AM Transmission and Receiver

I. Objective:

In this lab we are targeting the models for demonstrating the features of Amplitude Modulation (AM) transmission and reception. This model enables to select

1. Different types of message signals
2. The transmitter and receiver parameters (Modulation index and carrier frequency)

II. Theory:

AM is a modulation technique used in electronic communication, most commonly for transmitting information via a radio carrier wave. AM works by varying the strength (amplitude) of the carrier in proportion to the waveform being sent.

Consider a carrier wave (sine wave) of frequency f_c and amplitude A_c given by:

$C(t) = A_c Cos(2\pi f_c t + \phi)$.

Where ϕ is a constant phase.

The transmitted AM signal is of the form:

$$s(t) = a(t)\cos(2\pi f_c t + \phi) = A_c[1 + k_a m(t)]\cos(2\pi f_c t + \phi)$$

Where $m(t)$ represent the modulation waveform and k_a is the modulation index.

The AM receiver recovers $m(t)$ from $s(t)$. One method AM demodulation is to recover $m(t)=1+k_a m(t)$ and subtract the DC component to obtain $m(t)$.

To show how this is done in software with the USRP and GNURadio Companion (GRC), recall that the USRP source block has a complex output with real and imaginary components $i(t)$ and $q(t)$.

We can write the AM signal $s(t)$ as the real part of a complex signal:

$$s(t) = \mathrm{Re}[a(t)e^{j\phi}e^{j2\pi f_c t}] = \mathrm{Re}[\tilde{s}(t)e^{j2\pi f_c t}],$$

Where the complex envelope:

$$\tilde{s}(t) = a(t)e^{j\phi} = a(t)\cos\phi + ja(t)\sin\phi$$
$$= i(t) + jq(t)$$

Thus the USRP source block with frequency set to f_c will have outputs:

$i(t) = a(t)\cos\phi$, $q(t) = a(t)\sin\phi$.

To obtain $a(t)$, we take the magnitude of the complex envelope $\tilde{s}(t)$, thus we can write:

$$
\begin{aligned}
|\tilde{s}(t)| &= |i(t) + jq(t)| \\
&= |a(t)\cos\phi + ja(t)\sin\phi| \\
&= a(t)\,|\cos\phi + j\sin\phi| \\
&= a(t)\sqrt{\cos^2\phi + \sin^2\phi} = a(t)
\end{aligned}
$$

This shows that we can recover $a(t) = 1 + k_a m(t)$regardless of the value of ϕ.

The GRC *Complex to Magnitude* block allows us to obtain the magnitude of the complex envelope by performing the function $a(t) = |i(t) + jq(t)|$.

If there is frequency offset, then $\phi = 2\pi\Delta f t$, but as we have just seen, $|\tilde{s}(t)| = a(t)$ is not affected by the value of ϕ and thus not affected by any frequency offset Δf .

The USRP multiplies the real valued radio frequency signal $s(t)$ by $e^{j2\pi f_c t}$ to generate $i(t) + jq(t)$ .This process is called *complex downmixing* and is equivalent to the standard IQ receiver shown inFigure 1.

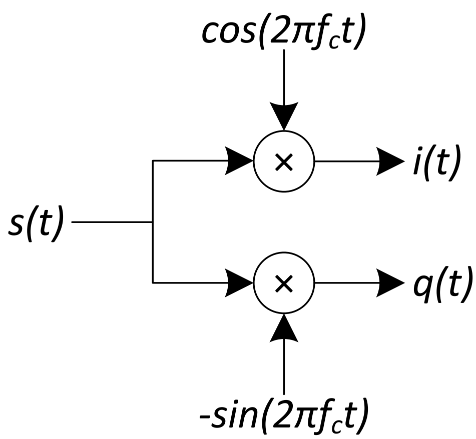


Figure 1 Complex Mixer

Recall:

$$
\begin{aligned}
&s(t) \leftrightarrow S(f) \\
&e^{-j2\pi f_c t} s(t) \leftrightarrow S(f + f_c)
\end{aligned}
$$

The spectrum $S(f)$ of the real radio frequency (RF) signal $s(t)$ will be symmetric about zero. After complex downmixing, the resulting signal is complex and the frequency spectrum $S(f + f_c)$ is no longer symmetric about zero.

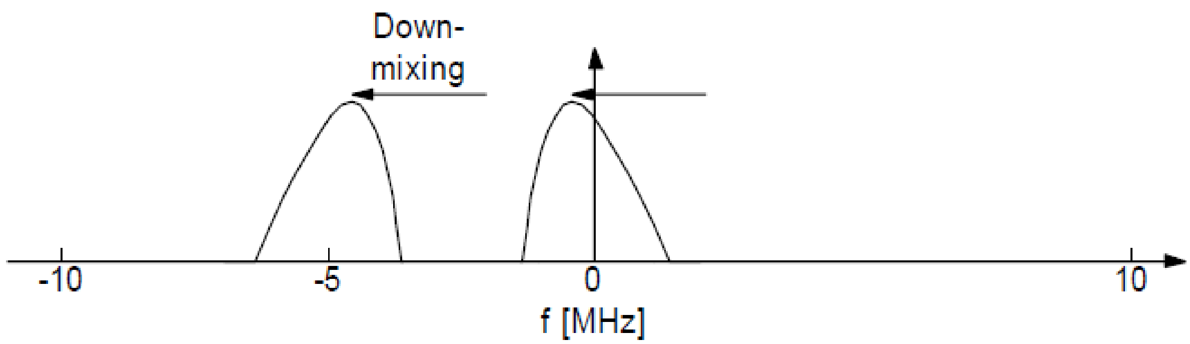
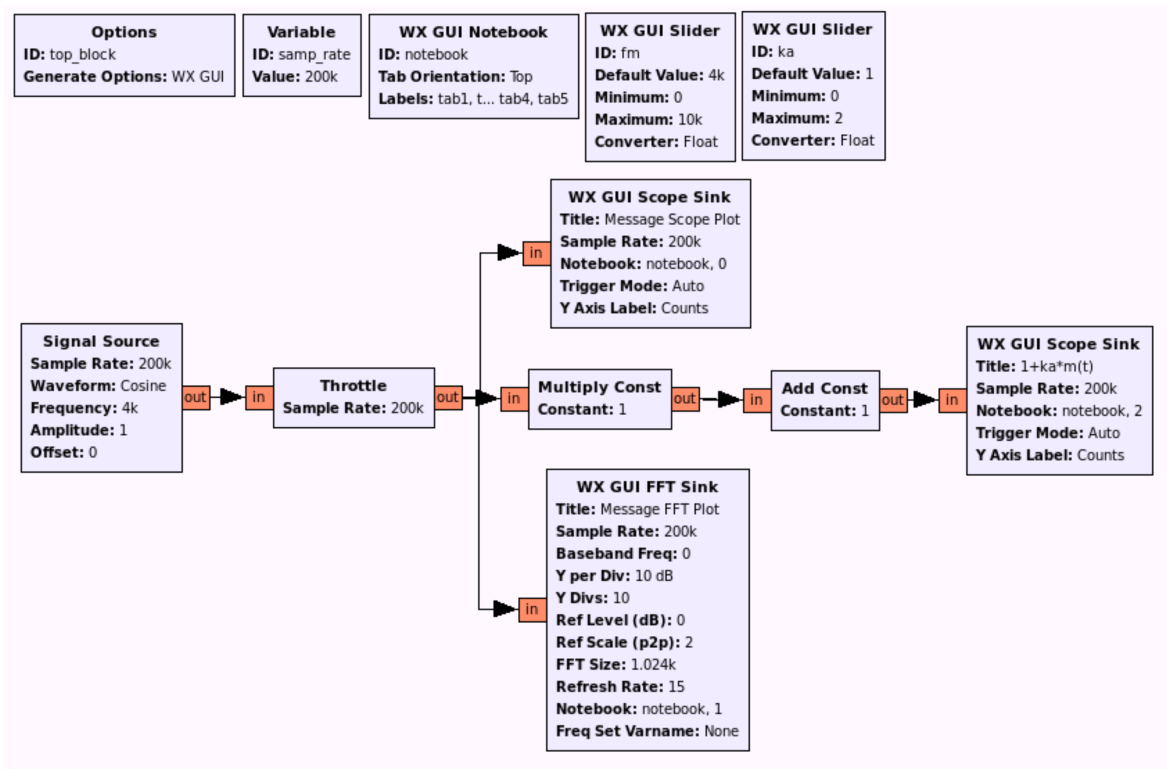


Figure 2Downmixing

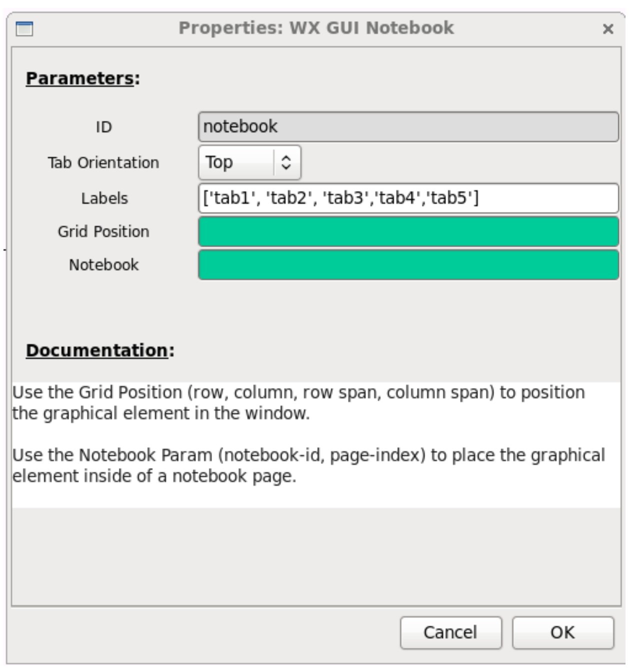
The complex signal output from the USRP source block $i(t) + jq(t)$ is band limited to the sampling rate of the USRP source block. The USRP source block output can be recorded to a file and used again at a later time. This file source will have the same sampling rate and bandwidth as the USRP sink block used to record it.

III. Amplitude Modulation

1- Construct the flow graph shown below consisting of a Signal Source, Throttle, Multiply Const and Add Const blocks.

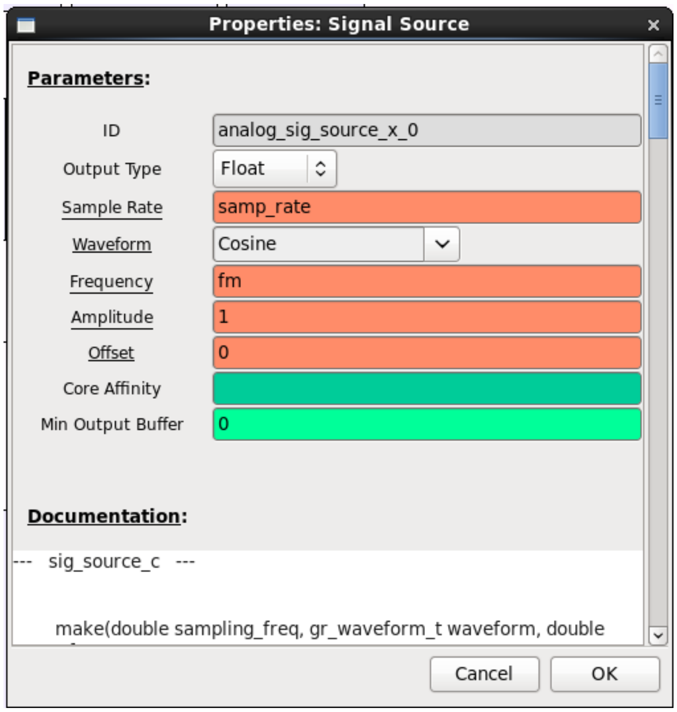


2- The WX GUI notebook block enables to show several plots in a single window using different tabs. Set the block as following so that you can see 5 different plots in a single display window.

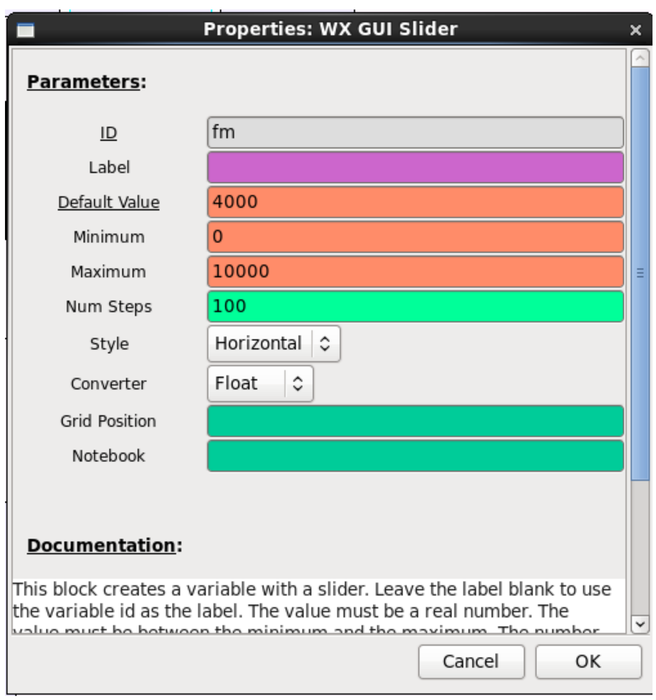


3- Set the Sample Rate in the variable block to 200 KHz.

4- Double-click on the Signal Source block. Set the parameters as below.



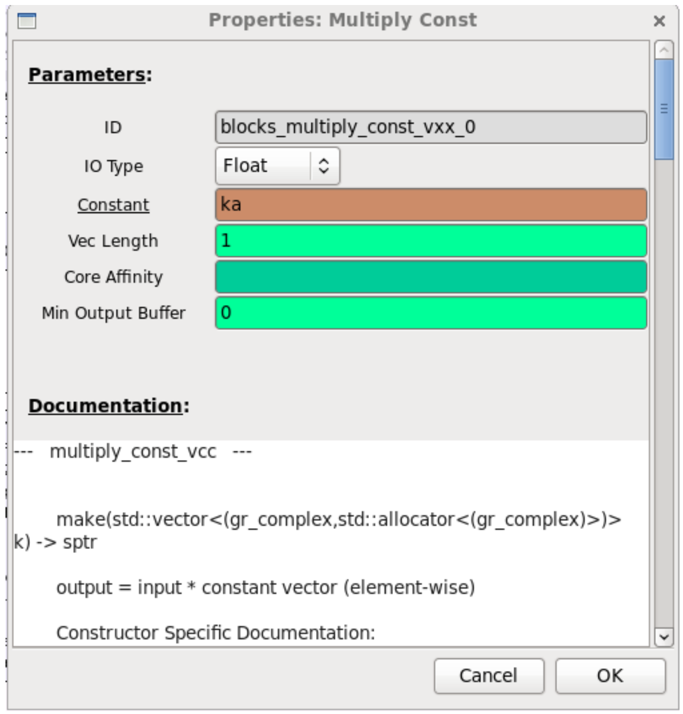
5- fm is the signal frequency which is controlled by the WX GUI Slider block with the following properties:



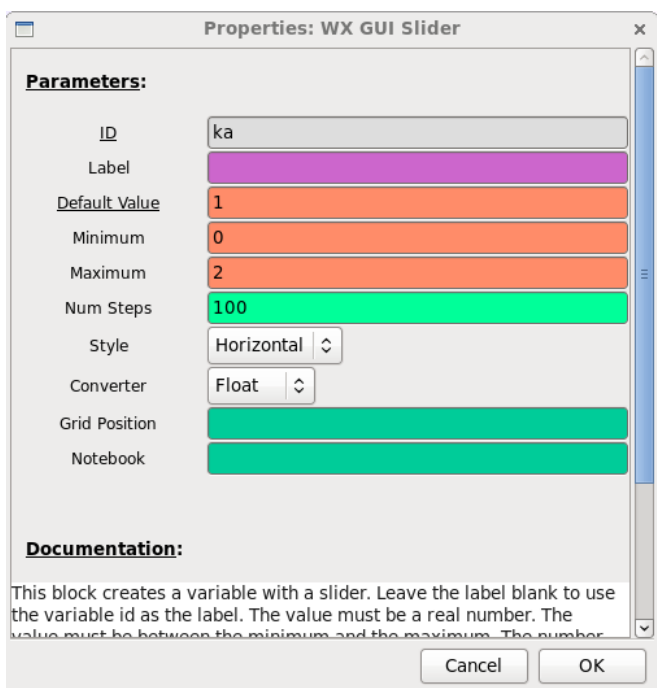
The fm slider enables you to change the signal frequency from 0 Hz to 10 KHz considering the default value of 4KHz and with step size equal to (10KHz-0)/100=100.

6- Set the Throttle sample rate to samp_rate.

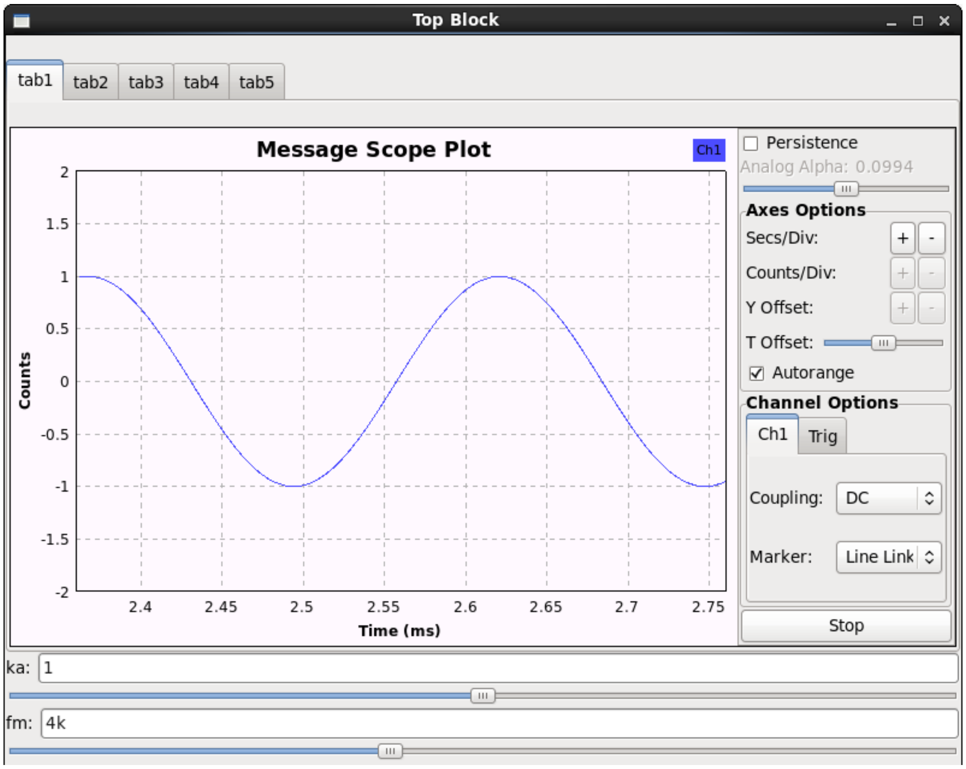
7- Double click on the multiply const block. This block controls the modulation index k_a.

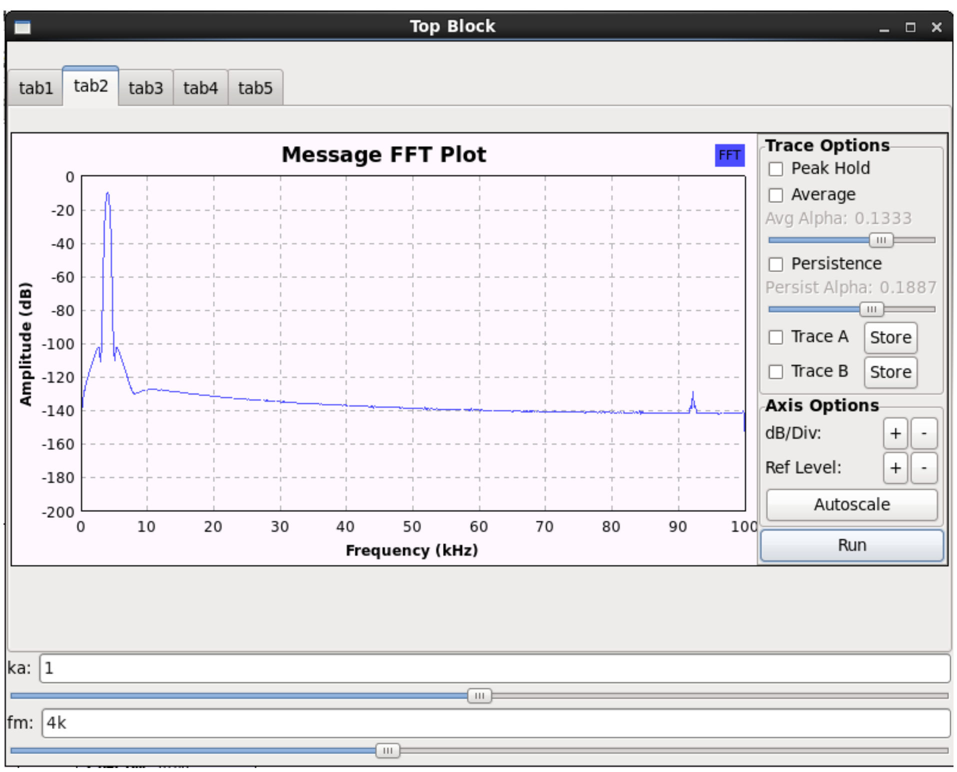


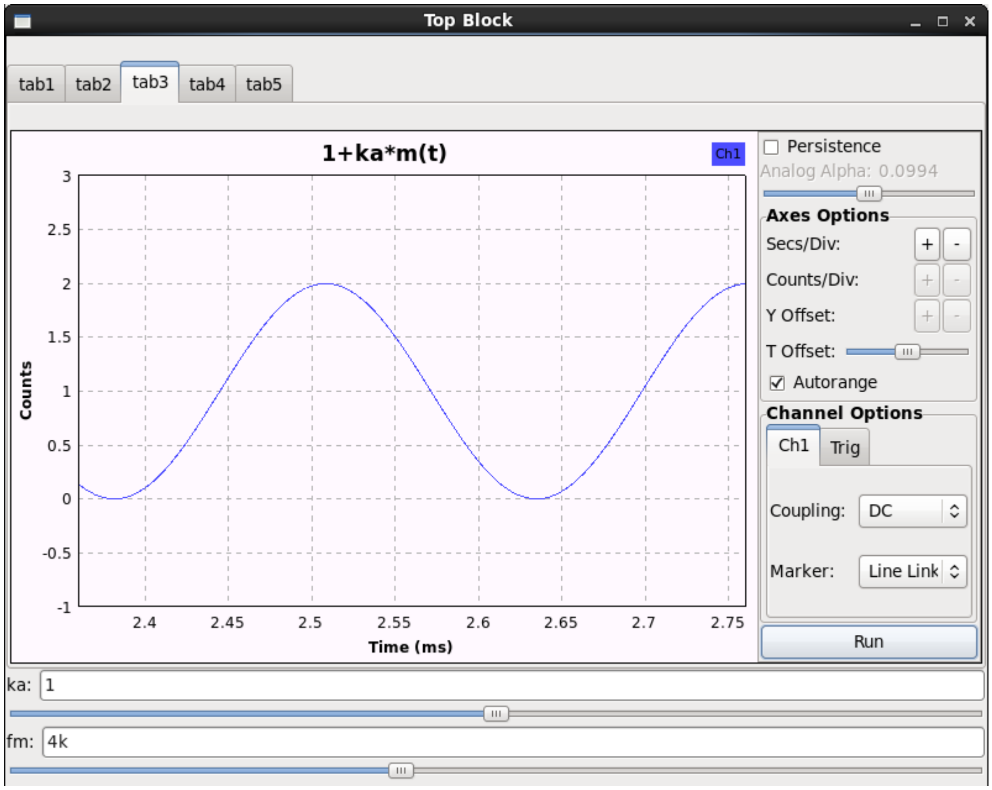
8- Use another WX GUI Slider to change the value of k_a in the interval [0,2]



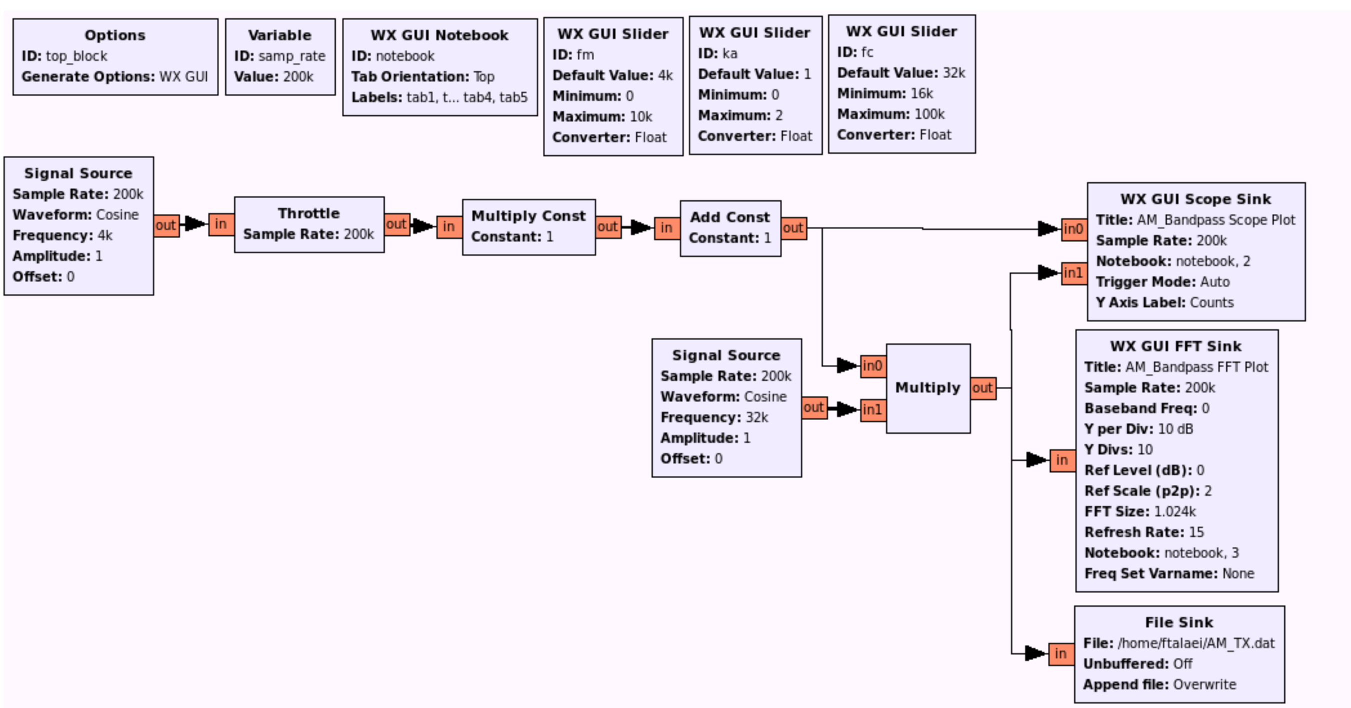
9-Use WX GUI Scop Sink and WX GUI FFT Sink to see the properties of the message signal *m(t)* and modulation waveform $1+k_a m(t)$ when changing the modulation index and the signal frequency. Following figures these signals.



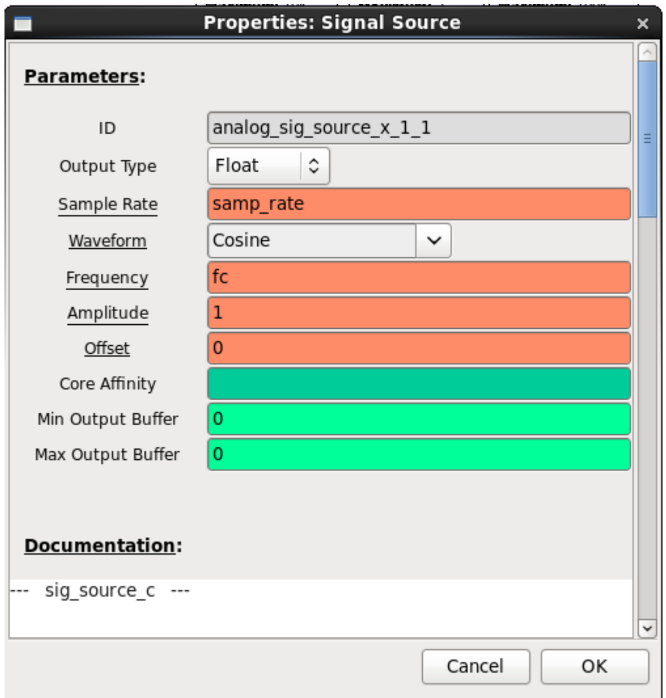




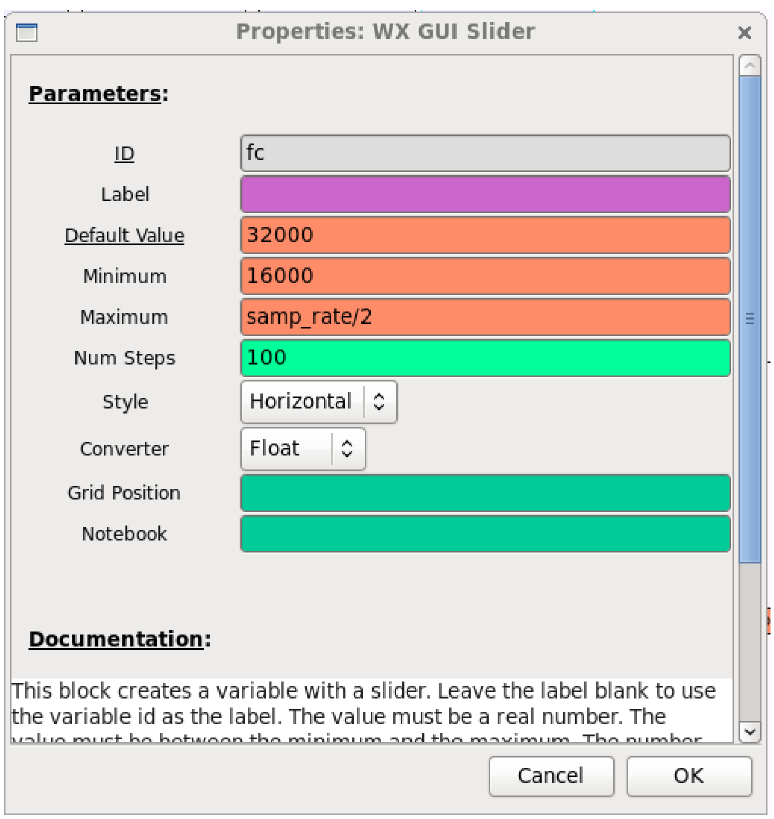
10- Expand the flow graph by multiplying the modulation waveform with the carrier signal to obtain the AM modulated waveform.



11- The carrier waveform is a cosine waveform with the following properties:

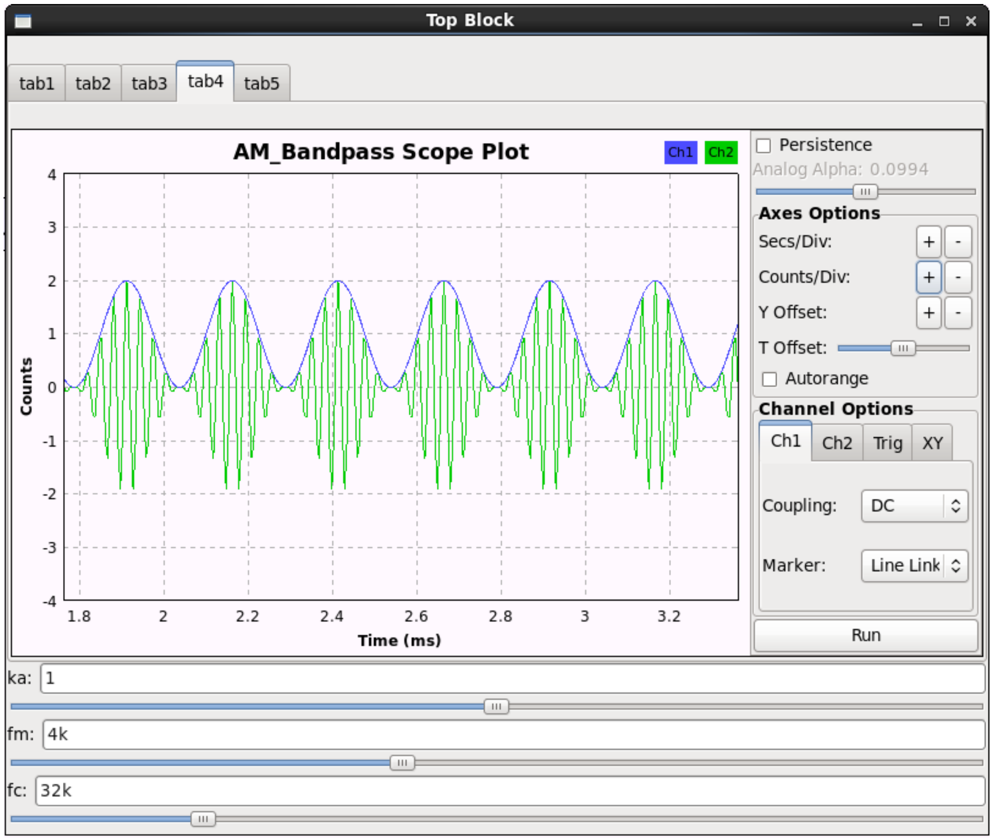


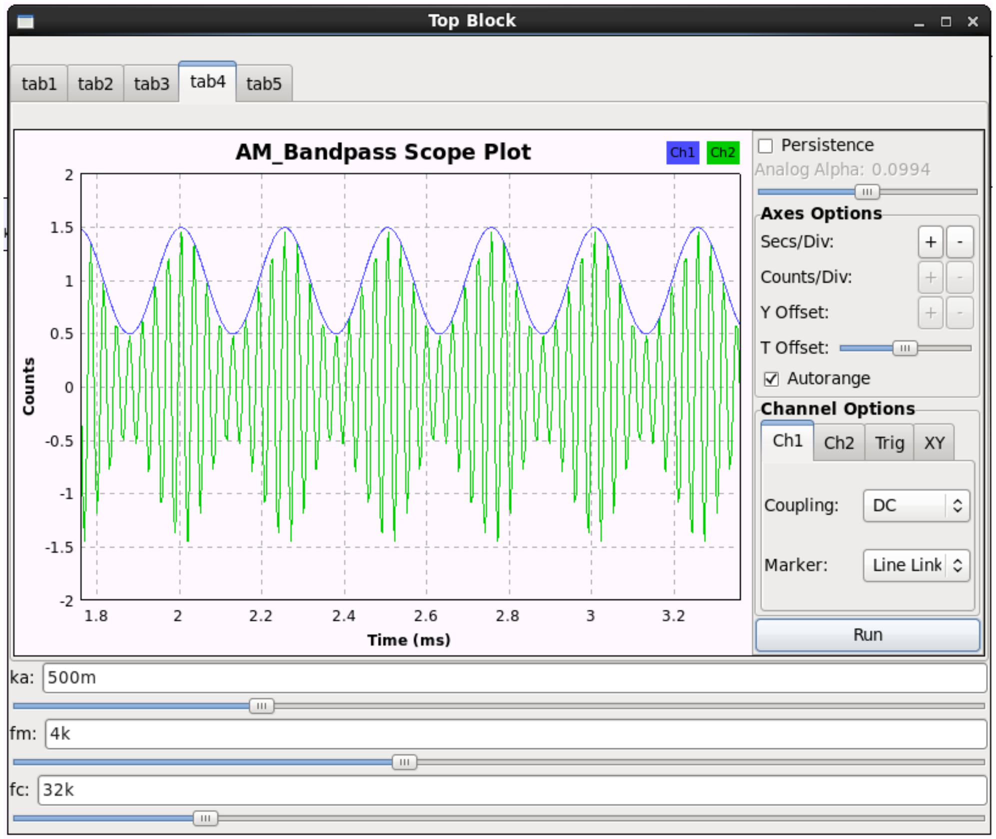
12- *fc* is the carrier frequency whose value is controlled by the WX GUI Slider.

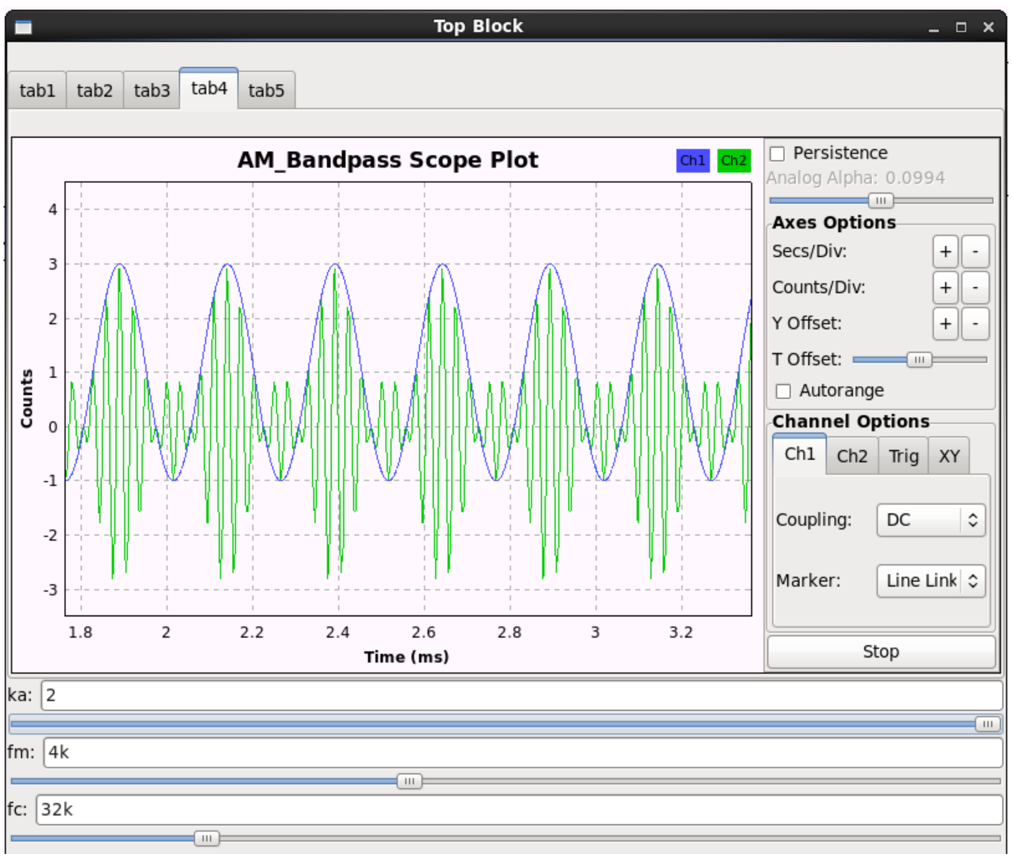


13- Use a WX GUI Scope Sink to observe the AM modulated signal and its correspondence message signal. Double click on the Scope Sink block and change the *Num Inputs* value to two. As it is shown in step ten, connect the first input to $(1+k_a*m(t))$ and the second input to $s(t)$.

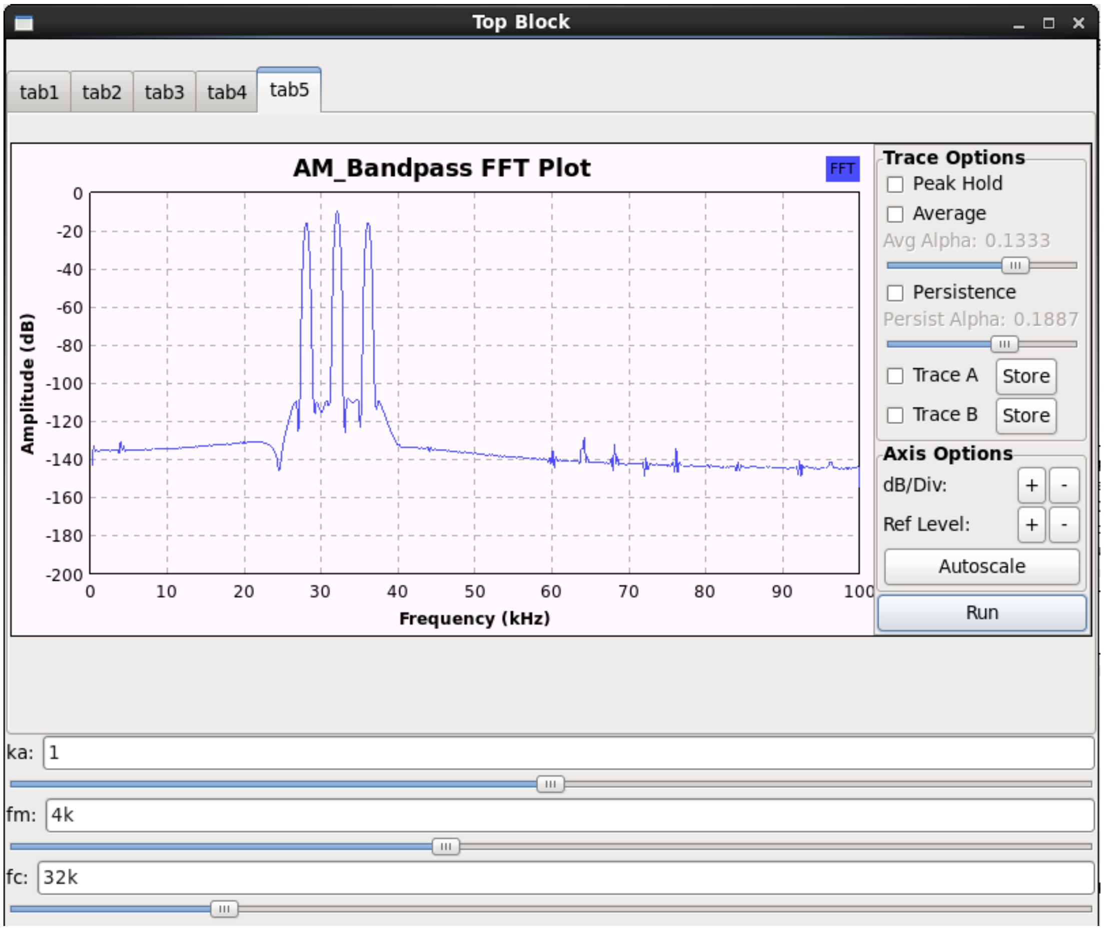
You can change the modulation index k_a and see how its affect the AM signal. The following figures show the Scope plots of AM signals and their correspondence envelopes $(1+k_a*m(t))$ for three different values of k_a.




Top Block
tab1
tab2
tab3
tab4
tab5
AM_Bandpass Scope Plot
Ch1
Ch2
Counts
Time (ms)
Persistence
Analog Alpha: 0.0994
Axes Options
Secs/Div:
Counts/Div:
Y Offset:
T Offset:
Autorange
Channel Options
Ch1
Ch2
Trig
XY
Coupling:
DC
Marker:
Line Link
Run
ka: 500m
fm: 4k
fc: 32k


Top Block
tab1
tab2
tab3
tab4
tab5
AM_Bandpass Scope Plot
Ch1
Ch2
Counts
Time (ms)
Persistence
Analog Alpha: 0.0994
Axes Options
Secs/Div:
Counts/Div:
Y Offset:
T Offset:
Autorange
Channel Options
Ch1
Ch2
Trig
XY
Coupling:
DC
Marker:
Line Link
Stop
ka: 2
fm: 4k
fc: 32k

14- You can also use the FFT sink block to see how k_a , fm and fc affect the spectrum of the AM signal. Following figure shows the spectrum of AM signal for $ka=1$, $fm=4KHz$ and $fc=32KHz$.

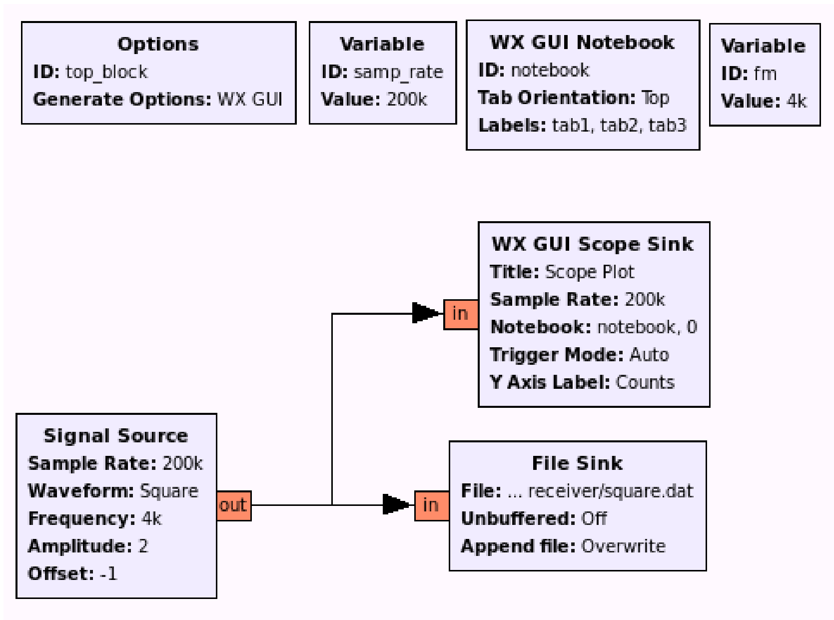


VI. General Messages

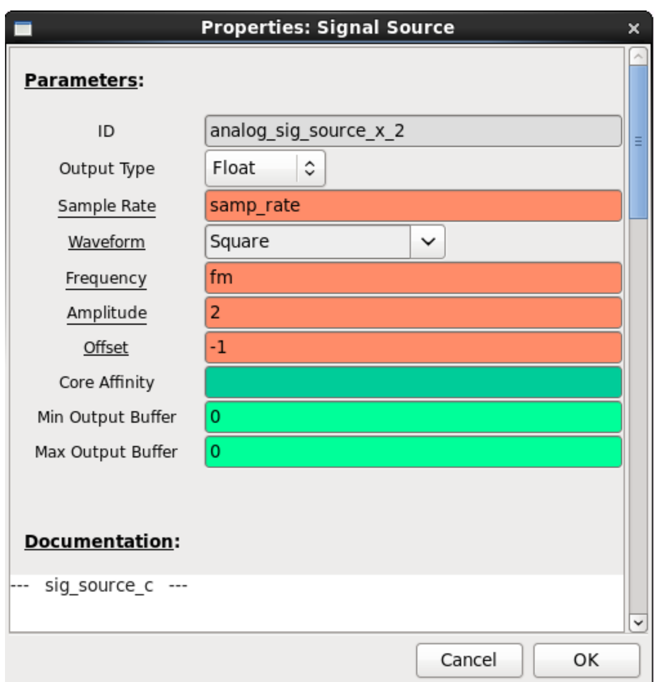
Until now, we have only used a sinusoidal message. In this part we want to create three other waveforms and modulating them using amplitude modulation.

a) Square wave with selectable frequency:

1) Use the following flowgraph to create a symmetric square waveform.

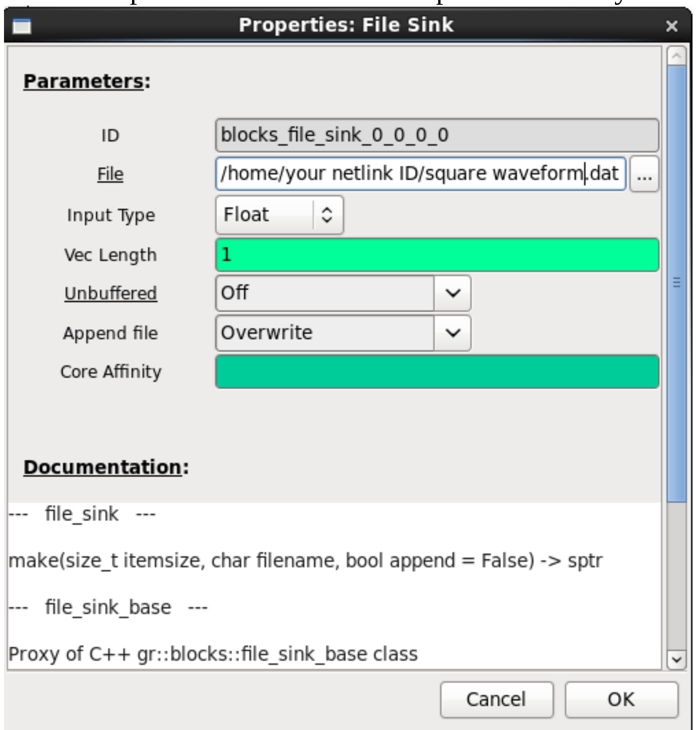


2) Set the parameters of the Signal Source block as below:

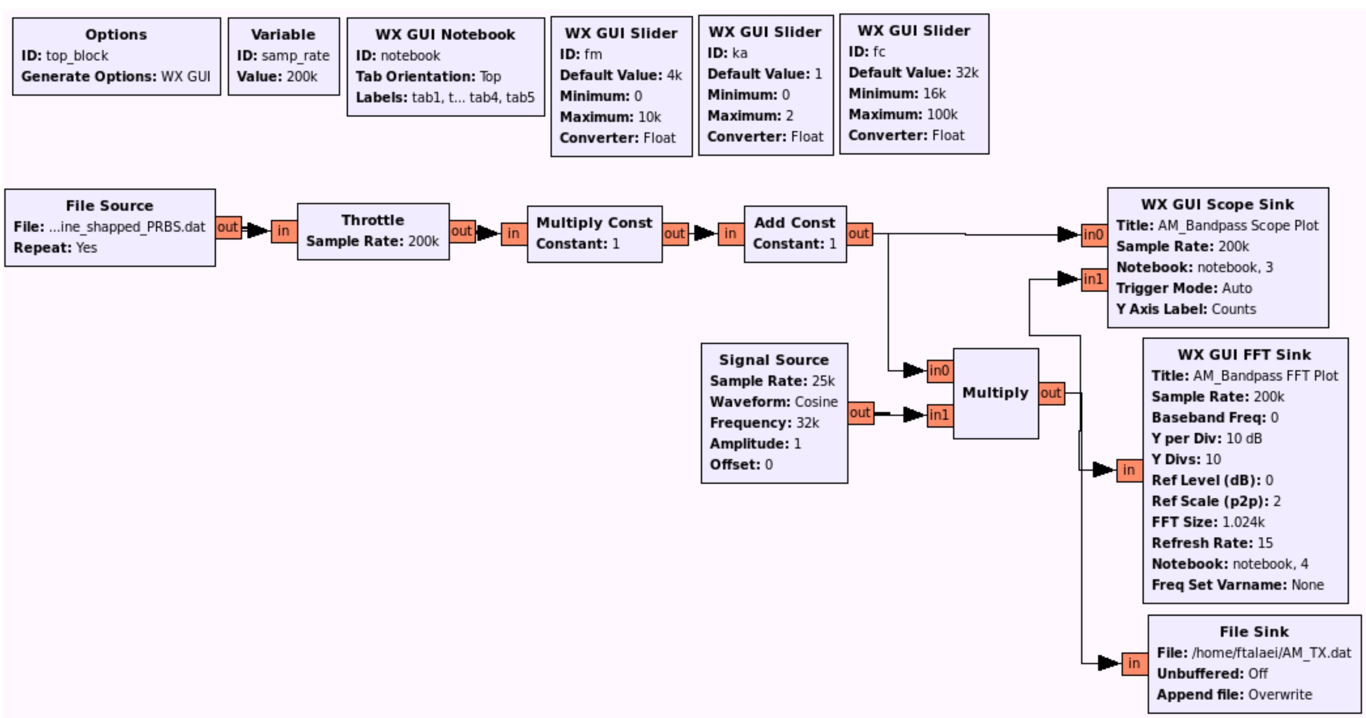


3) *fm* is the frequency of square waveform and its default value is set to 4KHz using a variable block with the same name.

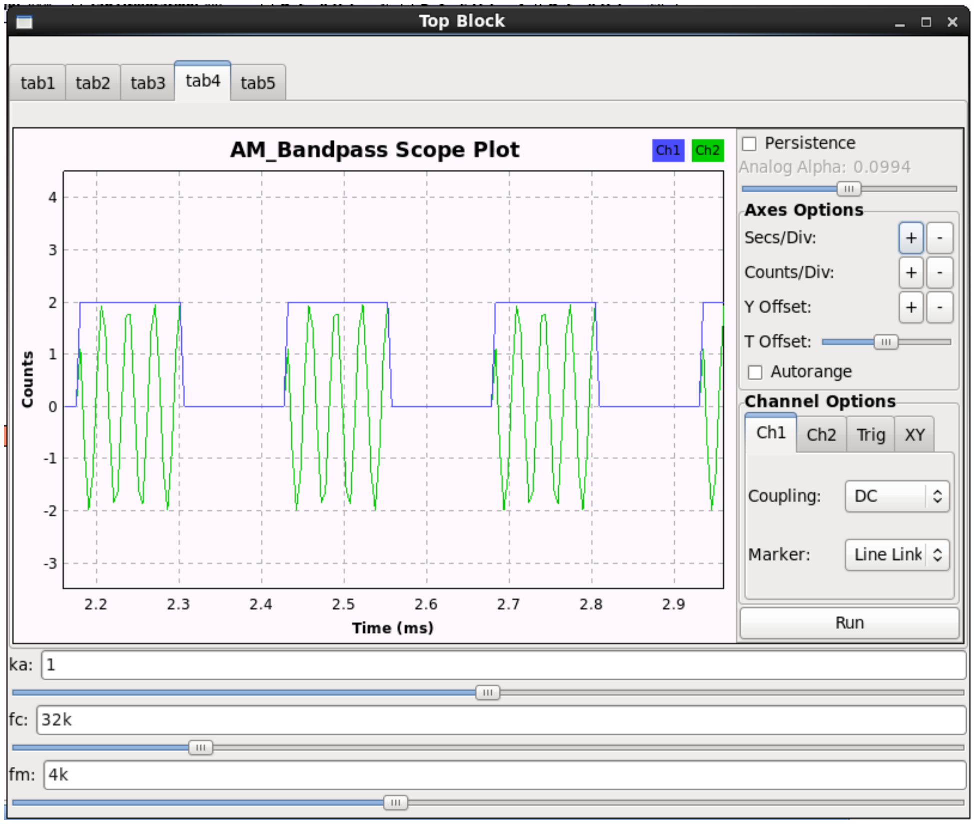
4) You can save the generated waveform using a File Sink. Double click on this block. Click on the ellipsis (…) next to the File parameter and choose the place in which you want to save your file.

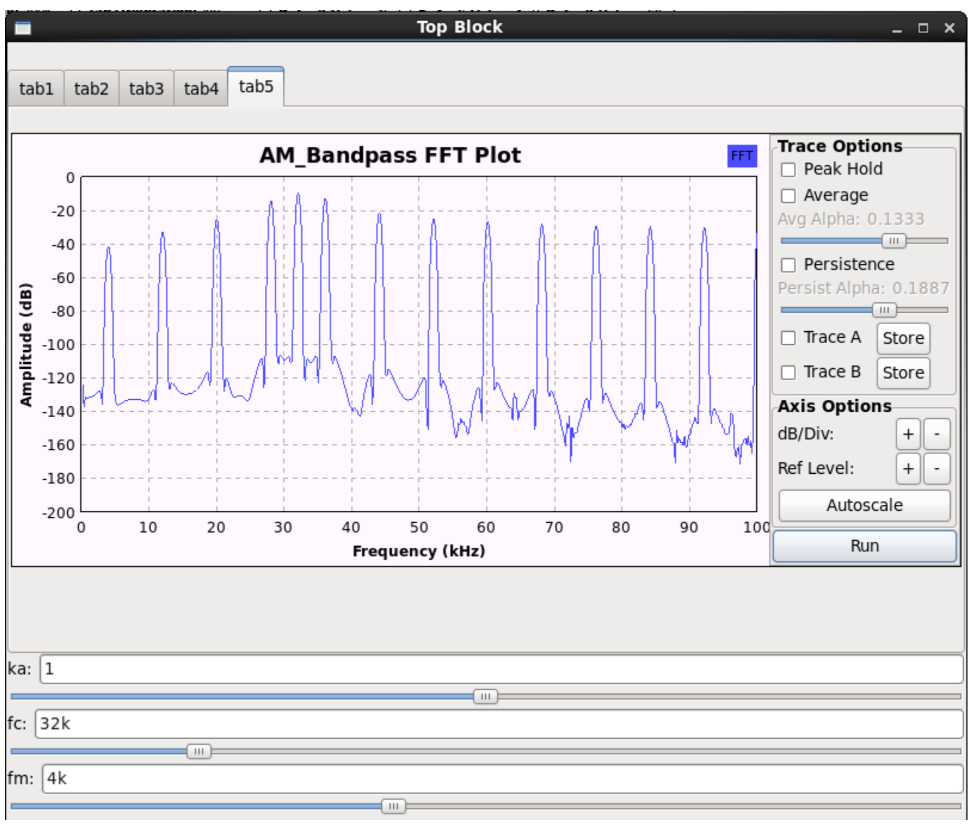


5) Now replace the Signal Source with a File Source and upload the saved message in the previous step for AM modulation:



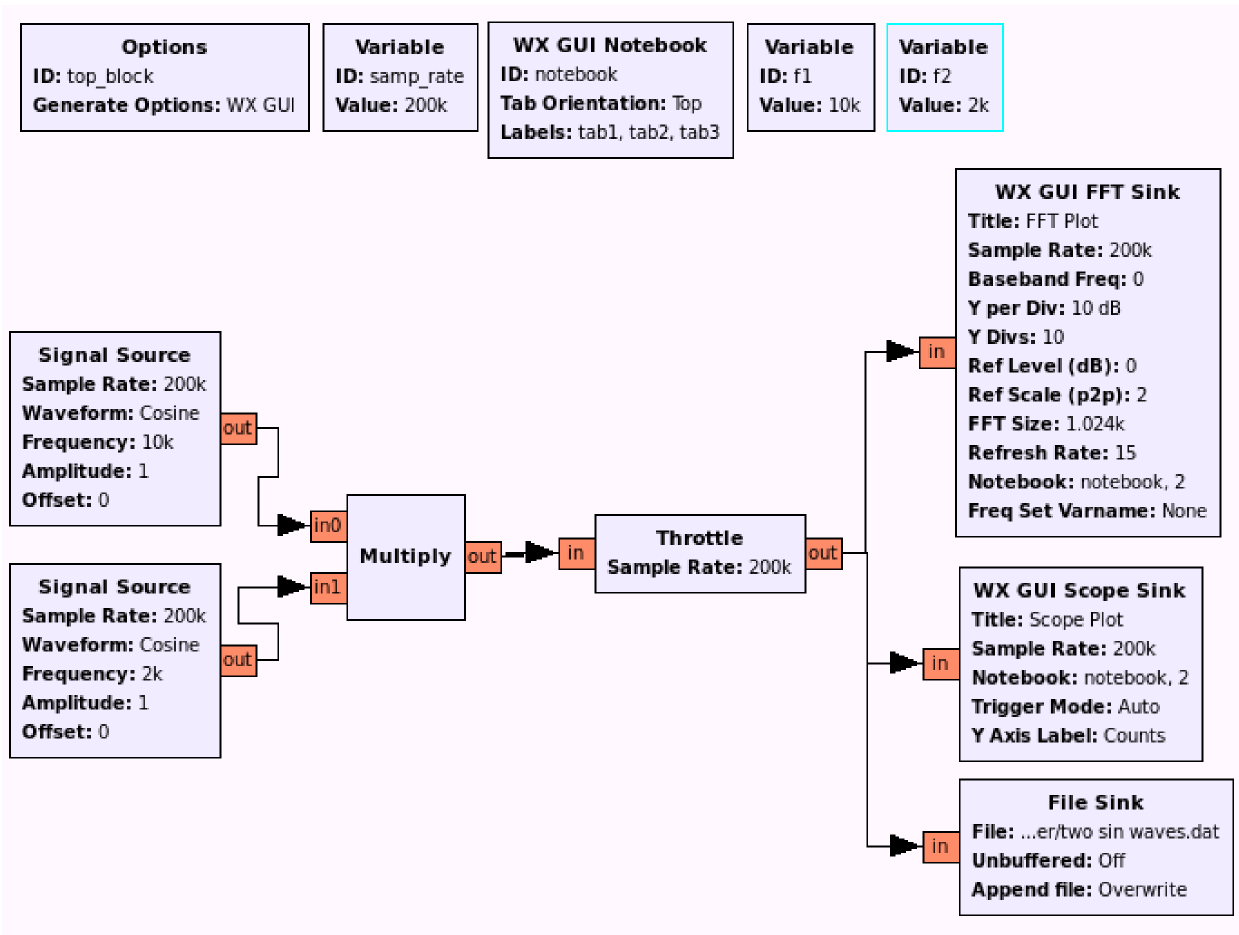
6) The following figures show the AM modulate signal and its spectrum.



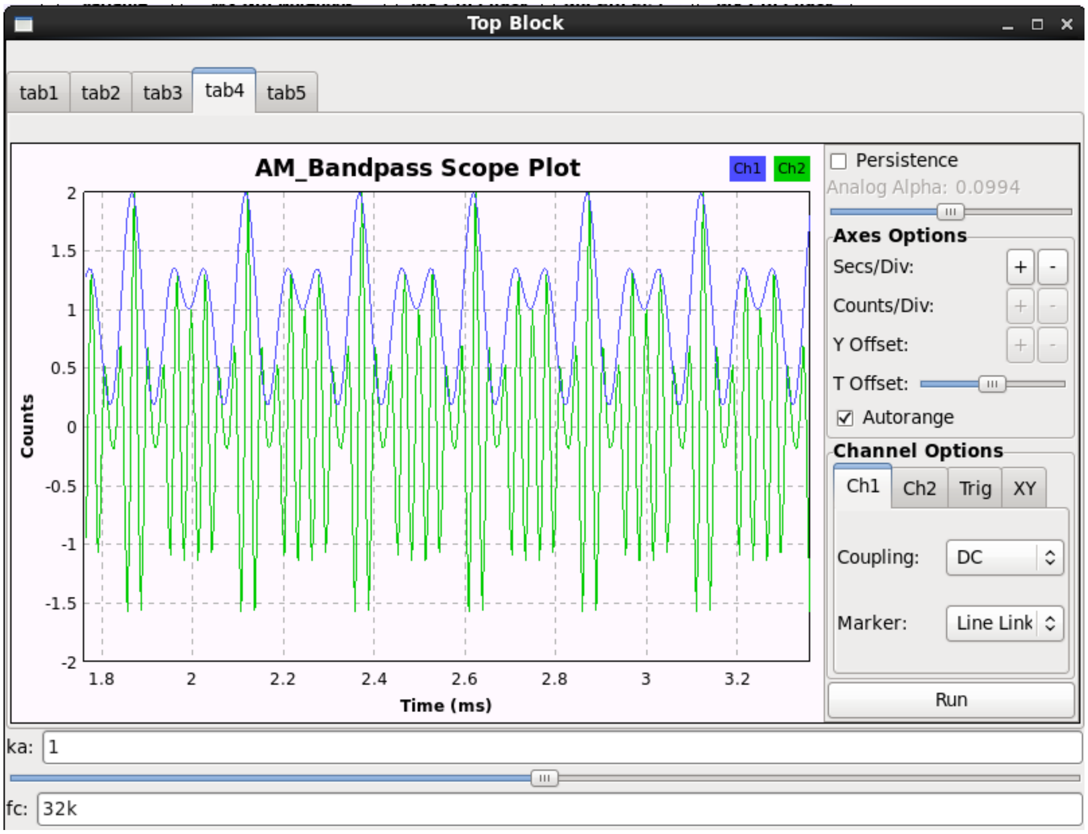


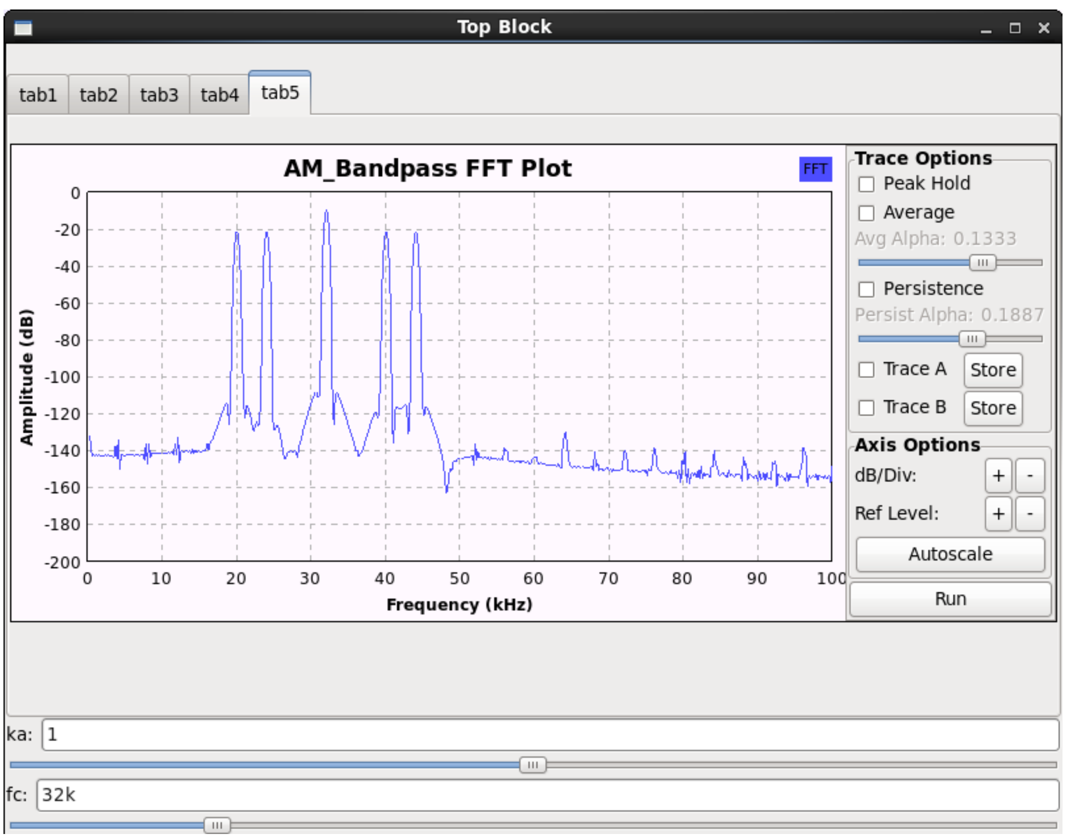
b) Two sine waves with selectable frequencies:

1) In the following graph, two sinusoidal signals with frequencies *f1* and *f2* are mixed together to create a two-tone signal with (*f1*-*f2*) and (*f1*+*f2*) tones. This signal is then saved using a File Sink.



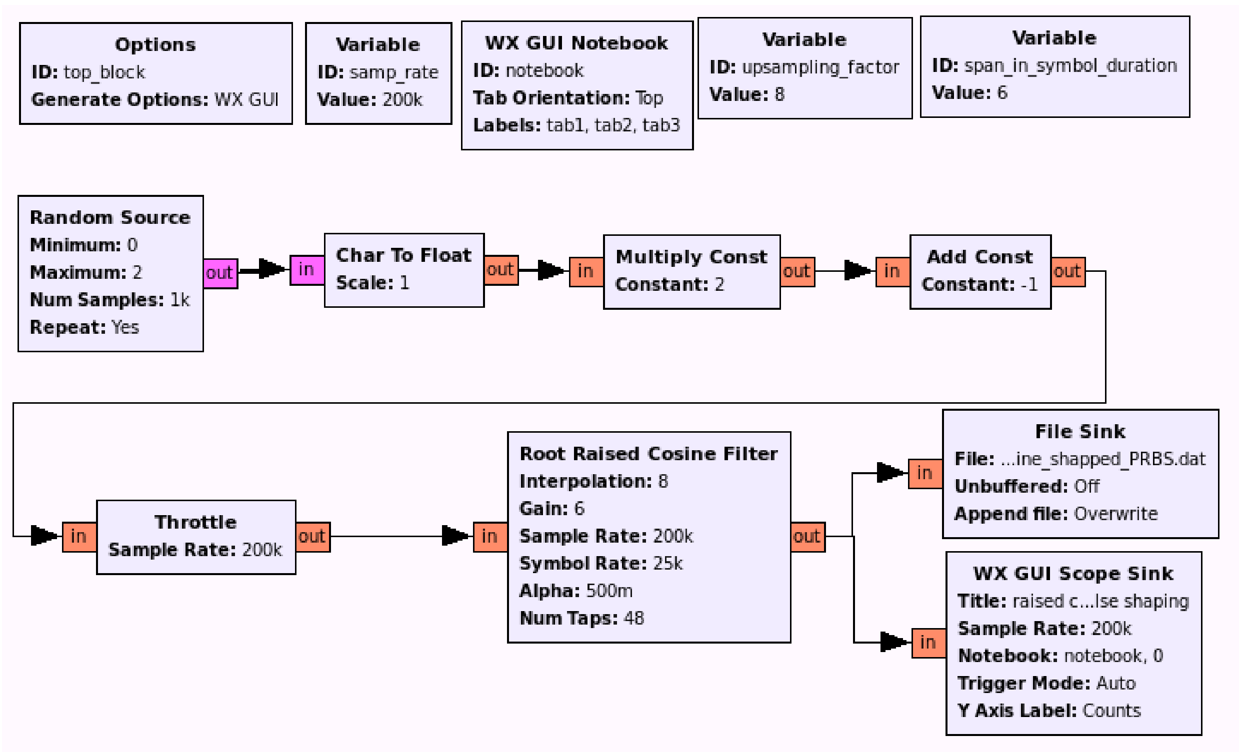
2) The following graph shows the AM signal and its correspondence two side spectrum.



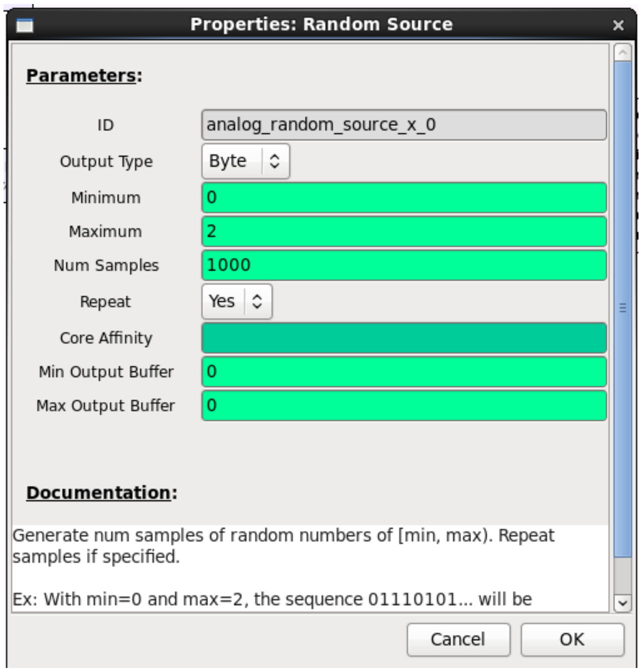


c) Baseband data waveform using Pseudo Random Binary Sequence (PRBS) for data and time domain raised cosine pulse shape over 6 symbols:

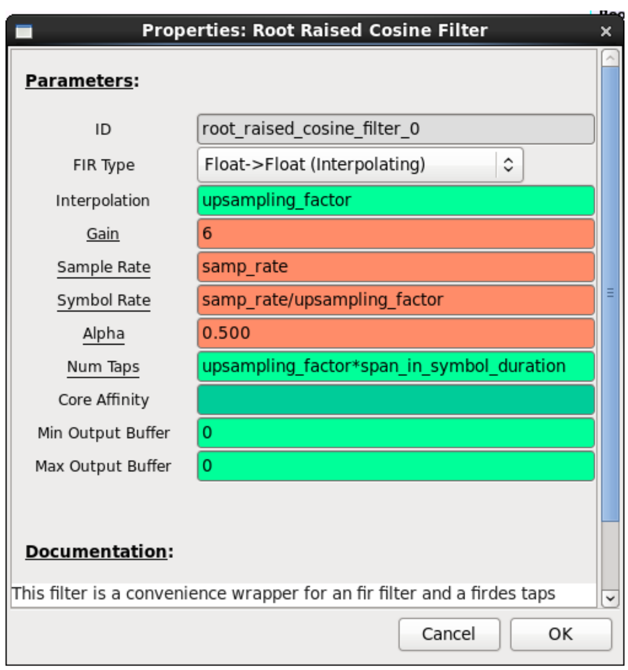
1) In the following flow graph a message signal is created from a sequence of random binary bits which is converted to a sequence of pulses using a raised cosine pulse shaping filter. This sequence is then modulated using the AM modulation scheme. The details will be discussed in the following.



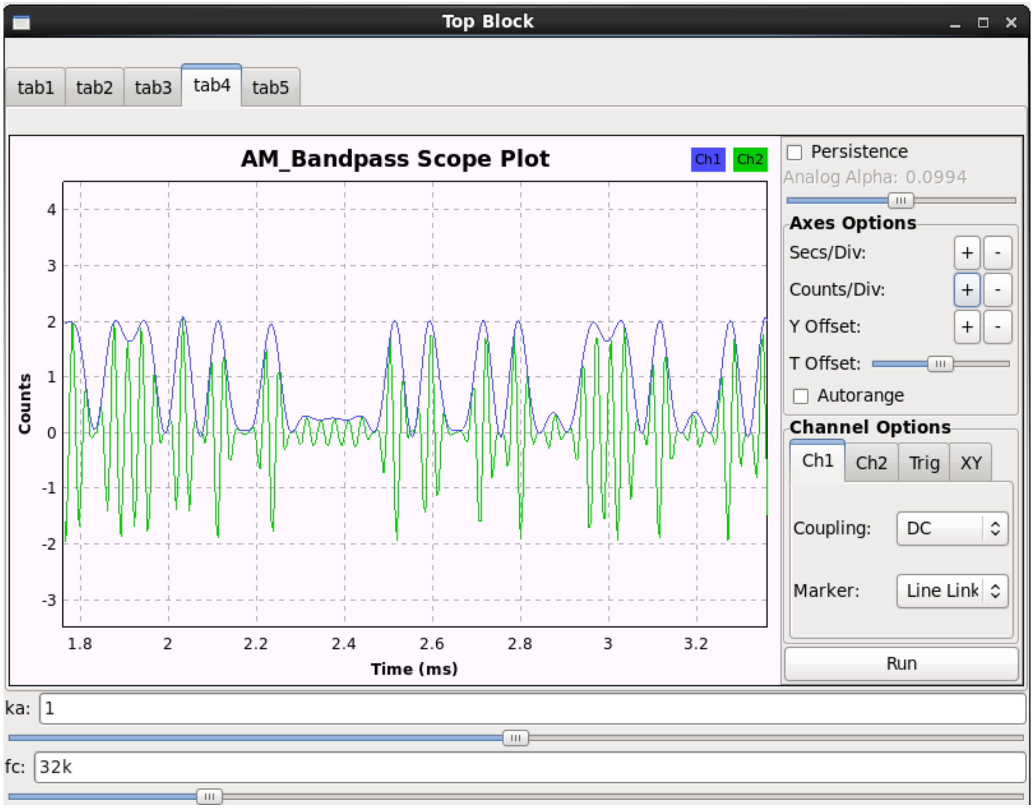
2) Set the parameters of Random Source as below. This block generates a sequence of 1000 random bits which is repeated by setting the Repeat option to "Yes". The output type is "Byte" which is then converted to "Float" type using a Char to Float block. The sequence of {0,1} bits are converted to {-1,1}, which is symmetric around zero, by setting the parameters of Multiply Const and Add Const blocks to 2 and -1 respectively.

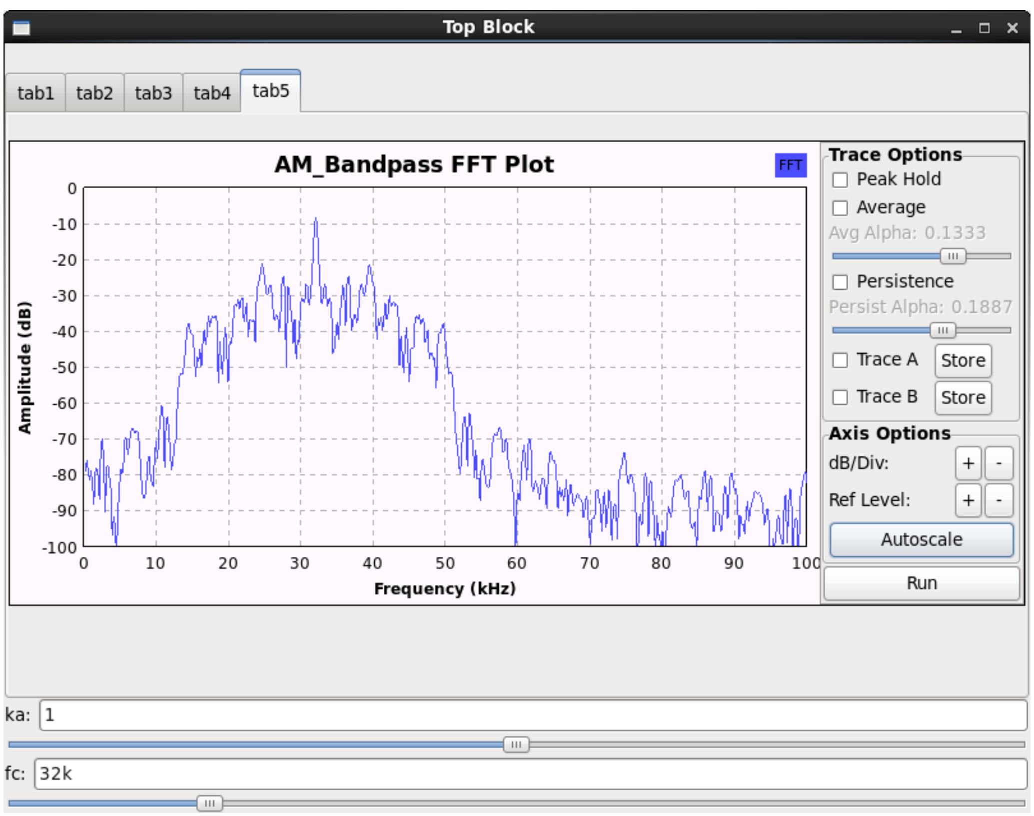


3) The sequence of {-1,1} is conveted to a sequence of pulses using the Root Raised Cosine Filter. The parameters of the filter are set as following:
The main parameter of a raised cosine filter is its roll-off factor (alfa), which indirectly specifies the bandwidth of the filter. Ideal raised cosine filters have an infinite number of taps. Therefore, practical raised cosine filters are windowed. The window length is controlled using the “span_in_symbol_duration” variable. In this example, we specify the window length as six symbol durations, i.e., the filter spans six symbol durations. Raised cosine filters are used for pulse shaping, where the signal is upsampled. Therefore, we also need to specify the upsampling factor. The “upsampling_ factor” is set to eight.
Symbol rate is also equal to samp_rate divided by the upsampling _factor.



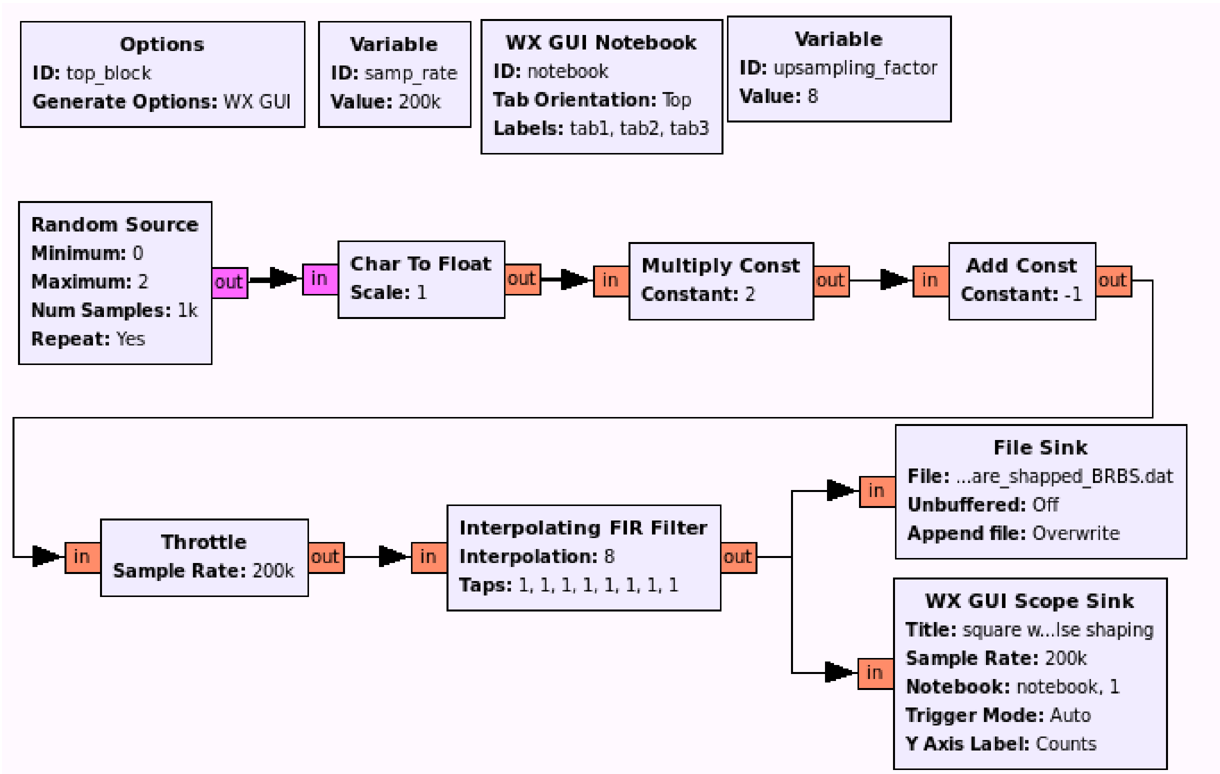
4) The following figures show the AM modulated signal and its spectrum.



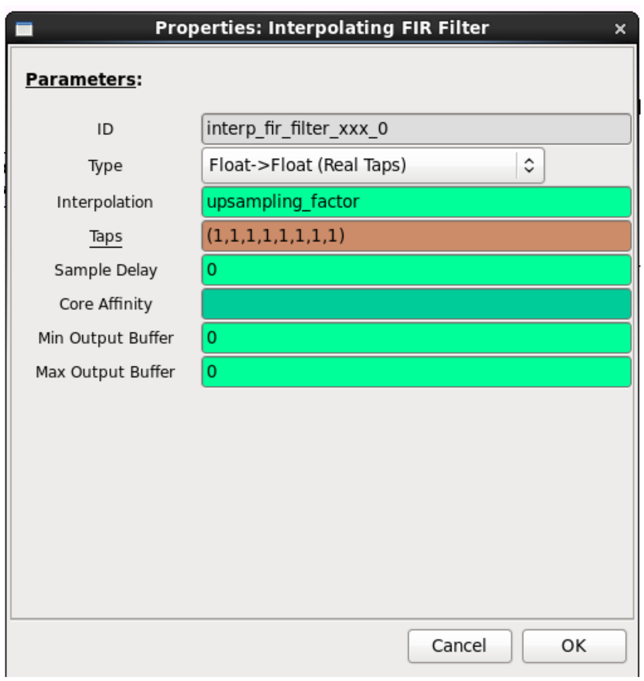


d) Baseband data waveform using PRBS for data and square pulse shape:

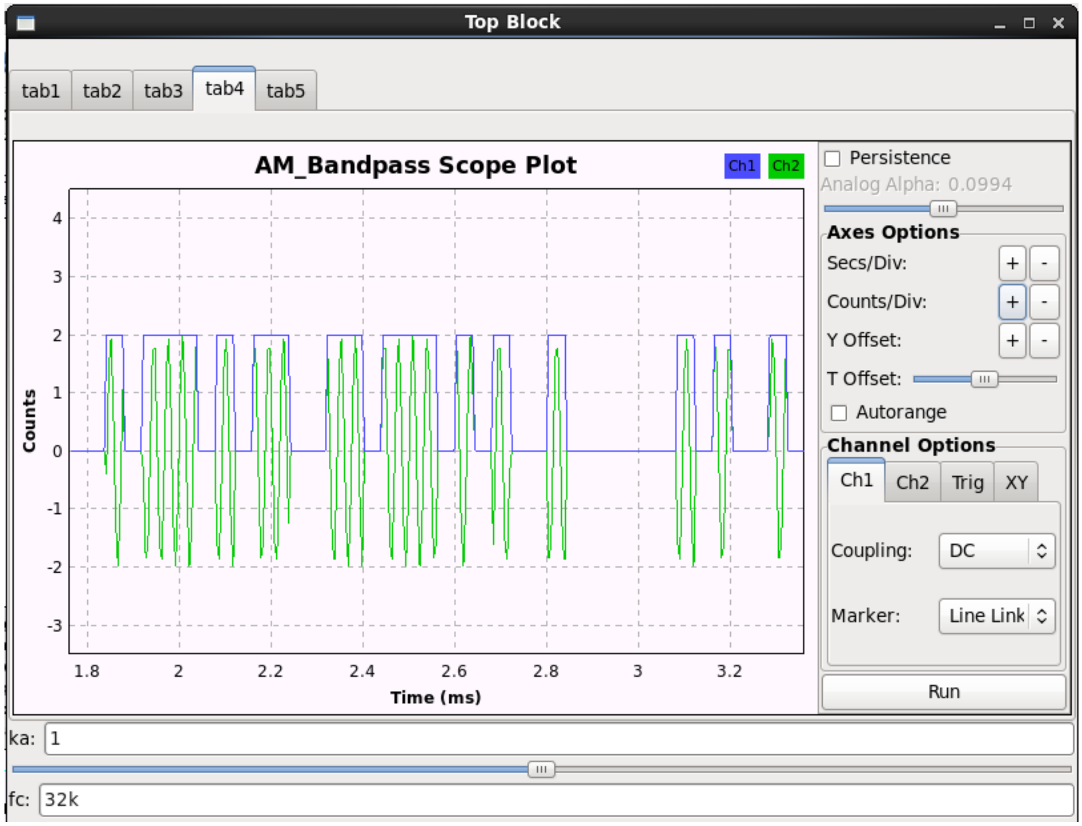
1) The following flowgraph uses the binary random sequence and square pulse shaping filter. Comparing to the flow graph of part c, in this figure the raised cosine filter is replaced by “ Interpolating FIR Filter” .

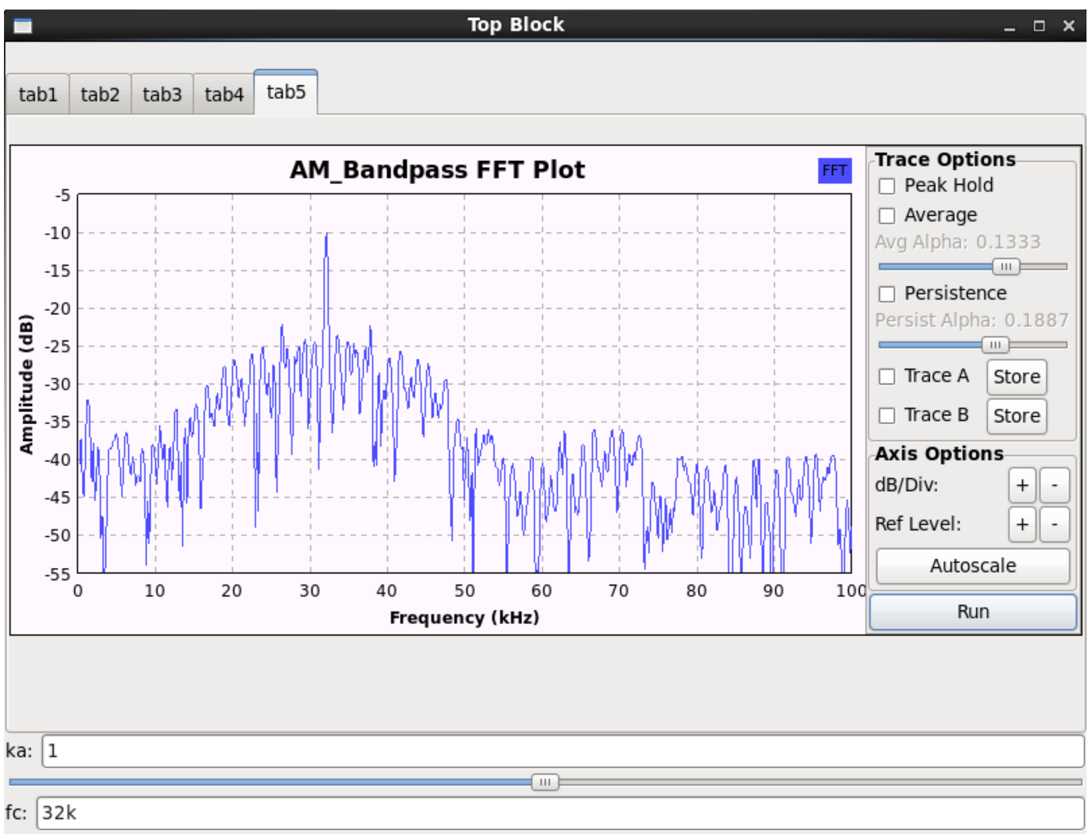


2) The parameters of the Interpolating FIR Filter are determined as following



3) The following figures show the AM modulated signal and its correspondence Spectrum.

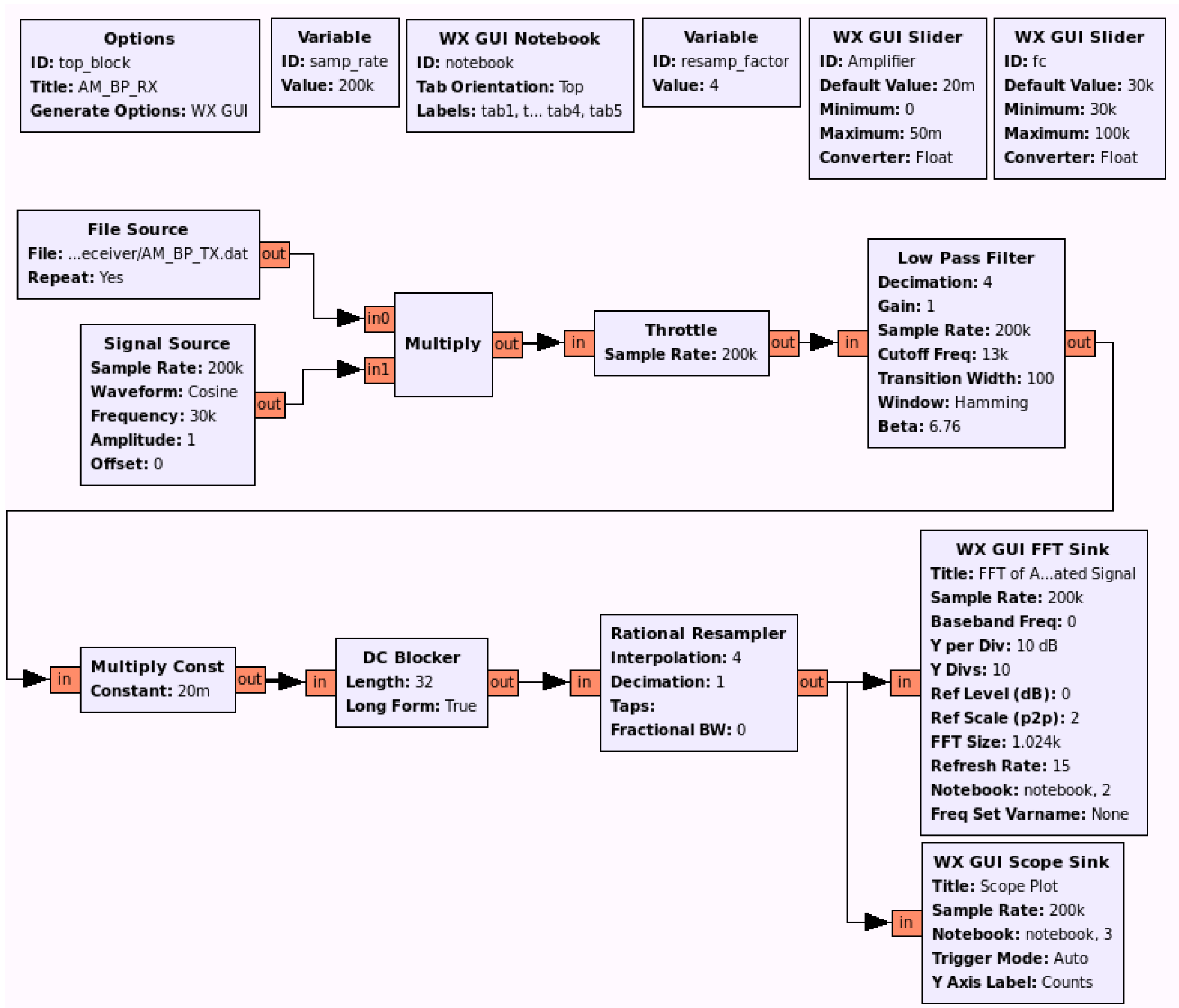




V. AM Demodulation:

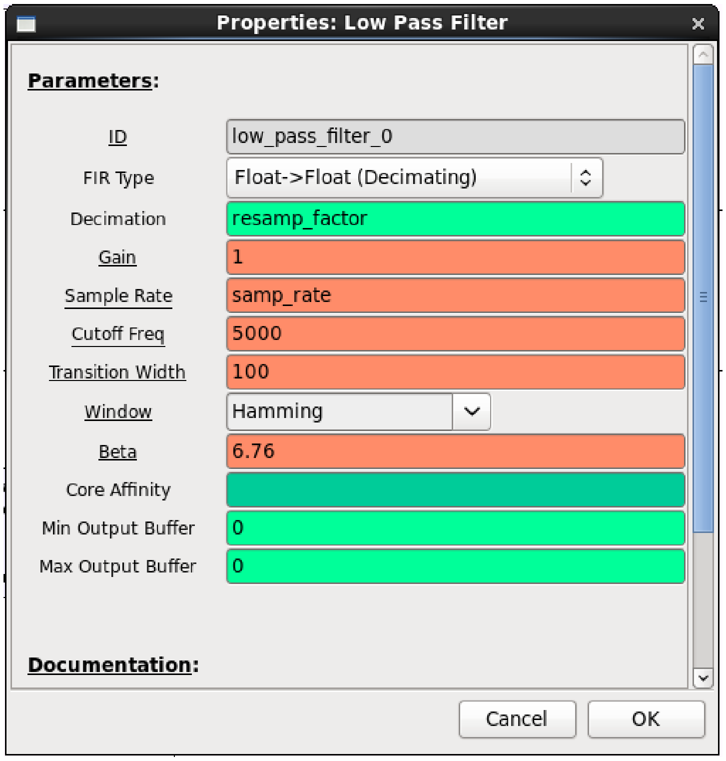
1) Based on part II , for recovering the AM modulated signal we first need to omit the effect of carrier frequency by multiplying the received signal with the carrier waveform and low pass filtering of it to obtain the baseband signal ($1+k_a m(t)$). The baseband signal is then passed through the DC blocker to obtain $k_a m(t)$.

The following flowgraph shows the structure of AM demodulator.

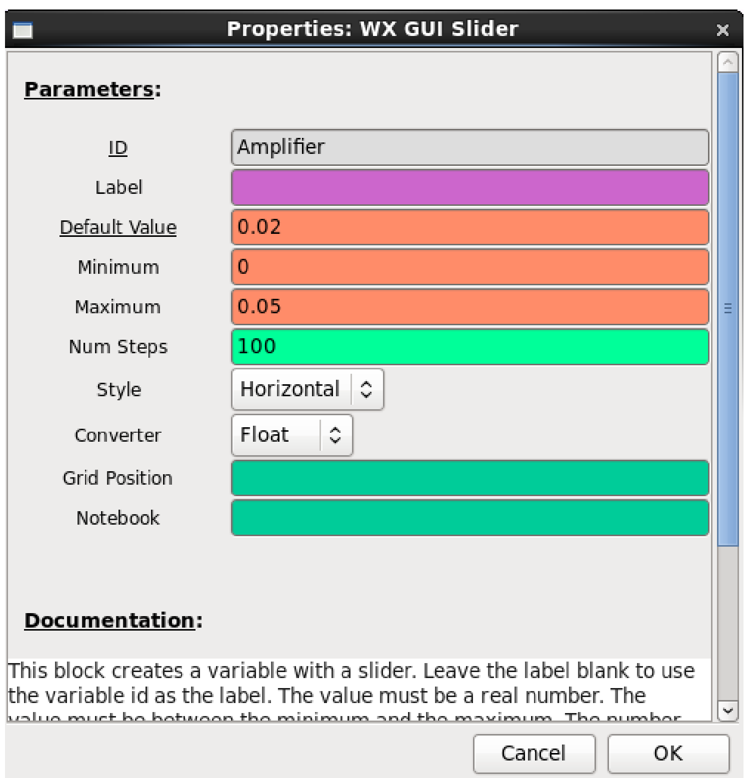


2) Using the source sink you can load the AM modulated signal that you save in the previous step. Double click on the File Source block and upload the Sinusoidal AM modulated signal. Set Repeat to Yes. This will cause the data to repeat so that you have a continuously playing signal.

3) As the frequency of the modulated signal in the previous step was 4 KHz you can set the cutoff frequency of the lowpass filter to 5Khz to only pass the sinusoidal message and omit the higher frequency components .Other parameters of the filter are chosen as following.

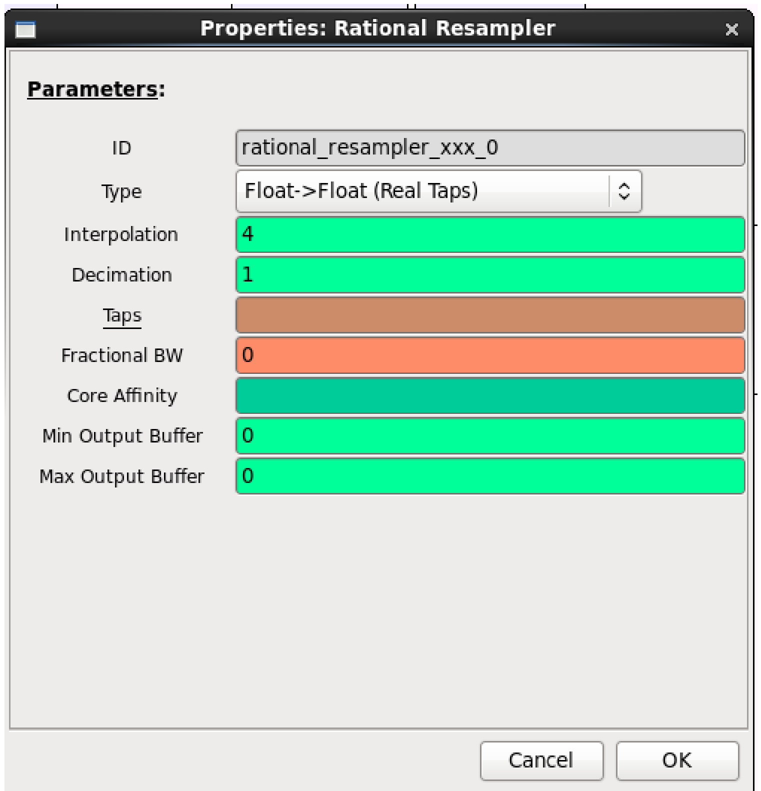


4) The output of the lowpass filter is multiplied with a constant value to intensify the power of received signal. The amplifier's gain is controlled by a WX GUI Slider with following properties:

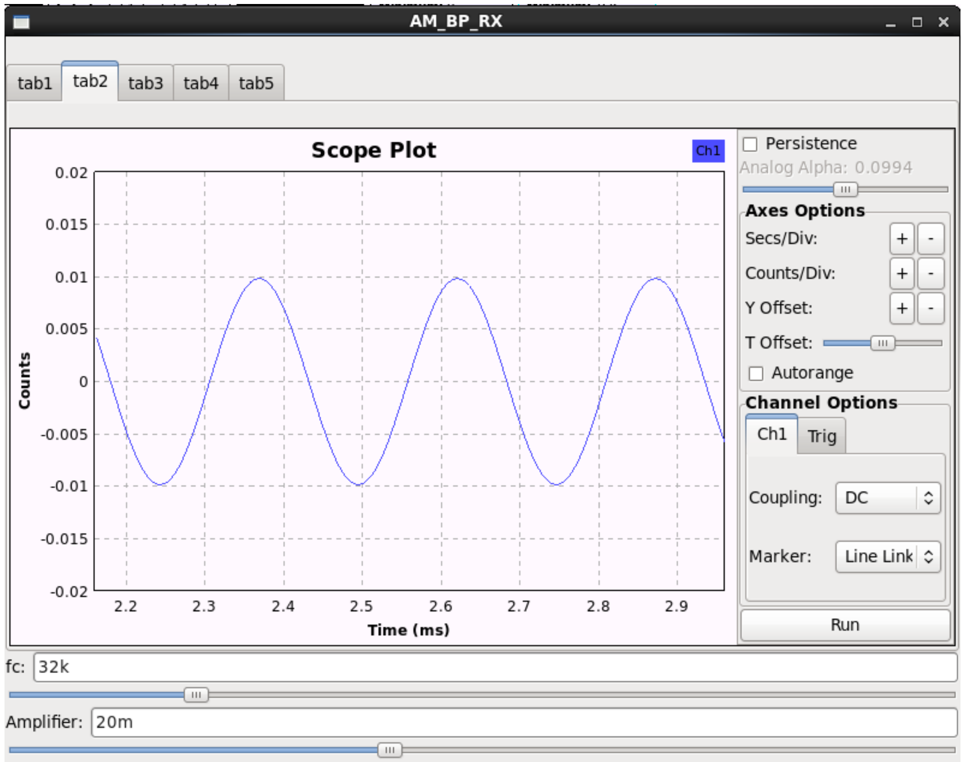


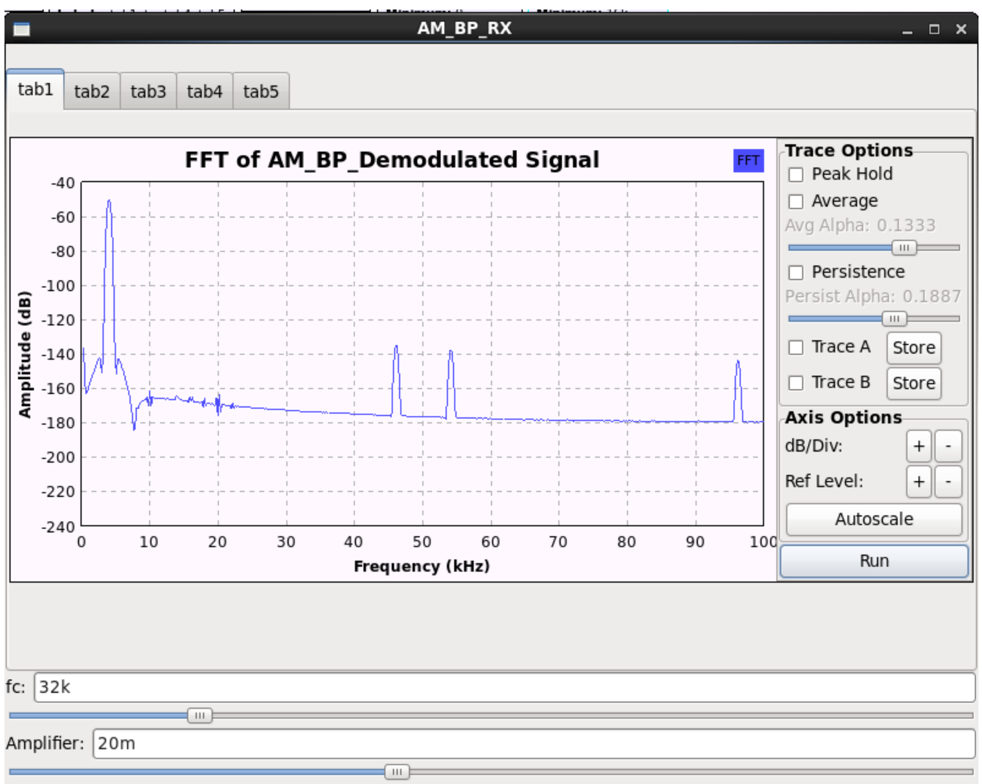
5) The DC Blocker is used to block the DC component.

6) The Decimation rate of the Low pass filter is set to four. So for recovering the signal frequency, we need to use a Rational Resampler to restore the original sampling rate. Double click on the Rational Resampler block and set the decimation and interpolation factors as following.



7) The following figures show the demodulated signal and its spectrum.
You can also use the above demodulator for other AM modulated waveforms of previous step by adjusting the parameters of the lowpass filter based on their properties.


AM_BP_RX
tab1
tab2
tab3
tab4
tab5
Scope Plot
Ch1
Counts
Time (ms)
Persistence
Analog Alpha: 0.0994
Axes Options
Secs/Div:
Counts/Div:
Y Offset:
T Offset:
Autorange
Channel Options
Ch1
Trig
Coupling:
DC
Marker:
Line Link
Run
fc:
32k
Amplifier:
20m


AM_BP_RX
tab1
tab2
tab3
tab4
tab5
FFT of AM_BP_Demodulated Signal
FFT
Amplitude (dB)
Frequency (kHz)
Trace Options
Peak Hold
Average
Avg Alpha: 0.1333
Persistence
Persist Alpha: 0.1887
Trace A
Store
Trace B
Store
Axis Options
dB/Div:
Ref Level:
Autoscale
Run
fc:
32k
Amplifier:
20m