The Global Positioning System

A Brief Overview

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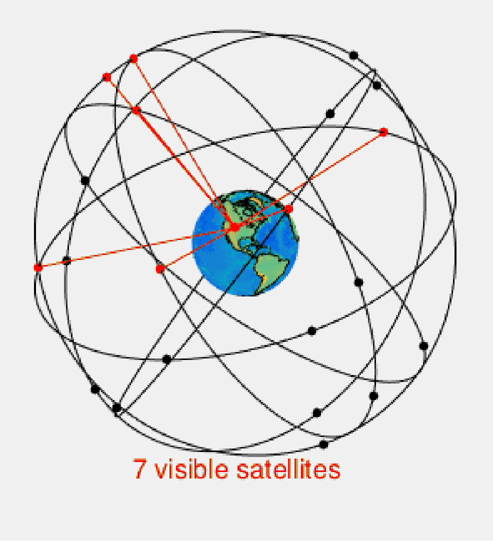
Fast Facts

- Owned & operated by the United States government (DoD/USAF)
  - Provides free* positioning (< 1 m accuracy) & timing services to global users
- Three system segments
  - Space (satellite constellation)
  - Control (ground-based monitor/command station network)
  - User (receivers in vehicles, smartphones, clocks)
- Created in early 1970s by USAF (Navstar)
  - Selective Availability (intentional degradation of civilian signals) disabled in 1990s by President Clinton

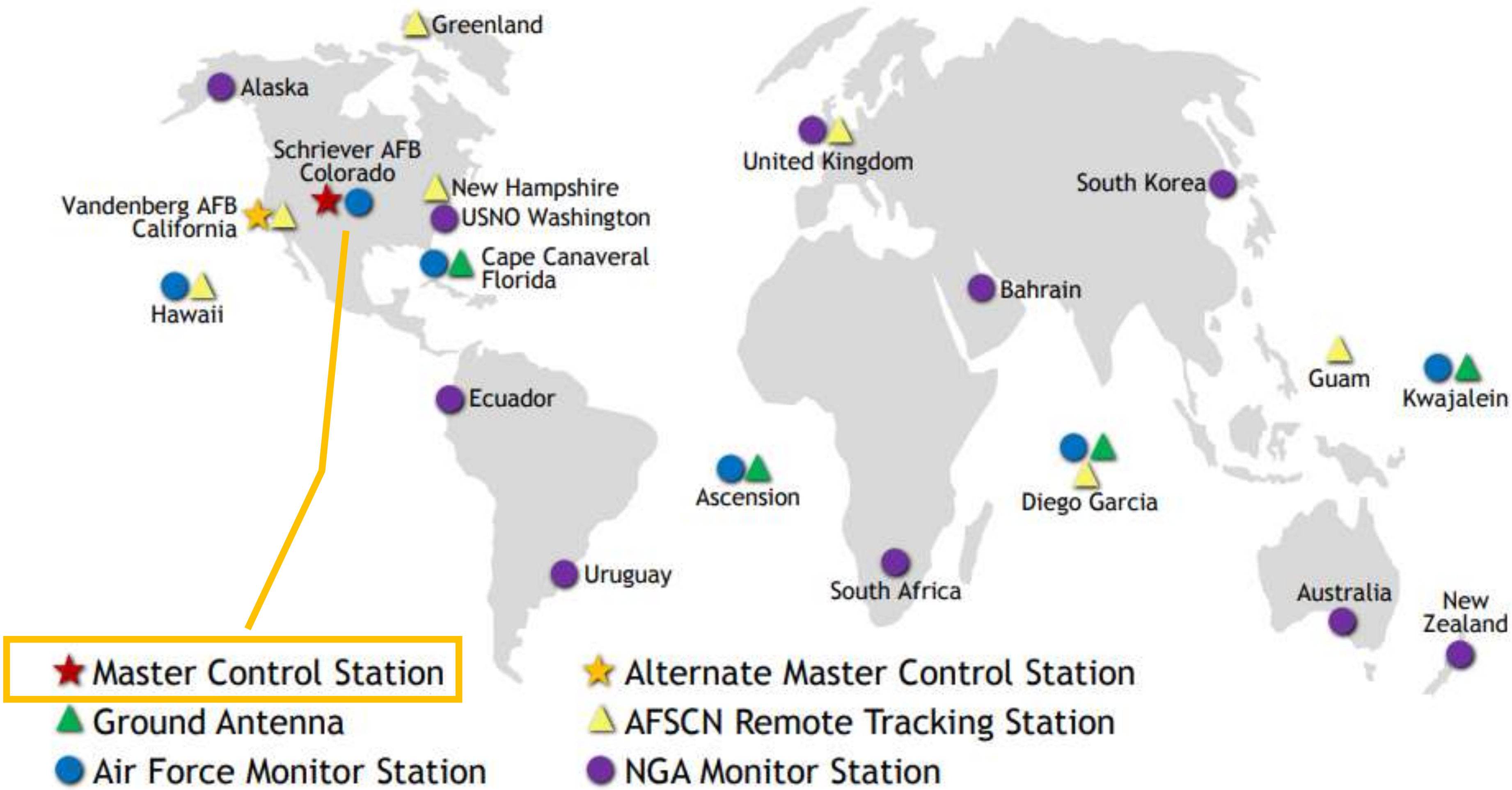
Space Segment



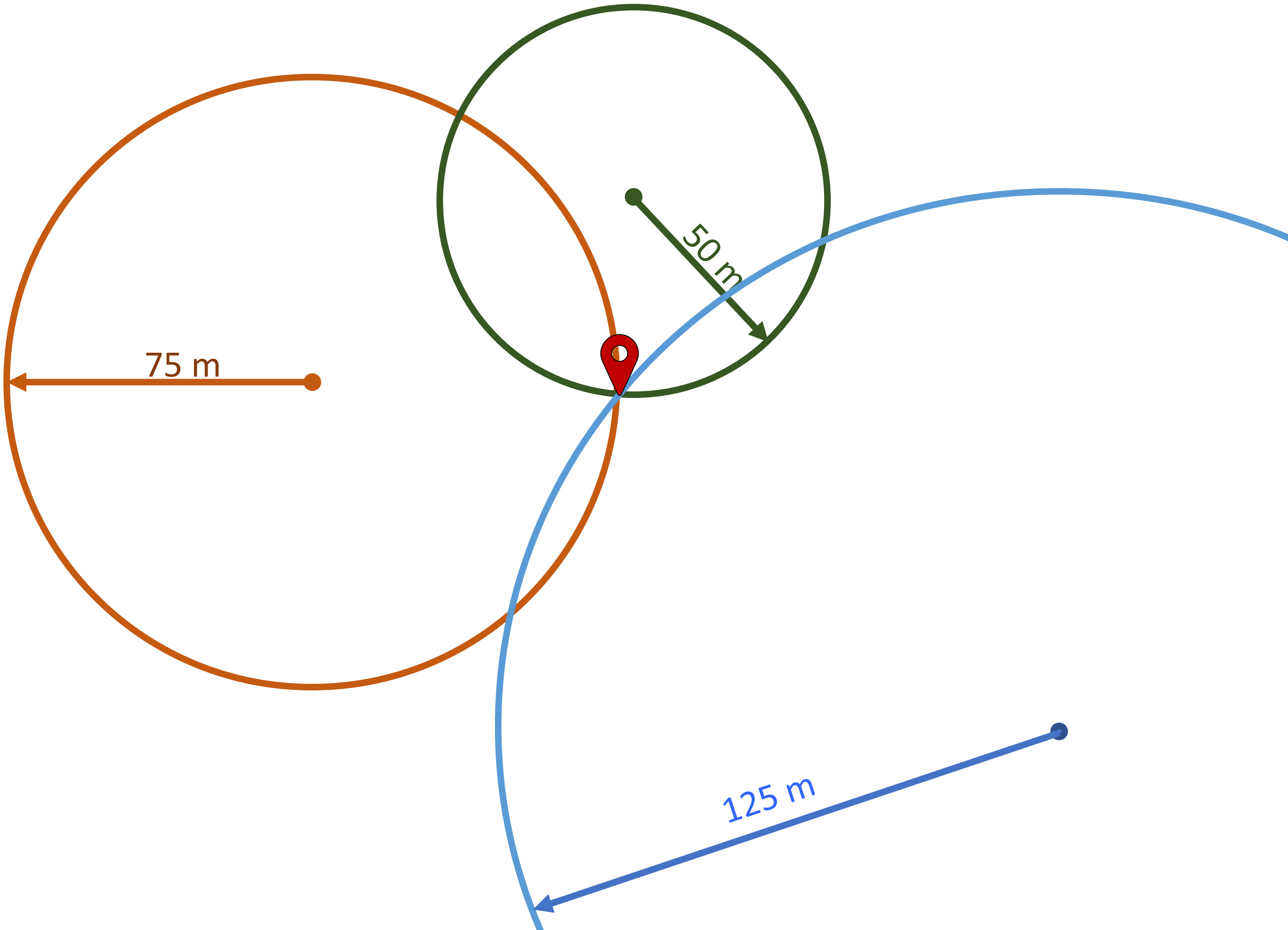
- Constellation of (currently) 31 satellites
  - 24 needed for operation – 6 orbital planes, 4 satellites each
  - MEO - ~20,000 km altitude
  - Generally 6+ satellites in view at any time for all global users (4 necessary)
  - Tend to outlive design life
- GPS III (first launch Dec 2018)
  - Higher power, more signals, all-digital

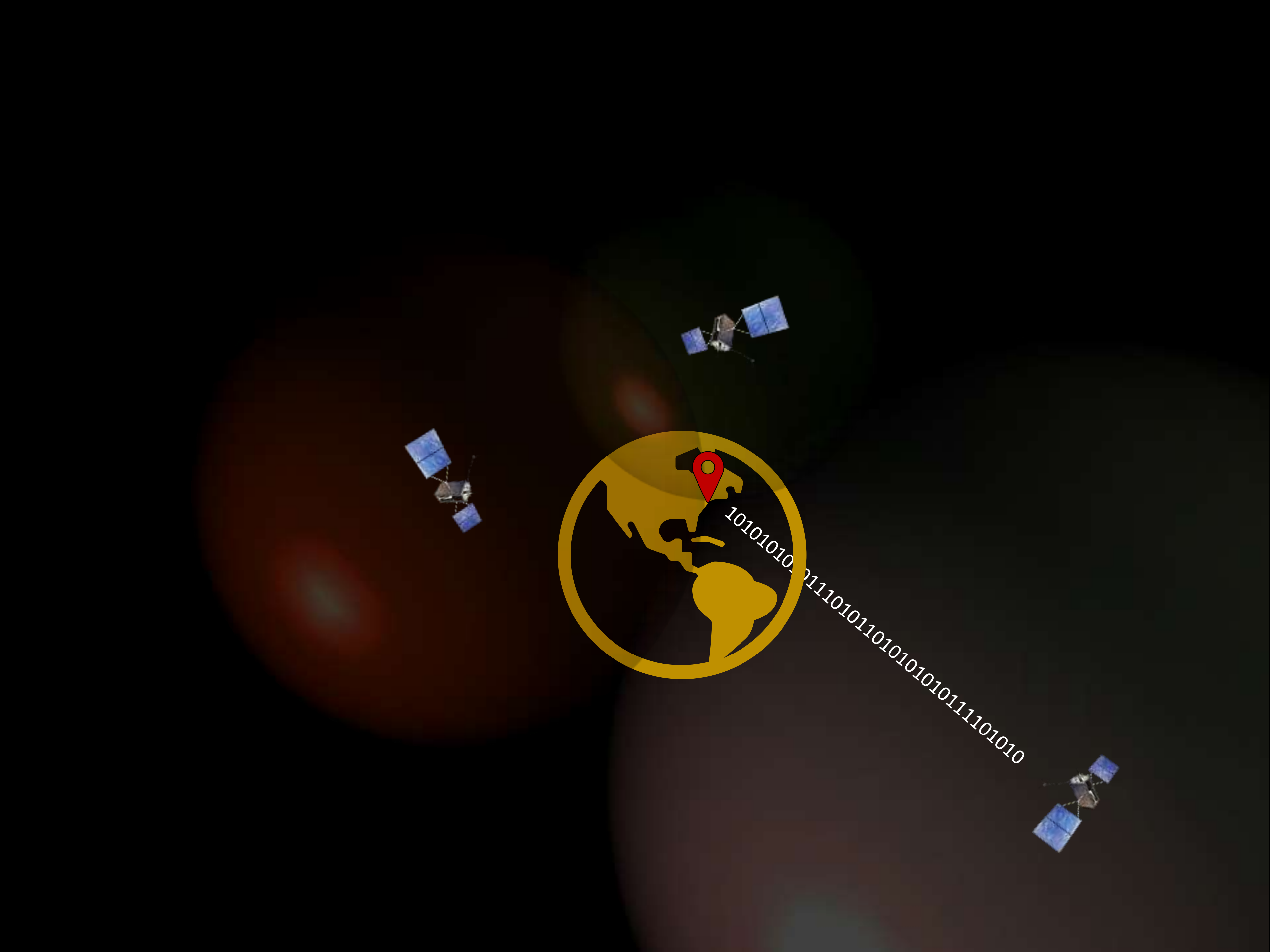
Control Segment

- Tracks satellites, uploads corrections and messages



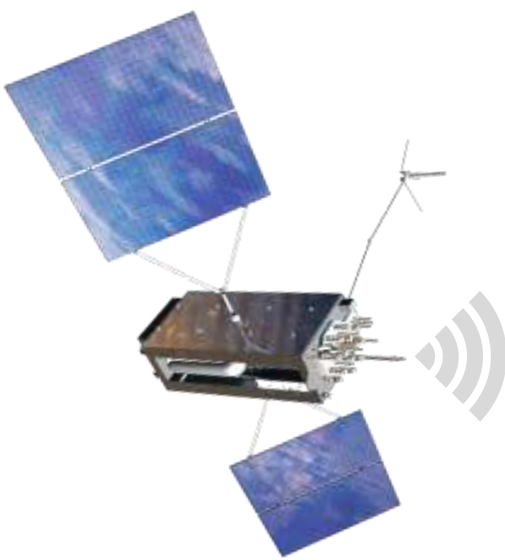
Triangulation

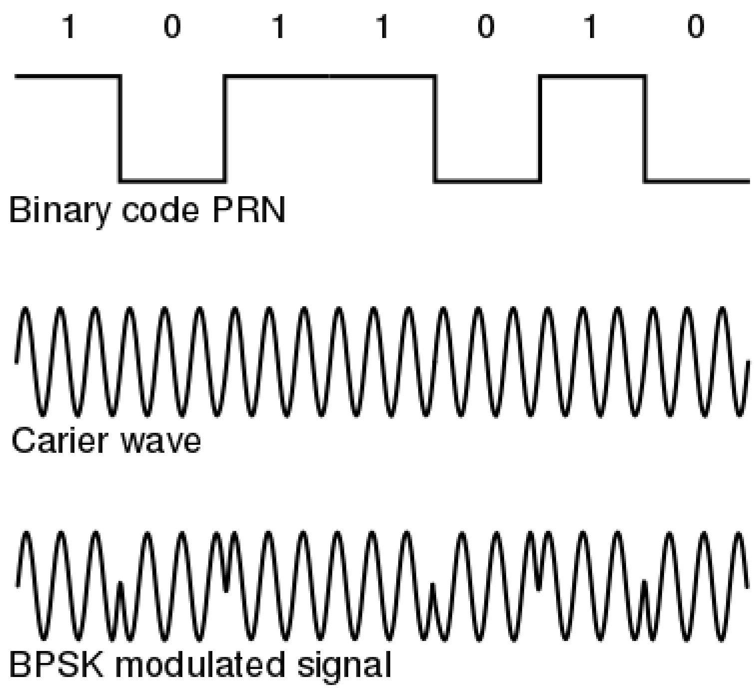




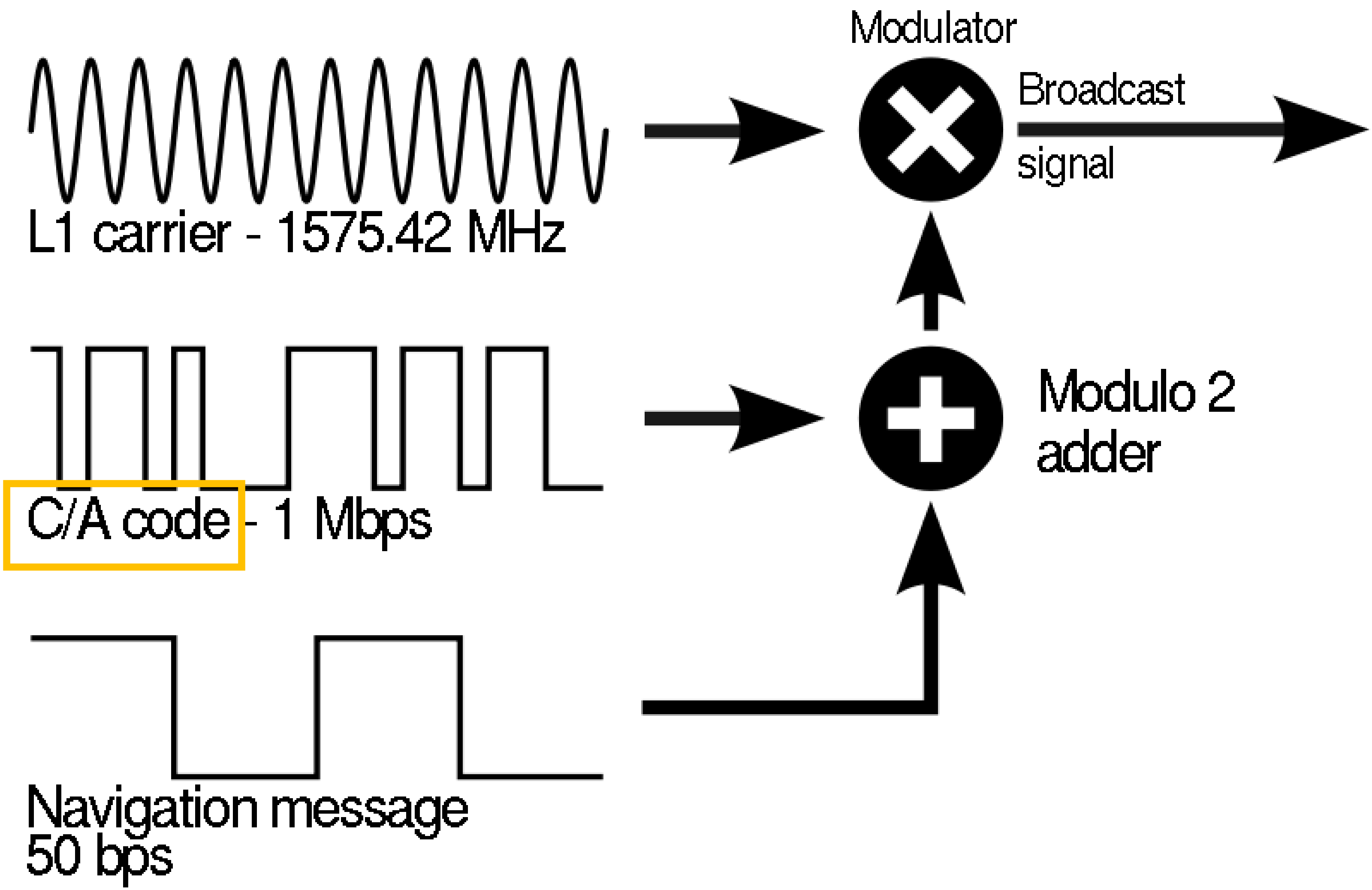
GPS Signals

- L-Band (1 – 2 GHz)
- Information transmitted by phase modulation (PM)



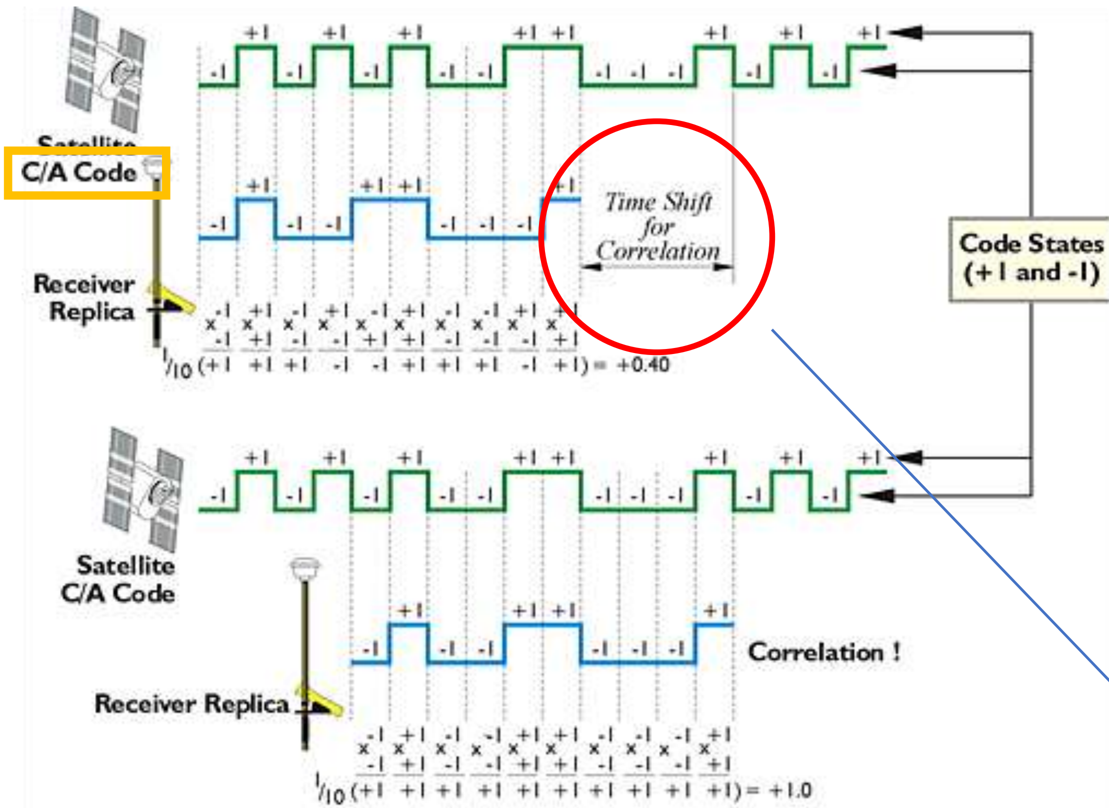


GPS Signals – Layered Structure



http://paul.luminos.nl/download/document/satellite_navigation.pdf

GPS Signals – Determining Distance



https://www.e-education.psu.edu/geog862/node/1756

$$\boldsymbol{\Delta t \cdot c = P}$$

$$(\boldsymbol{time \cdot rate = distance})$$

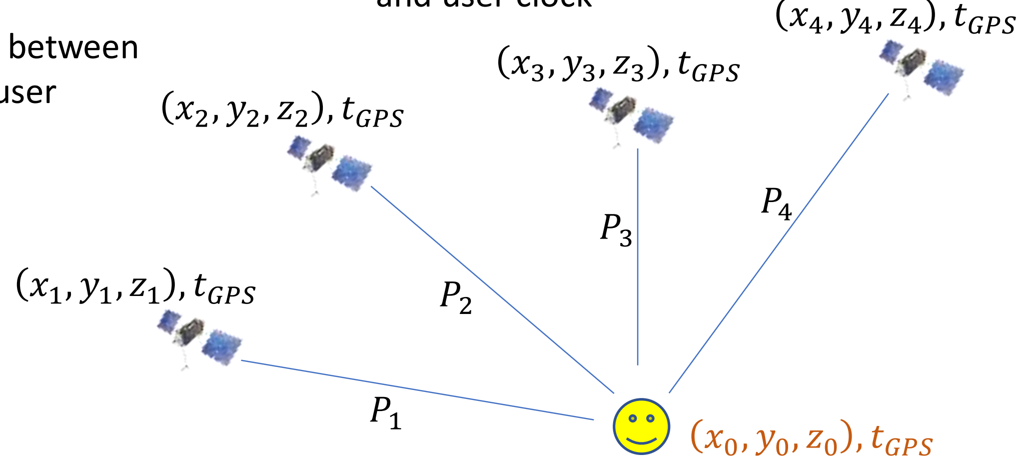
Determining Position (x_0, y_0, z_0)

$$P_1 = \sqrt{(x_1 - x_0)^2 + (y_1 - y_0)^2 + (z_1 - z_0)^2} + c(t_{GPS} - t_0)$$

$$P_2 = \sqrt{(x_2 - x_0)^2 + (y_2 - y_0)^2 + (z_2 - z_0)^2} + c(t_{GPS} - t_0)$$

$$P_3 = \sqrt{(x_3 - x_0)^2 + (y_3 - y_0)^2 + (z_3 - z_0)^2} + c(t_{GPS} - t_0)$$

$$\underbrace{P_4}_{\substack{\text{Pseudorange (distance) to satellites} \\ \text{(calculated from correlation time delay)}}} = \underbrace{\sqrt{(x_4 - x_0)^2 + (y_4 - y_0)^2 + (z_4 - z_0)^2}}_{\text{Position difference between satellite and user}} + \underbrace{c(t_{GPS} - t_0)}_{\text{Delay between GPS clock and user clock}}$$



<u>4 equations, 4 unknowns (we like this!)</u>

GPS Navigation Messages

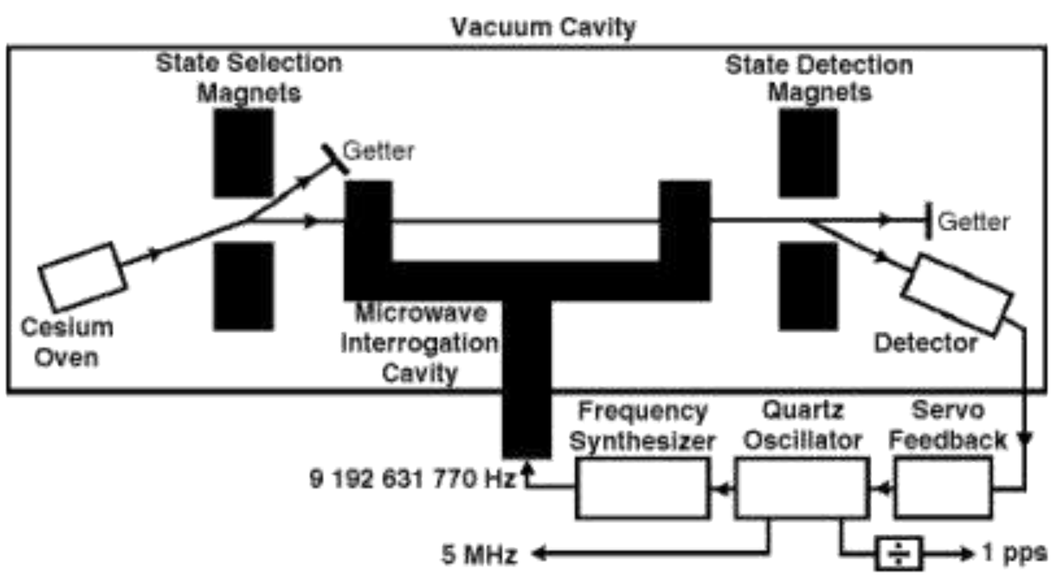
Navigation messages include:

- Time of signal generation
- Satellite position & velocity ("ephemeris data")
- Approximate position & velocity of all other GPS satellites ("almanac data")
- Satellite health/status
- Ionospheric corrections
- Time transfer information (Satellite-GPS Time delay, GPS Time-UTC delay)

GPS Clocks

- Cs/Rb atomic clocks onboard satellites & at monitor stations
  - Nanosecond-scale precision
  - Highly stable over time, still constantly corrected (monitor station uploads)
  - So precise, relativity must be taken into account on orbit (orbital speed & differences in gravitational pull from that on Earth's surface)

Atomic clock basic operation:



Lombardi, M., *NIST*

Some GPS Design Challenges

Problem	Resolution
• Satellite clocks not all synchronized to each other	• Create "ensemble time" – weighted average of clocks
• Satellite perturbations (geodesic, solar radiation)	• Model & predict ahead of time, upload corrections to satellites
• Urban/geographically challenging environments	• Local augmentation; multi-system receivers
• Atmospheric delay/attenuation	• Use multiple signal frequencies; model, predict, & correct

Demystifications

- GPS does **not** know where you are
  - Google knows where you are (thanks to GPS)
- GPS is not the only GNSS (Global Navigation Satellite System)
  - GLONASS (Russia), Galileo (EU), BeiDou (China)
- GPS is not just for positioning
  - Precise timing used for financial transactions, telecom, power grids
  - Signals used to measure land erosion, tectonic activity, sea level height

Further Reading

- http://www.gps.gov
- https://tf.nist.gov/general/pdf/1498.pdf

References & Credits

- United States Air Force
- Rakipi, et al, "Performance Analysis of a Positioning Algorithm Using Raw Measurements Taken from a GPS Receiver," 2013.
- Paulsava, Wikimedia