PRINCIPLES OF COMMUNICATION

Project Title: Performance of AM Receiver in the Presence of Noise

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AN OVERVIEW OF AM COMMUNICATION

The main objective of a communication system is to convey information using a channel, which acts as a medium for transferring information between a transmitter and receiver.
The information is often represented as a baseband signal which is nothing but a message signal.

Efficient use of communication channels often necessitates shifting the range of baseband frequencies to different frequency ranges that are more suitable for transmission. After the signal is received at the receiver end, it is essential to shift it back to its original frequency range, to put it simply we have to reconstruct the message signal, which is accomplished by using modulation techniques.

As the title suggests, we are doing amplitude modulation. **Amplitude modulation is the process of varying the amplitude of a carrier signal following a baseband signal.**

AMPLITUDE MODULATION

Consider a carrier signal c(t):

$c(t) = A_c \cos(2\pi f c t)$

A_C-Carrier Amplitude

f_C-Carrier Frequency

The general representation of the modulated message signal is given below:

$s(t) = Ac\,[1 + k_a m(t)] \cos(2\pi f c t)$

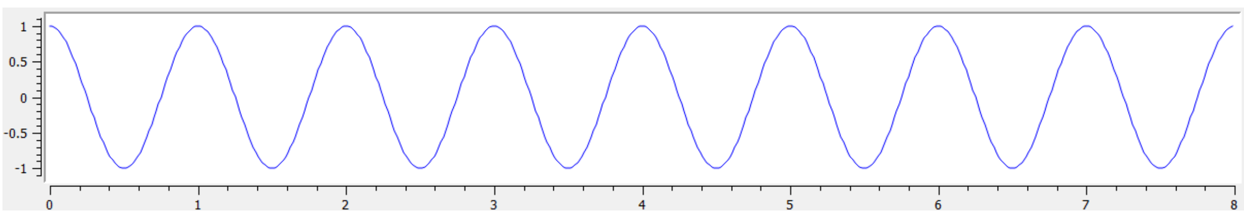
m(t): Message Signal.

k_a: A constant called Amplitude Sensitivity of the modulator is responsible for the generation of message signal m(t).

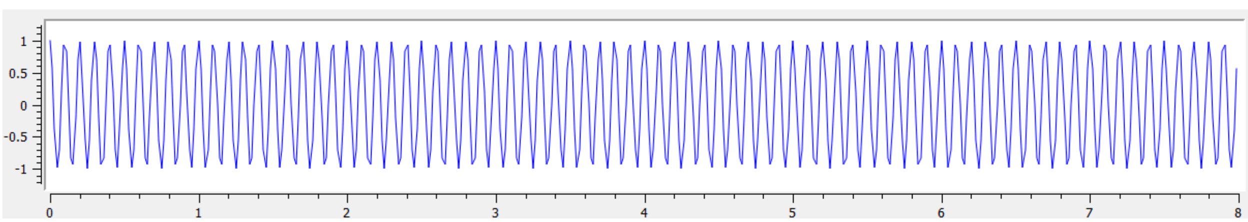
$|k_a m(t)| < 1$

Below is a graphical representation of a message signal, carrier signal, and the final modulated signal.

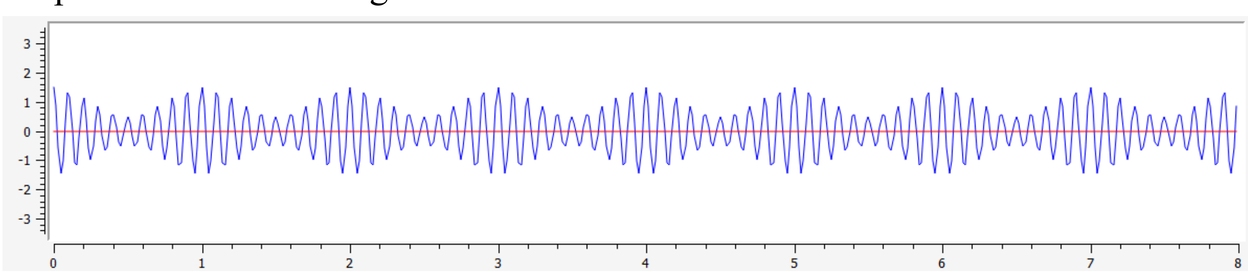
Message Signal



Carrier Signal



Amplitude Modulated Signal

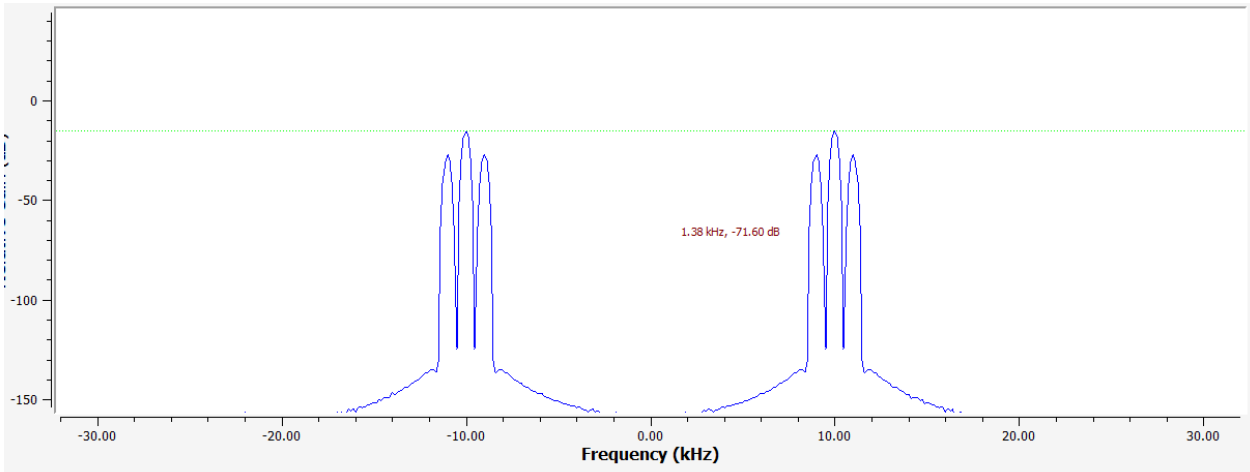


(Generated with the help of GNU Radio)

Now to plot the frequency domain representation of the modulated signal we have to take its Fourier transform:

$$S(f) = \frac{A_c}{2}[\delta(f - f_c)+\delta(f + f_c)] + \frac{K_a A_c}{2}[M(f - f_c) + M(f + f_c)]$$

Represented as:

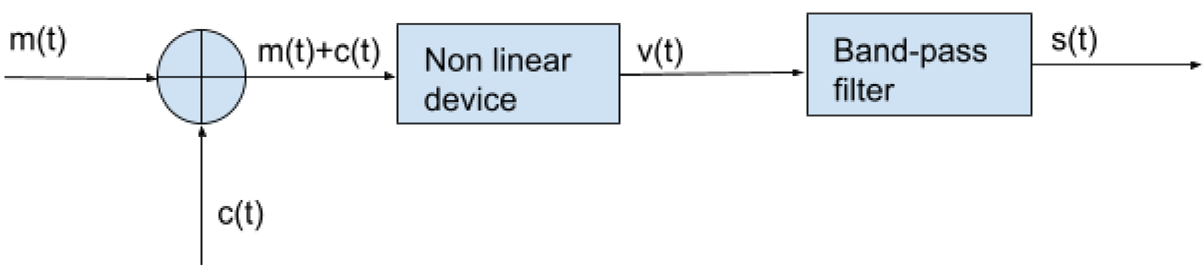


Also, we should note that the *transmission bandwidth* for an AM wave is twice the width of the message signal i.e. $B_T = 2W$.

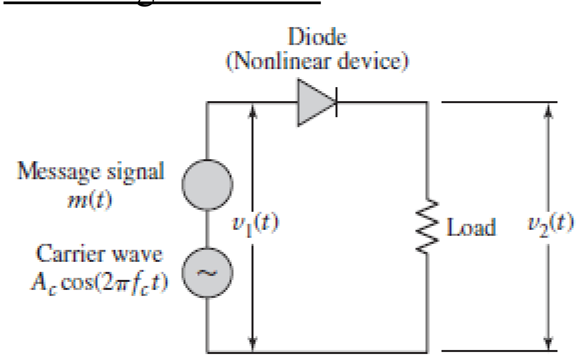
Amplitude Modulation can be accomplished by various devices like *switching modulators*, *square-law modulators, product modulators, quadrature amplitude modulators,* and so many others.

Some modulators are shown below:

Square Law Modulator



Switching Modulator



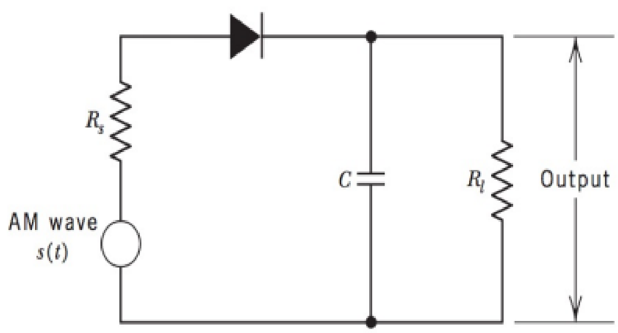
Some disadvantages of Amplitude Modulation:

- In amplitude modulation, we also send carrier signal with modulated signal, the transmission carrier signal requires additional power, hence some power is wasted.
- Amplitude modulation is wasteful of bandwidth since sending both sidebands requires more bandwidth.
- Less immune to noise.

AM DEMODULATION

The process of reconstructing or retrieving the message signal from the amplitude-modulated signal is called demodulation.
Demodulation can be accomplished by some detection techniques. A major technique is the *Envelope detection.*

Envelope Detection



When AM Wave passes through the diode, the diode clips the negative half cycle since the diode is in the OFF state during the negative half cycle and ON state during the positive half cycle.

On a positive half cycle of the input signal, the diode will be forward biased hence the diode in an ON state resulting in the charging of the capacitor to the peak value of the input signal.

When the input signal falls below the peak value, the diode will be reverse biased i.e. diode will be in OFF State, and the capacitor discharges slowly through the load resistor.

Consider the diode is an ideal diode, thus there will be a presence of a resistance '*rf*' in the forward-biased region and infinite resistance in the reverse-biased region.

The charging time constant :$(r_f + R_C)C << \frac{1}{f_c}$

The discharging time constant:$\frac{1}{f_c} << R_l C << \frac{1}{W}$

W is the message bandwidth.

<u>Disadvantages of Amplitude Demodulation</u>

- Noise generally affects the amplitude of the signal. Hence the reception of the actual signal would be difficult since it's hard to separate noise from the actual signal.
- AM signals are less immune to atmospheric interference, hence when receiving the signal the demodulator interprets that as a part of the actual signal and thus results in distortion.
- Thus generally the demodulation process of AM signals is not so accurate.

Performance of AM Receiver in the Presence of Noise

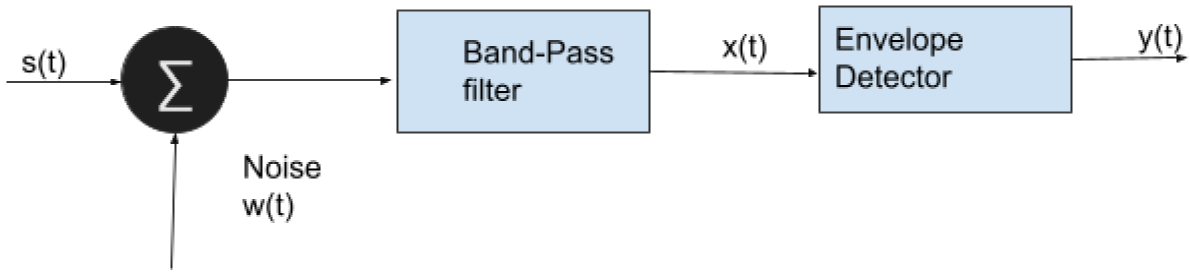
Noise in communication systems is the unwanted signals that corrupt or disturb the signal that we are transmitting.
AM is more vulnerable to noise since the amplitude of the carrier is varied concerning the message signal. Since most types of noise also impact amplitude, AM receivers are especially sensitive to noise, resulting in a low signal-to-noise ratio.
This high sensitivity to noise can lead to distortion, signal-fading, and poor audio quality.
Hence for AM receivers, in the presence of noise, the reconstruction of the message signal will not be accurate.
White noise, thermal noise, shot noise, atmospheric noise, and man-made noise are some examples of types of noise.
The basic noise that we mostly deal with is AWGN-Additive White Gaussian Noise.
It is widely used in theoretical models for noise analysis. It is added to the signal during transmission(additive). The term white implies that its power spectral density is constant across all the frequencies. The noise follows a Gaussian distribution, meaning the probability of noise values will be distributed across a bell curve, with most of those values centered around the mean.

<u>Requirements of AN AM Receiver</u>

AM Receiver receives the signal and demodulates it by using envelope detector.

- ➢ It should be cost effective.
- ➢ It should receive the corresponding message signal.
- ➢ The receiver should be able to tune and amplify the desired station.
- ➢ It should have an ability to reject the unwanted stations.
- ➢ Demodulation has to be done to all stations, irrespective of carrier signal frequency.

Noisy Model of an AM Receiver



s(t)-Modulated signal, w(t) or n(t)-white noise.

We know that $s(t) = A_c cos2\pi f_c t + A_c K_a m(t) cos2\pi f_c t$

Where $A_c cos2\pi f_c t$ is the carrier signal and $A_c K_a m(t)cos2\pi f_c t$ is the information bearing signal.

Average Power of carrier signal is:$\frac{A_c^2}{2}$

Average power of information bearing signal is:$\frac{A_c^2 K_a^2 P}{2}$

P is the average power of message signal m(t).

Hence average power of input signal is $\frac{A_c^2}{2} + \frac{A_c^2 K_a^2 P}{2} = \frac{A_c^2}{2}[1+K_a^2 P]$

Average power of input noise signal is:--*Noise power spectral density(PSD)*× *Bandwidth*

Noise PSD=$\frac{N_0}{2}$ and Bandwidth of AM is $2f_m$

Therefore Average input noise power=$\frac{N_0}{2} \times 2f_m = N_0 f_m$

- ➔ Let's calculate pre signal to noise ratio or <u>Channel SNR</u>(SNR_C)

$$SNR_C = \frac{Average\ power\ of\ modulated\ signal}{Average\ power\ of\ noise\ in\ message\ signal}$$

$$SNR_C = \frac{(1+K_a^2 P)A_c^2}{2N_0 f_m}$$

- ➔ Calculation post SNR or <u>Output SNR</u>(SNR_O)

$$SNR_O = \frac{Average\ power\ of\ demodulated\ output}{Average\ power\ of\ output\ noise}$$

Input to envelope detector is :$x(t) = s(t) + n(t)$

n(t) is the noise which is given by:$n(t) = n_I(t)cos(2\pi f_c t) - n_Q(t)sin(2\pi f_c t)$

Where $n_I(t)$ is in-phase component(real part)

$n_Q(t)$ is the quadrature component(imaginary part)

Input to envelope detector is:x(t)=s(t)+n(t)

$x(t) = A_c cos2\pi f_c t + A_c K_a m(t)cos2\pi f_c t + n_I(t)cos(2\pi f_c t) - n_Q(t)sin(2\pi f_c t)$

On simplifying:$x(t) = [A_c + A_c K_a m(t) + n_I(t)]cos(2\pi f_c t) - n_Q(t)sin(2\pi f_c t)$

Envelope detector eliminates the envelope of the carrier signal.

The output of envelope detector is:

$$y(t) = \sqrt{(A_c + A_c K_a m(t) + n_I(t))^2 + n_Q(t)^2}$$

We can ignore the quadrature component since it is much lesser compared to the other component

$y(t) = A_c + A_c K_a m(t) + n_I(t)$

This is the case when the average power of carrier signal is large compared to the average power of noise signal, then the signal term $Ac\,[\,1 + k_a m(\,t\,)]$ will be large compared with noise terms , therefore we have approximated the value of y(t) as given above.

If a capacitor(DC component) is connected after the envelope detector then we can eliminate the dc component A_c

Hence, $y(t) = A_c K_a m(t) + n_I(t)$

The average power of demodulated signal is :$A_c^2 K_a^2 P$

Average power of noise=$2N_0 W$

$$SNR_O = \frac{A_c^2 K_a^2 P}{2N_0 W}$$

Figure of Merit

Figure of merit(FOM) is the ratio of output SNR to channel SNR.

$$FOM = \frac{SNR_O}{SNR_C}$$

Larger the FOM, better the performance of the AM receiver.

$$FOM = \frac{SNR_O}{SNR_C} = \frac{\frac{A_c^2 K_a^2 P}{2N_O W}}{\frac{(1+K_a^2 P)A_c^2}{2N_O f_m}}$$

On simplifying $FOM = \frac{K_a^2 P}{1+K_a^2 P}$

$P = \frac{A_m^2}{2}$

$K_a A_m = \mu$

Therefore $FOM = \frac{\mu^2}{2+\mu^2}$

<u>If SYNCHRONOUS DETECTION is used:</u>

In synchronous detection, the received AM signal is mixed with a locally generated carrier signal that is in phase as the original carrier used in the transmitter. This multiplication demodulates the signal by shifting the desired baseband information down to a lower frequency that can then be separated with a low pass filter.

Received signal x(t) with noise:

$x(t) = A_C[1 + K_a m(t)]cos(2\pi f_c t) + n_I(t)]cos(2\pi f_c t) - n_Q(t)sin(2\pi f_c t)$

Demodulation with cosine signal, we multiply x(t) with $cos(2\pi f_c t + \phi)$

Which gives us:

$[Ac\,[\,1 + k_a m(\,t\,)]\,cos(\,2\pi fct\,) + n_I(t)cos(2\pi f_c t) - n_Q(t)sin(2\pi f_c t)]cos(2\pi f_c t + \phi)$

Using trigonometric identities we expand each other and finally we get:

$x(t)cos(2\pi f_c t + \phi) = \frac{1}{2}[Ac\,[\,1 + k_a m(\,t\,)]cos\phi + n_I(t)cos\phi + n_Q(t)cos\phi]$

The high frequency terms were eliminated by the low pass filter.

If the phase locked loop is employed , then phase angle becomes '0'.

Thus it is a coherent detector.

Therefore $y(t) = A_C K_a m(t) + n_I(t)$

The ½ part is avoided since the constant won't affect much significantly.

Thus we can draw a major conclusion that , **under the assumption that there is a high SNR at receiver input, the performance of synchronous detectors and envelope detectors are the same.**

Threshold Effect

If the SNR at receiver input is low, we will have to face a difficulty which happens due to an effect called Threshold effect, at which input signal strength drops below a certain value which we call as threshold value making the signal highly vulnerable to noise, due to which the output signal quality deteriorates.
Here the carrier-to-noise ratio would be smaller than unity. Therefore the noise term dominates and the performance changes.
Hence we cannot approximate the outcome as we have done in the above cases.
The Envelope detector output would be:

$$y(t) = y(t) = \sqrt{(A_c(1 + K_a m(t)) + n_I(t))^2 + n_Q(t)^2}$$

On expanding and simplifying we get:

$$y(t) = \sqrt{(n_I(t)^2 + n_Q(t)^2)[1 + \frac{2A_c n_I(t)}{n_I(t)^2 + n_Q(t)^2}(1 + K_a m(t))}$$

$$y(t) = V_n(t) + \frac{A_c n_I(t)}{V_n(t)}(1 + K_a m(t))$$

Where $V_n(t) = \sqrt{n_I(t)^2 + n_Q(t)^2}$ is the envelope of the noise signal.

Here $A_c^2(1 + K_a m(t))^2$ is small compared with other components.

The inferences we got from this output y(t) are:

- The signal and the components of noise are no longer additive at the output of the demodulator.
- We cannot capture the signal component properly since it is multiplied by the noise component making it difficult to distinguish.
- We can conclude that the system is operating below threshold.
- SNR cannot be defined properly.

Practical Cases where AM is used despite the presence of Noise

⇒ Due to high coverage area and lower infrastructure requirements for AM Radio, it is majorly used during natural disasters and in other emergency situations so that everyone receives the information in a broad way.

⇒ AM Radio has a long wavelength, therefore it is used in remote areas where other communication methods may not be feasible.

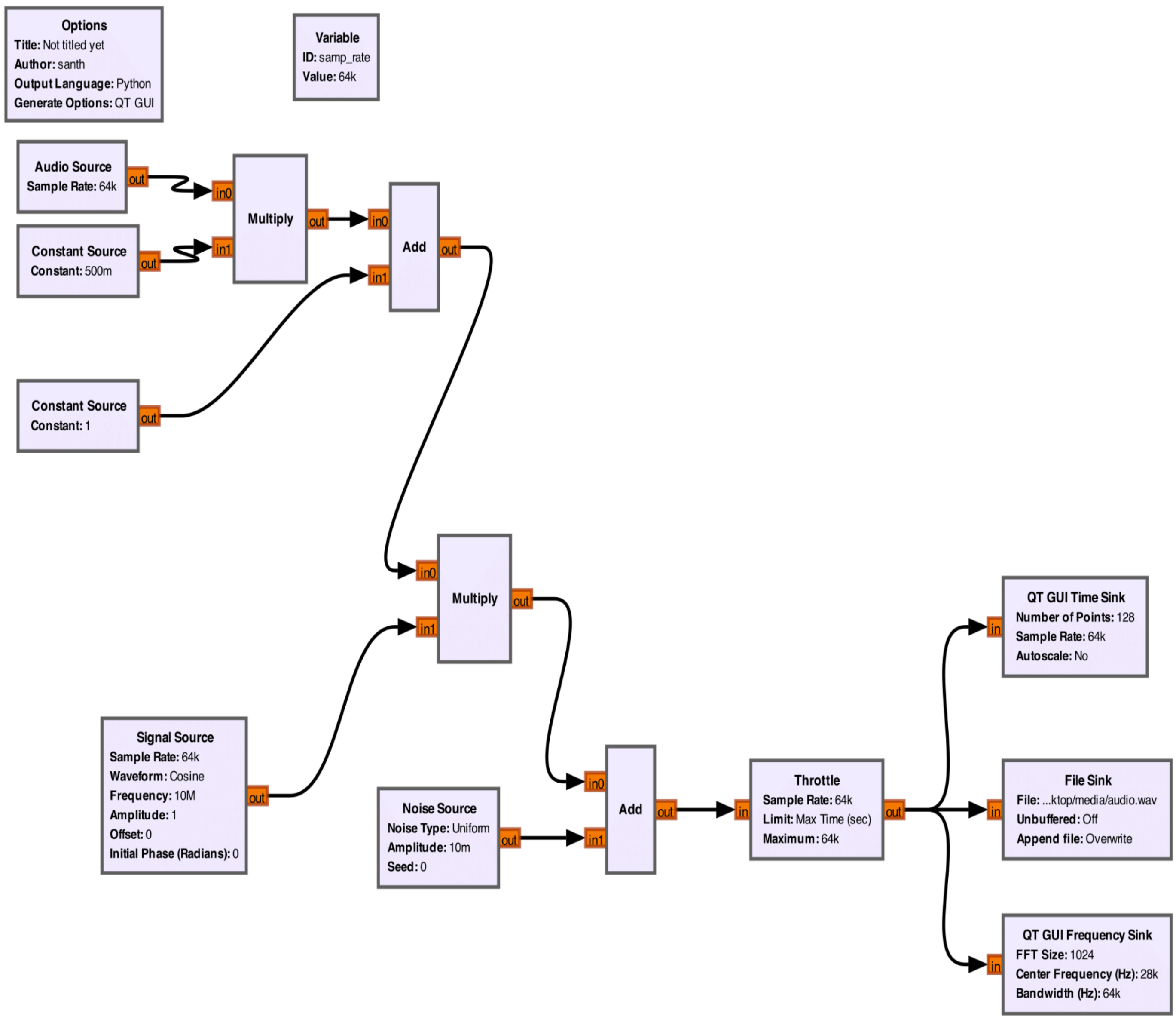
Some Ways to improve Noise immunity in AM Receiver

- ➢ By using Digital Signal Processing(DSP) technique in which the incoming analog signal is digitized. DSP algorithms can selectively filter out noise frequencies.
- ➢ Using an adaptive filter, which adjusts based on the noise environment, will significantly enhance the performance of the AM Receiver.
- ➢ Using synchronous detection over envelope detection can enhance the performance of AM Receiver since it uses a local oscillator synchronized with carrier frequency to capture the signal, reducing the impact of amplitude changes.

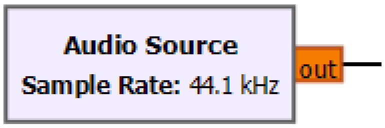
SIMULATION

Trying to apply the theory and concepts

1)*AM TRANSMITTER*



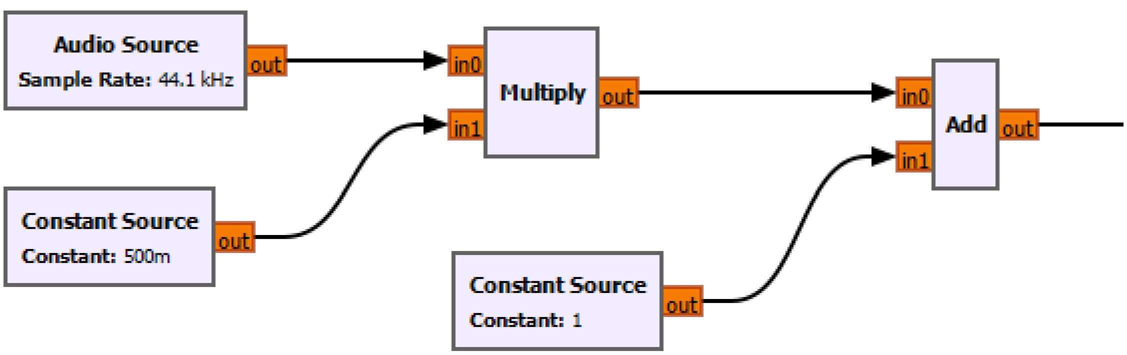
Audio Source:



Takes audio input for modulation.This is the message signal (m(t)) . It takes a microphone input from the laptop.

Constant Sources:

Adds offset and scaling factors.

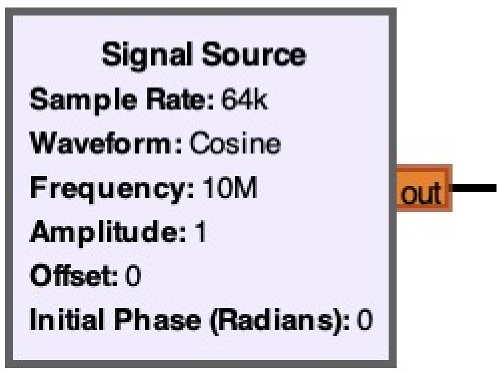


Multiplying $m(t)$ with k_a to get $k_a m(t)$ after multiplication block and adding 1 to get $1 + k_a m(t)$.

Taken k_a : 0.5

Carrier Signal Source:

Provides the carrier for modulation.

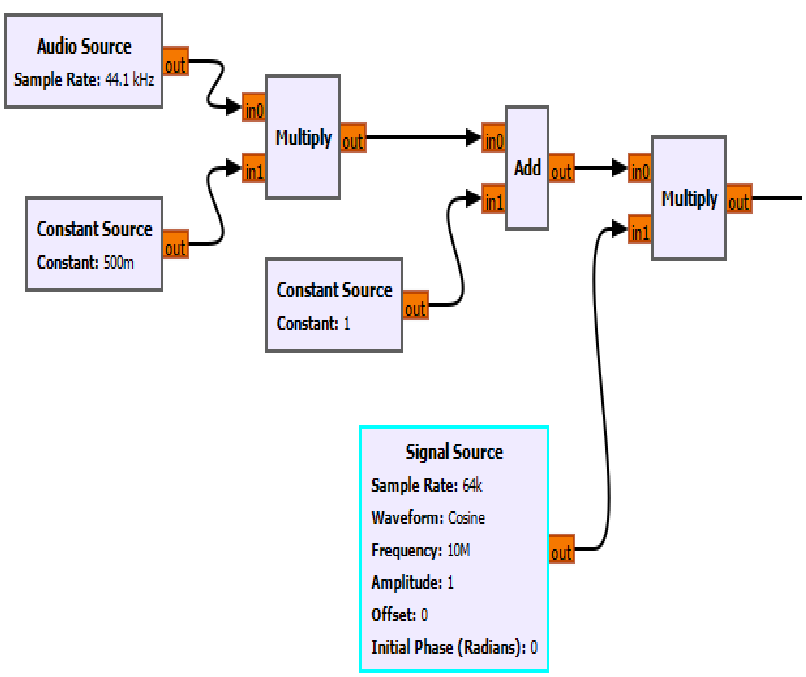


$$C(t) = A_c cos(2\pi f_c t)$$

f_c: 10^7

A_c: 1

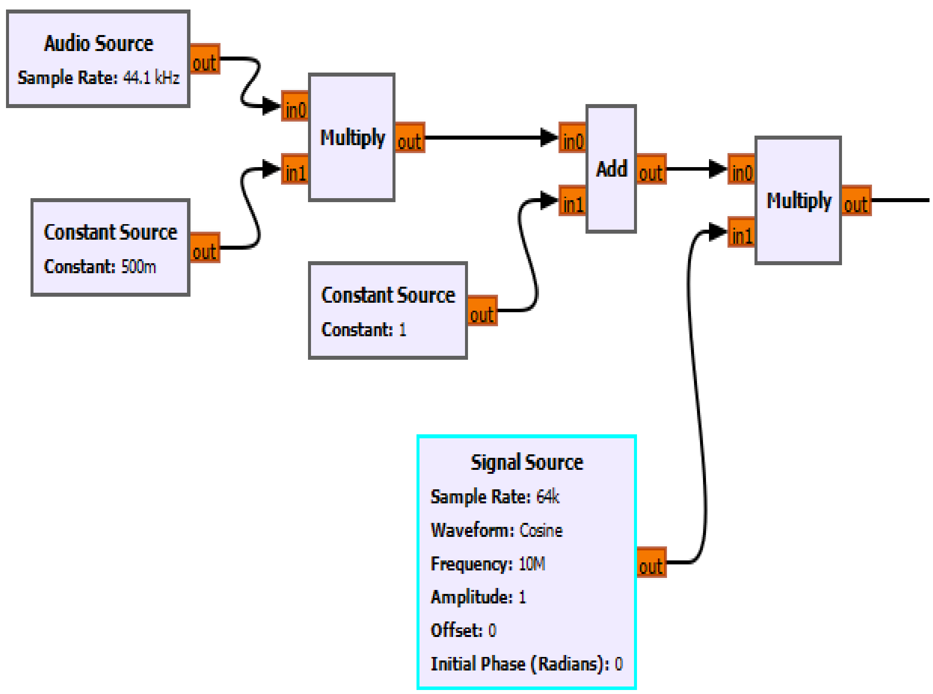
$$C(t) = cos(2\pi \times 10^7 t)$$



So after multiplying the signal from the add block with the carrier signal we get the amplitude-modulated signal.

Multipliers and Adders:

Combine and modulate the audio with the carrier



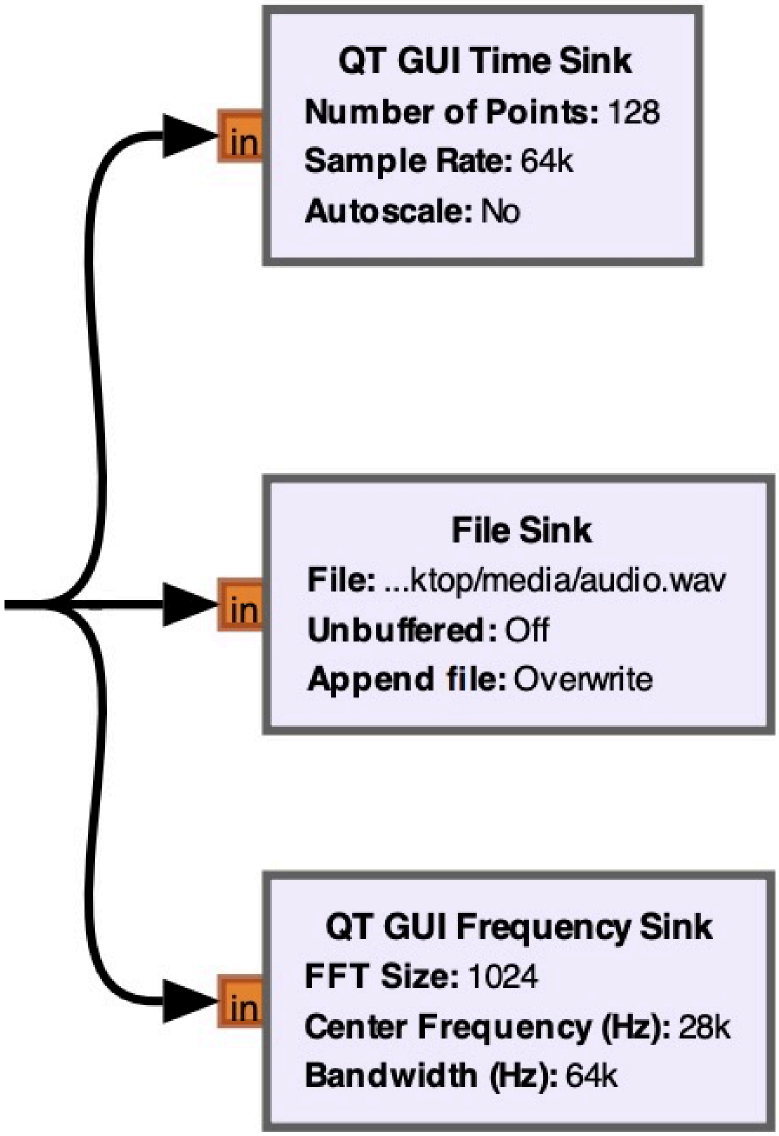
Throttle Block:

Controls sample flow.

Throttle flow of samples such that the average rate does not exceed the specific rate.

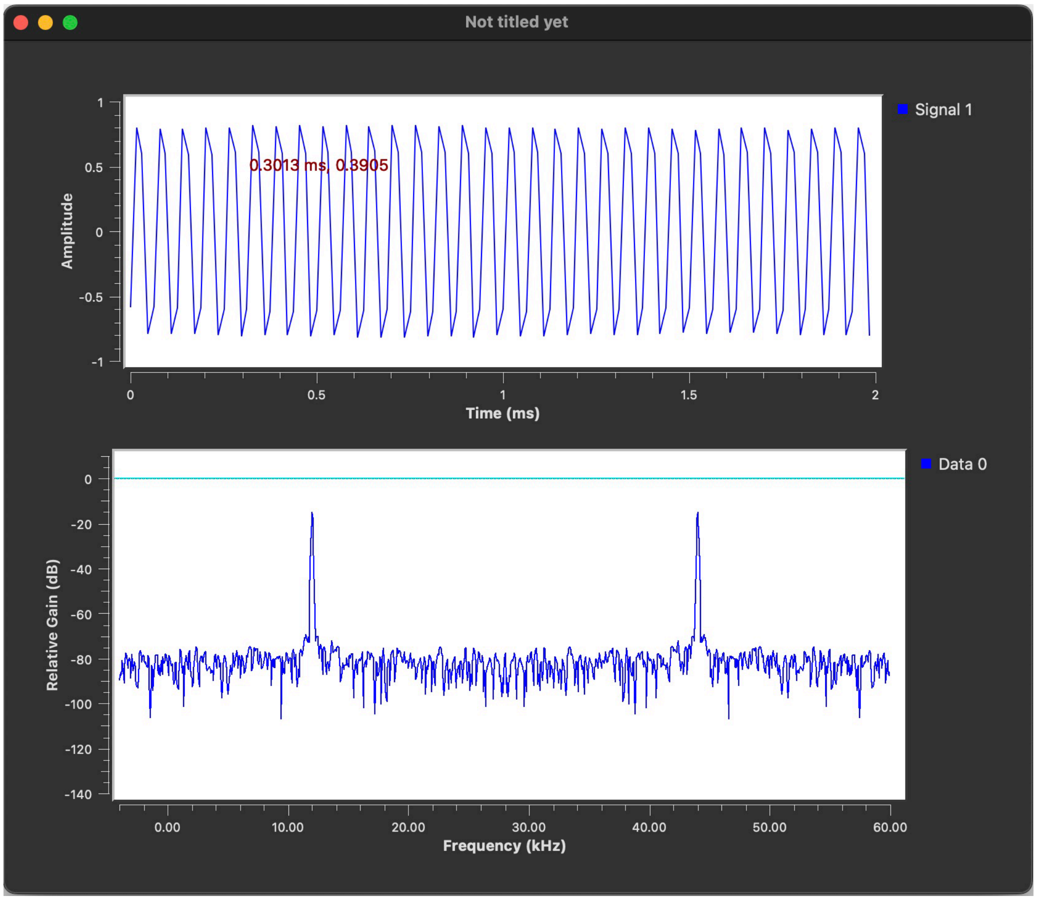
Output Sinks:

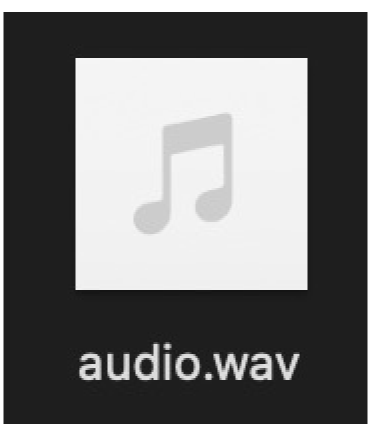
Visualize and save the transmitted AM signal.



The output is viewable in Gnuradio and is also stored into “audio.wav” file

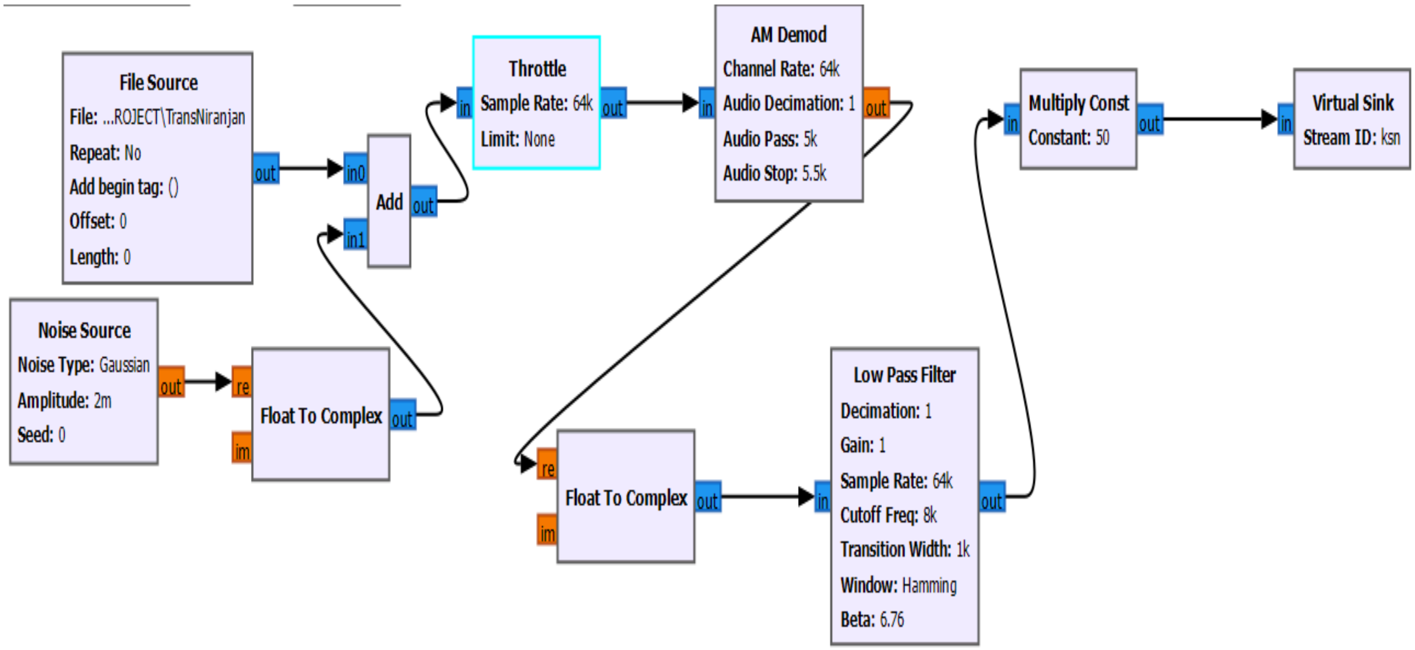
Output Graph of transmitter file

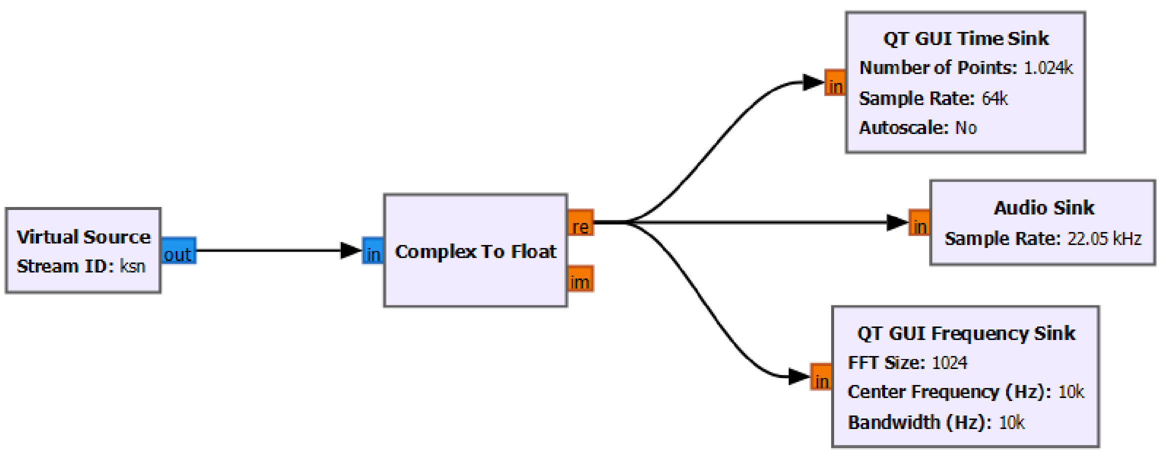




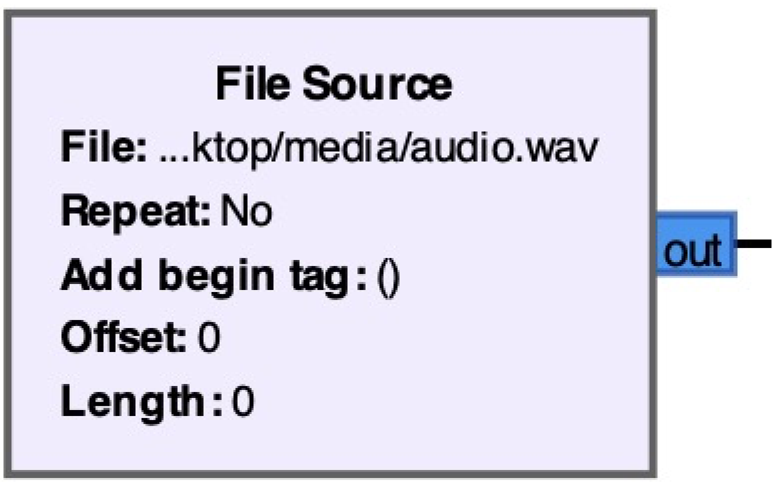
1)*AM RECEIVER*

File Source → Throttle → AM Demodulator → Complex to Float → Low Pass Filter → Multiply Const → Audio Sink / QT GUI Sinks.



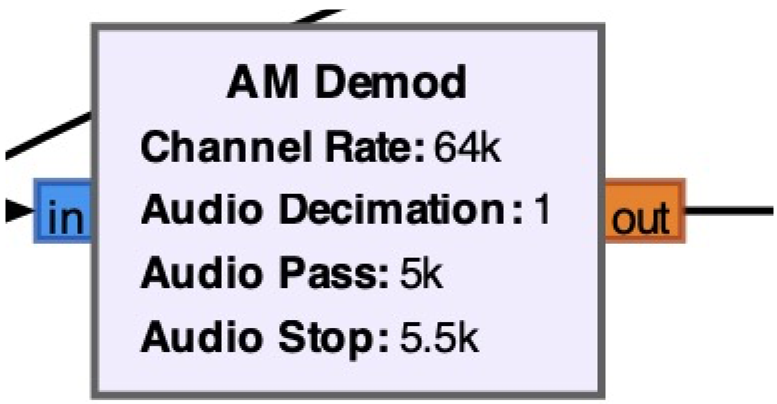


FILE Source:-



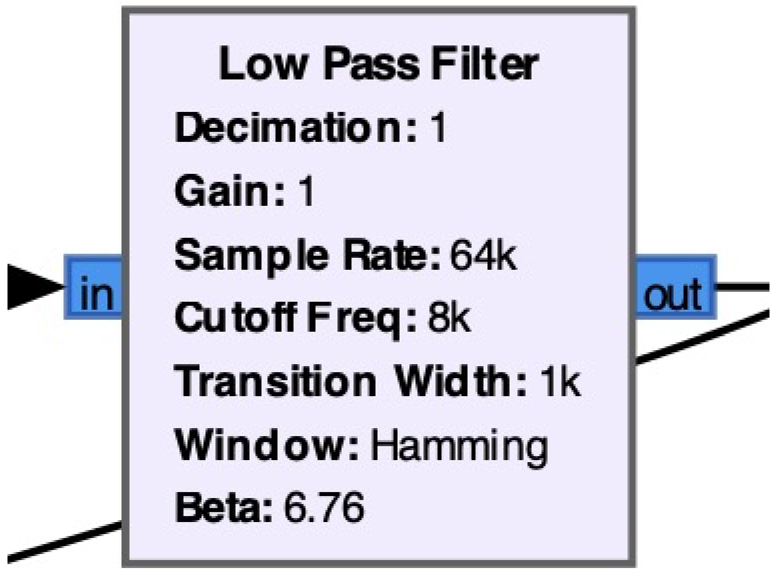
Taking Amplitude modulated signal with noise from the file.

AM Demodulation Block:



Extracts the audio signal from the AM-modulated input.(WIll contain some Noise)

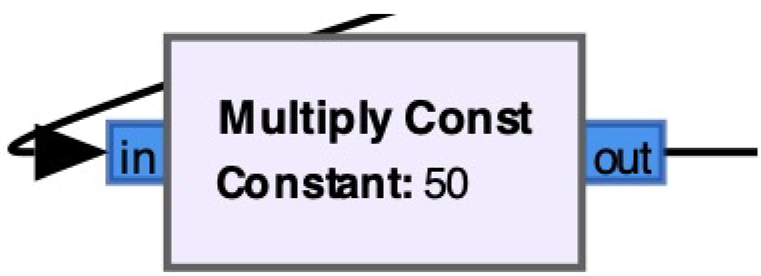
Low pass Filter:-



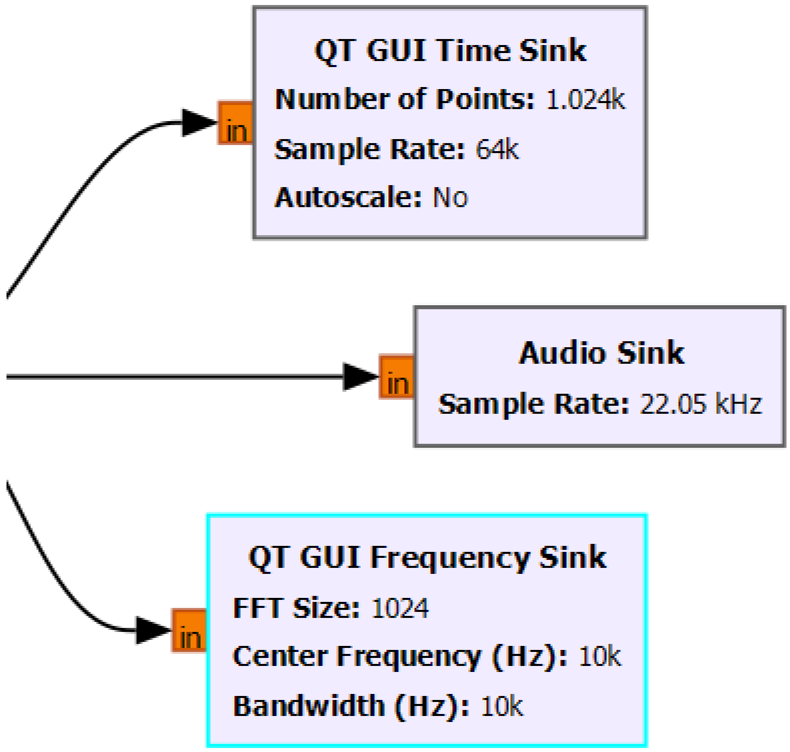
Filters out unwanted high-frequency components after demodulation.

Multiply constant:-

To amplify the Signal we use a multiply block.



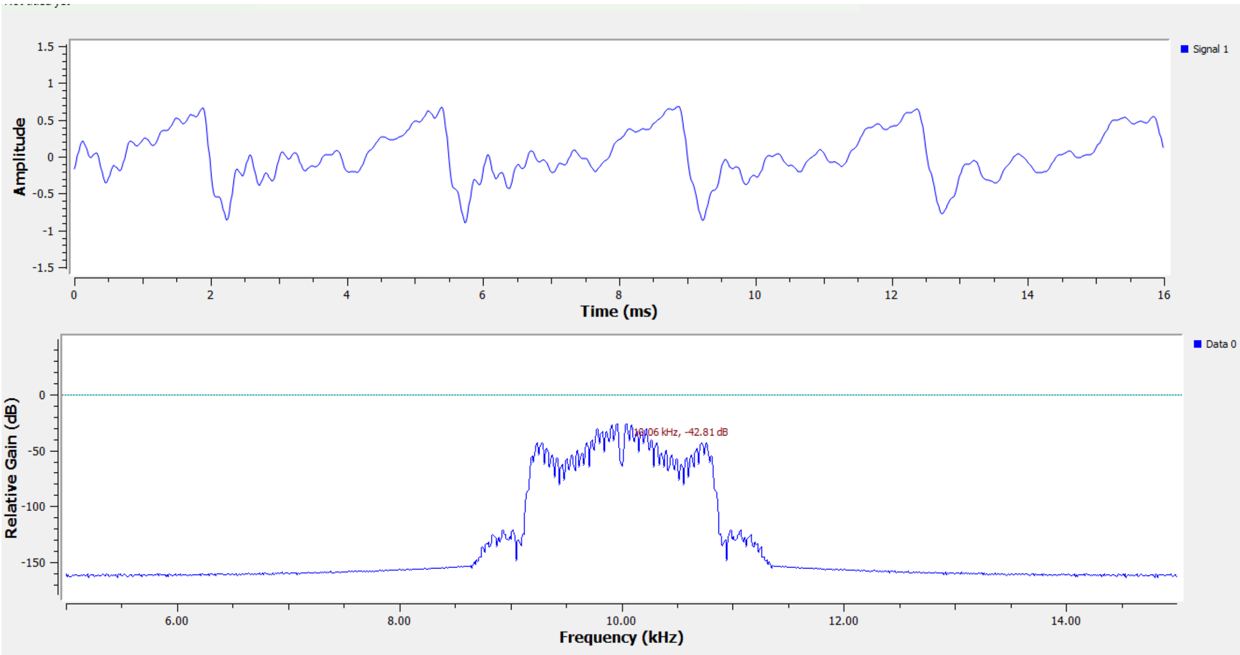
SINK Blocks



Using Audio Sink we can hear the signal through Speaker

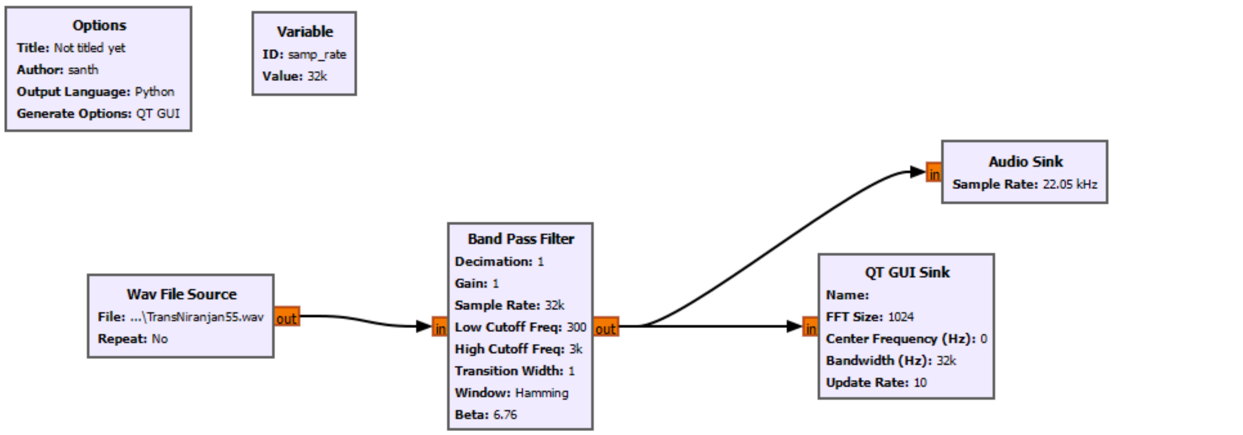
(PLEASE CHECK SIMULATION VIDEO TO SEE MORE DETAILS)

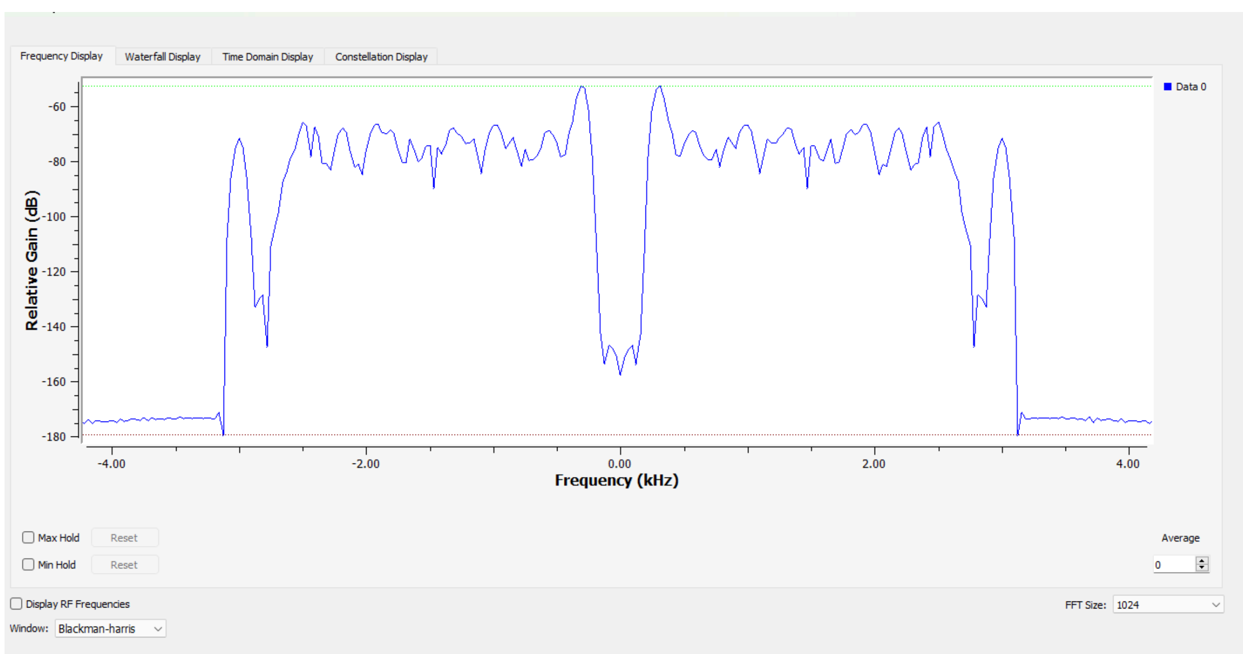
OUTPUT


Signal 1
Amplitude
1.5
1
0.5
0
-0.5
-1
-1.5
0
2
4
6
8
10
12
14
16
Time (ms)
Data 0
Relative Gain (dB)
0
-50
-100
-150
10.06 kHz, -42.81 dB
6.00
8.00
10.00
12.00
14.00
Frequency (kHz)

BANDWIDTH of VOICE

The output of the receiver is given as input in this flow graph representation to analyze the bandwidth of received audio signal.(voice BW:300 Hz to 3000 KHz)





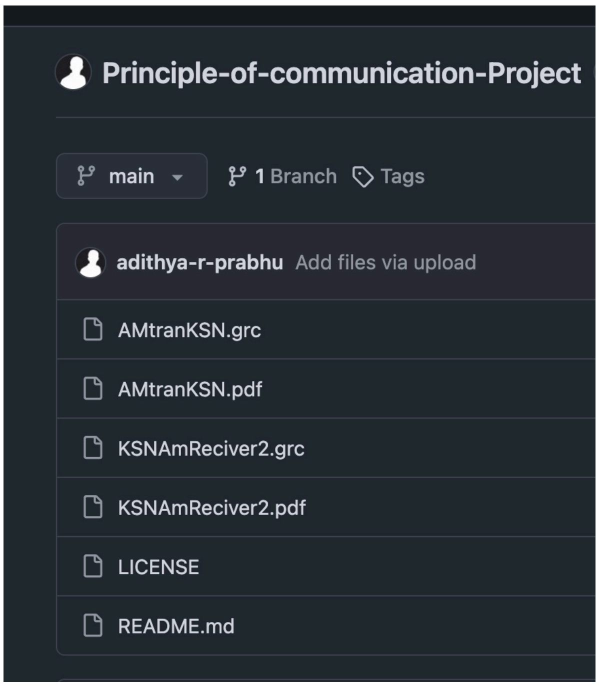
<u>CONCLUSION</u>

Throughout this project, we have observed that in cases where amplitude modulation is used, the method is very easily disturbed by any surrounding noise leading to poor results of an AM reception. Theoretical and simulation studies show that any amount of noise present in the communication system makes the quality of the signal drop very considerably causing the SNR to drop hence will result in either bad audio or data. Following that, the FOM and the SNR will be researched in order to assess the effectiveness of an AM system including the measures that can be introduced to increase its robustness to noise. Techniques such as phase lock loops, advanced filtering, and signal processing can be utilized in an AM receiver to enhance its performance in the presence of noise.

A.M is often interfered with by noise in the transmission but in case of emergency broadcasting systems, it can be used and also in rural areas of communication. It is cheap, easy to use, and has wide area coverage. There would be more applications and dependability in the case of AM with the presence of Technologies that minimize the effects of noise, especially useful in implementation in noisier environments.

THANK YOU

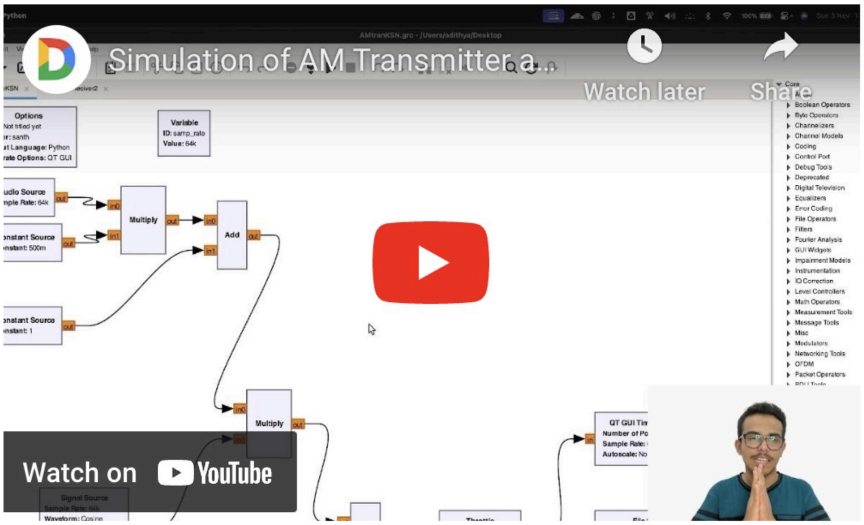
SIMULATION FILES



GITHUB:-https://github.com/adithya-r-prabhu/Principle-of-communication-Project

Simulation Video:-

Simulation of AM transmitter and Receiver https://youtu.be/aKnEOLAc6G0



REFERENCES:-

1)https://wiki.gnuradio.org/ (OFFICIAL GNURADIO DOCUMENTATION)

2)**Communication Systems by Simon Haykin**