Intro to GPS

Skye Sweeney
Skye@FLL-Freak.com

Know Your Sensor

Know your sensor!

Before you trust or use any sensor, you need to understand it. If not, you **WILL** be surprised

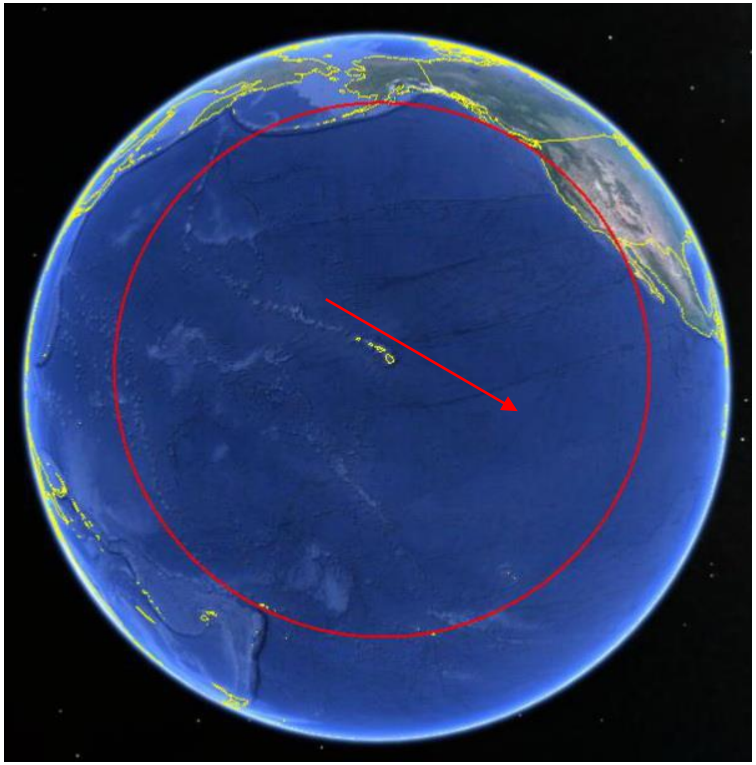
Three Major Segments

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

How does it work?

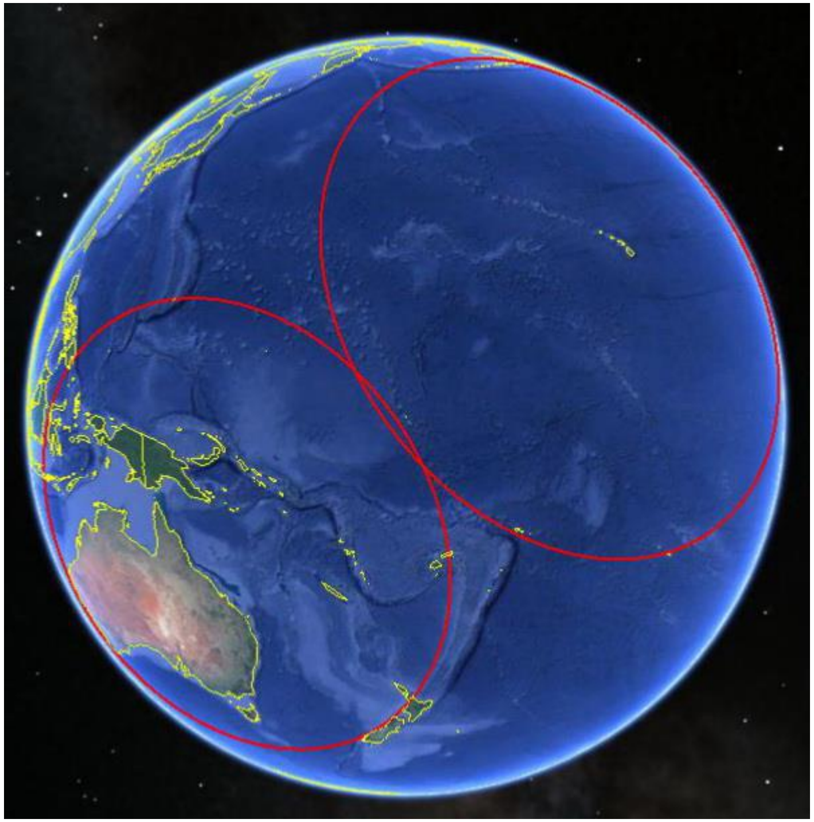
Let us start with an analogy. You are the Professor on Gilligan’s Island.

Plot the First Line Of Position



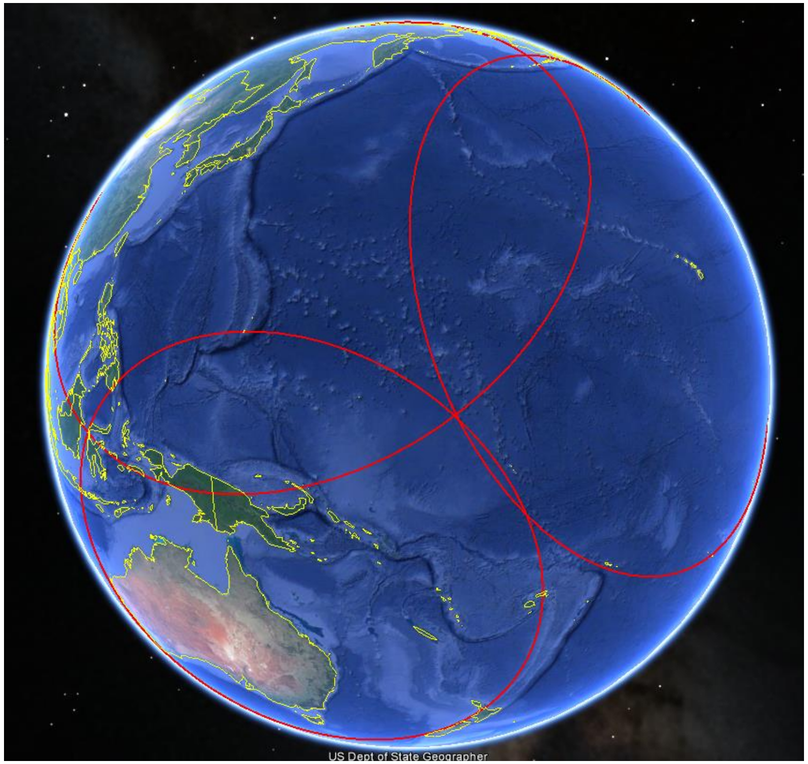
0.013957 => 2,600 miles

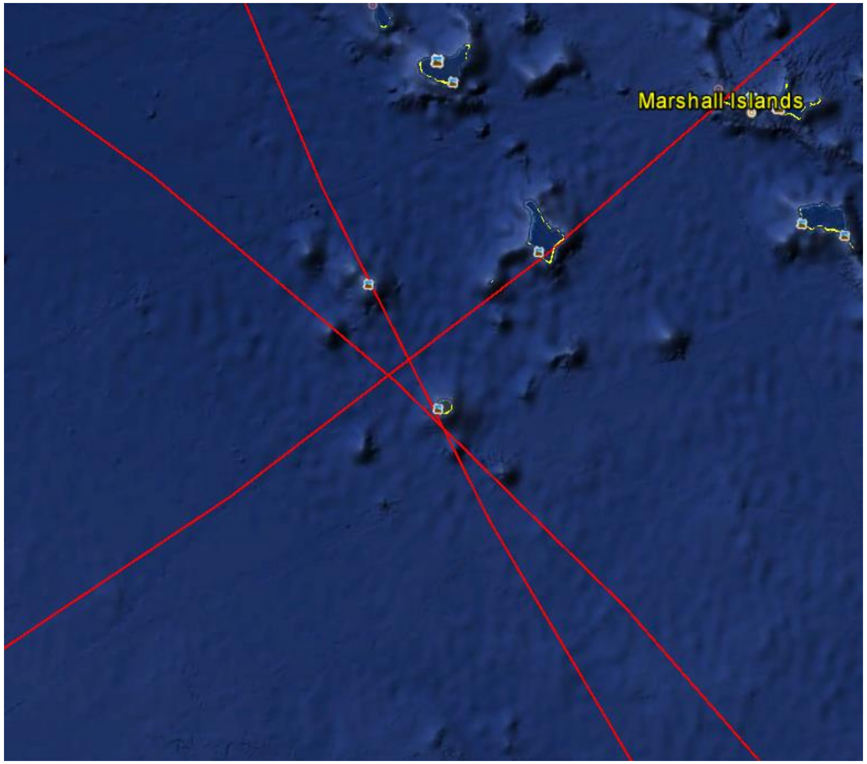
2nd Line Of Position



0.011815 => 2,200 miles

3rd Line Of Position





0.015038 => 2,800 miles

Initial Data

- So after three nights you have:
  - 600.313957 s (00:10:00.300000 + 0.013957)
  - 600.311815 s
  - 600.315038 s

600.313957 * 186280 => 111 million miles

Sun is only 92 million miles away!

First guess

So after subtracting 600 you get:

- 0.313957
- 0.311815
- 0.315038

Error triangle ½ the size of the Earth!

Second guess

So you make a new guess and subtract 600.2 you get:

- 0.113957
- 0.111815
- 0.115038

Error triangle is now the size of Colorado

Third Guess

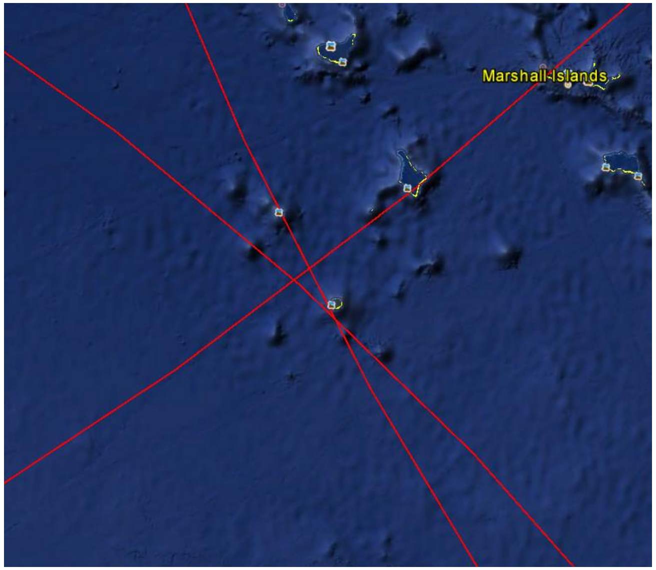
So you make a third guess and subtract 600.3 you get:

- 0.013957
- 0.011815
- 0.015038

Error triangle is the same as before.

Solution

- So by the end of the night, you now know where you are (more or less)
- As a bonus you know also know the exact time!



Back to GPS

- And this is pretty much how GPS works.
- The major differences are:
  – The AM stations are moving at 8,700 MPH!
    - Fast enough we need to account for relativity!
  – The SVs also 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 MPH * 0.0025)
- Therefore we need a minimum of 4 SVs to get 4 equations to solve for your position/time.
  - If you tell the GPS your altitude, you only need 3 SVs.

Overdetermined

- But what if can see more than 4 SVs?
  - Remember, you only need 4 to solve your position and time.
- Using the other SVs can allow you to get more accurate.
- 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 way to indicate how much error a position report is likely to have.

Dilution of Precision (DOP)

Errors can be reported in many ways

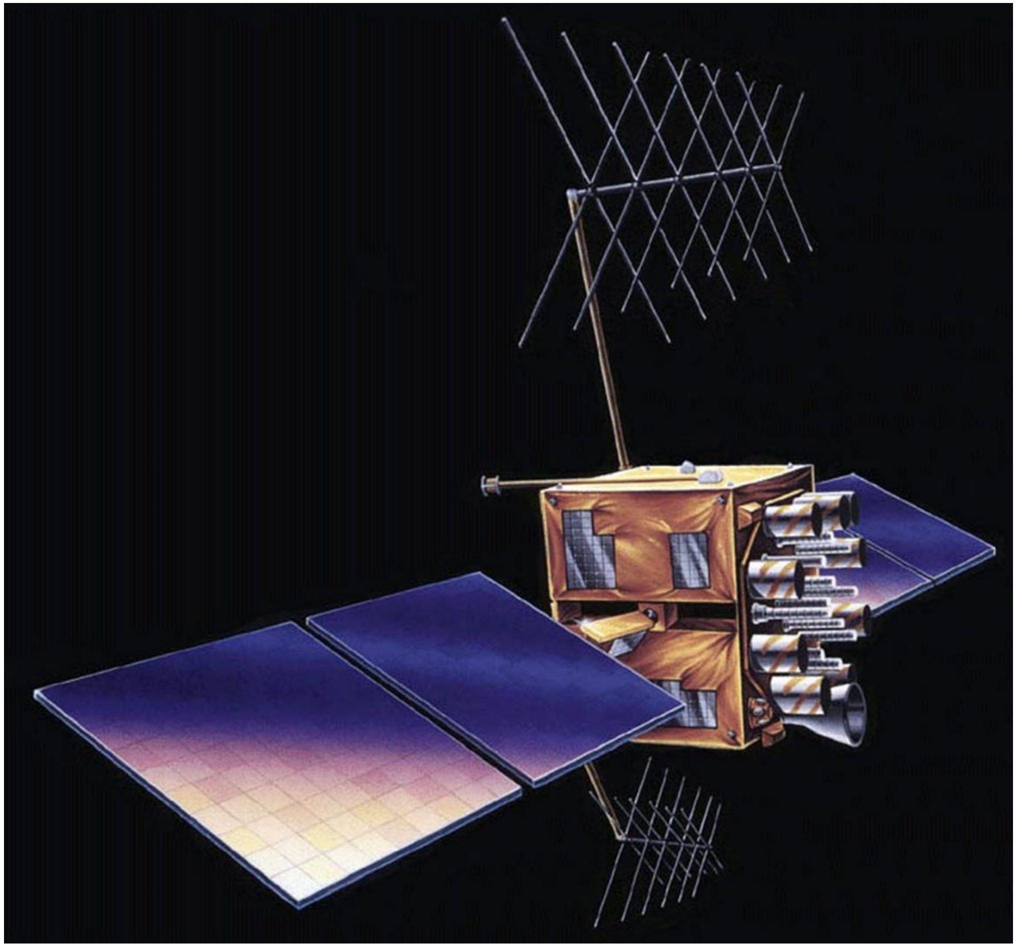
- hDOP - Horizontal DOP (lat and lon)
- vDOP – Vertical DOP
- tDOP – Time DOP (in seconds)
- gDOP - Geographic (x, y, and z)
- …

Dilution of Precision (DOP)

DOP takes into account:

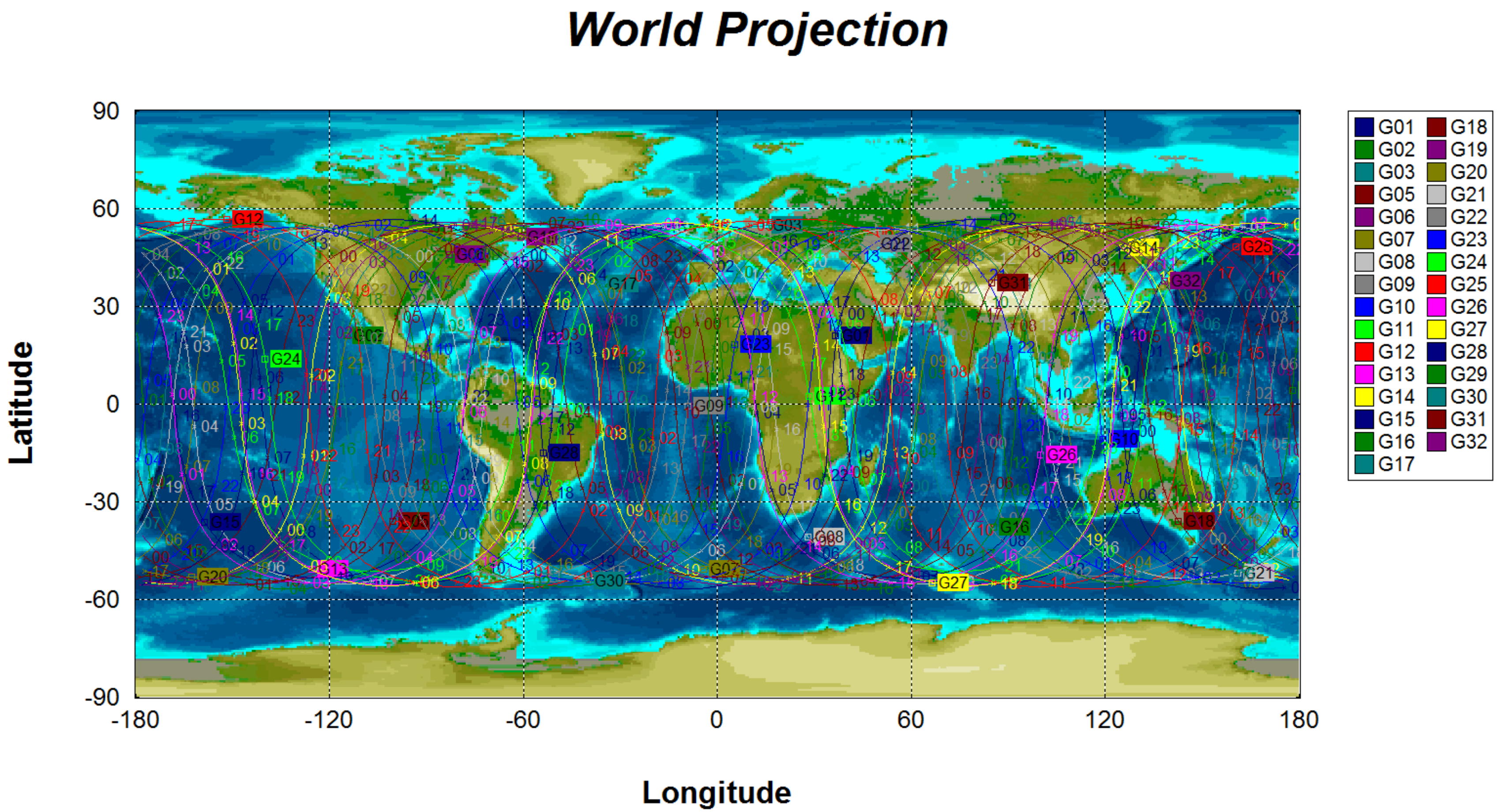
- Number of SVs in view
- Location of the SVs relative to you
- The current ionosphere distortion
- The variability in the overdetermined solutions

Space Segment



Size of a school bus!

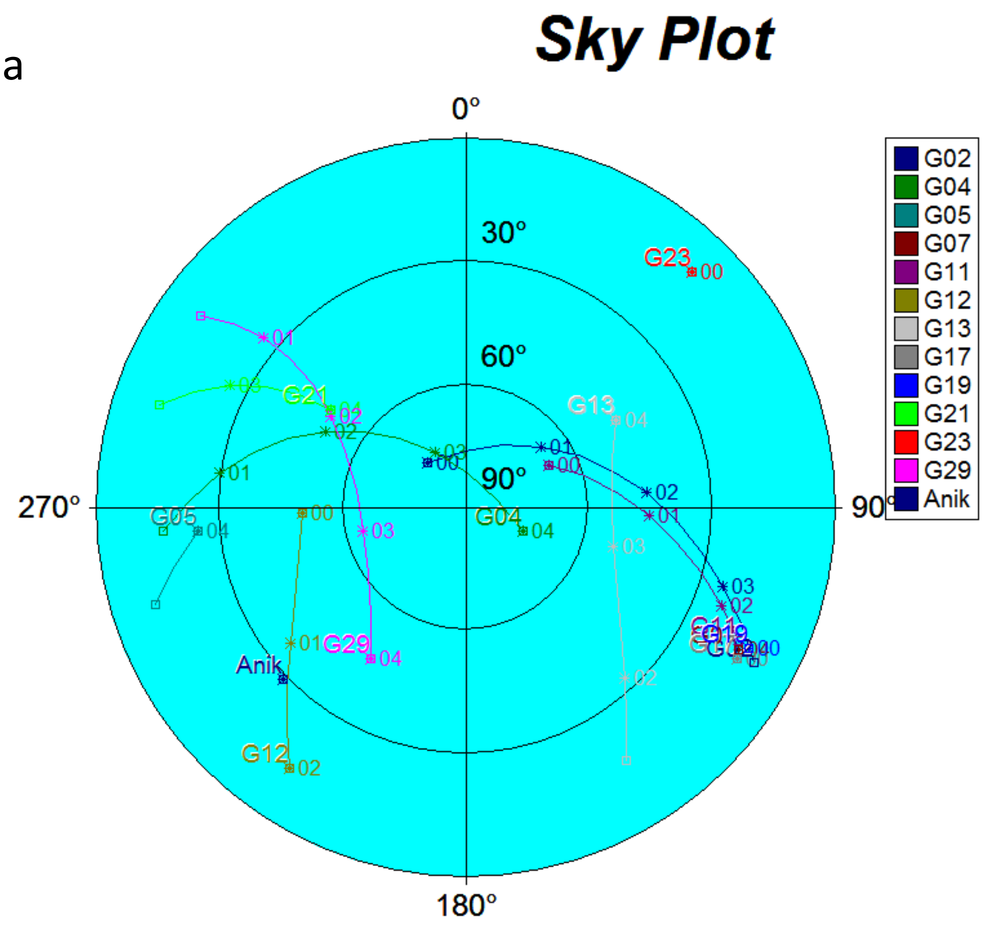
Sample Ground Track



"Trimble Office"

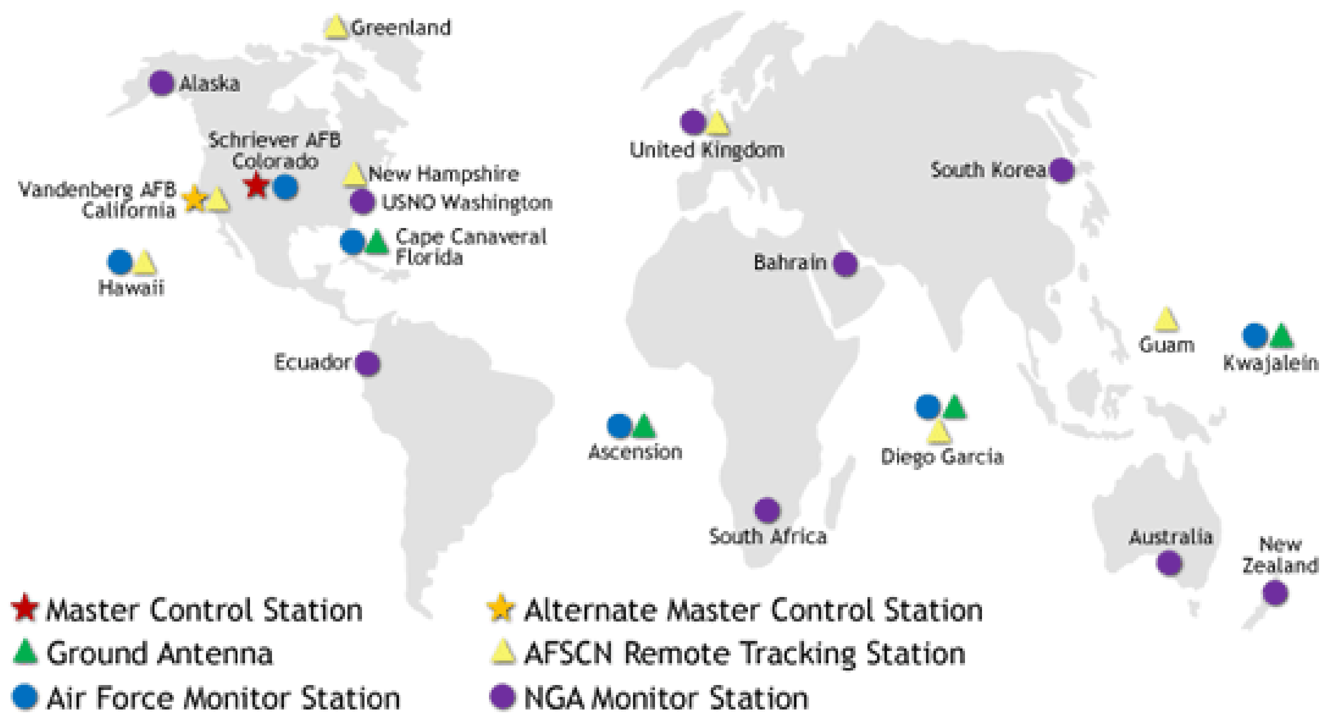
Local map

4 hours at Nashua



“Trimble Office”

Control Segment



Signaling

- SVs do not get data from User equipment.
  - Your GPS module does not send anything to the SVs. Only the Control segment talks to the SVs
- 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.
- The signal is distorted by the ionosphere.
  - The charge particles in this layer of the atmosphere can slow down the RF transmission speed. This is often the predominant error in GPS positions.

Signaling

- The primary civilian frequency (L1) is spread spectrum centered at 1.57542 GHz
- SVs send out a chirp that is synchronized to the GPS time that is common across all SVs.

Signaling

- The data comes down at a ‘staggering’ 50 bits every second (6.25 bytes per second).
- It takes 12 ½ minutes to transmit a full cycle of the various messages.

Ephemeris

The Ephemeris is data that is specific to the SV sending the data (orbit data)

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 is smart, it can speed this up by downloading different chunks from multiple SVs in parallel.

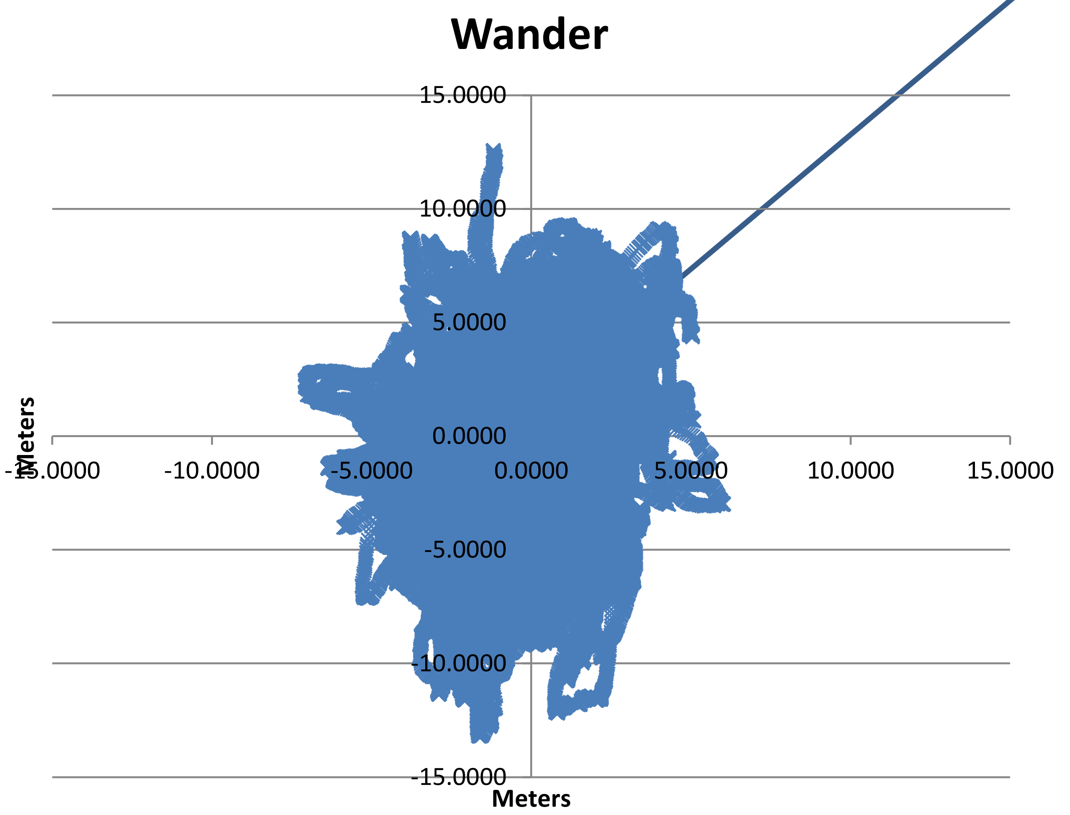
Almanac and Ephemeris

- Without the Ephemeris for each SV it is not possible to solve the equations.
- Without the Almanac, you can get a solution, but it will not take into account the current ionosphere errors.
- Waiting the full 12 ½ minutes for the Almanac will give you much improved results.

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 shadow of house

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 20 feet!

How can this then be useful?

- It might not be if you are trying to navigate 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.

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.

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 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 $6,000.
- But they can in fact drive errors down to the centimeter scale.
- Used on automated cars and farm tractors.
- ‘Reach RTK’ is a Kickstarter trying to do this on the ‘cheap’ ($500).

Theory class is over.

Types of receivers

- You have a few distinct choices.
  - Use a general purpose commercial receiver like a Garmin with a data link of some sort. Many have serial or USB.
  - Use an electronic module that provides the receiver and antenna as a whole.
  - Roll your own from the discreet receiver parts.

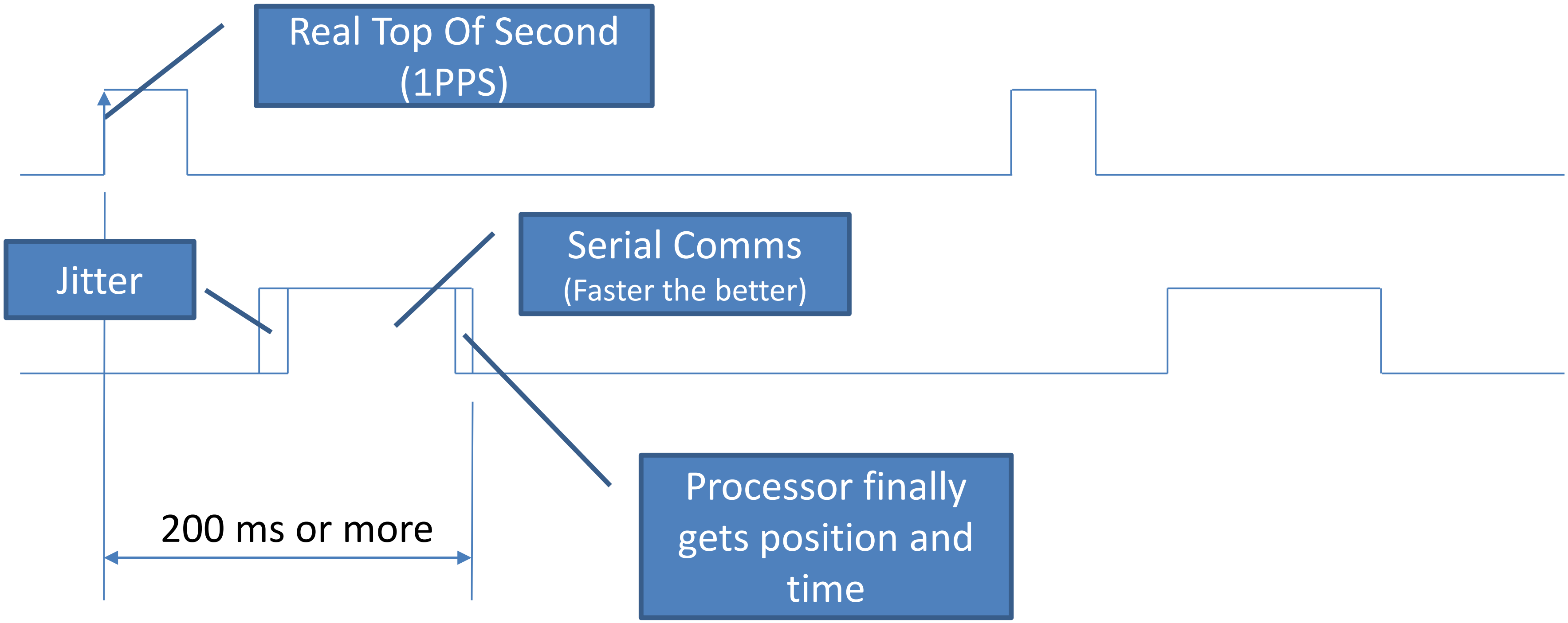
Pick a Module

- Start with something available from Sparkfun, AdaFruit, or vendors that make units for autopilots.
  - They will work
  - They will likely have an Arduino library
  - They will have some support from the vendor
  - They will have support from the web.

Discriminators

- Many GPS modules only do 1Hz updates.
  - This may not be fast enough for you
  - Some do 5 or 10Hz. Beware of those faking higher rate outputs by guessing and not calculating!
- Pick a receiver with at least 16 simultaneous channels.
- 1PPS output
  - Allows you to squeeze out extra accuracy
- Serial baud rate as fast as possible (115200 good)
- Cold/Warm/Hot start ability
- Works above 60K feet

1 PPS

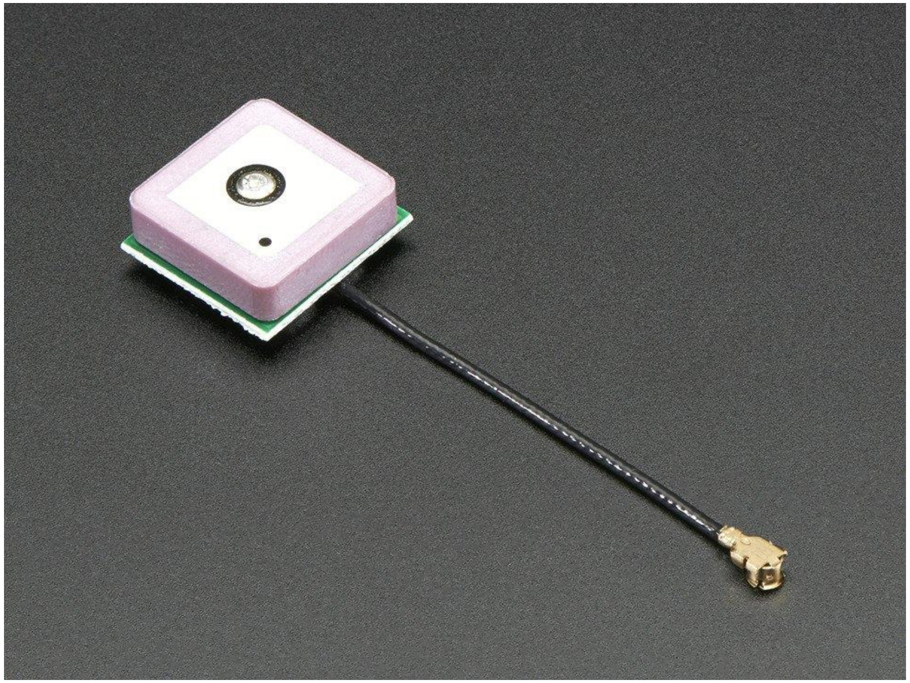


Feed 1PPS to an interrupt.
Capture processor time using 'millis()'
When you get position and time, you can also get the millis()
You now know how old the position is and can compensate.

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

Use an appropriate antenna



Types of Interfaces

- Interfaces
  - Serial (RS-232 levels)
  - Serial (digital levels)
  - I2C
  - SPI
  - USB

Types of Protocols

- Protocols
  - NMEA (ASCII based)
    - National Marine Electronics Association
  - Vendor specific
    - TSIP (Garmin)
    - UBX (uBlox)
    - SiRF Binary (SiRF)

NMEA

- Sentences look like:
  $GPGGA,123519,4807.038,N,01131.000,E,1,08,0.9,545.4,M,46.9,M,,*47
- Easy for humans to parse.
- Computationally expensive.

Binary Formats

- Impossible to make any sense of on the fly.
- Fairly complicated to setup to read.
  - A finite state machine is likely needed!
- Very fast computationally if your processor supports IEEE floating point numbers.

Recommendations

- Use a binary format when possible
- Provides better command and control

Remember

- Know your sensor!
- Realize that it can only give you a statistical answer.
- Ensure you only start to use results after the receiver has downloaded the Almanac
  - May take more than 12 1/2 minutes.

Worry about self jamming

- Since the GPS signal is so small, it is not difficult to jam it by mistake.

Run lots of Experiments!

- Create wander plots under real life conditions.
  - Motors running
  - Sensors in use
  - In the correct venue
- Are spikes in error accompanied by spikes in DOP?
- Do any of your other sensors cause glitches?
- Does the unit suffer from hysteresis?

Questions