

Intro to Software Defined Radios

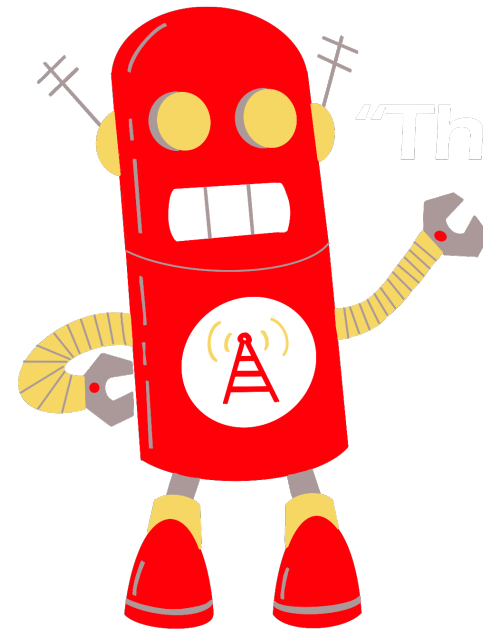
and GNU Radio

08/25/2025
SMARC
Technical
Presentation

Primary Presenter:

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- Assisted by **Gary Schafer** , **Don Mills**
and **Geoffrey Mark**



Don't Forget to
Get Your
Ticket!



SMARC

CLUB MEETING

AUGUST 25, 2025 @ 7 PM

JOIN US AT OUR NEXT CLUB MEETING FOR A
PRESENTATION ON SDR RADIO.

OUR PRESENTER, PAUL, KI5MIV, IS DONATING A SDR RADIO
WITH ANTENNAS THAT YOU CAN WIN!



EVERYONE WHO ATTENDS THE MEETING IN PERSON WILL RE-
CEIVE A TICKET. A DRAWING WILL BE HELD AFTER THE
PRESENTATION.

**YOU MUST BE
PRESENT TO WIN!!**



What is an SDR?

- A **Software-Defined Radio (SDR)** is a radio communication system where traditional hardware components like mixers, filters, amplifiers, modulators/demodulators, and **detectors**—are replaced or implemented by software running on a computer or embedded system.

Simplified Version of How an SDR Works

- In a conventional radio, each function (tuning, filtering, modulation, etc.) is handled by dedicated electronic circuits.
- In an SDR, the radio frequency (RF) signals are converted into digital signals using an **analog-to-digital converter (ADC)**.
- Once in digital form, most of the signal processing is done in software. A digital-to-analog converter (DAC) can be used to transmit signals back out.

SDR Key Advantages

Flexibility - A single SDR can handle many communication standards (FM, AM, SSB, Wi-Fi, LTE, etc.) simply by changing software.

Upgradability - Features and protocols can be updated without changing the hardware.

Wideband capability - SDRs can tune across a broad frequency spectrum.

Research & Experimentation - Popular with hobbyists, researchers, and military, since new modulation techniques can be tested without building new hardware.

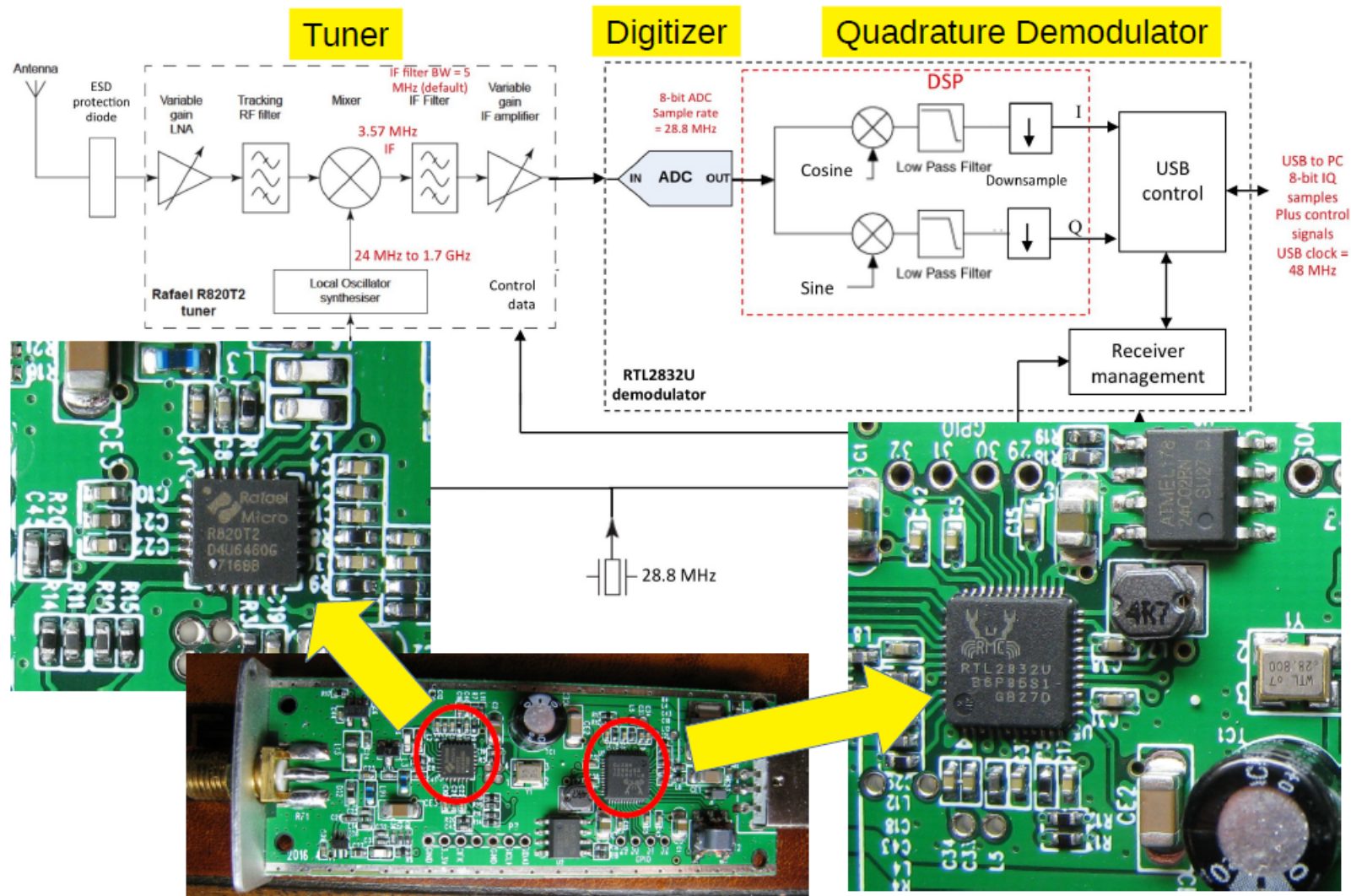
Meet the Ubiquitous RTL-SDR



The RTL-SDR can be used as a wide band radio scanner.
Applications include:

- Listening to VHF & HF amateur radio.
- Decoding ham radio [APRS packets](#).
- Listening to amateur radio hams on SSB with LSB/USB modulation.
- Listening to satellites and [the ISS](#).
- Decoding unencrypted [digital voice](#) transmissions such as P25/DMR/D-STAR.
- Use [rtl-sdr as a panadapter](#) for your traditional hardware radio.
- Using rtl-sdr as a [spectrum analyzer](#).
- And Many, Many More Applications

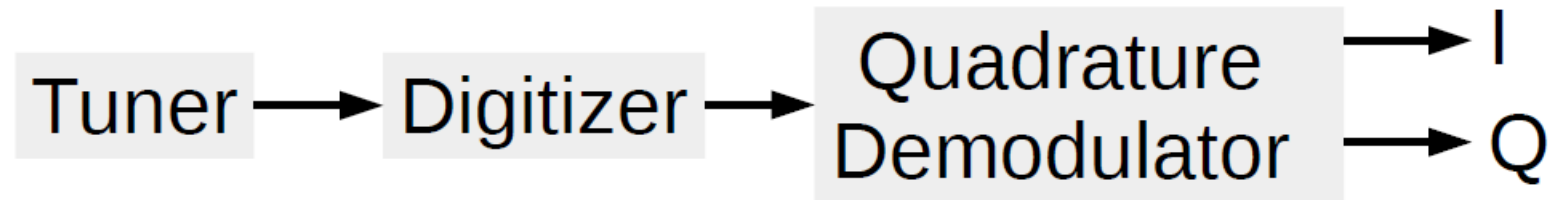
What's Inside an RTL-SDR?



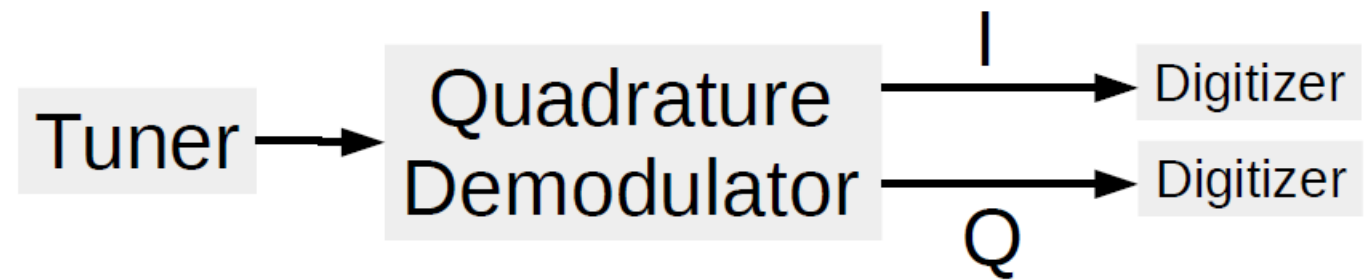
General SDR Flows

General SDR Signal Flows

RTL-SDR / Signalhound BB60C



HackRF One / USRP / LimeSDR



What's IQ and What's a Quadrature Demodulator?

Hold those questions. We will
revisit

IQ after we introduce GNU Radio.

Introducing GNU Radio



What is GNU Radio?

- GNU Radio is an **open-source software development toolkit** used to build and simulate software-defined radios (SDR). It provides signal processing blocks that can be connected together to process real-world signals – such as radio, television, satellite, or cellular communications – entirely in software.

Key Features of GNU Radio

- **Signal Processing Blocks:** Comes with a library of ready-to-use filters, modulators/demodulators, FFTs, and more.
- **Flowgraph Model:** Users build “flowgraphs,” which are diagrams of how signals are processed from input to output.
- **Hardware Integration:** Works with many SDR hardware platforms (e.g., USRP, RTL-SDR, HackRF) but can also run in simulation without hardware.
- **Cross-Platform:** Runs on Linux, macOS,
• and Windows.

Let's learn by
doing. We are
going to build
a simple FM
receiver

Switch to GNU Radio

The Lost in
Space Robot
says: “Danger
Danger!”

The next few slides might cause
your head to explode! LOL

What's an Imaginary Number?

An **imaginary number** is a number that, when squared, gives a negative result.

The simplest imaginary unit is i (in mathematics) or sometimes j (in engineering), defined as:

$$i = \sqrt{-1}$$

That means:

$$i^2 = -1$$

Examples

- $\sqrt{-4} = 2i$
- $\sqrt{-9} = 3i$

Why They Matter

Why They Matter

Imaginary and complex numbers are not just “made up” — they’re used in many real-world applications:

- **Electrical engineering** (AC circuits use j)
- **Quantum mechanics**
- **Signal processing**
- **Control theory**

Relationship to Complex Numbers

Relationship to Complex Numbers

Imaginary numbers are part of **complex numbers**, which have the form:

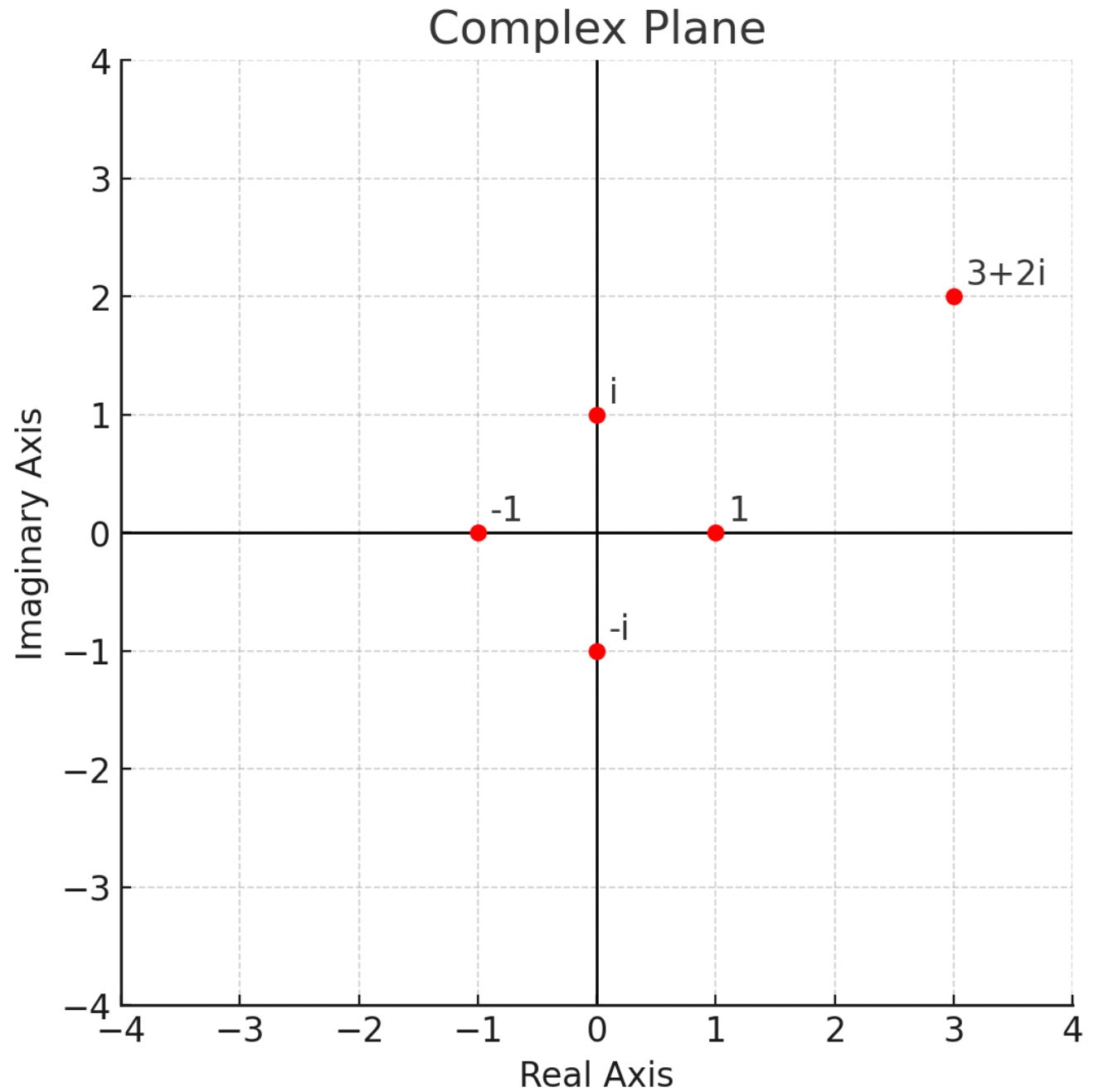
$$a + bi$$

where:

- a is the **real part**,
- bi is the **imaginary part**.

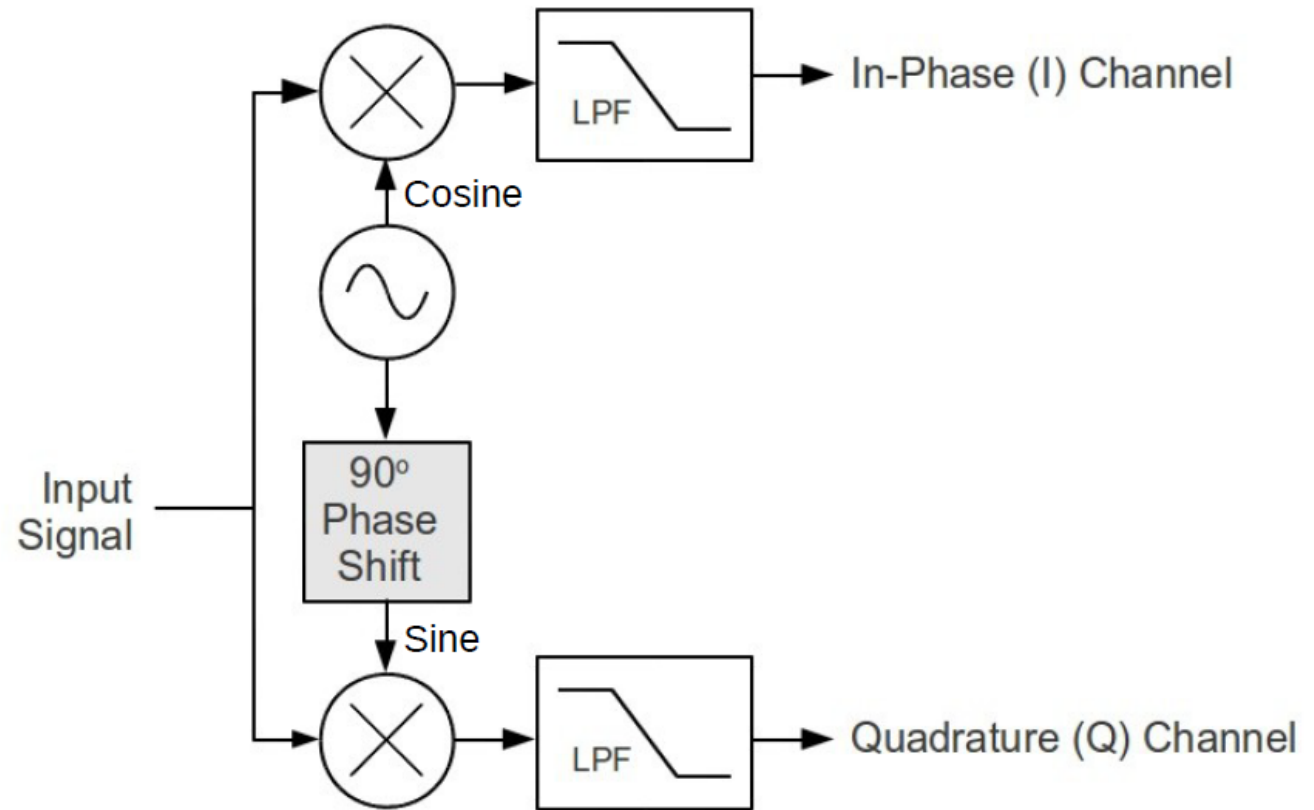
For example, $5 + 3i$ is a complex number.

Complex Plane



Quadrature Demodulator

Quadrature Demodulator

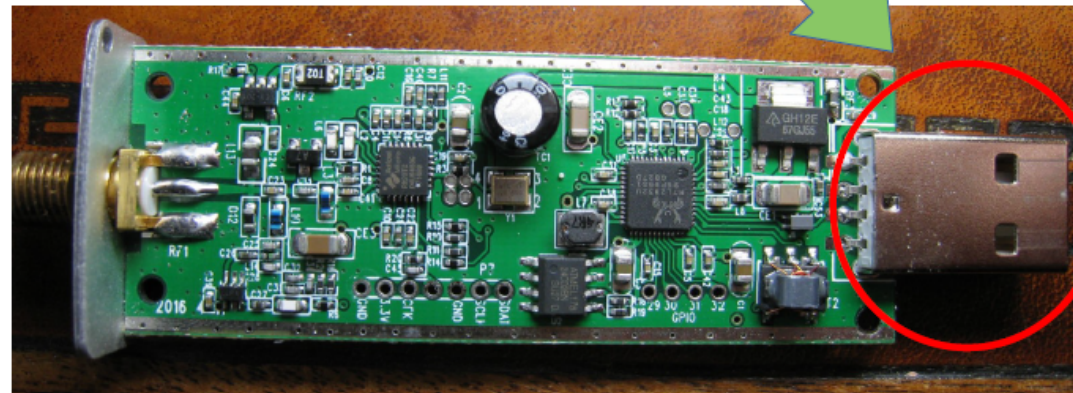


SDR Output

SDR Output

RTL-SDR Source
Sample Rate (sps): 2.4M
Ch0: Frequency (Hz): 90.9M
Ch0: Freq. Corr. (ppm): 0
Ch0: DC Offset Mode: Off
Ch0: IQ Balance Mode: Off
Ch0: Gain Mode: Manual
Ch0: RF Gain (dB): 10
Ch0: IF Gain (dB): 20
Ch0: BB Gain (dB): 20

I-Q-I-Q-I-Q...



Demo01

Sampling

Let's talk about sampling next

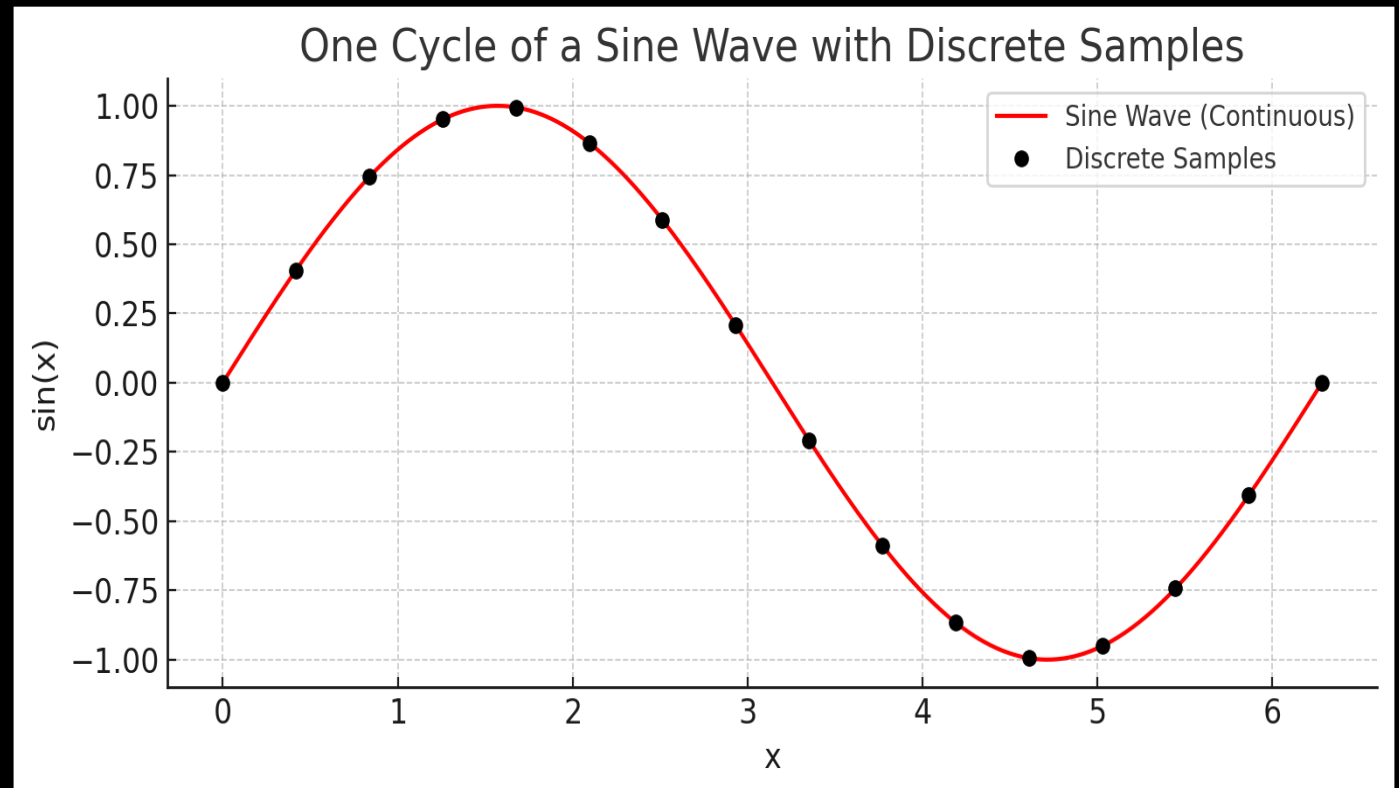
Nyquist Theorem

To accurately reconstruct a continuous signal from its samples, the sampling rate must be at least **twice the highest frequency** present in the signal.

Nyquist Theorem Example

Human hearing ranges up to about **20 kHz**. To record audio without losing information, the sampling rate must be at least **40 kHz**. That's why CD audio uses **44.1 kHz**.

Discrete Samples



What is Aliasing?

Aliasing is a phenomenon that occurs when a continuous signal is sampled at a rate that is too low to capture its changes accurately. As a result, **different signals become indistinguishable (or appear as “aliases” of each other)** after sampling.

Aliasing in Simple Terms

- Imagine you take snapshots of a moving object too slowly → it looks like it's moving differently than it actually is.
- Similarly, if you sample a signal too slowly, high-frequency components “fold back” and look like lower-frequency components.

Aliasing Example

- If a 9 Hz signal is sampled at 10 Hz:
- Nyquist frequency = 5 Hz
- The 9 Hz component will alias and appear as 1 Hz ($|9 - 10|$).
- So, instead of recording 9 Hz, we “**see**” a fake 1 Hz signal.

How to Prevent Aliasing

- **Sample fast enough:**
Ensure $f_s \geq 2f_{\max}$
- **Use an anti-aliasing filter:**
A low-pass filter before sampling removes frequencies above $f_s/2$, so no high frequencies fold back.

Aliasing Analogy

Think of a spinning wheel in a movie. If the frame rate (sampling) is too low, the wheel may look like **it's** spinning slower, backwards, or standing still – **that's** aliasing.

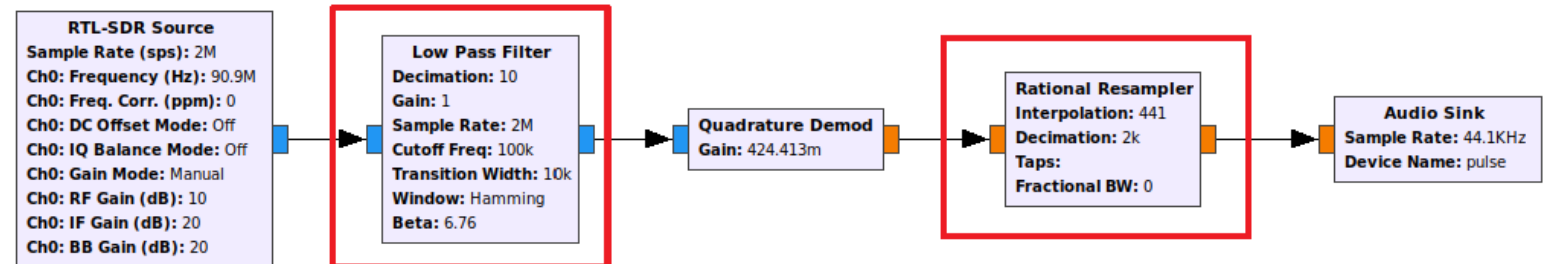
Sampling: Interpolation and Decimation

Sampling: Interpolation & Decimation

Problems:

- Digital systems must operate on whole samples; partial samples not allowed.
- SDR sample rate must be some specific value, but output must be a different value.
- Too many samples means too many computations and too much storage.

Answer: Interpolation (increase sample rate) and decimation (decrease sample rate) using integer values.



Interpolation and Upsampling

- Interpolation in the process of increasing the number of samples between two known data points. Interpolation in DSP increases the number of samples between discrete-time samples through the process of upsampling and low pass filtering. Interpolation increases the sampling rate for a signal such that a signal will appear to be sampled at a higher frequency.

Interpolation and Upsampling Continued

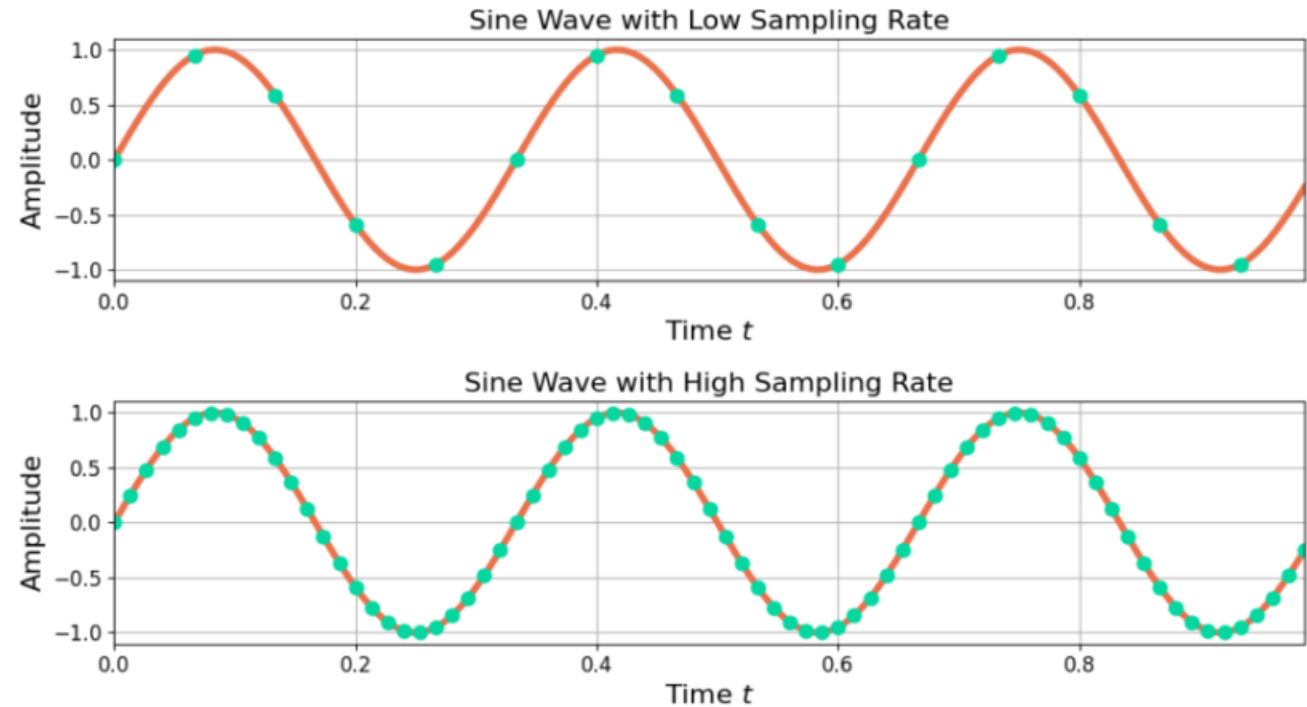


Figure 1: A sine wave with two different sampling frequencies.

Figure 1 shows the same sine wave with two sampling rates. Interpolation by 5 increases the number of samples, from 15 samples in low sampling rate sine wave to 125 samples in the high sampling rate sine wave. Interpolation is a two step process: upsampling followed by low pass filtering.

Interpolation and Upsampling

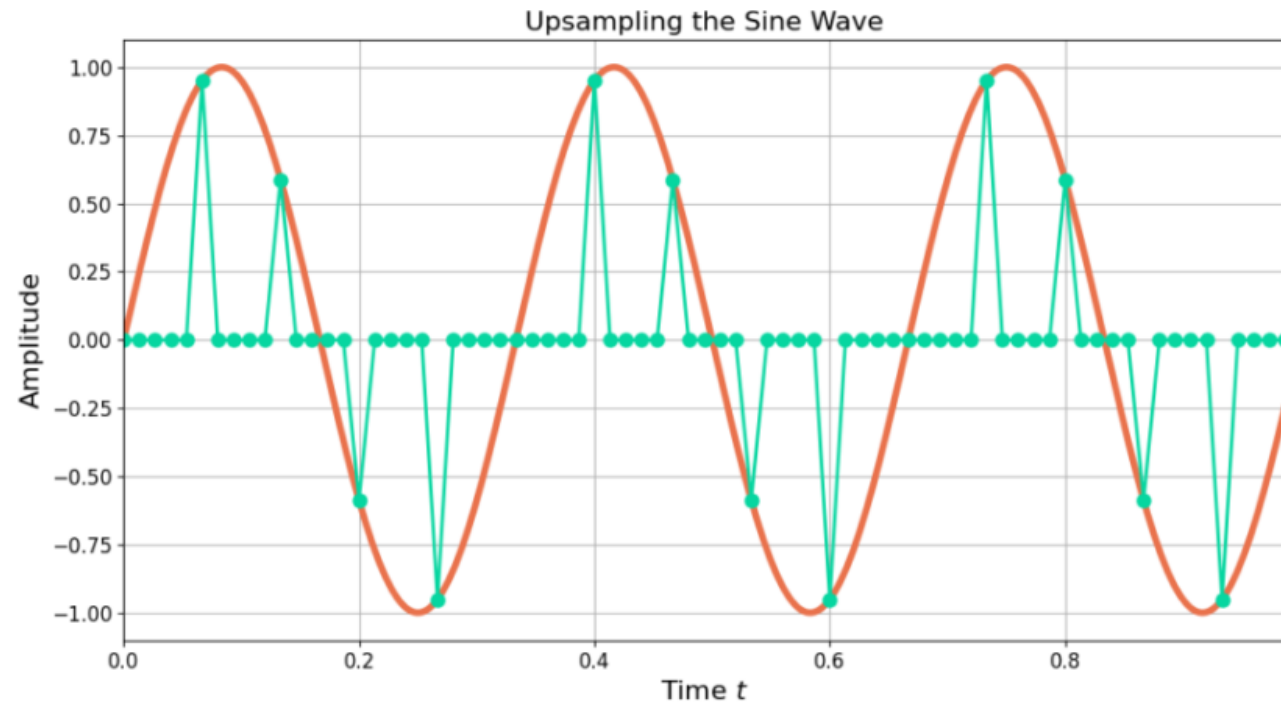


Figure 2: Upsampling by 5 is accomplished by zero-padding every sample with 4 zeros.

Upsampling is the process of zero-padding a time-series. Upsampling by M increases the number of samples by M through inserting $M-1$ zero samples after each input sample. Figure 2 shows the low sample rate sine wave being upsampled by 5. Each sample is followed by 4 zeros.

Increasing the number of output samples for every 1 input sample increases the sample rate. Increasing the number of samples by 5 equivalently increases the sampling rate by a factor of 5.

Interpolation and Upsampling

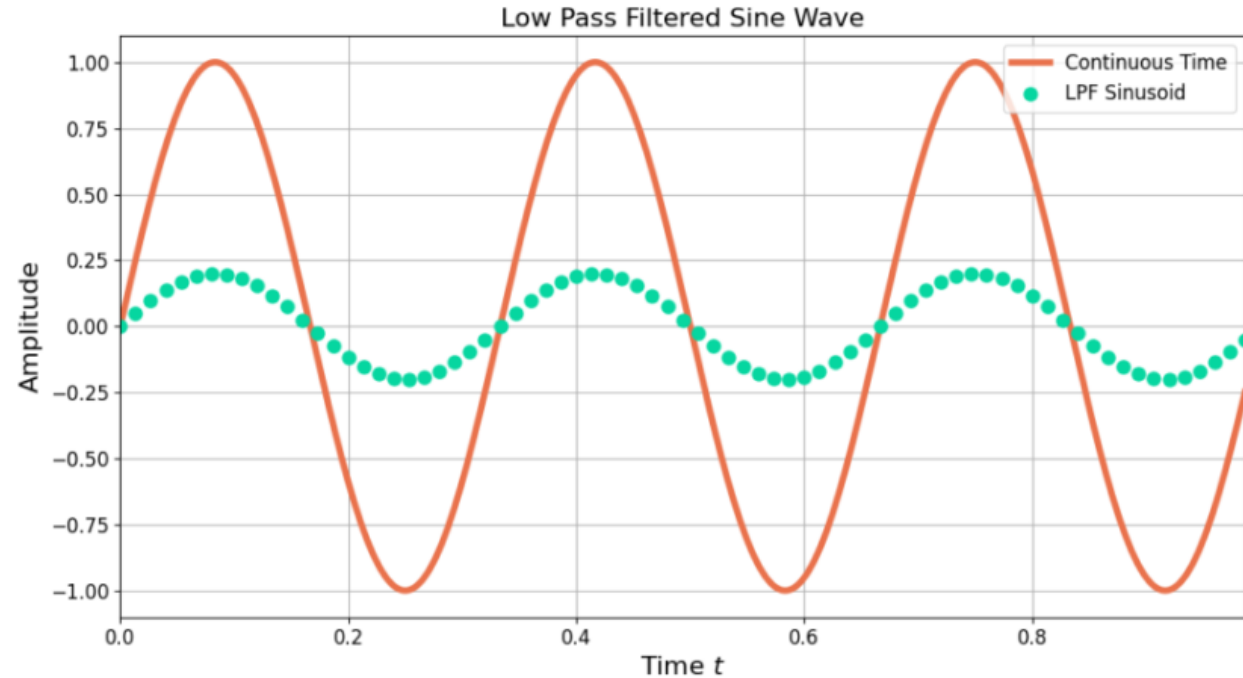


Figure 3: The result after low pass filtering the upsampled sine wave without a gain factor.

Low pass filtering is needed to smooth the zero-padded signal to fill in the gaps between the non-zero **samples**. See Figure 3.

Interpolation and Upsampling

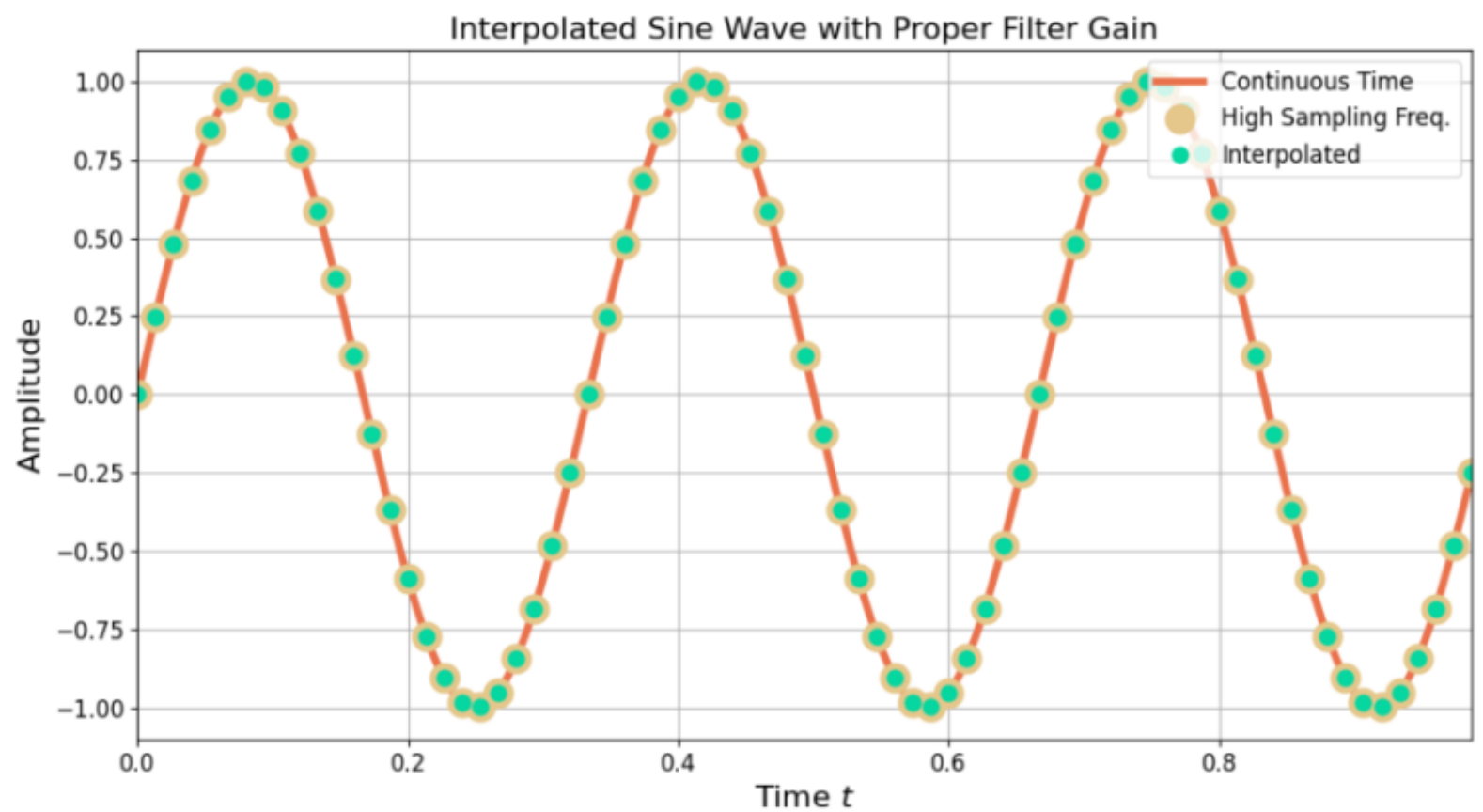
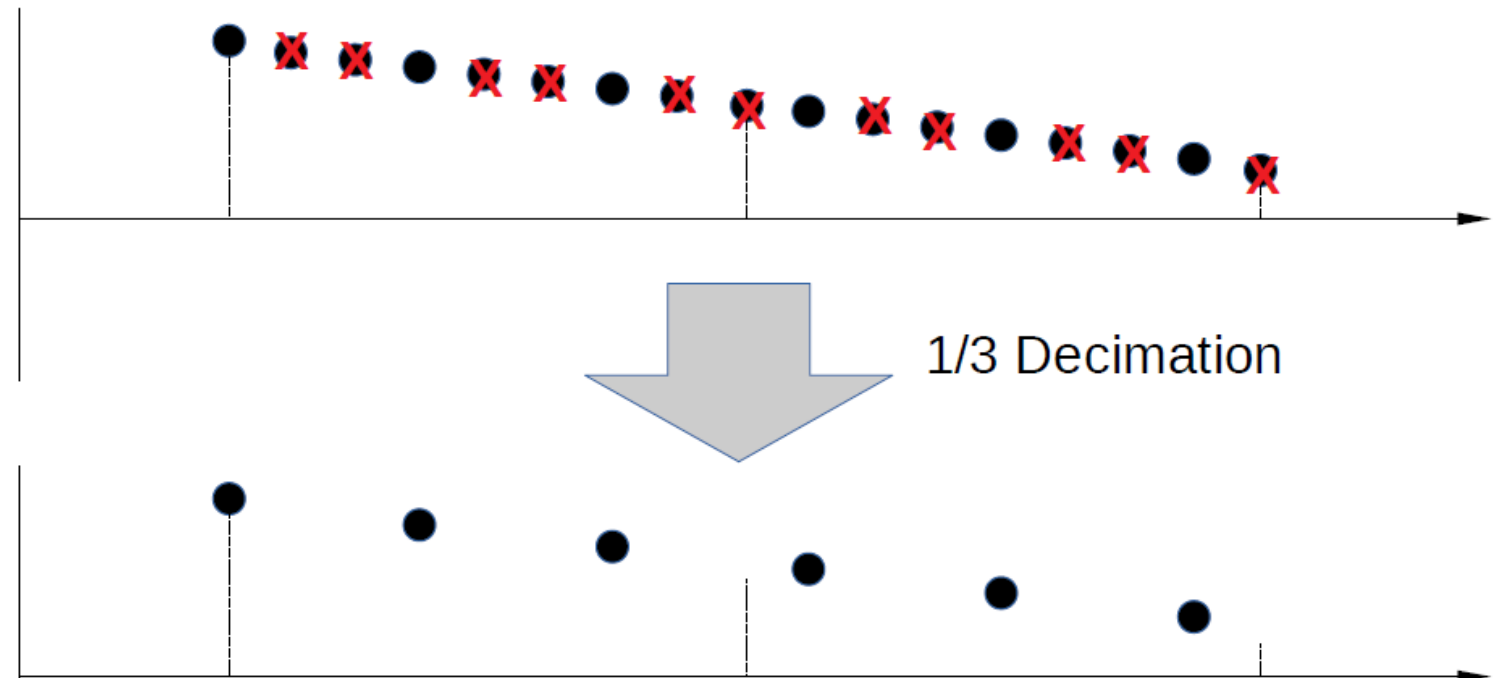


Figure 4: The sine wave after interpolation matches the sine wave which was natively sampled at a higher rate.

Sampling: Decimation

Decimation: Decrease sampling rate by dropping samples

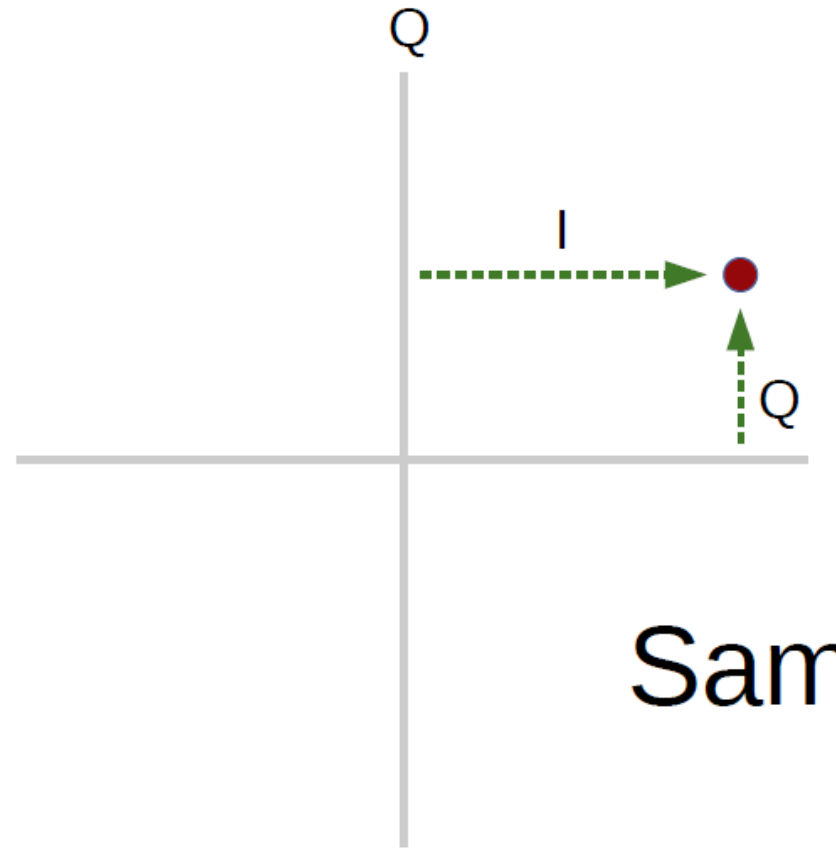
Sampling:
Decimation



$$\text{Final Sample Rate} = \text{Original Sample Rate} \times \frac{8}{3}$$

Complex Samples

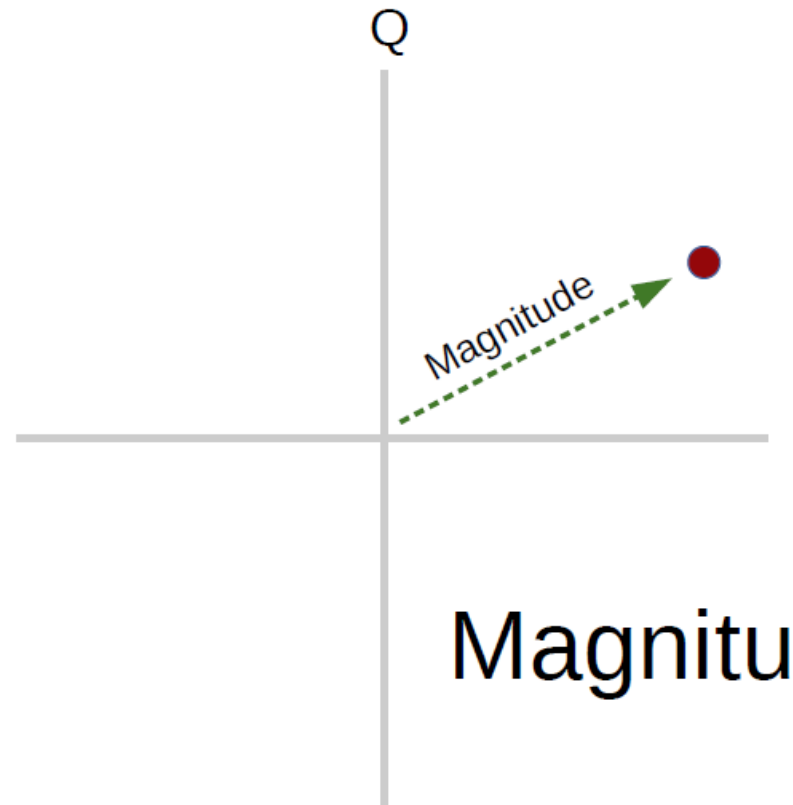
Complex Samples



$$\text{Samples} = I + jQ$$

Complex Samples

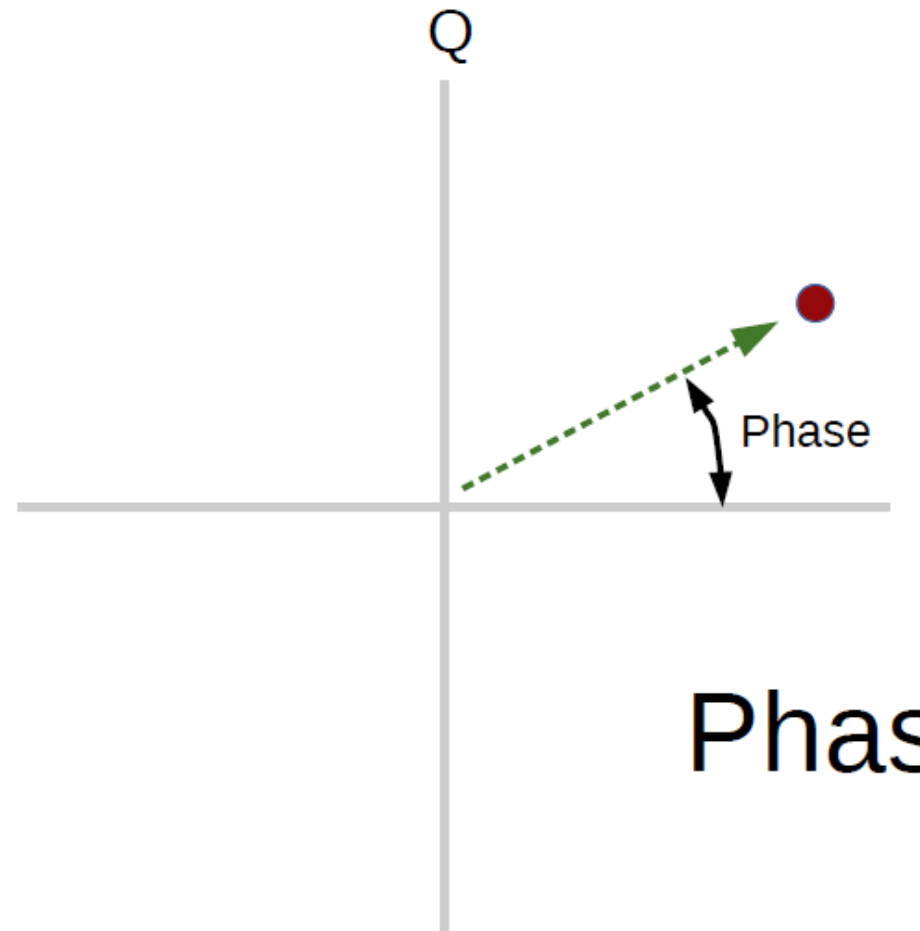
Magnitude
of a
Complex
Number



$$\text{Magnitude} = (I^2 + Q^2)^{(1/2)}$$

Complex Samples

Phase of a
Complex
Number



$$\text{Phase} = \text{atan}(Q/I)$$

Demodulation

Demodulation
Using
Complex
Numbers

$$AM = \text{Magnitude} = (I^2 + jQ^2)^{(1/2)}$$

$$PM = \text{Phase} = \text{atan}(Q/I)$$

$$FM = \frac{\text{Phase}_n - \text{Phase}_{n-1}}{\text{Sample Period}}$$

Fun Fact

The ICOM 7300 sampling rate is 124.032 MHz and it digitizes the entire HF spectrum after filtering out some unwanted frequencies to prevent overload (clipping) of the ADC. It is then down-converted in the digital domain (in an FPGA) and demodulated. There is aliasing at some VHF frequencies (outside the ham bands).

Narrowband FM and Single Sideband Receivers

Switch to GNU Radio and Look at
Narrowband FM and Single
Sideband Receivers

Resources

See my YouTube Channel:
paulmaine6433

You can download the files from:

GitHub Repository:

<https://github.com/pmaine/The-SDR-Guy>

Questions?



Let's See
Who Wins the
Door Prize!



Thanks for
Letting Us
Share about
SDR's!

