Lab 2: Calibration of a Digital System

NOTE: You will complete this assignment entirely remotely. Please use the RHL-RELIA website to capture screenshots and provide images as needed to answer the questions.

In this laboratory, students will learn how to calibrate a real digital system. Specifically, they will estimate the inherent error in two systems when attempting to operate at the same frequency.

Part 1: Error in the Frequency of a Digital System

In an ideal wireless communication system, all parameters are meticulously controlled and remain constant. However, in reality, various external factors can introduce deviations in these parameters. In a typical communication system, internal oscillators are utilized to generate reference frequencies for various operations within the system. Due to manufacturing variations and component tolerances, these internal oscillators are not identical. As a result, they introduce slight differences between transmitters and receivers, leading to variations in their performance. This difference is known as the "Sample Frequency Offset" (SFO). In simpler terms, if a transmitter operates at a frequency X, the receiver will detect it at a frequency X ± SFO, even when both the transmitter and receiver are set to the same frequency.

Each ADALM-PLUTO SDR is equipped with its own internal oscillator, resulting in a SFO within the RHL-RELIA lab that is composed of ADALM-PLUTOs. Although the SFO among ADALM-PLUTO SDR devices is minimal compared to its minimum bandwidth (BW) of approximately 600 kHz, it's crucial to confirm its presence. To do so, you can design a simple transmitter and receiver system that transmits a tone at a specific frequency, similar to what was done in Lab 0. This setup is illustrated in Figure 1a (transmitter) and Figure 1b (receiver), with both operating at a carrier frequency of **2.4 GHz.**

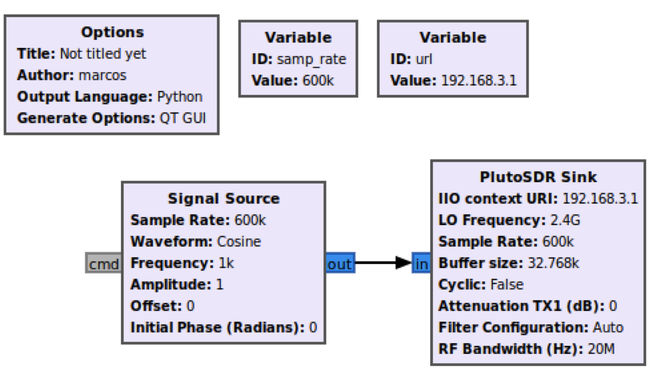

Figure 1a

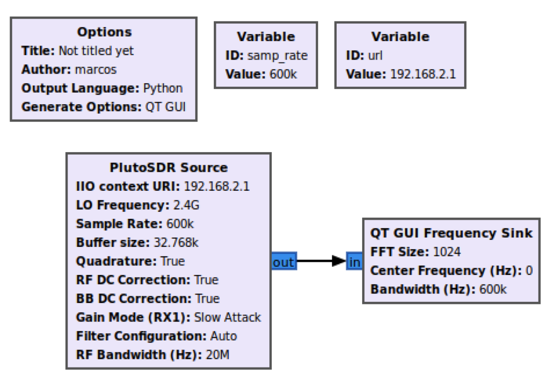

Figure 1b

There is a limitation of the SFO estimation that stems from the nature of the Fast Fourier Transform (FFT), which results in discrete frequency bins. These bins are determined by the bandwidth (BW) of the signal and the number of FFT points (nFFT). This relationship defines the **frequency resolution**, which represents the smallest frequency interval that can be distinguished by the FFT. Frequency resolution is obtained by:

$$\Delta f = BW/N \qquad (1)$$

Where:

Δf is the frequency resolution.
BW is the bandwidth of the frequency sink or sample rate of the system.
N is the number of FFT points (usually 1024).

To address this limitation, a low-pass filter can be employed. This filter acts like a "zoom in", focusing on specific frequencies within the bandwidth of interest and effectively reducing the frequency resolution to isolate and detect signals more accurately. Let's integrate a low-pass filter into your Receiver file, as depicted in Figure 2, to refine the frequency resolution by reducing the bandwidth.

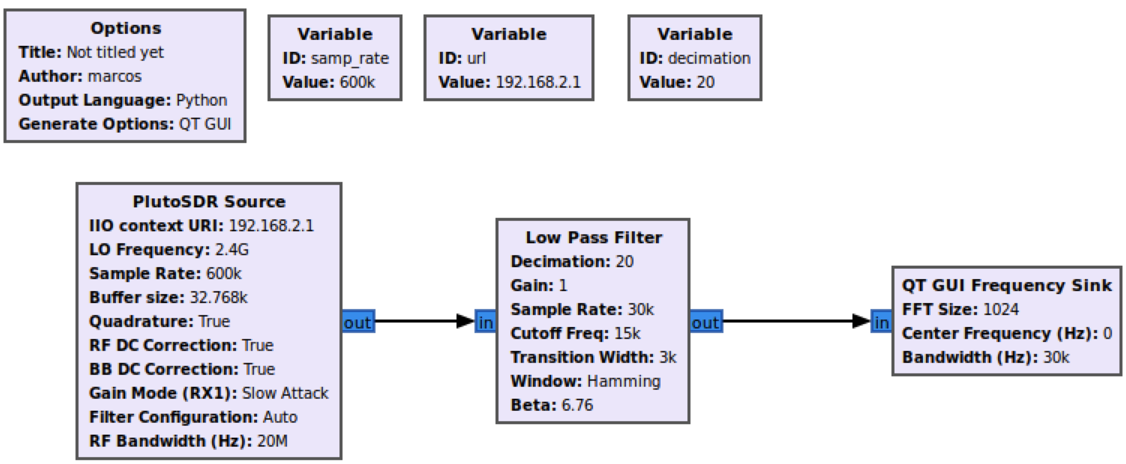

Figure 2

Q1. Frequency Error - Visualization (15 points)

For TX: IIO context URL: 192.168.3.1. If you use variable, write “192.168.3.1”.

For RX: IIO context URL: 192.168.2.1. If you use variable, write “192.168.2.1”.

1. Check Figure 1b and Figure 2, and calculate the frequency resolution in each case based on the equation (1)
2. Create GRC files and flowgraphs similar to Figure 1a (TX) and Figure 2 (RX). Obtain a screenshot of the plot using RHL-RELIA and annotate the value of the visible SFO.

3. Based on the value obtained in step (2), determine how many frequency bins the SFO is away from the frequency center. *Hint: A frequency bin is numerically equal to the frequency resolution.*

Part 2: Automatic Estimation of Frequency Error

Automated estimation of the SFO is preferred over manual estimation, especially when testing numerous digital systems. Automated estimation ensures consistency and efficiency, minimizing the risk of human error and saving time during testing. Figure 3 illustrates this process, with each block explained as follows:

It is recommended to create variables to avoid the repetition of numbers as it improves code readability and maintainability, reducing the risk of errors and facilitating future modifications.

- Stream to Vector: Group the upcoming data into packages (Num Items=1024).
- FFT: Convert the package from time to Frequency domain using FFT (Shift=Yes).
- Complex to Mag^2: Convert complex numbers to real numbers by calculating their magnitude.
- Log10: Convert to log scale (Vector Length=1024).
- Argmax: Input a vector of values and determine the maximum value along with its corresponding index (bin) in the vector.

Due to we are only interested in bin value then the other output must be connected to a Null Sink (otherwise GRC will find an error in the program)

- Short to Float: Convert type of variable.
- Add Const: Add a **positive or negative constant** value that must be half of the vector length (vlen/2).
- Multiply Const: Multiply by a **positive or negative** constant value that must be equal to (samp_rate/vlen).
- QT GUI Number Sink: Widget that plots the obtained value.

Also don’t forget to add a QT GUI Frequency Sink to plot the frequency spectrum.

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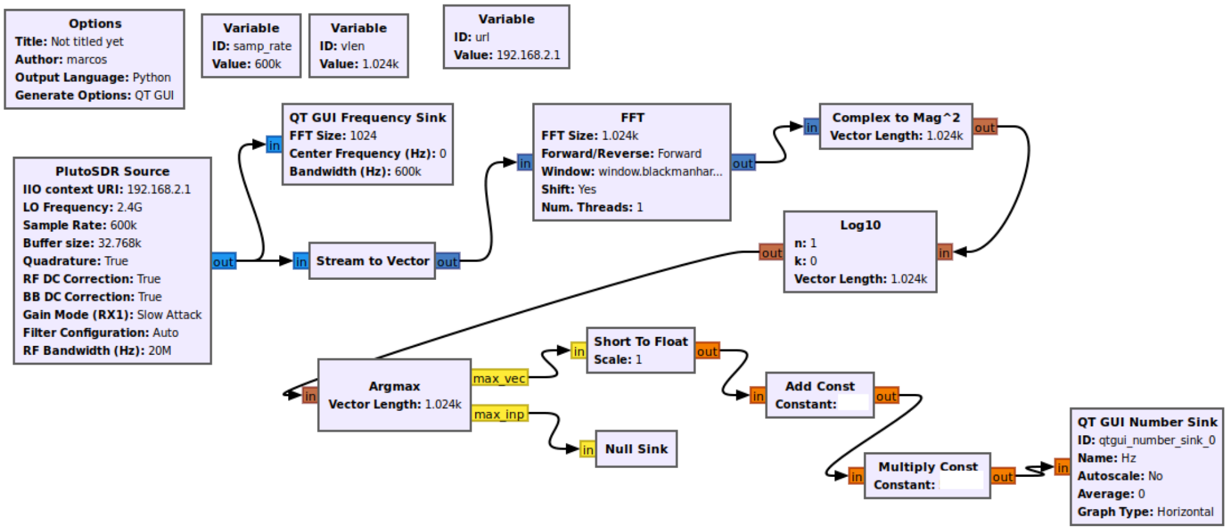

Figure 3

Q2. Frequency Error - Automatic Detection (35 points)

For TX: IIO context URL: 192.168.3.1. If you use variable, write "192.168.3.1".

For RX: IIO context URL: 192.168.2.1. If you use variable, write "192.168.2.1".

1. Create a receiver GRC file similar to Figure 3. Enter the parameters as it was indicated previously. You can use the transmitter GRC file from Figure 1a. Plot the results obtained. What is the error value you obtained?

2. The RHL-RELIA lab consists of 8 pairs of ADALM-Pluto devices, with each pair referred to as an instance. Access to each instance is randomly assigned based on availability. Therefore, students are likely to access different instances each time they use the lab. Consequently, each time a user accesses RHL-RELIA, they obtain a different SFO.

   Repeat the experiment in (1) until you have obtained the SFO for 4 distinct instances. Annotate both the instance identification and the SFO in the table below. The instance identification will appear above the title of the widgets. For example, in Figure 4, the instance identification is uw-s1i2.

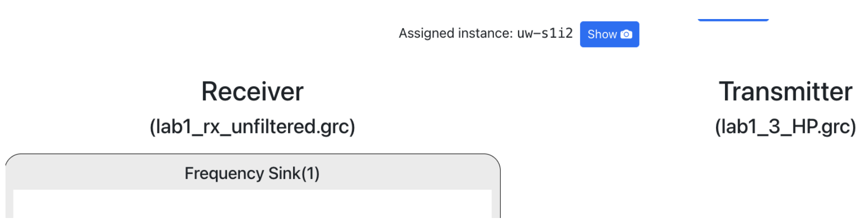

Figure 4. Instance in a RHL-RELIA transmission

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3. Also, calculate the SFO in terms of the number of frequency bins shifted and include it in the table. (1 bin = Δf)

RHL-RELIA Instance identification	SFO	Bins shifted

4. Is the SFO the same or close between different instances? If not, provide reasons why they are not the same or close.

5. What suggestions or ideas would you offer to minimize the impact of SFO in a wireless communication system to ensure that both the transmitter and receiver operate at the same frequency?

6. Describe in your own words how the flowgraph depicted in Figure 3, (from PlutoSDR Source Block to QT Number Sink Block), calculates the SFO.

Submission Instructions

Please compile your observations, analyses, and responses to the lab questions into a PDF report. Ensure that your report is well-organized, and include screenshots of relevant plots and visualizations where necessary. Clearly label and number your responses according to the corresponding question numbers.