Earth Science Applications of Space Based Geodesy

DES-7355

Tu-Th 9:40-11:05

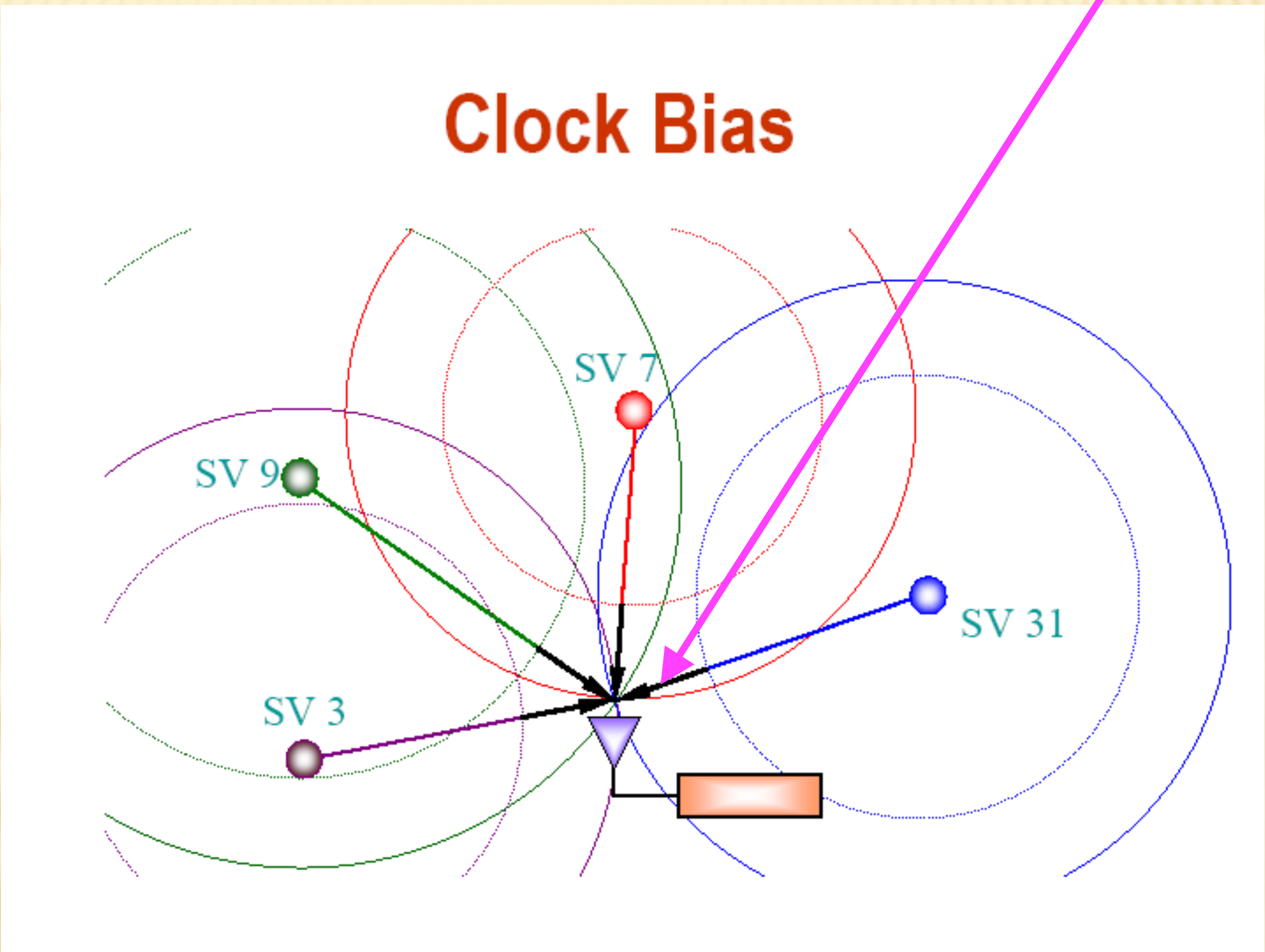
Seminar Room in 3892 Central Ave. (Long building)

Bob Smalley
Office: 3892 Central Ave, Room 103
678-4929
Office Hours – Wed 14:00-16:00 or if I'm in my office.

http://www.ceri.memphis.edu/people/smalley/ESCI7355/ESCI_7355_Applications_of_Space_Based_Geodesy.html

Class 5

Fourth satellite allows calculation of clock bias



http://www.unav-micro.com/about_gps.htm

step 3: getting perfect timing

now that we have precise clocks…
…how do we know when the signals left the satellite?

this is where the designers of GPS were clever…
…synchronize satellite and receiver so
they are generating same code at same time

We will look at this in more detail later

Mattioli-http://comp.uark.edu/~mattioli/geol_4733.html and Trimble

finally…

step 4: knowing where a satellite is in space

Satellites in known orbits

Orbits programmed into receivers

Satellites constantly monitored by DoD
…identify errors (ephemeris errors) in orbits
…usually minor

Corrections relayed back to satellite

Satellite transmits

Mattioli-http://comp.uark.edu/~mattioli/geol_4733.html and Trimble

step 4: knowing where a satellite is in space

Orbital data (ephemeris) is embedded in the satellite data message

Ephemeris data contains parameters that describe the elliptical path of the satellite

Receiver uses this data to calculate the position of the satellite (x,y,z)

http://www.unav-micro.com/about_gps.htm

Need 6 terms to define shape and orientation of ellipse

a – semi major axis

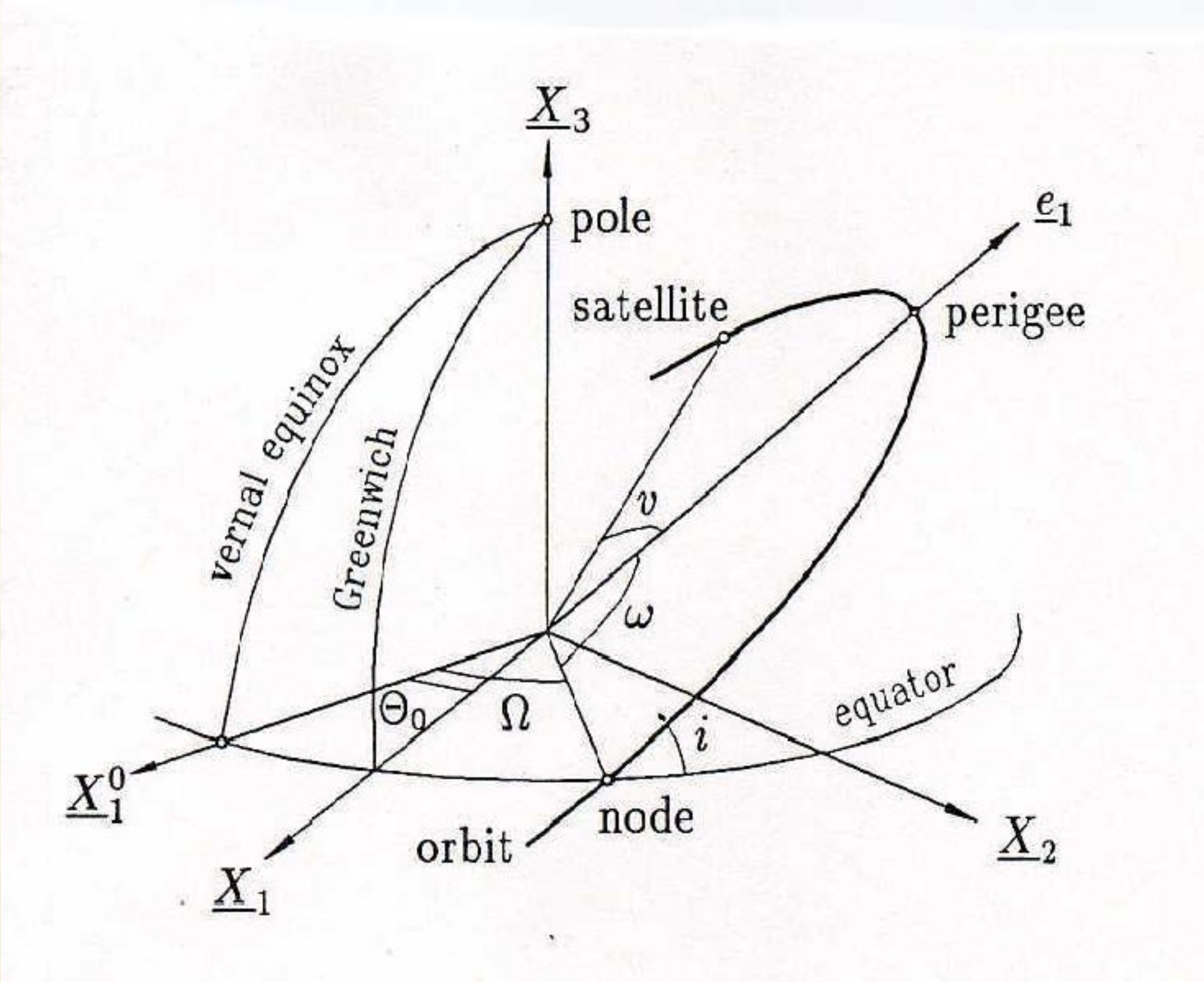
e – ecentricity

Ω – longitude ascending node

i – inclination

ω – argument of perigee

ν – true anomaly



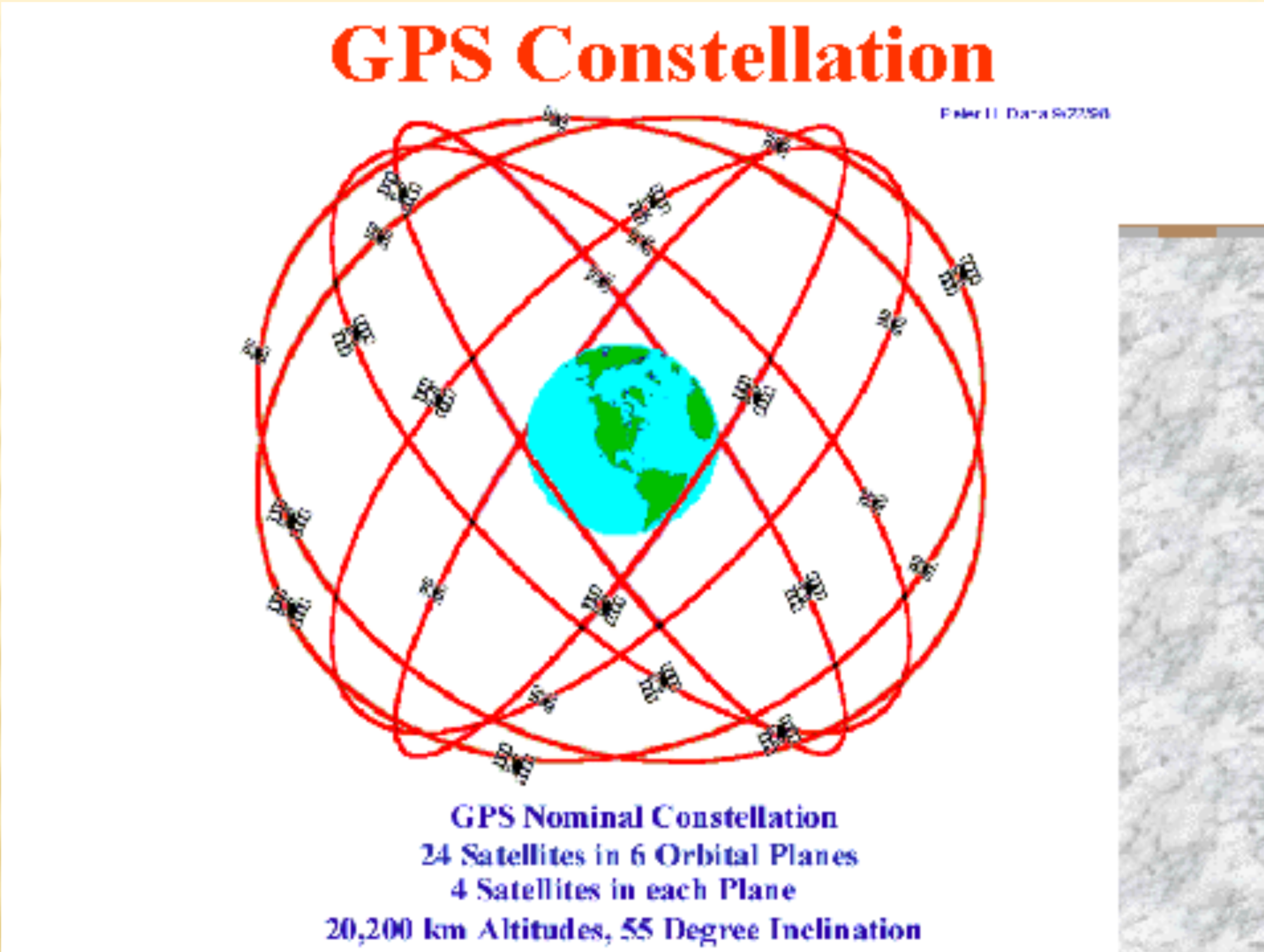
http://www.colorado.edu/engineering/ASEN/asen5090/asen5090.html

step 5: identifying errors

Will do later

THE GPS CONSTELLATION

- 24 operational space vehicles ("SV's")
  - 6 orbit planes, 4 SV's/Plane
  - Plus at least 3 in-orbit spares
- Orbit characteristics:
  - Altitude: 20,180 km (SMA = 26558 km)
  - Inclination: 55°



Simulation: GPS and GLONASS Simulation

A. Ganse, U. Washington , http://staff.washington.edu/aganse/

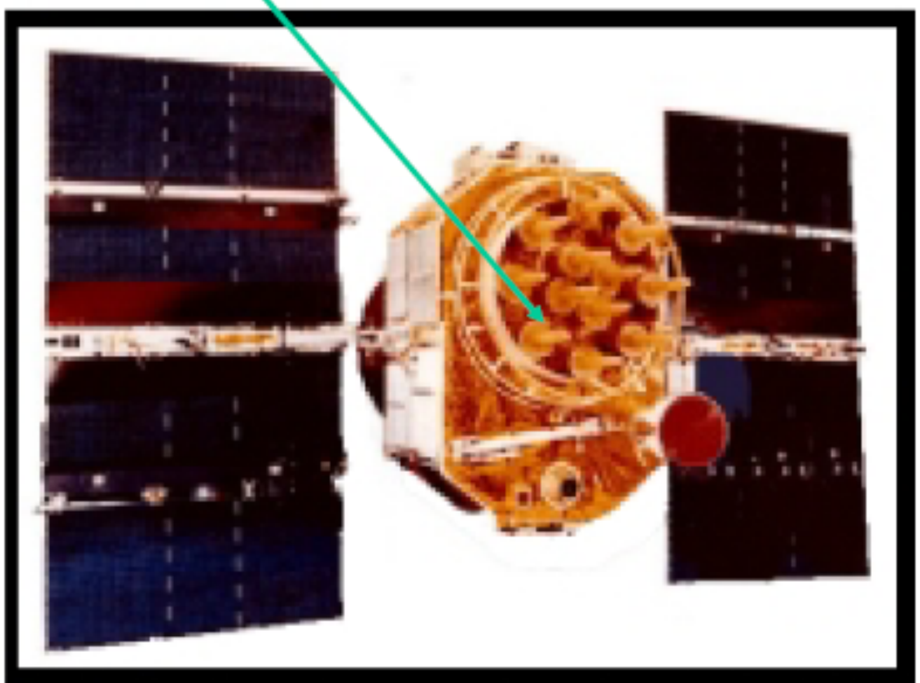
THE GPS CONSTELLATION

- More Orbit characteristics:
  - Eccentriciy: < 0.02 (nominally circular)
  - Nodal Regression: -0.004°/day (westward)
- The altitude results in an orbital period of 12 sidereal hours, thus SV's perform full revs 2/day.
- Period and regression lead to *repeating ground tracks*, i.e. each SV covers same "swath" on earth ~ 1/day.

A. Ganse, U. Washington , http://staff.washington.edu/aganse/

Navstar Satellite

Antenna Array



Block IIA Satellite

- **Block I** - Initial evaluation
  - 845 kg / 4.5 year design life
  - Launched 1978 - 85
- **Block II** - 63° to 55° inclination
  - Weight ~ 1500 kg / 7.5yrs
  - Restricted signals
- **Block IIA** - Advanced satellites (minor improvements)
- **Block IIR** - "Replenishment"
  - 2000 kg / 7.8 year life
  - Designed to operate for 14 days without ground contact
  - Can range and cross-link between themselves

From J. HOW, MIT

GPS VISIBILITY

- GPS constellation is such that between 5 and 8 SV's are visible from any point on earth
- Each SV tracked by a receiver is assigned a *channel*
- Good receivers are > 4-channel (track more than 4 SV's)
  - Often as many as 12-channels in good receivers
  - Extra SV's enable smooth handoffs & better solutions

GPS VISIBILITY

- Which SV's are used for a solution is a function of geometry
  - *GDOP*: Geometric Dilution of Precision
    - Magnification of errors due to poor user/SV geometry
  - Good receivers compute GDOP and choose "best" SV's

TIMING

- Accuracy of position is only as good as your clock
  - To know where you are, you must know when you are
  - Receiver clock must match SV clock to compute delta-T

TIMING

- SVs carry atomic oscillators (2 rubidium, 2 cesium each)
  - Not practical for hand-held receiver

TIMING

- Accumulated drift of receiver clock is called clock *bias*
- The erroneously measured range is called a *pseudorange*
- To eliminate the bias, a 4^{th} SV is tracked
  - 4 equations, 4 unknowns
  - Solution now generates X,Y,Z and b
- If Doppler also tracked, Velocity can be computed

GPS Time

GPS time is referenced to 6 January 1980, 00:00:00

GPS uses a week/time-into-week format

Jan 6 = First Sunday in 1980

GPS Time

GPS satellite clocks are essentially synched to *International Atomic Time (TAI)* (and therefore to UTC)

Ensemble of atomic clocks which provide international timing standards.

TAI is the basis for Coordinated Universal Time (UTC), used for most civil timekeeping

GPS time = TAI – 15s
Since 15 positive leap seconds since 1/6/1980

GPS Time

GPS time is different than GMT because GMT is continuously adjusted for Earth rotation and translation charges with respect to the sun and other celestial reference bodies.

GPS time shifts with respect to UTC as UTCis adjusted using positive or negative "leap" seconds to accommodate earth's slowing, etc.

GPS time is not adjusted for celestial phenomena since it is based on the behavior of atomic clocks monitoring the satellite system.

Mod from - A. Ganse, U. Washington , http://staff.washington.edu/aganse/, http://www.eomonline.com/Common/Archives/1996jan/96jan_gps.html

More About Time

GPS system time referenced to Master USNO Clock, but now implements its own "composite clock"

SV clocks good to about 1 part in 10^{13}

Delta between GPS SV time & UTC is included in nav/timing message

A. Ganse, U. Washington , http://staff.washington.edu/aganse/

More About Time

Correction terms permit user to determine UTC to better than 90 nanoseconds (~10^{-7} sec)

The most effective time transfer mechanism anywhere

A. Ganse, U. Washington , http://staff.washington.edu/aganse/

More About Time

Satellite velocity induces special relativistic time dilation of about -7.2 μsec/day

General relativistic gravitational frequency shift causes about 45.6 μsec/day

For a total 38.4 μsec/day

GPS clocks tuned to 10.22999999545 Mhz

(1 μsec -> 300 m, build up 1 μsec in 38 minutes if don't correct!)

A. Ganse, U. Washington , http://staff.washington.edu/aganse/, Klein thesis ch 3

More About Time

The 10-bit GPS-week field in the data "rolled-over" on August 21/22 1999 – some receivers probably failed!

GPS Signals

GPS signals are broadcast on 2 L-band carriers

L1: 1575.42 MHz
Modulated by C/A-code & P-code
(codes covered later)

L2: 1227.6 MHz
Modulated by P-code only

(3rd carrier, L3, used for nuclear explosion detection)

GPS Signals

Most unsophisticated receivers only track L1

If L2 tracked, then the phase difference (L1-L2) can be used to filter out *ionospheric delay*.

This is true even if the receiver cannot decrypt the *P-code* (more later)

L1-only receivers use a simplified correction model

For Signal-Heads Only

Antenna Polarization: RHCP

L1

Center Frequency: 1.57542 GHz

Signal Strength: -160 dBW

Main Lobe Bandwidth: 2.046 MHz

C/A & P-Codes in Phase Quadrature

For Signal-Heads Only

L2

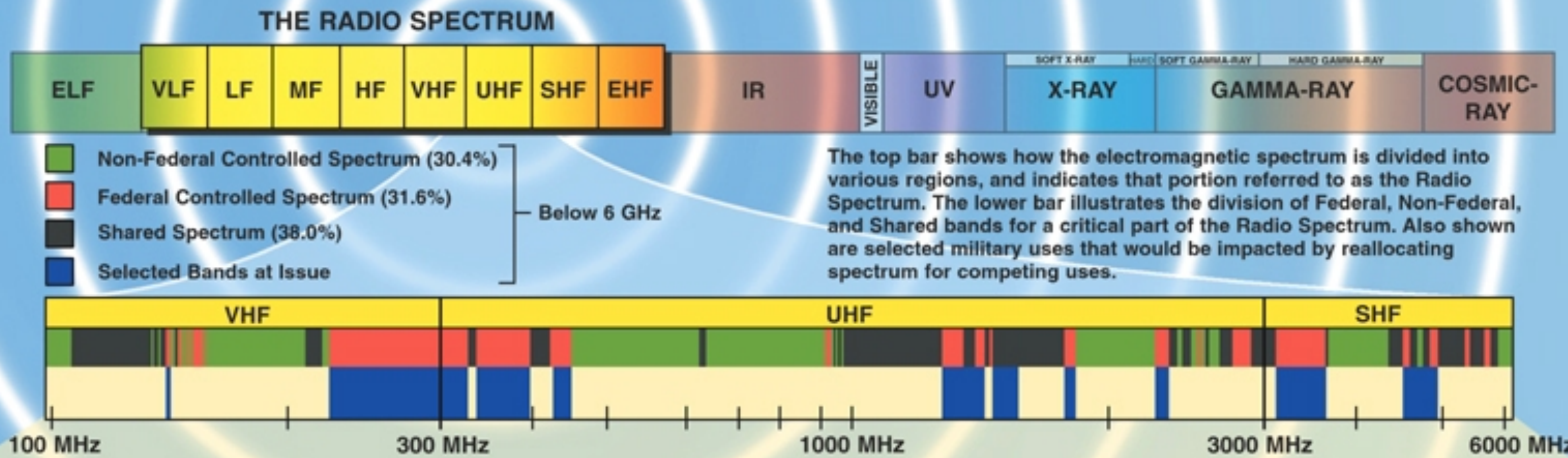
Center Frequency: 1.22760 GHZ

Signal Strength: -166 dBW

Code modulation is Bipolar Phase Shift Key (BPSK)

Total SV Transmitted RF Power ~45 W

Electromagnetic Spectrum



The top bar shows how the electromagnetic spectrum is divided into various regions, and indicates that portion referred to as the Radio Spectrum. The lower bar illustrates the division of Federal, Non-Federal, and Shared bands for a critical part of the Radio Spectrum. Also shown are selected military uses that would be impacted by reallocating spectrum for competing uses.

Selected Bands at Issue

138 - 144 MHz

Military Uses	Competing Uses
Land Mobile Radio	Little LEOs
Tactical Air / Ground / Air	Public Safety

225 - 400 MHz

Military Uses	Competing Uses
Tactical Air / Ground / Air	Little LEOs
Data Links	Public Safety
Satellite Comm	Terrestrial DAB
Military ATC	CMRS
Search & Rescue	Space Research
Executive Comm	
Tactical Comm	

400.15 - 401 MHz

Military Uses	Competing Uses
DMSP (↓)	MSS

420 - 450 MHz

Military Uses	Competing Uses
BM Surveillance and Early Warning Radars	Auxiliary Broadcast
Shipboard / Airborne Early Warning Radars	CMRS
Missile / Air Vehicle Flight Termination	Biomedical Telemetry
Troop Position Location	WLL
Anti-Stealth Radar	MSS
Foliage Penetration Radar	EES (active)

1215 - 1390 MHz

Military Uses	Competing Uses
Long / Medium Range Air Defense	MSS
Radio Navigation	NLMCS
Air Route Surveillance Radars	Wind Profiler Radars
Tactical Communications	
Test Range Support	
Air / Fleet Defense	
Drug Interdiction	
GPS	
Remote Satellite Sensors	
Nuclear Detection	

1435 - 1525 MHz

Military Uses	Competing Uses
Telemetry Supporting Entire Aerospace Industry	DAB / DARS
	MSS
	NLMCS

1755 - 1850 MHz

Military Uses	Competing Uses
DoD Satellite TT&C (↑)	PCS
Point-to Point Microwave	MDS
Air Combat Training Systems	3G Wireless / IMT 2000
Tactical Comm	
Tactical Data Links	

2200 - 2290 MHz

Military Uses	Competing Uses
DoD Satellite TT&C (↓)	PCS
Guided Missile Telemetry	MDS
Point to-Point Microwave	WLL

3100 - 3650 MHz

Military Uses	Competing Uses
High Power Mobile Radars	MDS
Shipboard ATC	WLL
Missile Links	FSS
Airborne Station Keeping	

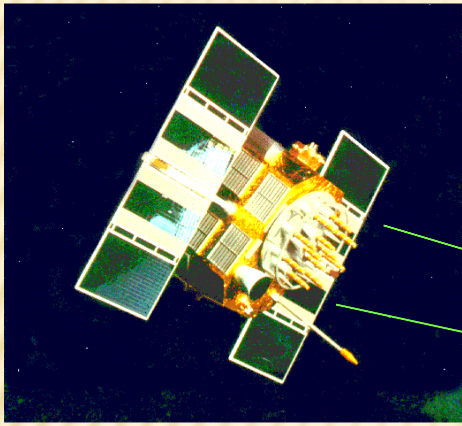
4400 - 4940 MHz

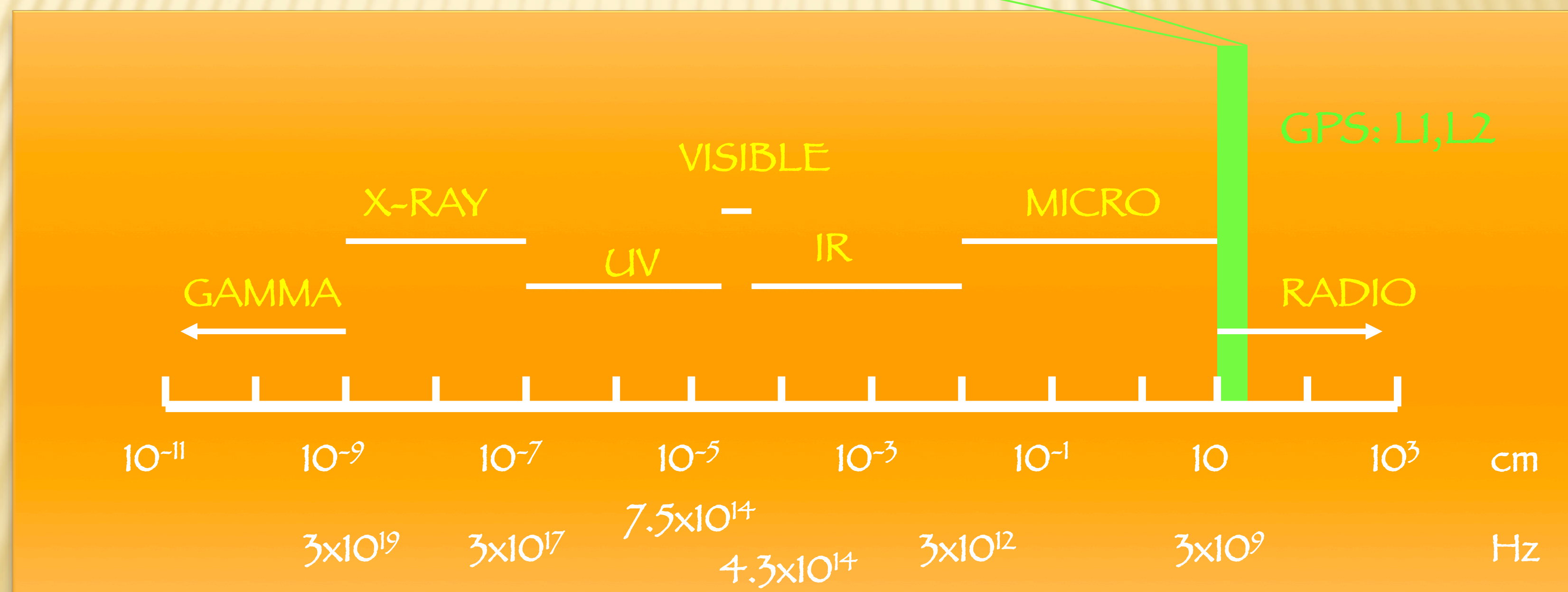
Military Uses	Competing Uses
Fixed Wideband Comm	GWCS
Mobile Wideband Comm	FSS
Command Links	Public Safety
Data Links	

ATC - Air Traffic Control
BM - Ballistic Missile
CMRS - Commercial Mobile Radio Service
DAB - Digital Audio Broadcast - Terrestrial
DARS - Digital Audio Radio Service - Satellite
DMSP - Defense Meteorological Satellite Program
FSS - Fixed Satellite Service
GPS - Global Positioning Satellite
GWCS - General Wireless Communications Service
IMT 2000 - 3rd Generation Mobile Telephony
LEO - Low Earth Orbit
MDS - Multipoint Distribution System
MSS - Mobile Satellite Service
NLMCS - New Land Mobile Communications Service
PCS - Personal Communications Service
TT&C - Tracking, Telemetry and Command
WLL - Wireless Local Loop

DoD Joint Spectrum Center
Annapolis MD 21402-5064 • http://www.jsc.mil

Signal: Electromagnetic Spectrum



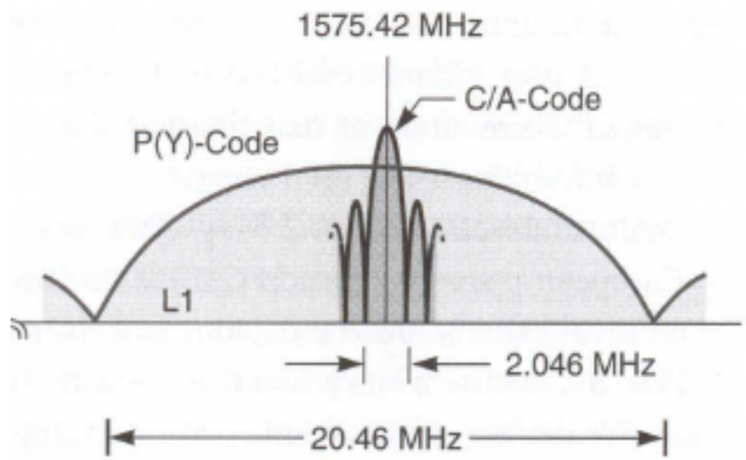


From Ben Brooks

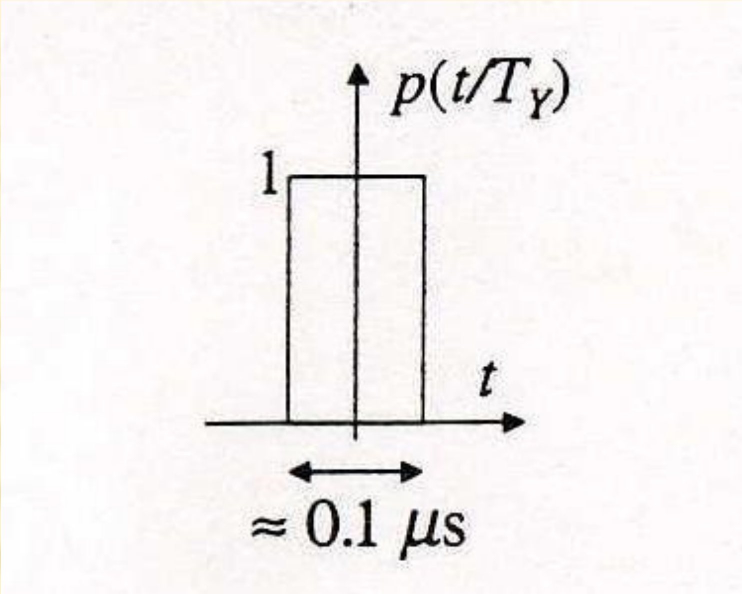
GPS Signal

- L-band carrier frequency was a compromise
  - At higher frequencies, ranging errors due to ionospheric effects reduce, but attenuation of signal power due to distance traveled increases

- GPS was first wide-spread use of spread spectrum technology
  - Code division multiple access (CDMA)
    - Allows multiple transmitters to use same frequency band
  - Adding code has the effect of "spreading" the signal
    - 2MHz (20MHz) band about the carrier at L_1 ~ 1575.42MHz

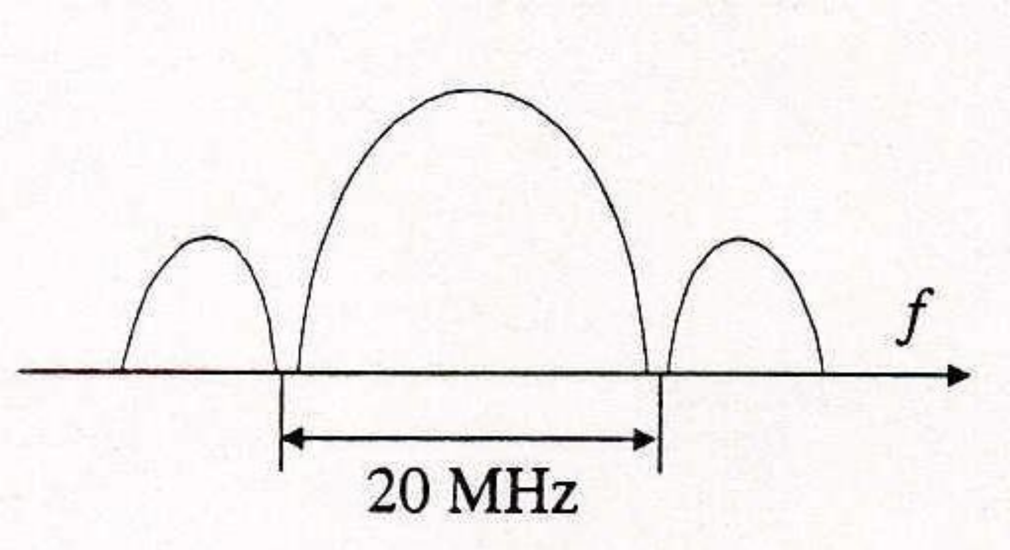


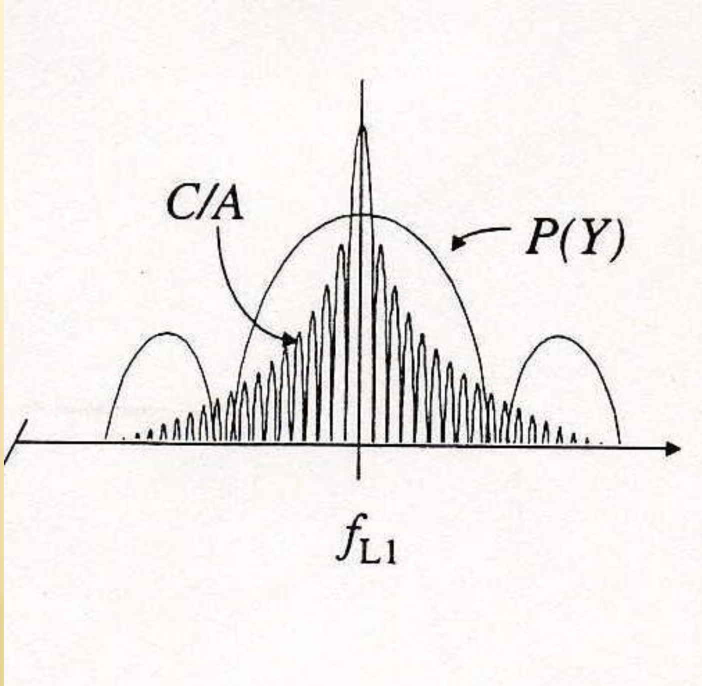
From J. HOW, MIT



Spectra of P and C/A code

(square wave in TD <--> sinc in FD)





http://www.colorado.edu/engineering/ASEN/asen5090/asen5090.html

Direct Sequence Spread Spectrum

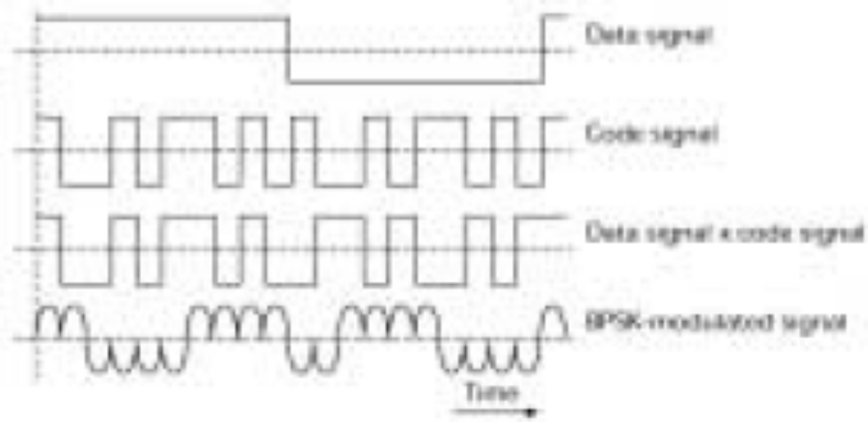


Fig 2: Generation of a DSSS Signal

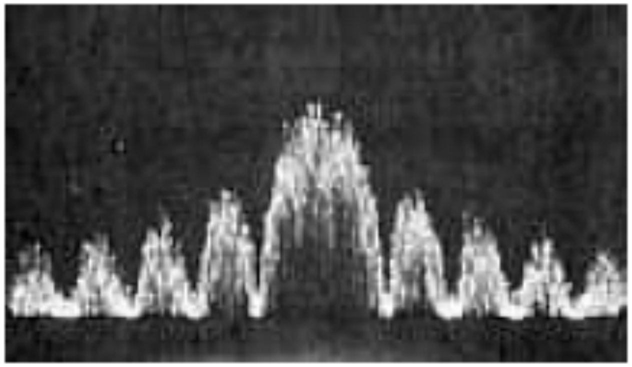


Fig 3: Spectrum of a DSSS Signal

http://www.ieee.org/organizations/history_center/cht_papers/SpreadSpectrum.pdf