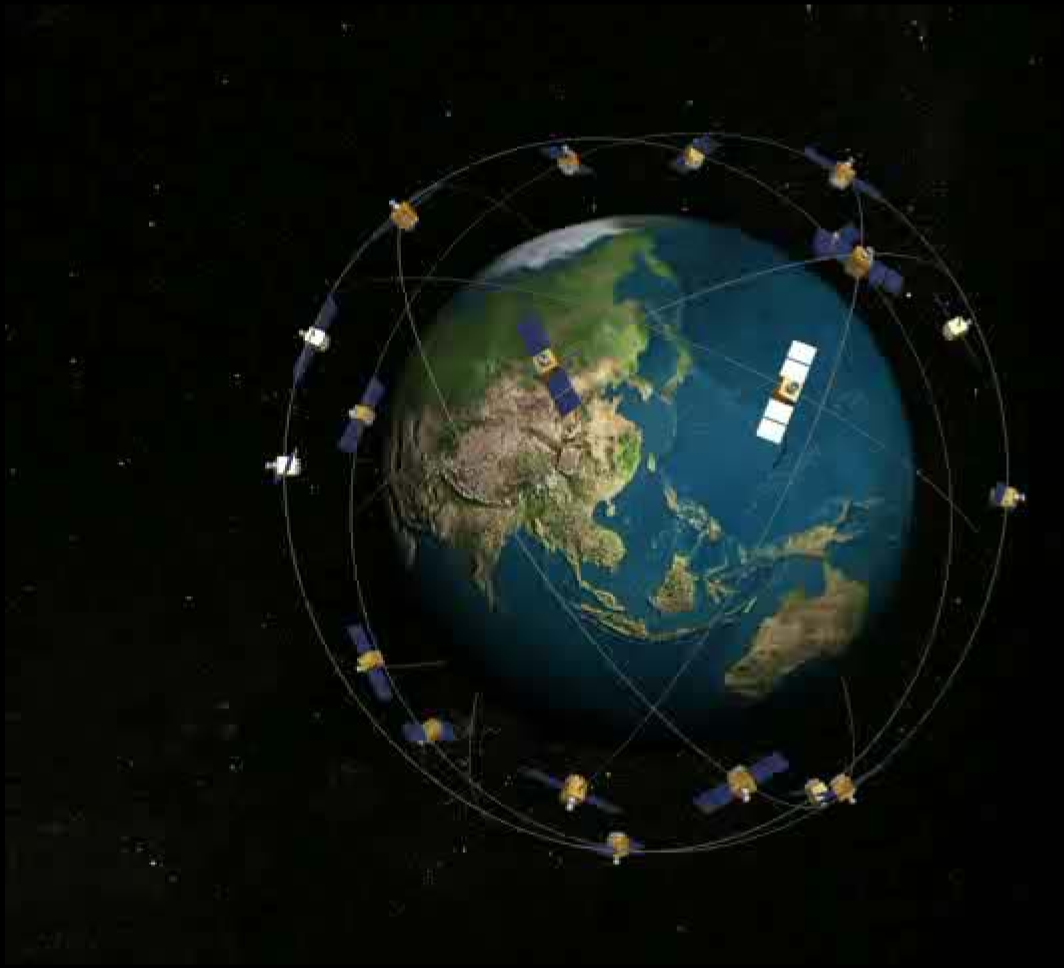
GPS Tutorial #2

Signals and Messages



Darren Sessions

GPS Tutorial #2

- PRN Codes
- Signal Structure
- Navigation message
- Error Sources

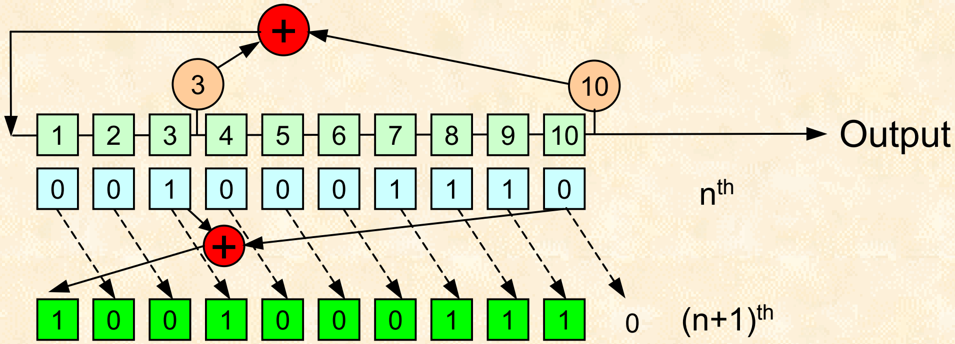
PRN Codes

- PRN = Pseudo Random Noise
  - Codes have random noise characteristics but are precisely defined.
- A sequence of zeros and ones, each zero or one referred to as a “chip”.
  - Called a chip because they carry no data.
- Selected from a set of Gold Codes.
  - Gold codes use 2 generator polynomials.
- Three types are used by GPS
  - C/A, P and Y

PRN Code Generation

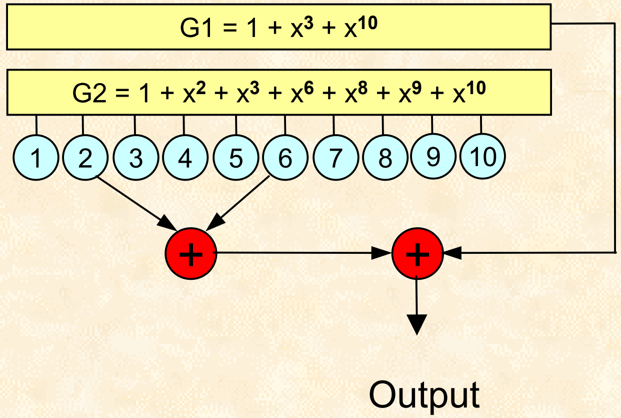
Tapped feedback
Shift register

Polynomial = $1 + x^3 + x^{10}$



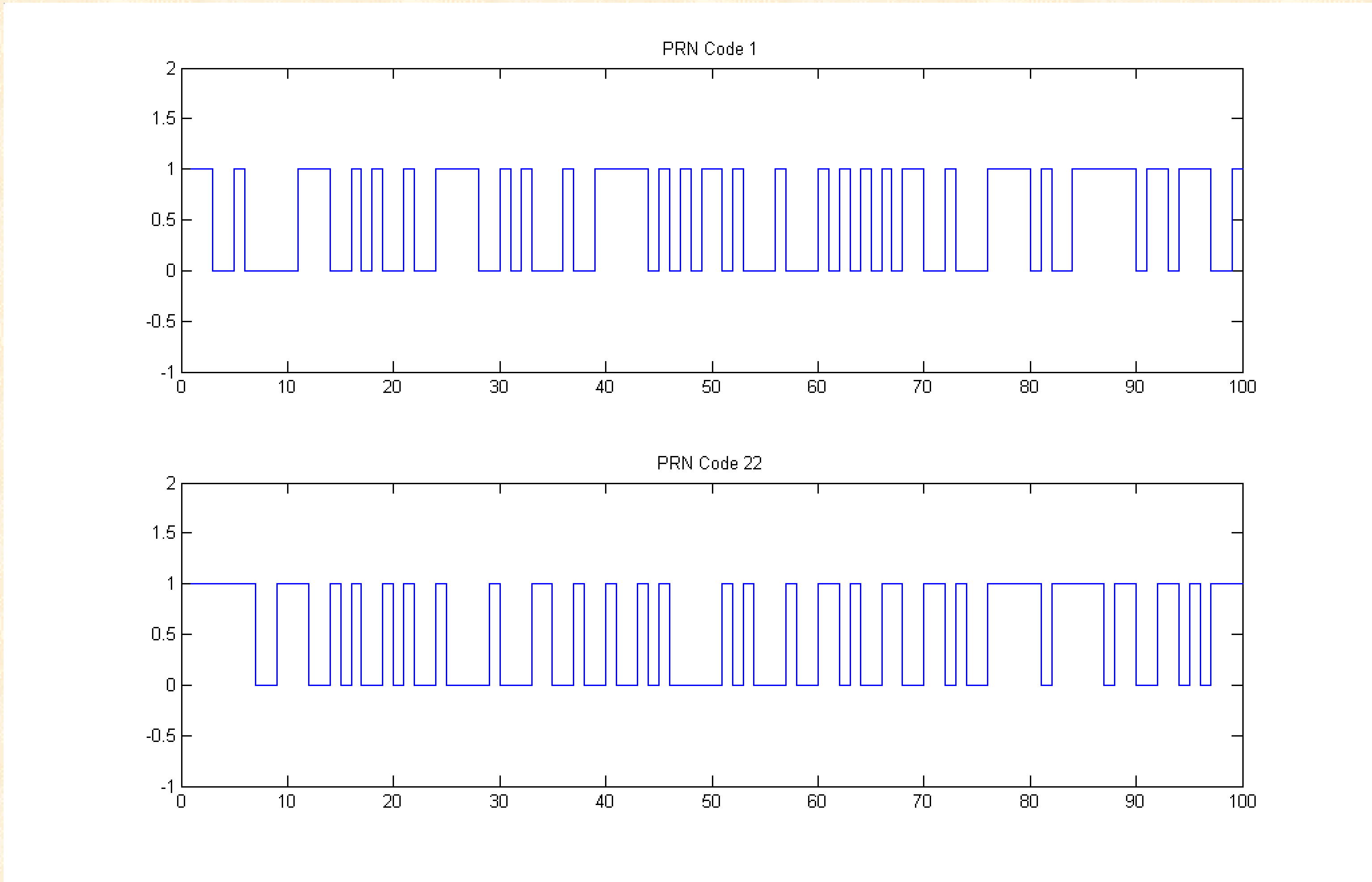
PRN Code Generator

(PRN 1 Shown)



PRN Code	Taps
1	$2 \oplus 6$
2	$3 \oplus 7$
3	$4 \oplus 8$

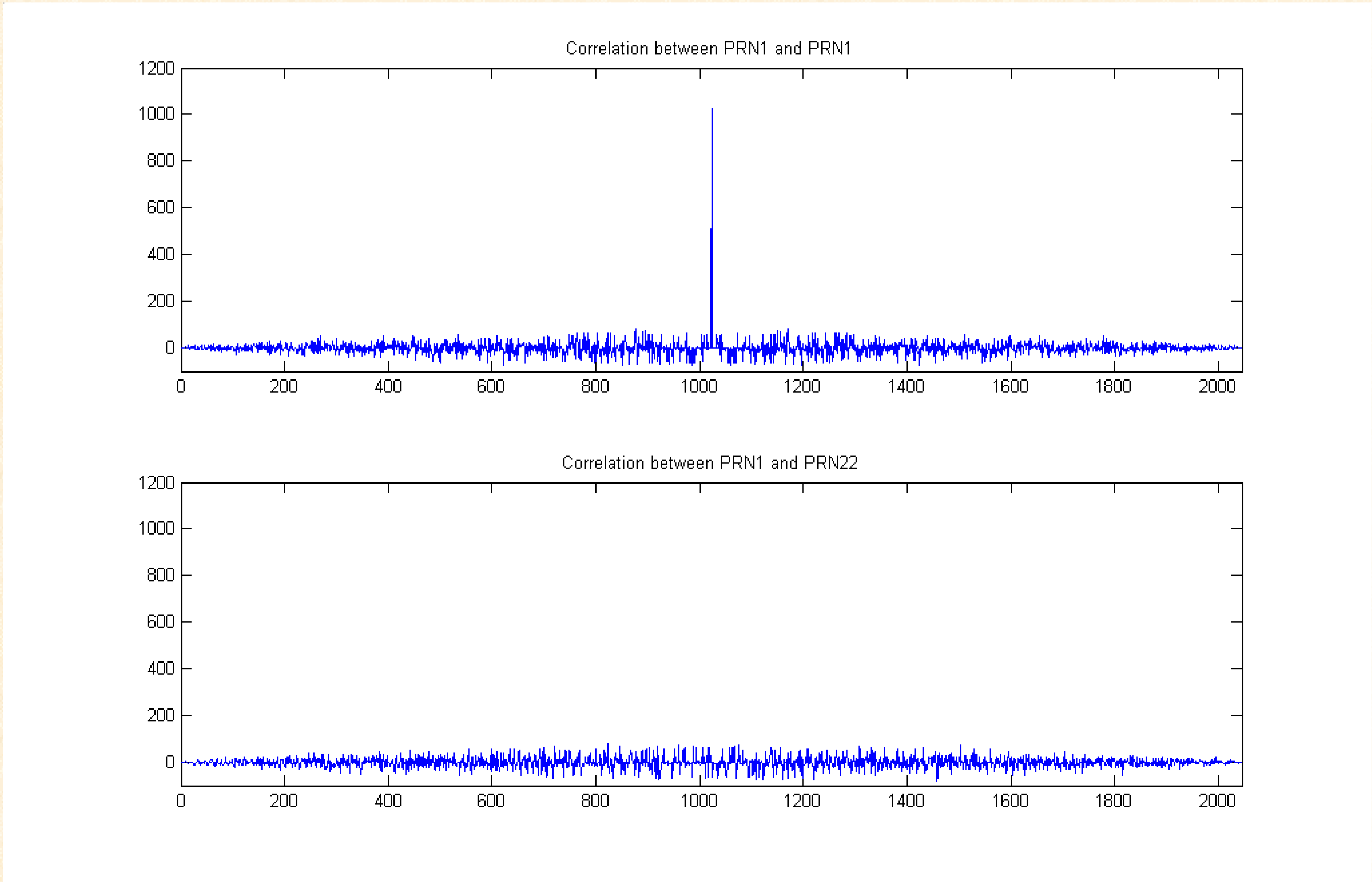
First 100 bits of PRN1 and PRN22



Code Correlation

- Correlation value
  - The number of bits between two codes that have the same value.
- Autocorrelation
  - Correspondence between a code and a phase shifted replica of itself.
- Cross Correlation
  - Correspondence between a code and a phase shifted version of another code (of the same length).

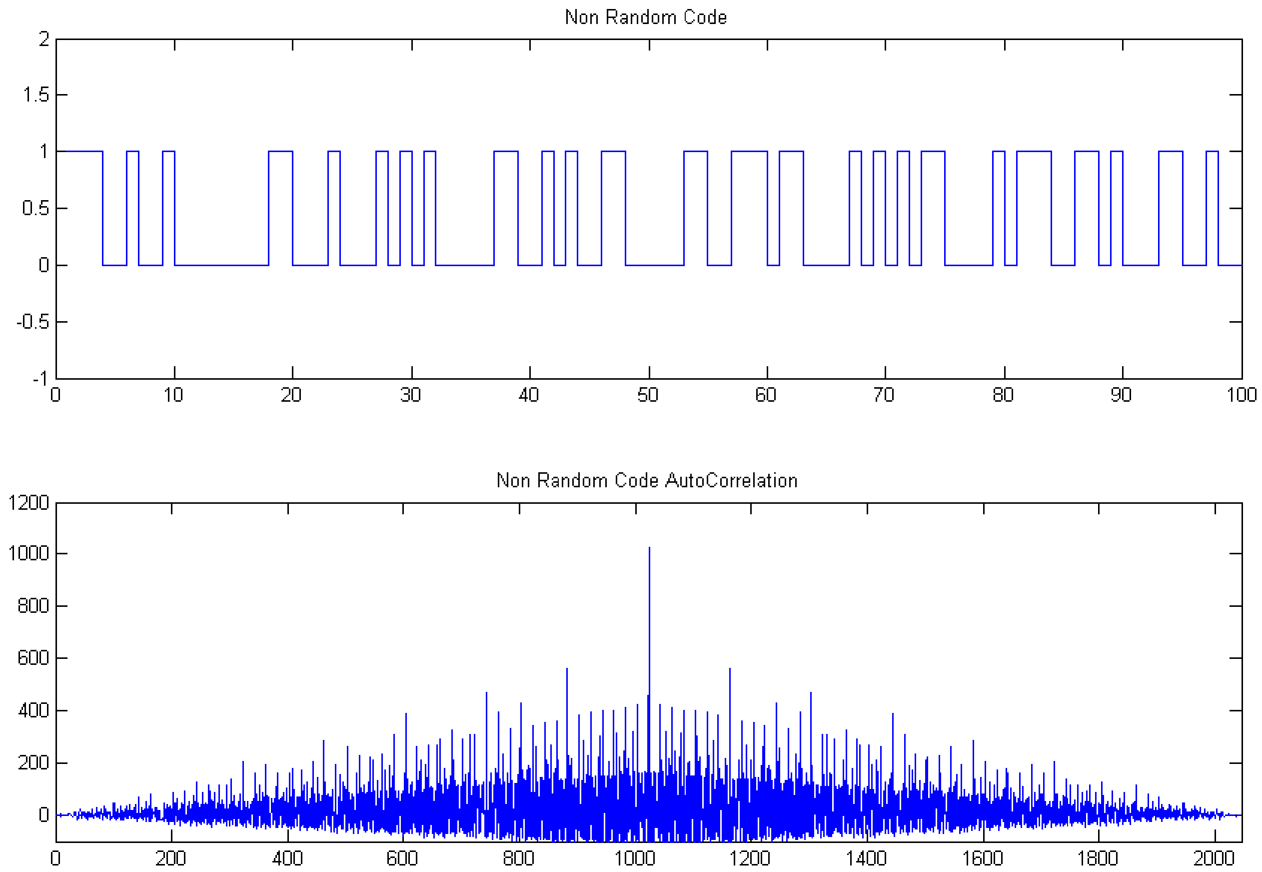
PRN Code Correlation



PRN Code properties

- High Autocorrelation value only at a phase shift of zero.
- Minimal Cross Correlation to other PRN codes, noise and interferers.
- Allows all satellites to transmit at the same frequency.
- PRN Codes carry the navigation message and are used for acquisition, tracking and ranging.

Non PRN Code



Non Random Code
2
1.5
1
0.5
0
-0.5
-1
0
10
20
30
40
50
60
70
80
90
100
Non Random Code AutoCorrelation
1200
1000
800
600
400
200
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000

C/A Code

- C/A Code (Coarse Acquisition).
  - Uses 2 10-bit generator polynomials.
  - 1023 bits long.
  - 1 ms duration.
  - Clock rate of 1.023MHz.
  - Repeats indefinitely.
  - Also referred to as Civil Access code.
- Only code needed for commercial receivers.

P-Code

- PRN codes used by the military.
- Uses different generator polynomials.
- 15,345,037 bits long.
- Has a duration of 7 days.
- Clock rate of 10.23MHz
- Y-Code
  - Replaces P-Code when anti-spoofing is enabled (encrypted).
- Not necessary for positioning

GPS Tutorial #1

- PRN Codes
- Signal Structure
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Signal Structure

- L1 carrier
  - 1575.42 MHz, ~19 cm wavelength
  - Modulated by both the C/A and P(Y) codes.
  - P(Y) code is 90 degrees out of phase from the C/A code.
- L2 carrier
  - 1227.60 MHz, ~24 cm wavelength
  - Modulated by the P(Y) code only.
- Both carriers are centered in 20.46 MHz wide protected bands.

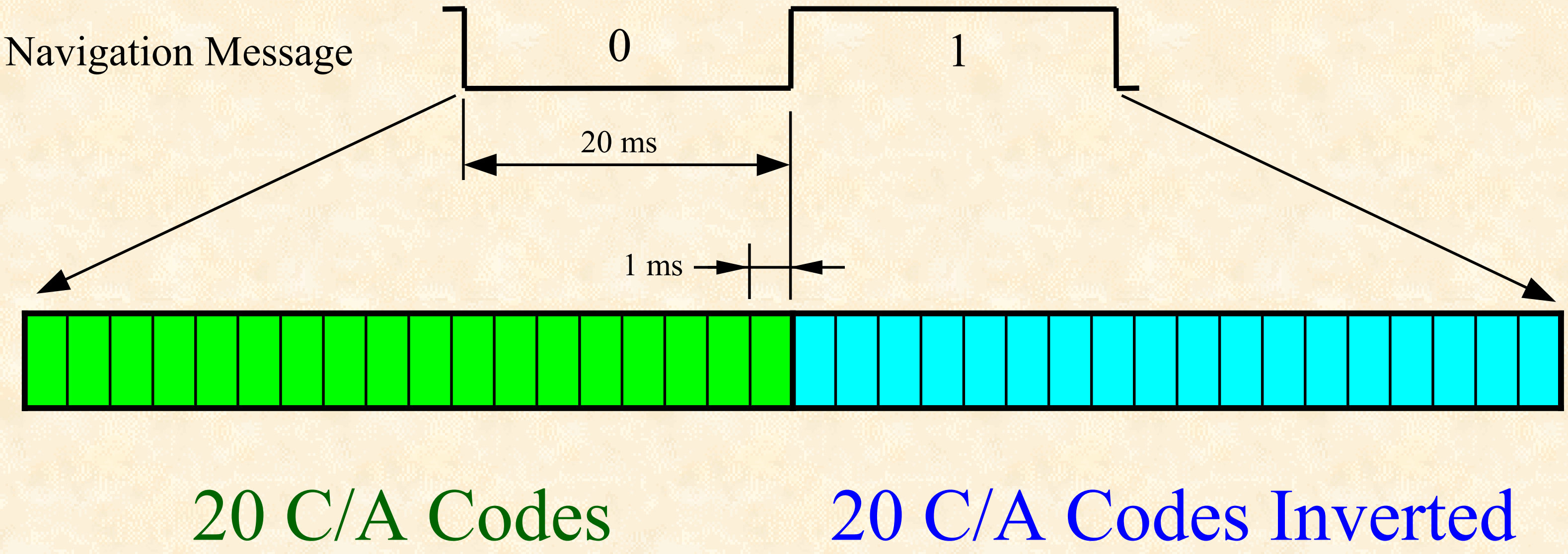
Signal Composition

- Navigation message
  - Bit stream with data rate of 50bps.
- C/A code.
  - Bit stream with a data rate of 1.023 mega chips per second.
- L1 Carrier
  - Sine wave with a frequency of 1.57542 GHz.

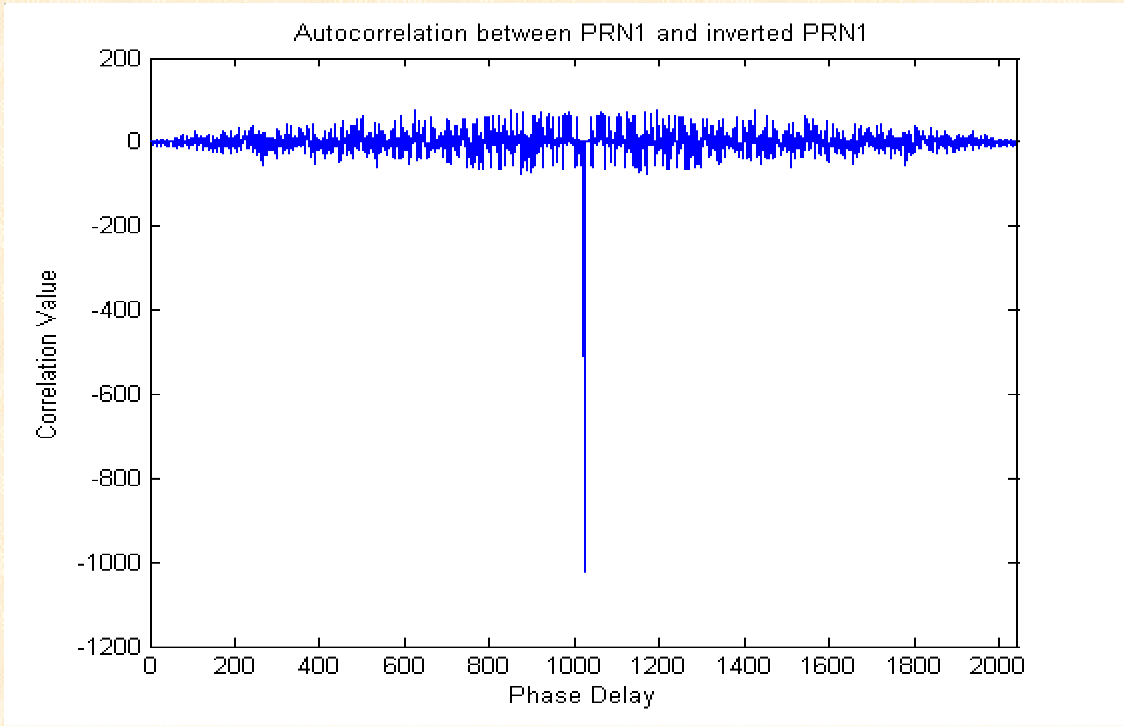
- L2 carrier and P(Y) codes will be primarily ignored for the remainder of this tutorial.

Combining Navigation Message with the C/A Code

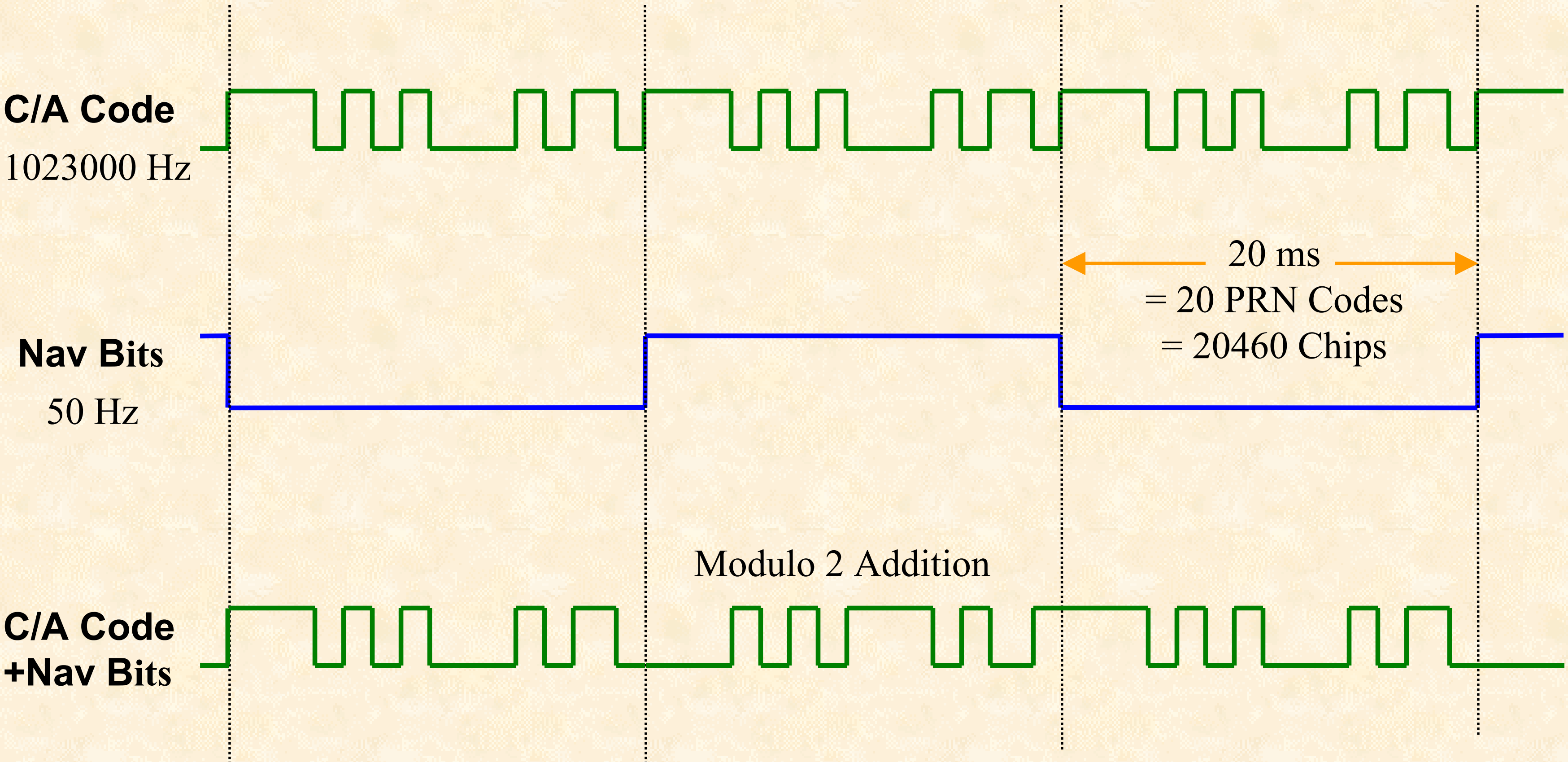
- Navigation message is modulo 2 added to C/A code.
- 20 C/A codes per Navigation Bit.



Autocorrelation with Inverted PRN Code

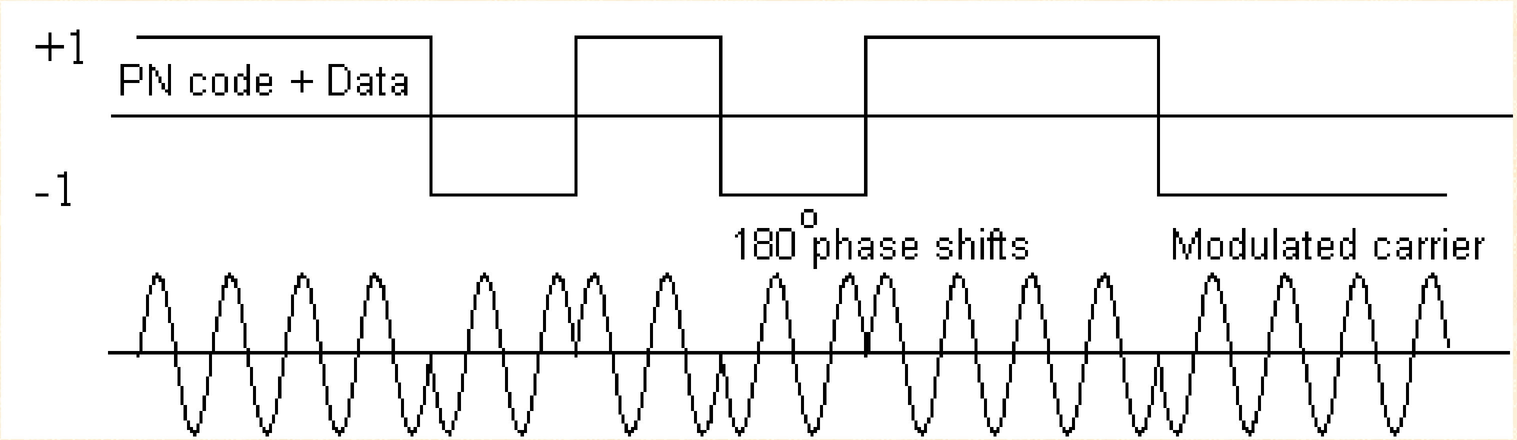


Navigation Message and C/A Code

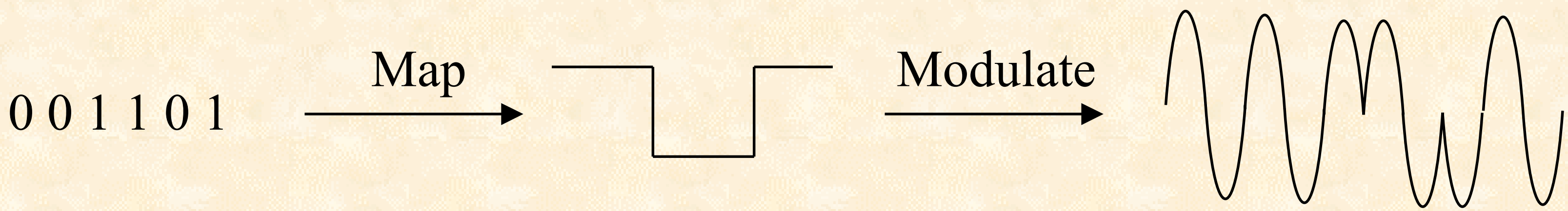


BPSK Modulation

- 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.



GPS Modulation Scheme



Bit Stream

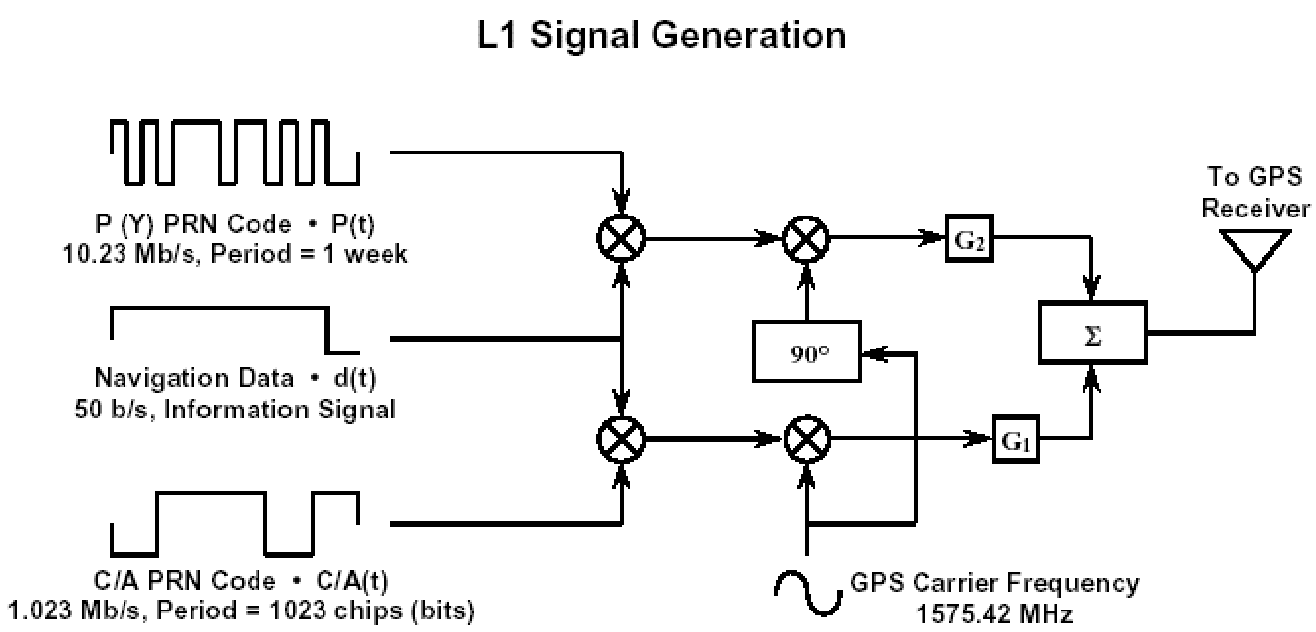
Analog Signal

Composite Signal

Navigation Message and C/A code combined

Carrier with BPSK Modulation

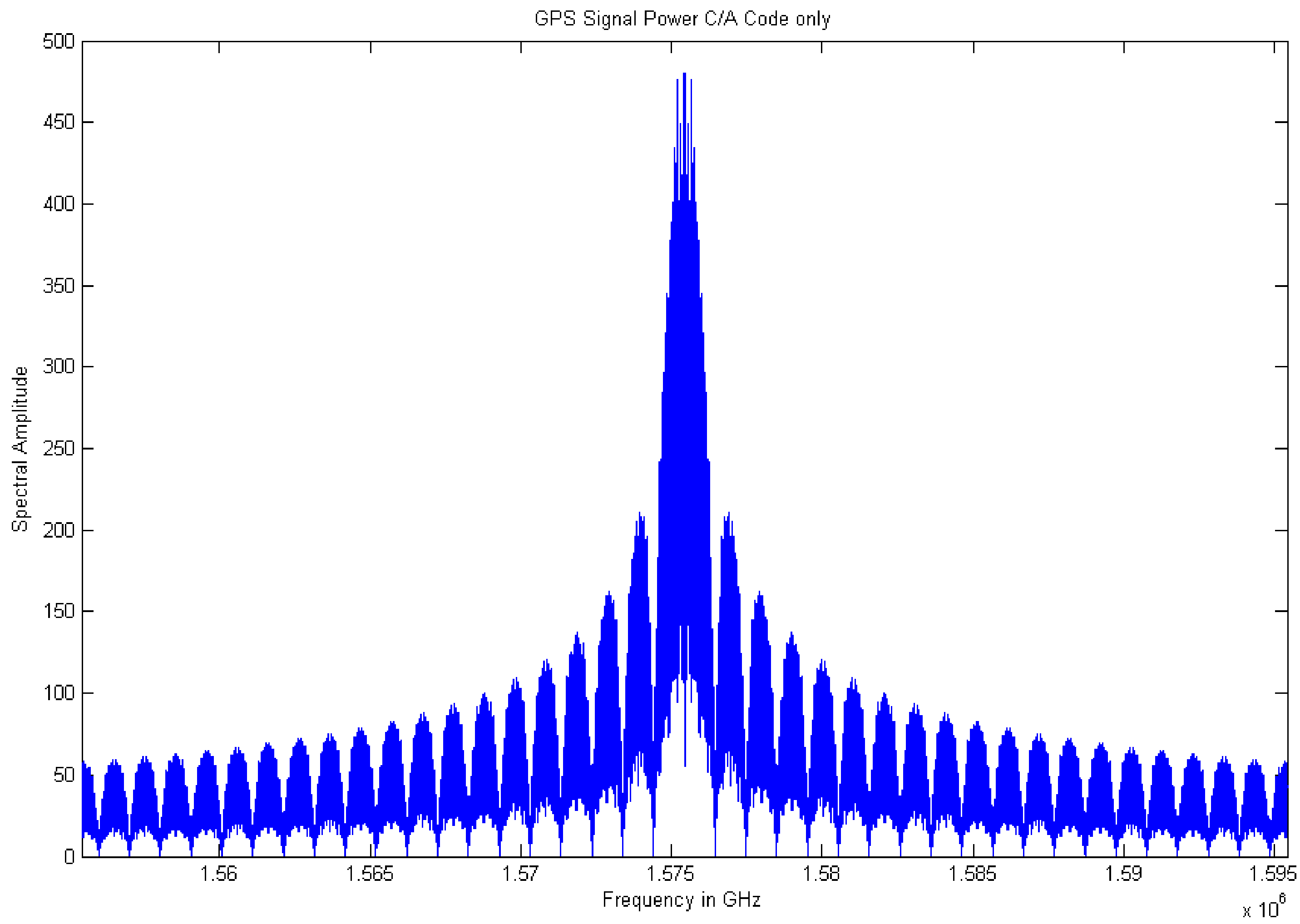
L1 Signal Generation



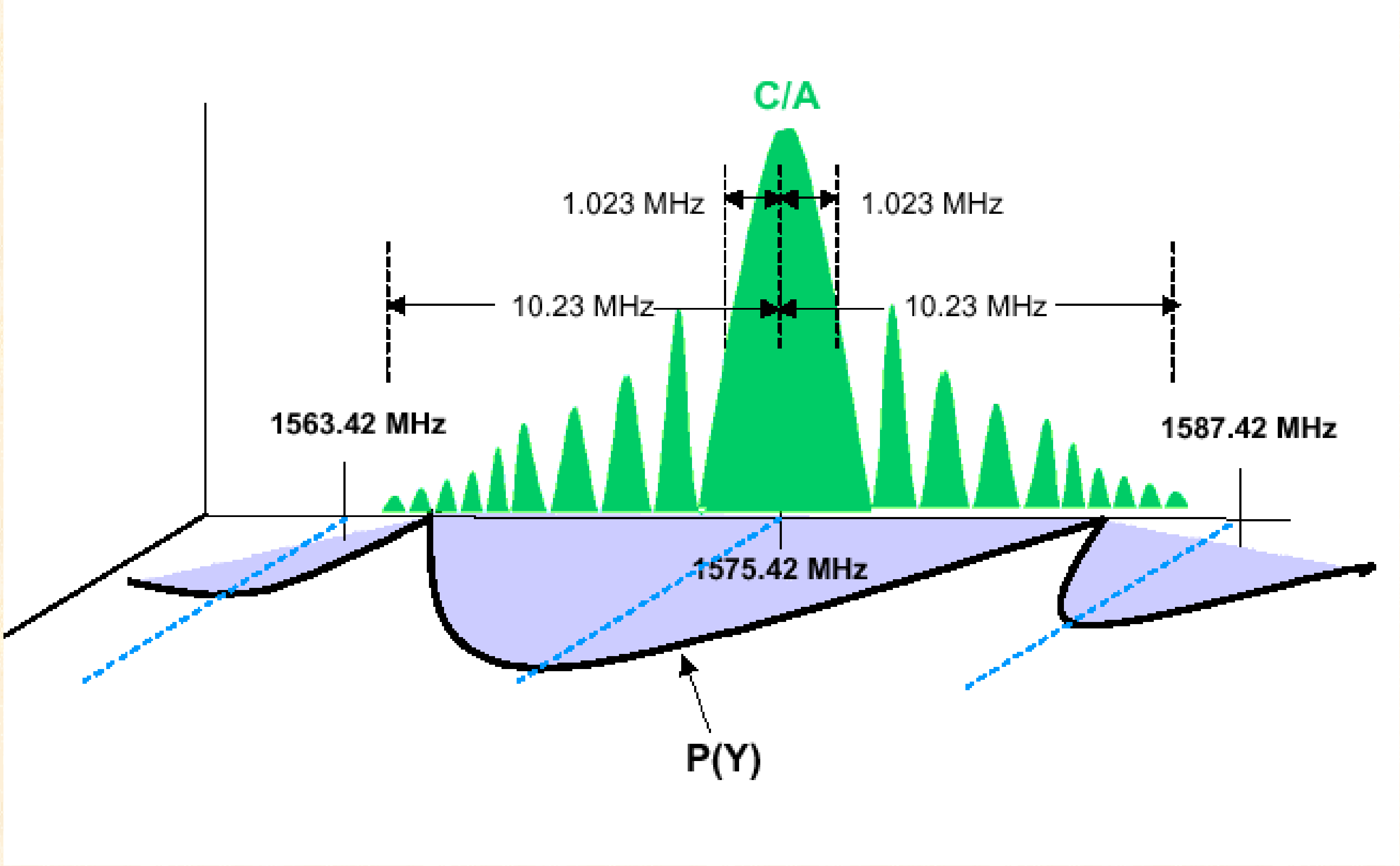
GPS-SPS Component

Mathematically: $S_{L1}(t) = G_1\ C/A_{SV}(t)\ d(t)\ \cos(w_c\ t) + G_2\ Y_{SV}(t)\ d(t)\ \sin(w_c\ t)$

L1 Signal Power C/A only



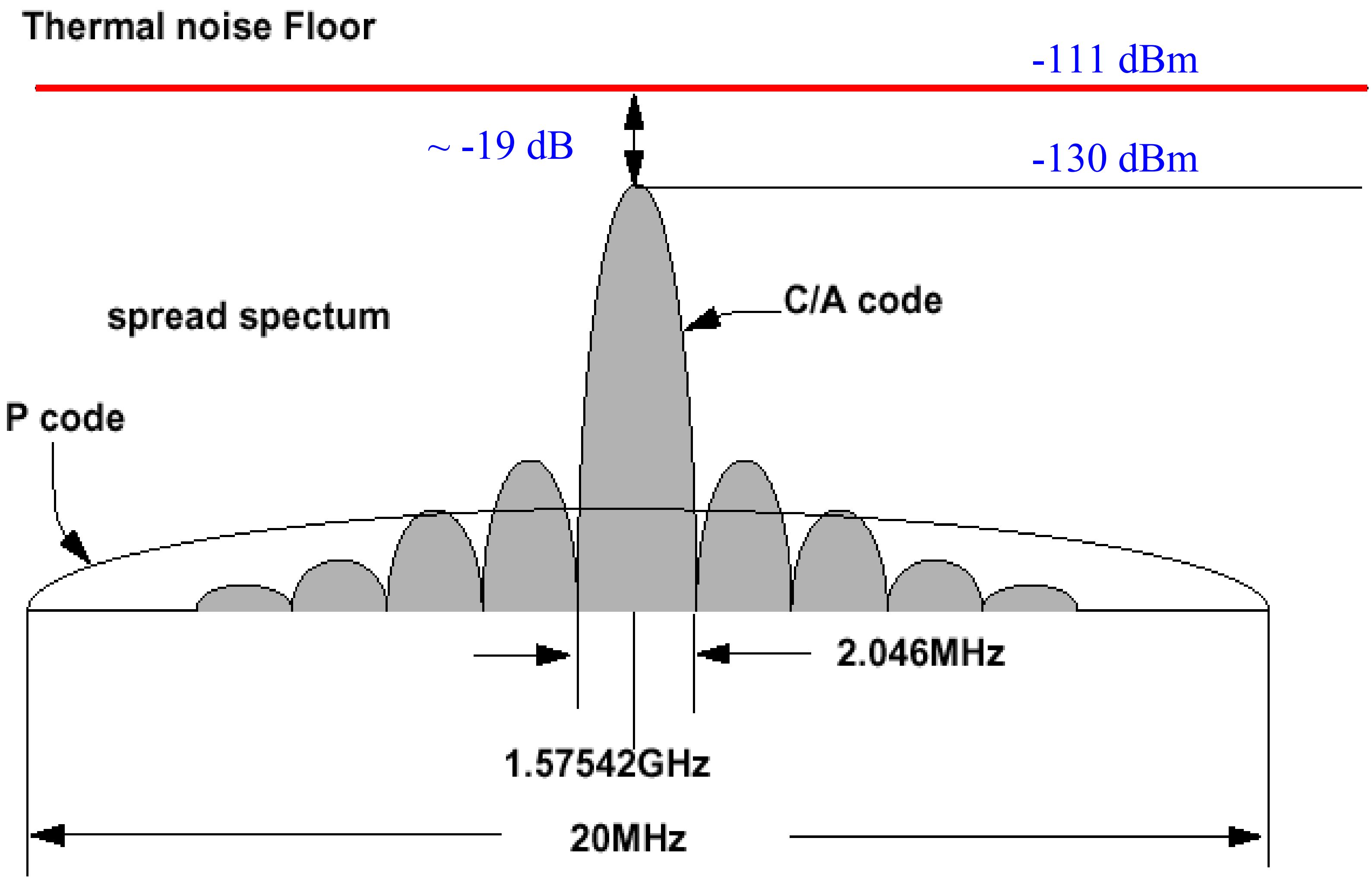
L1 Signal Power



Noise Power

- Noise power is defined as KTB
  - K = 1.3806e-23 J/S (Boltzmann's constant)
  - T = temperature in Kelvin (273)
  - B = bandwidth
- 2MHz BW (C/A code) = -111dBm
  - 640 nV into 50 ohms
- GPS signal power specified at –130dBm
  - 70 nV into 50 ohms

Received Signal



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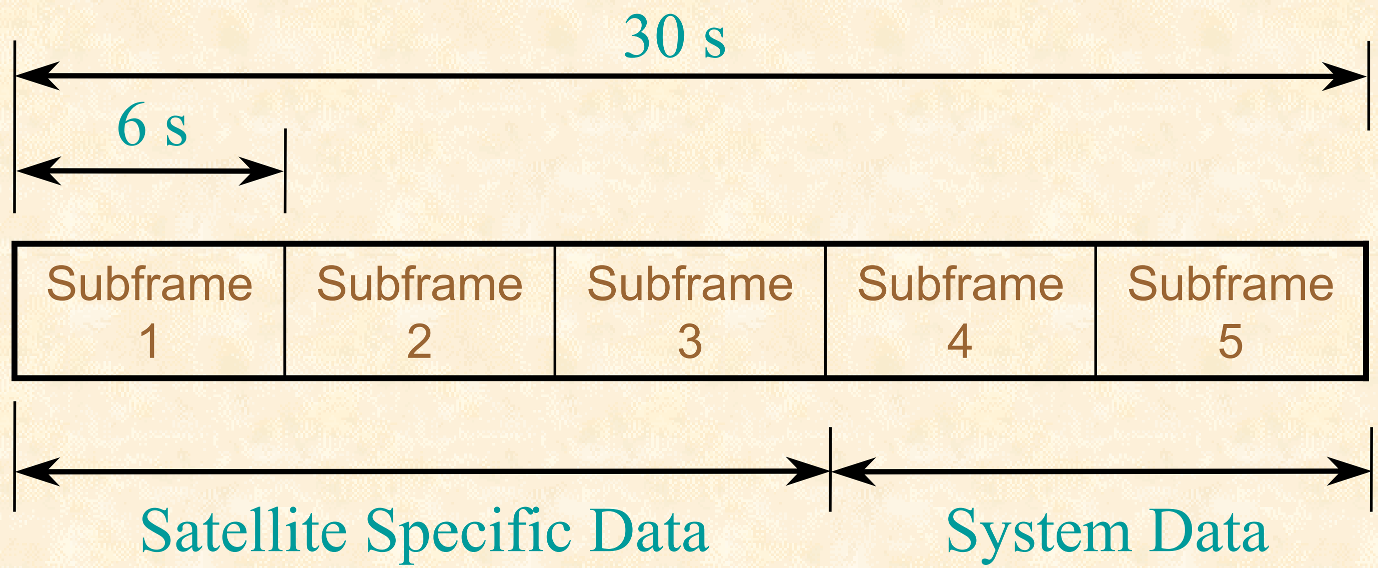
Navigation Message

- 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.

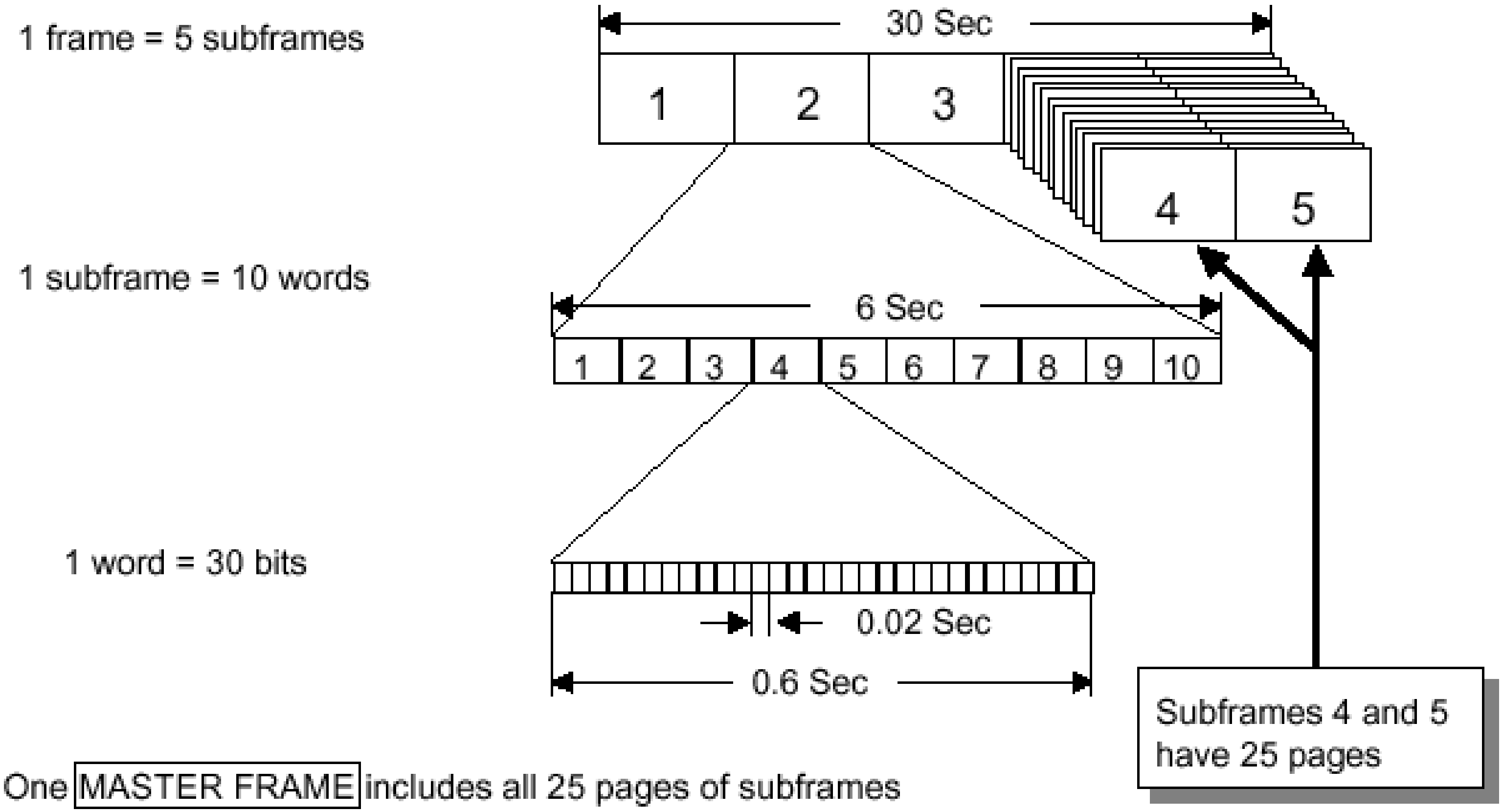


Navigation Subframe

- 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)



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

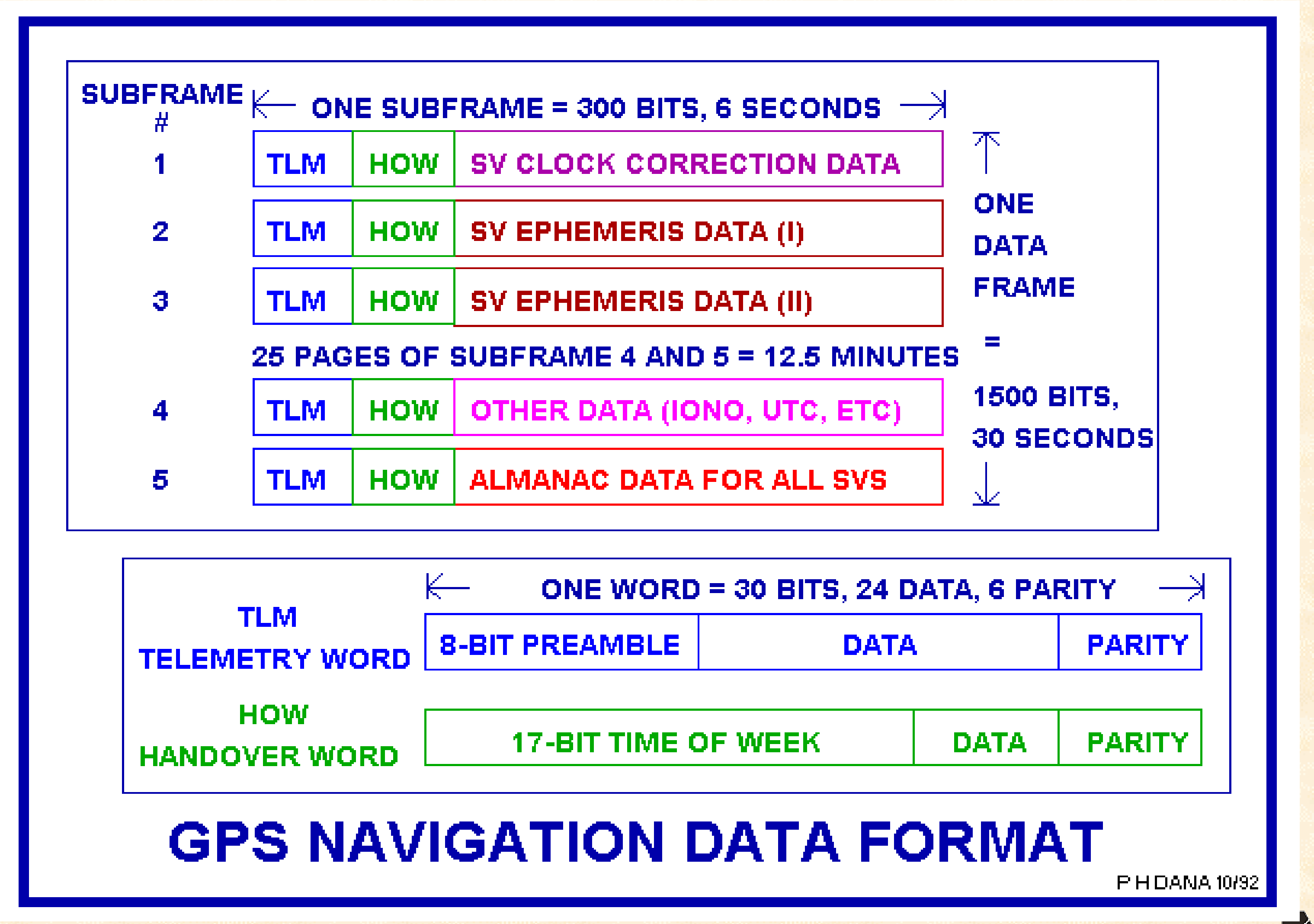
Subframe Data

- 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.

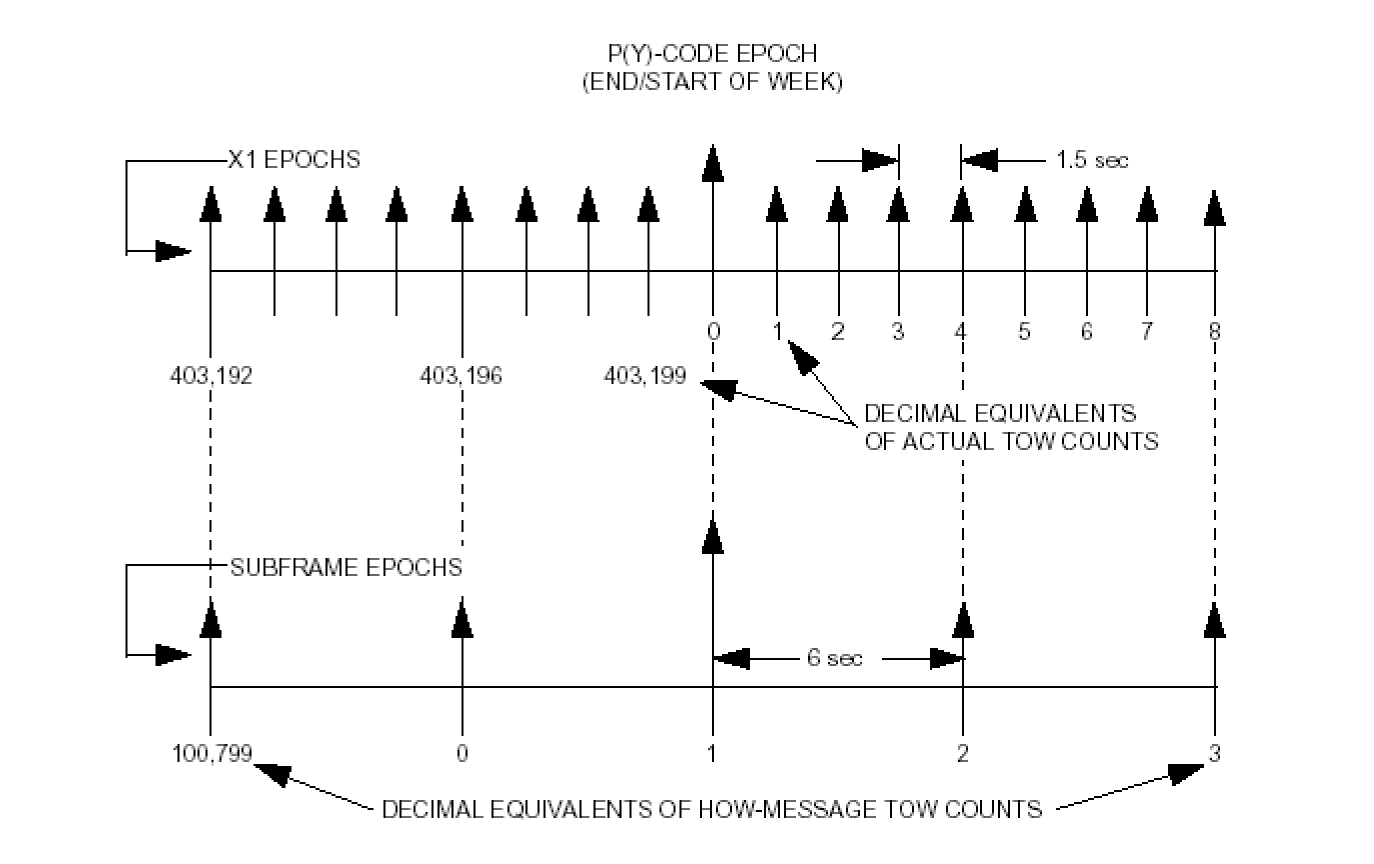
Subframe Data



GPS Time

- TOW – Time of Week
  - X1 epochs in 1.5 second increments
  - 17 MSB's are broadcast in HOW
  - Subframe epochs in 6 second increments
- Week Number
  - 1024 bit counter
  - Rollover occurred in 08/99
- GPS Time is continuous
  - UTC time has leap seconds
  - Currently a 13 second difference

Time of Week


P(Y)-CODE EPOCH
(END/START OF WEEK)
X1 EPOCHS
1.5 sec
0 1 2 3 4 5 6 7 8
403,192
403,196
403,199
DECIMAL EQUIVALENTS
OF ACTUAL TOW COUNTS
SUBFRAME EPOCHS
6 sec
100,799
0
1
2
3
DECIMAL EQUIVALENTS OF HOW-MESSAGE TOW COUNTS

Data Collection Times

- Cold start
  - No prior information – requires blind search.
  - Up to 36 seconds starting after acquisition of the 4th satellite.
- Warm start
  - Have almanac or old ephemeris and approximate position – speeds up search.
  - Up to 36 seconds after the 4th satellite.
- Hot start
  - Have valid ephemeris and approximate position.
  - Up to 6.6 seconds to collect valid time (1 subframe).

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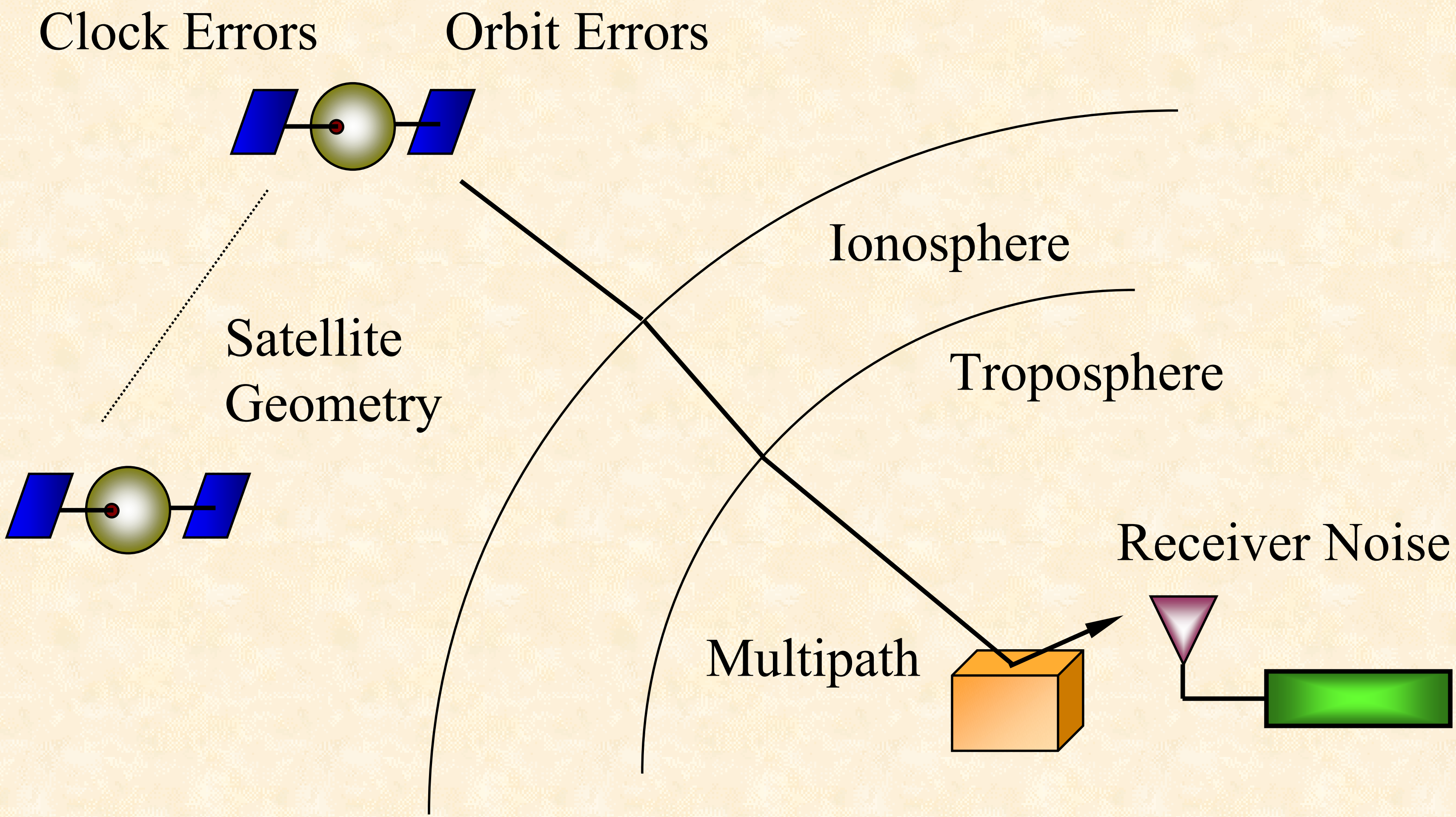
Error Sources



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

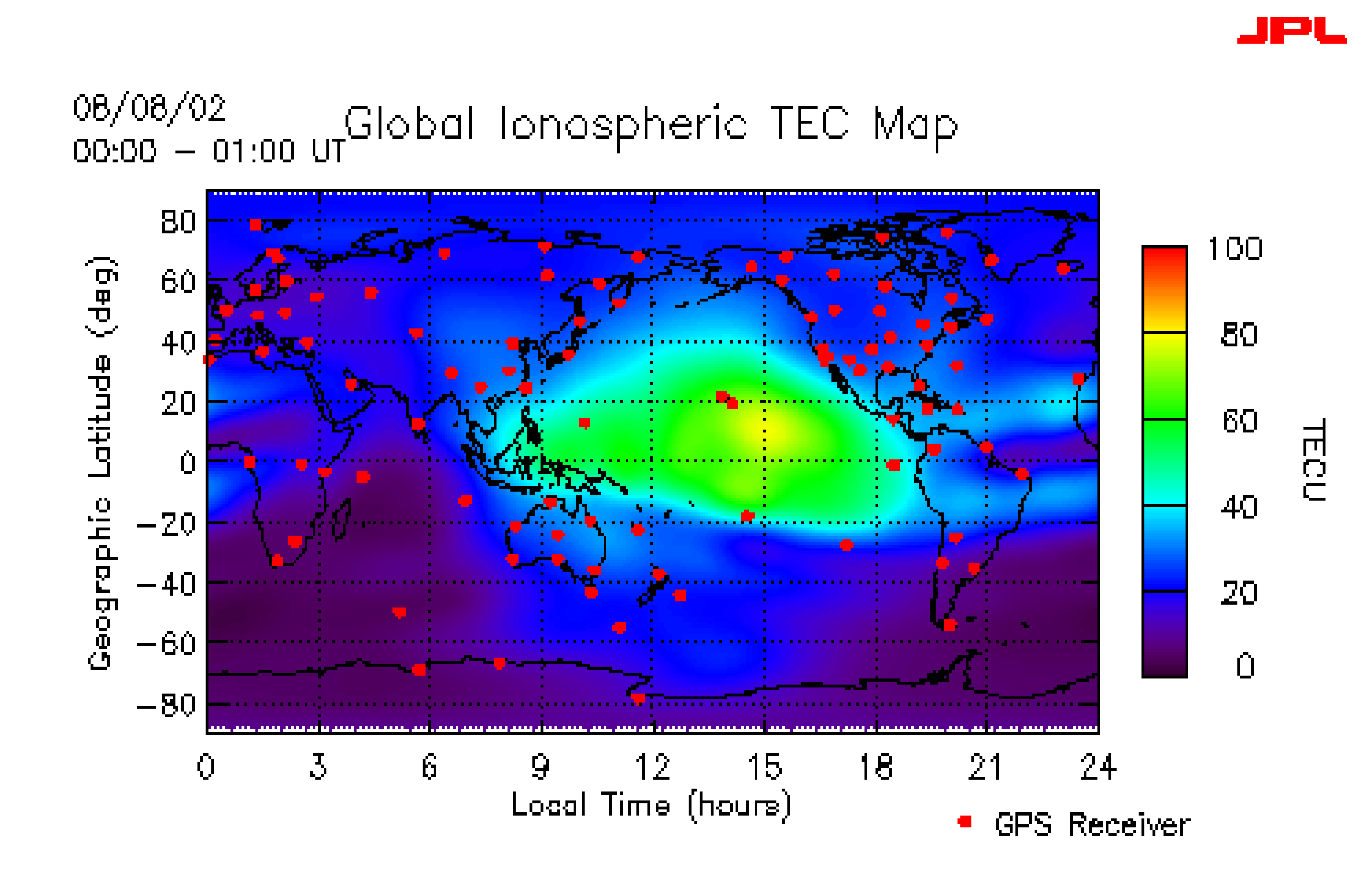
Ionospheric Errors

- 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



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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

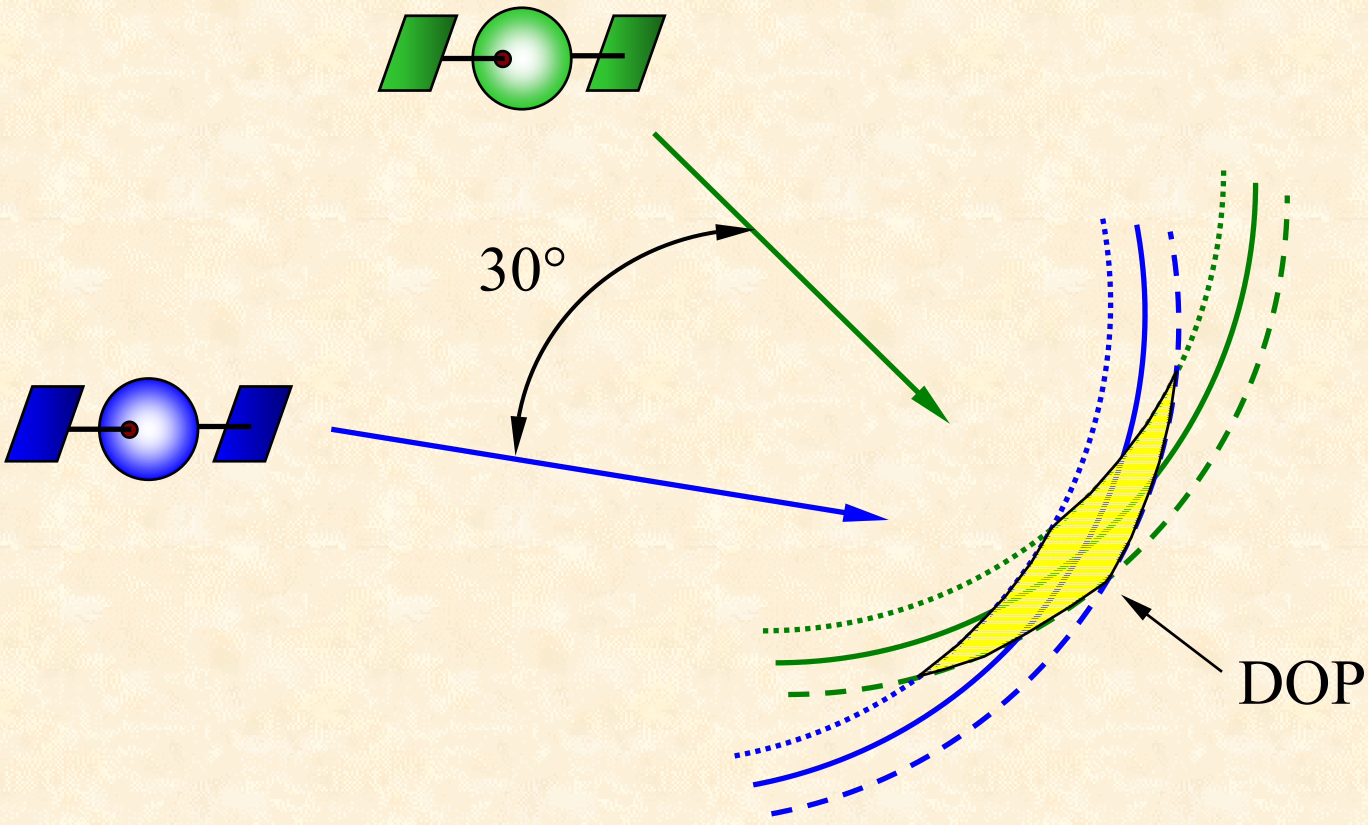
Receiver Noise

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

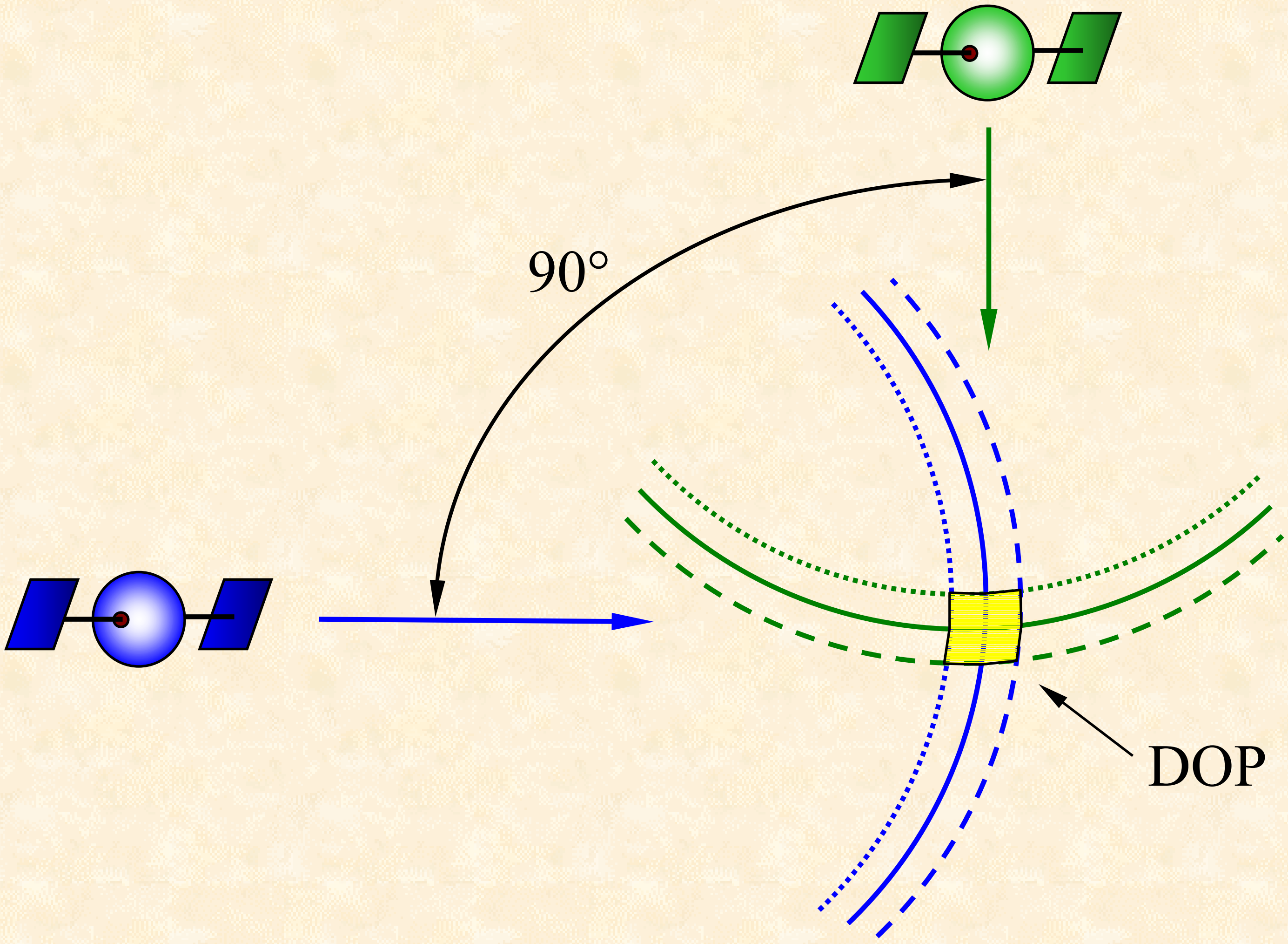
Satellite Geometry

- 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

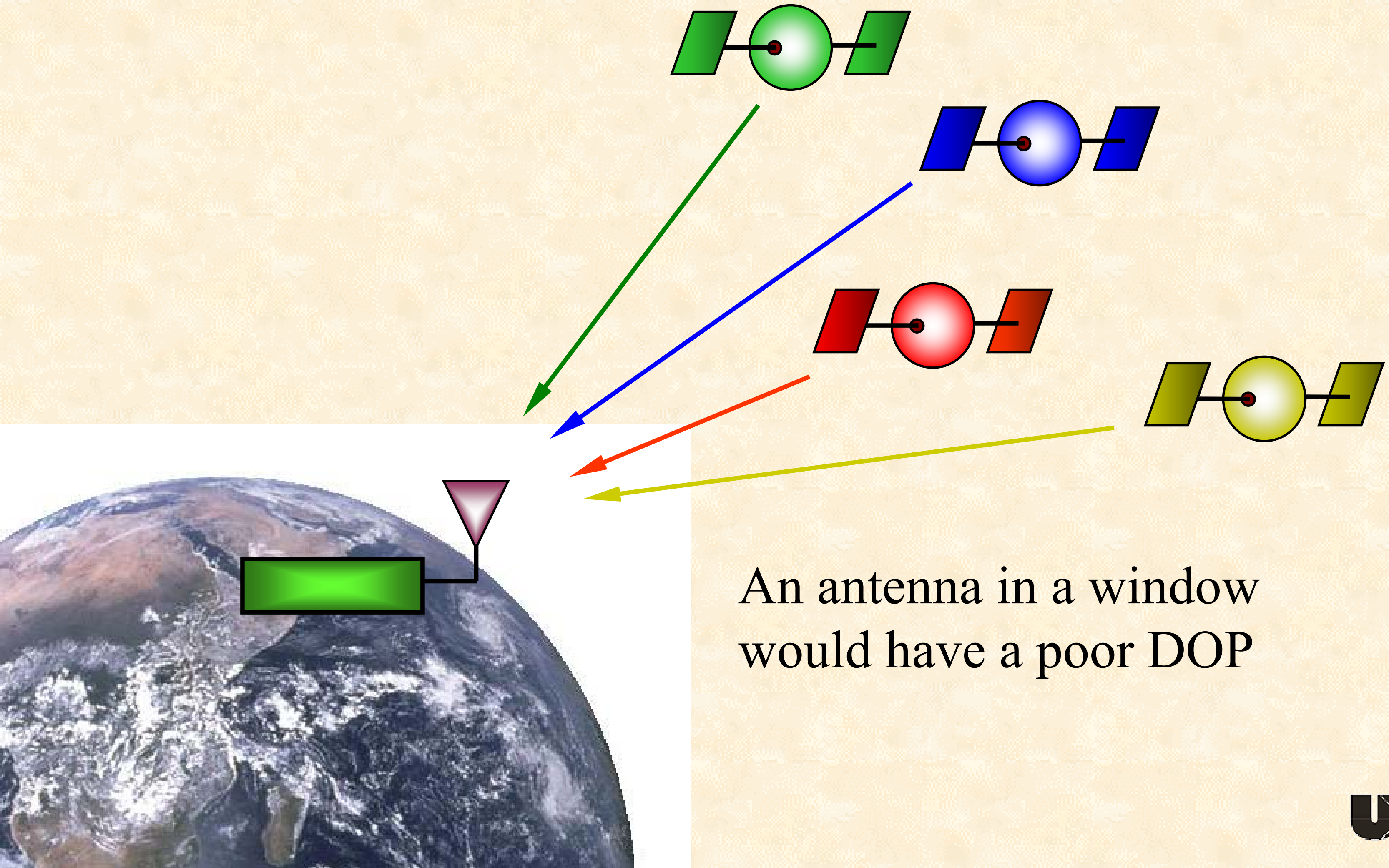
Intersecting Ranges



Intersecting Ranges

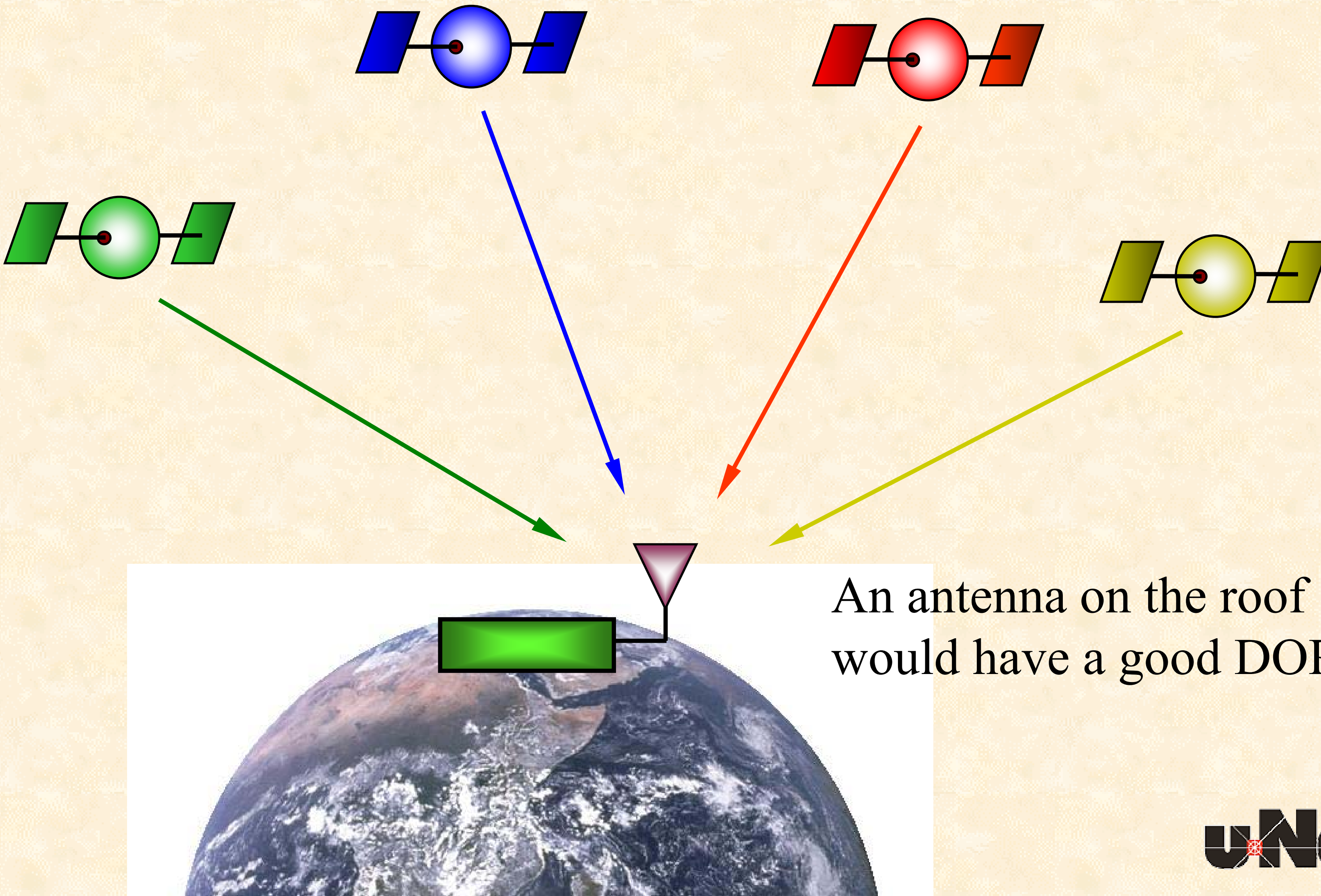


Poor DOP



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