GPS Tutorial

Signals and Data

Applications Engineering
u-Nav Microelectronics

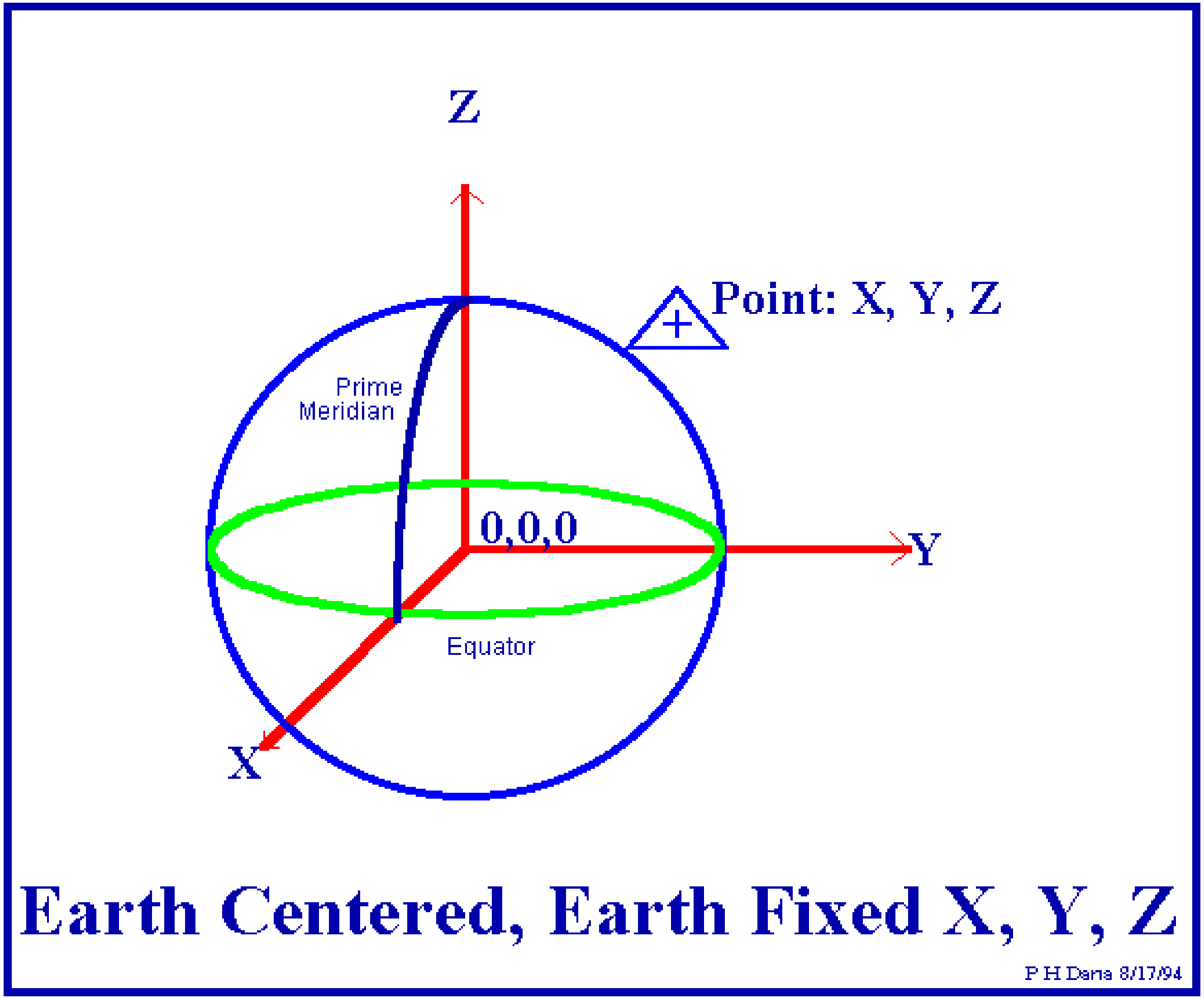
GPS Tutorial

- Geodetic Datum's
- Navigation Message
- Signal Structure
- Error Sources

Geodetic Datums

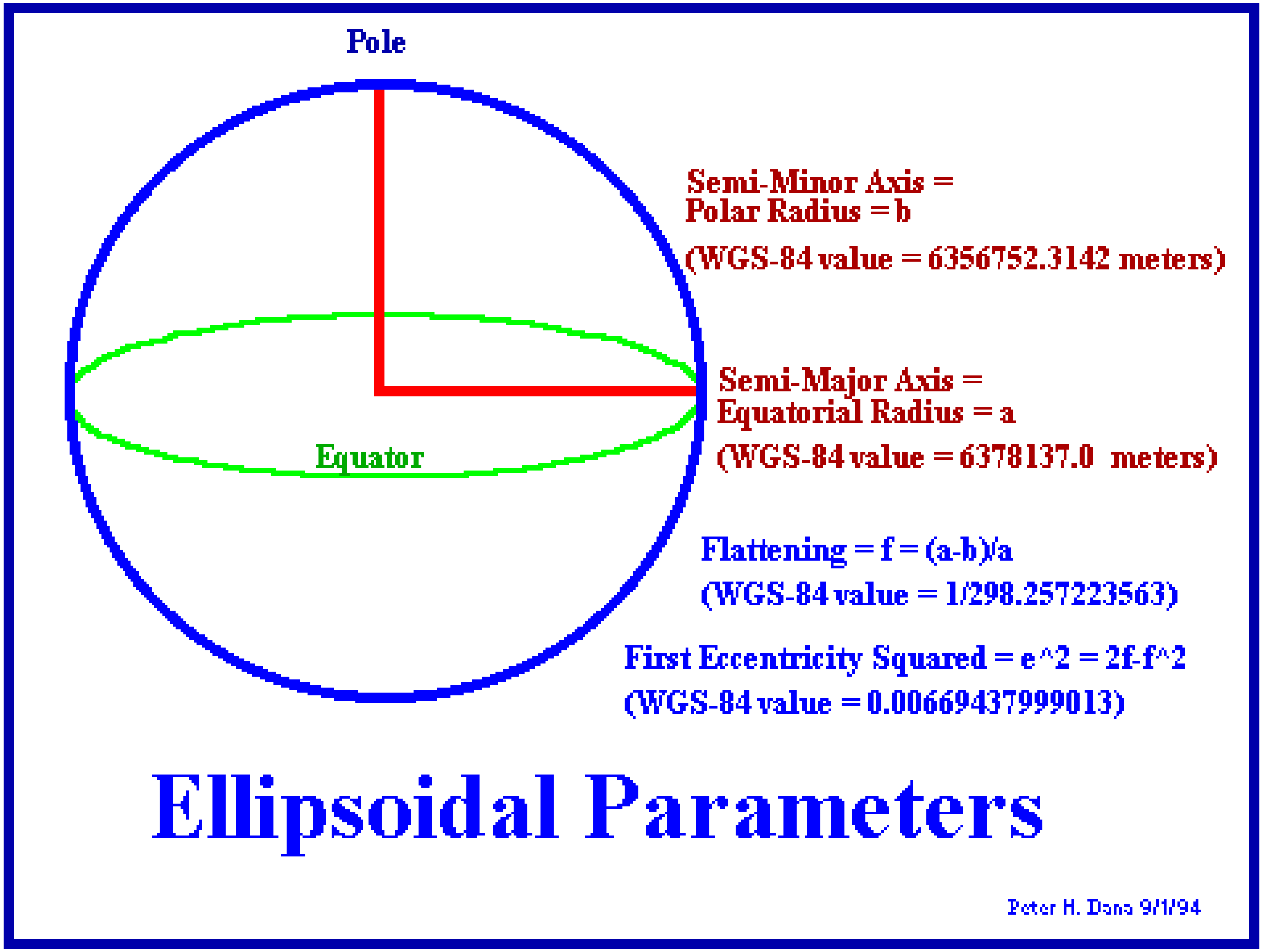
- Define the size and shape of the earth.
- Range from flat earth models to complex descriptions that include gravity and angular momentum.
- Using the wrong geodetic datum will result in position errors.
- Algorithms are used to convert between different datums.

ECEF Model

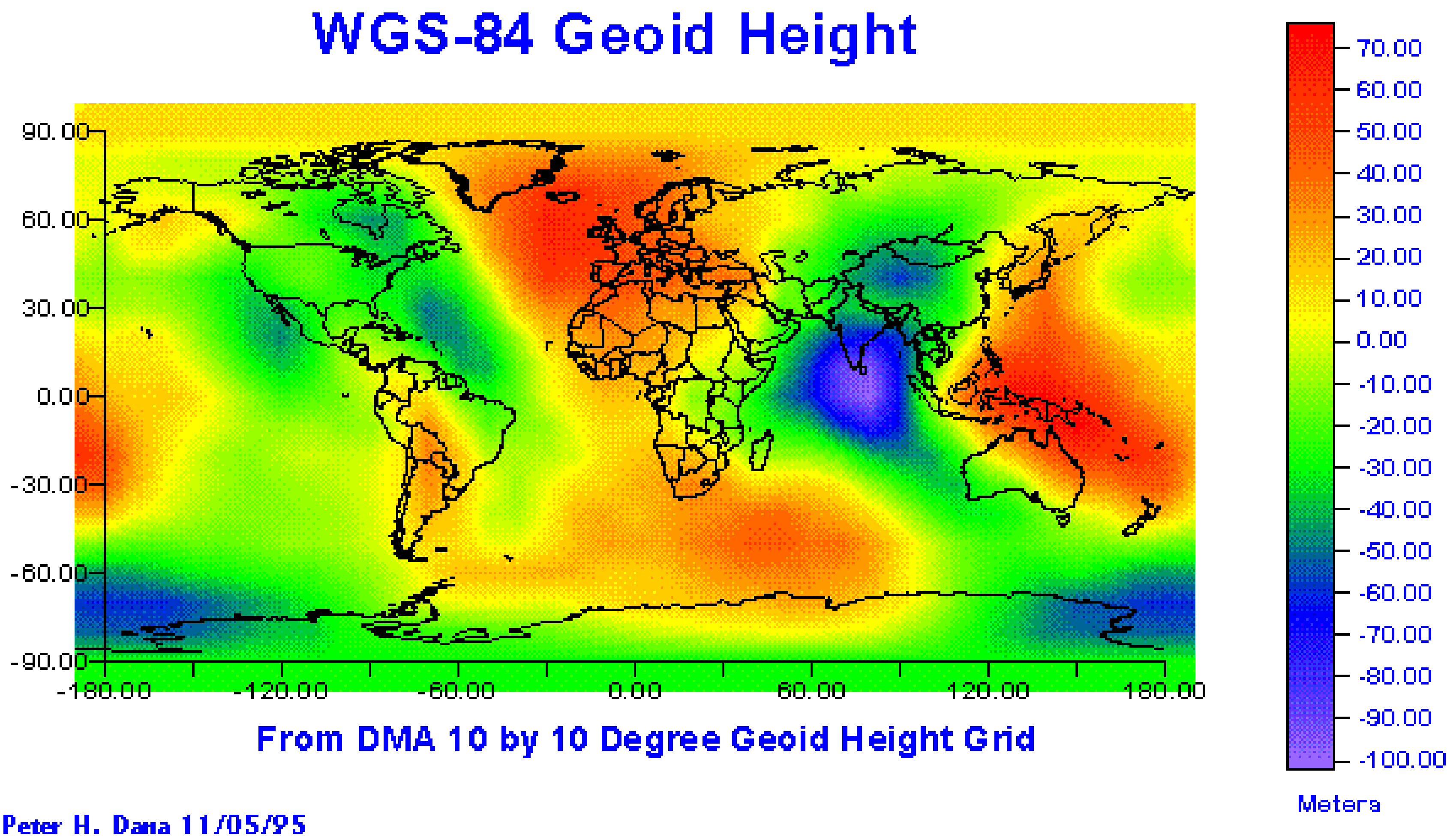


Z
Point: X, Y, Z
Prime
Meridian
0,0,0
Y
Equator
X
Earth Centered, Earth Fixed X, Y, Z
P H Dana 8/17/94

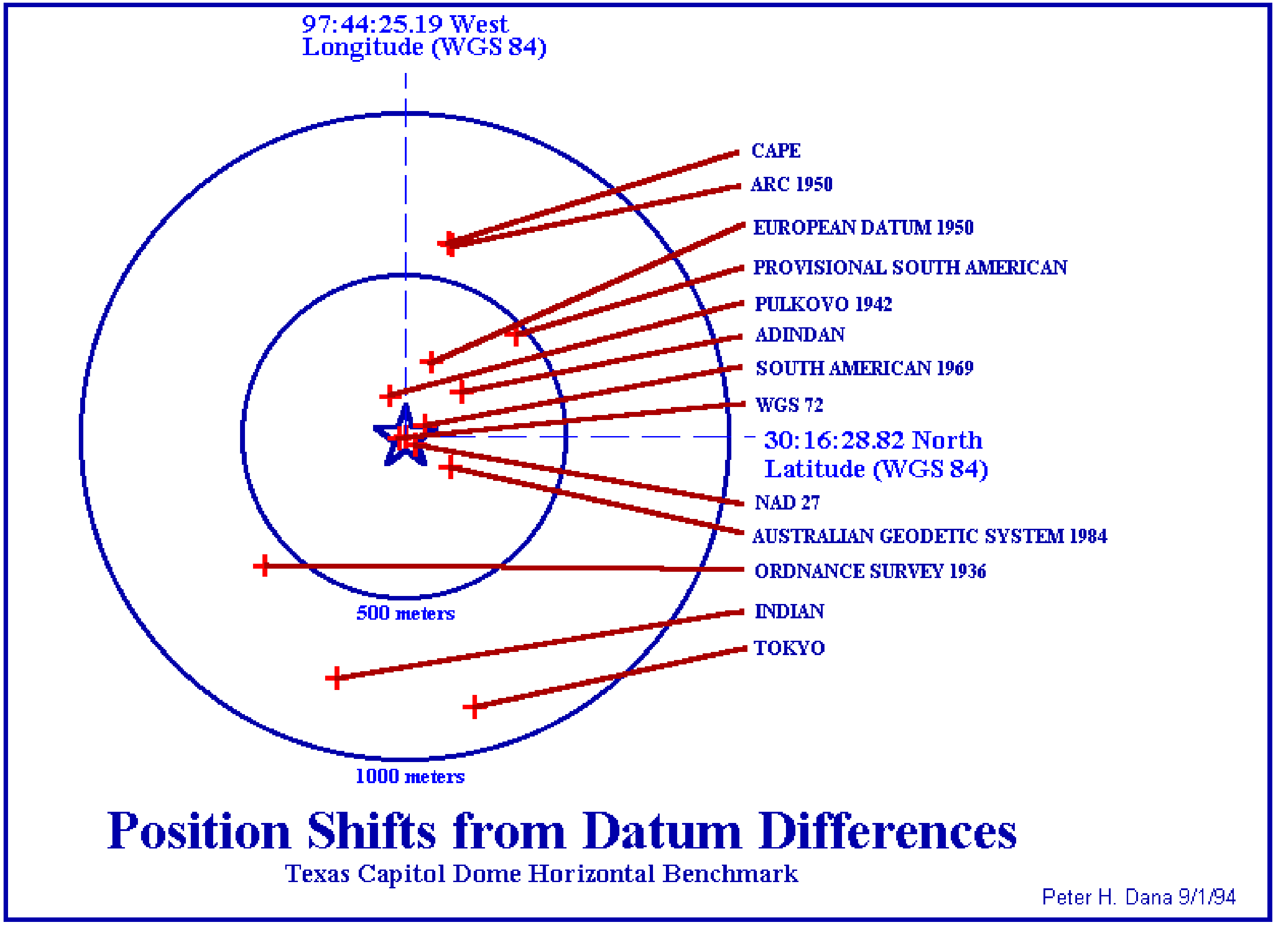
Reference Ellipsoid



WGS-84 Geoid Height



Datum Differences



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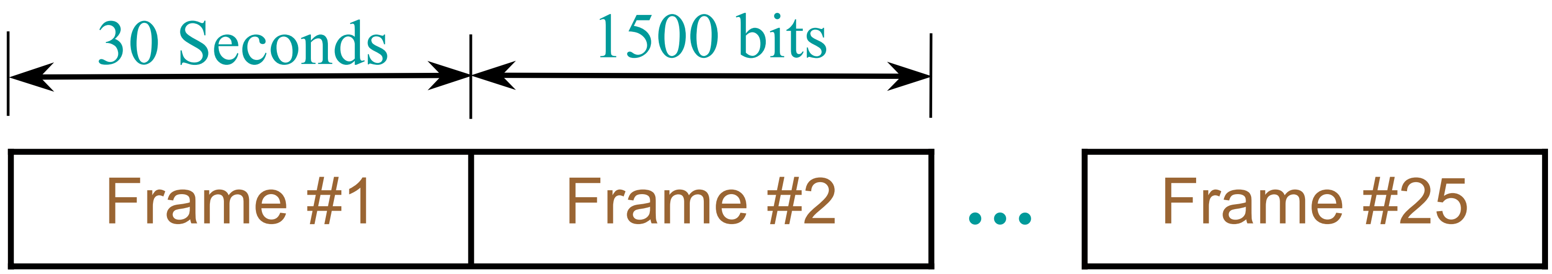
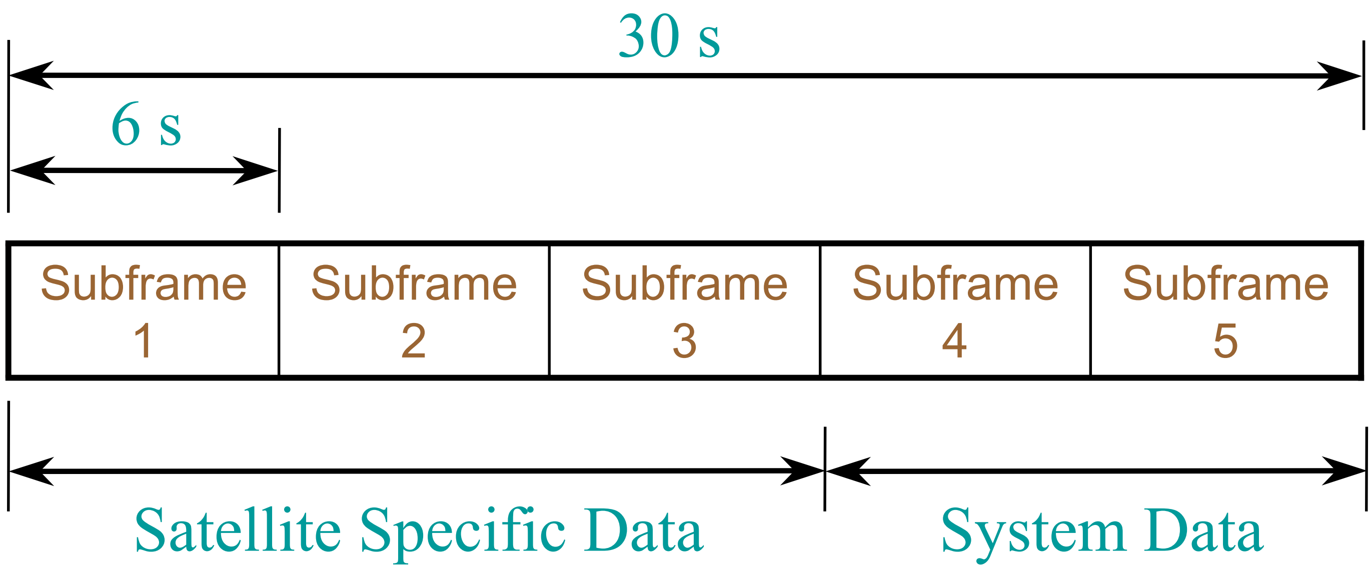
Navigation Message

- The navigation message is a bit stream of ones and zeros with a data rate of 50 Hz.
  - Message is divided into frames.
- Entire message is 25 frames.
  - Each frame has 1500 bits = 30 seconds.



Navigation Frame

- Each frame has 5 subframes.
  - First three subframes contain local data.
  - Last two subframes contain system data.



Navigation Subframe

- First 3 subframes repeat every 30 seconds.
  - Ephemeris and clock corrections.
- Last 2 subframes repeat every 12.5 minutes.
  - Almanac and Ionoshperic data.
- Each subframe contains 10 words.
  - Starts with preamble (10001011), ends with a zero.
- Each word contains 30 bits = 600 ms
  - 24 data bits and 6 parity bits.
  - Parity bits are the Hamming code for the word.

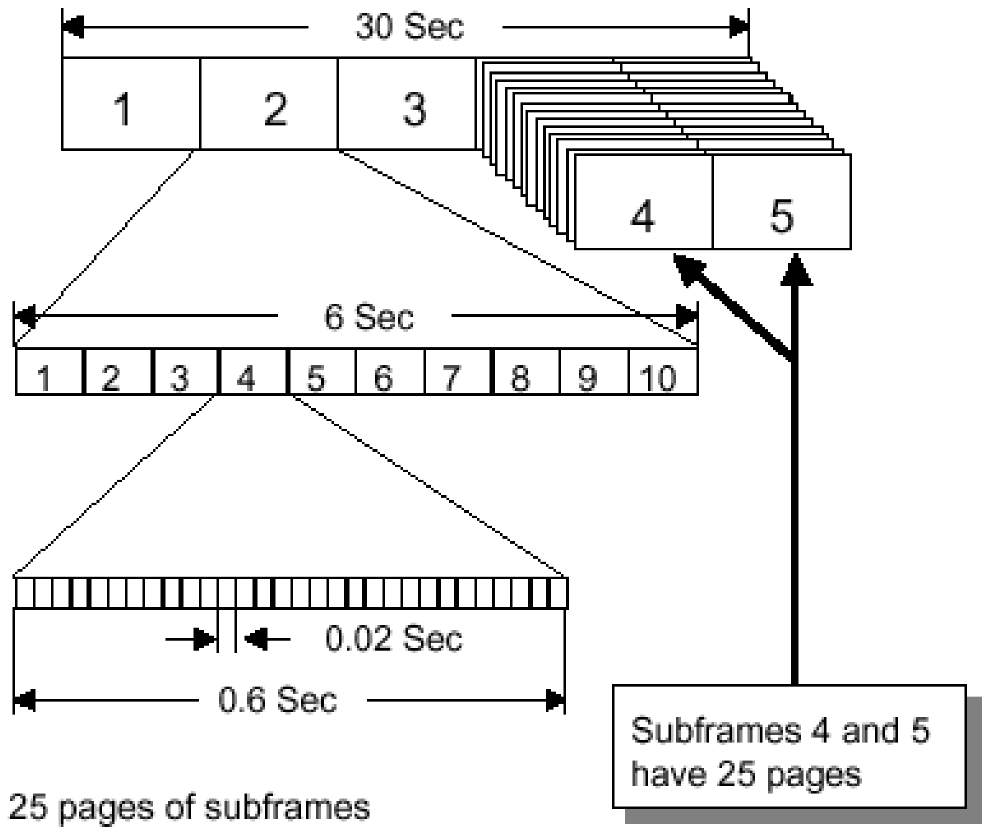
Navigation Frames

Basic message unit is one frame (1500 bits long)

1 frame = 5 subframes

1 subframe = 10 words

1 word = 30 bits



One MASTER FRAME includes all 25 pages of subframes 4 and 5 = 37,500 bits taking 12.5 minutes to transmit

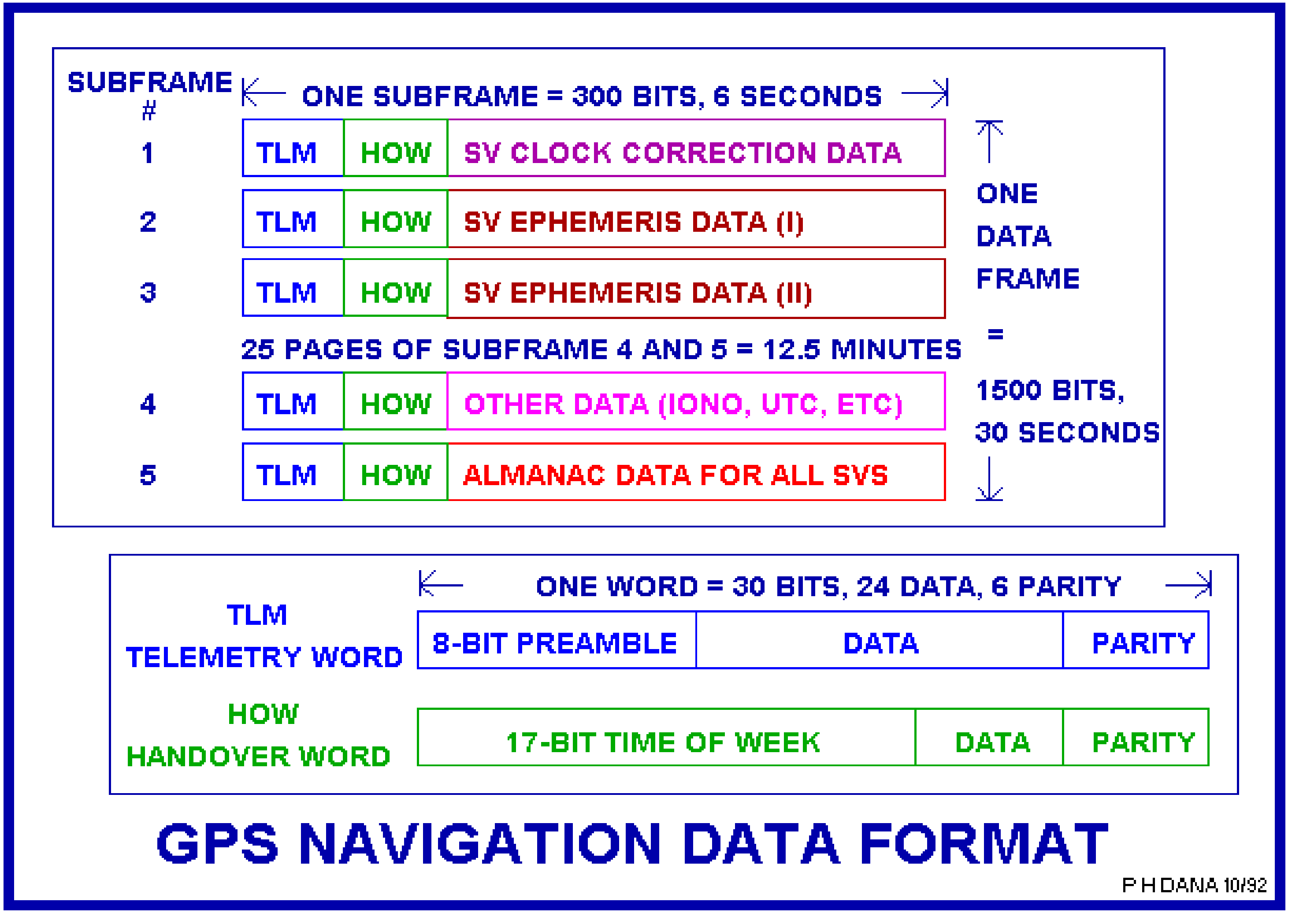
Subframe Data

- All subframes start with the TLM and HOW.
- First word is the telemetry word (TLM)
  - TLM contains an 8 bit preamble (10001011).
- Second word is Hand Over Word (HOW)
  - HOW contains 17 bit Time of Week (TOW)
    - TOW is synchronized to beginning of next subframe.
  - Contains ID of the subframe.

Subframe Data

- First subframe contains Satellite clock correction terms and GPS Week number.
- Frames two and three contain precise ephemeris data.
- Frame four contains Ionospheric and UTC data as well as almanac for SVs 25-32.
- Frame five contains almanac for SVs 1-24 and almanac reference time.

Subframe Data



Data Collection Times

- 1 word = 600 ms
  - Up to 1.18 seconds to collect a word.
  - Quick Start needs a valid word.
- 1 subframe = 6 seconds
  - Up to 6.6 seconds to collect a subframe.
  - Hot Start needs a valid time.
- 1 frame = 30 seconds
  - Up to 36 seconds to collect a frame
  - Warm and Cold Start need valid ephemeris.

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Signal Structure

- Carriers are pure sinusoidal waves.
- L1 frequency
  - 1575.42 MHz, ~19 cm wavelength
  - Modulated by both the C/A and P(Y) codes.
- L2 frequency
  - 1227.60 MHz, ~24 cm wavelength
  - Modulated by the P(Y) code only.

C/A code

- Coarse/Acquisition (Civil Access)
- 1023 bit pseudorandom noise (PRN) code
  - PRN is selected from a set of Gold codes
  - Gold codes are designed to minimize cross correlation
  - Different PRN for each SV
- Clock rate of 1.023MHz (chip rate)
- Repeats every 1ms
- C/A code is not encrypted

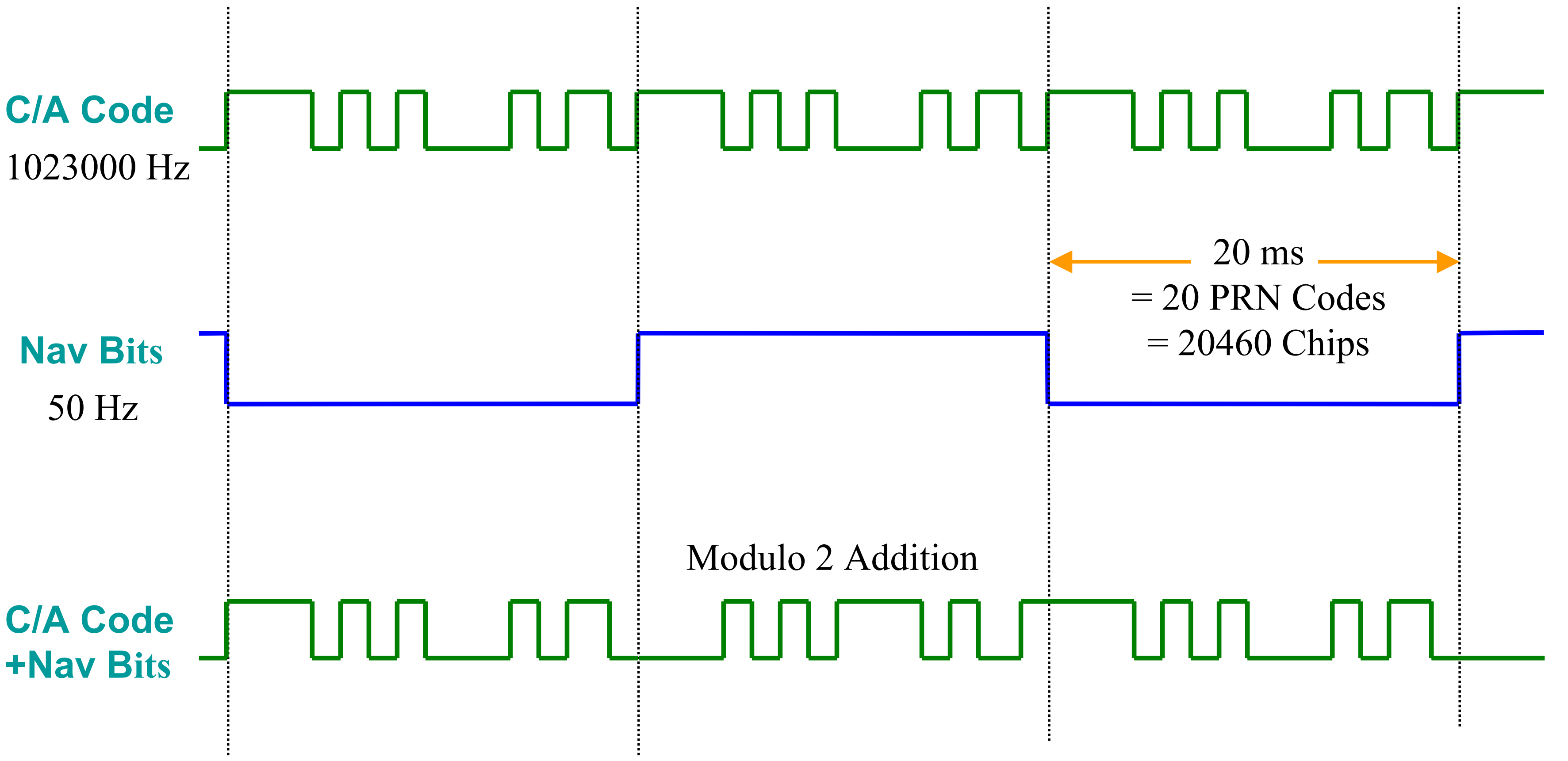
P(Y) Code

- Y refers to an encrypted version of P-code
- Clock rate of 10.23 MHz
- Repeats every 267 days
- Each SV transmits unique 7 day segment
- Transmitted on L1 and L2
- 90 degrees out of phase of C/A on L1

C/A Code Modulation

- Navigation message is 50 bps.
- 20 C/A codes per navigation bit.
- Navigation message is modulo 2 added to C/A code.
  - 1's in navigation message invert the PRN codes.
  - 1's effectively invert the autocorrelation function.

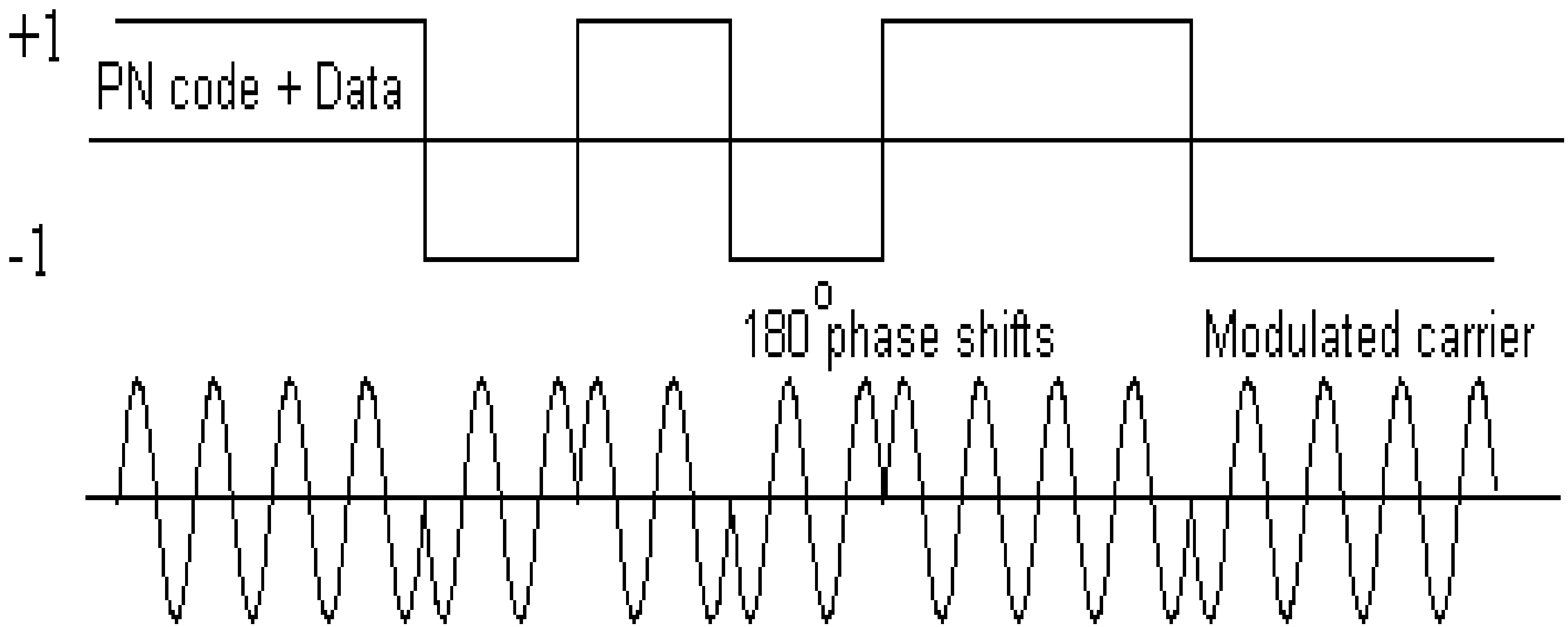
C/A Code Modulation



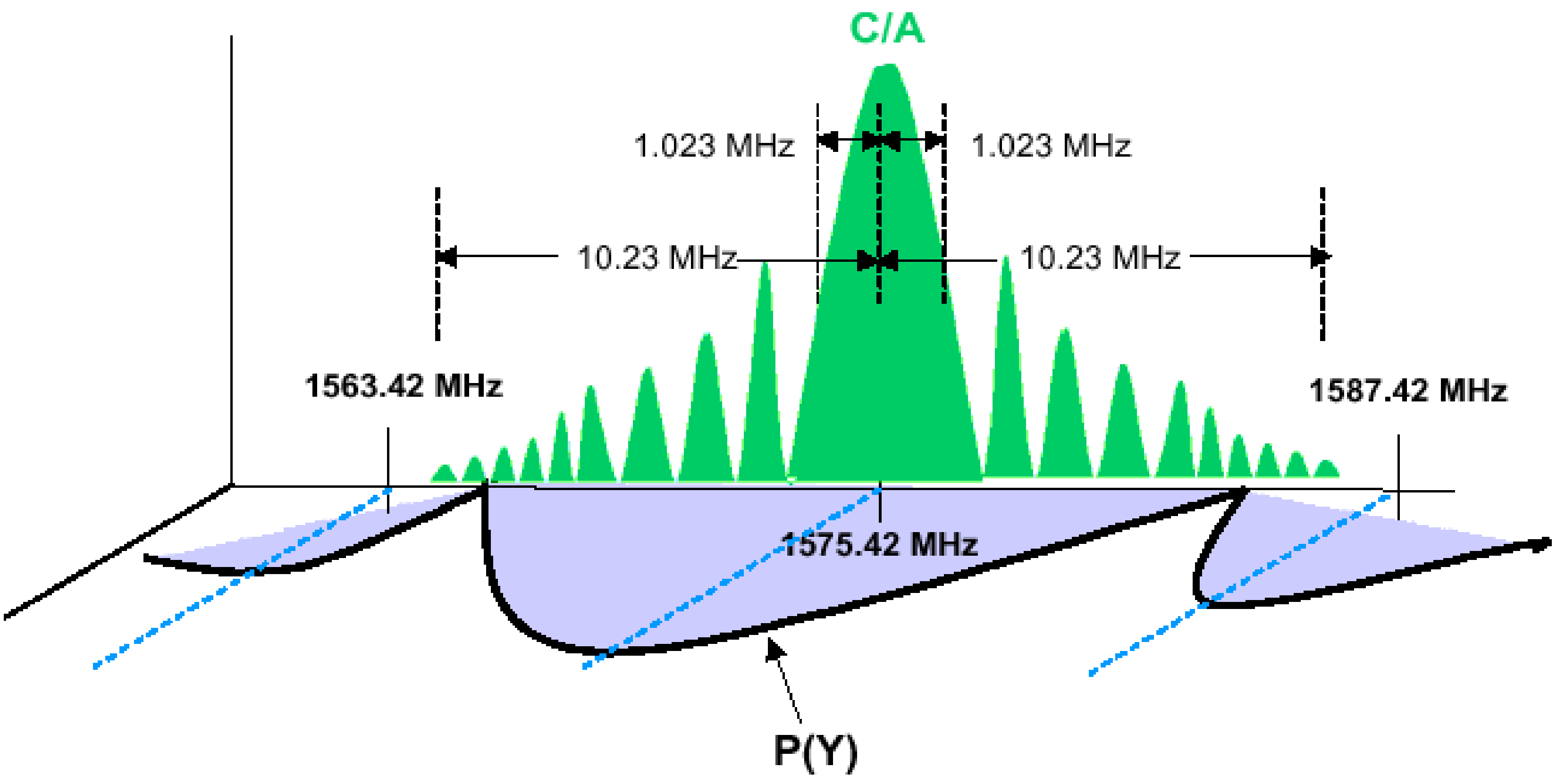
Carrier Modulation

- GPS uses binary phase shift keying (BPSK) to modulate the codes on to the carrier.
- Change in code state causes a 180 degree phase shift in carrier.
- BPSK spreads signal power around carrier by the code bandwidth.

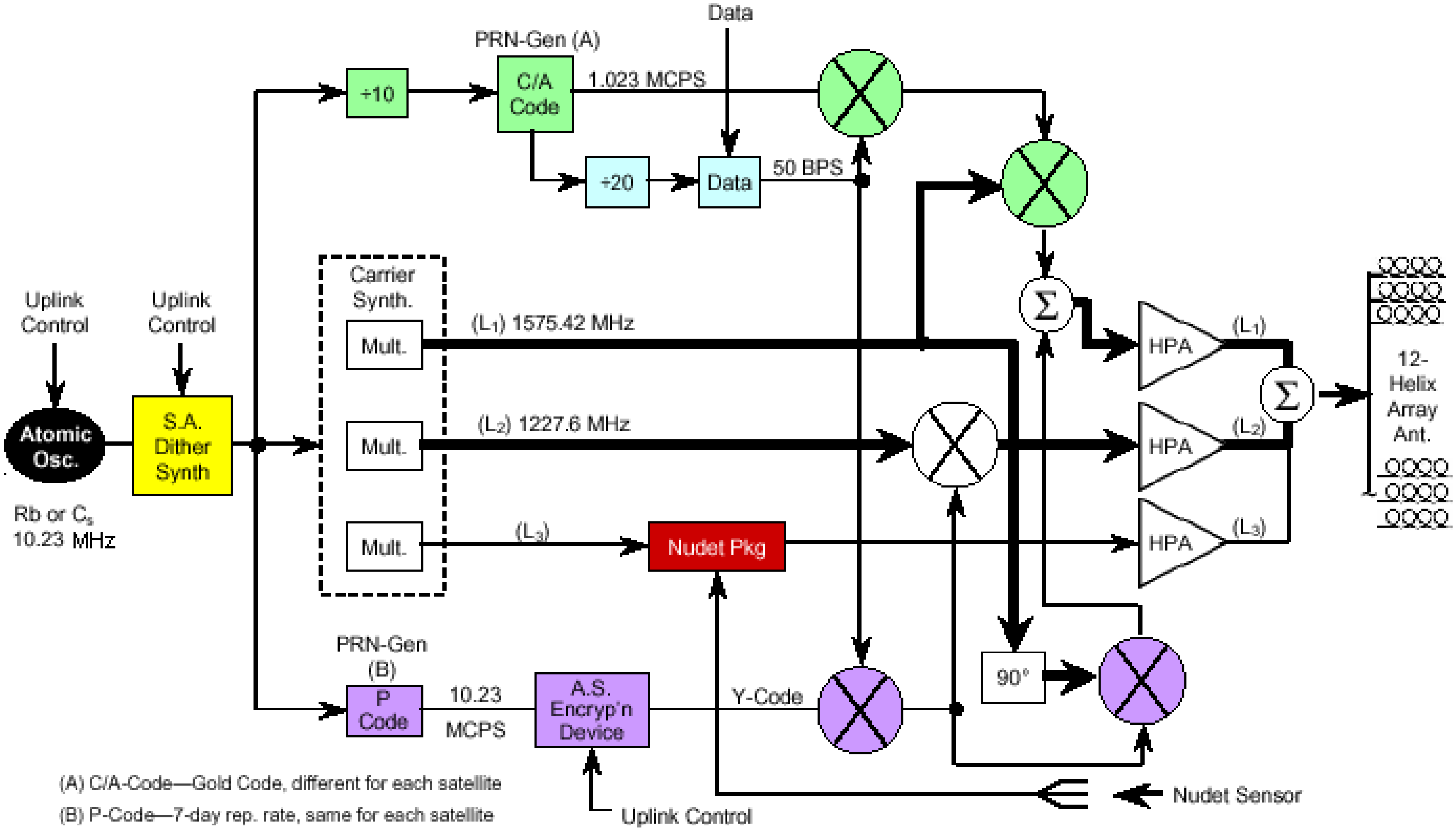
Binary Phase Modulation



L1 Signal Structure



SV Onboard Navigation Package



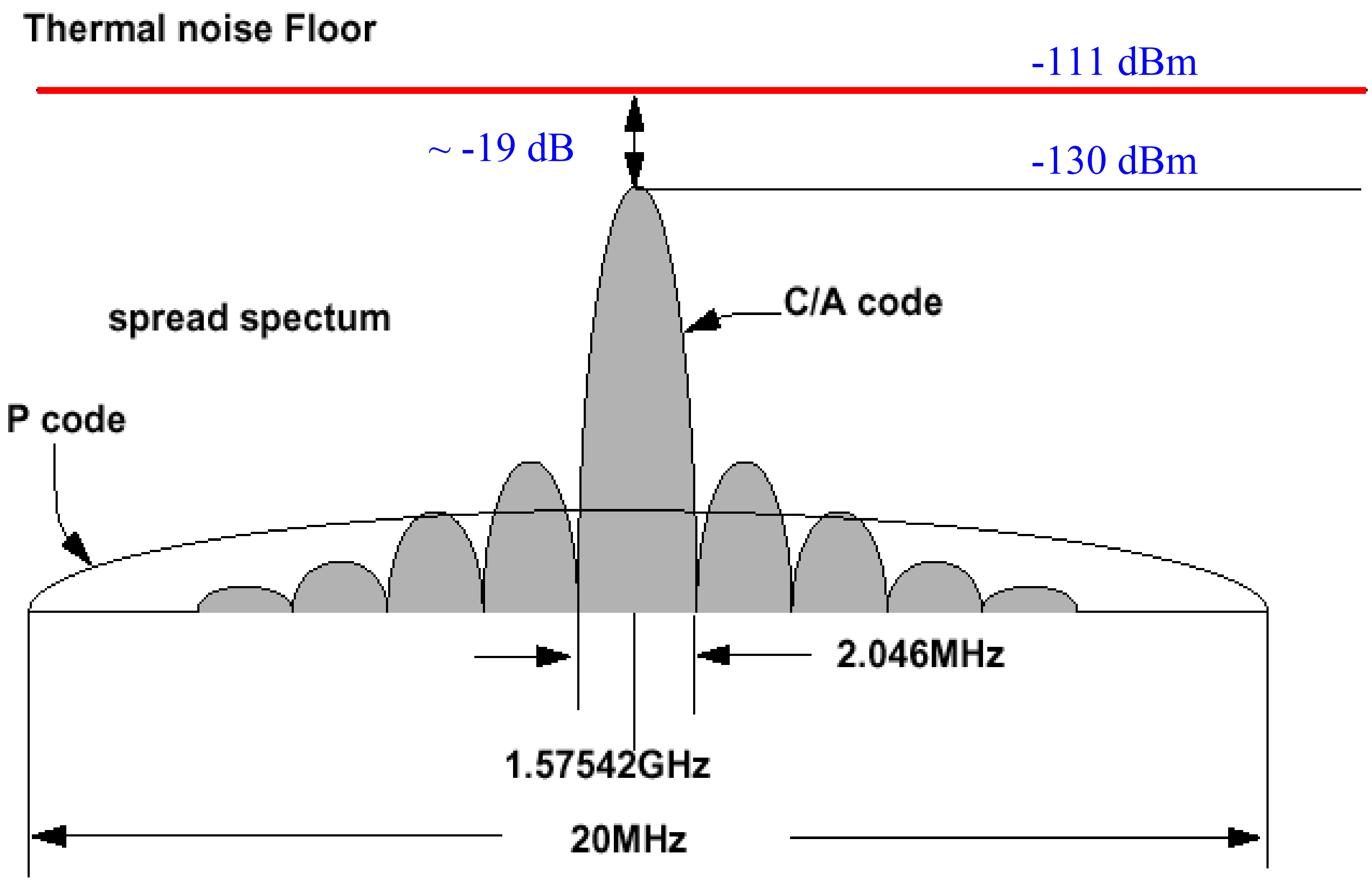
(A) C/A-Code—Gold Code, different for each satellite

(B) P-Code—7-day rep. rate, same for each satellite

Noise Power

- Noise power is defined as KTB
  - K = 1.3806e-23 J/S (Boltzmann's constant)
  - T = temperature in Kelvin (273)
  - B = bandwidth
- 1MHz BW (C/A code) = -114dBm
  - 600 nV into 50 ohms
- GPS signal power specified at –130dBm
  - 70 nV into 50 ohms

Received Signal



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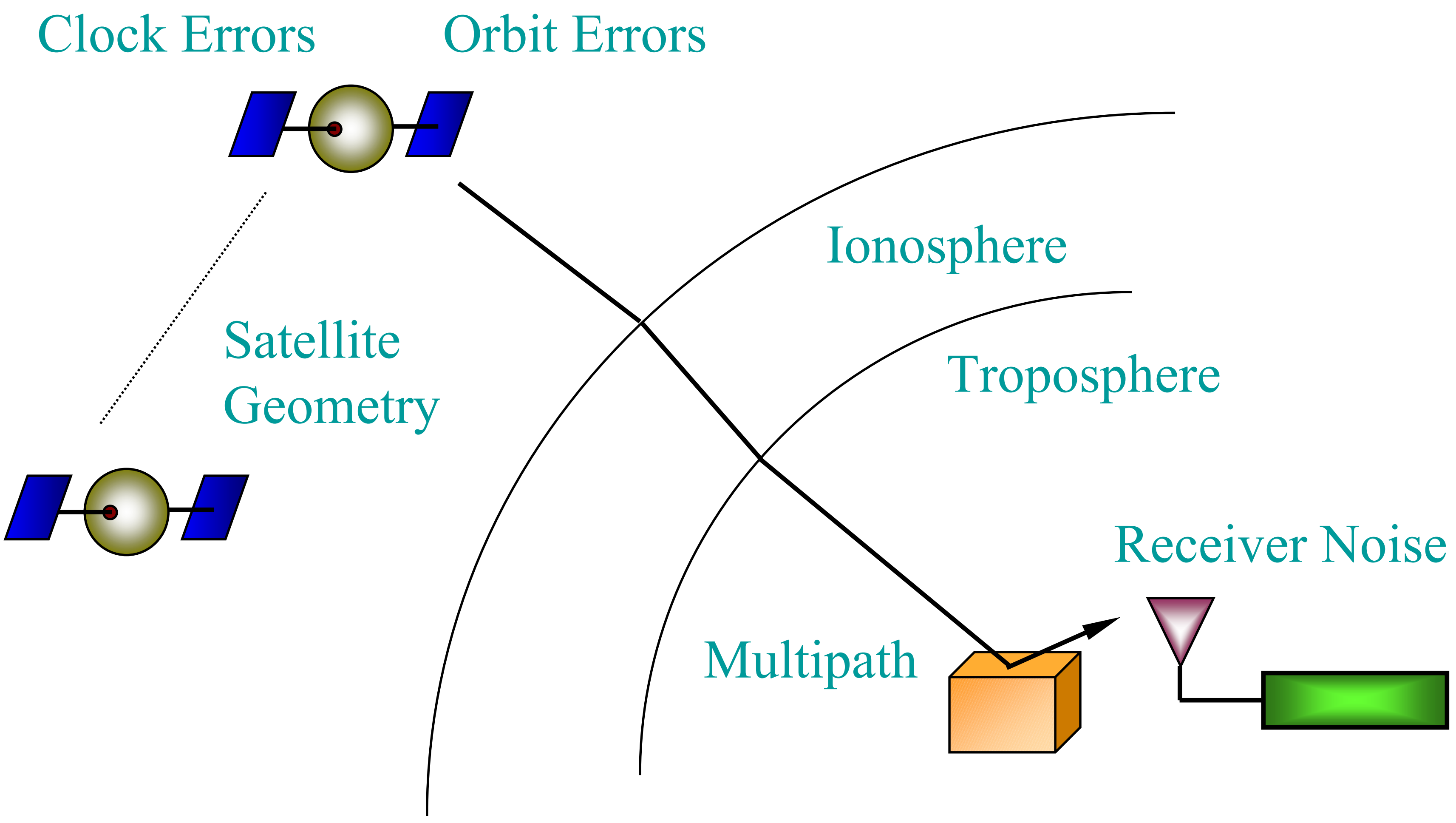
Error Sources



System Errors

- Satellite clock
  - Errors in modeling of the satellite clock offset and drift using a second order polynomial
  - Selective Availability
- Satellite orbit
  - Errors that exist within the Keplerian representation of the satellite ephemeris
  - Selective Availability

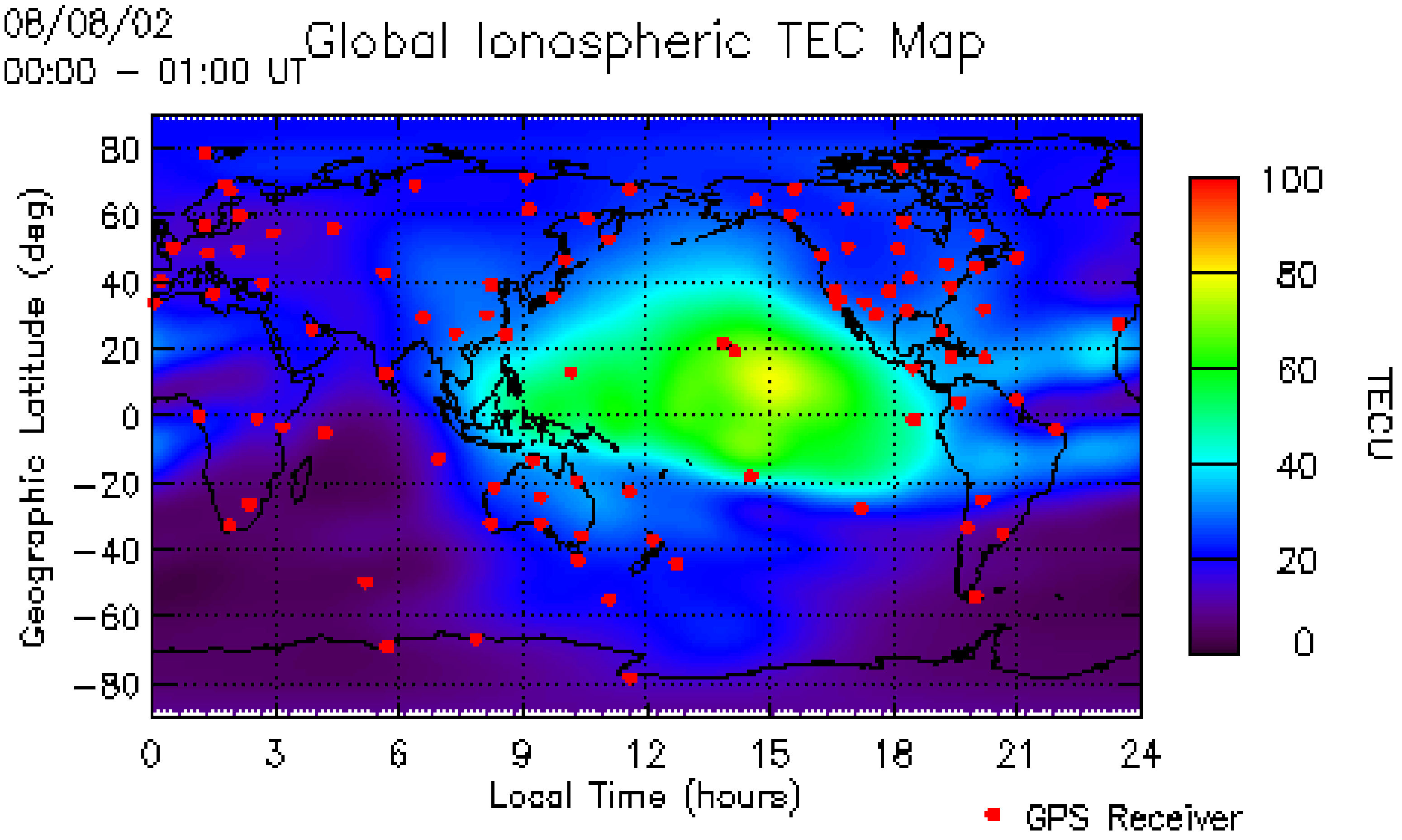
Ionospheric Errors

- 70 – 1000 km above the earth
- Dispersive medium affects the GPS signals
  - Carrier experiences a phase advance
  - Codes experience a group delay
- Delay is dependent on the total electron count (TEC)
  - Peaks during day due to solar radiation
  - Varies with geomagnetic latitude
  - Varies with satellite elevation

Ionospheric Errors

- Frequency dependent
  - Can be eliminated with dual frequency receivers (L1/L2)
- Reduce errors using Klobuchar model
  - Eight parameters are transmitted in the navigation message
  - Combined with an obliquity factor dependant on the satellite elevation
  - Provides an estimate within 50% of the true delay

Ionospheric Errors



Troposhperic Errors

- 0-70 km above the earth
- Delays both code and carrier measurements
- Not frequency dependent within L band
- Can be modeled
  - Dry component, 90% of the total refraction
  - Wet component, 10% of the total refraction
  - Temperature, pressure and humidity
  - Satellite elevation angle

Environmental Errors

- Multipath
  - Signals bounce off nearby surfaces before being received by the antenna
  - Causes a delay resulting in range error
- Signal degradation
  - Foliage
  - Buildings
  - Anything in the line of sight

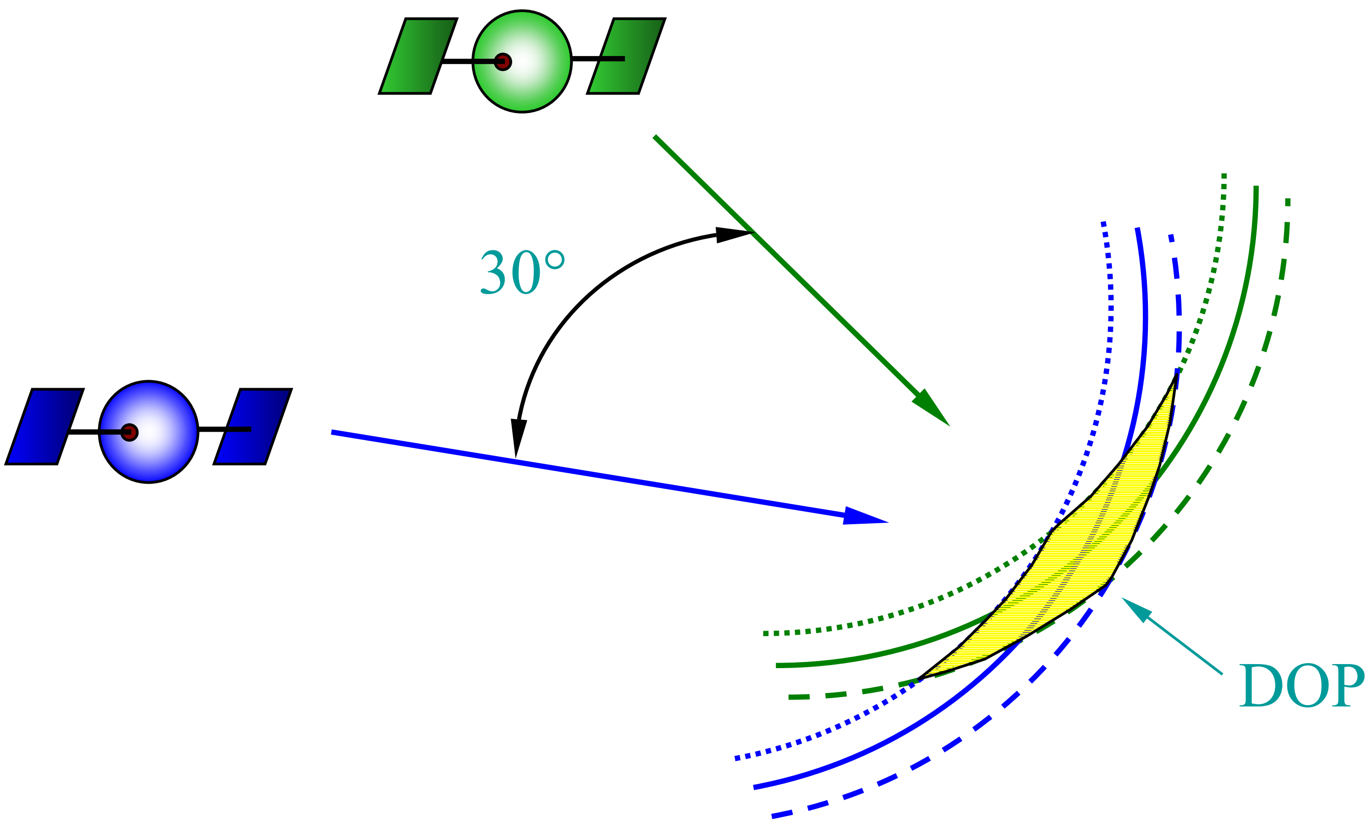
Receiver Noise

- Clock stability and accuracy
- A/D conversion
- Correlation process
- Tracking loops and bandwidths

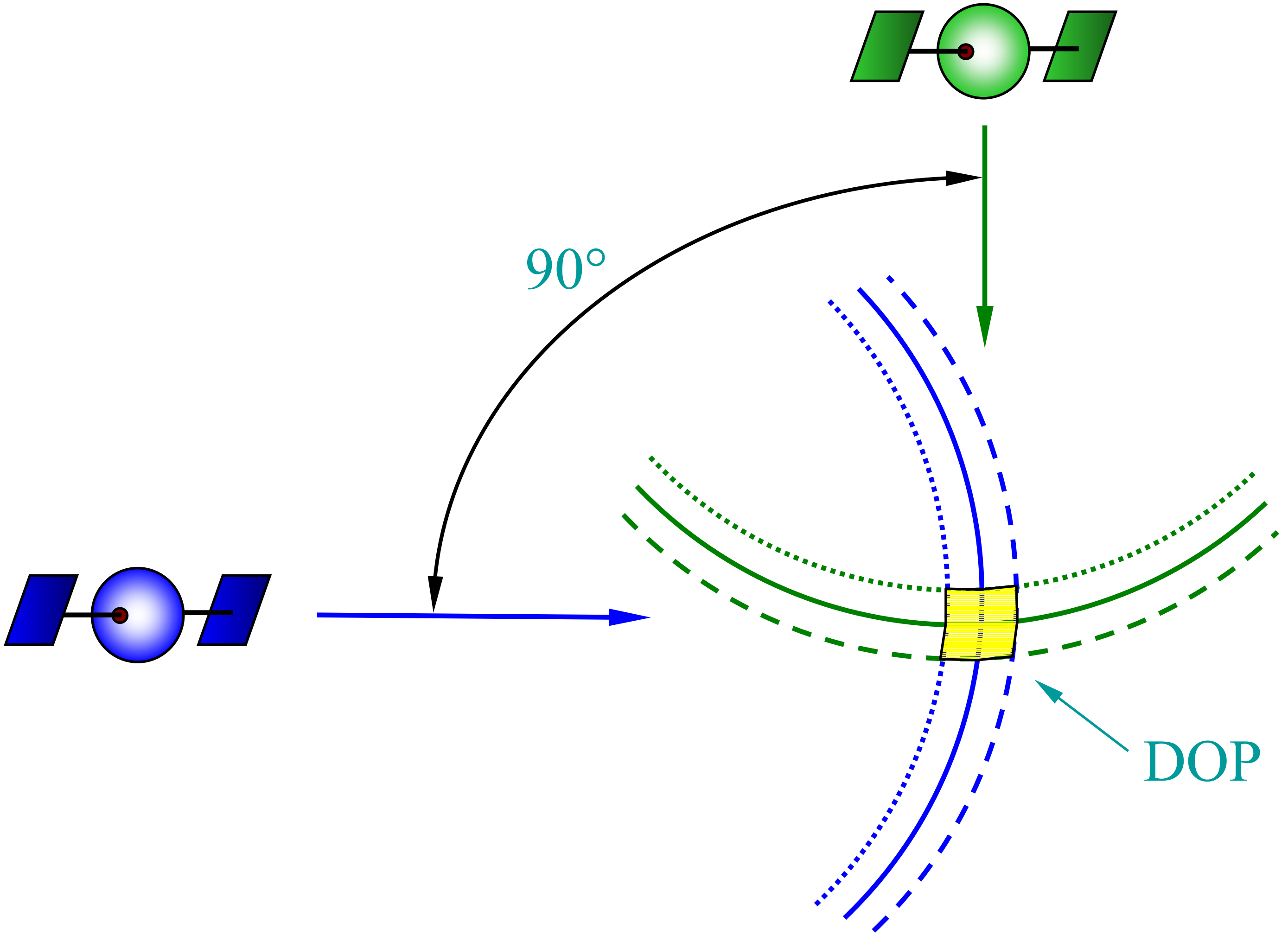
Satellite Geometry

- Relative position between the user and the GPS satellites affects the accuracy of the solution
- Geometric Dilution Of Precision (GDOP)
  - Position or spherical (PDOP)
  - Horizontal (HDOP)
  - Vertical (VDOP)
  - Time (TDOP)
- Lower DOP values result in better accuracy

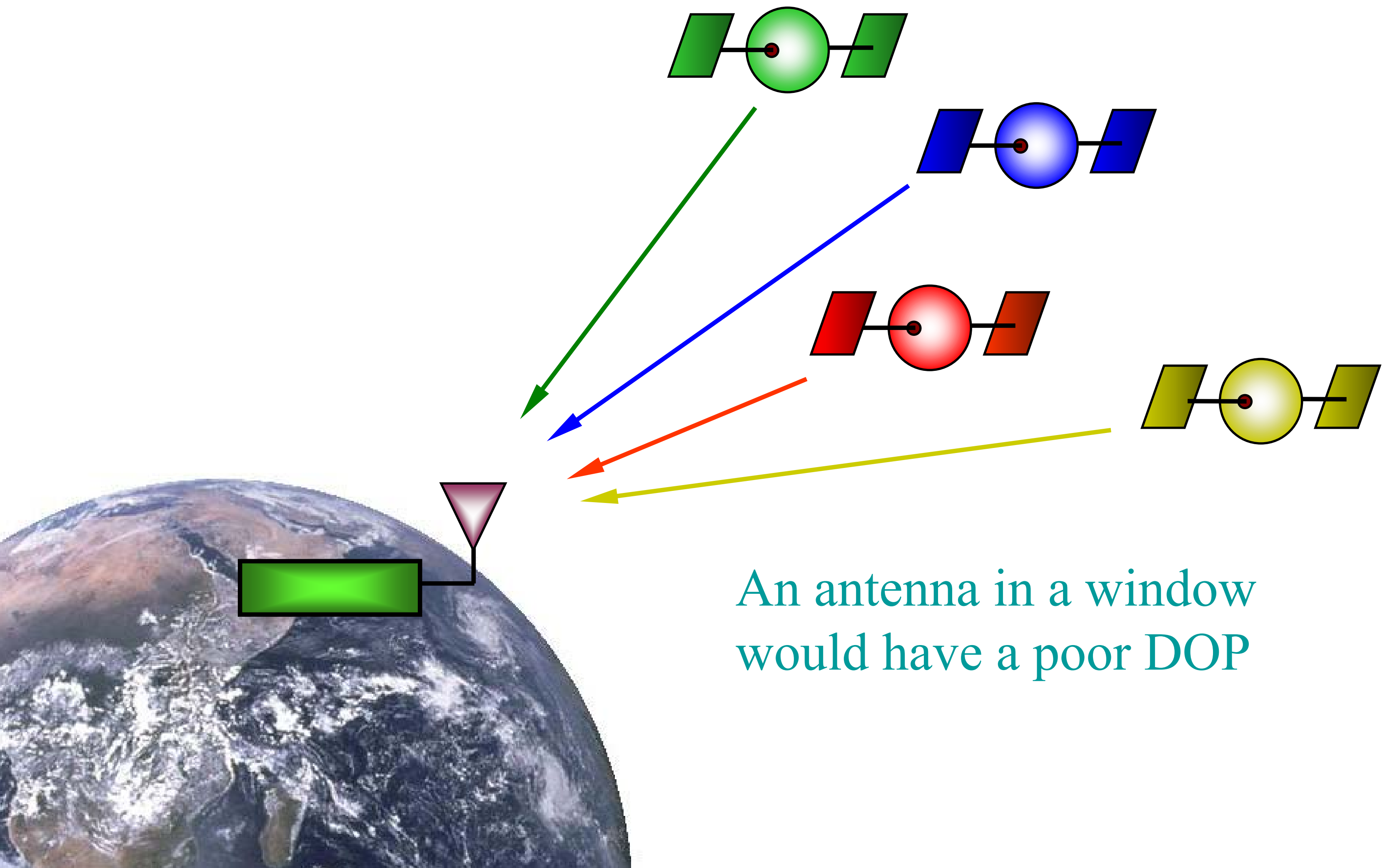
Intersecting Ranges



Intersecting Ranges

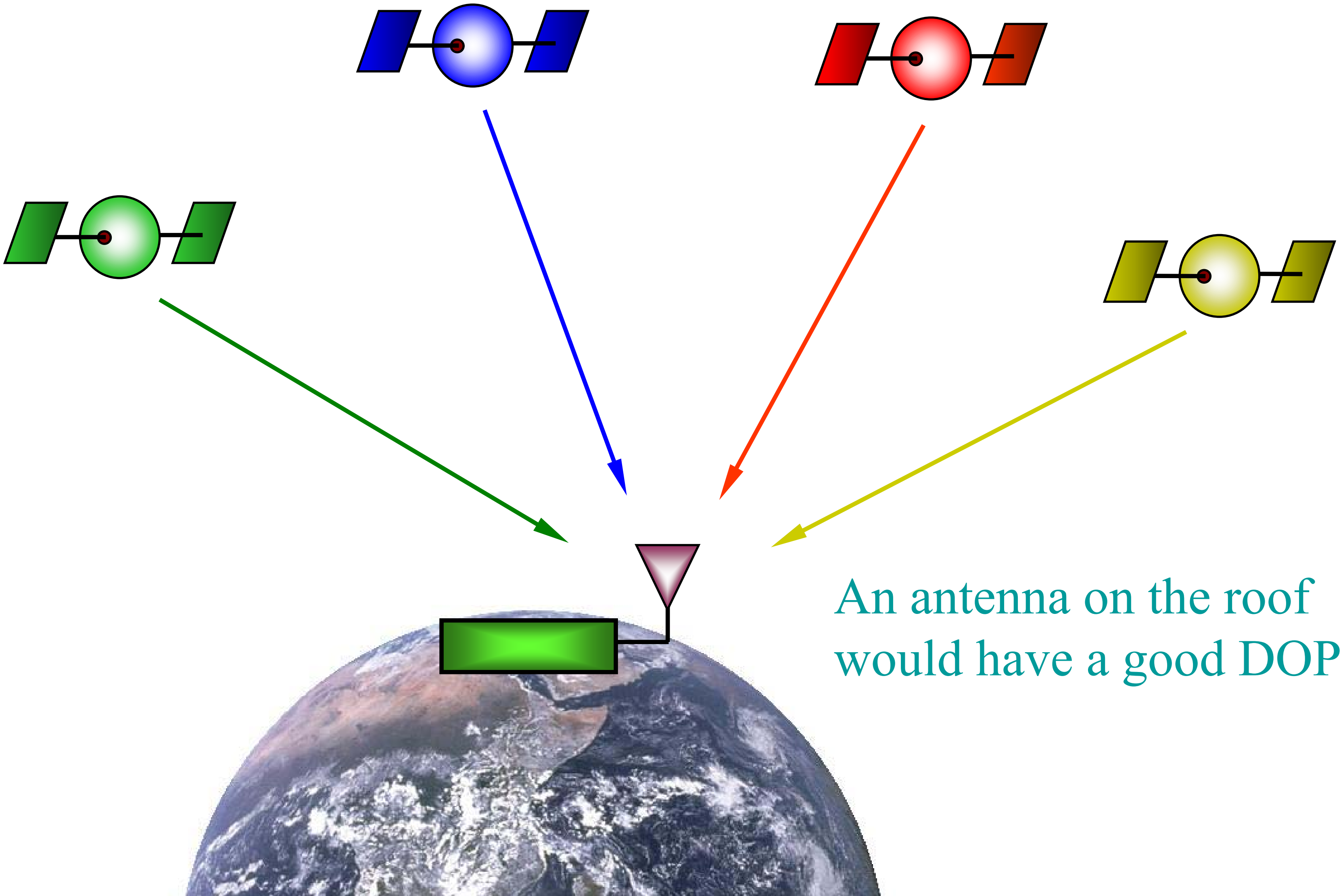


Poor DOP



An antenna in a window
would have a poor DOP

Good DOP



An antenna on the roof
would have a good DOP

Further Reading

- Elementary
  - http://www.trimble.com/gps/index.html
- Novice
  - http://www.colorado.edu/geography/gcraft/notes/gps/gps_f.html
- Expert
  - http://www.gmat.unsw.edu.au/snap/gps/gps_survey/principles_gps.htm