Design and Implementation of a GPS Receiver

Project Proposal

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Project Summary

At present, most commercial-off-the-shelf (COTS) receivers perform the majority of signal processing using analog circuitry, while the onboard microcontroller is used merely to perform simple tasks such as computing coordinate conversions or controlling the display. The objective of this project is to eliminate the majority of the analog circuitry and design and implement the signal processing stages of a GPS receiver using software in order to reduce overall cost, increase portability between applications, and make the device even smaller. While the hardware cannot be completely eliminated, it shall be reduced to a high-speed sampling device consisting of a downconverter and A/D converter. The sampled data shall then be processed by a DSP kit simulating a microcontroller implementation.
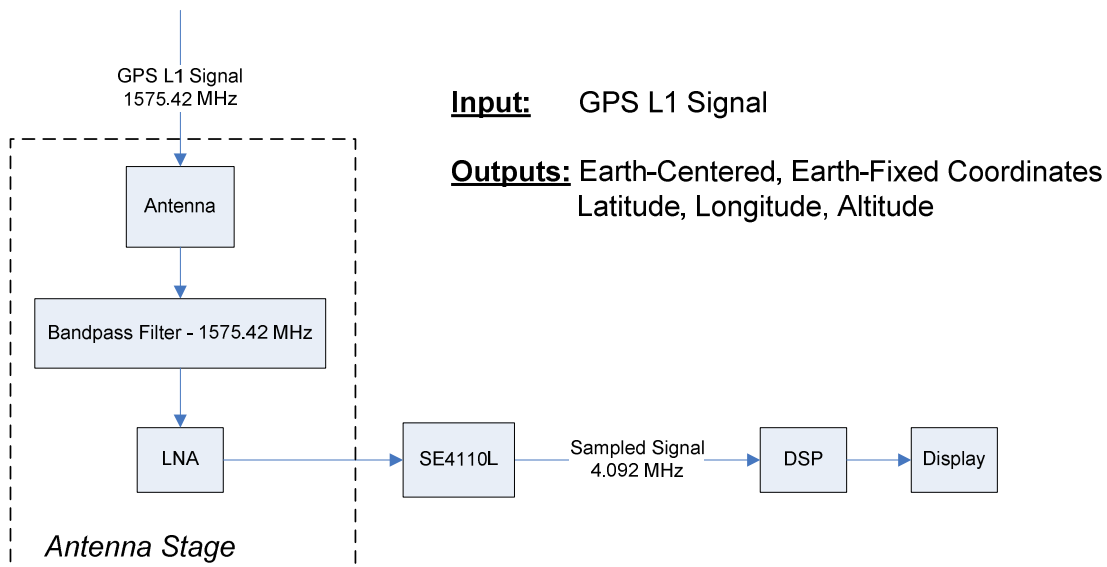
Goals

The goals of this project are described in detail below. The ultimate objective is to compute the user's position in real-time, while the rest of the objectives serve to make that goal achievable.

- Implement a software GPS L1 signal model
- Develop a software-based GPS receiver model for processing a sample input dataset
- Implement the model in a high-level language such as C++
- Process the raw data using an embedded system or DSP kit using the model developed
- Connect the embedded system or DSP kit to a sampling device and perform satellite signal acquisition
- Compute position in real-time

High-Level Block Diagram

Figure 1, below, shows the high-level block diagram for the project. The GPS L1 signal shall be received through an active GPS antenna. After the antenna stage, the SE4110L chipset shall be used to sample and down-convert the signal. A DSP kit shall then perform software processing and display the results.

Figure 1 – High-level Block Diagram

GPS L1 Signal
1575.42 MHz

Input: GPS L1 Signal

Outputs: Earth-Centered, Earth-Fixed Coordinates
Latitude, Longitude, Altitude

Antenna

Bandpass Filter - 1575.42 MHz

LNA

SE4110L

Sampled Signal
4.092 MHz

DSP

Display

Antenna Stage

Antenna Stage

Active GPS antennas are available from a variety of manufacturers and include at a minimum a low-noise amplifier and a bandpass filter. An active antenna is necessary due to the low transmit power of GPS satellites and the degradation and attenuation of the signal as it travels through the atmosphere.

SE4110L

The SE4110L is a complicated chipset consisting of a several sub-stages. The subsystems are very similar to those of a superheterodyne receiver with the addition of a high-frequency A/D converter. The device outputs the magnitude and sign of the received signal at 4.092 MHz. [2]   Figure 2, below, shows the functional block diagram from the SE4110L datasheet. Functionally, the SE4110L shall provide the digitally sampled GPS L1 signal to the DSP.

Figure 2 – SE4110L Functional Block Diagram [3]
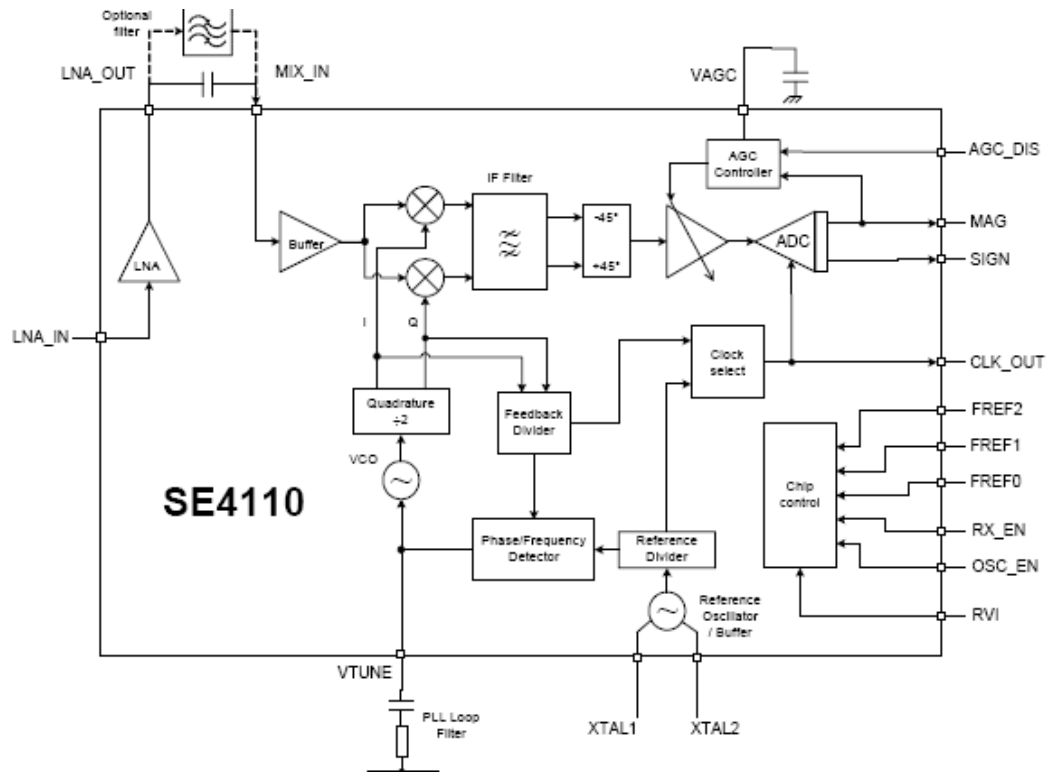
DSP Kit

A Spectrum Digital DSP Development System shall be used for signal processing. The development board is based on a TI C6000 DSP, which is capable of hardware floating-point operations. The DSP is clocked at 225 MHz, which should provide adequate processing power for most of the software operations and hardware interfacing.

Software Processing

The bulk of this project involves software processing of the sampled signal data. Figure 3, below, shows a modification on the basic scheme as used by Kai Borre et al. for calculating the time delay in the signal. [1]   The software shall work by performing a discrete Fourier transform (DFT) on the input signal and comparing it to a similar signal generated by a C/A PRN sequence generator.

Various delays are then applied to the C/A code sequence and each is correlated to the input signal. The highest correlation value is then used to adjust the delay. The delay shall then be used to determine the distance to a satellite.

The process shown in Figure 3 must be separately performed for each satellite to be acquired since the Gold (C/A) code for each satellite is different.

Figure 3 – High-Level Software Flowchart [1]
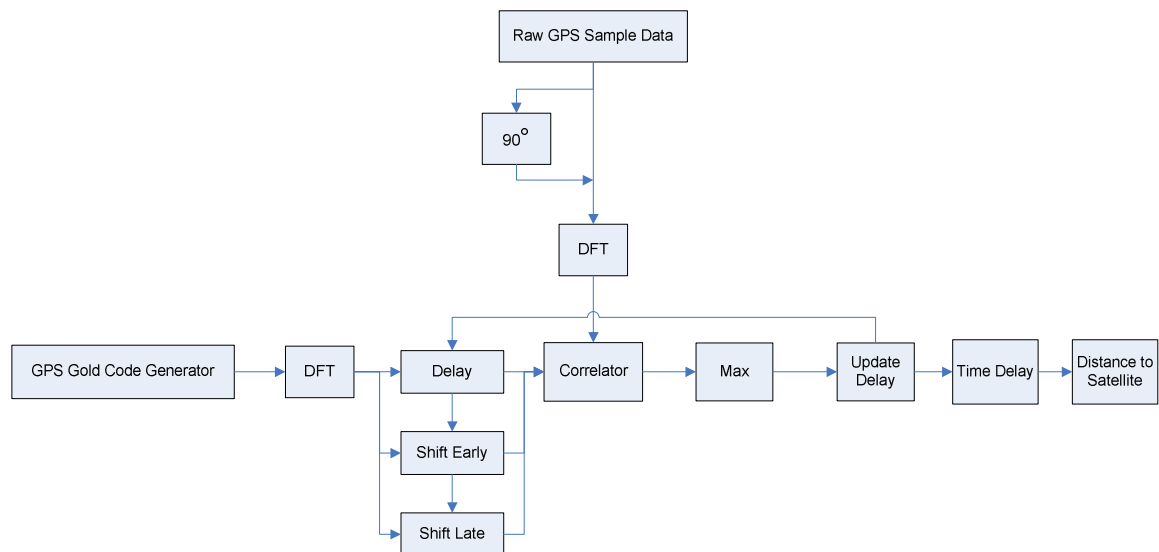
Subsystem Requirements

The subsystem requirements are given in Figure 4, below.

Figure 4 – Subsystem Requirements [1]

Error	Specification(s)
Position Error	100 m
Sampling Rate	4.092 MHz
Time to First Fix	Cold Start : 36 seconds
	Warm Start : 1 second
Display	Earth-centered, Earth-fixed Coordinates
	Latitude, Longitude, Altitude
	UTC Time
	Local Time

Position Error

The position error is determined with respect to the sampling rate. The sampling rate is 4.092 MHz, which is four times the chipping rate. Therefore, the distance to a single satellite can be determined to within ¼ of the distance related to 1 chip.

Calculation 1 – Satellite Ranging Precision

$$\lambda_{Chip} = \frac{c}{f} = \frac{3 \times 10^8 \frac{m}{s}}{1.023 \times 10^6 \frac{1}{s}} = 293.26\,m$$

$$Precision = \frac{\lambda_{Chip}}{4} = \frac{293.26\,m}{4} = 73.31\,m$$

Calculation 1, above, indicates that the position of a satellite can be determined accurately to within 73.31 m. However, this value does not take into account other error sources such as atmospheric effects, ephemeris errors (errors with respect to the satellites' orbits), and clock drift. [4]

Sampling Rate

The sampling rate is set by the SE4110L at 4.092 MHz. Other options are available, but the selected rate is the fastest available based on a factor that is an integer.

Time to First Fix

Acquisition requires that the satellite C/A PRN be correlated with the locally-generated C/A PRN and a complete frame of data be received. A frame lasts 30 seconds and is divided into 5 subframes lasting 6 seconds each. [1] Ideally, the time to first acquisition would depend solely on the length of the frame. However, it is quite likely that the first subframe would be received beginning somewhere other than the first byte. Therefore, the ideal acquisition time is 36 s. This specific acquisition is referred to as a "cold acquisition" and assumes that no previous data about the satellite is available. Commercial chips such as the SiRFstarIII GSD3t list the value as 36 s accordingly. [5]

If the frame data is already available, the position can be calculated as soon as the C/A PRN code is synchronized. This value should be very small with an approximate value of 1 s. Comparatively, the SiRFstarIII GSD3t lists the value as less than 1s.

Display

The display should be user-friendly and give the position in a variety of coordinate systems including Earth-centered, Earth-fixed (ECEF) and Latitude, Longitude, and Altitude (LLA). In addition, the UTC time should be displayed with a conversion to local time with the offset provided by the user.

Experimental Results

L1 Signal Generation

A GPS L1 signal model has been developed in M-script format for MATLAB using the model in Figure 5, on the next page, as described by Kai Borre et al. The signal is generated using two 10-bit shift registers, and the various signals for the different satellites are generated by selecting different positions in the first shift-register to connect the lines indicated as "Taps".
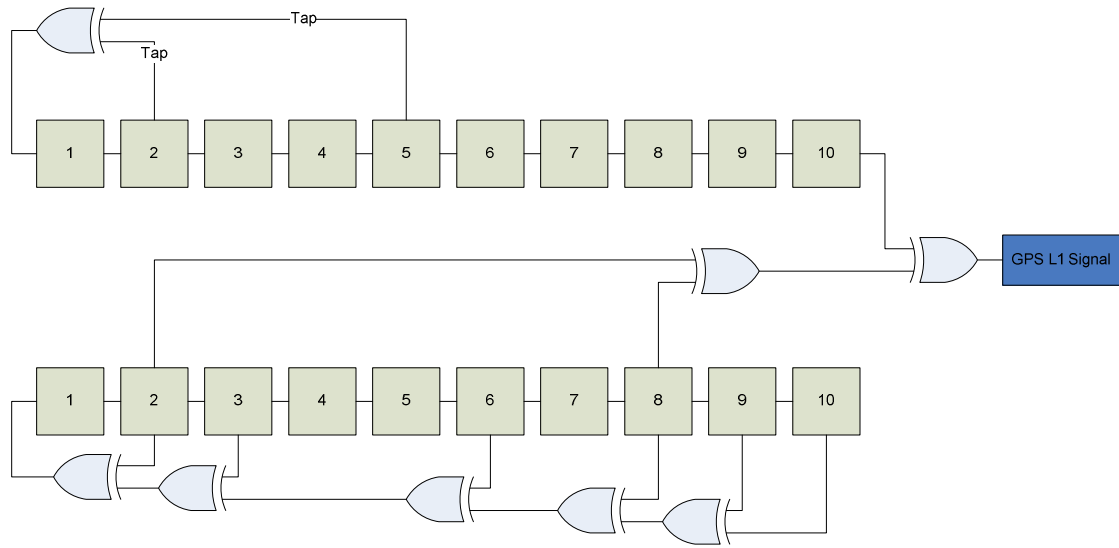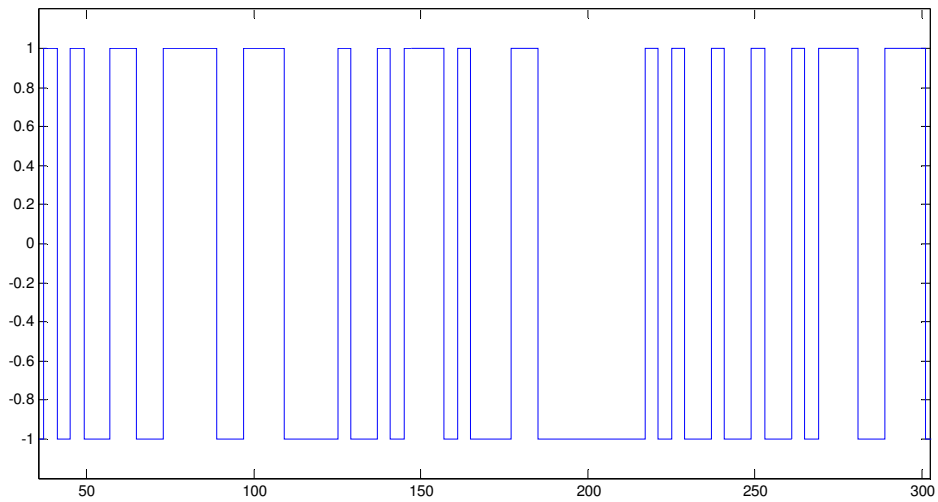
Figure 5 – GPS L1 Signal Generation [1]

Figure 6, below, shows a sample of the generated signal. The signal levels are adjusted such that the values are bipolar.
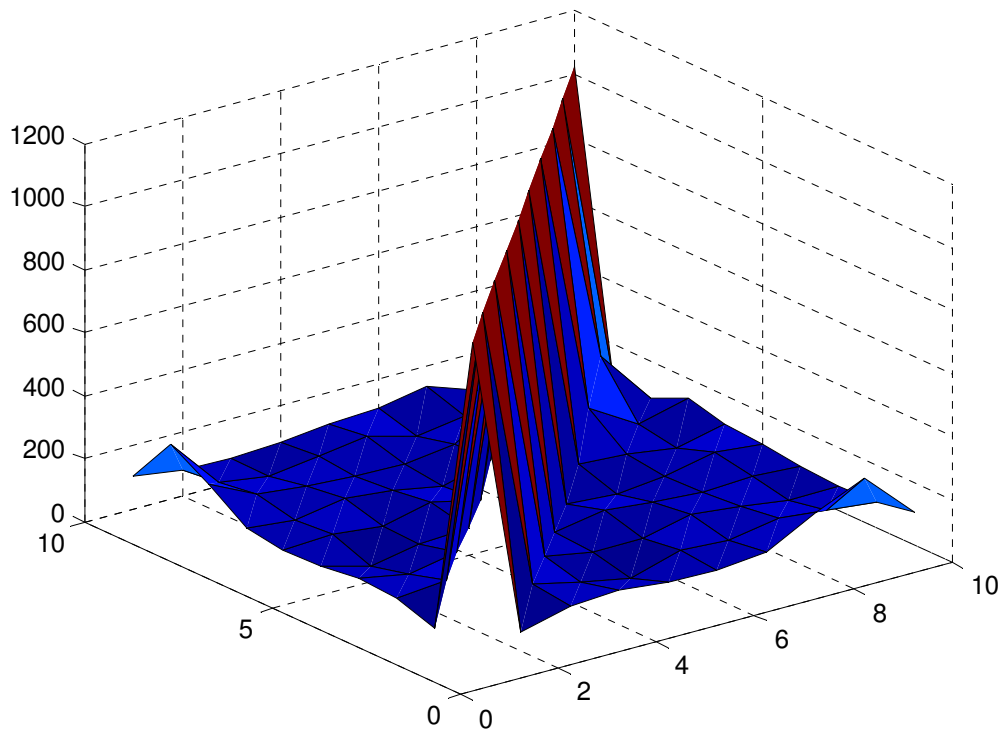
Figure 6 – Sample L1 Generation

The cross-correlation of the L1 signals is perhaps the most important property of the signals. Figure 7, below, shows the correlation values between the tap selections as indicated by the x and y axes.

Figure 7 – Cross-Correlation of L1 Signal

As the figure shows, the correlation is only high if the tap selection is identical. This allows the L1 signals to be individually detected amongst other L1 signals. Furthermore, the results in Figure 7 provide a preliminary indication that the L1 signal script works correctly.

Preliminary Measurements

Figure 8, below, shows FFT data taken while the SE4110L was powered with a 5 V supply and disconnected from the rooftop GPS antenna. The magnitude bit appears to have a spike near the 1.023 MHz L1 frequency, while the sign bit has a spike near the 4.092 MHz sampling frequency. As the GPS signal is masked by the noise floor, this information only indicates the operation of the SE4110L device.

Figure 8 – FFT Data from SE4110L
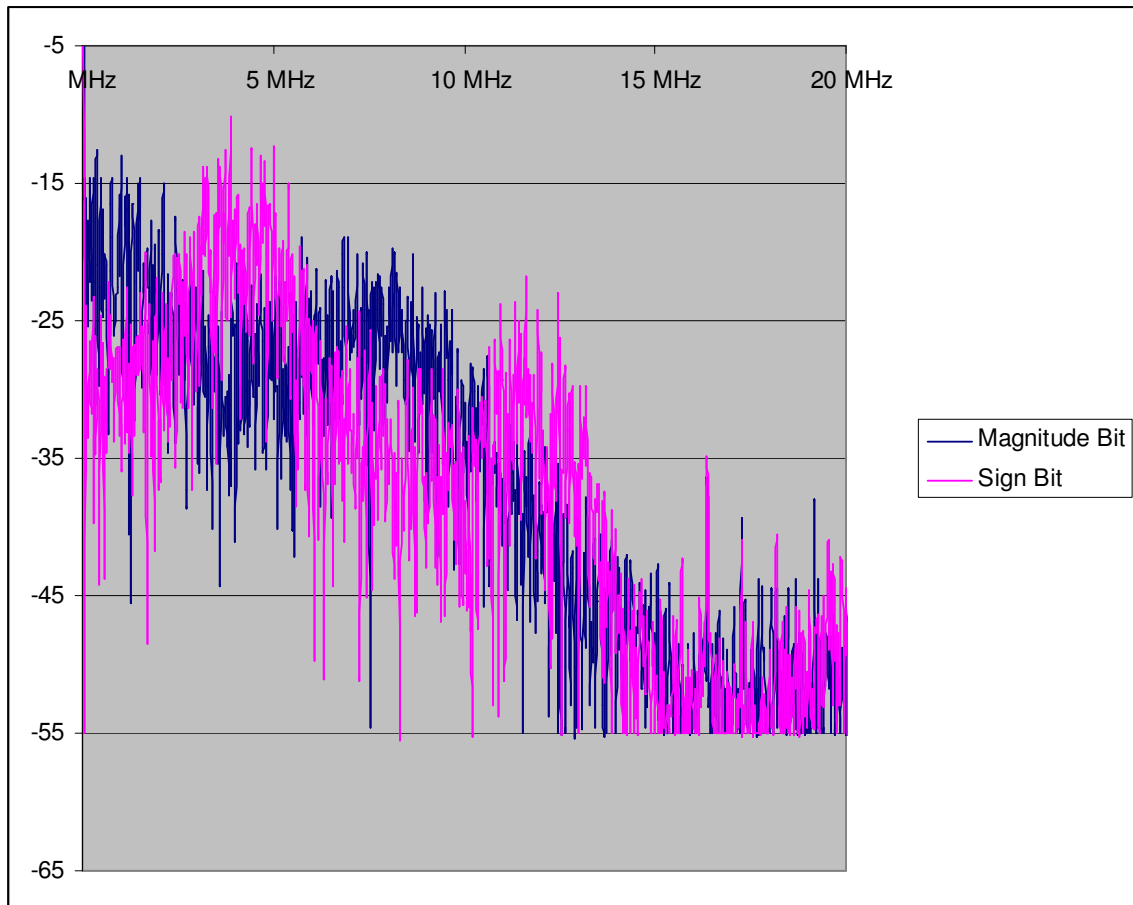
Patent Search

Figure 9, below, lists relevant results from a patent search. While several patents exist for software-defined radio applications and hardware GPS applications, the number of patents specifically for software-defined GPS applications appears limited.

Figure 9 – Relevant Patents

Patent Number	Description
20060074554	Software-defined GPS receivers and distributed positioning system
20067046193	Software GPS based integrated navigation
20067002515	GPS receiver using software correlation for acquisition and hardware correlation for tracking
2007213932	Computer Programmed with GPS Signal Processing Programs
2005162313	GPS Receiver (Software)

Equipment List

The equipment list is given in Figure 10, below. The listed equipment does not include simple components such as wires but does include all major components.

Figure 10 – Equipment List

Item	Description
SE4110L-EK1	Evaluation kit for receiving and sampling GPS signals
F-female to BNC-male	Adapter
BNC-female to MCX-male	Adapter
GPS Antenna	Antenna on roof of Jobst Hall
TMS320C6713 DSP Starter Kit	Digital Signal Processing Kit

Preliminary Schedule

The schedule for the spring semester is given in Figure 11, below. A significant amount of time is allowed for debugging and testing as it may difficult due to the nature of the L1 signal.

Figure 11 – Preliminary Schedule

Week	Activity
1/23-1/26	Create a model to process sampled GPS signal data
1/27-2/2	Continue developing GPS signal processing model
2/3-2/9	Develop software to sample data from the SE4110L using the DSP kit serial ports
2/10-2/16	Process sampled data using the GPS signal processing model
2/17-2/23	Modify the GPS signal processing model to be run on the DSP kit
2/24-3/1	Continue modifying the GPS signal processing model to be run on the DSP kit
3/2-3/8	Debug the GPS signal processing model while running it on the DSP kit
3/9-3/15	Continue debugging the GPS signal processing model while running it on the DSP kit
3/16-3/22	Develop GPS data interpretation model
3/23-3/29	Create coordinate conversion software
3/30-4/5	Design display
4/6-4/12	Develop and test display
4/13-4/19	System debugging and documentation
4/20-4/26	System debugging and documentation
4/27-5/3	System debugging and documentation

Conclusion

This project contains many challenges which can be foreseen and many more which cannot. Nonetheless, this project shall provide insight into the practicality of software-based GPS systems as well as their accuracy.

Bibliography

[1] Kai Borre, Dennis M. Akos, Nicolaj Bertelsen, Peter Rinder, and Soren Holdt Jensent, *Software-Defined GPS and Galileo Receiver : A Single-Frequency Approach.* Birkhauser: Boston, 2007, pp. 29, 83, 105.
[2] SiGe, SE4110L-EK1 Evaluation Board User Guide.
[3] SiGe, SE4110L Datasheet.
[4] Wikipedia, "Global Positioning System" [online], available from World Wide Web: <http://en.wikipedia.org/wiki/Global_Positioning-_System>.
[5] SiRF, "SiRFstarIII GSD3t" [online], available from World Wide Web: < http://www.sirf.com/products/gps_chip2e.html>.