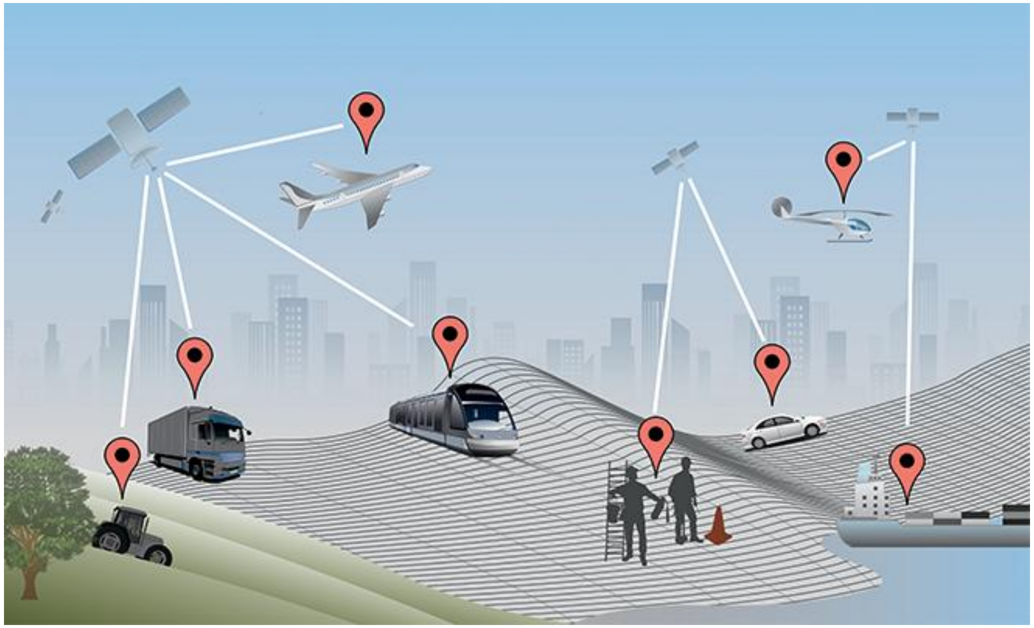
GNSS Systems

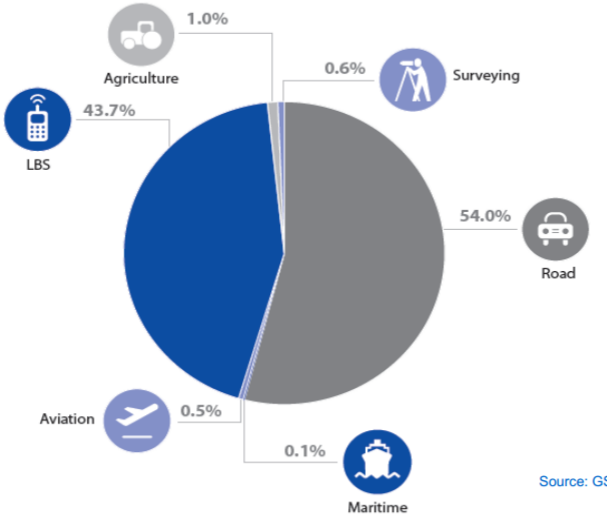
Common Questions and Answers

by

Barry Hack
Technical Specialist
Aeroflex UK

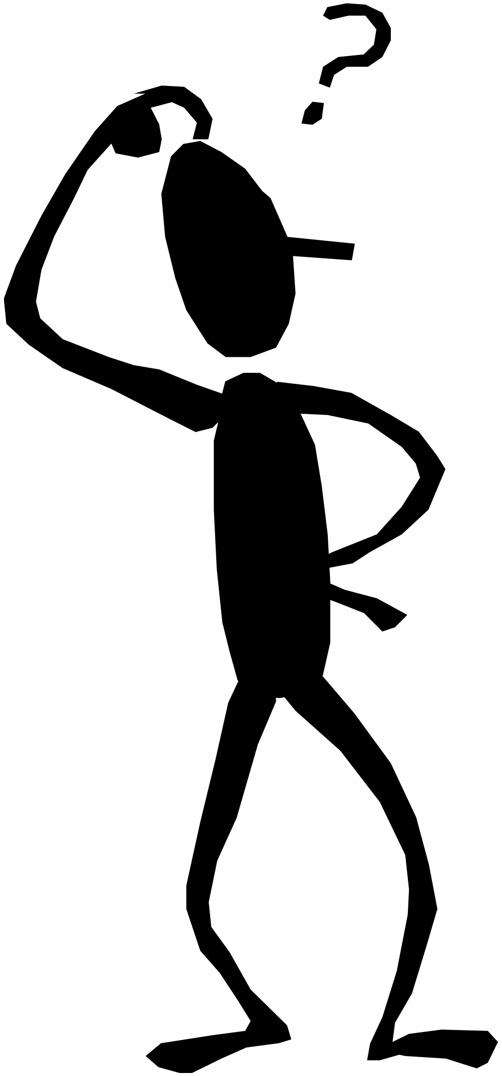
Uses of GNSS Systems





Source: GSA GNSS Market Report
May 2012

Question 1



- What is GPS ?

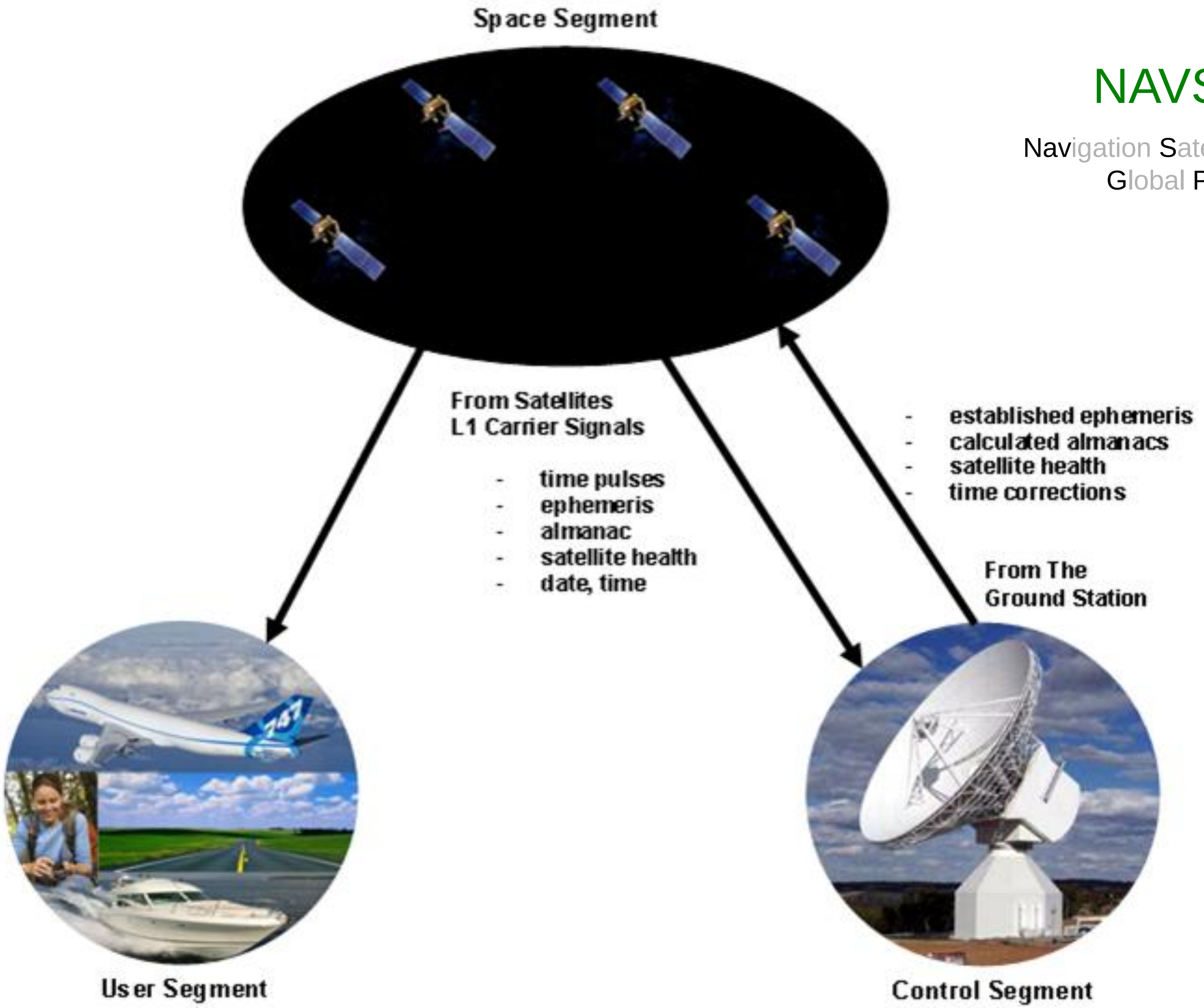
What is GPS

- **GPS is one example of a GNSS system**
  - **The full name is NAVSTAR GPS**
  - **A constellation of satellites which allow GPS receivers to define a location anywhere on planet Earth**
  - **Other systems are GLONASS, BIDOU, COMPASS, Galileo**

  - **GNSS:** Global Navigation Satellite System

- ***During this presentation, we will use ‘GPS’ as a general term to refer to the group of GNSS systems available today…***

GPS System



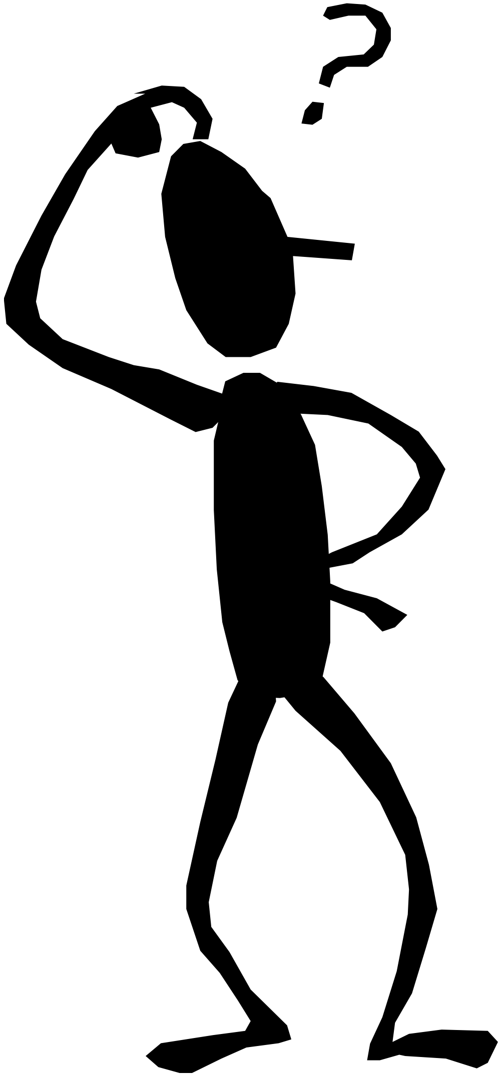
NAVSTAR GPS

Navigation Satellite Timing and Ranging
Global Positioning System

GPS Space Segment

- Space segment consists of the GPS space vehicles (SVs)
- Nominally 24 SV's plus spares
  - Each vehicle has a 12 hour orbit
  - Repeats same ground track daily
  - 6 orbital planes with 4 vehicles each
  - Planes are equally spaced 60 degrees apart
  - Inclined 55 degrees from equatorial plane
  - 20,200 km above the earth
  - 5 to 8 SV's visible from anywhere on earth

Question 2



- **When I start my GPS, why does it [sometimes] take a long time to find the signal ?**

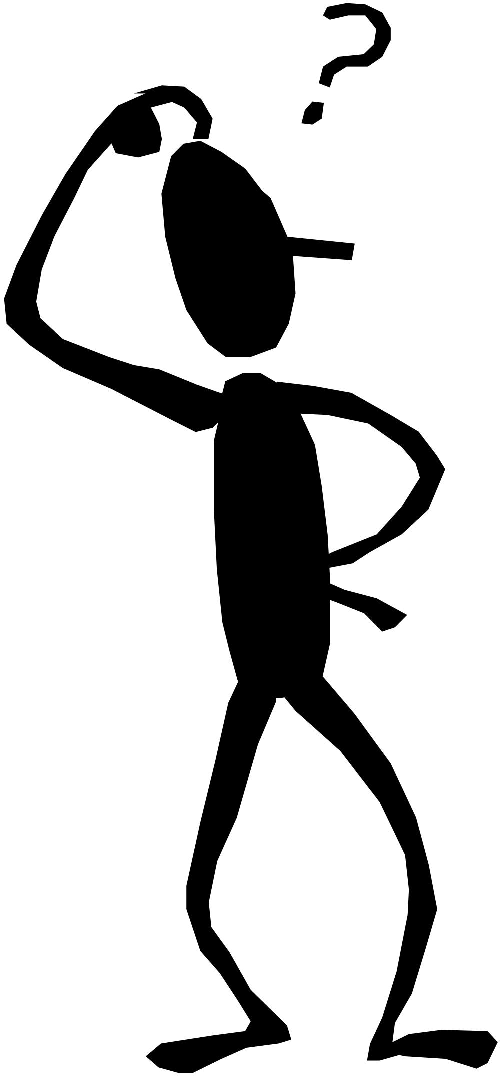
Getting a Position 'Fix'

- Need several satellites to get a 'fix'
  - Generally, more satellites mean better positional accuracy
- Obtain satellite positions
  - Decoded ephemeris from satellite message
- If your receiver has been off for 1-2 weeks then a new almanac needs to be downloaded
  - Can take 15 minutes
- Speeding up positional 'fix'
  - Modern GPS have multiple receivers
  - Helped by loading almanac from internet
  - Positional assistance from cellular network

Deciding Which Satellites (Almanac)

```
******** Week 572 almanac for PRN-03 ********
ID:                            03
Health:                        000
Eccentricity:                  0.1350402832E-001
Time of Applicability(s):     405504.0000
Orbital Inclination(rad):      0.9279594421
Rate of Right Ascen(r/s):     -0.8203642210E-008
SQRT(A)  (m 1/2):              5153.669922
Right Ascen at Week(rad):      0.3102266431E+001
Argument of Perigee(rad):      1.020882249
Mean Anom(rad):               -0.7818025351E+000
Af0(s):                        0.5941390991E-003
Af1(s/s):                      0.3637978807E-011
week:                           572
```

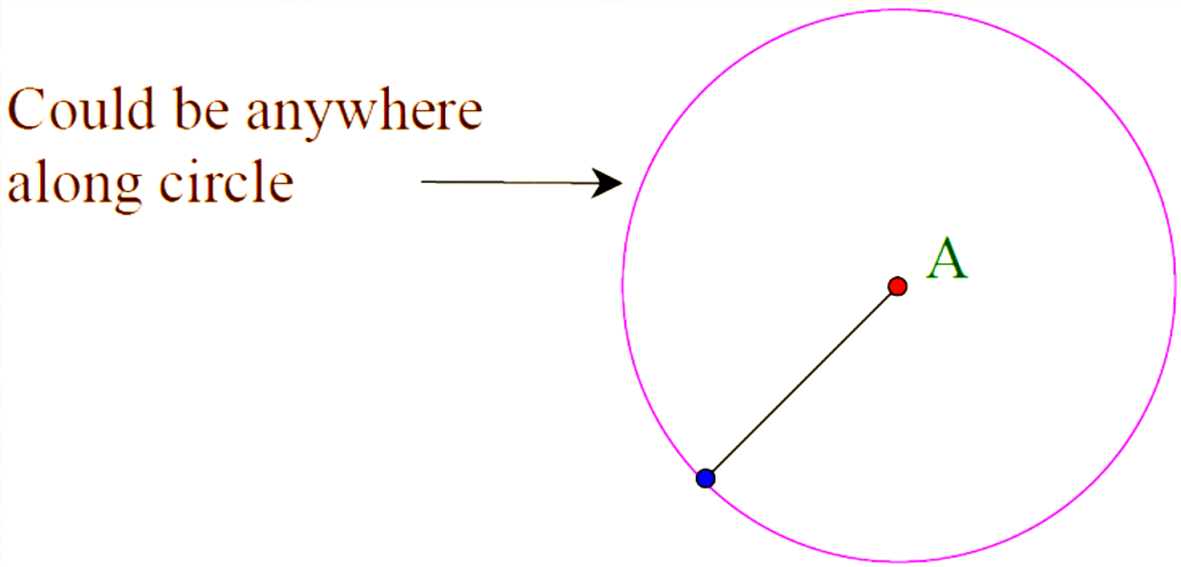
Question 3



- How many satellites do I need to get a good fix ?
- How do I get a position fix ?

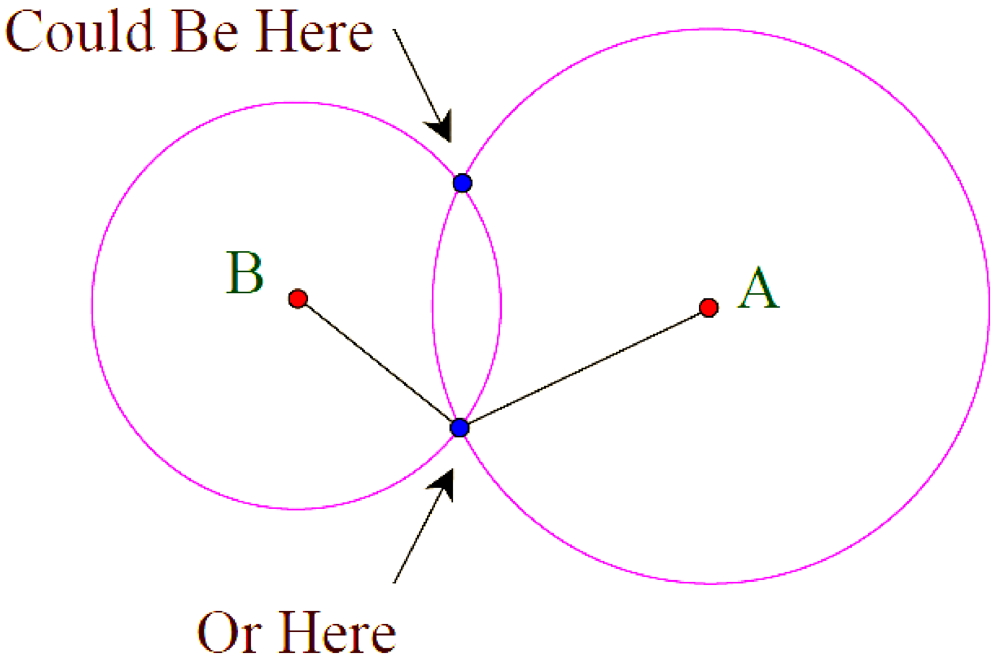
Triangulation in 2D

- **If location of point A is known, and the distance to point A is known, desired position lies somewhere on a circle**



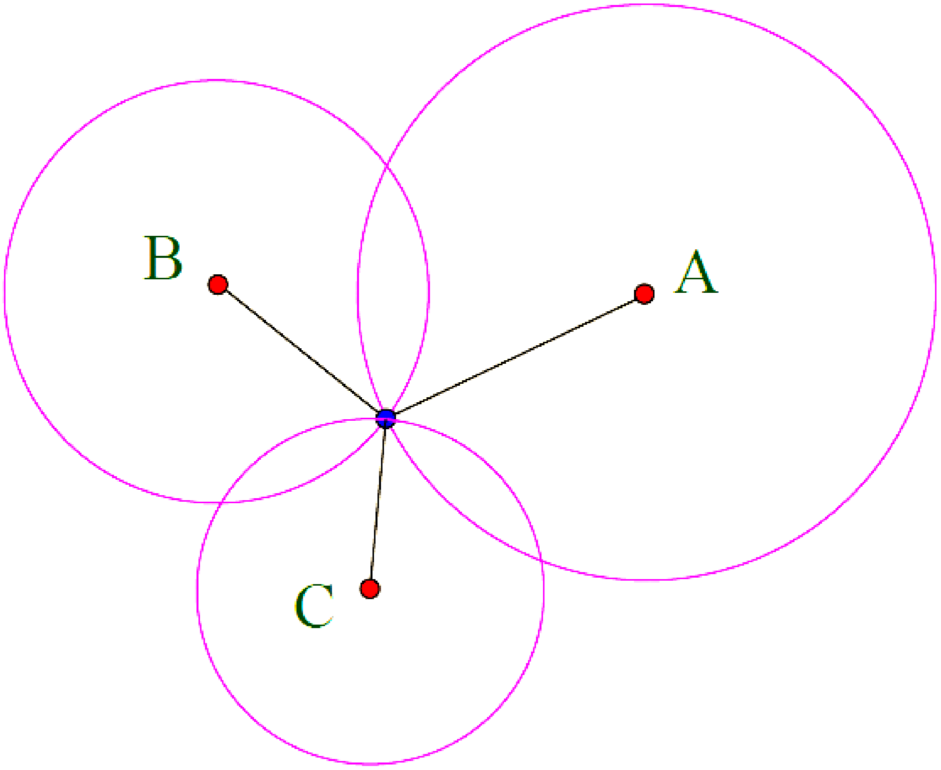
Triangulation in 2D

- Distance to two points is known
- Desired position is in one of two locations



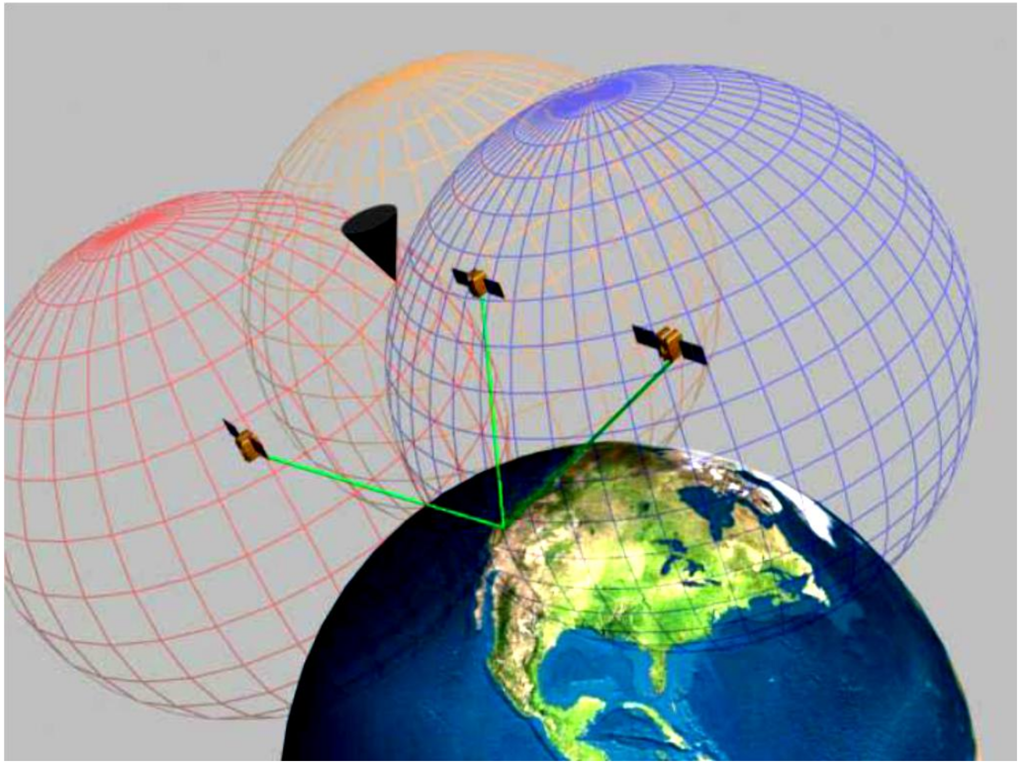
Triangulation in 2D

- Distance to three points is known
- Position is known!



Triangulation in 3D

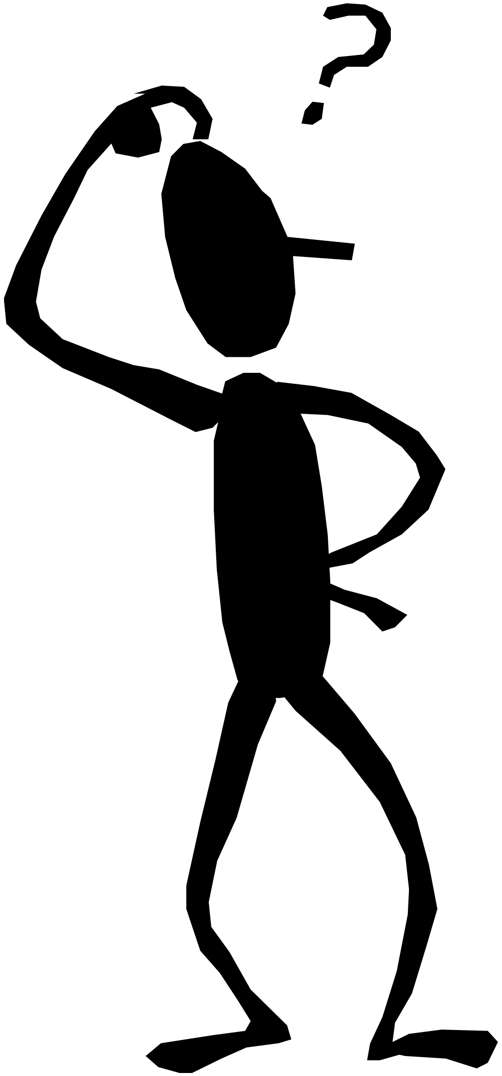
- Distance to three points is known
- Intersects at two points



Calculating a Position - Review

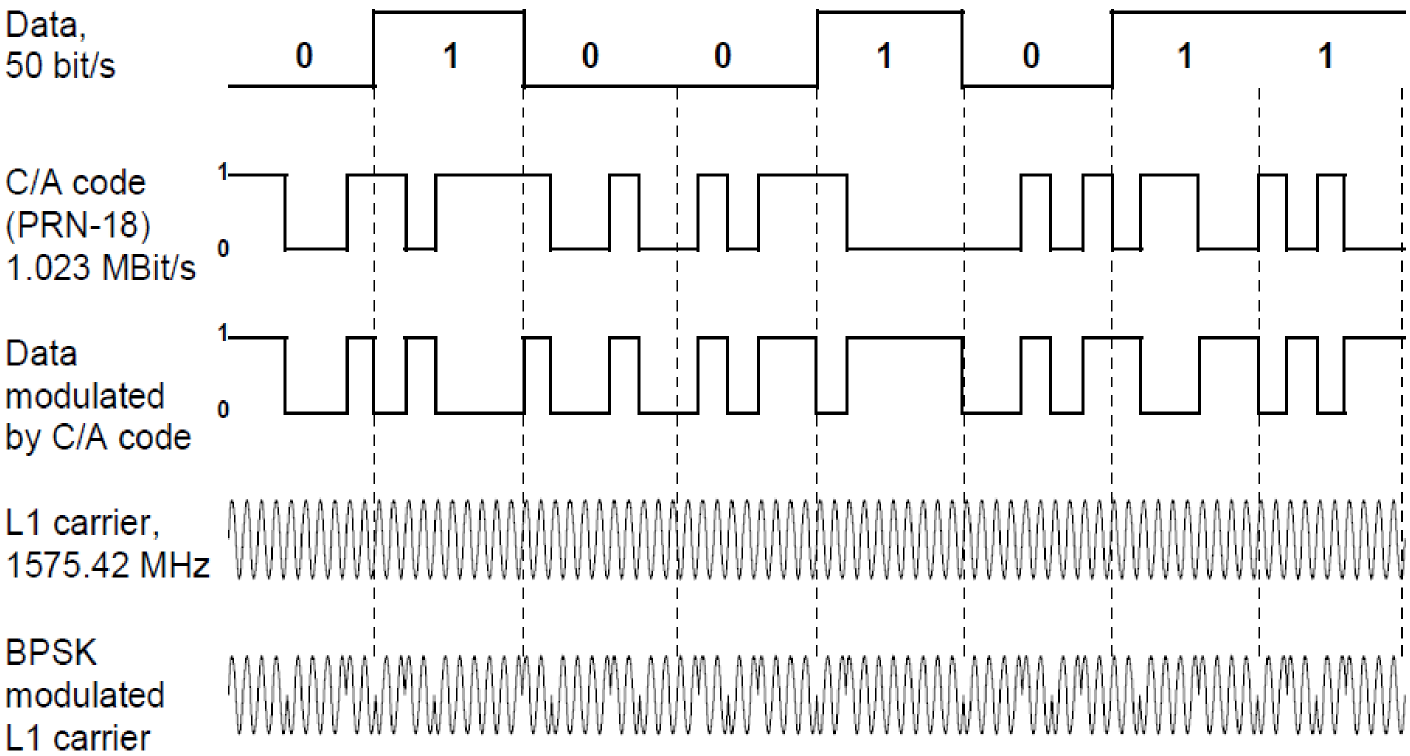
- Measure distance to satellites
  - Use pseudo ranges
- Obtain satellite positions
  - Decoded ephemeris from satellite message
- Perform triangulation calculations
  - Need at least 3 satellites for triangulation
- Adjust local clock bias to find 3D position
  - Need 4th satellite to adjust bias
- Adjust for Atmospheric Delay Errors
  - By software model or dual carrier frequencies
- Position is now known!

Question 4



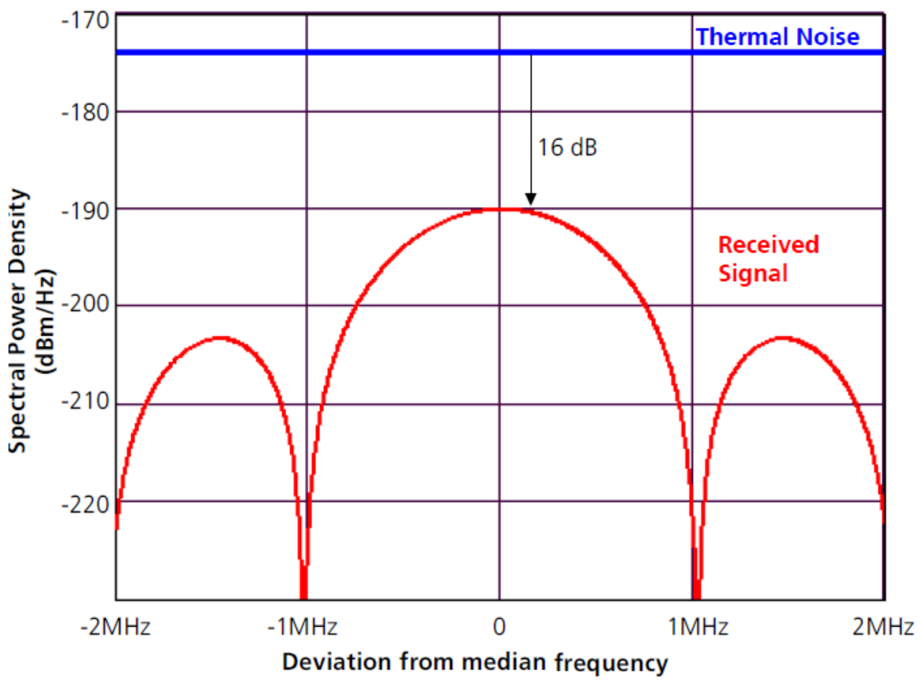
- How can the signal be received below the noise floor ?
- Surely we just decode noise ….

GPS Signal Data Structure



GPS Received Signal Strength

The power of the received GPS signal in open sky is at least -160dBW (-130dBm). The maximum of the spectral power density of the received signal is given as -190dBm/Hz. The spectral power density of the thermal background noise is about -174dBm/Hz (at a temperature of 290K). Thus the maximum received signal power is approximately 16dB below the thermal background noise level.

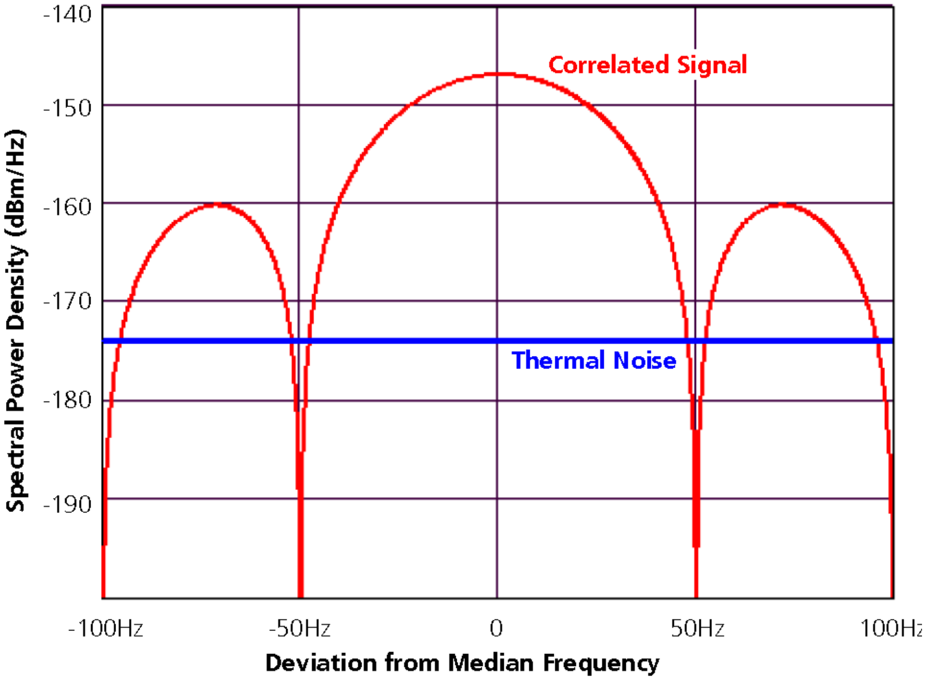


PRN Code & Frequency Correlation

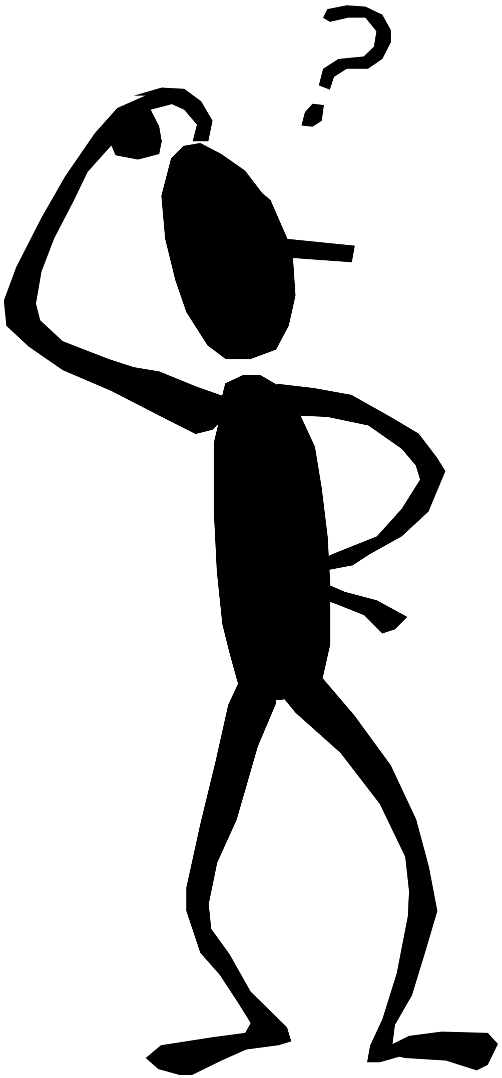
The spectral power density of the received GPS signal lays at approximately 16 dB below the spectral power density of the thermal or background noise. The demodulation and de-spreading of the received GPS signal causes a system gain G of:

$$G_G = \frac{\text{Modulation rate of C/A - Code}}{\text{Data rate of information signal}} = \frac{1023\,\text{kbps}}{50\text{bps}} = 20{,}500 = 43\text{dB}$$

After de-spreading, the power density of the usable signal is greater than that of the thermal or background signal noise.



Question 5

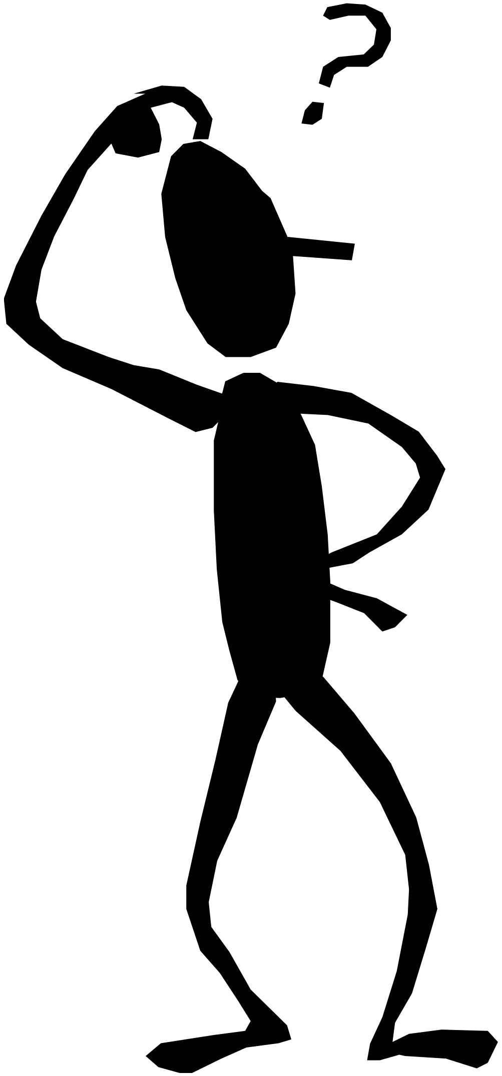


- Why do I sometimes lose the signal when I'm hiking in the forest or driving in the city ?

Receiver Sensitivity

- Signal in open air is at least 27dB above noise floor
  - See previous slides
- Tree cover and foliage, “bad weather”
  - Attenuates the signal level so that some satellites may not be received, modern receivers are better
  - Impairs position fix, less accurate or lost signal
- Tall buildings, tunnels, etc.
  - Satellites are obscured and cannot be received
  - Multi-path / reflections can help

Question 6

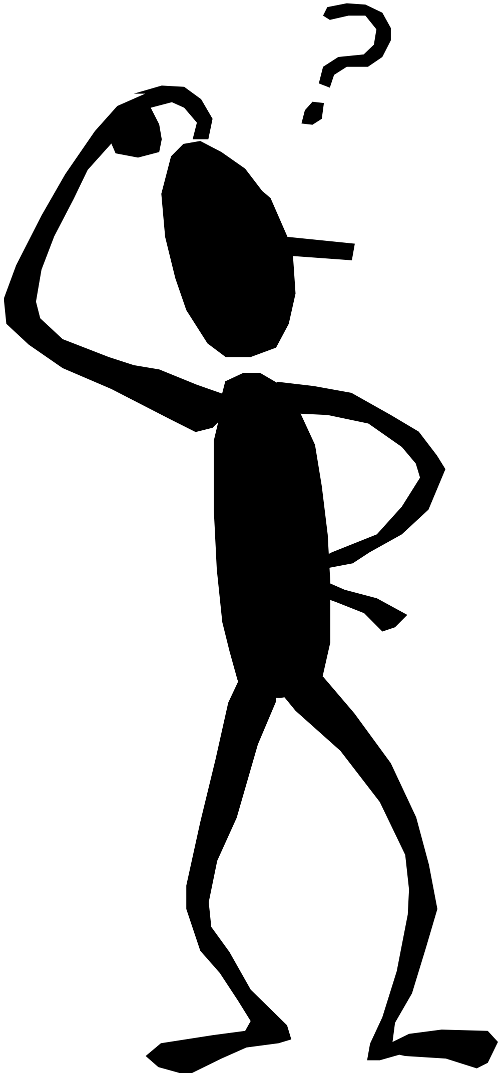


- Why does my GPS tell me my accuracy is changing between approximately 1m and 20m ?
- It usually gets better after a few minutes…

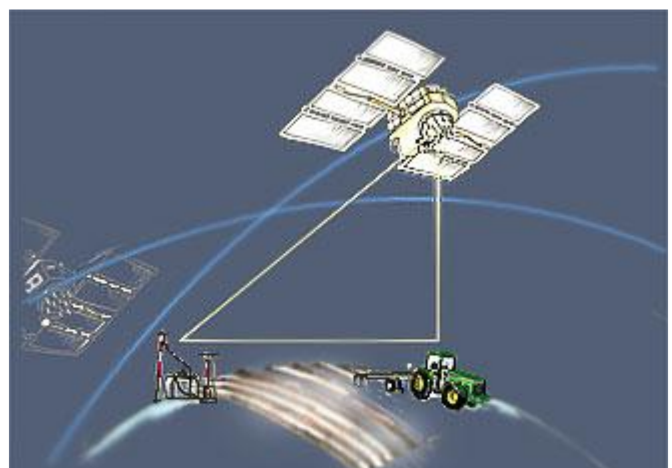
Positional Accuracy

- **Signal in improved with more satellites**
  - **Depends on their position relative to GPS receiver**
- **Signal is degraded by…**
  - **Atmospheric conditions can dominate**
  - **Weather**
  - **Foliage / tree cover**
  - **Buildings, tunnels, etc.**
  - **Multi-path**
  - **Timing Errors**
  - **Interference**
  - **Etc.**

Question 7



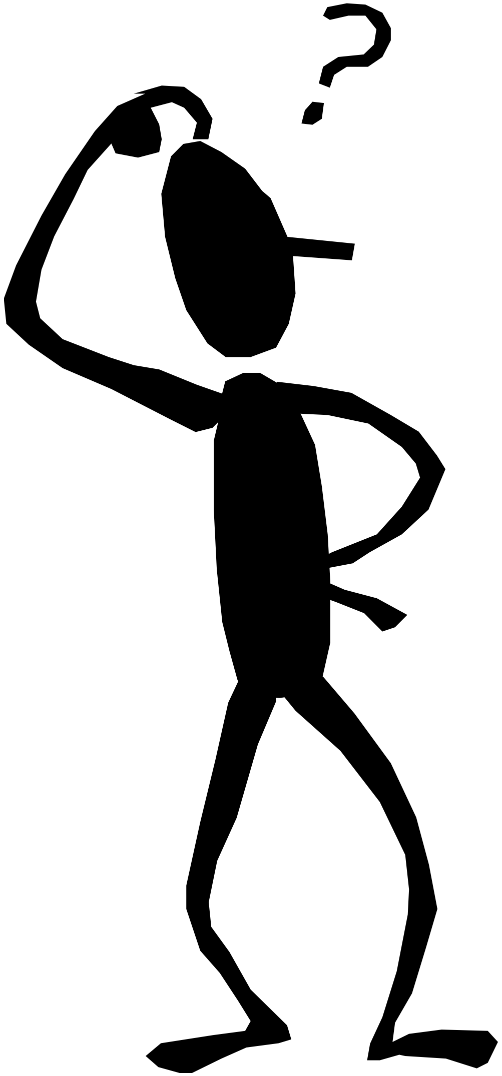
- Why do some people (e.g. farmers) claim to have <0.5m accuracy and can have automatic tractors to plough the fields?



Differential GPS

- **Where additional position accuracy is required**
  - **Employs ground stations with known fixed locations**
  - **Corrections are transmitted from ground stations at low frequencies (200-500kHz)**
  - **Requires an additional Differential Beacon Receiver (DBR) and an additional antenna**
  - **Accuracy is a function of the distance from the ground station**

Question 8



- Is GPS suitable for aircraft navigation?
- Could I fly and land an aircraft using GPS ?

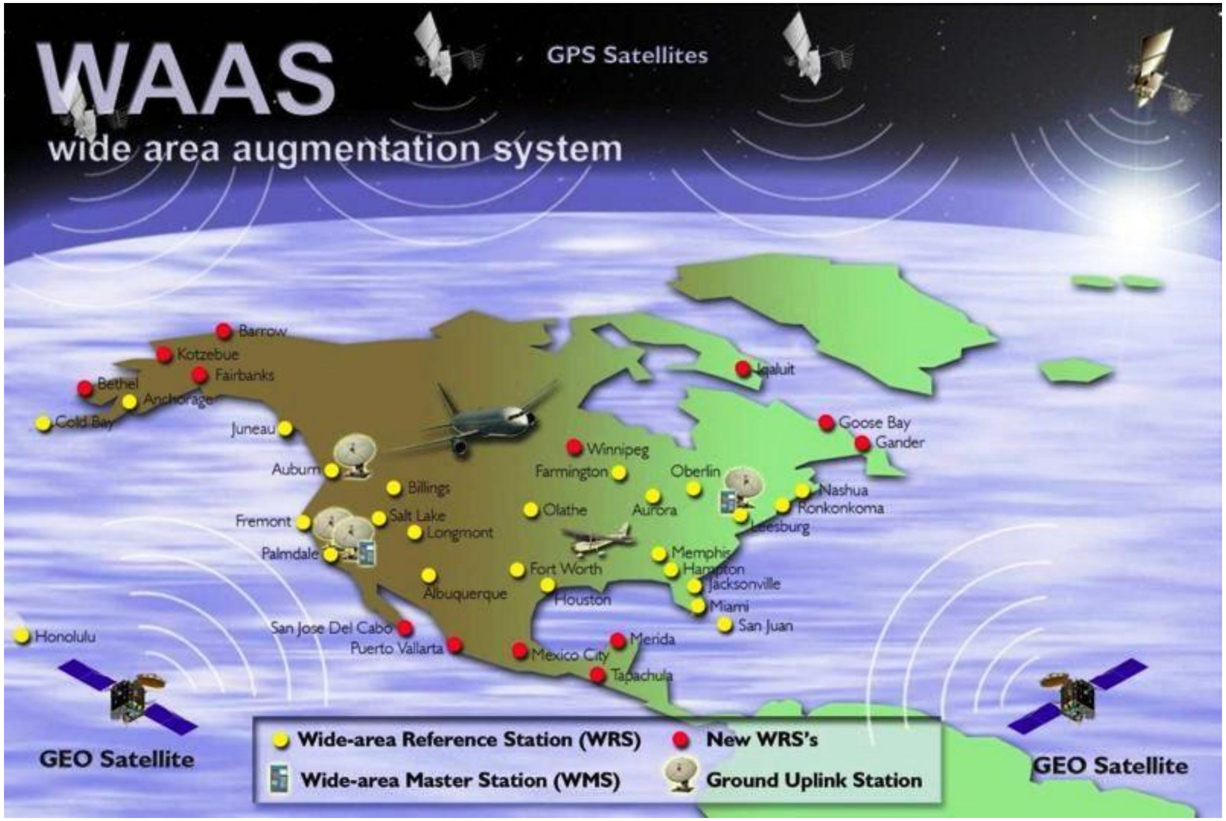
SBAS WAAS

- SBAS – Satellite Broadcast Augmentation System
  - USA – Wide Area Augmentation System (WAAS)
  - European Geostationary Navigation Overlay System (EGNOS)
- Used to make GPS and GLONASS more accurate and suitable for aviation use
  - Additional (2) satellites per system, transmit correction data every 5 seconds
    - Focused on USA and Europe
- Needs SBAS for approach and landing
  - Works alongside Marker Beacons, DME, ILS, etc.

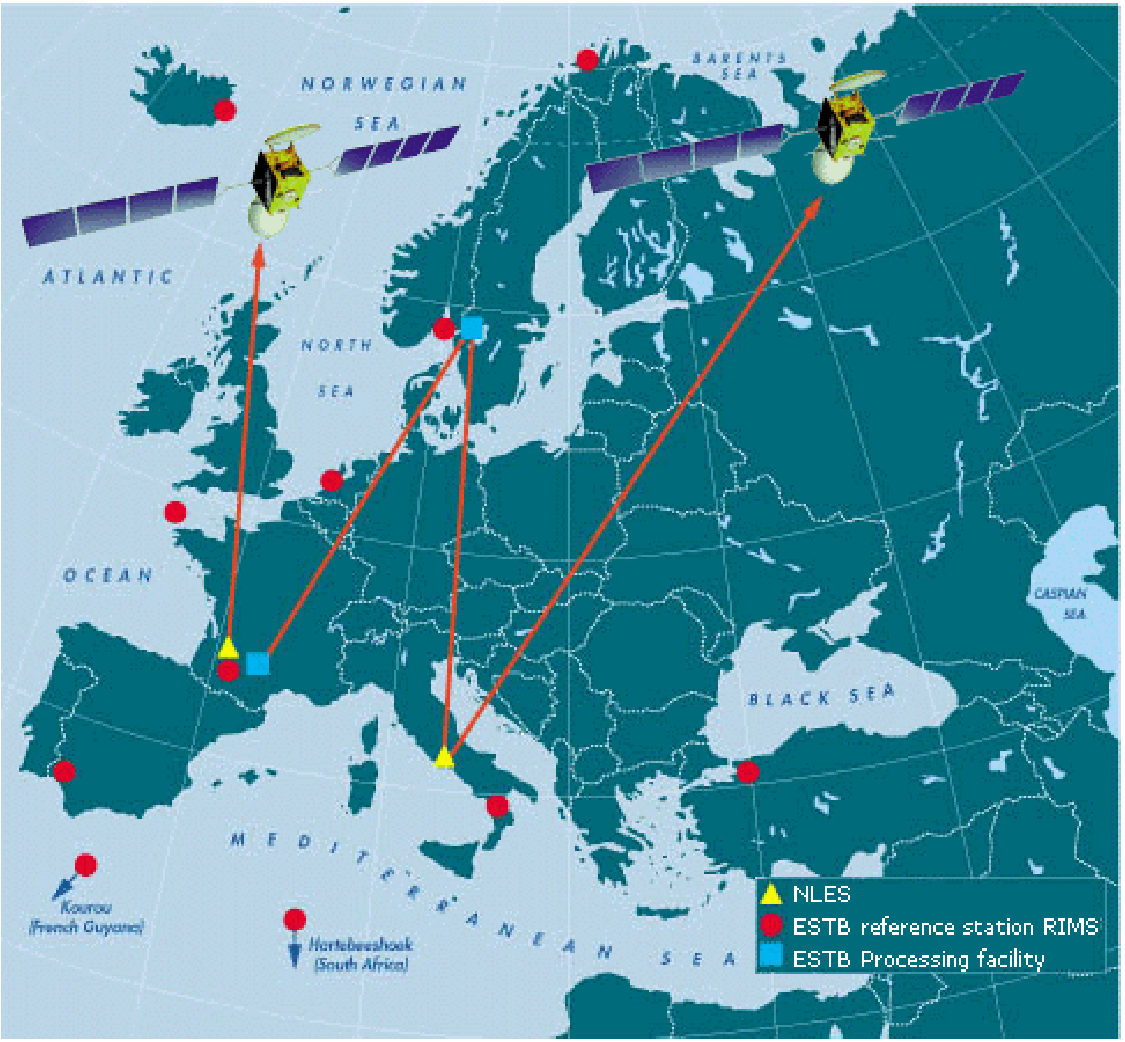
SBAS WAAS

- **Wide Area Augmentation System (WAAS)**
  - **Managed by the FAA**
  - **Communicates with several ground stations**
  - **Provides atmospheric corrections**
  - **Early warning of GPS failures**
  - **Same frequency as GPS**
  - **Higher data rate 250 Hz**
  - **Two Satellites are in geostationary orbits**

SBAS WAAS

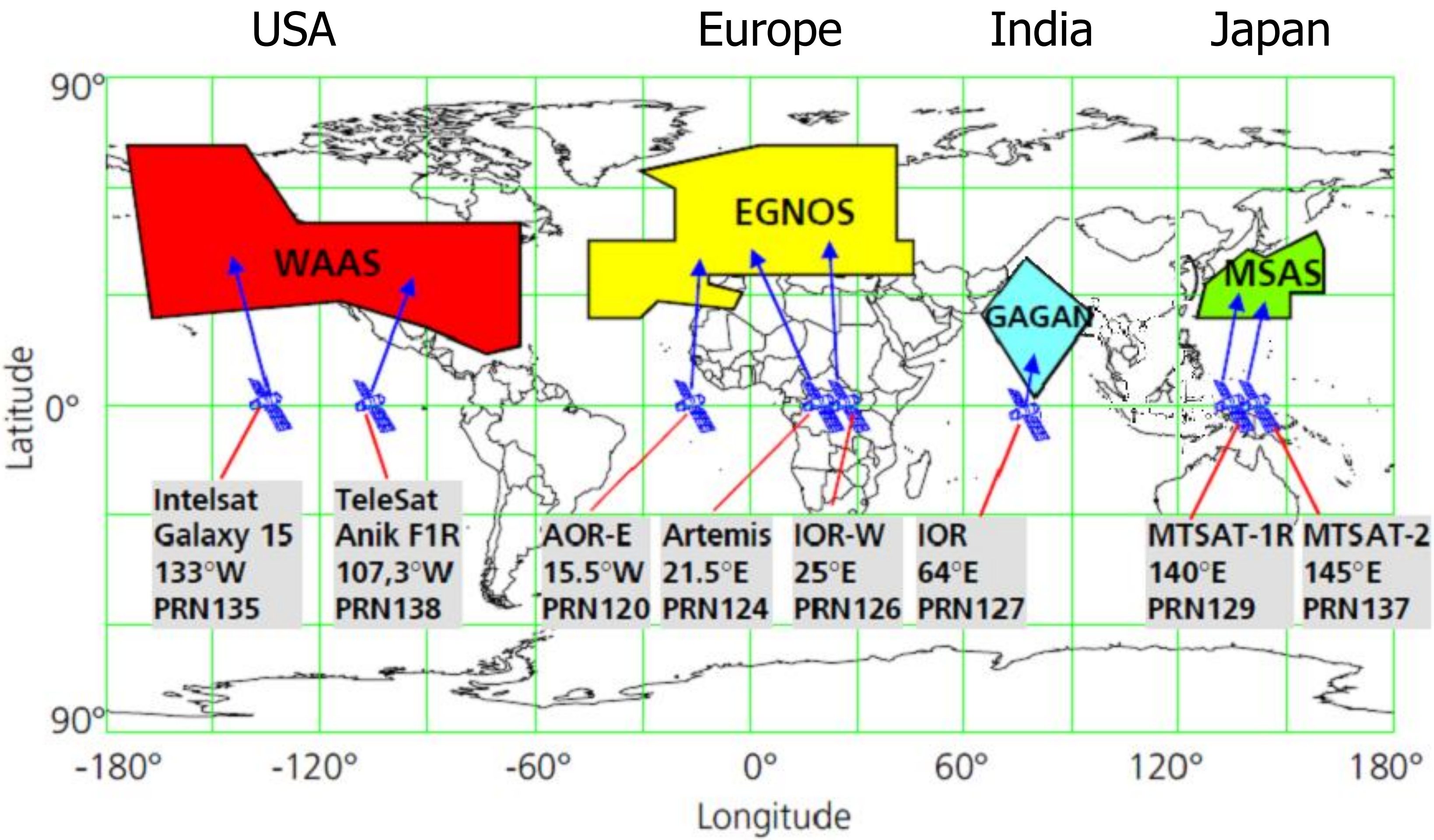

WAAS
wide area augmentation system
GPS Satellites
Barrow
Kotzebue
Fairbanks
Bethel
Anchorage
Cold Bay
Juneau
Iqaluit
Goose Bay
Gander
Winnipeg
Farmington
Oberlin
Auburn
Billings
Nashua
Ronkonkoma
Olathe
Aurora
Leesburg
Fremont
Salt Lake
Longmont
Palmdale
Memphis
Hampton
Fort Worth
Jacksonville
Albuquerque
Houston
Miami
San Juan
Honolulu
San Jose Del Cabo
Puerto Vallarta
Mexico City
Merida
Tapachula
GEO Satellite
Wide-area Reference Station (WRS)
New WRS's
Wide-area Master Station (WMS)
Ground Uplink Station
GEO Satellite

SBAS EGNOS



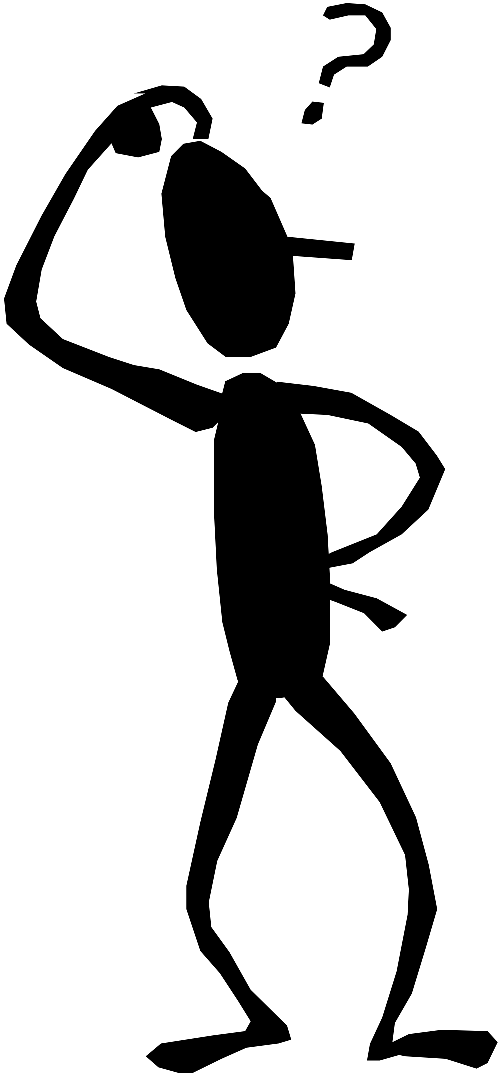
NORWEGIAN SEA
BARENTS SEA
ATLANTIC
OCEAN
NORTH SEA
CASPIAN SEA
BLACK SEA
MEDITERRANEAN SEA
Kourou (French Guyana)
Hartebeeshoek (South Africa)
NLES
ESTB reference station RIMS
ESTB Processing facility

SBAS



USA
Europe
India
Japan
90°
0°
90°
Latitude
WAAS
EGNOS
GAGAN
MSAS
Intelsat Galaxy 15 133°W PRN135
TeleSat Anik F1R 107,3°W PRN138
AOR-E 15.5°W PRN120
Artemis 21.5°E PRN124
IOR-W 25°E PRN126
IOR 64°E PRN127
MTSAT-1R 140°E PRN129
MTSAT-2 145°E PRN137
-180°
-120°
-60°
0°
60°
120°
180°
Longitude

Question 9



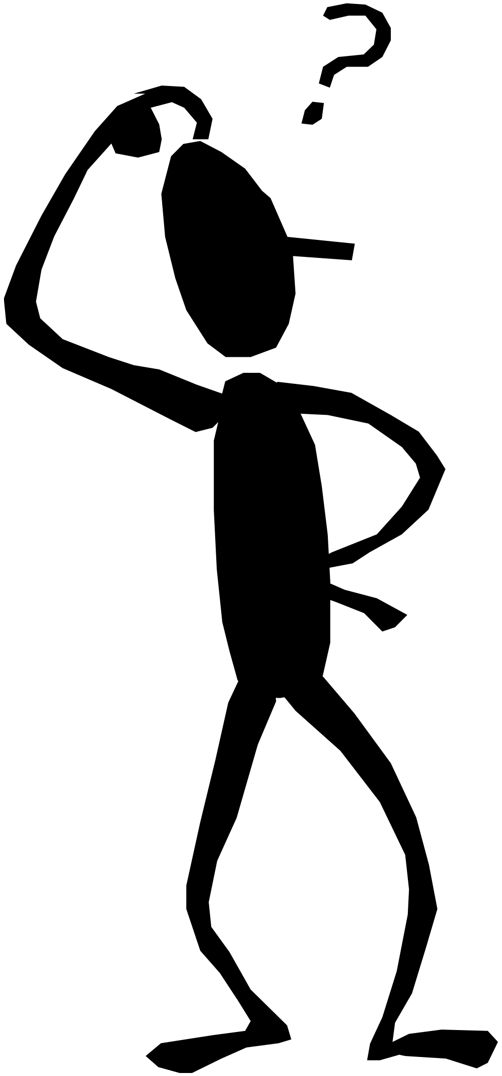
- **What is the difference between civilian and military use ?**

GPS User Segment

- Civilian
  - SPS - Standard Positioning Service
    - Uses single frequency L1
    - Uses C/A code only
    - Accurate to metres
    - S/A (Selective Availability) removed

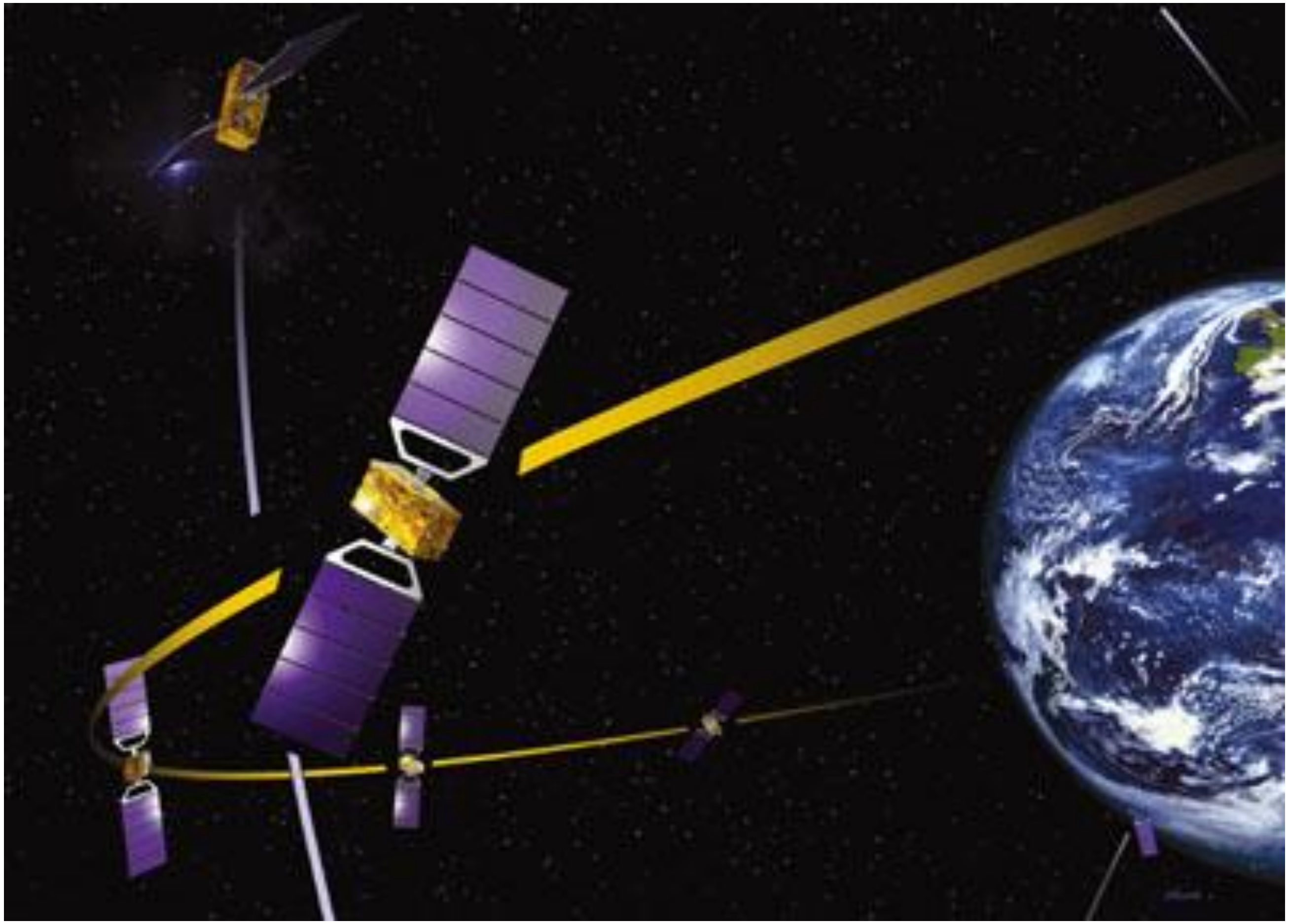
- Military
  - PPS - Precise Positioning Service
    - Uses two frequencies L1/L2
    - Uses C/A code and P-code
    - Accurate to centimetres

Question 10



- What is Galileo and will it work with my GPS ?
- What are the Russians and Chinese doing. Do they use GPS ?

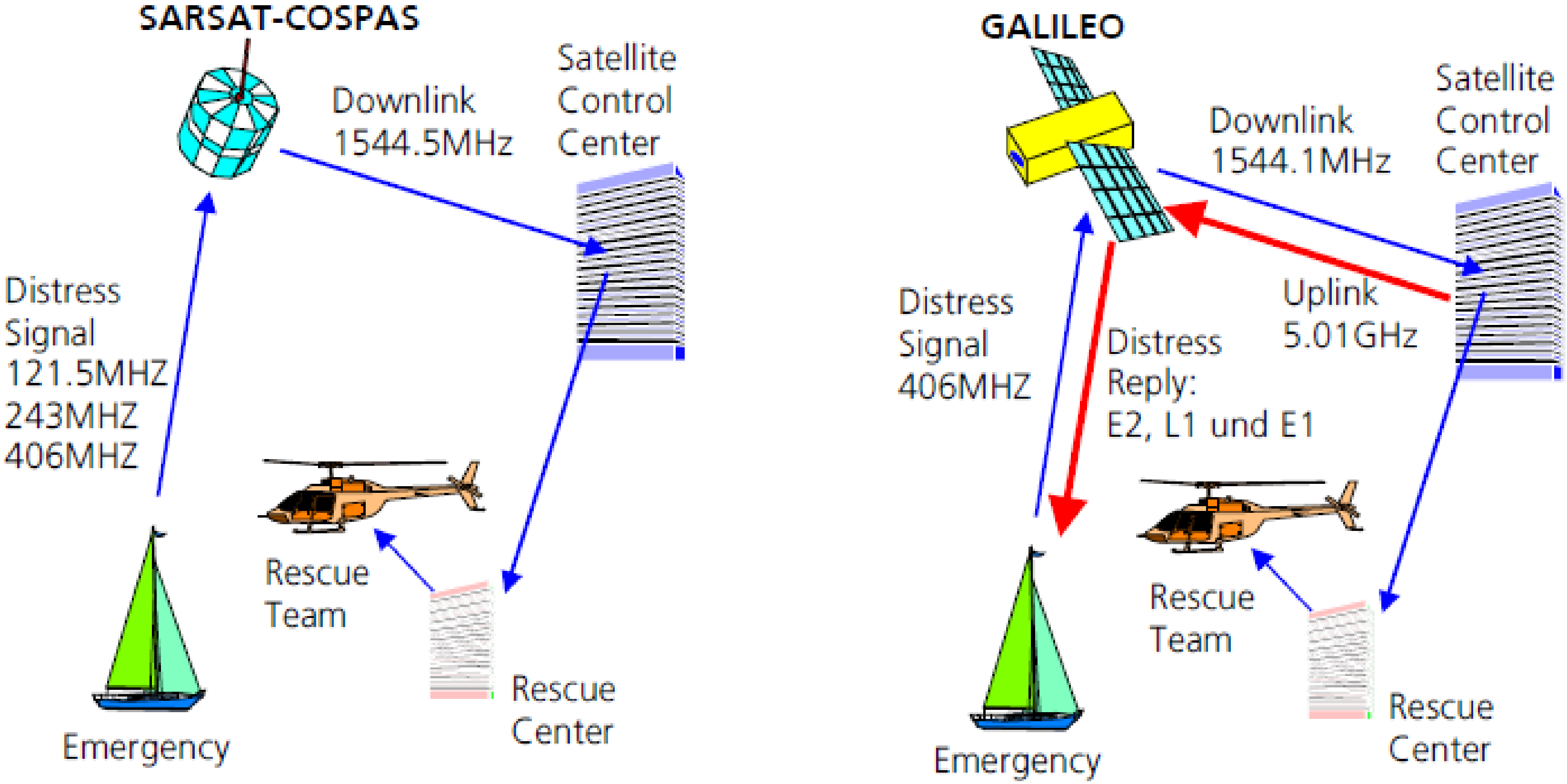
GPS Galileo



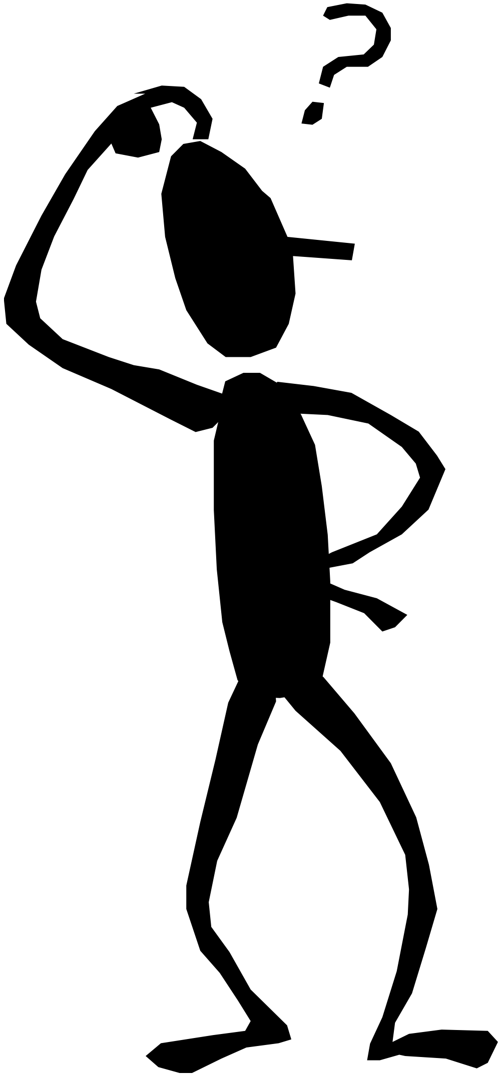
GPS Galileo

- **European Union GNSS**
- **30 SV's**
  - Orbital Altitude 23,222 km (medium earth orbit)
  - Three orbital planes, 56° inclination
  - Nine operational SV's and one spare per orbital plane
  - BOC Modulation - minimises interference with GPS BPSK
- **Four Navigation Services**
  - OS (Open Service) E1 accuracy <4m horiz/<8m vert
  - CS (Commercial Service) <1m horiz
  - PRS (Public Regulated Services) Police, Military, Automatic Landing, ATC
  - SoL (Safety of Life) COSPAS SARSAT

GPS Galileo SoL



Question 11



- Will GPS get better, e.g. more accuracy, better coverage, etc. ?

GPS Modernization

- U.S. National policy - GPS is a vital dual-use system
- For civil users, new signals/frequencies provide:
  - More robustness against interference, compensation for ionospheric delays
- For military users, new signals provide:
  - Enhanced ability to deny hostile GPS use, greater military anti-jam capability and greater security
- For both civil/military, system improvements in accuracy, reliability, integrity, and availability

GPS Modernization Signals Summary

Signal	Chipping Rate (Mchip/s)	Carrier frequency (MHz)	Comments
L1C/A	1.023	1575.42	1023-chip Gold codes repeat every ms
L1C	1.023	1575.42	10230-chip MBOC (6,1) Block III 2013
L2CS	1.023	1227.6	2 codes per SV each at 511.5 kHz
L1P(Y)	10.23	1575.42/1227.6	Repeats once/week
L5	10.23	1176.45	2 codes per SV
M	5.115	1575.42/1227.6	code modulated by 10.23 MHz square wave

GPS Modernization Accuracy

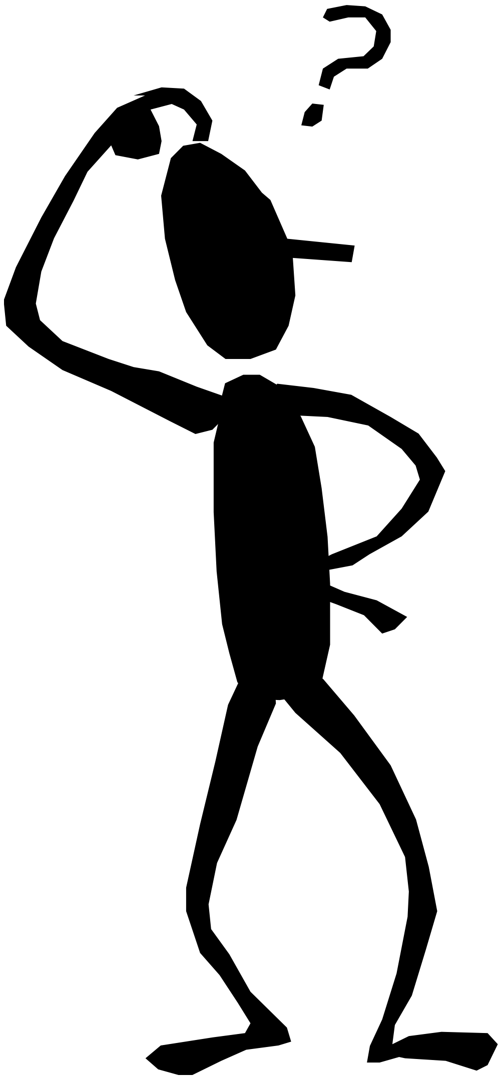
Error Source	Typical Range Error Magnitude (meters, 1σ)	
	Without SA	**Without SA plus 2 or more coded signals**
Selective Availability	0.0	0.0
Atmospheric Error Ionospheric Tropospheric	 7.0 0.2	 0.01 0.2
Clock and Ephemeris Error	2.3	2.3
Receiver Noise	0.6	0.6
Multipath	1.5	1.5
Total User Equivalent Range Error (UERE)	7.5	2.8
Typical Horizontal DOP (HDOP)	1.5	1.5
Total Stand-Alone Horizontal Accuracy, 95%	22.5	8.5

GPS Simulation

- **Aeroflex GPSG-1000**
  - **Portable 6 or 12 SV**
  - **GPS, Galileo, SBAS**

- **User Defined Scenarios**
  - **Static**
  - **Dynamic**
- **GPS Recording**
  - **Record a real walking, driving or flying scenario**
  - **Play back the scenario under controlled conditions**

GNSS Systems



Any questions?