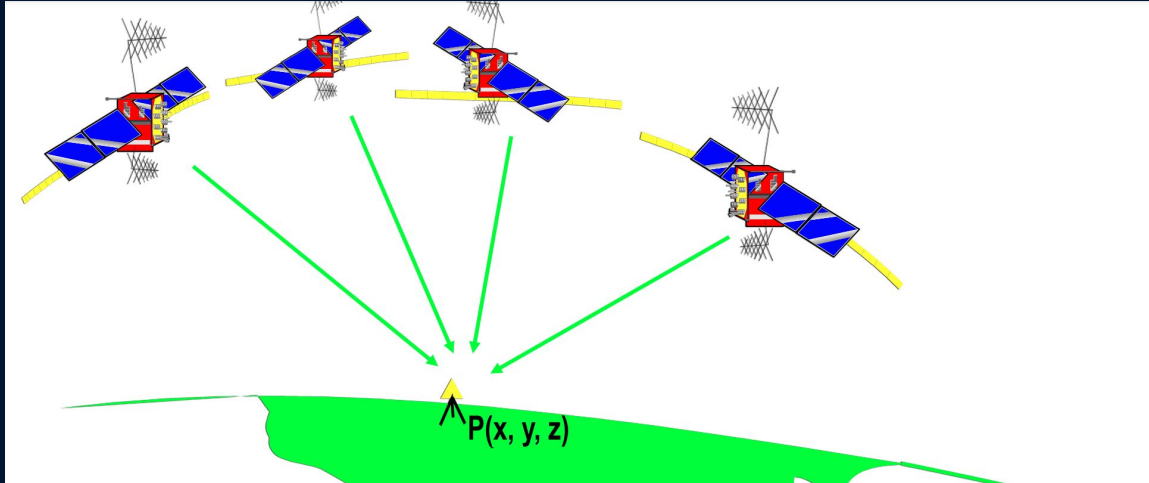
### Equipment setup



- ☐ A - Gns antenna
- ☐ <https://geodesy.noaa.gov/ANTCAL/>
- ☐ B - gns receiver
- ☐ 1 gns board
- ☐ 2 main board
- ☐ 3 gns firmware
- ☐ 4 operating system
- ☐ B - handheld
- ☐ 1 operating system
- ☐ 2 field software



# Global Positioning System Concept



User measures distance to four satellites

Satellites transmit their positions in orbit

User solves for position ( $X, Y, Z$  or  $\Phi, \lambda, h$ ) and clock error  $\Delta t$

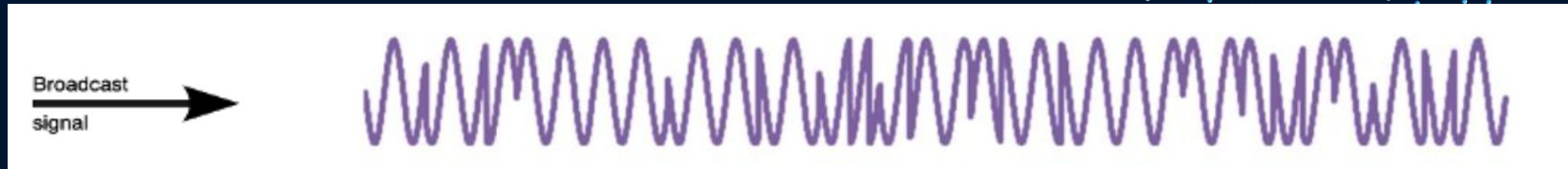
# GPS Standard Positioning Server (SPS)



L1 Carrier Wave, 1.575 MHz



Gold Code 1023 chip period, 1.023 Mchip/s, 1 ms repeat



Broadcast Signal (change of phase)



- ❑ Two/Three L band carriers

L1 1575.42 MHz

L2 1227.60 MHz

(L5 1176.45 MHz)

- ❑ Multiple spectrum modulated timing codes

|          |           |          |           |
|----------|-----------|----------|-----------|
| C/A code | 1.023 MHz | 1ms      | L1 only   |
| P code   | 10.23 MHz | 38 weeks | L1 and L2 |

- ❑ Navigation message

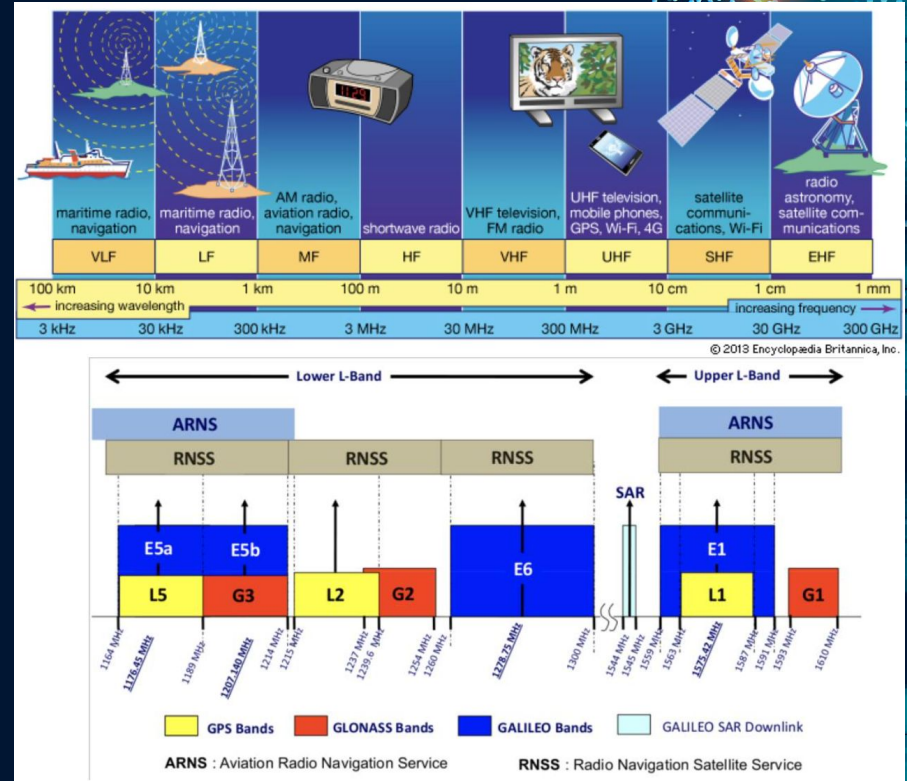
50 bps

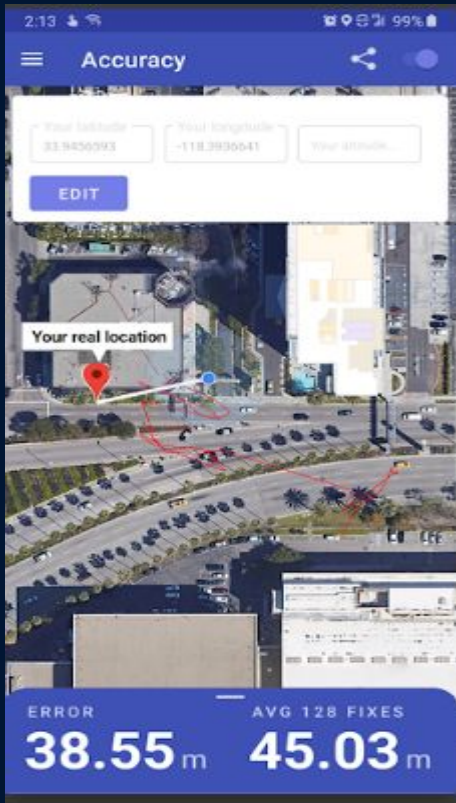
25 pages, 5 subframes

# GNSS Signals



GNSS signals are transmitted and received at low power in a narrow frequency range, they only work with a clear sky view, and they are easily vulnerable to **Jamming** and **Spoofing**





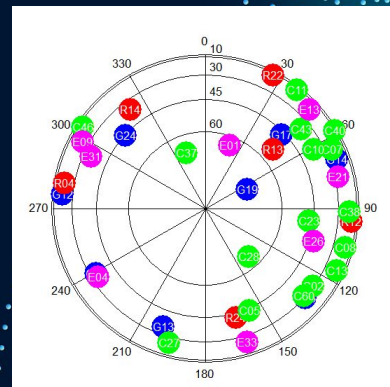
<https://play.google.com/store/apps/details?id=com.android.gpste&hl=en>





| #        | PRN            | Eleva...  | AZimuth | L1/... | L2/E2/E5A SNR | L5/E3/E5B SNR | ... | Satellite X   | Satellite Y   | Satellite Z  |
|----------|----------------|-----------|---------|--------|---------------|---------------|-----|---------------|---------------|--------------|
| 5        | G15            | 36.6      | 244.8   | 49.7   | 44.7          |               |     | 26140759.925  | 2814330.613   | 4433957.191  |
| 6        | G17            | 46.8      | 44.2    | 48.9   | 44.7          |               |     | 1811542.956   | 16392821.953  | 21251250.619 |
| 7        | G19            | 73.3      | 62.4    | 51.1   | 44.7          |               |     | 10766566.065  | 17724718.883  | 16435310.052 |
| 8        | G24            | 39.9      | 315.1   | 48.0   | 44.7          | 52.0          |     | 15777729.260  | -1114086.442  | 21073972.956 |
| 9        | R03            | 15.0      | 234.0   | 45.3   | 42.2          |               |     | 25121110.708  | -645041.841   | -4154007.891 |
| 10       | R04            | 21.5      | 285.4   | 46.1   | 44.3          |               |     | 20637377.788  | -6033803.015  | 12668907.570 |
| 11       | R12            | 19.6      | 90.8    | 43.7   | 39.9          |               |     | -6464157.869  | 23552941.472  | 7424591.978  |
| 12       | R13            | 52.3      | 39.6    | 40.4   | 41.4          |               |     | 4119946.007   | 14999939.105  | 20198794.835 |
| 13       | R14            | 31.6      | 321.4   | 50.3   | 45.0          |               |     | 12946919.338  | -3396911.229  | 21722939.020 |
| 14       | R24            | 41.9      | 164.6   | 51.6   | 46.6          |               |     | 15120256.087  | 20506951.643  | -1353295.367 |
| 15       | C02            | 31.7      | 124.4   | 41.7   | 46.4          | 41.2          |     | 4298823.960   | 41896547.593  | -648656.119  |
| 16       | C05            | 46.4      | 155.9   | 45.7   | 48.8          | 43.5          |     | 21830292.181  | 36022957.862  | -1271587.613 |
| 17       | C07            | 24.1      | 62.6    | 42.9   | 45.2          | 40.6          |     | -15242453.409 | 29406491.579  | 26016858.348 |
| 18       | C08            | 18.7      | 105.4   | 39.3   | 46.7          | 40.0          |     | -9963995.119  | 40993693.577  | 2155789.294  |
| 19       | C10            | 35.5      | 58.3    | 44.5   | 46.8          | 43.0          |     | -7820954.639  | 29344130.403  | 29342110.863 |
| 20       | C11            | 13.3      | 37.6    | 41.2   | 47.6          | 40.5          |     | -11185242.013 | 10514521.454  | 23374820.016 |
| 21       | C13            | 18.8      | 115.0   | 41.6   | 46.0          | 40.1          |     | -6092770.503  | 41775782.536  | -2760247.624 |
| 22       | C23            | 49.3      | 89.5    | 52.0   | 51.5          | 50.0          |     | 3691769.046   | 24380684.477  | 13074244.649 |
| 23       | C27            | 24.8      | 195.8   | 47.9   | 45.0          | 44.6          |     | 22688929.045  | 13663380.136  | -8779772.004 |
| 24       | C28            | 65.4      | 138.7   | 53.2   | 52.1          | 50.6          |     | 14247926.695  | 22349701.227  | 8743927.332  |
| 25       | C37            | 62.2      | 339.2   | 53.2   | 52.7          | 50.5          |     | 14286079.771  | 8833944.452   | 22297781.061 |
| 26       | C38            | 19.3      | 91.1    | 38.2   | 41.0          | 37.7          |     | -14251015.812 | 38475851.262  | 10131233.488 |
| 27       | C43            | 36.3      | 50.1    | 50.2   | 47.9          | 46.6          |     | -2859036.572  | 17689536.004  | 21399887.416 |
| 28       | C46            | 13.1      | 303.3   | 43.3   | 44.0          | 42.8          |     | 16532639.055  | -13145143.424 | 18212522.609 |
| 29       | C60            | 32.9      | 130.3   | 48.5   | 49.0          | 45.8          |     | 7286709.652   | 41458696.446  | -2440695.416 |
| 30       | E01            | 61.0      | 13.9    | 50.9   | 51.1          |               |     | 9931994.169   | 13580591.346  | 24354856.419 |
| 31       | E04            | 36.9      | 242.3   | 45.9   | 50.6          |               |     | 29128834.459  | 3399782.086   | 3999696.391  |
| 32       | E09            | 22.5      | 302.3   | 43.6   | 45.0          |               |     | 19237081.463  | -10213122.366 | 20046627.041 |
| 33       | E13            | 20.1      | 47.3    | 43.6   | 45.9          |               |     | -10333001.197 | 15781410.194  | 22820385.765 |
| 34       | E21            | 27.9      | 72.2    | 46.8   | 44.3          |               |     | -6961114.320  | 23859853.562  | 16075493.170 |
| 35       | E26            | 42.1      | 107.0   | 48.4   | 50.0          |               |     | 3566252.362   | 28228926.289  | 8179822.867  |
| 36       | E31            | 32.6      | 294.6   | 47.8   | 47.1          |               |     | 22291271.268  | -5752052.742  | 18605059.469 |
| 37       | E33            | 24.5      | 163.1   | 45.2   | 45.2          |               |     | 14512896.850  | 23901899.198  | -9689489.599 |
| Sky Plot | Satellite List | SNR Graph | Error   |        |               |               |     |               |               |              |

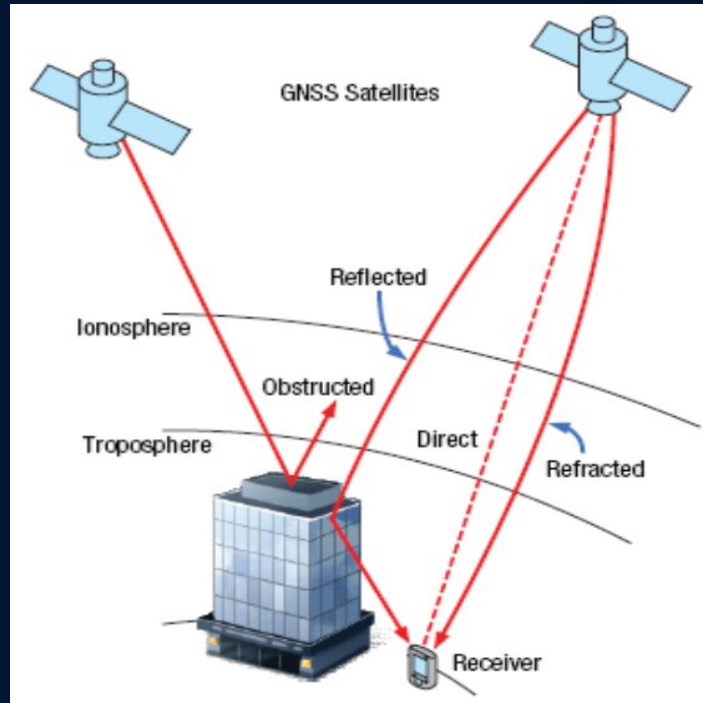
| GPS | GLONASS | Galileo | BeiDou |
|-----|---------|---------|--------|
| 8   | 8       | 8       | 14     |
| 8   | 7       | 8       | 14     |
| 7   | 6       | 7       | 10     |
| 9   | 8       | 8       | 17     |
| 8   | 7       | 9       | 13     |
| 8   | 8       | 8       | 13     |
| 9   | 8       | 9       | 18     |



# Propagation



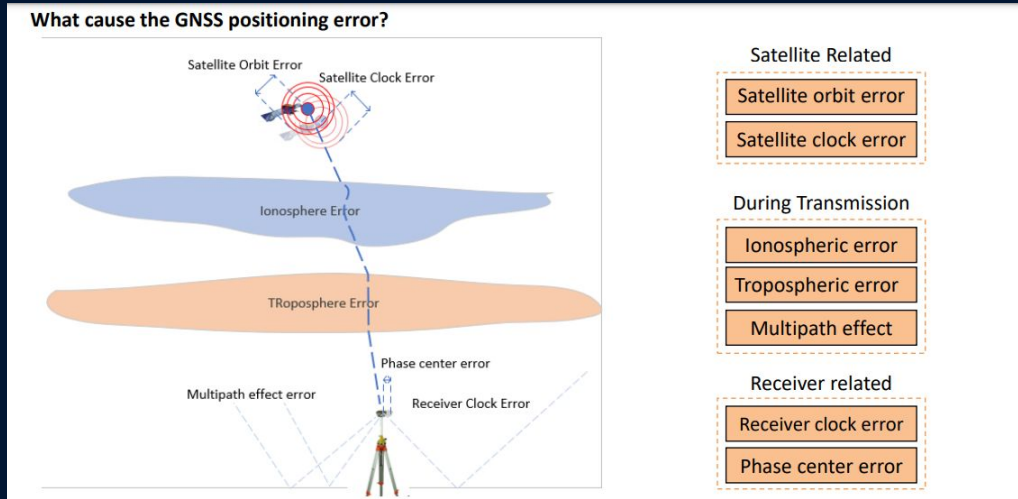
- ❑ GNSS signals pass through the near-vacuum of space, then through the various layers of the atmosphere to the earth, as illustrated in the figure below:



# Computation



- ❑ In summary, here are the GNSS error sources that affect the accuracy of pseudorange calculation:



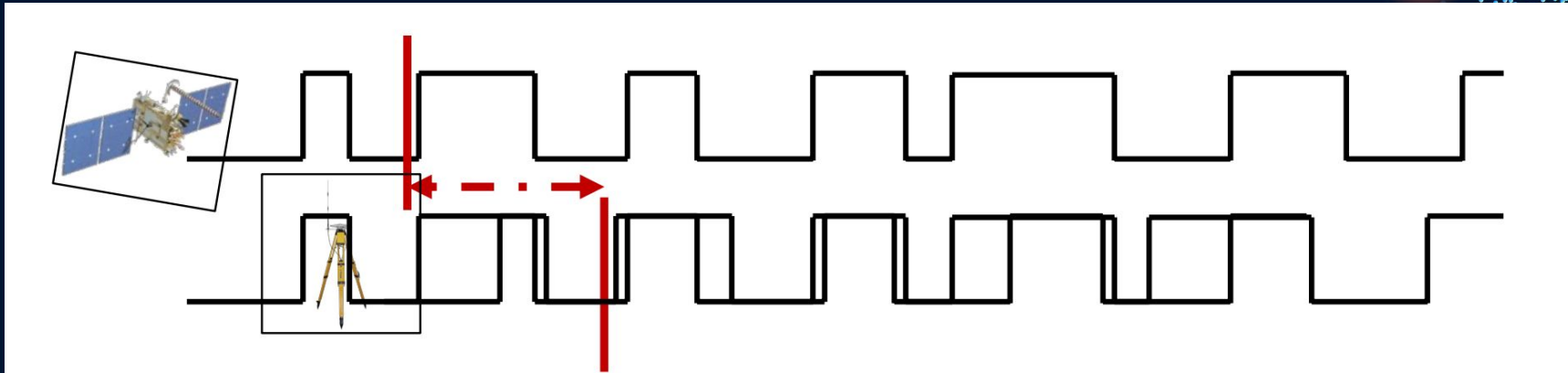
| Contributing Source | Error Range |
|---------------------|-------------|
| Satellite clocks    | $\pm 2$ m   |
| Orbit errors        | $\pm 2.5$ m |
| Ionospheric delays  | $\pm 5$ m   |
| Tropospheric delays | $\pm 0.5$ m |
| Receiver noise      | $\pm 0.3$ m |
| Multipath           | $\pm 1$ m   |

- ❑ The degree with which the above pseudorange errors affect positioning accuracy depends largely on the geometry of the satellites being used. This will be discussed later in this training.

# Code Based Positioning



- Each satellite transmits a unique “Gold” code or PRN
- Receiver superimposes the code with its own “local code” (from it’s ALMANAC]
- The receiver compares the code received from the satellite and the local receiver generated code to determine the ‘travel time’
- It does this by sliding and comparing the code at intervals



Measure the time difference between two unique elements in the pseudo random noise code (PRN) & multiply by the speed of light

# Positioning Methods



- 2 main observables for positioning
  - › CODE
  - › CARRIER



# Propagation



- ❑ To determine accurate positions, we need to know the range to the satellite. This is the direct path distance from the satellite to the user equipment
- ❑ The signal will “bend” when traveling through the earth’s atmosphere
- ❑ This “bending” increases the amount of time the signal takes to travel from the satellite to the receiver
- ❑ The computed range will contain this propagation time error, or atmospheric error
- ❑ Since the computed range contains errors and is not exactly equal to the actual range, we refer to it as a “pseudorange”

# Propagation



- ❑ The ionosphere contributes to most of the atmospheric error. It resides at 70 to 1000 km above the earth's surface.
- ❑ Free electrons resides in the ionosphere, influencing electromagnetic wave propagation
- ❑ Ionospheric delay are frequency dependent. It can be virtually eliminated by calculating the range using both L1 and L2
- ❑ The troposphere, the lowest layer of the Earth's atmosphere, contributes to delays due to local temperature, pressure and relative humidity
- ❑ Tropospheric delay cannot be eliminated the way ionospheric delay can be
- ❑ It is possible to model the tropospheric delay then predict and compensate for much of the error

# Propagation



- ❑ Signals can be reflected on the way to the receiver. This is called “multipath propagation”
- ❑ These reflected signals are delayed from the direct signal, and if strong enough, can interfere with the direct signal
- ❑ Techniques have been developed whereby the receiver only considers the earliest-arriving signals and ignore multipath signals, which arrives later
- ❑ It cannot be entirely eliminated

# Reception



- ❑ Receivers need at least 4 satellites to obtain a position. If more are available, these additional observations can be used to improve the position solution
- ❑ GNSS signals are modulated by a unique pseudorandom digital sequence, or code. Each satellite uses a different pseudorandom code
- ❑ Pseudorandom means that the signal appears random, but actually repeats itself after a period of time
- ❑ Receivers know the pseudorandom code for each satellite. This allows receivers to correlate (synchronize) with the GNSS signal to a particular satellite
- ❑ Through code correlation, the receiver is able to recover the signal and the information they contain

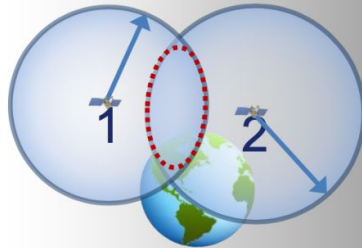


# Position Fixing (Trilateration)



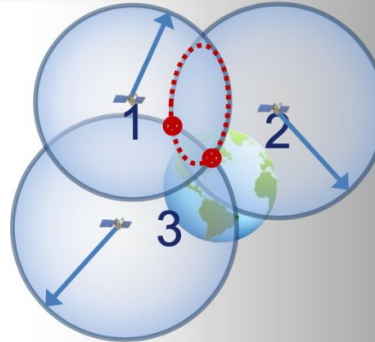
## 1 satellite:

- The receiver knows where the satellite is, and
- can calculate how far away it is based on the time delay, but
- does not know the direction to the satellite



## 2 satellites:

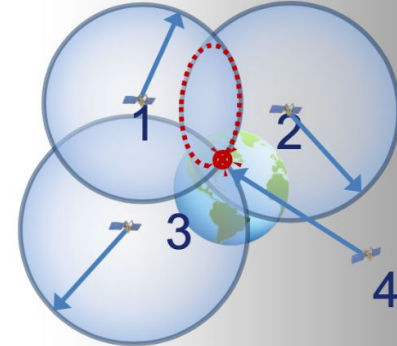
- The software in the receiver can combine the distances to reduce the possible position to somewhere on a circle



## 3 satellites:

- The software can further reduce the possible locations to just two – and one of them can be discounted because it will be improbable.
- So do we really need a fourth satellite?

*Time accuracy is important  
The travel time is short – the  
signal travels 20,000 km in  
0.075 seconds.*



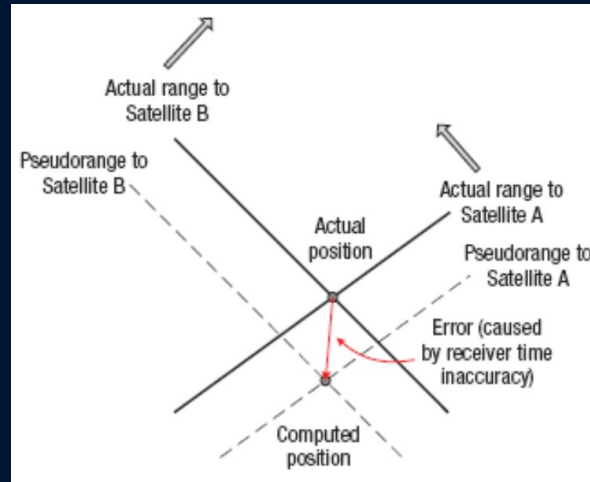
## 4 satellites:

- The clock in the receiver is much less accurate than the atomic clocks in the satellites – which are constantly being monitored and corrected by the ground station.
- The fourth satellite will correct the receiver clock to the same level of accuracy and make the position more accurate.

# Computation



- ❑ Due to receiver clock error, the intersecting points between the range of satellite A and B do not match with the actual position

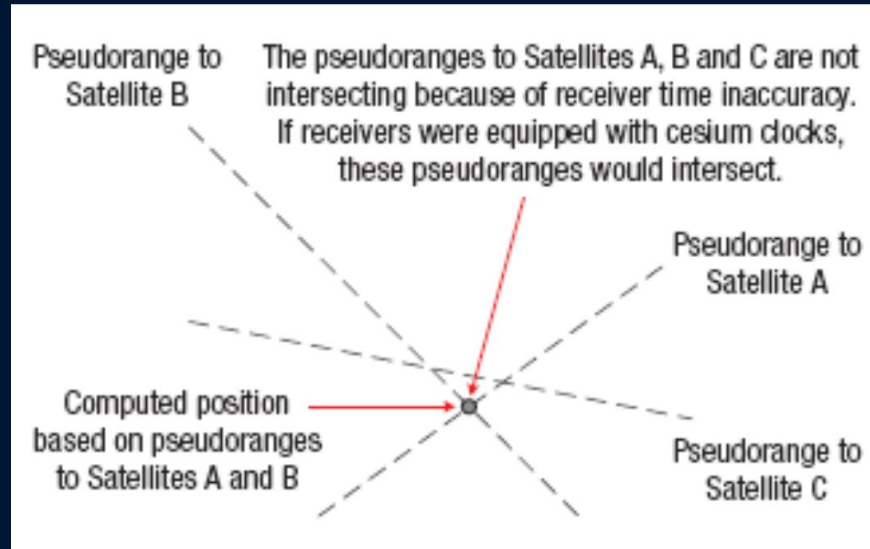


- ❑ Receiver clocks are not nearly as accurate as satellite clocks. Their typical accuracy is only about 5 parts per million.
- ❑ When multiplied by the speed of light, the resulting accuracy is within +/- 1500 meters

# Computation



- ❑ When we now compute the range of the third satellite, the points will not intersect to a single computed position

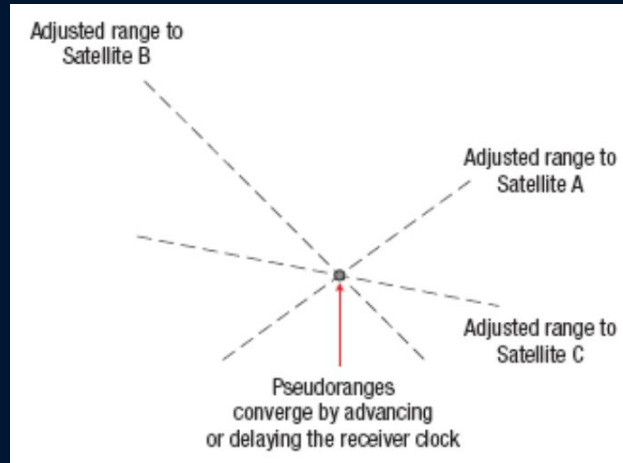


- ❑ The receiver knows that the pseudoranges to the three satellites do not intersect due to receiver clock errors

# Computation



- ❑ The receiver can advance or delay its clock until the pseudoranges to the three satellites converge at a single point

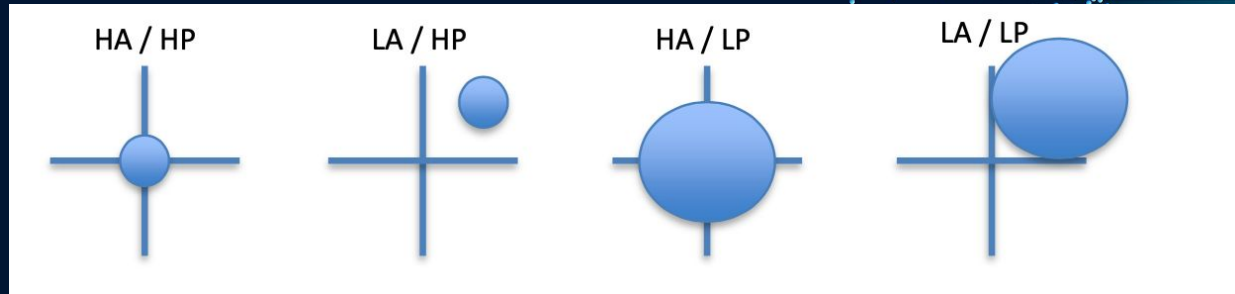


- ❑ Through this process, the satellite clock has now been “transferred” to the receiver clock, eliminating the receiver clock error
- ❑ The receiver now has both a very accurate position and a very accurate time
- ❑ When you extend this principle to a three-dimensional world, we will need the range of a fourth satellite to compute a position

# Required Navigation Performance (RNP)



- ❑ **Availability** is the percentage of time the position, navigation or timing solution that can be computed by the user. Values vary greatly according to the specific application and services used but typically range from 95 to 99.9%. We can speak of two types of availability:
  - › **System availability:** is what GNSS Interface Control Documents (ICDs) refer to.
  - › **Overall availability:** takes into account the receiver performance and the user's environment. Values vary greatly according to the specific use cases and services used.
- ❑ **Accuracy** is the difference between true and computed solution (position or time). This is expressed as the value within which a specified proportion –usually 95%- of samples would fall if measured. This report refers to positioning accuracy using the following convention: centimetre-level: 0-10cm; decimetre level: 10-100cm; metre- level: 1-10 metres.
- ❑ **High Accuracy vs High Precision .....**



# Required Navigation Performance (RNP)



- ❑ Continuity the ability of a system to perform its function (deliver PNT services with the required performance levels) without interruption once the operation has started. It is usually expressed as the risk of discontinuity and depends entirely on the timeframe of the application. A typical value is around  $1 \cdot 10^{-4}$  over the course of the procedure where the system is in use.
- ❑ Integrity is a term used to express the ability of the system to provide warnings to users when it should not be used. It is the probability of a user being exposed to an error larger than the alert limits without timely warning. The way integrity is ensured and assessed, and the means of delivering integrity-related information to users are highly application dependent. Throughout this report, the “integrity concept” is to be understood at large, i.e. not restricted to safety-critical or civil aviation definitions but also encompassing concepts of quality assurance/quality control as used in other applications and sectors.

# Other Key Requirements



- ❑ **Robustness** relates to spoofing and jamming and how the system can cope with these issues. It is a more qualitative than quantitative parameter that depends on the type of attack or interference the receiver is capable of mitigating. Robustness can be improved by authentication information and services.
- ❑ **Authentication** gives a level of assurance that the data provided by a positioning system has been derived from real signals. Radio frequency spoofing may affect the positioning system resulting in false data as output of the system itself.
- ❑ **Time To First Fix (TTFF)** is a measure of time between activation of a receiver and the availability of a solution, including any power on self-test, acquisition of satellite signals and navigation data and computation of the solution. It mainly depends on data that the receiver has access to before activation: cold start (the receiver has no knowledge of the current situation and must thus systematically search for and identify signals before processing them – a process that can take up to several minutes); warm start (the receiver has estimates of the current situation – typically taking tens of seconds) or hot start (the receiver understands the current situation – typically taking a few seconds).
- ❑ **High precision** GNSS systems dramatically improve precision using GNSS correction data to cancel out GNSS errors and give a sharply defined solution.

# Other Key Performance Parameters



- ❑ **Power consumption** is the amount of power a device uses to provide a position. The power consumption of the positioning technology will vary depending on the available signals and data. For example, GNSS chips will use more power when scanning to identify signals (cold start) than when computing a position. Typical values are in the order of tens of mW (for smartphone chipsets).
- ❑ **Resiliency** is the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions; includes the ability to recover from deliberate attacks, accidents, or naturally occurring threats or incidents. A resilient system will change its way of operations while continuing to function under stress, while a robust system at the end will reach a failure state without being able to recover.
- ❑ **Connectivity** refers to the need for a communication and/or connectivity link of an application to be able to receive and communicate data to third parties. Connectivity relies on the integration with both satellite and terrestrial networks, such as 5G, LEOs, or LPWANs.

# Other Key Performance Parameters



- ❑ **Interoperability** refers to the characteristic of a product or system, whose interfaces are completely understood, to work with other products or systems, in either implementation or access, without any restrictions (e.g. ability of GNSS devices to be combined with other technologies and the possibility to merge the GNSS output with the output coming from different sources).
- ❑ **Traceability** can be illustrated by a traceable measurement is one that can be related to national or international standards using an unbroken chain of measurements, each of which has a stated uncertainty. For Finance applications, knowledge of the traceability of the time signal to UTC is essential to ensure regulatory compliance at the time-stamp.
- ❑ **Calibration** is a term related to the calibration of a GNSS Timing Receiver. It is the process of measuring the different biases of the GNSS signals propagation through the antenna cable and equipment hardware in order to characterize them and take them into account when computing the timing solution.

# GNSS Overview

- ❑ Real-Time Signal for Navigation
  - › Range Measurements
- ❑ Accurate Timing
- ❑ Accurate Satellite Ephemeris
- ❑ Propagation Delay minimal or estimable
- ❑ Choice of Frequencies free from Interference
- ❑ **Calibration**



# Thank you for Your Participation

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