Summary

• Review:
  – Examined methods for measuring distances
  – Examined GPS codes that allow a type of distance measurement and phase to be measured

• Today:
  – Examine how the range measurements are defined and used
  – Use of carrier phase measurements
  – Examine RINEX format and look at some “raw” data

Pseudorange measurements

• When a GPS receiver measures the time offset it needs to apply to its replica of the code to reach maximum correlation with received signal, what is it measuring?
  • It is measuring the time difference between when a signal was transmitted (based on satellite clock) and when it was received (based on receiver clock).
  • If the satellite and receiver clocks were synchronized, this would be a measure of range
  • Since they are not synchronized, it is called “pseudorange”
Basic measurement types

• Pseudorange:

$$P_k^p = (t_k - t_p) \cdot c$$

Where $P_k^p$ is the pseudorange between receiver $k$ and satellite $p$; $t_k$ is the receiver clock time, $t_p$ is the satellite transmit time; and $c$ is the speed of light.

This expression can be related to the true range by introducing corrections to the clock times:

$$t_k = \tau_k + \Delta t_k$$
$$t_p = \tau_p + \Delta t_p$$

$	au_k$ and $\tau_p$ are true times; $\Delta t_k$ and $\Delta t_p$ are clock corrections.

Basic measurement types

• Substituting into the equation of the pseudorange yields

$$P_k^p = \left[ (t_k - t_p) + (\Delta t_k - \Delta t_p) \right] \cdot c$$

$$P_k^p = \rho_k^p + (- \Delta t_k \cdot c) + \Delta \tau_k + A_k^p$$

$\rho_k^p$ is true range, and the ionospheric and atmospheric terms are introduced because the propagation velocity is not $c$.

Basic measurement types

• The equation for the pseudorange uses the true range and corrections applied for propagation delays because the propagation velocity is not the in-vacuum value, $c = 2.99792458 \times 10^8$ m/s.

• To convert times to distance $c$ is used and then corrections applied for the actual velocity not equaling $c$. In RINEX data files, pseudorange is given in distance units.

• The true range is related to the positions of the ground receiver and satellite.

• Also need to account for noise in measurements.
Pseudorange noise

- Pseudorange noise (random and not so random errors in measurements) contributions:
  - **Correlation function width**: The width of the correlation is inversely proportional to the bandwidth of the signal. Therefore the 1MHz bandwidth of C/A produces a peak 1 usec wide (300m) compared to the P(Y) code 10MHz bandwidth which produces 0.1 usec peak (30m).
  - Rough rule is that peak of correlation function can be determined to 1% of width (with care). Therefore 3 m for C/A code and 0.3 m for P(Y) code.

- More noise sources
  - **Thermal noise**: Effects of other random radio noise in the GPS bands.
    - Black body radiation: \( I = \frac{2kT}{\lambda^2} \) where \( I \) is the specific intensity in, for example, watts/m²/Hz ster, \( k \) is Boltzman’s constant, 1.380 x 10⁻²³ watts/Hz/K and \( \lambda \) is wavelength.
    - Depends on area of antenna, area of sky seen (ster-radians), temperature \( T \) (Kelvin) and frequency. Since C/A code has narrower bandwidth, tracking it in theory has 10 times less thermal noise power (depends on tracking bandwidth) plus the factor of 2 more because of transmission power.
    - Thermal noise is general smallest effect
  - **Multipath**: Reflected signals (discussed later)

Pseudorange noise

- The main noise sources are related to reflected signals and tracking approximations.
- High quality receiver: noise about 10 cm
- Low cost receiver ($200): noise is a few meters (depends on surroundings and antenna)
- In general: C/A code pseudoranges are of similar quality to P(Y) code ranges. C/A can use narrowband tracking which reduces amount of thermal noise.
- Precise positioning (P-) code is not really the case.
Phase measurements

- Carrier phase measurements are similar to pseudorange in that they are the difference in phase between the transmitting and receiving oscillators. Integration of the oscillator frequency gives the clock time.
- Basic notion in carrier phase: \( \phi = f \Delta t \) where \( \phi \) is phase and \( f \) is frequency.

\[ \phi_k(t_r) = \phi_k(t_r) - \phi_p(t_r) + N_k(t) \]

- The carrier phase is the difference between phase of receiver oscillator and signal received plus the number of cycles at the initial start of tracking.
- The received phase is related to the transmitted phase and propagation time by

\[ \phi_r(t_r) = \phi_t(t_r) = \phi(t_r - \rho_k/c) = \phi(t_r) - \dot{\phi}(t_r) \cdot \rho_k/c \]

- The rate of change of phase is frequency. Notice that the phase difference changes as \( \rho/c \) changes. If clocks perfect and nothing moving then would be constant.
- Subtle effects in phase equation
  - Phase received at time \( t = \) phase transmitted at \( t-\tau \) (riding the wave)
  - Transmitter phase referred to ground time (used later). Also possible to formulate as transmit time.
Phase measurements

• When phase is used it is converted to distance using the standard L1 and L2 frequencies and vacuum speed of light.
• Clock terms are introduced to account for difference between true frequencies and nominal frequencies. As with range ionospheric and atmospheric delays account for propagation velocity.

Precision of phase measurements

• Nominally phase can be measured to 1% of wavelength (~2mm L1 and ~2.4 mm L2)
• Again effected by multipath, ionospheric delays (~30m), atmospheric delays (3-30m).
• Since phase is more precise than range, more effects need to be carefully accounted for with phase.
• Precise and consistent definition of time of events is one the most critical areas.
• In general, phase can be treated like range measurement with unknown offset due to cycles and offsets of oscillator phases.

GPS Data file formats

• Receivers use there own propriety (binary) formats but programs convert these to standard format called Receiver Independent Exchange Format (RINEX)
• teqc available at http://www.unavco.org/facility/software/teqc/teqc.html is one of the most common
• The link to the RINEX format is:
  http://igscb.jpl.nasa.gov/igscb/data/format/rinex2.txt
Examine Rinex file data

- Next set of plots will look at the contents of a rinex file.
- Examples for one satellite over about 1 hour interval:
  - Raw range data
  - Raw phase data
  - Differences between data
Raw range data

![](image1)

Raw phase data (Note: sign)

![](image2)

L2-L1 range differences

![](image3)
L2-L1 phase differences

Zoomed L2-L1 phase

Plot characteristics

- Data set plotted etab.plt.dat
- Notice phase difference is opposite sign to range difference (discuss more in propagation lectures)
- More manipulation can be made of data: How about C1-L1*
Summary

• Looked at definitions of data types
• Looked at data and its characteristics.
• Next class, we finish observables and will examine:
  – Combination of range and phase that tell us more things
  – How well with a simple model can we match the data shown.
  – Where do you get GPS data?