Frequency Modulation: Introduction and Concepts

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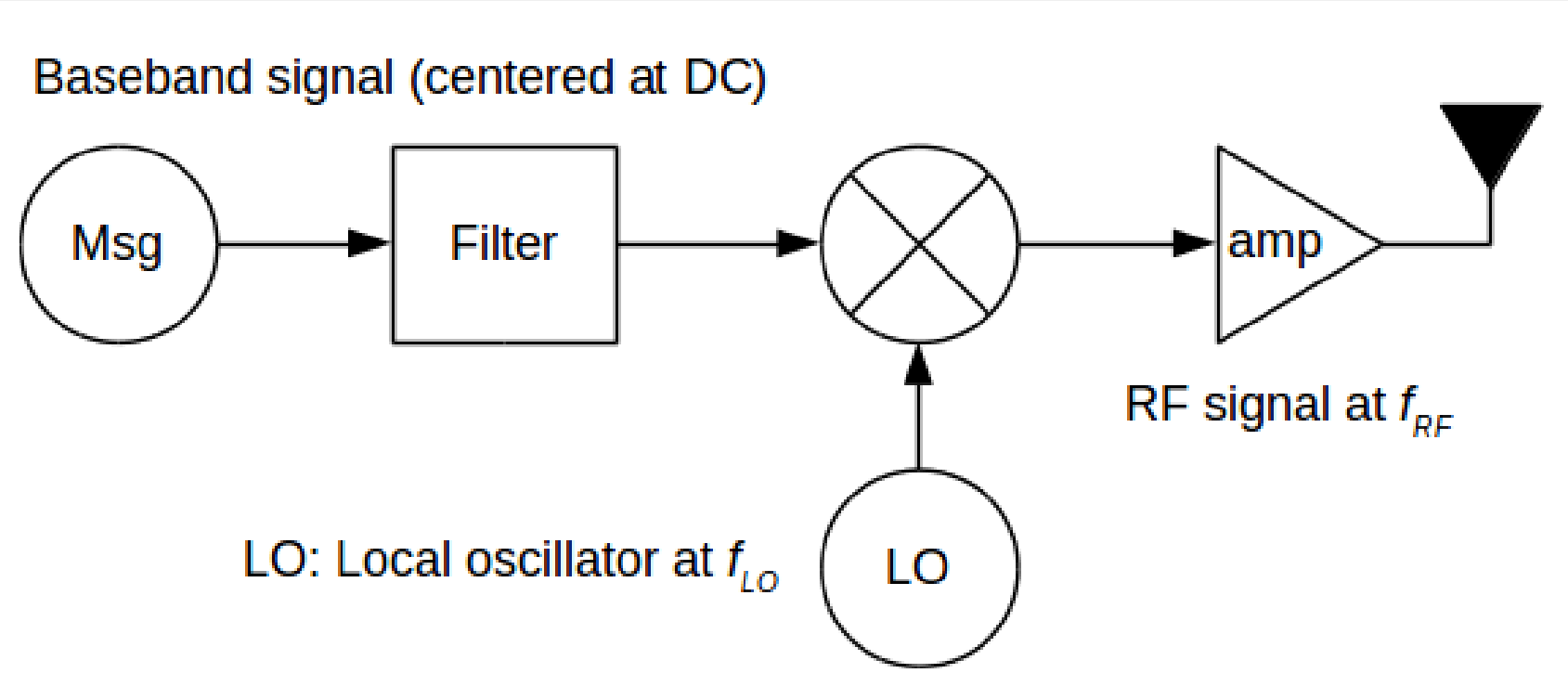
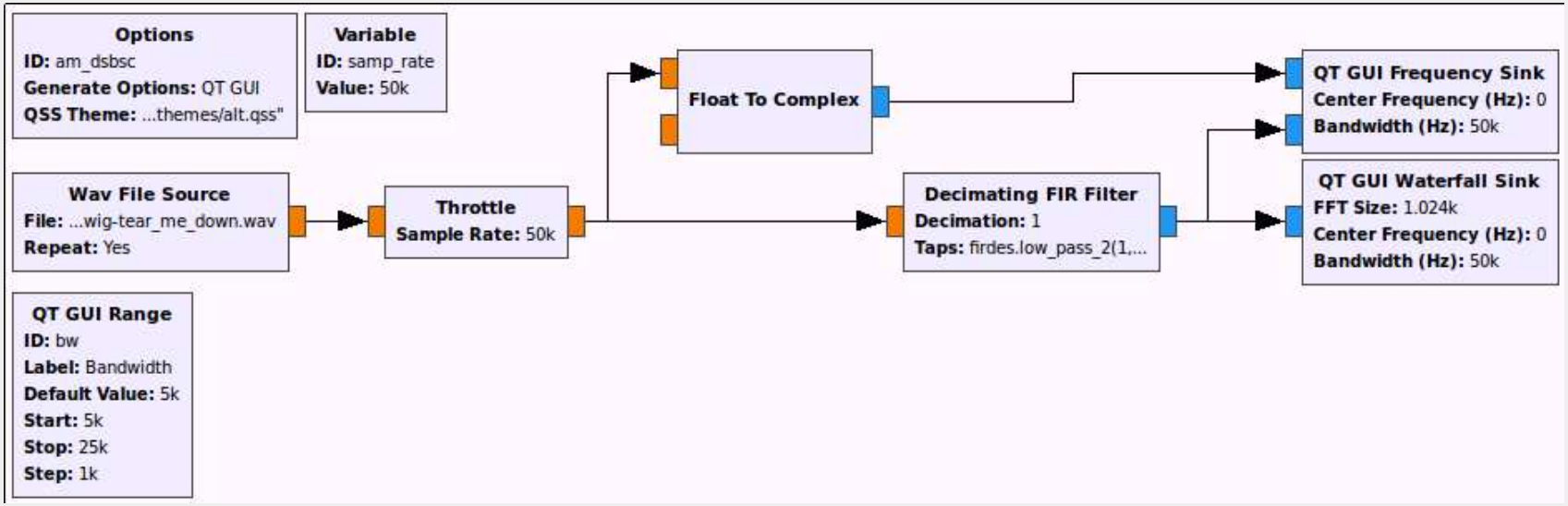
"It is proved that the frequency modulation system using a spacing or compensating wave is inferior to the amplitude variation system both as to the width of the frequency band occupied and as to distortion of signal wave form."

- John R. Carson, "Notes on the Theory of Modulation"

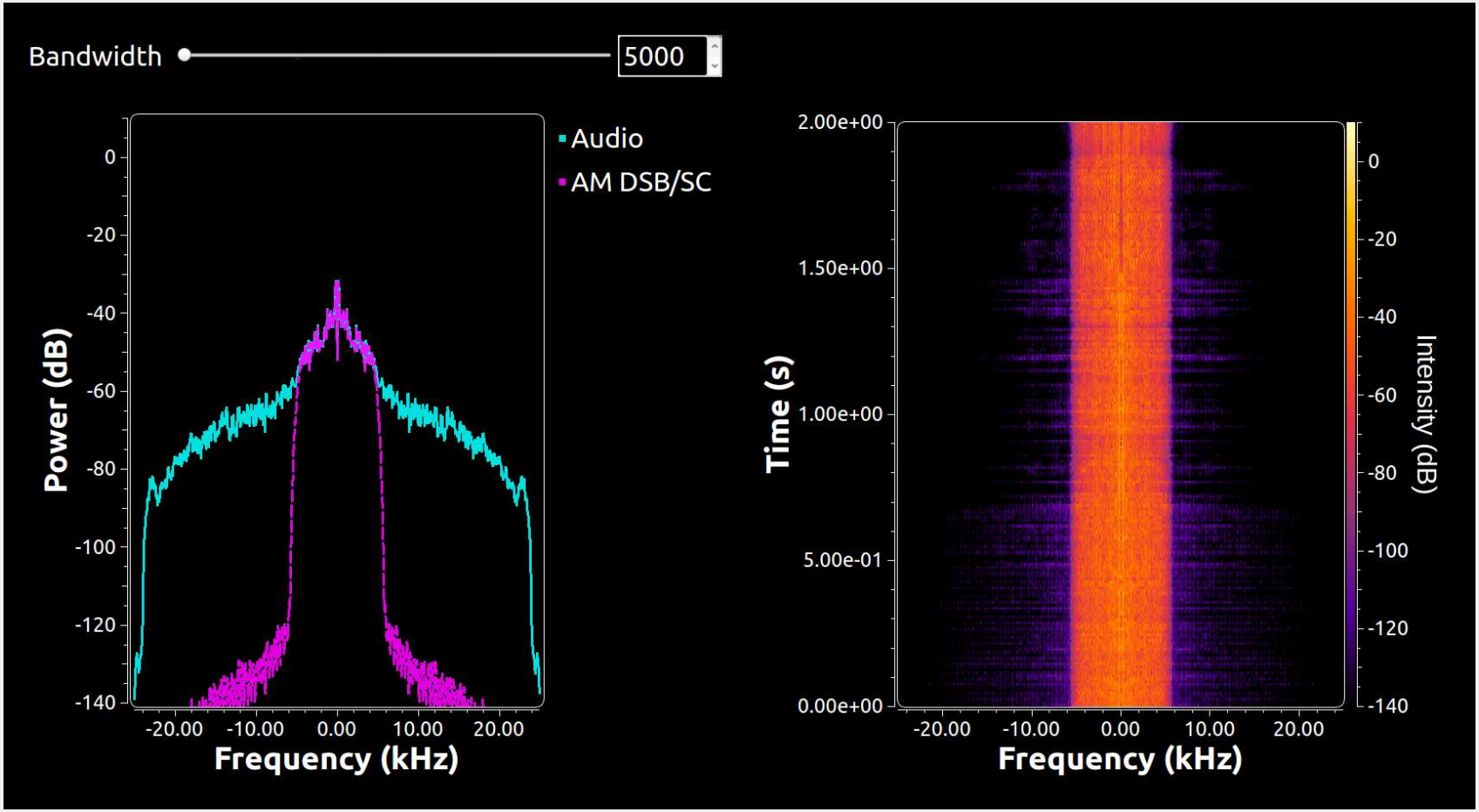
Amplitude Modulation



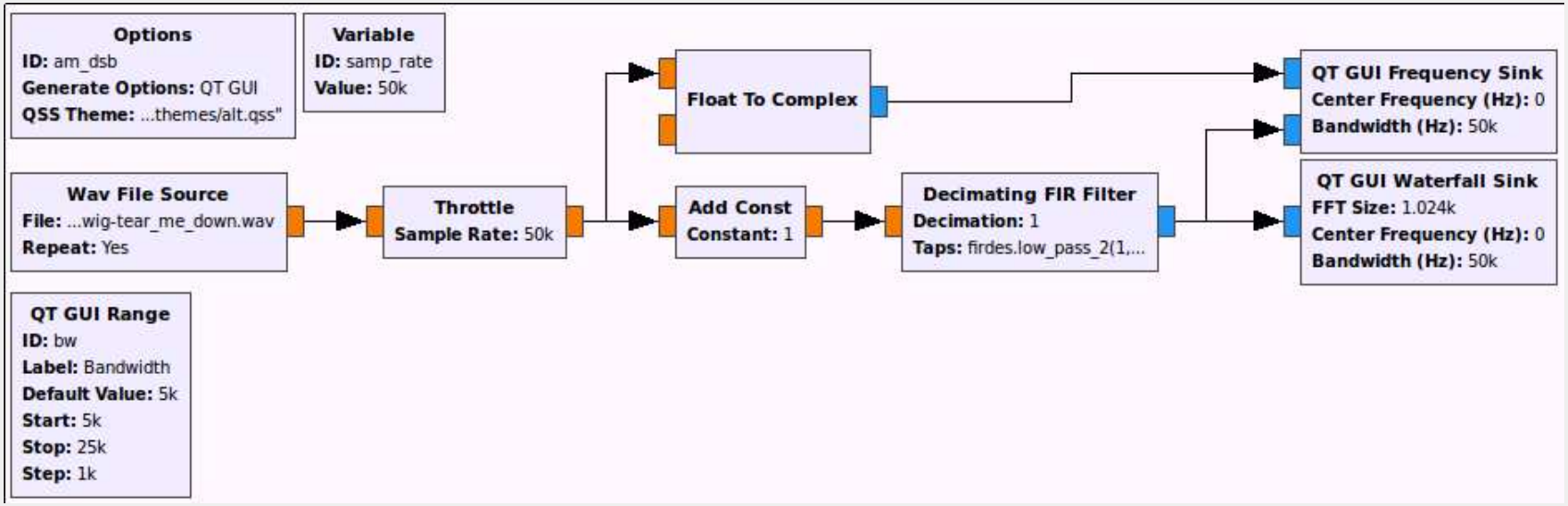
Double Sideband, Suppressed Carrier



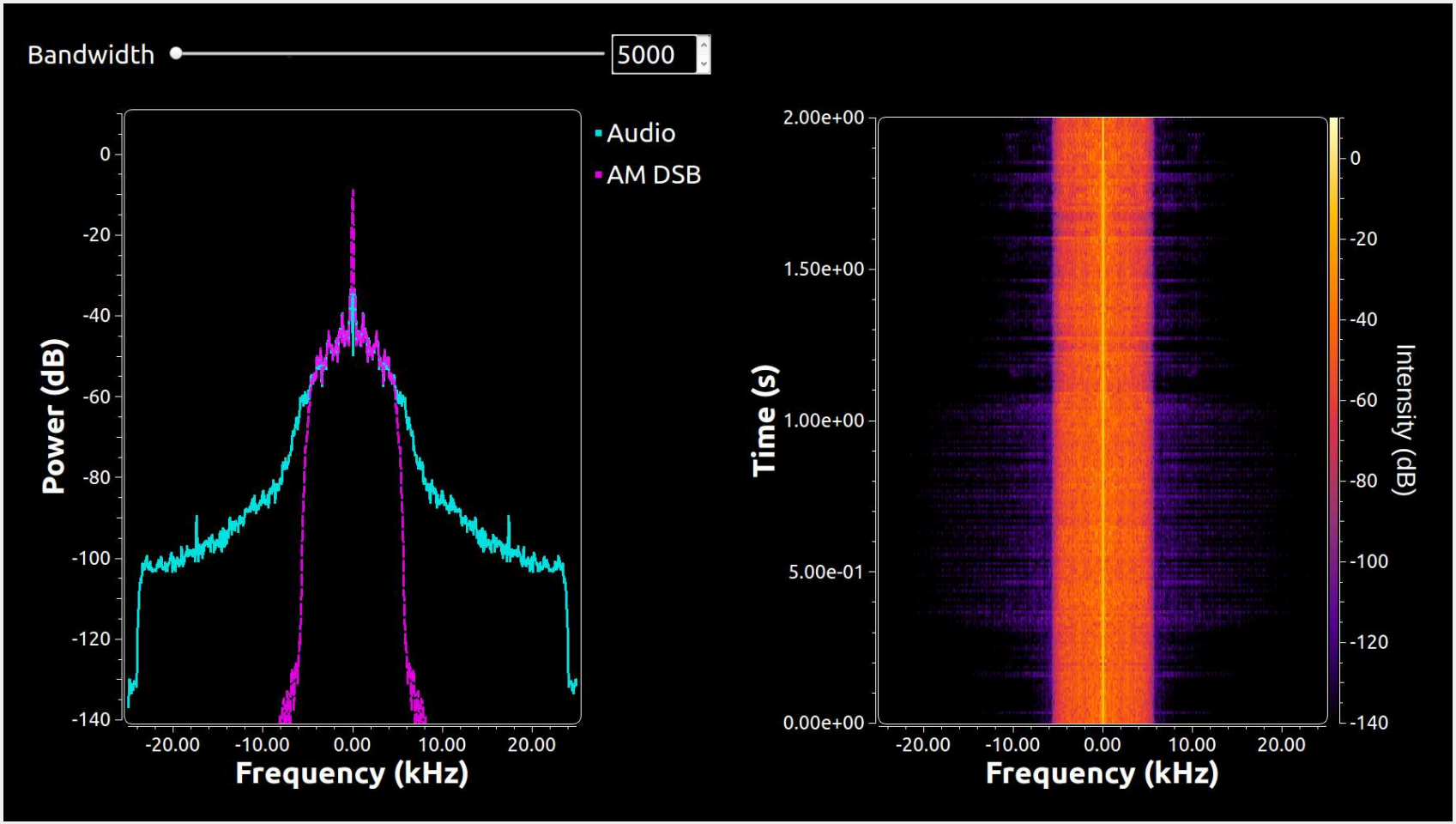
Double Sideband, Suppressed Carrier



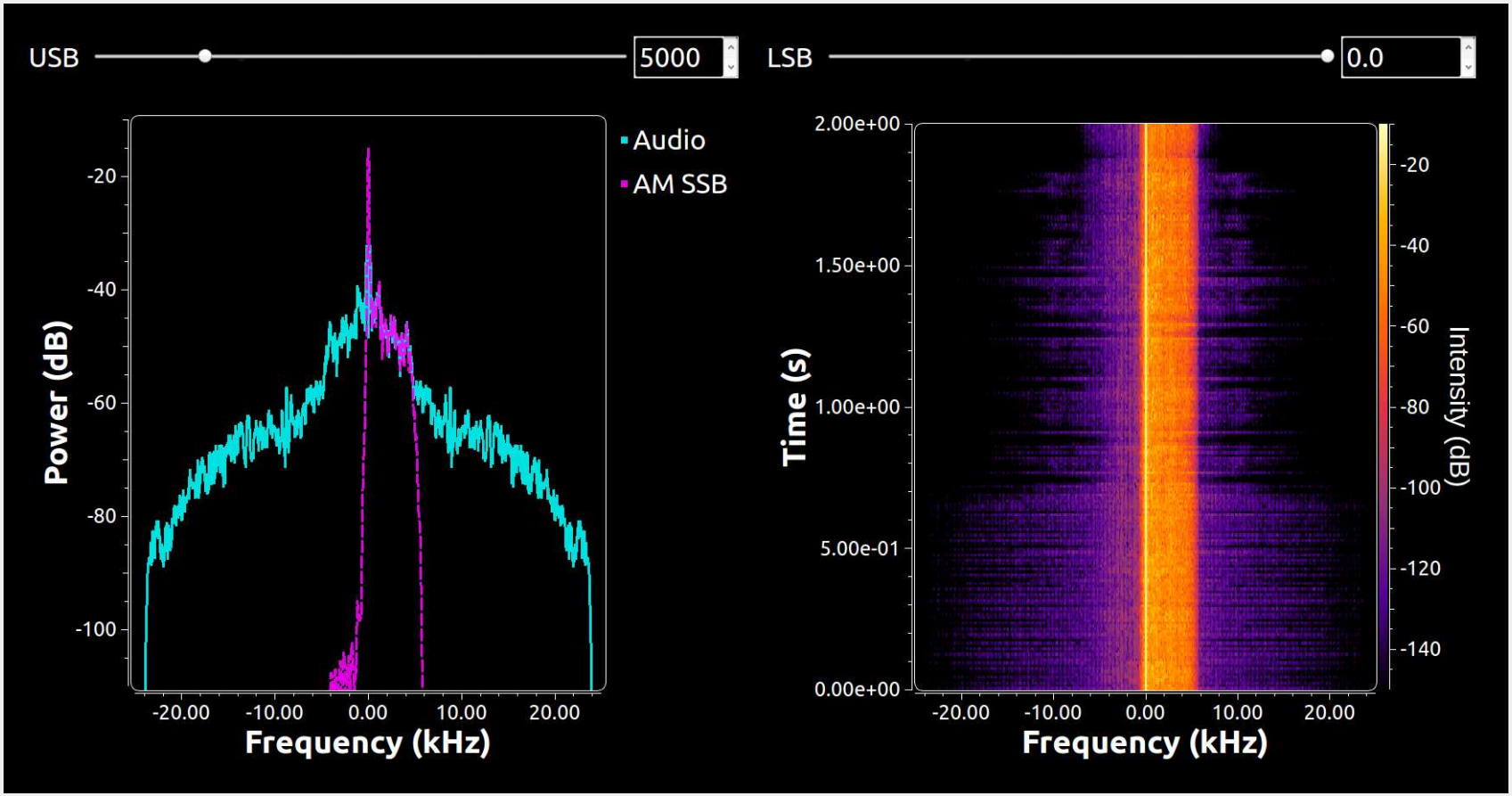
Double Sideband (With Carrier)



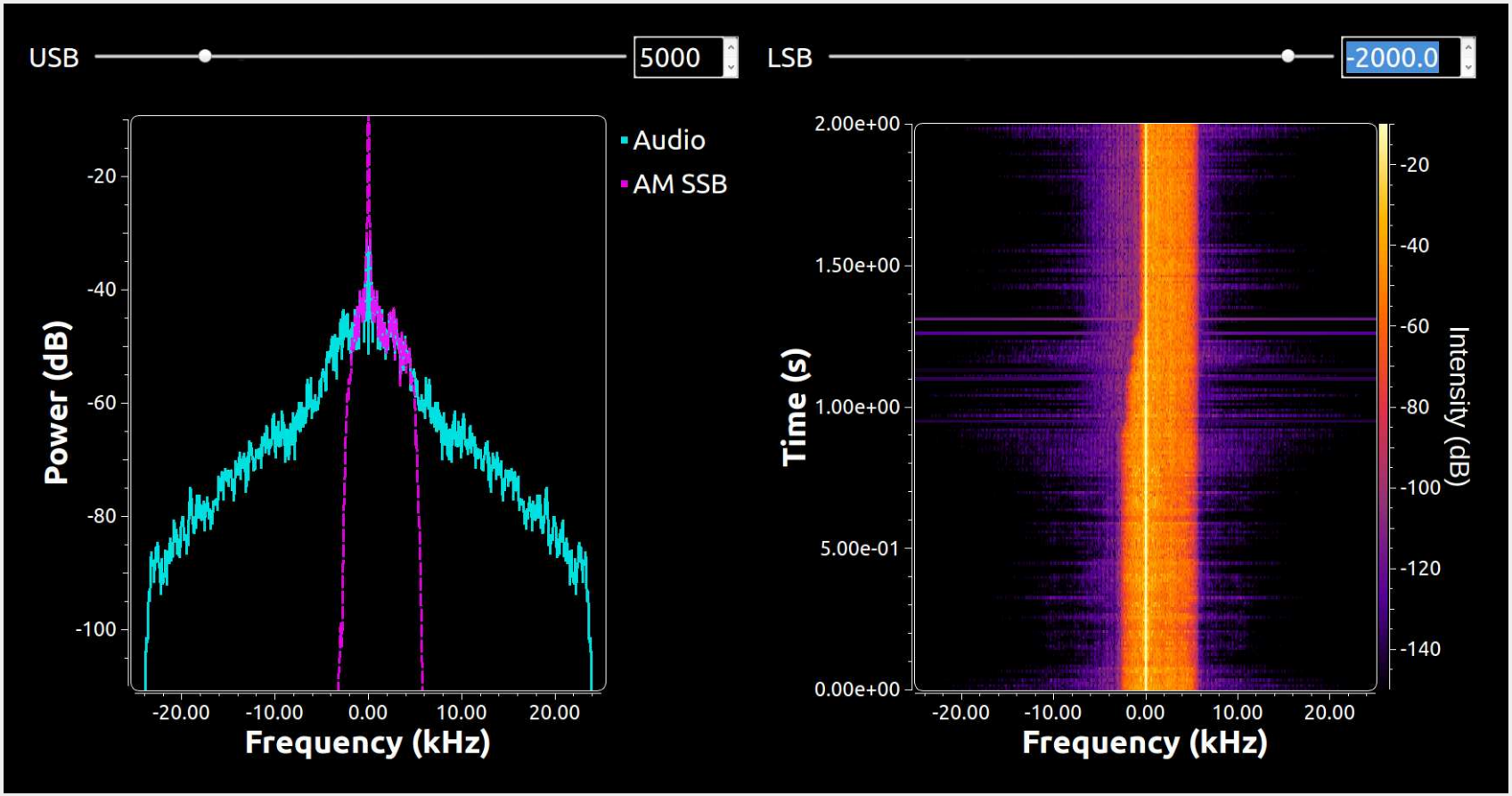
Double Sideband (With Carrier)



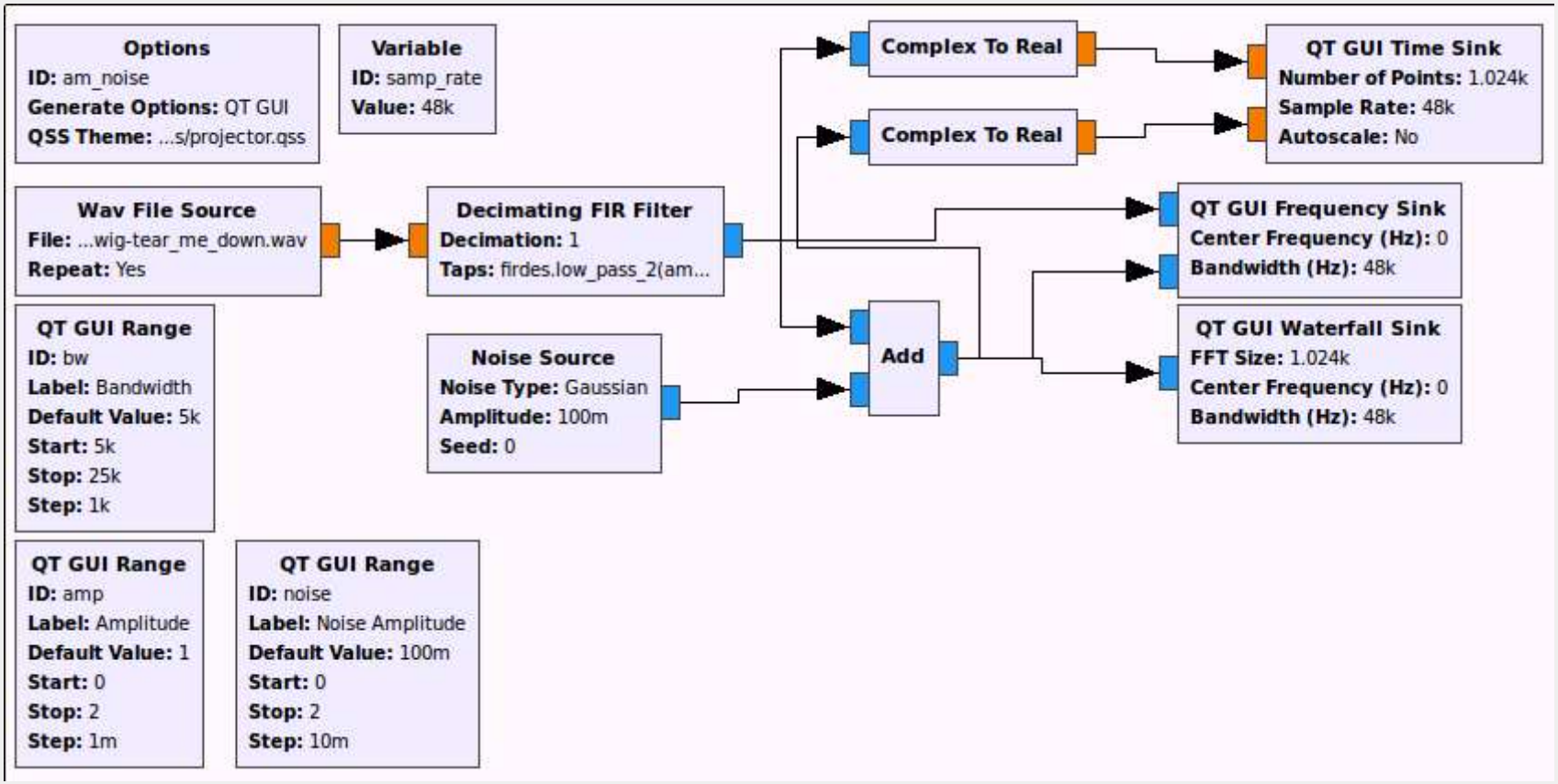
Single Sideband (Upper)



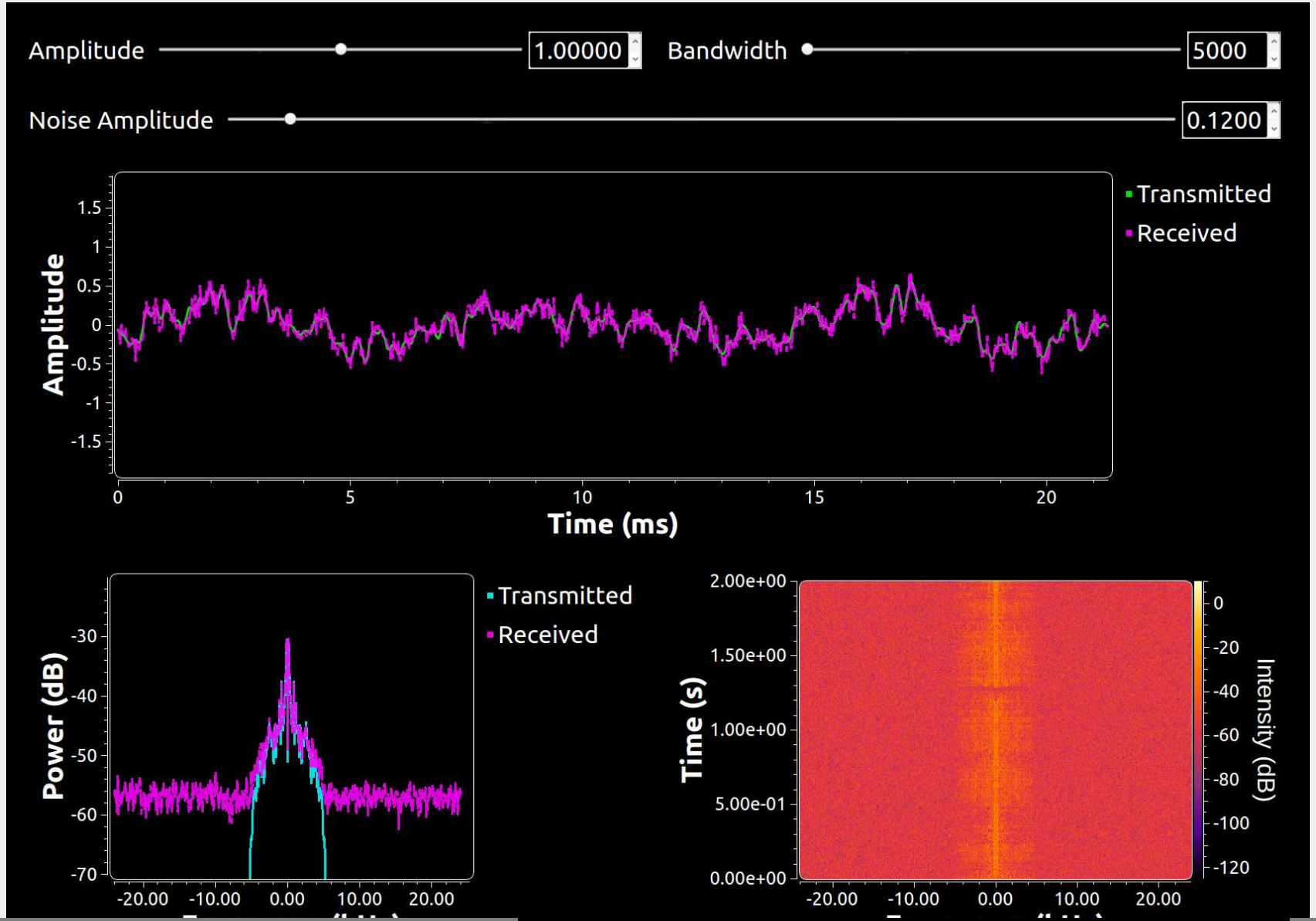
Single Sideband (Vestigial)



Problem with noise: Information in amplitude



Problem with noise: Noise changes amplitude

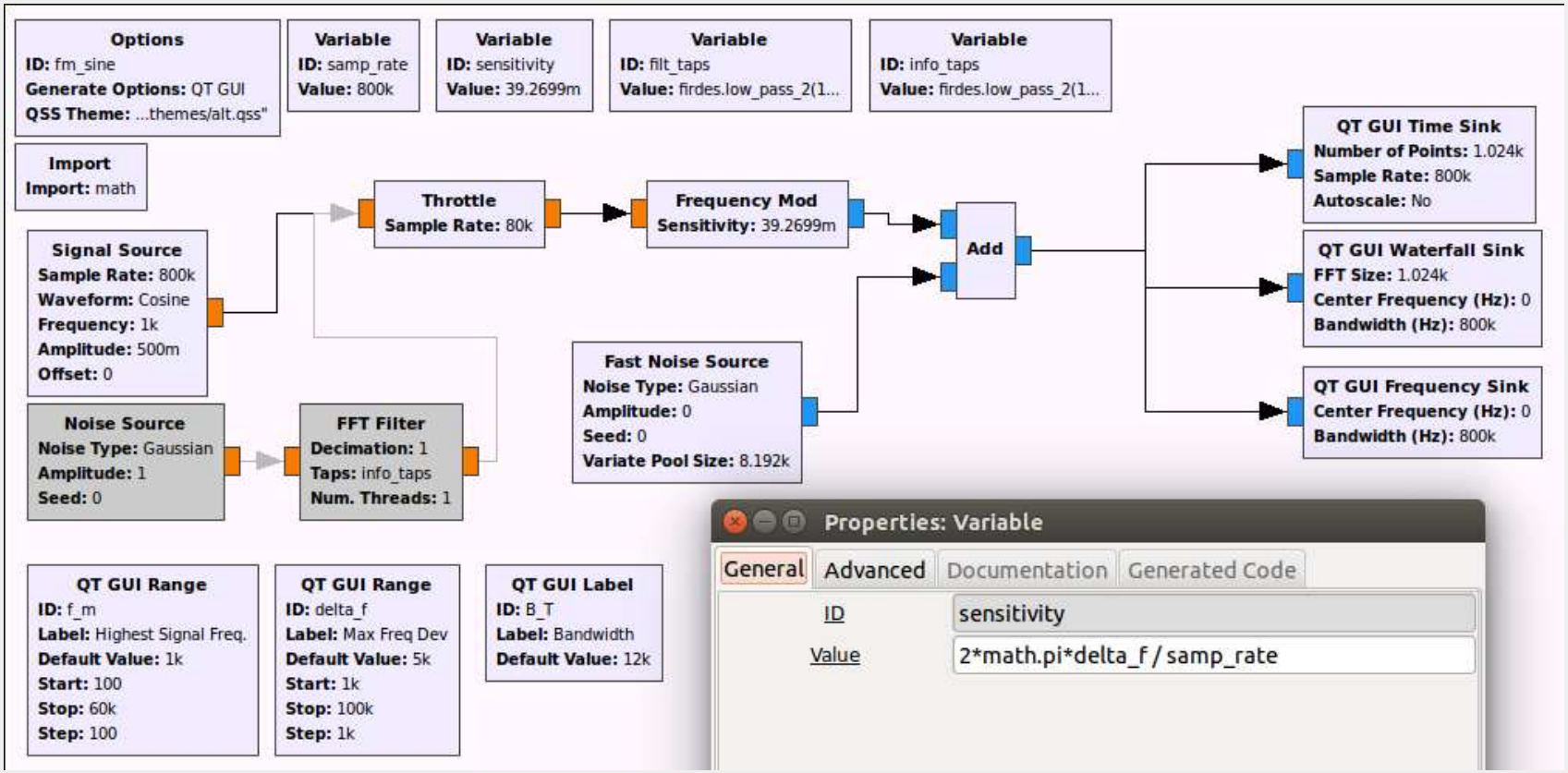


"This superiority will increase as methods of dealing with ignition noise, either at its source or at the receiver, are improved"

- Edwin H. Armstrong, "A Method of Reducing Disturbances in Radio Signaling by a System of Frequency Modulation"

E. H. ARMSTRONG
The discoverer of the "feed-back" circuit, in the uniform of a major in the Signal Corps during the war

FMing a Sine Wave



Frequency Modulation:

Continuous Time

$$y(t) = cos\left(2\pi f_\Delta \int_0^t x(\tau)d\tau\right)$$

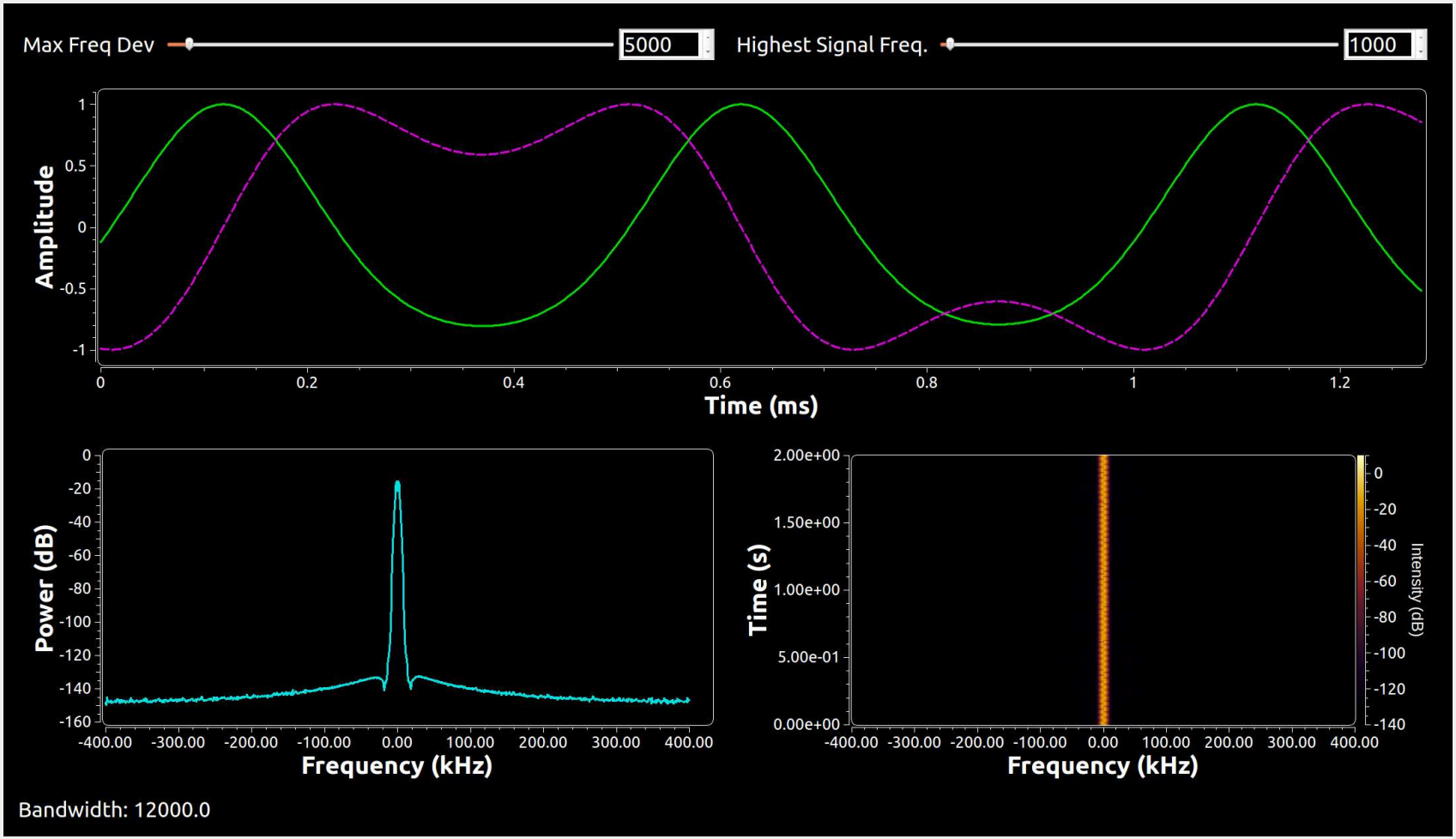
Discrete Time

$$y[n] = cos\left(2\pi \frac{f_\Delta}{f_s} \sum x[n]\right)$$

$$y[n] = cos\left(\eta \sum x[n]\right), \quad \eta = 2\pi \frac{f_\Delta}{f_s}$$

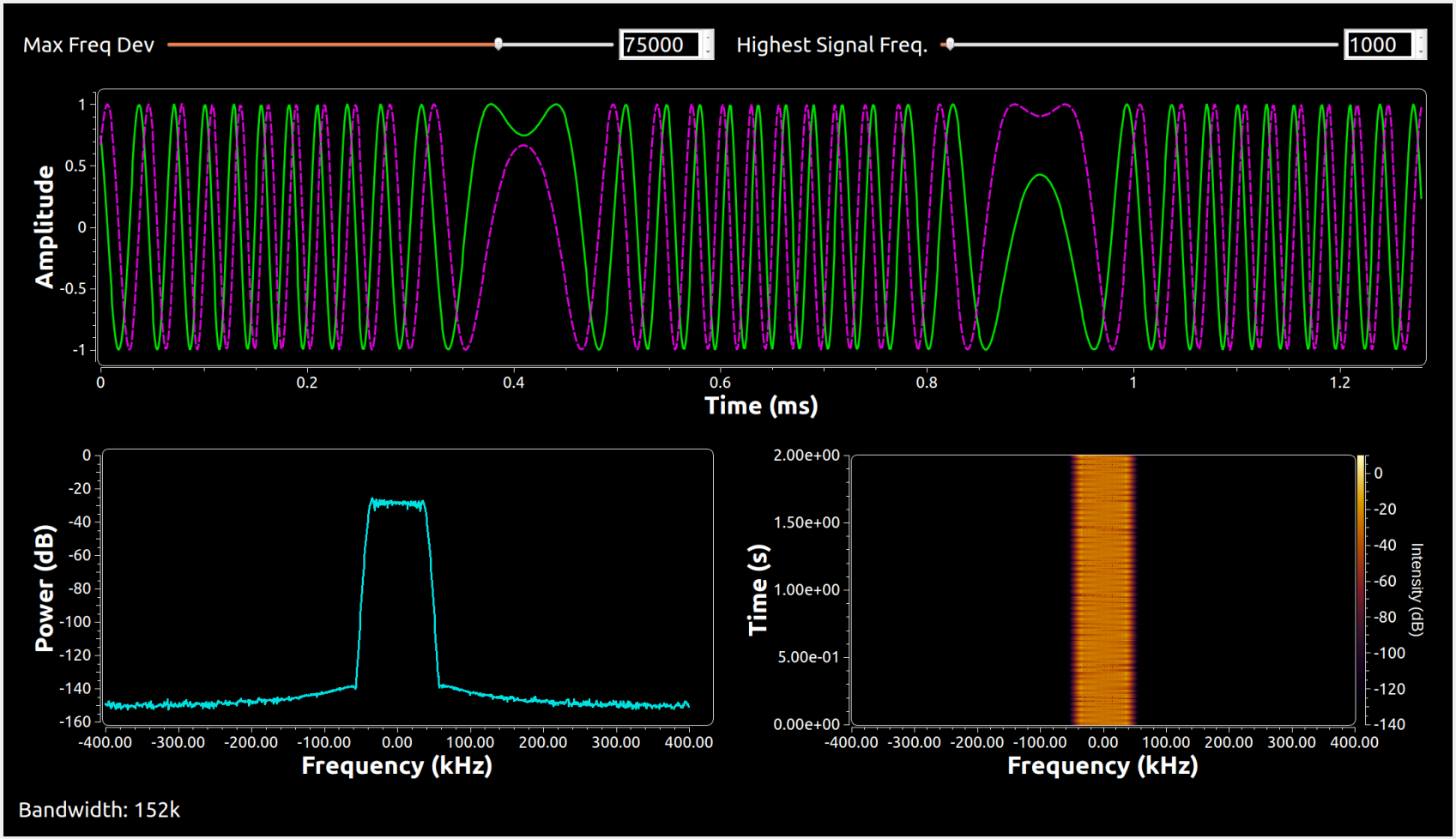
We call η the *sensativity*.

FMing a Sine Wave:
$f_s = 800$ ksps, $f_\Delta = 5$ kHz, $f_m = 1$ kHz



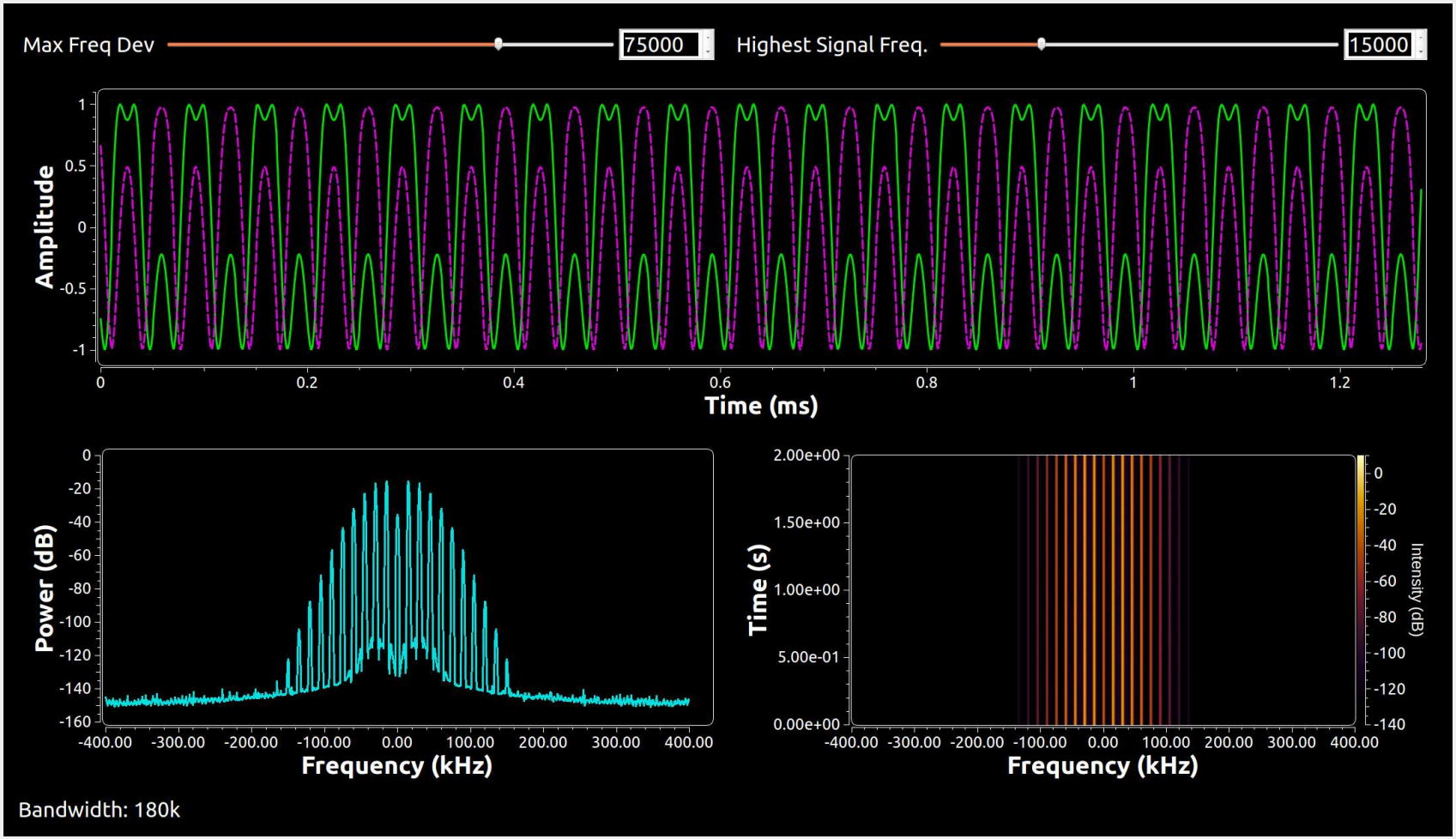
FMing a Sine Wave

$f_s = 800$ ksps, $f_\Delta = 75$ kHz, $f_m = 1$ kHz



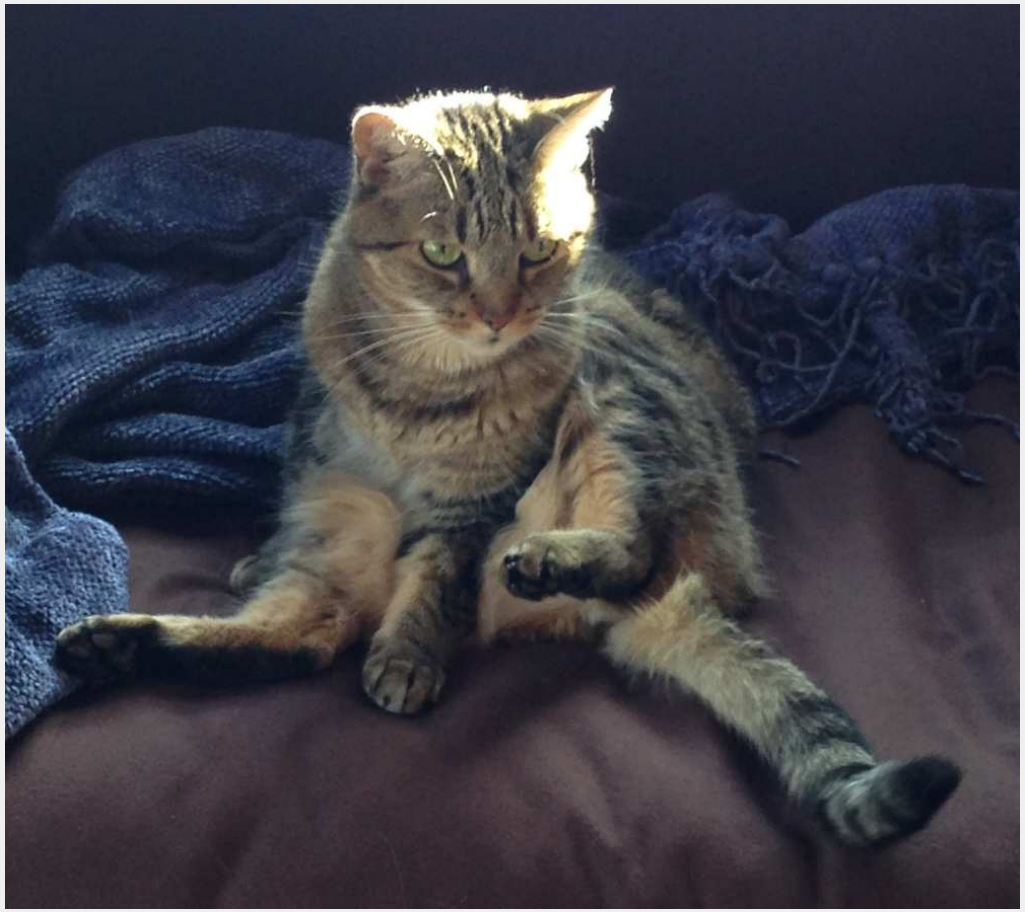
FMing a Sine Wave

$f_s = 800$ ksps, $f_\Delta = 75$ kHz, $f_m = 15$ kHz



Bessel Functions!

WAT!



No, let's skip that.

Ok, good.

More practically speaking, what's the signal bandwidth?

Definitions – Assumes sinusoid input

- f_Δ: maximum frequency deviation from the carrier
- f_m: the highest frequency component in the original signal

Carson's Rule

$$B_T = 2(f_\Delta + f_m)$$

Generally assumed to under-represent the signal bandwidth

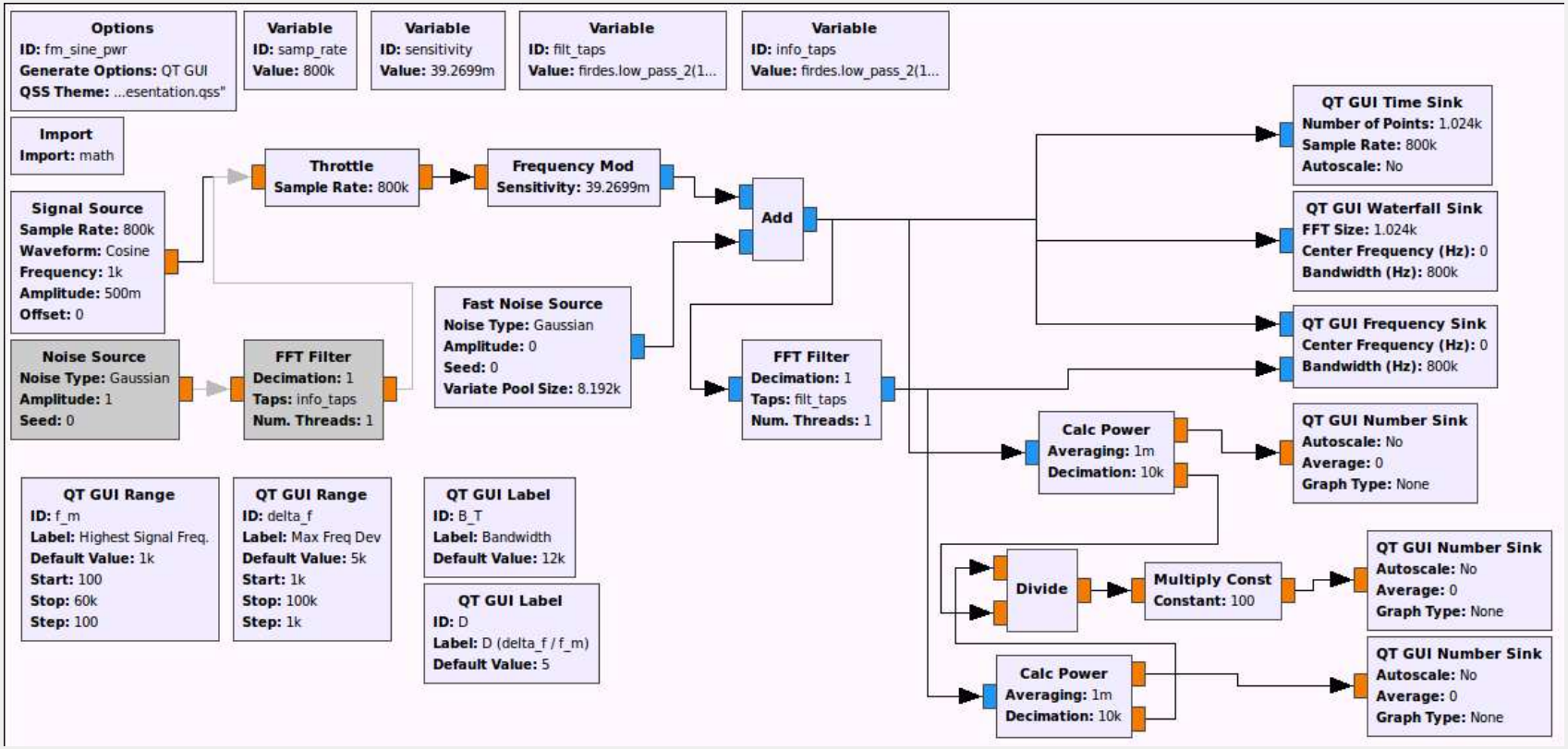
Carlson's Rule

$$B_T = 2(f_\Delta + 2f_m)$$

More realistic calculation of the bandwidth

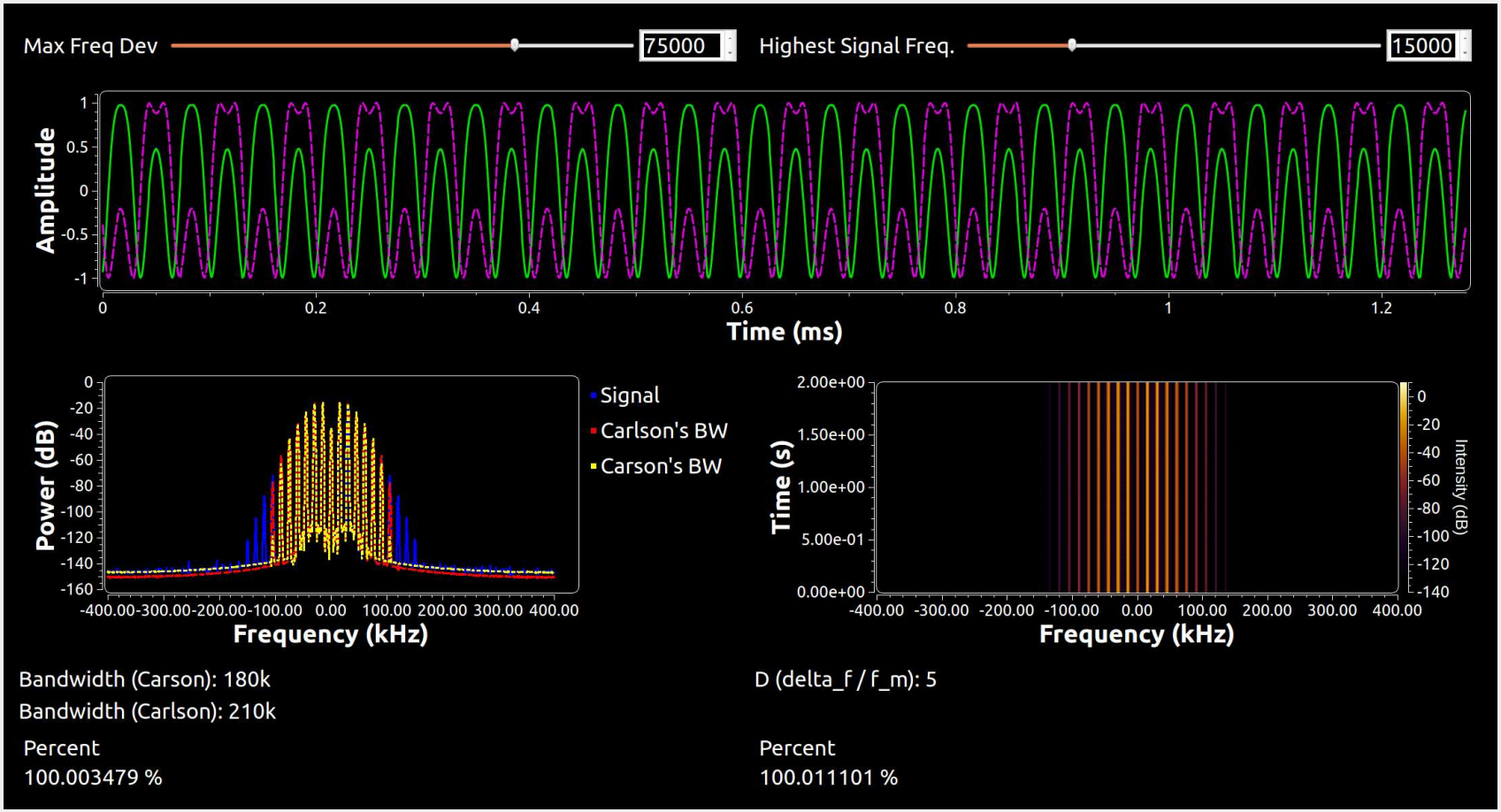
What's the practical difference?

Filter to the bandwidth of the different rules



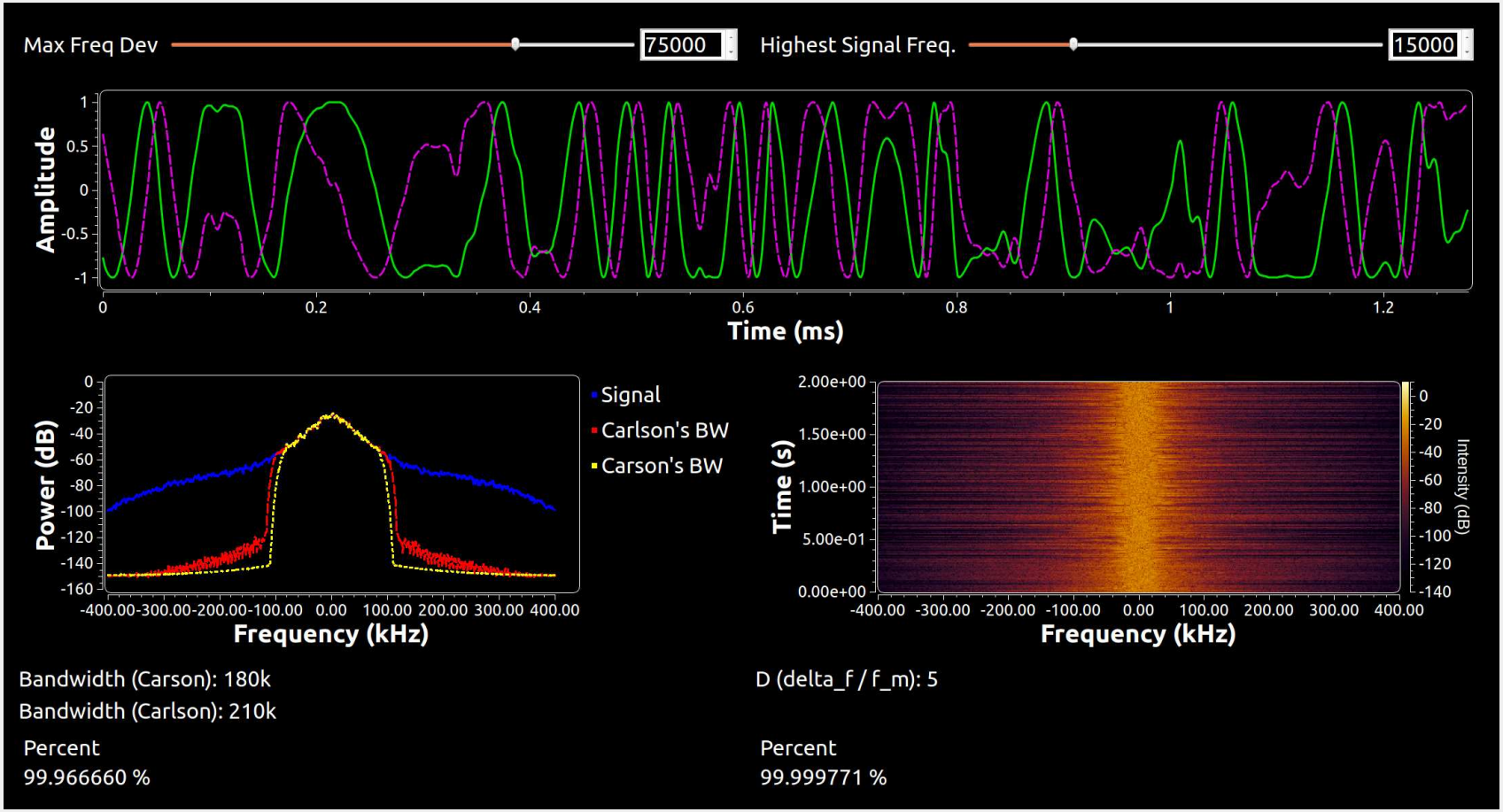
What's the practical difference?

Not much.



Actually running into numerical issues with float32's it's so close.

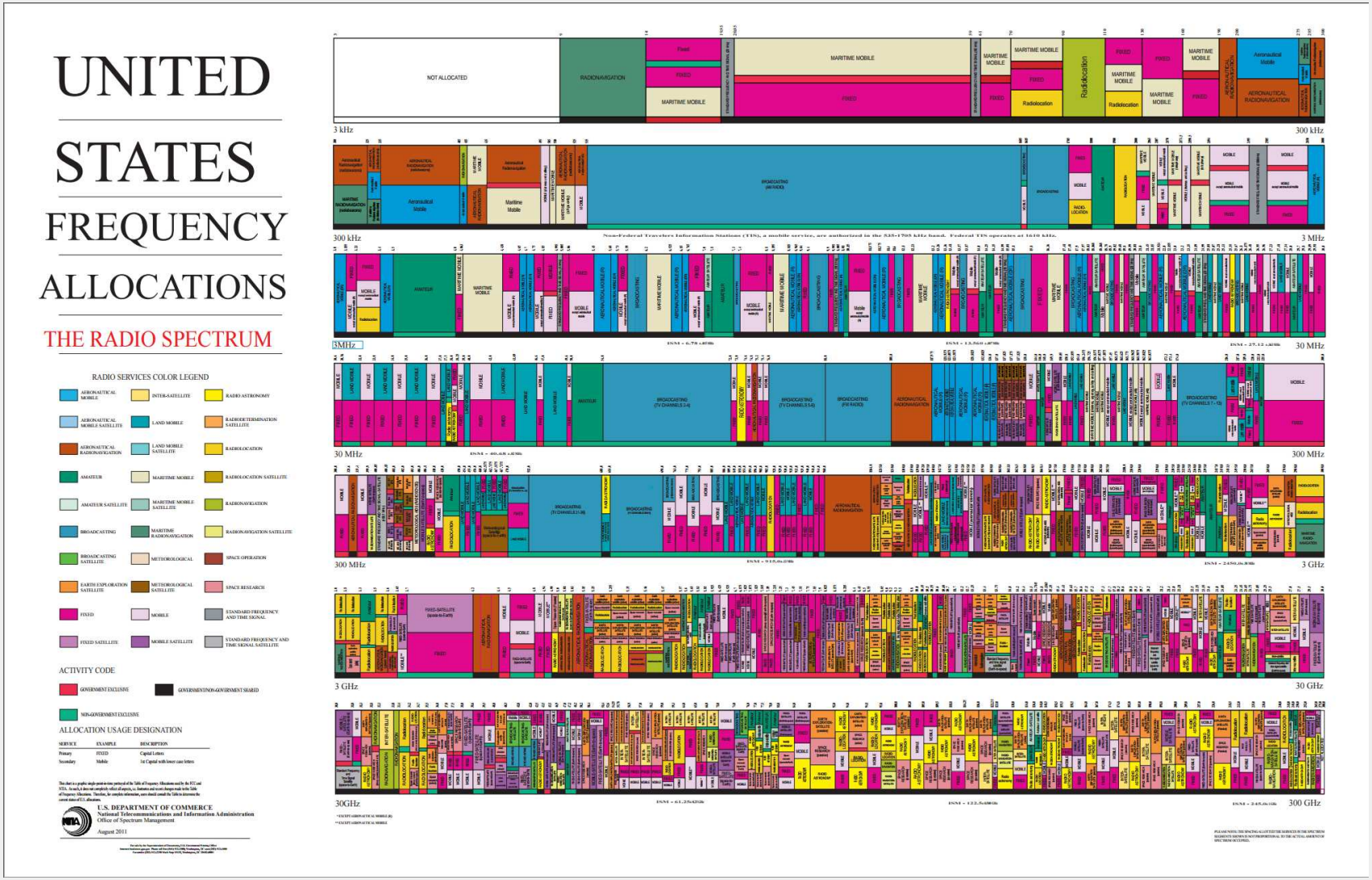
What about with a real song?



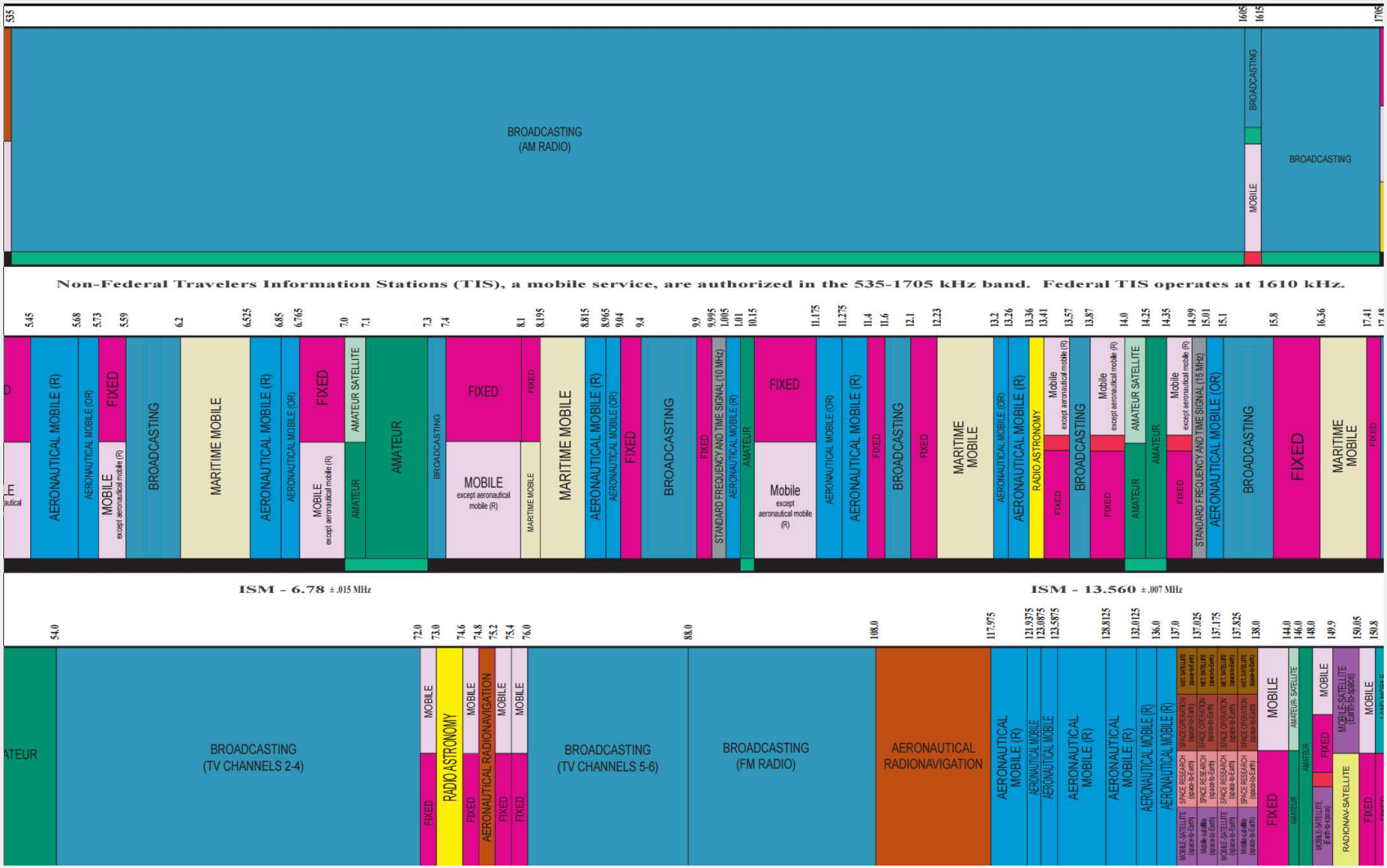
"The thrill, believe me, is as much in the battle as in the victory."

- David Sarnoff

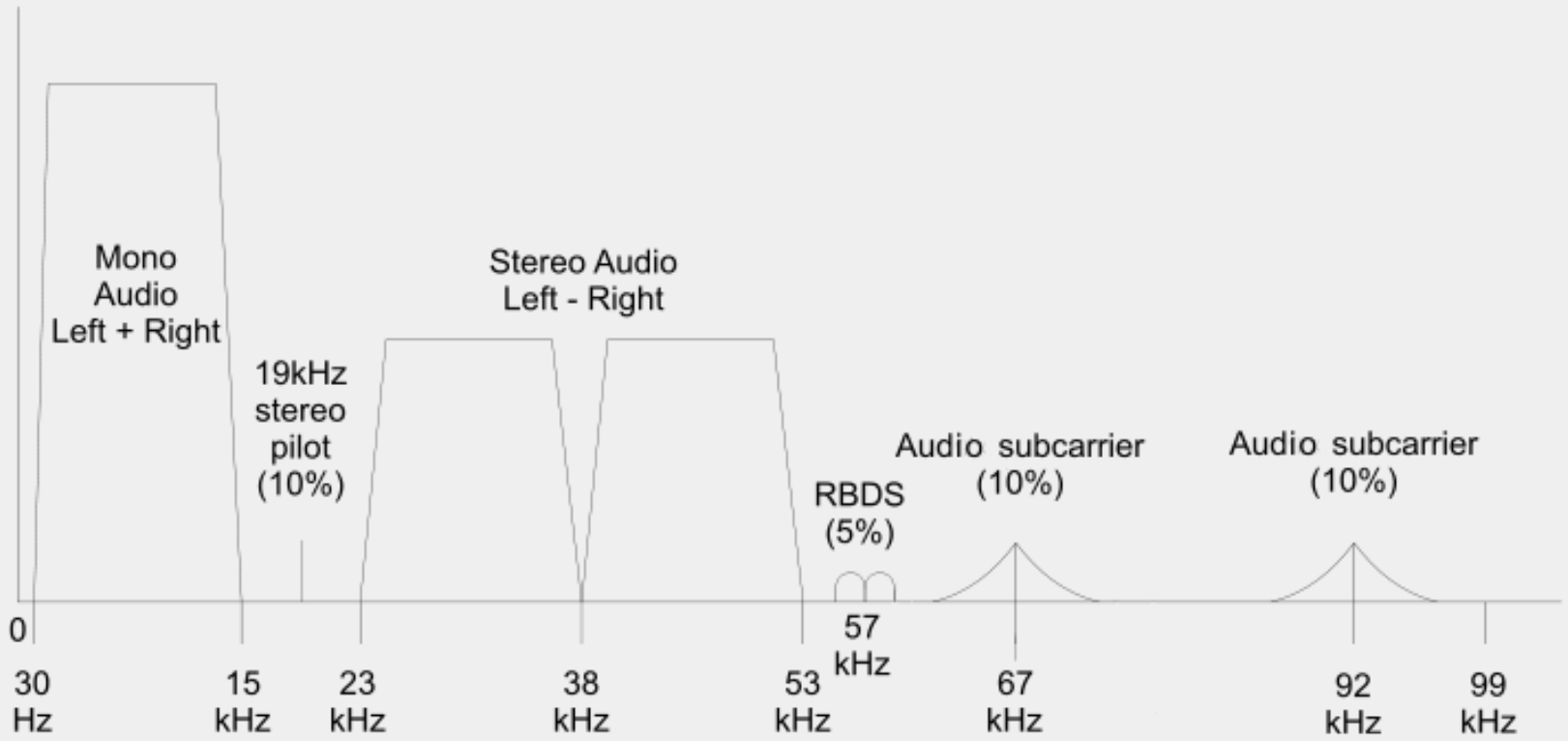
Spectrum Allocation



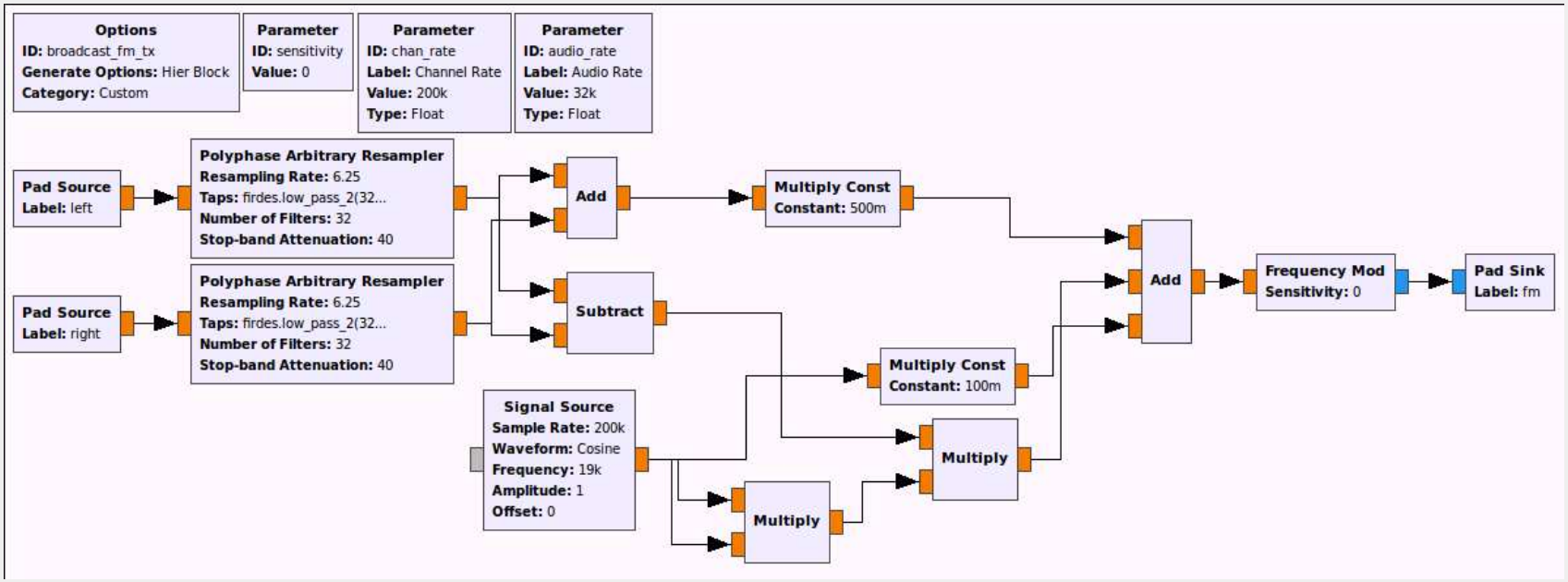
AM and FM Bands



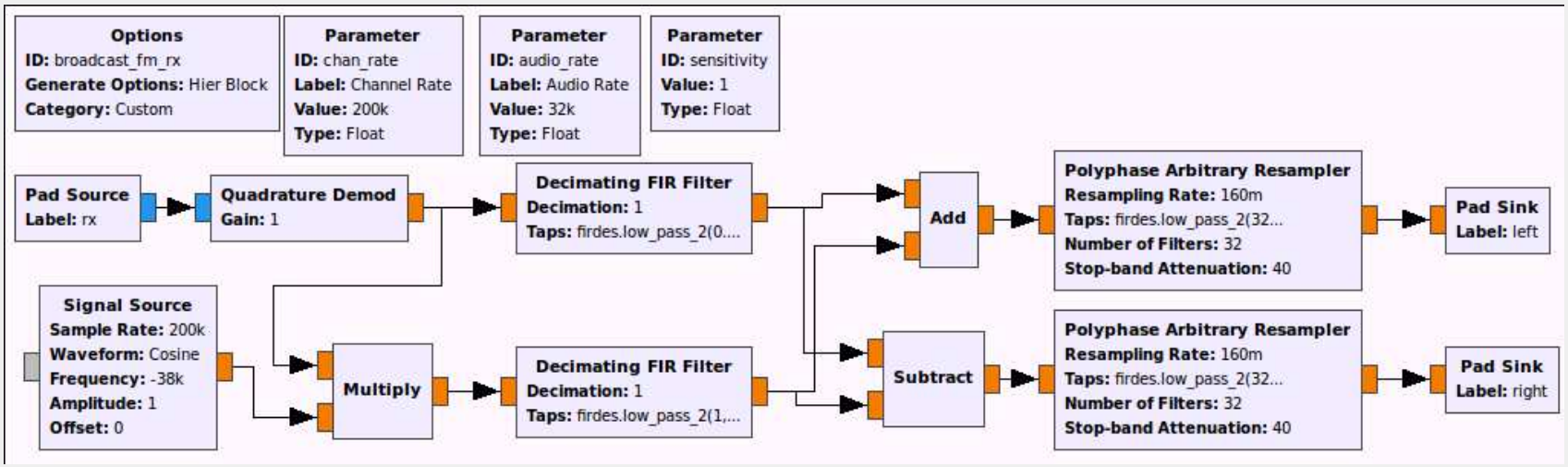
FM Spectrum and Information Composition



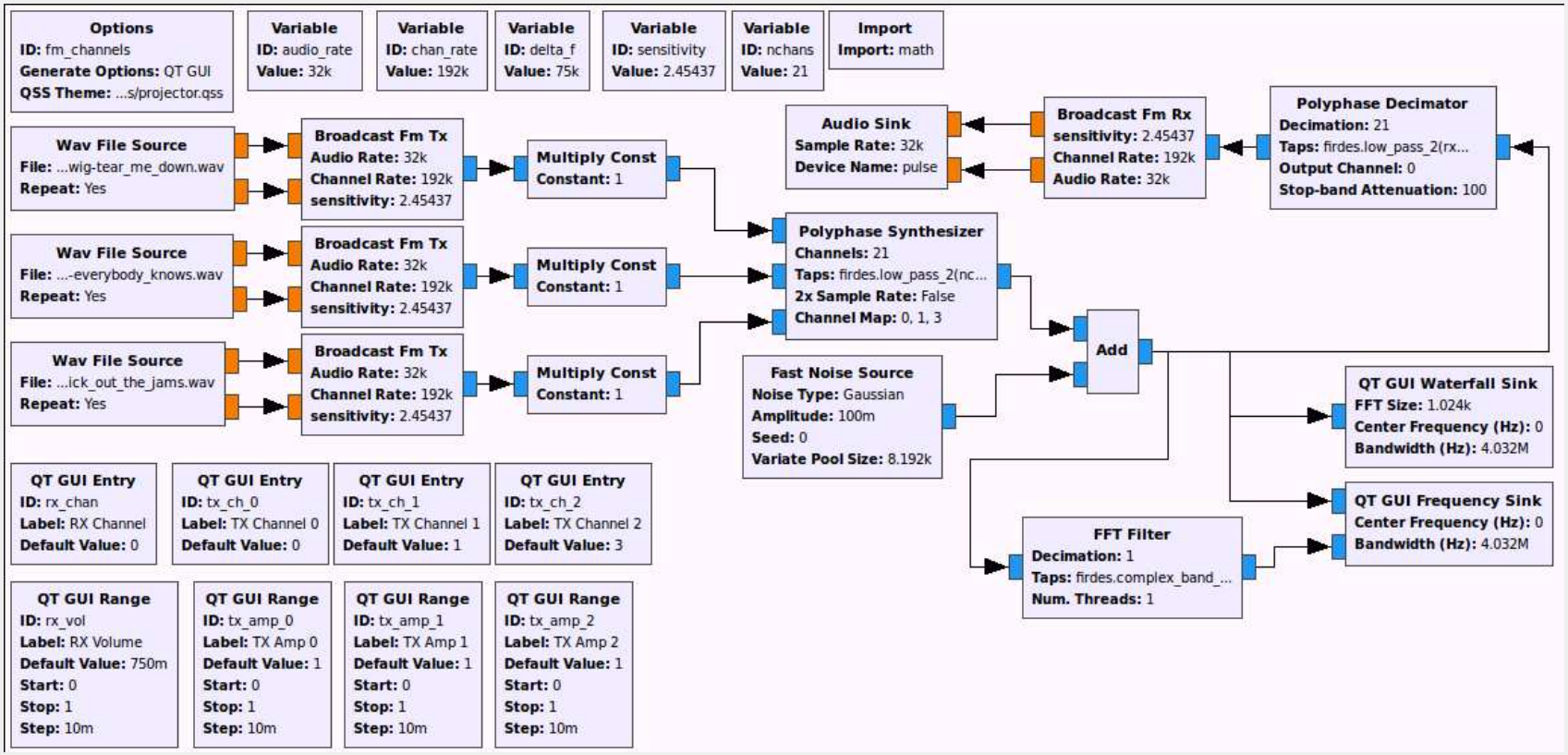
Modulating Stereo FM



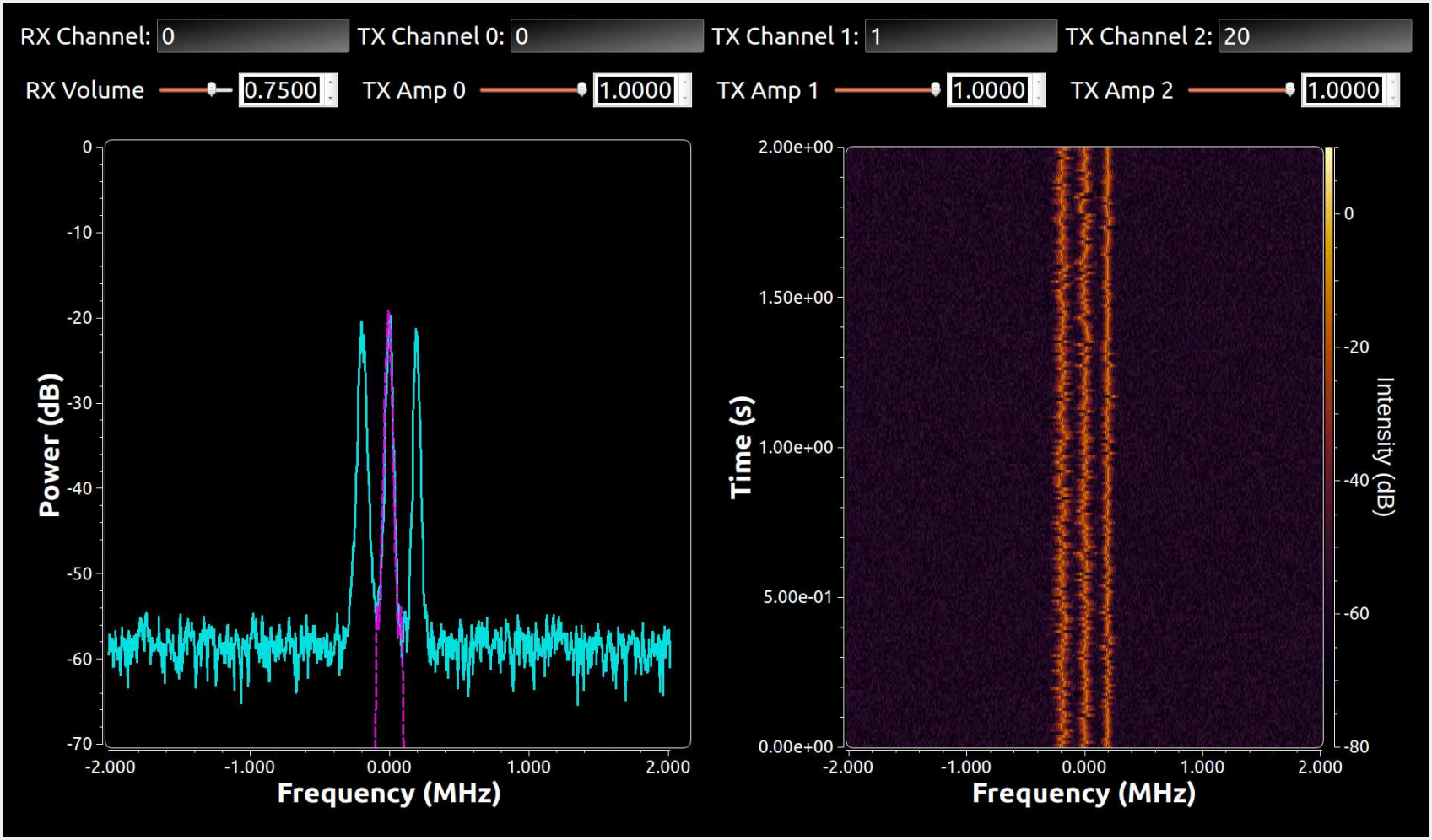
Demodulating Stereo FM



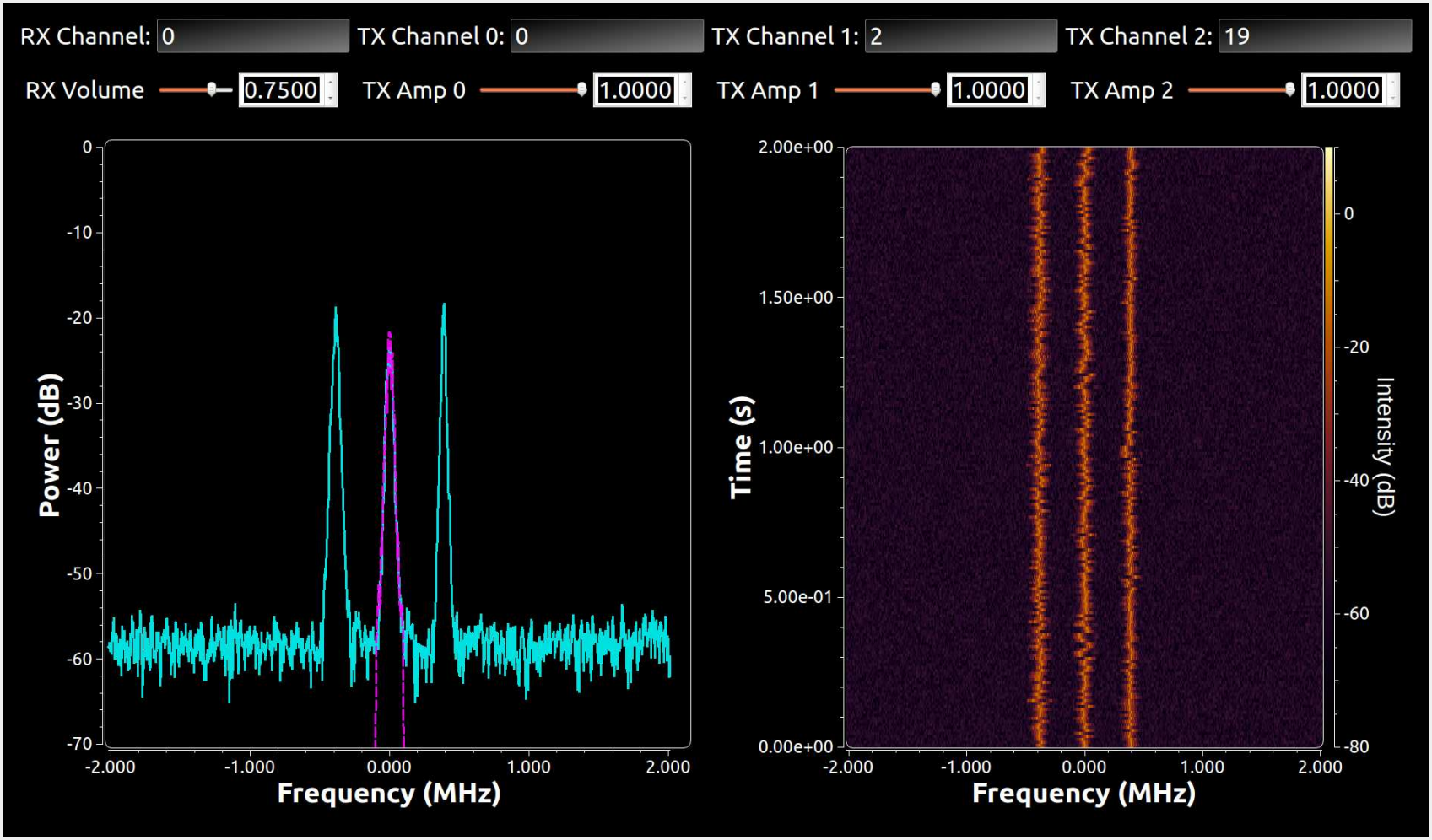
Channelizing FM



Single-Channel Spacing (bad)

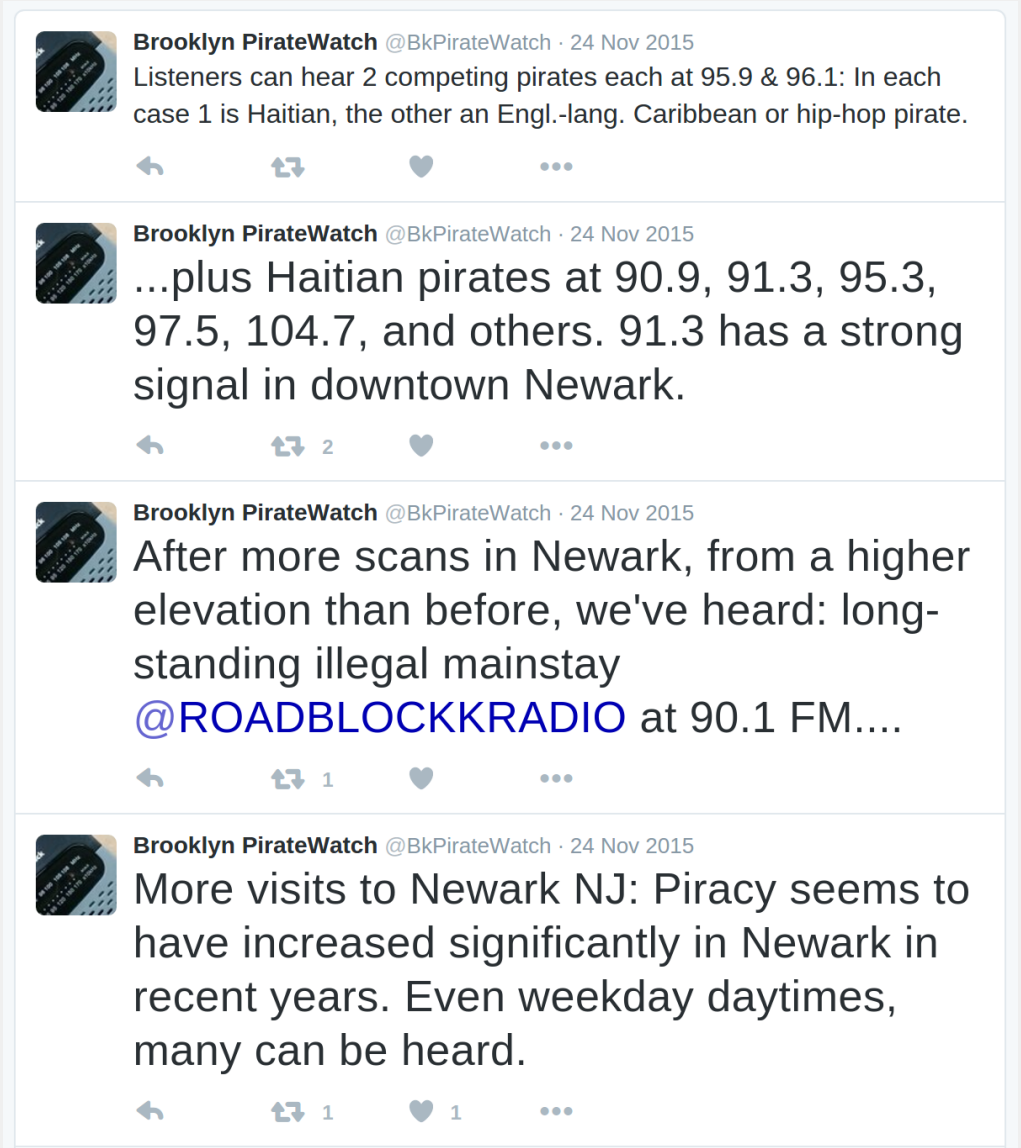


Empty Channel Between Stations



"Welcome to radio free America."
- Happy Harry Hardon (Christian Slater), *Pump Up the Volume*

Pirates on the airwaves



Brooklyn PirateWatch @BkPirateWatch · 24 Nov 2015
Listeners can hear 2 competing pirates each at 95.9 & 96.1: In each case 1 is Haitian, the other an Engl.-lang. Caribbean or hip-hop pirate.

Brooklyn PirateWatch @BkPirateWatch · 24 Nov 2015
...plus Haitian pirates at 90.9, 91.3, 95.3, 97.5, 104.7, and others. 91.3 has a strong signal in downtown Newark.

Brooklyn PirateWatch @BkPirateWatch · 24 Nov 2015
After more scans in Newark, from a higher elevation than before, we've heard: long-standing illegal mainstay @ROADBLOCKKRADIO at 90.1 FM....

Brooklyn PirateWatch @BkPirateWatch · 24 Nov 2015
More visits to Newark NJ: Piracy seems to have increased significantly in Newark in recent years. Even weekday daytimes, many can be heard.

Pirates!

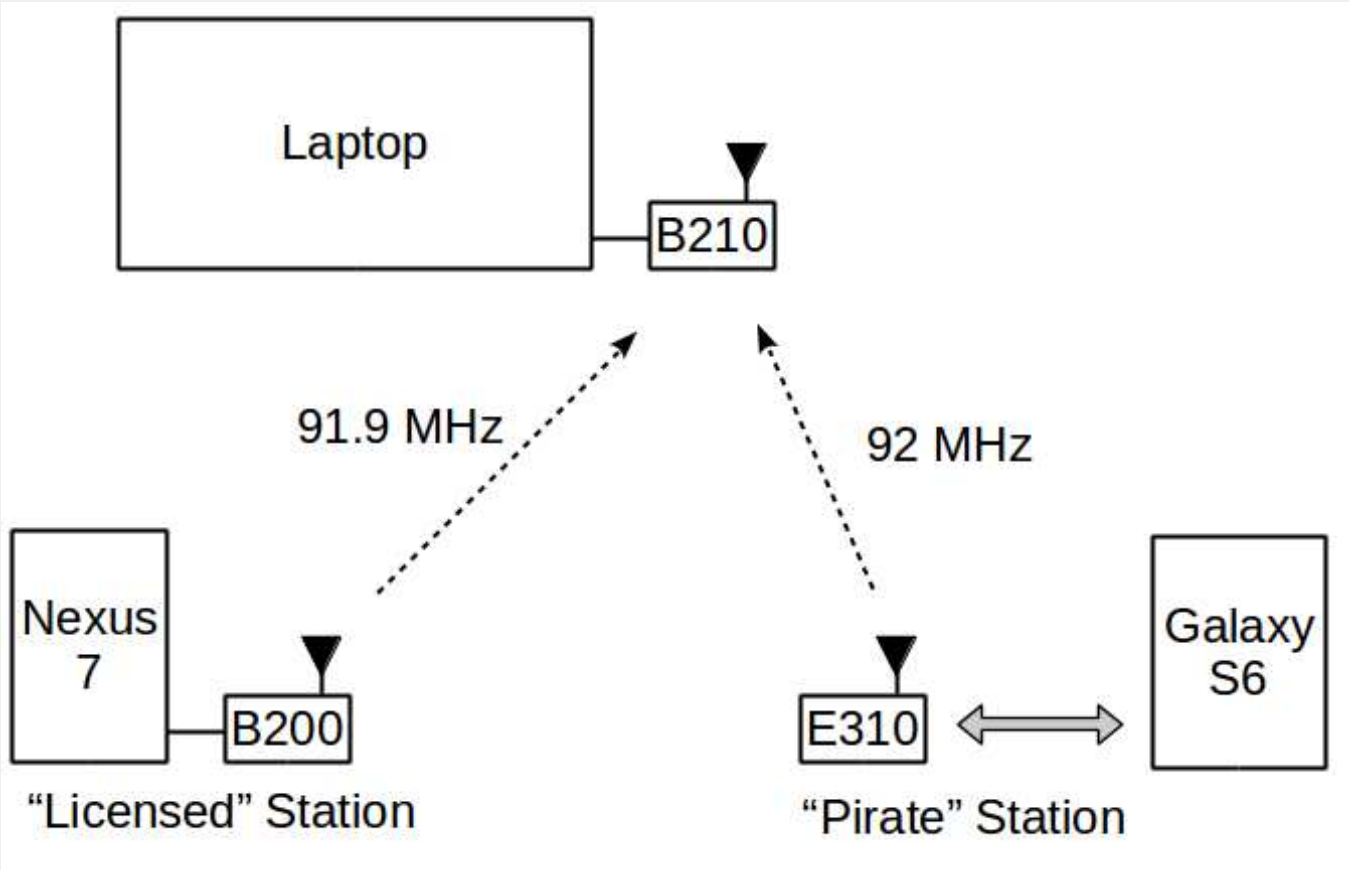
- Cultural
  - Play music you and your community want.
- Political
  - Talk religion and politics.
- Ecomonic
  - Sell local ads.

Localization

- The Internet is too large, too global.
- Restricted to a geographic niche.
- Ownership of medium and equipment.

What's the issue?

- High demand for spectrum.
- Interference and the FM Capture Effect.



Exploring the FM Capture Effect

- Receiver Station:
  - Standard GNU Radio FM receiver with B210.
- FM “Broadcaster”:
  - Android device connected to B200.
  - GNU Radio app on Android.
  - Controls frequency and gain of B200; FM sensitivity of transmitter.
- Pirate station:
  - E310 running FM broadcast.
  - Android App remotely controls system.
  - Changes any E310 radio parameter.

Questions?

So be it.