ECE448 Spring 2026

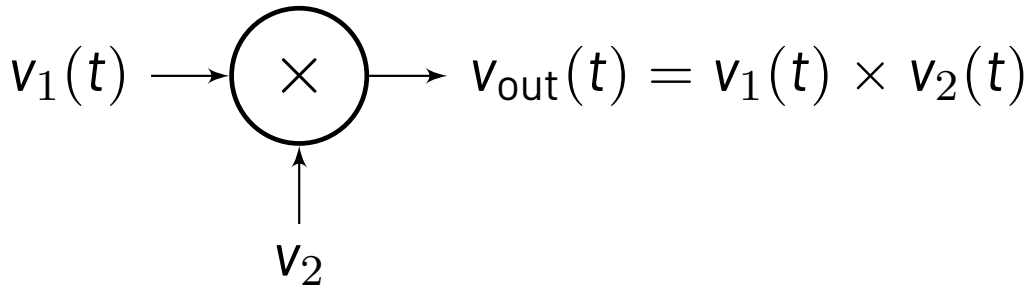
L04-sdr-introduction

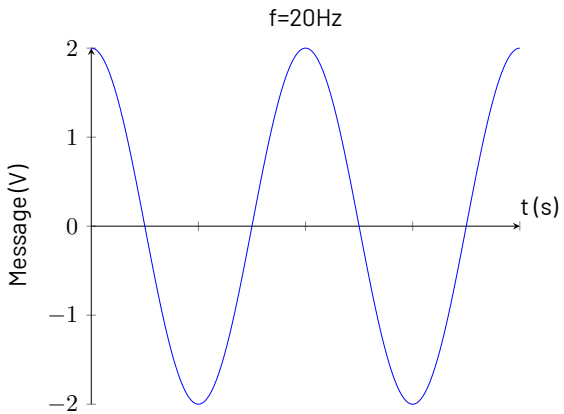


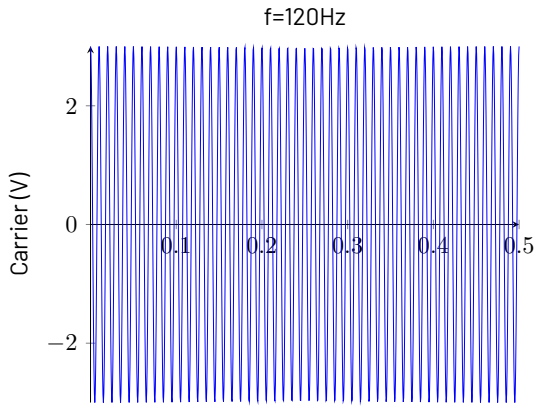
Today

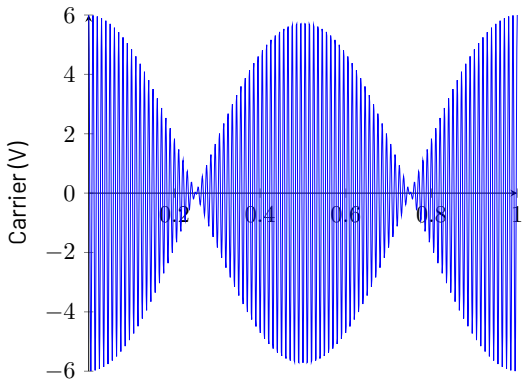
- Software Defined Radios
- Superheterodyne Architecture
- IQ data
- Examples

Function Multiplier



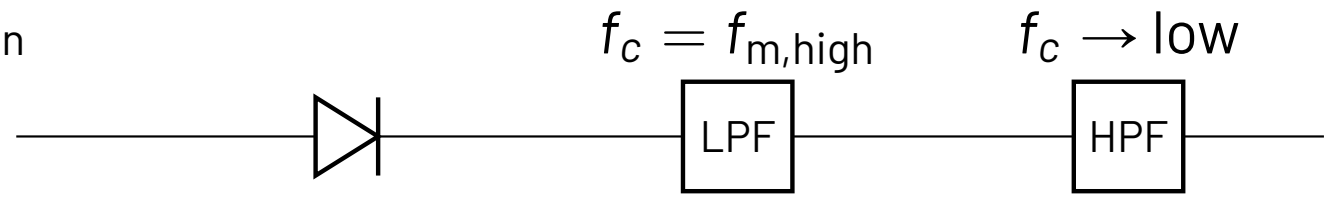


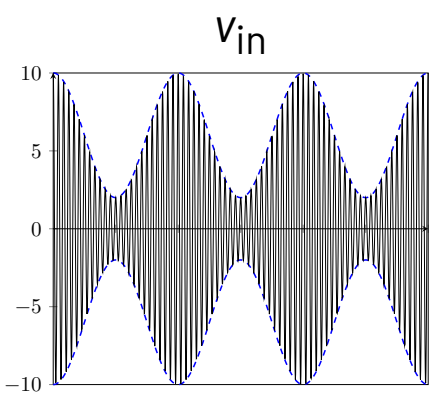


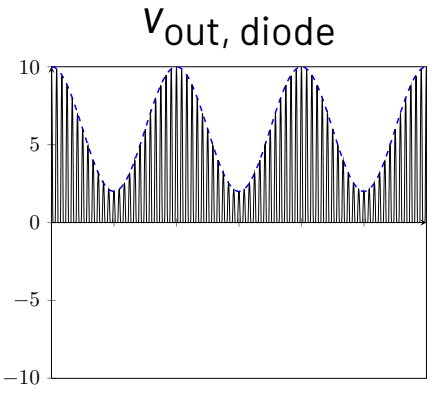


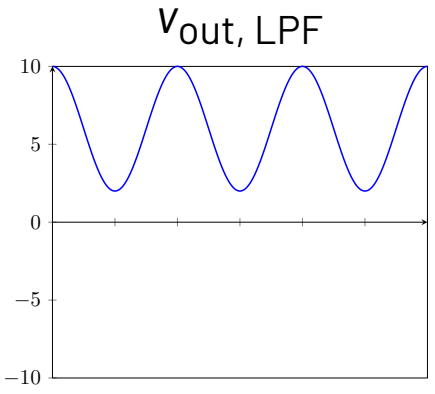
$$v_m(t) \quad \times \quad v_c(t) \quad = \quad v_{out}$$

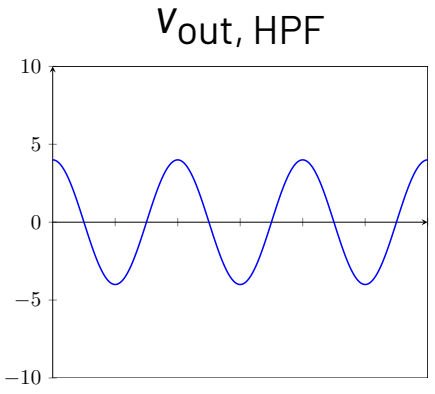
Envelope Detector



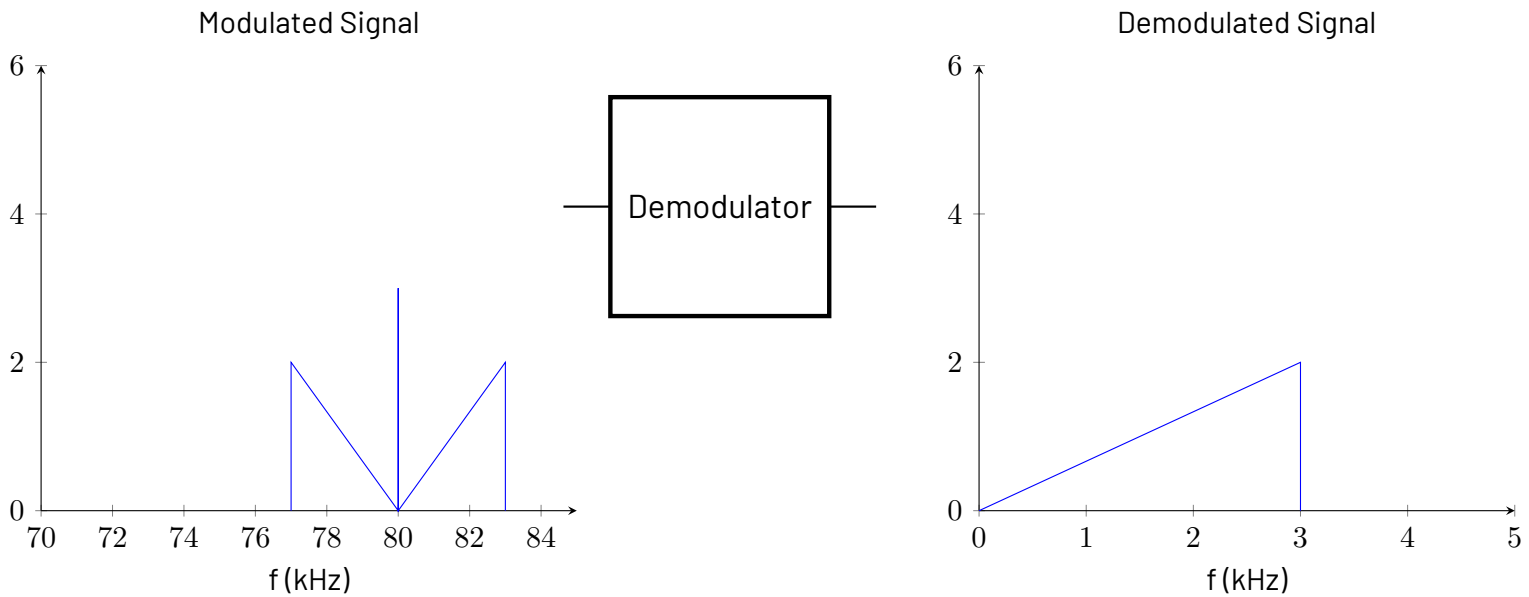




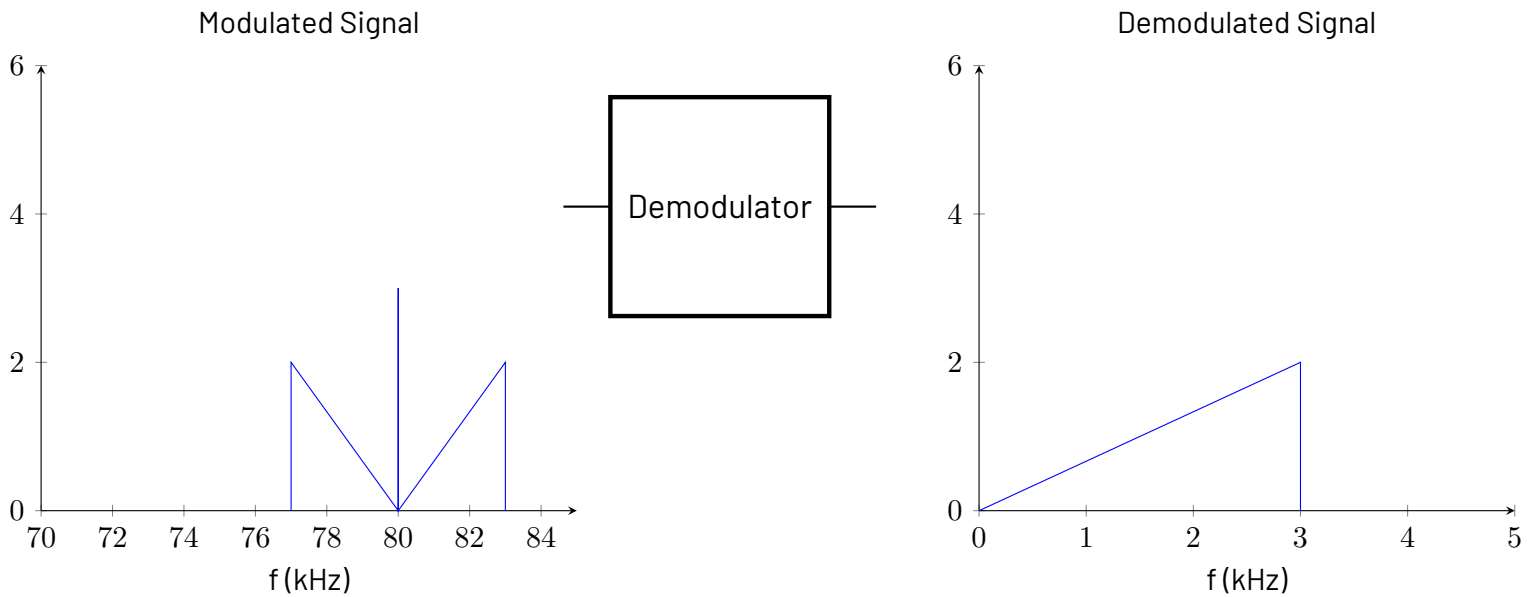




Synchronous Detector

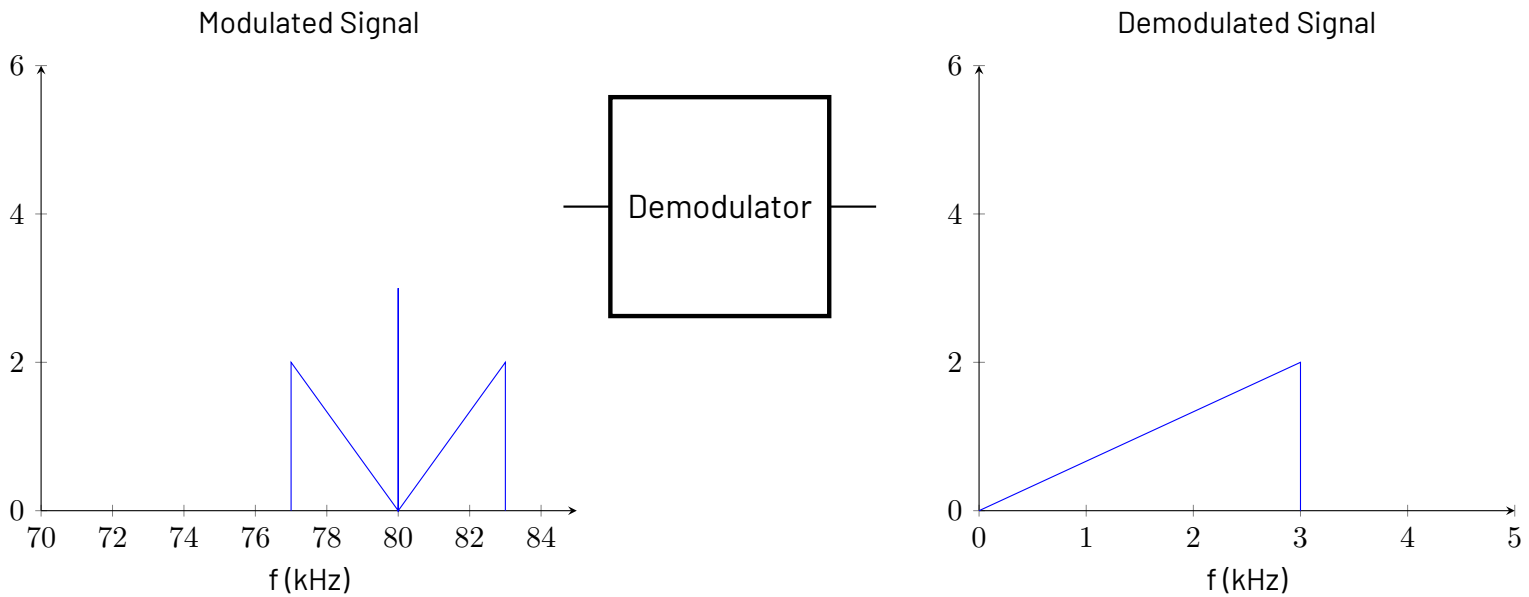


Synchronous Detector



$$\alpha = \frac{A_m}{B} = \frac{2 * \left(\frac{A_c A_m}{2}\right)}{BA_c} = \frac{2 * 2}{3} = 1.333$$

Synchronous Detector



$$\alpha = \frac{A_m}{B} = \frac{2 * \left(\frac{A_c A_m}{2}\right)}{BA_c} = \frac{2 * 2}{3} = 1.333$$

The signal is overmodulated $\longrightarrow$ need synchronous detection!

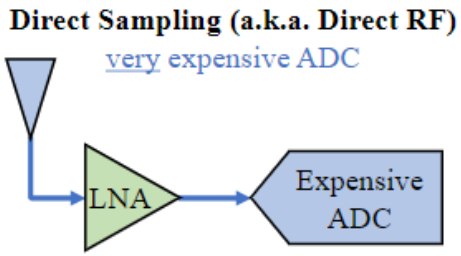
What is an SDR?

- "A radio in which *some* or *all* of the physical layer is defined by software"
- Characteristics:

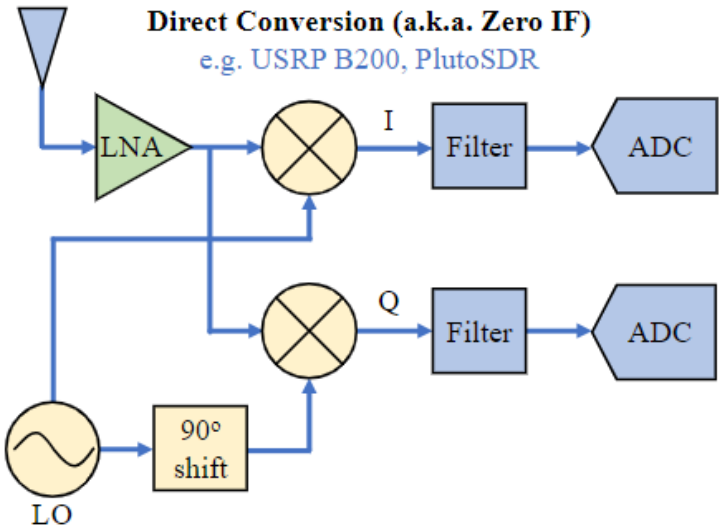
- Applications



Receiver Architectures: Direct Sampling/ZeroIF

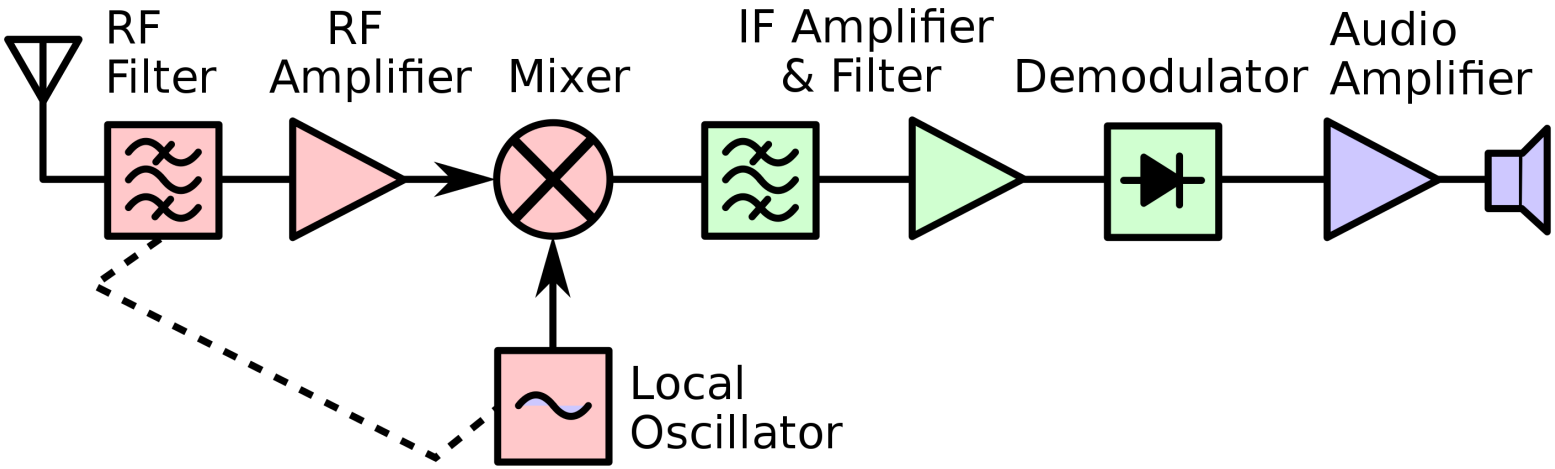


https://wirelesspi.com/direct-conversion-zero-if-receiver/



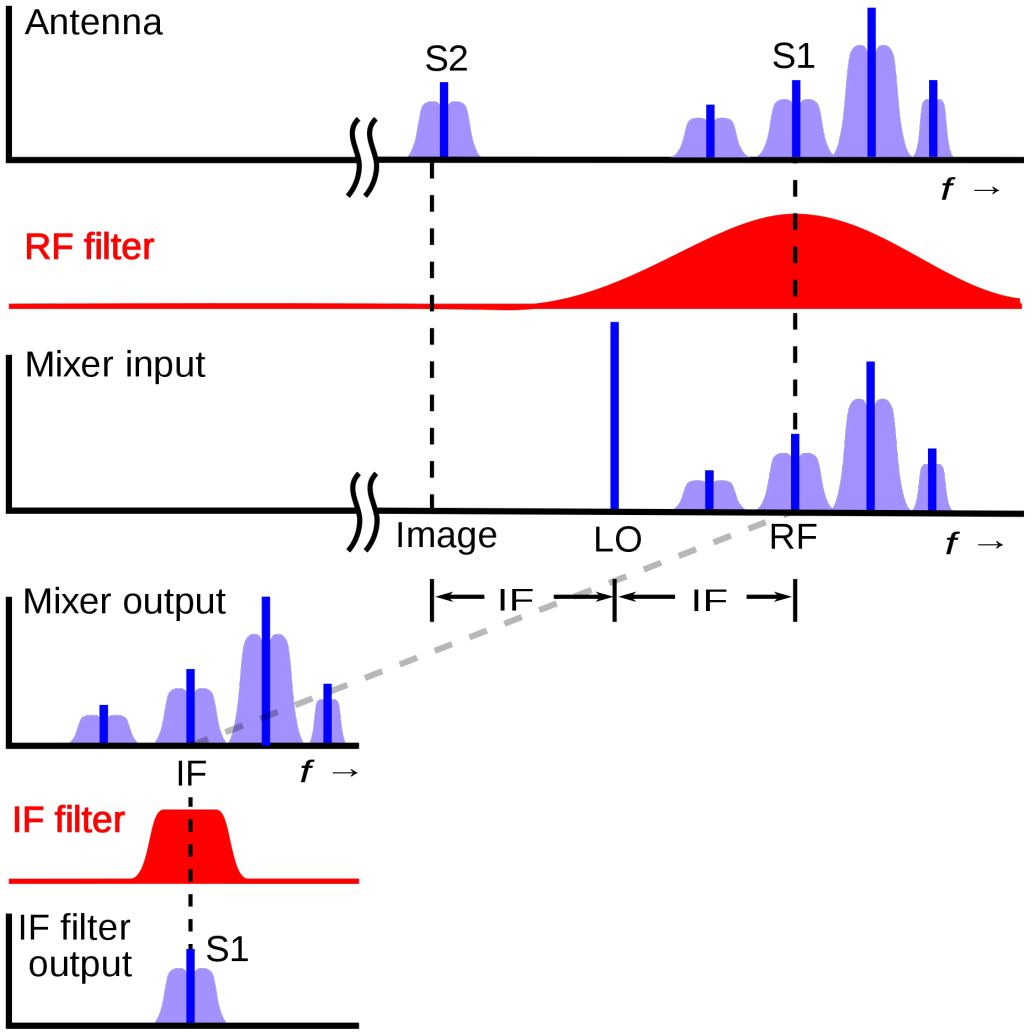
https://wirelesspi.com/direct-conversion-zero-if-receiver/

Superheterodyne Receiver



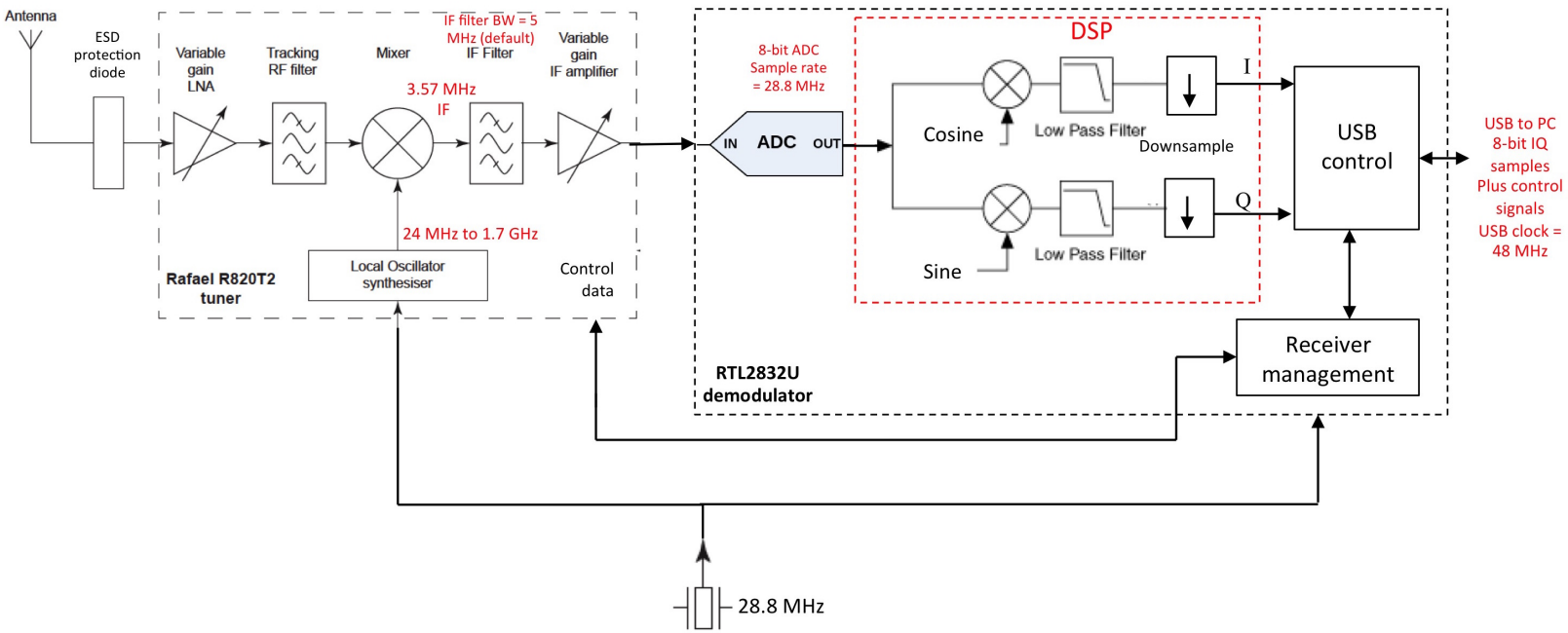
https://wirelesspi.com/the-heterodyne-principle-and-the-superheterodyne-receiver/

Superheterodyne Receiver



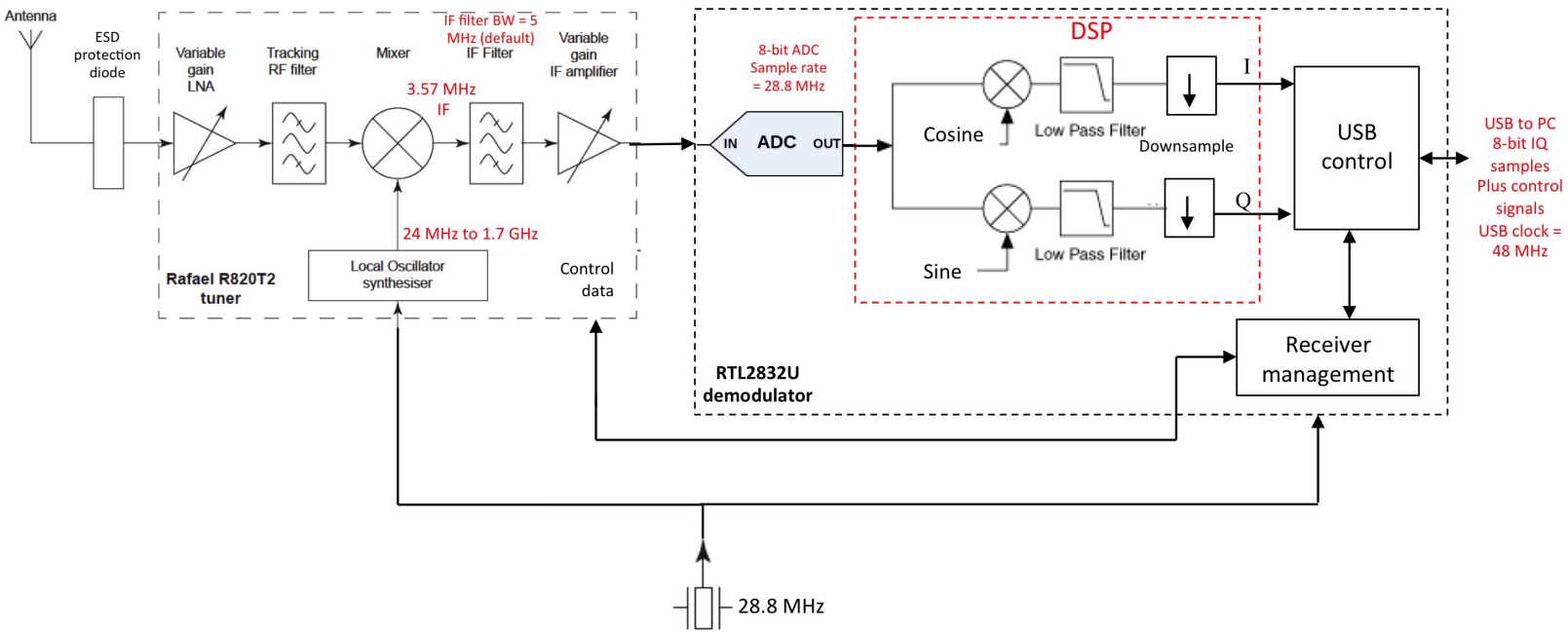
RTL-SDR Receiver

Simplified Block Diagram of NooElec RTL-SDR



RTL-SDR Receiver

Simplified Block Diagram of NooElec RTL-SDR



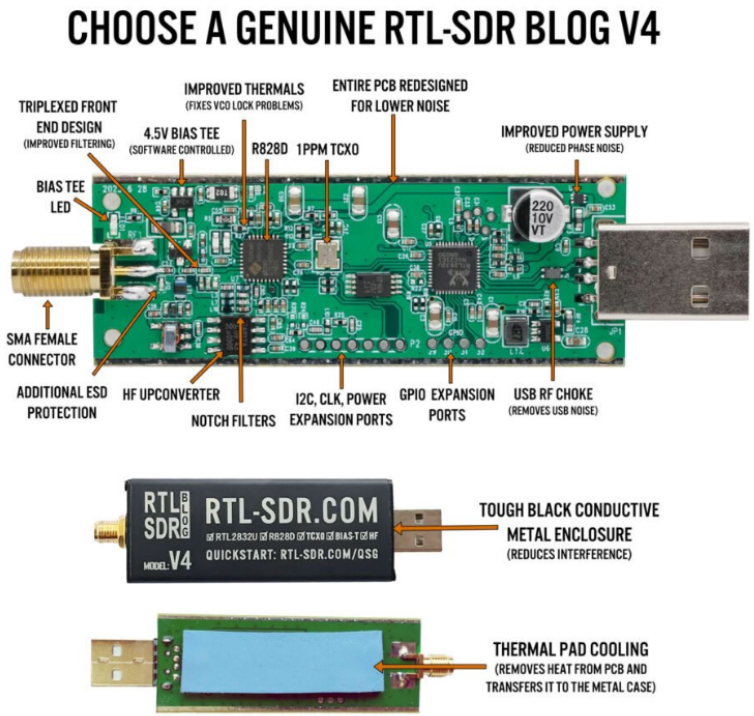
RTL-SDR

-
-
-
-


RTL SDR BLOG
RTL-SDR.COM
☑ RTL2832U ☑ R828D ☑ TCXO ☑ BIAS-T ☑ HF
MODEL: V4
QUICKSTART: RTL-SDR.COM/QSG
RTL SDR BLOG
RTL-SDR.COM
☑ RTL2832U ☑ R828D ☑ TCXO ☑ BIAS-T ☑ HF
MODEL: V4
QUICKSTART: RTL-SDR.COM/QSG

RTL-SDR

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-
-


CHOOSE A GENUINE RTL-SDR BLOG V4
TRIPLEXED FRONT END DESIGN (IMPROVED FILTERING)
IMPROVED THERMALS (FIXES VCO LOCK PROBLEMS)
ENTIRE PCB REDESIGNED FOR LOWER NOISE
4.5V BIAS TEE (SOFTWARE CONTROLLED)
R828D
1PPM TCXO
IMPROVED POWER SUPPLY (REDUCED PHASE NOISE)
BIAS TEE LED
SMA FEMALE CONNECTOR
ADDITIONAL ESD PROTECTION
HF UPCONVERTER
NOTCH FILTERS
I2C, CLK, POWER EXPANSION PORTS
GPIO EXPANSION PORTS
USB RF CHOKE (REMOVES USB NOISE)
RTL-SDR.COM
QUICKSTART: RTL-SDR.COM/QSG
V4
TOUGH BLACK CONDUCTIVE METAL ENCLOSURE (REDUCES INTERFERENCE)
THERMAL PAD COOLING (REMOVES HEAT FROM PCB AND TRANSFERS IT TO THE METAL CASE)

Ettus x310

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SDRs: Practical Questions

- Frequency shift
- Negative Frequencies?
- Waterfall plot
- Tradeoffs
- Software

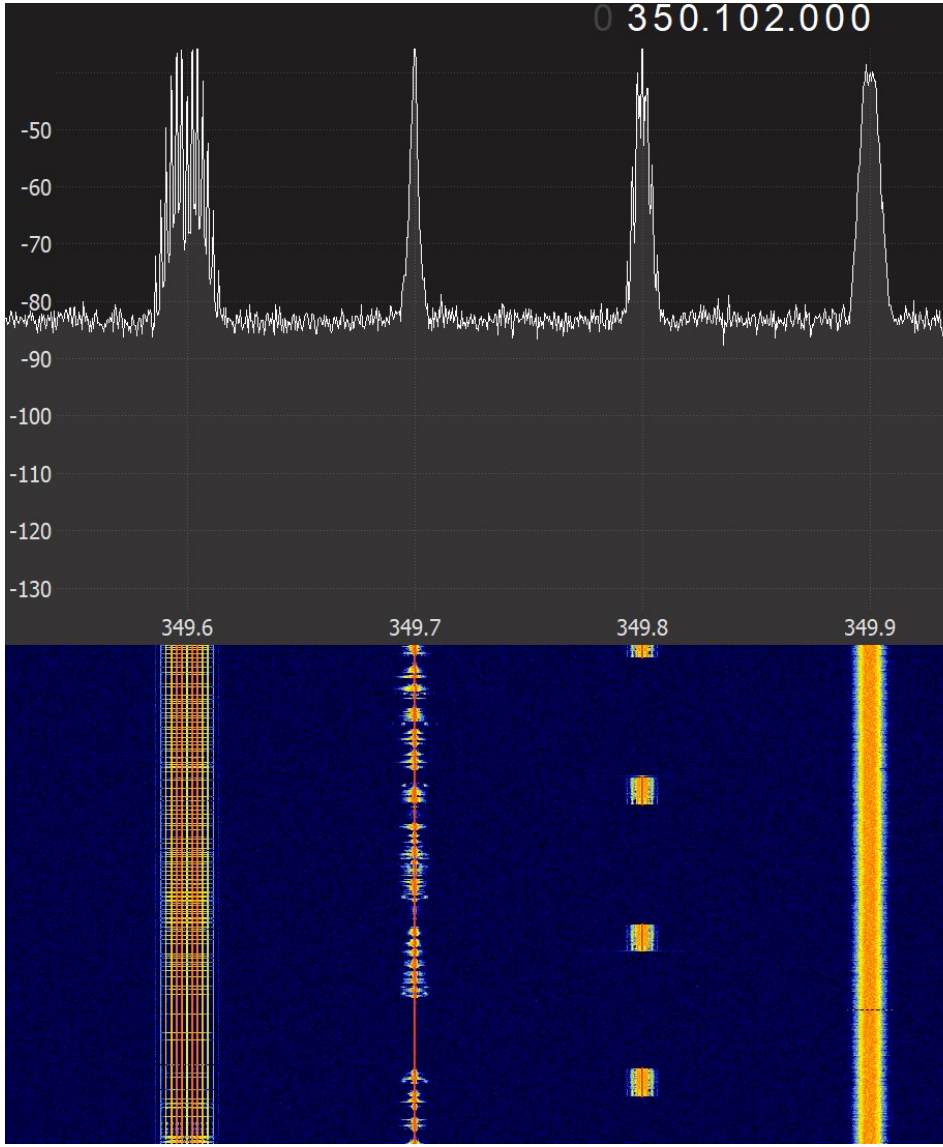
Software

- GNURadio
- GQRX
- SDR Angel
- SDR #
- Sigdigger
- URH



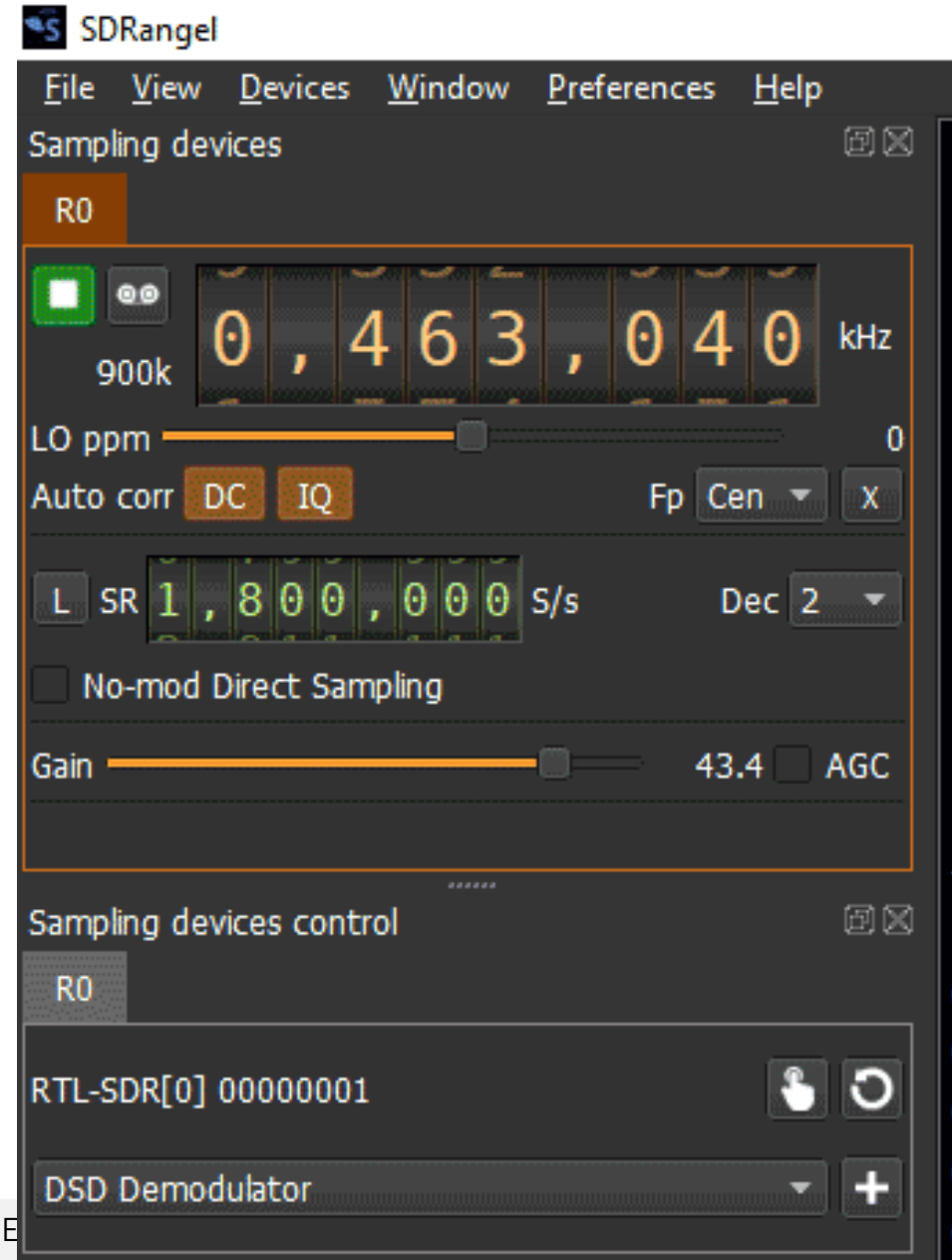
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SOFTWARE

- GNURadio
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- SDR Angel
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Software

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Software

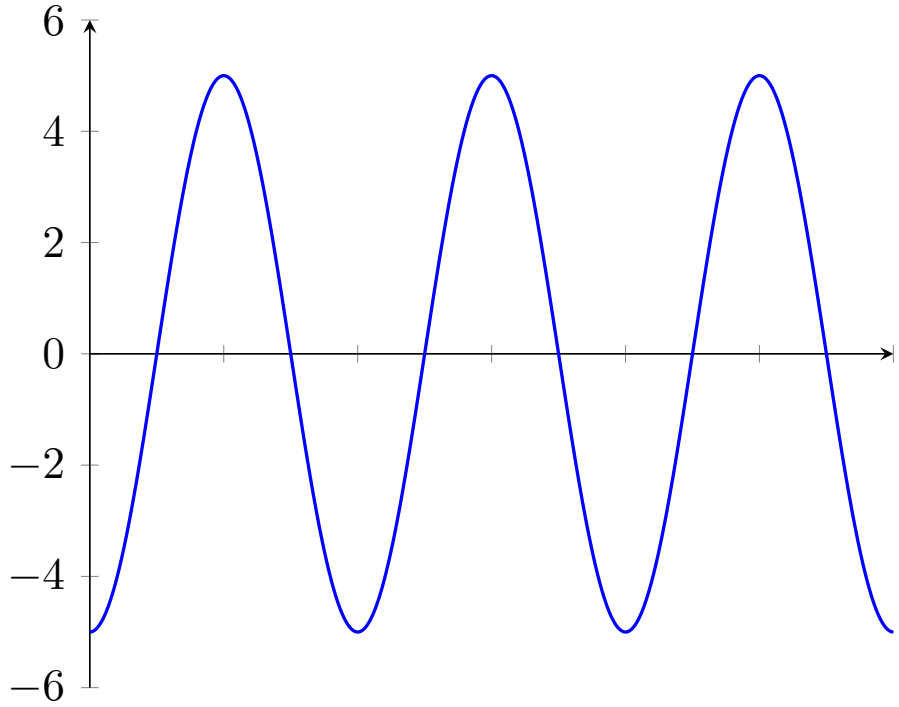
- GNURadio
- GQRX
- SDR Angel
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- URH

Today

- Software Defined Radios
- IQ data
- Examples

IQ Data

$$x(t) = \cos\left(2\pi f t + \phi\right)$$



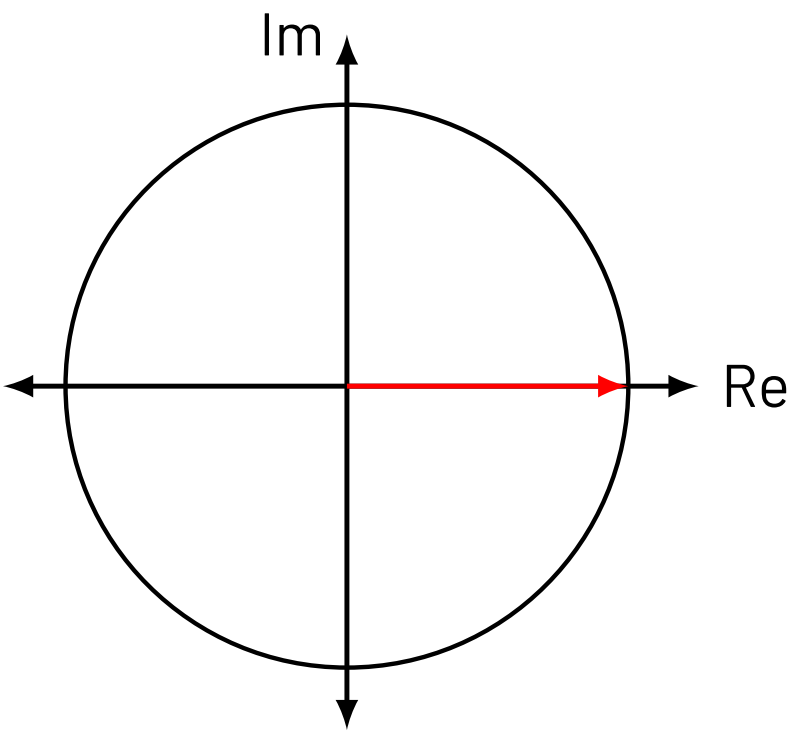
IQ data is a way to transmit both _____ and _____ without _____.

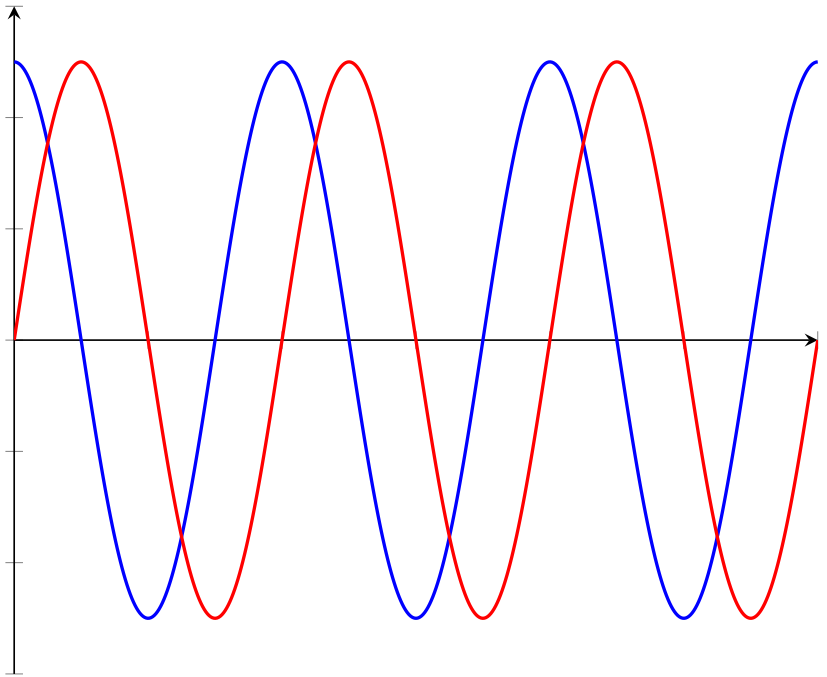
$$\left(\sqrt{I^2 + Q^2}\right) \cos\left[2\pi f t + \tan^{-1}\left(\frac{Q}{I}\right)\right]$$

Complex Plane

IQ DEMO

Complex Plane

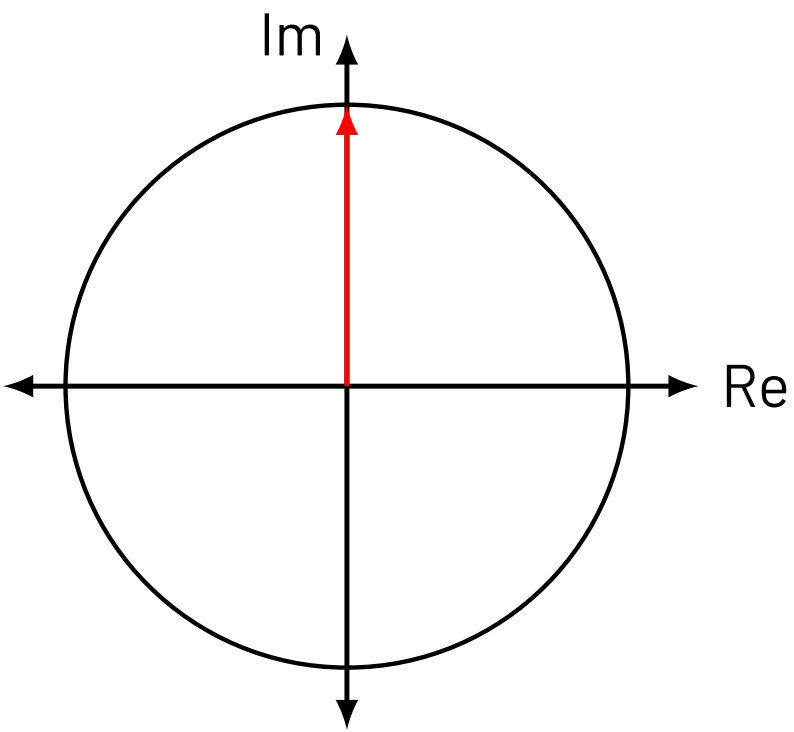


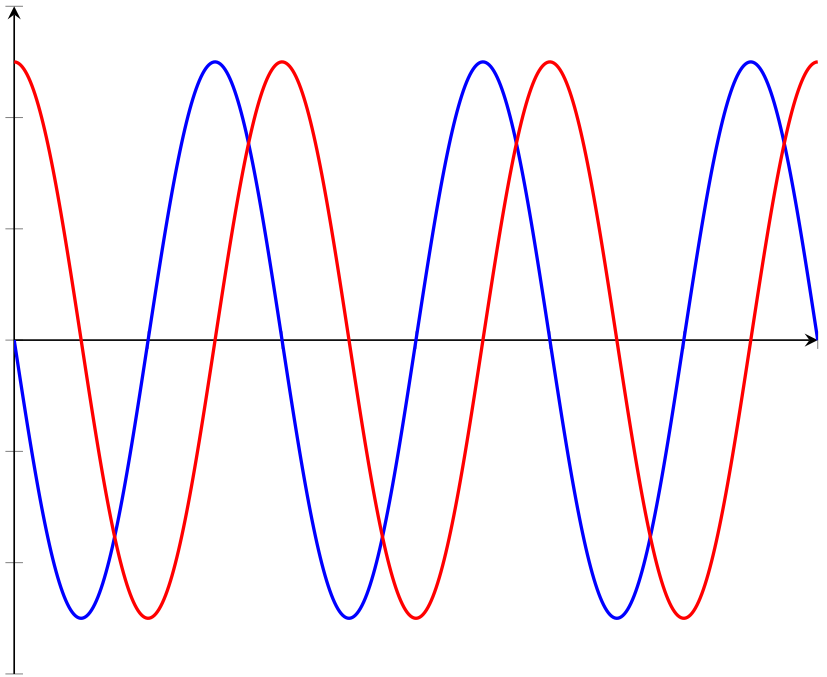


$I =$

$Q =$

Complex Plane

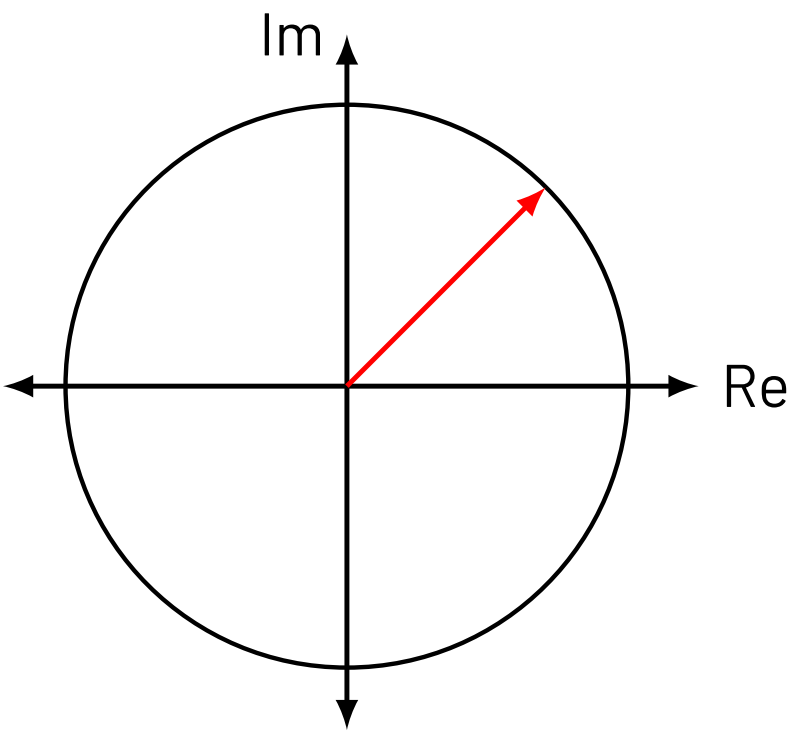


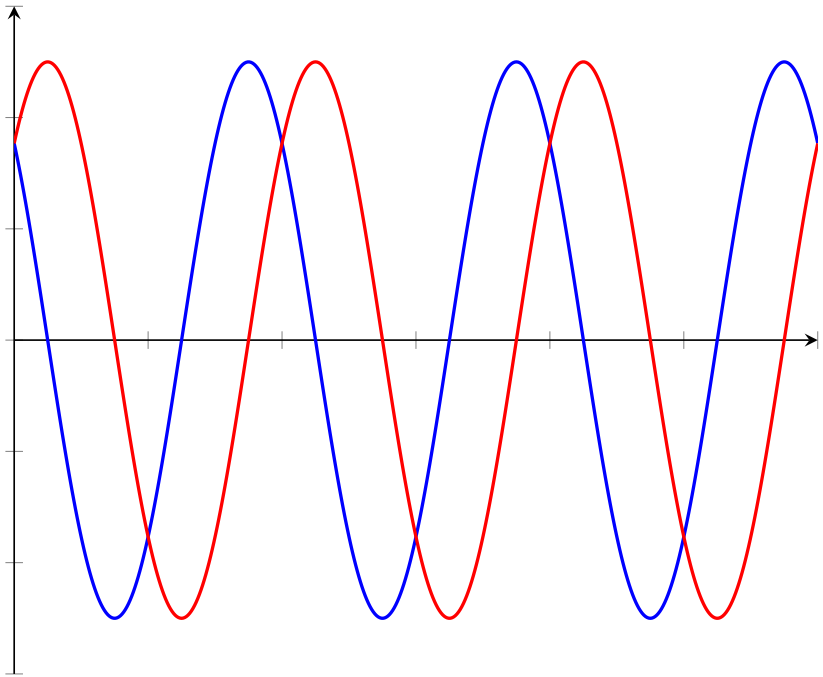


$I =$

$Q =$

Complex Plane

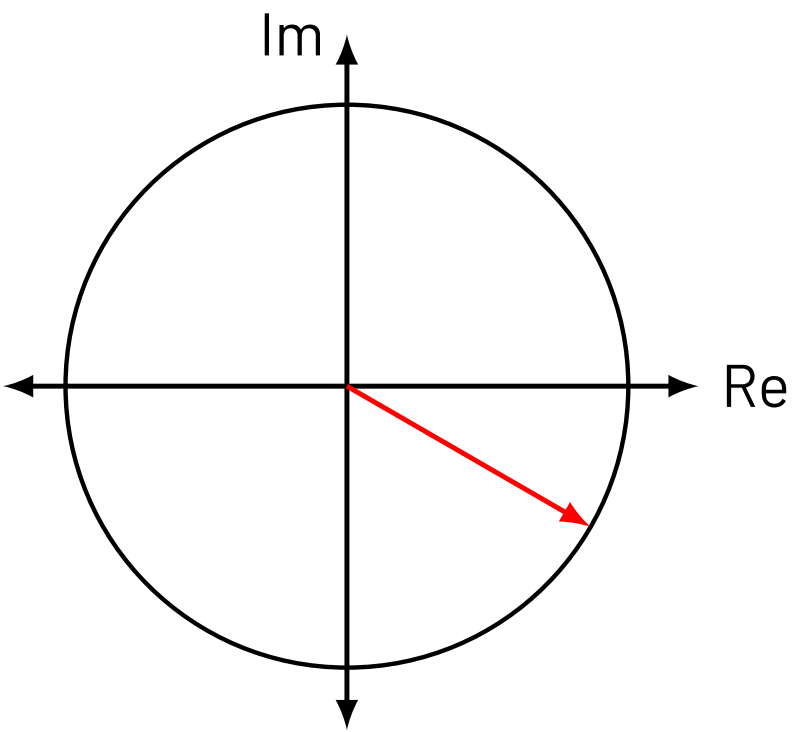


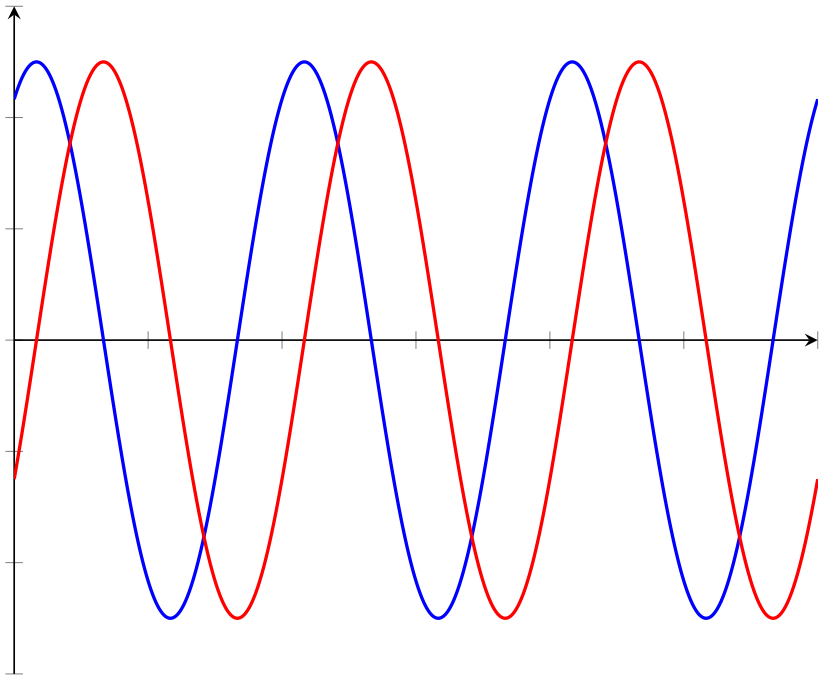


$I =$

$Q =$

Complex Plane

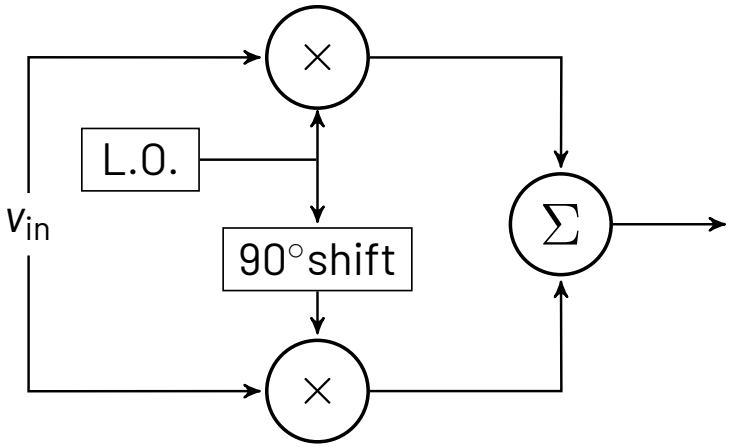




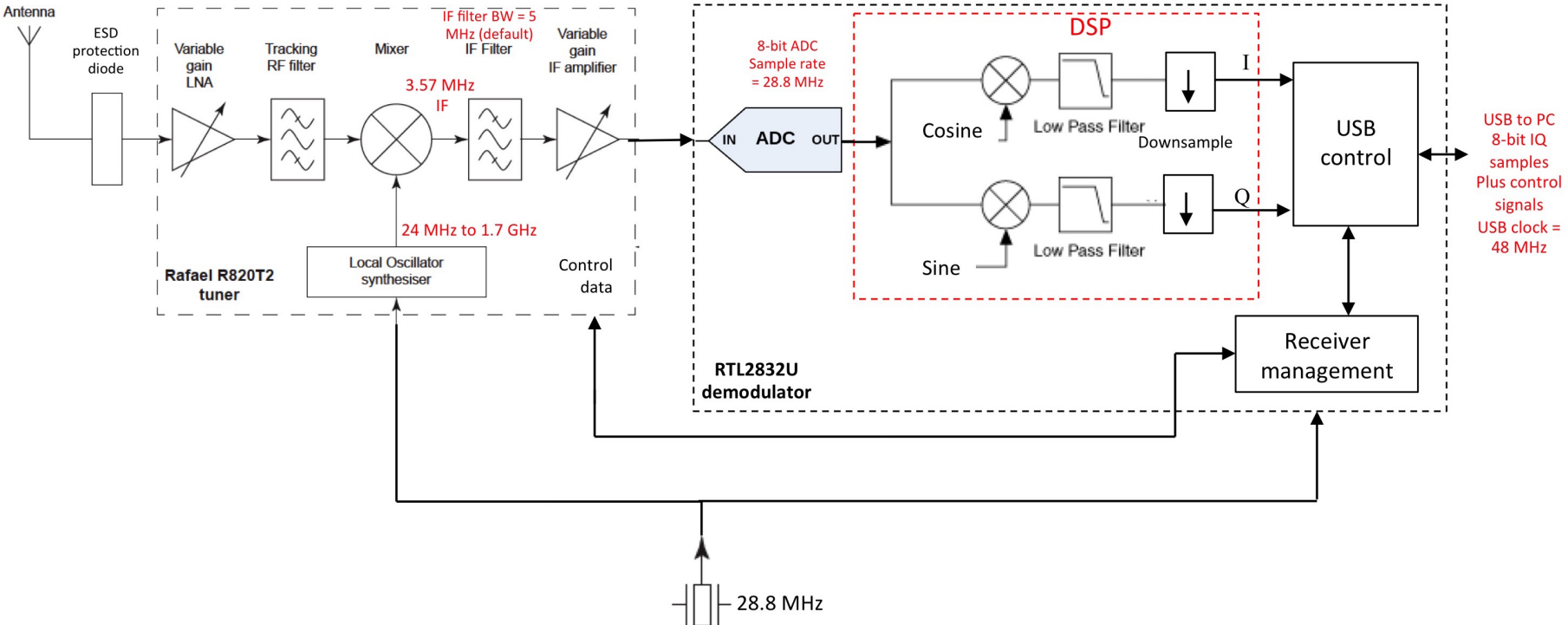
$I =$

$Q =$

INSIDE THE SDR



$$v(t) = I\cos(2\pi ft) + Q\sin(2\pi ft)$$



Working with IQ Data

- IQ data is stored as pairs of 32-bit floats
- Working with data in Python:

```
import numpy as np
import matplotlib.pyplot as
f = np.fromfile(open('filen
plt.plot(f)
plt.show()
```

- Average power of a digital signal is:

$$P = \frac{1}{N} \sum_{n=1}^{N} |x[n]|^2$$

- How would we calculate PSD in Python?

Power Spectral Density

- Take the FFT of a selection of x samples. The output will be x-long array of complex floats.
- Take the magnitude of the FFT output, which provides us 1024 real floats.
- Square the resulting magnitude to get power.
- Normalize: divide by the FFT size (x) and sample rate (F_s).
- Convert to dB using $10\log_{10}()$
- Perform an FFT shift

SDRs and Sampling

- You already know about Nyquist
- But what does this mean for SDRs?
- Let's investigate w/ GNURadio...

DEMO

GNURadio

The following instructions come from GNURadio Wiki:

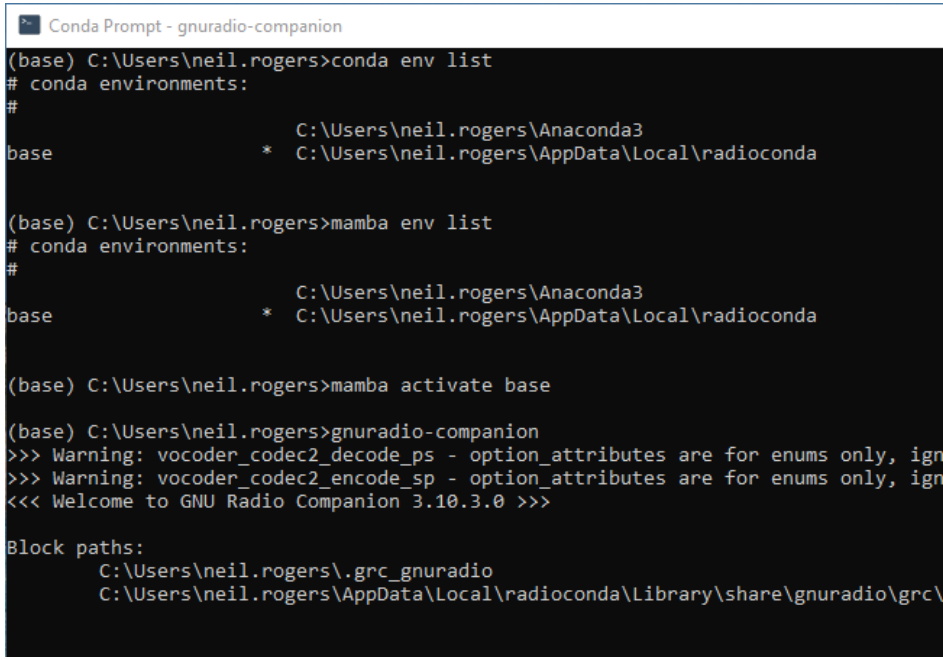
- Install miniforge (which is a conda install)
- Open the conda prompt
- Install mamba: `conda install mamba`
- Create a conda env: `mamba create -n gnuradio`
- Activate the env: `mamba activate gnuradio`
- Configure conda channels
  `mamba config --env --add channels conda-forge`
  `mamba config --env --set channel_priority strict`
- Install gnuradio `mamba install gnuradio`
- Upgrade all your packages: `mamba upgrade --all`
- You'll want UHD: `mamba install gnuradio-uhd`
- There are LOTS of additional packages.

Today

- GNURadio Overview
- Sinks/Sources
- Data types
- Hardware
- Simple receiver example

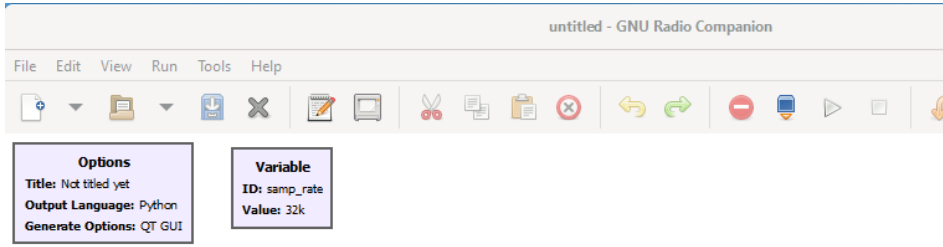
Getting Started

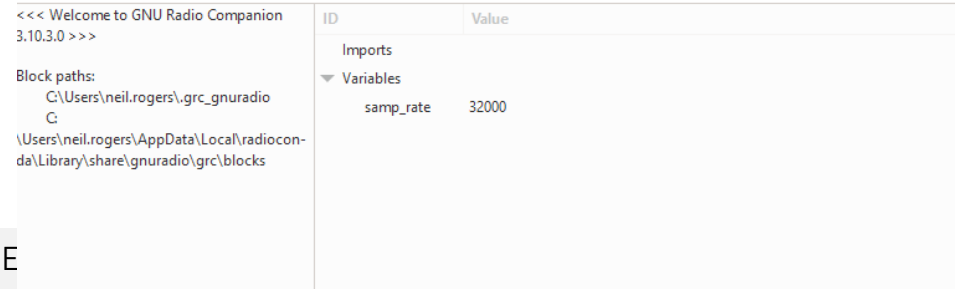
- In your Windows menu, search for mamba prompt
- See the environments installed: mamba env list
- Activate radioconda: mamba activate gnuradio
- Start gnuradio: gnuradio-companion



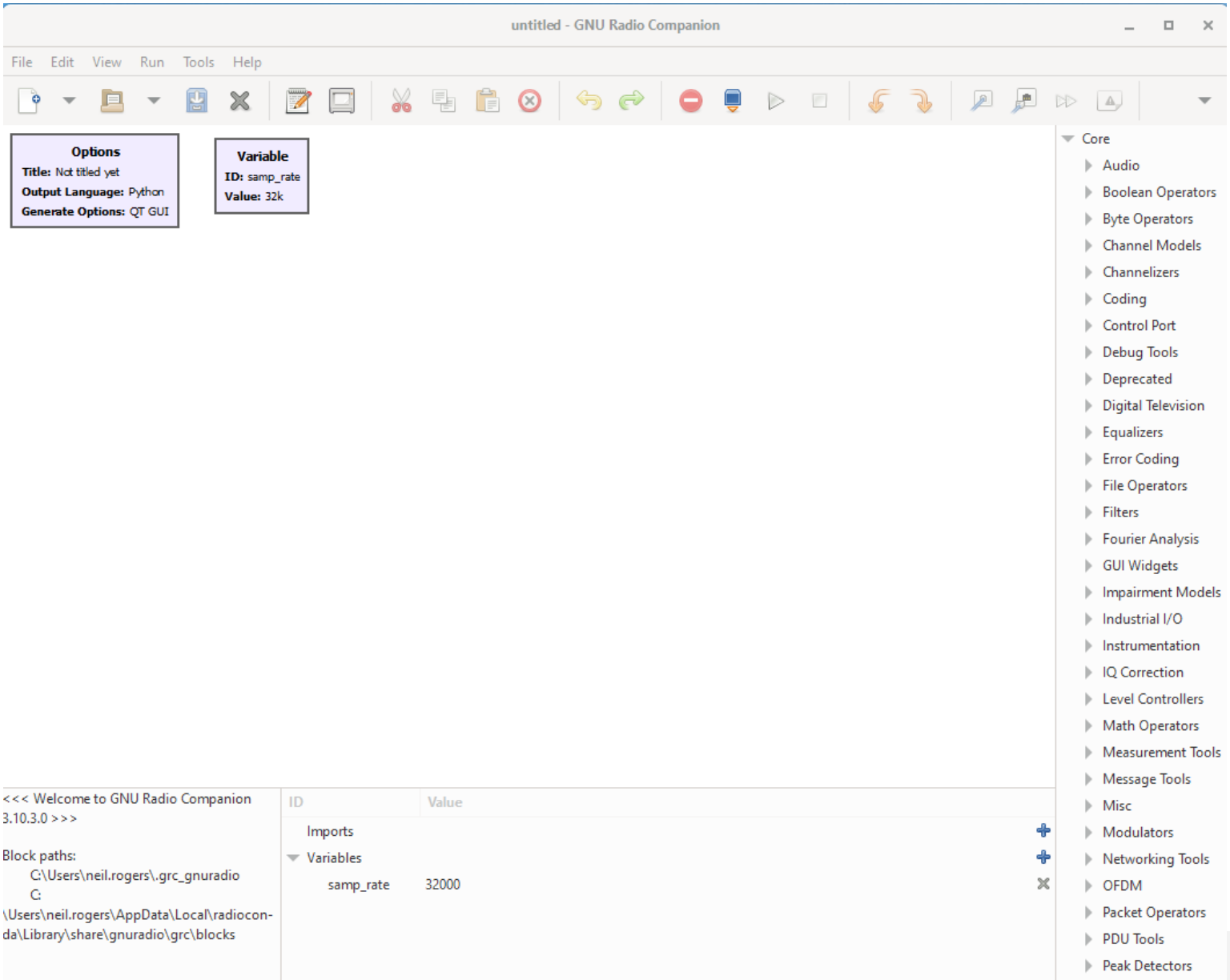
Getting Started

- In your Windows menu, search for `mamba prompt`
- See the environments installed: `mamba env list`
- Activate radioconda: `mamba activate gnuradio`
- Start gnuradio: `gnuradio-companion`





Main Window

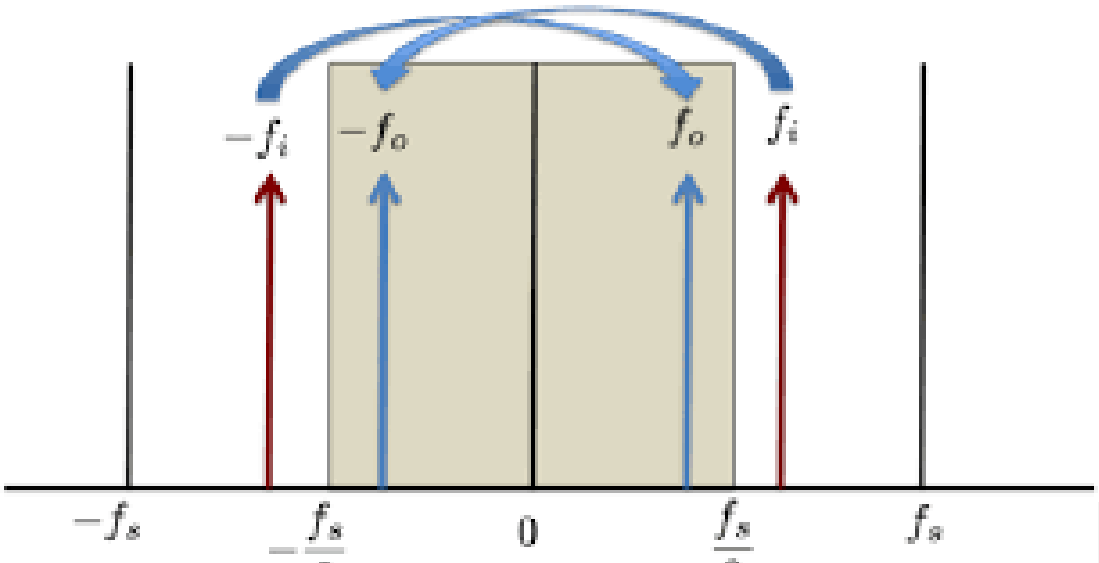

untitled - GNU Radio Companion
File Edit View Run Tools Help
Options
Title: Not titled yet
Output Language: Python
Generate Options: QT GUI
Variable
ID: samp_rate
Value: 32k
Core
Audio
Boolean Operators
Byte Operators
Channel Models
Channelizers
Coding
Control Port
Debug Tools
Deprecated
Digital Television
Equalizers
Error Coding
File Operators
Filters
Fourier Analysis
GUI Widgets
Impairment Models
Industrial I/O
Instrumentation
IQ Correction
Level Controllers
Math Operators
Measurement Tools
Message Tools
Misc
Modulators
Networking Tools
OFDM
Packet Operators
PDU Tools
Peak Detectors
<<< Welcome to GNU Radio Companion 3.10.3.0 >>>
Block paths:
C:\Users\neil.rogers\.grc_gnuradio
C:\Users\neil.rogers\AppData\Local\radiocon-da\Library\share\gnuradio\grc\blocks
ID
Value
Imports
Variables
samp_rate
32000

Data Types


Types - Color Mapping
Complex Float 64
Complex Float 32
Complex Integer 64
Complex Integer 32
Complex Integer 16
Complex Integer 8
Float 64
Float 32
Integer 64
Integer 32
Integer 16
Integer 8
Bits (unpacked byte)
Async Message
Bus Connection
Wildcard
Close

Sampling

- We all know Nyquist, but what happens when we violate it?
- Remember, we are dealing with digital signals
- Analog Devices



Hardware

- Hackrf $\longrightarrow$ check version with $\mathrm{hackrf_info}$
- UHD $\longrightarrow$ $\mathrm{uhd_usrp_probe}$
- GQRX
- NBFM