

Principles of GPS

What is GPS?

How does it work?

Principles of GPS

- GPS: Global Positioning System is a worldwide radio-navigation system formed from a constellation of 24 satellites and their ground stations.
- A simplistic explanation: GPS uses these “man-made stars” as reference points to calculate positions accurate to a matter of meters.
- Radio-based navigation system funded and developed by DoD
 - First Satellite Launch in 1978
 - Initial operation in 1993
 - Fully operational in 1995
- System is called NAVSTAR
 - **NAV**igation with **S**atellite **T**iming **A**nd **R**anging
 - Referred to as GPS
- Series of 24 satellites, 6 orbital planes, 4 satellite vehicles (SV) on each plane
- Works anywhere in the world, 24 hours a day, in all weather conditions and provides:
 - Location or positional fix
 - Velocity
 - Direction of travel
 - Accurate time



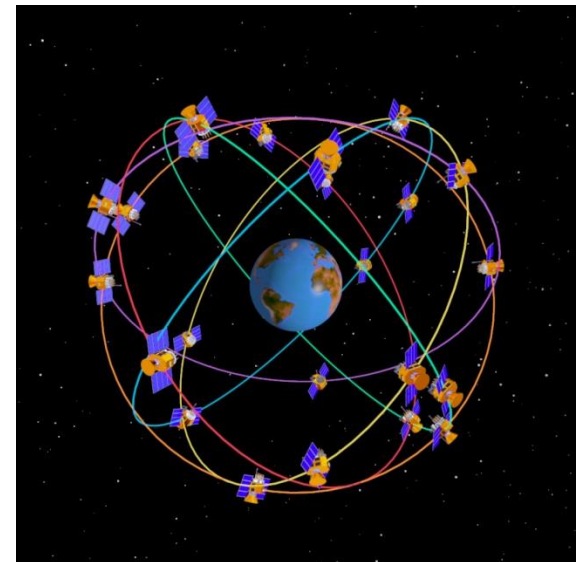
Principles of GPS

The Global Positioning System is comprised of three segments.

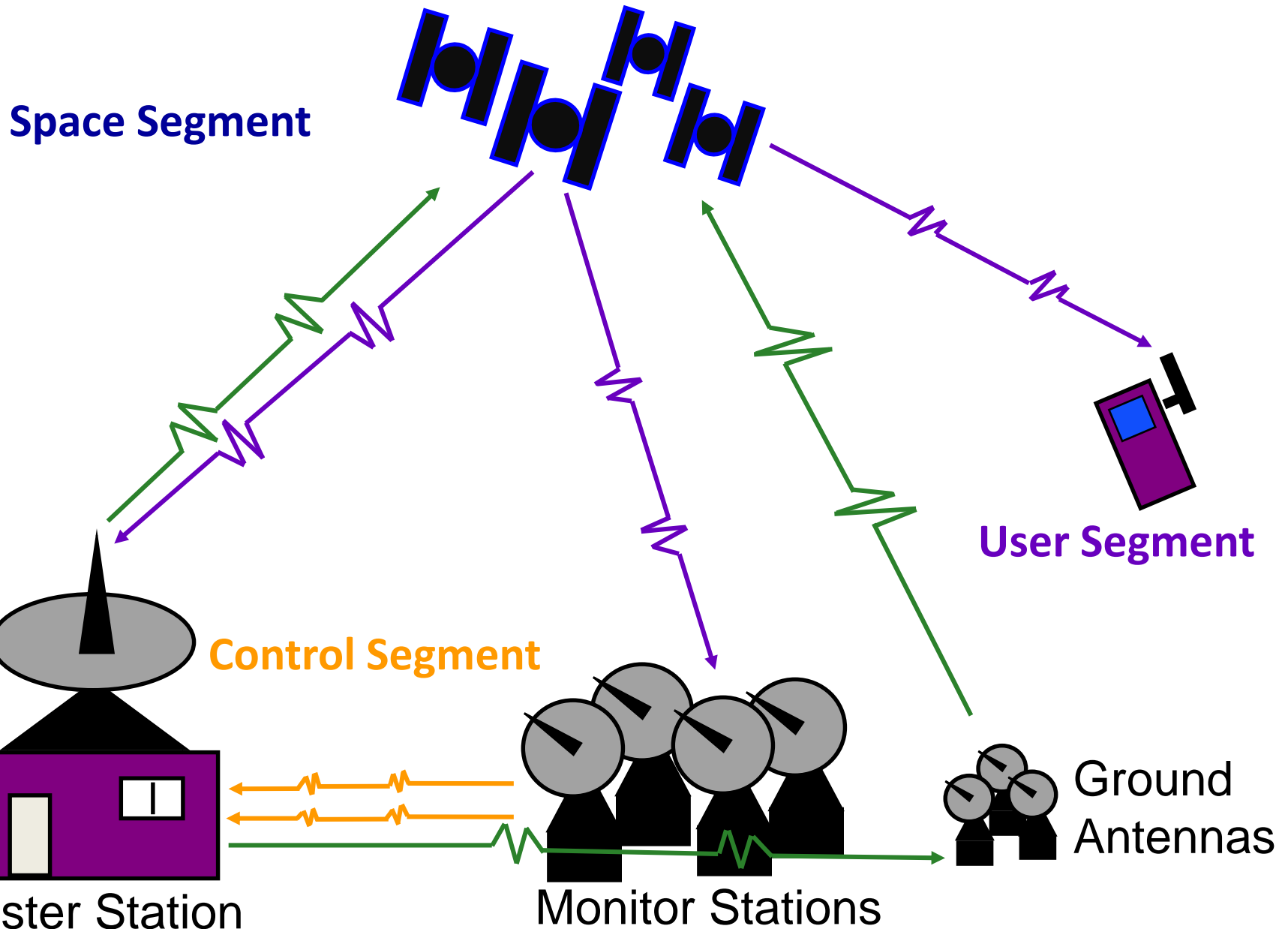
Control Segment

Space Segment

User Segment

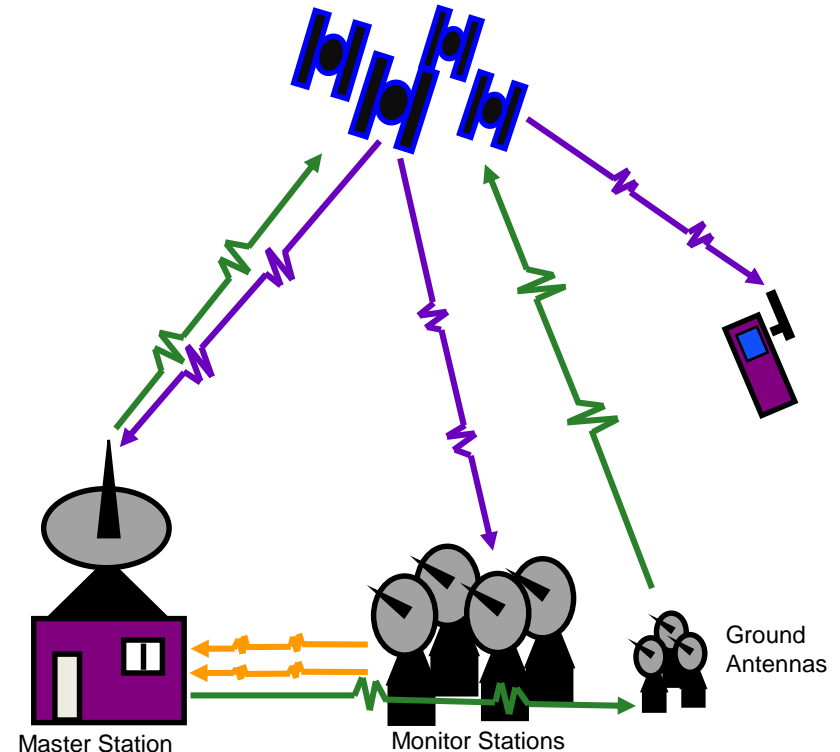


Three Segments of the GPS



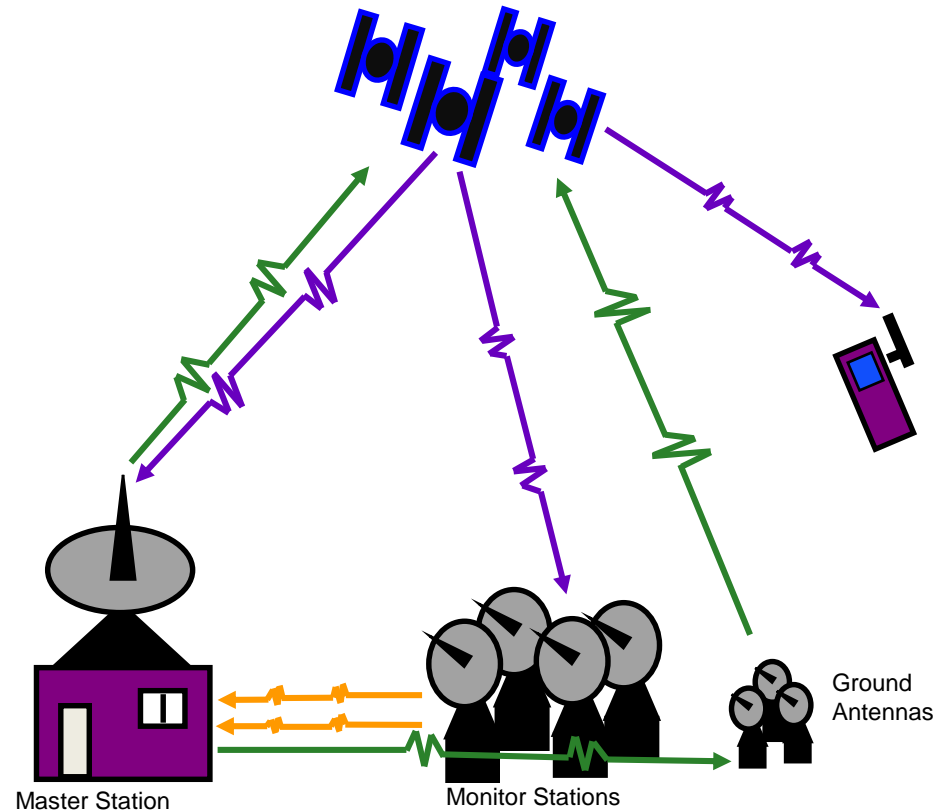
Control Segment

- The Control segment is made up of a Master Control Station (MCS), four monitor stations, and three ground antennas (plus a reserve antenna at Cape Canaveral used primarily for pre-launch satellite testing) used to uplink data to the satellites.
- The Master Control Station, or MCS (also known as the Consolidated Satellite Operations Center) is located at the US Air Force Space Command Center at Schriever Air Force Base (formerly Falcon AFB) in Colorado Springs, Colorado. It's responsible for satellite control and overall system operations.

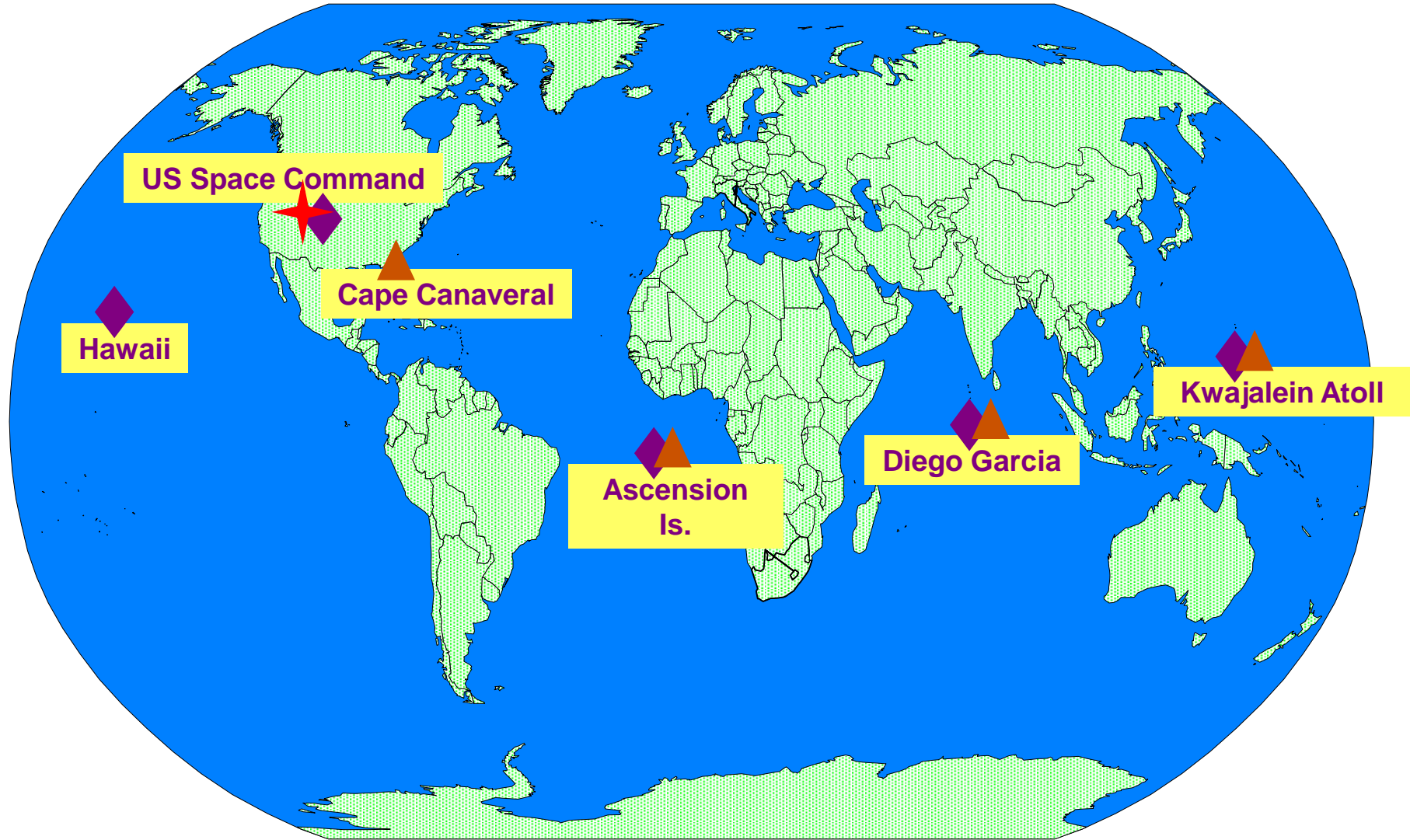


Control Segment

- Monitor stations (MS) are unmanned remote sensors that passively collect raw satellite signal data and re-transmit it in real time to the MCS for evaluation. Monitor stations basically function as very precise radio receivers, tracking each satellite as it comes into view.
- Ground antennas are remotely controlled by the MCS. Ground antennas transmit data commands received from the Master Control Station to GPS satellites within their sky view



Control Segment



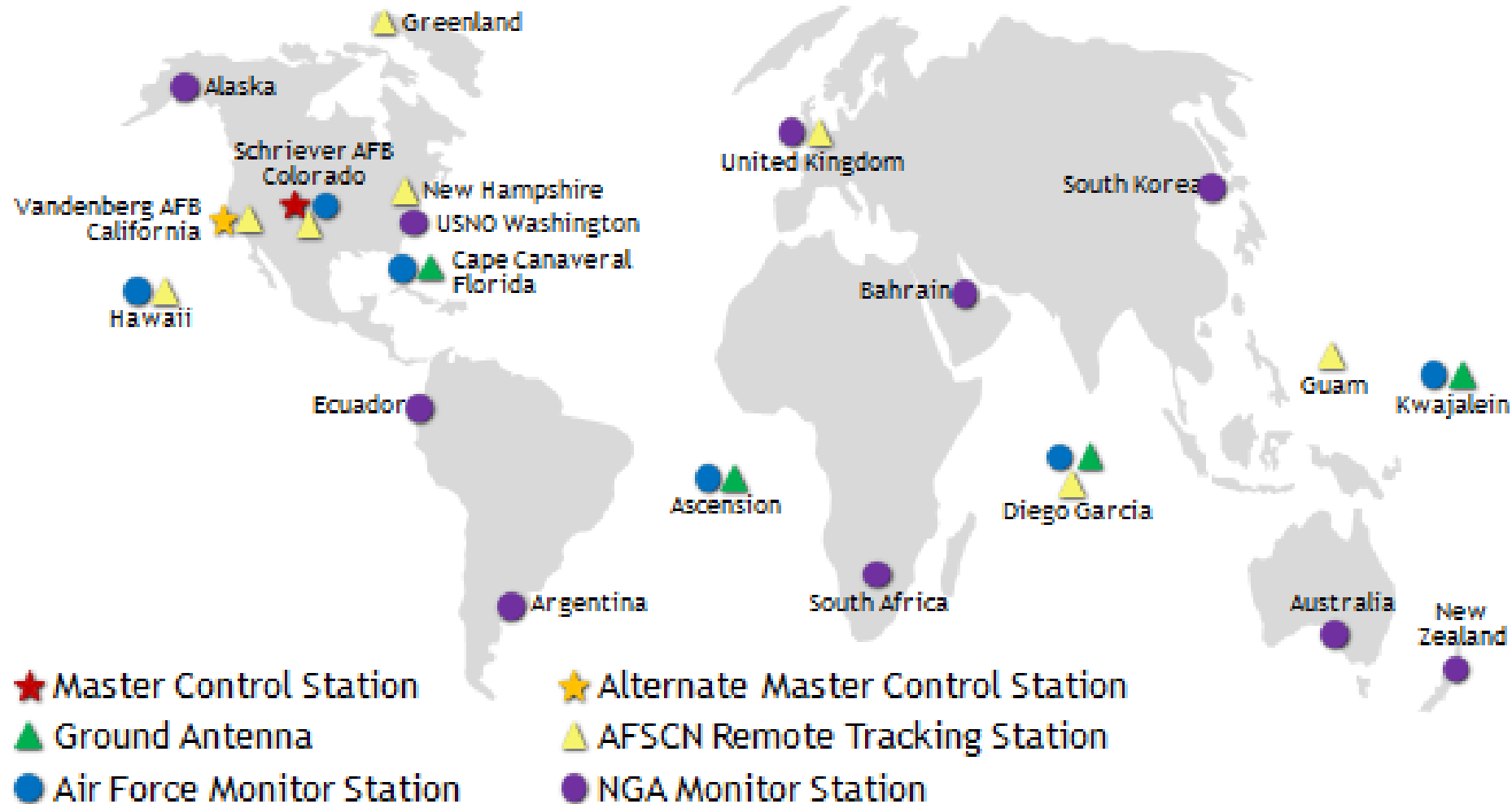
Control Segment

★ Master Control Station

◆ Monitor Station

▲ Ground Antenna

Control Segment



Control Segment

The MCS uplinks data to GPS satellites which includes:

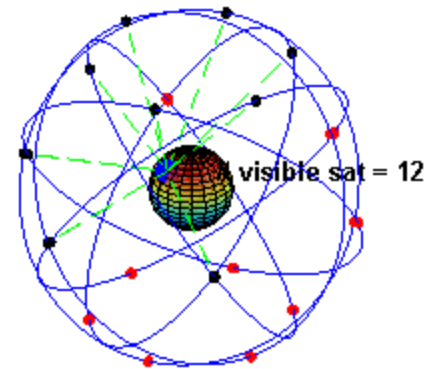
- Clock-correction factors for each satellite; necessary to ensure that all satellites are operating at the same precise time (known as “GPS Time”).
- Atmospheric data (to help correct most of the distortion caused by the GPS satellite signals passing through the ionosphere layer of the atmosphere).



Control Segment

The MCS uplinks data to GPS satellites which includes:

- Almanac, which is a log of all GPS satellite positions and health, and allows a GPS receiver to identify which satellites are in its hemisphere, and at what times.
- An almanac is like a schedule telling a GPS receiver when and where satellites will be overhead. Transmitted continuously by all satellites, the almanac allows GPS receivers to choose the best satellite signals to use to determine position.

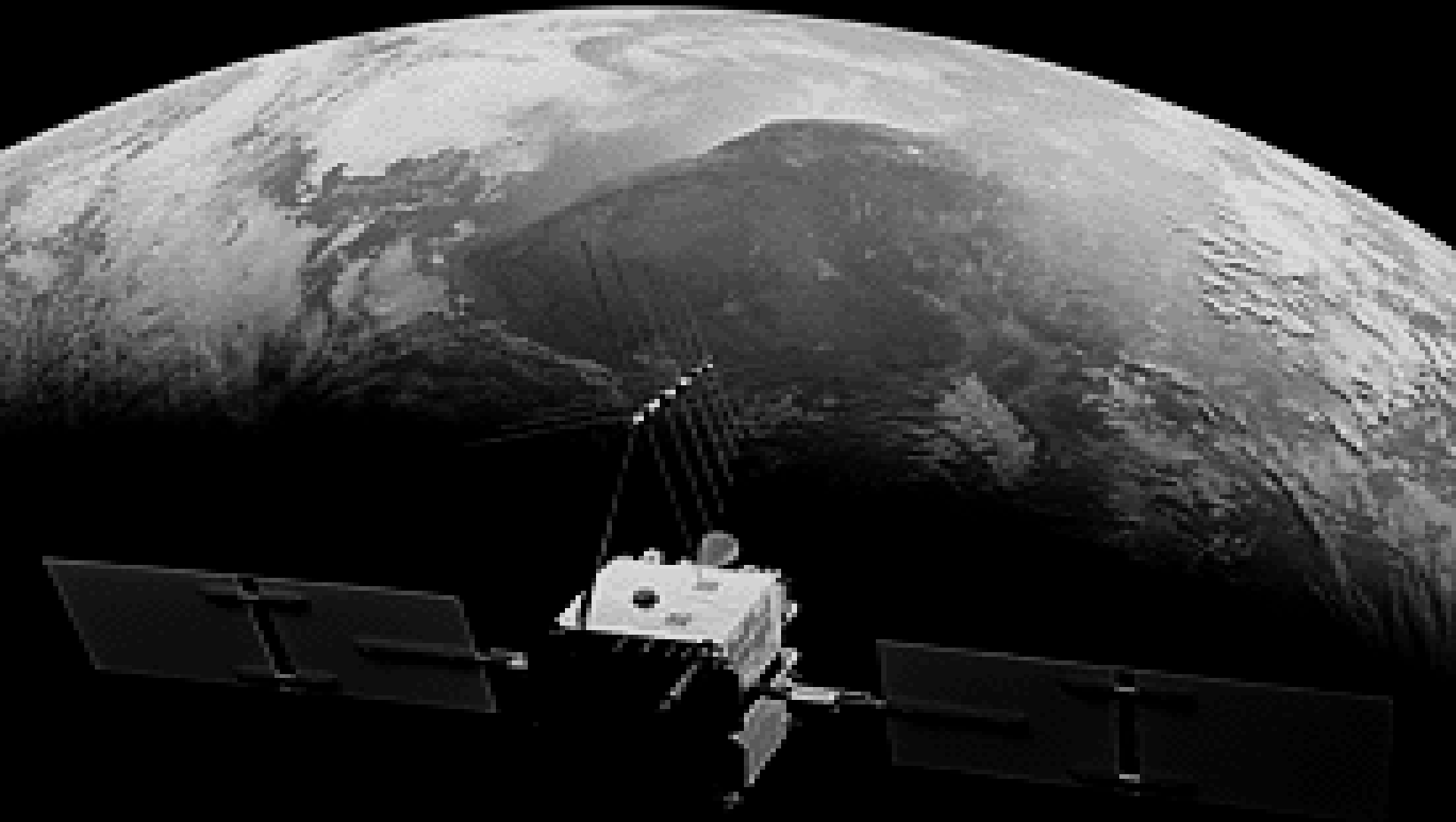


Control Segment

The MCS uplinks data to GPS satellites which includes:

- Ephemeris data is unique to each satellite, and provides highly accurate satellite position (orbit) information for that GPS satellite alone. It does not include information about the GPS constellation as a whole. Ephemeris information is also transmitted as a part of each satellite's time signal.
- By using the information from the GPS satellite constellation almanac in conjunction with the ephemeris data from each satellite, the position of a GPS satellite can be very precisely determined for a given time.

Space Segment



Space Segment

- The space segment is an earth-orbiting constellation of 24 active and five spare GPS satellites circling the earth in six orbital planes. Each satellite is oriented at an angle of 55 degrees to the equator. The nominal circular orbit is 20,200-kilometer (10,900 nautical miles) altitude. Each satellite completes one earth orbit every twelve hours (two orbits every 24 hours). That's an orbital speed of about 1.8 miles per second, so that each satellite travels from visible horizon to horizon in about 2 hours.
- Each satellite has a design life of approximately 10 years, weighs about 2,000 pounds, and is about 17 feet across with its solar panels extended.

Space Segment

- Each satellite transmits as part of its signal to ground stations and all users the following information:
 - Coded ranging signals (for triangulation)

Sequences of 0s and 1s (zeroes and ones), which allow the receiver to determine the travel time of radio signal from satellite to receiver. They are called Pseudo-Random Noise (PRN) sequences or PRN codes.
 - Ephemeris position information
 - Atmospheric data
 - Clock correction information defining the precise time of satellite signal transmission (in GPS Time), and a correction parameter to convert GPS Time to UTC.
 - An almanac containing information on the GPS constellation, which includes location and health of the satellites.

User Segment

- Military.
- Search and rescue.
- Disaster relief.
- Surveying.
- Marine, aeronautical and terrestrial navigation.
- Remote controlled vehicle and robot guidance.
- Satellite positioning and tracking.
- Shipping.
- Geographic Information Systems (GIS).
- Recreation.

Four Primary Functions of GPS

- Position and coordinates.
- The distance and direction between any two points.
- Travel progress reports.
- Accurate time measurement.

Global Navigation Satellite Systems

- NAVSTAR
 - USA
- GLONASS
 - Russians
- Galileo
 - Europeans
- Beidou
 - Chinese

How does GPS Work?

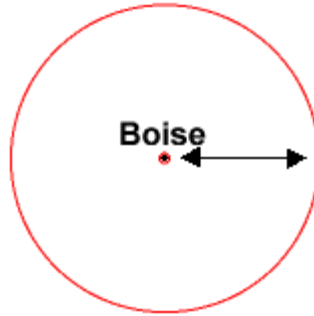
Triangulation

- A GPS receiver's job is to locate four or more of these satellites, figure out the distance to each, and use this information to deduce its own location.
- This operation is based on a simple mathematical principle called **triangulation** or **trilateration**.
- Triangulation in three-dimensional space can be a little tricky, so we'll start with an explanation of simple two-dimensional trilateration.

An Example of 2D Triangulation

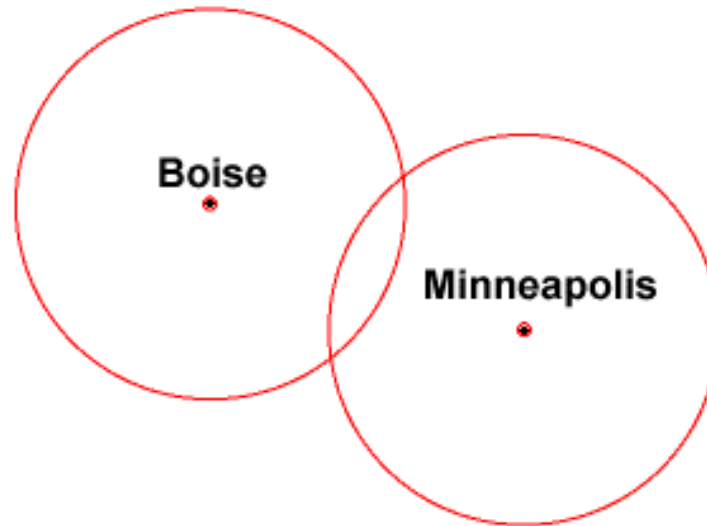
- Imagine you are somewhere in the United States and you are TOTALLY lost -- for whatever reason, you have absolutely no clue where you are.
- You find a friendly local and ask, "Where am I?" He says, "You are 625 miles from Boise, Idaho."
- This is a nice, hard fact, but it is not particularly useful by itself. You could be anywhere on a circle around Boise that has a radius of 625 miles

Where in the U.S. am I?



- To pinpoint your location better, you ask somebody else where you are.
- She says, "You are 690 miles from Minneapolis, Minnesota." If you combine this information with the Boise information, you have two circles that intersect.

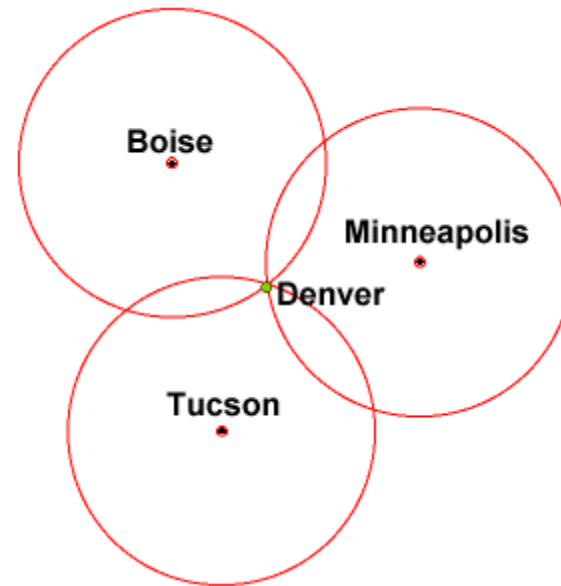
Where in the U.S. am I? (Cont'd)



- If a third person tells you that you are 615 miles from Tucson, Arizona, you can eliminate one of the possibilities, because the third circle will only intersect with one of these points. You now know exactly where you are...

Where in the U.S. am I? (Cont'd)

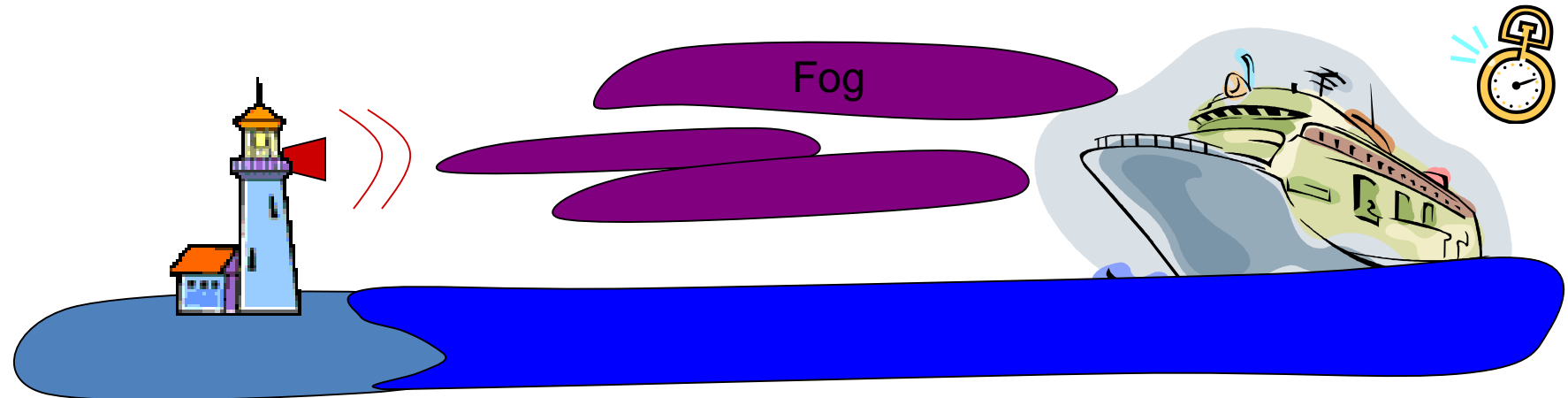
- You are in Denver, CO!



- This same concept works in three-dimensional space, as well, but you're dealing with **spheres** instead of circles.

Another 2D Example

- Consider the case of a mariner at sea (receiver) determining his/her position using a foghorn (transmitter).
- Assume the ship keeps an accurate clock and mariner has approximate knowledge of ship's location.



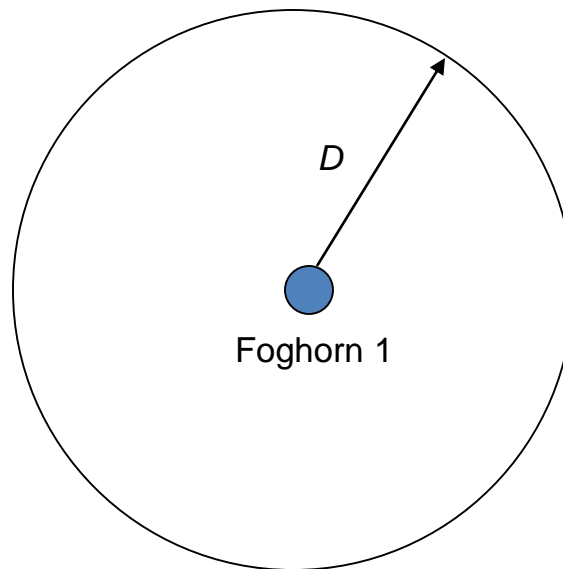
Foghorn Example

- Foghorn whistle is sounded precisely on the minute mark and ship clock is synchronized to foghorn clock.
- Mariner notes elapsed time from minute mark until foghorn whistle is heard.
- This propagation time multiplied by speed of sound is distance from foghorn to mariner's ear.

$$\text{Distance} = \text{Speed} \times \text{Time}$$

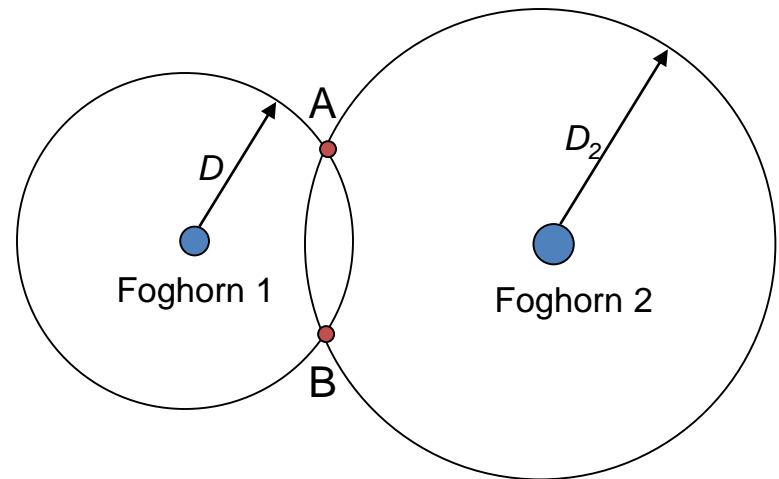
Foghorn Example (Cont'd)

- Based on measurement from one such foghorn, we know mariner's distance (D) to foghorn.
- With measurement from one foghorn, mariner can be located anywhere on the circle denoted below:



Foghorn Example (Cont'd)

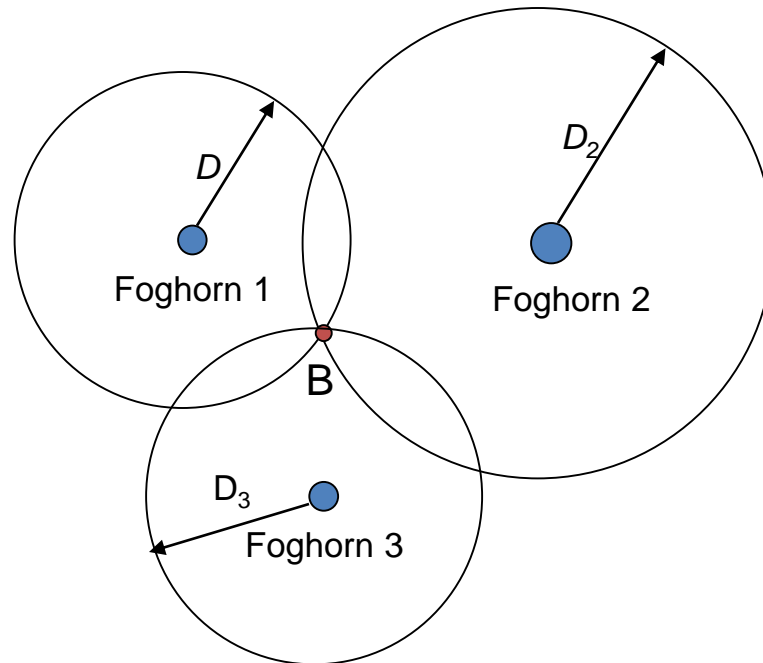
- If mariner simultaneously measured time range from 2nd foghorn in same way.
- Assuming, transmissions synchronized to a common time base and mariner knows the transmission times. Then:



• Possible Location of Mariner

Foghorn Example (Cont'd)

- Since mariner has approximate knowledge of ship's location, he/she can resolve the ambiguity between location A and B.
- If not, then measurement from a third foghorn is needed.

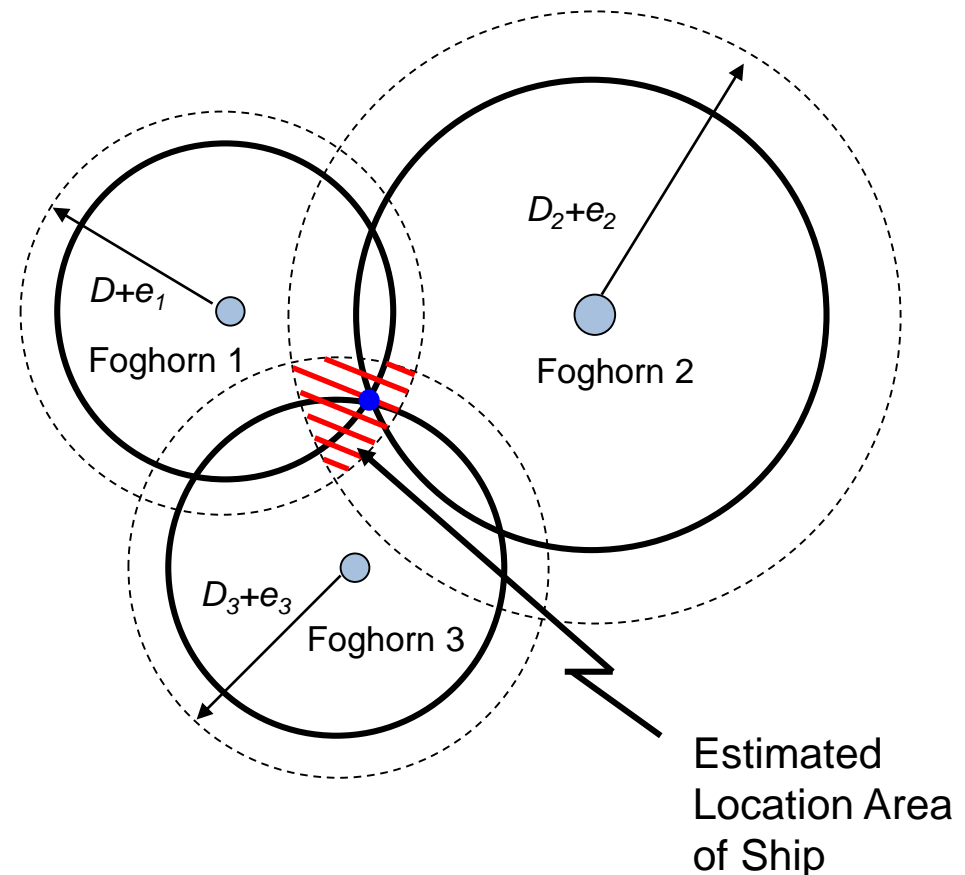


How Foghorn Relates to GPS

- The foghorn examples operates in 2D space. GPS performs similarly but in 3D.
- The foghorn examples shows how time-of-arrival of signal (whistle) can be used to locate a ship in a fog. In this time-of-arrival of signal, we assumed we knew when the signal was transmitted.
- We measured the arrival time of the signal to determine distance. Multiple distance measurements from other signals were used to locate the ship exactly.

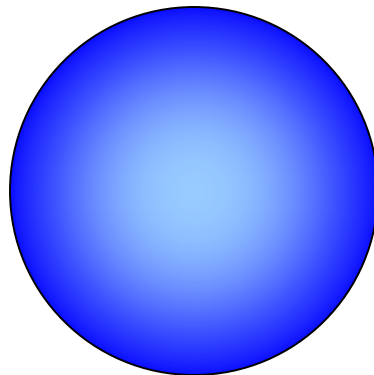
Foghorn Example: Consider Effect of Errors

- Foghorn/mariner discussion assumed ship's clock was precisely synchronized to foghorn's time base.
- This may not be the case → errors in TOA measurements.
- If we make a fourth measurement, we can remove this uncertainty.



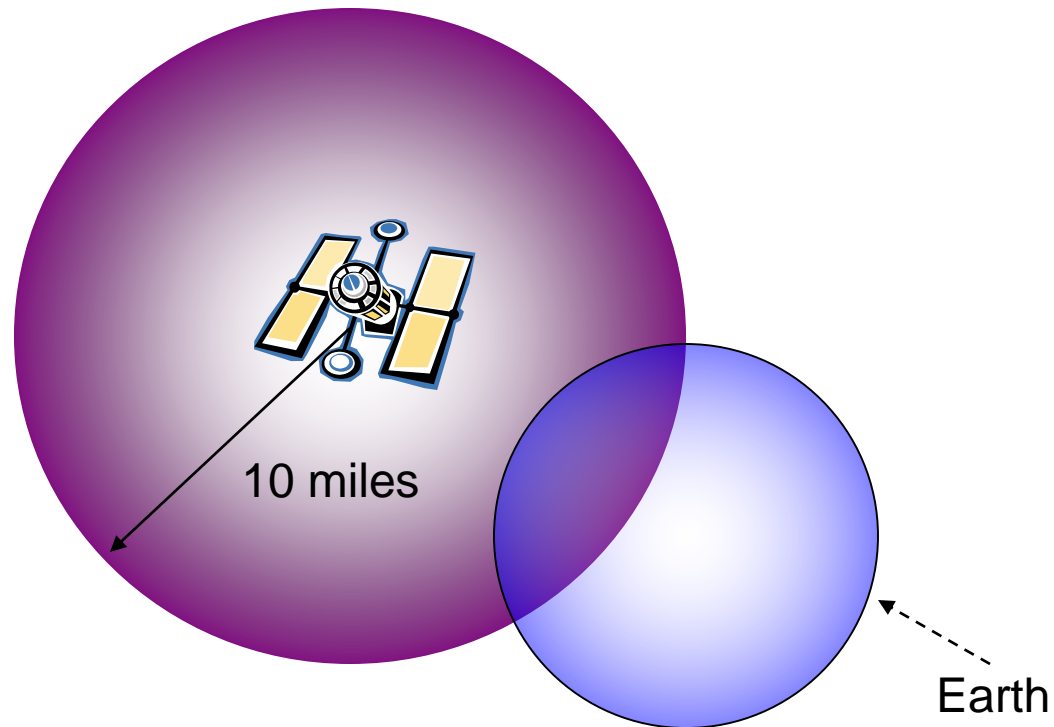
3D Triangulation

- Fundamentally, three-dimensional trilateration is not much different from two-dimensional trilateration, but it's a little trickier to visualize.
- Imagine the radii from the examples in the last section going off in all directions. So instead of a series of circles, you get a series of spheres.



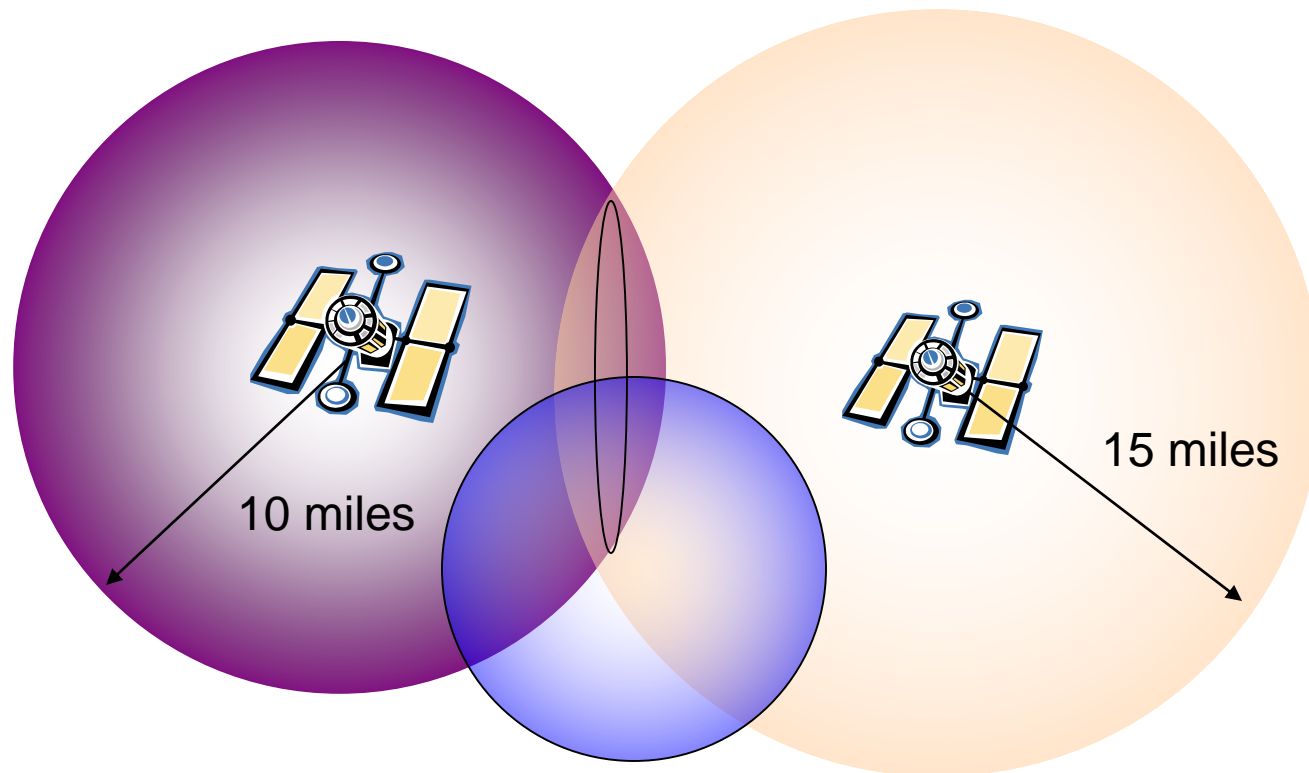
GPS Triangulation

- If you know you are 10 miles from satellite A in the sky, you could be anywhere on the surface of a huge, imaginary sphere with a 10-mile radius.



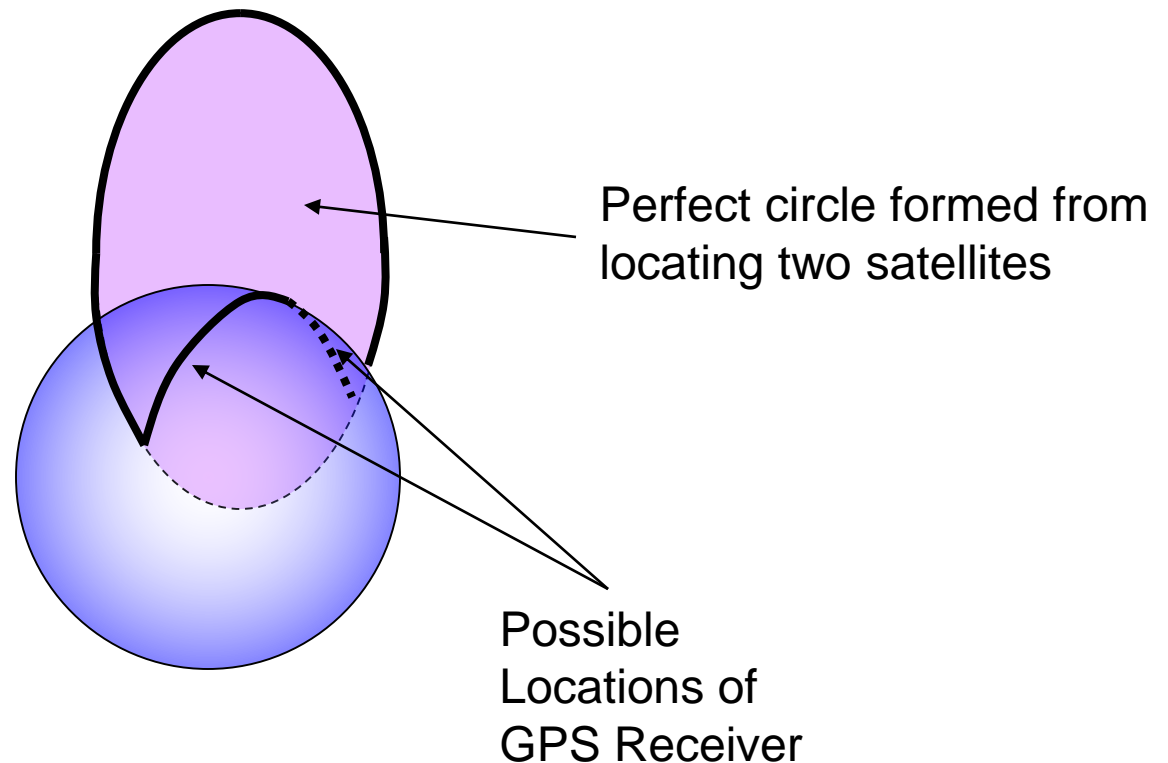
GPS Triangulation (Cont'd)

- If you also know you are 15 miles from satellite B, you can overlap the first sphere with another, larger sphere. The spheres intersect in a perfect circle.



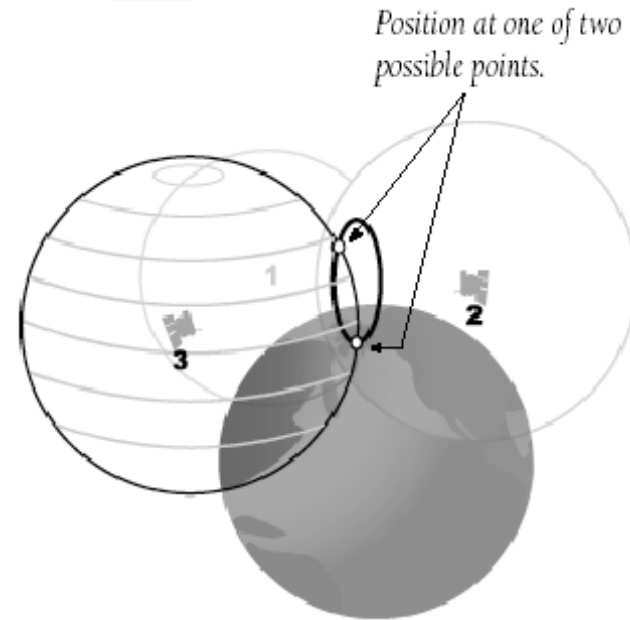
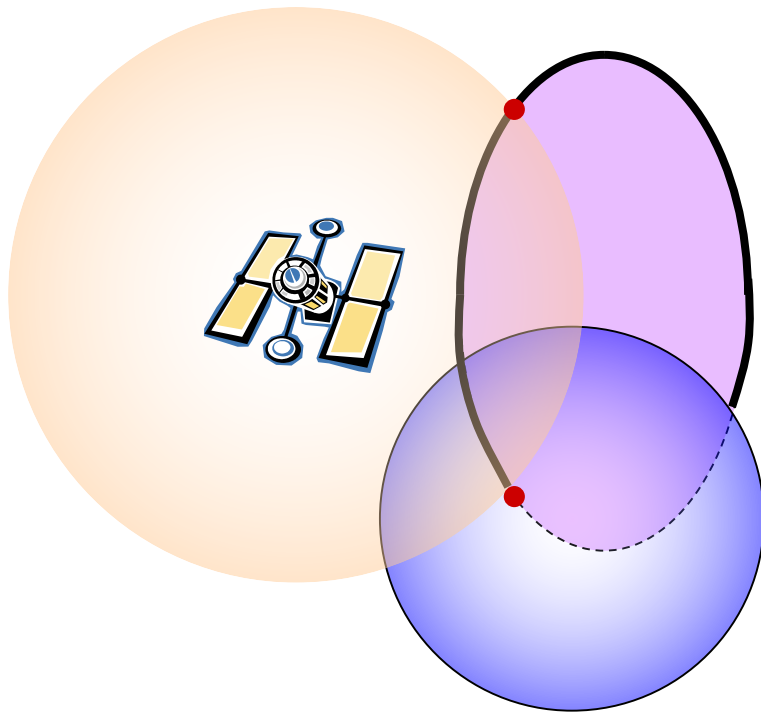
GPS Triangulation (Cont'd)

- The circle intersection implies that the GPS receiver lies somewhere in a partial ring on the earth.

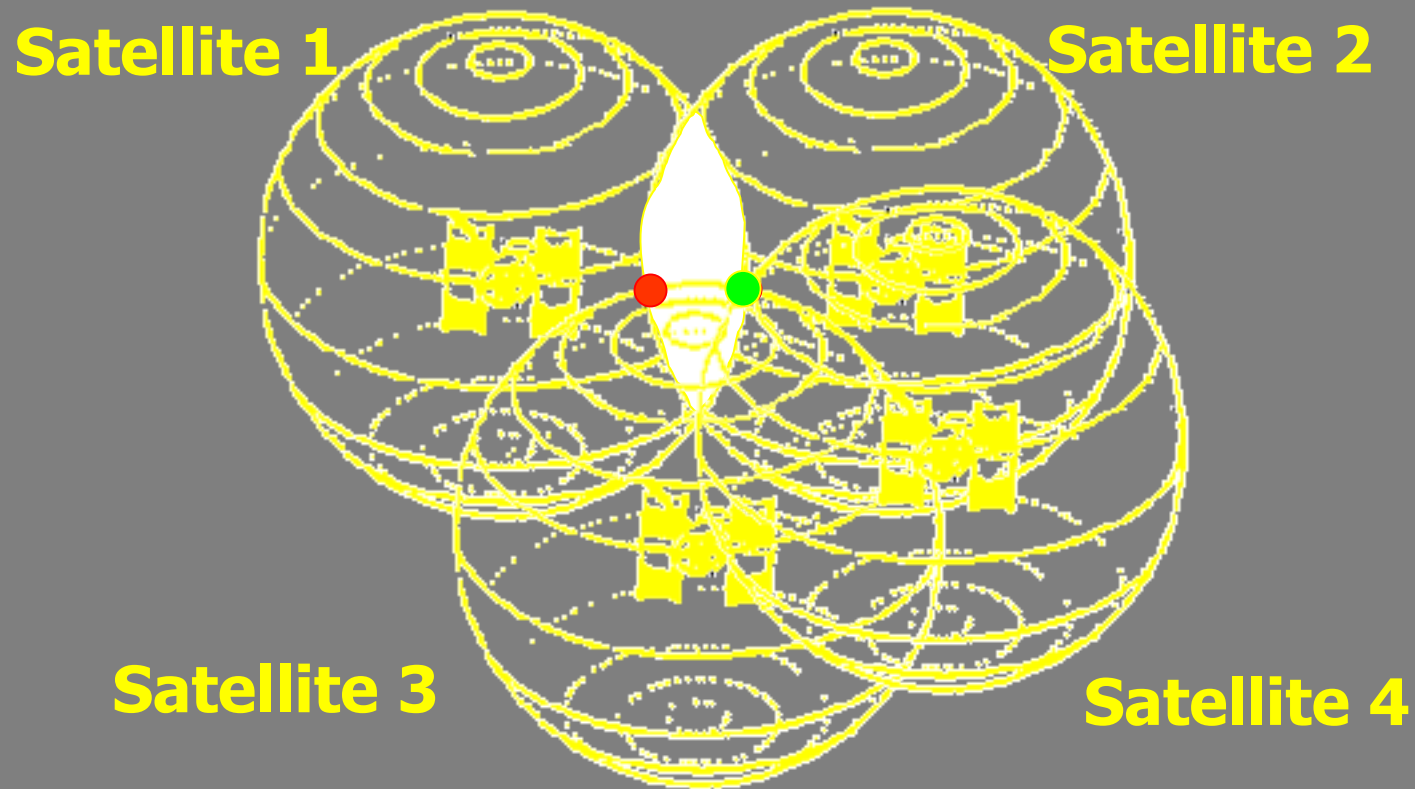


GPS Triangulation (Cont'd)

- If you know the distance to a third satellite, you get a third sphere, which intersects with this circle at two points.

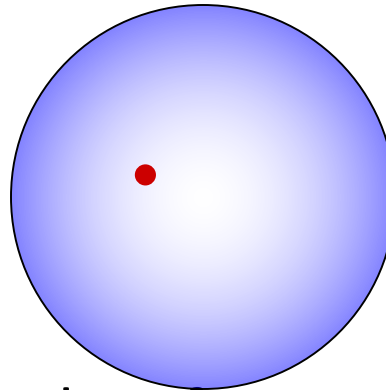


Triangulation



GPS Triangulation (Cont'd)

- The Earth itself can act as a fourth sphere -- only one of the two possible points will actually be on the surface of the planet, so you can eliminate the one in space.



- Receivers generally look to four or more satellites, however, to improve accuracy and provide precise altitude information.

GPS Receivers

- In order to make this simple calculation, then, the GPS receiver has to know two things:
 - The location of at least three satellites above you
 - The distance between you and each of those satellites
- The GPS receiver figures both of these things out by analyzing high-frequency, low-power radio signals from the GPS satellites.

GPS Receivers (Cont'd)

- Better units have multiple receivers, so they can pick up signals from several satellites simultaneously.
- Radio waves travel at the speed of light (about 186,000 miles per second, 300,000 km per second in a vacuum).
- The receiver can figure out how far the signal has traveled by timing how long it took the signal to arrive. (Similar to foghorn example.)