Lab 1: Signal Processing in Wireless Communication

In this laboratory, students will explore the significance of signal processing by applying digital filters to the signal and analyzing the resulting quality.

> *NOTE: You will complete this assignment either remotely or with Physical Kits. If assigned to work remotely, please use screenshots from the RHL-RELIA website to answer the questions. If using Physical Kits, utilize screenshots from the GNU Radio Companion Software (GRC) to respond to the questions. Choose between RHL-RELIA or GRC depending on the mode you are instructed to use.*

Part 1: Understanding the Function of Digital Filters (Simulation)

Digital filters are crucial components in communication systems, aiding in the extraction, isolation, or manipulation of signals. Utilizing digital signal processing techniques, they operate on discrete-time signals. Categorized by their frequency response and processing method, digital filters fulfill tasks such as signal conditioning, noise reduction, and spectral shaping.

GNU Radio Companion (GRC) provides a wide range of predefined blocks for configuring digital filters quickly. These blocks allow users to easily implement various types of filters, such as low-pass, high-pass, band-pass, and band-stop filters, by simply dragging and dropping them into the signal flow diagram. This graphical interface simplifies the process of designing and configuring filters, enabling users to adjust parameters and visualize the filter's response in real-time. GRC's intuitive interface accelerates the filter configuration process, making it accessible to both novice and experienced users alike.

Let's begin by leveraging the wide spectrum feature of noise. Noise contains energy across a broad range of frequencies, meaning it's not confined to a specific frequency band but instead spans a wide range of frequencies as it is illustrated in Figure 1.

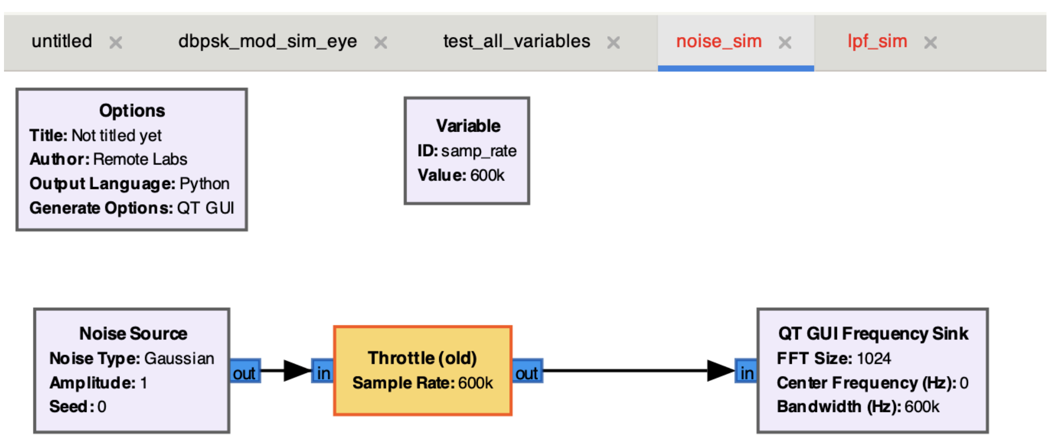

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Figure 1

Low Pass Filter (LPF)

A digital low-pass filter is a type of filter used in digital signal processing to allow low-frequency components of a signal to pass through while attenuating higher-frequency components. In GRC there is a block named “Low Pass Filter” and the parameters are summarized below and illustrated in Figure 2.

Table 1

Adapted from https://wiki.gnuradio.org/index.php/Low_Pass_Filter

FIR Type (R)	Specify whether input/output is real or complex.
Decimation	Decimation rate of filter, must be an integer, and cannot change in real time.
Gain (R)	Scaling factor applied to output.
Sample Rate (R)	Input sample rate.
Cutoff Freq (R)	Cutoff frequency in Hz.
Transition Width (R)	Transition width between stop-band and pass-band in Hz.
Window (R)	Type of window to use.
Beta (R)	The beta parameter only applies to the Kaiser window.

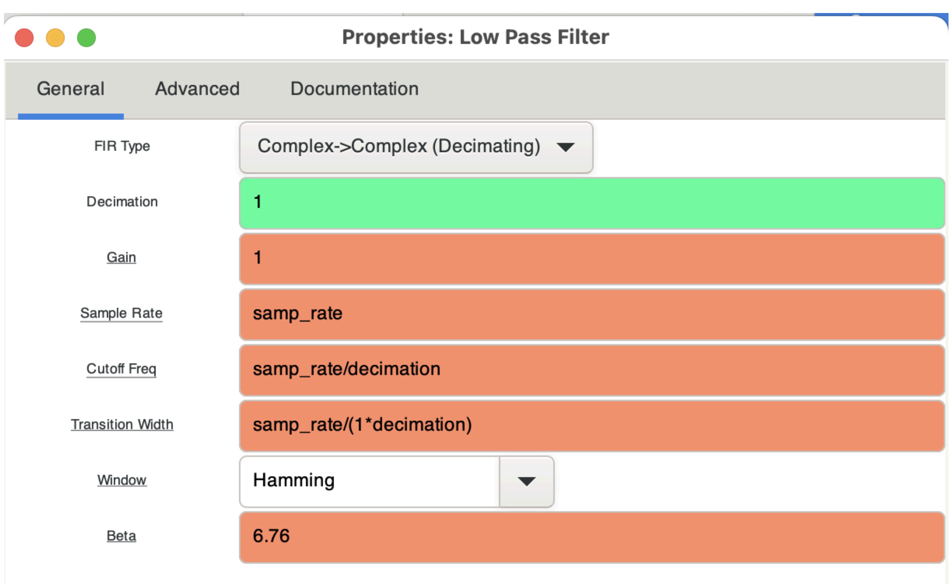

Figure 2

Now let's insert a Low Pass Filter to the right of the Noise Source and throttle blocks like in Figure 3 to see its effect.

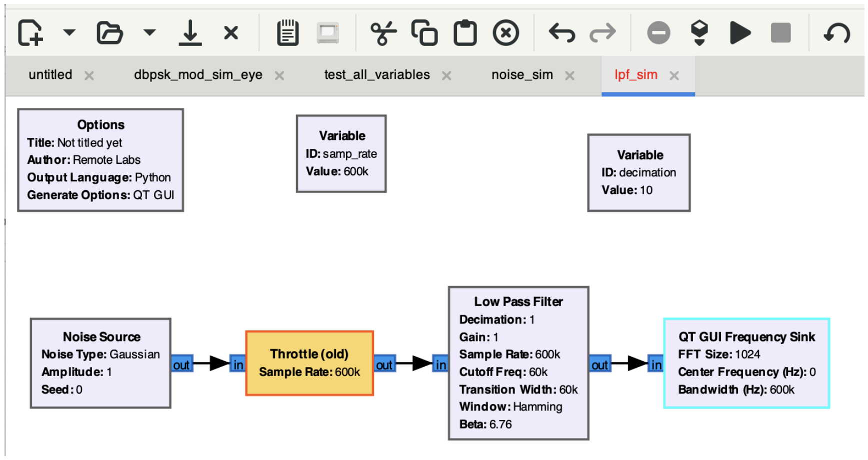

Figure 3

Q1. <u>Noise System (15 points)</u>

1. Create a GRC file and flowgraph similar to Figure 1 above and utilize either RHL-RELIA or GRC to simulate the frequency response. Take screenshots of the plots to illustrate your findings.

   Use the following variable in GRC:

   samp_rate=600000 (Avoid using "600K" as GRC won't recognize units)

2. Generate a GRC file and flowgraph similar to Figure 3 above and leverage either RHL-RELIA or GRC to simulate the frequency response. Take screenshots of the plots to illustrate your findings.

   Utilize the following variables/parameters in GRC:

   - *samp_rate=600000 (Avoid using "600K" as GRC won't recognize units)*
   - *decimation=10*

   In Low Pass Filter block:

   - *Decimation=1*
   - *Sample Rate=samp_rate*
   - *Cut Off Freq=samp_rate/decimation*
   - *Transition=samp_rate/decimation*

2.1. Determine the frequency range of the band pass of the Low Pass Filter.
2.2. Calculate the attenuation (in dB) of the pass band over the noise.

Part 2: Effect of Digital Filters with ADALM-Pluto SDR

NOTE: If you are using Physical Kits, please proceed to the section "Setting up ADALM-Pluto on your computer" first. If you are working remotely, you may continue.

Now, let's construct a practical system using the ADALM-PLUTO SDR. We'll transmit a 20kHz tone and assess its transmission, exploring how filters can enhance the signal quality. To do this, we'll design one basic transmitter file (Figure 4) and two receivers: one without a filter (Figure 5) and one with a low-pass filter (Figure 6).

Transmitter
This system will transmit a sine wave modulated at 1.8 GHz with a frequency of 20 kHz.

In the transmitter flowgraph, design similarly to what was done in Lab 0 and define two variables:

- freq_op=1.8 GHZ (Write the number with all zeros, as GRC doesn't recognize units)
- freq_tx=20 kHz (Write the number with all zeros, as GRC doesn't recognize units)

Input the LO Frequency in the PlutoSDR Sink as:

- IIO context URL: 192.168.3.1. If you use variable, write "192.168.3.1" (including quotation marks)
- LO Frequency = freq_op + freq_tx

Save this GRC file and label it as a transmitter. (You can name it something like "basic_tx.grc")

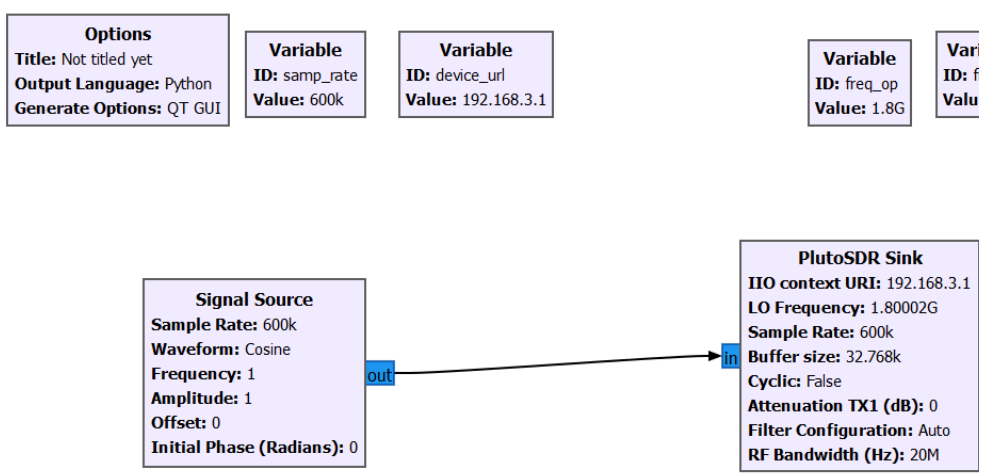

Figure 4

Receiver without Filter

Now, let's shift our focus to the Receiver without a filter (Figure 5), which resembles Lab 0 with the following parametesr:

PlutoSDR Source block:

- LO Frequency = 1.8 GHZ (Write the number with all zeros, as GRC doesn't recognize units)
- IIO context URL: 192.168.2.1. If you use variable, write "192.168.2.1" (including quotation marks)
- Gain mode: Manual
- Manual Gain (dB): 70

QT GUI Frequency Sink block:

- FFT Size: 512 or 1024 (depending on your preferences)

Save this GRC file and identify it as a receiver without a filter. (You can name it something like "basic_rx_unfiltered.grc")

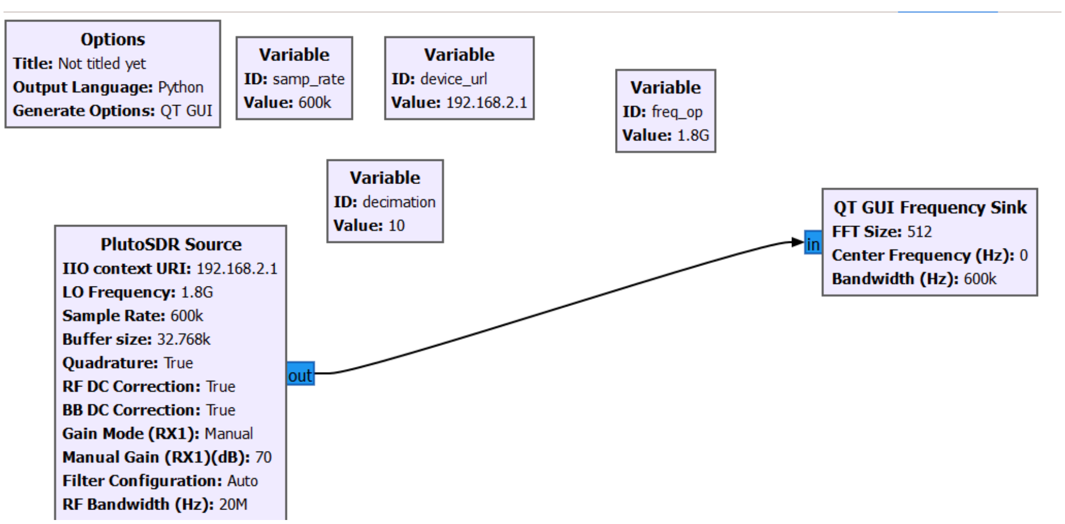

Figure 5

Receiver with Filter

Now, let's focus on creating a Receiver with a filter with the following parameters as shown in Figure 6. Define these two variables:

- decimation=10
- samp_rate=600000 *(Avoid using "600K" as GRC won't recognize units)*

And these parameters in the Low Pass Filter block:

- *FIR Type=Complex->Complex (Decimating)*
- Decimation=1

- Sample Rate=samp_rate
- Cut Off Freq=samp_rate/decimation
- Transition=samp_rate/decimation

Save this GRC file and identify it as a receiver with a filter. (You can name it something like "basic_rx_filtered.grc").

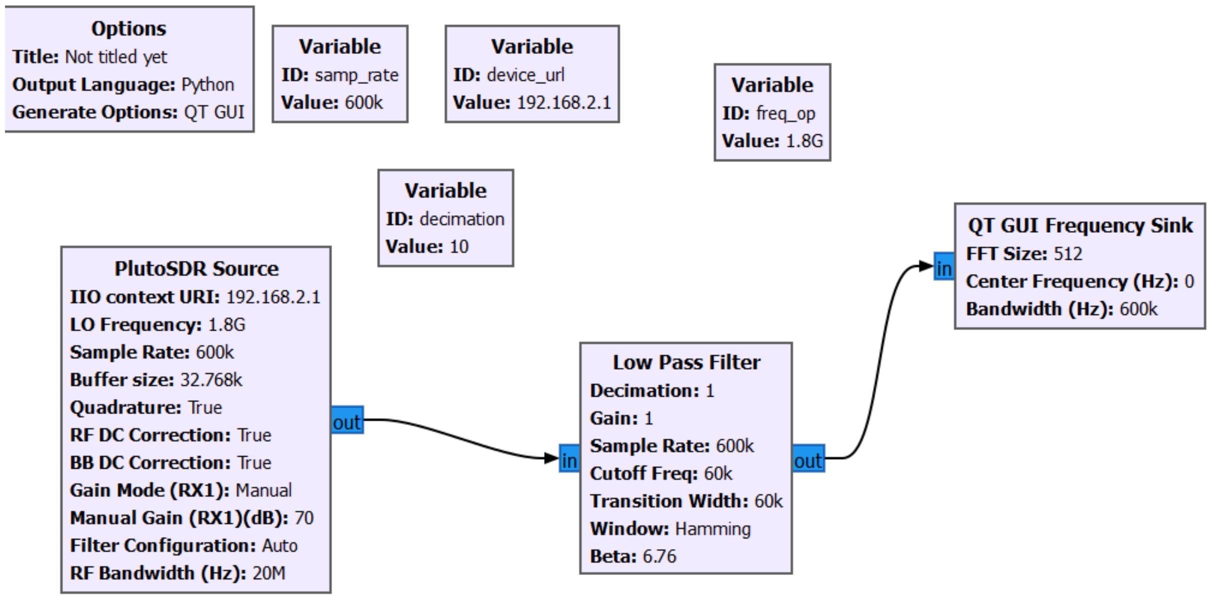

Figure 6

Q2. Digital System - Low Pass Filter (20 points)

1. Run your transmitter file and your receiver without filter file in either RHL-RELIA or GRC, and take screenshots of the plots to illustrate your findings.
2. Based on your screenshot, can you distinguish the signal at 20 kHz (or a nearby frequency)? If so, what is the power value (in dB) of that tone? Locate the strongest peak following the 20 kHz tone and estimate its power value (in dB)?
3. Now run your transmitter file and your receiver with a filter file in either RHL-RELIA or GRC, and take screenshots of the plots to illustrate your findings.
4. Based on your screenshot, Locate the strongest peak following the 20 kHz tone that you located in (1) and estimate its power value (in dB)? How much less is compared to the power value found in (1)?
5. Compare the results of the two experiments and describe the advantages and disadvantages of using a low-pass filter system.

Q3. Digital System - High Pass Filter (20 points)

Now, conduct a similar exercise as Q2, but this time utilize a High Pass Filter instead of a Low Pass Filter. This time, transmit a tone of 260kHz.

Instructions:

In the transmitter GRC
freq_Op=1.8 GHZ (Write the number with all zeros, as GRC doesn't recognize units)
freq_tx=260 kHz

In the receiver without filter GRC
You can use the same file that you use in Q2

In the receiver filtered GRC

- *samp_rate=600000 (Avoid using "600K" as GRC won't recognize units)*
- *decimation=10*

This is the parameters you can use in your "High Pass Filter" block

- *FIR Type=Complex->Complex (Decimating)*
- *Decimation=1*
- *Sample Rate=samp_rate*
- *Cut Off Freq=samp_rate/2 - samp_rate/decimation*
- *Transition=samp_rate/2 - samp_rate/decimation*

1. Run your transmitter file and your receiver without filter file in either RHL-RELIA or GRC, and take screenshots of the plots to illustrate your findings.
2. Based on your screenshot, can you distinguish the signal at 260 kHz (or a nearby frequency)? If so, what is the power value (in dB) of that tone? Locate the strongest peak following the 260 kHz tone and estimate its power value (in dB)?
3. Now run your transmitter file and your receiver with the high-pass filter file in either RHL-RELIA or GRC, and take screenshots of the plots to illustrate your findings.
4. Based on your screenshot, Locate the strongest peak following the 260 kHz tone that you located in (1) and estimate its power value (in dB)? How much less is compared to the power value found in (1)?
5. Describe your observations and provide an explanation of a scenario where a high-pass filter can be beneficial in digital wireless communication.

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.