HOW GPS WORKS

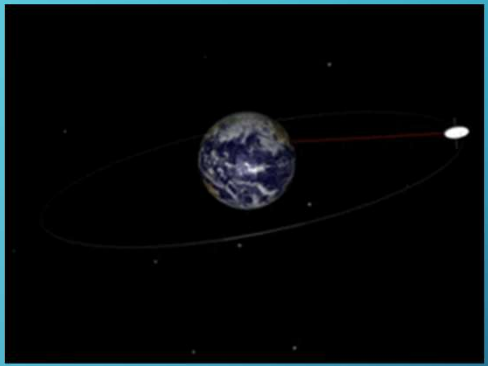
MARK DUEWIGER
11/03/2022

- ❑ I AM CONSIDERING PROVIDING A SHORT 10 TO 20 MINUTES PRESENTATION EXPLAINING HOW SOMETHING WORKS.
- ❑ I AM THINKING I (OR SOMEONE ELSE) COULD DO THESE
  - ➢ They could be done on tech slam days
  - ➢ Or 2 or 3 could be done as the main topic for the evening
- ❑ YOUR THOUGHTS?
- ❑ ANY TOPICS YOU WOULD LIKE SEE COVERED?

THREE SEGMENTS IN THE GPS SYSTEM

- Space Segment
- Control Segment
- User segment

SPACE SEGMENTS



- 24 satellites - 21 active, 3 spares
- All contain very accurate atomic clocks
- High orbit (12,000 miles)
- Travel at 7,000mph. Orbit period 12 hours
- Solar powered. Should last 10 years
- Transmits on several low power frequencies

MD1

SPACE SEGMENT (CONT.)

- Civilians use L1
- 1575.42MHz in UHF
- About 50 watts of power
- Signal is “line of sight”
- What is broadcast
  - “Pseudorandom” time signals
  - Unique satellite identifier

A phase III GPS satellite

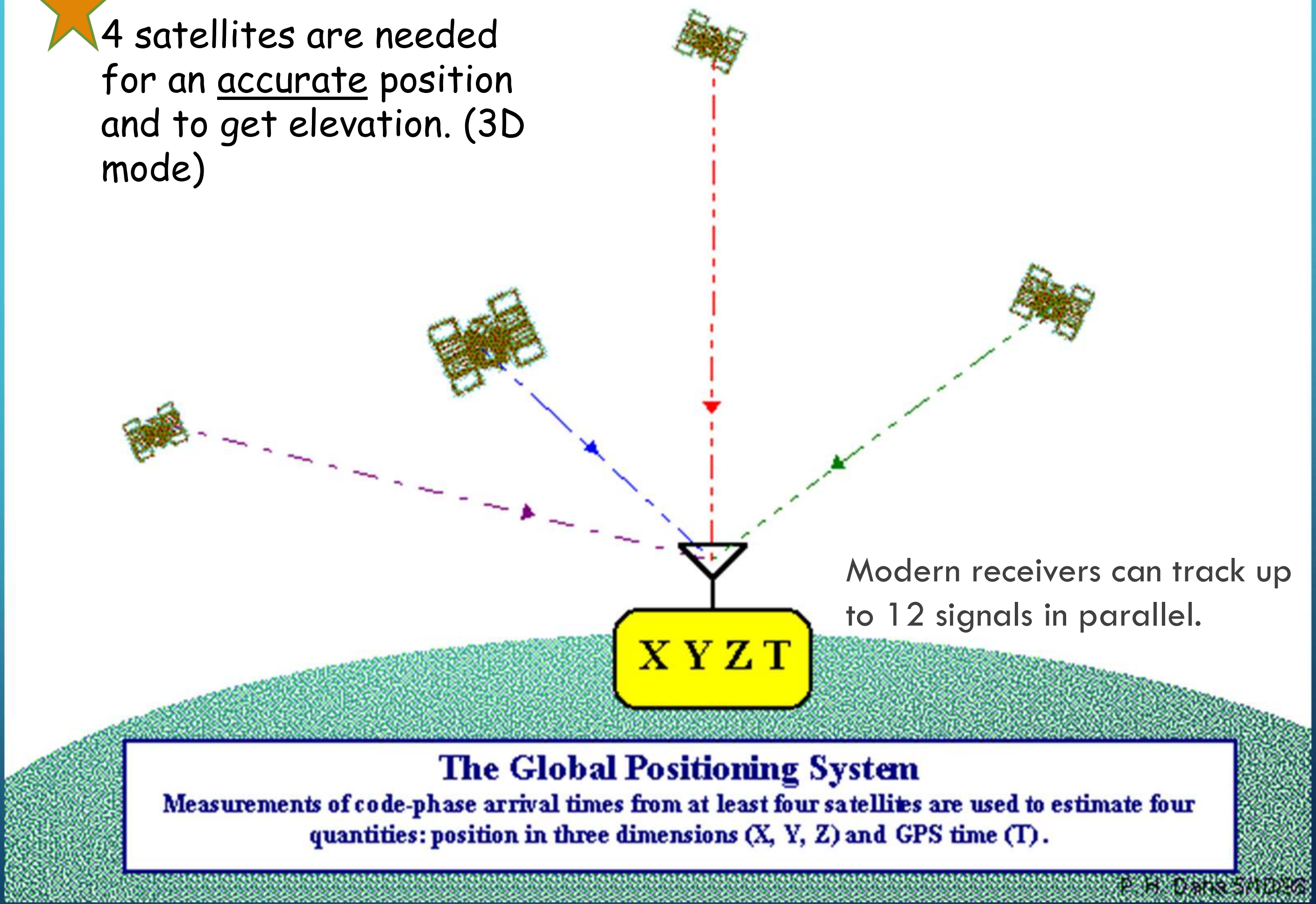
SPACE SEGMENT (CONT.)

- Coded Signals
  - To calculate the travel time from the satellite to the unit. (time of arrival)
  - Travel time multiplied by speed of light equals satellite range or distance from the unit.
- Also broadcasts
  - satellite orbital and clock information (almanac),
  - general system status information (ephemeris)

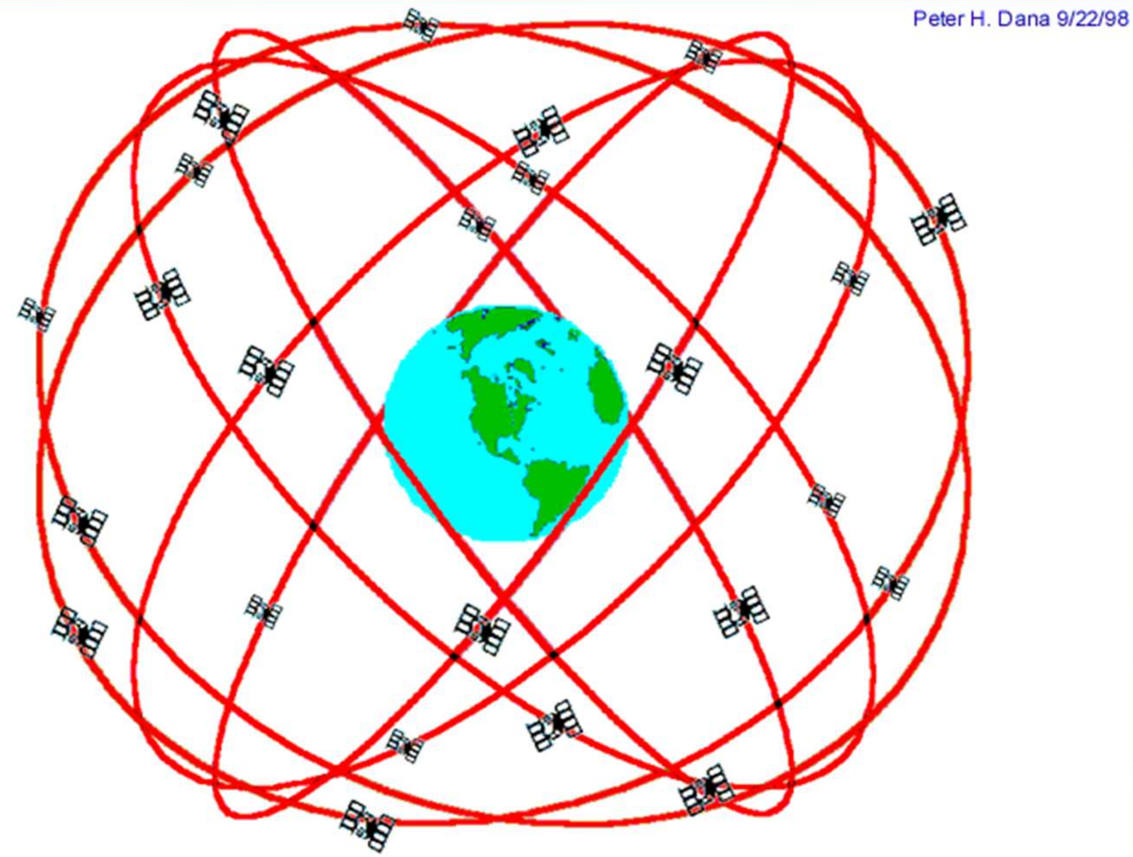
Very basic packet structure

Satellite Number orbital and clock info general system status	Travel time (time of arrival)

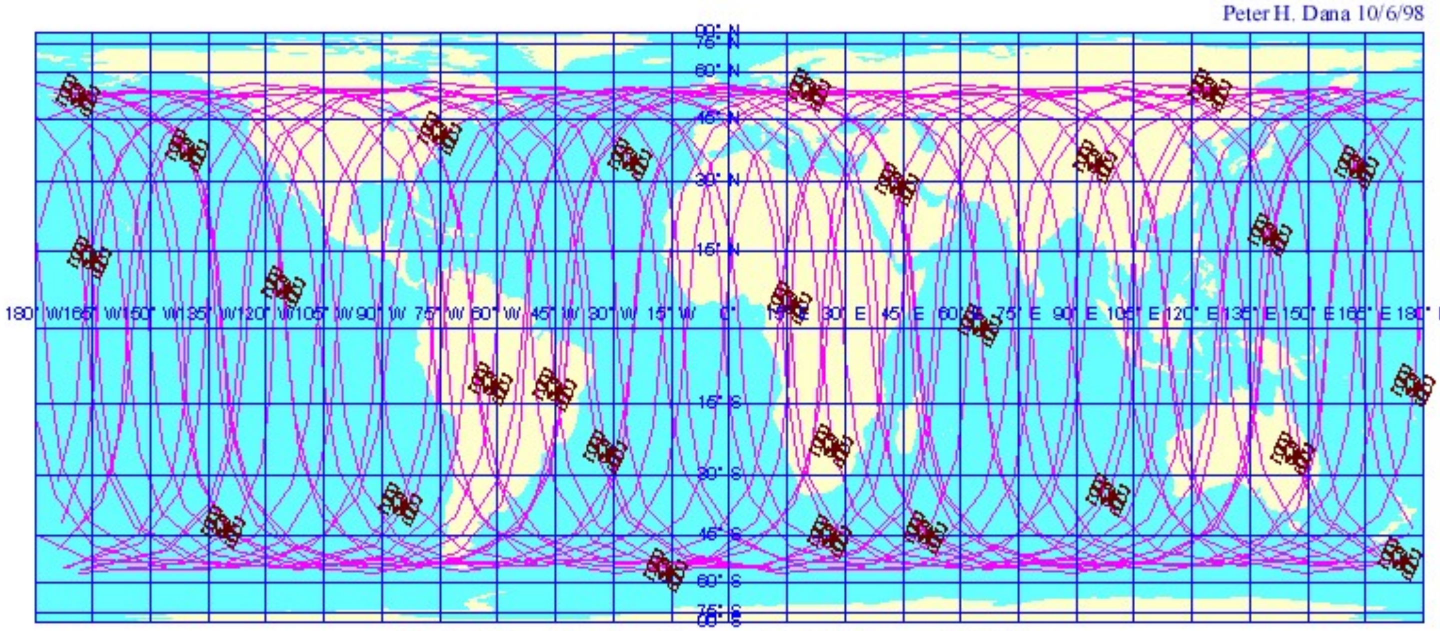
4 satellites are needed for an <u>accurate</u> position and to get elevation. (3D mode)



Modern receivers can track up to 12 signals in parallel.



GPS Nominal Constellation
24 Satellites in 6 Orbital Planes
4 Satellites in each Plane
20,200 km Altitudes, 55 Degree Inclination



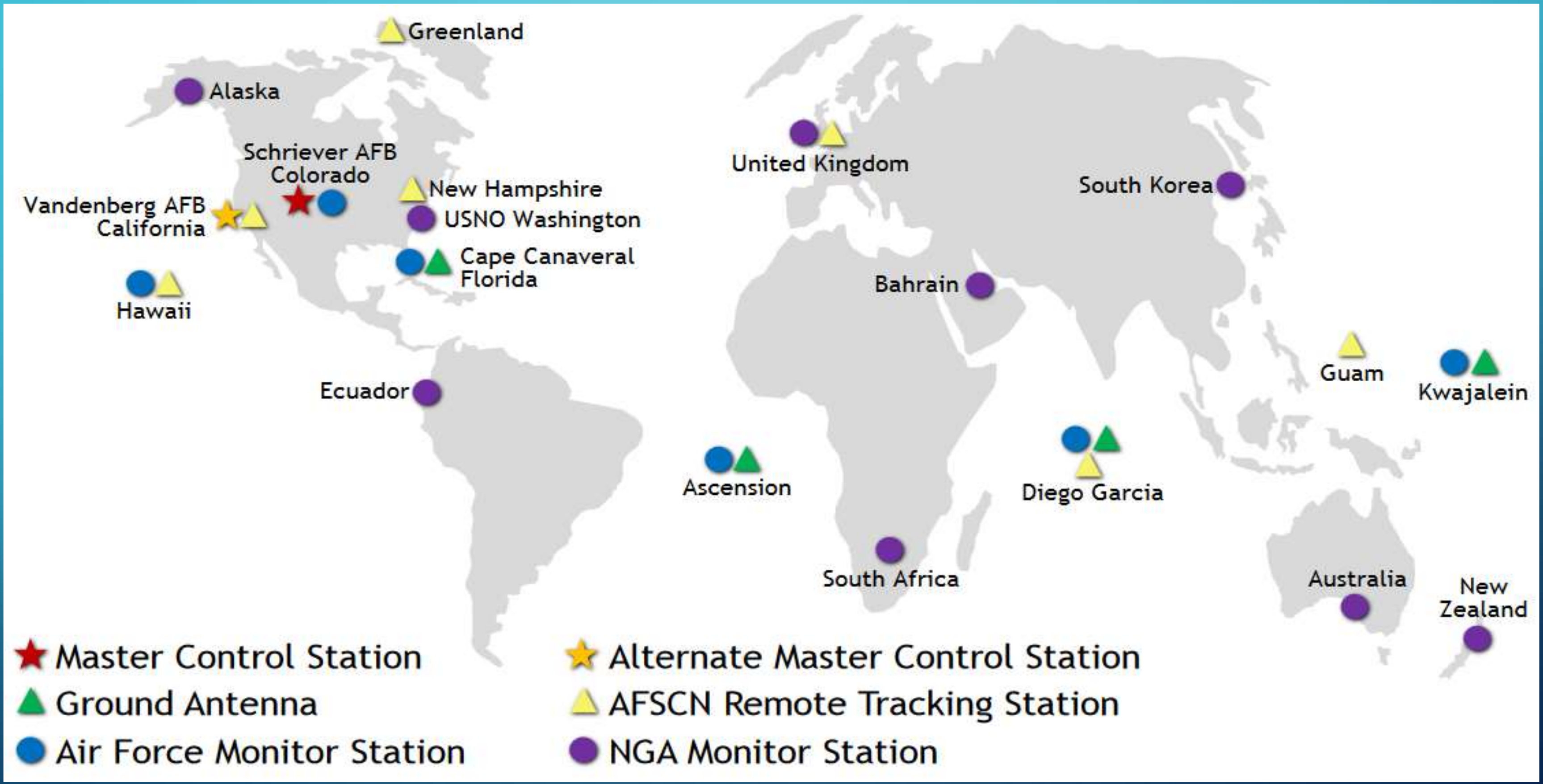
Global Positioning System Satellites and Orbits
for 27 Operational Satellites on September 29, 1998
Satellite Positions at 00:00:00 9/29/98 with 24 hours (2 orbits) of Ground Tracks to 00:00:00 9/30/98

CONTROL SEGMENT

- Total of five ground control stations.
- Four unmanned.
- Master control station.
  - monitors the entire system.
  - broadcasts updates to satellites.
  - Located in Colorado Springs.

CONTROL SEGMENT

- Ground-based monitoring and upload stations
- Control orbit and timing information



USER SEGMENT

- GPS receiver on the ground.
- Person using the system.

etic GPS Receivers

Military Applications

Cell phone:

- ✓ Directions
- ✓ Location of friends
- ✓ Track someone's location
- ✓ ETC.

- Capable of sub-centimeter accuracy
- Bulky, expensive
- High-precision applications such as surveying, geodetics

Precise timing for SONET networks
Other Communications applications

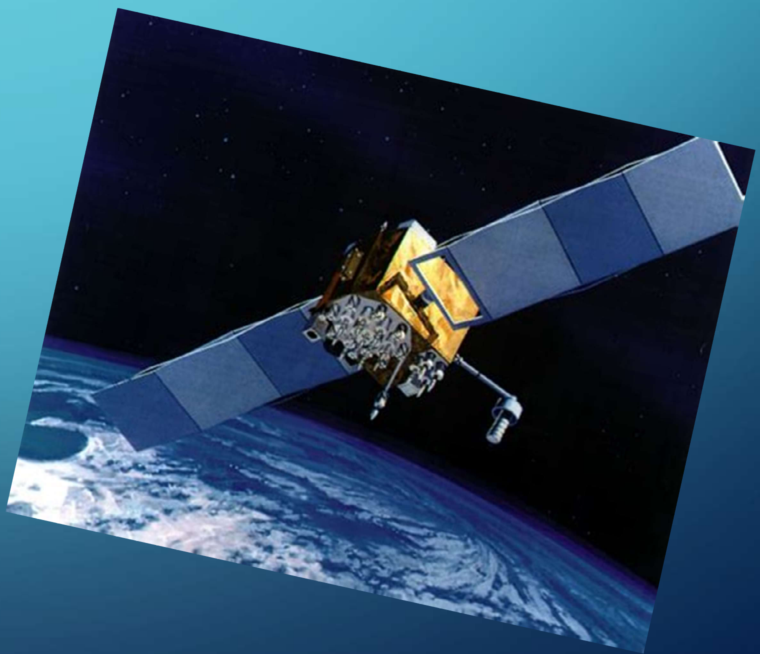
HOW DOES GPS WORK?

Now we know the components of a GPS system. Understanding how it works I should be straight forward

- Receiver needs to know
  - Where are the satellites (at least 4)?
  - How far away are they?
- Special information the receiver picks up:
  - Almanac – approximate locations of all the satellites, continuously broadcast. Good for 30 days. Helps rapid signal location.
  - Ephemeris – updated correction information good for four to six hours.

USING THE TIME SIGNAL

- All the satellites and the receiver use the same time signal
- Distance from satellite determined by time delay between time signal and "time of arrival".
- Basic formula:
  - **velocity X travel time= distance**



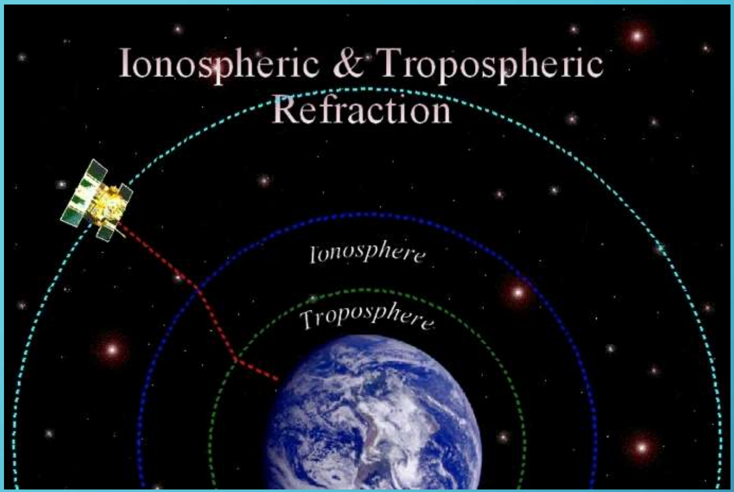
USING THE TIME SIGNAL (CONTINUED)

- The receiver generates the same “pseudo-random” code as the satellites.
- Tries to match its code with the satellite’s.
- The delay or shift tells it how long the signal took to reach the receiver.
- The receiver’s clock not as accurate as the satellite’s. Clock error corrected by using signal from four satellites.

The real world is not ideal and much of the design is correcting errors. Errors are identified in red

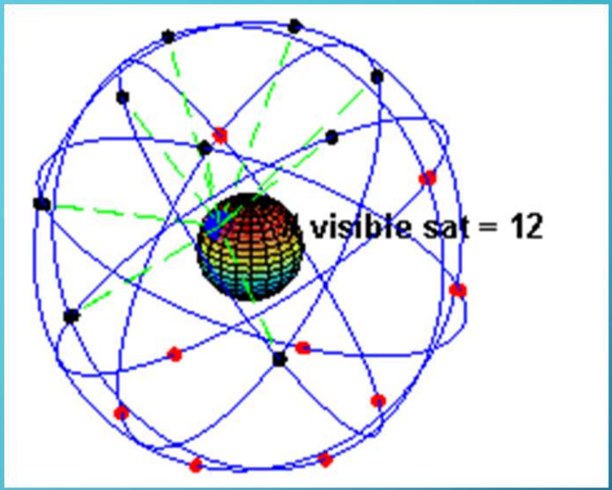
SOURCES OF ERROR

- Ionosphere and troposphere
- **Refraction of signals**
- Weather
- Signal transmission errors and noisy channels
- Signal multi-path timing errors
- Receiver clock errors
- Orbital or ephemeris errors
- Minimum or less than minimun Number of satellites visible
- Satellite position geometry
- Relativistic errors due to gravitational fields
- Satellites bounce around not a smooth ride
- **Sometimes the GPS signal from the satellite doesn't follow a straight line.**



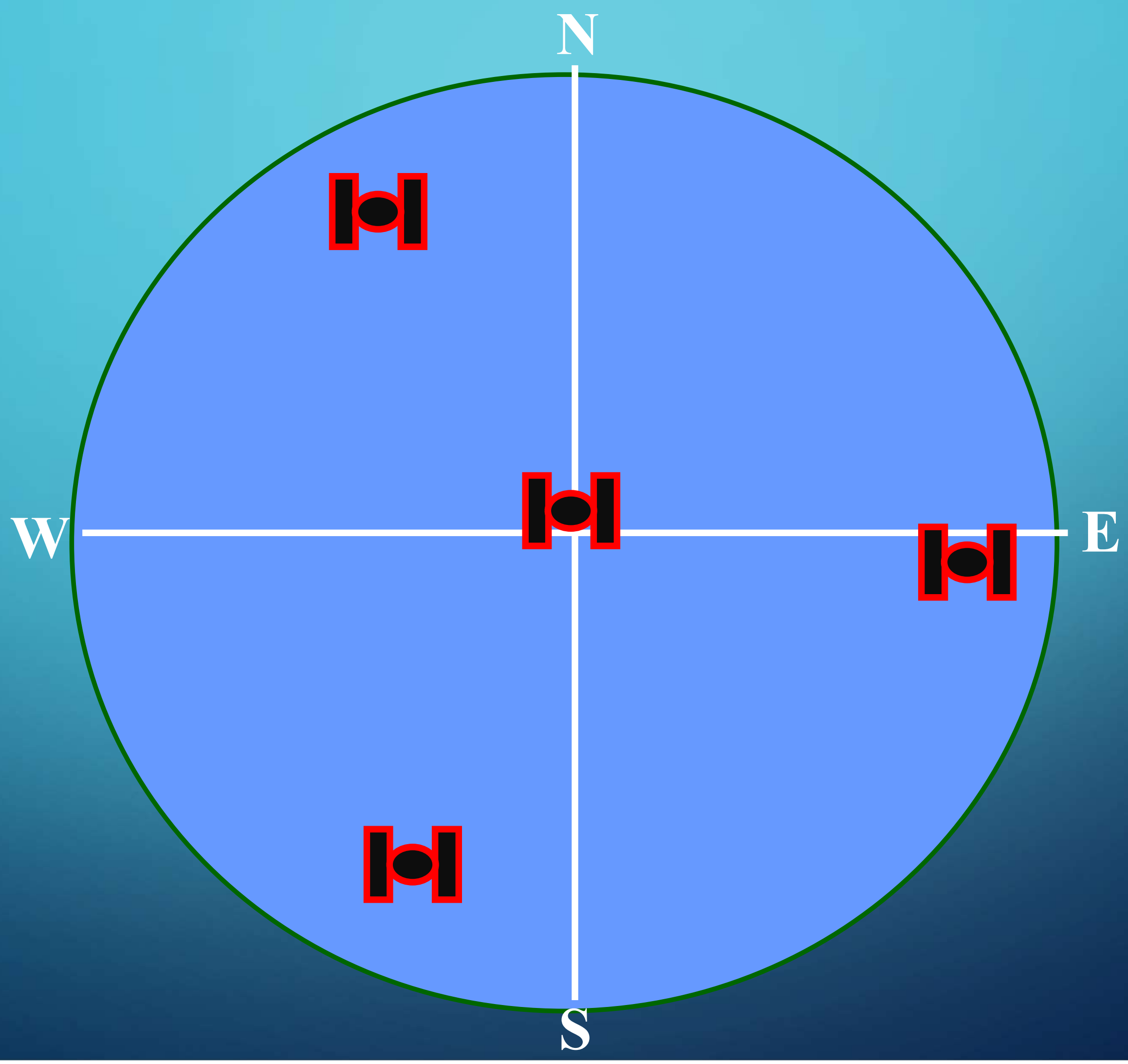
Example of Refraction

SOURCES OF ERROR

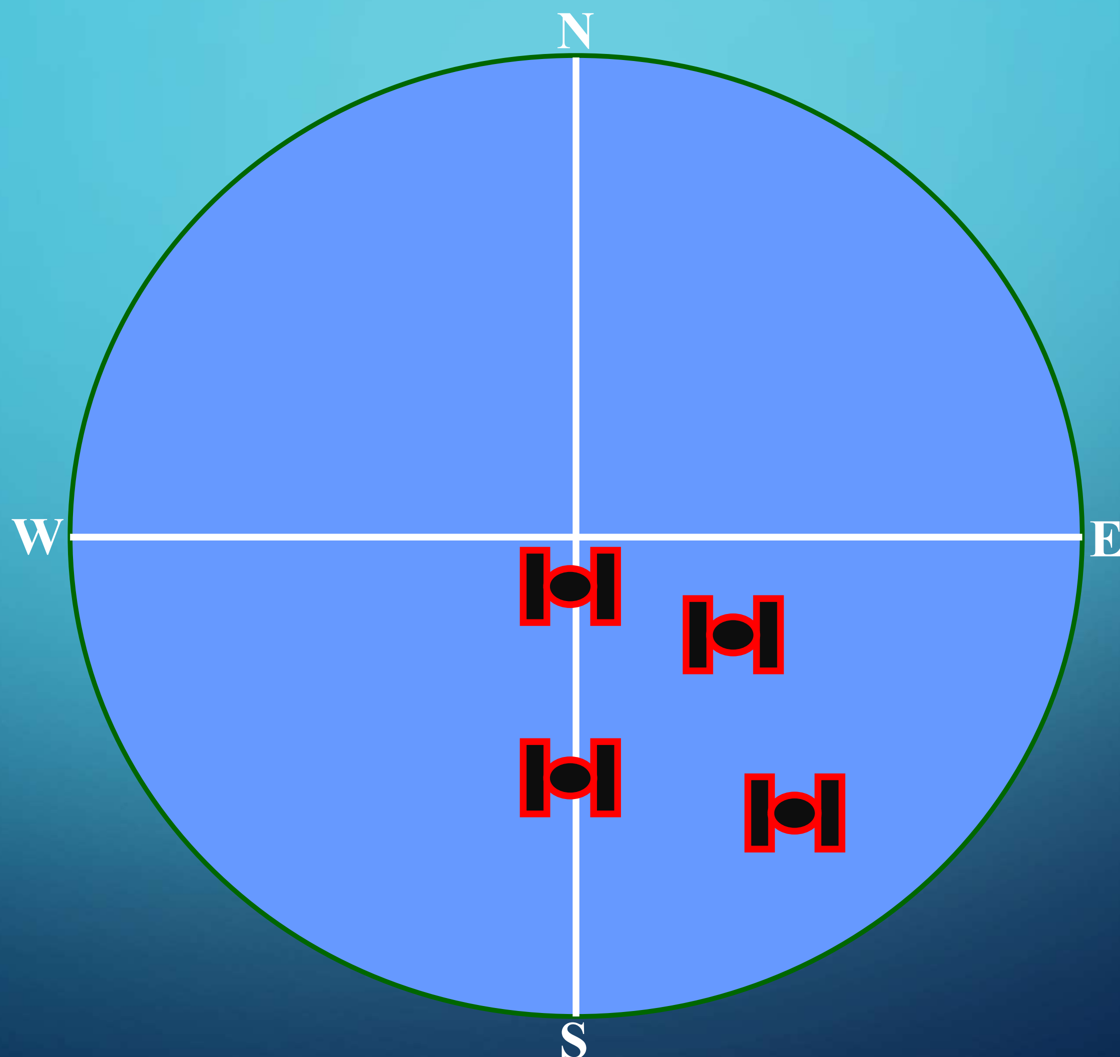


- The biggest: **selective availability (*SA*).**
  - Intentional degradation by the military for security.
  - Do not want to give the enemy the same accuracy as you.
- Previously limited precision to 100 meters.
- Turned off on May 2, 2000.
- Now can get accuracies as good as 6 meters or better without correction.

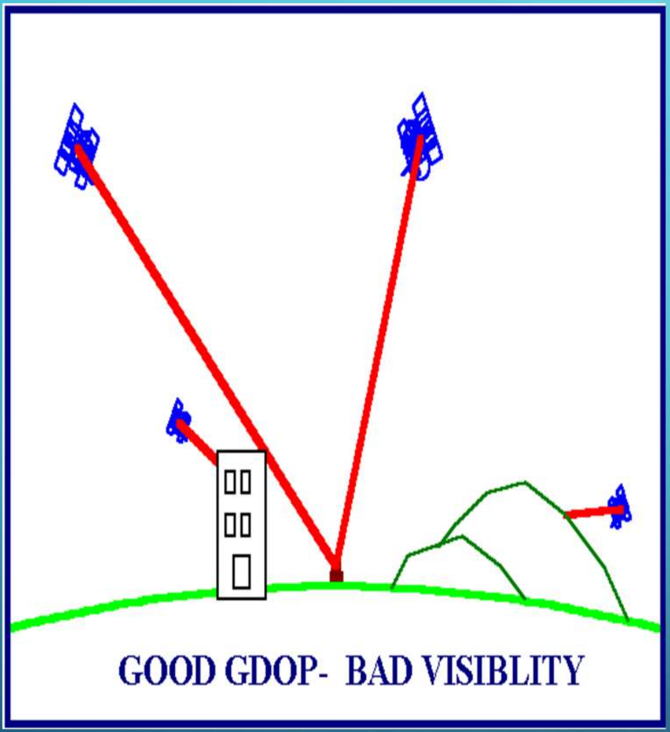
IDEAL SATELLITE GEOMETRY



POOR SATELLITE GEOMETRY



GPS CANNOT "SEE" THROUGH OBJECTS!

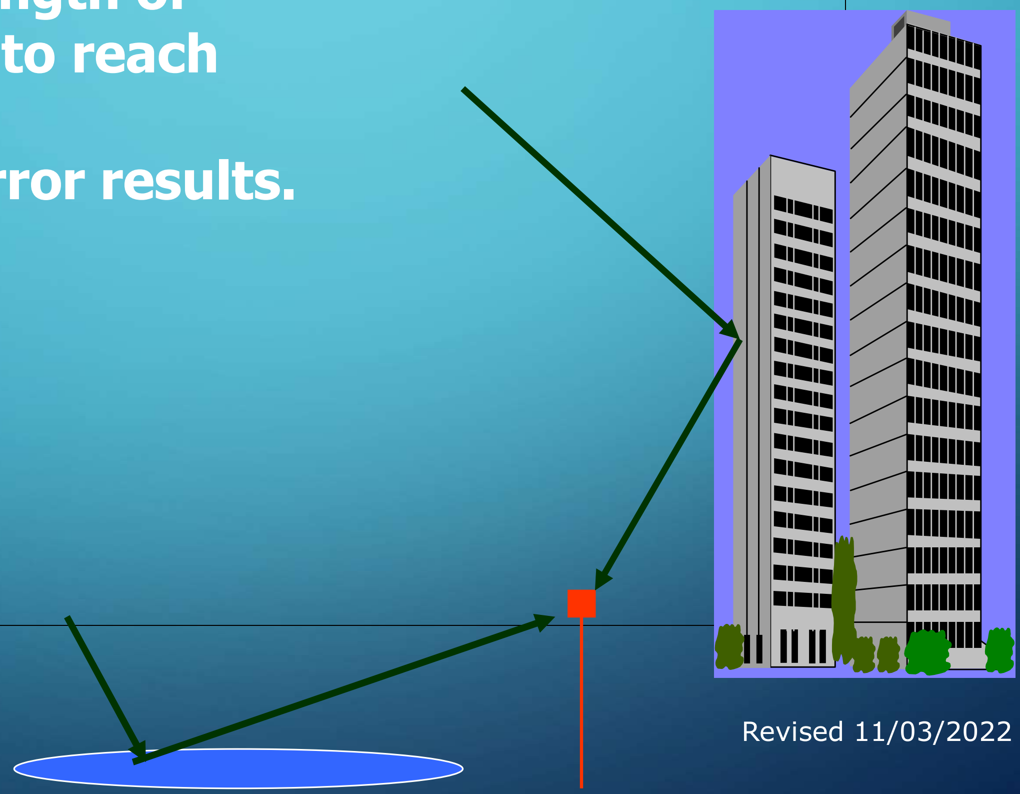


Some of the newer satellites and receivers can receive through thinner solid objects like cars, building walls and forest canopy.

Terrain and larger buildings are still too big.

MULTIPATH ERROR

- A signal that bounces of a smooth object and hits the receiver antenna.
- Increases the length of time for a signal to reach the receiver.
- A big position error results.
    - Gravel roads
    - Open water
    - Snow fields
    - Rock walls
    - Buidlings

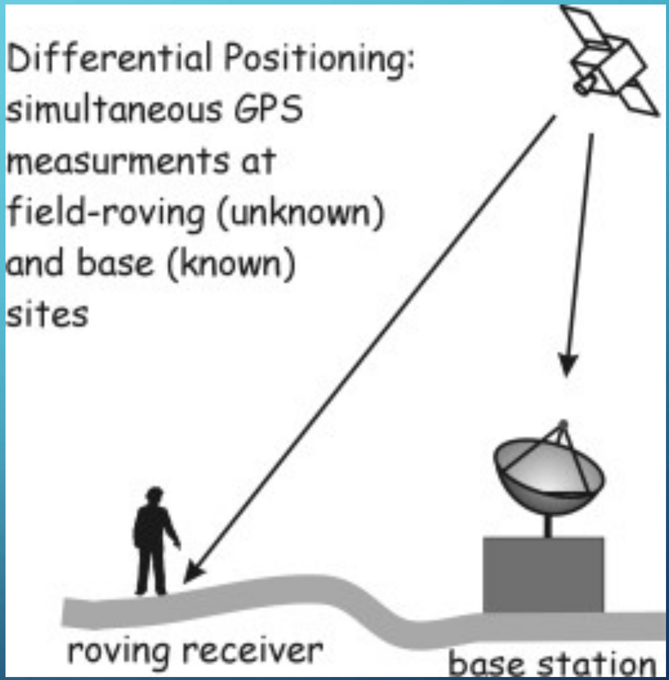


DIFFERENTIAL CORRECTION

- To overcome errors
- A reference station of known locations compares its calculated location with the known.
- Calculates a correction factor good for the general area
- Correction can be
  - Broadcast in real time
  - Or added to existing data, post-processing

DIFFERENTIAL CORRECTION

Differential correction is a technique that greatly increases the accuracy of the collected GPS data. It involves using a receiver at a known location - the "base station"- and comparing that data with GPS positions collected from unknown locations with "roving receivers."



WHAT THE FIRST GPS RECEIVER LOOKED LIKE

Relativistic errors due to gravitational fields

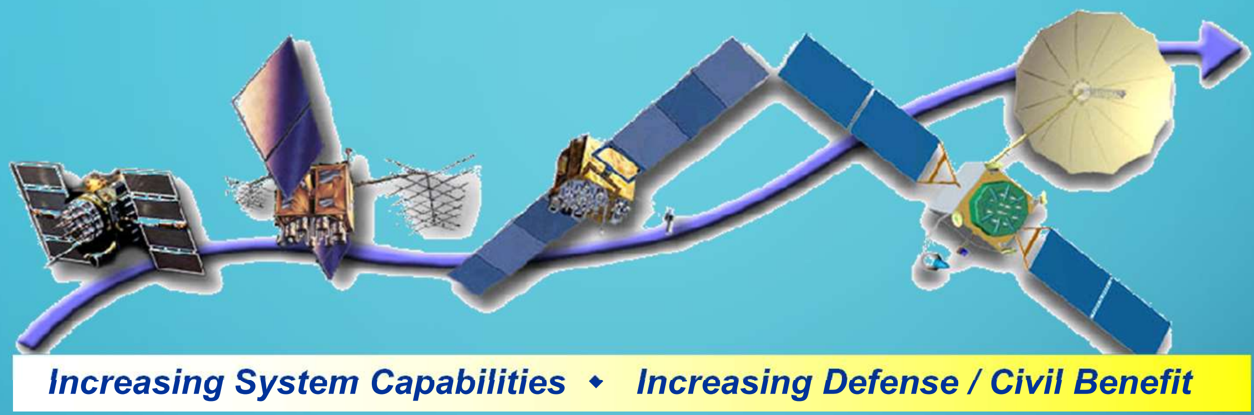
- I worked with a guy who worked at the Rockwell Science Center.
  - Worked on GPS
  - Had a picture of the user equipment for the first receiver.
  - He said that this will fit in a Cell Phone in 5 to 10 years
  - He was right

Note: this is not the actual GPS receiver that was used, but is a set of racks of similar size.

RELIABILITY OF SATELLITES

- Rockwell won the contract to develop and build, the first set of satellites
- Rockwell won the contract to develop and build, the second set of satellites
  - The life expectancy of the first build was 10 years
- Motorola won the contract to develop and build, the third set of satellites
- The first set had so few failures they lasted much longer than the 10 years
- The government decided that they would not launch the Second set of satellites
  - They could save the launch cost for the second set.
  - The launch cost is more than the cost to develop and build the satellites

GPS MODERNIZATION PROGRAM



Block IIA/IIR

Basic GPS

- Standard Service
  - Single frequency (L1)
  - Coarse acquisition (C/A) code navigation
- Precise Service
  - Y-Code (L1Y & L2Y)
  - Y-Code navigation

Block IIR-M, IIF

IIR-M: IIA/IIR capabilities plus

- 2nd civil signal (L2C)
- M-Code (L1M & L2M)

IIF: IIR-M capability plus

- 3rd civil signal (L5)
- Anti-jam flex power

Block III

- Backward compatibility
- 4th civil signal (L1C)
- Increased accuracy
- Increased anti-jam power
- Assured availability
- Navigation surety
- Controlled integrity
- Increased security
- System survivability

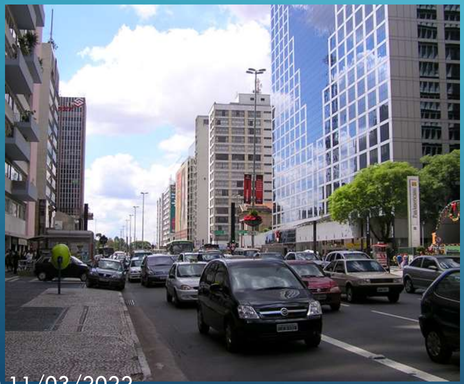
GPS MODERNIZATION – NEW CIVIL SIGNALS

- Second civil signal “L2C”
  - Designed to meet commercial needs
  - Higher accuracy through ionospheric correction
  - Available since 2005 without data message
    - Currently, 7 IIR-Ms transmitting L2C
  - After 2020 with L2C and L5 online, the USG will no longer support semi-codeless access to military GPS signals
  - Full capability: 24 satellites ~2016

- Third civil signal “L5”
  - – Designed to meet demanding requirements for transportation safety-of-life
  - – Uses highly protected Aeronautical Radio Navigation Service (ARNS) band
  - – On orbit broadcast 10 APR 2009 on IIR-20(M) secured ITU frequency filing
    - Is operational on 1st IIF (SVN-62)
  - – Full capability: 24 satellites ~2018

GPS MODERNIZATION – FOURTH CIVIL SIGNAL (L1C)

Under Trees



Urban Canyons

- Fourth civil signal "L1C"
  - Designed with international partners for interoperability
  - Modernized civil signal at L1 frequency
    - More robust navigation across a broad range of user applications
    - Improved performance in challenged tracking environments
    - Original signal retained for backward compatibility
  - Specification developed in cooperation with industry recently completed
  - Launches with GPS III in 2014
  - On 24 satellites by ~2021

Bilateral Cooperation

- **U.S.-EU** GPS-Galileo Cooperation Agreement signed in June 2004
  - Four working groups set up under the Agreement
- **U.S.-Russia** Joint Statement issued December 2004
  - Working Groups: compatibility/interoperability, search/rescue
- **U.S.-Japan** Joint Statement on GPS Cooperation 1998
  - Quasi Zenith Satellite System (QZSS) designed to be fully compatible and highly interoperable with GPS
  - QZSS monitoring stations established and operating in Hawaii and Guam

REFERENCES

- GPS Overview
  - FORT 130 Forest Mapping Systems
- GPS Basics
  - Monica Spicker   2010
- Global Positioning System (GPS)
  - Math 437/837
  - CISC490/850
- An introduction to GPS technology
- What is GPS
  - Larson GPS MiddleSchool
- GPS and Worldwide GNSS Interoperability
  - Kenneth Hodgkins