UNIVERSITY OF BRADFORD
MAKING KNOWLEDGE WORK

School of Engineering, Design and Technology

Satellite Navigation

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Topics

- What is satellite navigation?
- History
  - TRANSIT System
- GPS
- GLONASS
- Galileo
- Competition, Cooperation, Prospective

What is satellite navigation?

Satellite Navigation

"Navigation using information transmitted from satellites via radio waves"

"A navigation method, pinpoint your location anywhere on earth using satellites"

Why by satellite?

- Signal reception is better than by terrestrial
- Signals can pass through clouds and rain
- As long as a satellite is in the receiver's horizon, a signal is always perceivable
- Worldwide
- High accuracy

History

History

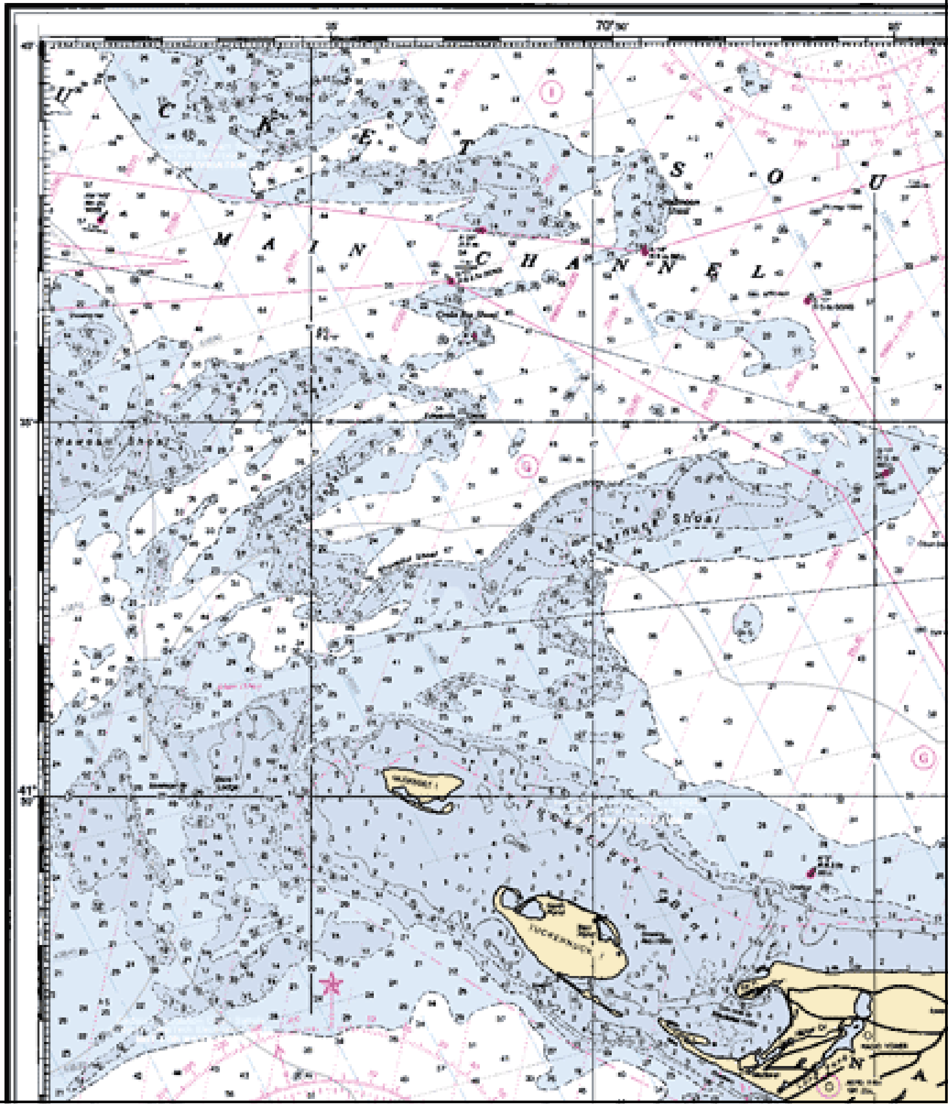
- The Russians kept the Doppler-effect in mind with the launch of Sputnik I in 1957
  "*To keep radio contact with a moving object, you have to keep changing your frequency*"
- The Americans discovered how to invert this in 1959 with the start of the TRANSIT navigation system, known as "Navy Navigation Satellite System
  "*If you know the position of the satellite, you can determine your relative position to it*"

TRANSIT System - Concept

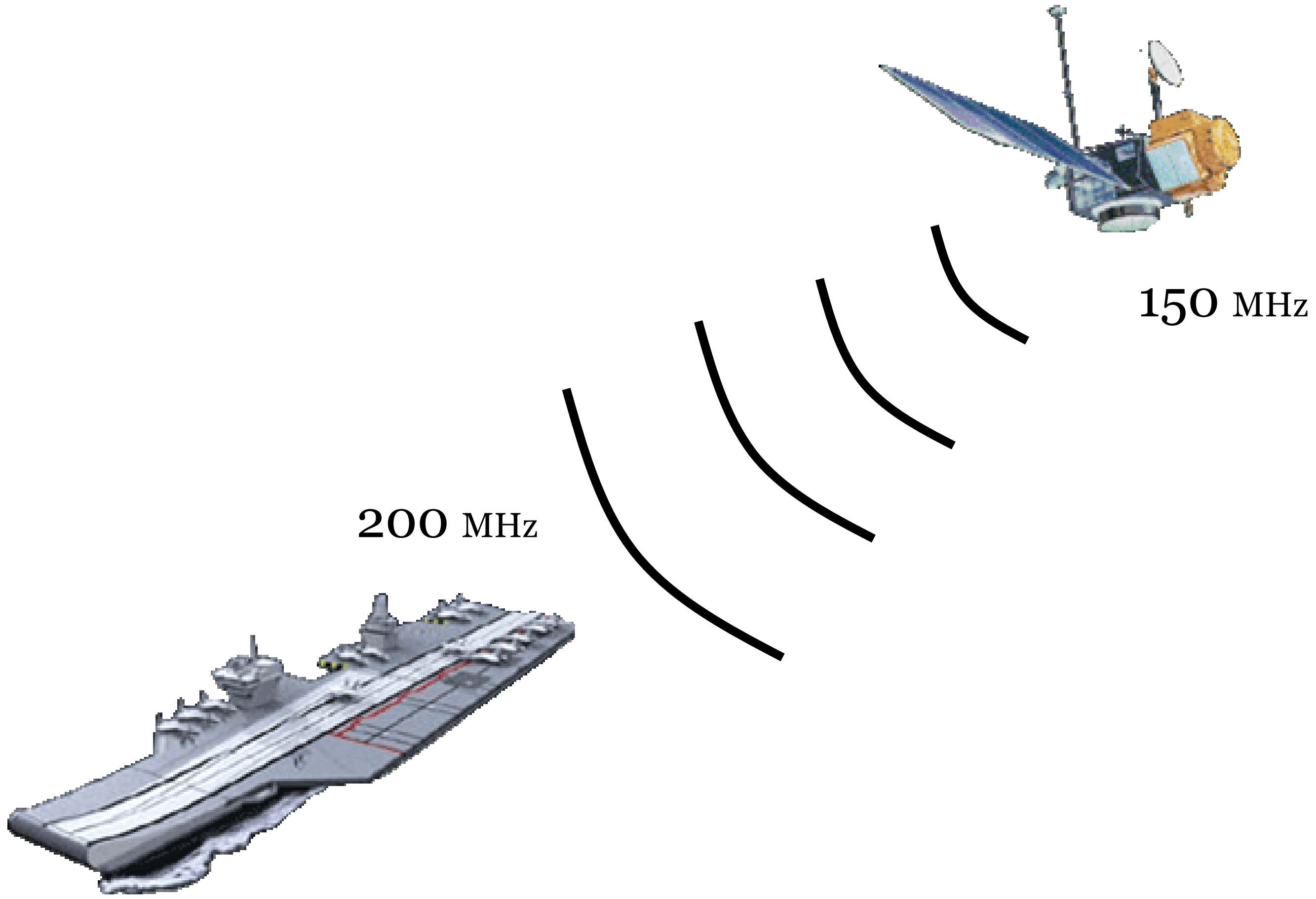
Navy Navigation Satellite System

- Satellite sends its exact position and time over a fixed frequency
- Receiver monitors the difference between the received frequency and the expected frequency
- When these frequencies are equal, the satellite is directly above the receiver

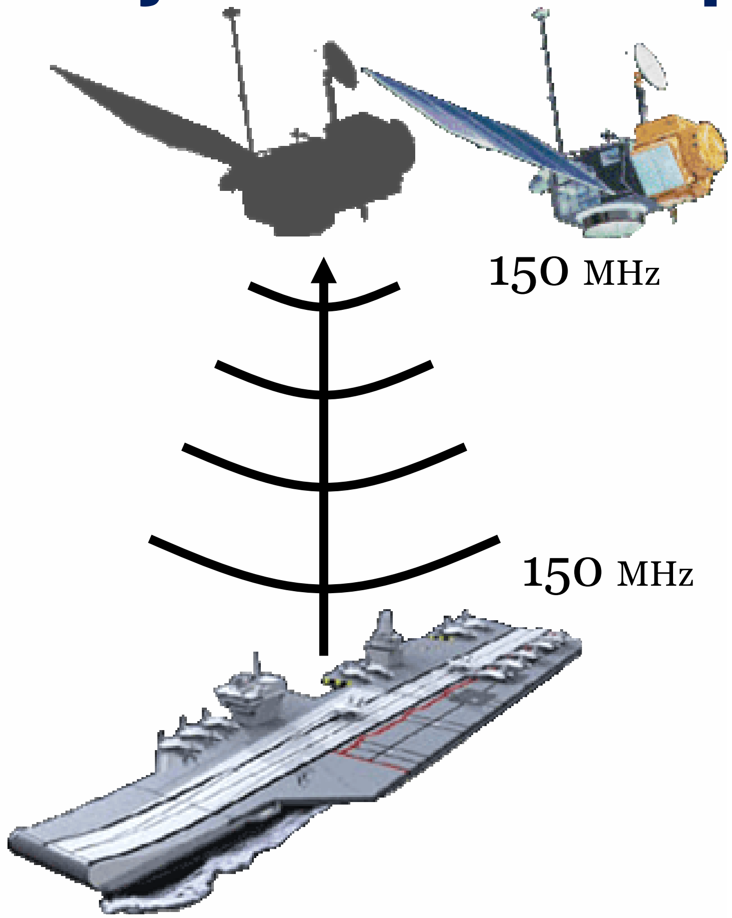
TRANSIT System - Example



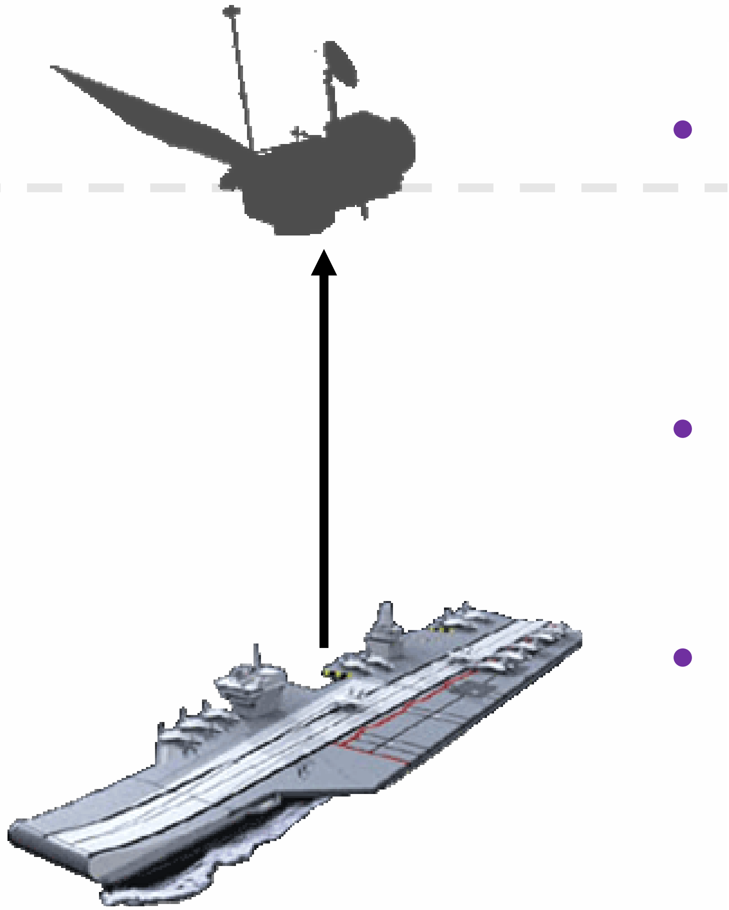
TRANSIT System - Example



TRANSIT System - Example

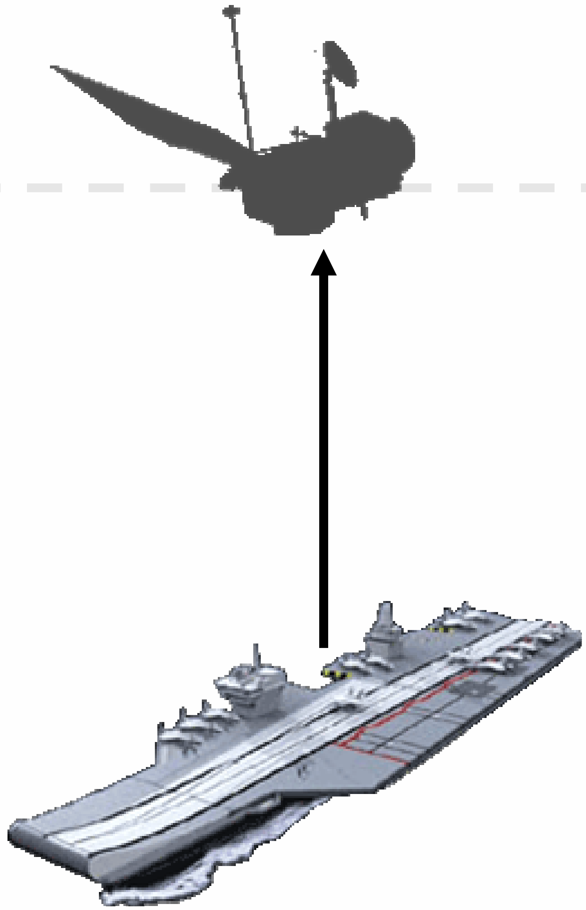


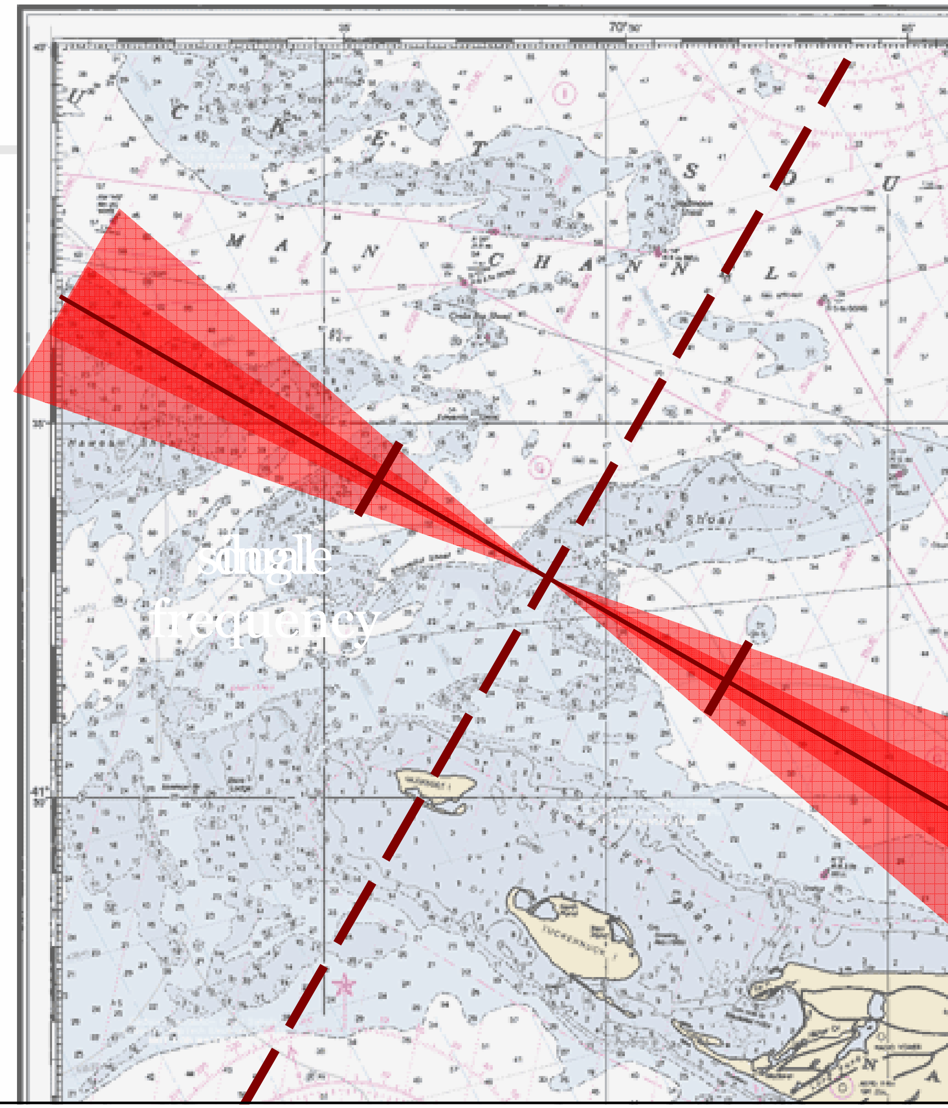
TRANSIT System - Positioning



- The receiver only knows that the satellite is neither approaching nor departing
- So the ship must be on a line perpendicular to the orbit of the satellite
- With Doppler shift calculation, it will tell the receiver distance from orbit but not which side
  - Two possible locations remain

TRANSIT System - Positioning





TRANSIT System – Pros and Cons

- Pros
  - Up and running 2 years after concept
  - Only need 1 satellite per measurement
- Cons
  - Low orbit + few satellites = bad coverage
  - Receiver needs a continuous signal
  - Receiver has to wait for satellite to pass overhead
  - Only up to 500/25 meter accuracy
  - Assumes sea level altitude
- The TRANSIT was abandoned in 1996, due to GPS success

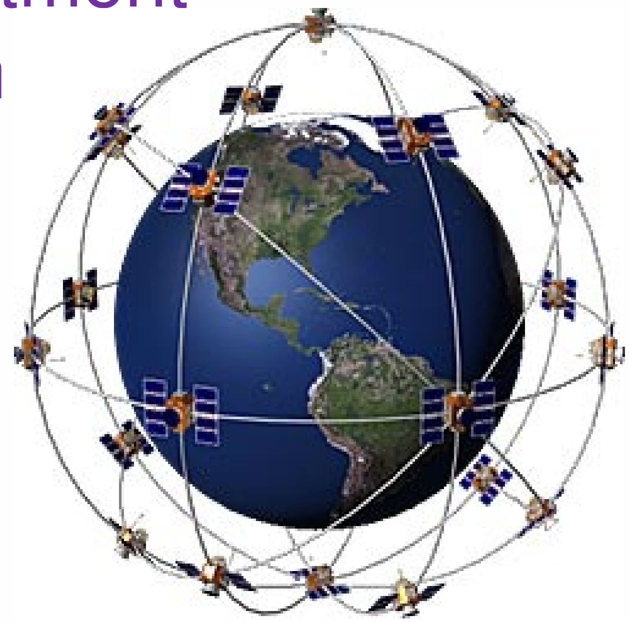
NAVSTAR - GPS

Navigation Satellite Timing and Ranging

Global Positioning System

What is GPS? (1)

- A satellite-based navigation system
  - Made up of a network of 24 satellites (21 active satellites, plus 3 spares)
  - Placed into orbit by the U.S. Department of Defence, started development in 1973 for military application
    - In 1980s, available for civilian use
  - Six orbital planes (orbit containing multiple satellites)
    - Four satellite per plane



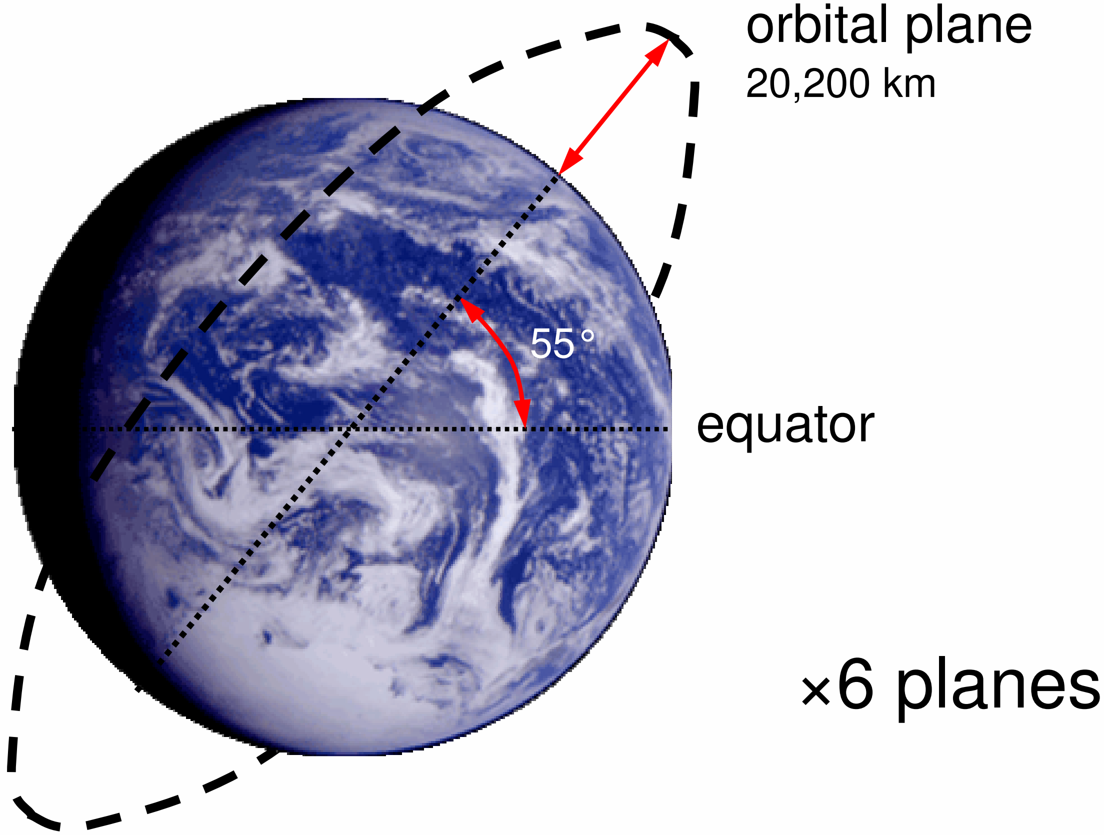
What is GPS ? (2)

- GPS works in any weather conditions, determine location, velocity and time, anywhere in the world, 24 hours a day – for free
- See GPS video, GPS Application Exchange website

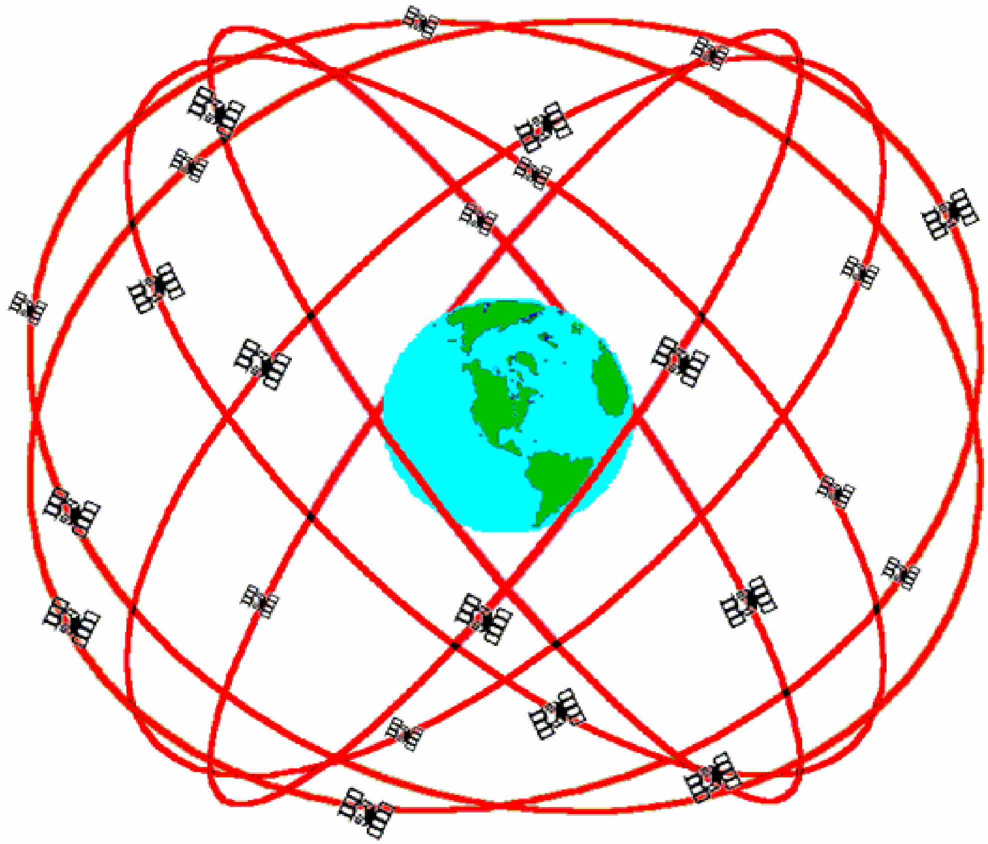
GPS History

- First three prototype satellites "Timation" from 1967-1974
- First prototype configuration "Block I" of 10 satellites from 1978-1985
- Current configuration is the "Block II" from 1989-1994
  - Planned full function with all 24 satellites by the late '80s
  - Delayed partially because of the '86 Challenger Space Shuttle disaster

GPS Configuration



GPS Configuration - Summary



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

GPS Technology – Three Segments

- GPS technology requires three segments
  - Space segment
  - Control segment
  - User segment

GPS Space Segments (1)

- 24 satellites orbit the earth twice a day in specific pattern
  - Travel at approximately 7,000 miles per hour, 20,200 km above the earth's surface
  - GPS receiver around the world can receive signals from at least four of the satellites
- Each GPS satellite constantly sends coded radio signals (pseudorandom code) to earth

GPS Space Segments (2)

- GPS satellite signals contain the following information:
  - Particular satellite that sending the information
  - Where that satellite should be at any given time
  - Whether or not the satellite working properly
  - The date and time
- Powered by solar energy, backup batteries
- Each satellite built to last about 10 years

GPS Control Segments (1)

- Responsible for constantly monitoring satellite health, signal integrity and orbital configuration from ground
- Monitor stations (MS)
  - 6 MS located around the world
  - Each station constantly monitors and receives info from GPS satellites
  - Sends orbital and clock information to master control station (MCS)

GPS Control Segments (2)

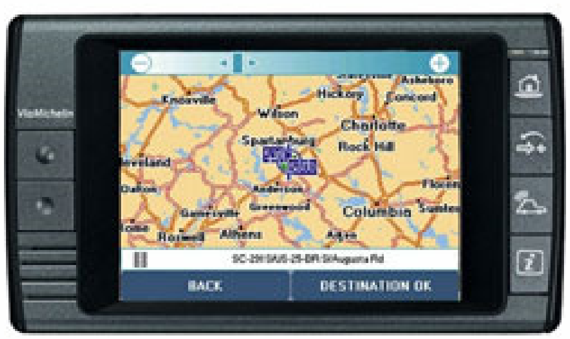
- Master control station (MCS)
  - Located near Colorado Springs in Colorado
  - Constantly receives GPS satellite orbital and clock information from the MS
  - Controller make precise correction to data
  - Send info to GPS satellites using ground antennas
- Ground antennas (GA)
  - Receive the corrected orbital and clock information from the MCS
  - Send corrected information to appropriate satellites

GPS Control Segments (3)

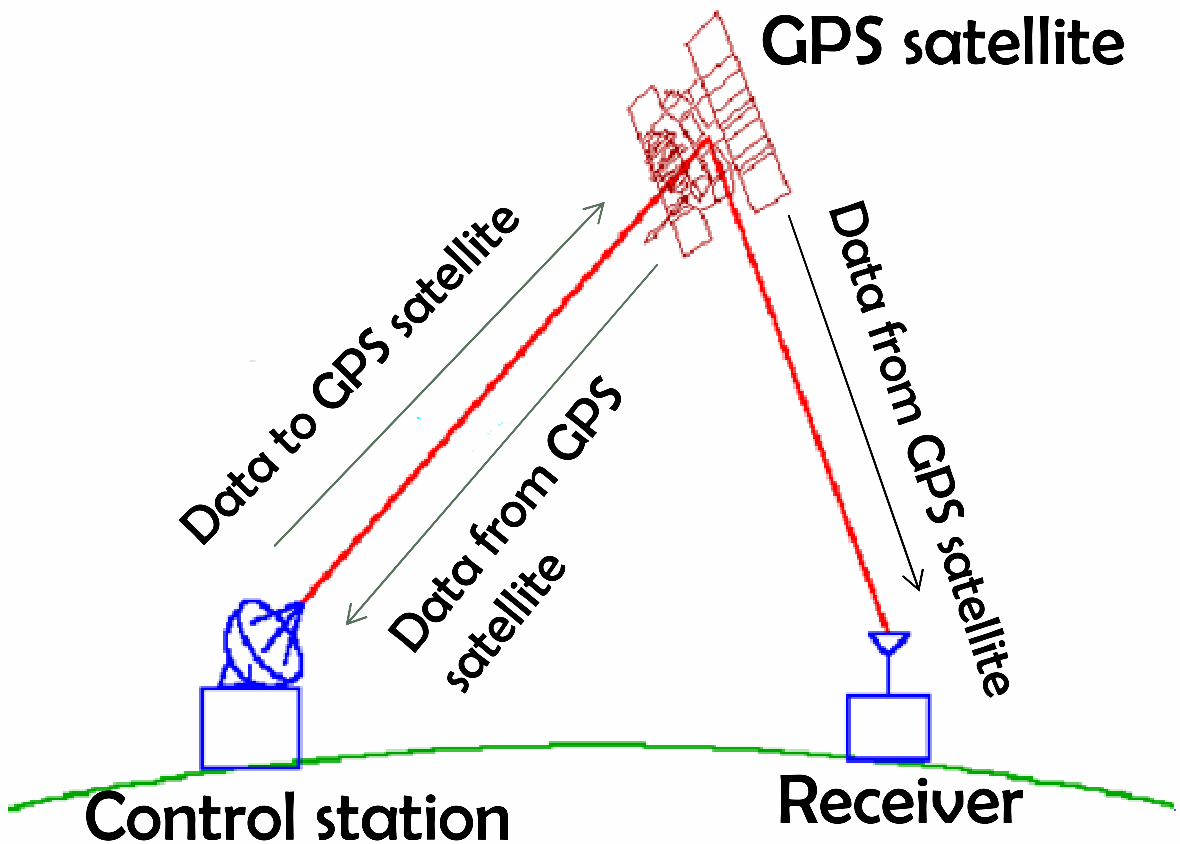
Global Positioning System (GPS) Master Control and Monitor Station Network

User segment

- Consist of GPS receiver
- Receiver collects and processes signal from GPS satellites
- Uses the information to determine and display your location, speed, time
- Does not transmit any information back to satellites



Three Segments Works - Summary



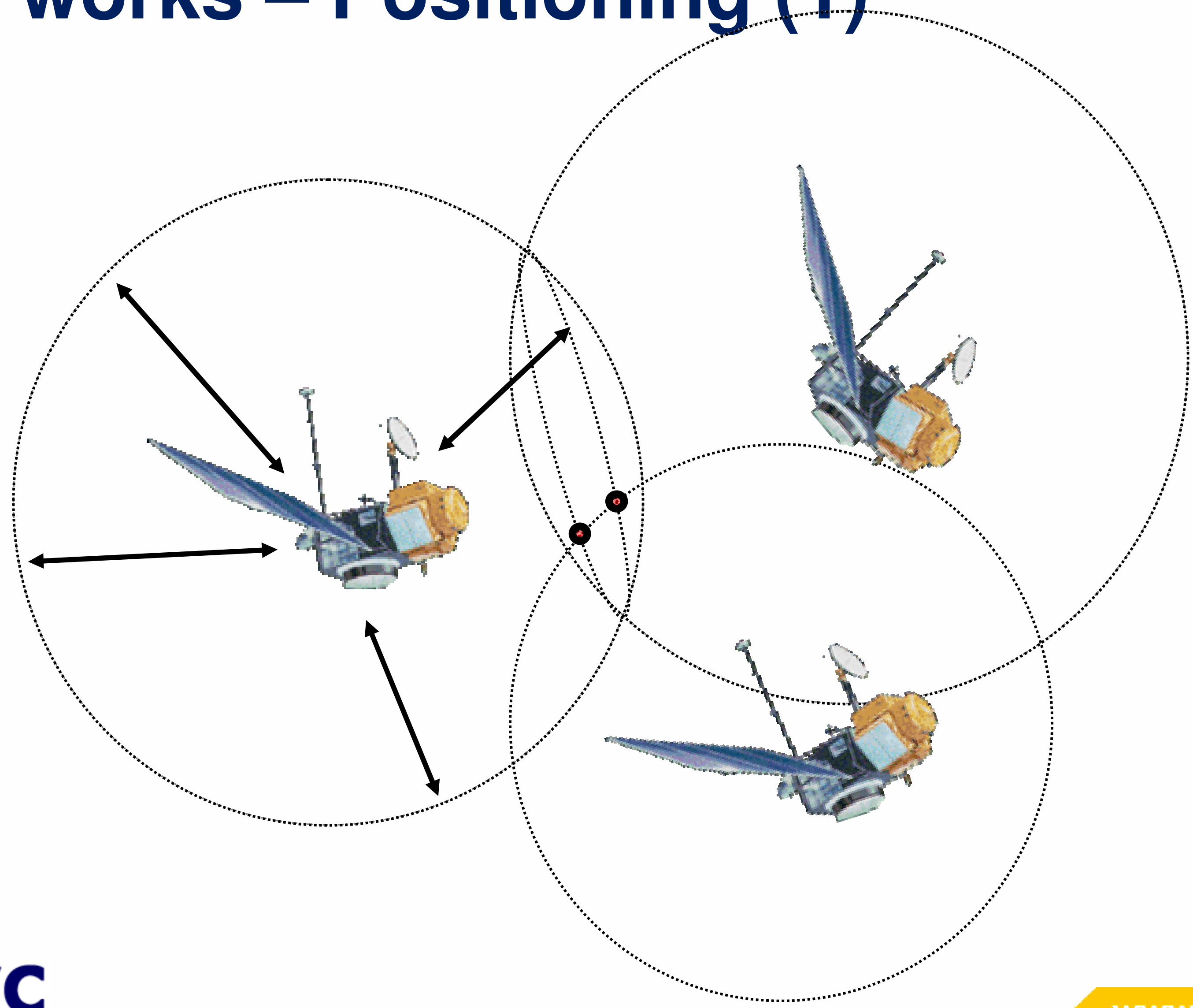
How it works – Concept (1)

- See GPS principles video
- GPS satellites circle earth twice a day in a very precise orbit and transmit a signal to earth
- A GPS receiver receives a signal from a GPS satellite
- It calculates the difference from the current time and the time sent by the satellite

How it works - Concept (2)

- Time different tells GPS receiver "how far away" the satellite is from receiver
  - Multiply that travel time by the speed of light and you've got distance
- Receiver receives a signal from another two satellites - again calculates the distance from them
- Knowing its distance from three known locations - receiver use triangulation to calculate the user's exact position

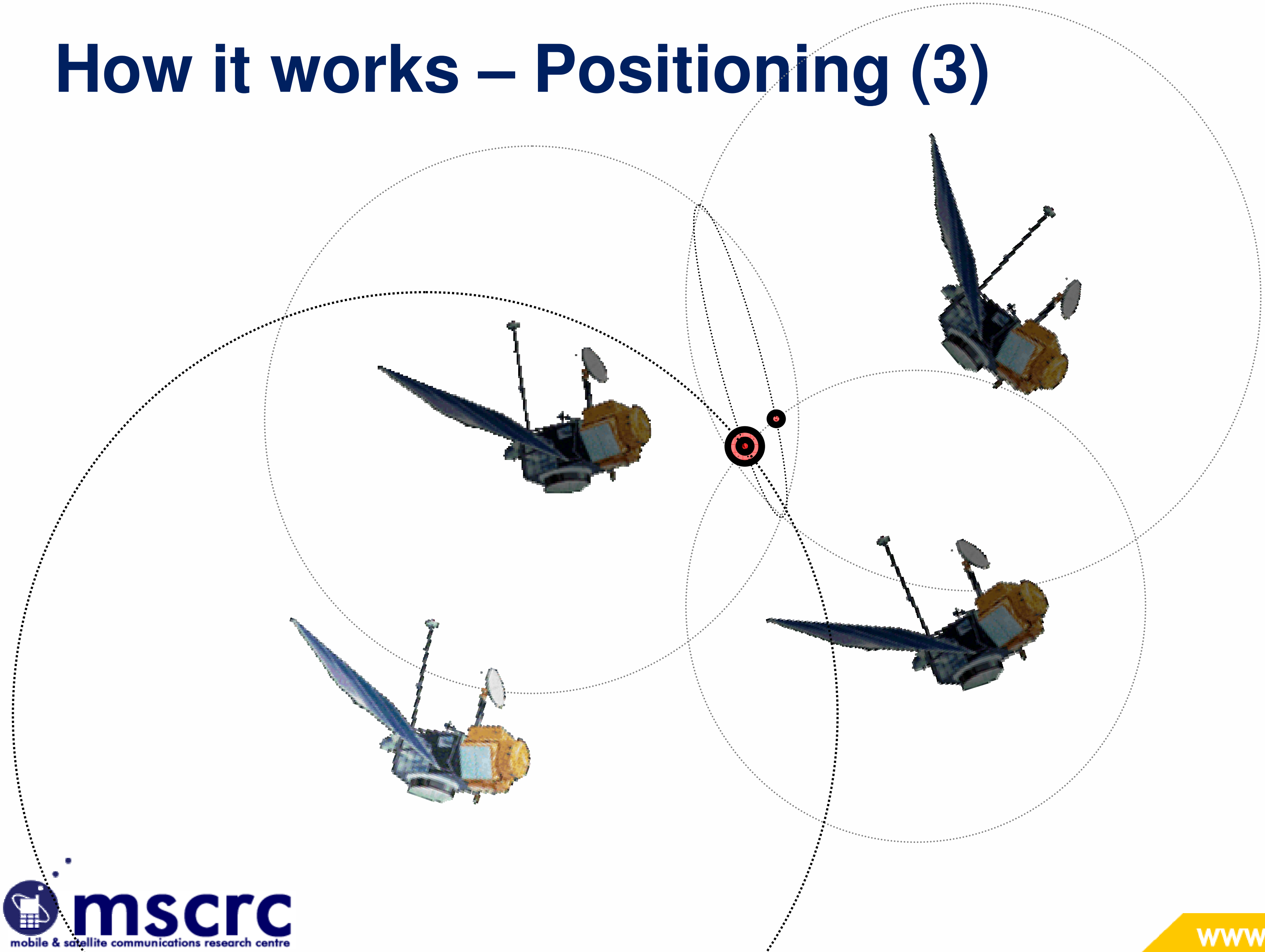
How it works – Positioning (1)



How it works – Positioning (2)

- There are two possible locations
- One is practically impossible, so it can be ruled out
  - Too far away from Earth (too high)
  - Velocity is not realistic
- Still, we need a fourth satellite
  - Confirm this location
  - Give altitude measurement
  - Improve accuracy

How it works – Positioning (3)



GPS Satellite Requirements

- Each satellite must be uniquely identified
- Satellites must know their exact position
- Satellites must know the exact time
  - 2 rubidium & 2 cesium atomic clocks
  - At least once every 4 hours, it synchronizes position and time with a Monitoring Station (MS)

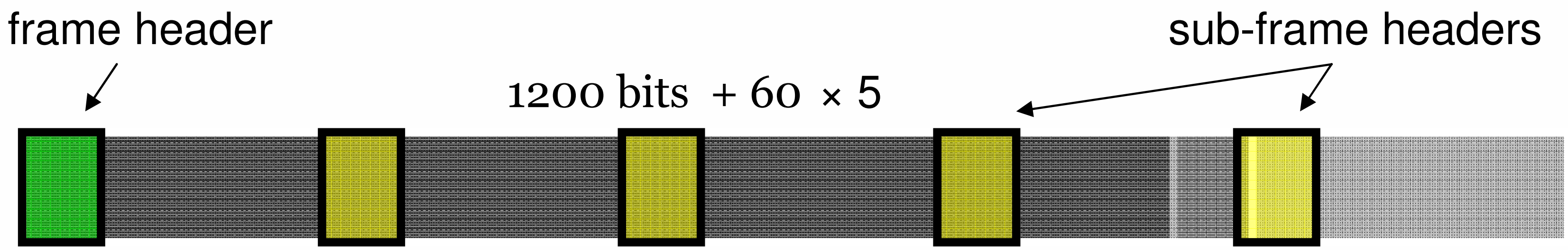
GPS Receiver

- The receiver has a simple digital clock
- It doesn't have to be spot-on
- It just has to get the travel time of each satellite's signal relative to each other
- But this means we do need a fourth satellite

GPS Broadcast

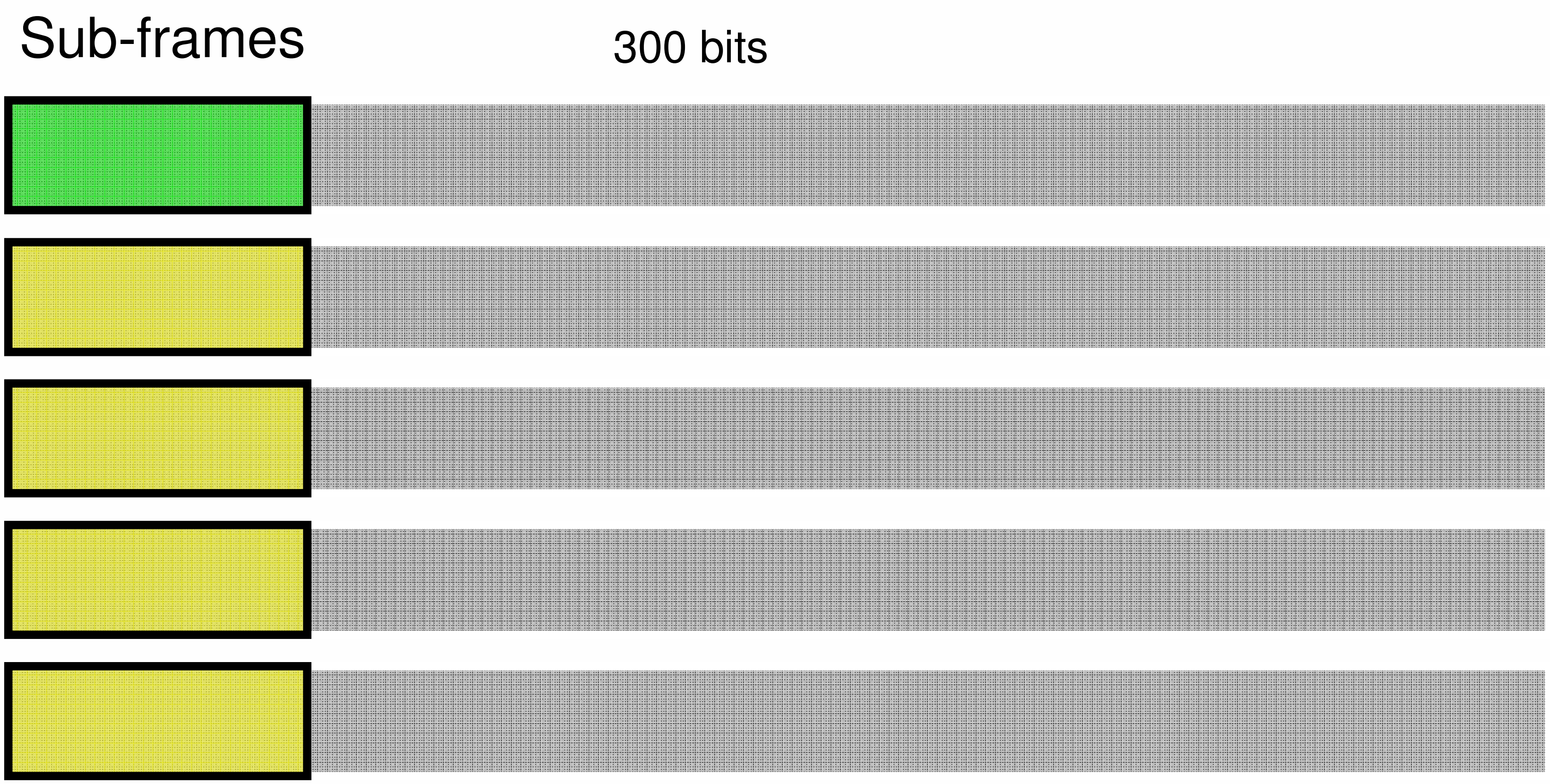
- Satellites broadcast over two reserved frequencies
  - L1 frequency, at 1575.42 MHz, used for civil & military receivers
  - L2 frequency, at 1227.6 MHz, used for military only
- L1 carries a coarse acquisition code, C/A code, which can be identified by civil receivers
- L1 & L2 carry a precise code, P code, which can only be identified by the U.S. military

Content of the Broadcast



- We need to send, say, 1200 bits of data
- The beginning of each frame must be identifiable
- A receiver shouldn't have to wait until the next broadcast to join

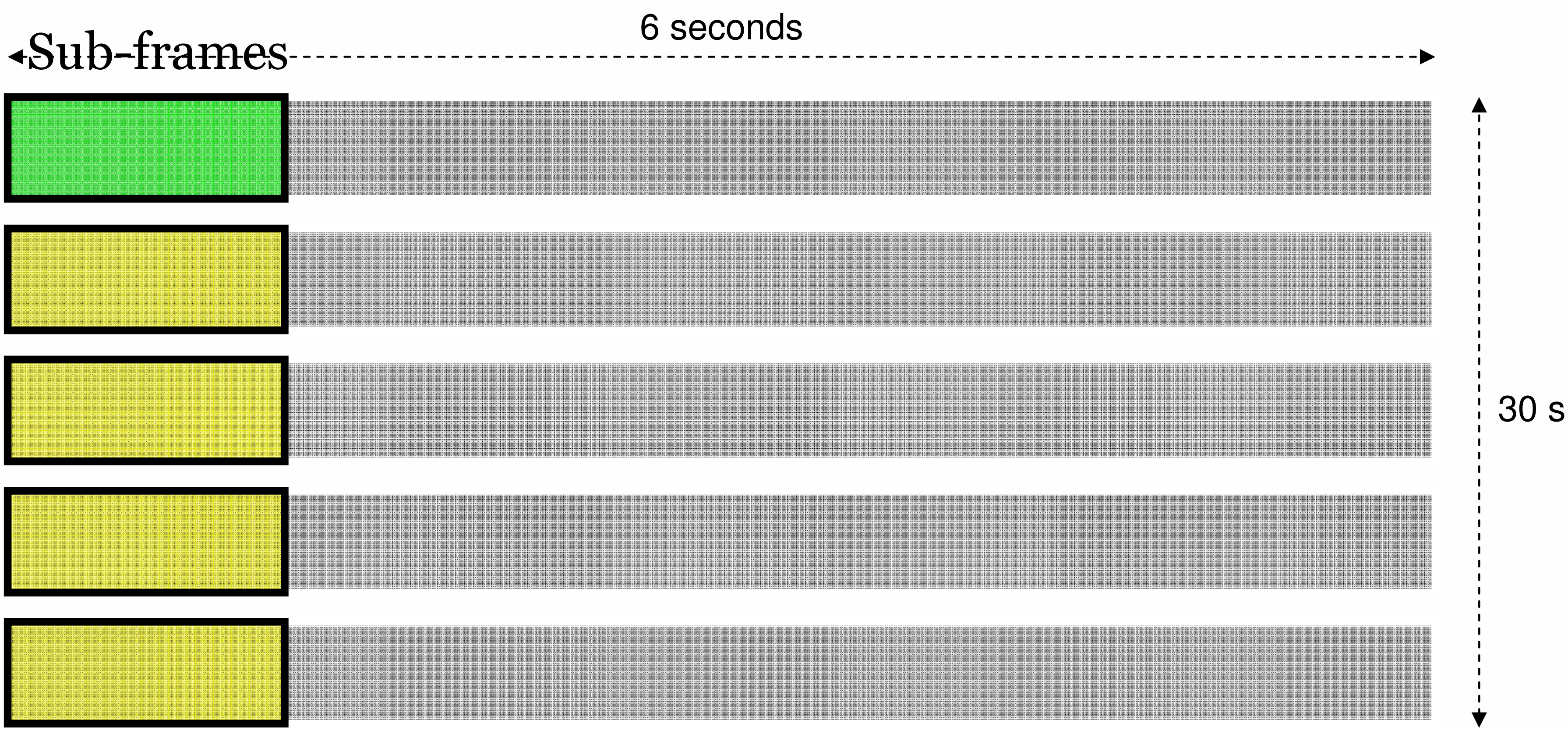
Content of the Broadcast



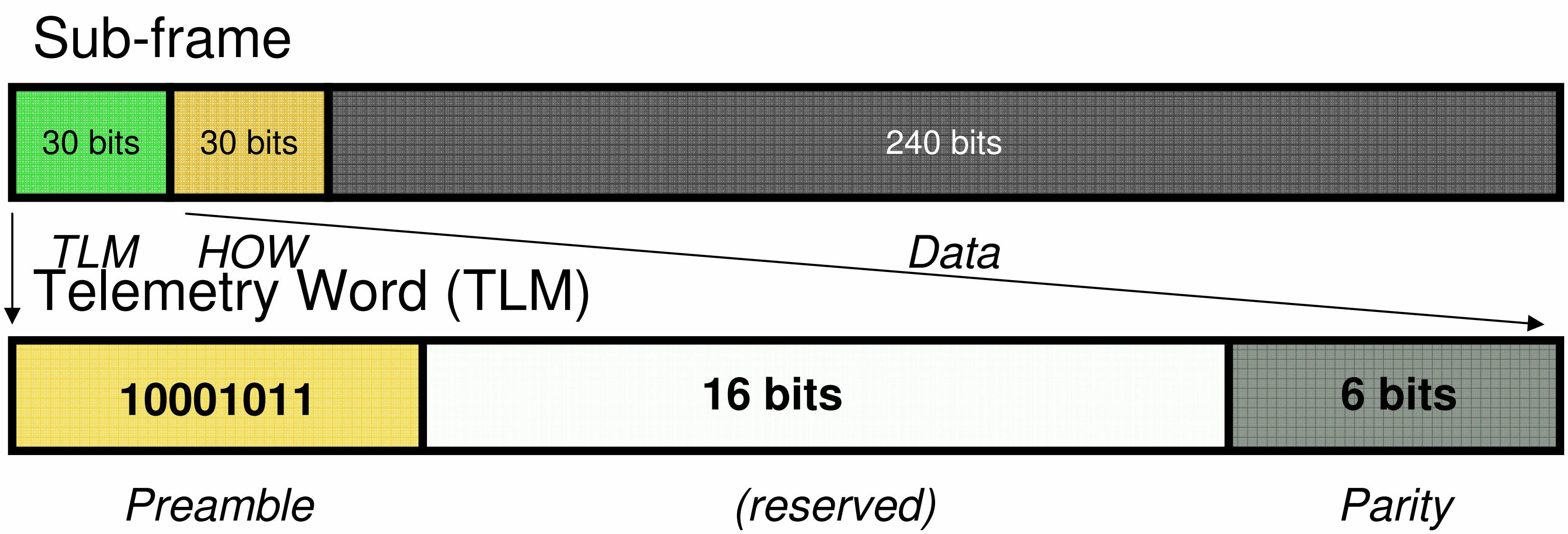
Content of the Broadcast

- The Navigation Message is transmitted over the L1 frequency
- The message is carried at exactly 50 Hz
  - That's 50 bits per second
- To send a sub-frame of 300 bits, it takes precisely 6 seconds
- So a frame is repeated every 30 seconds

Content of the Broadcast

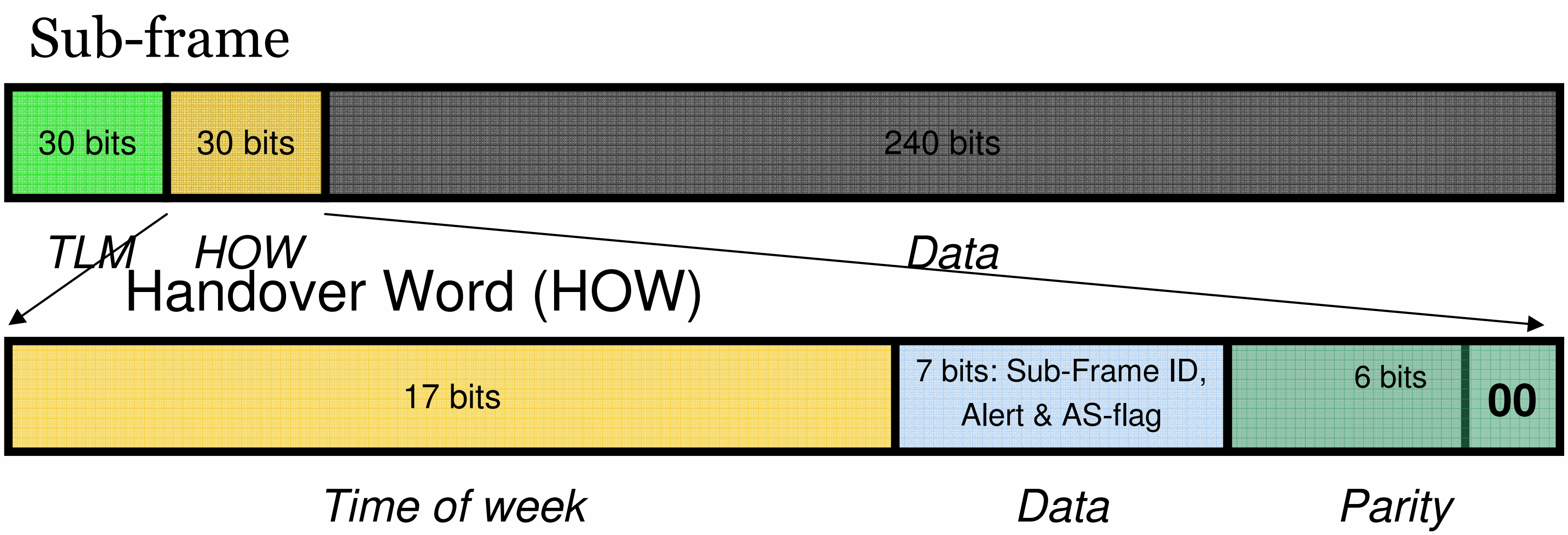


Content of the Broadcast



- Telemetry Word states the beginning of the sub-frame, 1st stage of recognitions for receiver
- Contains reserved information
- Ending with 6 bits parity

Content of the Broadcast

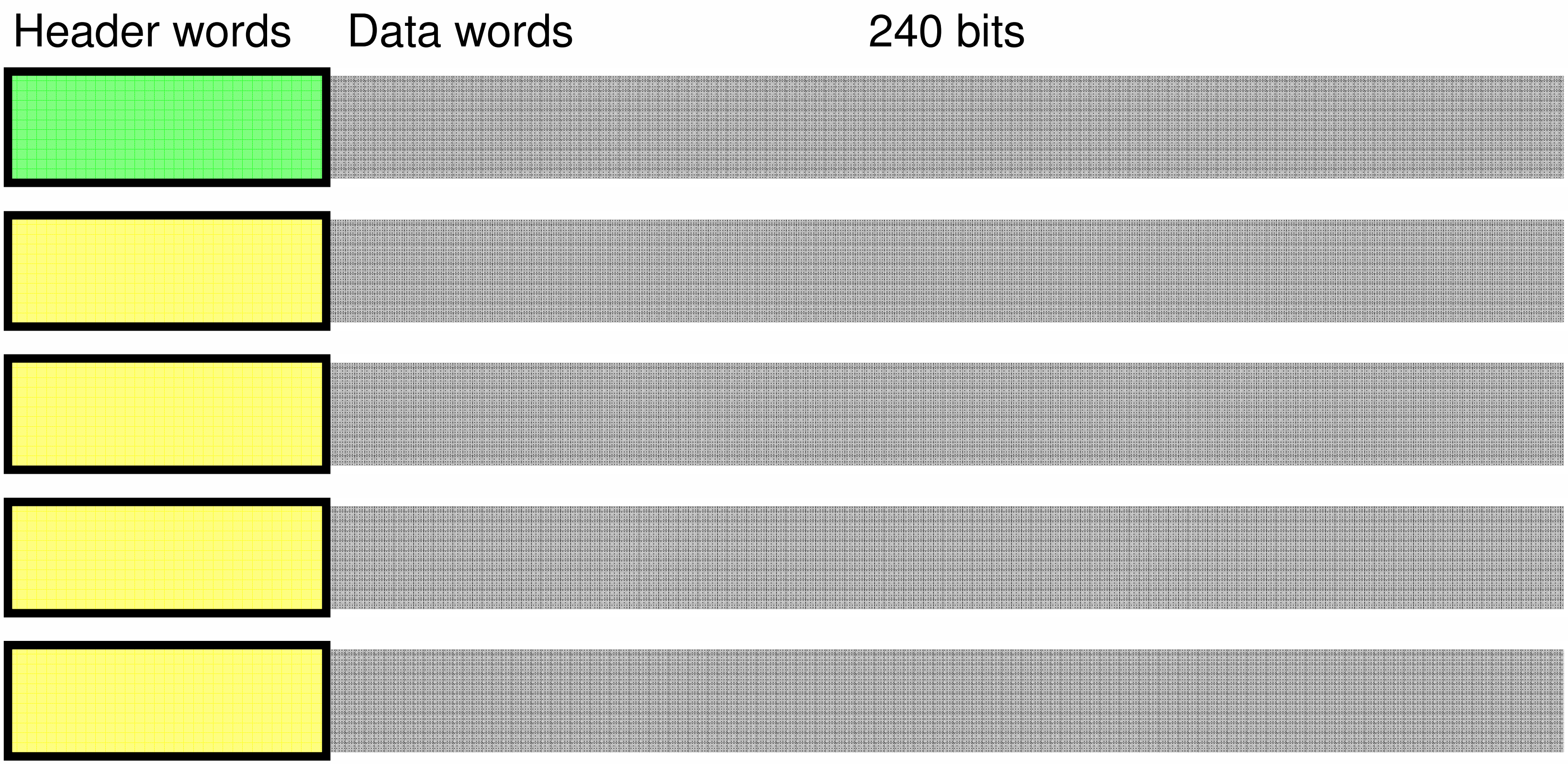


- Handover Word states the time of week: the first significant data the Rx can use
- Also states the current sub-frame
- Alert flag: tells receiver if of possible inaccuracy

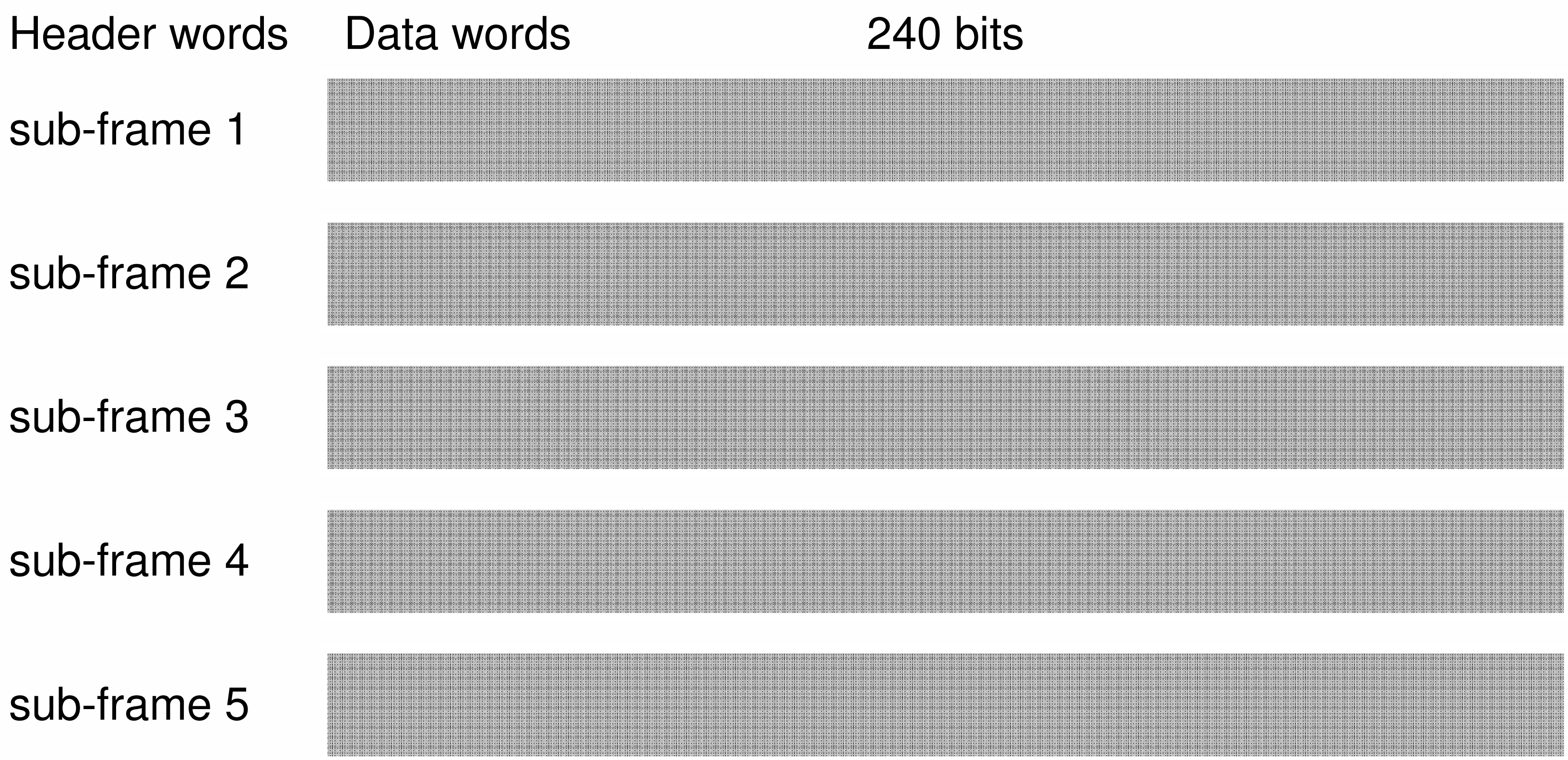
Reception of the Broadcast

- Acquire lock on frequency
- Search for the preamble
- Collect the following 16 bits of reserved data from TLM & check it with the parity
- Gather all the data from the HOW and check the parity again
- Identify the current sub-frame and start gathering data after HOW's two 0-bits

GPS Data in the Broadcast



GPS Data in the Broadcast



GPS Data in the Broadcast

Header words	Data words	240 bits
sub-frame 1	Satellite clock & health data	
sub-frame 2	Satellite ephemeris (position) data	
sub-frame 3		
sub-frame 4	Support data to be sent to Monitoring Station over 25 looping pages	
sub-frame 5		

GPS Data in the Broadcast

Header words	Data words	240 bits
sub-frame 1	Satellite clock & health data	
sub-frame 2	Satellite ephemeris (position) data	
sub-frame 3		

- Every sub-frame is split up in 10 words
  (word = block of 30-bits)
- The data is in words 3-10
  $8 \times 30 = 240$ bits

GPS Data in the Broadcast

- Receiver can use this data (sub-frames 1 – 3) to pinpoint his relative location to particular satellite – because it knows
  - Time elapsed to send signal
  - Position of that satellite at the time the broadcast was sent
- Where the other satellites are
- Receiver now only needs to calculate the time from the other three satellites – put the satellite in a pseudo range
  - This can happen at the same time!

GPS Applications

- Location - "where am I?"
- Navigation - "where am I going?"
  - Process of getting something from one location to another
- Tracking
  - Process of monitoring it as it moves along
- Mapping – "where is everything else?"
- Timing
  - Bringing precise timing to the world

GPS Limitations

- The chosen microwave-frequencies are highly sensitive
- They can't even pass through thin foliage!
- This means reduced service
  - Worse coverage
  - "Multi-path": Range errors by signal bounce
- During wartime, the U.S. reduces accuracy or even shuts down civil GPS

GLONASS

GLONASS

- USSR now Russian operated system
  - ГЛОНАСС - ГЛОбальная НАвигационная Спутниковая Система
  - translated: GLObal'naya NAvigatsionnaya Sputnikovaya Sistema
  - English: Global Navigation Satellite System
- Development began 1976
  - Goal of full coverage by 1991

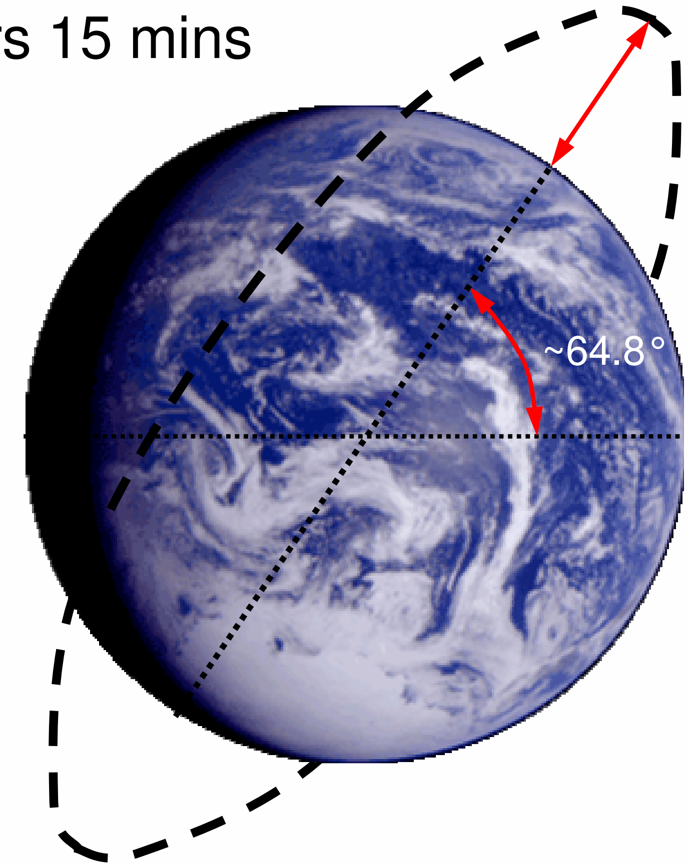
GLONASS Satellites

- First satellites launched 12 October 1982
- Partial operation from 1991
- Constellation of 21 operating satellites (+ 3 on-orbit spares) in three orbital planes completed in 1995
- Satellites:

Satellite	Number	Dates	Design/Average Lifetime
Block IIa	6	1986-1988	16 months
Block IIb	6 (12 launched)	1987	2 years/22 months
Block IIv	25	1988-2000	3 years (1 later launch made 68 months)
Uragan-M	8 (14 planned)	2001-	7 years
Uragan-K		2008-	10-12 years

GLONASS Configuration

Orbital period of ~11 hrs 15 mins



×3 planes

Planes separated by 120° and have latitude separation of 15°

GLONASS Decay

- Fell into disrepair after collapse of Russian economy
  - Constellation completed in December 1995
  - Only partial coverage currently due to lifetime of original Block II satellites
  - 8 satellites in operation at start of 2002

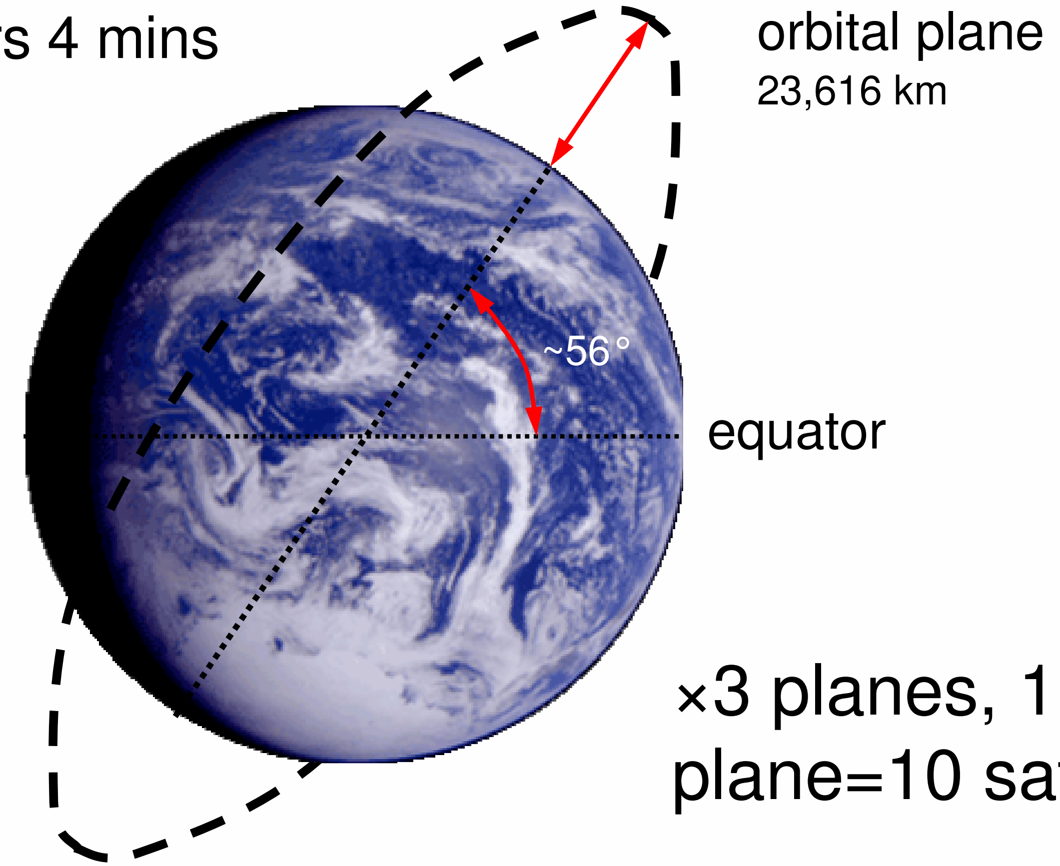
GLONASS Current Status

- In August 2001 decision made to restore system
  - Aim of continuous global coverage by 2011
  - Co-operation with Indians (ISRO) from 2004
  - 8 satellites launched in 2007 with aim of restoring coverage by 2009
  - Some discussion with USA & EU over interoperability with GPS & Galileo
- See GLONASS official website

Galileo

Galileo Configuration

Orbital period of ~14 hrs 4 mins



×3 planes, 1 plane=10 satellites

- 27 actives satellites, 3 spare satellites

Galileo Concept

- See Galileo Concept Video
- Four navigation services and one Search and Rescue service
- Six different navigation signals
- Three carrier frequencies (L2, L2 & L5)
- Better performance than other satellite navigation systems
- Compatibility and interoperability with other satellite navigation systems

Galileo Services (1)

- Open Service
  - Free of user charge
- Safety of Life Service
  - OS with timely warnings of integrity problems
- Commercial Service
  - Two additional signals improve accuracy
- Public Regulated Service
  - Two additional signals for high continuity

Galileo Services (2)

- Search and Rescue Service
  - Finds a beacon broadcasting a distress signal
  - Broadcasts the distress signal and beacon location globally

Competition

Competition GPS against Galileo (1)

- The U.S. disliked the upcoming competitor Galileo
- Such accuracy poses a threat to the U.S. military
- GPS III (announced in 2000), currently in development, will match or surpass Galileo's accuracy
  - Adds new civilian capability – interoperable with Galileo – as well as military
  - New safety of life service
  - Intended to be fully operational by 2013

Competition GPS against Galileo (2)

- The EU wants to be more than the consumer and partner in the background
- The EU dislikes the U.S.'s reduced accuracy policy
- They want to improve the existing service
- They want fully civil satellite navigation
- They want to have a guarantee that the service is always available

Cooperation

Cooperation GPS & Galileo (1)

- Political issues put aside, GPS and Galileo will cooperate
- Galileo will complement the existing GPS in accuracy and availability
- However, Galileo will also be able to run independently

Cooperation GPS & Galileo (2)

- All the satellites will be able to communicate with each other
- Existing GPS-receivers will be able to make use of Galileo

Prospective

Prospective

- Galileo was originally planned to be fully active in 2008
  - Now looking at 2010 and beyond due to funding problems etc.
- Improved signal strength
  - Global positioning within buildings
  - Major improvements within cities
- "Always functioning" guarantee
  - Aircraft might be allowed official usage
- Improved service
  - Improved performance for existing uses
  - New uses

Home Work

Homework

- Understand and summarise
  - "GPS pseudo Range"

Interesting Links/Articles

- Mobile Phone Navigation for Blind People
  - http://mobileactive.org/new-seeing-eye-dog-mobil
  - http://www.themobiblog.com/2007/11/seeing-eye-dog-mobile-phone.html
  - http://www.sciencedaily.com/videos/2007/0207-helping_the_blind_see.htm
- GPS tutorial
  - http://www.trimble.com/gps/index.shtml
  - http://www.colorado.edu/geography/gcraft/notes/gps/gps_f.html