ECE 531: Software Defined Radio

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Lecture 1

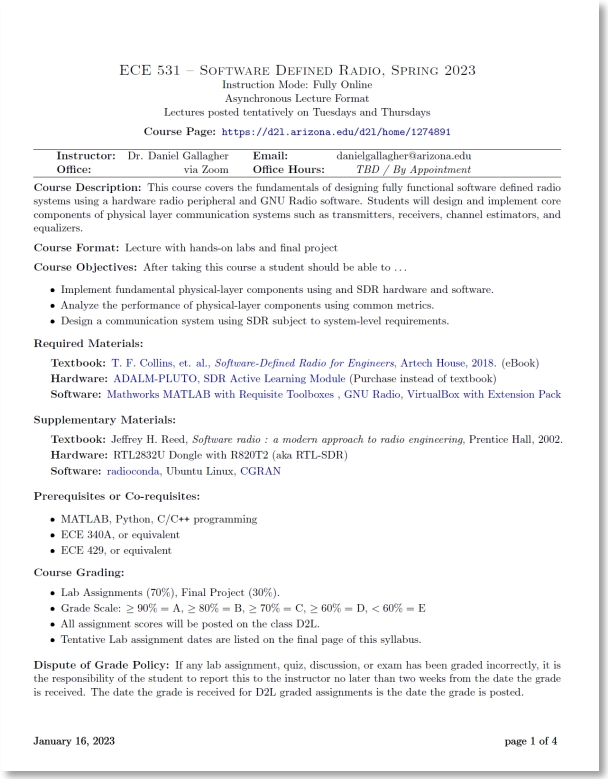
Topics:

- Course Information
- Overview of Software Defined Radio
- Introduction to Common SDR Hardware and Software

Course Introduction

- Course objective is to provide a hands-on learning experience using Software-Defined Radio
- The course will build upon theory learned in previous courses.
  - Including: digital signal processing (DSP), signals and systems, and communication systems.

Syllabus



ECE 531 – Software Defined Radio, Spring 2023
Instruction Mode: Fully Online
Asynchronous Lecture Format
Lectures posted tentatively on Tuesdays and Thursdays

Course Page: https://d2l.arizona.edu/d2l/home/1274891

Instructor:	Dr. Daniel Gallagher	**Email:**	danielgallagher@arizona.edu
Office:	via Zoom	**Office Hours:**	*TBD / By Appointment*

Course Description: This course covers the fundamentals of designing fully functional software defined radio systems using a hardware radio peripheral and GNU Radio software. Students will design and implement core components of physical layer communication systems such as transmitters, receivers, channel estimators, and equalizers.

Course Format: Lecture with hands-on labs and final project

Course Objectives: After taking this course a student should be able to . . .

- Implement fundamental physical-layer components using and SDR hardware and software.
- Analyze the performance of physical-layer components using common metrics.
- Design a communication system using SDR subject to system-level requirements.

Required Materials:

Textbook: T. F. Collins, et. al., *Software-Defined Radio for Engineers*, Artech House, 2018. (eBook)
Hardware: ADALM-PLUTO, SDR Active Learning Module (Purchase instead of textbook)
Software: Mathworks MATLAB with Requisite Toolboxes , GNU Radio, VirtualBox with Extension Pack

Supplementary Materials:

Textbook: Jeffrey H. Reed, *Software radio : a modern approach to radio engineering*, Prentice Hall, 2002.
Hardware: RTL2832U Dongle with R820T2 (aka RTL-SDR)
Software: radioconda, Ubuntu Linux, CGRAN

Prerequisites or Co-requisites:

- MATLAB, Python, C/C++ programming
- ECE 340A, or equivalent
- ECE 429, or equivalent

Course Grading:

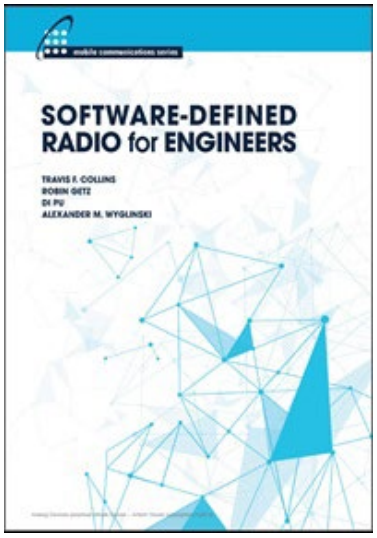
- Lab Assignments (70%), Final Project (30%).
- Grade Scale: $\geq 90\% = A$, $\geq 80\% = B$, $\geq 70\% = C$, $\geq 60\% = D$, $< 60\% = E$
- All assignment scores will be posted on the class D2L.
- Tentative Lab assignment dates are listed on the final page of this syllabus.

Dispute of Grade Policy: If any lab assignment, quiz, discussion, or exam has been graded incorrectly, it is the responsibility of the student to report this to the instructor no later than two weeks from the date the grade is received. The date the grade is received for D2L graded assignments is the date the grade is posted.

January 16, 2023 page 1 of 4

Course Textbook

- **Software-Defined Radio for Engineers**, by Travis F. Collins, Robin Getz, Di Pu, and Alexander M. Wyglinski, 2018, ISBN-13: 978-1-63081-457-1.
- Ebook is available for free under a perpetual license from Analog Devices Inc. (ADI)
  - https://www.analog.com/en/education/education-library/software-defined-radio-for-engineers.html
- Printed copy available for purchase, if preferred



Other Books:

- *Software Radio: A Modern Approach to Radio* Engineering 1st Edition, by Jeffrey H. Reed
- *Rf and Baseband Techniques for Software Defined Radio*, by Peter Kenington
- *Software Defined Radio Using MATLAB & Simulink and the RTL-SDR, by Robert W Stewart*

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What is Software Defined Radio?

- Software Defined Radio (SDR) refers to a class of reconfigurable radio system where almost all of the Physical Layer (PHY) is implemented in software using DSP algorithms rather than hardware components
- Signals are processed digitally to determine radio function
  - General Purpose Processor (x86, ARM..)
  - Reprogrammable Logic (FPGA)
  - Has some software control over RF front-end operations such as transmission carrier frequency.
- Technique uses general purpose computers (like your laptop), plus a radio peripheral, to transmit or receive arbitrary radio signals
- Takes what would typically be implemented in physical hardware components and moves them into software signal processing
- Simplest commonly available SDR is a sound card
  - Sound card permits user to produce or record arbitrary waveforms of sounds at audio rates
  - SDR uses an antenna rather than a speaker and microphone

History of SDR Development

- "Software-defined radio" first coined by Joseph Mitola in the early 1990's to refer to the class of reprogrammable or reconfigurable radios
- SDR technology was available since the 1970s

- First publicly funded SDR development initiative was SpeakEasy I/II by the U.S. military
  - Employed programmable microprocessors for implementing more than ten military communication standards
  - Transmission carrier frequencies ranged from 2 MHz to 2 GHz
  - Allowed for upgrades of new functional blocks, such as modulation schemes and coding schemes
  - SpeakEasy II was the first SDR platform to involve FPGA modules for implementing digital baseband functionality
  - Physical size of prototype fit in the back of a truck
  - Read "*SPEAKeasy, the Military Software Radio*" by Upmal and Lackey in IEEE Communications Magazine (IEEE Press, 1995)

SDR Applications

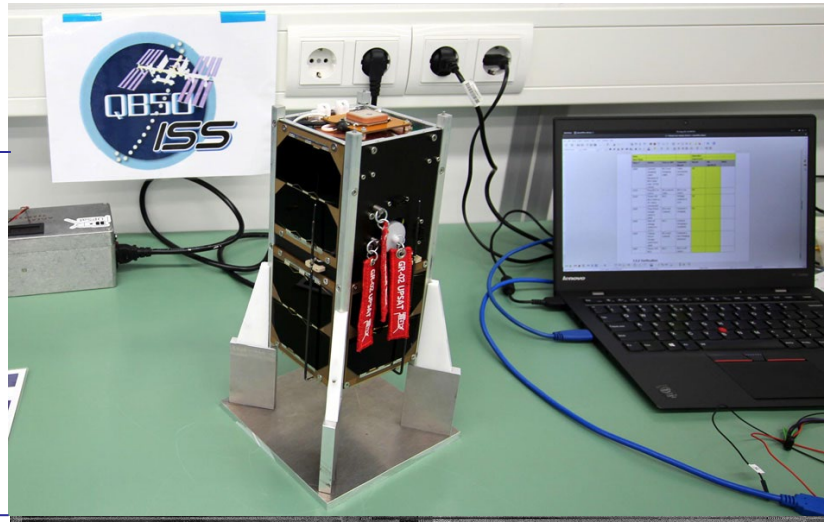
- Amateur Radio
- Radio Astronomy
- Track aircraft and ships
- Rapid Prototyping of Radio Systems
- Reconfigurable radio
  - Update functionality with software change
- Cellular base stations
  - OpenBTS (Open Base Transceiver Station)
  - Software based GSM access point
  - Used to aid in disaster response
- Cognitive radio
- Cybersecurity
- Wireless forensics
- Wireless research… inventing future technologies
- Satellite transceivers (i.e. CubeSats, SatNOGS)

SDR Applications (Cont.)

Satellite Transceivers

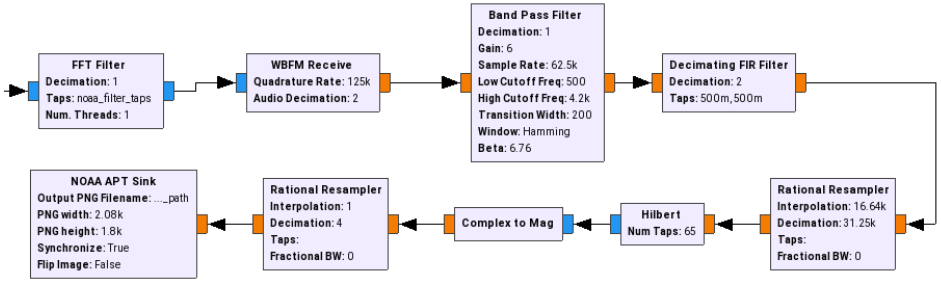
UPSat

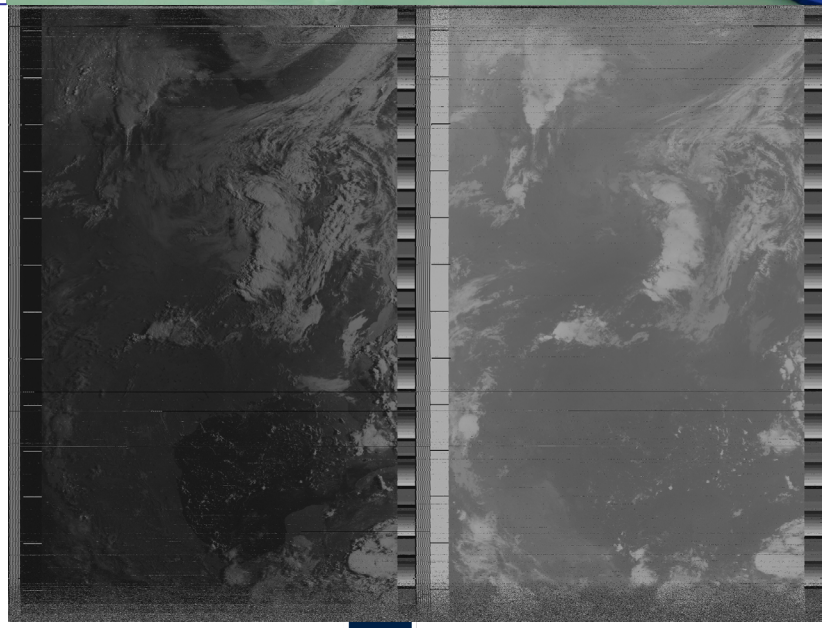
- First open-source hardware/software cubesat
- Part of the QB50 project



APT (Automatic Picture Transmission)

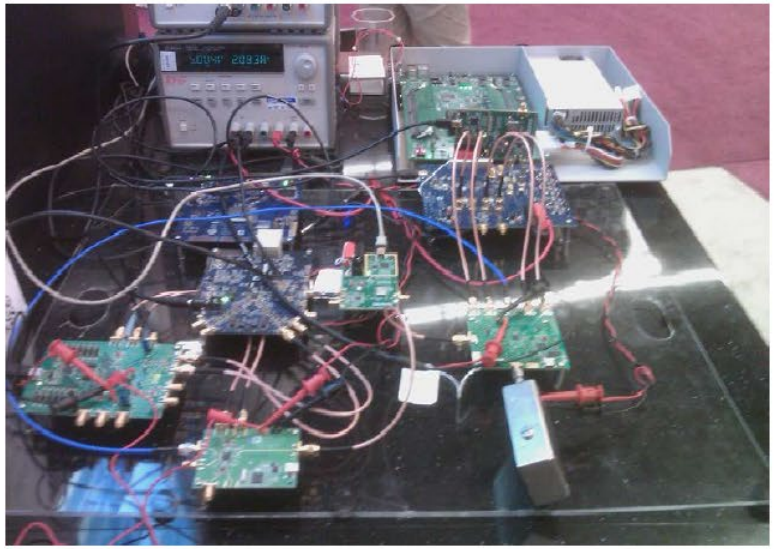
- Analog image transmission used by NOAA weather satellites
- AM over FM @ 34 kHz bandwidth

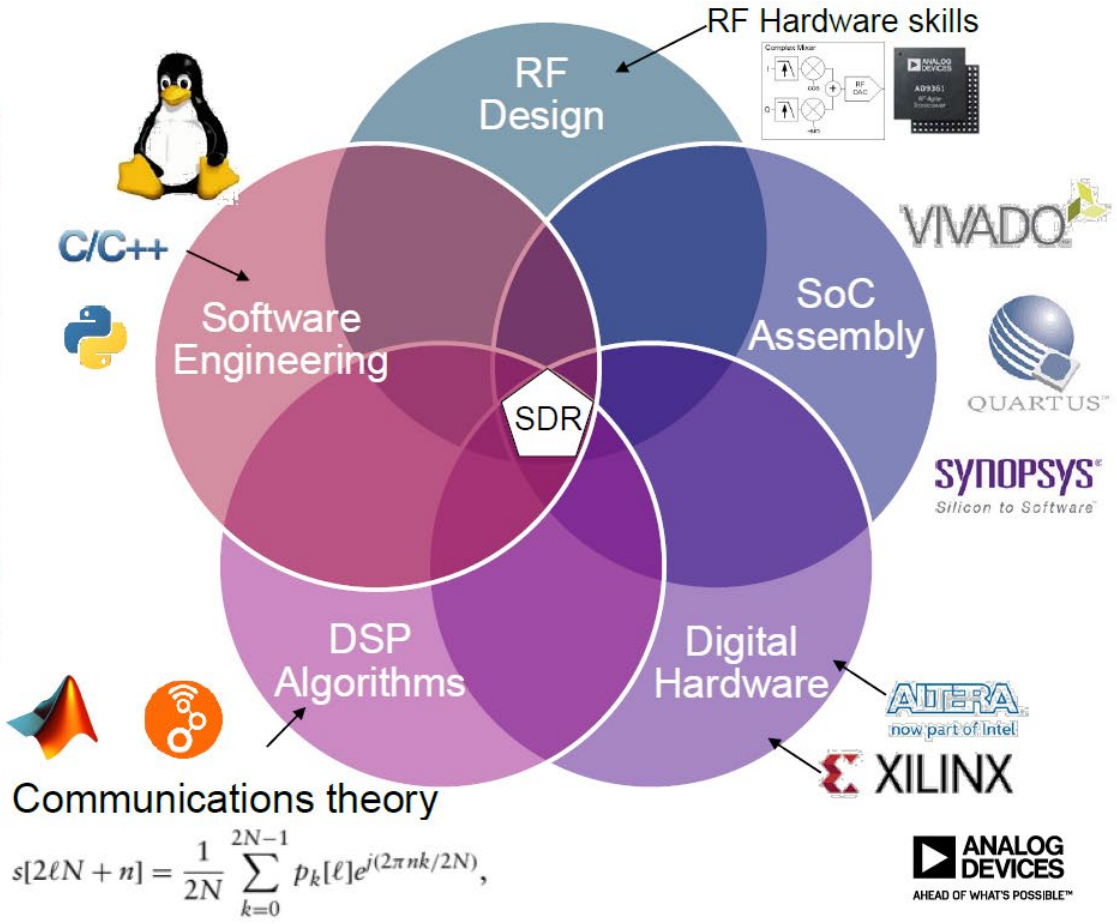




Source: Manolis Surligas, Libre Space Foundation, GRCon18

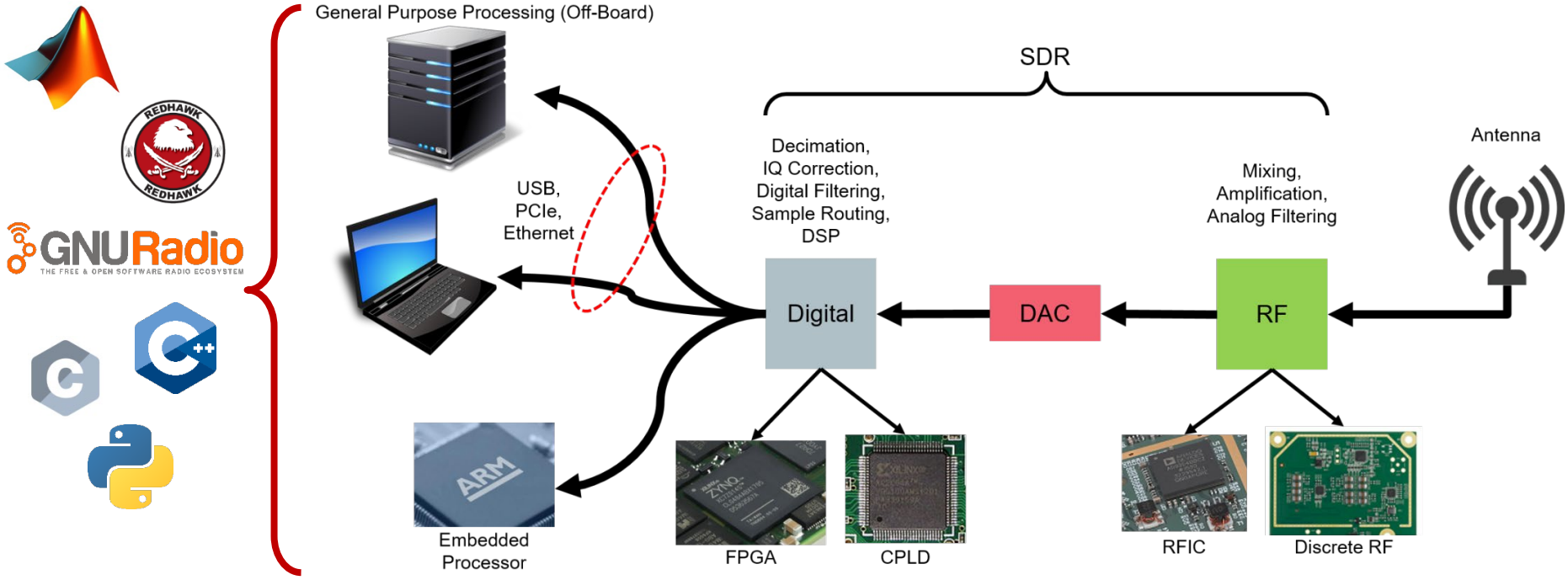
SDR Technical Complexity





SDR Intersects Many Fields of Engineering

SDR Systems



SDR Hardware

- Ettus USRP
  - USRP = Universal Software Radio Peripheral
  - Industry leader in SDR peripherals
  - Cost: $700 - $10k

- RTL-SDR
  - R820T RTL2832U based RX-only SDR
    - Many generic versions available
    - Originally sold overseas as a DVB-T tuner
  - Frequency Range: ~ 24 MHz - 1766 MHz
  - Max Bandwidth: ~ 2.4 MHz
  - Cost: $10-25

- ADALM PLUTO (PlutoSDR)
  - A low cost full duplex TX and RX device designed by Analog Devices for use as a learning platform
  - Frequency Range: 70 - 6000 MHz
  - Max Bandwidth: 56MHz
  - Cost: $149-250

- This is just a small subset of the current SDR hardware available

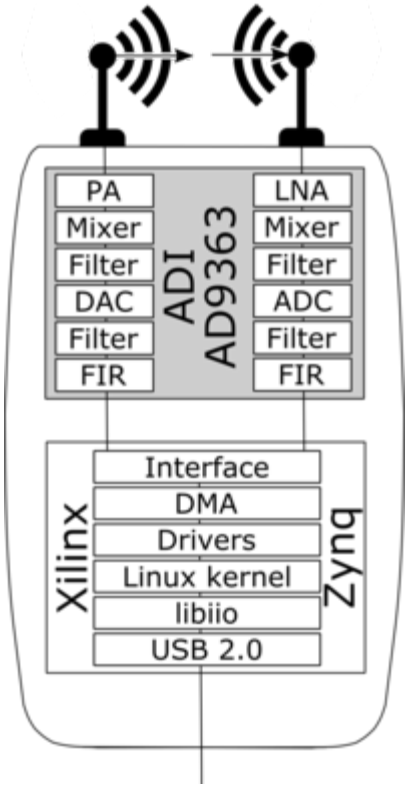
ADALM-PLUTO (PlutoSDR)

- ADALM = Analog Devices Advanced Learning Module
- Why “Pluto”?
- Documentation at: wiki.analog.com

- Includes:
  - PlutoSDR
  - Loopback SMA cable
  - 2 wideband antennas for TX & RX
  - USB cable

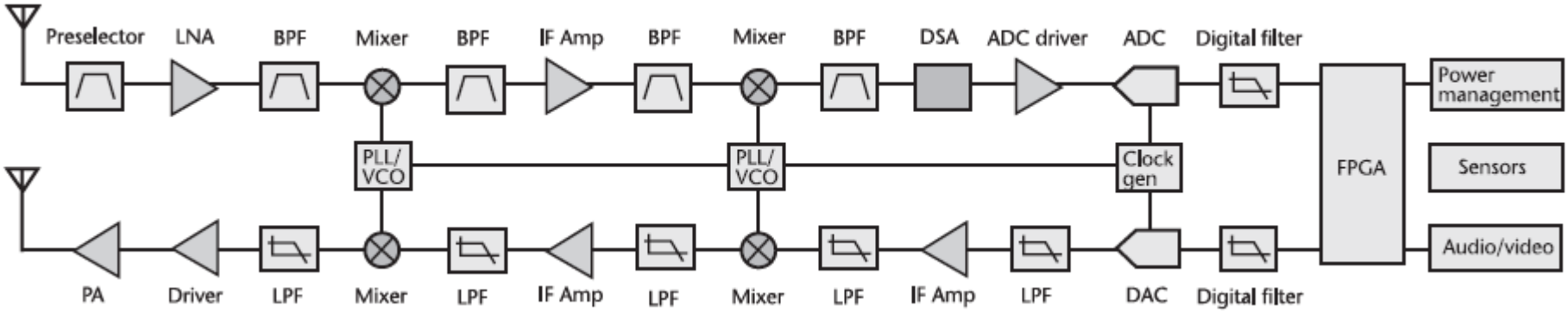
- Support for MATLAB, GNU Radio, Simulink, Python, C++, Linux Shell, and other common software tools using IIO
- Compatible with Windows, Linux, Mac OSX

- Xilinx Zynq processor provides embedded ARM platform and customizable FPGA
  - Firmware source HDL available on GitHub
- Mounts as a USB storage device
- Embedded Linux OS
  - Accessible via SSH

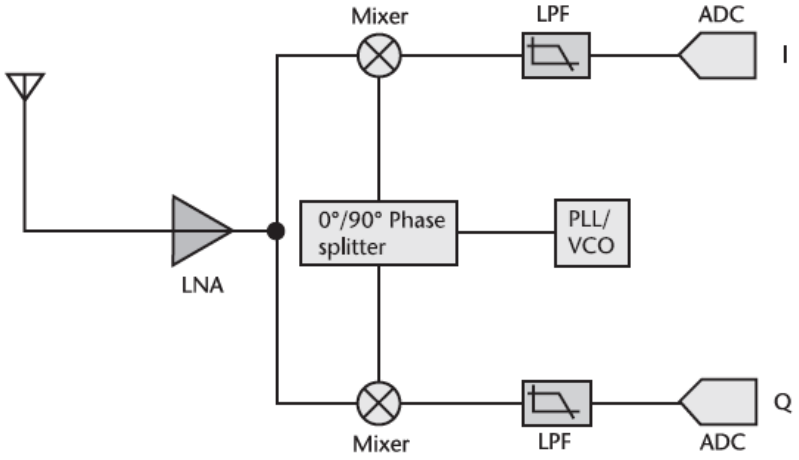


Radio Architecture : Traditional vs SDR

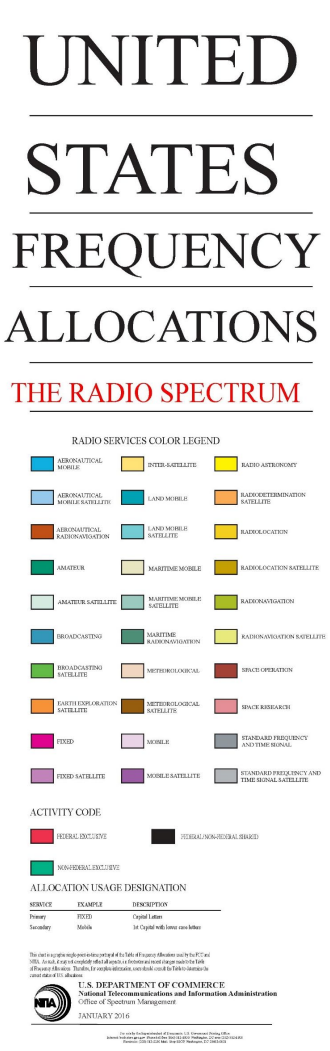
Traditional Super Heterodyne Transceiver



Direct-Conversion, or Zero-IF Transceiver



Frequency Bands (U.S.)



0.0-0.3 MHz

0.3-3.0 MHz

3.0-30 MHz

30-300 MHz

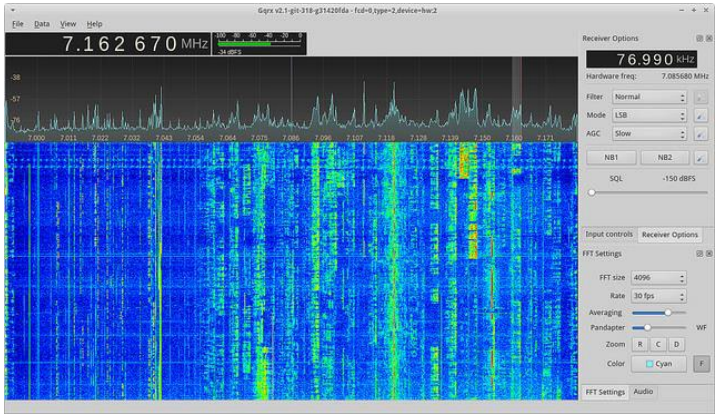
300-3,000 MHz

3-30 GHz

30-300 GHz

SDR SoftwareTools

- MATLAB / Simulink
  - Hardware Support Packages
  - Requires additional toolboxes to use with SDR
  - UA academic license is available to students at no cost
- GNU Radio
  - Open-source framework for SDR and signal processing
  - Very active and knowledgeable community
    - Out-of-Tree (OOT) Modules
- Other software
  - NI LabVIEW
  - IIOScope
  - GQRX
  - SDR#, HDSDR, SDRangel
  - And more…



You are encouraged to experiment with all SDR software freely available

ECE 531 Class SDR Toolkit

- MATLAB
  - UA Licence for Students
- GNU Radio
  - Windows and Linux Versions
  - Versions 3.7, 3.8, and 3.10
- VirtualBox & instant-gnuradio
  - Linux virtual machine with SDR tools needed for class and labs is uploaded to D2L
- Industrial IO and IIO-Oscilloscope
  - Windows and Linux Versions

- Historically, Linux versions recommended
  - Less true recently with software evolutions