12.215 Modern Navigation

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Summary of last class

- Today we covered Electronic Distance Measurement (EDM)
- History
- Methods:
  - Theory: Propagating electromagnetic signals
  - Timing signal delays
  - Use of phase measurements
  - Application areas (other than GPS)
- Left you with thought of how we solve the duty cycle (not transmitting all the time) and user interaction with GPS?

Today's Class

- Fundamentals of GPS
- Method of encoding GPS signals (bi-phase, quadrature modulation)
- Fundamentals of correlation methods used
- Specifics of the GPS system
  - Frequencies
  - Chip rates
  - Data rates and message content

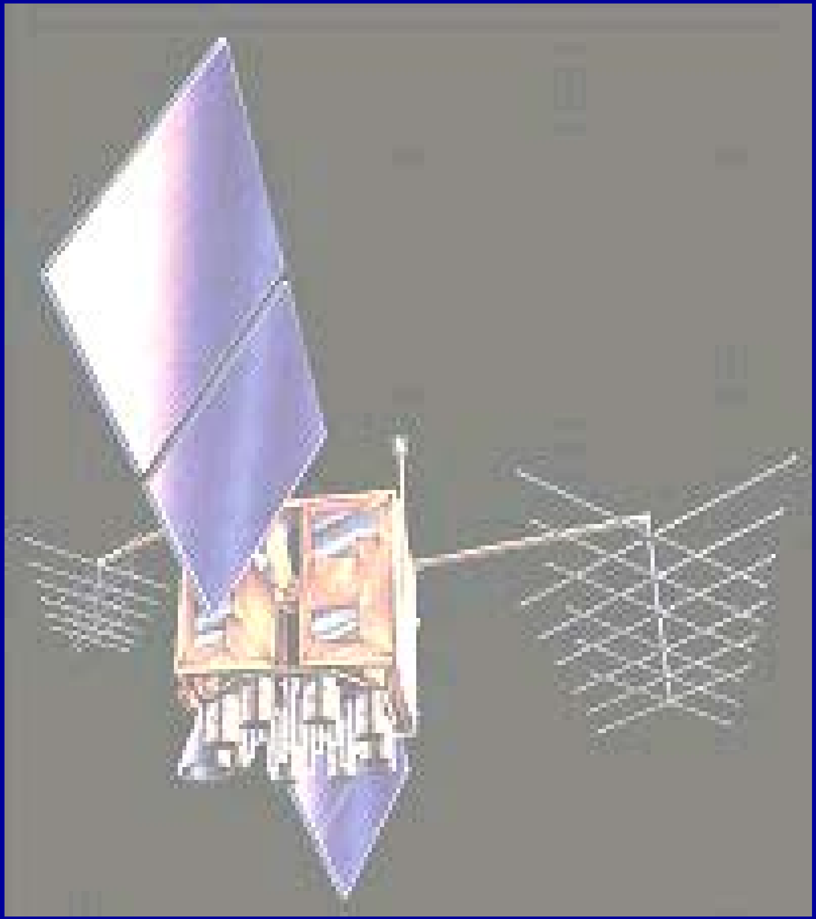
GPS Original Design

- Started development in the late 1960s as NAVY/USAF project to replace Doppler positioning system
- Aim: Real-time positioning to < 10 meters, capable of being used on fast moving vehicles.
- Limit civilian ("non-authorized") users to 100 meter positioning through the use of Selective Availability (SA). We discuss this later but basically it not limit civilian accuracy.

GPS Design

- Innovations:
  - Use multiple satellites (originally 21, now ~28)
  - All satellites transmit at same frequency
  - Signals encoded with unique “bi-phase, quadrature code” generated by pseudo-random sequence (designated by PRN, PR number): Spread-spectrum transmission.
  - Dual frequency band transmission:
    - L1 ~1.5 GHz, L2 ~1.25 GHz

Latest Block IIR satellite (1,100 kg)



Measurements

- Measurements:
  - Time difference between signal transmission from satellite and its arrival at ground station (called "pseudo-range", precise to 0.1–10 m)
  - Carrier phase difference between transmitter and receiver (precise to a few millimeters)
  - Doppler shift of received signal
- All measurements relative to "clocks" in ground receiver and satellites (potentially poses problems).

Measurement usage

- "Spread-spectrum" transmission: Multiple satellites can be measured at same time all at the same frequency.
- Since measurements can be made at same time, ground receiver clock error can be determined (along with position: more later).
- Signal

$$V(t,\vec{x}) = V_o \sin[2\pi(ft - \vec{k}.\vec{x}) + \pi C(t)]$$

$C(t)$ is code of zeros and ones (binary).

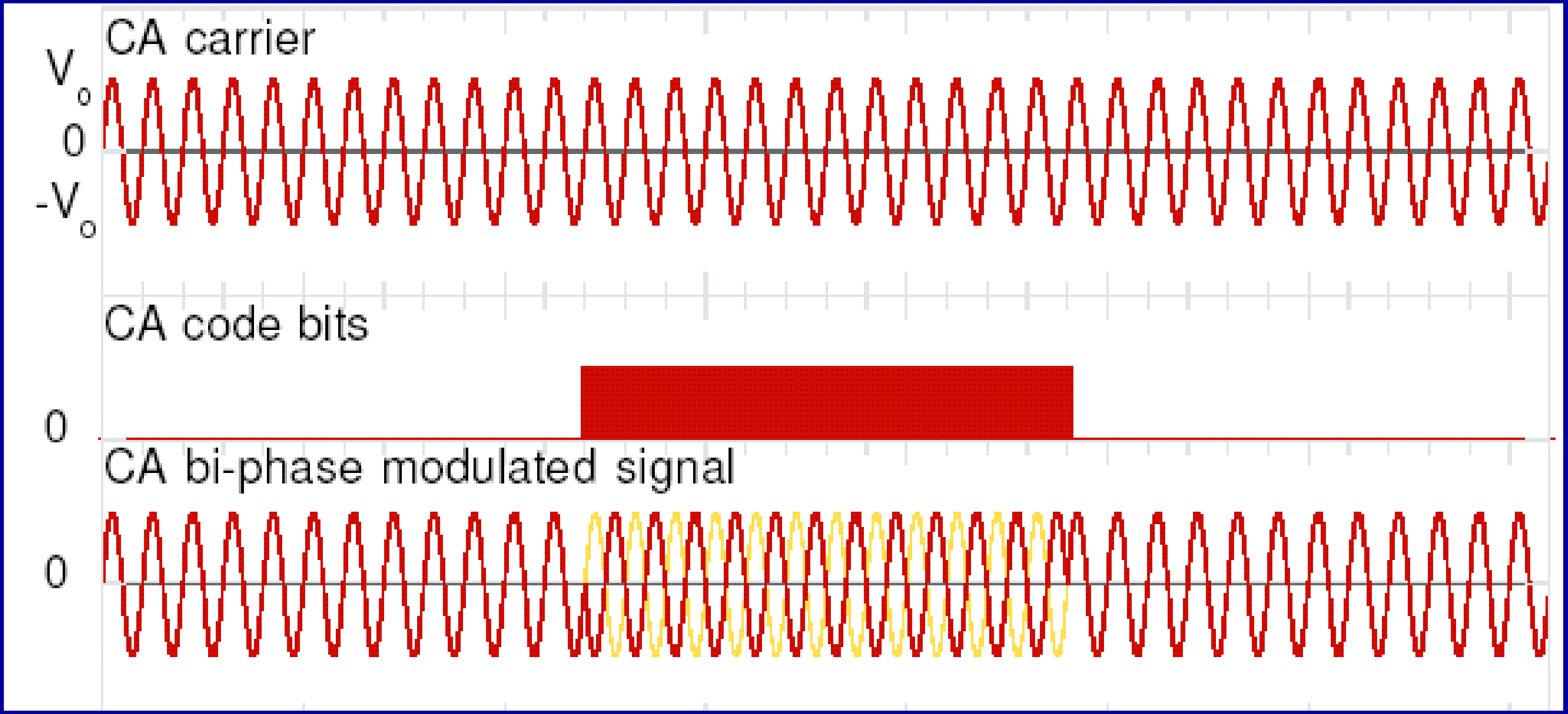
Varies discretely at 1.023 or 10.23 MHz

Measurements

- Since the C(t) code changes the sign of the signal, satellite can be only be detected if the code is known (PRN code)
- Multiple satellites can be separated by “correlating” with different codes (only the correct code will produce a signal)
- The time delay of the code is called the pseudo-range measurement (pseudo because it has contributions from the non-synchronized clocks).
- Two codes are written on the signal: C/A coarse acquit ion code and P(Y) code for precise positioning
- The rates of the codes are written is called the Chip rate.

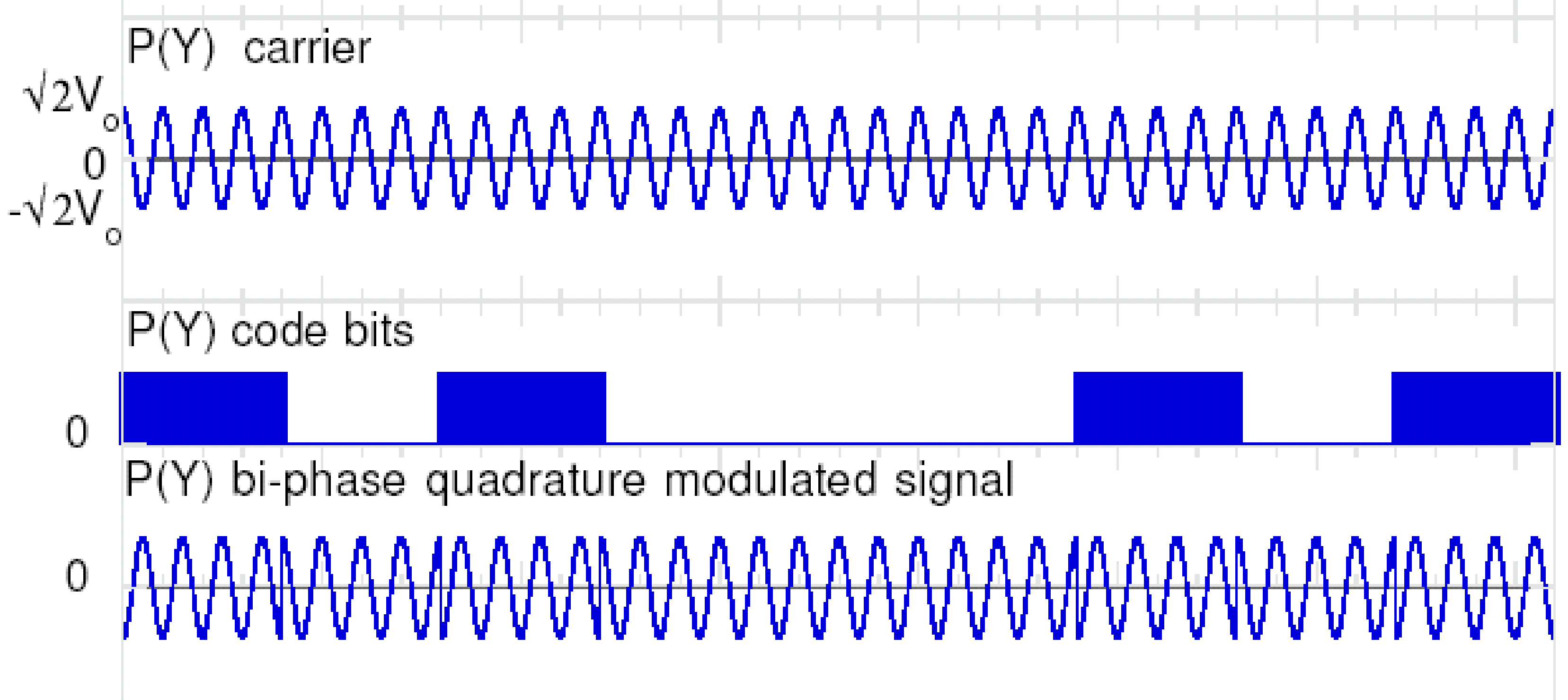
Basic C/A code structure

- Shown on figure below. Effectively changing the sign of phase acts like a “negative” pulse

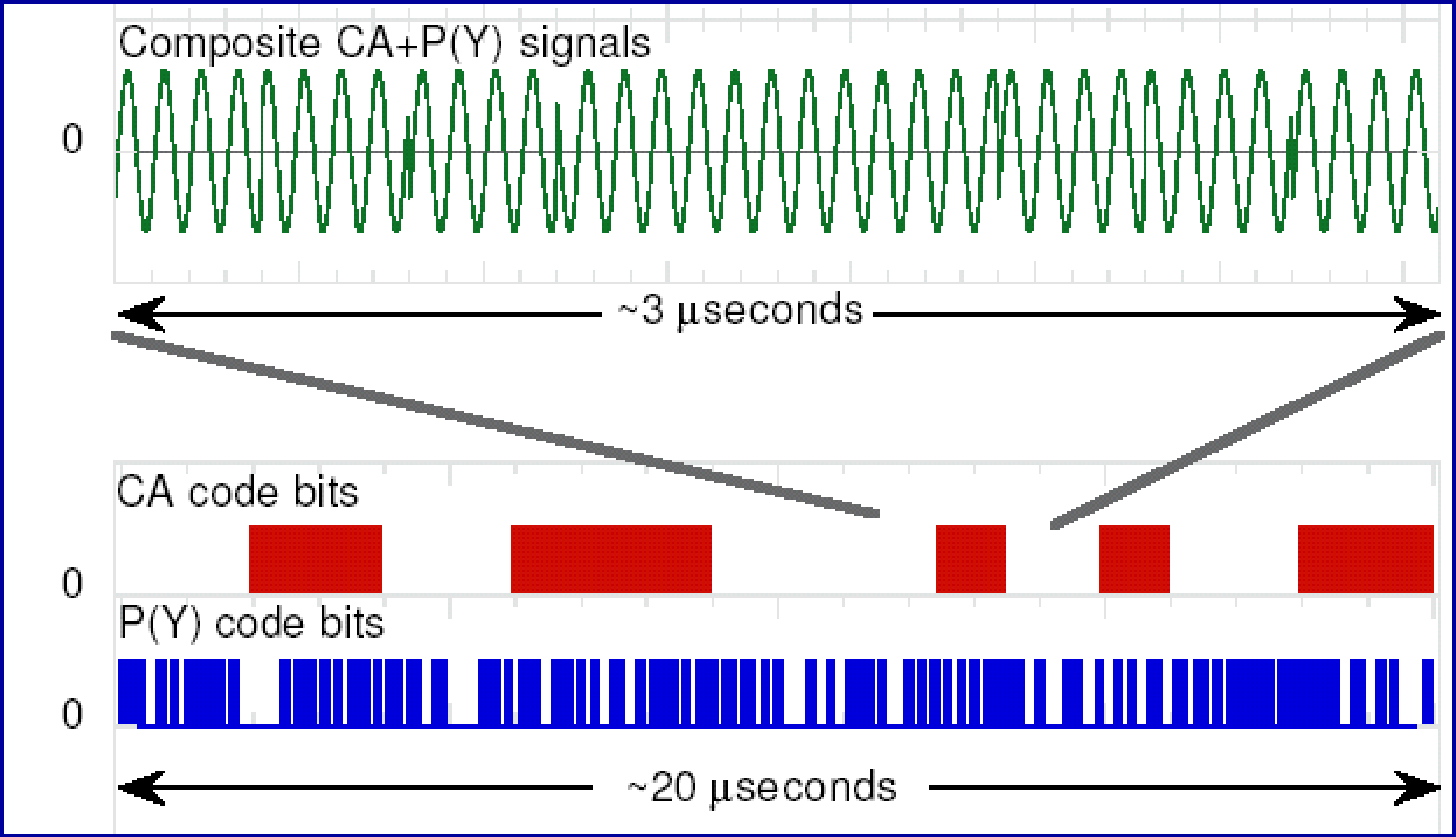


Basic P-code structure

- Basic structure of P code (Y-code when anti-spoofing on). Generated at 10 times the rate of CA code.



Combined signal

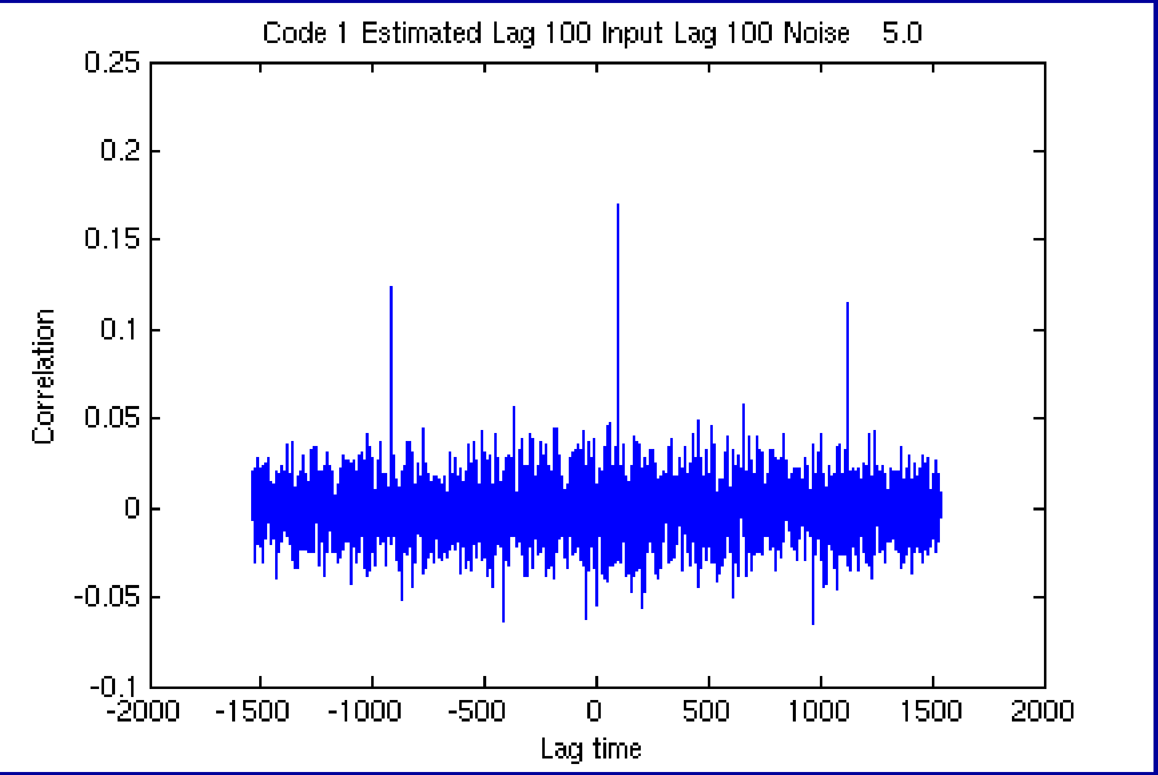


Combined signal

- In the combined signal, P-code is written 90 degrees out of phase with the C/A code (quadrature). Also has half the power but this is not critical to operation of system.
- Although, all satellites transmit at the same frequency the code differences allow them to be separated. It also means that you can track satellites knowing only the C/A code and the Y-code (as we have at the moment).
- The following Matlab code demonstrates the basic idea GPSSim.m

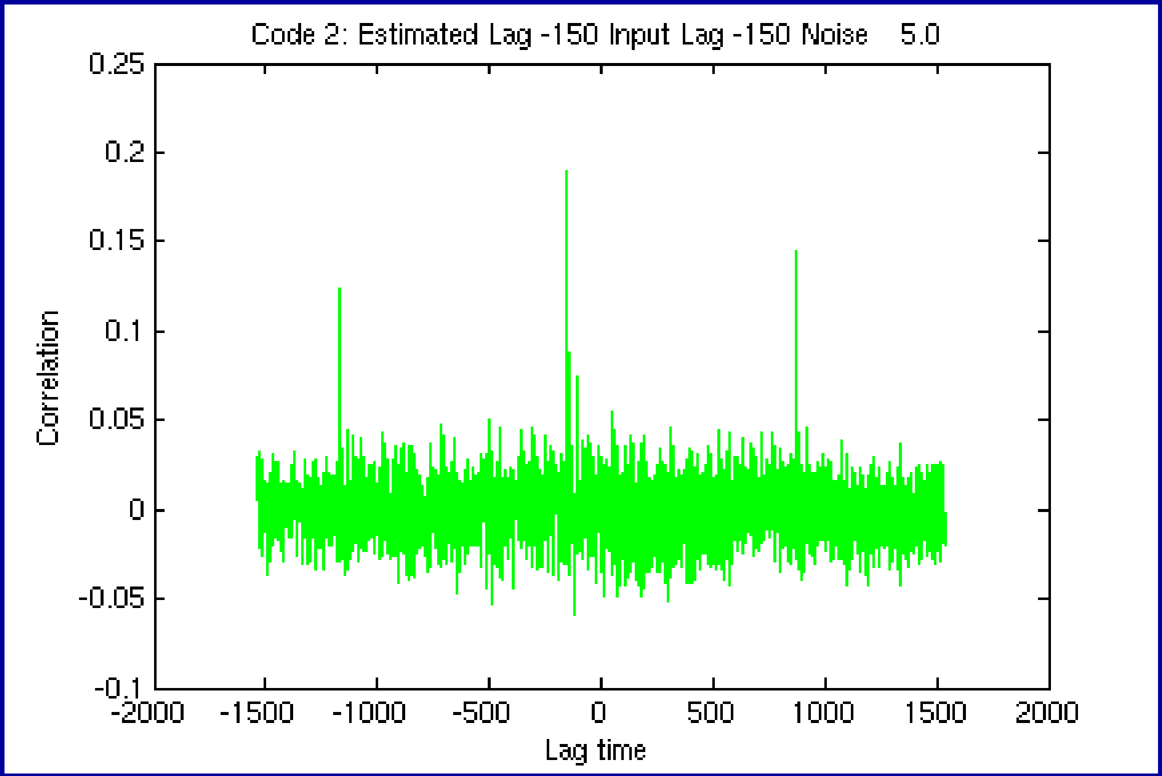
Results from GPSSim

- Correlation with GPS satellite 1 at specified lag. There are multiple peaks because signal repeats as in GPS



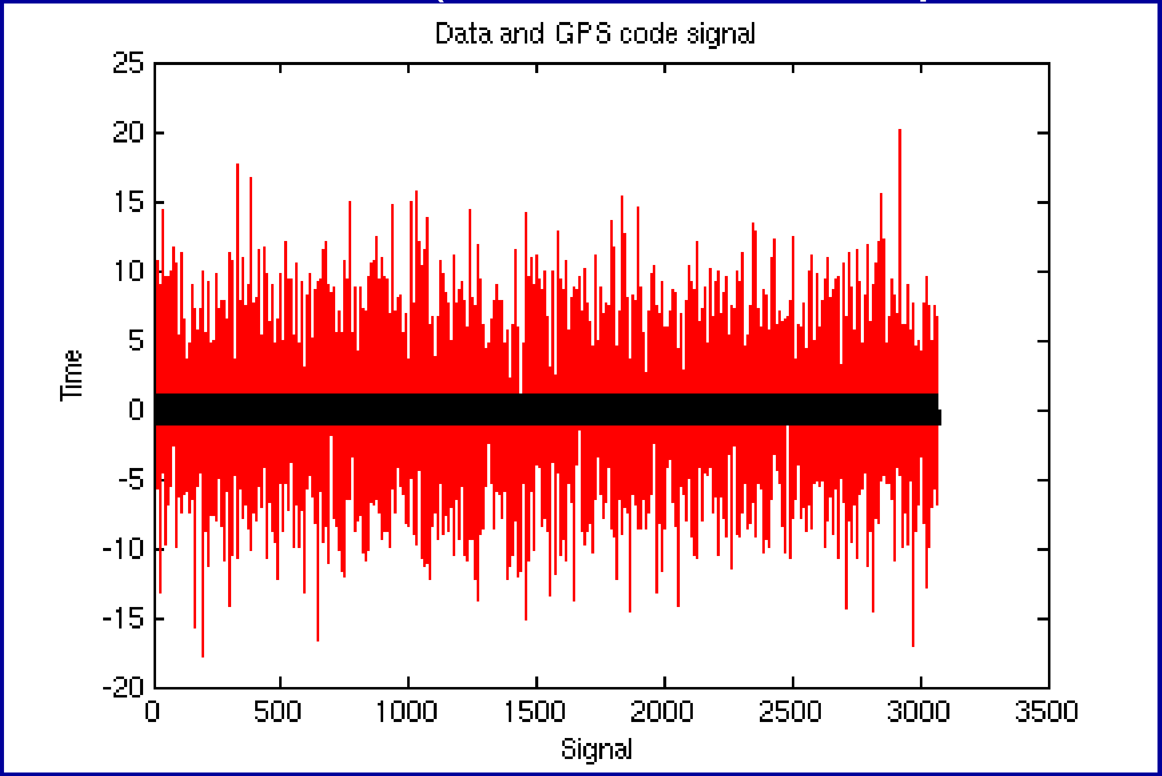
Second imbedded Satellite

- Contained in the signal is noise plus 2 GPS satellites. The second GPS satellite correlation function is:



Nature of the signal

- Red is the “observed” signal and black is the imbedded code signal. Despite the small level, we can still correlate OK (use Matlab to experiment).



Basic GPS signal generation

- In the GPS satellites, the C/A and P codes are generated precisely aligned with the clock in the satellite. (Clock is not prefect and can have errors of many μsec).
- In the receiver, a replica of the code is generated precisely aligned with the receiver clock which can have errors of many milli-seconds and sometimes numbers of seconds.
- The receiver correlates the replica with received signal (which is dominated by noise -- spread spectrum).

Basic GPS operation

- The peak in the correlation function, tells the receiver the time offsets of the codes
- This time offset is the sum of the differences in clock times (satellite and receiver) and the time delay of propagation of the signal (range to satellite/speed of light)
- There is a 1.023 msec ambiguity in C/A code range which is resolved by decoding the data message on signal
- Data message is written at 15 bits/seconds and contains information about the estimated error in the satellite clock, the ephemeris of the satellite and information about all the satellites in the GPS constellation (almanac).
- The ephemeris lets the receiver calculate where the satellite was located at time of transmission.

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- Fundamentals of correlation methods used (Matlab code)
- Specifics of the GPS system
  - Frequencies
  - Chip rates
  - Data rates and message content
- Homework number 4 is due Monday November 18.