Overview of GPS

Personal Introduction

- Live off Harris Road near NE Blvd
- Work at BAE Systems
- Embedded software engineer for 35 years
  - Last 10+ years working with GPS receivers

Global Navigation Satellite System (GNSS)

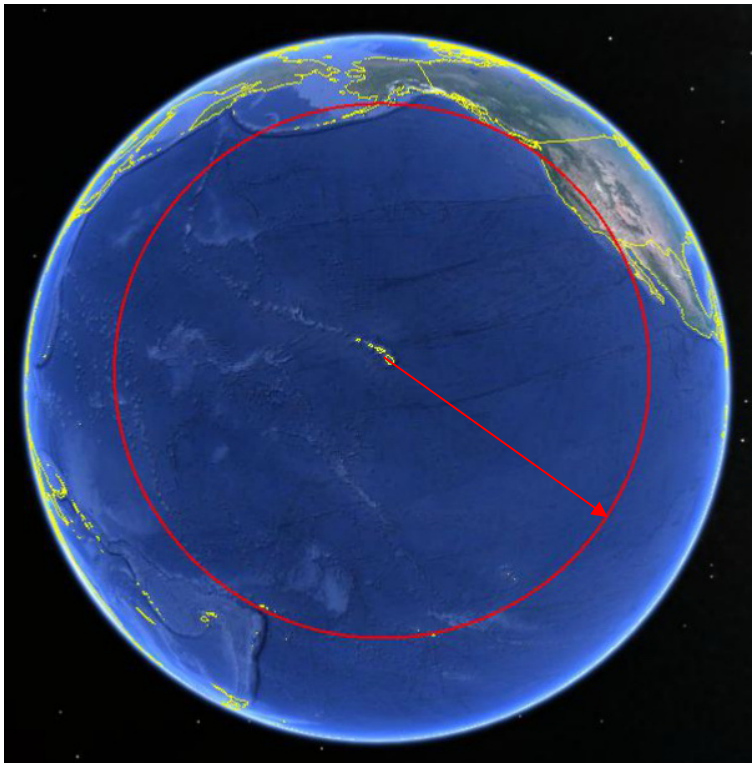
- USA: GPS (32 SVs)
- Russia: GLONASS (24 SVs)
- Europe: Galileo (30 SVs)
- China: BeiDou (22 SVs)

- They all work pretty much the same way.

How does it work?

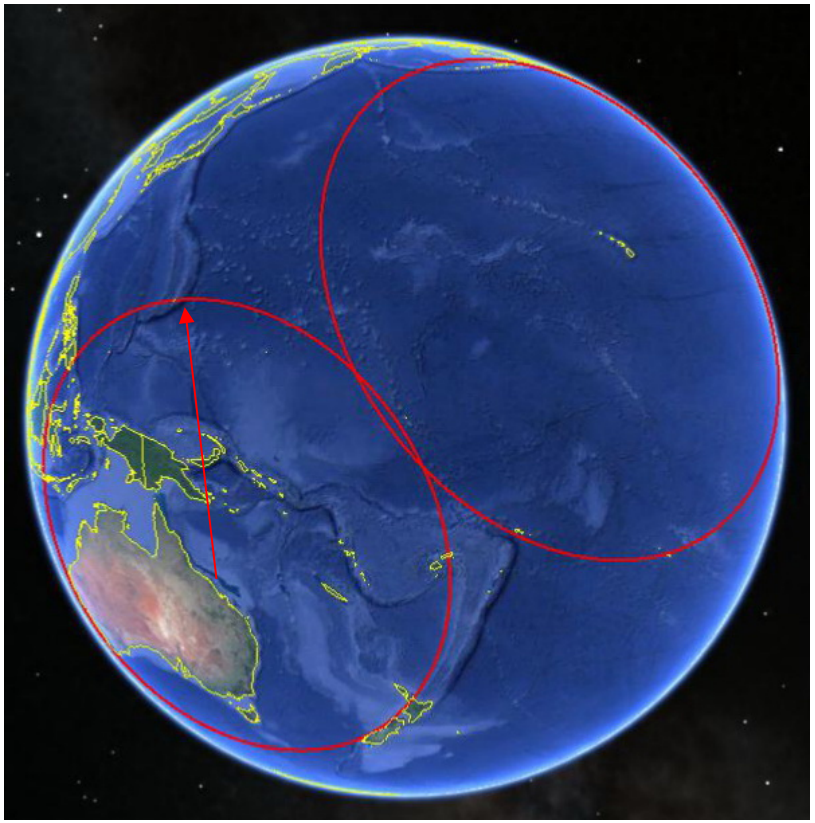
Let us start with an analogy. You are the Professor on Gilligan's Island.

Plot the First Line Of Position



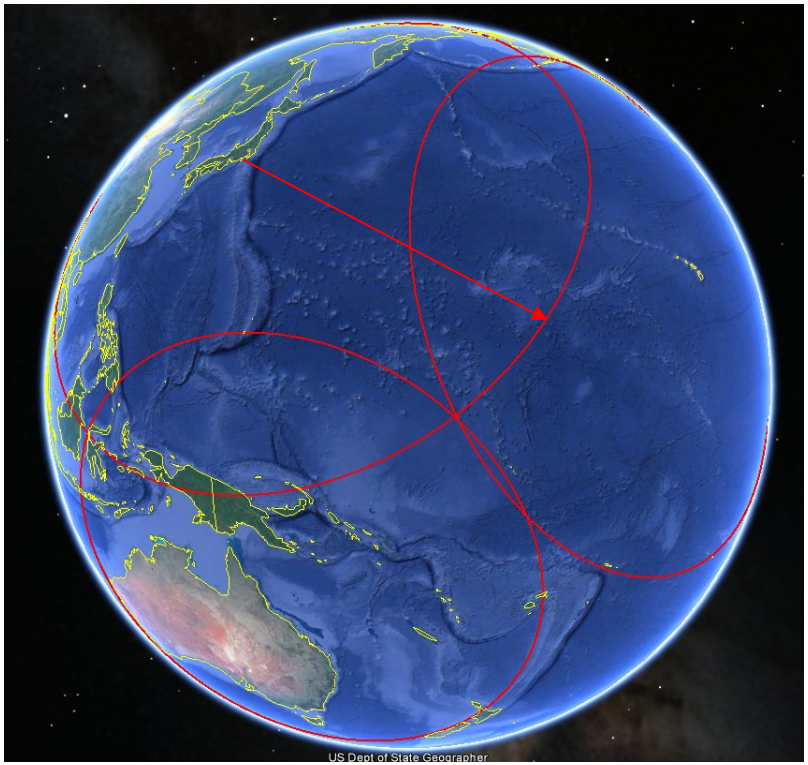
0.013957 => 2,600 miles

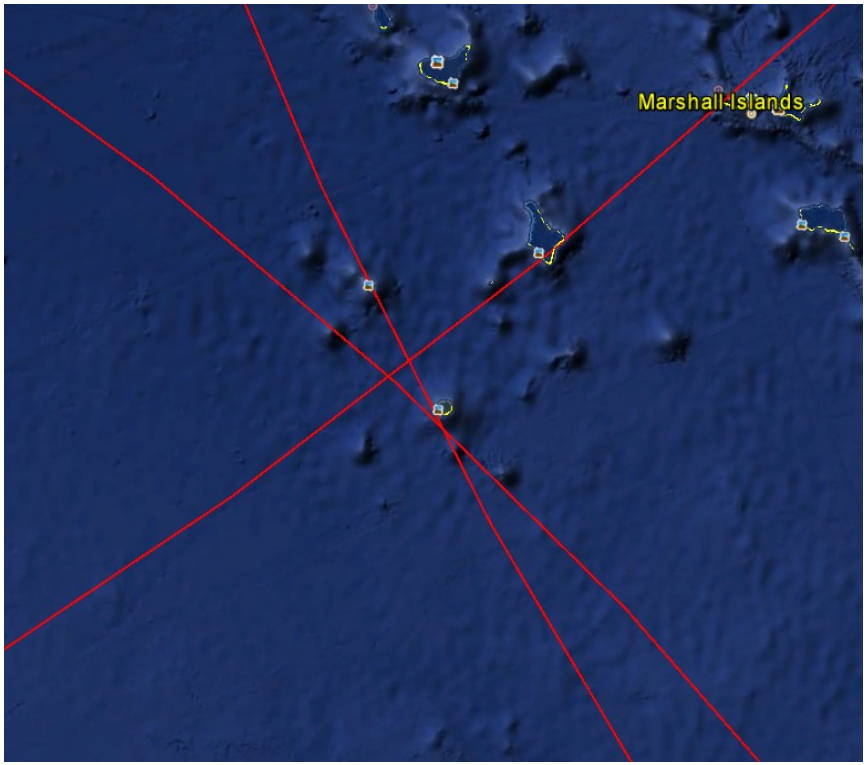
2nd Line Of Position



0.011815 => 2,200 miles

3rd Line Of Position





0.015038 => 2,800 miles

Geo-location

- This is the very crude basics of GPS
- Measure the time of arrival of chirps.
- Compute how long they were traveling.
- Draw circles around the transmission points.
- Pick the center of the resulting triangle.

Initial Data

- So after three nights you have:
  - 600.313957 s
  - 600.311815 s
  - 600.315038 s

600.313957 * 186280 => 111 million miles
Sun is only 92 million miles away!

Lost In Space

First Guess

Subtract 600 seconds

- 0.313957 -> 58,459 miles
- 0.311815 -> 58,060 miles
- 0.315038 -> 58,660 mils

Error triangle ½ the size of the Earth!

Second guess

Subtract 600.2 seconds

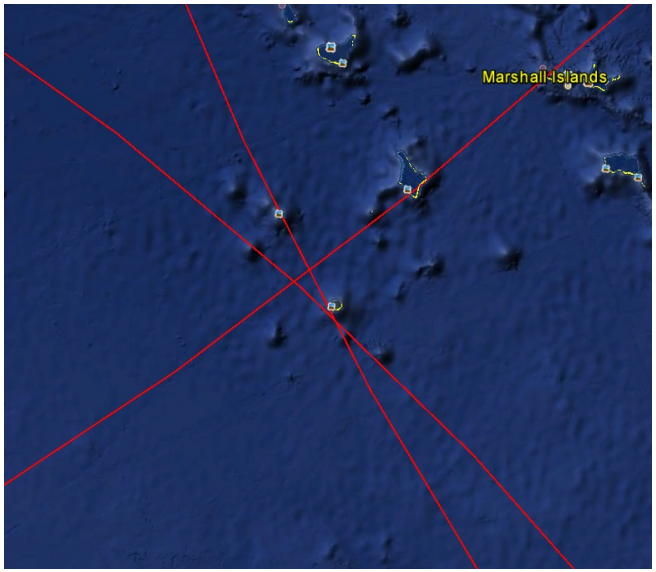
- 0.113957 -> 21,219 miles
- 0.111815 -> 20,820 miles
- 0.115038 -> 21,420 miles

Error triangle is now the size of Colorado

Third Guess

Subtract 600.3

- 0.013957 -> 2,600 miles
- 0.011815 -> 2,200 miles
- 0.015038 -> 2,800 miles



As a bonus you know also know the exact time!

Differences

- The transmitters are moving at 8,700 MPH!
  - Fast enough we need to account for relativity!
- The SVs send out information as to where they are.
- GPS solves for time, X, Y, and **Z** position.
- The SVs send out pulses several times a second and not once a day!

4 SVs as a Minimum

- There are 4 variables you need to determine.
  - X, Y, Z positions and time.
- Our equations “Pseudo Ranges” have to do with how long it takes a signal to move from an SV to our location. (e.g. 186400 Miles per second * 0.0025)
- Therefore we need a minimum of 4 SVs to get 4 equations to solve for time and position.

Overdetermined Solution

- But what if can see more than 4 SVs?
- Assume we can see 5. We can solve for position using groups of

  1, 2, 3, 4 -> Pos 1

  1, 2, 3, 5 -> Pos 2

  1, 2, 5, 4 -> Pos 3

  1, 5, 3, 4 -> Pos 4

  5, 2, 3, 4 -> Pos 5
- If the receivers can see 10 SVs, then it can generate 210 solutions!
- It could average these, but in fact it uses more advanced math to find a way to combine the answers into the best guess.

Dilution of Precision (DOP)

Just a fancy word for how much error is likely to be in a position computation.

Dilution of Precision (DOP)

DOP can be computed in many ways

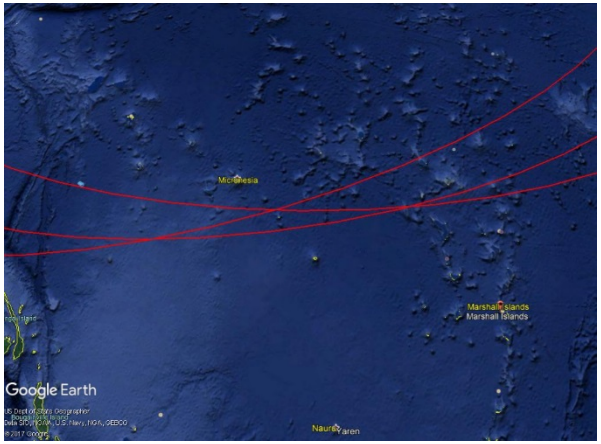
- hDOP - Horizontal DOP (lat and lon)
- vDOP – Vertical DOP
- tDOP – Time DOP (in seconds)
- gDOP - Geographic (x, y, and z)
- …

Rare to see these from devices like a smartphone or car GPS.

Dilution of Precision (DOP)

DOP takes into account:

- Number of SVs in view
- The variability in the over-determined solutions
- Location of the SVs relative to you



- The current ionosphere distortion

GPS Vs. Mapping

GPS provides:

- X, Y, Z
- Time
- DOP, and the like

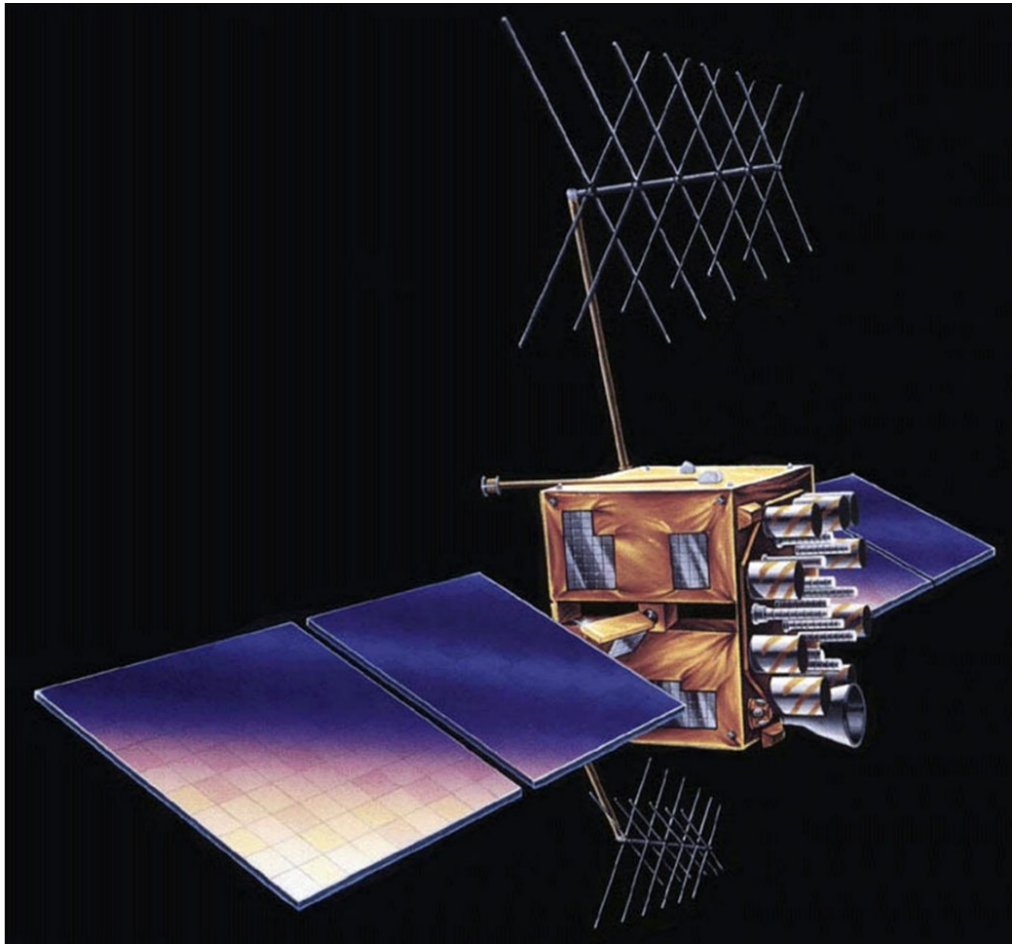
GPS **DOES NOT**:

- Draw maps
- Provide navigation instructions
- Tell you businesses that are near by.

Three Major Segments

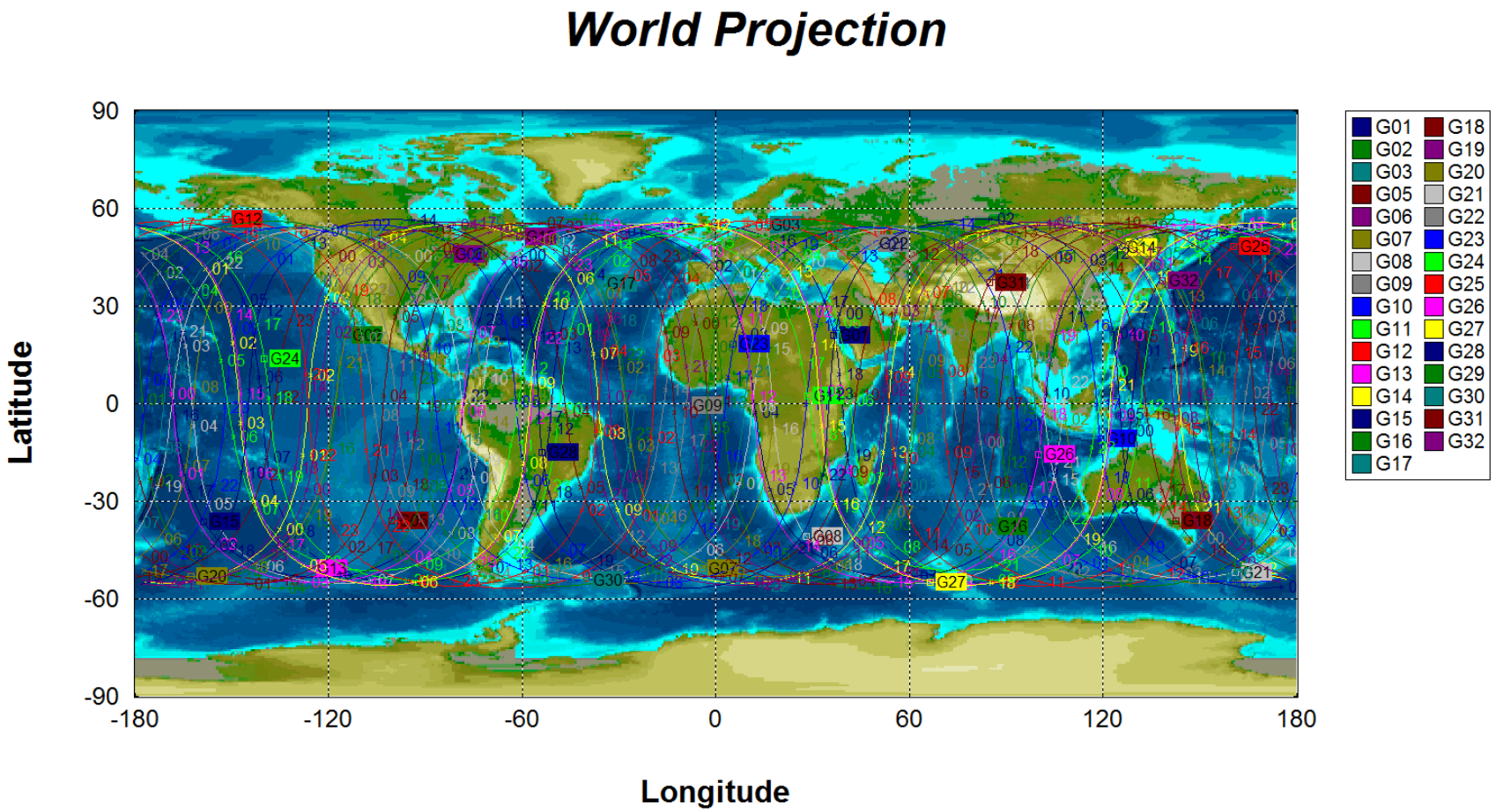
- Space Segment
  - 24 active, 6 spares, and a few special Satellite Vehicles (SV)s
- User Segment
  - The receiver you own!
- Control Segment
  - Command and control of SVs

Space Segment



Size of Mini Cooper!

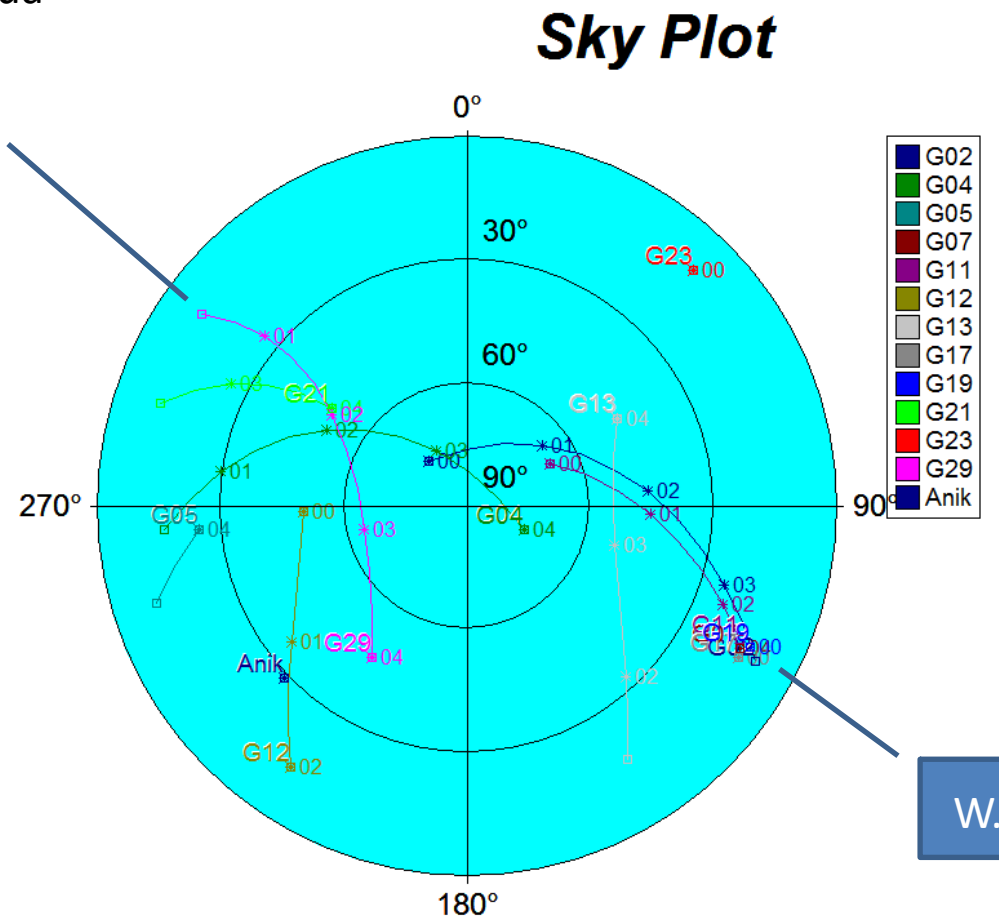
Sample Ground Track



"Trimble Office"

Local map

4 hours at Nashua

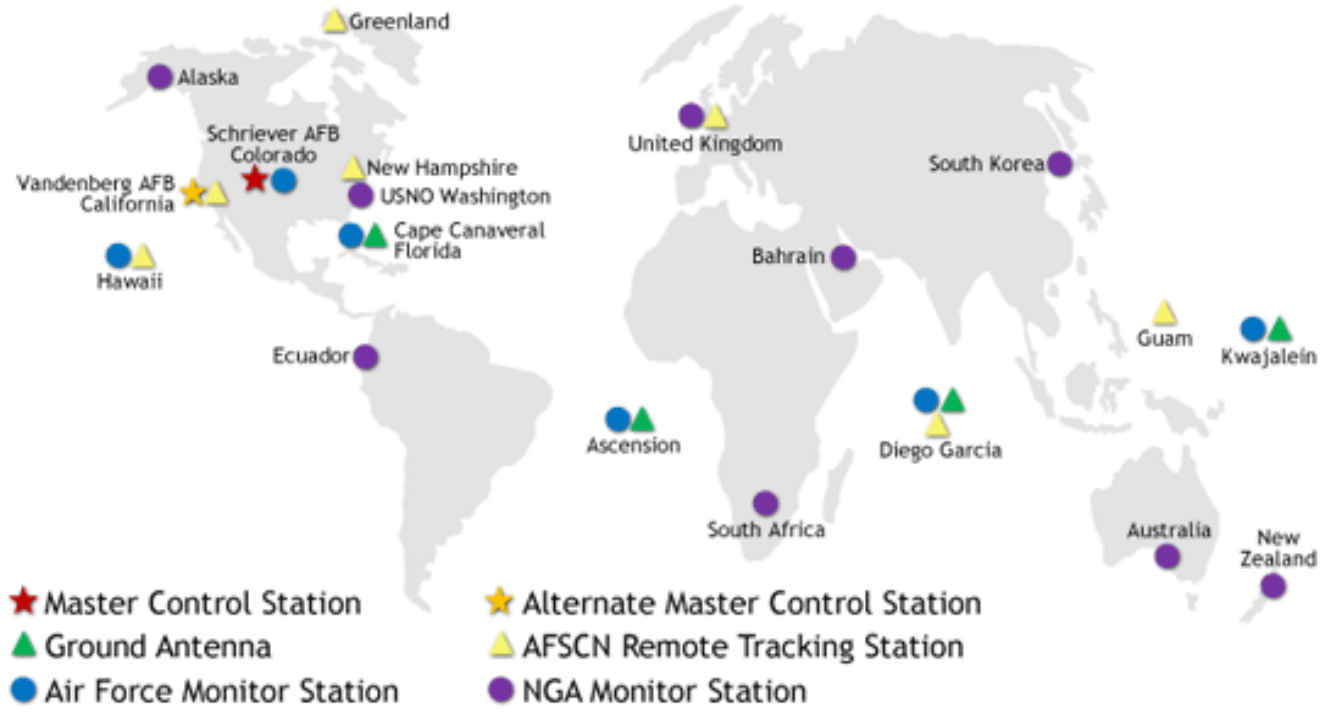


Alaska

W. Africa

"Trimble Office"

Control Segment



User Segment

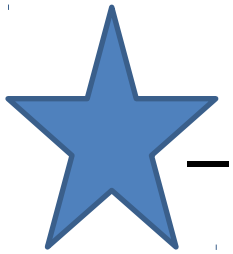
- This is the receiver that computes locations
  - Commercial units
  - Military units

Signaling

- SVs do not get data from the User Segment.
  - Your GPS does not send anything to the SVs. Only the Control Segment talks to the SVs over highly encrypted radios.
- The strength of the SV signal is miniscule at the earth's surface.
  - Sophisticated signal processing must be used to pull the signal from the background noise.
- GPS signals are totally blocked by metals
  - Buildings, cars, some window coatings.
- GPS signals are absorbed by water molecules
  - Foliage, monsoon rains, rain covered antennas

Signaling

- The signal is distorted by the ionosphere.
  - The charged particles in this layer of the atmosphere can slow down the RF transmission speed in non regular ways.
  - This is the **predominant** error in GPS positions.
  - The ionosphere ebbs and flows on a minute by minute basis.
  - Solar flares and other space weather can cause serious havoc.



Signaling

- The primary civilian frequency (L1) is spread spectrum centered at 1.57542 GHz
- SVs change frequencies at precise times. These changes are the chirps the GPS uses to figure out signal travel times.
- SVs have highly accurate atomic clocks to meet the strict timing. Jitter is less than 5 billionths of a second. Long term drift is essentially zero.

Signaling

- The data comes down at a ‘staggering’ 50 bits every second (6.25 bytes per second).
  - Compare that to your average network speed of 10 million bits per second!
- It takes 12 ½ minutes to transmit a full cycle of the various messages.
  - Critical parts are duplicated to have them available more frequently.

Ephemeris

- The Ephemeris is data that is specific to the SV sending the data (orbital data)
- It only takes a few seconds to get the Ephemeris data from the satellite.

Almanac

- The Almanac is data related to the whole Space Segment.
- It provides information about the current propagation delays through the ionosphere.
  - The Ground Segment computes what the delays must be and uploads that information to the SVs to download to the User Segment.
- It takes a full 12 ½ minutes to download the Almanac from a single SV.
- If your receiver has access to the web, it can download the almanac that way much faster.

Almanac and Ephemeris

- Without the Ephemeris for each SV in view it is not possible to solve the Pseudo Range equations.
- Without the Almanac, you can get a solution, but it will not take into account the current ionosphere errors.
- Waiting for the Almanac will give you much improved results.

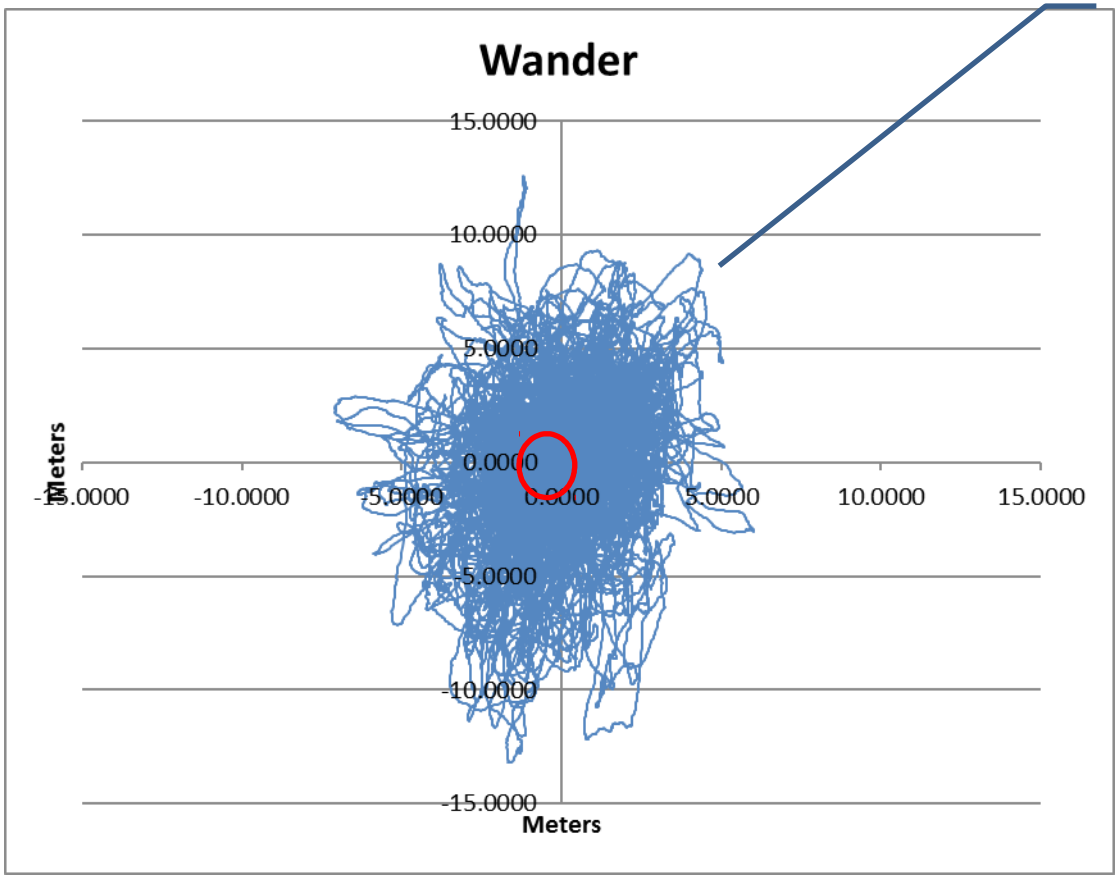
Selective Availability

- GPS can purposely introduce an error into the system.
- This is to prevent an enemy from using our own system to target us during a time of war.
- Military GPS units know how to remove the error.
- SA was turned off in May 2000 by a presidential order.
- This made the GPS system useful for commercial applications.
  - Thank you Bill Clinton!

Accuracy of the System

- Assuming
  - Non military receiver
  - Selective Availability not active (currently off)
  - Good view of lots of SVs (10+)
  - Good orientation to the user
  - Minimal multipath errors
  - Low sun spot activity
  - …
- Then, **7.8 meters horizontally 95% of the time** (spec)
  - In practice **+- 3.0 meters 63% of the time**.
  - Vertical error is often **MUCH** worst, sometimes exceeding +-50 meters!

Typical Wander Diagram



Standard Deviation is 1.9m
Max is 13m or 39 feet!
Over 12 hours in my backyard

How can this be right?

My Garmin navigation GPS always has me on the road right where I am. It does not show me off the road by 39 feet!

How can this be useful?

- It might not be if you are trying to navigate a robot in a small maze.
- If you are trying to sail an autonomous boat from California to Hawaii, pretty good!
- Perhaps you have other information that you can leverage.
  - Roads, other sensors,

www.seacharger.com

Ways to Compensate
(Augmented GPS)

- The biggest contributor to error is ionosphere distortion. If you had better knowledge of the distortion, you could get a better answer.
- Various systems were invented for this exact purpose.

Multi Frequency Receivers

- Ionosphere distorts some frequencies more than others.
- If the SVs transmit at different frequencies you can ‘subtract out’ the ionosphere errors.
- Mostly military receivers as the other frequencies are encrypted.

Differential GPS (DGPS)

- For DGPS you need a base station in reasonable proximity (+- 200 miles) to your operating area.
- The base station sends corrections out over radio.
- You have a radio that gets the corrections and applies them to your answer.
- The outcome is about +- 1.5 meters (95% of the time).
- The DGPS receiver is expensive, heavy, and requires a monthly subscription.

Wide Area Augmentation System (WAAS)

- Developed by the FAA for precision aircraft navigation and landing for the continental USA.
- Special SV (Anik) transmits corrections.
- The expected error here is +- 4m (95% of the time)
- Many receivers provide this service.

RTK Systems

- These require special and expensive equipment
- Total system might be as little as $6,000.
- But they can in fact drive errors down to the centimeter scale.
- Used on autonomous farm tractors and survey equipment.
- ‘Reach RTK’ is a Kickstarter trying to do this on the ‘cheap’ ($500).

Types of receivers

- General purpose commercial receiver like a Garmin used for hiking.
- Commercial receivers used for car navigation.
- Electronic modules embedded in things like cell phones, car trackers, military devices.

Cold/Warm/Hot Start

- Cold (60+ seconds)
  - Unit has no idea where it is or what time it is.
  - Must scan the sky for every possible SV
  - Must then get the Ephemeris for each SV
- Warm (30 seconds)
  - Unit has a rough idea of where and what time it is.
  - All it needs to do is download the Ephemeris
- Hot (0.100 seconds)
  - Unit knows where it is and what time it is.
  - Has the current Ephemeris
  - Has the current Almanac
  - Often done by uploading data from web

Take Aways

- GPS only provides position and time.
- You compute how far away from the SV you are by how long it took the signal to get to you.
- If you have 4 SVs, the intersection of all those circles tells you where you are.
- With more than 4 SVs, you can get a better solution.
- The solution is only statistical not absolute in nature.
- The DOP indicates the accuracy.
- You can only get very accurate results with augmentation systems

Questions