GNSS Standard Positioning Service

An introduction to the
GNSS Standard Positioning
Service

Finding a position using GNSS

The basic process stages for the Standard Positioning Service (SPS) are:

- Create the GNSS signal. Each GNSS satellite creates a signal which identifies the satellite, carries information about where the satellite is (navigation message), and includes a timing reference, using pseudorandom noise (PRN), that allows the receiver to work out its distance from the satellite.

- The receiving of the GNSS signal. A receiver has a number of channels. Each channel can process the data from one satellite.

- The decoding of the signal. The receiver decodes the navigation message and the distance message – pseudorandom noise (PRN) code.

- An algorithm is used to turn the navigation message into an X, Y, Z coordinate of the satellite.

- Another algorithm is used to get the pseudorange of the satellite to the receiver from the distance message.

- An algorithm turns the X, Y, Z coordinates and pseudoranges of several satellites into the X, Y, Z position of the receiver.

- Finally the receiver can translate the X, Y and Z coordinates into latitude, longitude and altitude (using reference frames).

Time: the time radio signals take to travel is crucial to the operation of GNSS.

This difference (0.0854 – 0.0667) of 0.0187 seconds is crucial to determining the position of the Observer

25,590km takes radio around 0.0854 seconds to reach the Observer

20,000km takes radio around 0.0667 seconds to reach the Observer

Observer

Observer's (receiver's) horizon

The speed of light (radio) c = 299,792 km/s

The Earth ~12,742km in diameter

The GPS Orbit ~20,000km above the surface of the Earth.
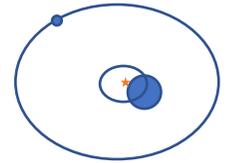
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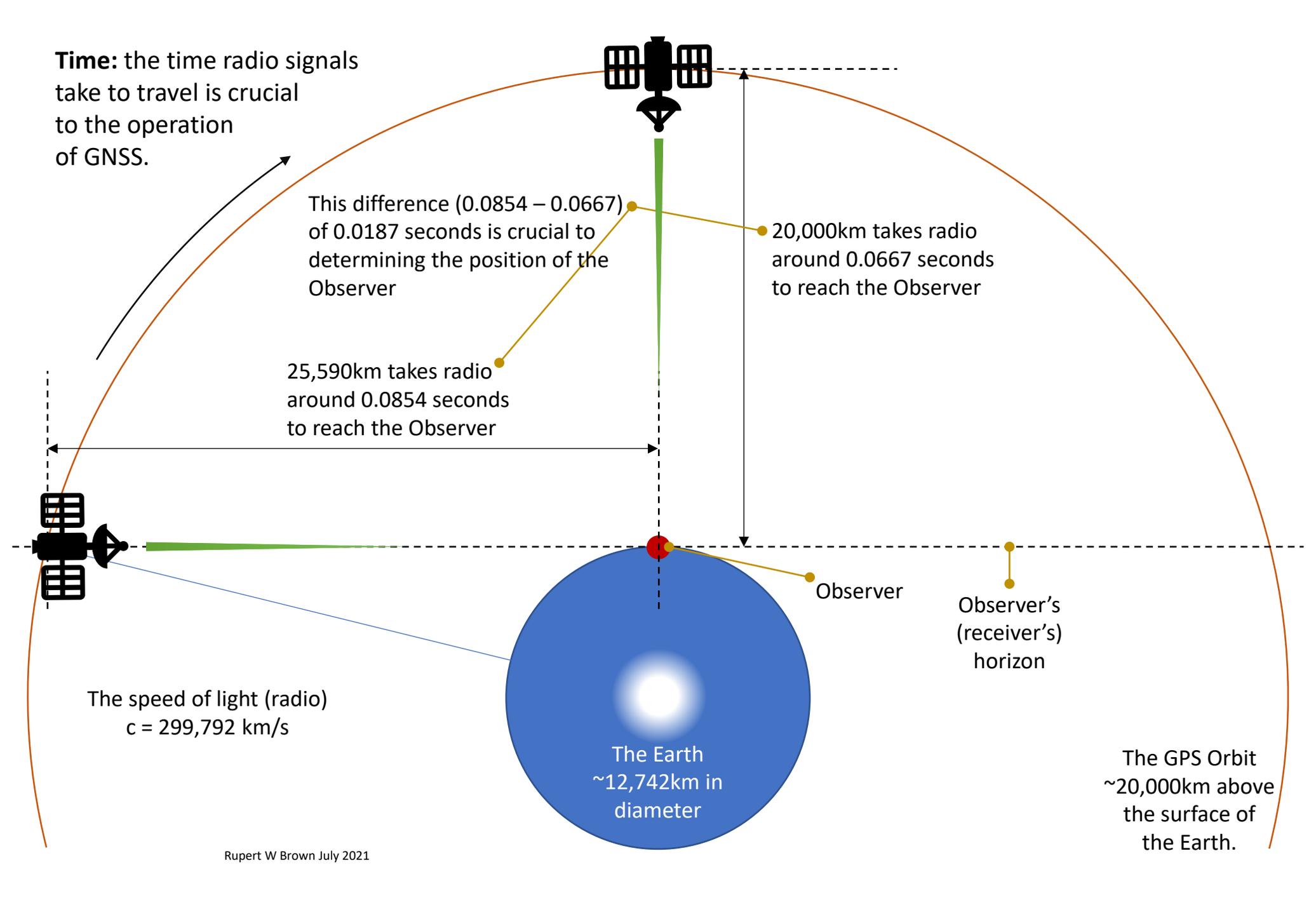
Location in orbit: specifying the location of a satellite – the navigation message

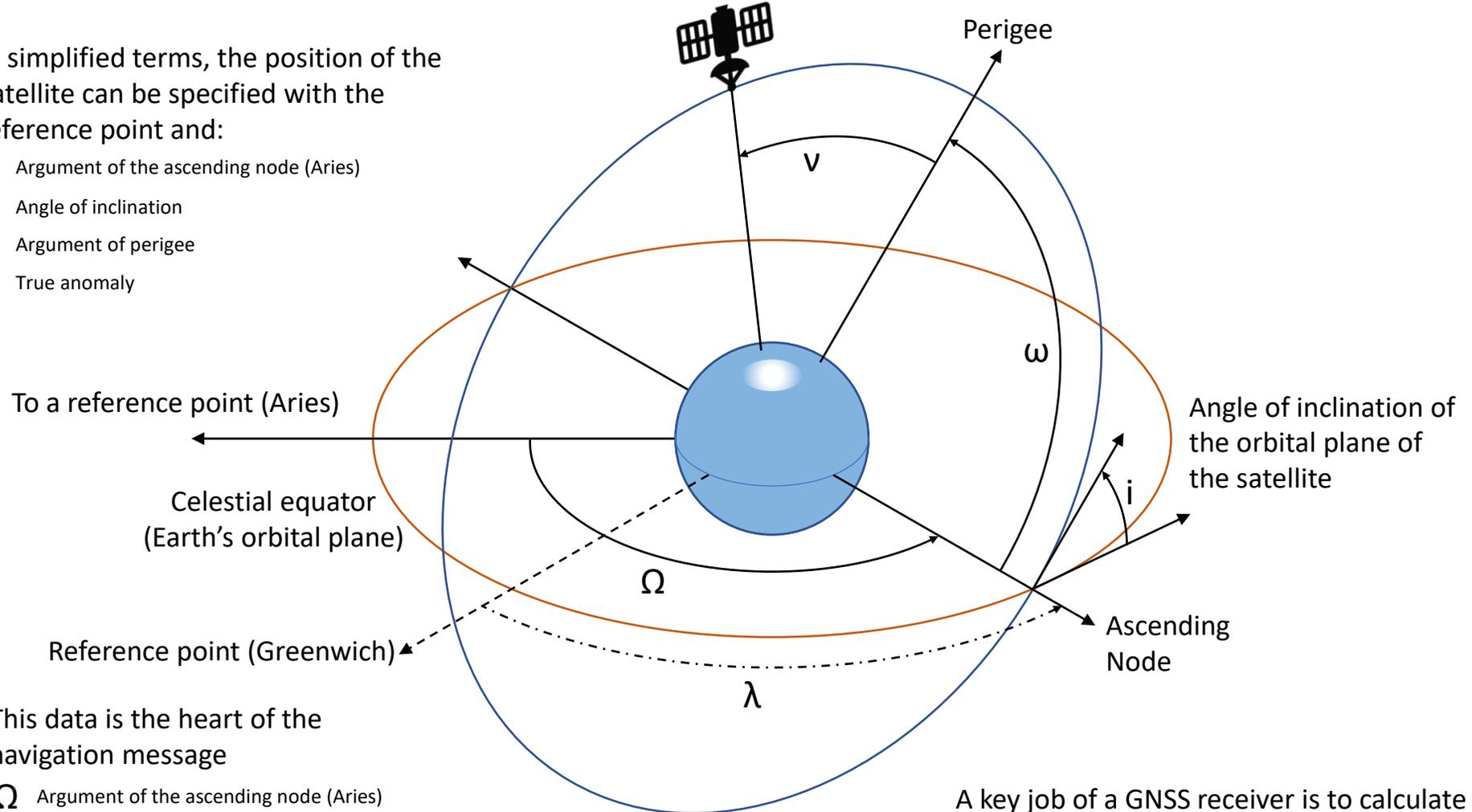This diagram represents the orbit as circular with an *eccentricity* of 0.

The reality is that two bodies usually have elliptical orbits around their centre of mass – barycentre – and have an eccentricity greater than 0.

In simplified terms, the position of the Satellite can be specified with the reference point and:

Ω   Argument of the ascending node (Aries)

i   Angle of inclination

ω   Argument of perigee

v   True anomaly

Perigee

v

ω

To a reference point (Aries)

Celestial equator (Earth's orbital plane)

Angle of inclination of the orbital plane of the satellite

i

Ω

Ascending Node

Reference point (Greenwich)

λ

This data is the heart of the navigation message

Ω   Argument of the ascending node (Aries)

i   Angle of inclination

ω   Argument of perigee

v   True anomaly

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A key job of a GNSS receiver is to calculate the position of a satellite using Ω i ω and v, then convert that position into the X, Y and Z of the Terrestrial Reference Frame.

The form of the signal from GNSS satellites

The navigation message and the PRN code are "mixed together" with the carrier frequency to create a composite broadcast signal.

GNSS signals are transmitted across several frequencies. For GPS these are L1 (1575.42 Mhz), L2 (1227.60 MHz) and L5 (1176.45 MHz).
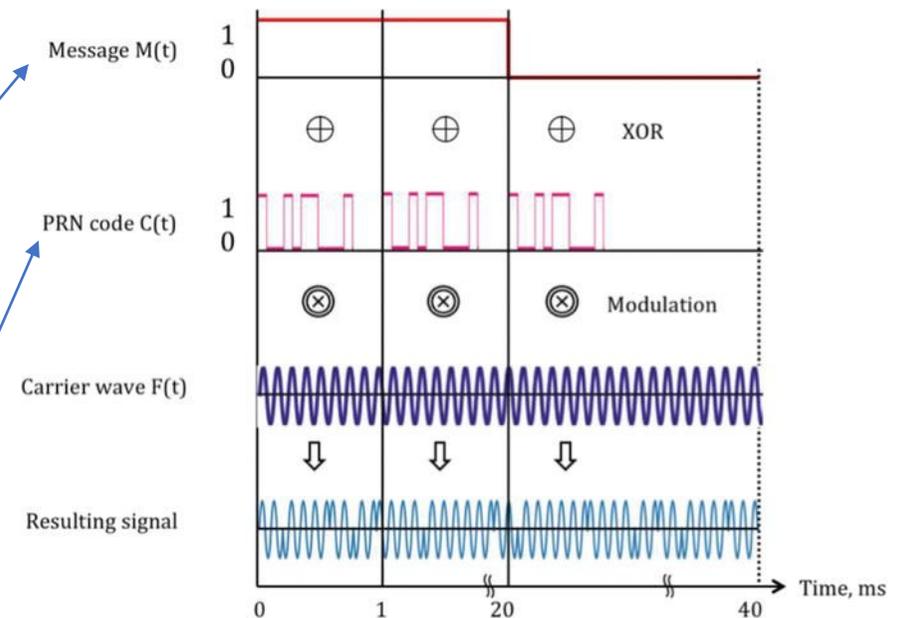
The GNSS signal carries navigation data:

Parameter	Explanation
t_{oe}	Ephemerides reference epoch in seconds within the week
$\sqrt{a}$	Square root of semi-major axis
e	Eccentricity
M_o	Mean anomaly at reference epoch
ω	Argument of perigee
i_o	Inclination at reference epoch
Ω_0	Longitude of ascending node at the beginning of the week
Δn	Mean motion difference
$\dot{i}$	Rate of inclination angle
$\dot{\Omega}$	Rate of node's right ascension
c_{uc}, c_{us}	Latitude argument correction
c_{rc}, c_{rs}	Orbital radius correction
c_{ic}, c_{is}	Inclination correction
a_0	Satellite clock offset
a_1	Satellite clock drift
a_2	Satellite clock drift rate

This data is organised into 25 frames. Each frame is Divided into five subframes containing 10 30 bit words. The whole message takes 12.5 minutes to transmit at 50 bps. The navigation message modulates the carrier frequency.

The ranging signal is based on a pseudo random number (PRN) code. Each satellite has a unique PRN code of 1,023 bits which is repeated every millisecond.

The PRN code is used to modulate the signal frequency (carrier wave).

To prepare the GNSS signal for transmission by the satellite, first an XOR operation is applied to combine the binary navigation message with the code. If the message bit and the code chip are the same, the result is 0; if they are different, the result is 1. Second, the combined signal is merged with the carrier using binary phase shift keying (BPSK) modulation: a "0" bit leaves the carrier signal intact, whereas a "1" bit causes the signal to be multiplied by –1 and shifts the carrier by 180°.

Ref: "GNSSs, Signals, and Receivers" By Mohamed Tamazin, Malek Karaim and Aboelmagd Noureldin
"GNSS DATA PROCESSING Volume I: Fundamentals and Algorithms" by J. Sanz Subirana, J.M. Juan Zornoza and M. Hernández-Pajares
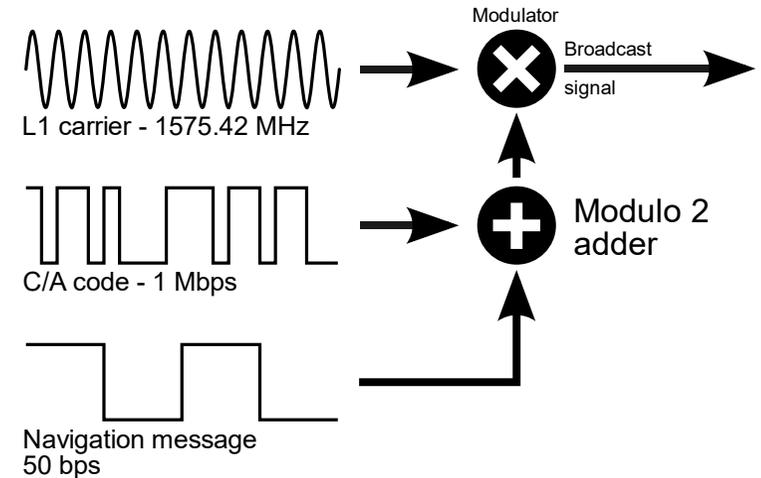
Who is who?: CDMA, chips and codes

If all the GNSS satellites are broadcasting on the same frequency, how come the signals don't get mixed up? How do we know what comes from where?

The answer to this puzzle lies in understanding how Code Division Multiple Access (CDMA) works. Every GNSS satellite is allocated the entire transmission band all of the time. The trick is that each satellite's message is coded using their unique PRN code. The key to CDMA is to be able to extract the desired signal while rejecting everything else as random noise.
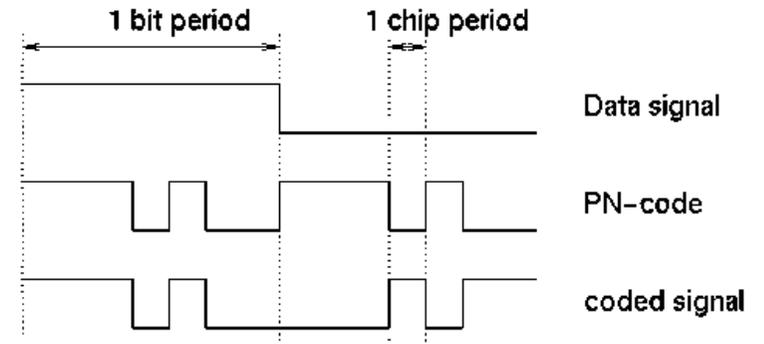
In CDMA, each message bit is subdivided into m short intervals called chips. Each satellite is assigned a unique 1,023 bit chip sequence (PRN code). To transmit 1 bit (of the navigation message), a satellite sends its chip sequence. To transmit a 0 bit, it sends the one's complement of its chip sequence. For example, if satellite A is assigned the chip sequence 00011011, it sends a 1 bit by sending 00011011 and a 0 bit by sending 11100100.

For GPS, the navigation message is sent at the very sedate rate of 50 bits per second. The rate at which the chips are sent (the chipping rate) is 1.023 mega bits per second. This means that a chip (PRN code) is transmitted in a microsecond. The navigation message and chips modulate the carrier frequency – for L1 this is 1575.42 Mhz.

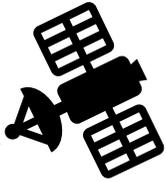The wave length of the carrier frequency – for L1 this is 1575.42 Mhz – is c = 299,792,000 m/s divided by 1,575,420,000 hz which gives 0.1903 m or about 19 cm. This is significant for *carrier phase* positioning.
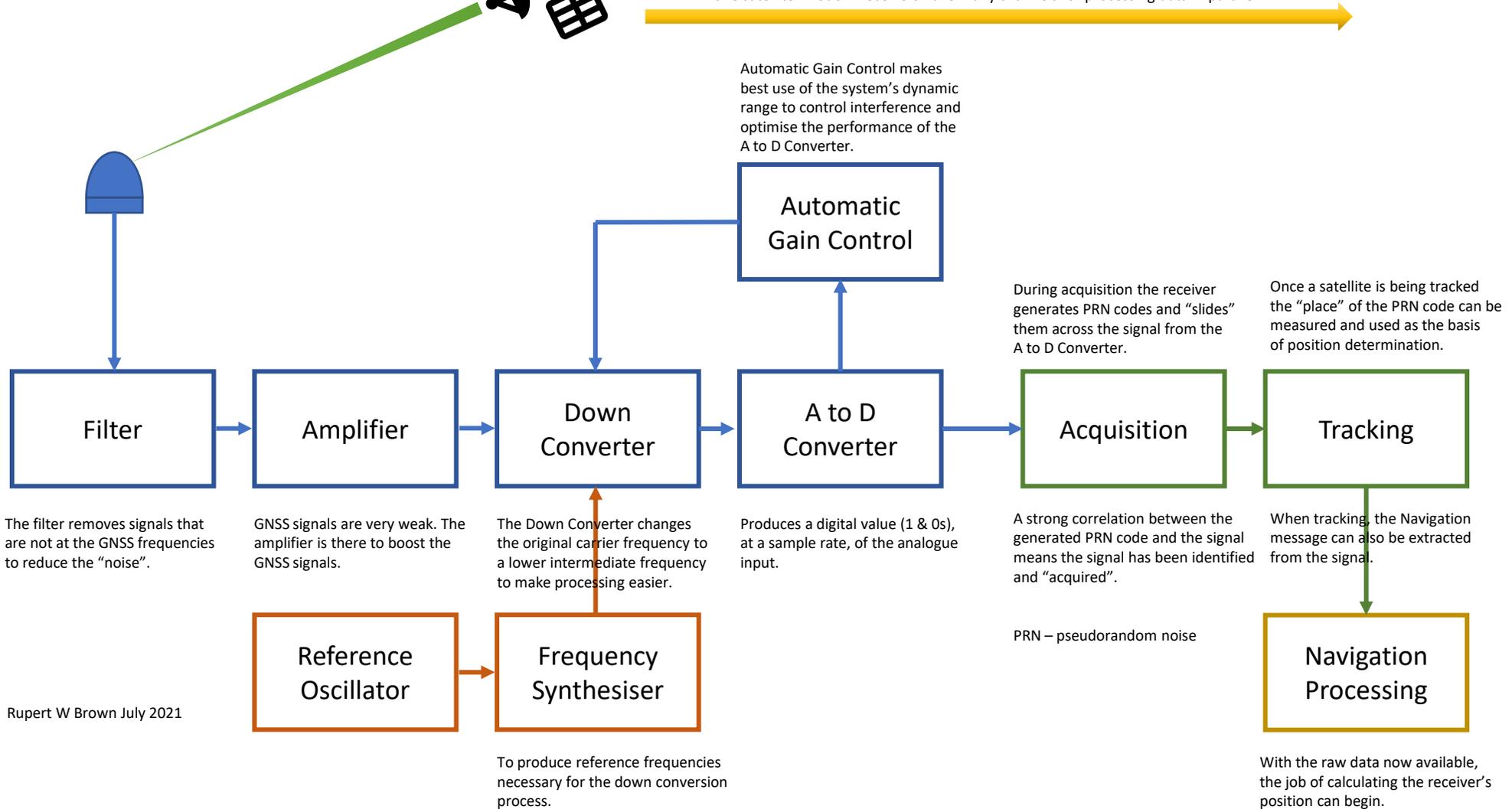

L1 carrier - 1575.42 MHz

C/A code - 1 Mbps

Navigation message
50 bps

Modulator

Broadcast signal

Modulo 2 adder

1 bit period   1 chip period

Data signal

PN-code

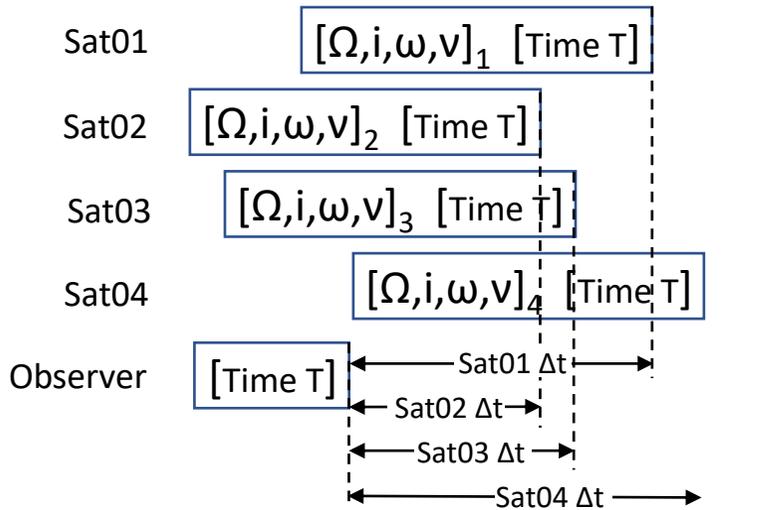coded signal

GNSS Receivers
Front End

These boxes represent one channel within the receiver – one channel processing data from one satellite. Modern receivers have many channels for processing data in parallel.

Automatic Gain Control makes best use of the system's dynamic range to control interference and optimise the performance of the A to D Converter.

Automatic Gain Control

During acquisition the receiver generates PRN codes and "slides" them across the signal from the A to D Converter.

Once a satellite is being tracked the "place" of the PRN code can be measured and used as the basis of position determination.

Filter

Amplifier

Down Converter

A to D Converter

Acquisition

Tracking

The filter removes signals that are not at the GNSS frequencies to reduce the "noise".

GNSS signals are very weak. The amplifier is there to boost the GNSS signals.

The Down Converter changes the original carrier frequency to a lower intermediate frequency to make processing easier.

Produces a digital value (1 & 0s), at a sample rate, of the analogue input.

A strong correlation between the generated PRN code and the signal means the signal has been identified and "acquired".

When tracking, the Navigation message can also be extracted from the signal.

PRN – pseudorandom noise

Reference Oscillator

Frequency Synthesiser

Navigation Processing

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To produce reference frequencies necessary for the down conversion process.

With the raw data now available, the job of calculating the receiver's position can begin.

Position: determining a position on Earth using GNSS radio signals

Navigation messages and PRN codes sent from the satellites are received by the Observer at different times. The receiver uses the PRN code to work out the distance to the satellite.

Sat01 $[\Omega, i, \omega, \nu]_1$ [Time T]

Sat02 $[\Omega, i, \omega, \nu]_2$ [Time T]

Sat03 $[\Omega, i, \omega, \nu]_3$ [Time T]

Sat04 $[\Omega, i, \omega, \nu]_4$ [Time T]

Observer   [Time T]

Sat01 Δt

Sat02 Δt

Sat03 Δt

Sat04 Δt

Messages sent at the same time by the satellites are received at different times by the Observer because the signals have to travel different distances. These time differences can be used to calculate those distances. With a knowledge of the satellites' positions and their distance from the Observer, the Observer can calculate its position on the Earth's surface.

Sat04

Observer

Sat01

Sat03

Sat02

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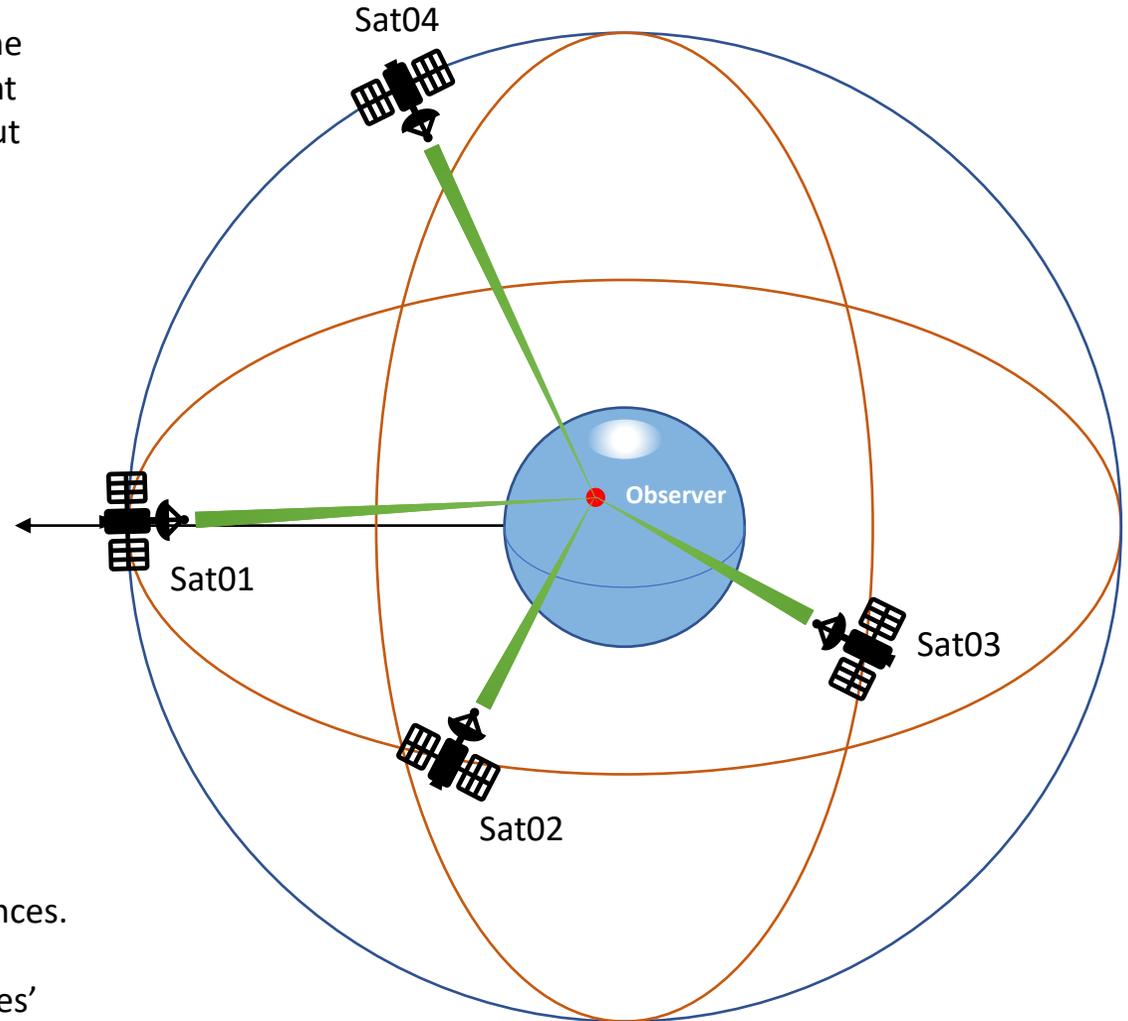
Navigation Processing
The Navigation Message

The basic process is:

Compute the time t_k from the ephemerides reference epoch t_{oe} (expressed in seconds in the GPS week)

Compute the mean anomaly for t_k

Solve (iteratively) the Kepler equation for the eccentric anomaly E_k

Compute the true anomaly v_k

Compute the argument of latitude u_k from the argument of perigee ω, true anomaly v_k and corrections c_{uc} and c_{us}

Compute the radial distance r_k, considering corrections c_{rc} and c_{rs}

Compute the inclination i_k of the orbital plane from the inclination i_o at reference time t_{oe}, and corrections c_{ic} and c_{is}

Compute the longitude of the ascending node λ_k (with respect to Greenwich)

Compute the coordinates in the TRS frame, applying three rotations (around u_k, i_k and λ_k) => X, Y and Z
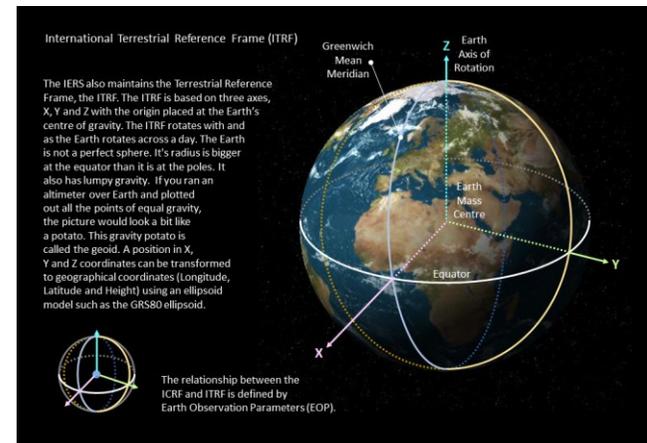
(X_n, Y_n, Z_n)

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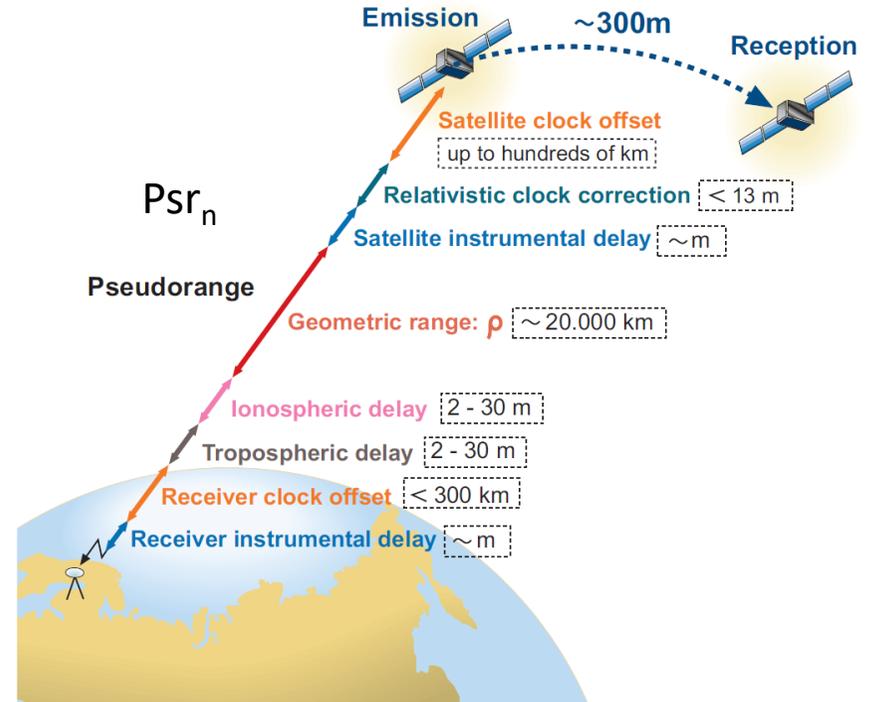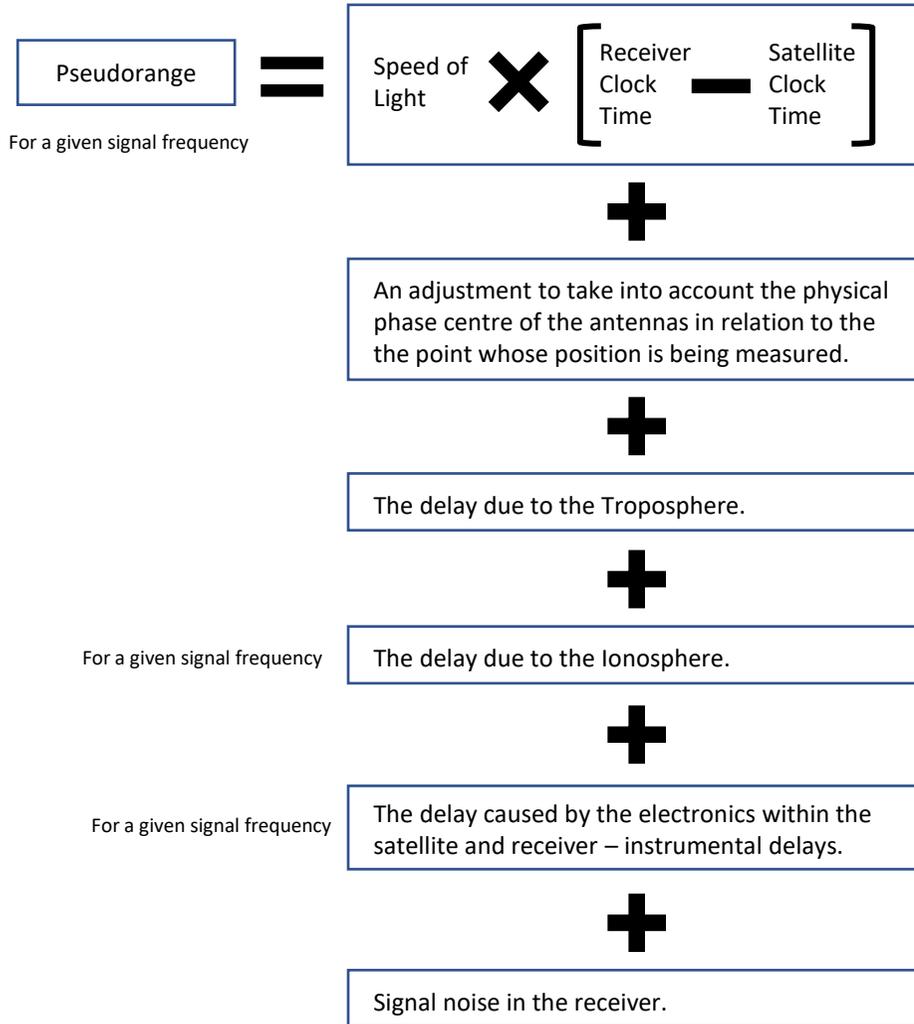| Parameter	Explanation
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a_2	Satellite clock drift rate

The data in that Navigation message
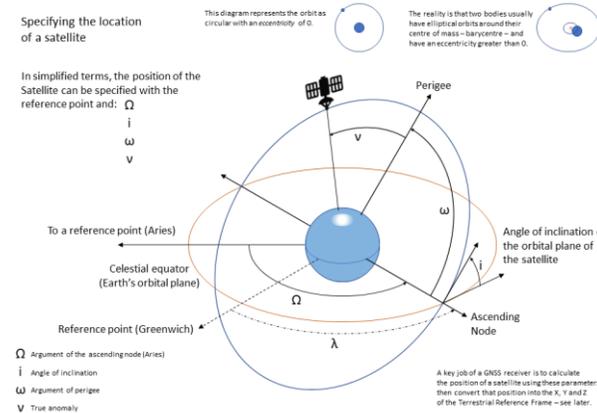
The meaning of those terms

The X, Y, Z reference frame

Navigation Processing
The Distance Message (Pseudorange)

| Pseudorange | **=** | Speed of Light **×** [Receiver Clock Time **—** Satellite Clock Time] |

For a given signal frequency

+

An adjustment to take into account the physical phase centre of the antennas in relation to the the point whose position is being measured.

+

The delay due to the Troposphere.

+

For a given signal frequency

The delay due to the Ionosphere.

+

For a given signal frequency

The delay caused by the electronics within the satellite and receiver – instrumental delays.

+

Signal noise in the receiver.

Emission   ~300m   **Reception**

Psr_n

Pseudorange

Satellite clock offset — up to hundreds of km

Relativistic clock correction — < 13 m

Satellite instrumental delay — ~m

Geometric range: ρ — ~20.000 km

Ionospheric delay — 2 - 30 m

Tropospheric delay — 2 - 30 m

Receiver clock offset — < 300 km

Receiver instrumental delay — ~m

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Navigation Processing
Putting it together – the position

Start with a point corresponding to the approximate position of a receiver.

Creating a n by n matrix, with n = number of satellites, containing:
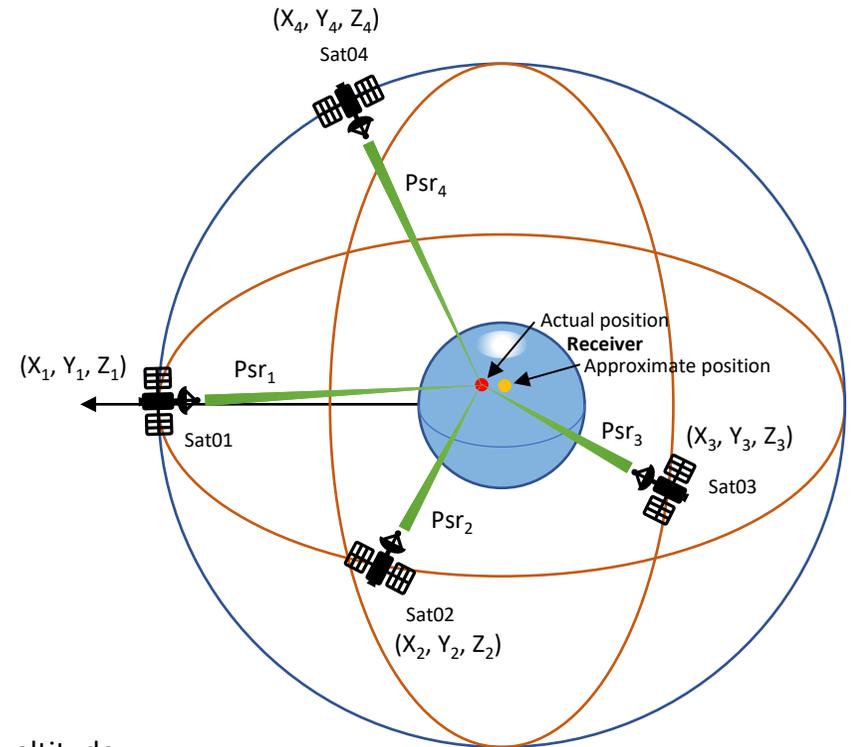
X, Y, Z delta to the approximate position:
Based on that approximate position, the position of the satellite and the pseudorange, derive a linear approximation (linearization) to the actual position – as an X, Y, Z delta to the approximate position.

Find the actual position *best fit* by solving the matrix equation using a least squares adjustment and producing a new value for the approximate position of the receiver.

Iterate again with this new value of the approximate position of the receiver till the X, Y, Z deltas to the approximate position fall below an acceptable threshold – **the receiver's position is found**.

Convert X, Y and Z into latitude, longitude, altitude.

(X_4, Y_4, Z_4)
Sat04
Psr_4
Actual position
Receiver
Approximate position
(X_1, Y_1, Z_1) Psr_1
Sat01
Psr_3 (X_3, Y_3, Z_3)
Sat03
Psr_2
Sat02
(X_2, Y_2, Z_2)

This can be considered to be a Standard Positioning Service (SPS).

The Accuracy of SPS

A report produced by the US William J. Hughes Technical Center for the US Federal Aviation Administration in 2017 states that the Standard Position Service gives a position that is:

- Within 3.9 m of the actual vertical position 95% of the time, and

- Within 1.9 m of the actual horizontal position 95% of the time.

That sounds pretty good. However, the actual performance you experience depends on many things including, but not limited to:

- The quality of your receiver. The quality of your GNSS antenna and the electronics behind it can have significant impacts on performance,

- The number of satellites your receiver can see. Generally the more satellites, the more data, the better the position,

- Multi-path effects. If the satellite signals are bouncing around nearby structures, the reflected signals can confuse the receiver,

- The accuracy of the navigation message transmitted by the satellite. If, for whatever reason, the satellite clock is a little bit off, or the satellite is a little out of its orbit then the calculated position can be thrown out too.

- The atmosphere. Both the ionosphere and troposphere can have effects on the signals which can add errors to a position.

The other signals and codes broadcast by GNSS satellites can improve that accuracy. Now there are also augmentation systems available which send additional signals that greatly improve accuracy and often carry signal integrity information. Some of these are available to the general public and some are not.

GNSS Receiver Quality

There is a huge difference in the quality of GNSS receivers, both in the way they are built and in the data and models they use to determine position. Considerations include:

- The quality of the antenna - its sensitivity and its tuned accuracy.
- The receiver electronics - external RF noise handling, its sensitivity and multipath GNSS signal handling.
- Supporting data on which GNSS satellites should be visible at any given time or place.
- The number of channels the receiver has to track GNSS satellites.
- The ability of the receiver to pick up more than one GNSS frequency.
- The ability of the receiver to pick up signals from more than one GNSS constellation.
- The accuracy of the clock within the receiver.
- The use (or not) of precise orbit and clock files, rather than those broadcast by the satellite.
- The quality and sophistication of ionospheric and tropospheric models.
- The application (or not) of corrections for solid Earth tides, ocean loading and pole tides.
- The ability (or not) to fix position based on the carrier signal phase by solving the position of the carrier wave within the signal - resolving ambiguity.
- The use of a position correction service.

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