How GPS Works

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Background

- Kalman Filter

  Is an algorithm that uses a series of measurements observed over time, containing statistical noise and other inaccuracies, and produces estimates of unknown variables that tend to be more accurate than those based on a single measurement alone. Developed in the early 60's, first used on Apollo.
- Code Division Multiple Access (CDMA)

  Form of transmission known as Direct Sequence Spread Spectrum. Allows multiple users to use a single frequency. Envisioned in the 1940's. Found wide spread use in the cellular telecommunications arena in the 1980s (Qualcomm)
- Pseudo Random Codes or pseudo-random-noise code (PRN codeI

  Has a spectrum similar to a random sequence of bits but is deterministically generated. Unlike random noise, it is easy to generate exactly the same sequence at both the transmitter and the receiver, so the receiver's locally generated sequence has a very high correlation with the transmitted sequence. The most commonly used sequences in direct-sequence spread spectrum systems are maximal length sequences, Gold codes, Kasami codes, and Barker codes.
- Gold Codes

  type of binary sequence that have bounded small cross-correlations within a set, which is useful when multiple devices are broadcasting in the same frequency range. A set of Gold code sequences consists of 2n + 1 sequences each one with a period of 2n − 1.

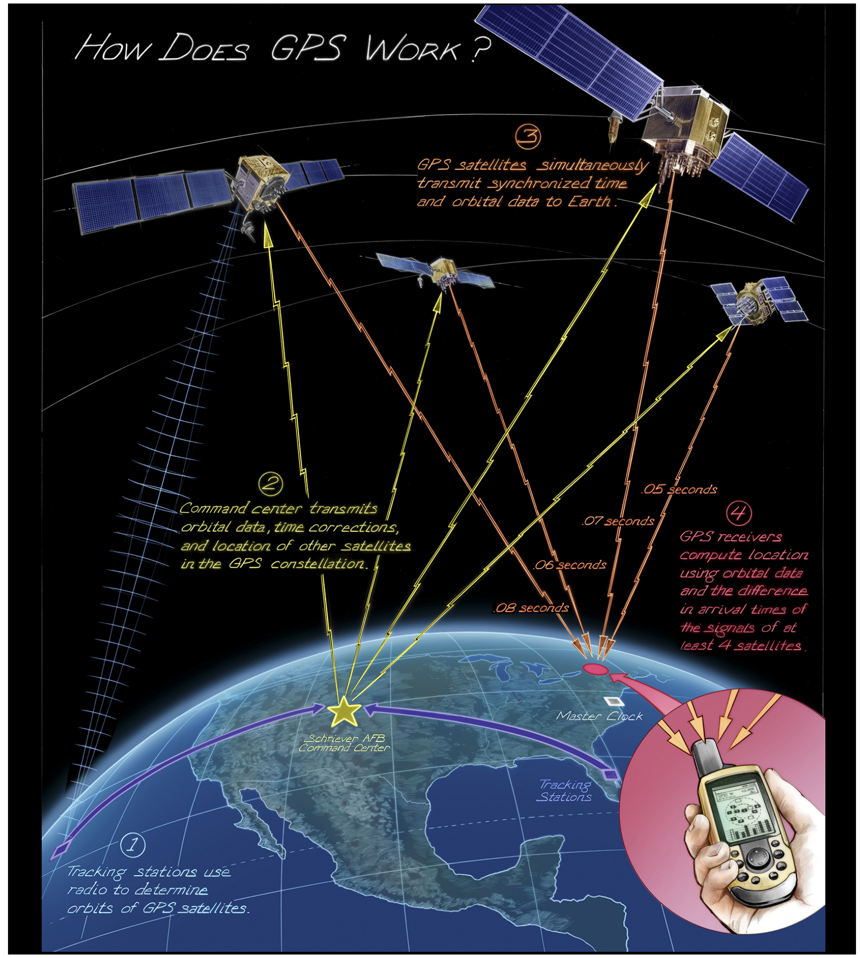
The Simple Answer

1. Tracking stations use radio signals to determine orbits of GPS satellites.

2. Command center transmits orbital data, time corrections, and location of other satellites in the GPS constellation.

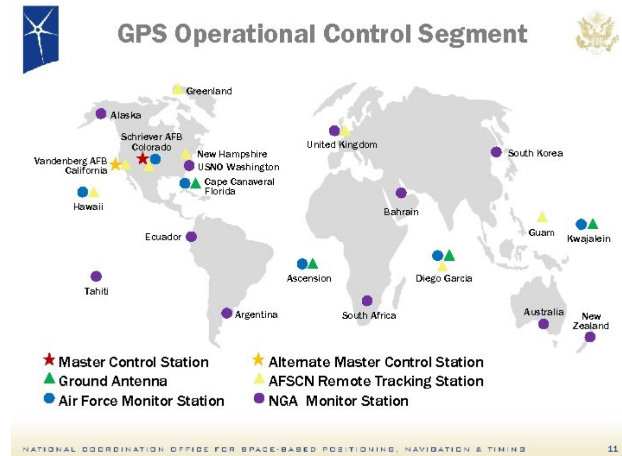
3. GPS satellites simultaneously transmit synchronized time and orbital data to Earth.

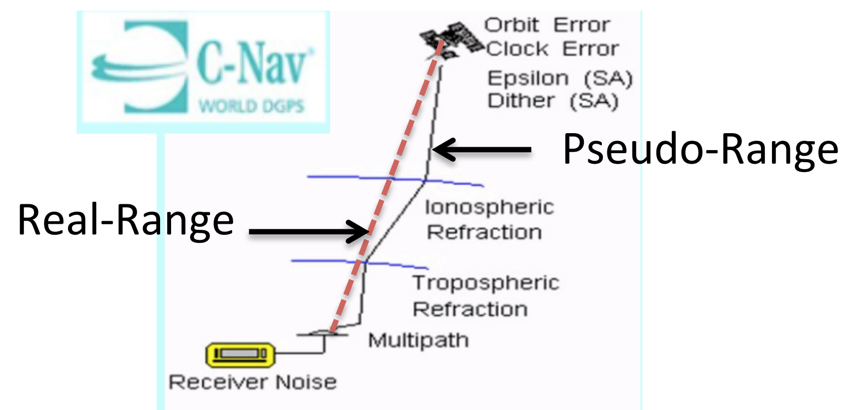
4. GPS receivers compute location using orbital data and the difference in arrival times of the signals of at least 4 satellites.



Tracking stations use radio signals to determine orbits of GPS satellites.

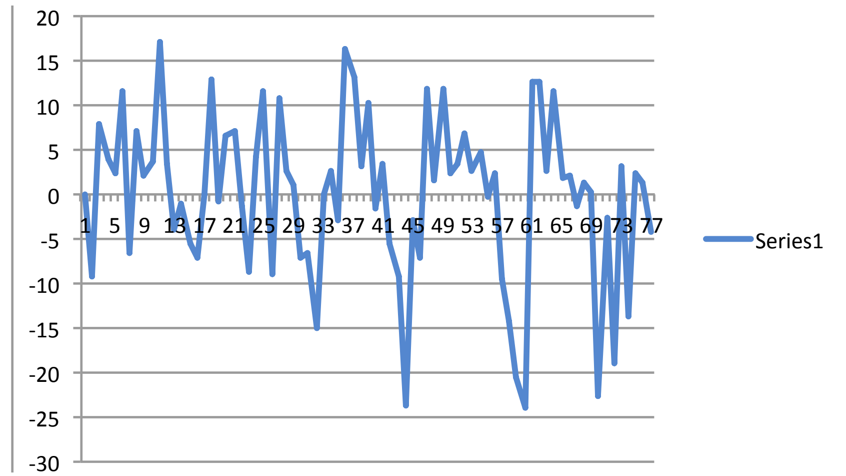
- There are 11 GPS ~~Tracking~~ Monitor stations who use the GPS signals to measures the Pseudo-Range to each satellite in view
- Periodically the Monitor Stations sends all the Pseudo-Ranges to the MASTER CONTROL STATION
- At the MASTER CONTROL STATION the Pseudo-Ranges are feed into a series computer programs (Orbit estimators and Kalman Filters) to derive the orbital and clock parameters of each satellite to a high degree of accuracy

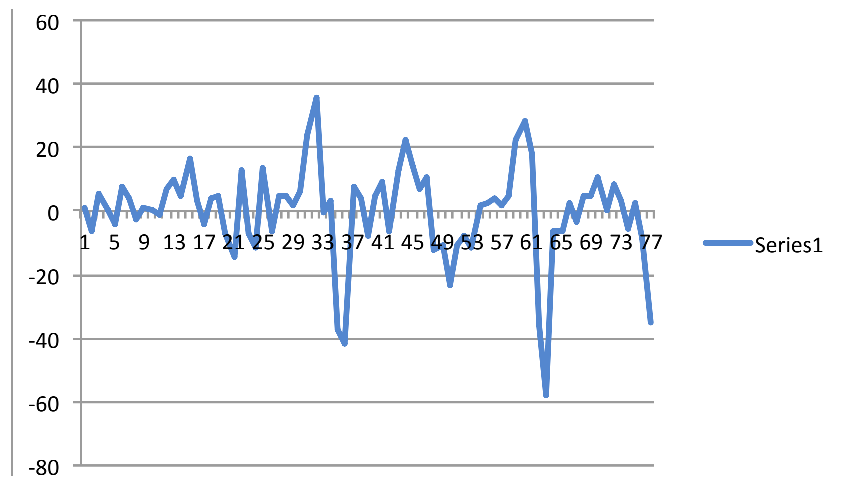




Pseudo-Range

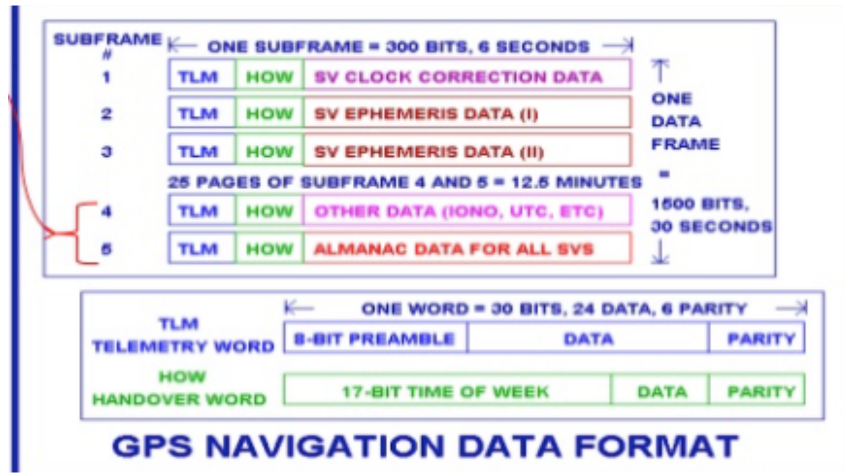
- Raw Pseudo-Ranges were collected for low and high elevations
- Differences were calculated and data was normalize
- Low elevation showed more variation but data was under ±25m
- High elevation should less variation but had large data swings

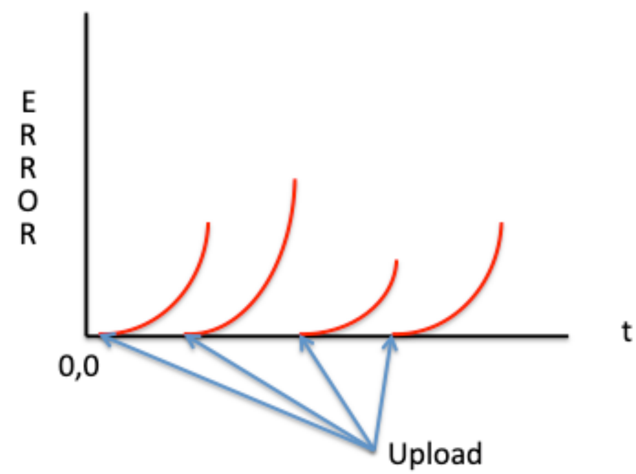




Command center transmits orbital data, time corrections, and location of other satellites in the GPS constellation.

- The orbital and clock parameters are then turned into uploads for each satellite
- Uploads to the satellite carry NAV data and instructions when to broadcast the NAV data
- Please note the orbital and clock parameters are estimates who's error grows over time but a reset back to zero when a upload occurs. Age Of Data term in the NAV message tells a user how fresh the data is



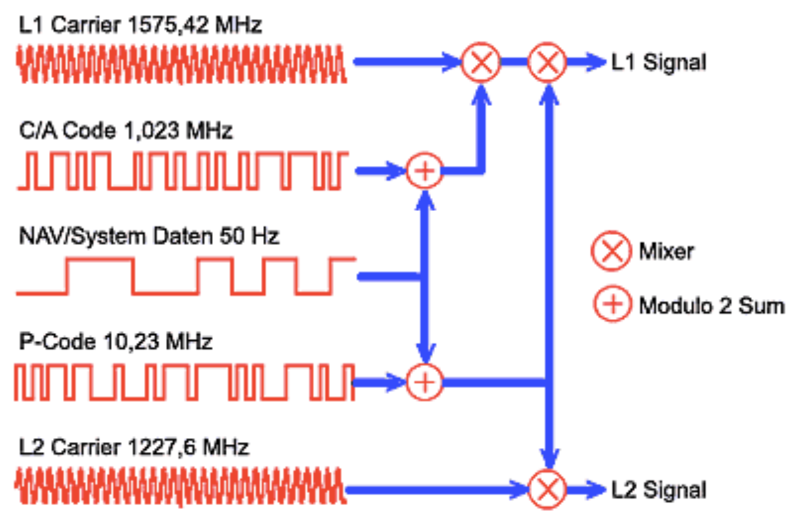


https://www.slideshare.net/MohammedHusain20/4-gps-introduction-amp-gps-messages

GPS satellites simultaneously transmit synchronized time and orbital data to Earth.

- GPS satellites
  - uses Code Division Multiple Access (CDMA) modulation to transmit the signal (many users)
  - Transmit at two frequencies so a large part of the error can be removed (atmospheric effects)
  - Requires an atomic clock to keep time
    - Clock is set to run at a lower frequency to compensate for relativity

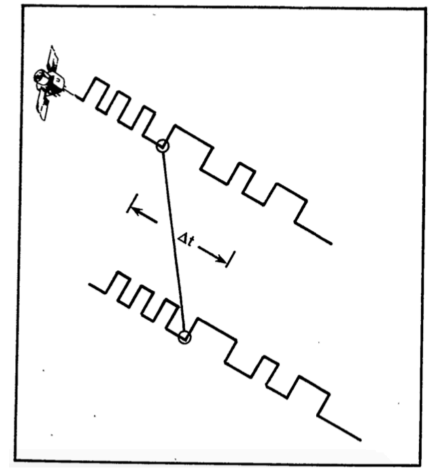
Composition of the signals from GPS satellites

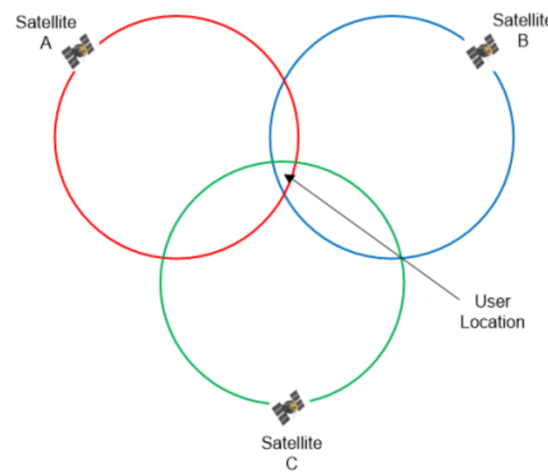


1) Source: http://www.kowoma.de/en/gps/signals.htm)

GPS receivers compute location using orbital data and the difference in arrival times of the signals of at least 4 satellites.

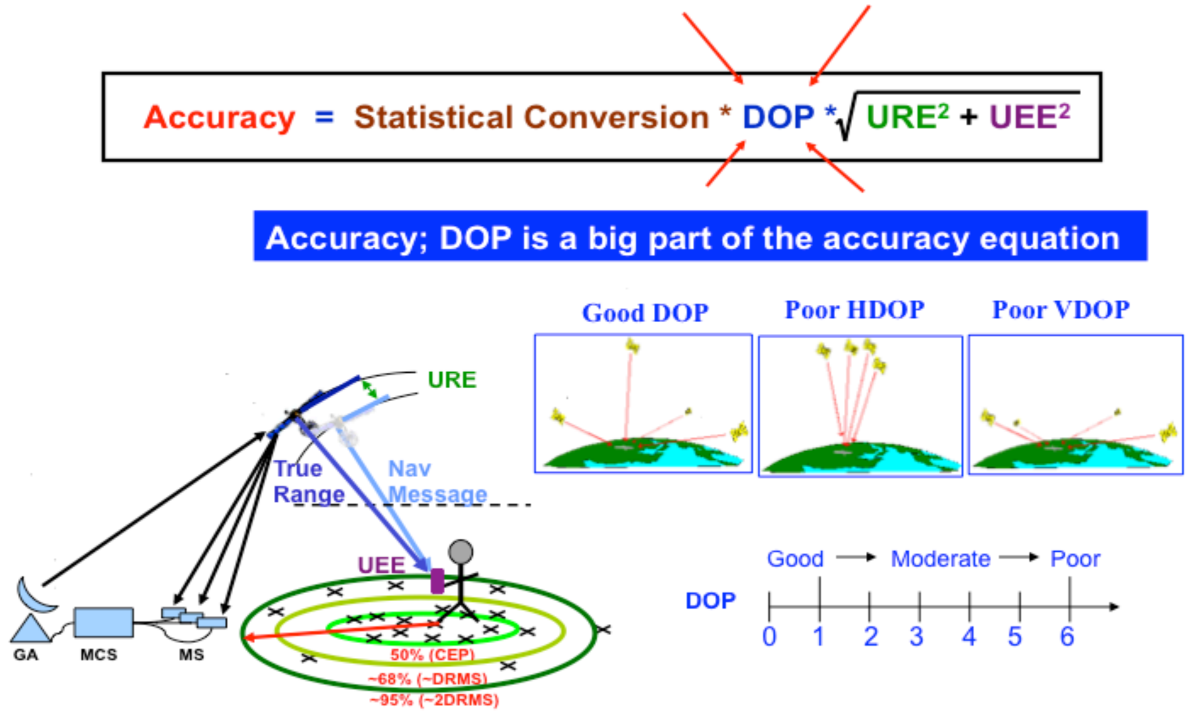
- Using Pseudo Random codes, a receiver calculates the distance to each satellite. Distance is calculated by measuring the time offset of the codes
- By reading the NAV message, it can figure out where the satellite's position when it transmitted the code segment
- Due to errors accumulating from aging of data, the solution will be an area not a point
- A forth satellite is needed to reduce time uncertainty
- Finally an estimator (Kalman Filter) is needed to get the best guess of the location





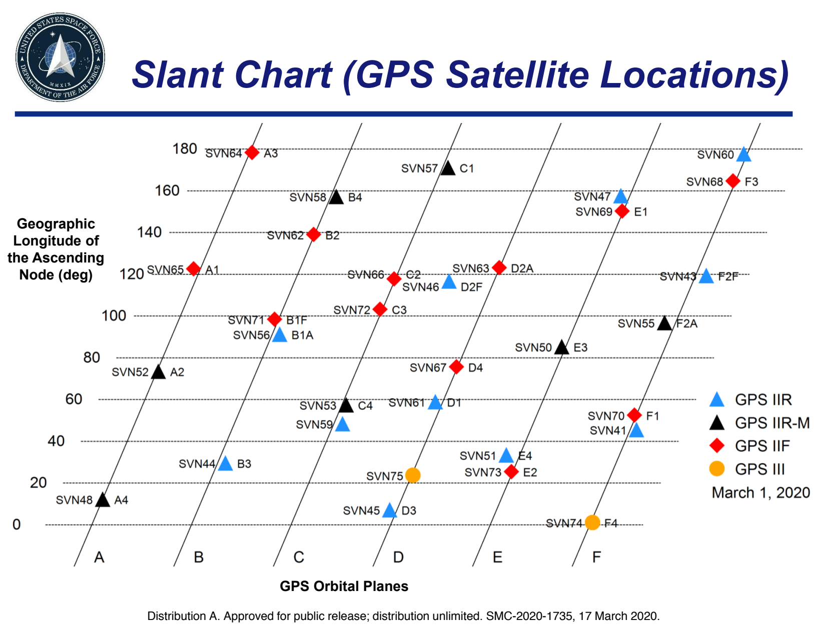
Accuracy is Driven by Dilution Of Precision

- NAV accuracy is affected by three variables
  - User Equip. Error (UEE), controlled by receiver (difference between reported position and truth
  - User Range Error (URE), Attributed to the satellite (difference between broadcast position and truth, ability of the CS to model Clock and Orbital errors is key to improving this)
  - Dilution Of Precision (DOP), controlled by space architecture
- DOP variations will cause accuracy fluctuations



A Short History of the GPS Constellation

- The original (BLK I) GPS Constellation had three planes, 18 satellites at 61° inclination
  - Provided great coverage all over the (smooth) earth
- Due to the choice of the launch vehicle and operational needs, the operational constellation (BLK II) was set to six planes, 21 satellites with 3 spare at 55° inclination
  - Provided great coverage all over the (smooth) earth but due the inclination less coverage at the poles
- We are now at 24+3 constellation which provides DOP holes coverage and resiliency to CONUS
- As the user base grew so did expectations. Users noted DOP holes, poor performance in urban canyons and susceptibility to jammers
  - GPS is investigating using all GNSS assets and investigating ways to counter jammers



Hints to get the best accuracy out of GPS

- Use all GNSS satellites in view
  - Lowest DOP
- Use the latest (IIF and III) satellites
  - Lowest URE
- Find the satellite with the smallest Age Of Data term
  - Has the least amount of error growth
- Turn on your receiver and let it track satellites for a period of time before trusting the output
  - Estimators need to be running for a period of time before measurements can converge on a solution
- Use a receiver with a atomic clock
  - Stable and smallest time offsets