Module 11

Modern Navigation Systems

Navigating with GPS

Module 11B

GPS Signal Architecture

Summary of Module 11

- The module begins with a description of the GPS space segment (i.e., the satellite constellation). (11A)
- **This is followed by a description of the signal structure that provides the "ranging codes" used by GPS receivers in order to determine position, velocity, etc. (11B)**
- Students will use actual GPS almanac data to compute azimuth (i.e., values for Hc) and elevation angles to GPS satellites from an assumed position on earth, as was done in Module 5. (11C)

Reading

- Read Chapter 5, “Satellite Navigation Systems,” of the primary text (Kayton & Fried).
- Download and peruse ICD 200, which describes the “space segment” and “navigation user interfaces”
  - Download from Blackboard, or from
  - http://www.gps.gov/technical/icwg/meetings/2010/03/10/AFD-100302-042.pdf

Viewing

- After reading and listening to this module, watch the MP4 file entitled “GPS Receiver Video”

Use of PRNs for ranging codes

- GPS pseudorandom codes are nothing more than a seemingly random (but actually non-random) sequence of 1’s and 0’s
  - The sequence for each satellite is different
  - The particular codes used by GPS are from a family of codes called “Gold” codes
- When each satellite transmits its sequence (which repeats every 20 milliseconds) there exists an “all 1’s” portion of the sequence (which is 10 bits long) for each satellite is aligned in time across the constellation of satellites at the time of transmission from the satellite
- But, because of different travel time delays (since the distance to a receiver from each satellite is different), the sequences are not aligned when received by the GPS user.
- The receiver converts these measurements to “pseudoranges” as described (rather cryptically) in the primary text.
- Then, using detail from the navigation message, these data are used to compute a position fix, along with estimates of speed and velocity (the latter including the direction of travel, e.g., one’s heading.

The navigation message (recap from 11A)

- The C/A code transmits it PRNs at 1,023,000 code ‘chips” per second.
- Superimposed on this is a 50 bit per second “navigation” message, which provides the orbital parameters and clock error estimates for each of the satellites
- This message permits ranging information derived from reception of the prn codes to be converted into a navigation fix using the trigonometry described in the previous modules (e.g., the equations of Richharia, et al.)

From chapter 5 of Kayton and Fried

The GPS navigation message is the information supplied to the GPS users from a GPS satellite. These data are provided via the 50-bps data bit stream modulated on the PRN codes described in Section 5.5.5, providing the user with the information needed to navigate [34]. Among other data, the user is provided with information from which can be computed the position and velocity of the satellite and the time and frequency offset of its clock, as well as information to resolve ambiguities in the received C/A code. The other information includes almanacs for determining the position, velocity, and clock offsets of the other satellites, an ionosphere model and a description of the time offset between GPS system time and universal coordinated time (UTC).

Frames, Subframes, and TLM and HOW Words The GPS navigation message consists of a frame of five 300-bit subframes spanning 30 seconds of time as illustrated in Figure 5.16 [7, 8]. Each six-second subframe consists of ten

The Navigation Processor

- GPS receivers measure the relative offsets of the PRNs received from each satellite
- These are turned into relative time delays
- These are turned into “pseudoranges” by scaling via the speed of light
- Three-dimensional trigonometry is used to turn these ranges into a GPS receiver position fix, typically in a floating point processor

GPS Signal Description Details

- These are captured in a variety of GPS Program Office Interface Control Documents (ICDs), which are publically available to all
- ICD-200 is used for the discussion that follows

Gold Codes, Air Force Style – from ICD-200

3.2.1.3 C/A-Code. The PRN C/A-Code for SV ID number i is a Gold code, Gi(t), of 1 millisecond in length at a chipping rate of 1023 Kbps. The Gi(t) sequence is a linear pattern generated by the modulo-2 addition of two subsequences, G1 and G2i, each of which is a 1023 chip long linear pattern. The epochs of the Gold code are synchronized with the X1 epochs of the P-code. As shown in Table 3-I, the G2i sequence is a G2 sequence selectively delayed by pre-assigned number of chips, thereby generating a set of different C/A-codes. Assignment of these by GPS PRN signal number is given in Table 3-I. Additional PRN C/A-code sequences with assigned PRN numbers are provided in Section 6.3.5.1, Table 6-I

C/A Code Generation

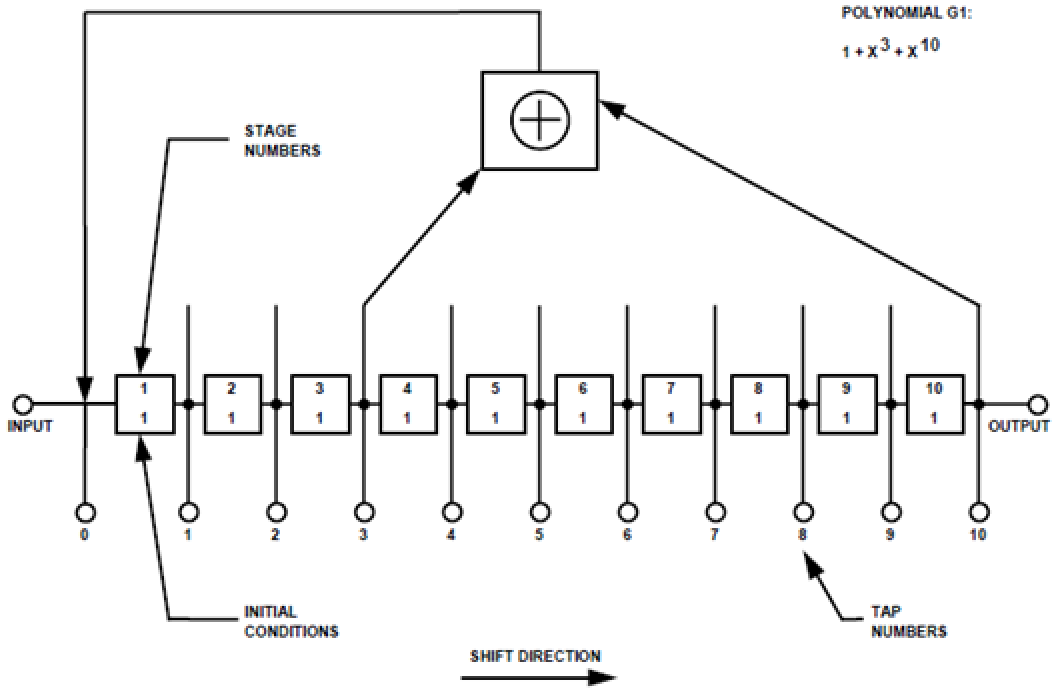
3.3.2.3 C/A-Code Generation. Each Gi(t) sequence is a 1023-bit Gold-code which is itself the modulo-2 sum of two
1023-bit linear patterns, G1 and G2i. The G2i sequence is formed by effectively delaying the G2 sequence by an
integer number of chips. The G1 and G2 sequences are generated by 10-stage shift registers having the following
polynomials as referred to in the shift register input (see Figures 3-8 and 3-9).

G1 = X10 + X3 + 1, and

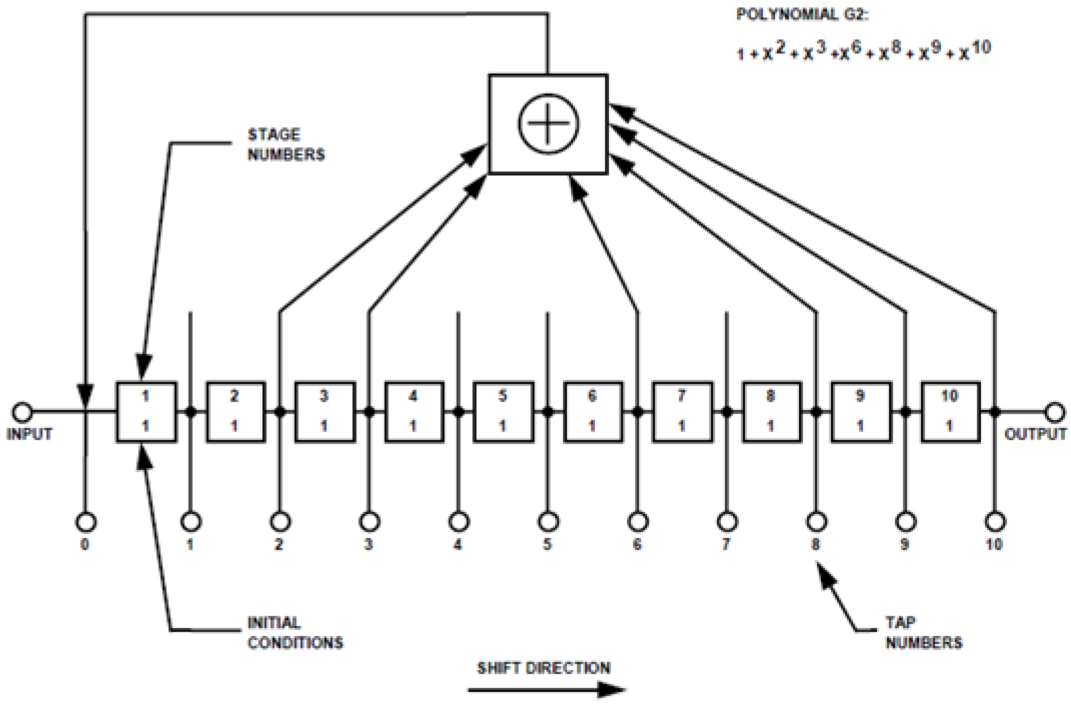
G2 = X10 + X9 + X8 + X6 + X3 + X2 + 1.

The initialization vector for the G1 and G2 sequences is 1111111111.

First C/A Polynomial (i.e., shift register onboard the satellite)



Second C/A Polynomial, also onboard the satellite



Gold Code and Nav Message Generation

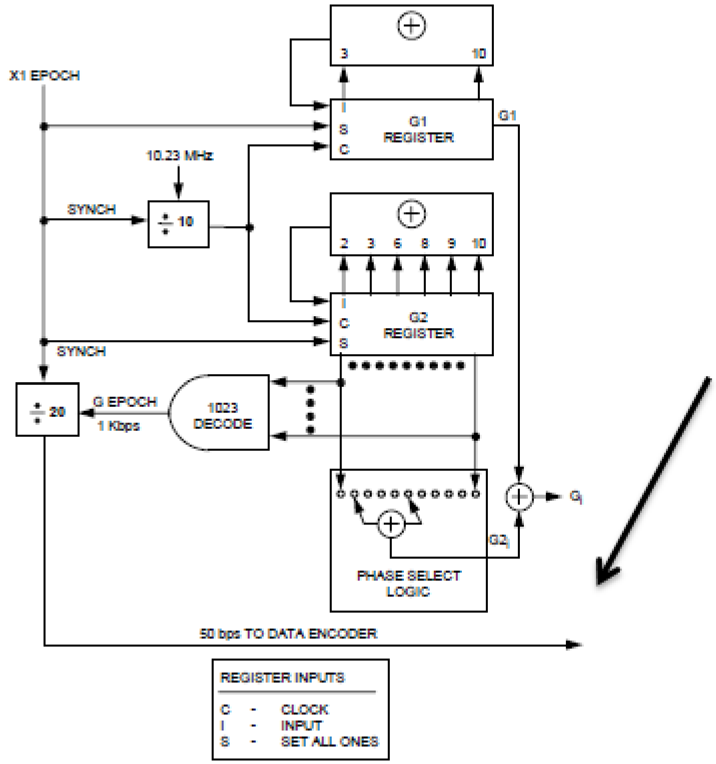


Figure 3-10. Example C/A-Code Generation

Note: 50 bps "baseband Navigation message" contains orbital parameters for the entire constellation of GPS satellites. This is needed in order to convert code tracking information into a navigation fix.

Forming the PRNs for each Satellite

Table 3-I. Code Phase Assignments (sheet 2 of 2)

SV ID No.	GPS PRN Signal No.	Code Phase Selection C/A(G2$_i$)****	Code Phase Selection (X2$_i$)	Code Delay Chips C/A	Code Delay Chips P	First 10 Chips Octal* C/A	First 12 Chips Octal P
20	20	4 ⊕ 7	20	472	20	1715	4343
21	21	5 ⊕ 8	21	473	21	1746	
22	22	6 ⊕ 9	22	474	22	1763	
23	23	1 ⊕ 3	23	509	23	1063	
24	24	4 ⊕ 6	24	512	24	1706	
25	25	5 ⊕ 7	25	513	25	1743	
26	26	6 ⊕ 8	26	514	26	1761	
27	27	7 ⊕ 9	27	515	27	1770	
28	28	8 ⊕ 10	28	516	28	1774	
29	29	1 ⊕ 6	29	859	29	1127	
30	30	2 ⊕ 7	30	860	30	1453	
31	31	3 ⊕ 8	31	861	31	1625	
32	32	4 ⊕ 9	32	862	32	1712	
***	33	5 ⊕ 10	33	863	33	1745	
***	34**	4 ⊕ 10	34	950	34	1713	
***	35	1 ⊕ 7	35	947	35	1134	
***	36	2 ⊕ 8	36	948	36	1456	
***	37**	4 ⊕ 10	37	950	37	1713	4343

* In the octal notation for the first 10 chips of the C/A code as shown in this column, the first digit (1) represents a "1" for the first chip and the last three digits are the conventional octal representation of the remaining 9 chips. (For example, the first 10 chips of the C/A code for PRN Signal Assembly No. 1 are: 1100100000).

** C/A codes 34 and 37 are common.

*** PRN sequences 33 through 37 are reserved for other uses (e.g. ground transmitters).

**** The two-tap coder utilized here is only an example implementation that generates a limited set of valid C/A codes.

⊕ = "exclusive or"

NOTE: The code phase assignments constitute inseparable pairs, each consisting of a specific C/A and a specific P code phase, as shown above.

Rules for combining Gold Code polynomial offsets to produce the Satellite-specific PRNs

GPS "User Segment"

- The following material describes the Zarlink and Plessey family of GPS receiver chips
  - o The Zarlink is the receiver architecture that is demonstrated in the MP4 recording for this module.
- The receiver reverses the processes performed by the satellites
  - o Note the use of tracking loops
- Supporting material is available at Zarlink's web site.

The Plessey GPS 1020 GPS integrated circuit

GP1020

TYPICAL GPS RECEIVER (Fig. 2)

All satellites use the same L1 frequency of 1575·42MHz, but different Gold codes, so a single front-end may be used. To achieve better sky coverage it may be desirable to use more than one antenna, in which case separate front-ends will be needed.

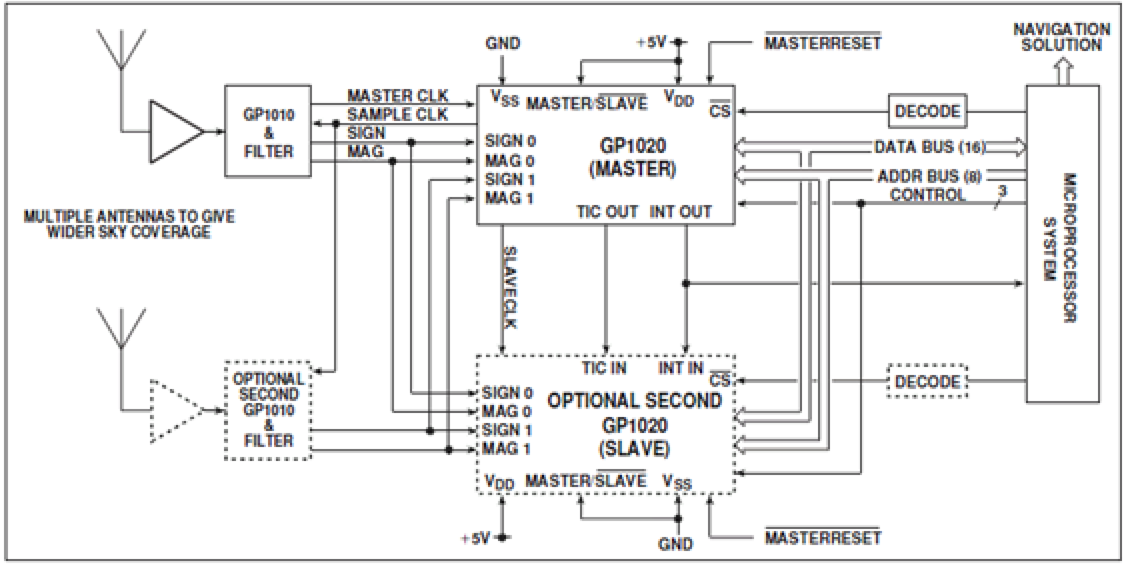


Fig. 2 GPS receiver simplified block diagram

The Plessey GP2010 GPS "front end" receiver chip

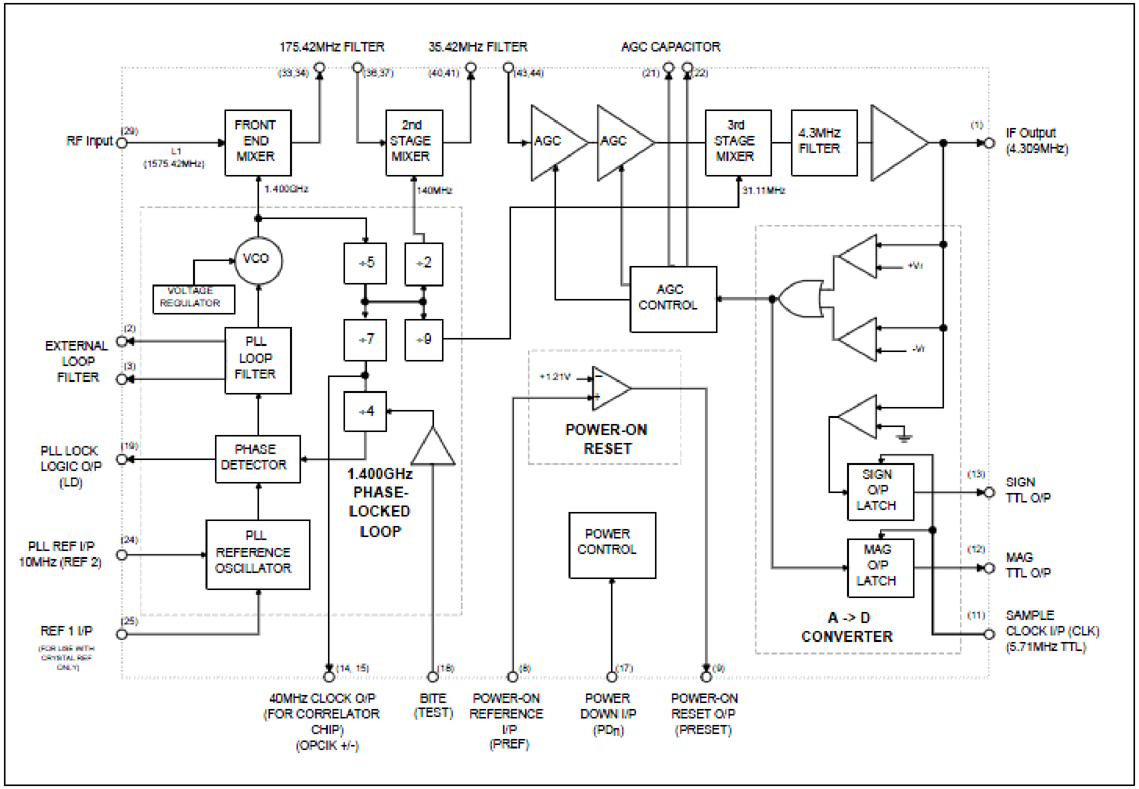


Fig. 2 Block diagram of GP2010

Plessey Tracker/Correlator module

GP1020

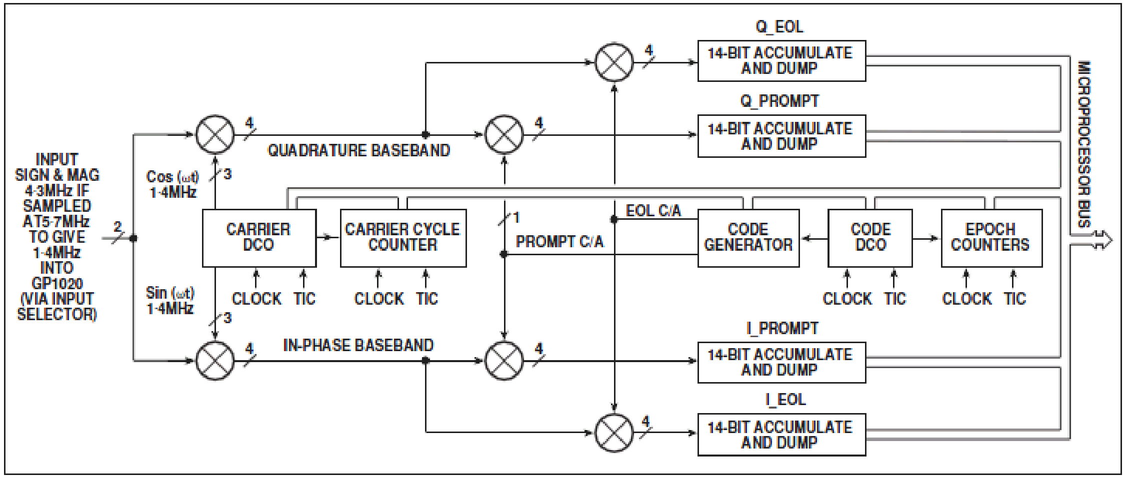


Fig. 11 Tracking module simplified block diagram

GPS Radio Frequency Link Budgets

- Link budgets are the subjects of Satcom courses (e.g., 525.440 and 525.789)
- However, note that the power levels of the received signals are less than kTB, where B is the 2 MHz signal bandwidth and T is a typical receiver noise temperature of ~100 Kelvin.
- The processing gain of (1023 chips per second) divided by the demodulated signal rate of 50 bps provides the processing gain needed to raise the recovered signal above the system noise floor.

GPS RF Signal Characteristics

Table 3-Va. Received Minimum RF Signal Strength for Block IIA, IIR, IIR-M IIF, and III Satellites (20.46 MHz Bandwidth) ~~over the Bandwidth Specified in 3.3.1.1~~

SV Blocks	Channel	Signal	
		P(Y)	C/A or L2 C
~~II/~~IIA/IIR	L1	-161.5 dBW	-158.5 dBW
	L2	-164.5 dBW	-164.5 dBW
IIR-M/IIF	L1	-161.5 dBW	-158.5 dBW
	L2	-161.5 dBW	-160.0 dBW
III	L1	-161.5 dBW	-158.5 dBW
	L2	-161.5 dBW	-158.5 dBW

ICD200

GPS signal spectrum

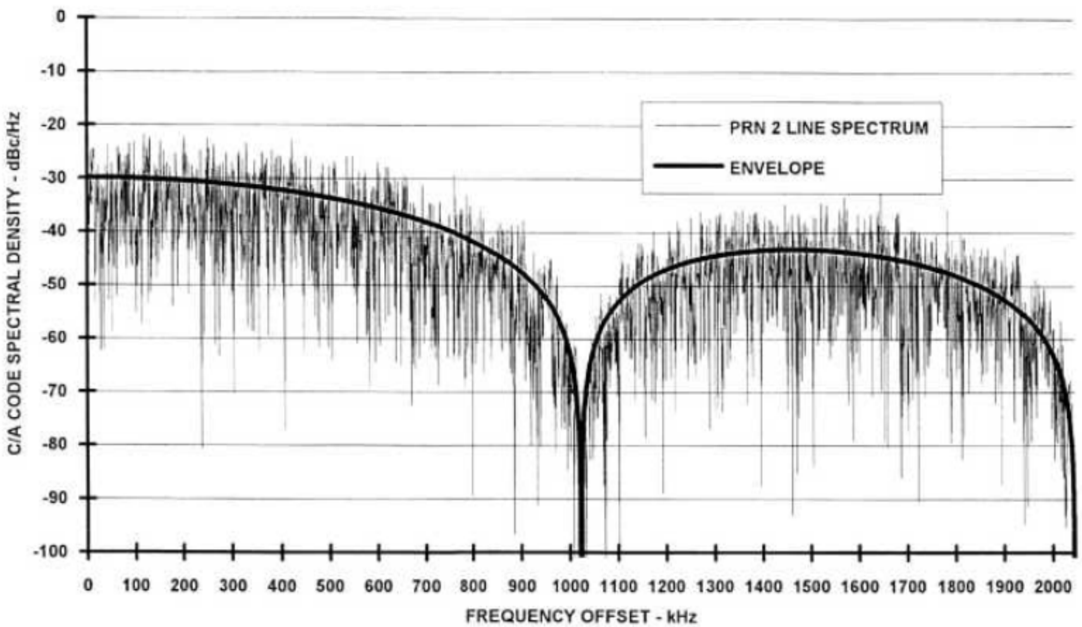


Figure 5.15 PRN 2 C/A code spectral density.

This is a classic (sin x)/x spread spectrum signal, as shown in the primary text by Kayton & Fried.

Assignment 11-2

1. Compute the distance from a point on the earth to a GPS satellite that is located at the horizon. Express your answer in meters, and compare it to the distance in meters to a satellite that is directly overhead.
2. Compute the travel time, at the speed of light, for each of these two signals.
3. The chip time of a PRN is about 1 microsecond, which corresponds to a travel distance of 1000 feet when the speed of light is approximated as 1 foot per nanosecond. A typical tracking loop in a radio receiver can track a signal to a precision of about 5% of a code chip. Given this, estimate the accuracy of a C/A code receiver, before consideration of GDOP. Compare this to the position error numbers presented in the MP4 video.

End of Mod 11B