North Texas NTMS Microwave Society

SDR Basics

Jim McMasters KM5PO

January 17th, 2025

SDR high level

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- Software defined radio is a radio communication system where components that conventionally have been implemented in analog hardware (e.g. mixers, filters, amplifiers, modulators/demodulators, detectors, etc.) are instead implemented by means of software on computer or embedded system[1].
- A basic SDR system may consist of a computer equipped with a sound card, or other analog-to-digital converter, preceded by some form of RF front end. Significant amounts of signal processing are handed over to the general-purpose processor, rather than being done in a special-purpose hardware (electronic circuits).
- Such a design produces a radio which can receive and transmit on widely different frequencies and different radio protocols based solely on the software used.

SDR Basics

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- Today our presentation will take us through:
  - If you are an engineering student, why you should consider SDR
  - If you are thinking about a ham radio license
  - How an analog receiver tunes an on-the-air signal
  - How a software defined receiver tunes a signal including
    - Conversion from analog to digital
    - Complex numbers and mixing
    - Negative frequency
    - IF filtering/bandwidth limiting via down sampling
  - How a software defined transmitter creates a signal including
    - Digital up conversion
    - Satisfying Nyquist requirements
    - Complex interpolation filter
  - Breakdown on 3 popular SDR units to identify the key elements
  - A demo of GNUradio synthesizing real and complex waveforms

Help wanted

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- SDR or “Signal processing Engineers” are in demand

Software Defined Radio (SDR) Engineer

Caliola Engineering, LLC
Colorado Springs, CO

What we require:

- MS OR BS plus 2 years' experience in Electrical Engineering, Mathematics or Physics or a related professional technical
- Experience solving technical problems in the areas of wirel processing, and signals collection.
- Strong background in scientific programming using languages such as C, C++, Python.
- Experience developing communication system components for SDR frameworks like GNU Radio.
- Experience with standard RF lab equipment (e.g., oscilloscopes, spectrum analyzers, signal generators, etc.).
- Experience integrating SDR components with external systems and software.
- Experience with wireless digital communication systems, in particular modern digital modulation techniques and modem design.
- Proven track record of being resourceful and creative, and willing to contribute to a multidisciplinary and face-paced engineering environment.
- Awareness of relevant industry standards, regulations and best practices in RF design and safety.
- This position requires the ability to obtain and maintain a security clearance, which is issued by the U.S. Government. Security clearances may only be granted to U.S. citizens. In addition, applicants who accept a conditional offer of employment may be subject to government security investigation(s) and must meet eligibility requirements for access to classified information.

Software Defined Radio (SDR) Engineer
Caliola Engineering, LLC — Colorado Springs, CO
At Caliola, SDR engineers are problem solvers who enjoy solving hard technical problems quickly and creativity and applying innovative approaches to solve...
$90,788 - $177,158 a year Quick Apply

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Help wanted

KRATOS

Digital Signal Processing Engineer

Kratos Defense - 3.3 ★

Colorado Springs, CO

Apply Now

Experience and Skills:

- Must be a self-starter and able to work closely in a fast paced, small engineering team which includes other software engineers, DSP engineers, hardware engineers, systems engineers, and test engineers
- Must have an active Top-Secret security clearance with the ability to obtain an SCI
- Education and/or background in digital signal processing and satellite communications specifically in modulation detection and characterization
- Team player and capable of working in a fast paced, team environment

Preferred Skills and Experience

- Satellite communications, geolocation, or other RF communications experience
- Familiarity and experience with Linux operating systems
- Familiarity with GNU Radio and Software Defined Radios (SDR)
- Software development experience with languages such as C or C++, or Python, or Cuda
- Familiarity with containerized environments such as Docker
- Experience with common engineering lab and test equipment such as oscilloscopes and spectrum analyzers
- Experience with Agile program execution methodologies

#LI-Onsite

Competitive salary based on experience and education

Salary Range: $130,000-$170,000

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Help wanted

Signal Processing Specialist - Geospatial Intelligence

Muon Space
Mountain View, CA

Apply Now

Qualifications

- Experience with digital signal processing techniques related to RF instruments
- Experience developing algorithms using data from RF instruments
- Exceptional skills in python-based development and analysis
- Ability to work with a distributed, interdisciplinary team (scientists, engineers, data support, all working at different locations)

Preferred Qualifications

- Experience with problems requiring precision timing
- Experience with geolocation of RF transmitters
- Experience with GNU Radio
- Experience developing retrieval algorithms from satellite Earth observations
- Understanding of the principles of scientific instruments
- Familiarity with cloud native systems (AWS, Flyte)

Salary

The salary range for this role is $95K- $195K and will depend on a candidate's skills, geographic location, qualifications, and experience as defined during the interview process.

About Muon Space

Founded in 2021, Muon Space is an end-to-end Space Systems Provider that designs, builds, and operates LEO satellite constellations delivering mission-critical data. Our

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Help wanted

SDR SW Engineer (GNU Radio)

Comcentric Inc. - 3.9 ★
Austin, TX

Quick Apply

Full Job Description

We are seeking a **SDR SW Engineer** for a long term remote contract - goal is to convert contractors to perm employees..

Looking for US Citizens.

Responsibilities

- Analyze and Design SDR systems
- Develop a real-time capable transceiver in GNU Radio + FPGA based hardware
- Work with a test engineer to validate the design
- Work with an application engineer to support customer demos and requested capabilities
- Support implementing and improving new algori
- Support IP development and packaging for futur

Qualifications

- BS in Computer Science or related field (MS or Ph
- Experience with Linux, C++, and Python
- Git experience, or equivalent source code manag
- Experience with modern software development practices and Continuous Integration/Continuous Development (CI/CD)
- Experience with open-source GNU Radio software and/or Software Defined Radio

SDR SW Engineer (GNU Radio)
Comcentric Inc. — Austin, TX 3.9 ★
BS in Computer Science or related field (MS or PhD highly preferred). Work with a test engineer to validate the design. Analyze and Design SDR systems.
Estimated: $108K - $137K a year Quick Apply

Unlicensed TX operation

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- Transmitting on-the-air with SDR
  - If you are not licensed then you may use the following frequencies

Type of band	Frequency range		Power	Usage	Range
Family Radio Service (FRS)	462-467 MHz	UHF	.5 to 2 watts	Short-range comms for families, hiking, campling, local comms	A few miles in open areas
Multi-Use Radio Service (MURS)	151-154 MHz	VHF	2 watts	Small business and personal comms, external antennas allowed. Driveway alarms, handheld radios, farm comms	A few miles in open areas
Citizen Band (CB) Radio	26.965-27.405 MHz	HF	4 watts AM, 12 watts SSB	Truckers/hobbyists	Several miles, E layer skip possible
Wireless Microphones/Intercoms	49 and 902-928 MHz	HF/VHF		Microphones, baby monitors and intercom	Close range
Industrial, Scientific and Medical (ISM) Band	902-928 MHz	UHF		Wi-Fi, Bluetooth and RFID	Close range
Industrial, Scientific and Medical (ISM) Band	2.4-2.5 GHz	uWave		Wi-Fi, Bluetooth and RFID	Close range
Industrial, Scientific and Medical (ISM) Band	5.725-5.875 GHz	uWave		Wi-Fi, Bluetooth and RFID	Close range

With a ham radio license

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- Transmitting on-the-air with SDR
  - As a “Technician” class licensee you have the following VHF/UHF/uWave privileges (plus some HF band usage)

Ham band	Main propagation	other propagation
6 meters (50 MHz – 54 MHz)	Groundwave & Ionospheric reflection	Moonbounce/meteor scatter
2 meters (144 MHz – 148 MHz)	Groundwave & Ionospheric reflection (rare)	Moonbounce/meteor scatter
1.25 meters (222 MHz – 225 MHz)	Groundwave & Ionospheric reflection (rare)	Moonbounce/meteor scatter
70 centimeters (420 MHz – 450 MHz)	Ground wave	Moonbounce
33 centimeters (902 MHz – 928 MHz)	Ground wave	Moonbounce
23 centimeters (1.24 GHz – 1.3 GHz)	Ground wave	Moonbounce
13 centimeters (2.3 GHz – 2.45 GHz)	Ground wave	Moonbounce/rain scatter
9 centimeters (3.3 GHz – 3.5 GHz)	Ground wave	Moonbounce/rain scatter
6 centimeters (5.65 GHz – 5.925 GHz)	Ground wave/tower & building scatter	Moonbounce/rain scatter
3 centimeters (10.00 GHz – 10.500 GHz)	Ground wave/tower & building scatter	Moonbounce/rain scatter
1.2 centimeters (24.00 GHz – 24.25 GHz)	Ground wave/tower & building scatter	Moonbounce/rain scatter
6 mm (47.0 GHz – 47.2 GHz)	Ground wave/tower & building scatter	Moonbounce/rain scatter

Obtaining a license

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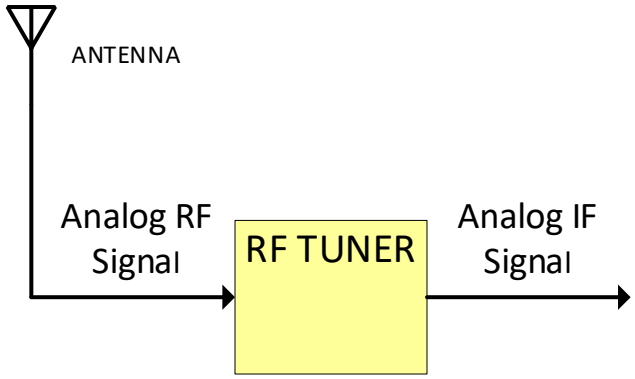
- Cowtown Amateur Radio Club (K5COW) testing
  - Testing for ham radio licensing is conducted at the Cowtown ARC club house twice a month (2nd and 4th Thursday at 7pm).
  - Prefer pre-registration however walk-ins are welcome
  - K5COW - Cowtown Amateur Radio Club - Get Your License

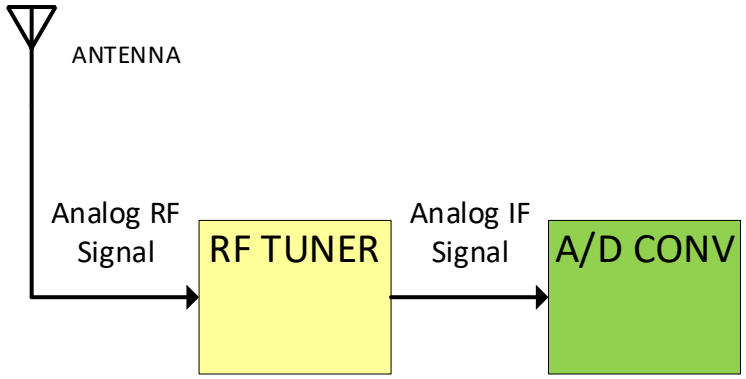
Analog receiver

- RF tuner down converts analog RF signals to analog IF frequencies



Analog receiver

- A/D CONV – Analog to Digital converter will convert the analog voltage variation to a set of digital values.



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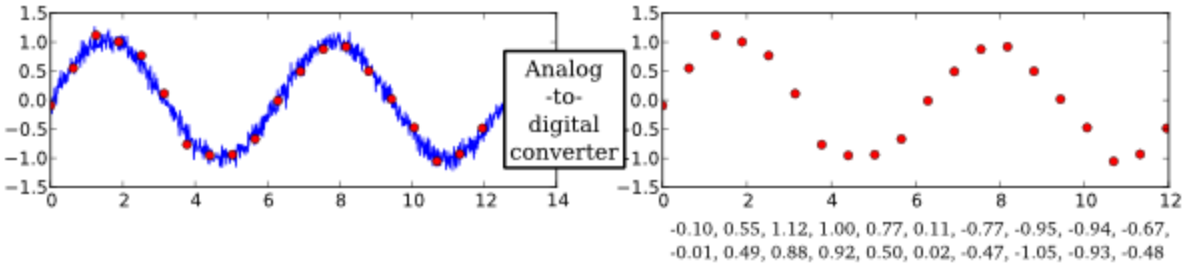
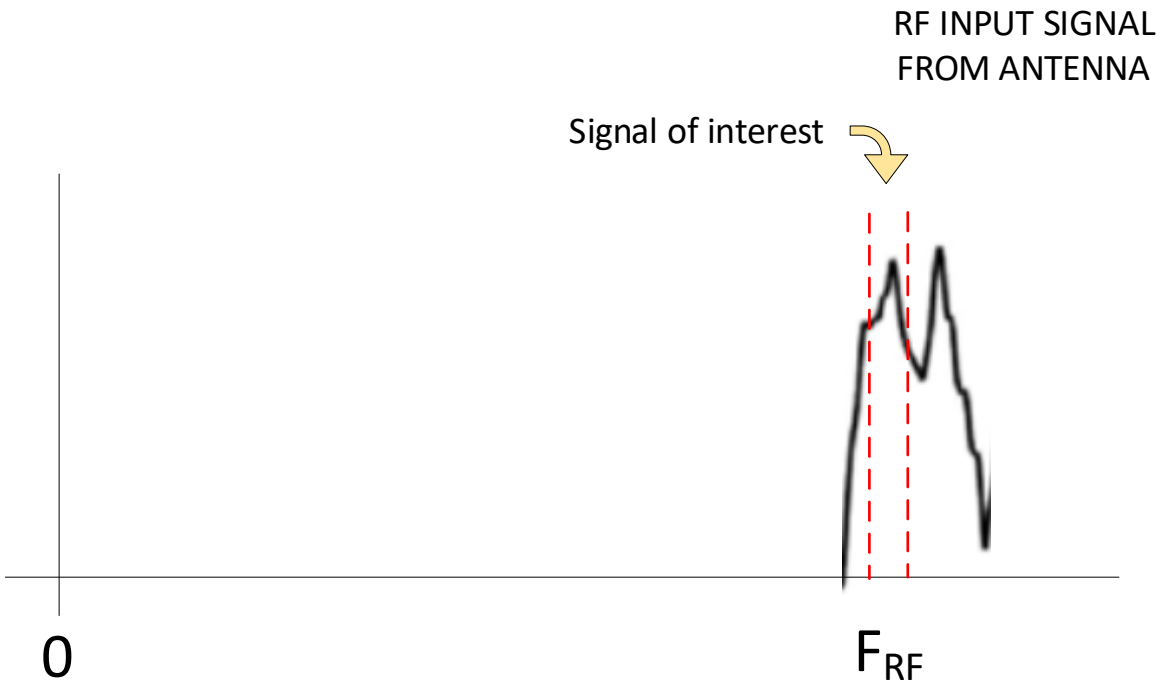


- This digital signal can thus be represented by a sequence of numbers, called samples. A fixed time interval between samples establishes a signal sampling rate.
- The Nyquist-Shannon theorem states that the sample rate must be at least twice the bandwidth of the signal to avoid aliasing. For example if the highest frequency you want to capture is 20,000 Hz, you need to sample at least 40,000 Hz to enable 100% reconstruction

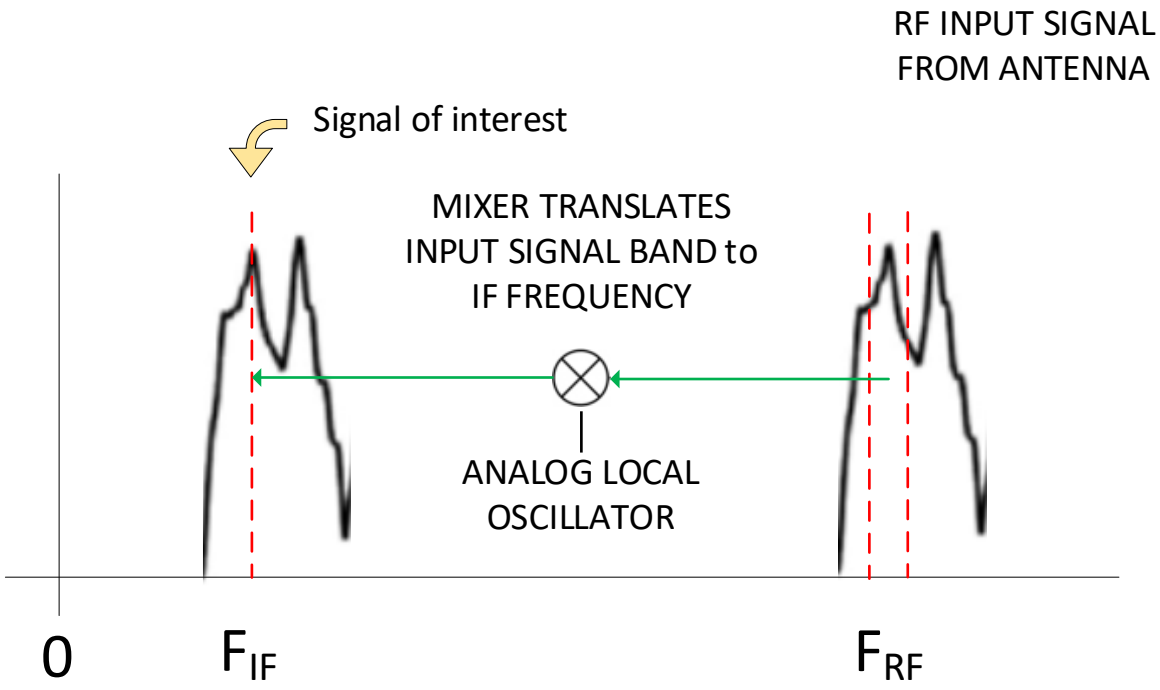
Analog RF tuner receiver mixing

- Signal band of interest is defined by dashed lines



Analog RF tuner receiver mixing

- Signal band of interest is defined by dashed lines
- Analog mixer translates the RF input signal F_{RF} to IF frequency



Analog RF tuner receiver mixing

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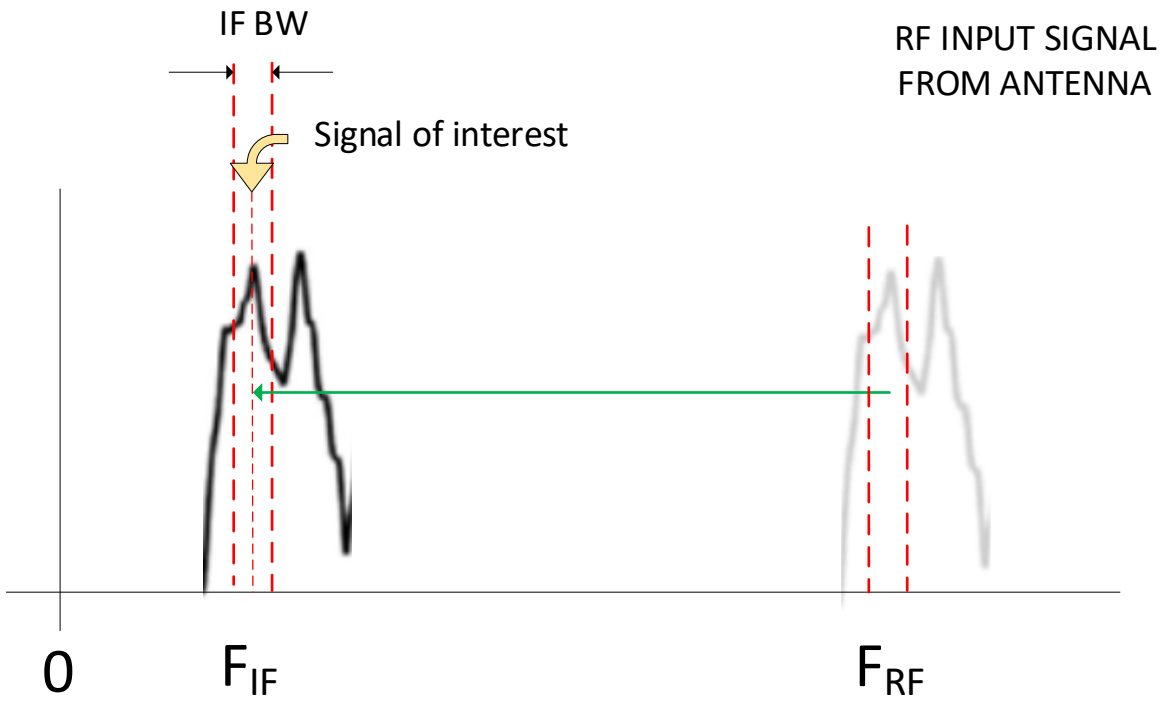
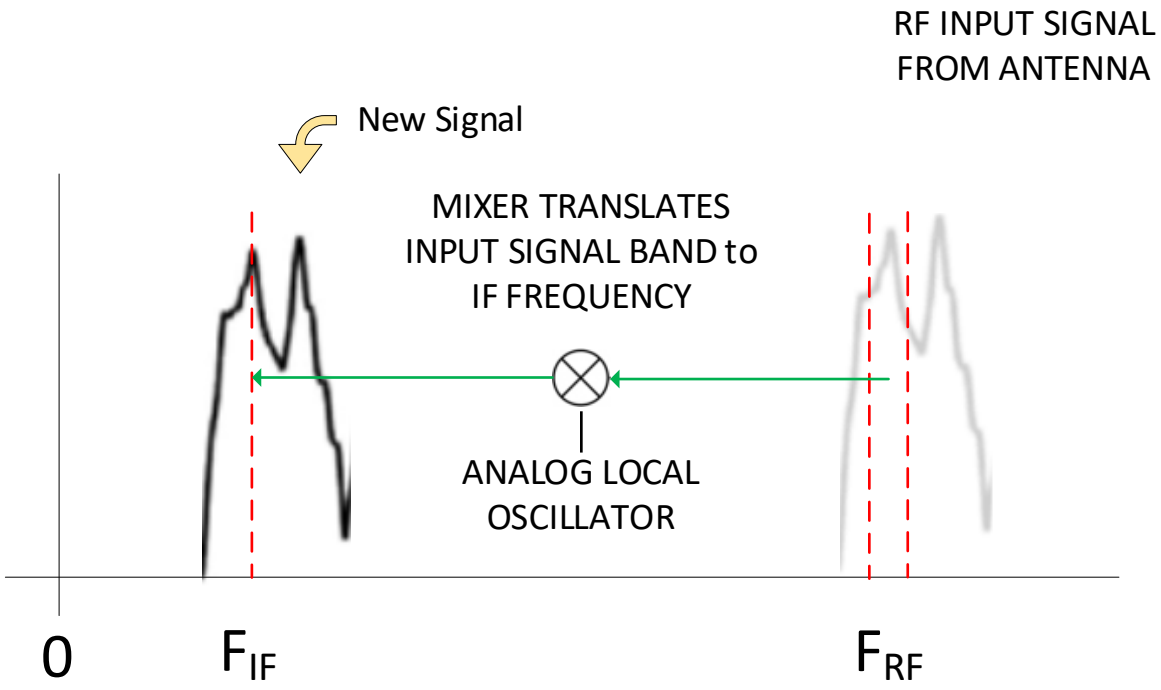
- IF bandpass filter passes only the signal bandwidth of interest



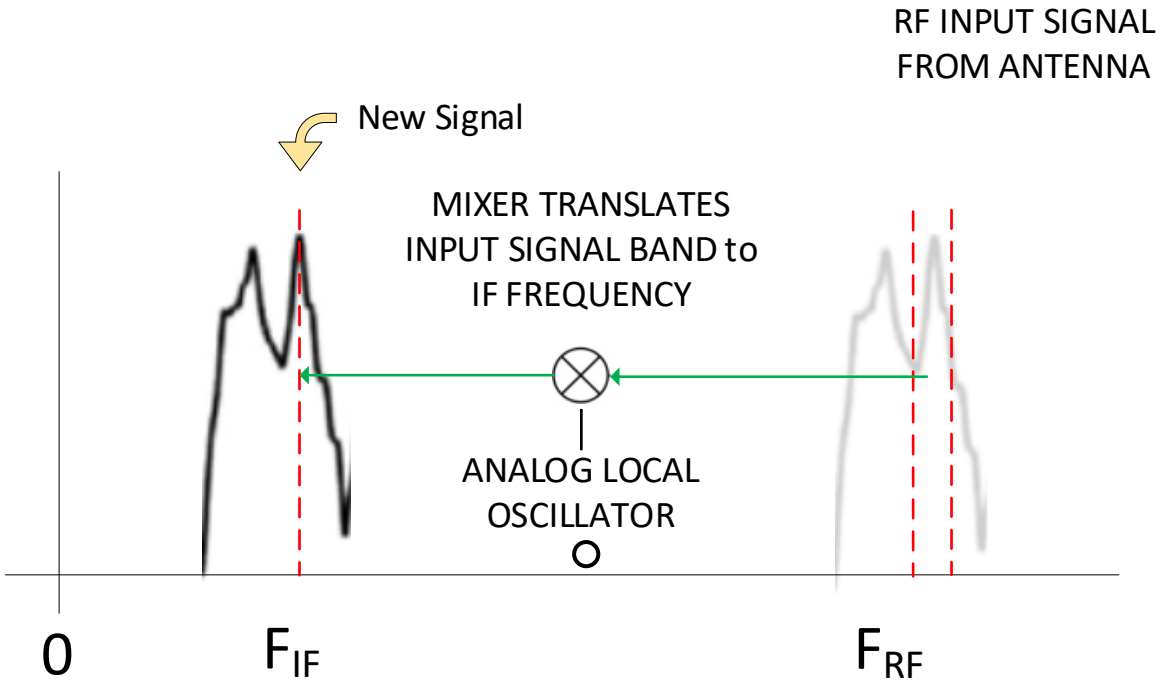
Analog RF tuner receiver mixing

- Suppose you want to receive a different signal



Analog RF tuner receiver mixing

- Frequency translation (amount of shift) is controlled by setting local oscillator frequency
- Tune to another “station” by changing the local oscillator frequency



Analog RF tuner receiver mixing

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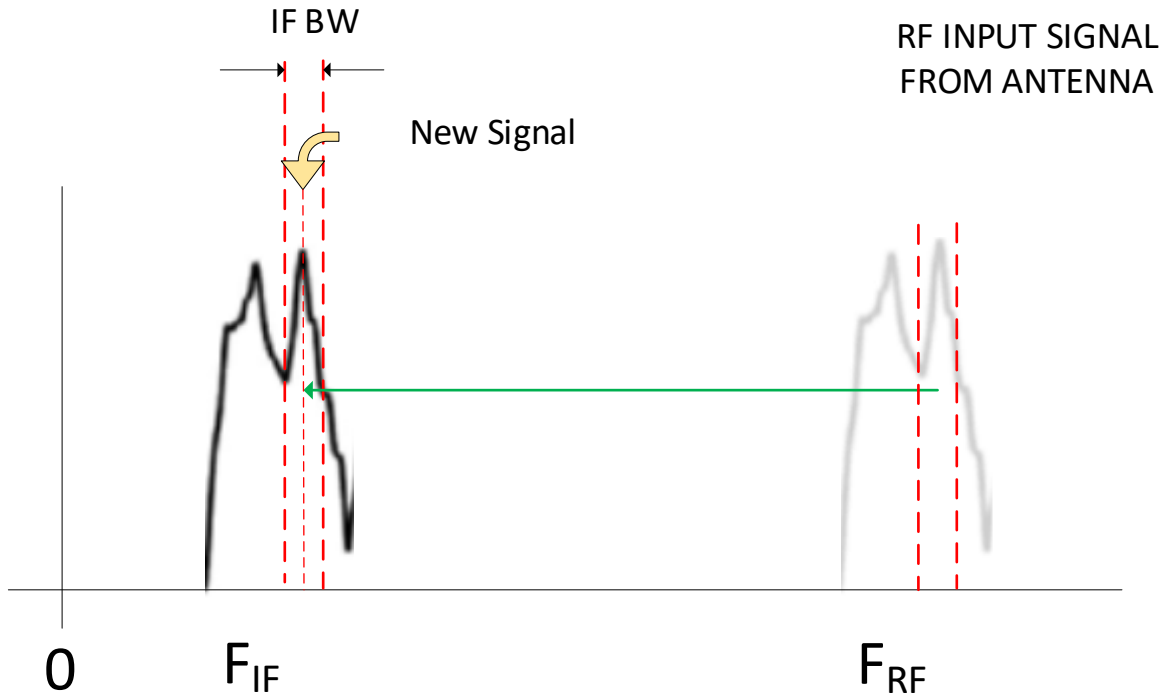

Analog RF tuner receiver mixing

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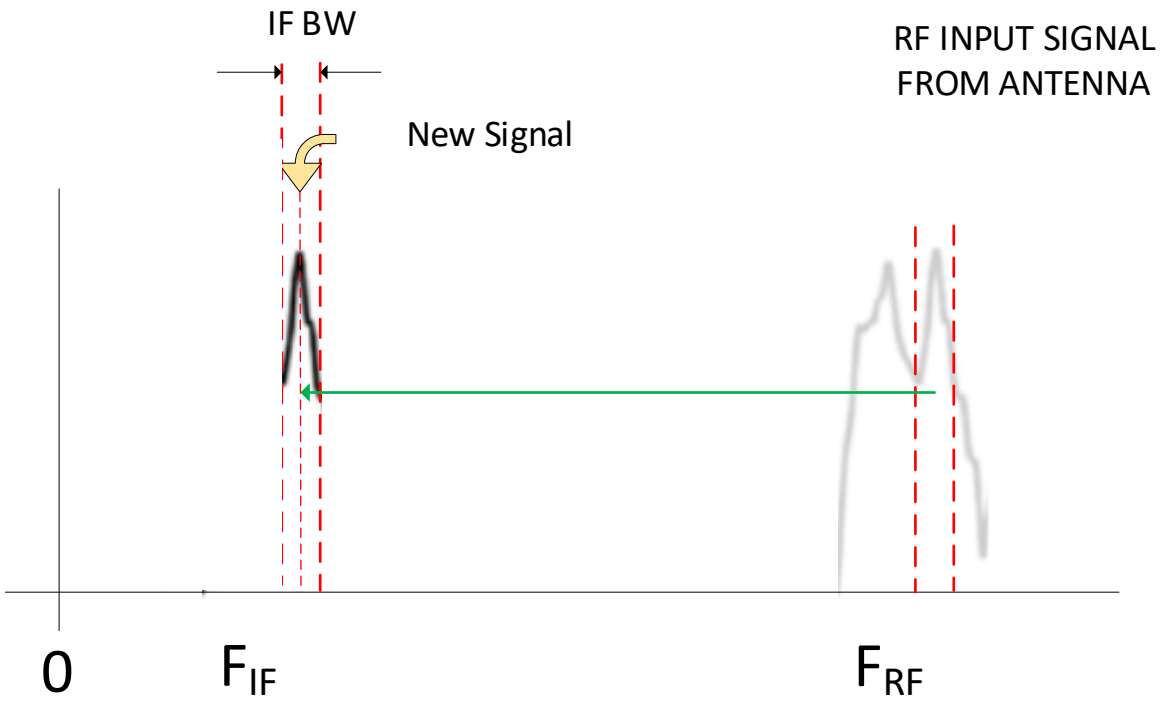
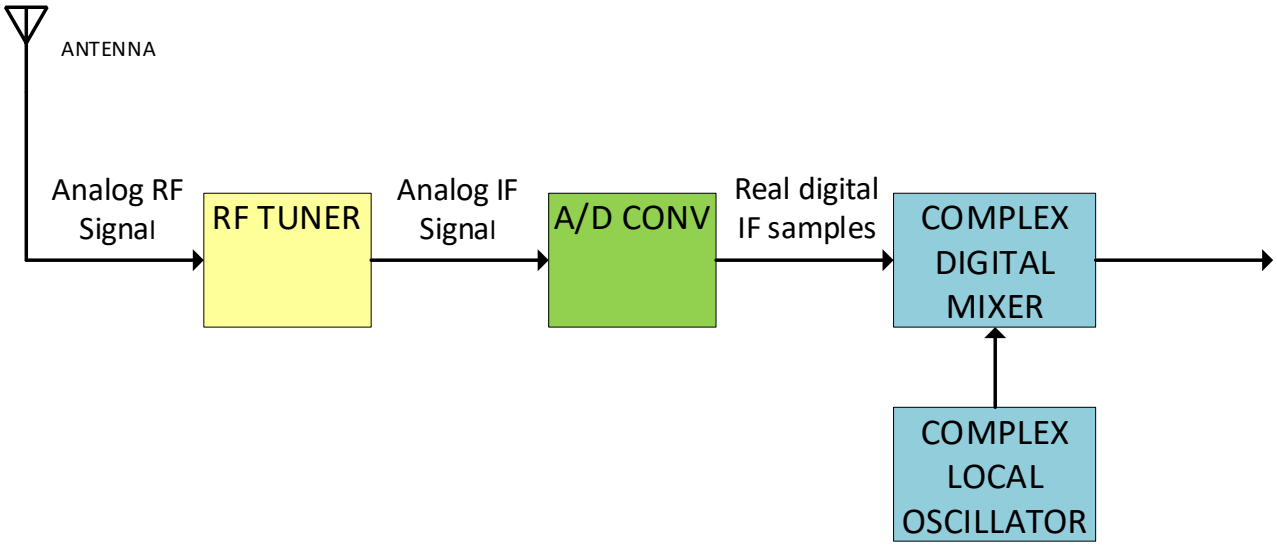


Software Radio Receiver

- RF Tuner down converts analog RF signals to analog IF frequencies
- A/D converter digitizes the IF signal creating real digital samples
- Digital Mixer & Local Oscillator *translate* digital IF to complex baseband



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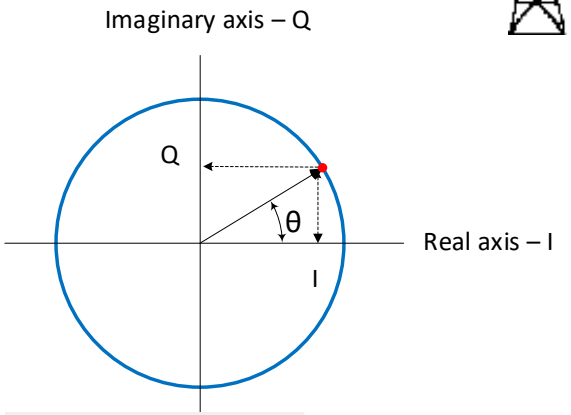
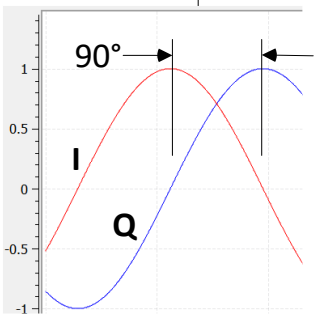
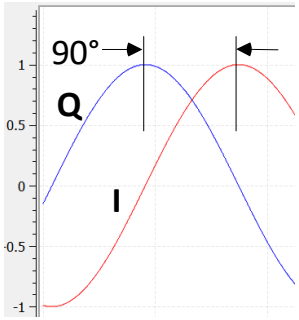
Complex Signals

- Think of a rotating wheel centered on a horizontal (real) I axis and a vertical (imaginary) Q axis
- As the wheel rotates, a point on the edge of the wheel moves left and right along the I axis, and up and down along the Q axis
- If the wheel rotates at a constant speed, the values of I and Q are 90 degrees out of phase
- If the I component peaks before the Q component then we generate a positive frequency
- If the Q component peaks before the I component then we generate a negative frequency
- You can think of a complex signal as a rotating vector with two components:
- I = Cos θ and Q = sin θ, with a positive or negative rotation





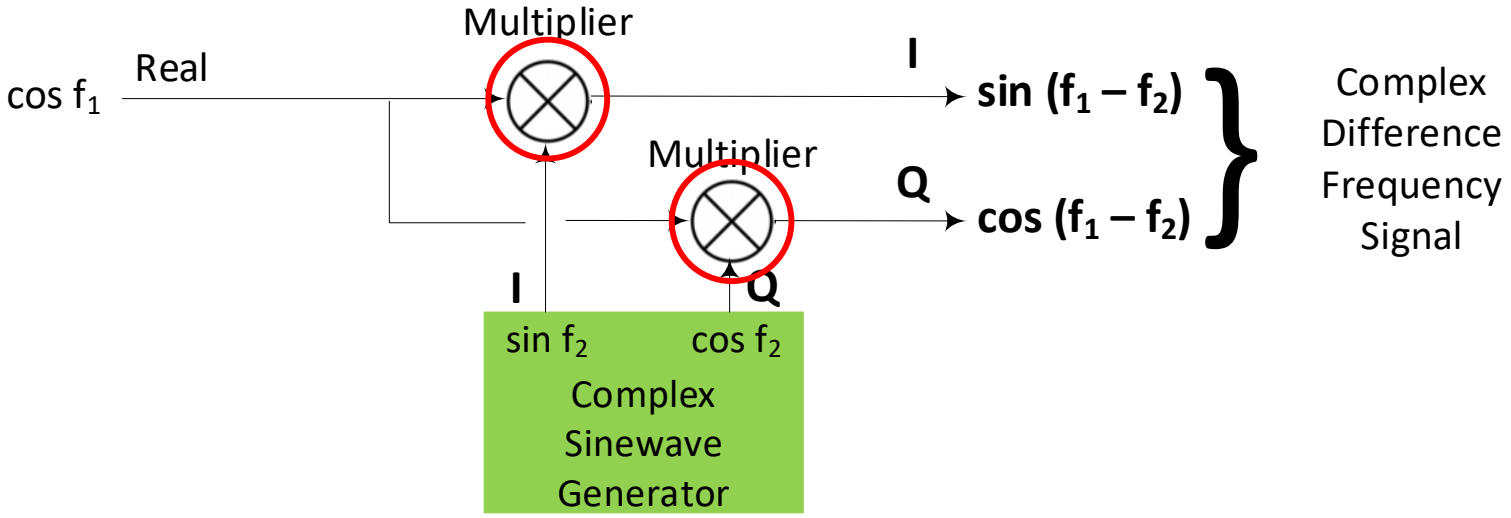
Positive Frequency



Negative Frequency

How to make a Complex signal

- Multiply a real signal (f_1) by a complex sinewave signal generator (f_2)

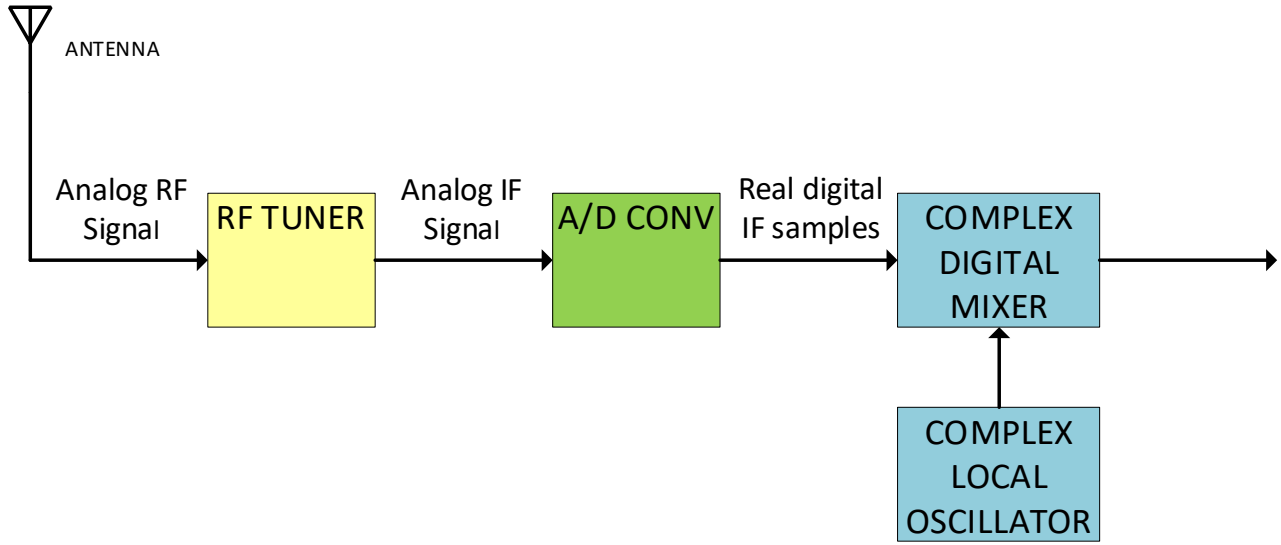


- From math class
  - $\cos f_1 \times \sin f_2 = \frac{1}{2}\{\sin (f_1 - f_2) + \sin (f_1 + f_2)\}$
  - $\cos f_1 \times \cos f_2 = \frac{1}{2}\{\cos (f_1 - f_2) + \cos (f_1 + f_2)\}$
- Remove the higher frequency sum components
- Complex multiplication performs two operations
  - Translates the input signal (f_1) down to the difference frequency ($f_1 - f_2$)
  - Converts the real input signal to a complex difference frequency signal

- Note that this page has animations that can be viewed in the powerpoint version

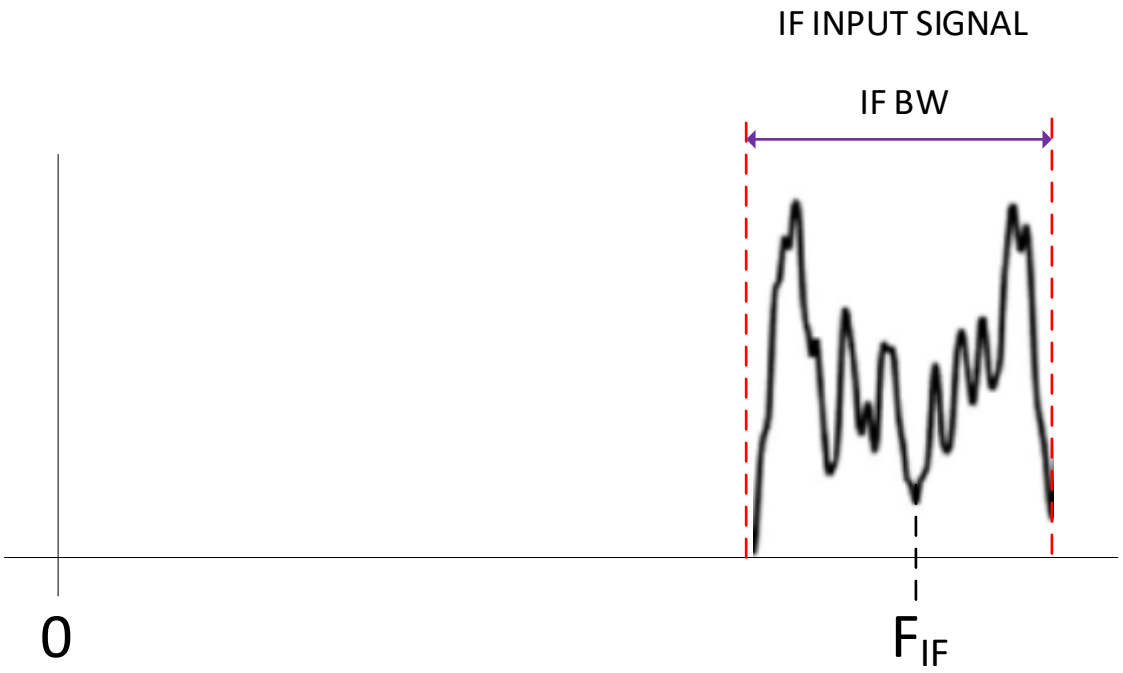
Software Radio Receiver

- RF Tuner down converts analog RF signals to analog IF frequencies
- A/D converter digitizes the IF signal creating real digital samples
- Digital Mixer & Local Oscillator *translate* digital IF to complex baseband



Complex Digital Translation

- IF band contains many signals within its bandwidth



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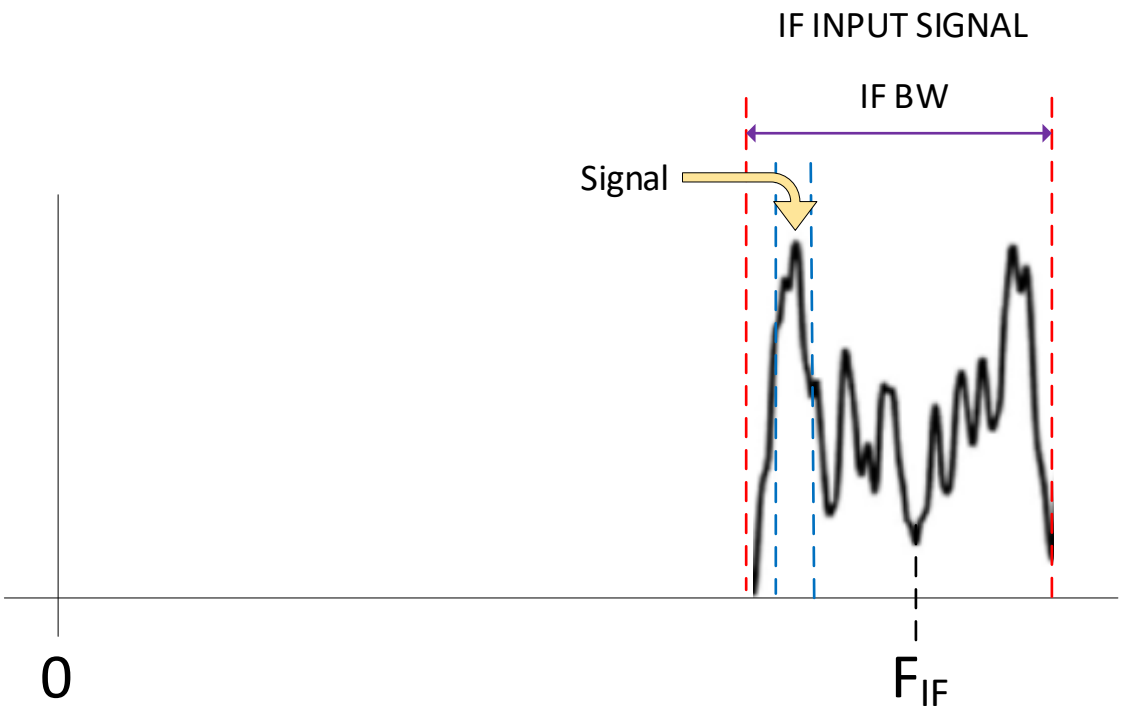
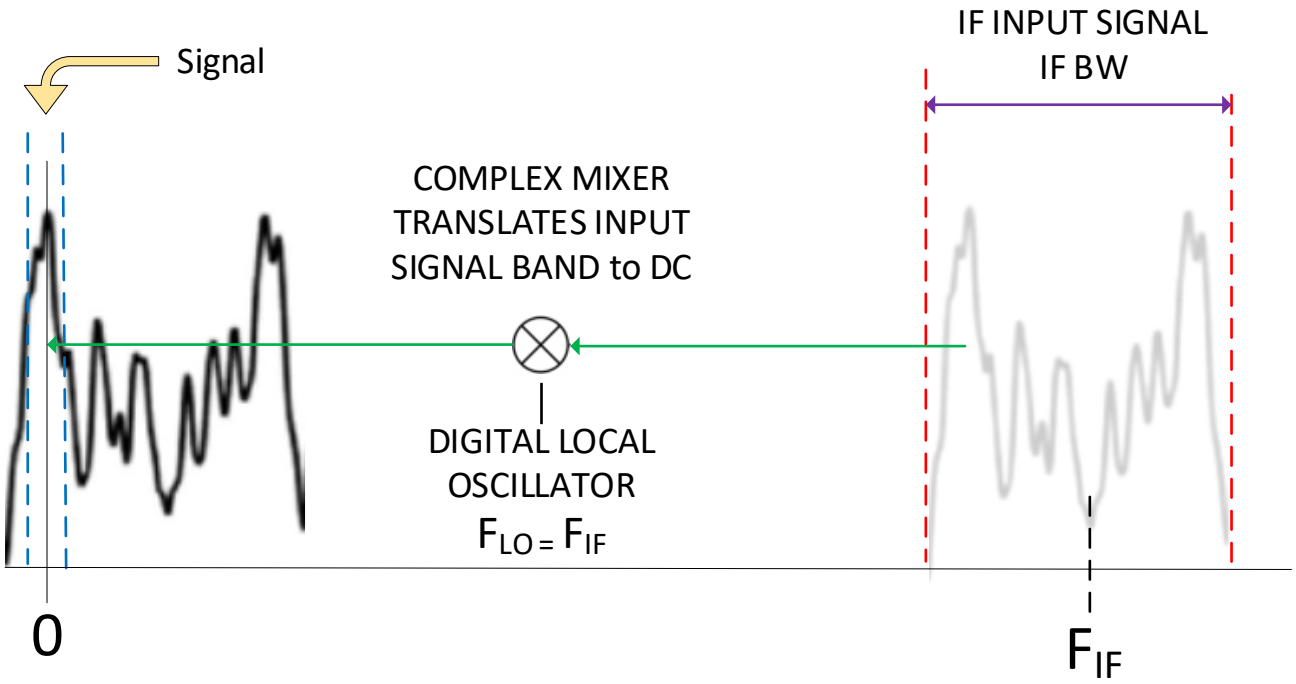


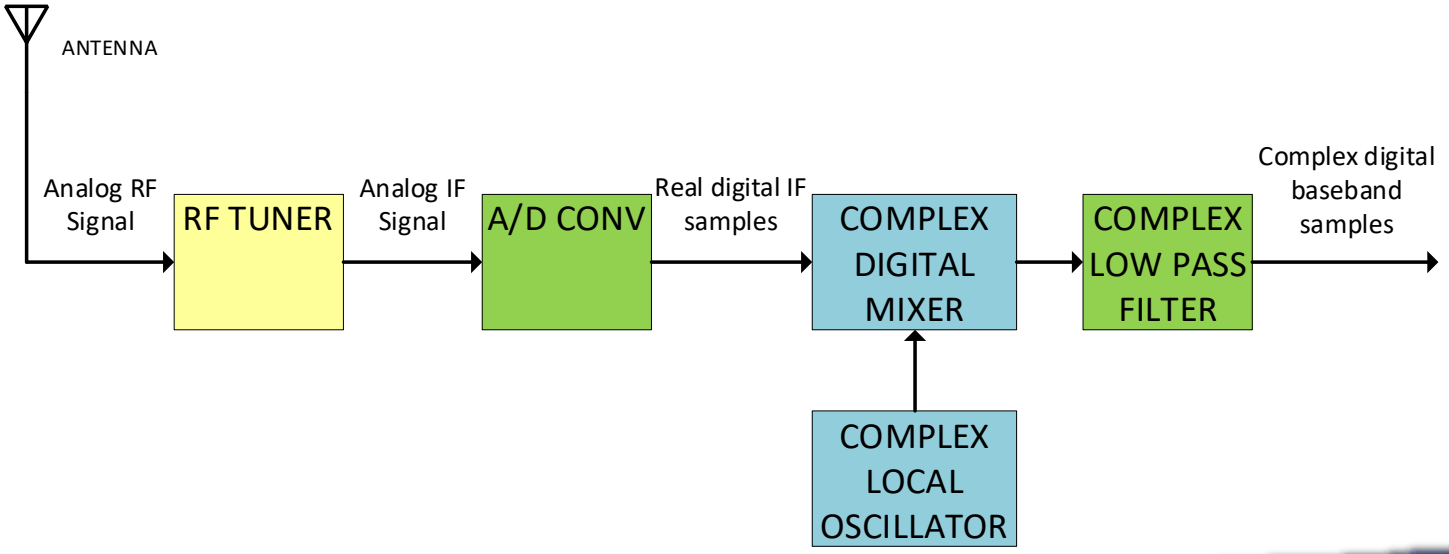
Complex Digital Translation

- IF band contains many signals within its bandwidth
- Digital complex mixer translates desired input signal within the IF band directly down to 0 Hz or DC as a complex signal



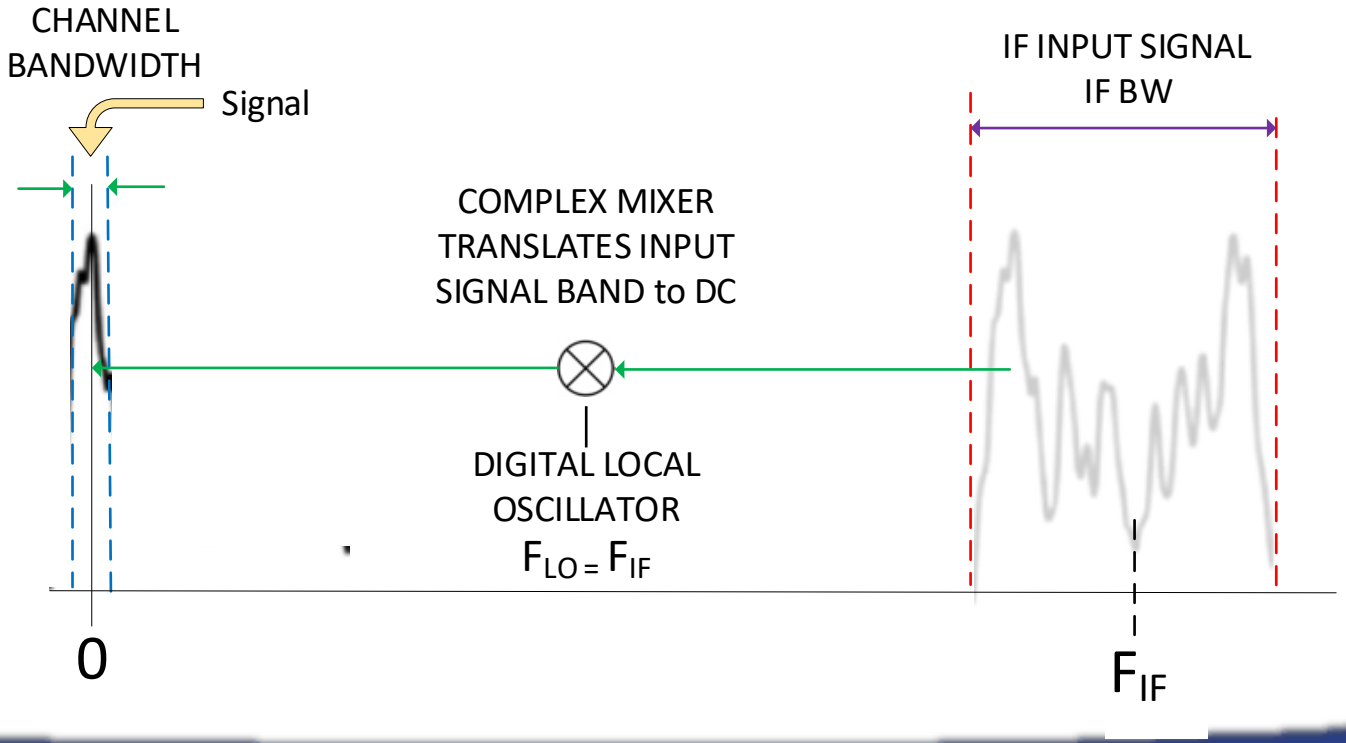
Software Radio Receiver

- RF Tuner down converts analog RF signals to analog IF frequencies
- A/D converter digitizes the IF signal creating real digital samples
- Digital Mixer & Local Oscillator translate digital IF to complex baseband
- Complex digital FIR low pass filter limits the baseband signal bandwidth



Filter Bandlimiting

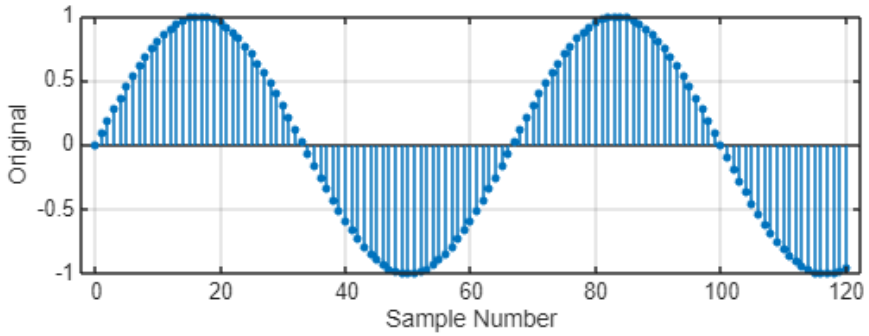
- Complex Low Pass Filter bandwidth is set to match desired bandwidth of received channel
- At the output of the Low Pass Filter, the complex baseband signal bandwidth has been reduced



LPF output signal downsampling

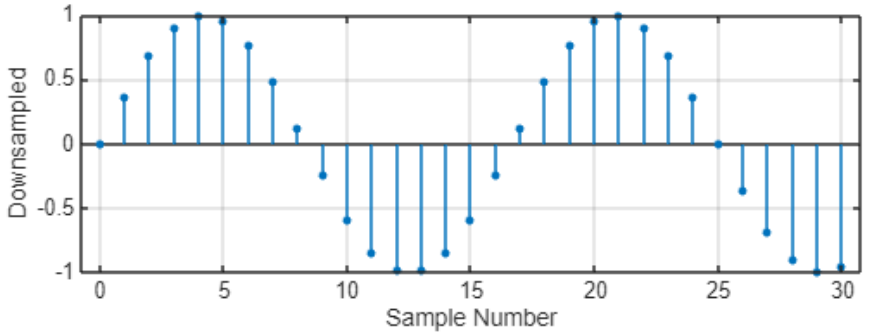
- Since the LPF output is band limited, Nyquist tells us we can lower the sample rate
- Down sampling ("Decimation" in GNUradio) means keeping one of every n samples

FIR output rate before downsample AD sample rate: Fs



Sinusoidal sampled at 2 KHz then downsampled by a factor of 4

Downsample filter output Baseband sample rate: Fs/N



NTMS simulation in MathWorks

MathWorks®

LPF output signal downsampling

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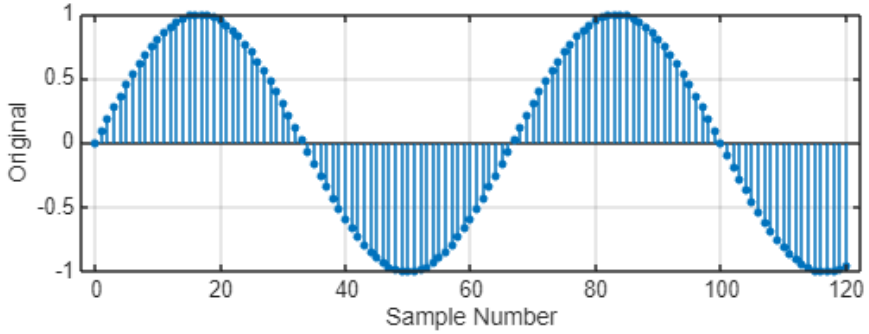
- If the decimated output sample rate is kept above the Nyquist limit, no information is lost
- Benefit: Same information can be processed easier in a DSP, transmitted at a lower rate, or stored in less memory

FIR output rate before downsample AD sample rate: Fs



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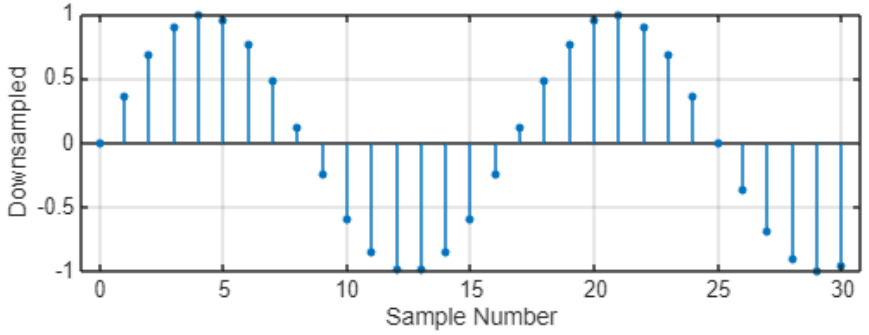
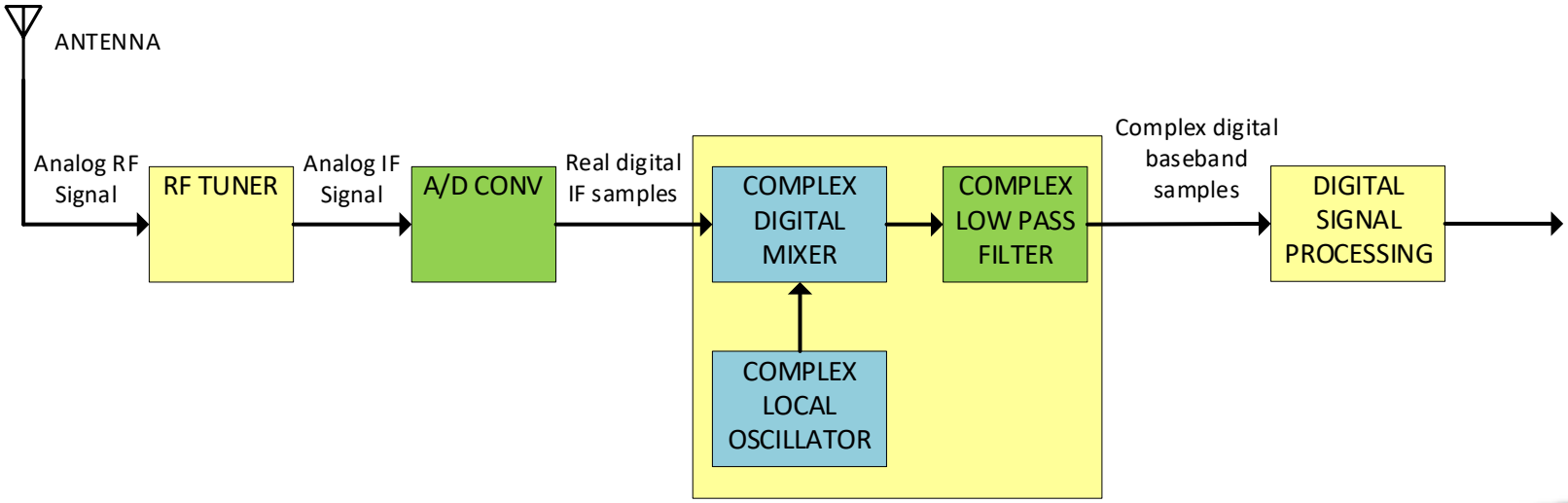


NTMS simulation in MathWorks

MathWorks®

Software Radio Receiver

- RF Tuner down converts analog RF signals to analog IF frequencies
- A/D converter digitizes the IF signal creating real digital samples
- Digital Mixer & Local Oscillator translate digital IF to complex baseband
- Complex digital FIR low pass filter limits the baseband signal bandwidth
- The Mixer, Local Oscillator and Down sampling Low Pass Filter could be named a Digital Down Converter
- Digital signal processing stage performs signal demodulation, etc.



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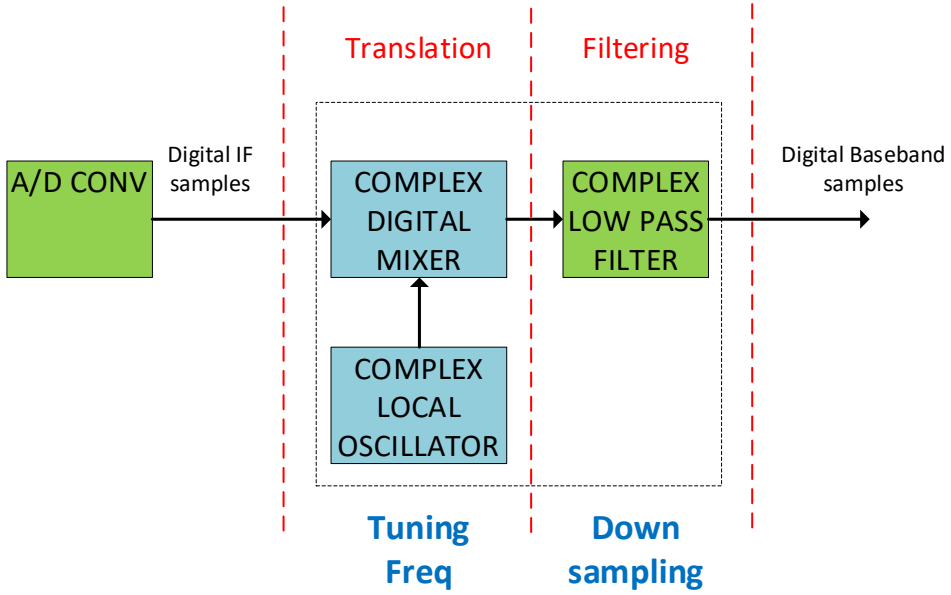
Digital Down Conversion

- A two-step process
- Frequency Translation
  - Tuning (down conversion frequency) is controlled by Local Oscillator setting
- Low Pass Filtering
  - Down sampling setting controls filter bandwidth AND down sample rate
  - As the filter bandwidth becomes lower, the down sample factor increases



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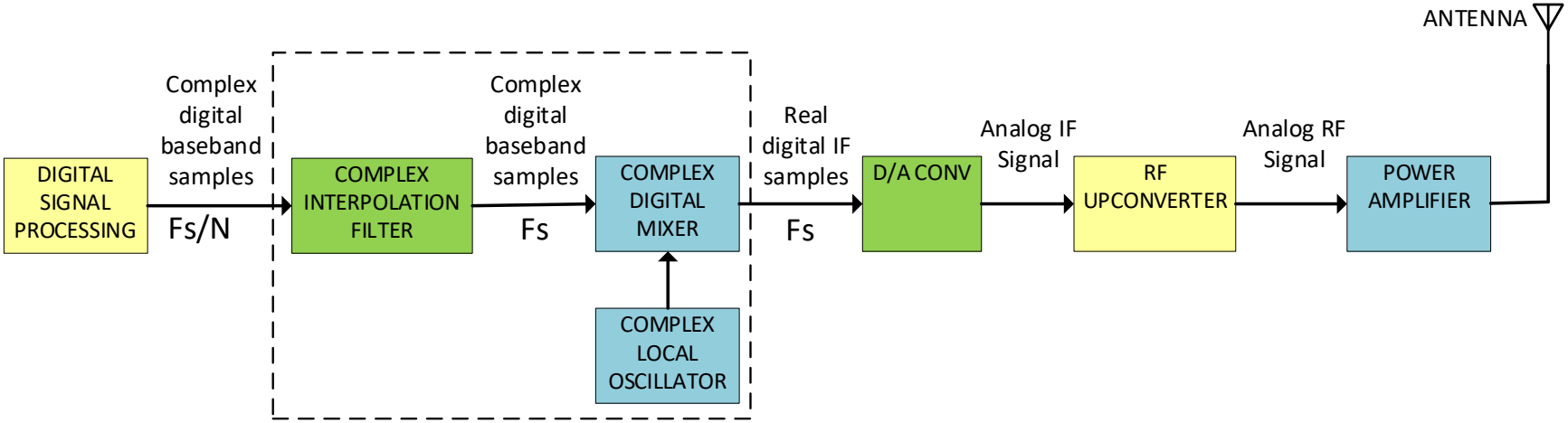
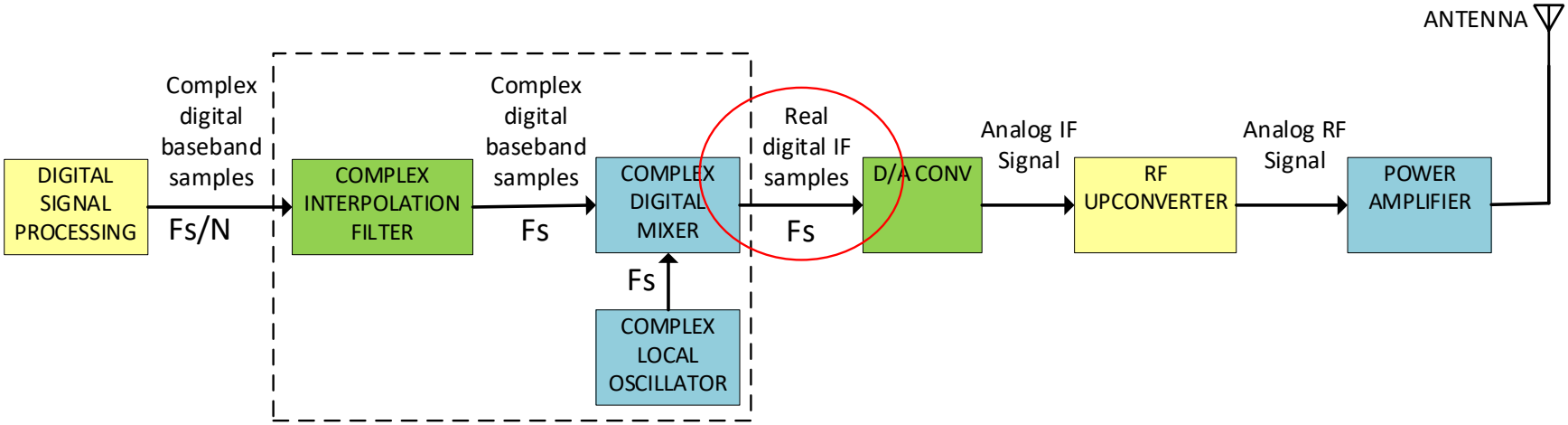
Software Radio Transmitter

- DSP stage generates complex baseband digital signal
- Digital Up Converter translates complex digital baseband to real IF
- D/A converter converts real digital IF samples to analog IF signal
- RF Upconverter translates analog IF signals to analog RF frequencies
- Power amplifier boosts signal energy to antenna



Digital Up Conversion

- D/A output rate must be high enough to satisfy Nyquist for IF output



Digital Up Conversion

- D/A output rate must be high enough to satisfy Nyquist for IF output
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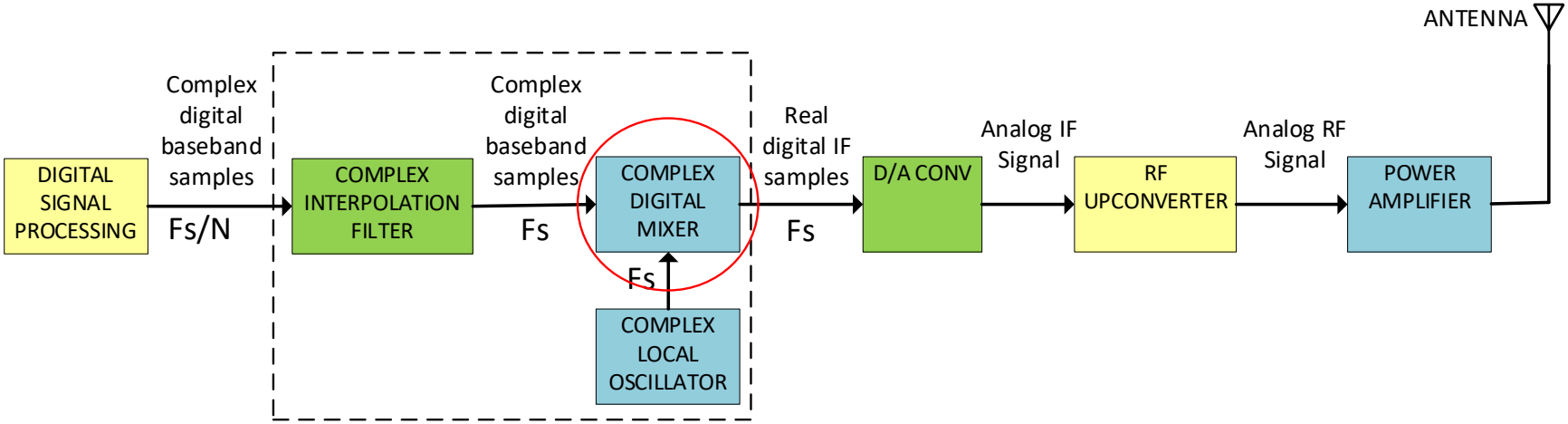
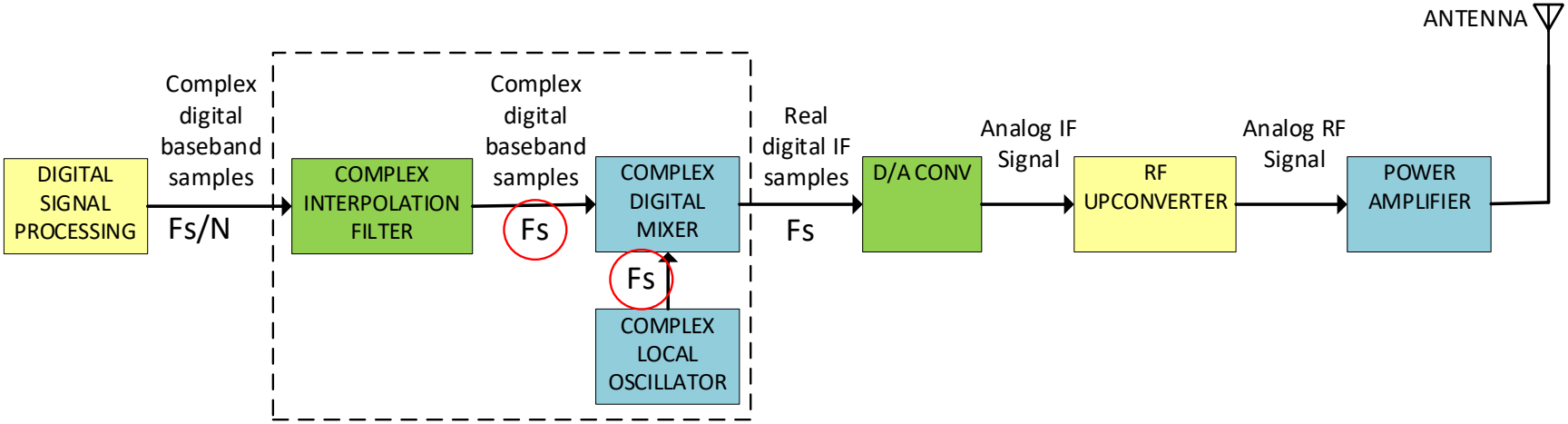


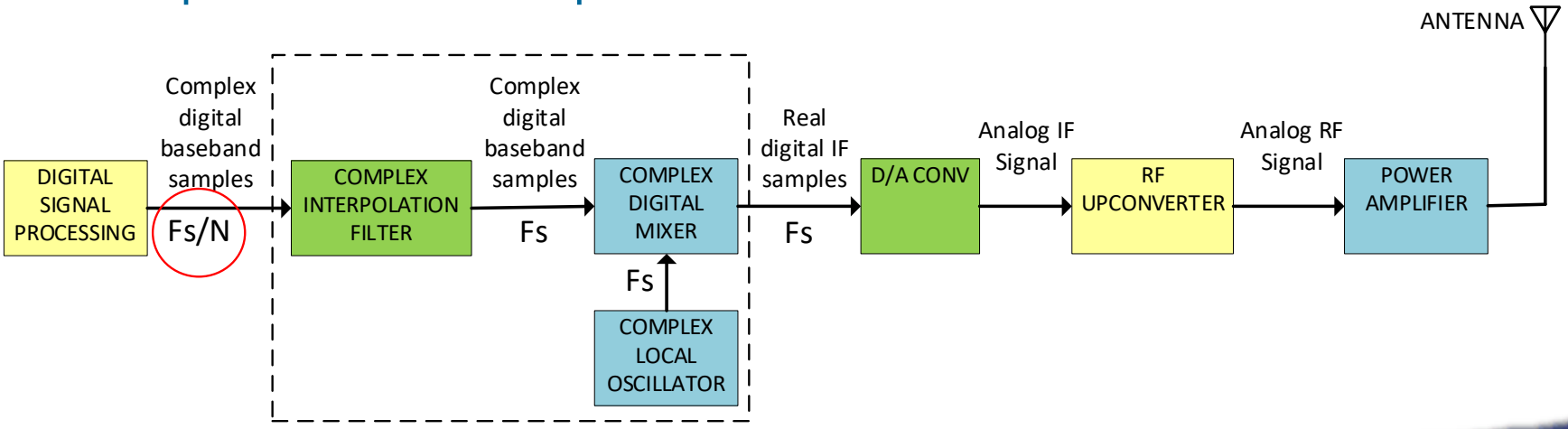
Digital Up Conversion

- D/A output rate must be high enough to satisfy Nyquist for IF output
- Digital mixer translates baseband samples up to IF frequency
- Mixer must deliver output samples at the D/A sample rate
- Mixer generates one output sample for each of two input samples
- Local oscillator & baseband sample rate must be at D/A sample rate



Digital Up Conversion

- D/A output rate must be high enough to satisfy Nyquist for IF output
- Digital mixer translates baseband samples up to IF frequency
- Mixer must deliver output samples at the D/A sample rate
- Mixer generates one output sample for each of two input samples
- Local oscillator & baseband sample rate must be at D/A sample rate
- Digital baseband input sample rate is much lower
- Interpolation filter is required



Complex Interpolating Filter

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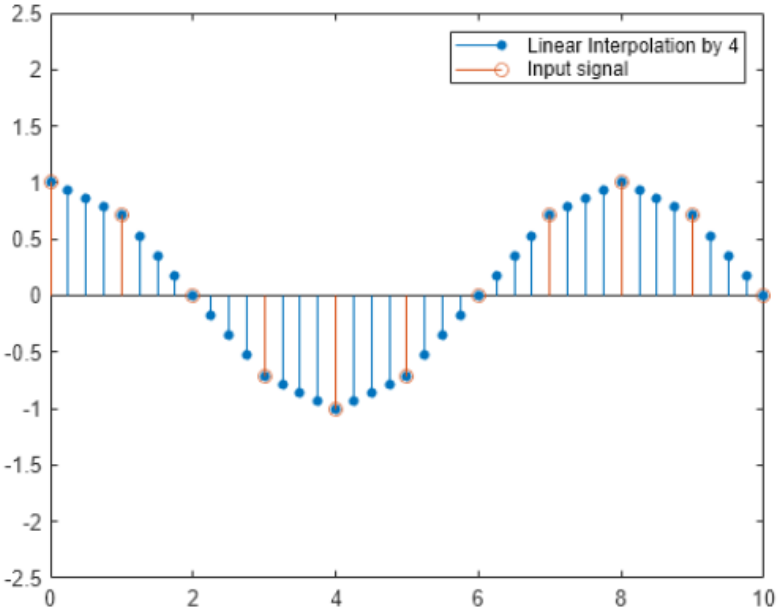
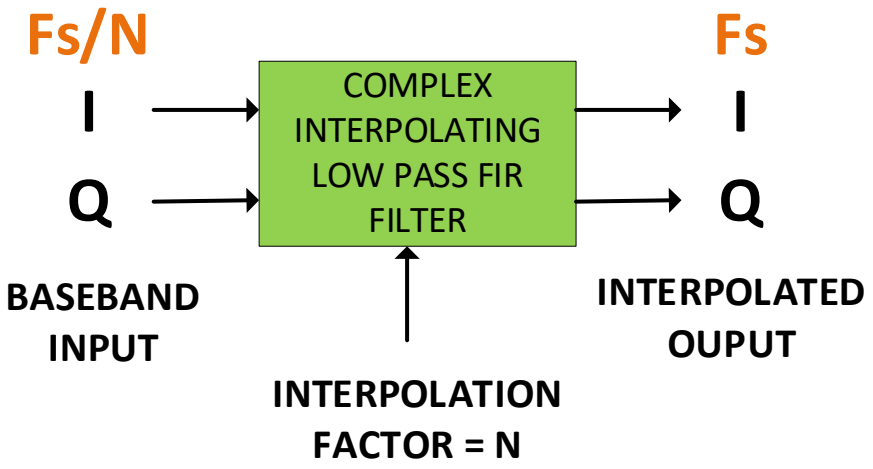
- Interpolation filter increases the sampling rate of the complex baseband input signal
- Interpolation Factor N determines the ratio





Baseband Input

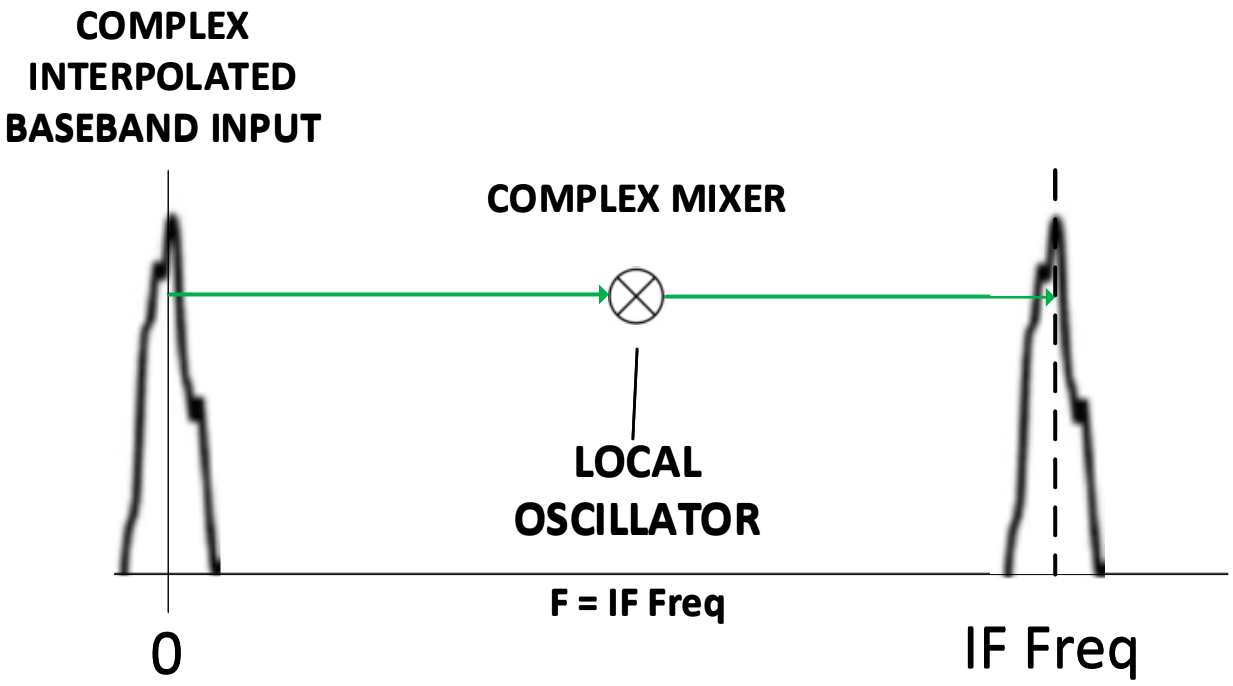
Sample Rate: Fs/N

Interpolating Filter Output

Sample Rate: Fs

Frequency Domain View

- Now, the interpolated baseband sample rate matches the Fs rate required at the mixer input
- Digital mixer translates complex baseband signal up to an IF frequency



Software Radio Transmitter

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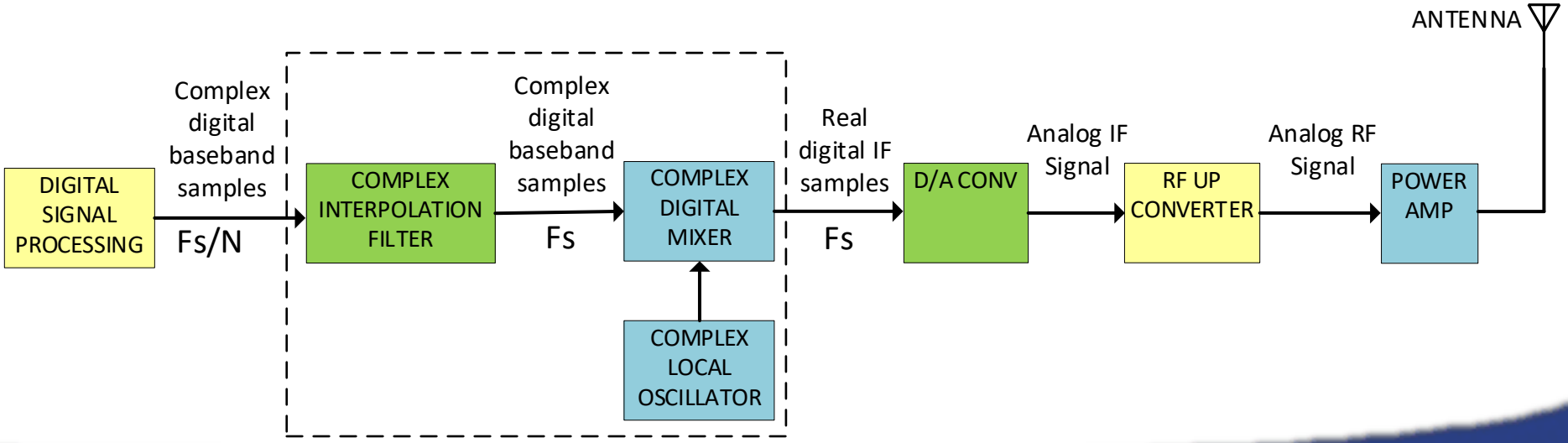
- DSP stage generates complex digital baseband signal samples
- Digital up converter translates complex digital baseband to real IF
- D/A converter converts real digital IF samples to analog IF signal
- RF upconverter translates analog IF frequencies to analog RF frequencies
- Power amplifier boosts signal energy to antenna



Summary

- Complex Signals
  - Two Signal Components: I and Q
  - Positive and Negative Frequencies
  - Complex mixing translates Real signal and converts to Complex
- Software Radio Systems
  - Receiver systems use analog RF front end (mixers) to convert RF down to IF
  - Transmitter systems use analog RF back end (mixers) to convert IF up to RF
- SDR programming interfaces come in a variety
  - Simple intuitive clients which have ready-made components
  - Clients which expose detail control parameters
  - Software development environment clients which provide granular control

Pluto block diagram

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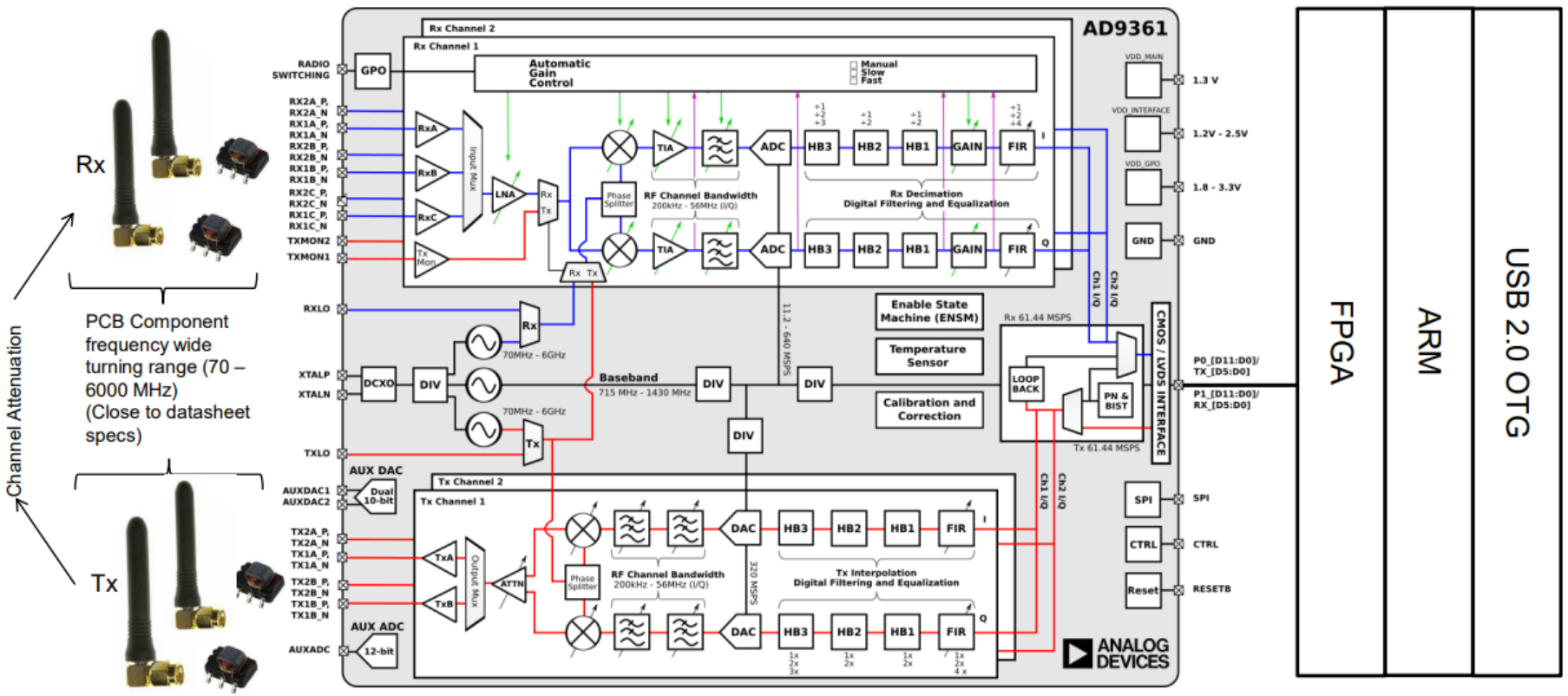

HackRF design

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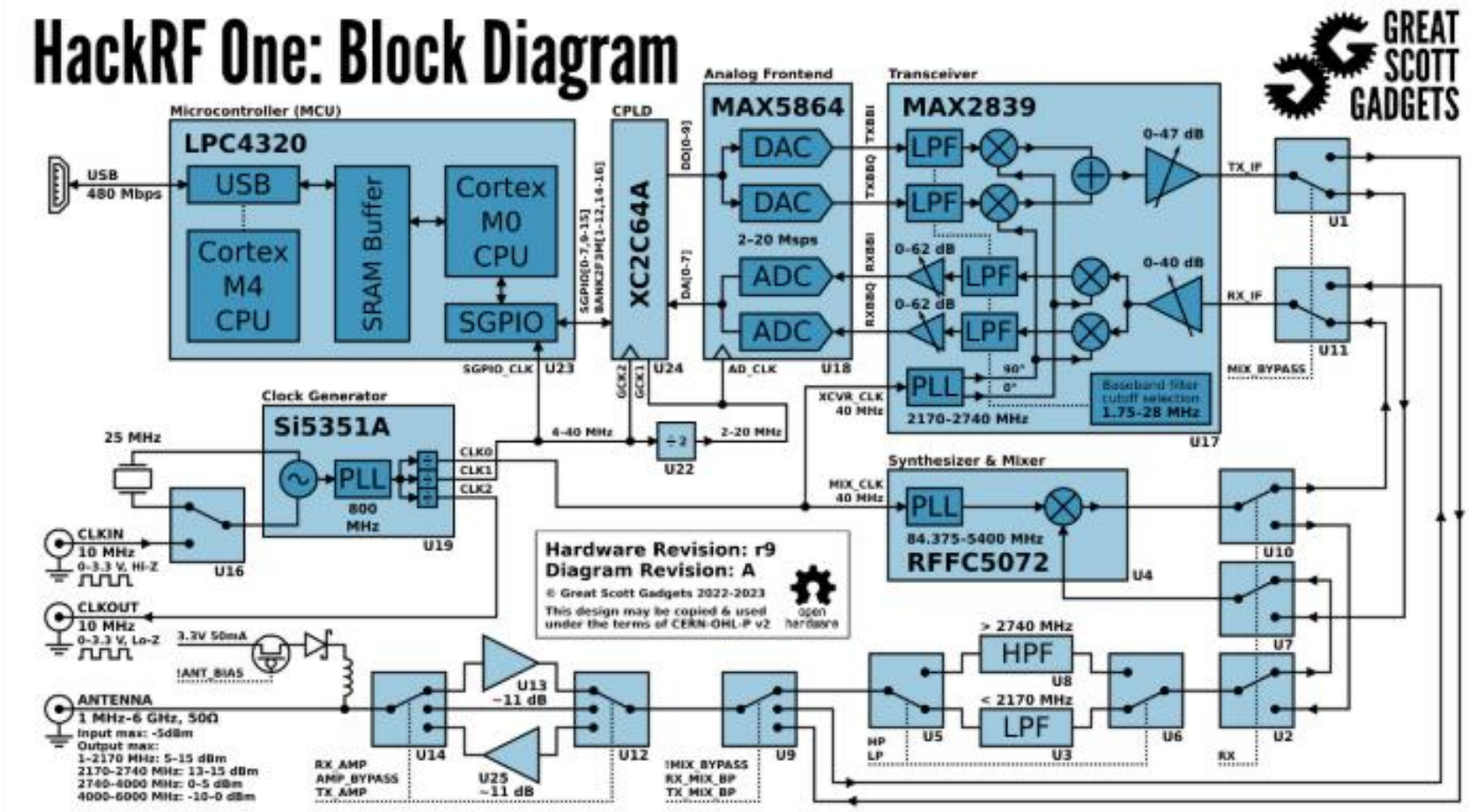

RTL-SDR

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V4 R828D RTL2832U 1PPM TCXO SMA Software Defined Radio (Dongle Only)

Brand: RTL-SDR Blog

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RTL-SDR

- A Linux kernel developer discovered that the RTL2832 IC manufactured by RealTek is more than just a classic DVB-T (Digital Video Broadcasting – Terrestrial) decoder (watch TV on computer).
- Link to an implementation of DVB-T with GNU Radio
- It can collect I/Q samples and send them directly to the host — a function that was intended by the chip manufacturer to decode FM radio.
- It's not possible to transmit with the RTL-SDR.

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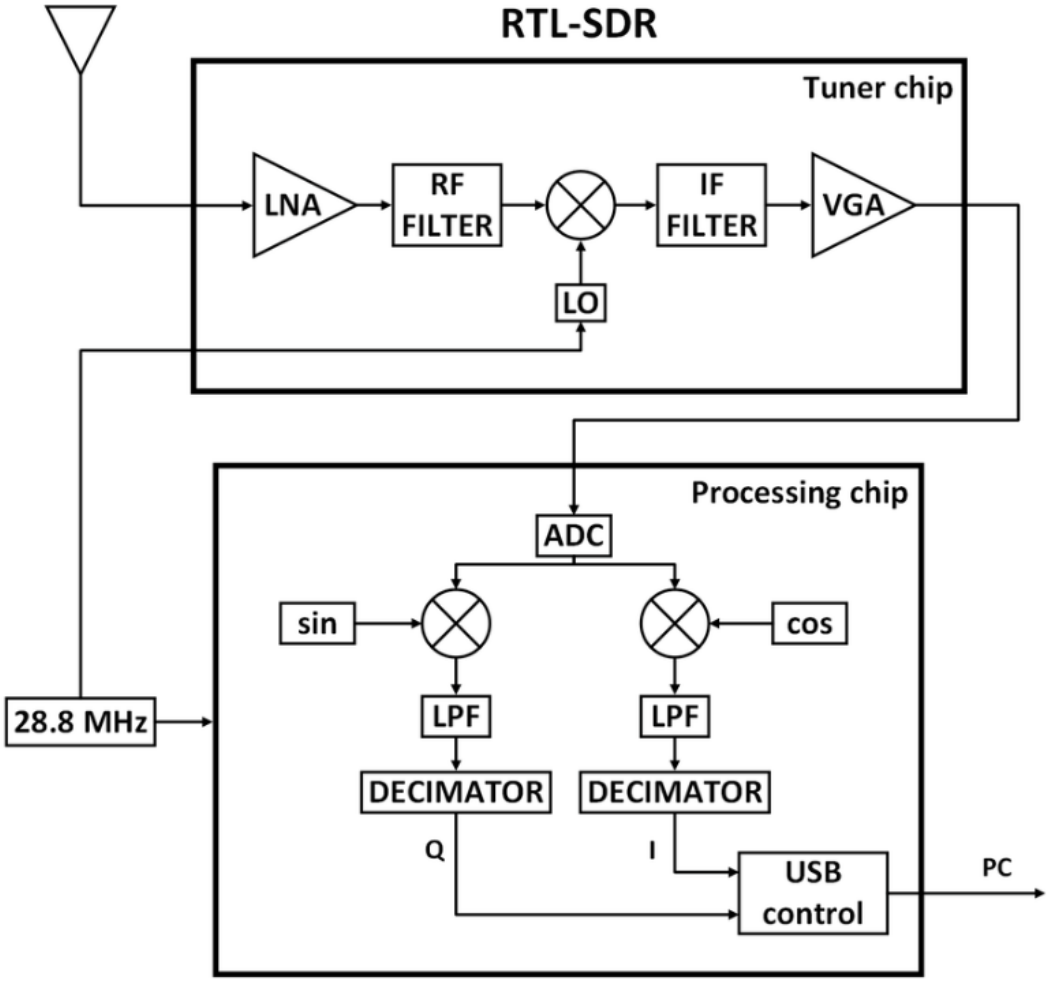
RTL-SDR



Demo with GNUradio

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- Complex Signals
  - Two Components: I and Q

Questions?

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