GNU Radio Tutorials

Labs 1 – 5

Balint Seeber
Ettus Research

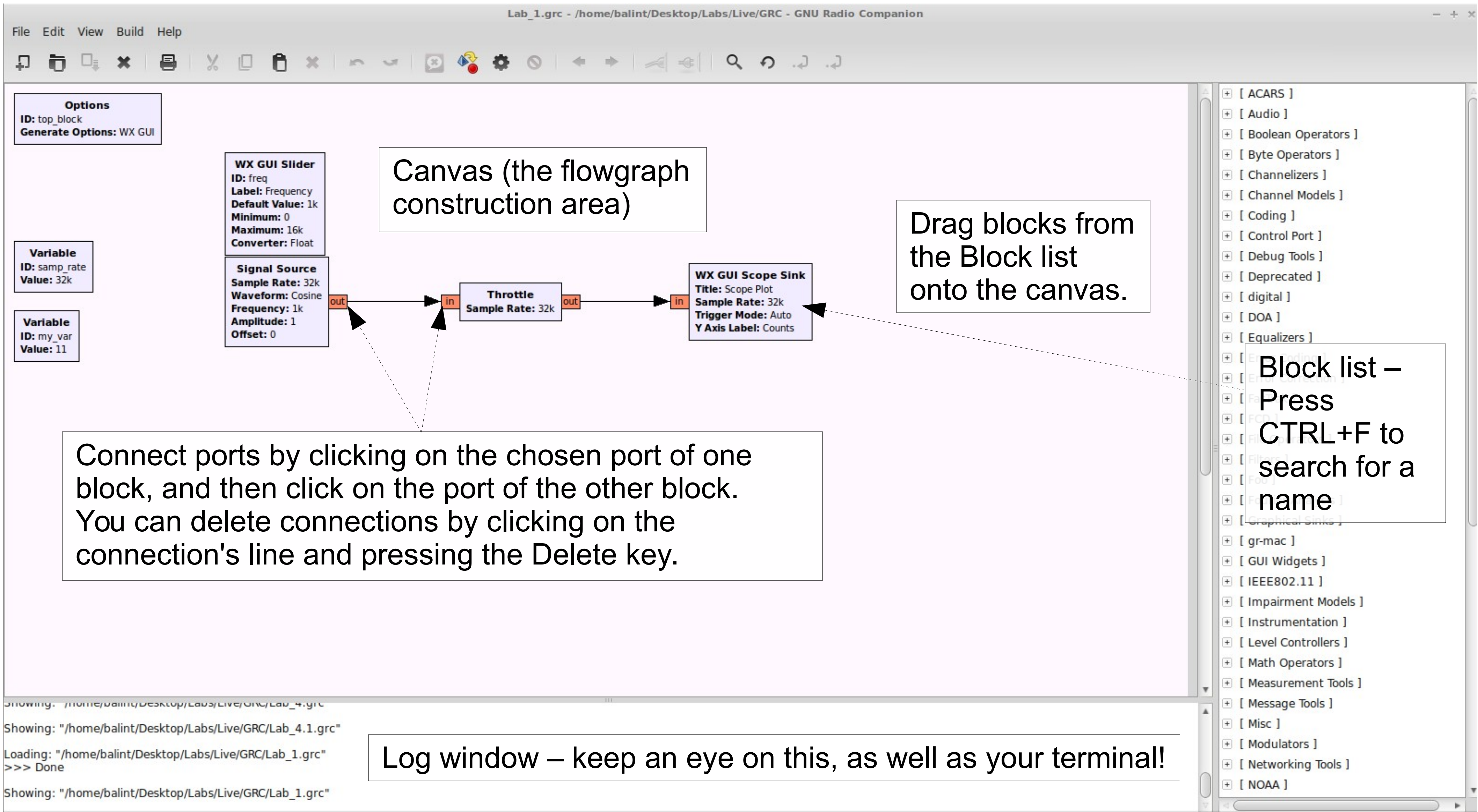
Version 1.0 (18^{th} April 2014)

Comments & suggetions welcome:
balint@ettus.com
@spenchdotnet

Lab 1

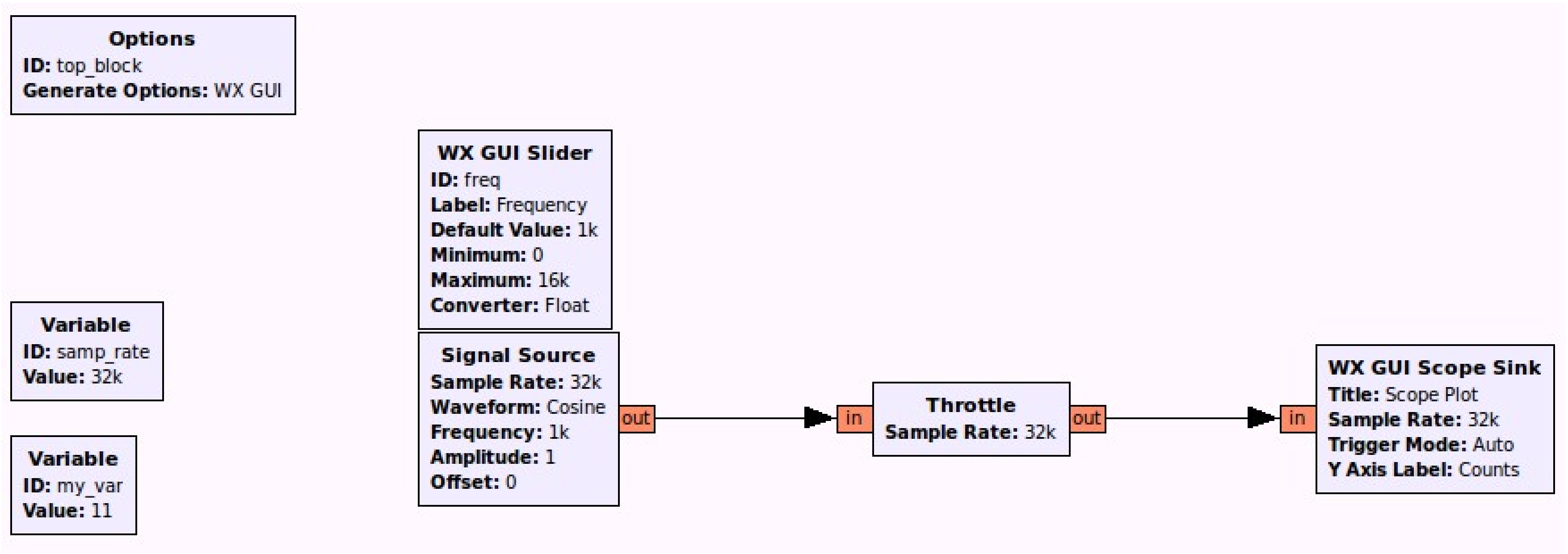
- Open GNU Radio Companion:
  - Open a Terminal/Console/Command Prompt
  - Run 'gnuradio-companion'

Lab 1



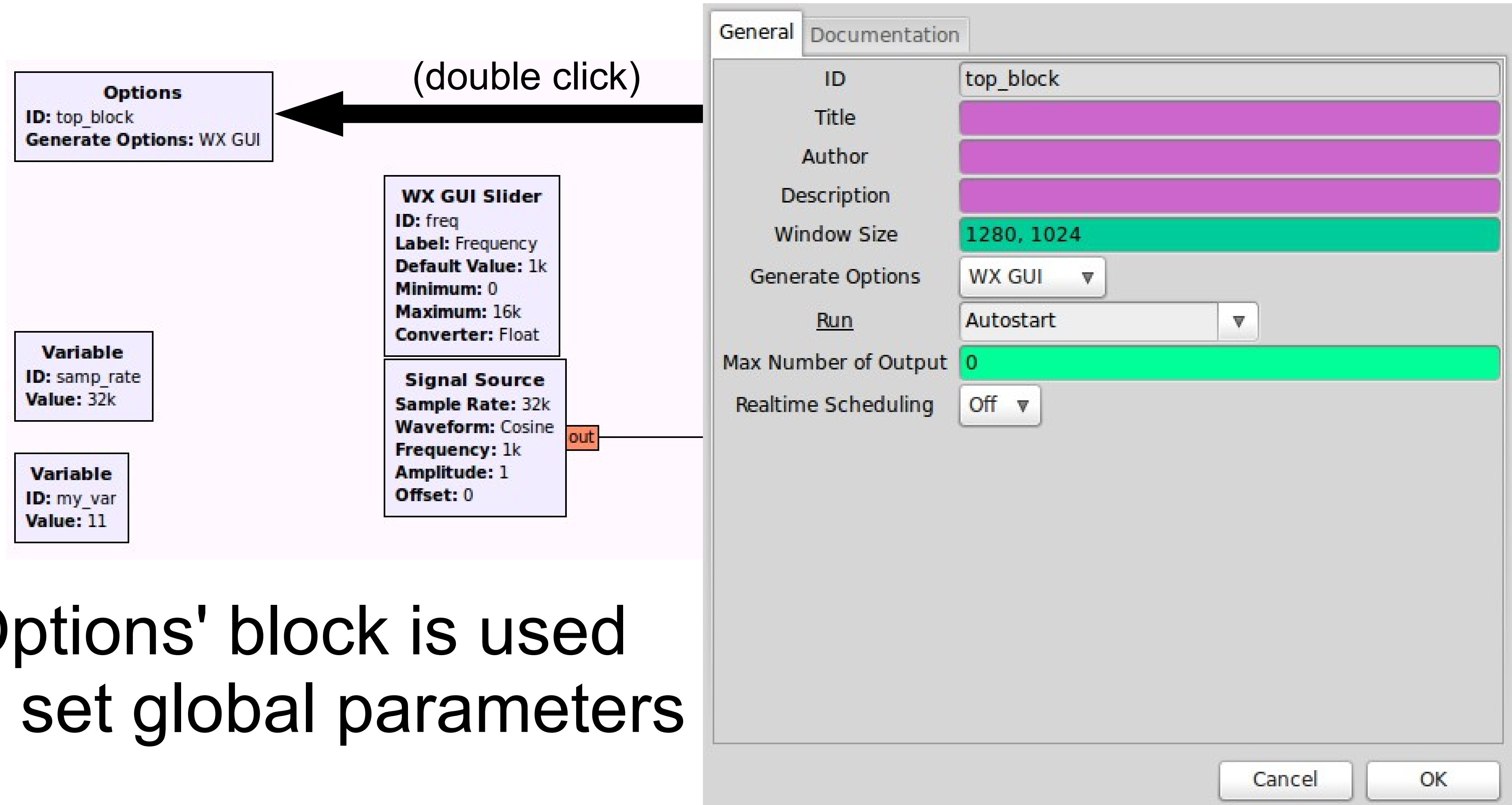
Lab_1.grc - /home/balint/Desktop/Labs/Live/GRC - GNU Radio Companion
File Edit View Build Help
Options
ID: top_block
Generate Options: WX GUI
WX GUI Slider
ID: freq
Label: Frequency
Default Value: 1k
Minimum: 0
Maximum: 16k
Converter: Float
Canvas (the flowgraph construction area)
Variable
ID: samp_rate
Value: 32k
Signal Source
Sample Rate: 32k
Waveform: Cosine
Frequency: 1k
Amplitude: 1
Offset: 0
Variable
ID: my_var
Value: 11
Throttle
Sample Rate: 32k
WX GUI Scope Sink
Title: Scope Plot
Sample Rate: 32k
Trigger Mode: Auto
Y Axis Label: Counts
Drag blocks from the Block list onto the canvas.
Block list – Press CTRL+F to search for a name
Connect ports by clicking on the chosen port of one block, and then click on the port of the other block. You can delete connections by clicking on the connection's line and pressing the Delete key.
Showing: "/home/balint/Desktop/Labs/Live/GRC/Lab_4.1.grc"
Loading: "/home/balint/Desktop/Labs/Live/GRC/Lab_1.grc"
>>> Done
Showing: "/home/balint/Desktop/Labs/Live/GRC/Lab_1.grc"
Log window – keep an eye on this, as well as your terminal!
[ACARS]
[Audio]
[Boolean Operators]
[Byte Operators]
[Channelizers]
[Channel Models]
[Coding]
[Control Port]
[Debug Tools]
[Deprecated]
[digital]
[DOA]
[Equalizers]
[gr-mac]
[GUI Widgets]
[IEEE802.11]
[Impairment Models]
[Instrumentation]
[Level Controllers]
[Math Operators]
[Measurement Tools]
[Message Tools]
[Misc]
[Modulators]
[Networking Tools]
[NOAA]

Lab 1



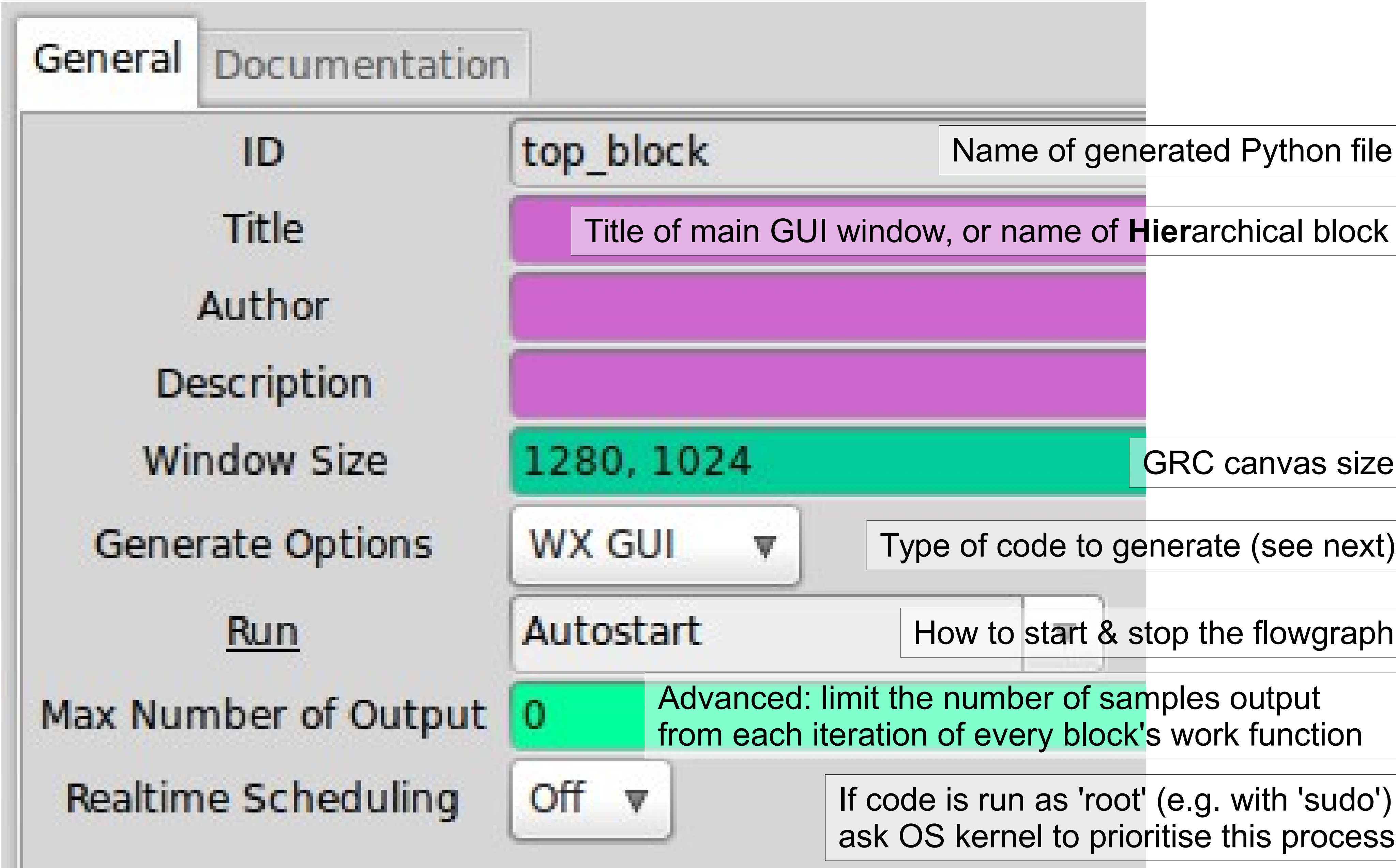
Create a sine wave & inspect the generated samples with a (time-domain) Scope Sink

Lab 1

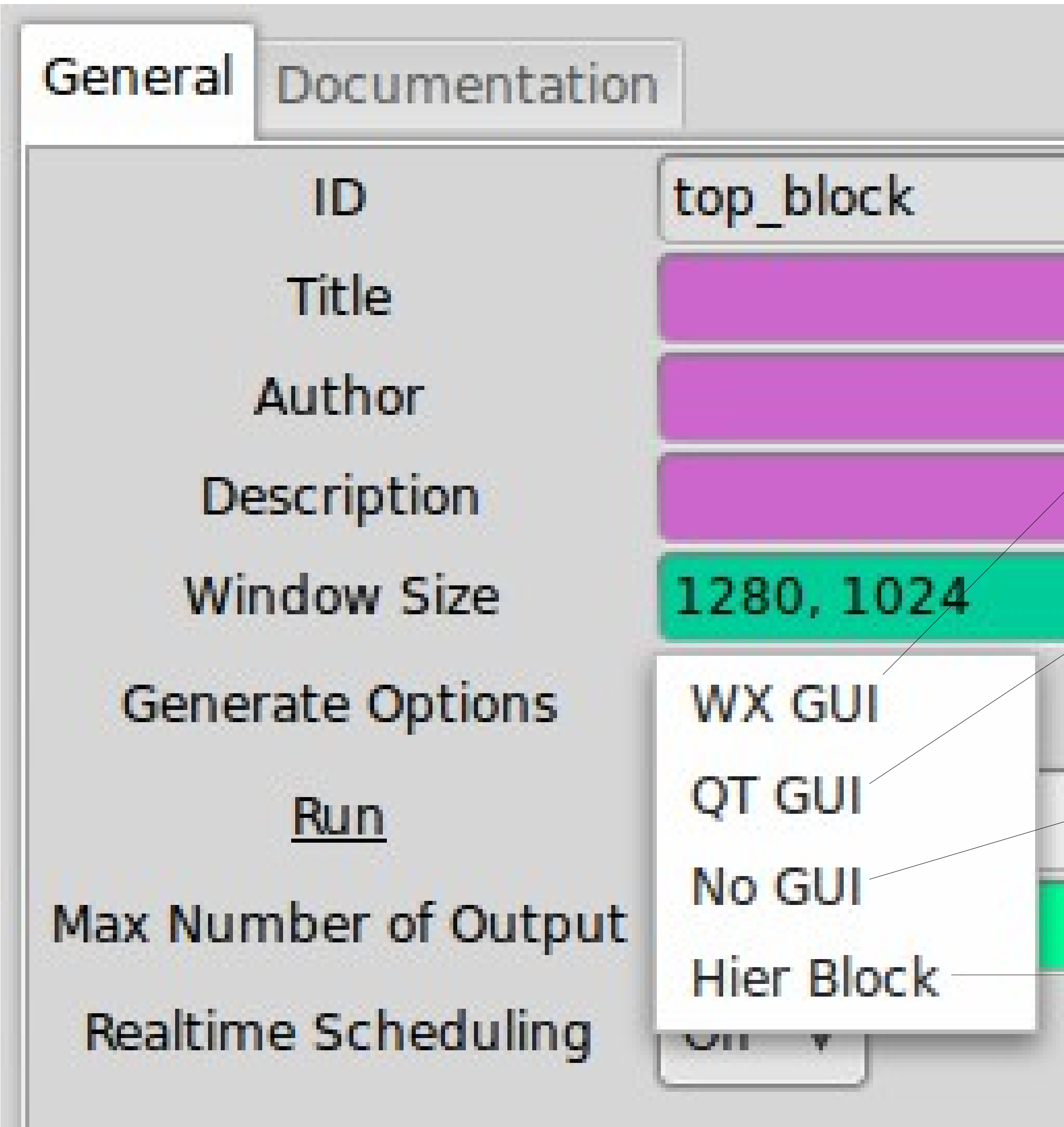


'Options' block is used to set global parameters

Lab 1


General
Documentation
ID
top_block
Name of generated Python file
Title
Title of main GUI window, or name of **Hier**archical block
Author
Description
Window Size
1280, 1024
GRC canvas size
Generate Options
WX GUI
Type of code to generate (see next)
Run
Autostart
How to start & stop the flowgraph
Max Number of Output
0
Advanced: limit the number of samples output from each iteration of every block's work function
Realtime Scheduling
Off
If code is run as 'root' (e.g. with 'sudo') ask OS kernel to prioritise this process

Lab 1



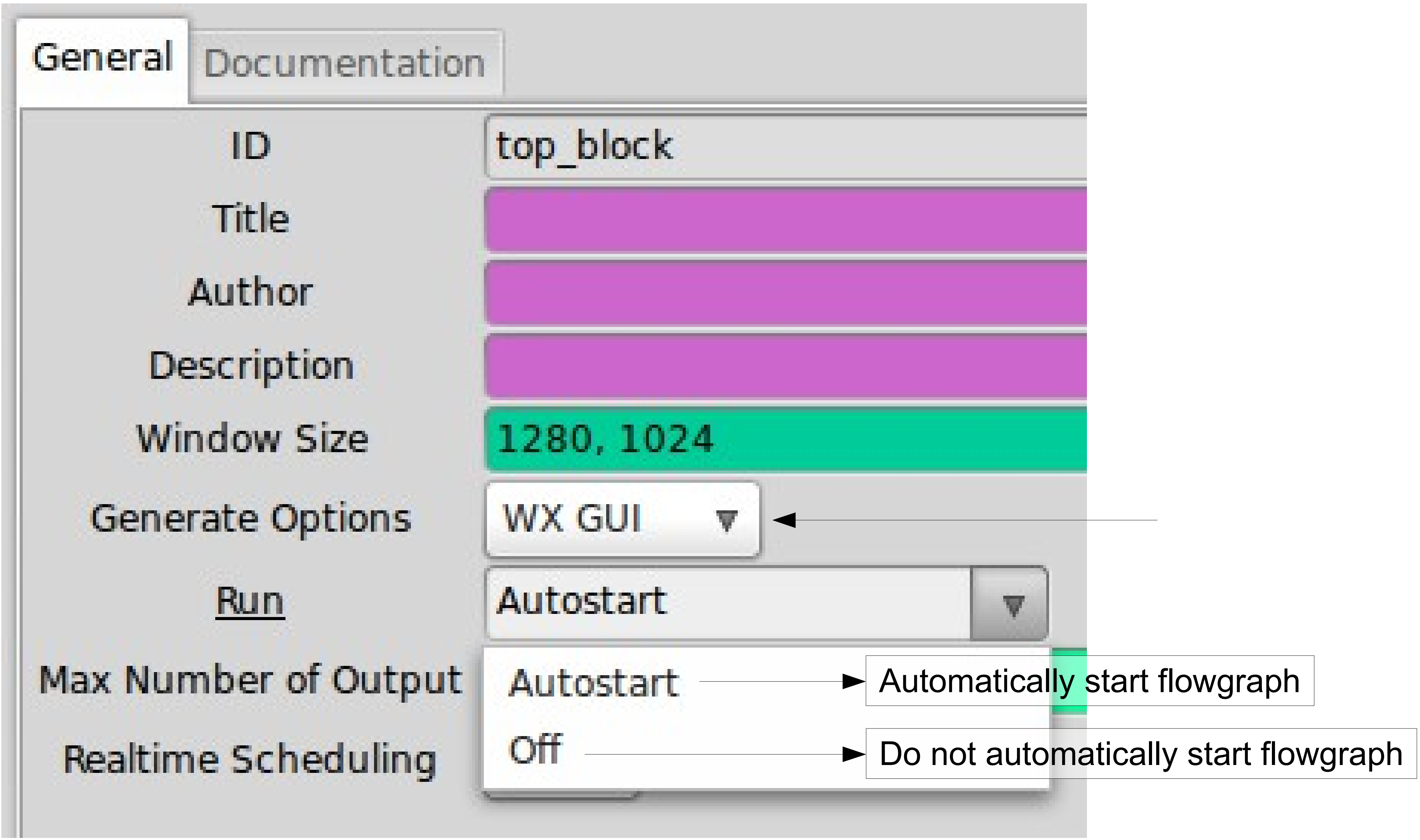
GUI app using WX toolkit
(use WX GUI blocks)

GUI app using Qt toolkit
(use Qt GUI blocks)

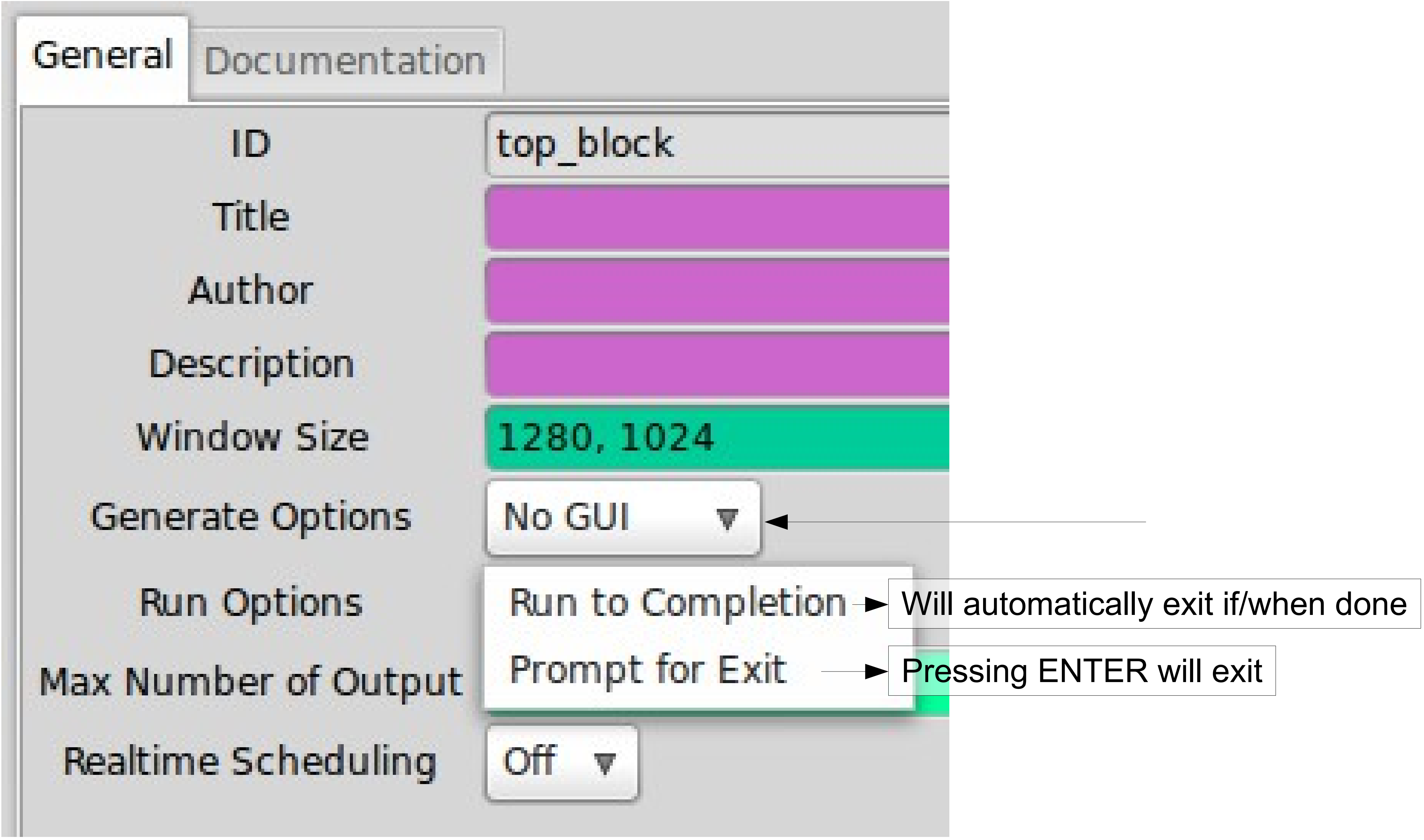
Command-line app without GUI
(text-based, run in a console)

Create a **Hier**archical block
that will appear in the block list
(a reusable component, not an app
– use Pad Source/Sink blocks to
expose ports, and Parameter blocks
to expose configuration variables)

Lab 1

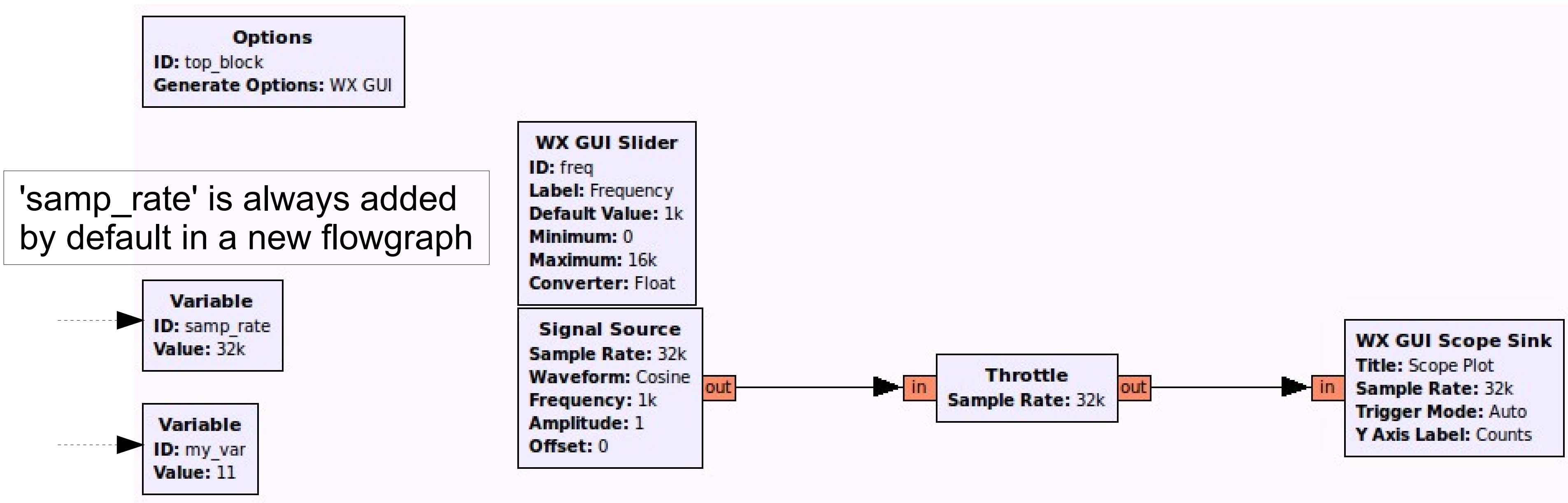

General
Documentation
ID
top_block
Title
Author
Description
Window Size
1280, 1024
Generate Options
WX GUI
Run
Autostart
Max Number of Output
Realtime Scheduling
Autostart
Off
Automatically start flowgraph
Do not automatically start flowgraph

Lab 1



General
Documentation
ID
top_block
Title
Author
Description
Window Size
1280, 1024
Generate Options
No GUI
Run Options
Run to Completion
Prompt for Exit
Max Number of Output
Realtime Scheduling
Off
Will automatically exit if/when done
Pressing ENTER will exit

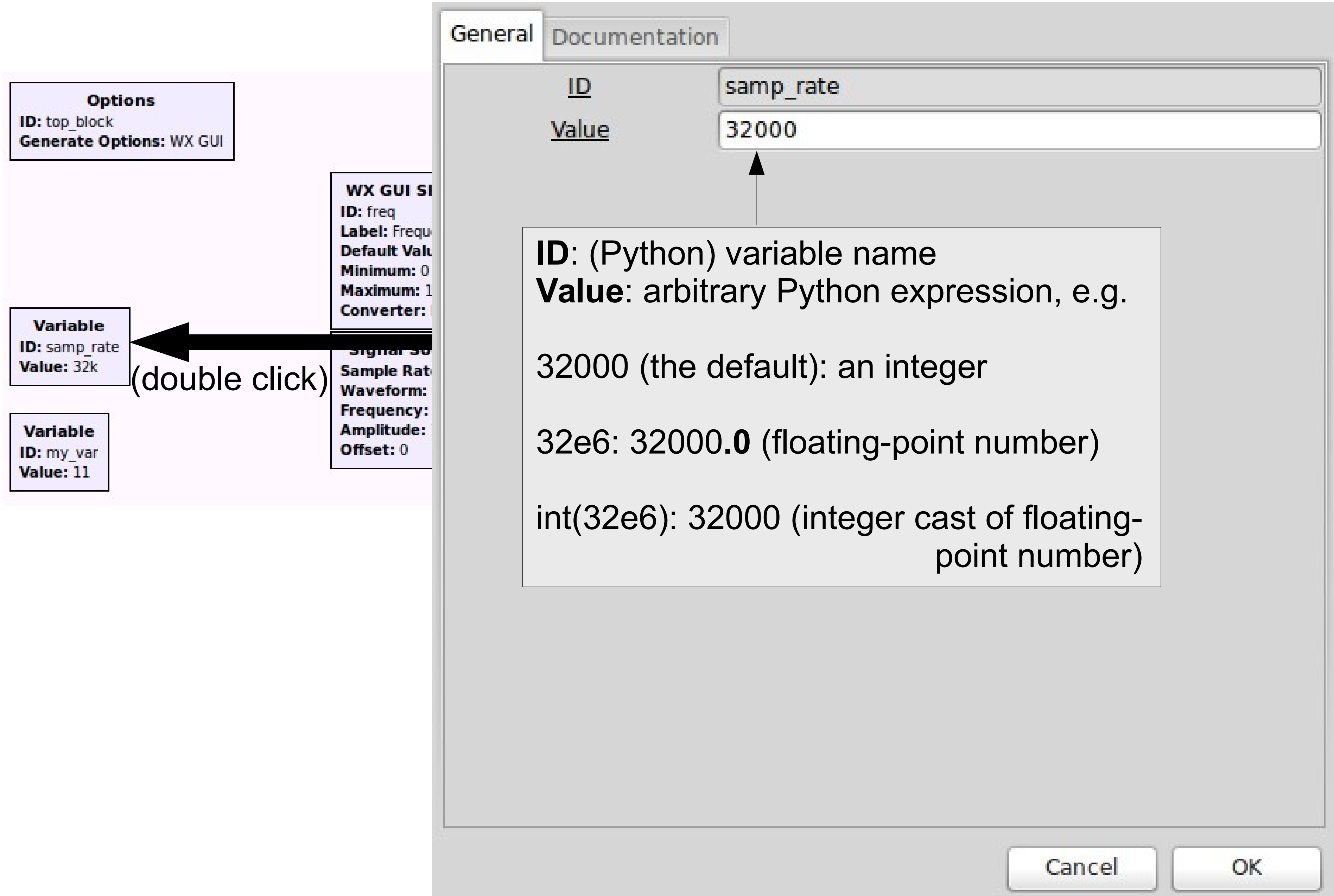
Lab 1



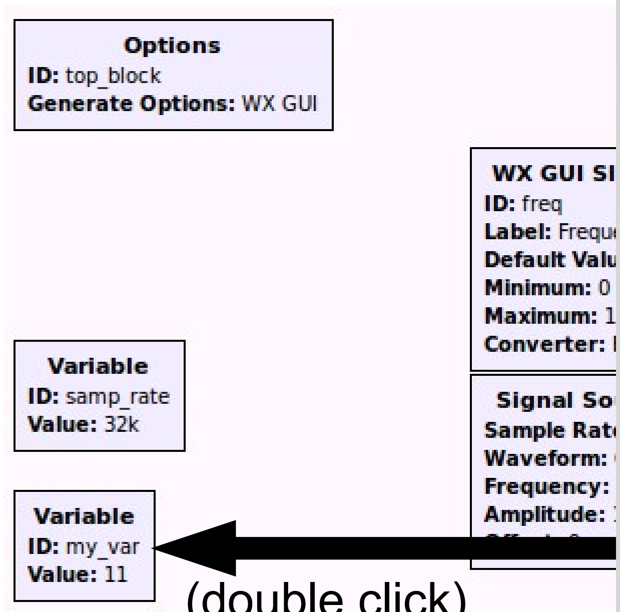
Variable: a block that contains an arbitrary Python expression.

You can refer to it in another block by its **ID**.

Lab 1

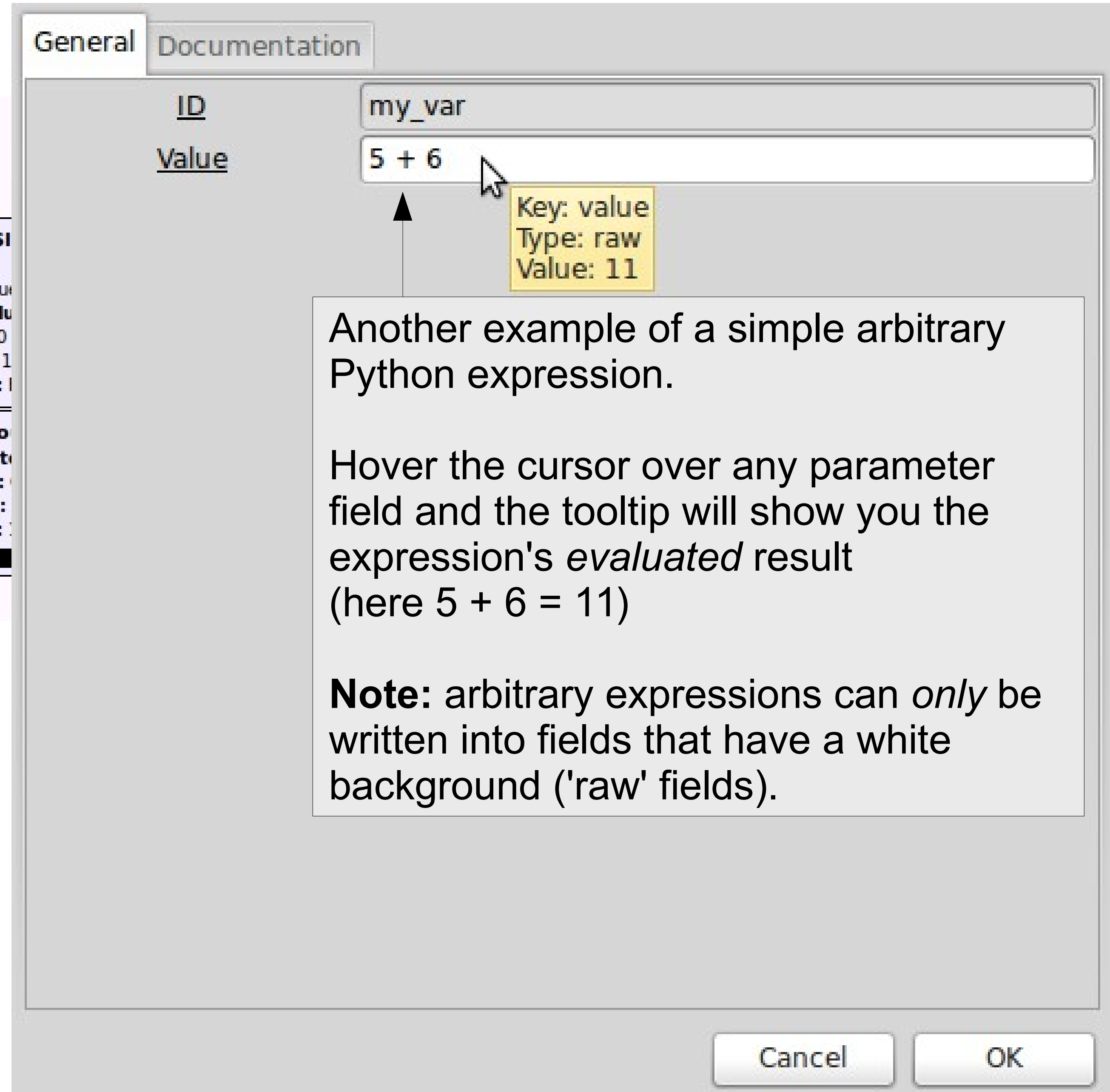

Options
ID: top_block
Generate Options: WX GUI
WX GUI Sl
ID: freq
Label: Frequ
Default Valu
Minimum: 0
Maximum: 1
Converter:
Variable
ID: samp_rate
Value: 32k
(double click)
Sample Rat
Waveform:
Frequency:
Amplitude:
Offset: 0
Variable
ID: my_var
Value: 11
General
Documentation
ID
samp_rate
Value
32000
ID: (Python) variable name
Value: arbitrary Python expression, e.g.
32000 (the default): an integer
32e6: 32000**.0** (floating-point number)
int(32e6): 32000 (integer cast of floating-point number)
Cancel
OK

Lab 1



(double click)

'my_var' is just for show here (it doesn't actually do anything useful in this flowgraph).

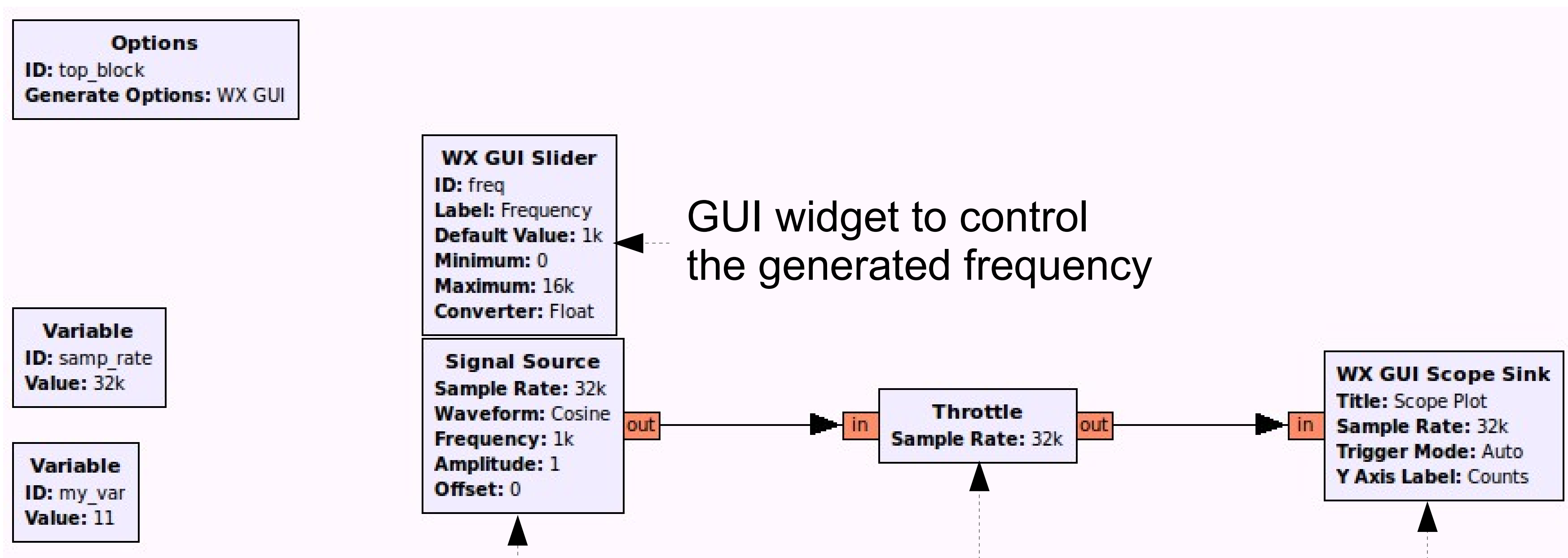


Another example of a simple arbitrary Python expression.

Hover the cursor over any parameter field and the tooltip will show you the expression's *evaluated* result
(here 5 + 6 = 11)

Note: arbitrary expressions can *only* be written into fields that have a white background ('raw' fields).

Lab 1



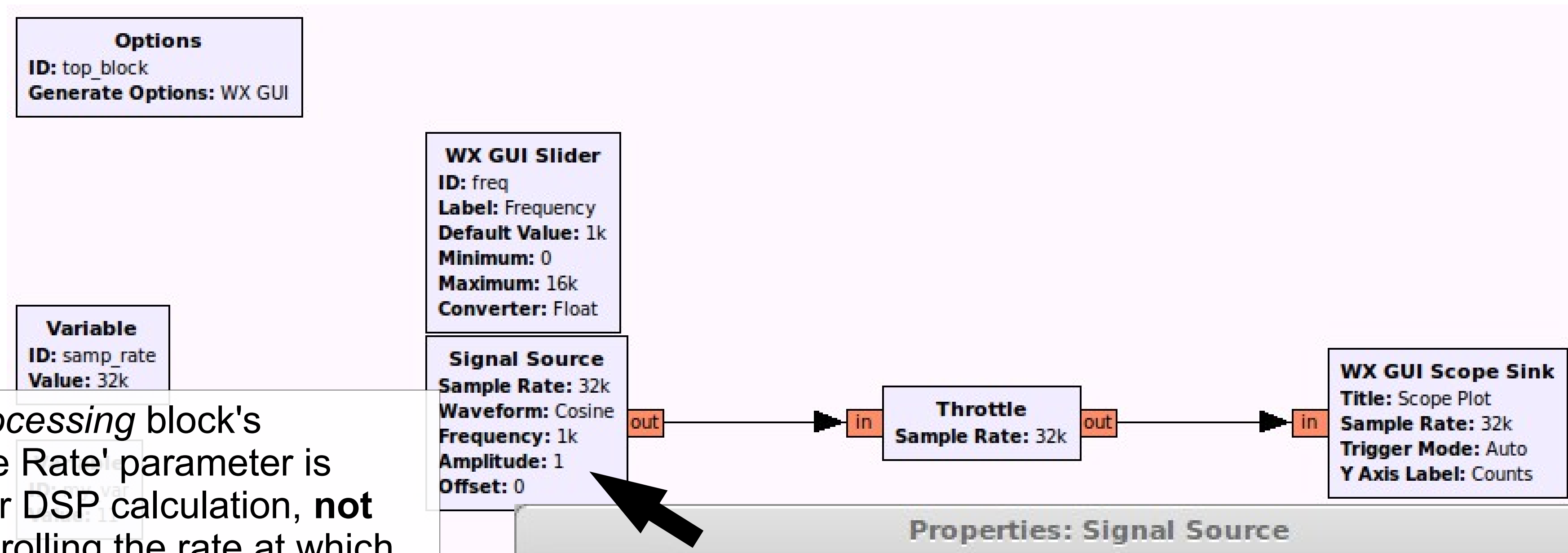
GUI widget to control the generated frequency

Synthesises a sine wave

GUI widget to plot samples in the time-domain

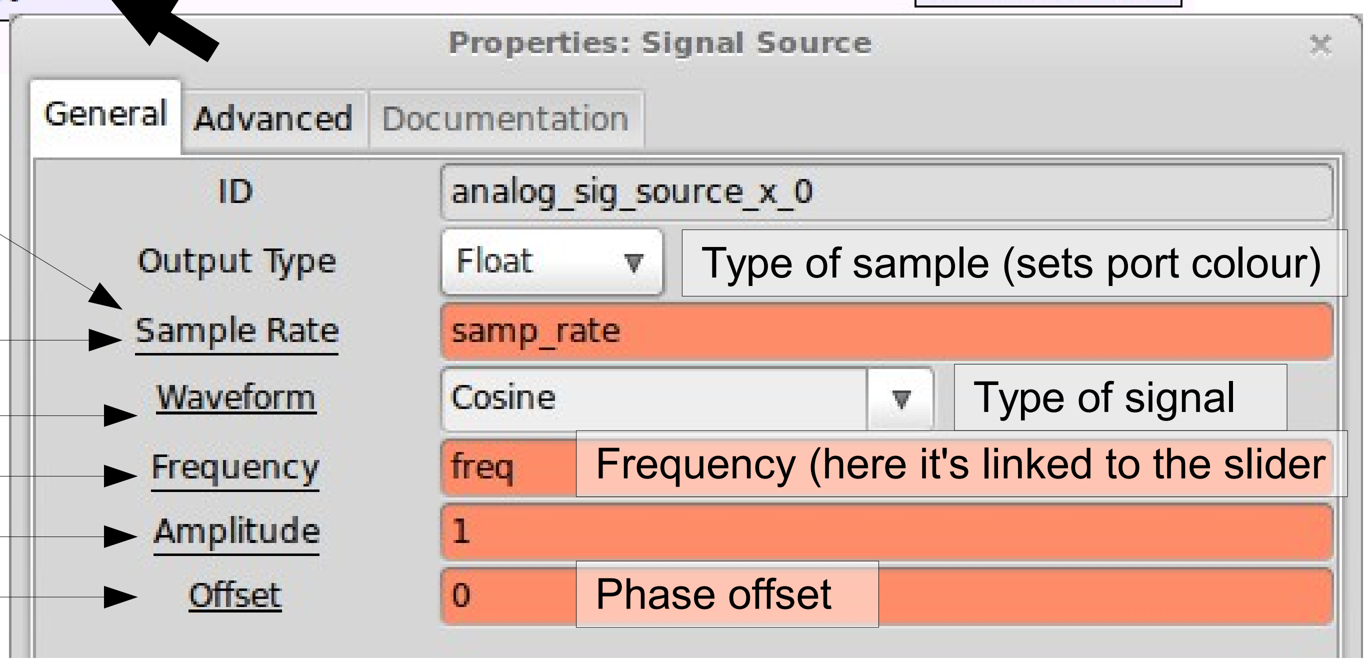
Will throttle the rate at which samples pass through this block (thus setting the rate at which samples pass through the whole flow graph).

Lab 1



Any *processing* block's 'Sample Rate' parameter is used for DSP calculation, **not** for controlling the rate at which samples are produced.
This is distinct from a *hardware* (or Throttle) block where it **is** used to control sample flow.

An underline indicates changing the parameter via any dependent variable will cause the block to trigger an internal callback and update its state (i.e. perform a real-time parameter change)



Sample Rate (DSP)

- If calculating a sine wave where a given frequency *in Hertz* is desired, you actually need to know the sample rate too. This is because the mathematical representation requires both values to calculate the individual sample amplitude at any specific point in time.
- The actual sample rate value used can be anything. It just so happens you'll usually use the same value as in the rest of your flowgraph so that everything will be consistent (operate in the same sample rate domain).

Sample Rate (DSP)

- Think of it as being used to calculate the discrete step size from one sample to the next within a DSP operation (e.g. the time step when calculating the amplitude of the next sample in the sine wave generator)

Sample Rate (Hardware)

- Distinct from mathematical (DSP) calculation, sample rate also refers to the rate at which samples pass through the flowgraph.
- If there is no rate control, hardware clock or throttling mechanism, the samples will be generated, pass through the flowgraph and be consumed as fast as possible (i.e. the flowgraph will be CPU bound).
- This is desirable if you want to perform some fixed DSP on stored data as quickly as possible (e.g. read from a file, resample and write it back).

Sample Rate (Hardware)

- Only a block that represents some underlying hardware with its own clock (e.g. USRP, sound card), or the Throttle Block, will use 'Sample Rate' to set that hardware clock, and therefore have the effect of applying rate control to the samples in the flowgraph.
- A Throttle Block will simply apply host-based timing (against the 'wall clock') to control the rate of the samples it produces (i.e. samples that it makes available on its outputs to downstream blocks).

Sample Rate (Hardware)

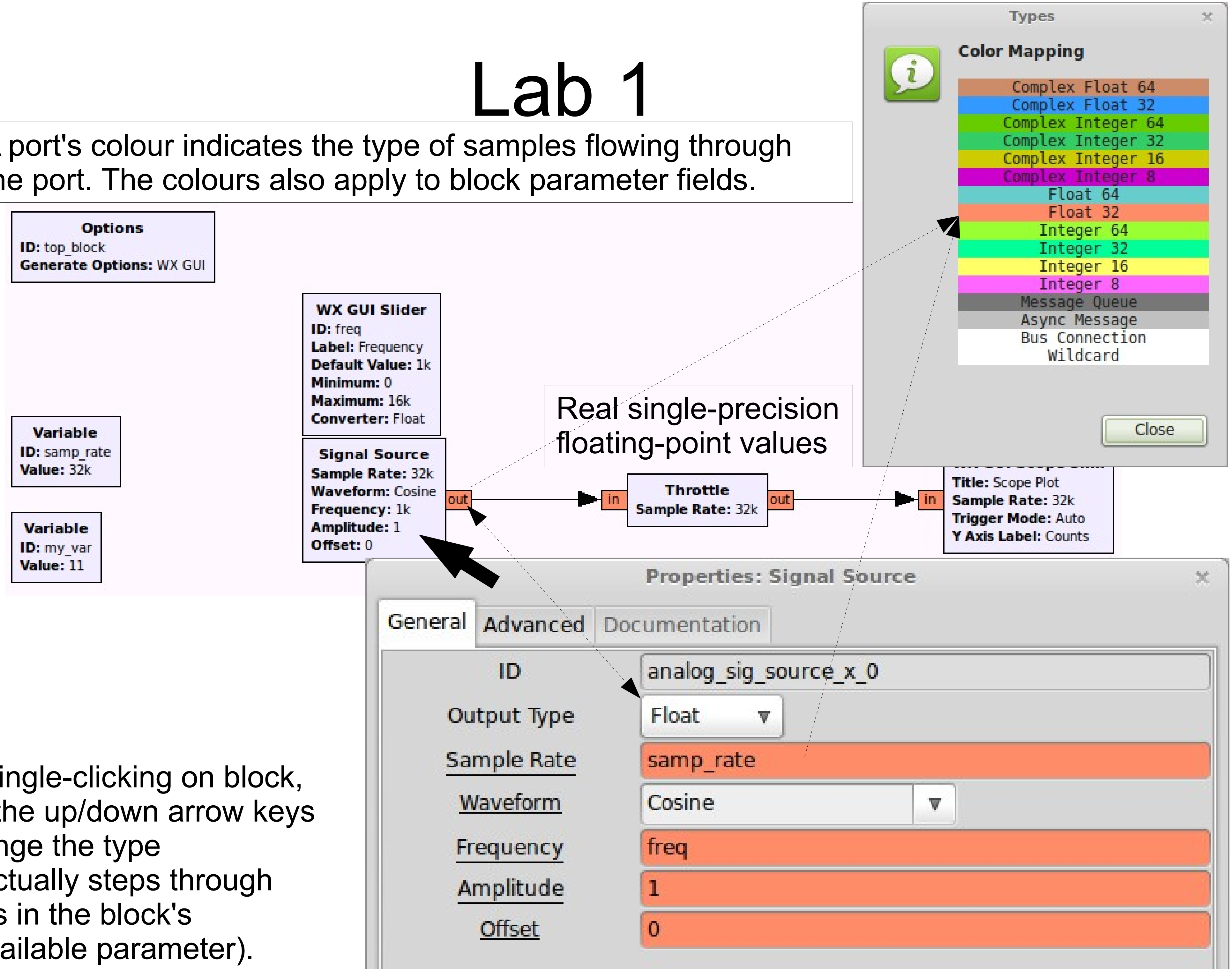
- A hardware Sink block will consume samples at a fixed rate (relative to the wall clock)
- The Throttle Block, or a hardware Sink block, will apply 'back pressure' to the upstream blocks (the rate of work of the upstream blocks will be limited by the throttling effect of this rate-controlling block)
- A hardware Source block will produce samples at a fixed rate (relative to the wall clock)

Sample Rate (Hardware)

- In general, there should only ever be one block in a flowgraph that has the ability to throttle sample flow.
- Otherwise you need to be very careful with multiple, unsynchronised clock sources: they will eventually go out of sync and cause overflows/underruns as their production/consumption rates will differ.
  - This is the 'two clock' problem (discussed later)
  - Work arounds: allow non-blocking I/O, and/or tweak resampling rates to account for the clock offsets

Lab 1

A port's colour indicates the type of samples flowing through the port. The colours also apply to block parameter fields.

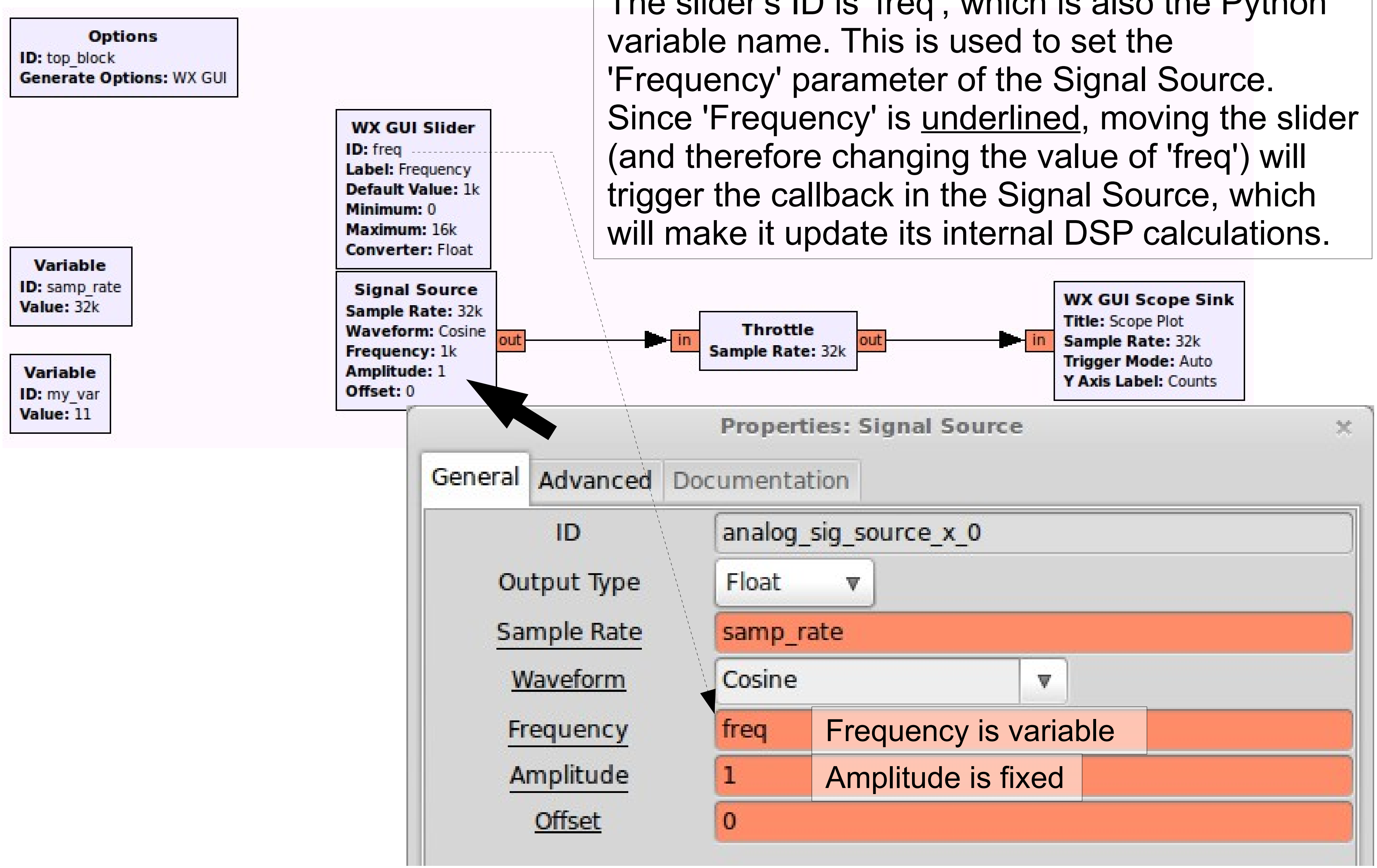


Real single-precision floating-point values

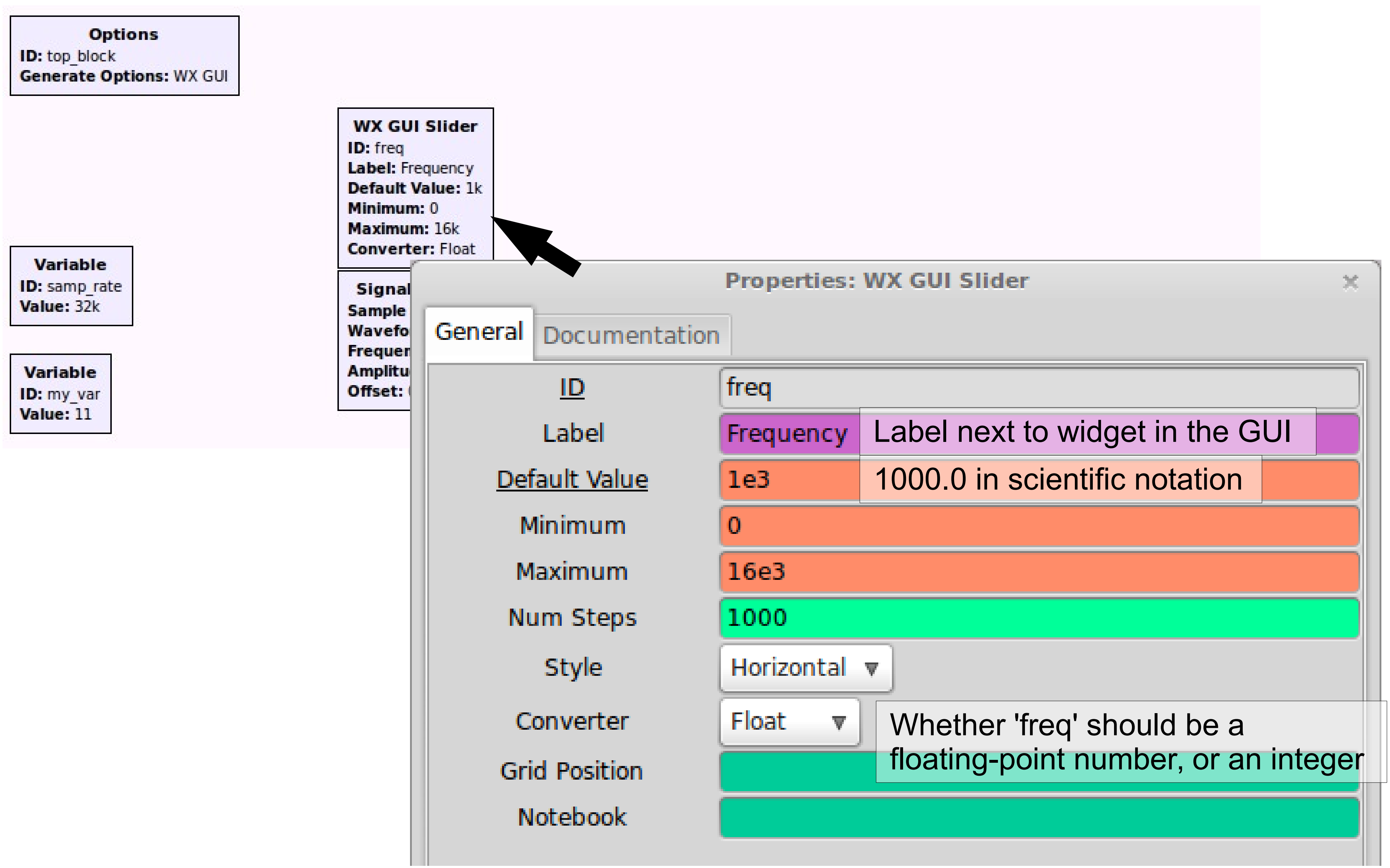
Tip:
After single-clicking on block, press the up/down arrow keys to change the type (this actually steps through options in the block's first available parameter).

Lab 1

The slider's ID is 'freq', which is also the Python variable name. This is used to set the 'Frequency' parameter of the Signal Source. Since 'Frequency' is underlined, moving the slider (and therefore changing the value of 'freq') will trigger the callback in the Signal Source, which will make it update its internal DSP calculations.

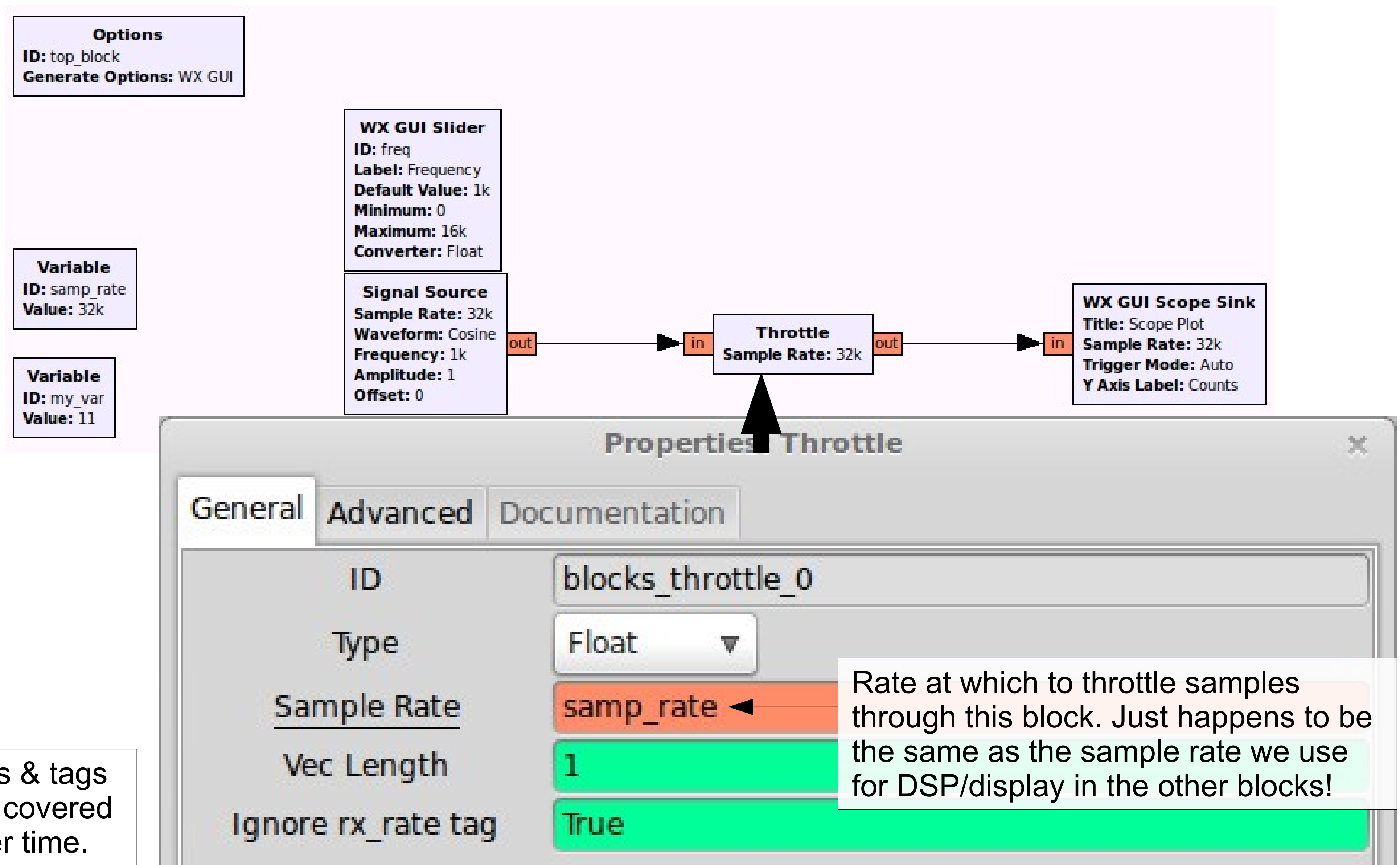


Lab 1



Options
ID: top_block
Generate Options: WX GUI
WX GUI Slider
ID: freq
Label: Frequency
Default Value: 1k
Minimum: 0
Maximum: 16k
Converter: Float
Variable
ID: samp_rate
Value: 32k
Variable
ID: my_var
Value: 11
Properties: WX GUI Slider
General
Documentation
ID
freq
Label
Frequency
Label next to widget in the GUI
Default Value
1e3
1000.0 in scientific notation
Minimum
0
Maximum
16e3
Num Steps
1000
Style
Horizontal
Converter
Float
Whether 'freq' should be a floating-point number, or an integer
Grid Position
Notebook

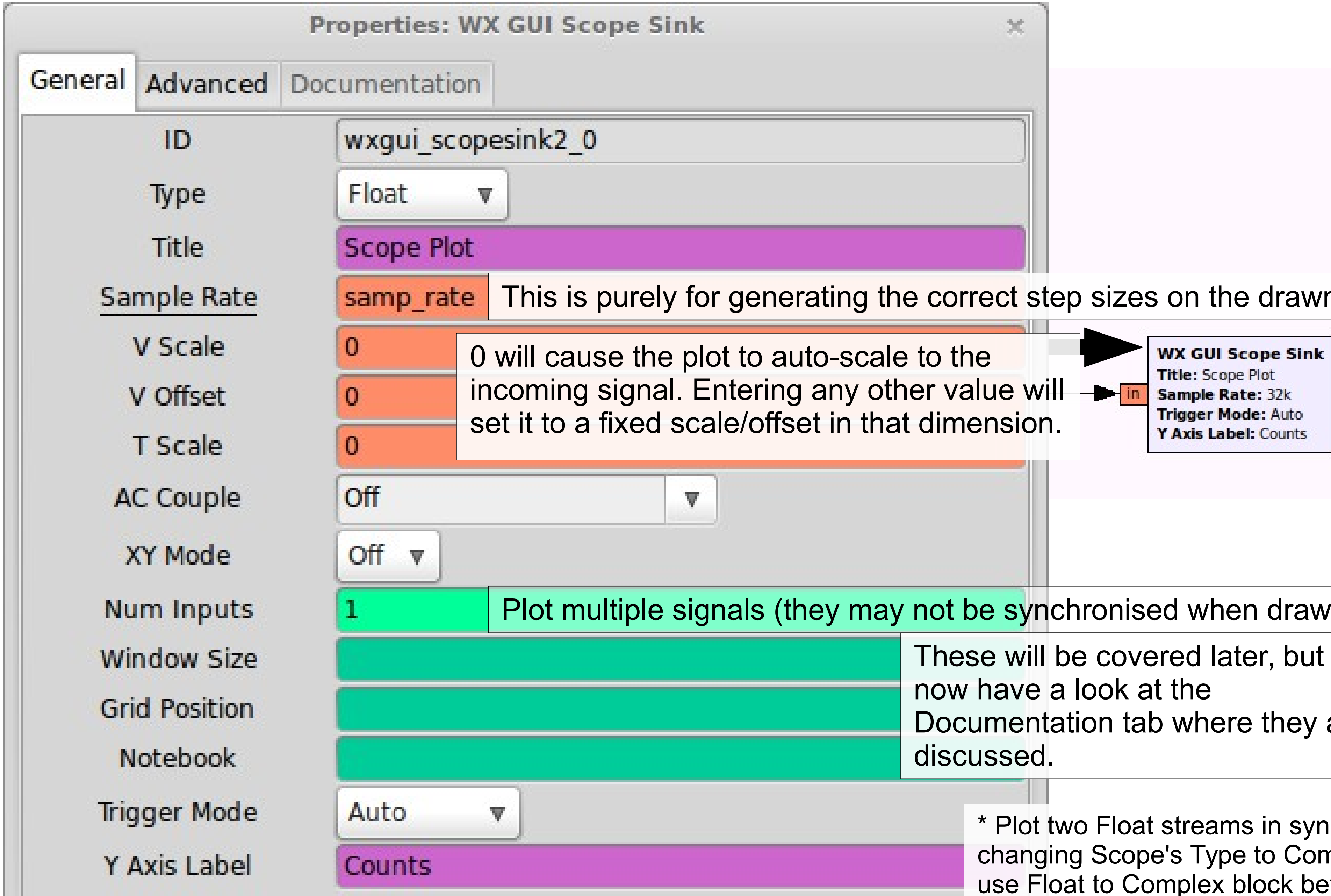
Lab 1



Rate at which to throttle samples through this block. Just happens to be the same as the sample rate we use for DSP/display in the other blocks!

Vectors & tags will be covered another time.

Lab 1



This is purely for generating the correct step sizes on the drawn X-axis!

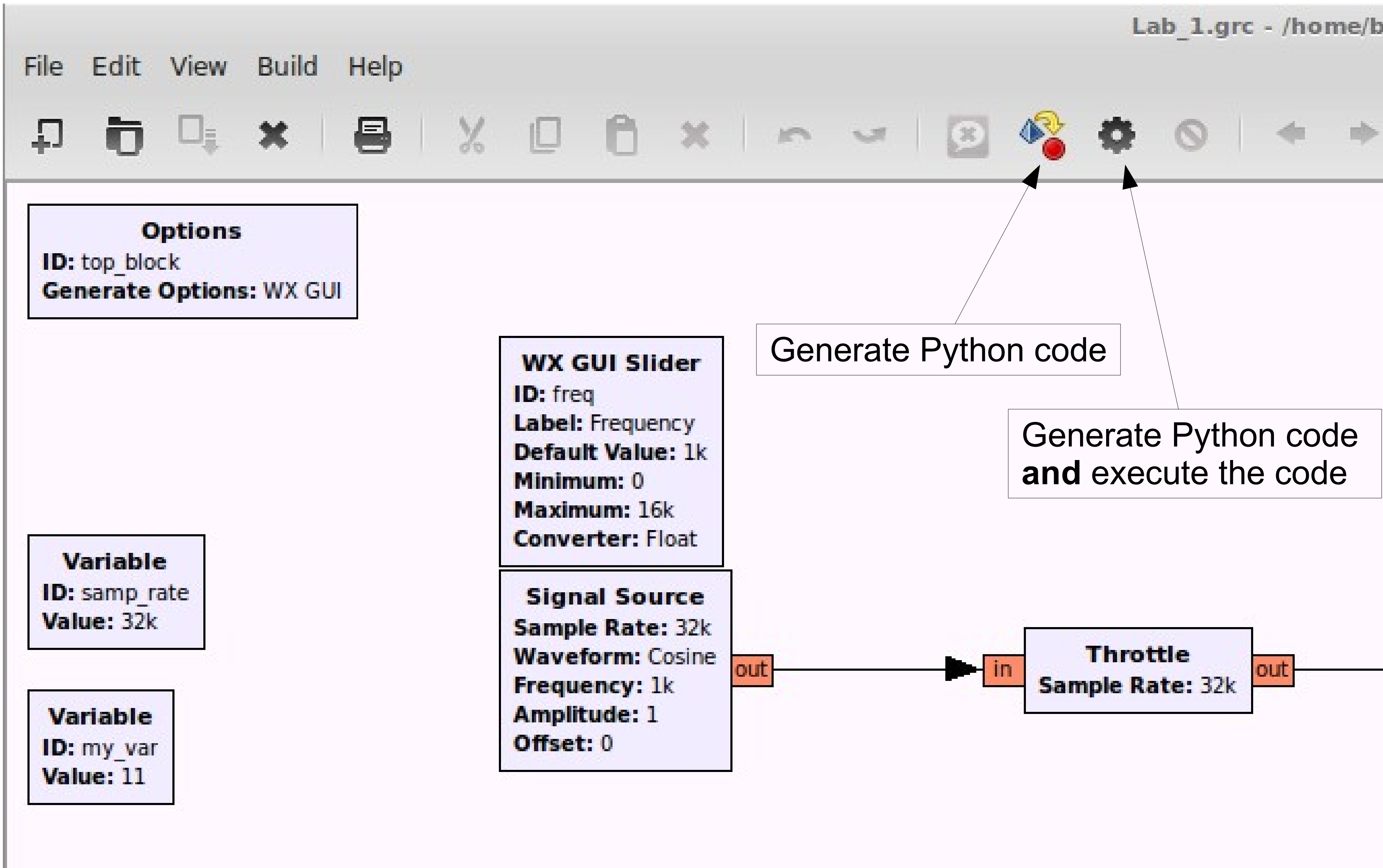
0 will cause the plot to auto-scale to the incoming signal. Entering any other value will set it to a fixed scale/offset in that dimension.

Plot multiple signals (they may not be synchronised when drawn*!)

These will be covered later, but for now have a look at the Documentation tab where they are discussed.

* Plot two Float streams in sync by changing Scope's Type to Complex, and use Float to Complex block beforehand.

Lab 1



Lab_1.grc - /home/ba
File Edit View Build Help
Options
ID: top_block
Generate Options: WX GUI
WX GUI Slider
ID: freq
Label: Frequency
Default Value: 1k
Minimum: 0
Maximum: 16k
Converter: Float
Generate Python code
Generate Python code and execute the code
Variable
ID: samp_rate
Value: 32k
Signal Source
Sample Rate: 32k
Waveform: Cosine
Frequency: 1k
Amplitude: 1
Offset: 0
out
in
Throttle
Sample Rate: 32k
out
Variable
ID: my_var
Value: 11

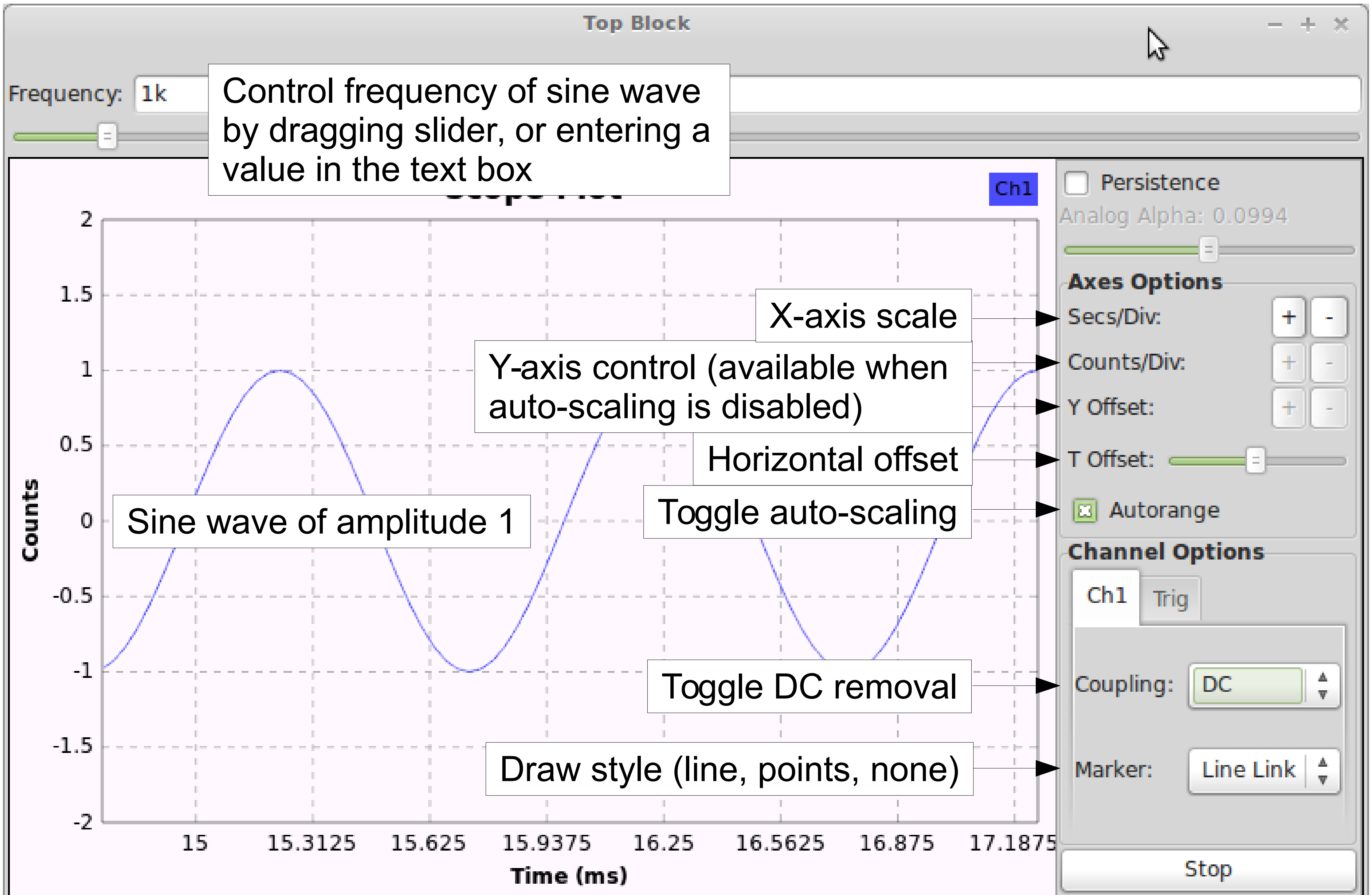
Lab 1

Python code generated by GRC

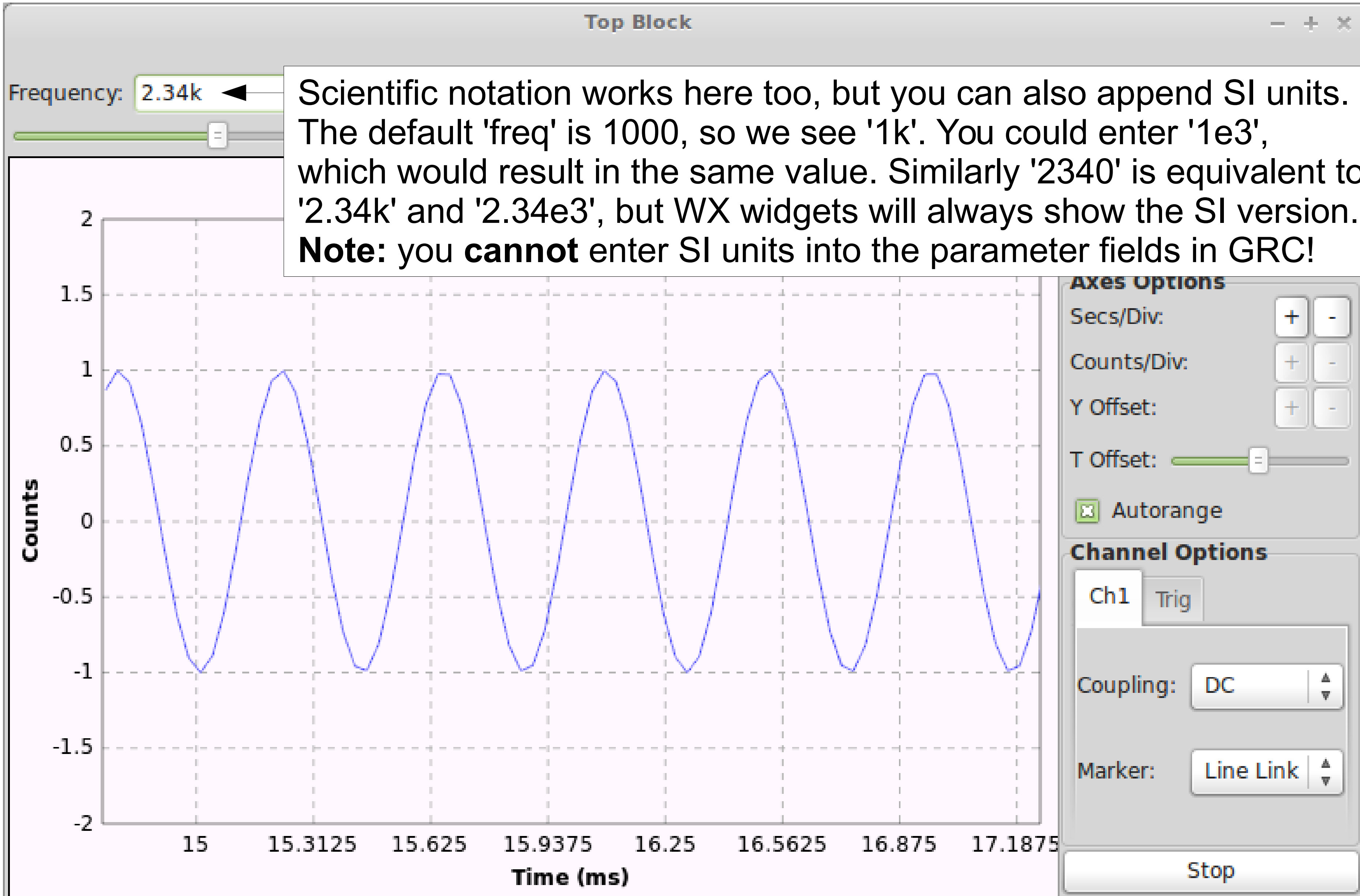
```
#!/usr/bin/env python
##################################################
# Gnuradio Python Flow Graph
# Title: Top Block
# Generated: Wed Apr 16 14:11:52 2014
##################################################

from gnuradio import analog
from gnuradio import blocks
from gnuradio import eng_notation
from gnuradio import gr
from gnuradio import wxgui
from gnuradio.eng_option import eng_option
from gnuradio.filter import firdes
from gnuradio.wxgui import forms
from gnuradio.wxgui import scopesink2
from grc_gnuradio import wxgui as grc_wxgui
from optparse import OptionParser
import wx

class top_block(grc_wxgui.top_block_gui):

    def __init__(self):
        grc_wxgui.top_block_gui.__init__(self, title="Top Bloc

        ##################################################
        # Variables
        ##################################################
        self.samp_rate = samp_rate = 32000
        self.my_var = my_var = 5 + 6
        self.freq = freq = 1e3

        ##################################################
        # Blocks
        ##################################################
        _freq_sizer = wx.BoxSizer(wx.VERTICAL)
        self._freq_text_box = forms.text_box(
            parent=self.GetWin(),
            sizer=_freq_sizer,
            value=self.freq,
            callback=self.set_freq,
            label="Frequency",
            converter=forms.float_converter(),
            proportion=0,
        )
        self._freq_slider = forms.slider(
            parent=self.GetWin(),
            sizer=_freq_sizer,
            value=self.freq,
            callback=self.set_freq,
            minimum=0,
            maximum=16e3,
            num_steps=1000,
            style=wx.SL_HORIZONTAL,
            cast=float,
```

```
            trig_mode=wxgui.TRIG_MODE_AUTO,
            y_axis_label="Counts",
        )
        self.Add(self.wxgui_scopesink2_0.win)
        self.blocks_throttle_0 = blocks.throttle(gr.sizeof_float*1, samp_rate,True)
        self.analog_sig_source_x_0 = analog.sig_source_f(samp_rate, analog.GR_COS_WAVE, freq, 1, 0)

        ##################################################
        # Connections
        ##################################################
        self.connect((self.analog_sig_source_x_0, 0), (self.blocks_throttle_0, 0))
        self.connect((self.blocks_throttle_0, 0), (self.wxgui_scopesink2_0, 0))


# QT sink close method reimplementation

    def get_samp_rate(self):
        return self.samp_rate

    def set_samp_rate(self, samp_rate):
        self.samp_rate = samp_rate
        self.analog_sig_source_x_0.set_sampling_freq(self.samp_rate)
        self.wxgui_scopesink2_0.set_sample_rate(self.samp_rate)
        self.blocks_throttle_0.set_sample_rate(self.samp_rate)

    def get_my_var(self):
        return self.my_var

    def set_my_var(self, my_var):
        self.my_var = my_var

    def get_freq(self):
        return self.freq

    def set_freq(self, freq):
        self.freq = freq
        self.analog_sig_source_x_0.set_frequency(self.freq)
        self._freq_slider.set_value(self.freq)
        self._freq_text_box.set_value(self.freq)

if __name__ == '__main__':
    import ctypes
    import sys
    if sys.platform.startswith('linux'):
        try:
            x11 = ctypes.cdll.LoadLibrary('libX11.so')
            x11.XInitThreads()
        except:
            print "Warning: failed to XInitThreads()"
    parser = OptionParser(option_class=eng_option, usage="%prog: [options]")
    (options, args) = parser.parse_args()
    tb = top_block()
    tb.Start(True)
    tb.Wait()
```

Lab 1

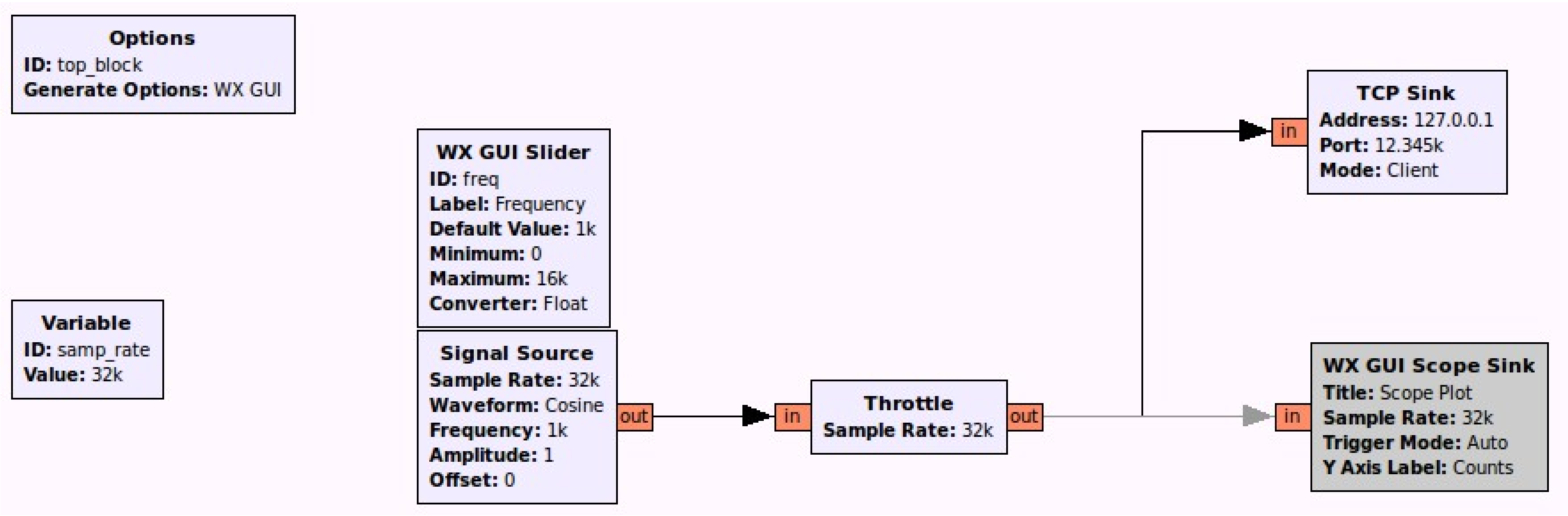

Top Block
Frequency:
1k
Control frequency of sine wave by dragging slider, or entering a value in the text box
Ch1
Persistence
Analog Alpha: 0.0994
Axes Options
X-axis scale
Secs/Div:
Y-axis control (available when auto-scaling is disabled)
Counts/Div:
Y Offset:
Horizontal offset
T Offset:
Toggle auto-scaling
Autorange
Sine wave of amplitude 1
Channel Options
Ch1
Trig
Toggle DC removal
Coupling:
DC
Draw style (line, points, none)
Marker:
Line Link
Stop
Counts
Time (ms)
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
15
15.3125
15.625
15.9375
16.25
16.5625
16.875
17.1875

Lab 1



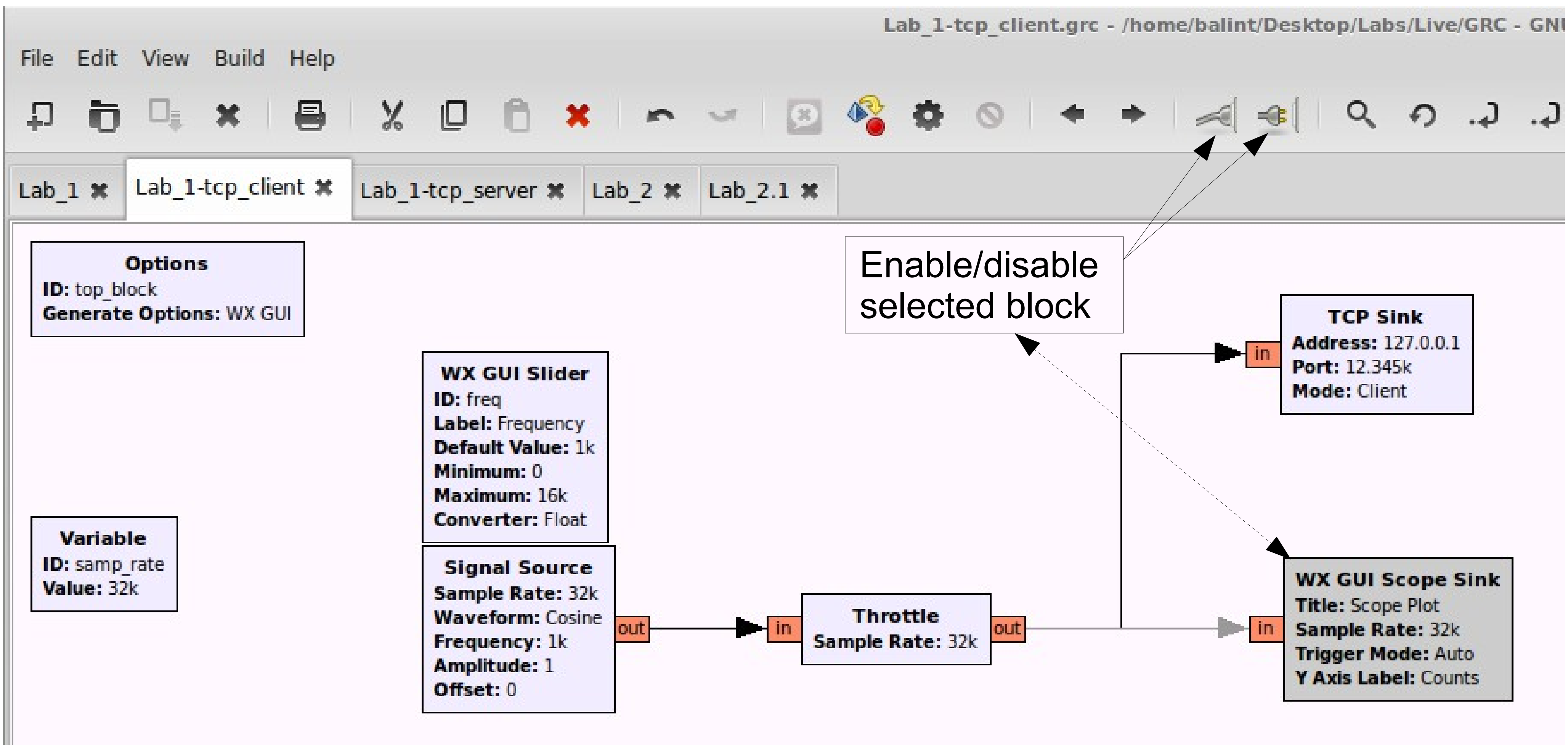
Scientific notation works here too, but you can also append SI units. The default 'freq' is 1000, so we see '1k'. You could enter '1e3', which would result in the same value. Similarly '2340' is equivalent to '2.34k' and '2.34e3', but WX widgets will always show the SI version. **Note:** you **cannot** enter SI units into the parameter fields in GRC!

Lab 1: TCP Client (producer)

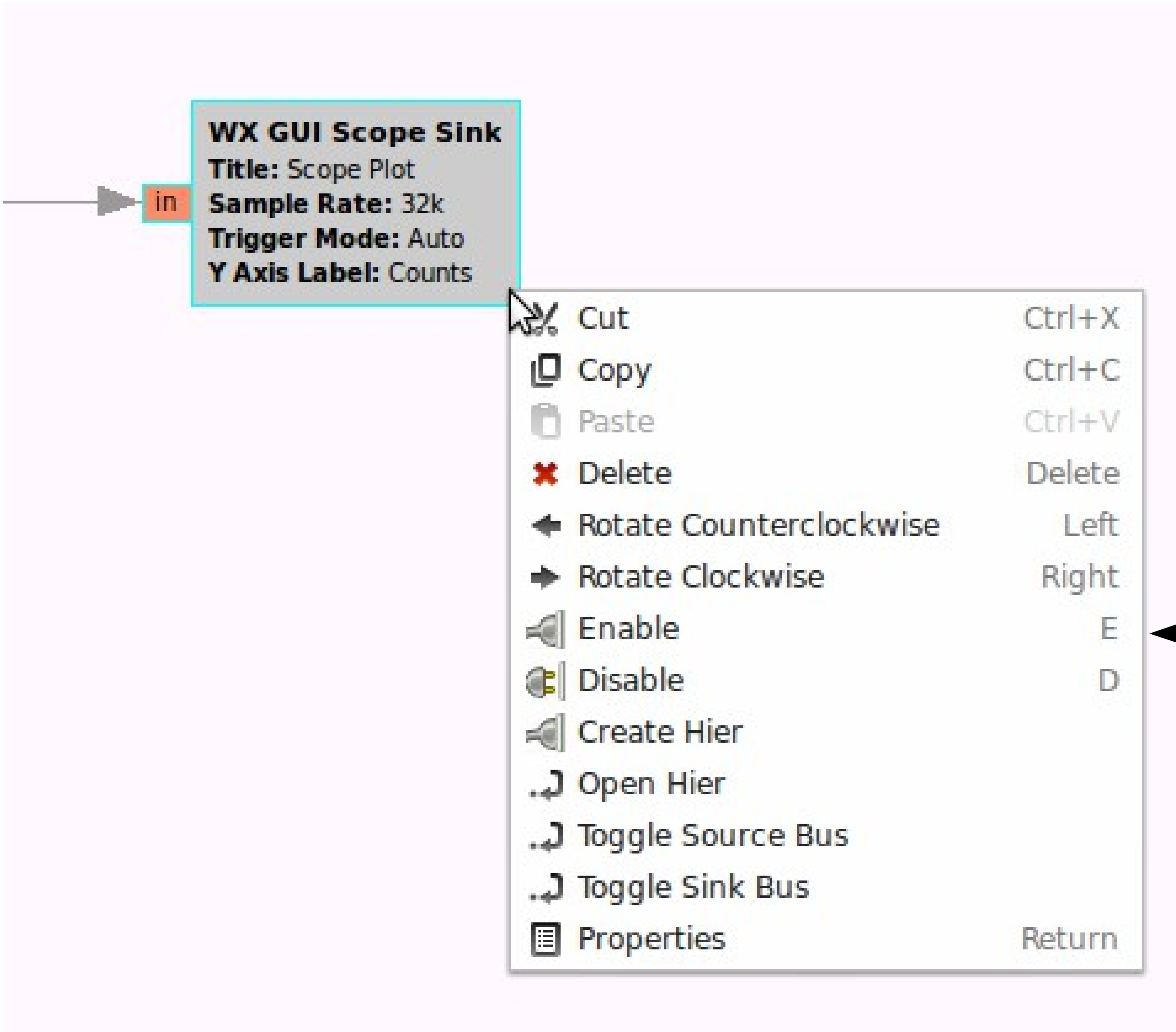


Create a sine wave & transmit generated samples over a TCP connection

Lab 1: TCP Client (producer)

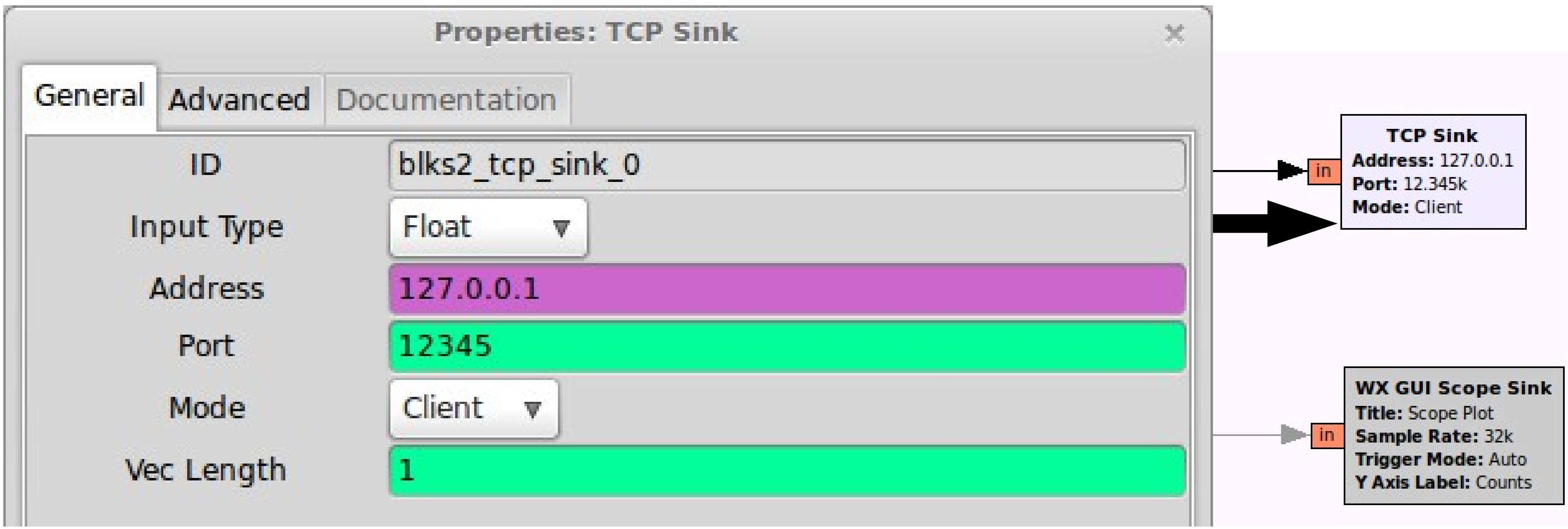


Lab 1: TCP Client (producer)



Tip:
Make note of the keyboard shortcuts in the block context menu.

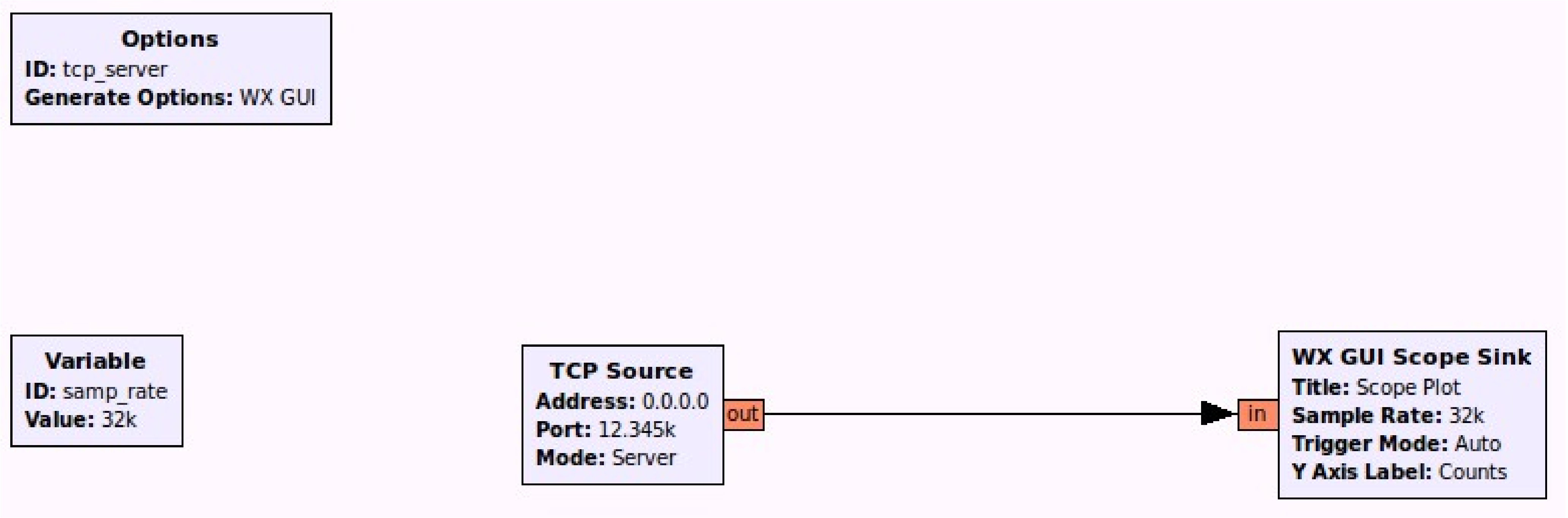
Lab 1: TCP Client (producer)



Tip:
The flowgraph will not start unless a TCP connection is established. If the TCP connection fails, a Python exception will be thrown and program will not start.

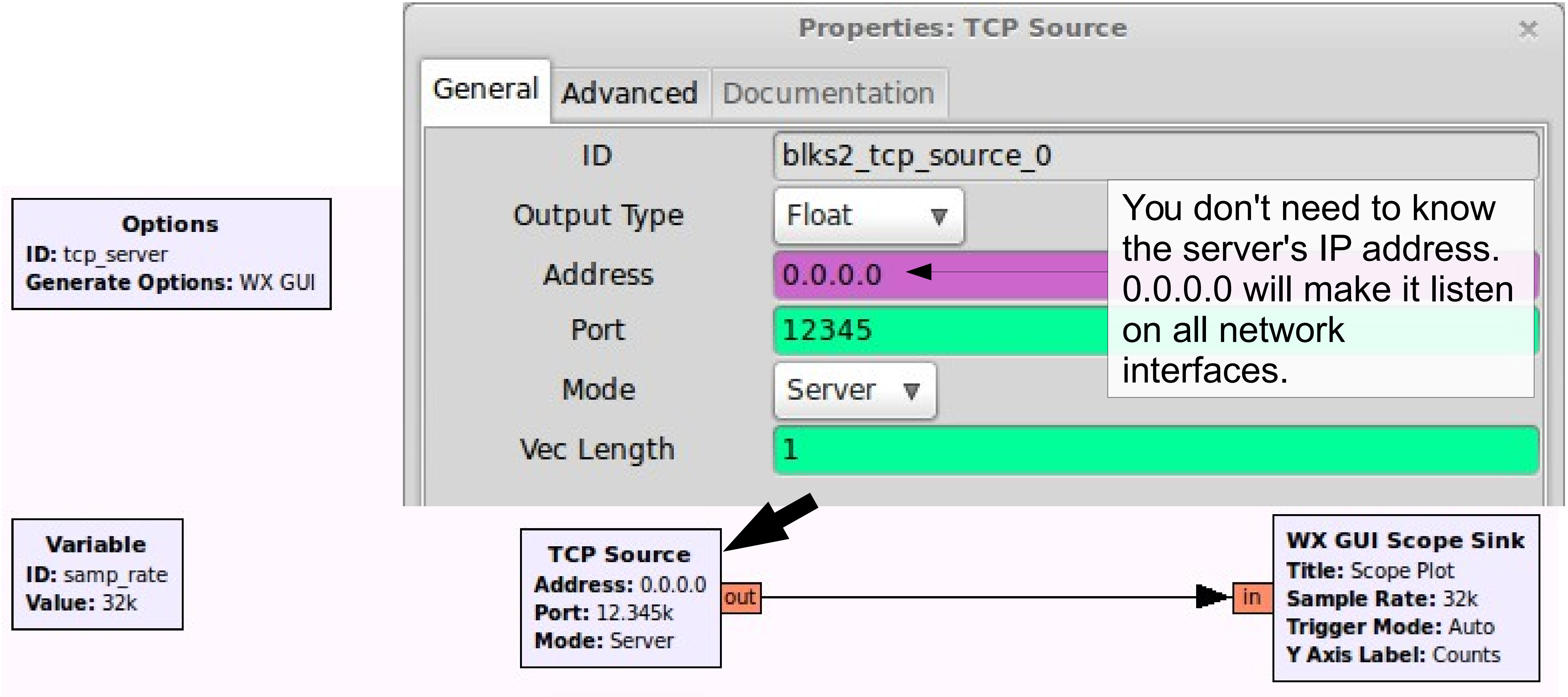
* The current TCP Source/Sink implementation does not work on Windows

Lab 1: TCP Server (consumer)



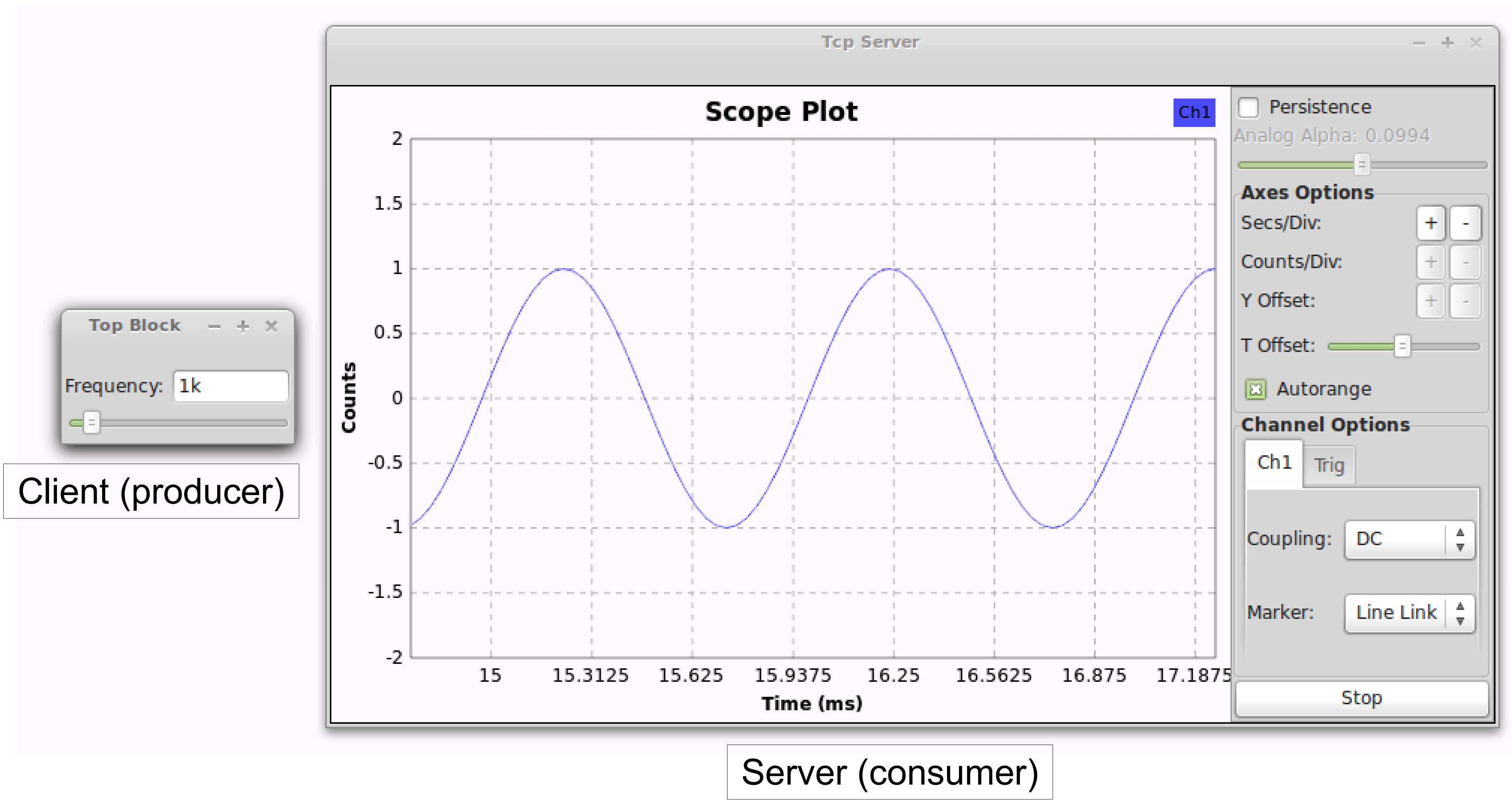
Receive samples from an incoming TCP connection and plot on a Scope Sink

Lab 1: TCP Server (consumer)



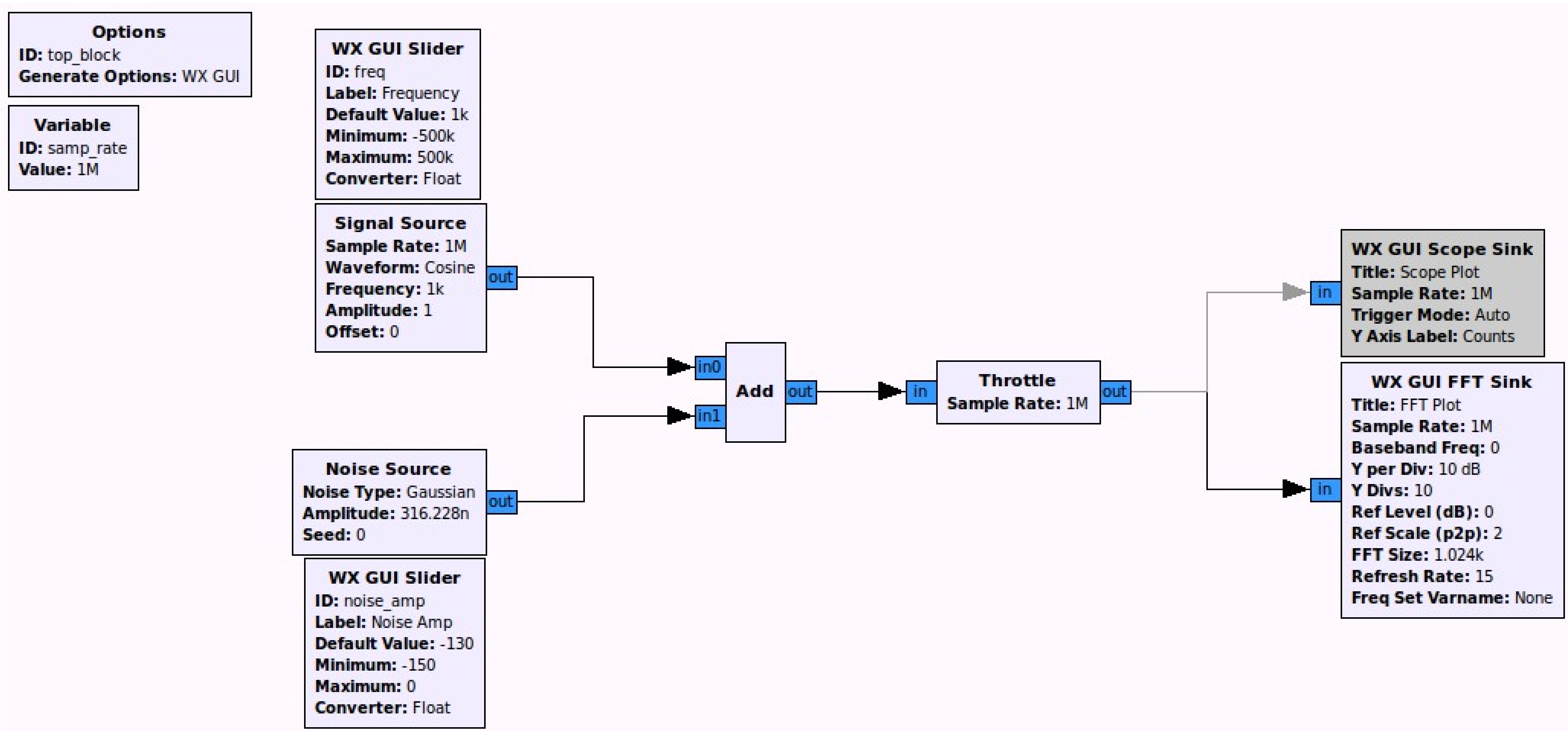
Tip:
The flowgraph will not start until a TCP connection is accepted.
In this case the GUI will not appear until the client has connected.

Lab 1: TCP Server & Client



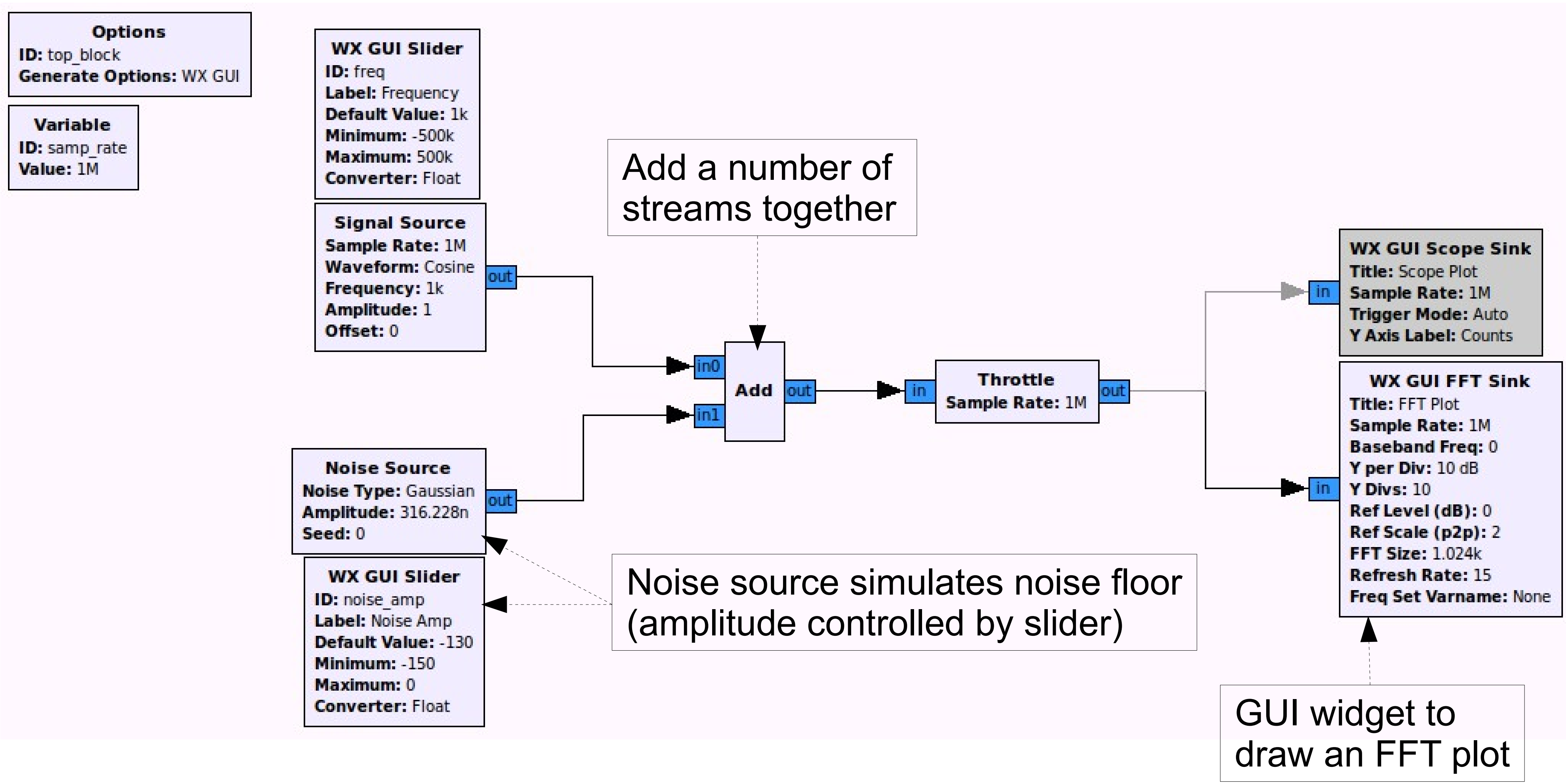
Tip: you can run each application separately on two network-connected machines.
Just change the client's destination IP address to the machine on which the server is running.

Lab 2

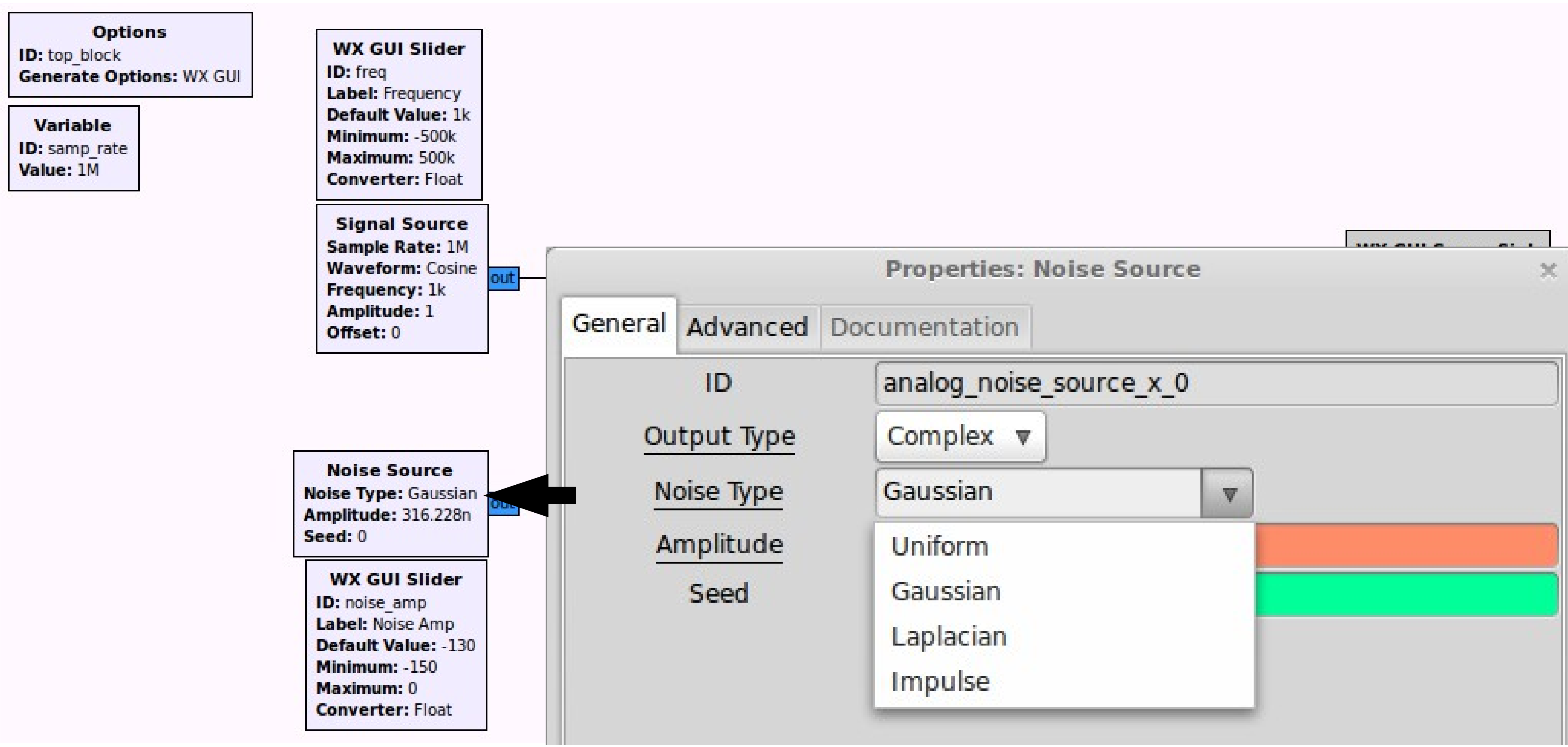


Generate a sine wave & some noise, add both, and plot the resulting signal in the frequency domain.

Lab 2

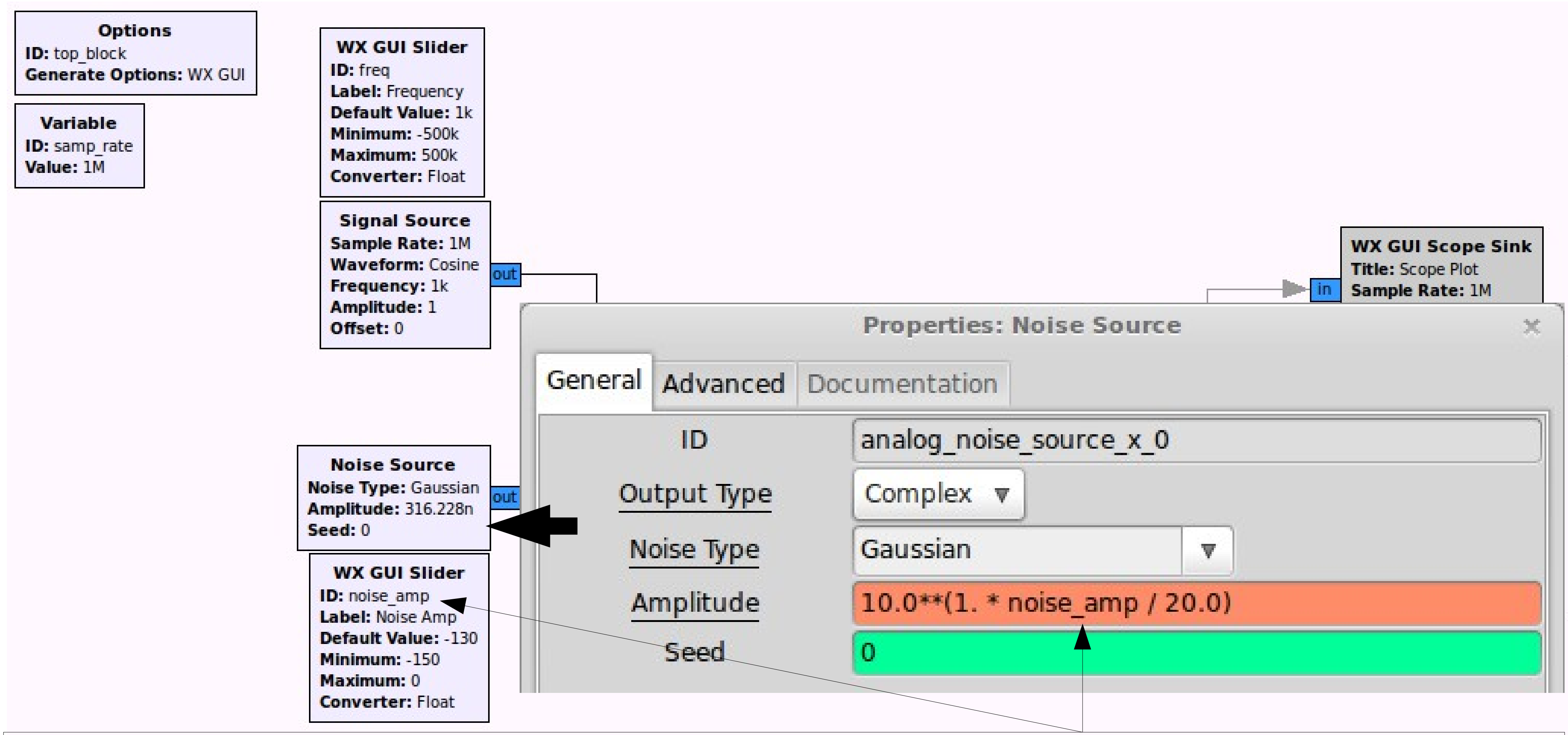

Options
ID: top_block
Generate Options: WX GUI
Variable
ID: samp_rate
Value: 1M
WX GUI Slider
ID: freq
Label: Frequency
Default Value: 1k
Minimum: -500k
Maximum: 500k
Converter: Float
Signal Source
Sample Rate: 1M
Waveform: Cosine
Frequency: 1k
Amplitude: 1
Offset: 0
out
Add a number of streams together
in0
in1
Add
out
in
Throttle
Sample Rate: 1M
out
WX GUI Scope Sink
Title: Scope Plot
Sample Rate: 1M
Trigger Mode: Auto
Y Axis Label: Counts
in
WX GUI FFT Sink
Title: FFT Plot
Sample Rate: 1M
Baseband Freq: 0
Y per Div: 10 dB
Y Divs: 10
Ref Level (dB): 0
Ref Scale (p2p): 2
FFT Size: 1.024k
Refresh Rate: 15
Freq Set Varname: None
in
Noise Source
Noise Type: Gaussian
Amplitude: 316.228n
Seed: 0
out
WX GUI Slider
ID: noise_amp
Label: Noise Amp
Default Value: -130
Minimum: -150
Maximum: 0
Converter: Float
Noise source simulates noise floor (amplitude controlled by slider)
GUI widget to draw an FFT plot

Lab 2



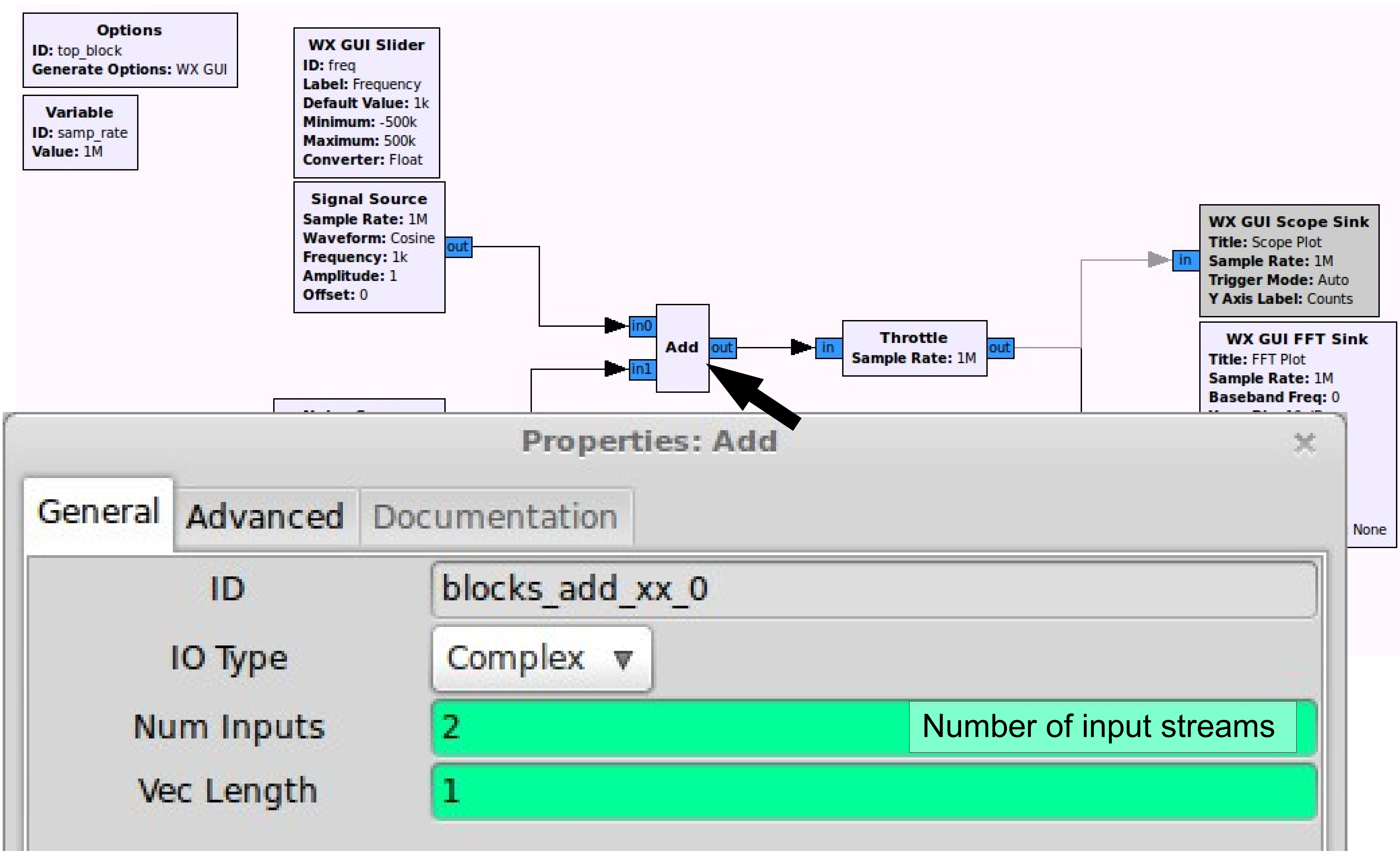
Options
ID: top_block
Generate Options: WX GUI
Variable
ID: samp_rate
Value: 1M
WX GUI Slider
ID: freq
Label: Frequency
Default Value: 1k
Minimum: -500k
Maximum: 500k
Converter: Float
Signal Source
Sample Rate: 1M
Waveform: Cosine
Frequency: 1k
Amplitude: 1
Offset: 0
out
Noise Source
Noise Type: Gaussian
Amplitude: 316.228n
Seed: 0
WX GUI Slider
ID: noise_amp
Label: Noise Amp
Default Value: -130
Minimum: -150
Maximum: 0
Converter: Float
Properties: Noise Source
General
Advanced
Documentation
ID
analog_noise_source_x_0
Output Type
Complex
Noise Type
Gaussian
Amplitude
Seed
Uniform
Gaussian
Laplacian
Impulse

Lab 2

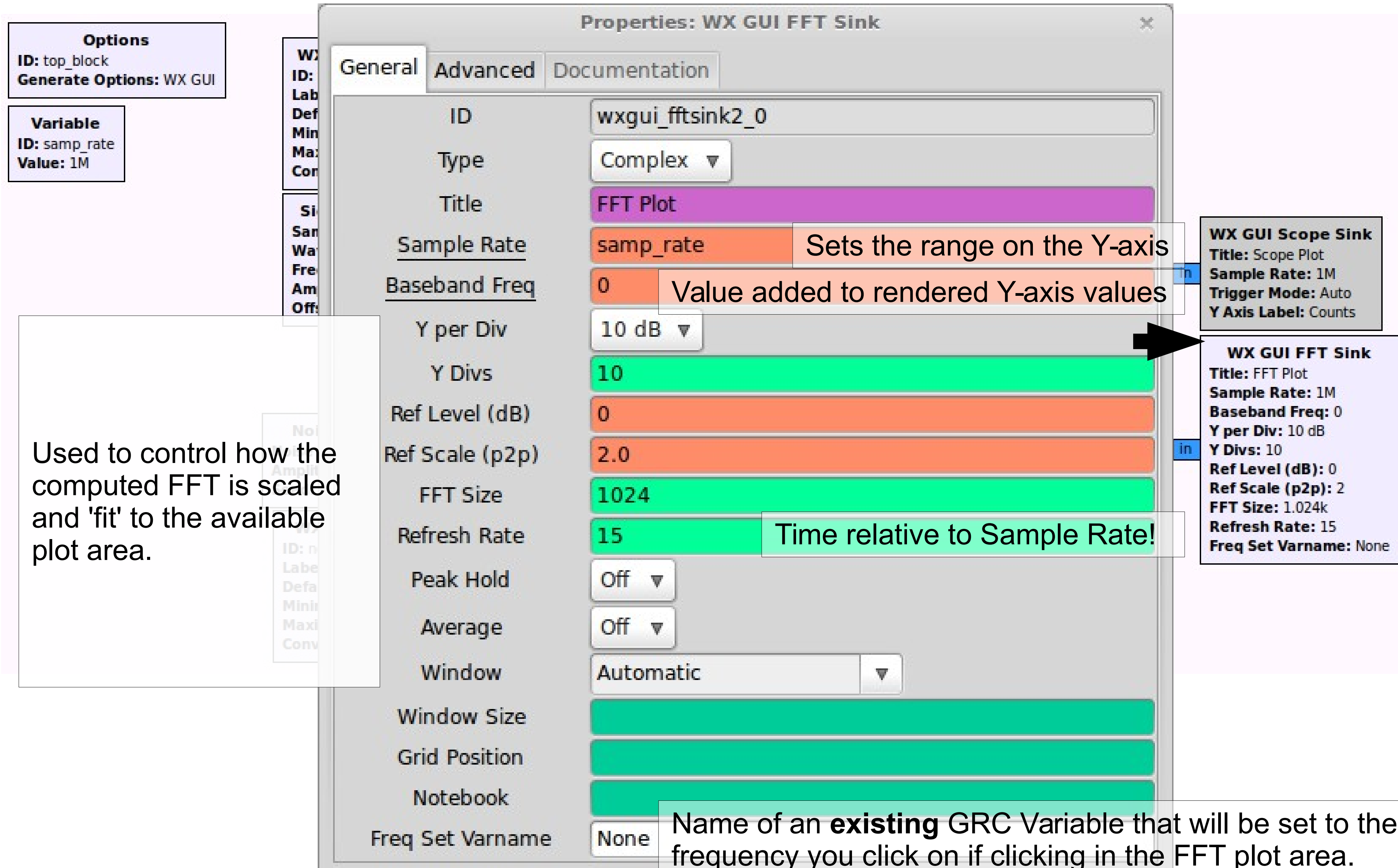


'noise_amp' is the slider value, which (here) we interpret in dB, as opposed to a linear sample ampltitude value (e.g. '1.0').
Therefore we need to convert the value in dB to an actual linear ampltiude value ('volts') for use by the block (i.e. reverse the 'log10' function). The decimal points are added to force Python to compute with floating-point values (otherwise it would round and produce integers).

Lab 2


Options
ID: top_block
Generate Options: WX GUI
Variable
ID: samp_rate
Value: 1M
WX GUI Slider
ID: freq
Label: Frequency
Default Value: 1k
Minimum: -500k
Maximum: 500k
Converter: Float
Signal Source
Sample Rate: 1M
Waveform: Cosine
Frequency: 1k
Amplitude: 1
Offset: 0
out
in0
in1
Add
out
in
Throttle
Sample Rate: 1M
out
in
WX GUI Scope Sink
Title: Scope Plot
Sample Rate: 1M
Trigger Mode: Auto
Y Axis Label: Counts
WX GUI FFT Sink
Title: FFT Plot
Sample Rate: 1M
Baseband Freq: 0
None
Properties: Add
General
Advanced
Documentation
ID
blocks_add_xx_0
IO Type
Complex
Num Inputs
2
Number of input streams
Vec Length
1

Lab 2



Sets the range on the Y-axis

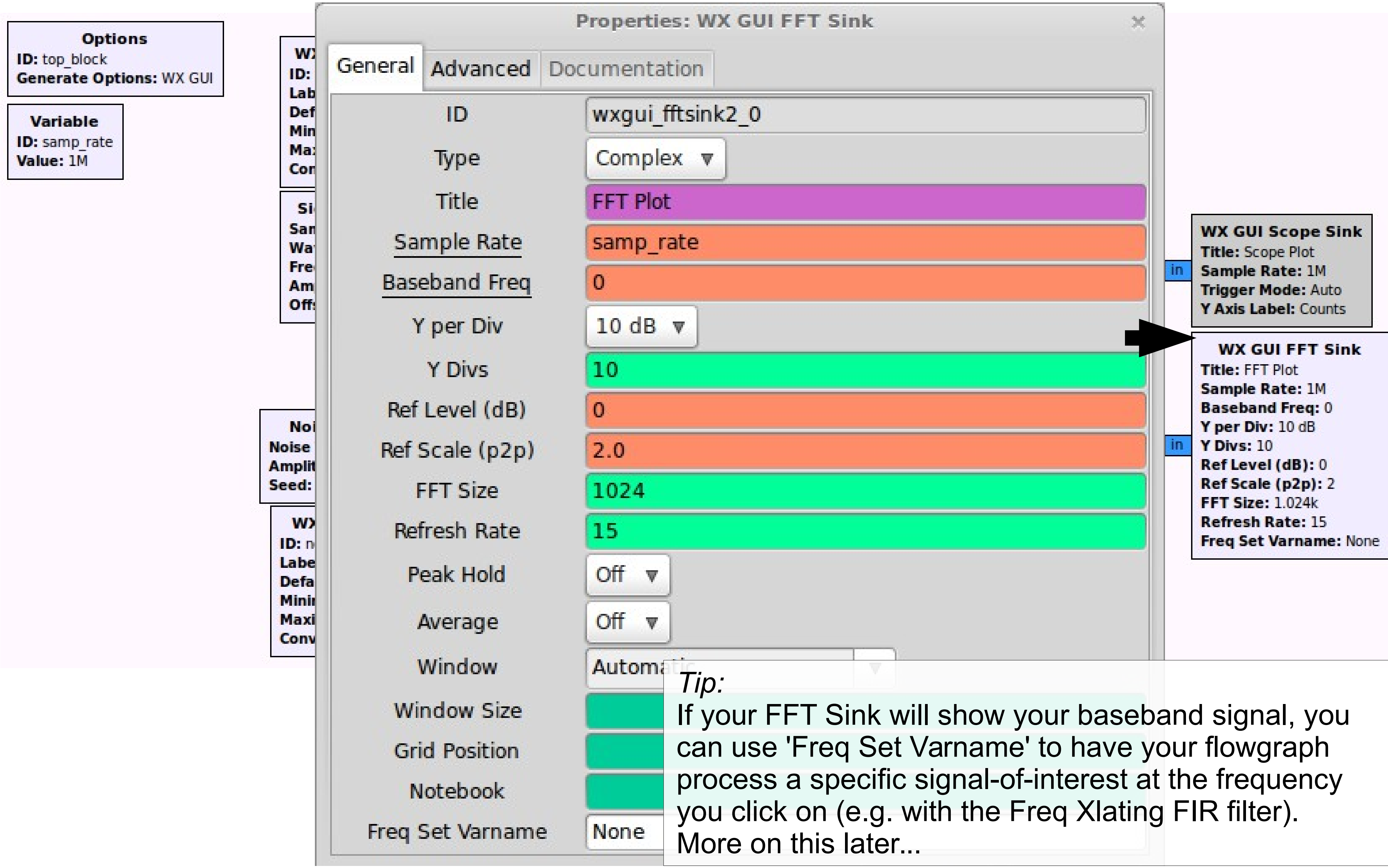
Value added to rendered Y-axis values

Used to control how the computed FFT is scaled and 'fit' to the available plot area.

Time relative to Sample Rate!

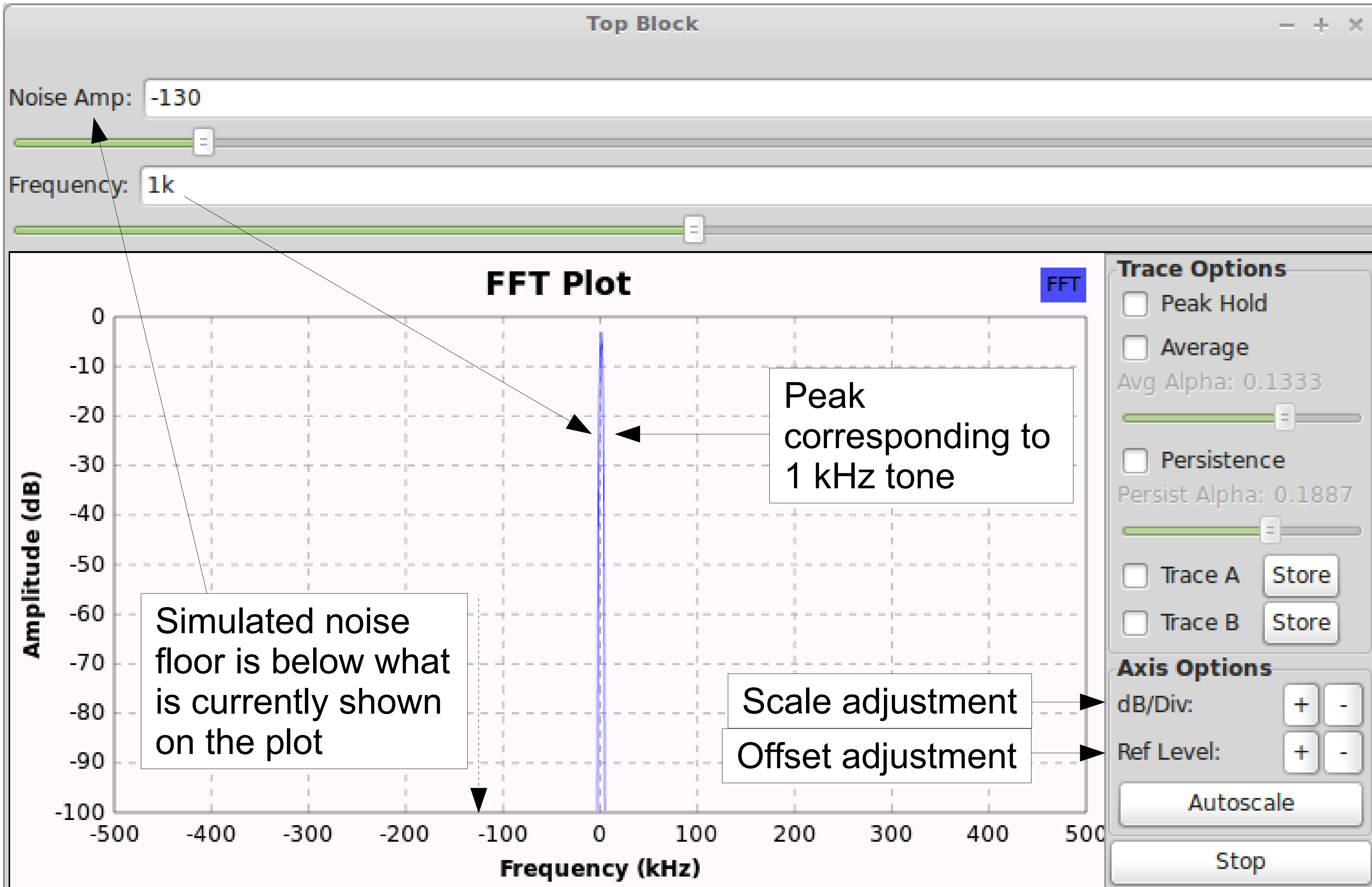
Name of an **existing** GRC Variable that will be set to the frequency you click on if clicking in the FFT plot area.

Lab 2



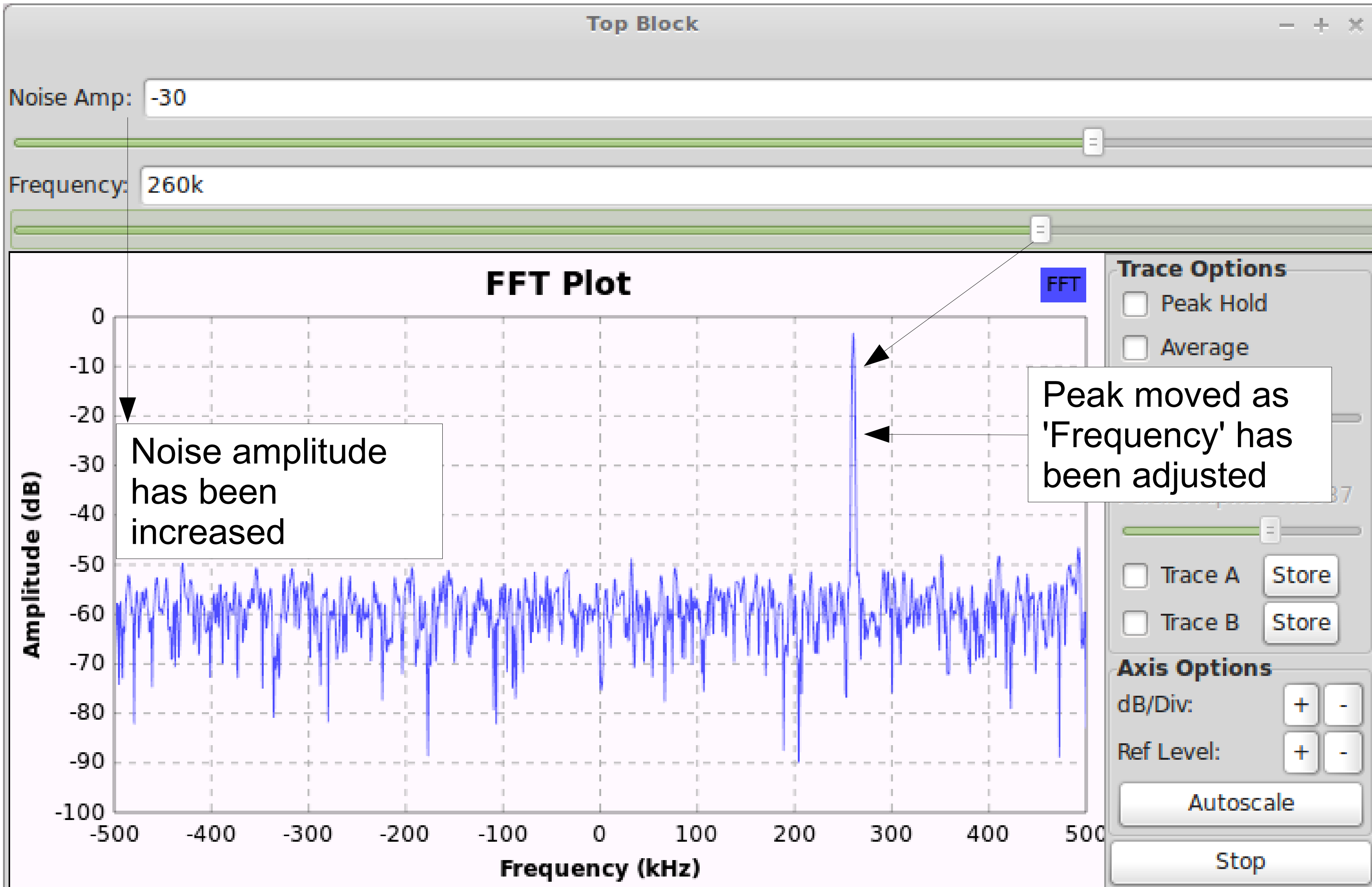
Tip:
If your FFT Sink will show your baseband signal, you can use 'Freq Set Varname' to have your flowgraph process a specific signal-of-interest at the frequency you click on (e.g. with the Freq Xlating FIR filter). More on this later...

Lab 2



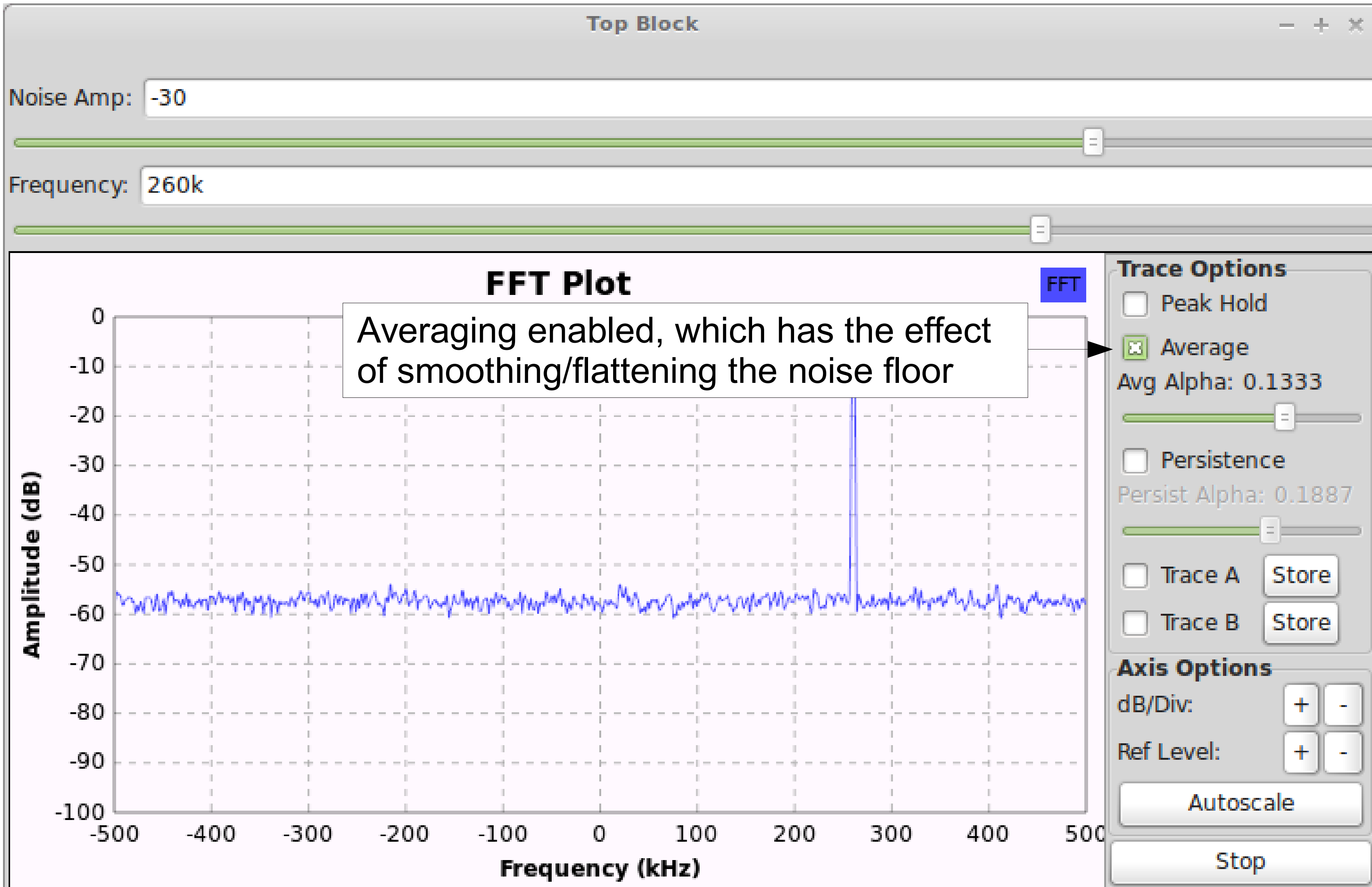
Top Block
Noise Amp: -130
Frequency: 1k
FFT Plot
FFT
Amplitude (dB)
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-500
-400
-300
-200
-100
0
100
200
300
400
500
Frequency (kHz)
Peak corresponding to 1 kHz tone
Simulated noise floor is below what is currently shown on the plot
Scale adjustment
Offset adjustment
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
Stop

Lab 2

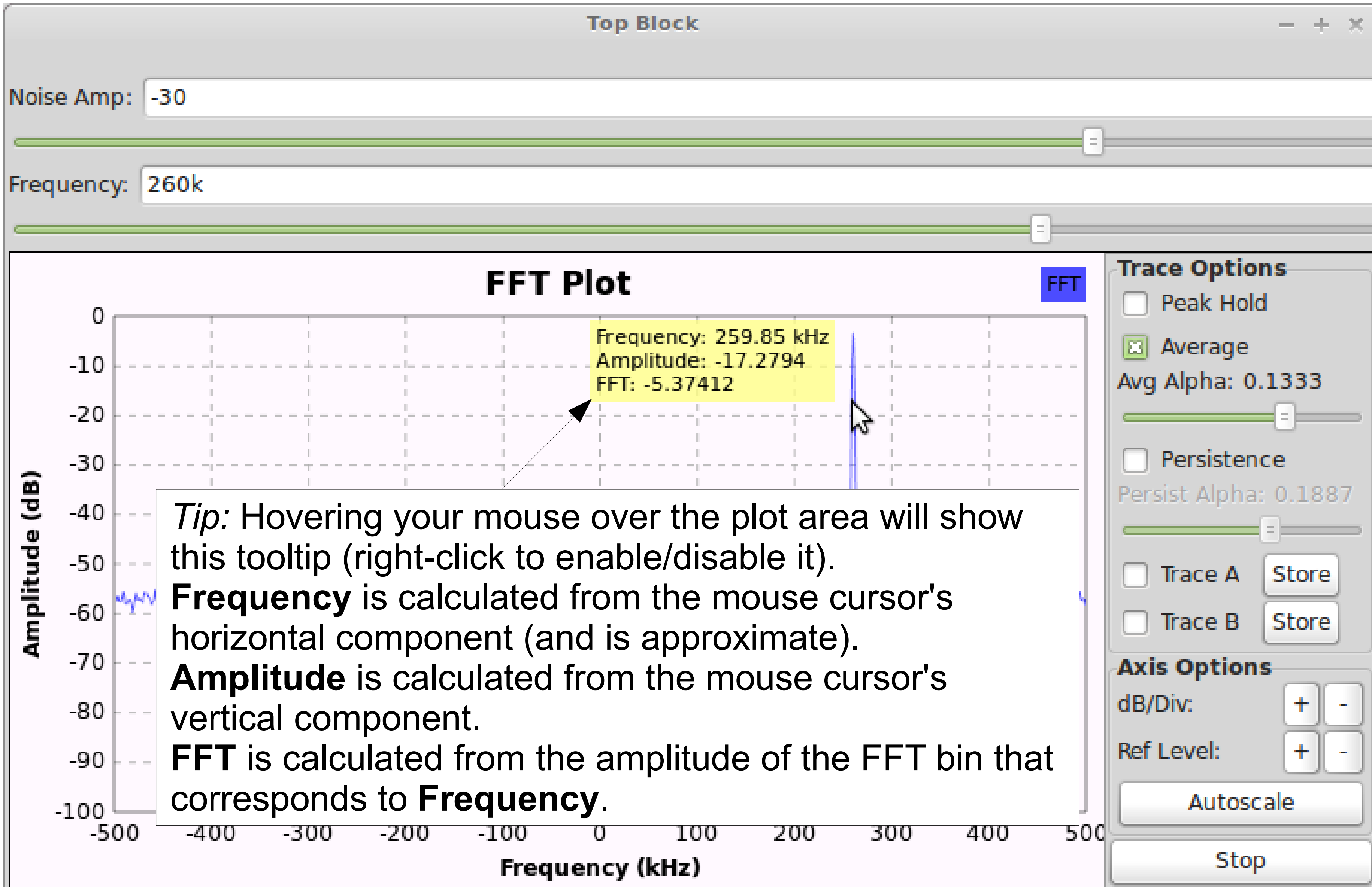


Top Block
Noise Amp: -30
Frequency: 260k
FFT Plot
FFT
Amplitude (dB)
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-500
-400
-300
-200
-100
0
100
200
300
400
500
Frequency (kHz)
Noise amplitude has been increased
Peak moved as 'Frequency' has been adjusted
Trace Options
Peak Hold
Average
Trace A
Store
Trace B
Store
Axis Options
dB/Div:
+
-
Ref Level:
+
-
Autoscale
Stop

Lab 2

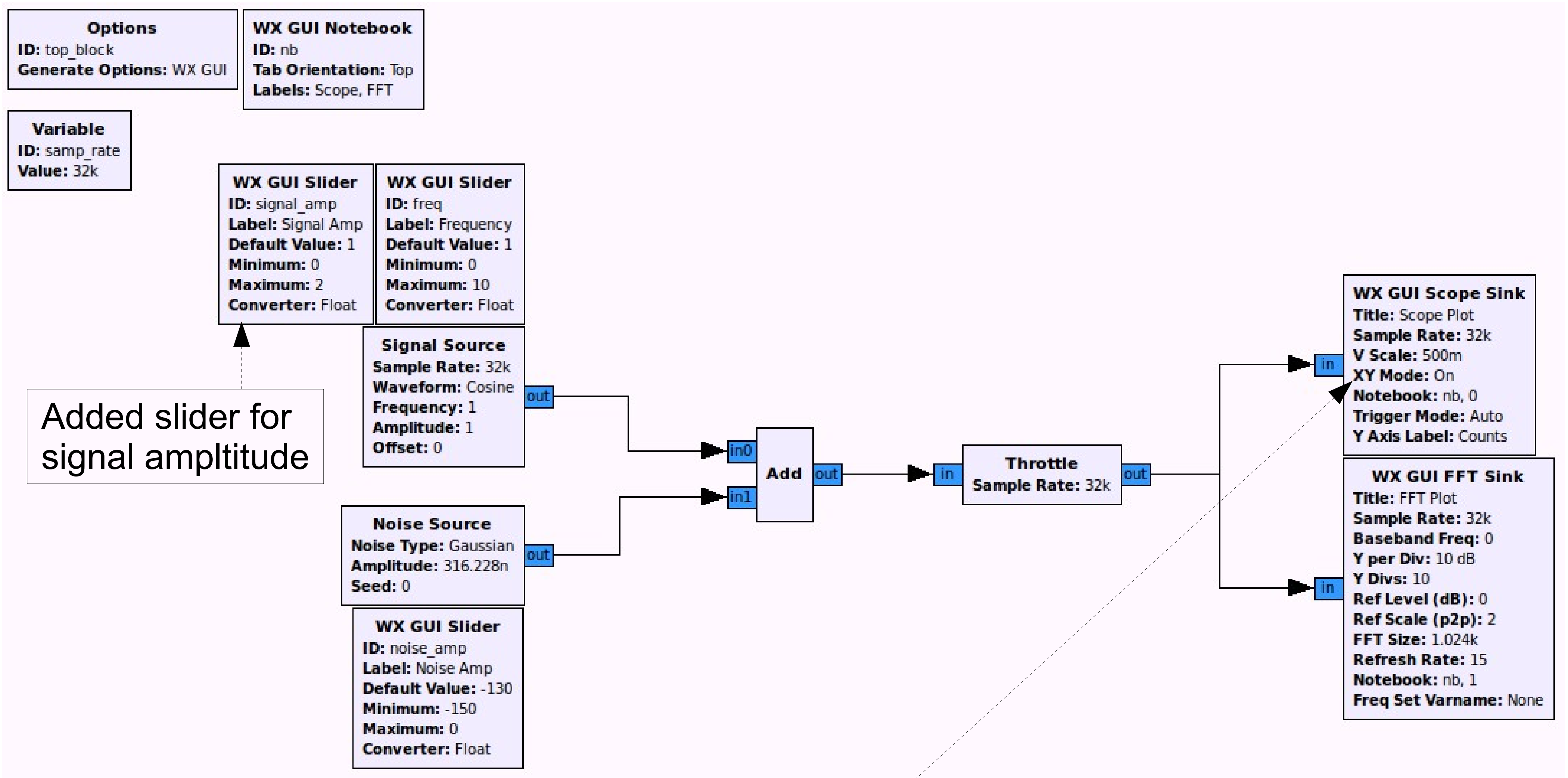

Top Block
Noise Amp: -30
Frequency: 260k
FFT Plot
FFT
Averaging enabled, which has the effect of smoothing/flattening the noise floor
Amplitude (dB)
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-500
-400
-300
-200
-100
0
100
200
300
400
500
Frequency (kHz)
Trace Options
Peak Hold
Average
Avg Alpha: 0.1333
Persistence
Persist Alpha: 0.1887
Trace A
Store
Trace B
Store
Axis Options
dB/Div:
Ref Level:
Autoscale
Stop

Lab 2



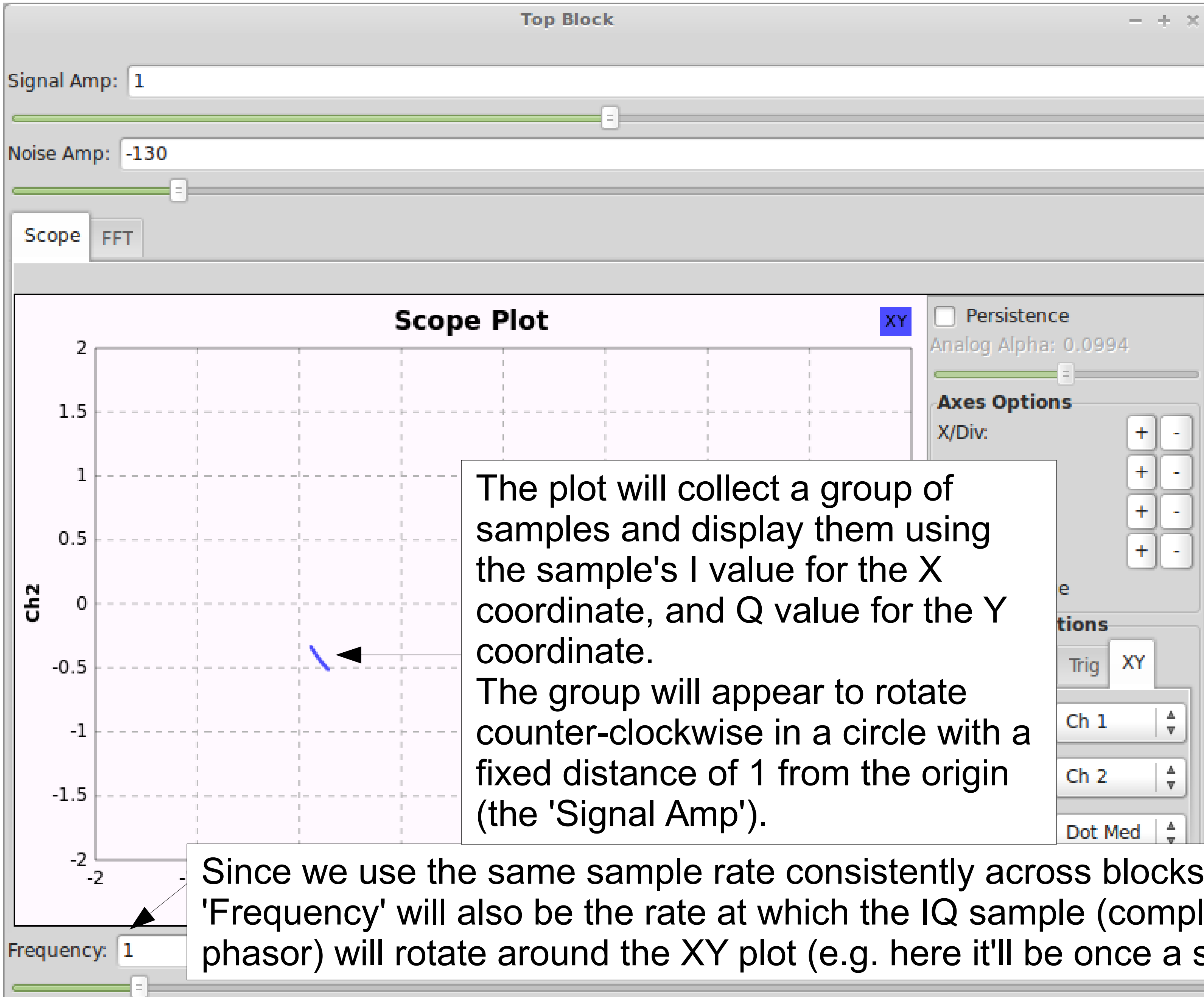
Tip: Hovering your mouse over the plot area will show this tooltip (right-click to enable/disable it).
Frequency is calculated from the mouse cursor's horizontal component (and is approximate).
Amplitude is calculated from the mouse cursor's vertical component.
FFT is calculated from the amplitude of the FFT bin that corresponds to **Frequency**.

Lab 2: XY Mode



Use a Scope Sink in XY Mode so we can observe the characteristics of an IQ (quadrature) signal

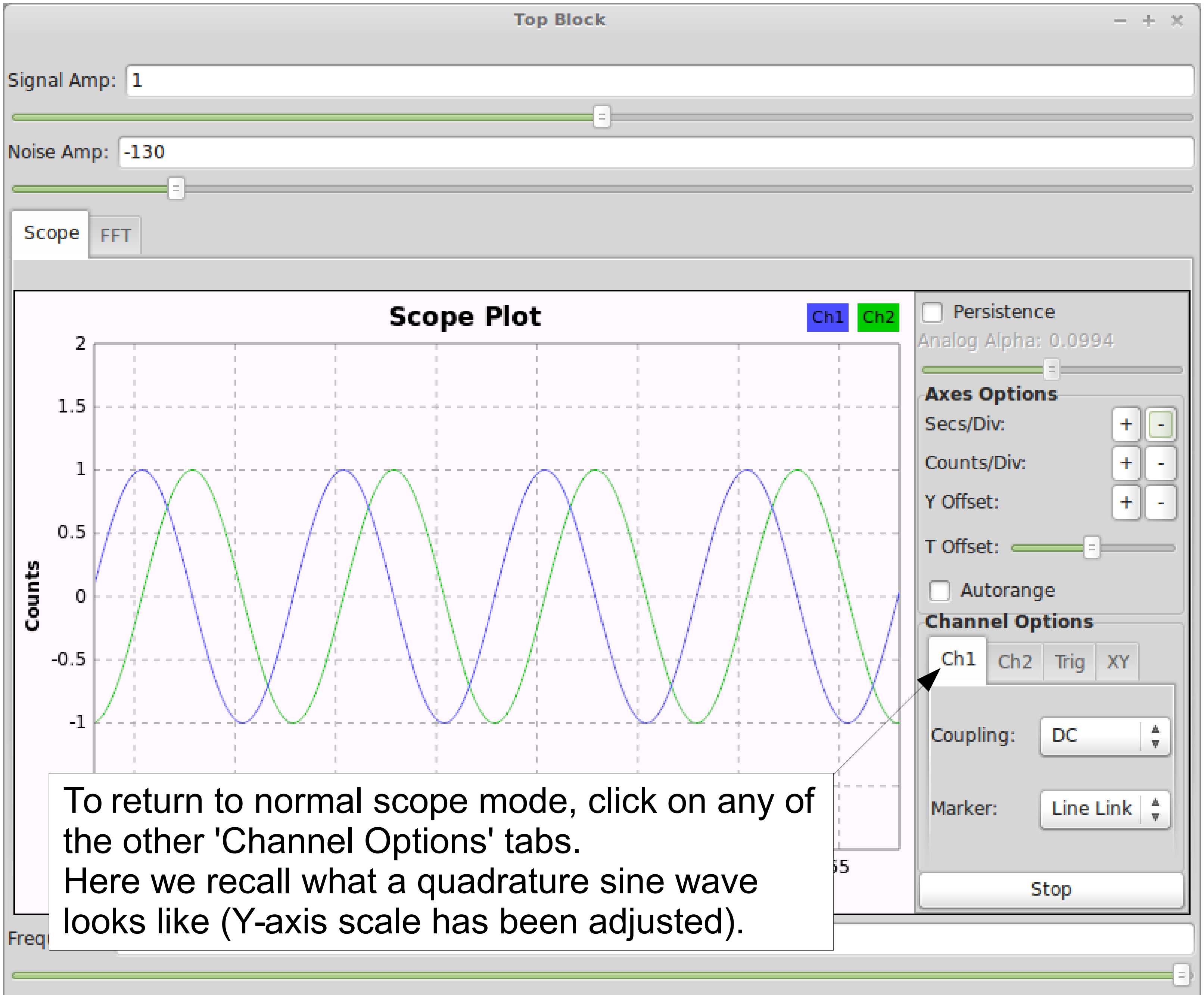
Lab 2: XY Mode



The plot will collect a group of samples and display them using the sample's I value for the X coordinate, and Q value for the Y coordinate.
The group will appear to rotate counter-clockwise in a circle with a fixed distance of 1 from the origin (the 'Signal Amp').

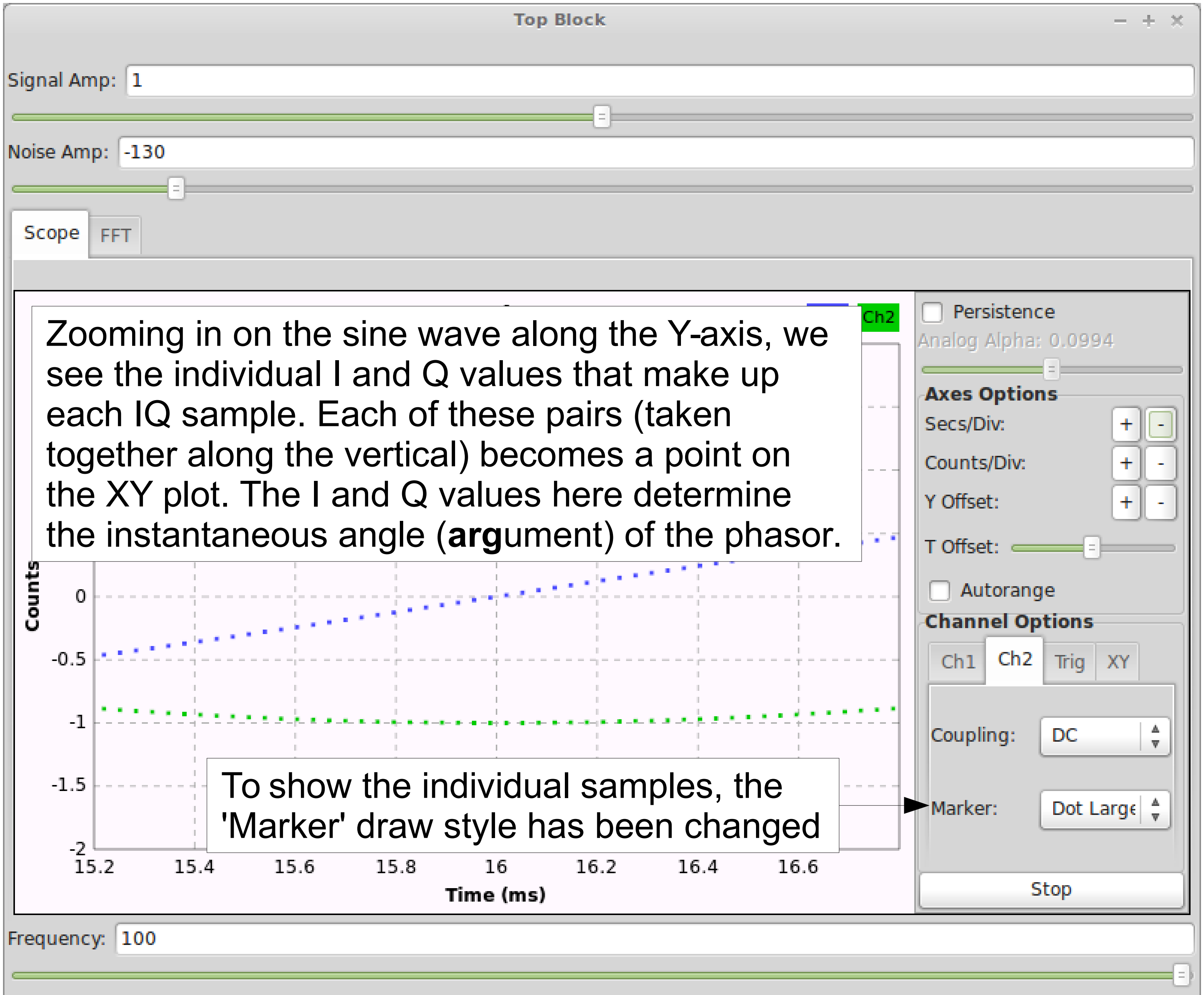
Since we use the same sample rate consistently across blocks, 'Frequency' will also be the rate at which the IQ sample (complex phasor) will rotate around the XY plot (e.g. here it'll be once a second).

Lab 2: XY Mode



To return to normal scope mode, click on any of the other 'Channel Options' tabs.
Here we recall what a quadrature sine wave looks like (Y-axis scale has been adjusted).

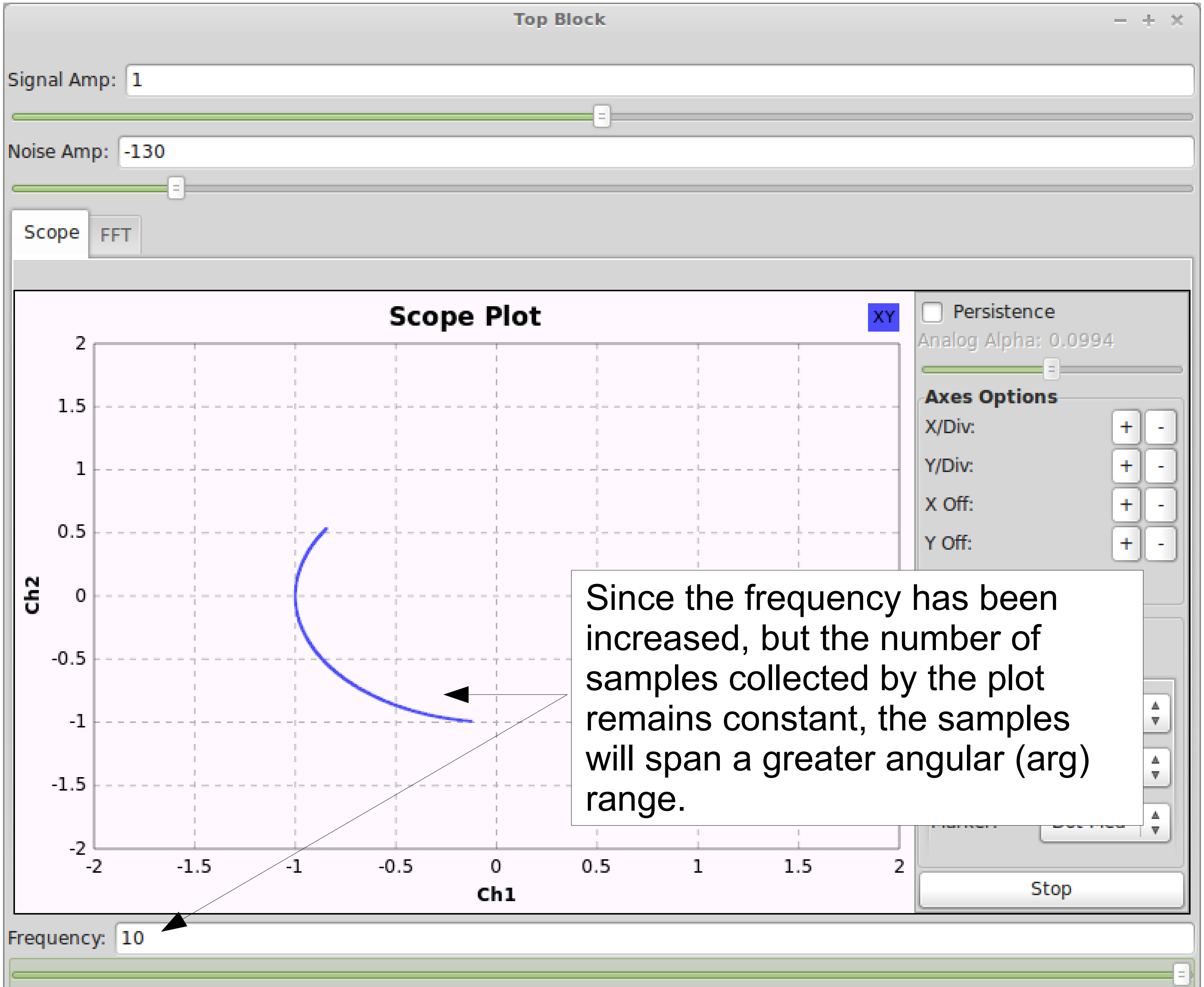
Lab 2: XY Mode



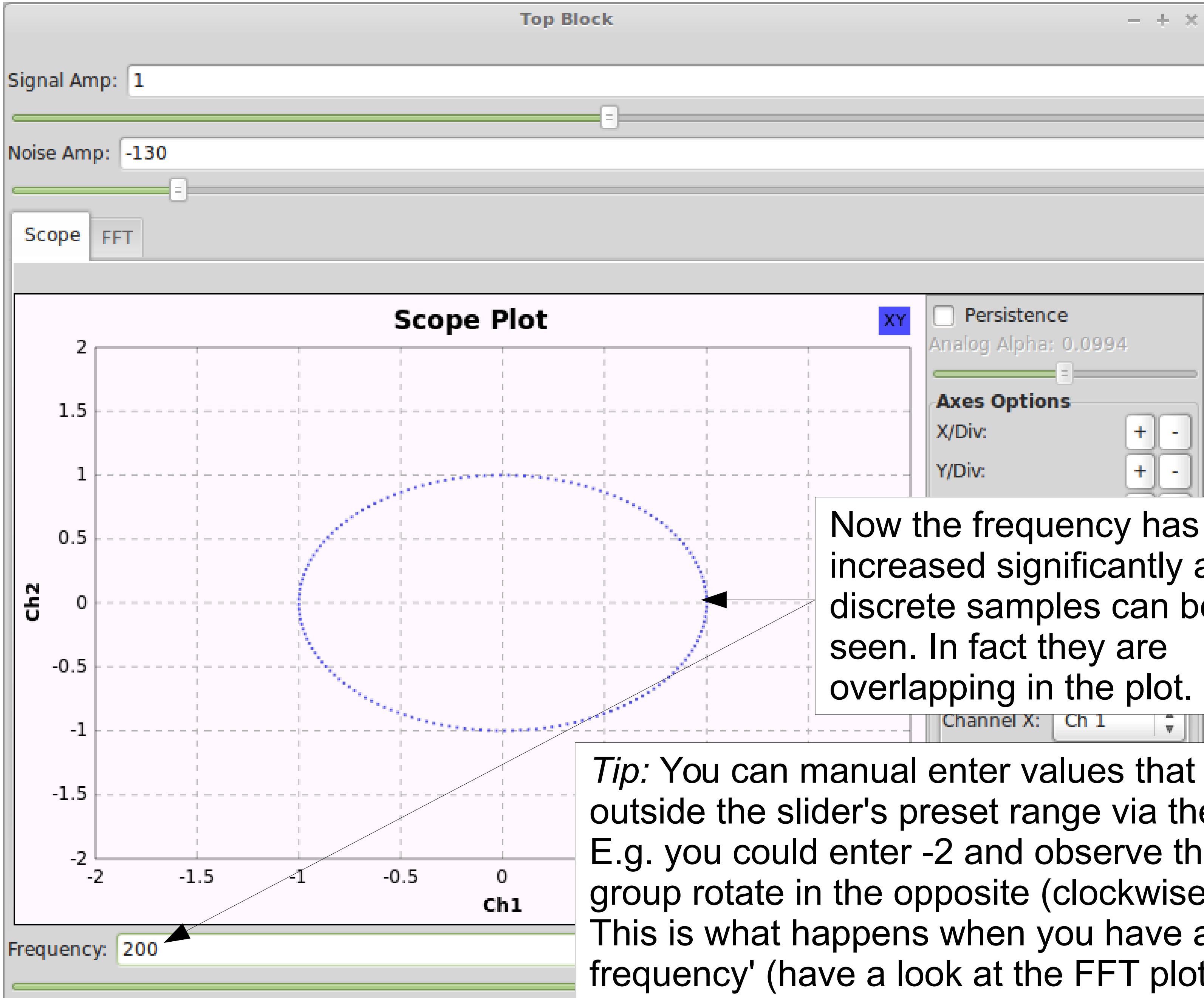
Zooming in on the sine wave along the Y-axis, we see the individual I and Q values that make up each IQ sample. Each of these pairs (taken together along the vertical) becomes a point on the XY plot. The I and Q values here determine the instantaneous angle (**arg**ument) of the phasor.

To show the individual samples, the 'Marker' draw style has been changed

Lab 2: XY Mode


Top Block
Signal Amp: 1
Noise Amp: -130
Scope
FFT
Scope Plot
XY
Persistence
Analog Alpha: 0.0994
Axes Options
X/Div:
Y/Div:
X Off:
Y Off:
Stop
Ch2
Ch1
Frequency: 10
Since the frequency has been increased, but the number of samples collected by the plot remains constant, the samples will span a greater angular (arg) range.

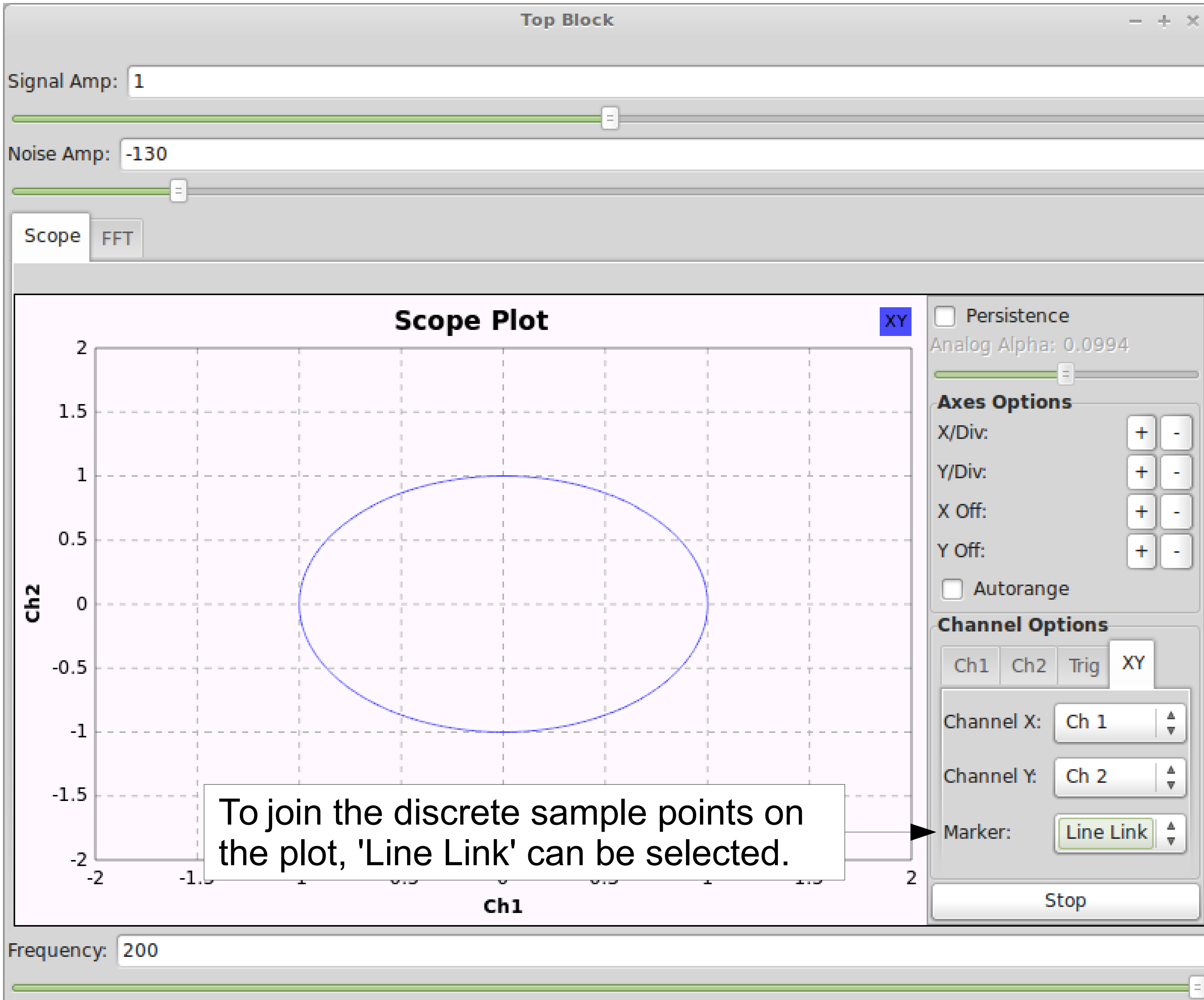
Lab 2: XY Mode



Now the frequency has been increased significantly and the discrete samples can be seen. In fact they are overlapping in the plot.

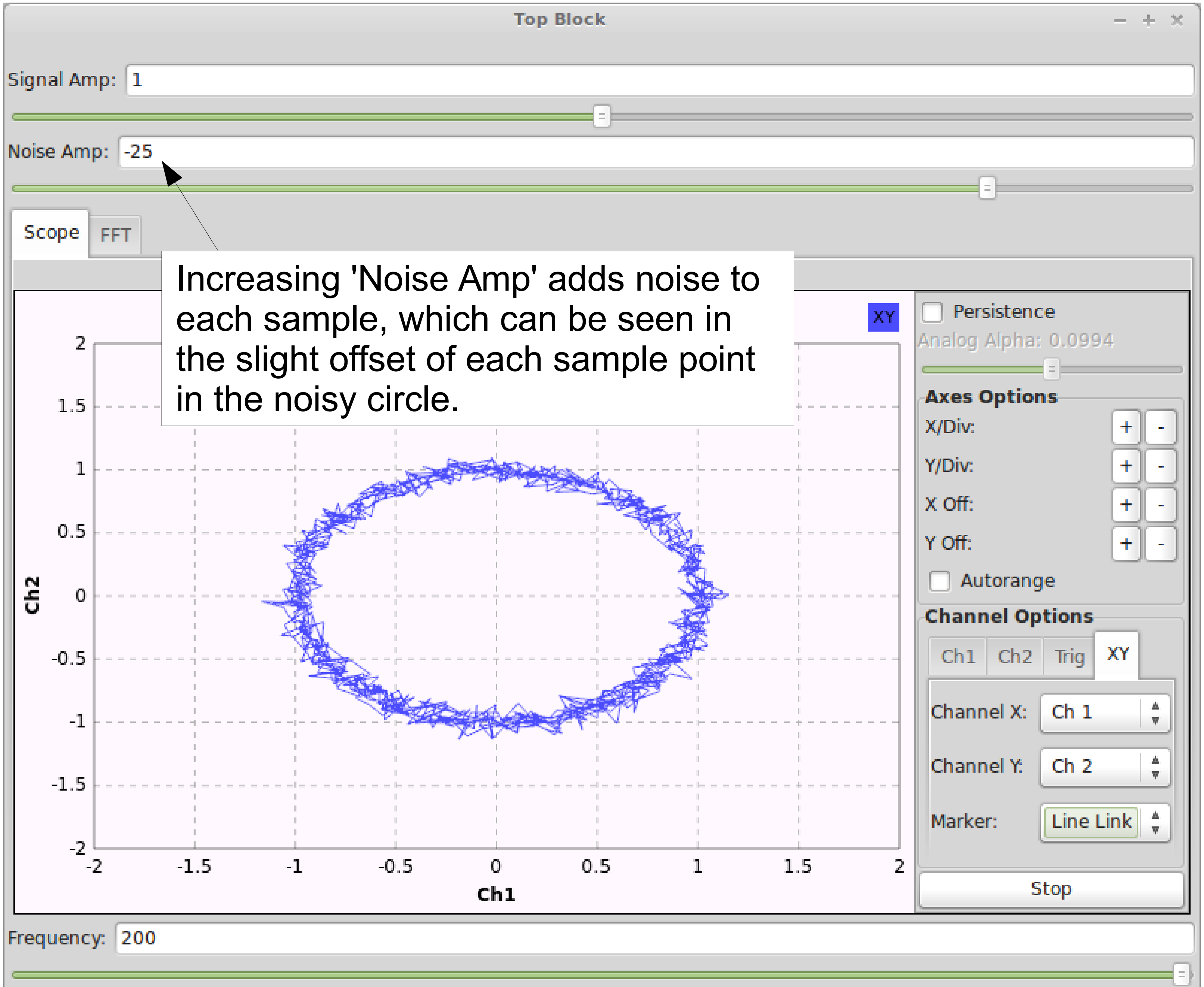
Tip: You can manual enter values that are outside the slider's preset range via the text box. E.g. you could enter -2 and observe the sample group rotate in the opposite (clockwise) direction. This is what happens when you have a 'negative frequency' (have a look at the FFT plot).

Lab 2: XY Mode



To join the discrete sample points on the plot, 'Line Link' can be selected.

Lab 2: XY Mode

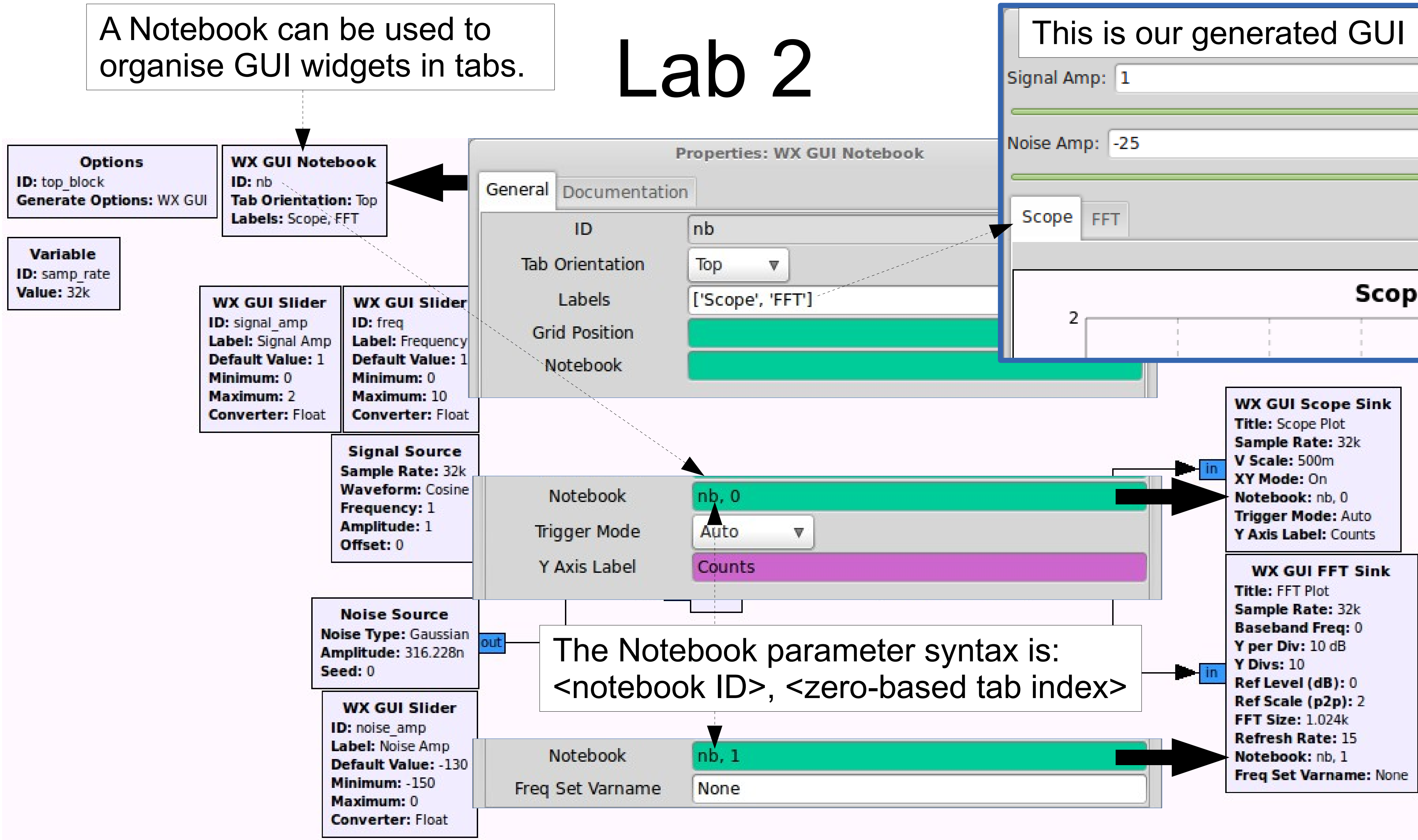


Top Block
Signal Amp: 1
Noise Amp: -25
Scope
FFT
Increasing 'Noise Amp' adds noise to each sample, which can be seen in the slight offset of each sample point in the noisy circle.
XY
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
Ch2
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
Ch1
Persistence
Analog Alpha: 0.0994
Axes Options
X/Div:
Y/Div:
X Off:
Y Off:
Autorange
Channel Options
Ch1
Ch2
Trig
XY
Channel X: Ch 1
Channel Y: Ch 2
Marker: Line Link
Stop
Frequency: 200

Lab 2

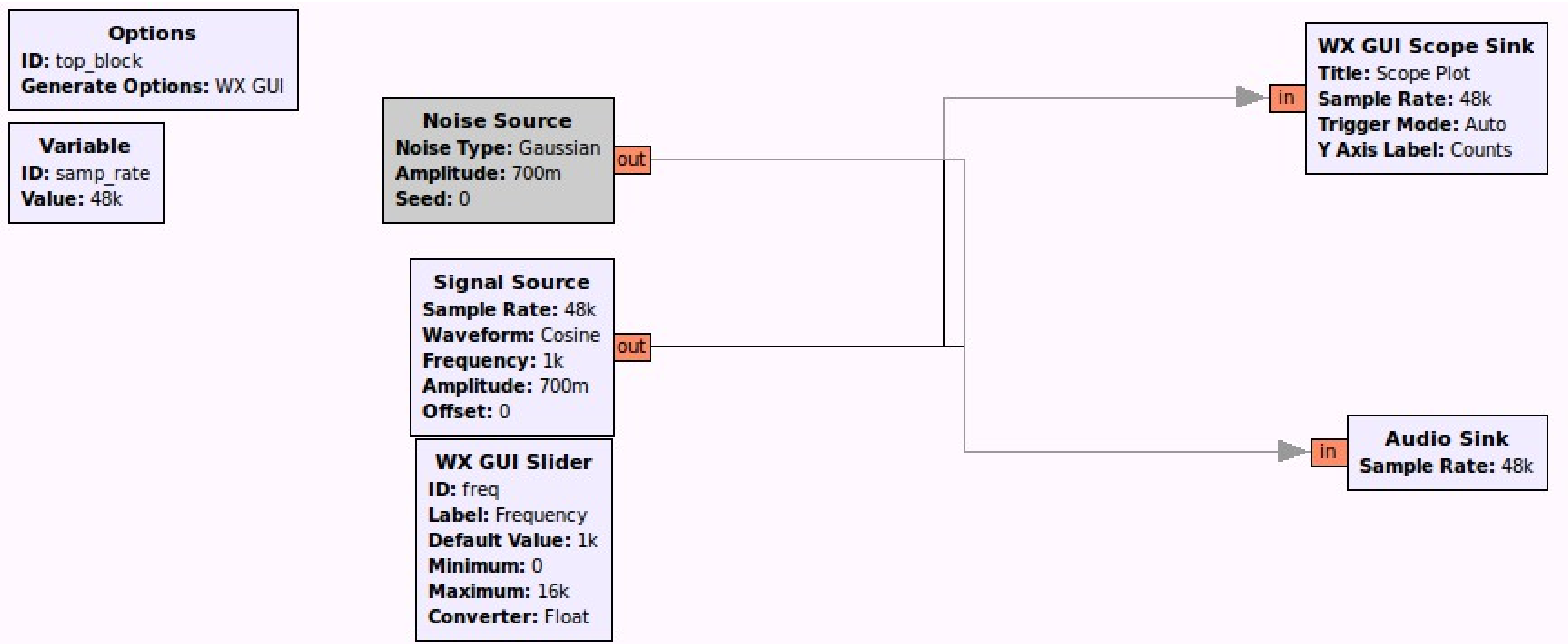
A Notebook can be used to organise GUI widgets in tabs.

This is our generated GUI



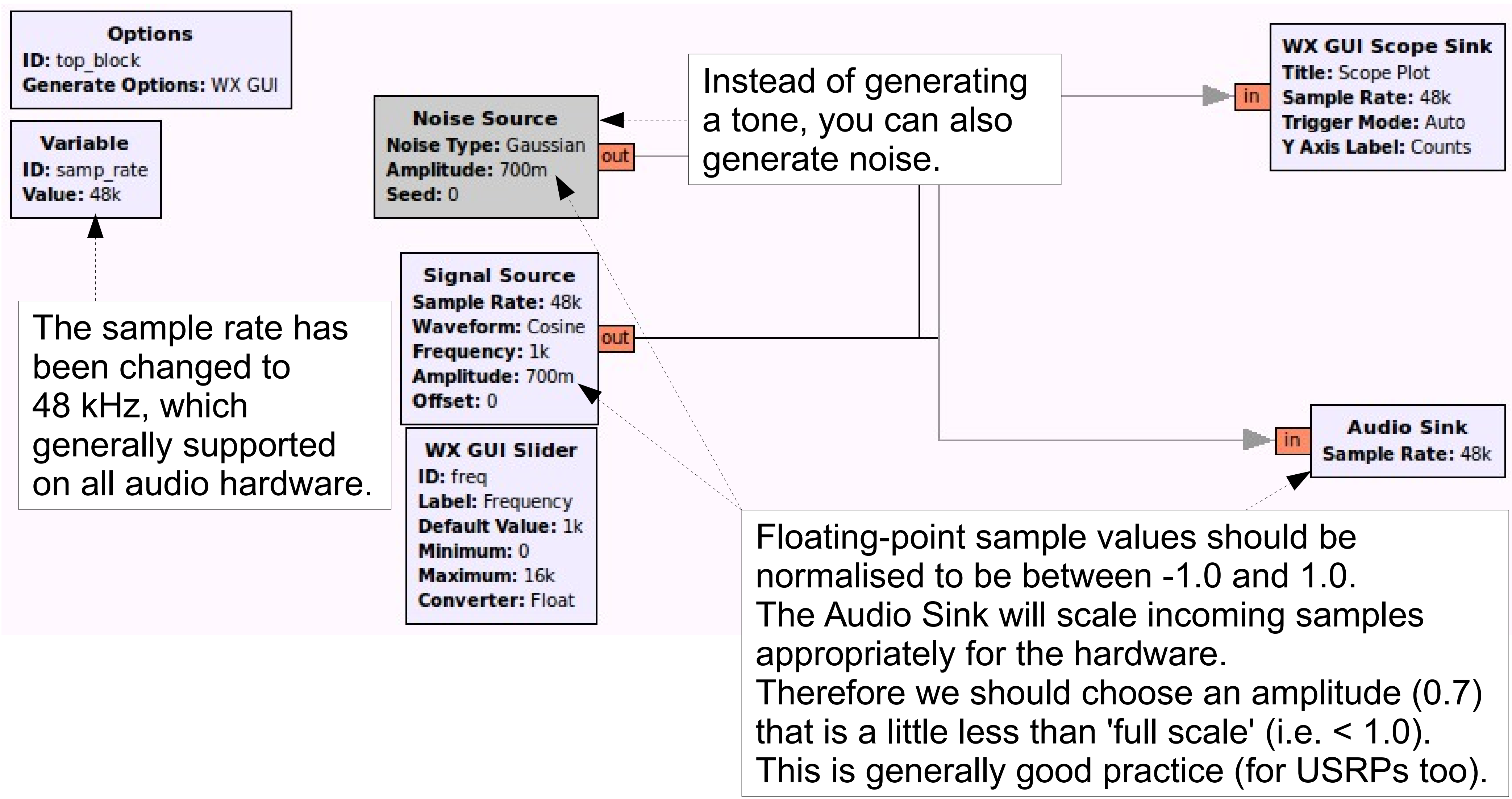
The Notebook parameter syntax is:
<notebook ID>, <zero-based tab index>

Lab 3: Audio



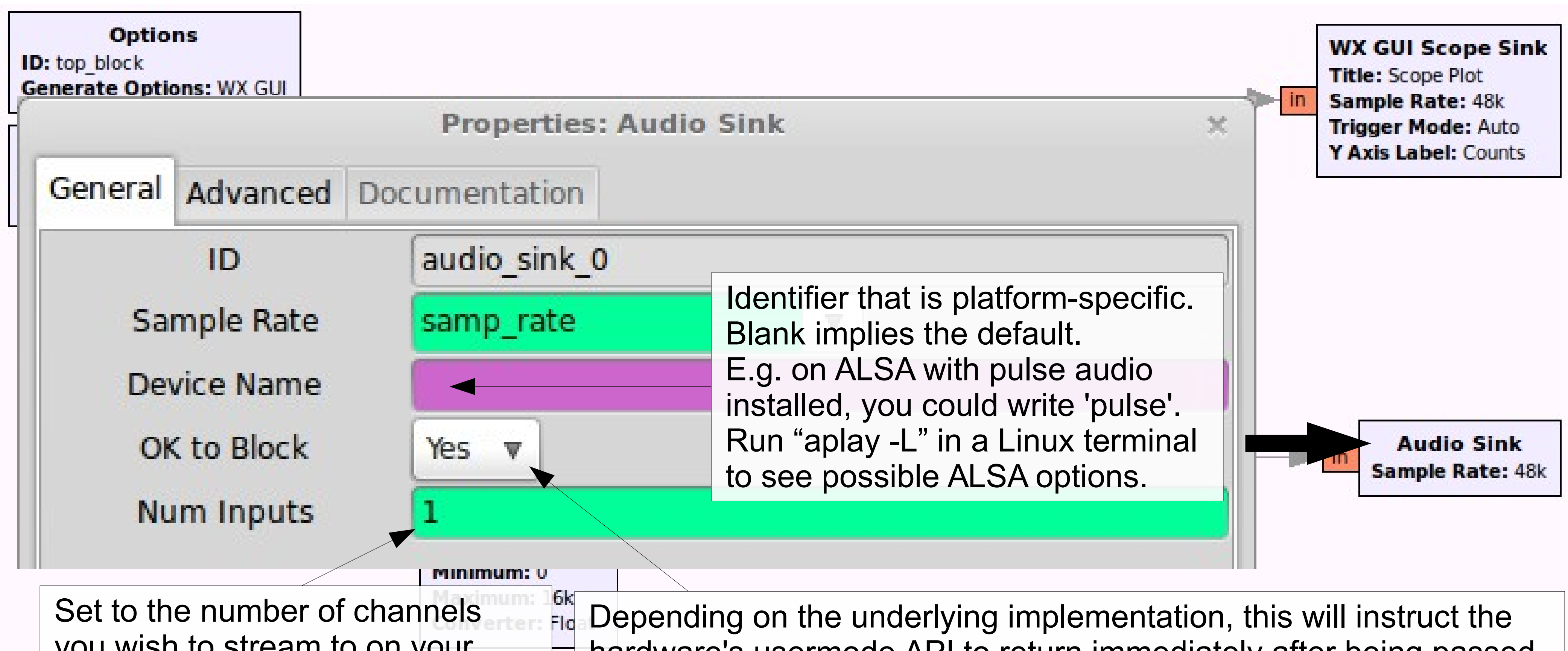
Output a single tone from the computer's soundcard

Lab 3: Audio



Options
ID: top_block
Generate Options: WX GUI
Variable
ID: samp_rate
Value: 48k
Noise Source
Noise Type: Gaussian
Amplitude: 700m
Seed: 0
out
Instead of generating a tone, you can also generate noise.
WX GUI Scope Sink
Title: Scope Plot
Sample Rate: 48k
Trigger Mode: Auto
Y Axis Label: Counts
in
Signal Source
Sample Rate: 48k
Waveform: Cosine
Frequency: 1k
Amplitude: 700m
Offset: 0
out
The sample rate has been changed to 48 kHz, which generally supported on all audio hardware.
WX GUI Slider
ID: freq
Label: Frequency
Default Value: 1k
Minimum: 0
Maximum: 16k
Converter: Float
Audio Sink
Sample Rate: 48k
in
Floating-point sample values should be normalised to be between -1.0 and 1.0.
The Audio Sink will scale incoming samples appropriately for the hardware.
Therefore we should choose an amplitude (0.7) that is a little less than 'full scale' (i.e. < 1.0).
This is generally good practice (for USRPs too).

Lab 3: Audio



Identifier that is platform-specific.
Blank implies the default.
E.g. on ALSA with pulse audio installed, you could write 'pulse'.
Run “aplay -L” in a Linux terminal to see possible ALSA options.

Set to the number of channels you wish to stream to on your audio hardware (e.g. 2 for stereo)

Depending on the underlying implementation, this will instruct the hardware's usermode API to return immediately after being passed a buffer of audio samples (non-blocking mode), or wait until they are consumed (blocking mode).
See next page for details.

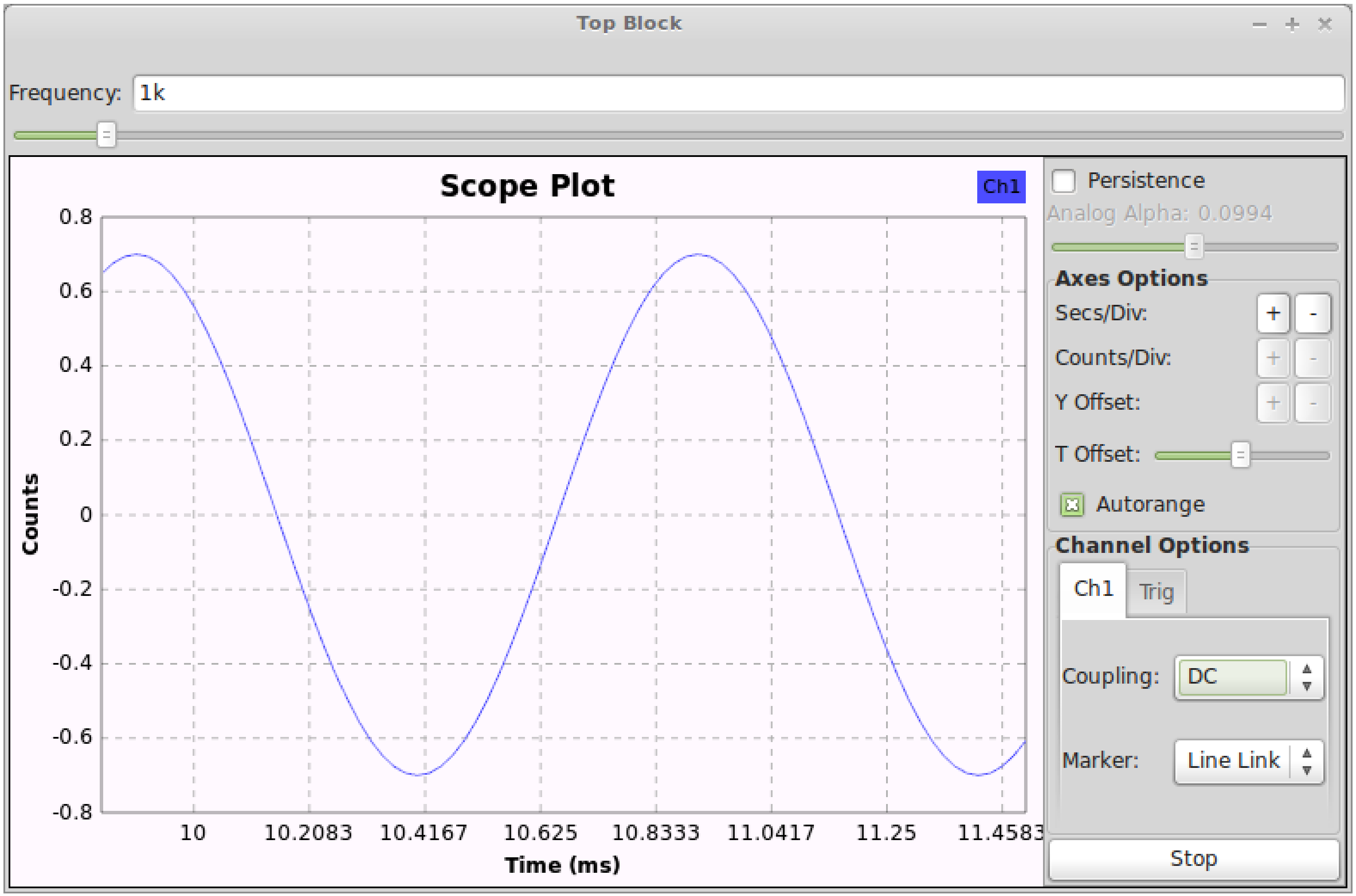
Lab 3: Audio

- Blocking mode ('OK to Block') will apply upstream backpressure, which is good when the Audio Sink is the only hardware device in the flowgraph.
- This can be problematic if the flowgraph source is, for example, a USRP. The source is then also hardware that has its own internal clock and will be throttling the sample production rate while the Audio Sink is throttling consumption with its own unsynchronised clock. This is called the '*two clock*' problem.

Lab 3: Audio

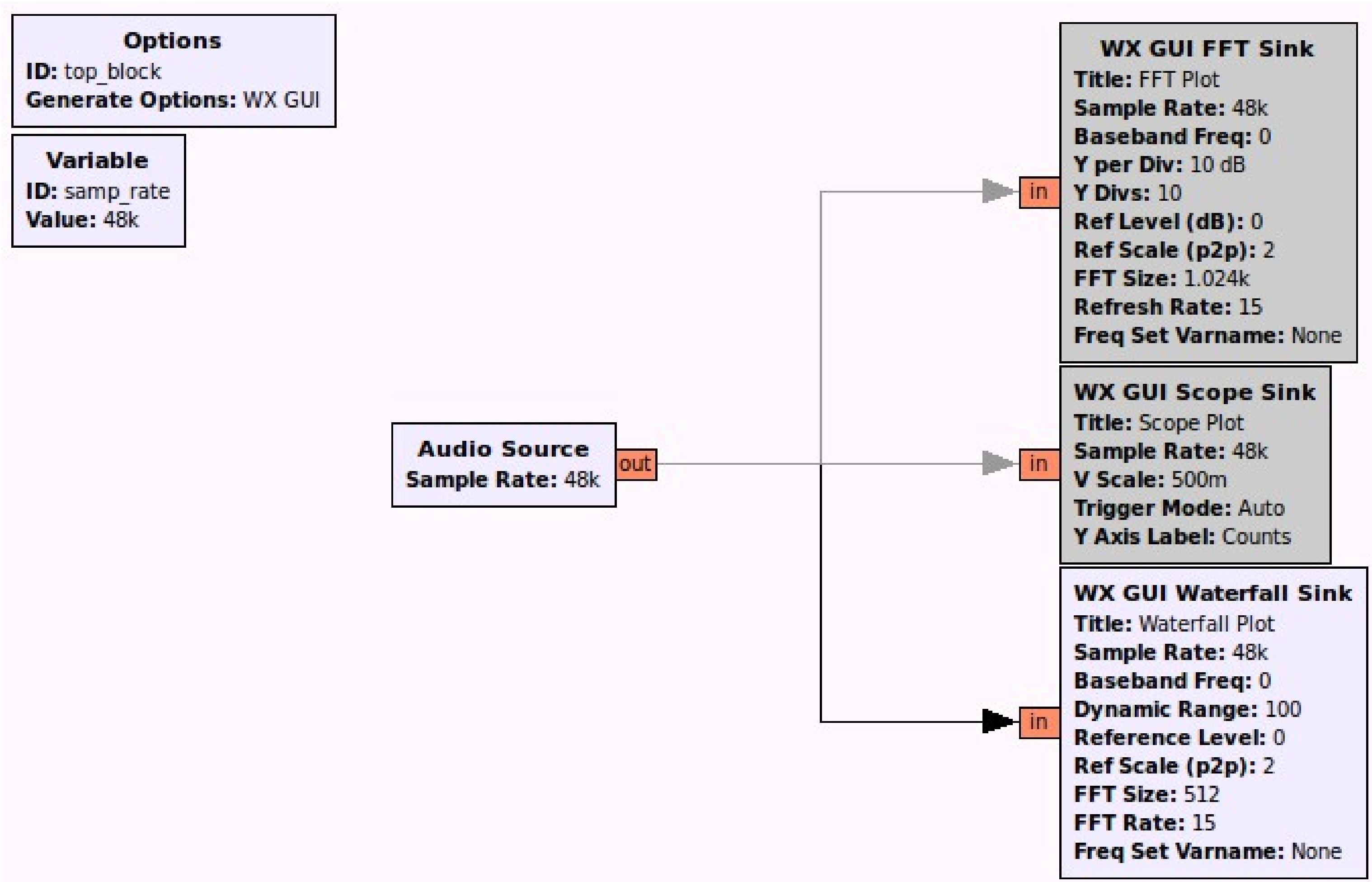
- To workaround this two clock problem, set the Audio Sink to non-blocking mode (*not* 'OK to Block') so that it will never hold up the flowgraph (i.e. not apply backpressure). It will consume samples as normal, but if there is ever an excess (e.g. the USRP is producing samples a little faster than the Audio Sink can consume) it will drop the samples (might cause audio glitches).
- This does not solve the case where samples are being produced *slower* than the Audio Sink's consumption rate (this will produce an underrun: audio will sound choppy and 'aU' will be printed).

Lab 3: Audio



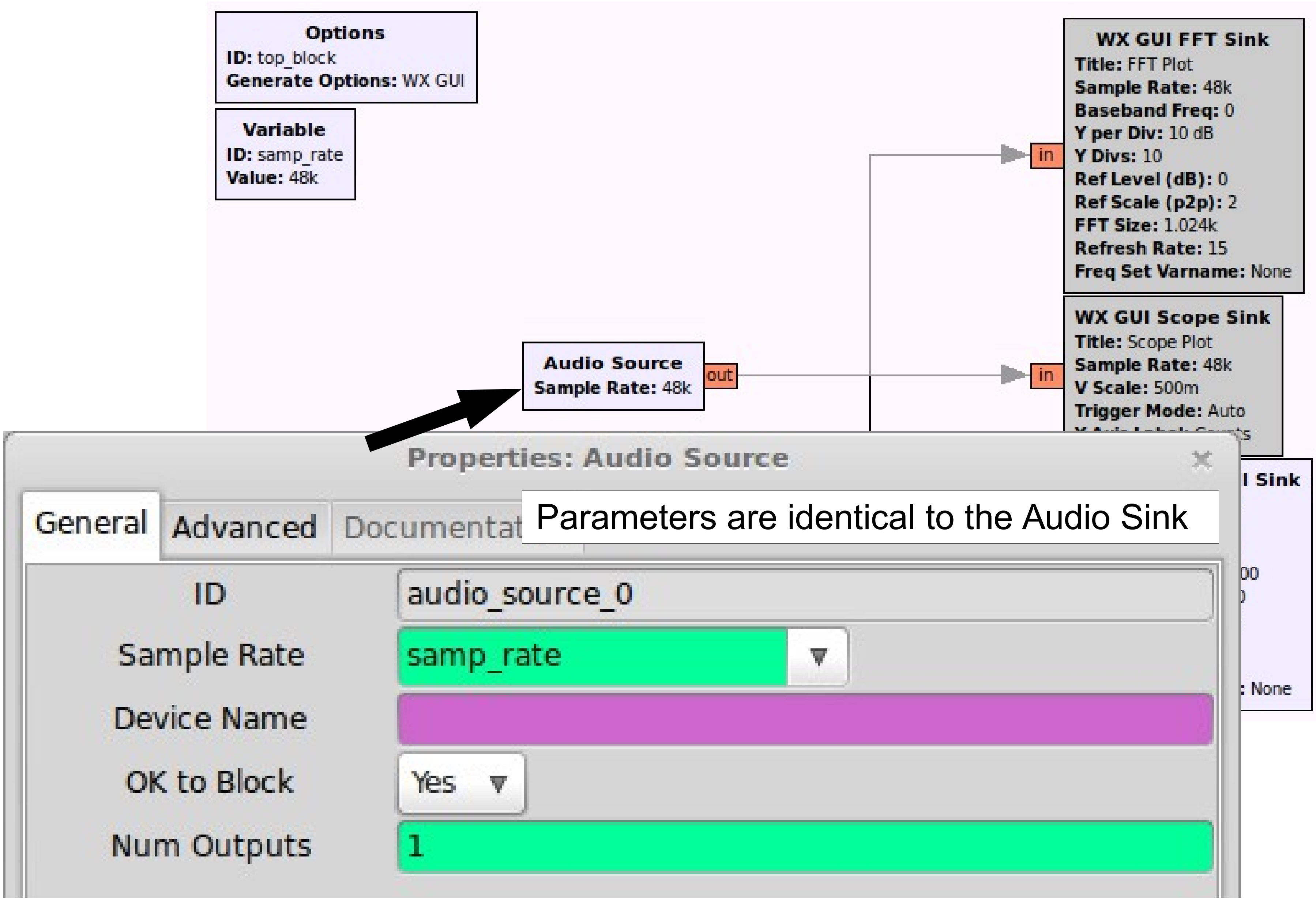
Same sine wave as before, but now we hear it emanating from the computer's speakers.

Lab 3: Audio

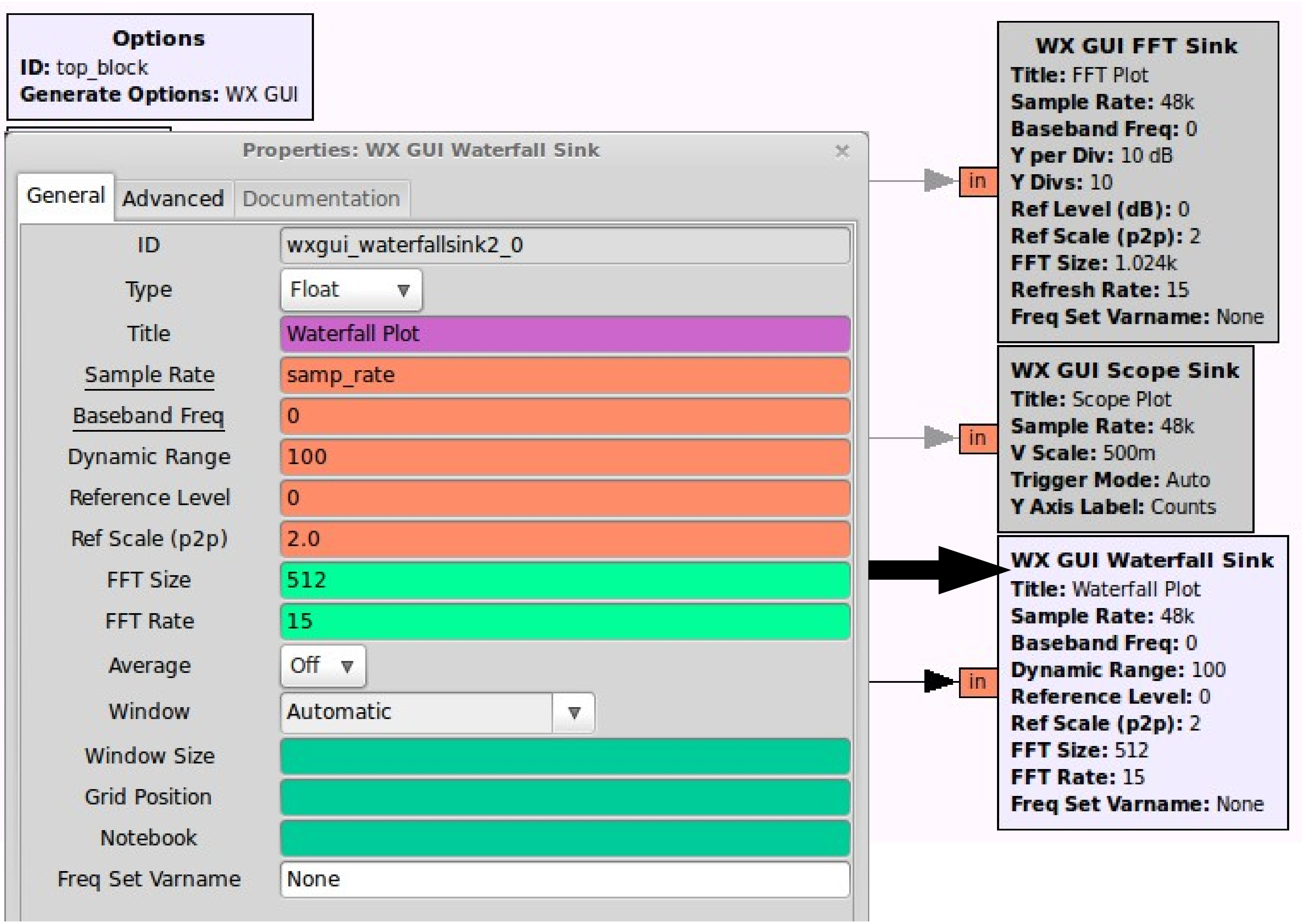


Visualise the audio sampled by a soundcard on a time-based scrolling FFT (waterfall/spectrogram).

Lab 3: Audio

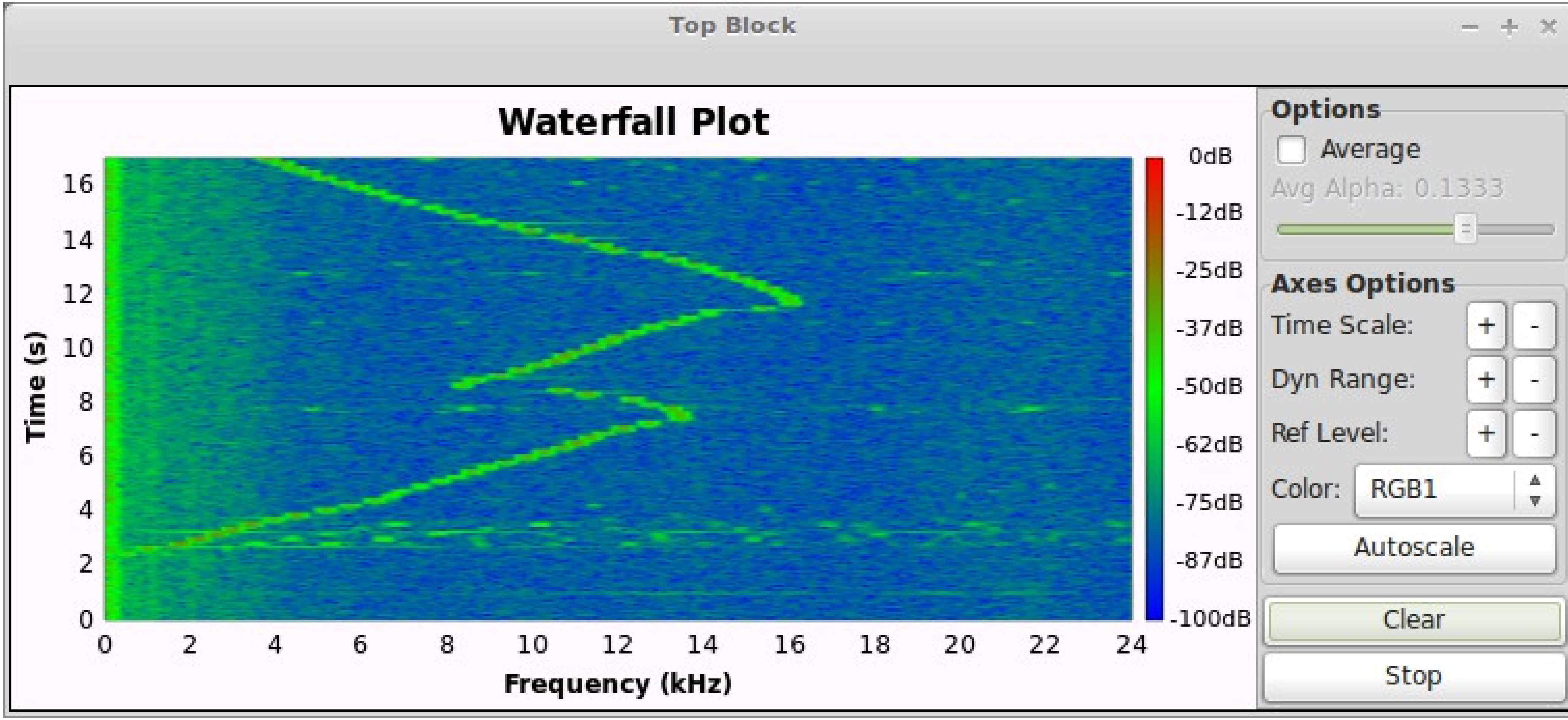

Options
ID: top_block
Generate Options: WX GUI
Variable
ID: samp_rate
Value: 48k
WX GUI FFT Sink
Title: FFT Plot
Sample Rate: 48k
Baseband Freq: 0
Y per Div: 10 dB
Y Divs: 10
Ref Level (dB): 0
Ref Scale (p2p): 2
FFT Size: 1.024k
Refresh Rate: 15
Freq Set Varname: None
in
WX GUI Scope Sink
Title: Scope Plot
Sample Rate: 48k
V Scale: 500m
Trigger Mode: Auto
in
Audio Source
Sample Rate: 48k
out
Properties: Audio Source
General
Advanced
Documentat
Parameters are identical to the Audio Sink
ID
audio_source_0
Sample Rate
samp_rate
Device Name
OK to Block
Yes
Num Outputs
1

Lab 3: Audio



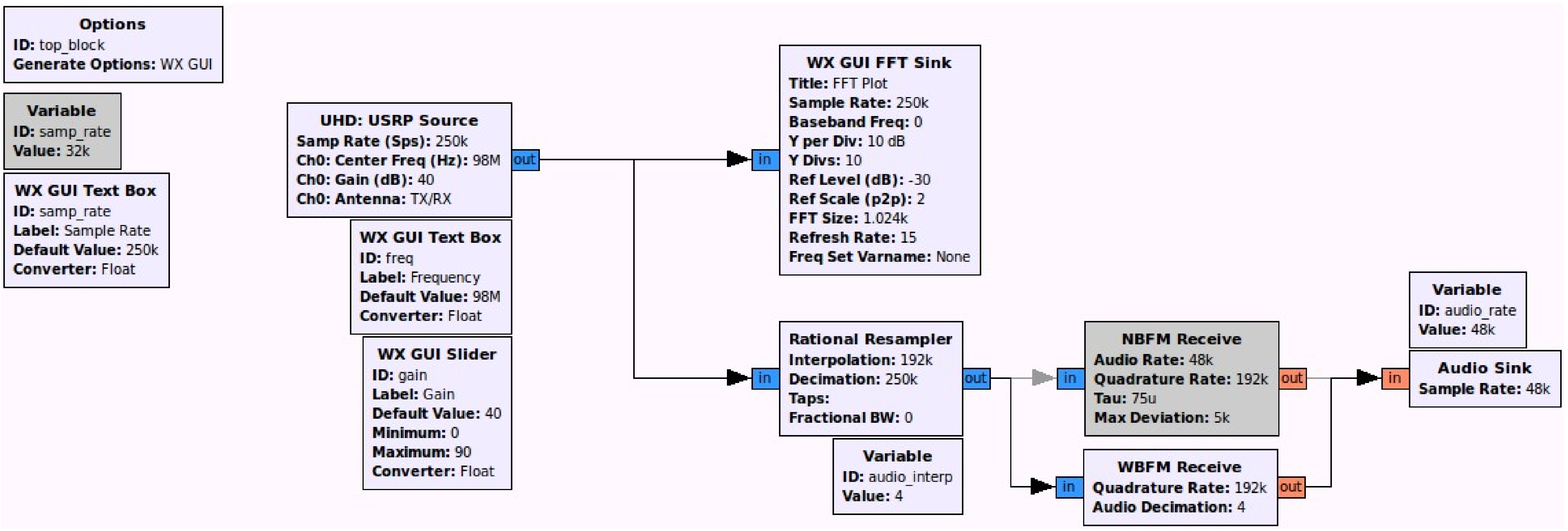
Parameters are identical to the FFT Sink

Lab 3: Audio



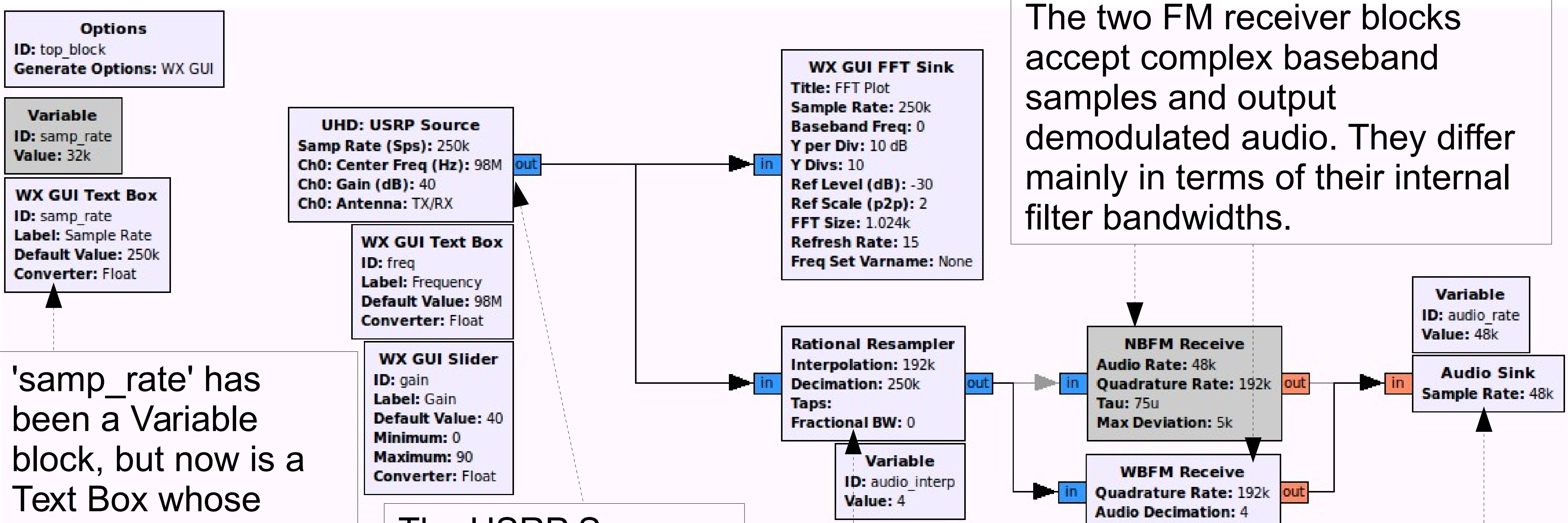
Running the sine wave generator program at the same time, and changing the frequency. This is a rough 'loopback' test where the computer's microphone listens to its speakers.

Lab 4: FM RX



Receive a baseband signal using a USRP and listen to it using a narrow- or wide-band FM demodulator

Lab 4: FM RX



The two FM receiver blocks accept complex baseband samples and output demodulated audio. They differ mainly in terms of their internal filter bandwidths.

'samp_rate' has been a Variable block, but now is a Text Box whose value can be changed at runtime

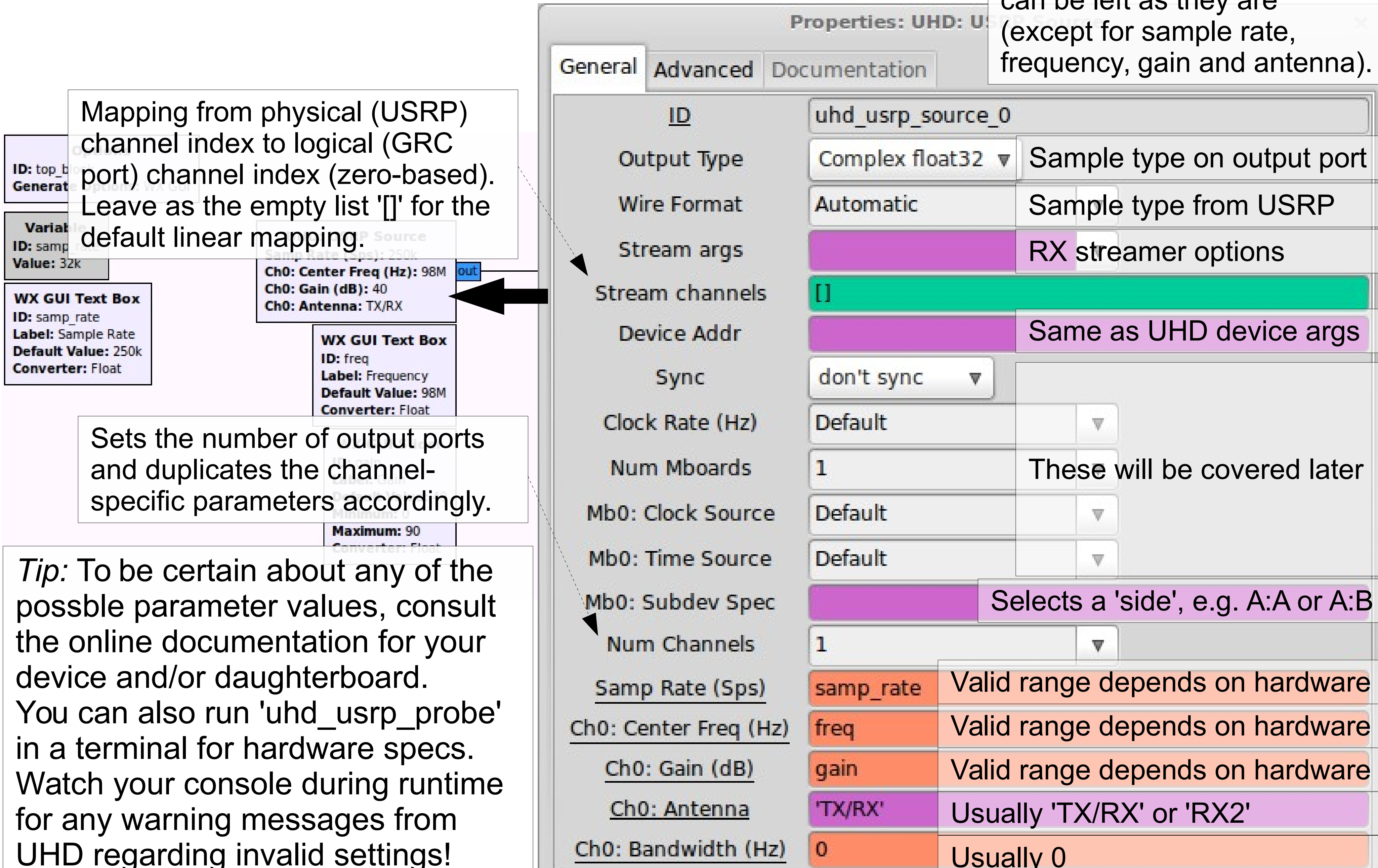
The USRP Source block will produce baseband samples by sampling RF on a selected antenna at a particular frequency, sample rate and gain

A Rational Resampler will adapt the notional rate of a stream by interpolating/decimating overall, as needed.
This is necessary here because USRP rates are not integer multiples of Audio Sink rates.

Disable 'OK to Block' to work around 'two clock' problem

Lab 4: FM RX

Tip: usually all parameters can be left as they are (except for sample rate, frequency, gain and antenna).



Mapping from physical (USRP) channel index to logical (GRC port) channel index (zero-based). Leave as the empty list '[]' for the default linear mapping.

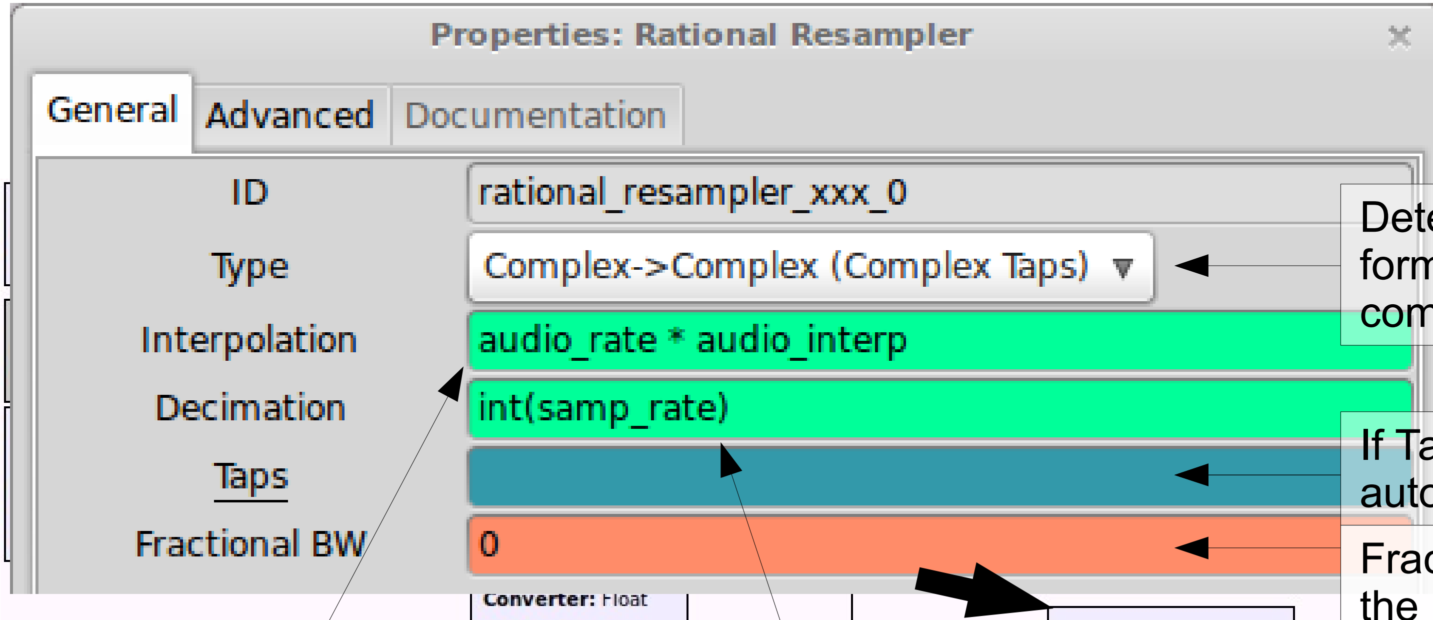
Sets the number of output ports and duplicates the channel-specific parameters accordingly.

Tip: To be certain about any of the possble parameter values, consult the online documentation for your device and/or daughterboard. You can also run 'uhd_usrp_probe' in a terminal for hardware specs. Watch your console during runtime for any warning messages from UHD regarding invalid settings!

Lab 4: FM RX

- This example uses the USRP B200
- Valid ranges:
  - Antenna: TX/RX, RX2
  - Frequency: 70 MHz – 6 GHz
  - RX Gain: 0 – 73 (default of ~25 is a good starting point)
  - Sample Rate: 62.5 ksps – 56 Msps (62.5e3 - 56e6)
    - Default **M**aster **C**lock **R**ate = 32e6 (max: 61.44e6)
    - (MCR / sample rate) **must** be an integer, and **should** be divisible by 4 for the best RF performance (flat spectrum)
    - MCR can be changed with “master_clock_rate=X” in Device Addr, where X is new MCR in Hz (e.g. 40e6)
- A 'O' on the console indicates an overrun, and occurs when the host is not able to consume samples quickly enough.

Lab 4: FM RX



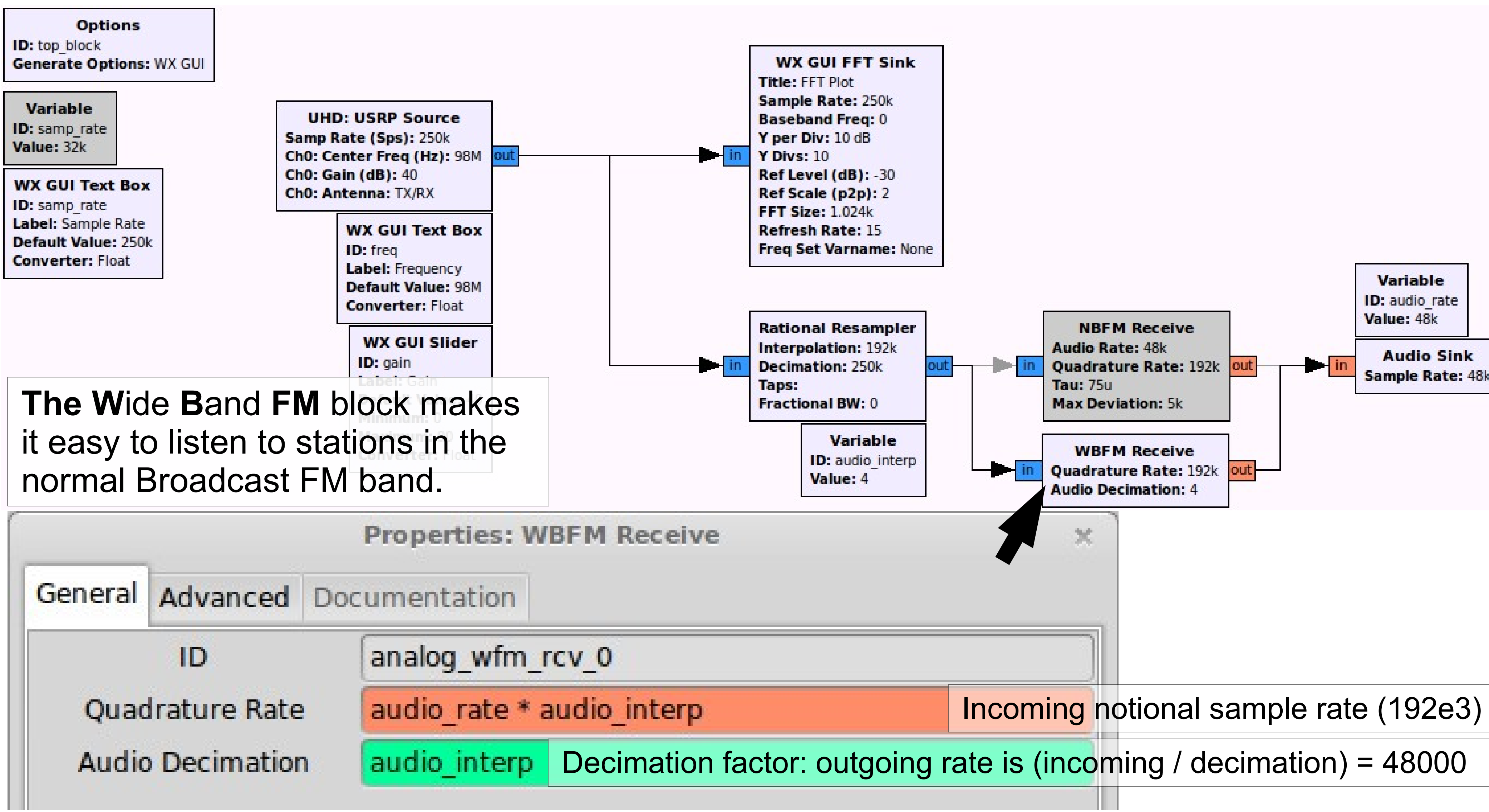
Determine the input & output sample format, and what format (real or complex) the filter taps will be

If Taps is left blank, the taps are automatically computed

Fractional BW affects the shape of the low-pass filter that is generated when no filter taps are supplied. Specifically it determines how steep the low-pass rolloff is. Leaving the default 0 tells the code to select a reasonable default (currently 0.4)

We need to adapt the USRP rate to something suitable for the Audio Sink. The default 'samp_rate' value is 250e3, which sets the rate at which the USRP produces samples. The Audio Sink is configured for a sample (consumption) rate of 48e3, but (250000 / 48000) is not an integer. We can cheat here and set Decimation to be the incoming notional sample rate (250000), and the Interpolation to be a different (non-divisible) outgoing notional sample rate (192000*). The code will calculate the GCD. Since the parameters must be integers, and 'samp_rate' is a floating-point number, we use the Python function 'int' to convert it to an integer.
* 'audio_rate' is multiplied by 4 ('audio_interp') because the demodulator blocks will perform additional decimation (by 4). Specifically the WBFM block should be given a high rate (i.e. high bandwidth signal since FM broadcast channels are 200 kHz wide).

Lab 4: FM RX



The Wide **B**and **FM** block makes it easy to listen to stations in the normal Broadcast FM band.

Incoming notional sample rate (192e3)

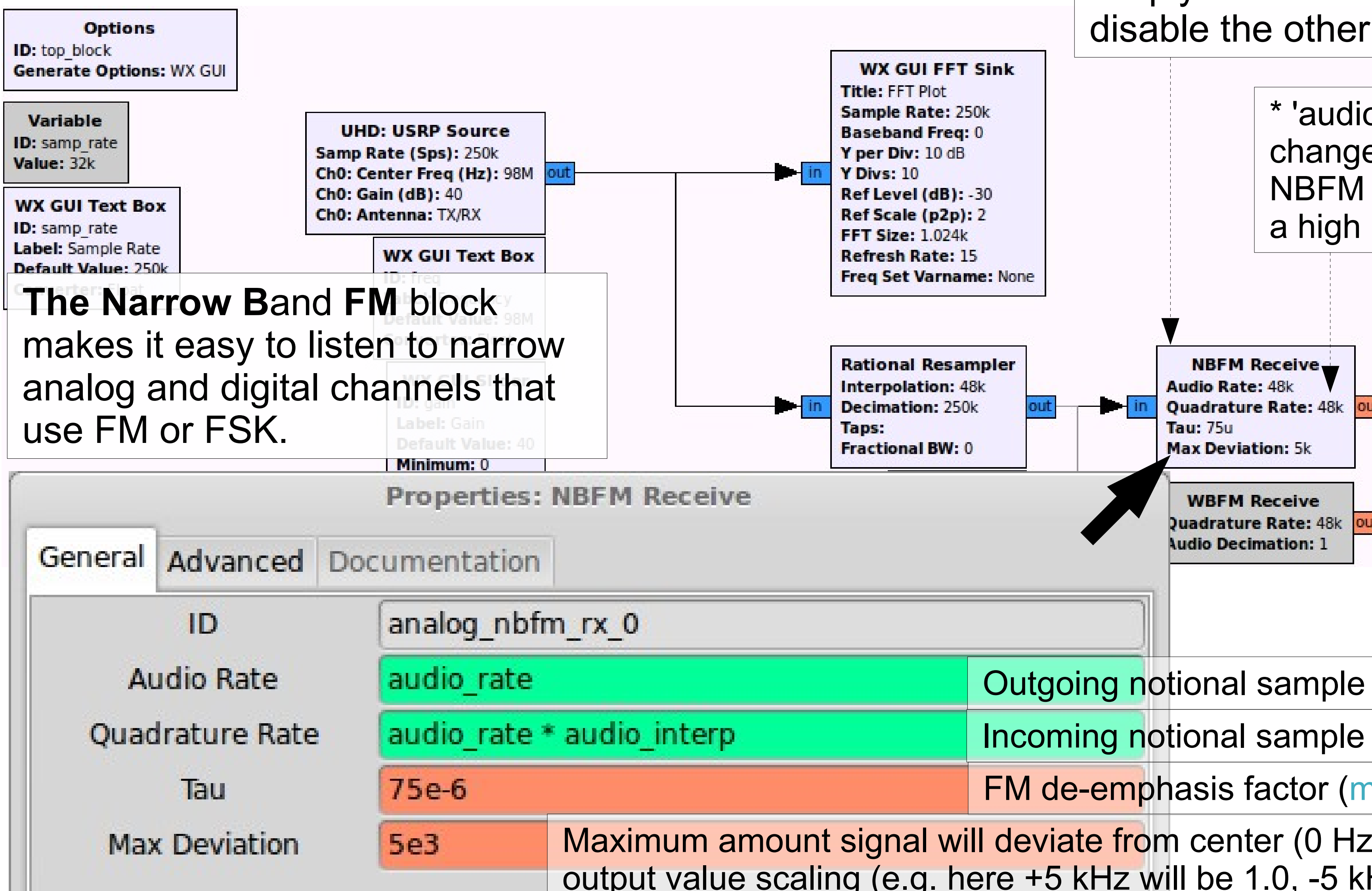
Decimation factor: outgoing rate is (incoming / decimation) = 48000

Lab 4: FM RX

To switch between modulators in this example, simply enable one block and disable the other.

* 'audio_interp' is changed to 1 here as NBFM doesn't need such a high bandwidth signal

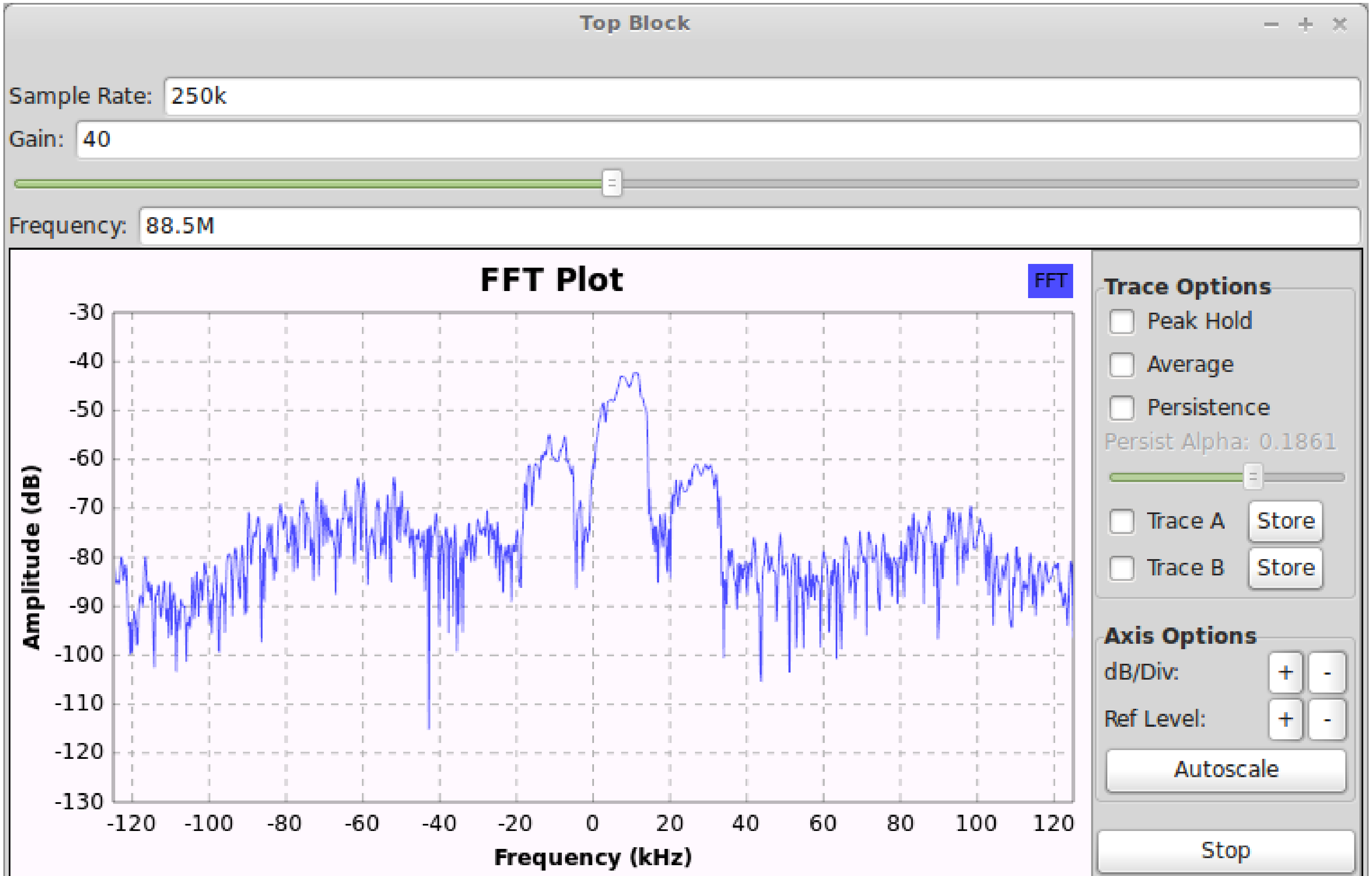
The Narrow Band FM block makes it easy to listen to narrow analog and digital channels that use FM or FSK.



Audio Rate	Outgoing notional sample rate (48000)
Quadrature Rate	Incoming notional sample rate (**48000***)
Tau	FM de-emphasis factor (more on Wikipedia)

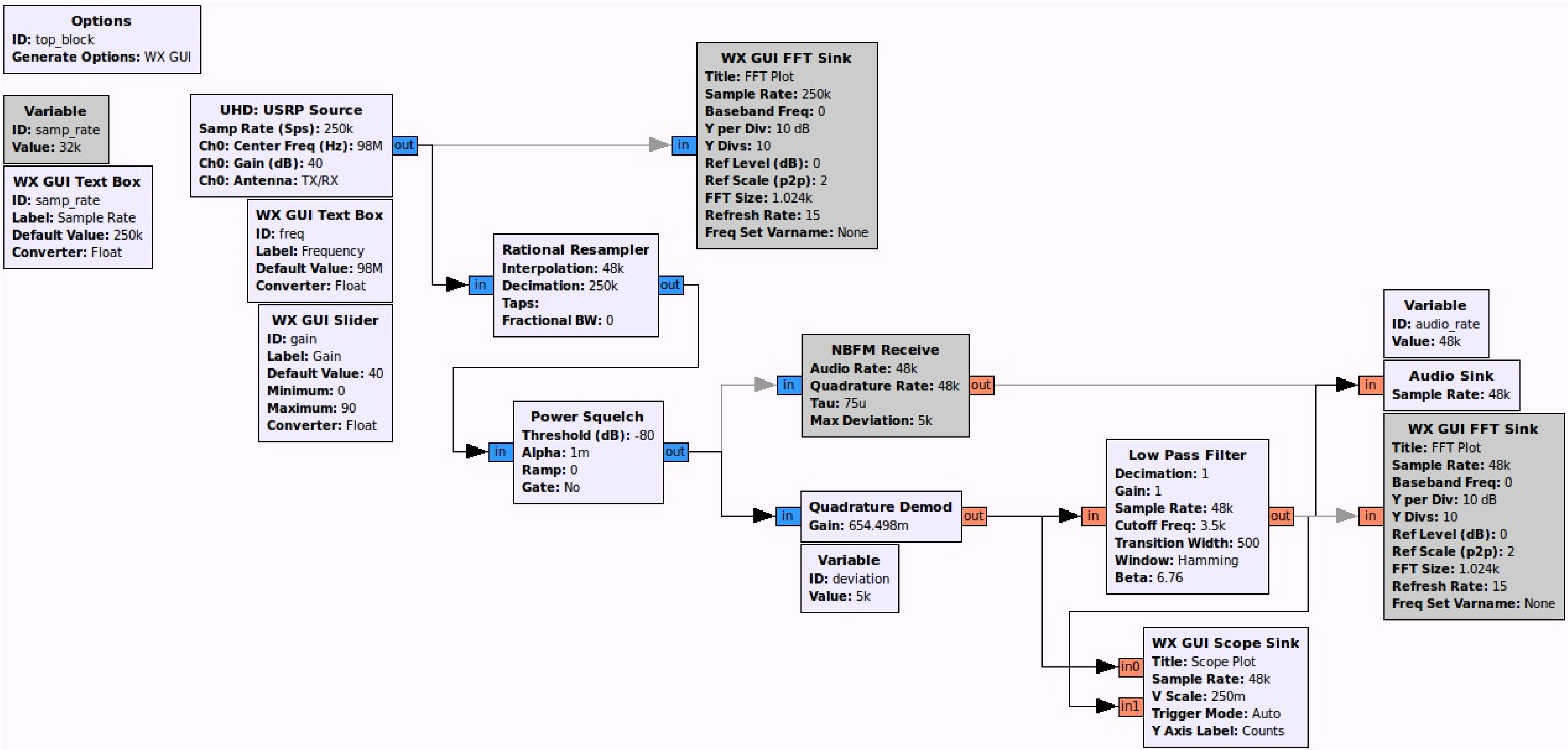
Max Deviation: Maximum amount signal will deviate from center (0 Hz). This determines output value scaling (e.g. here +5 kHz will be 1.0, -5 kHz will be -1.0).

Lab 4: FM RX



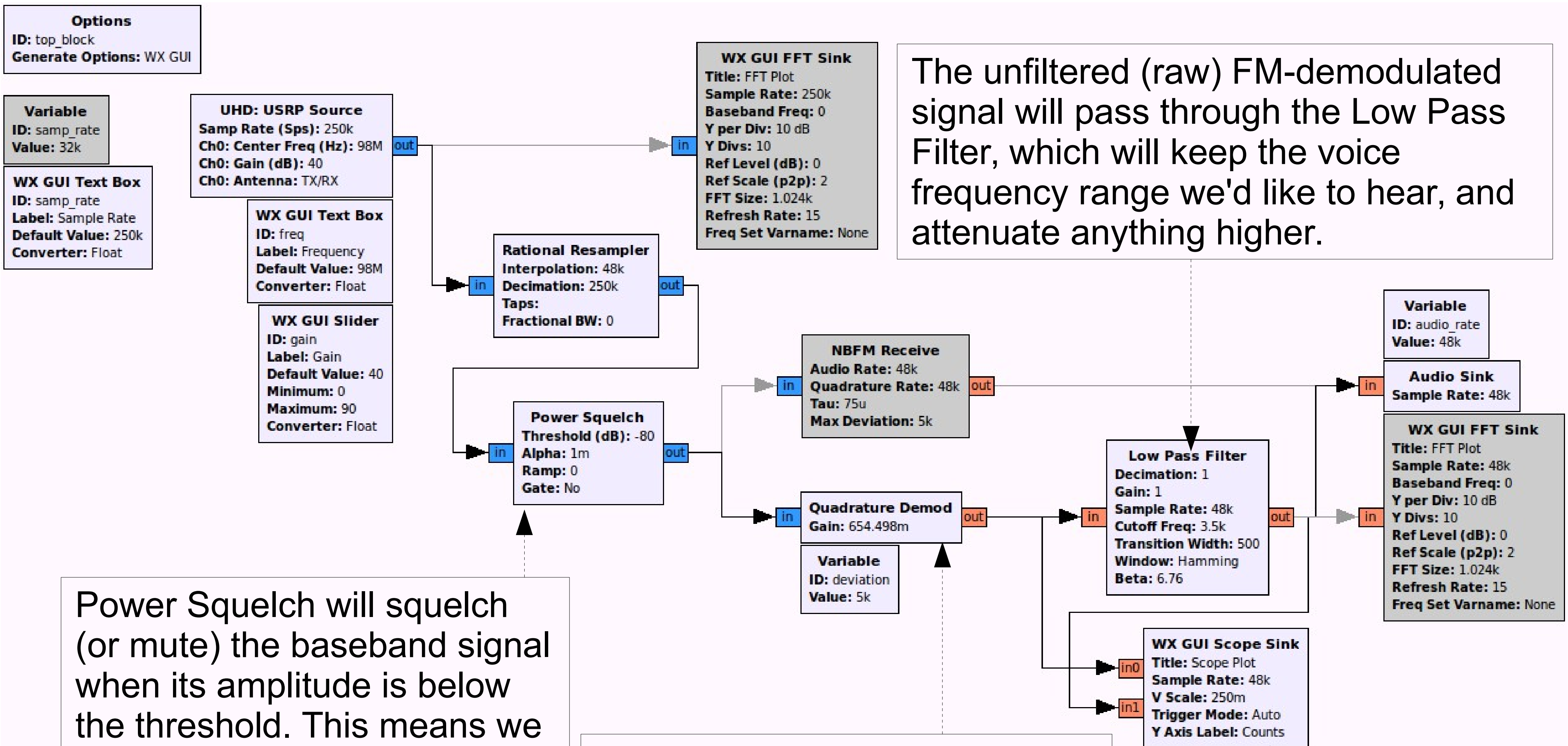
The baseband spectrum (a local radio station) in shown on the FFT plot, and the signal at the center of the spectrum is demodulated producing audio coming out of the host's soundcard.

Lab 4: Manual FM RX



Repeat the Narrow Band FM reception example, but perform the individual demodulation steps.

Lab 4: Manual FM RX



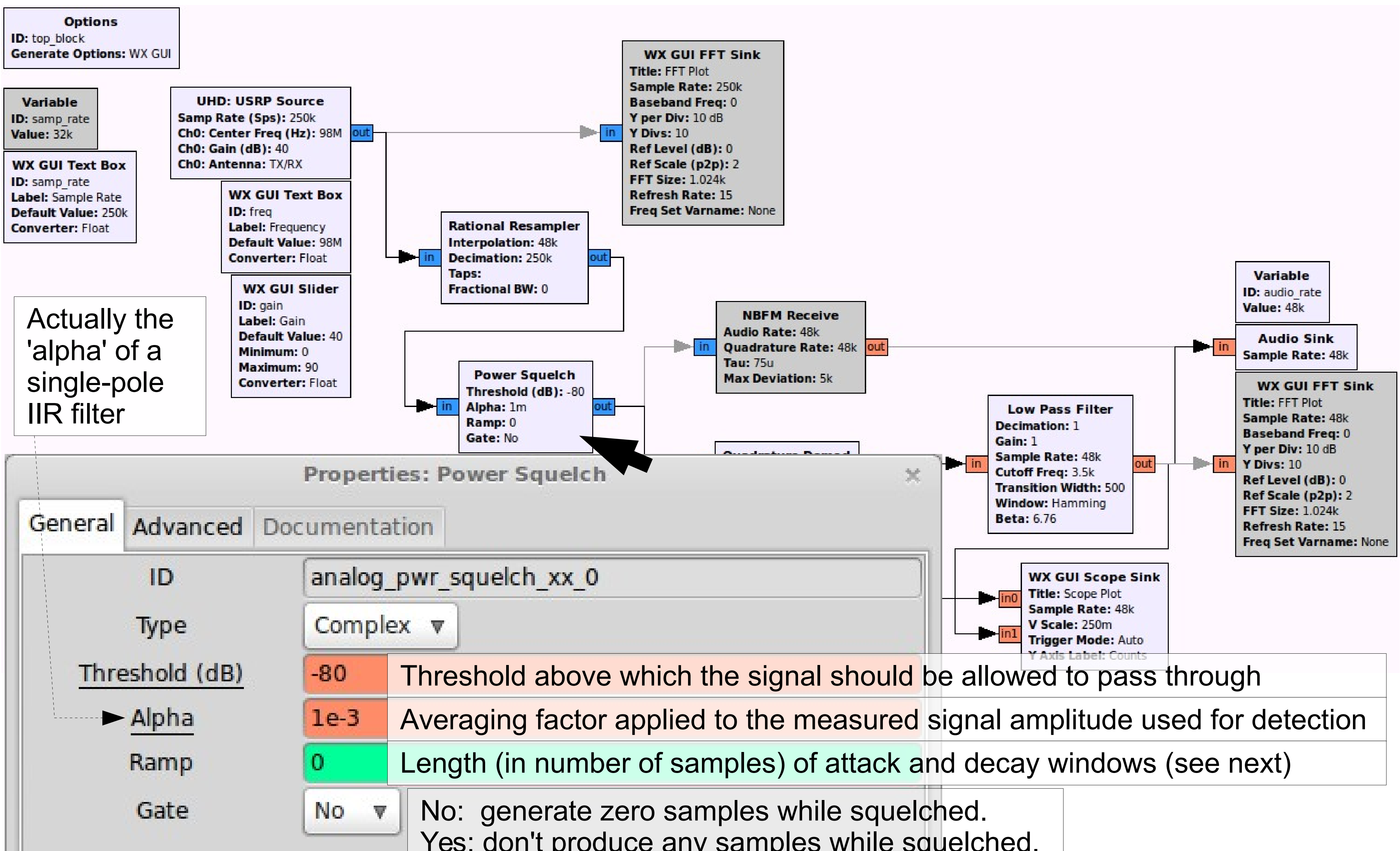
The unfiltered (raw) FM-demodulated signal will pass through the Low Pass Filter, which will keep the voice frequency range we'd like to hear, and attenuate anything higher.

Power Squelch will squelch (or mute) the baseband signal when its amplitude is below the threshold. This means we can avoid listening to noise.

The Quadrature Demodulator is the key part of demodulating an FM signal. The 'deviation' is the maximum frequency shift we expect.

The Scope Sink will plot both the unfiltered and filtered signal.

Lab 4: Manual FM RX



Actually the 'alpha' of a single-pole IIR filter

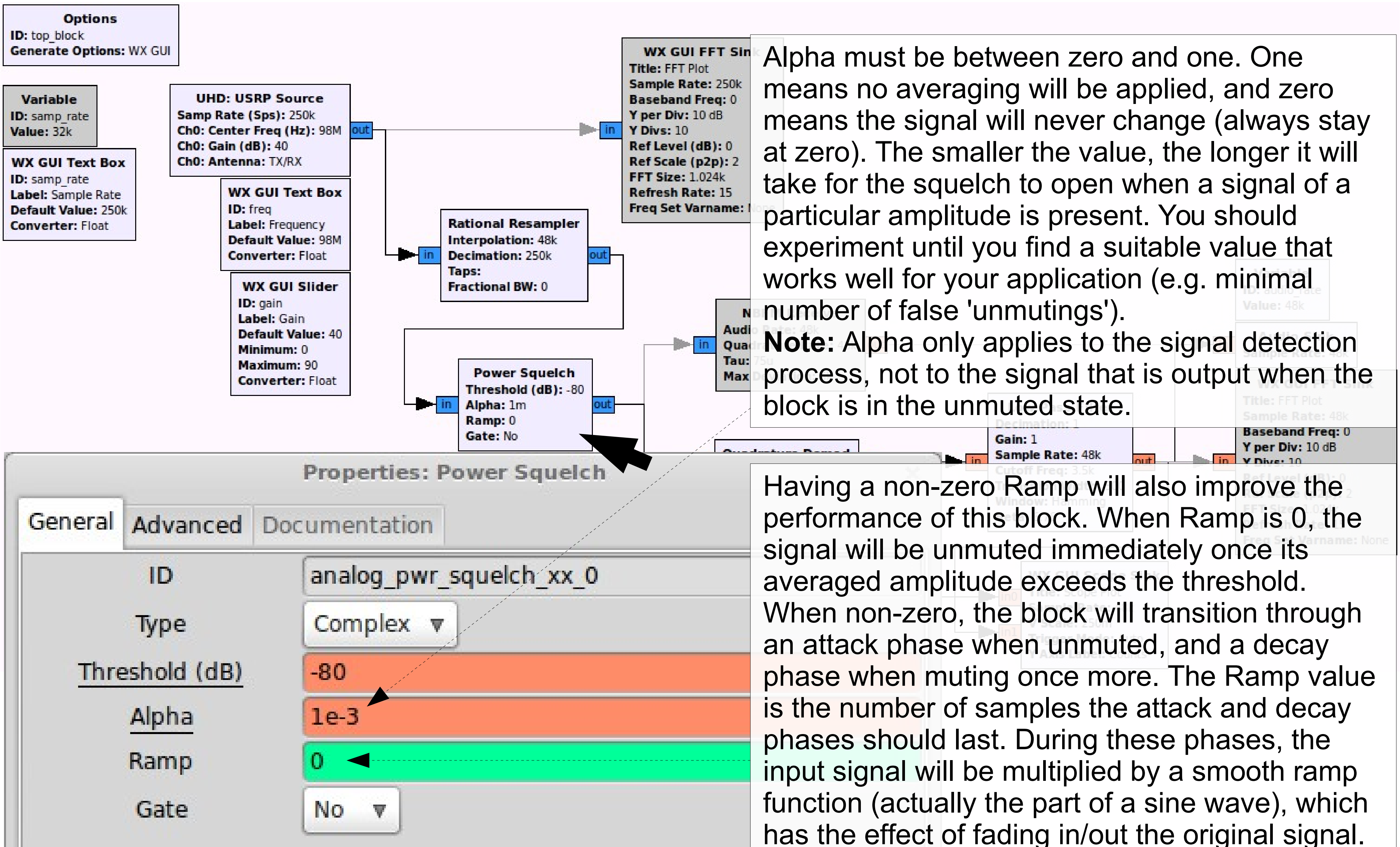
Threshold above which the signal should be allowed to pass through

Averaging factor applied to the measured signal amplitude used for detection

Length (in number of samples) of attack and decay windows (see next)

No: generate zero samples while squelched.
Yes: don't produce any samples while squelched.

Lab 4: Manual FM RX



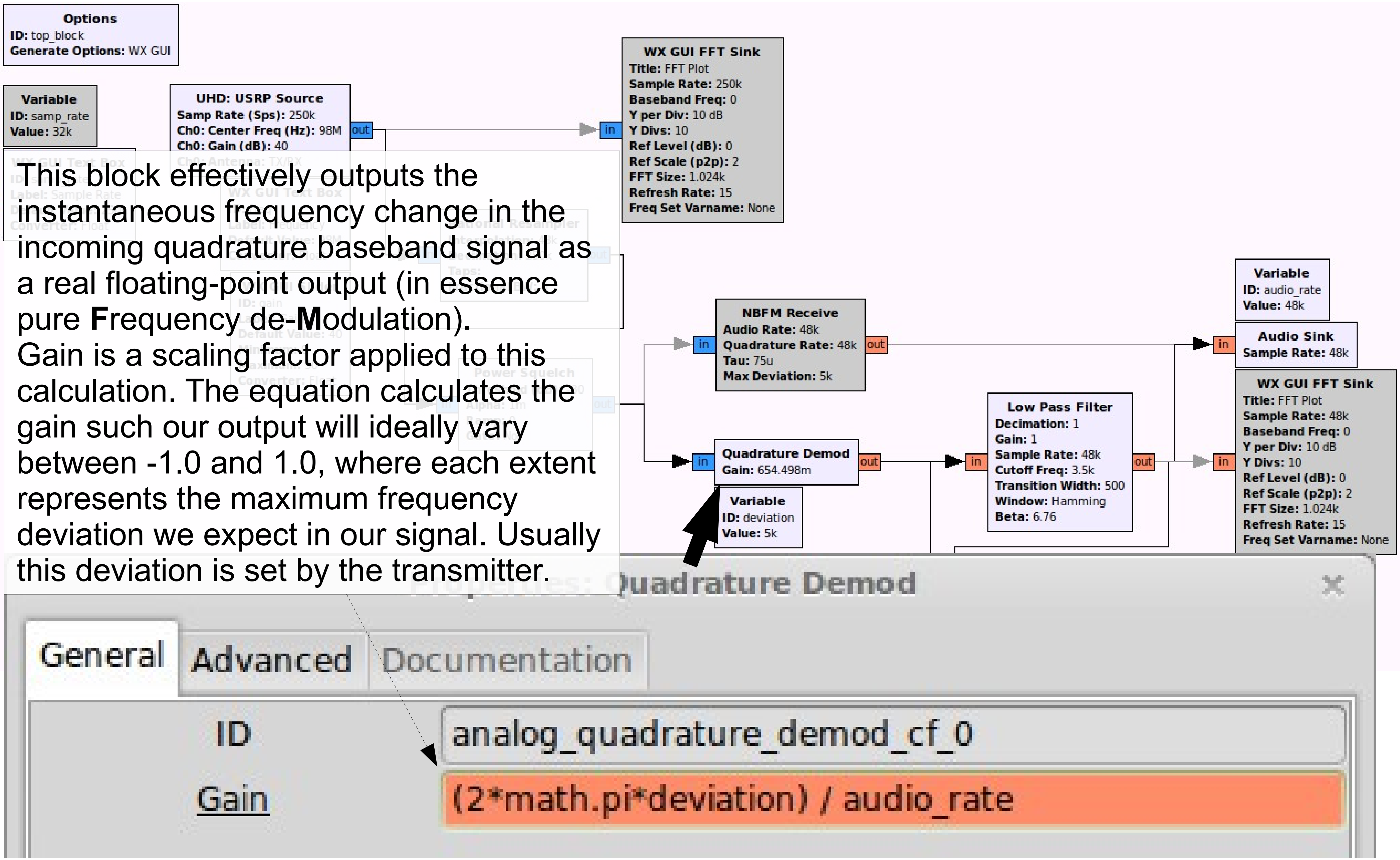
Alpha must be between zero and one. One means no averaging will be applied, and zero means the signal will never change (always stay at zero). The smaller the value, the longer it will take for the squelch to open when a signal of a particular amplitude is present. You should experiment until you find a suitable value that works well for your application (e.g. minimal number of false 'unmutings').

Note: Alpha only applies to the signal detection process, not to the signal that is output when the block is in the unmuted state.

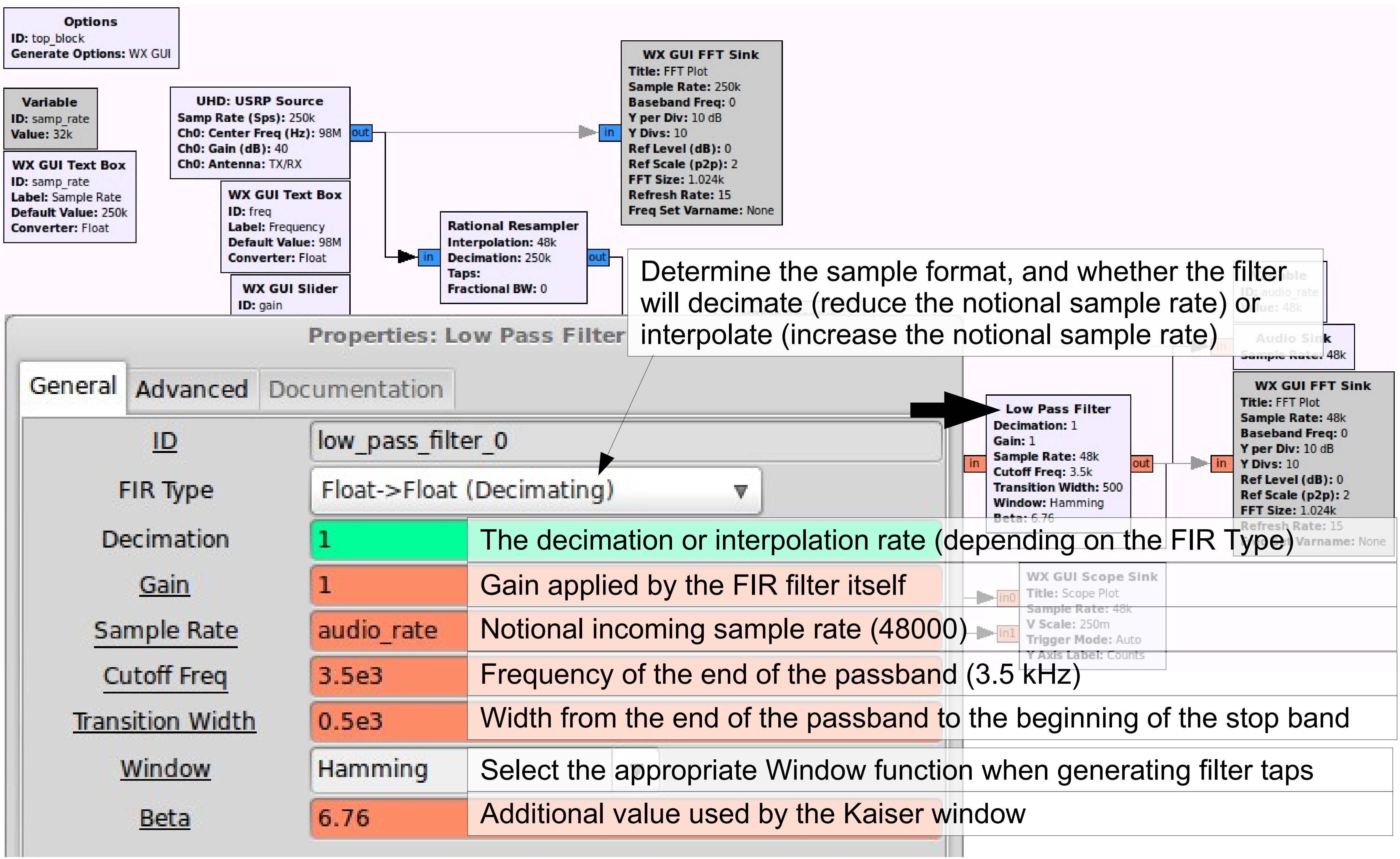
Having a non-zero Ramp will also improve the performance of this block. When Ramp is 0, the signal will be unmuted immediately once its averaged amplitude exceeds the threshold. When non-zero, the block will transition through an attack phase when unmuted, and a decay phase when muting once more. The Ramp value is the number of samples the attack and decay phases should last. During these phases, the input signal will be multiplied by a smooth ramp function (actually the part of a sine wave), which has the effect of fading in/out the original signal.

Lab 4: Manual FM RX

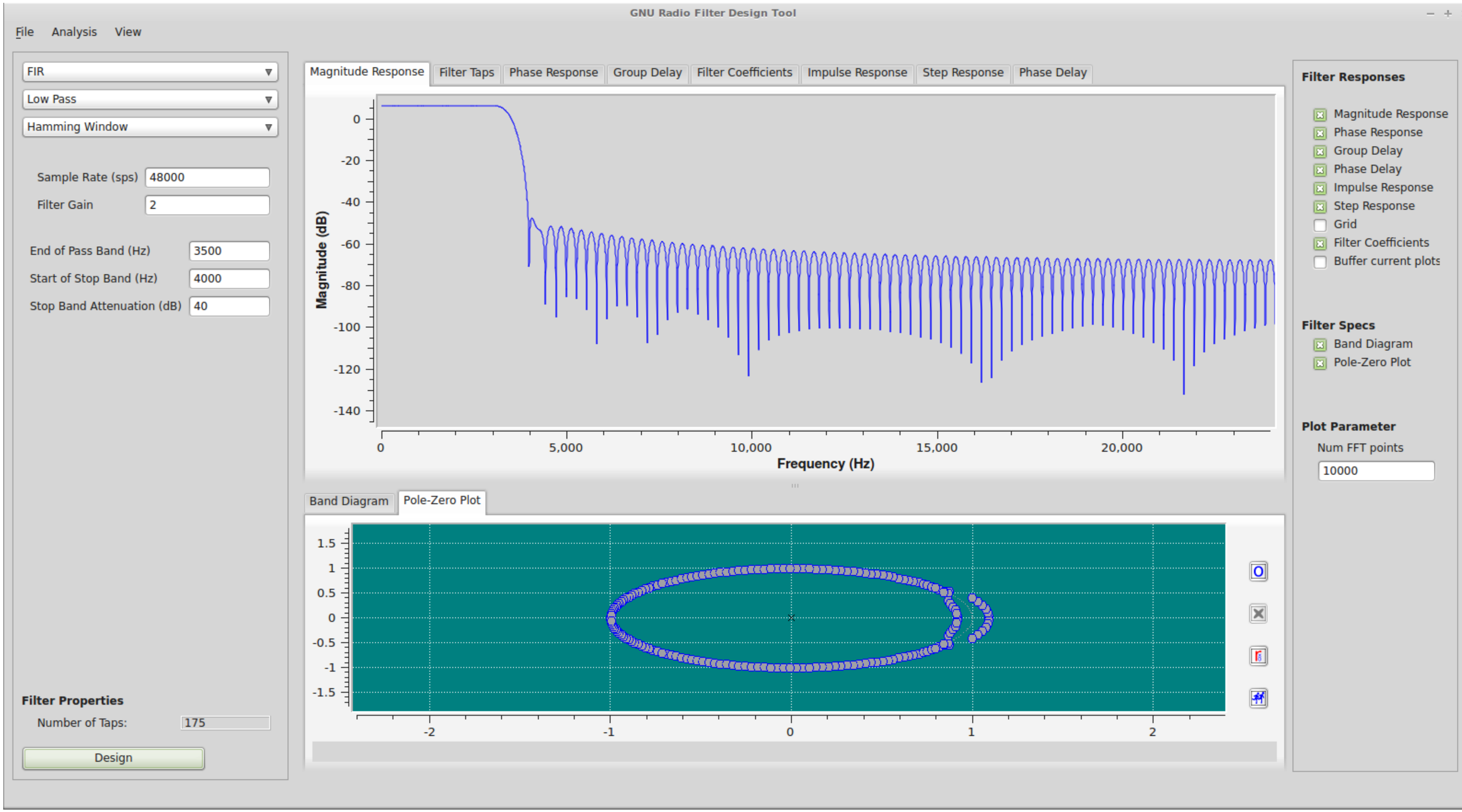
This block effectively outputs the instantaneous frequency change in the incoming quadrature baseband signal as a real floating-point output (in essence pure **F**requency de-**M**odulation).
Gain is a scaling factor applied to this calculation. The equation calculates the gain such our output will ideally vary between -1.0 and 1.0, where each extent represents the maximum frequency deviation we expect in our signal. Usually this deviation is set by the transmitter.



Lab 4: Manual FM RX



Lab 4: Manual FM RX



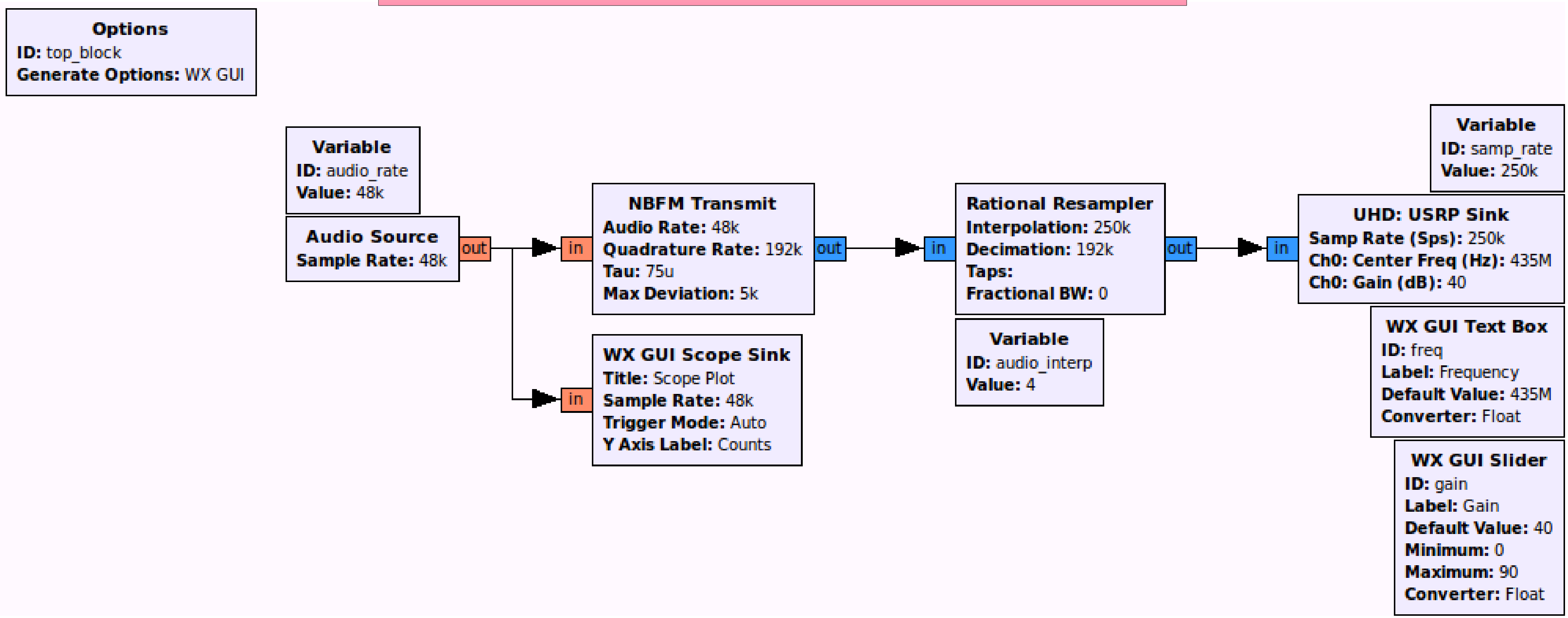
The Filter Design Tool (run 'gr_filter_design') is a GUI that allows you to interactively design different types of filters. Once you're happy with your design, you can place an Interpolating/Decimating FIR Filter block into your GRC flowgraph and set its taps using the filter coefficients output by the designer.

Lab 4: Manual FM RX

The baseband signal will be demodulated as before, however audio will only be heard if there is a strong-enough signal present at the center of the spectrum to open the squelch. The Scope Sink shows the raw demodulated signal (a whistle) in blue, and the low-pass filtered (and therefore slightly delayed) signal in green, which is output to the Audio Sink.

Lab 5: FM TX

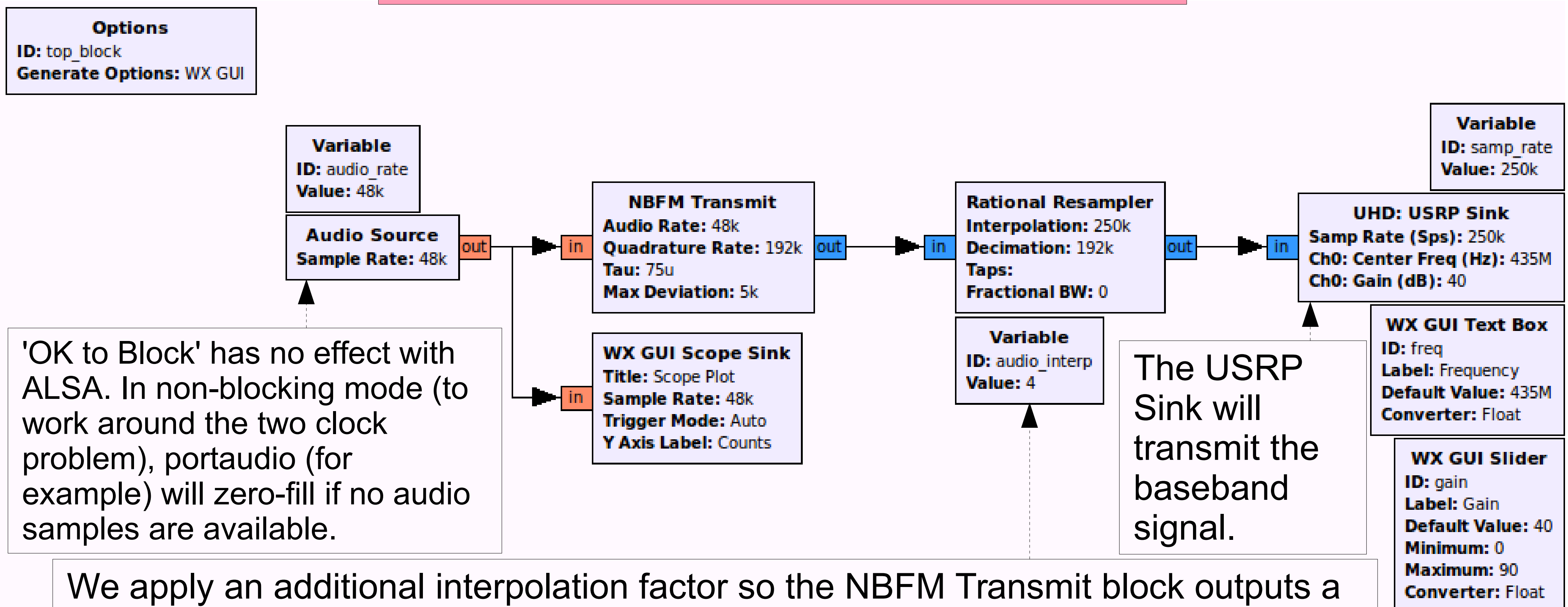
You need to have a valid amateur radio (HAM) license to actually transmit on the frequency in this example!



Sample audio from your soundcard and transmit it from a USRP using a **N**arrow **B**and **FM** carrier.

Lab 5: FM TX

You need to have a valid amateur radio (HAM) license to actually transmit on the frequency in this example!



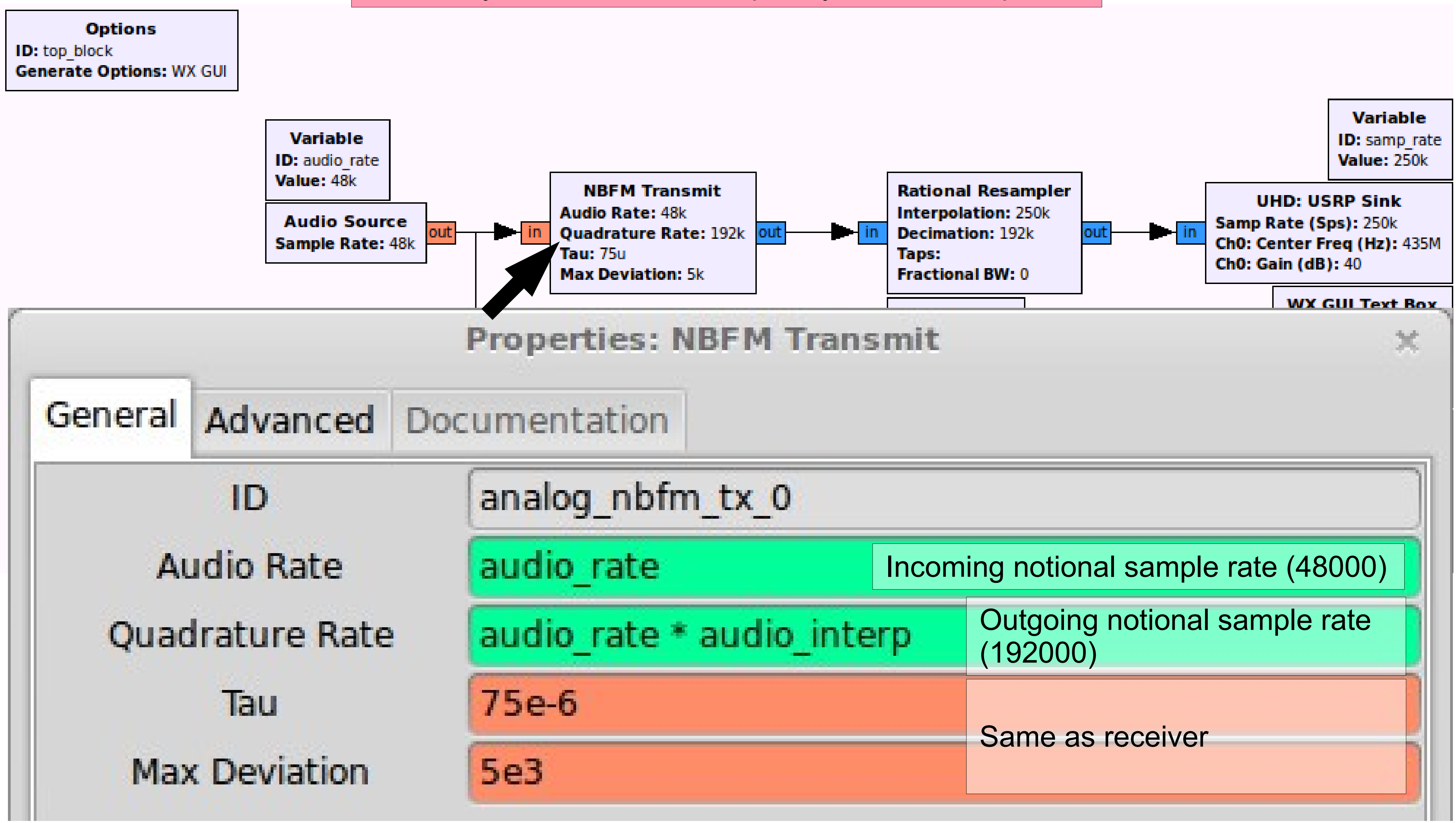
'OK to Block' has no effect with ALSA. In non-blocking mode (to work around the two clock problem), portaudio (for example) will zero-fill if no audio samples are available.

The USRP Sink will transmit the baseband signal.

We apply an additional interpolation factor so the NBFM Transmit block outputs a higher notional sample rate (192000), and then we resample for the USRP (to 250000).
In transmit chain, you will usually be able to control the modulated signal's notional baseband rate (here it is 192000, i.e. prior to resampling for the USRP).
This makes for a tradeoff between a higher-rate, potentially higher-quality synthesised baseband signal (at the expense of processing power), or saving CPU cycles for lower-quality. This choice is usually application-/signal-specific.

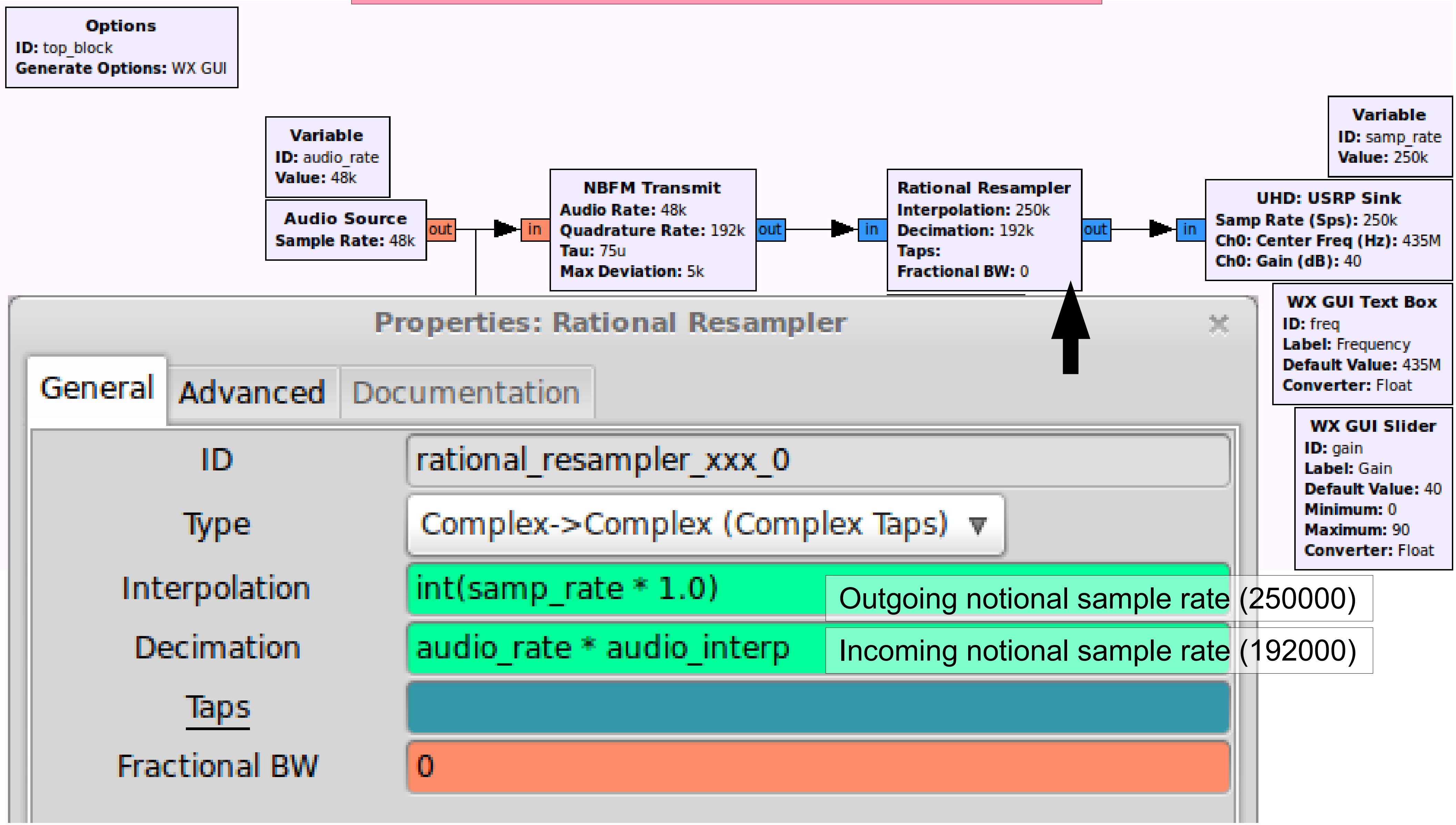
Lab 5: FM TX

You need to have a valid amateur radio (HAM) license to actually transmit on the frequency in this example!



Lab 5: FM TX

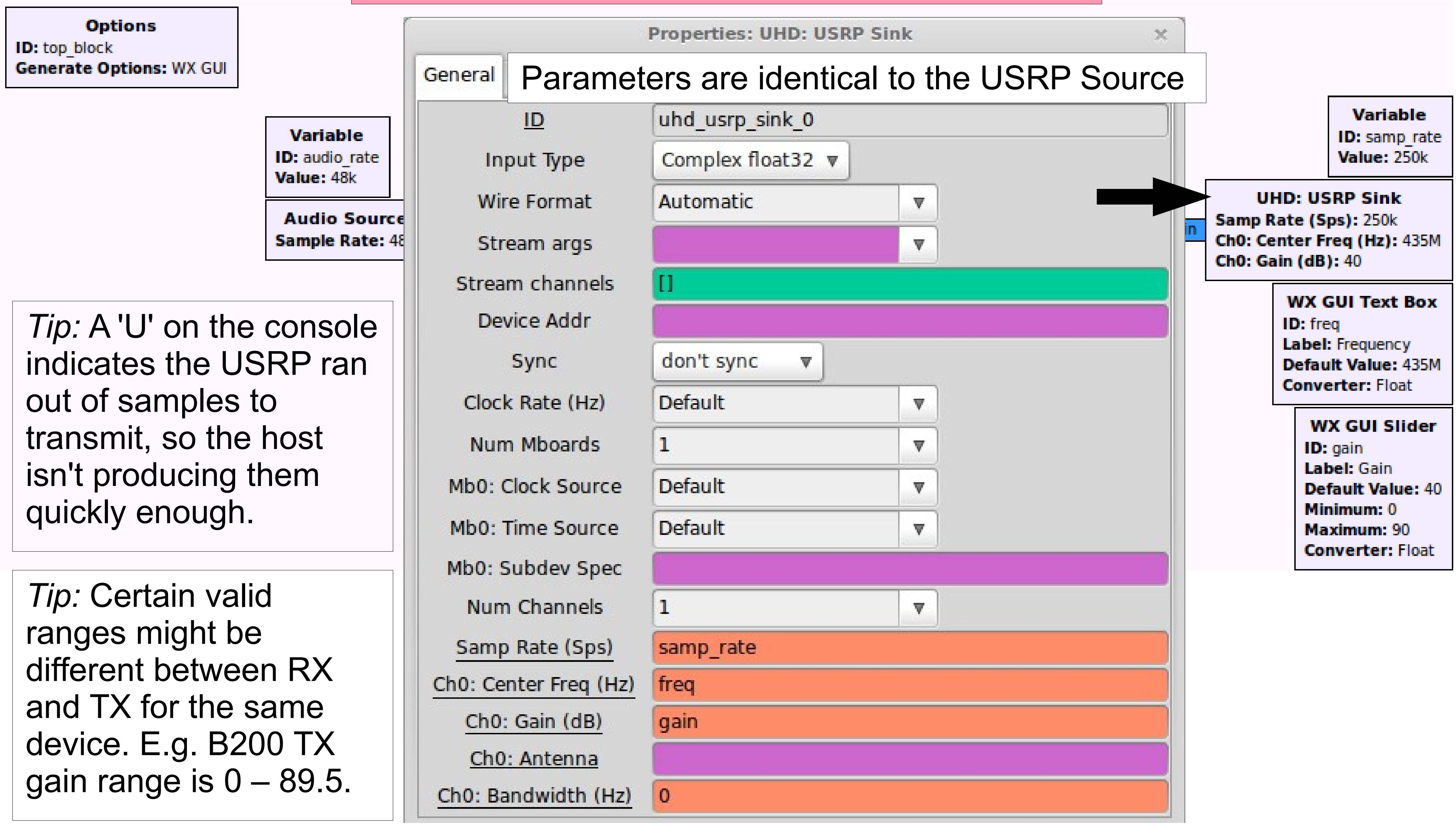
You need to have a valid amateur radio (HAM) license to actually transmit on the frequency in this example!



Lab 5: FM TX

You need to have a valid amateur radio (HAM) license to actually transmit on the frequency in this example!

Parameters are identical to the USRP Source



Tip: A 'U' on the console indicates the USRP ran out of samples to transmit, so the host isn't producing them quickly enough.

Tip: Certain valid ranges might be different between RX and TX for the same device. E.g. B200 TX gain range is 0 – 89.5.

Lab 5: FM TX

You need to have a valid amateur radio (HAM) license to actually transmit on the frequency in this example!

The audio (a whistle) picked up by the sound card will be shown in the scope plot, and transmitted by the USRP at the selected frequency.

Lab 5: FM TX

- If you see lots of the letter 'U' in the console, the transmit chain of the USRP is experiencing underruns: samples cannot be produced quickly enough by the host.
- In this example (under Linux/ALSA) it will occur because of the 'two clock' problem, but cannot be fixed by changing 'OK to Block' since the Audio Source is producing samples that are all being consumed without issue, but it happens to be doing this a little too slowly.

Lab 5: FM TX

- It is possible to cheat by adding a 'fudge', or 'twiddle', factor to the Interpolation rate at the Rational Resampler.
- In the example it was:
  - int(samp_rate * 1.0)
- We can ask the resampler to produce *more* samples for the same number of input samples so that the USRP will always have enough samples to transmit
- The Interpolation rate would become:
  - int(samp_rate * 1.01)
  - The notional output rate was increased by 1% (1.0 + 0.01), which equals = 252500.
    The USRP UHD Sink will *still* consume at 250000.

GNU Radio:

http://gnuradio.org/

CGRAN:

http://cgran.org/

Ettus Research:

http://ettus.com/

UHD Docs:

http://files.ettus.com/uhd_docs/doxymanual/html/