

12.540 Principles of the Global
Positioning System
Lecture 07

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<http://geoweb.mit.edu/~tah/12.540>

Today' s Lecture

- Examine specifics of GPS signals
- Multiple modulations on same carrier signal
- Structure of signals
- GPS receiver operation and satellite acquisition.

Specifics of GPS signal

- GPS transmits at two frequencies
 - L1 1575.42 MHz ($2 \times 77 \times 10.23$ MHz)
 - L2 1227.60 MHz ($2 \times 60 \times 10.23$ MHz)
 - Wavelengths L1 ~190 mm; L2 ~244 mm
- Codes:
 - Course acquisition code (C/A) Chip rate (rate at which phase might change) 1.023 MHz
 - Precise positioning code (P code) 10.23 MHz
 - Y-code (Antispoofing code) also 10.23 MHz derived by multiplying P-code by ~20KHz code (highly classified)

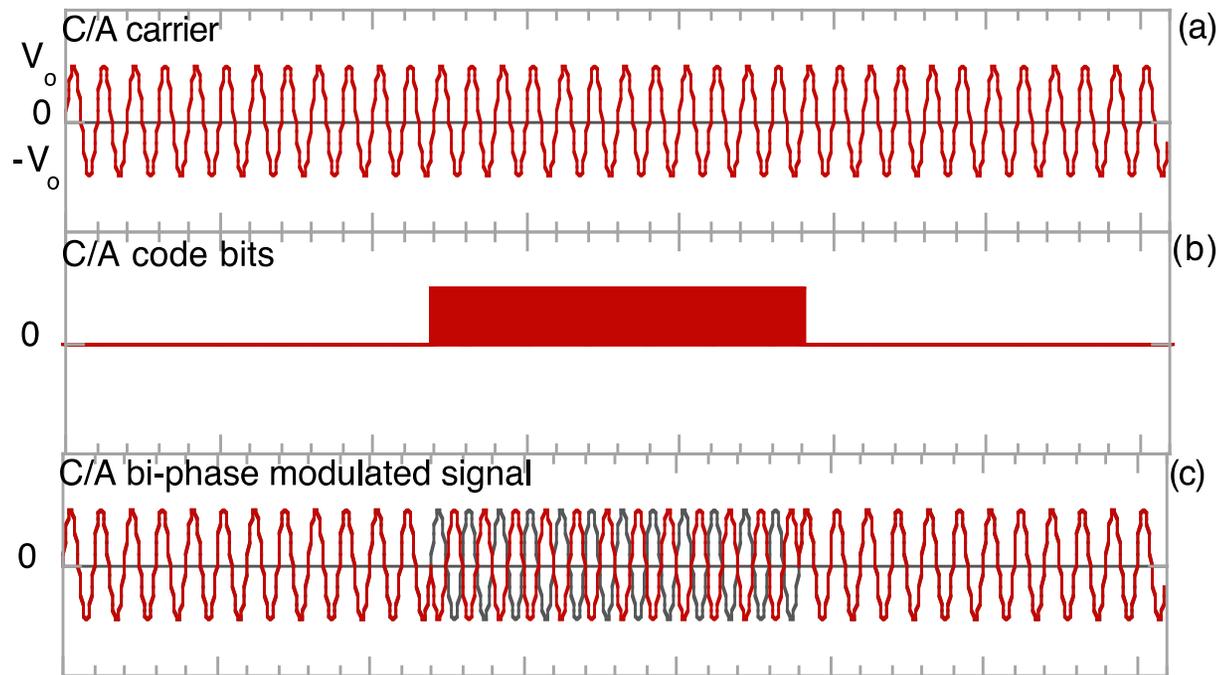
Specifics of GPS

- Code lengths:
 - C/A code is 1023 bits long
 - P-code is 37 weeks long (2×10^{14} bits in code)
 - Only one P-code, satellites use different weeks from same code (P-code repeats each week)
 - As far as we know Y-code never repeats (again classified)
- Data message: Implemented by changing sign of code at rate of 50 bits/second (low data rate)

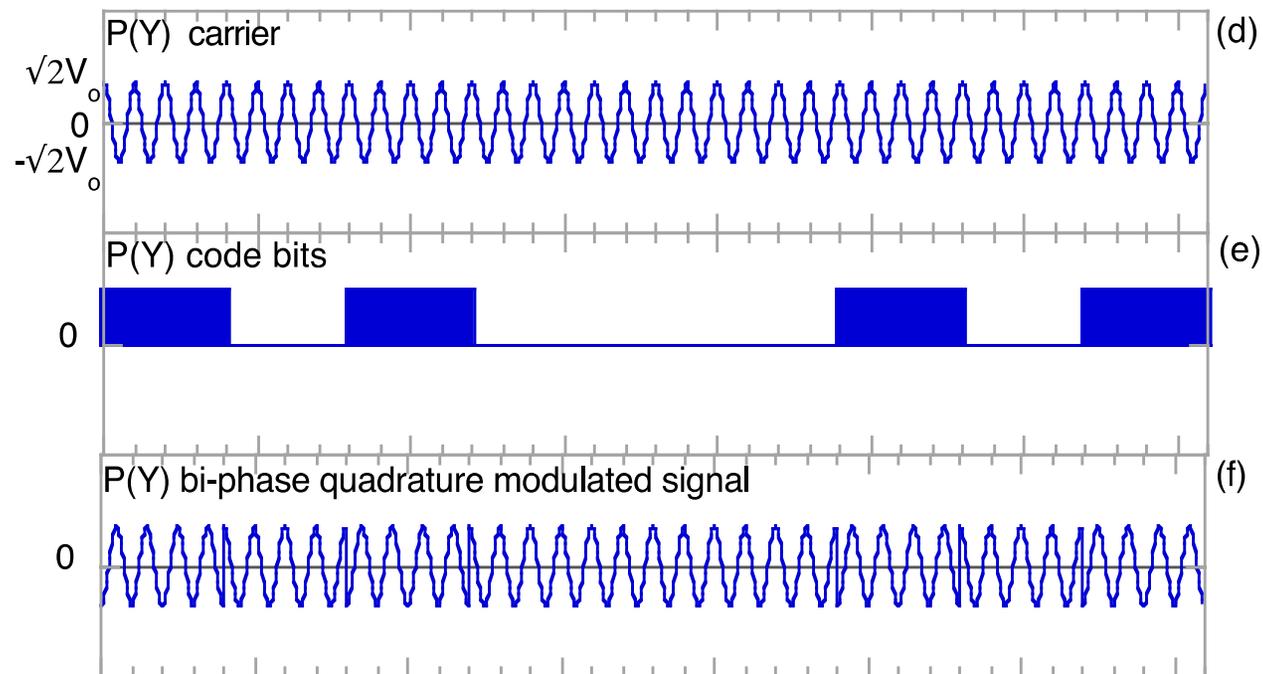
Specifics of GPS

- 10.23 MHz is fundamental frequency in GPS
- All radiofrequencies and codes generated from the same 10.23MHz crystal whose long term stability is controlled by Cesium or Rubidium clock (older satellites)
- The following graphics show schematically the construction of the GPS signal

CA Code Modulation

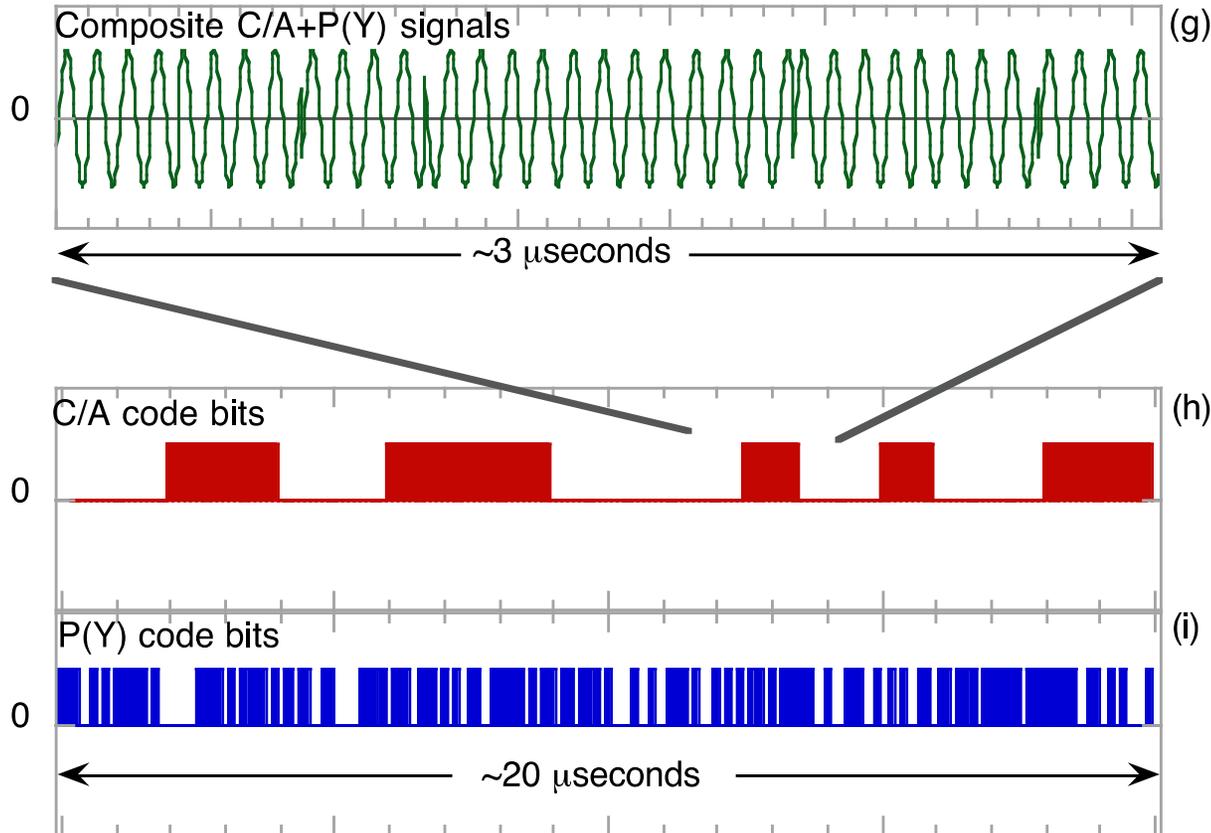


P-Code generation



P-code rate should 10 times higher than C/A code

Composite: Sum of C/A and P code



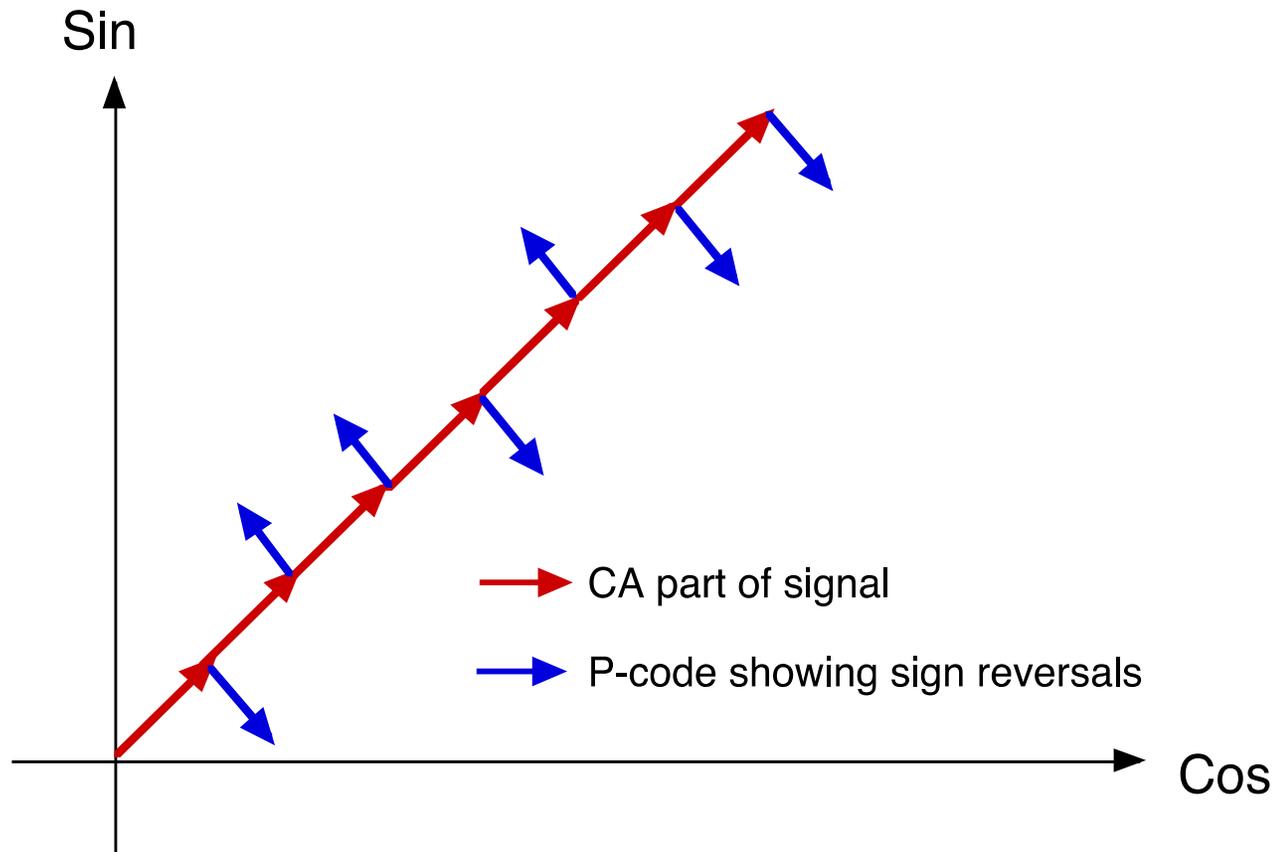
Composite GPS signal

- Last few slides show construction of composite signal
- There are sets of phase reversals on the L1 signal: C/A code at rate of 1.023 MHz and the P(Y) code add 90° out of phase at a rate of 10.23 MHz
- How do you the GPS signal if you don't know both codes (since each reverses the sign and should average to zero)? Answer next slide

Tracking knowing only C/A code

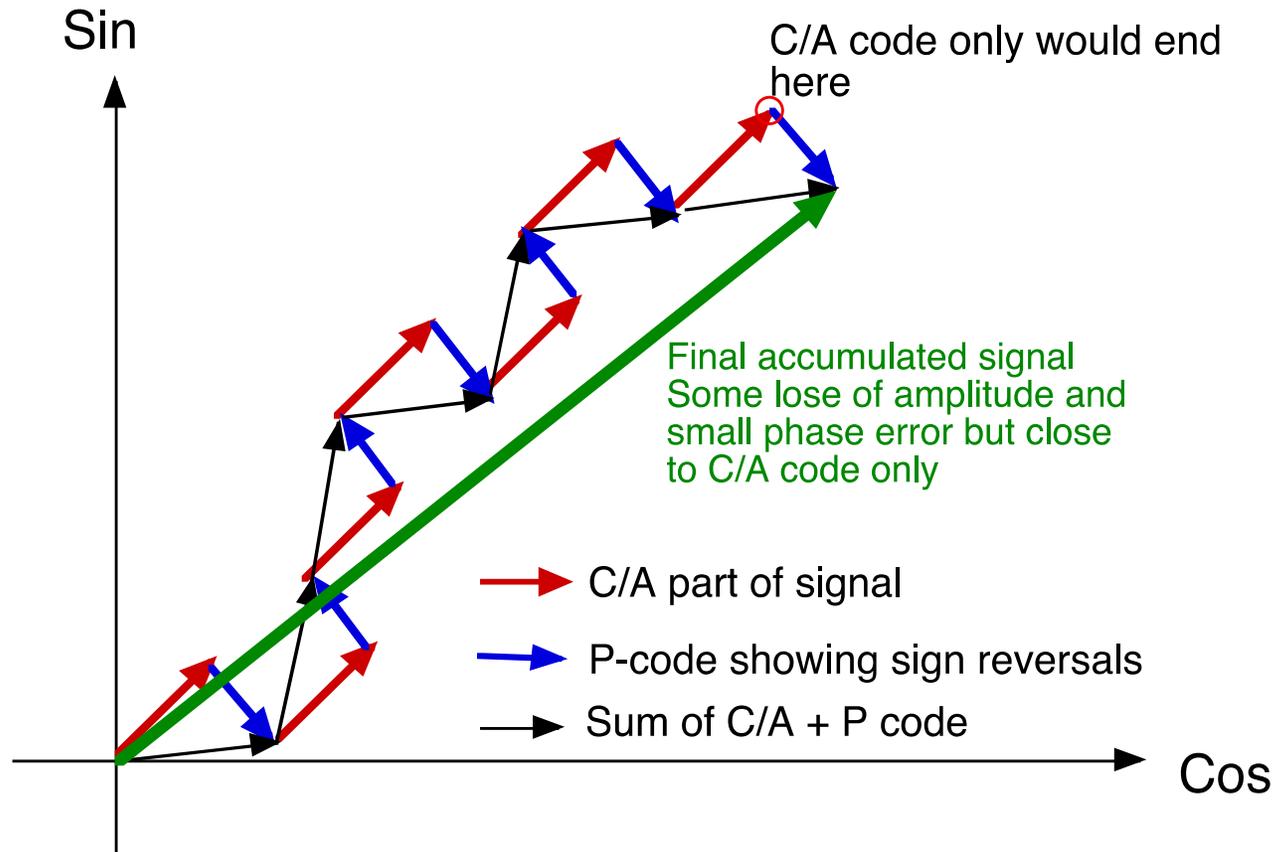
- Tracking is possible for two reasons:
 - P-code is written with 50% power
 - P-code is written out of phase
- Phasor diagram shows how this works
- Assume that C/A code known, so that sign reversals from C/A code are removed
- Consider tracking in $\sim 0.1 \mu\text{sec}$ ($1/10.23 \text{ MHz}$) segments of data (no range change and frequencies match exactly)

Tracking phasor diagram



Basic signal variation showing sign reversals of P-code

Sum of phasors as signal is tracked



Tracking GPS

- So tracking GPS at L1 with only the C/A code known poses no real problems
- Since the P-code is 10-times the rate of C/A code, there are nominally an equal number of sign reversals for P-code and so there is normally no bias (example shows odd number of sign reversals).
- For an 10-bit sequence the number of reversals is not normally even but averaged over 1 ms duration of C/A code (10230 bits) it averages closes to zero (criteria for good code design)

“Codeless” tracking

- On the L1 GPS signal both C/A and P(Y)-codes are written, but at L2 only P(Y) code is written. How to track L2 since without code, signal will average to zero?
- Three basic methods:
 - Codeless tracking: First method. Square the L2 signal. This removes the π phase changes but half the wavelength. Used until the early 1990's. Not used anymore. Requires Doppler shift to separate satellites and can have problems when Doppler shift is the same for two satellites

“Codeless” tracking

- Second method (still in use):
 - Cross-correlation of L1 (C/A removed) with L2. Since the C/A is known, it can be digitally removed from L1 signal leaving just the P(Y) code plus noise behind. Since the P(Y) code also is present in the L2 signal, cross correlation allows the time and phase differences to be determined. For L2 tracking to correct ionospheric delay (discussed in future classes) this is all that is needed.
 - Since GPS signal is below noise level (spread spectrum), this is noisy method (but not as bad as squaring since L1 signal is stronger than L2)
 - Averaging times to get signal can be as long as 10 seconds (compared to 10-100 ms for L1)

“Reduced” code tracking

- The third class of methods: Reduced code tracking:
 - Several patented (actually codeless methods are patented) are used here and go under names like Z-tracking (Ashtech).
 - These all assume the P-code is known and that the Y-code is a slowly modulated version of P-code (~20 KHz rates)
 - Basically pieces of the L2 signal are correlated using the P-code, but at the rate of Y-code additional modulation (called W-code), incoherent averages are formed because the code may have changed sign.
 - Because of low W-code rate, these tracking loops can be quite sensitive (averaging intervals of 100 ms)
 - Latest generation of receivers use these methods.

Acquisition and Future changes

- For geodetic receivers that track L2, usually an additional delay in start up while L2 is acquired (not always with latest receivers)
- PRN 17 (SV53) the first Block IIRM (launched 2005-09-30) has CA code written in L2 channel.
- For Block IIF GPS satellites, there is a third civilian frequency (L5) at lower frequency than L2 ($1176.45 = 115 * 10.23$ MHz). First launch was 2009/03/24 (PRN01/SVS49 IIR/M). L5 is meant to be a civilian frequency (it is in the Aeronautical Radionavigation Service Band (ARSB) and therefore somewhat protected. This launch was to protect the L5 allocation
- PRN25/SVS62 launched 10/5/28 and PRN01/SVS63 launched 11/7/16 are true IIF satellites
- It will not have additional encryption.

Basic Acquisition of GPS signal

- To track GPS, you need to know when the code changes occur. When searching for satellite signal how do you know this?
- You don't, but since C/A repeats every millisecond (1023 bits), you only need to search over a time range of 1 ms.
- Basic acquisition mode: The receiver generates the 1023 bits of the C/A code of the satellite it wants to acquire

Acquisition of satellites

- This code sequence multiplies in the incoming signal at different time lags over a 1 ms interval
- If the code sample does not line up with the signal from the satellite, the sum of multiplied signal will be close to zero.
- The lags that are close to the correct time offset will sum to larger values (because more of the bits in the code line up).
- Lags that generate the best correlation are refined with a finer search and iteratively the receiver code can be synchronized with the satellite

Acquisition of signal

- Nominally GPS can be detected with 1 ms of data but measurement is noisy.
- The detection of the signal only tells you time with a 1 ms ambiguity (ie., the receiver does not the specific ms segment it is tracking)
- To resolve the ms ambiguity usually requires decoding the data message and looking at the pattern of bits to make sense of the data message.
- Since the data message is transmitted at 50 bits/sec this can take a number of seconds to get enough bits to know what they represent.

Tracking GPS

- After the receiver has locked on the GPS signal and determined its own clock time using the data message format it can start tracking other satellites
- Modern receivers have parallel tracking channels (12-channel receivers) so they in principle acquire multiple satellites in at the same time.
- Watching a GPS acquire satellites, suggests that parallel acquisition is not normally done (ie., one satellite will be acquired first and once this is done more follow. Probably makes programming simpler.)

Some possible problems (rare)

- Two classes of problem can occur in the acquisition and subsequent processing
 - Time wrong by multiple milliseconds. Sometimes happens in geodetic and hand-held receivers, often when there is another problems such as poor tracking in urban area. Since $1\text{ms} = 300\text{ km}$ position from receiver can be very wrong. Restart receiver usually solves problem
 - Since code is bi-phase and change by π due to data message, “integer cycles” in phase can be half cycle off. Rare these days but old receivers can have half cycle slips.

Data message

- Data message transmitted at 50 bits/second
- It is transmitted in 5 frames each of 10 30-bit words
- Sub-frames 1-3 contain broadcast ephemeris message for satellite being tracked
- Sub-frames 4-5 contain almanac information (reduced version of broadcast ephemeris for other satellites). Cycles through satellites
- See ICD-GPS-200 for details

Data message

- The 5 frames take 6 seconds each to broadcast so 30 seconds to get complete message (broadcast ephemeris for satellite plus almanac for one other satellite)
- Complete almanac takes 12.5 minutes to receive.
- Once one satellite is locked, the almanac is used to search for other satellites

Receiver start up

- The length of time a GPS receiver takes before it outputs good data and positions depends on starting condition
 - Hot start: Only recently turned off and back on again. Since all the satellite ephemerides are good and do not need to be re-read, receiver clock and position known, start can be a few seconds.
 - Warm start: Turned for a day or so. Clock probably OK, if position still OK (receiver can tell be how long it takes to acquire satellites), generally start-up takes a few minutes
 - Cold start: Turned off for some time: Can take tens of minutes to half an hour to start. May go into auto-locate mode where it assumes nothing about position

Receiver start up

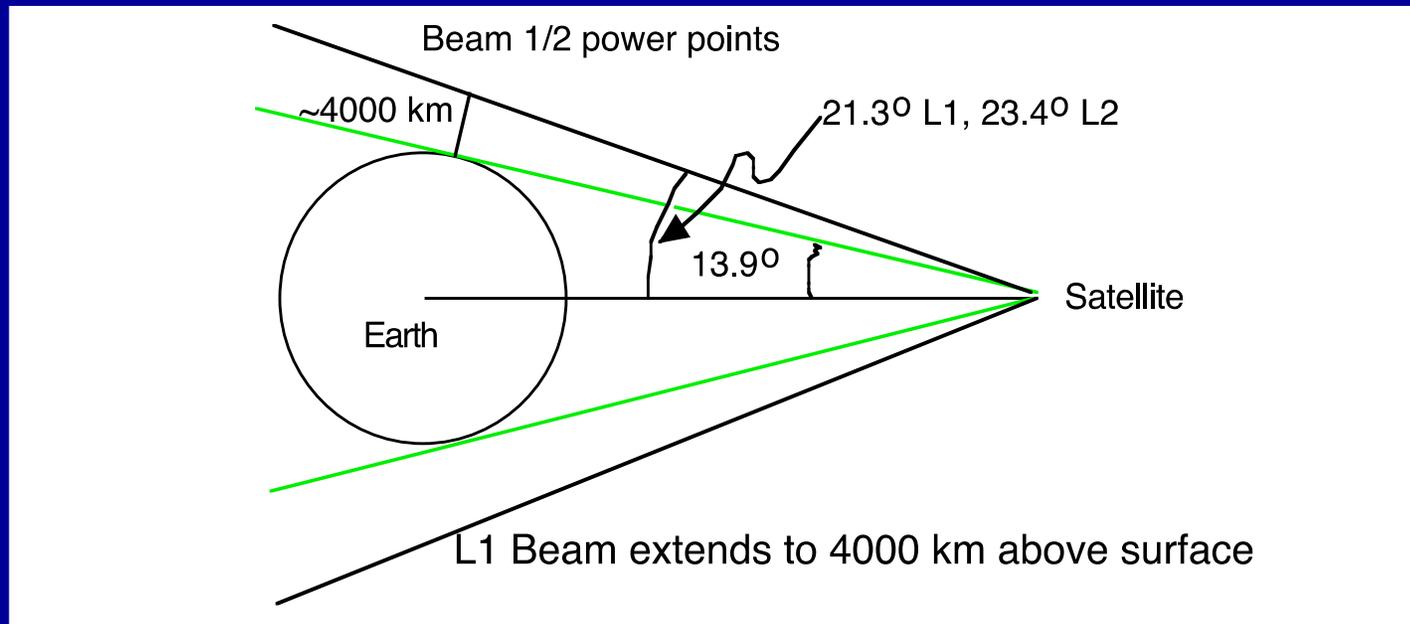
- General procedure is to:
 - Acquire one satellite to get time and almanacs
 - Acquire two more satellites to get 2-D position (assumes height is last value or value given by receiver)
 - Acquire 4th satellite to get 3-D position (talk about how this is done in later classes)
 - Acquire any other satellites that should be visible
- Most receivers use a type Kalman filter and so position and velocity states are estimated

Some guidelines

- If you are going to use a GPS receiver in poor viewing conditions (e.g. downtown area or heavy foliage), best to lock on satellites before entering area – tracking will be much more complete in bad conditions
- Some receivers make selection of satellites to get first position based on first seen ones. If these satellites become obstructed before full positioning is started, they will continue to wait for these satellites and not operate until they are reacquired. In these cases, best to turn receiver off and start again.

Satellite Coverage

- The GPS satellites point their transmission antenna to the center of the Earth.
- Main beam at L1 is 21.3° half width, at L2 23.4° (due to lower frequency)



Summary

- Examined basics of GPS signal structure and how signal is tracked
- Looked at methods used to acquire satellites and start tracking
- Next week look at observable definitions and how they are used

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