EE2033 Integrated System Lab

Mini Project Report

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Introduction

The mini-project consists of two tasks.

- Task 1:

We are required to employ Pluto Adalm, RTL-SDR, Analog Discovery 2, LTSPICE, GNURadio with the given specification (Design B) and design a filter to suppress the interference at the Intermediate Frequency (IF, signal from the RTL-SDR). The objective is to maximise the packet success rate (PSR), shorten the time taken to achieve the desired number of packets, with cost in mind.

- Task 2

We are also required to modify a grc file to support transmission of the message using Binary FSK modulation.

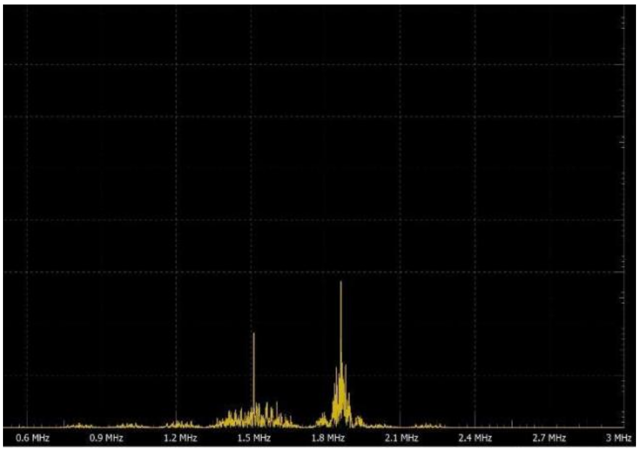
Task 1

Specifications (Design B)

Pluto Sink Settings	**Unit**	**Specifications**
samp_rate	Hz	1.6M
Pluto Carrier Frequency (fc)	GHz	1.3
Symbol Rate (fsym)	Bits x 10^3/sec	200
Signal Amplitude (Asig)		0.2
Interference Frequency (fint)	Hz	360k
Interference Amplitude (Aint)		0.3
Interference Symbol Rate	bits/sec	50k
RTL-SDR Source		
samp_rate	Hz	1.6M
RTL-SDR Carrier Frequency (freq)	GHz	1.3
AD2 Settings		
samp_rate	Hz	4M
opamp_file settings		
fs_in	Hz	4M
fs_out	Hz	1.6M
Final Presentation Message		Hello

The table above shows the design B specifications that we need to follow for the task 1. Based on the given specifications, we characterised our filter.

Experimental Result



We first used AD2 to test the output signal with full interference. We can see that the signal is mainly located at 1.5MHz, with a spread of 200kHz (left and right), and the interference is mainly located at 1.86MHz, with a spread of 50kHz. We can also see the magnitude of the interference is about 1.5 times the original signal.

Analysis

Since RTL-SDR has an intermediate frequency (IF) of 1.5MHz, after receiving the signal using RTL-SDR, the received signal is not at the baseband. The interference frequency that received using RTL is $1.5MHz + 360kHz = 1.86MHz$.

Since the symbol rate of the signal is 200kHz, the first null bandwidth of the signal is between $1.5MHz - 200kHz = 1.30MHz$ and $1.5MHz + 200kHz = 1.70MHz$. Therefore, to minimise the interference for design B, the lowpass filter should ideally have a cut-off frequency at 1.70MHz and significantly attenuate the frequency component at 1.86MHz.

This is actually consistent with the experiment result as shown above.

FilterPro Design

We decided to use the 4^{th} order low pass filter. Even though higher order filters (for example, 6^{th} and above) has a higher attenuation, we chose the 4^{th} order filter mainly due to the following reasons:

- Increasing in the number of stages will increase the output noise power of the cascaded system. As a result, the output will be more noisy, which may negatively affect the result.

- We design the filter with cost in mind. Higher order low pass filters require more components (opamp, resistors and capacitors), which will increase the cost. Also, we were worried that we do not have enough components (resistors and capacitors) to build the higher order filer.

- Higher order filter increases the complexity of the circuit. It will be more difficult to debug the circuit if anything goes wrong, such as misconnection or poor contact.

- The min GBW requirement is much larger than 200MHz for 3rd stage onwards. However, the opamp with the largest GBW that we have is LM7171, which is 200MHz.

Settings

- Type: low pass filter

- Order: 4th order

- Cut-off frequency: 1.7 MHz

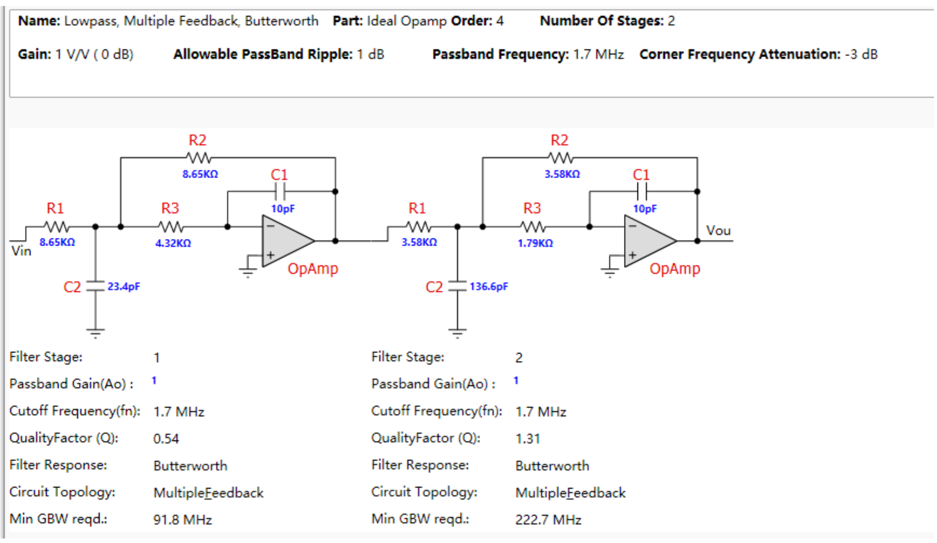
- Topology:

Theoretically, both topology can achieve the same functionality. However, one obvious advantage of Sallen-Key is that it requires fewer components (1 resistor less for each stage) compared to the Multiple-Feedback topology.

Due to the difficulty of getting the components with desired parameter, at first we choose Sallen-Key as the topology for our filter design. The simulation on LTspice worked fine, but when we implemented on the breadboard, the output was very distorted. There was no connection problems as checked by the GA. He suggested us to try the other topology. So we finally chose multiple feedback topology.

- Respond type:

We first chose Butterworth as the starting point, since it has the smoothest response curve and has no ripples. It is mostly flat and smooth near the cut-off frequency. The figure below shows its schematics based on the design using FilterPro.



The components needed to build the 4th order Butterworth filter are as shown below in the bill of materials.

Name	Quantity	Part Number	Value	Description
R1 (Stage 1)	1	Standard	8.65KΩ	Resistor
R2 (Stage 1)	1	Standard	8.65KΩ	Resistor
R3 (Stage 1)	1	Standard	4.32KΩ	Resistor
C1 (Stage 1)	1	Standard	10pF	Capacitor
C2 (Stage 1)	1	Standard	23.4pF	Capacitor
OpAmp (Stage 1)	1	Standard		Ideal OpAmp
R1 (Stage 2)	1	Standard	3.58KΩ	Resistor
R2 (Stage 2)	1	Standard	3.58KΩ	Resistor
R3 (Stage 2)	1	Standard	1.79KΩ	Resistor
C1 (Stage 2)	1	Standard	10pF	Capacitor
C2 (Stage 2)	1	Standard	136.6pF	Capacitor
OpAmp (Stage 2)	1	Standard		Ideal OpAmp

Op-amp

We initially planned to use one LM6172 as the first stage and LM7171 as the second stage. This is because LM7171 has a GBW of 200MHz, which is near the min GBW requirement 222.7MHz.

However, since LM6172 has two built in opamps and its GBW is relatively high, we finally decided to use one LM6172. This saves the cost by half.

This is the schematic for LM6172.

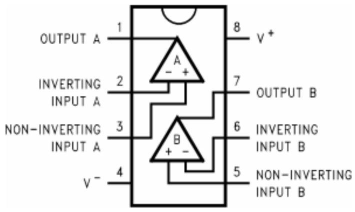
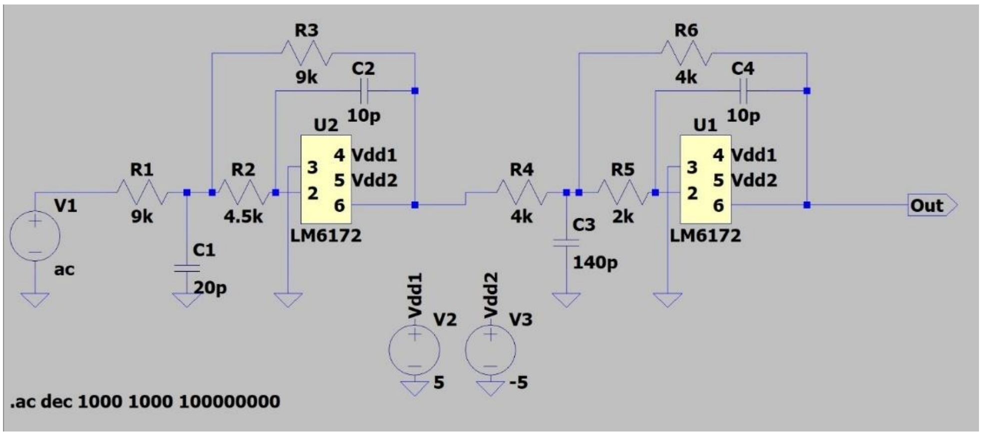


Figure 1. Top View 8-Pin
See Package Numbers P (PDIP) and D (SOIC)

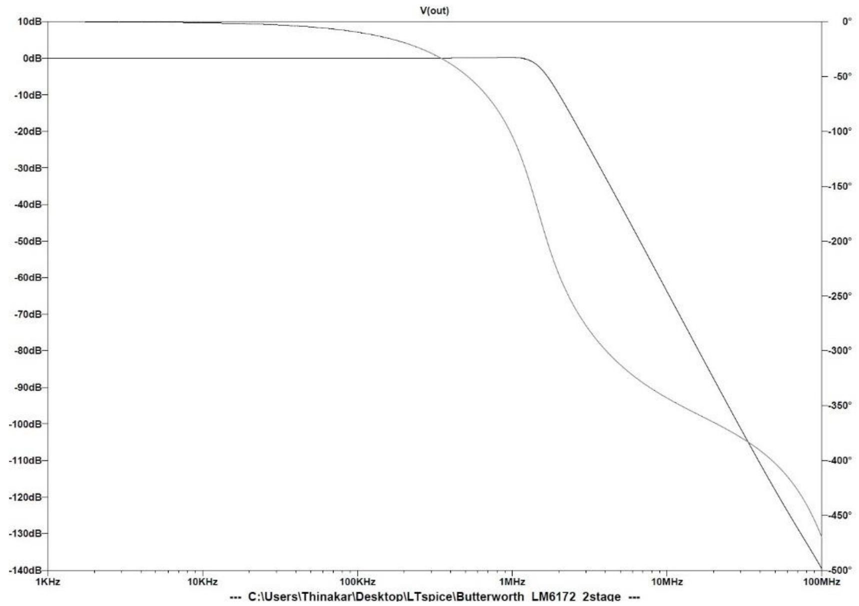
LTspice Simulation

Schematic of 4th order Butterworth filter:



(This was first simulated using the values of resistors and capacitors that we had.)

Bode plot:



We have noticed that there is a large discrepancy between the plot given by FilterPro and the plot simulated by LTspice.

Tuning process

After many iterations of FilterPro → LTSpice → Breadboard, we realised that we were facing three significant problems:

1. We did not have some of the resistors and capacitors with the values stated in the LTspice

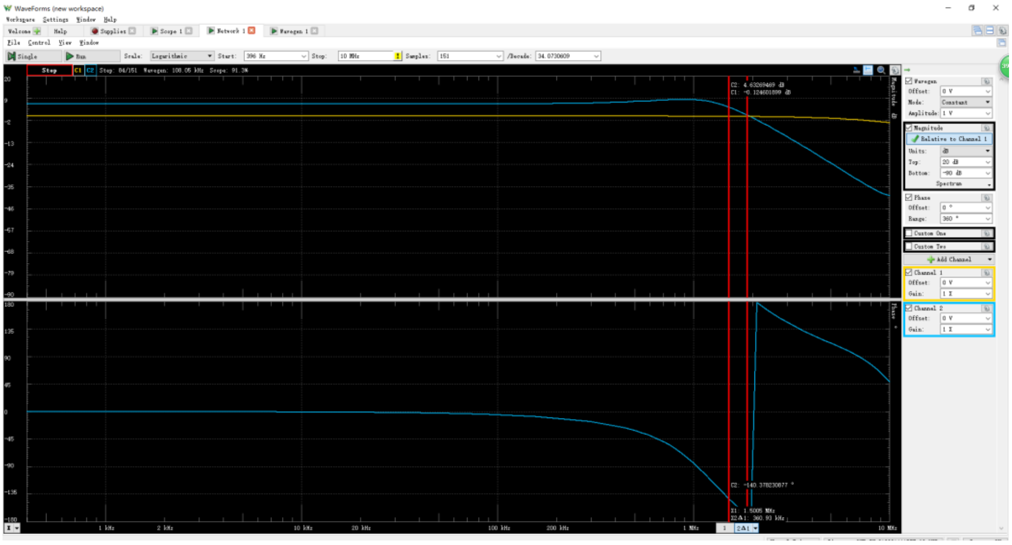
2. The errors of resistors and capacitors are very large. For example, a ‘100k’ resistor is measured as 80k from the multimeter reading.

3. Sometimes the simulation worked, but there was no PSR value showing out when we really tested on the breadboard.

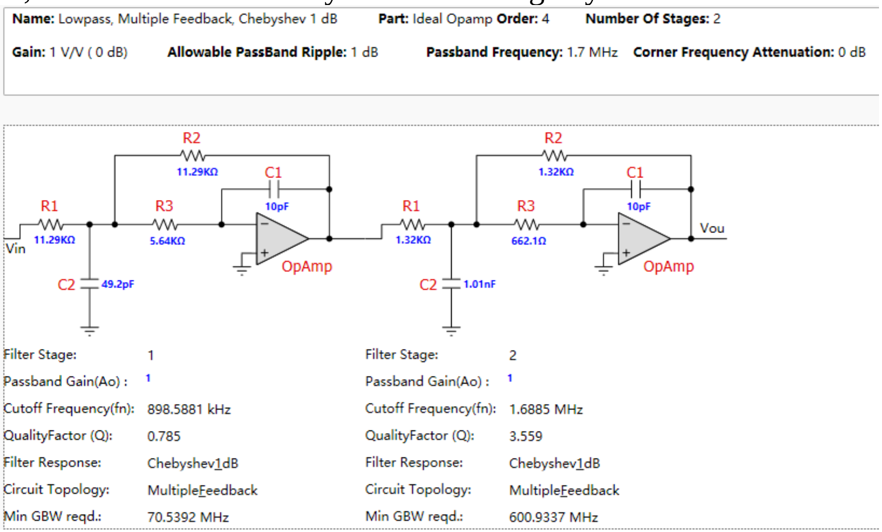
As a result, we decided to use a more direct approach. We directly tuned the filter by changing the value of the resistance and capacitance on the breadboard and see the changes in the response from the Bode diagram on AD2. The goal is to let the 3dB cut-off frequency as close as 1.7MHz.

This can be quickly done using variable resistors, or simply put a resistor in parallel with a resistor on the breadboard, to observe the response if the value of the resistor decreases. Same goes for capacitors.

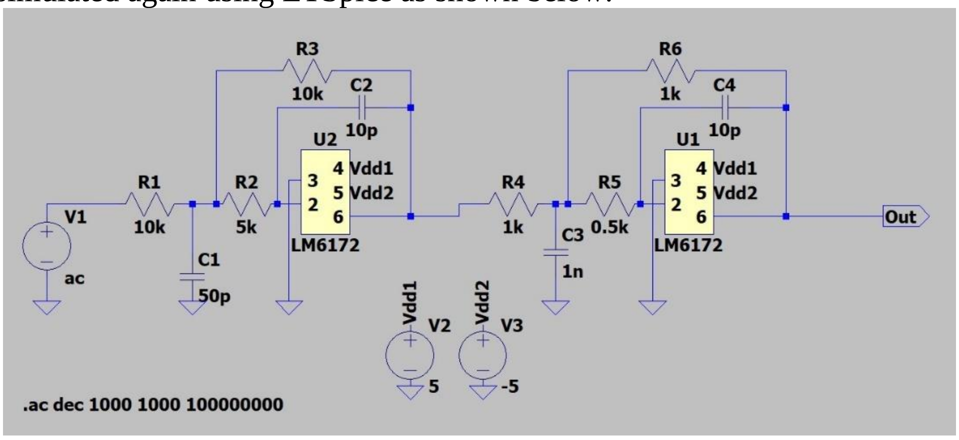
We once put a capacitor in parallel with the capacitor connected to ground at the second stage, and noticed that the cut-off frequency became nearer to the desired value. Then we realise we actually changed it from a Butterworth to a Chebyshev response type. The Bode plot from AD2 is shown below. (Note that the gain increases because one variable resistor increased.)



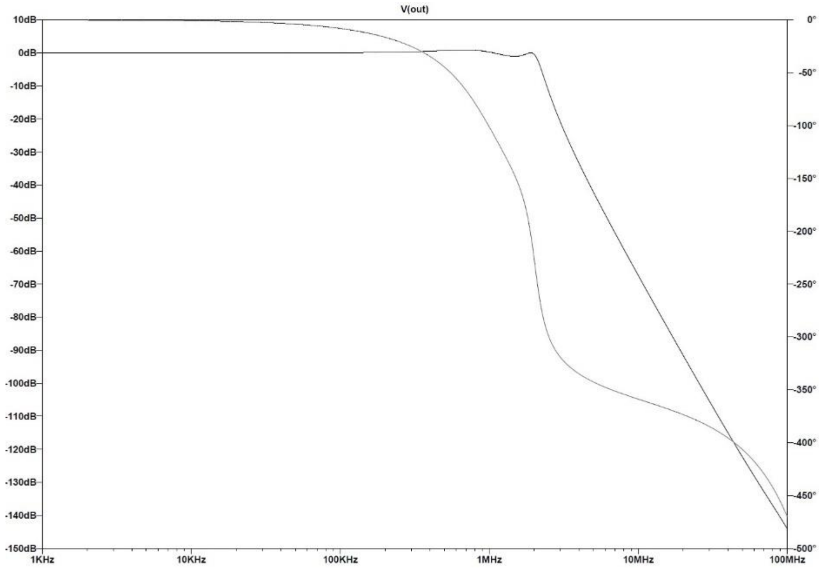
Following this, we recreated the Chebyshev filter design by FilterPro as shown below.



and then simulated again using LTSpice as shown below.



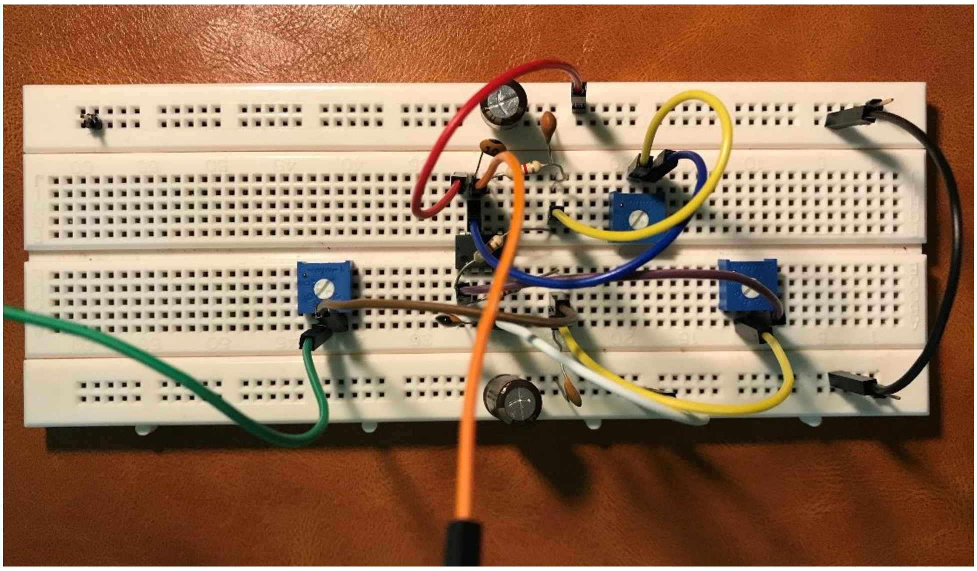
Bode plot:



Comparing with the bode plot of Butterworth previously, we can see the bode plot of Butterworth looks nice in simulation, but in reality it is not necessarily so. However, for Chebyshev, even though there are some small oscillations around the 3dB cut-off frequency, it is very sharp so that the signal can be attenuated more effectively, since the frequency of the signal and interference is quite near. So we decide to continue tuning with Chebyshev.

Actual Design

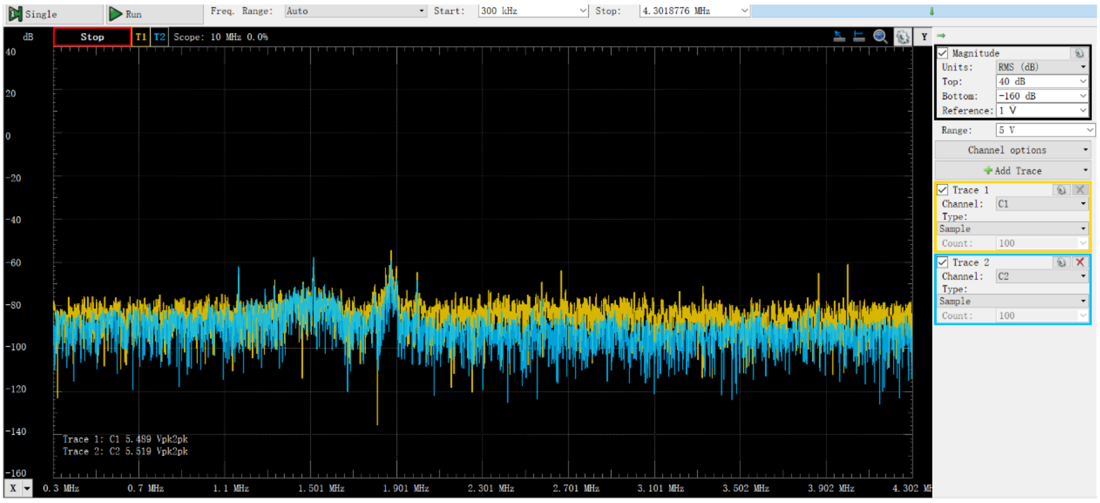
After some further tuning of resistors and capacitors, we finally get our design as shown below.



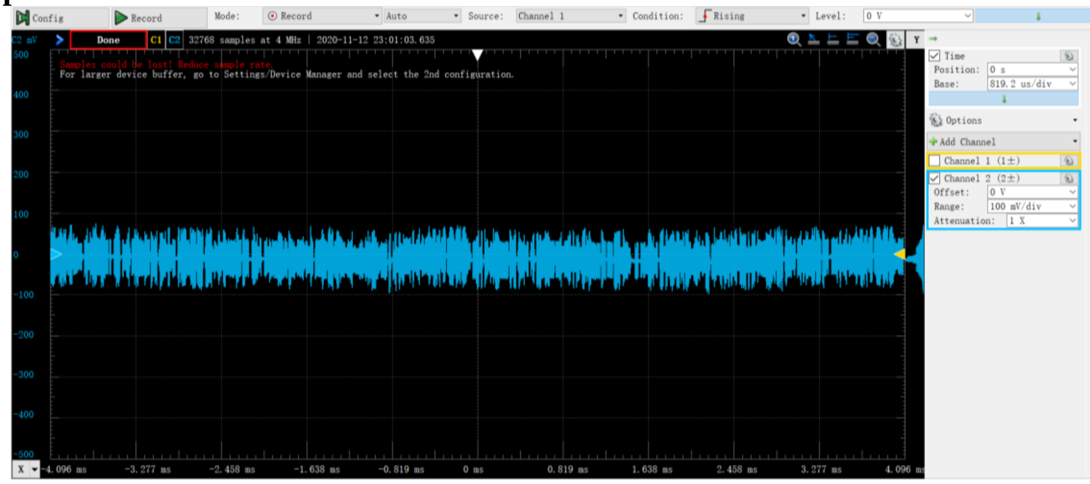
Result:

Full interference (0.3):

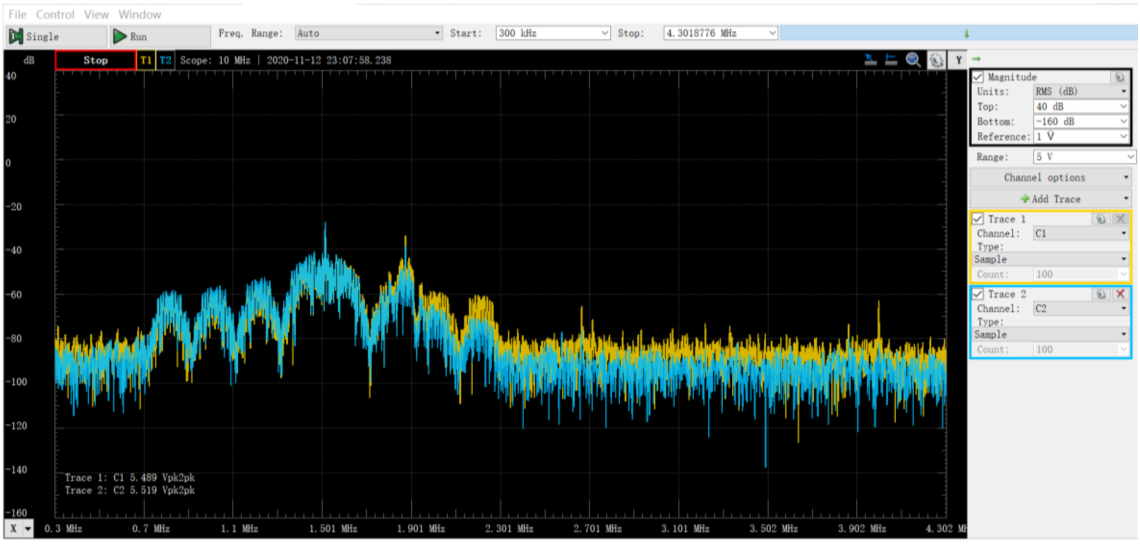
Spectrum:



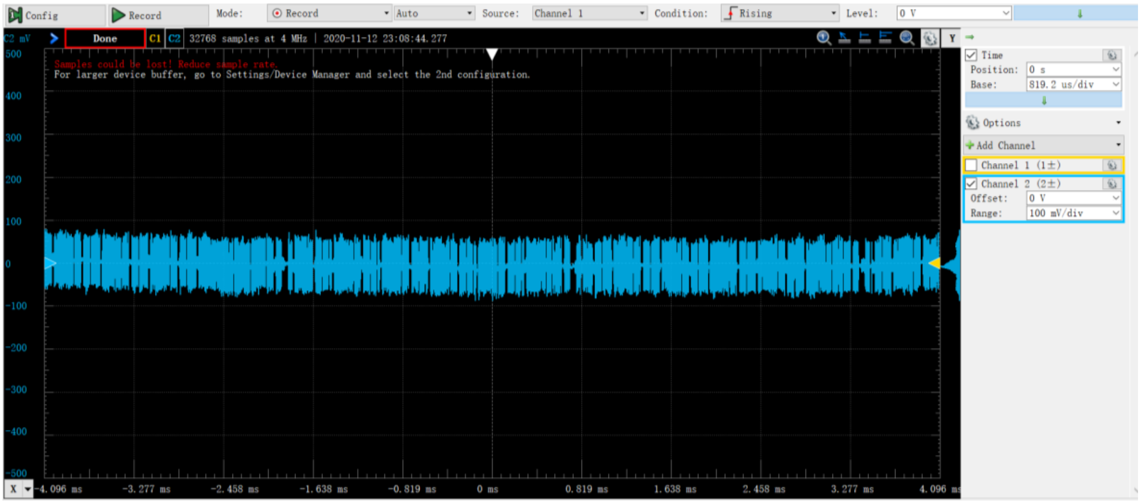
Output:



1/3 interference (0.1):
Spectrum:

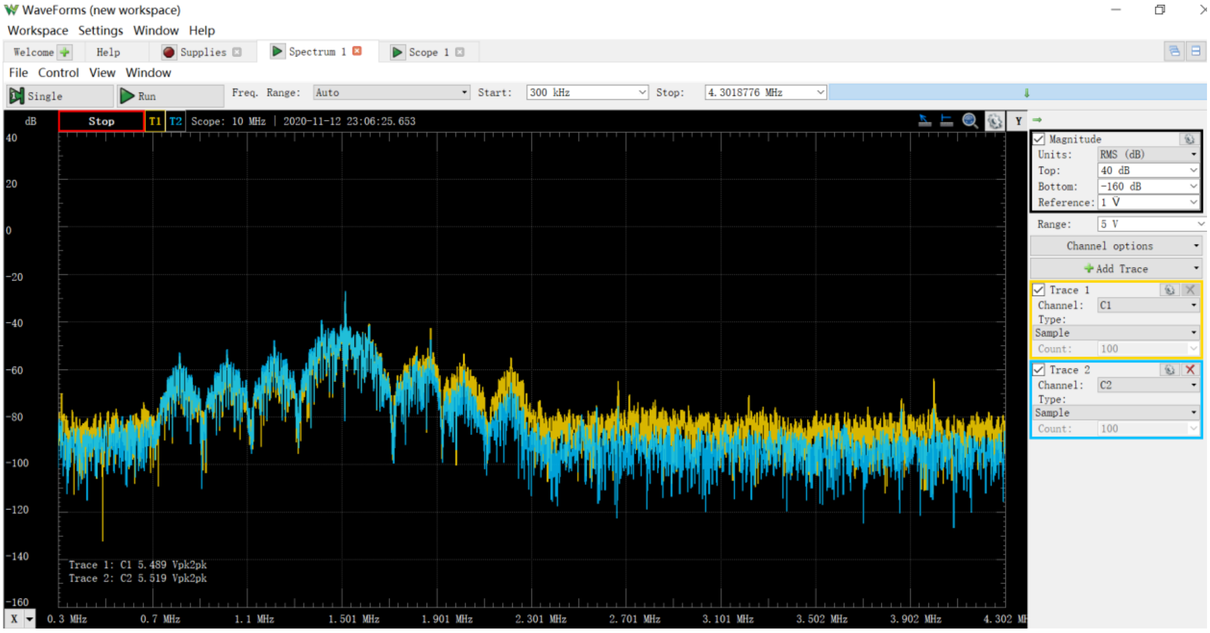


Output:

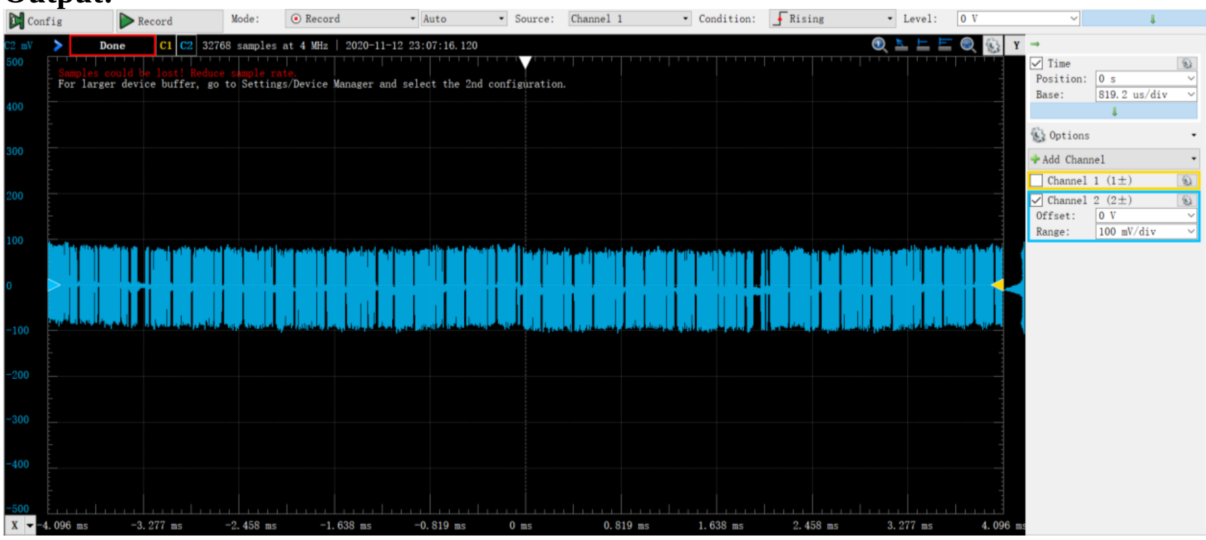


1/10 interference (0.03):

Spectrum:



Output:



Interference	PSR	Time of reaching 1000 packet /sec
full	**0.302**	**6.3**
1/3	**0.642**	**4.31**
1/10	**0.754**	**3.43**

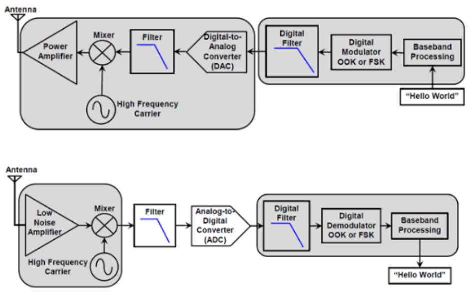
We can see from the above spectrum and scope graph that the filter can indeed attenuate the interference. The performance is better with smaller interference amplitude.

Conclusion

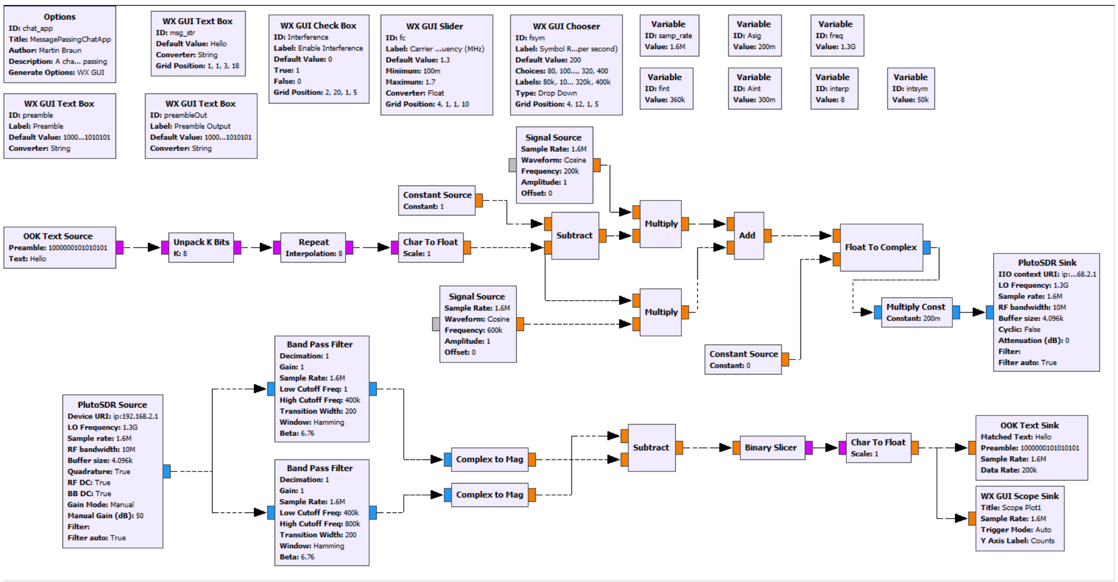
In this project, our team manage to design, simulate, construct and characterize an 4th-order low pass filter that is able to suppress interference at 1.86MHz while maximally preserving the original message signal. One of the key takeaways by performing task 1 is that simulation is essential in the designing process. Simulation can give us a solid foundation at the start, which can saves us a lot of time. However, we cannot rely too much on the simulation result. Trial and error is required to improve the performance of the design. It was quite unfortunate that we did not get the PSR for the full interference test, which might partially due to the noise in the environment at that time. Nevertheless, this project has helped us gain a deeper understanding of the wireless transmission and communication.

Task 2

Task 2 is to send a message, which is a letter sequence, by binary FSK (BFSK)

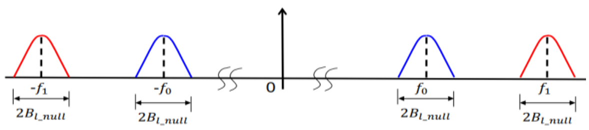


This is the transceiver grc file for task 2 as shown below. The implementation is based on our lecture notes.

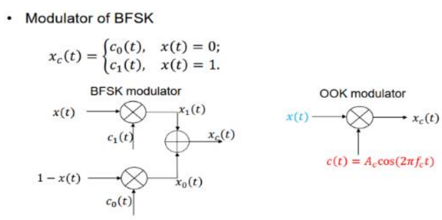


- sampling rate: 1.6MHz
- symbol rate: 200kHz
- carrier frequency: 1.3GHz

PSR is about 0.764



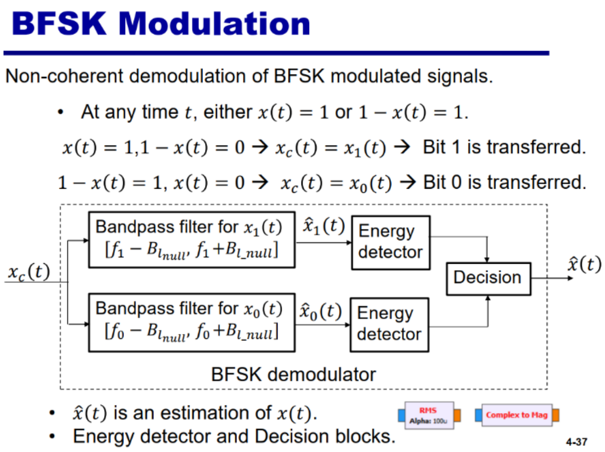
Modulator



We set the sampling rate as 1.6MHz (same as task 1). There is a restriction that the high cut-off frequency of bandpass filter is less or equal than half of sampling rate. So we set

- $f_0 = 200kHz$, where $x(t) = 0$.
- $f_1 = 600kHz$, where $x(t) = 1$.

Demodulator



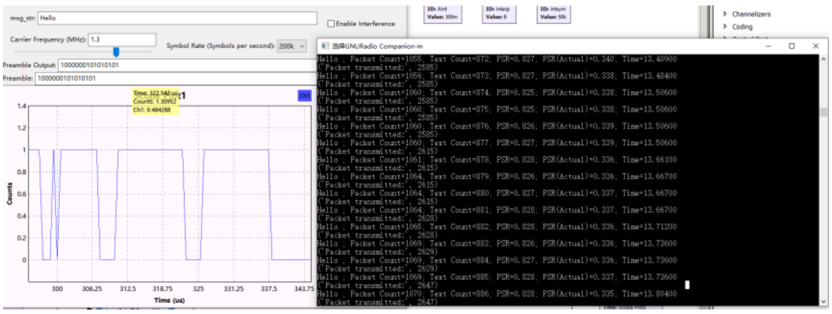
Since the symbol rate is 200k, $2B_{null} = 2 \times 200k = 400k$

Hence, we set the first bandpass filter as from 1Hz to 400kHz, and the second bandpass filter as from 400Hz to 800kHz. Then we use magnitude of the resultant signal as an energy detector. Then we determine whether it is 1 or 0 by comparing the magnitude of the signal located at frequency f_0 and f_1, which are filtered out by the two bandpass filters. The comparison is done by taking the difference of the magnitude of the two signal and compare it with 0. If 200kHz signal is stronger, then 0 is transmitted. If 600kHz signal is stronger, then 1 is transmitted.

Evaluation

One finding is that if we increase the carrier frequency f_1 to 800k while the rest remains the same, the PSR can increase to 0.828 (as shown below). We did not use this for submission because we are unable to explain this. Since the high cut-off of the bandpass filter is exactly at 800k, the higher half of null bandwidth of f_1 should be filtered out. However, it actually works with a better performance. It is probably because the larger the two carrier frequency separates, the less interference there will cause to one another, so that the final PSR is higher.

This task gives us a hands-on experience on how to transmit and receive signals using BFSK. The factors effecting the transmission using BFSK will be something that we want to explore in the future.



EE2033 Survey Questions

Circle a number to indicate how true each statement is of you. All of your responses will be kept anonymous and confidential, which will not affect your marks at all. There are no right or wrong responses, so please be open and honest.

Learning Outcomes

1	Able to use GNUradio and software-defined radio to construct simple communication system	1 (Not agree)	2	3	4 (Agree)
2	Able to use Filterpro and LTSpice to design filter.	1 (Not agree)	2	3	4 (Agree)
3	Able to use oscilloscope to observe and measure signals.	1 (Not agree)	2	3	4 (Agree)
4	Able to describe the signal processing in OOK modulation.	1 (Not agree)	2	3	4 (Agree)
5	Able to employ right antenna for the desired carrier frequency.	1 (Not agree)	2	3	4 (Agree)

E-learning

1	All the teaching materials organized based on course topics are sufficient	1 (Strongly disagree)	2 (Disagree)	3 (OK)	4 (Agree)	5 (Strongly agree)
2	The lab manuals are sufficiently detailed to understand the objective and to follow in each lab	1 (Strongly disagree)	2 (Disagree)	3 (OK)	4 (Agree)	5 (Strongly agree)
3	The mini-project materials are sufficient to understand the objectives and to follow	1 (Strongly disagree)	2 (Disagree)	3 (OK)	4 (Agree)	5 (Strongly agree)
4	The online activities (live lectures, lecture videos, instructions sent by emails and LumiNUS) are effective to support teaching	1 (Strongly disagree)	2 (Disagree)	3 (OK)	4 (Agree)	5 (Strongly agree)
5	The announcements, emails Q&A , forum and conferencing (through Zoom) are effective in guiding your progress through the lab and mini-project	1 (Strongly disagree)	2 (Disagree)	3 (OK)	4 (Agree)	5 (Strongly agree)
6	The announcements and emails are sufficient to guide you in your learning progress	1 (Strongly disagree)	2 (Disagree)	3 (OK)	4 (Agree)	5 (Strongly agree)
7	The comments in your marked lab reports are clear to help you to understand and learn from mistakes made	1 (Strongly disagree)	2 (Disagree)	3 (OK)	4 (Agree)	5 (Strongly agree)
8	You are able to self-evalute your learning at the end of each lab , quiz and project assessments	1 (Strongly disagree)	2 (Disagree)	3 (OK)	4 (Agree)	5 (Strongly agree)
9	Comments Face-to-face session is preferred for this module. Some problems are hard to explain clearly online or via email.					

Circle a number to indicate how true each statement is of you. All of your responses will be kept anonymous and confidential, which will not affect your marks at all. There are no right or wrong responses, so please be open and honest.

Learning Outcomes

1	Able to use GNUradio and software-defined radio to construct simple communication system	1 (Not agree)	2	3	4 (Agree)
2	Able to use Filterpro and LTSpice to design filter.	1 (Not agree)	2	3	4 (Agree)
3	Able to use oscilloscope to observe and measure signals.	1 (Not agree)	2	3	4 (Agree)
4	Able to describe the signal processing in OOK modulation.	1 (Not agree)	2	3	4 (Agree)
5	Able to employ right antenna for the desired carrier frequency.	1 (Not agree)	2	3	4 (Agree)

E-learning

1	All the teaching materials organized based on course topics are sufficient	1 (Strongly disagree)	2 (Disagree)	3 (OK)	4 (Agree)	5 (Strongly agree)
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8	You are able to self-evalute your learning at the end of each lab , quiz and project assessments	1 (Strongly disagree)	2 (Disagree)	3 (OK)	4 (Agree)	5 (Strongly agree)
9	Comments Newer computers have very few usb-a ports, maybe can provide cables with multiple output.					