Dual Frequency GPS Receiver Implementation in GNSS-SDR

By Danielle Skufca, ECE '18

Introduction

Accurate location and timing information is critical to almost any military mission. GPS technology is constantly evolving to generate more accurate navigation solutions; however, current GPS receivers are expensive and difficult to update. This paper discusses implementing a software-defined dual frequency GPS receiver using the open-source software program called GNSS-SDR. The receiver has the capability to correct for ionospheric scintillation (noise in the signal caused by the signal passing through the ionosphere) and can be quickly modified, updated, and implemented on other standard processors because all the algorithms are software-defined instead of hardware-defined.

Dual Frequency GPS Receiver Basics

The basic functionality of any GPS receiver can be broken into a few different steps: signal acquisition, signal tracking, data demodulation, and calculation of the navigation solution. This section discusses the basics of each function specific to the operation of a dual-frequency receiver.

Signal Acquisition

The first function in a GPS receiver is acquiring the satellite signals that the receiver will use to generate the navigation solution. The receiver must measure the time delay and frequency shift of incoming signals from four distinct and visible satellites. In a single frequency receiver, only one signal from each satellite is acquired. A dual frequency receiver must acquire two signals from each satellite, in this case the L1 (1575.42 MHz) and L2 (1227.60 MHz) GPS carrier frequencies [2].

Signal Tracking

Once the receiver has measured the time delay and frequency shift associated with each carrier frequency from each satellite (a total of eight time delay and eight frequency shift measurements), the receiver uses the information to begin tracking each of the sixteen incoming signals. For each incoming signal, the receiver generates a model of the expected signal based on the measured time delay and frequency shifts. The expected signal—as well as a slightly time advanced and a slightly time delayed version of the expected signal—is then compared with the incoming signal. The time delay and frequency shift measurements are continuously updated so that the expected signal best correlates with the incoming signal [2].

Data Demodulation

Once the receiver is appropriately tracking all sixteen signals, it must recover the data sent from each satellite [1]. Since the data bits sent on the L1 and L2 bands from each satellite are the same, only the data from one frequency must be demodulated. Thus data demodulation is completely the same in both single frequency and dual frequency receivers.

Generating a Navigation Solution

Finally, a GPS receiver generates a location estimation using the time delay and frequency shift measurements from the tracking phase. Here the

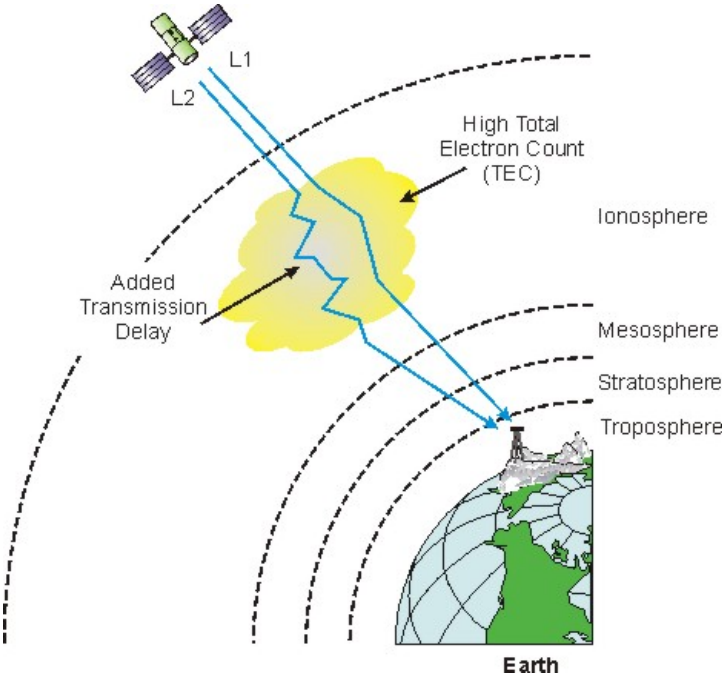

Figure 1. Ionospheric Scintillation [9]

advantage of the dual frequency receiver becomes clear. Ionospheric scintillation occurs when the signals from the satellite pass through the atmosphere they encounter zones of air that contains high levels of extra electrons, causing the signals to be deflected and delayed (see Figure 1). Since the scintillation is inconsistent for each signal, it can cause errors in the receiver's original location estimate, which is completely based off the time delays and frequency shifts of the incoming satellite signals. By measuring two frequencies from each satellite, the receiver can compare the time delay and frequency shift measurements for each satellite, and correct for the error caused by ionospheric scintillation. Thus, a dual frequency receiver can generate more accurate location estimations than a single frequency receiver [4]. Using the more accurate location estimation and the data from the satellite signal, the dual frequency receiver generates its final position, velocity, and time more rapidly than a single frequency receiver.

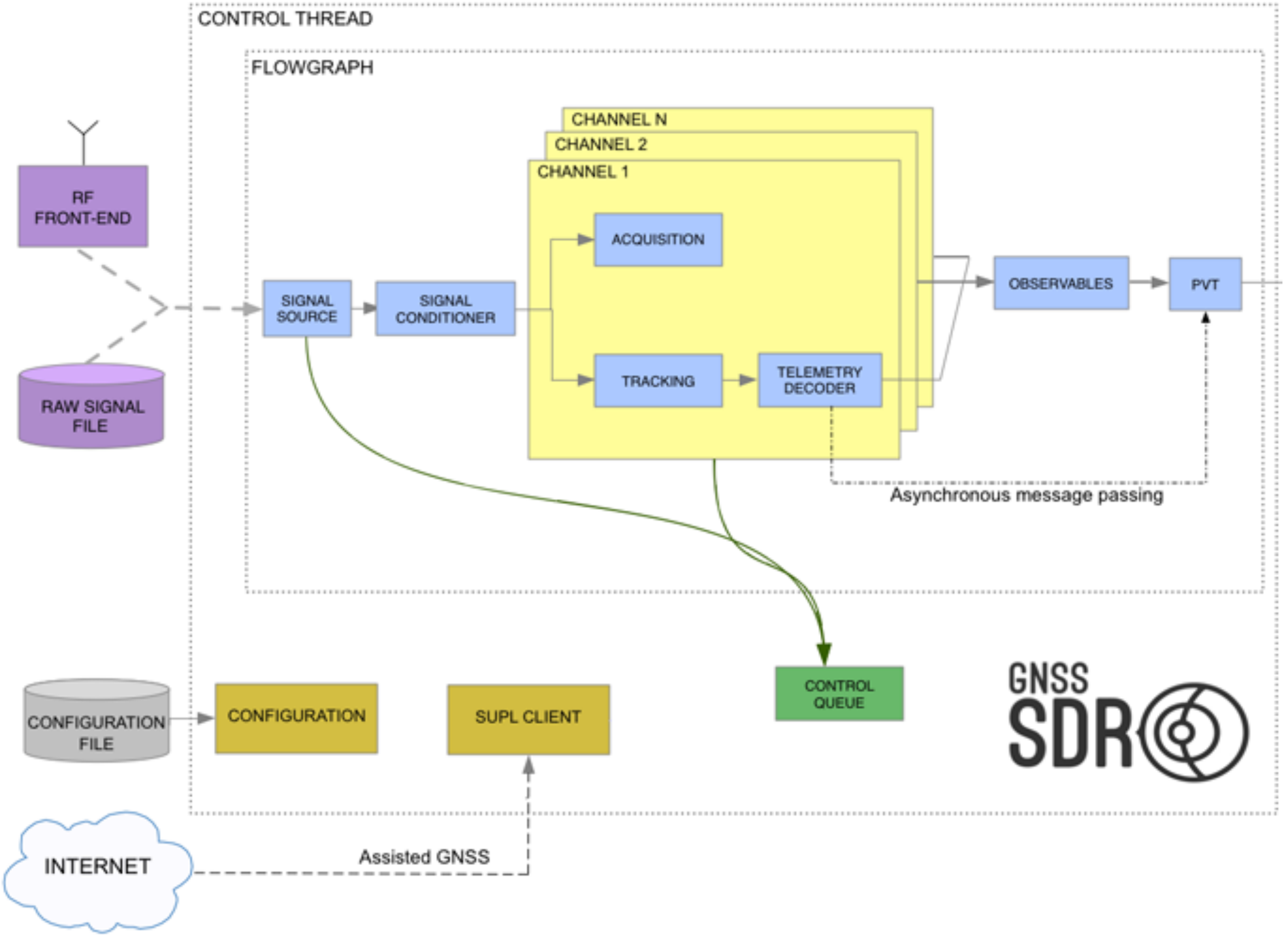

Figure 2. GNSS-SDR System Diagram [7]

GNSS-SDR Software Structure

Existing Code Structure

The GNSS-SDR code is structured as a series of functions, each defined by the part of the receiving process they are relevant to and by the type of satellite signal that they process. The software links together the appropriate functions based on user specifications by using a *Control Plane*. The *Control Plane* effectively creates a flow graph (see Figure 2) of the necessary functions for the user-specified receiver. It then uses a class called *ControlThread* to run all of the functions and produce the navigation solution [7].

At the beginning of our senior design project, GNSS-SDR had the capability to process multiple signals from each satellite at the same time. GNSS-SDR did not perform the dual frequency correction to obtain more accurate location estimates or have any functions that could perform acquisition or tracking on the L2CL GPS signal [7].

Dual Frequency Correction Algorithms

The dual frequency correction algorithms will be added to GNSS-SDR as a function in the *Observables* block (the same block that calculates the receiver's location estimation). The receiver will use the distance-to-satellite approximations (referred to as pseudoranges) from the tracking of each frequency on a given satellite to generate a more accurate approximation of the distance between the satellite and the receiver using the following equation:

$$\hat{r}^{(k)} = \frac{\left(f_1^2/f_2^2\right)\hat{r}_1^{(k)} - \hat{r}_2^{(k)}}{\left(f_1^2/f_2^2\right) - 1}$$

where f_1 and f_2 are the two carrier frequencies received (in this case 1575.42 MHz and 1227.60 MHz), $\hat{r}_1^{(k)}$ and $\hat{r}_2^{(k)}$ are the pseudoranges generated from each signal from the kth satellite, and $\hat{r}^{(k)}$ is the more accurate pseudorange from the kth satellite [4]. From the corrected pseudoranges, the receiver can calculate its true location in the same manner as a single frequency receiver. However, the dual frequency receiver will converge on its true location more quickly than a single frequency receiver.

Advantages of Software Implementation

Since this receiver is software-defined, it is not constrained to operating on a very specific hardware device as most current GPS receivers are. Just about any standard processor can be used as a GPS receiver as long as the appropriate front-end antenna or data file is provided. Thus, a dual-frequency GPS receiver will be available to anyone with a standard processor and appropriate front-end hardware [3].

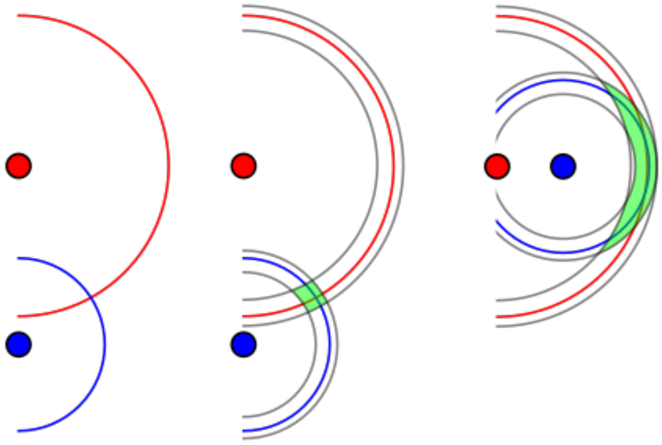

Figure 3. Geometric Dilution of Precision [used under CC0 license]

Additionally, the software-defined property of the receiver means that the receiver can change the way it operates depending on the environment. Sometimes not all satellites emit both frequencies, limiting the satellites that a dual-frequency receiver communicates with, and possibly causing the precision of the receiver to be reduced. In order to minimize the area of uncertainty in the measurement, the satellites should be as diverse as possible (see Figure 3).

The on-off capability is also critical if the receiver can't find four or more satellites that emit both frequencies. Turning off the dual-frequency capability allows the receiver to operate as a single frequency receiver in order to find its location. Since the receiver is software-defined, it will be able to operate even in environments where there are not enough visible satellites that emit both L1 and L2 signals.

Conclusion

A dual-frequency software-defined GPS receiver can be implemented by modifying the open-source software GNSS-SDR to perform an ionospheric scintillation correction on the measured pseudoranges. The scintillation corrections allow the receiver to produce more accurate location estimations, also producing the true location more quickly then a single frequency receiver. Since the receiver is software-defined, it can be used by anyone with a standard processor and the appropriate front-end radio or data file. Additionally, the dual frequency capability can be turned on or off, allowing the receiver to be optimized for its environment.

References

Papers

1. Backén, S., Nordenvaad, M. L., & Akos, D. (2009). A novel software defined research receiver architecture. In *Proceedings Of The 13th Iain World Congress*. Retrieved from http://ltu.diva-portal.org/smash/get/diva2:1008628/FULLTEXT01.pdf

2. Johansson, F., Mollaei, R., Thor, J., & Uusitalo, J. (1998, August 21). GPS Satellite Signal Acquisition and Tracking.

3. Thompson, E. A., Clem, N., Renninger, I., & Loos, T. (2012). Software-defined GPS receiver on USRP-platform. Intelligent Algorithms for Data-Centric Sensor Networks, 35(4), 1352–1360. https://doi.org/10.1016/j.jnca.2012.01.020

Books

4. Betz, J. W. (n.d.). *Engineering Satellite-Based Navigation and Timing: Global Navigation Satellite Systems, Signals, and Receivers*. Retrieved November 13, 2017, from http://ieeexplore.ieee.org.ezproxy.library.tufts.edu/xpl/bkabstractplus.jsp?reload=true&bkn=7394655

5. K Borre. (2007). *A software-defined GPS and Galileo receiver: a single-frequency approach*. Boston: Birkhauser. Retrieved from http://link.springer.com/10.1007/978-0-8176-4540-3

6. Kaplan, E. D., & Hegarty, C. (2006). *Understanding GPS: Principles and Application*s (Second Edition). Artech House.

General Intro Information

7. Fernández-Prades, C. (2017). Documentation. Retrieved November 13, 2017, from http://gnss-sdr.org/docs/

8. GNSS Receivers General Introduction. (n.d.). Retrieved November 7, 2017, from http://www.navipedia.net/index.php/GNSS_Receivers_General_Introduction

9. GPS And Geosciences. (2017, November 4). Retrieved April 4, 2018, from https://spotlight.unavco.org/how-gps-works/gps-basics/gps-and-geosciences.html