Hardware/Software Codesign for Wireless Systems (E168b)

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Lab 3: Satellite Acquisition

Introduction

In this lab, you will learn about the process for acquiring signals from GPS satellites. The lab will guide you through five different progressively more realistic and complicated GPS signals. The first set of data you will analyze consists of a satellite PRN code (a sequence of 0's and 1's with no noise) that has an unknown offset. It is your task to determine both which satellite this code represents and the offset from the beginning of the data to the beginning of the PRN code. The next data set consists of a satellite PRN code modulated with a carrier that has a known frequency and phase. You will need to demodulate the signal and then again determine which satellite is present and the offset from the beginning of the data. After these fairly basic examples, you will search for satellites in real GPS data, which has a signal to noise ratio of approximately -20dB. For your third search, you will be given the frequency and phase of the carrier. In the fourth, you will know only the frequency. In the fifth and most realistic situation, even the frequency will have uncertainty because of the Doppler effect.

This is a long lab. Start early. Get as far as you can. Partial credit will be given for each scenario solved.

Part 1: PRN code offset

Each GPS satellite transmits a PRN code that is used to identify the satellite, track the signal from the satellite, and determine the boundaries of transmitted data from the satellite. A "chip" corresponds to a bit in the code, and each PRN code contains 1023 chips that repeat each millisecond. A millisecond of a PRN code sampled at 16.3676 MHz has been provided in *data1.mat*, and you will need to determine whether PRN code represents satellite 1, 2, or 3 and the offset from the beginning of the data to the beginning of the code to the nearest half-chip.

1) Given this information, what is the chip rate (chips/second) of the PRN code?
2) How many samples are there per chip?
3) Which satellite is in the mystery signal?
4) What is the phase offset? Give your answer in units of chips, accurate to the nearest ½ chip.

Part 2: Carrier Frequency Modulation

To effectively transmit satellite signals over long distances and to ensure that the signals will not interfere with other RF signals, the satellite PRN codes are modulated with a carrier signal. This carrier signal is at 1.57542 GHz, which is then down-converted to an intermediate frequency (IF) at the GPS receiver. For this part of the lab, please use the data signal in *data2.mat*. It has been modulated with a IF carrier x(t) = $\cos(2\pi(4130400) + \pi/3)$. Plot the signal both before and after demodulating, and make sure that you understand what you are seeing. You will need to determine whether the PRN code belongs to satellite 7, 8, or 9 and its offset.

5) Show plots of the data before and after demodulation. Explain why they have the form that they do. What are the first 4 chips of the signal?
6) Which satellite is in the mystery signal?
7) What is the phase offset? Give your answer in units of chips, accurate to the nearest ½ chip.

Part 3: GPS satellite acquisition with known carrier frequency and phase

Real GPS data contains many satellites and is dominated by noise. The data provided to you in the Lab 3 directory (TrimbleDataSet.mat) has only 3 bits of resolution per sample; plot the data to get an idea of the actual received signal. In this part of the lab, you will demodulate the GPS data with a the carrier signal x(t) = $\cos(2\pi(4128910) + 5\pi/4)$ and determine whether satellite 4 or 5 is present and the code offset.

8) Can you identify the first 4 chips of the signal by inspection?
9) What changes to your code from Part 2 are necessary to find the data in the noise?
10) Which satellite is in the mystery signal?
11) What is the phase offset? Give your answer in units of chips, accurate to the nearest ½ chip.

Part 4: GPS satellite acquisition with known carrier frequency

The carrier phase is not known when satellites are being acquired, and so to find the satellites the following algorithm can be used if the carrier frequency is known, where is x(t) is now the received signal.

$$I = \int_0^T x(t)\cos(wt)dt \qquad (1)$$

$$Q = \int_0^T x(t)\sin(wt)dt \qquad (2)$$

Where I and Q have the following property:

$$\sqrt{I^2 + Q^2} = C \qquad (3)$$

This result allows for the detection satellites even when the phase of the carrier is unknown. The demodulations and correlations must be performed twice, once with each reference signal, but the sum of their squares will now be independent of the phase of the carrier signal on x(t). Your task is to use this algorithm and find whether GPS satellite 10 or 11 is present and determine its offset for the given carrier frequency of 4131899 Hz.
12) Which satellite is in the mystery signal?
13) What is the phase offset? Give your answer in units of chips, accurate to the nearest ½ chip.
14) If you run your code from Part 3 on this mystery signal, do you find the correct satellite? If so, why bother with this I and Q business?

Part 5: Realistic GPS Satellite acquisition

In reality, there is uncertainty in the frequency of the carrier signal due to potential Doppler shifts caused by the motion of the satellites. These shifts can cause up to a 5 kHz change from the nominal IF carrier frequency of 4.1304 MHz.. In order to find satellites under these conditions, the searches must be performed in different "Doppler bins." This means that the carrier frequency is adjusted by a set frequency interval and the search is performed at each carrier frequency. An acceptable bin size for this search is 500 Hz. When the satellite signal is found in one of the frequency bins, a more refined search can be performed on the given bin to better determine the carrier frequency. Accurately determining the carrier frequency will be important for the system to track the signal and extract the data. Your task is to perform a search to determine which satellite, 12 or 13, is present. As a hint, the Doppler shift is less than 2 kHz. You will need to give an estimate of the carrier frequency and the offset of the code. Good luck.

15) Which satellite is in the mystery signal?
16) What is the phase offset? Give your answer in units of chips, accurate to the nearest ½ chip.
17) What is the actual IF carrier frequency of the satellite? Give your answer to the nearest 500 Hz.
18) How long does your program take to find the correct satellite?
19) If you didn't know which of the 32 satellites were present and only know the Doppler shift is within +/- 5 KHz, how long would it take for your code to find which satellite(s) are in a mystery signal?

What to Turn In

Turn in answers to each of the questions, along with your commented Matlab code for each part.