Sistemas de Comunicaciones basados en Radio Definida por Software (SDR)

Dr. Ing. Alejandro José Uriz

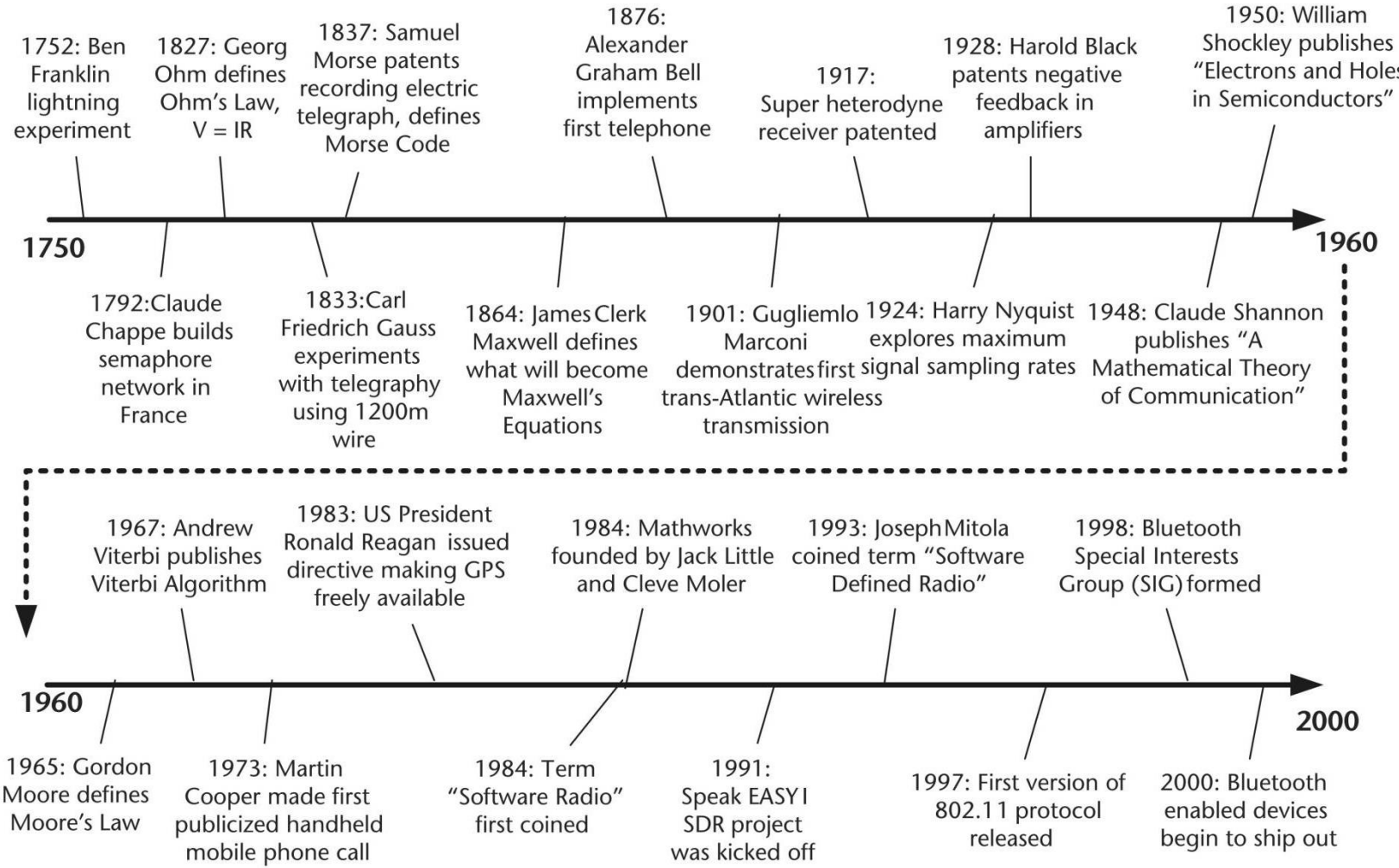
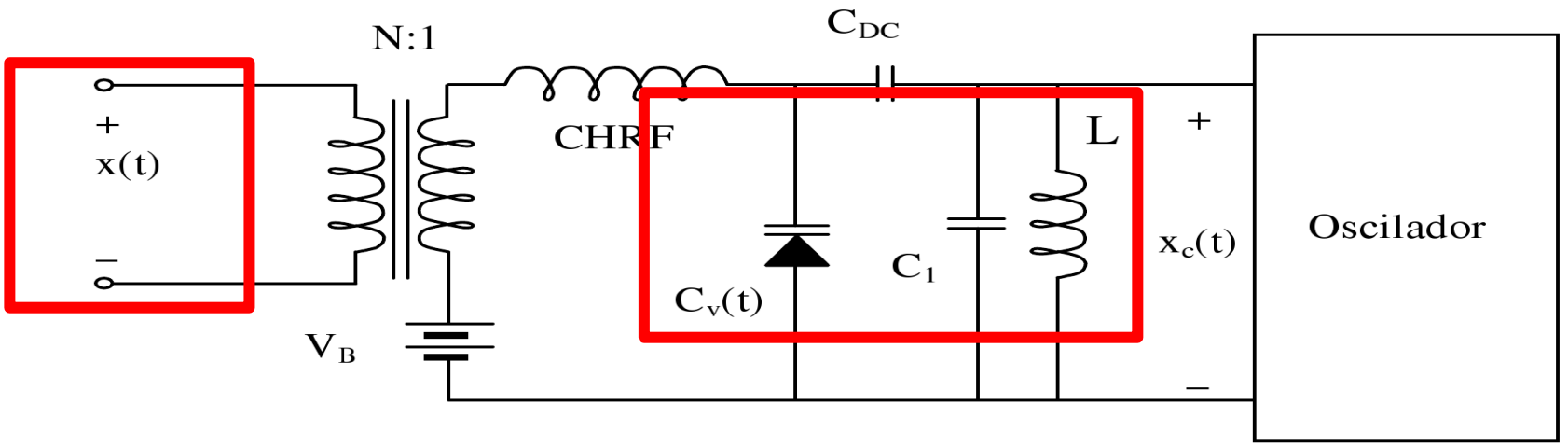


Figure 1.1 Timeline of several key milestones in communications.

Método directo de generación de FM



Este circuito consiste en un VCO. Su frecuencia de resonancia depende de L y C. La capacidad total del sistema es controlada mediante *x(t)*.

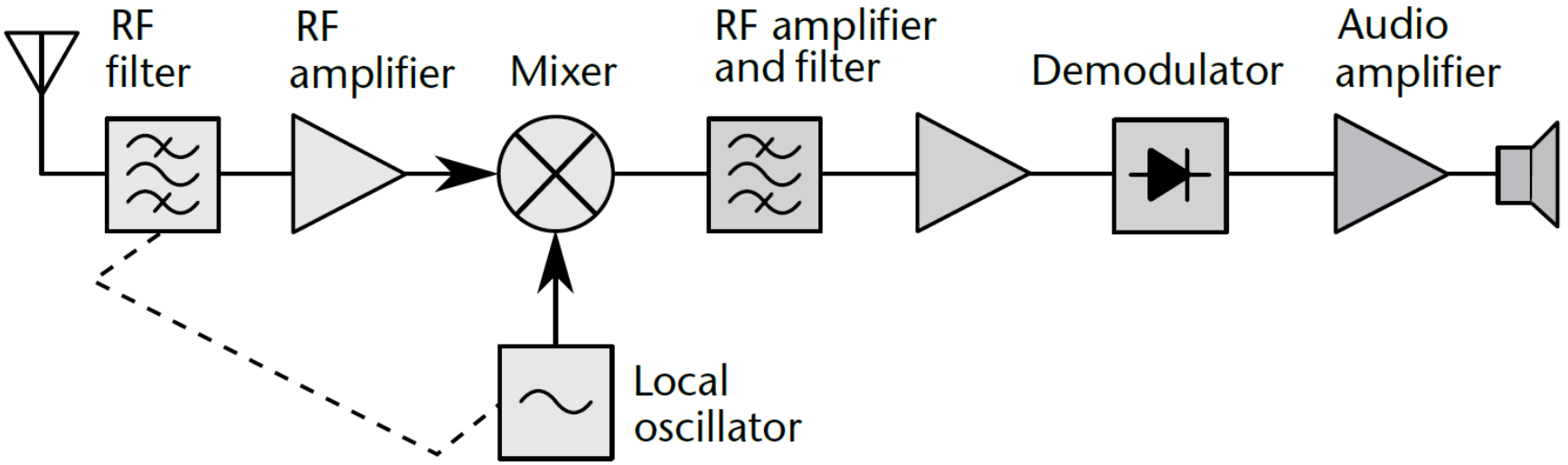
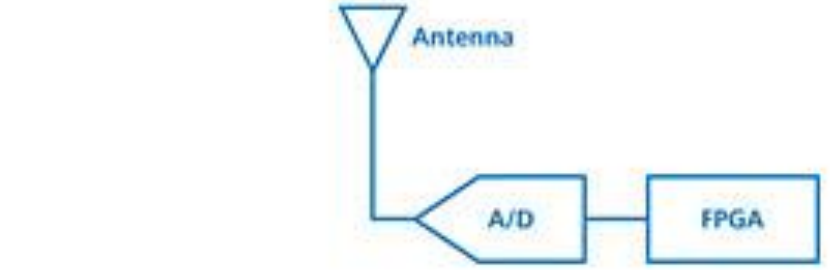
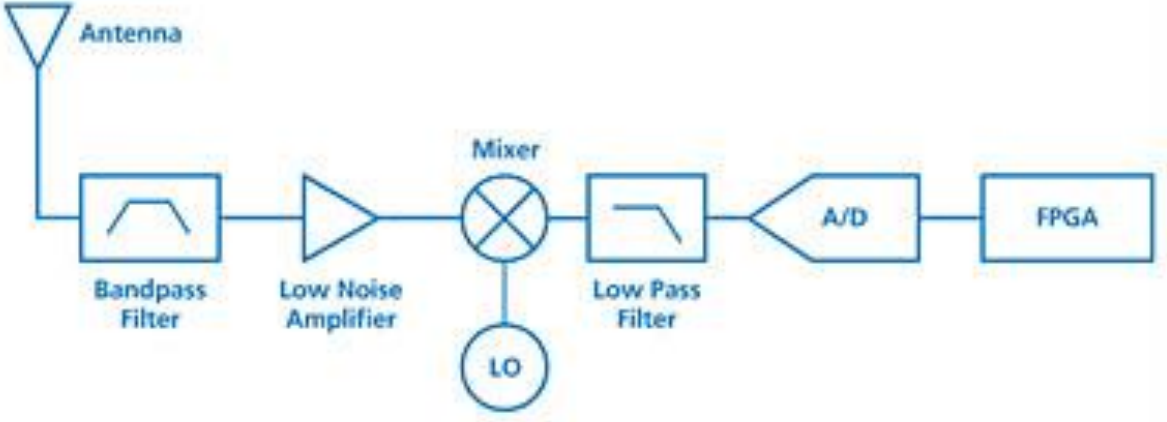


Figure A.3 Single-conversion superheterodyne radio receiver. The incoming radio signal from the antenna (left) is passed through an RF filter to attenuate some undesired signals, amplified in a radio frequency (RF) amplifier, and mixed with an unmodulated sine wave from a local oscillator. The result is a beat frequency or heterodyne at the difference between the input signal and local oscillator frequencies, a lower frequency called the IF. The IF signal is selected and strengthened by several IF stages that bandpass filter and amplify the signal. The IF signal is then applied to a demodulator that extracts the modulated audio signal. An audio amplifier further amplifies the signal, and the speaker makes it audible.

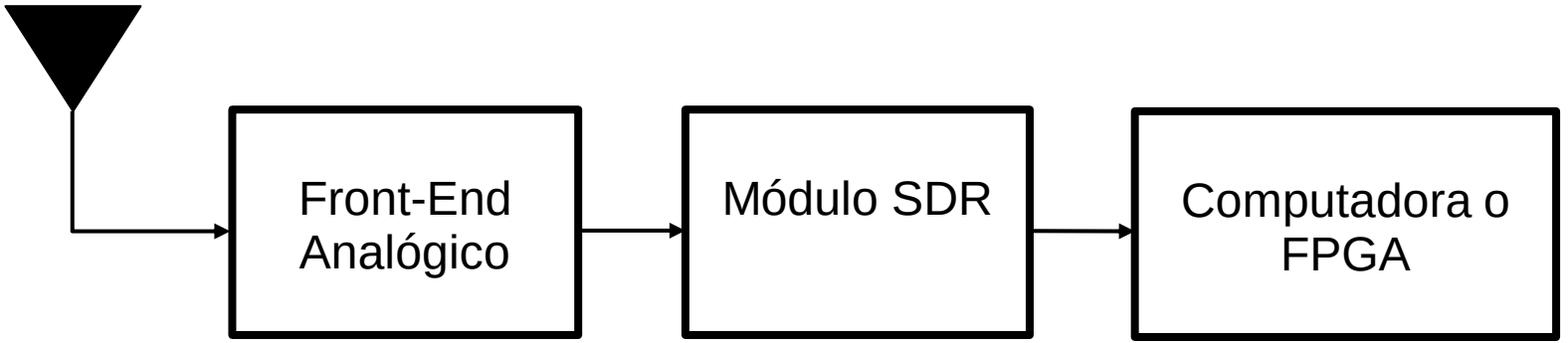
FIGURE 1 THE SOFTWARE-DEFINED RADIO RECEIVER IN ITS IDEAL AND PRACTICAL FORMS

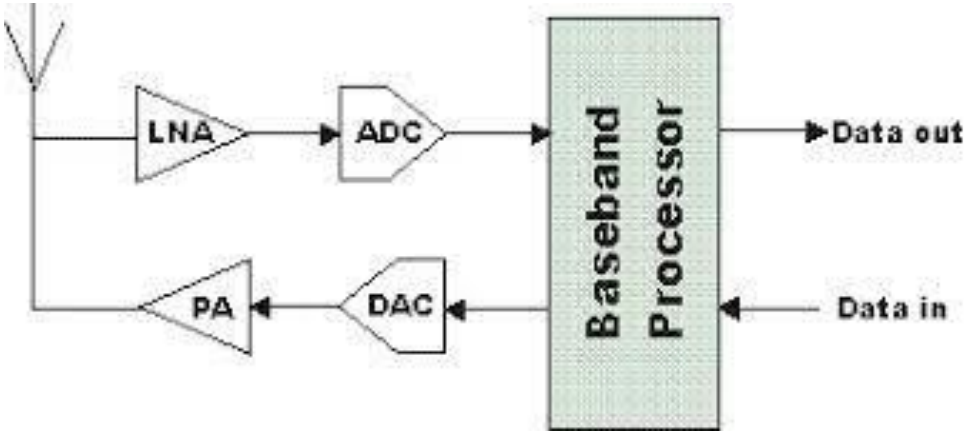


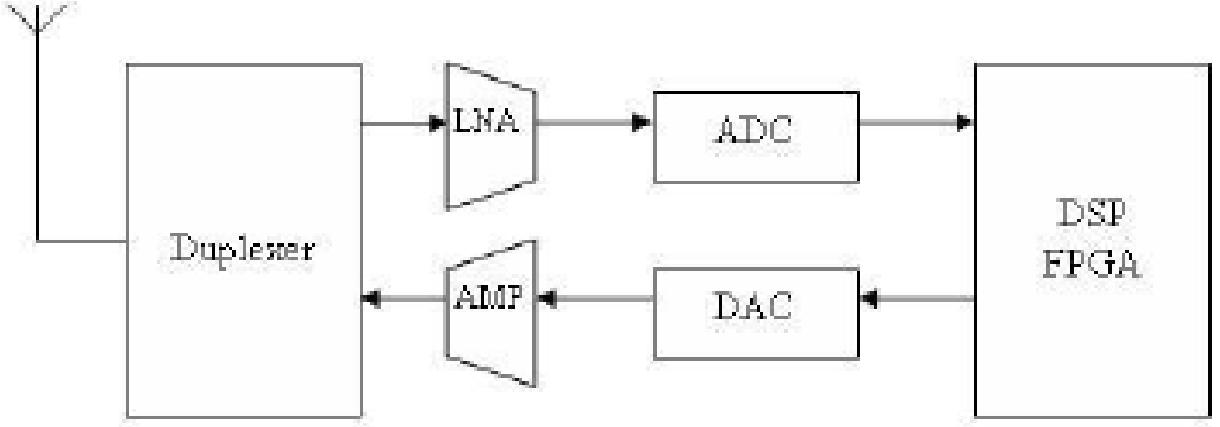
(a) Ideal SDR



(b) Practical SDR


Front-End
Analógico
Módulo SDR
Computadora o
FPGA


LNA
ADC
Baseband Processor
Data out
PA
DAC
Data in


Duplexer
LNA
ADC
DSP FPGA
AMP
DAC

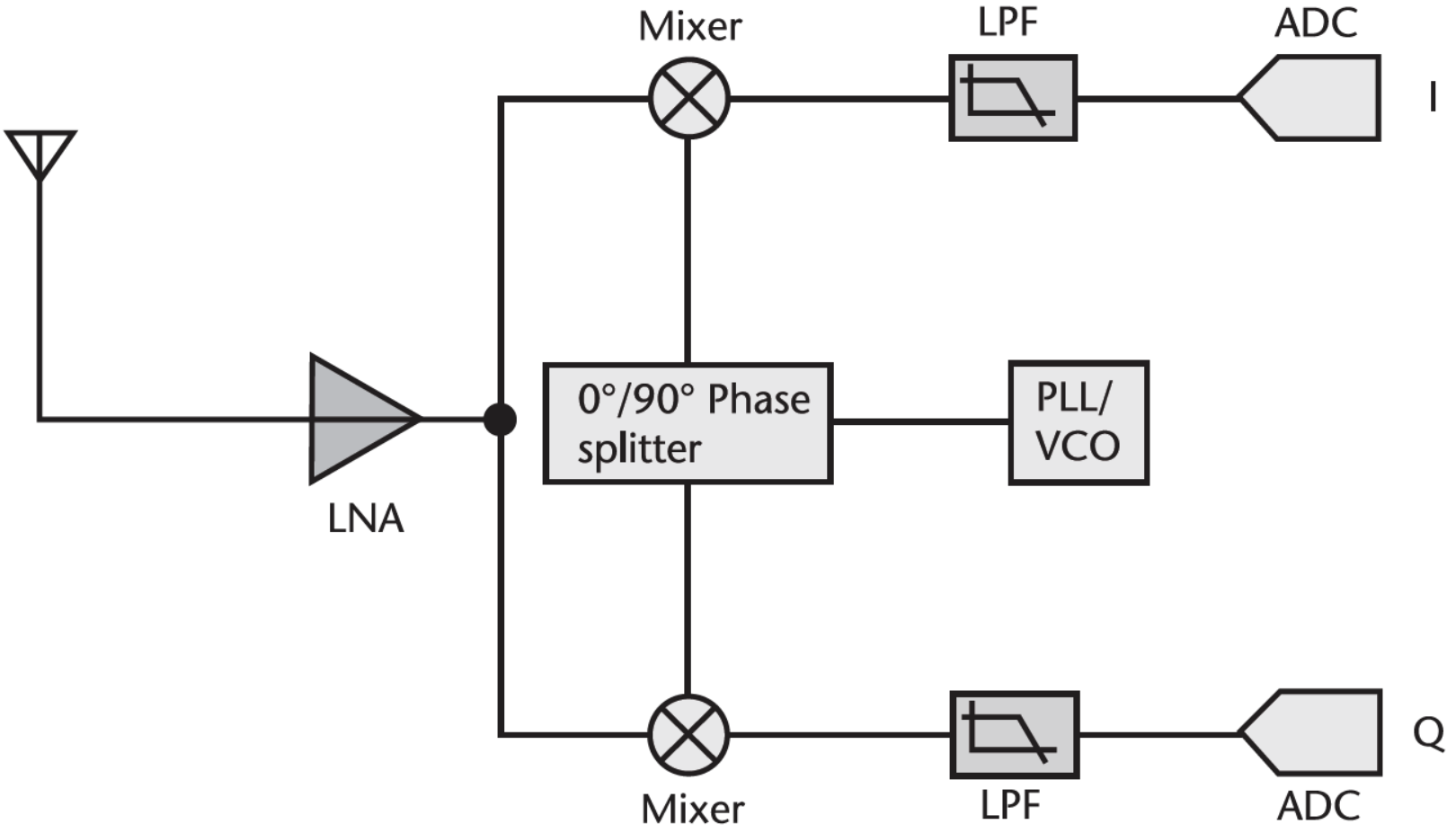
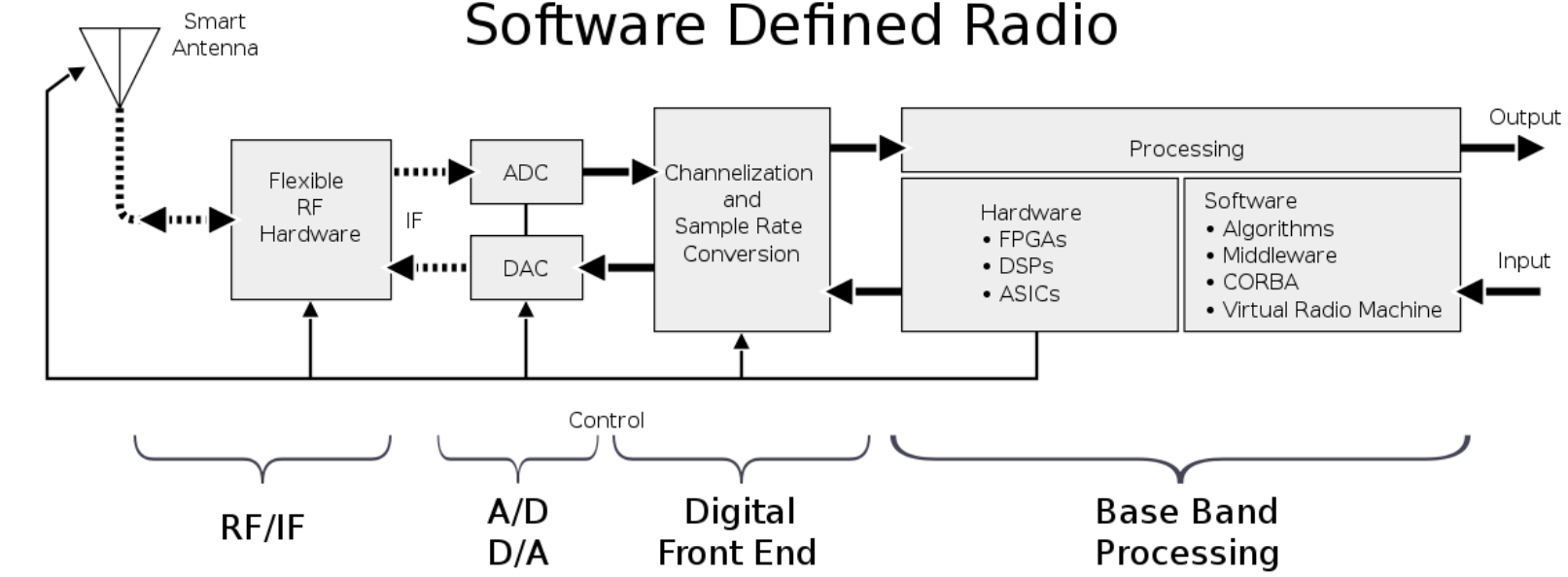
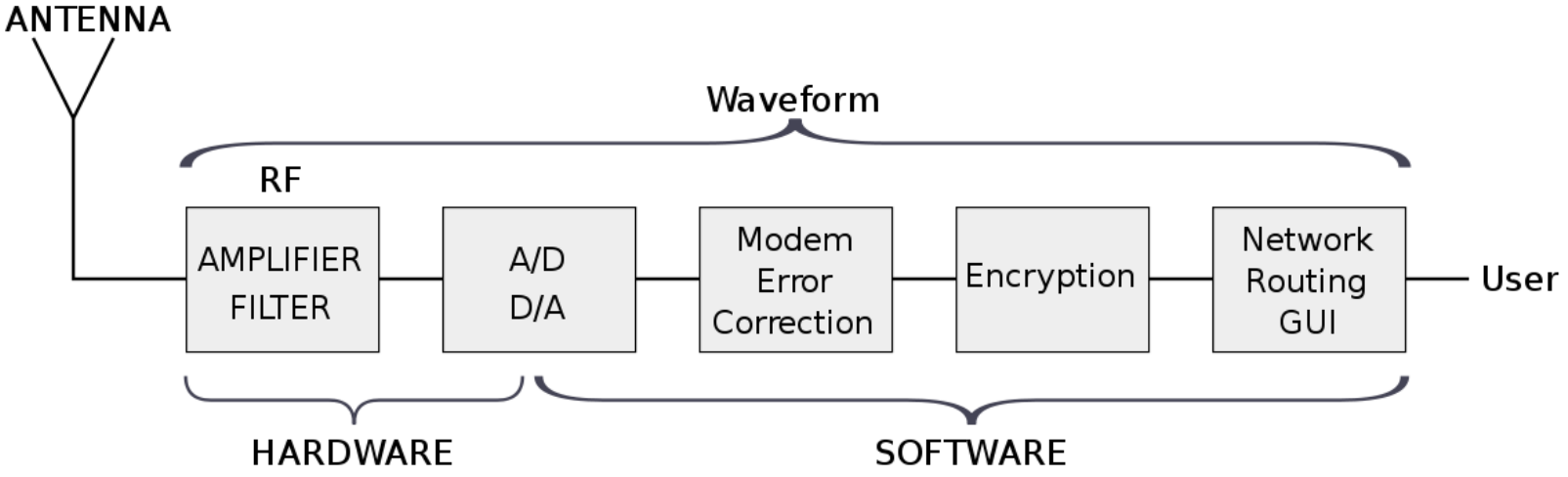


Figure 1.7 Zero IF architecture [4].

Software Defined Radio





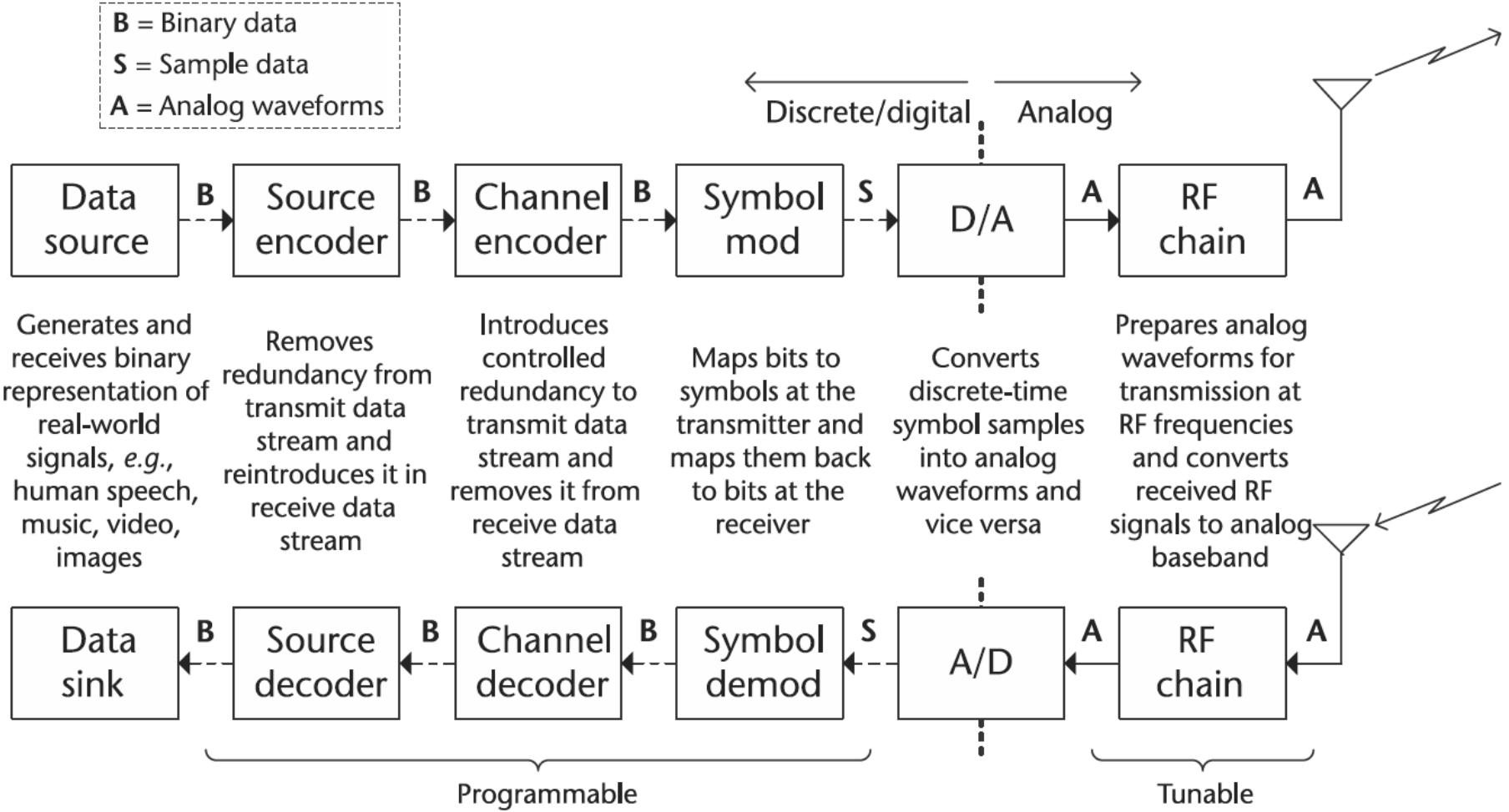
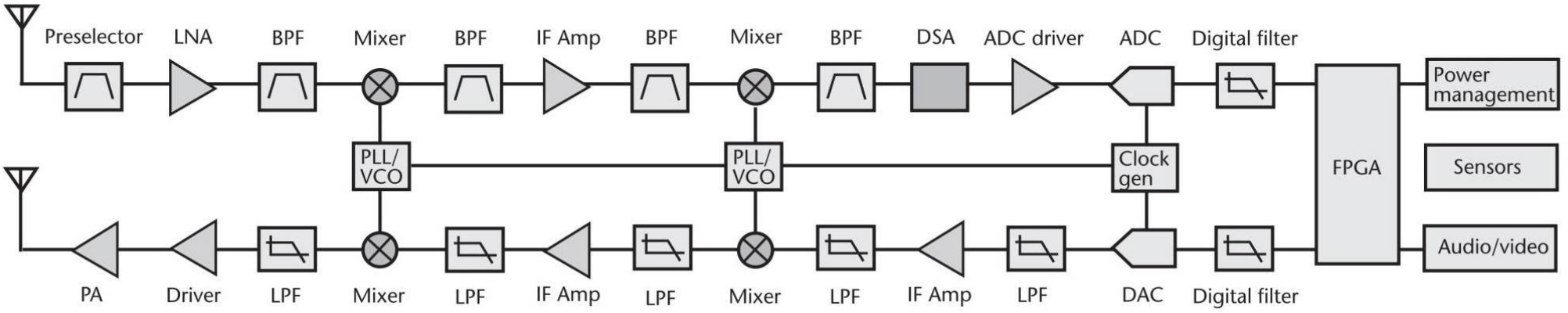
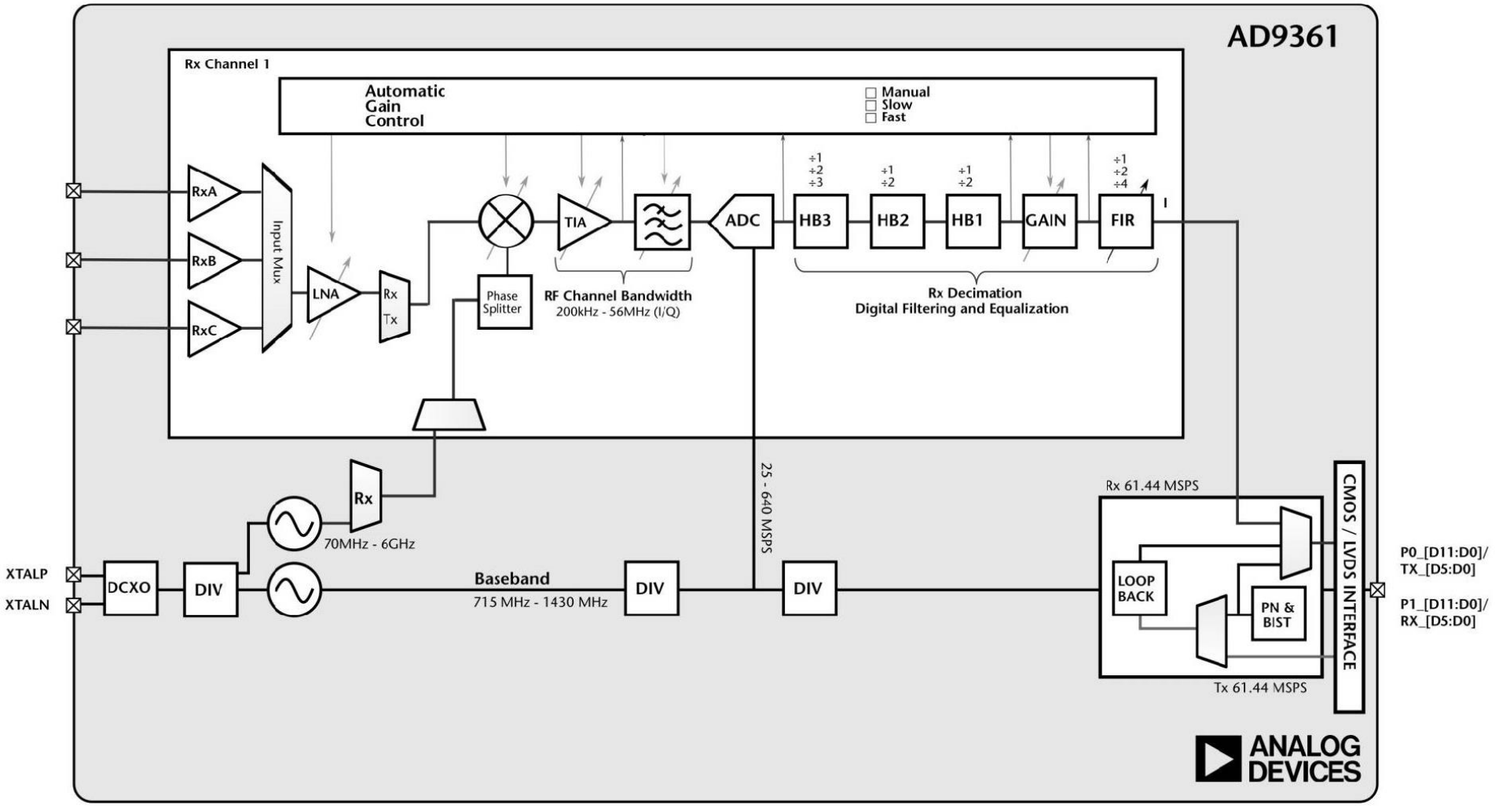
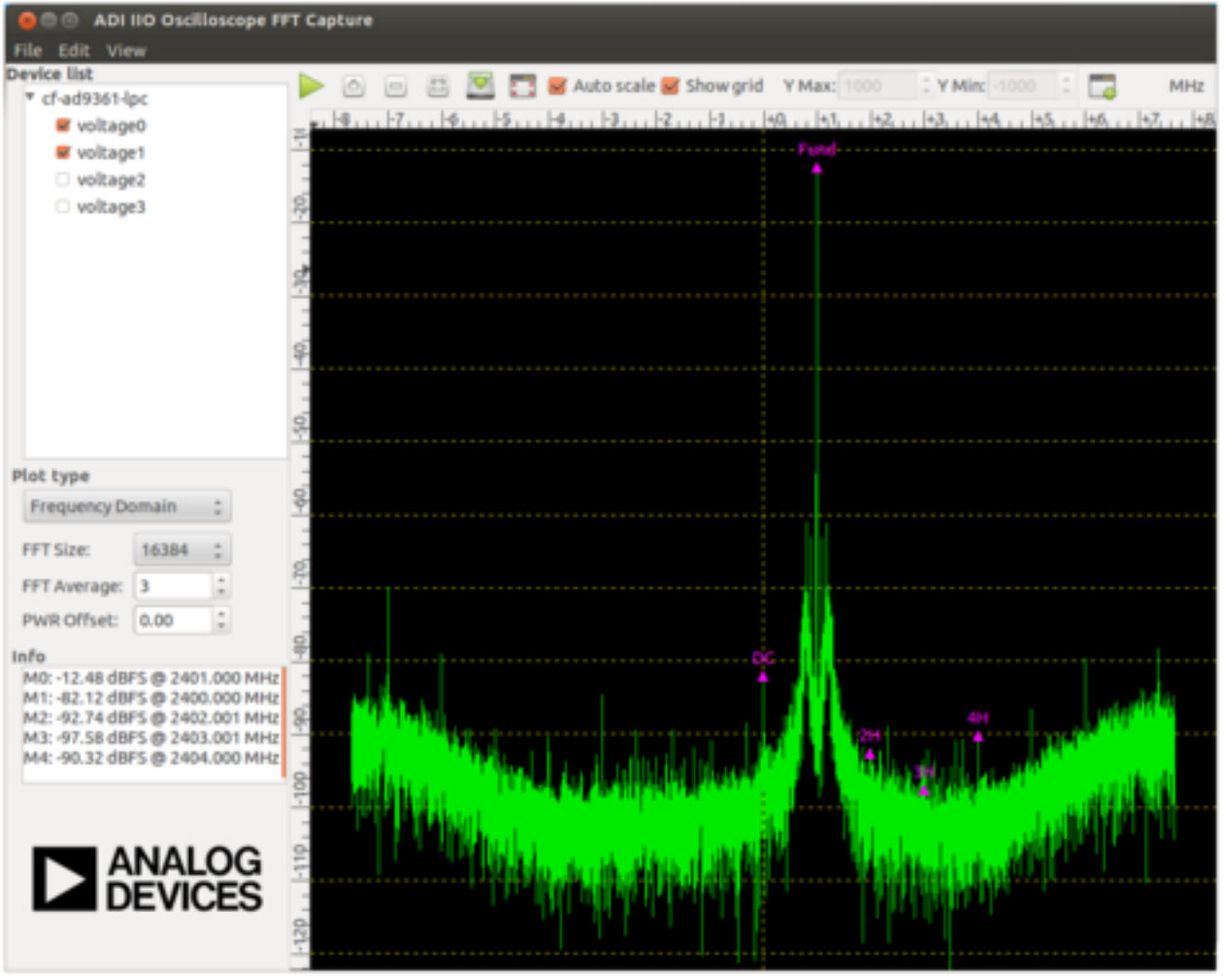


Figure 1.3 An illustration describing some of the important components that constitute a modern digital communications system. Note that for a SDR-based implementation, those components indicated as programmable can be realized in either programmable logic or software.

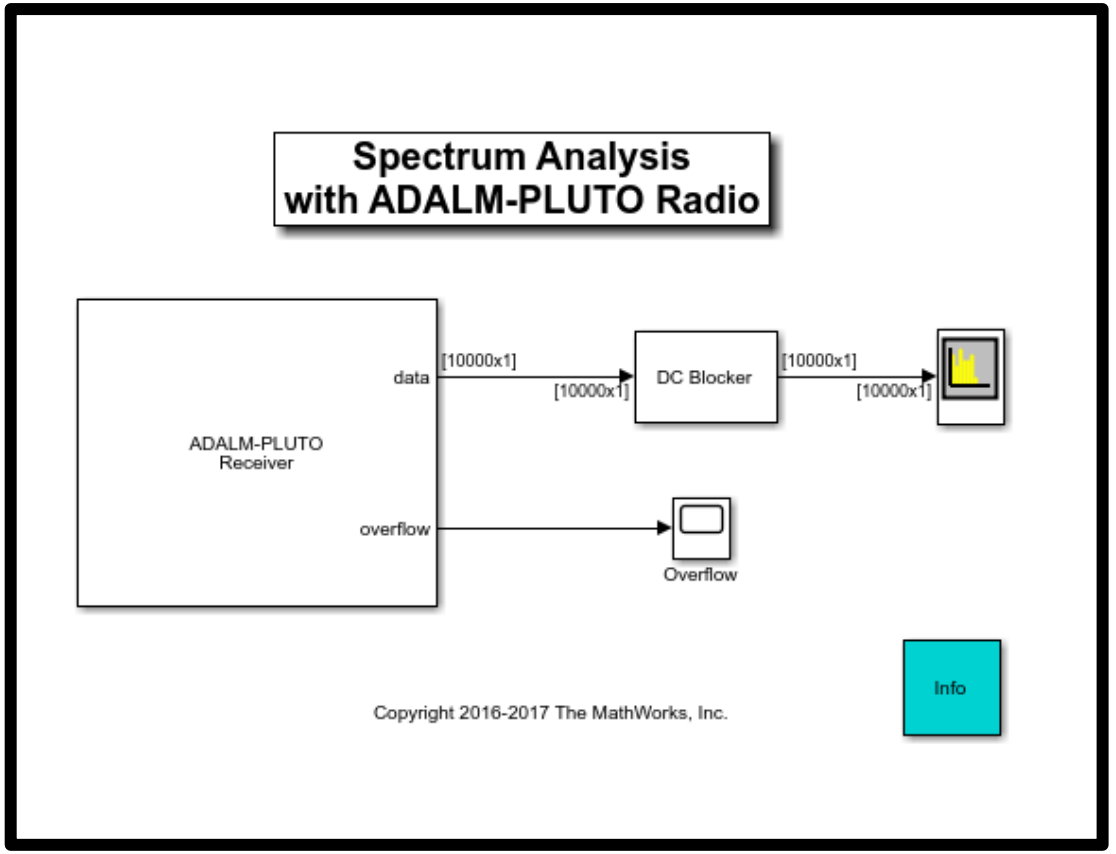

Preselector
LNA
BPF
Mixer
BPF
IF Amp
BPF
Mixer
BPF
DSA
ADC driver
ADC
Digital filter
Power management
PLL/ VCO
PLL/ VCO
Clock gen
FPGA
Sensors
Audio/video
PA
Driver
LPF
Mixer
LPF
IF Amp
LPF
Mixer
LPF
IF Amp
LPF
DAC
Digital filter

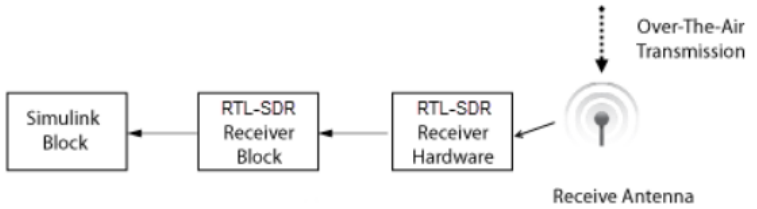

AD9361
Rx Channel 1
Automatic Gain Control
Manual
Slow
Fast
RxA
RxB
RxC
Input Mux
LNA
Rx
Tx
Phase Splitter
TIA
RF Channel Bandwidth
200kHz - 56MHz (I/Q)
ADC
÷1
÷2
÷3
HB3
÷1
÷2
HB2
÷1
÷2
HB1
GAIN
÷1
÷2
÷4
FIR
I
Rx Decimation
Digital Filtering and Equalization
25 - 640 MSPS
Rx
70MHz - 6GHz
XTALP
XTALN
DCXO
DIV
Baseband
715 MHz - 1430 MHz
DIV
DIV
Rx 61.44 MSPS
LOOP BACK
PN & BIST
Tx 61.44 MSPS
CMOS / LVDS INTERFACE
P0_[D11:D0]/
TX_[D5:D0]
P1_[D11:D0]/
RX_[D5:D0]
ANALOG DEVICES

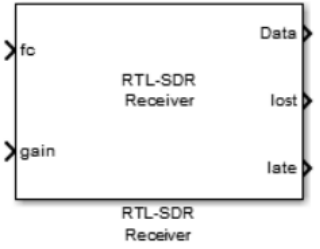
ADI IIO Oscilloscope



MatLab







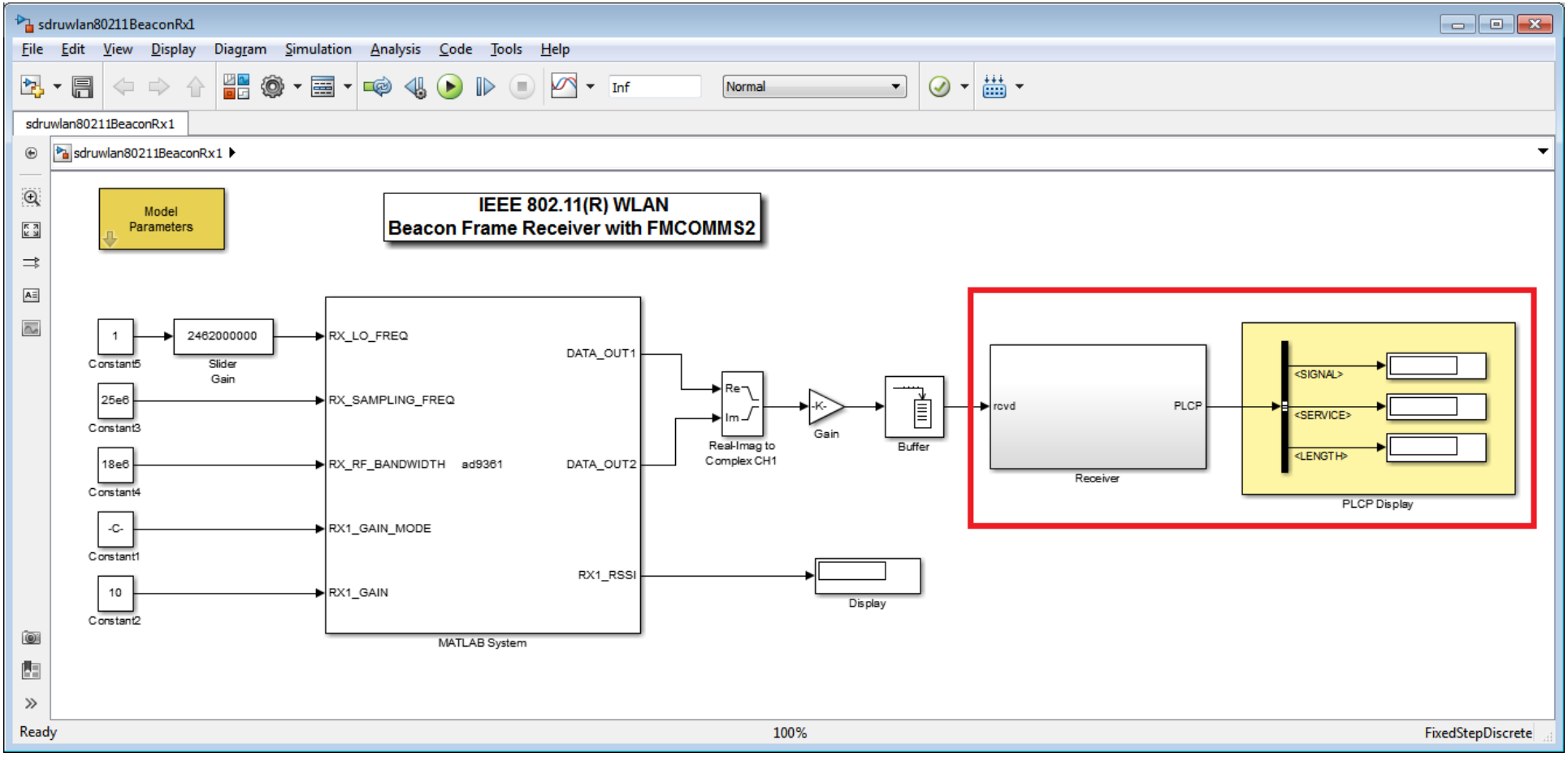
Ports

Input

`fc` — Center frequency
positive scalar

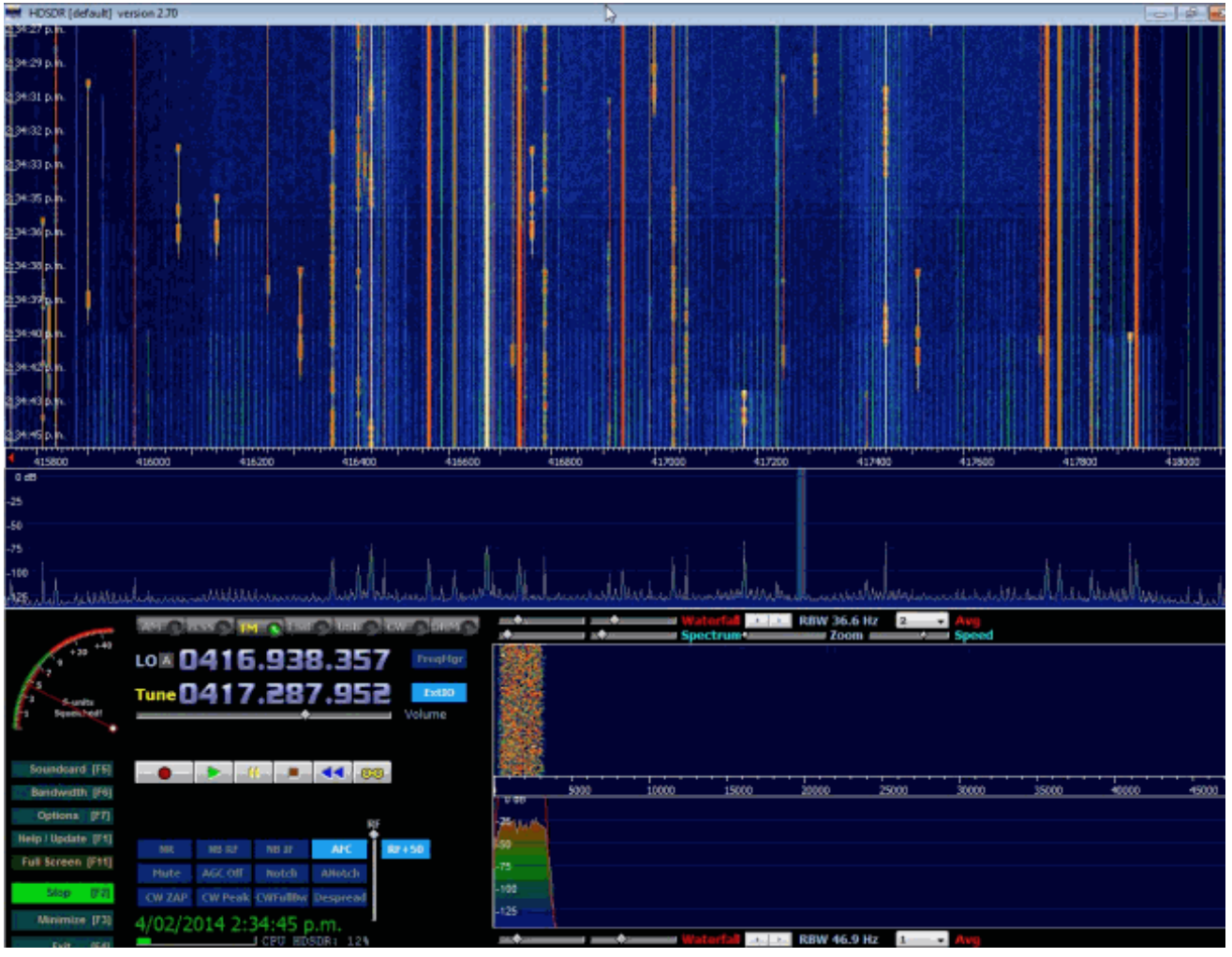
`gain` — Receiver gain
scalar

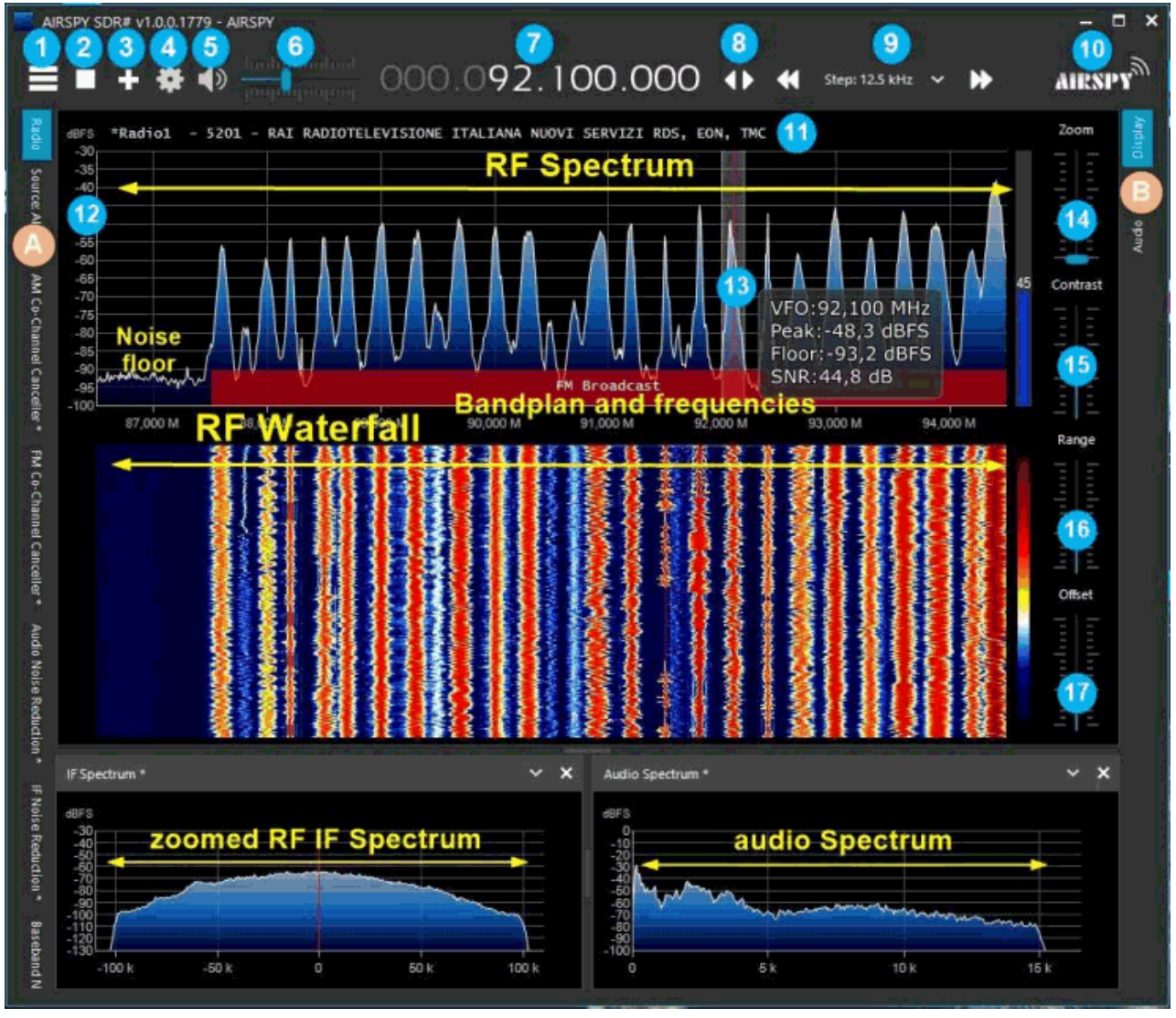
Fuente: https://la.mathworks.com/

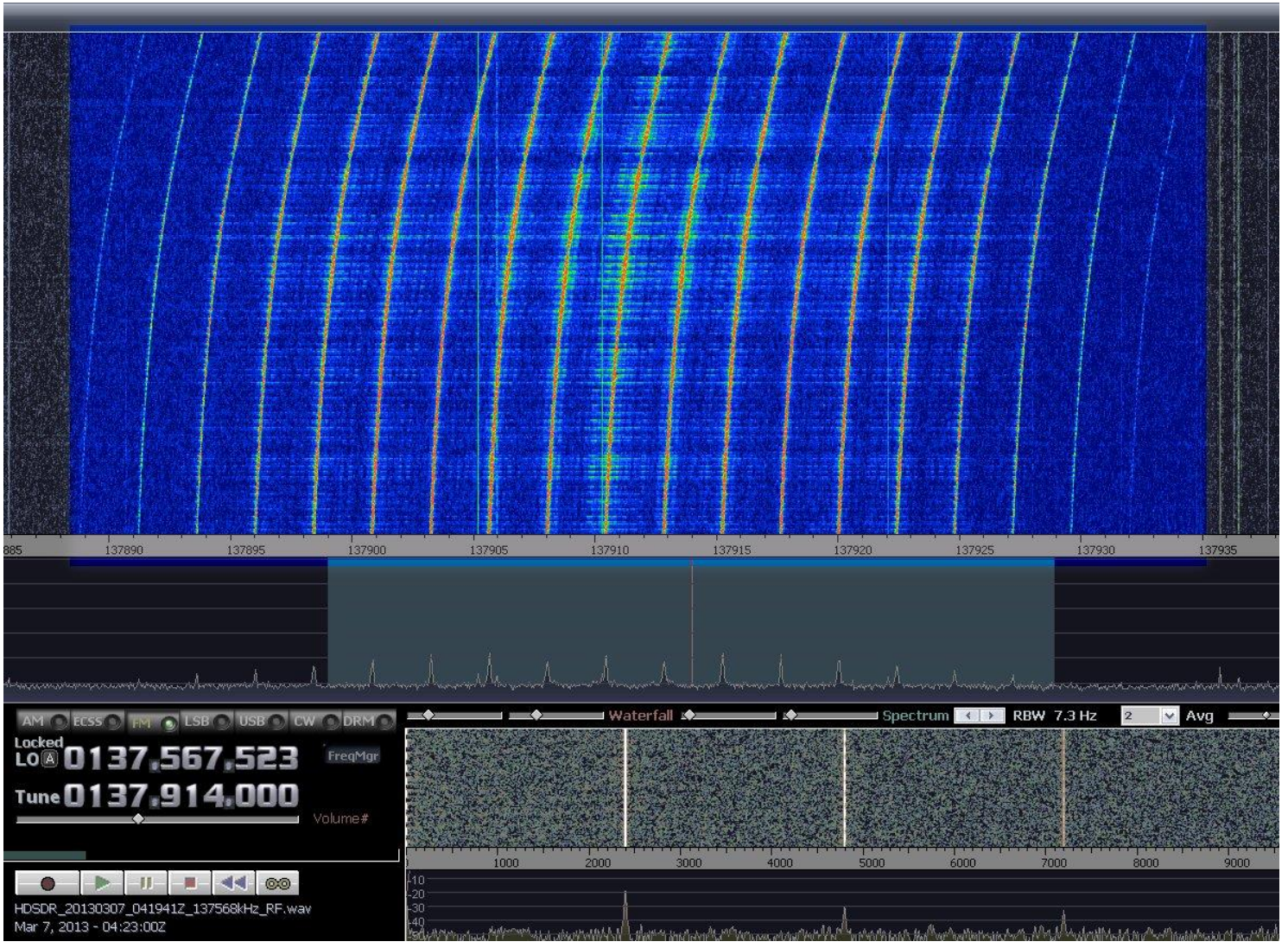

sdruwlan80211BeaconRx1
File Edit View Display Diagram Simulation Analysis Code Tools Help
Inf
Normal
sdruwlan80211BeaconRx1
Model Parameters
IEEE 802.11(R) WLAN
Beacon Frame Receiver with FMCOMMS2
1
Constant5
2462000000
Slider Gain
25e6
Constant3
18e6
Constant4
-C-
Constant1
10
Constant2
RX_LO_FREQ
RX_SAMPLING_FREQ
RX_RF_BANDWIDTH
ad9361
RX1_GAIN_MODE
RX1_GAIN
DATA_OUT1
DATA_OUT2
RX1_RSSI
MATLAB System
Re
Im
Real-Imag to Complex CH1
-K-
Gain
Buffer
rcvd
PLCP
Receiver
<SIGNAL>
<SERVICE>
<LENGTH>
PLCP Display
Display
Ready
100%
FixedStepDiscrete

Diseño basado en modelos

HDSDR


HDSDR [default] version 2.70
LO A 0416.938.357
Tune 0417.287.952
Volume
Soundcard [F5]
Bandwidth [F6]
Options [F7]
Help / Update [F1]
Full Screen [F11]
Stop [F2]
Minimize [F3]
Mute
AGC Off
Notch
ANotch
CW ZAP
CW Peak
Despread
4/02/2014 2:34:45 p.m.
Waterfall
Spectrum
RBW 36.6 Hz
Zoom
Avg
Speed
RBW 46.9 Hz


AIRSPY SDR# v1.0.0.1779 - AIRSPY
1
2
3
4
5
6
7
000.092.100.000
8
9
Step: 12.5 kHz
10
AIRSPY
Radio
Source: Ai
A
AM Co-Channel Canceller *
FM Co-Channel Canceller *
Audio Noise Reduction *
IF Noise Reduction *
Baseband N
dBFS *Radio1 - 5201 - RAI RADIOTELEVISIONE ITALIANA NUOVI SERVIZI RDS, EON, TMC
11
RF Spectrum
12
13
VFO:92,100 MHz
Peak:-48,3 dBFS
Floor:-93,2 dBFS
SNR:44,8 dB
Noise floor
FM Broadcast
Bandplan and frequencies
87,000 M
90,000 M
91,000 M
92,000 M
93,000 M
94,000 M
RF Waterfall
Zoom
14
Contrast
15
Range
16
Offset
17
Display
B
Audio
IF Spectrum *
zoomed RF IF Spectrum
-100 k
-50 k
0
50 k
100 k
Audio Spectrum *
audio Spectrum
0
5 k
10 k
15 k



https://www.creationfactory.co/2013/03/noaa-apt-satellite-night-time-weather.html

Google Collab

Eye Diagram and ISI.ipynb

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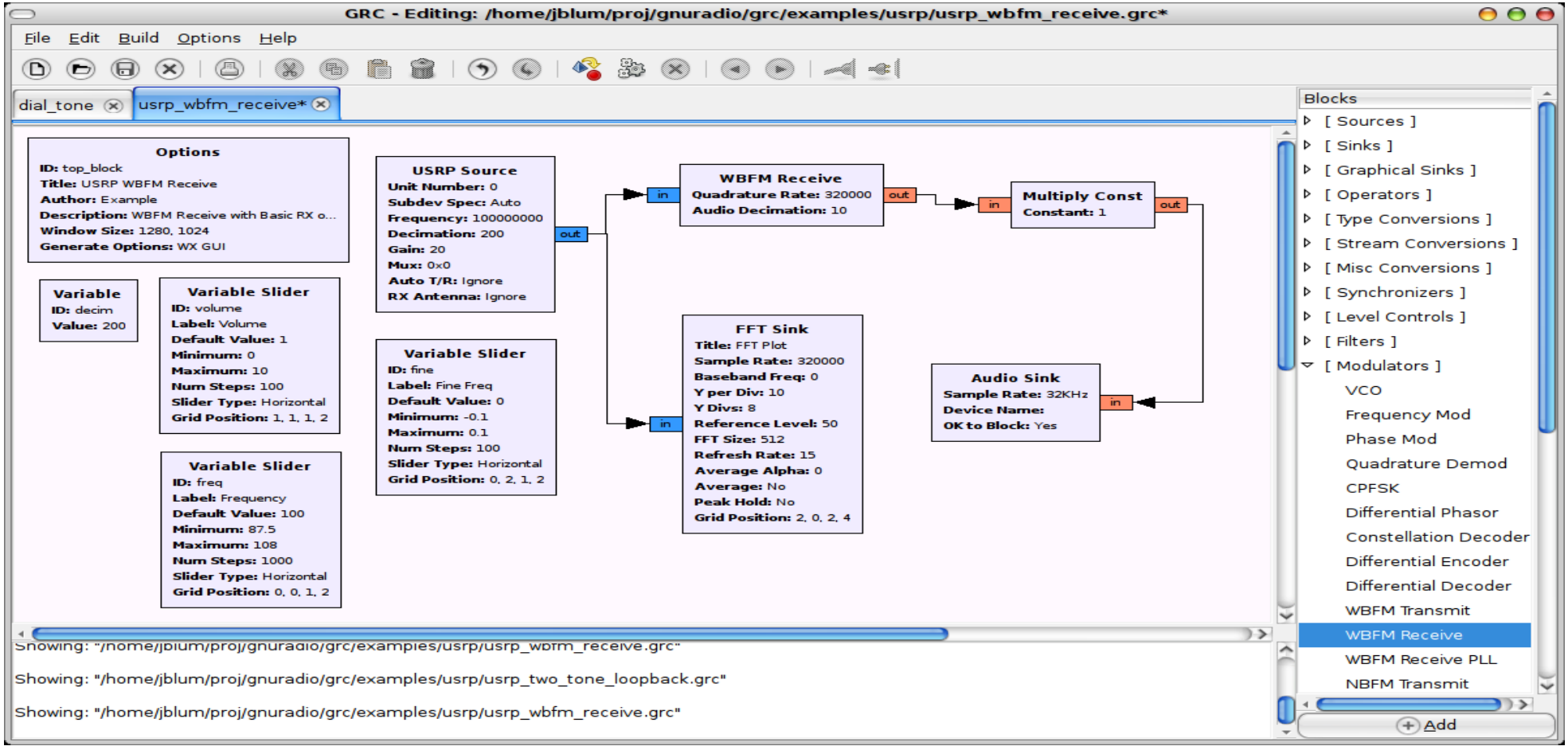
```
[ ] #------------------ Transmitter configuration parameters ------------------

    num_bits    = 2**13   # Number of transmitted bits
    sps         = 8       # Samples per symbol
    span        = 12      # The filter is truncated to span symbols
    beta        = 1       # Excess-bandwidth parameter
    sample_rate = 4e6     # Sample rate RX and TX paths[Samples/Sec]
```

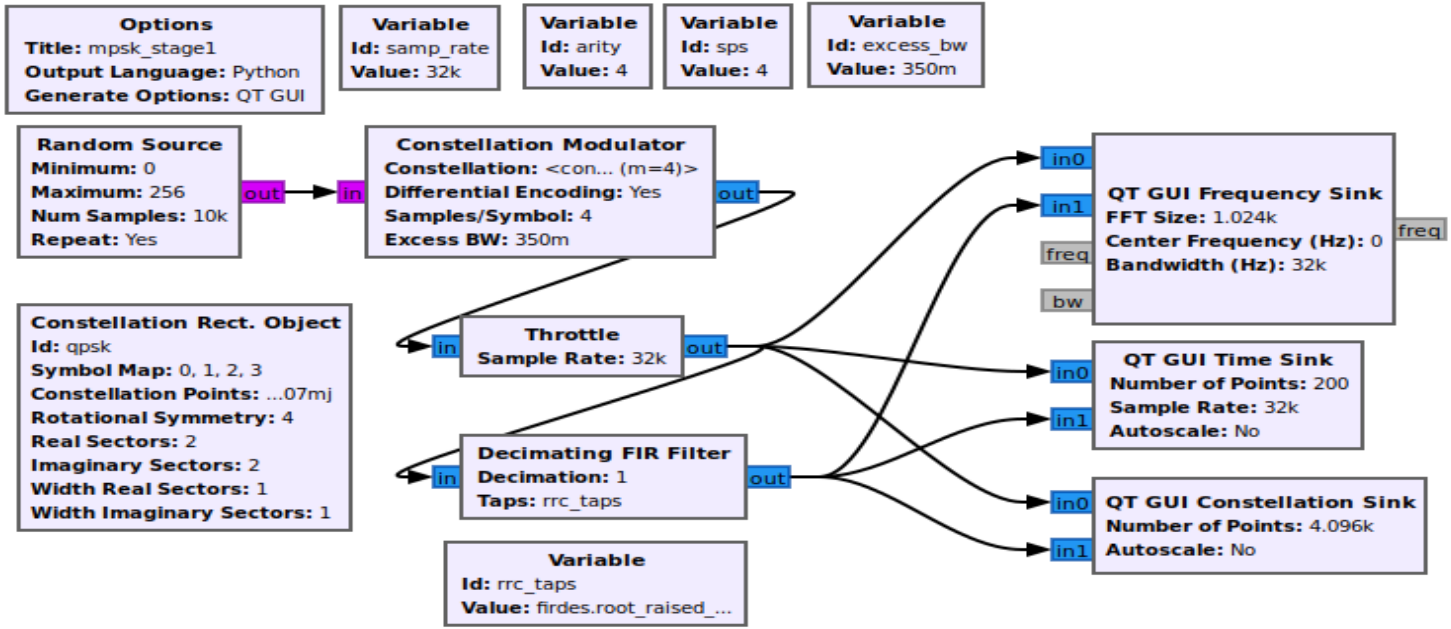
```
[ ] #------------------------------ SDR Parameter Configuration -------------------------------

    Uri              = "ip:10.0.0.71"
    SamplingRate     = sample_rate   # Sample rate RX and TX paths[Samples/Sec]
    Loopback         = 1             # 0=Disabled, 1=Digital, 2=RF

    TxLOFreq         = 910e6         # Carrier frequency of TX path [Hz]
    TxAtten          = -40           # Attenuation applied to TX path, valid range is -90 to 0 dB [dB]
    TxRfBw           = 2e6           # Bandwidth of front-end analog filter of TX path [Hz]

    RxLOFreq         = TxLOFreq      # Carrier frequency of RX path [Hz]
    GainControlModes = "slow_attack" # Receive path AGC Options: slow_attack, fast_attack, manual
    RxHardwareGain   = 0             # Gain applied to RX path. Only applicable when gain_control_mode is set to 'manual'
    RxRfBw           = TxRfBw        # Bandwidth of front-end analog filter of RX path [Hz]
    RxBufferSize     = 2**20-1
```

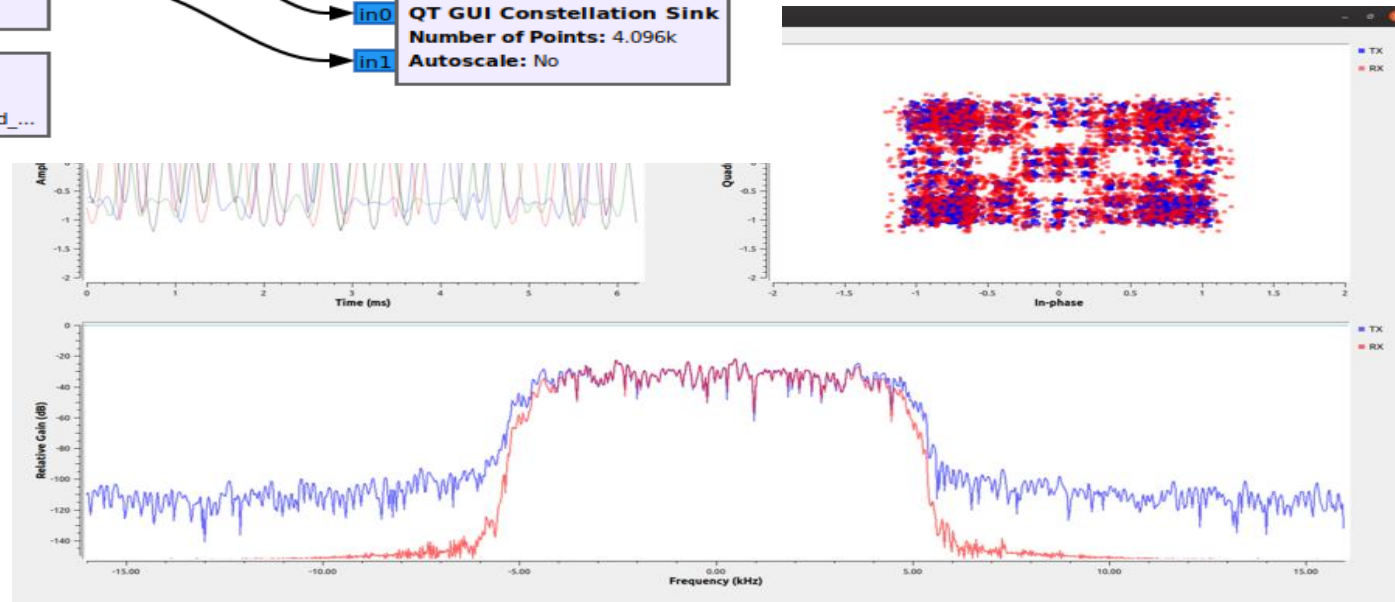
```
[ ] #-------------------- Root Raised Cosine Filter Function --------------------

    def rcosdesign(beta,span,sps):
        index     = np.arange(-(span*sps)/2,(span*sps)/2,1)
        Ts        = sps
        rrcFilter = np.array([])

        for n in index:
            if n == Ts/(4*beta) or n == -Ts/(4*beta):
                aux       = beta*((np.pi+2)*np.sin(np.pi/(4*beta))+(np.pi-2)*np.cos(np.pi/(4*beta)))/(np.pi*np.sqrt(2))
                rrcFilter = np.append(rrcFilter,aux)
```

GNU RADIO


GRC - Editing: /home/jblum/proj/gnuradio/grc/examples/usrp/usrp_wbfm_receive.grc*
File Edit Build Options Help
dial_tone
usrp_wbfm_receive*
Options
ID: top_block
Title: USRP WBFM Receive
Author: Example
Description: WBFM Receive with Basic RX o...
Window Size: 1280, 1024
Generate Options: WX GUI
Variable
ID: decim
Value: 200
Variable Slider
ID: volume
Label: Volume
Default Value: 1
Minimum: 0
Maximum: 10
Num Steps: 100
Slider Type: Horizontal
Grid Position: 1, 1, 1, 2
Variable Slider
ID: freq
Label: Frequency
Default Value: 100
Minimum: 87.5
Maximum: 108
Num Steps: 1000
Slider Type: Horizontal
Grid Position: 0, 0, 1, 2
USRP Source
Unit Number: 0
Subdev Spec: Auto
Frequency: 100000000
Decimation: 200
Gain: 20
Mux: 0x0
Auto T/R: Ignore
RX Antenna: Ignore
out
Variable Slider
ID: fine
Label: Fine Freq
Default Value: 0
Minimum: -0.1
Maximum: 0.1
Num Steps: 100
Slider Type: Horizontal
Grid Position: 0, 2, 1, 2
in
WBFM Receive
Quadrature Rate: 320000
Audio Decimation: 10
out
in
Multiply Const
Constant: 1
out
FFT Sink
Title: FFT Plot
Sample Rate: 320000
Baseband Freq: 0
Y per Div: 10
Y Divs: 8
Reference Level: 50
FFT Size: 512
Refresh Rate: 15
Average Alpha: 0
Average: No
Peak Hold: No
Grid Position: 2, 0, 2, 4
in
Audio Sink
Sample Rate: 32KHz
Device Name:
OK to Block: Yes
in
Showing: "/home/jblum/proj/gnuradio/grc/examples/usrp/usrp_wbfm_receive.grc"
Showing: "/home/jblum/proj/gnuradio/grc/examples/usrp/usrp_two_tone_loopback.grc"
Showing: "/home/jblum/proj/gnuradio/grc/examples/usrp/usrp_wbfm_receive.grc"
Blocks
[Sources]
[Sinks]
[Graphical Sinks]
[Operators]
[Type Conversions]
[Stream Conversions]
[Misc Conversions]
[Synchronizers]
[Level Controls]
[Filters]
[Modulators]
VCO
Frequency Mod
Phase Mod
Quadrature Demod
CPFSK
Differential Phasor
Constellation Decoder
Differential Encoder
Differential Decoder
WBFM Transmit
WBFM Receive
WBFM Receive PLL
NBFM Transmit
Add

Ejemplo QPSK





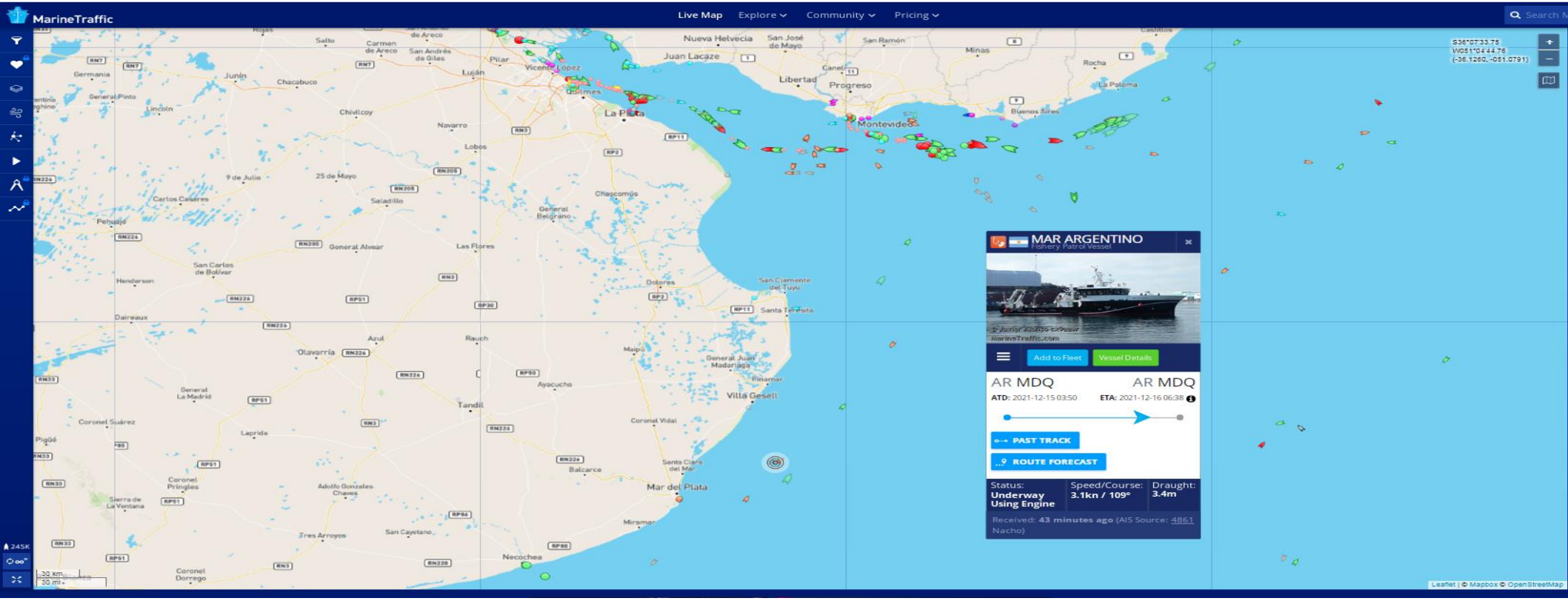
Algunos módulos de GNU Radio Companion

Algunos ejemplos de módulos para instalar en GNU Radio son los siguientes:

- gr-satellites
- gr-adsb
- gr-IEEE802-15-4
- gr-lora
- gr-gsm
- gr-isdtv
- gr-bluetooth
- gr-iridium
- gr-IEEE802-11

Se pueden encontrar más en: https://www.cgran.org/

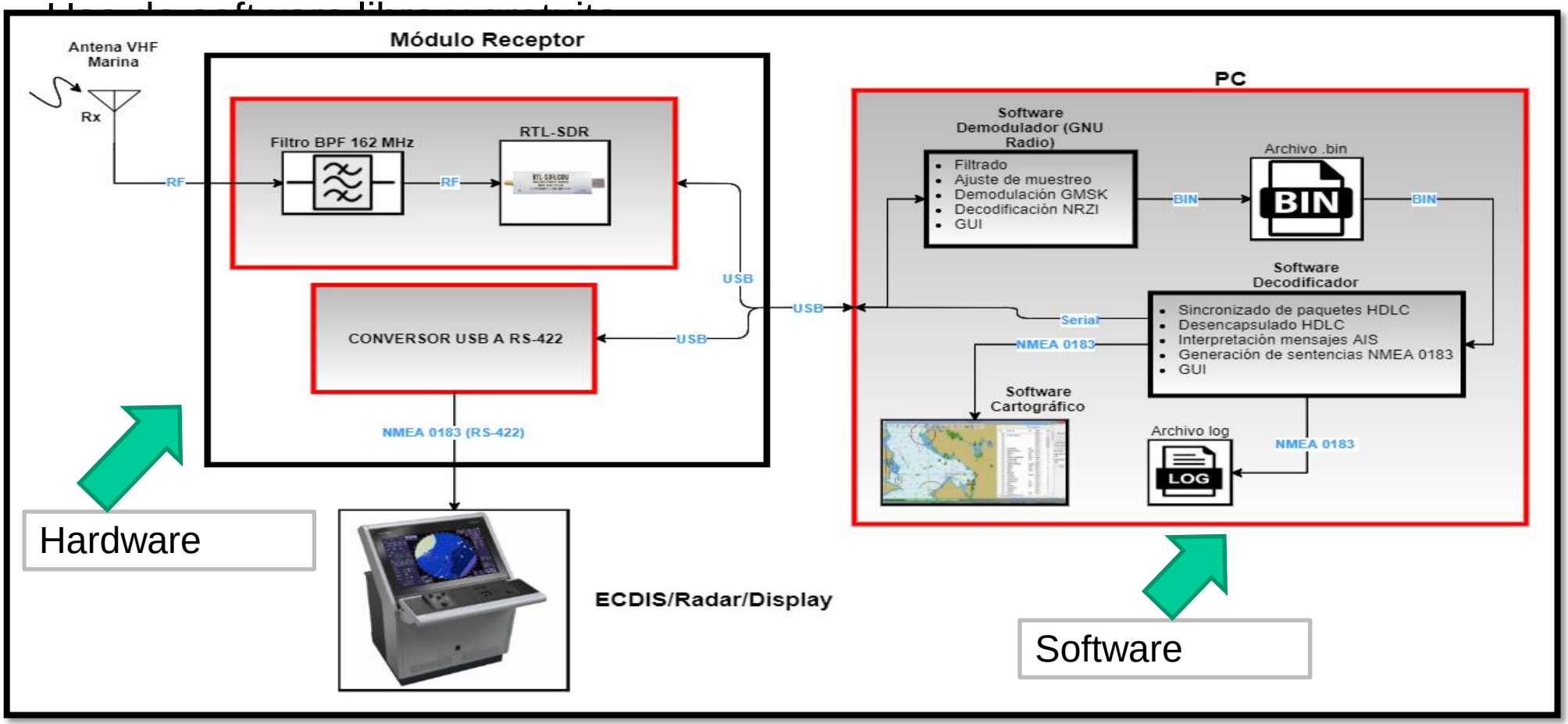
Ejemplo avanzado: Receptor AIS

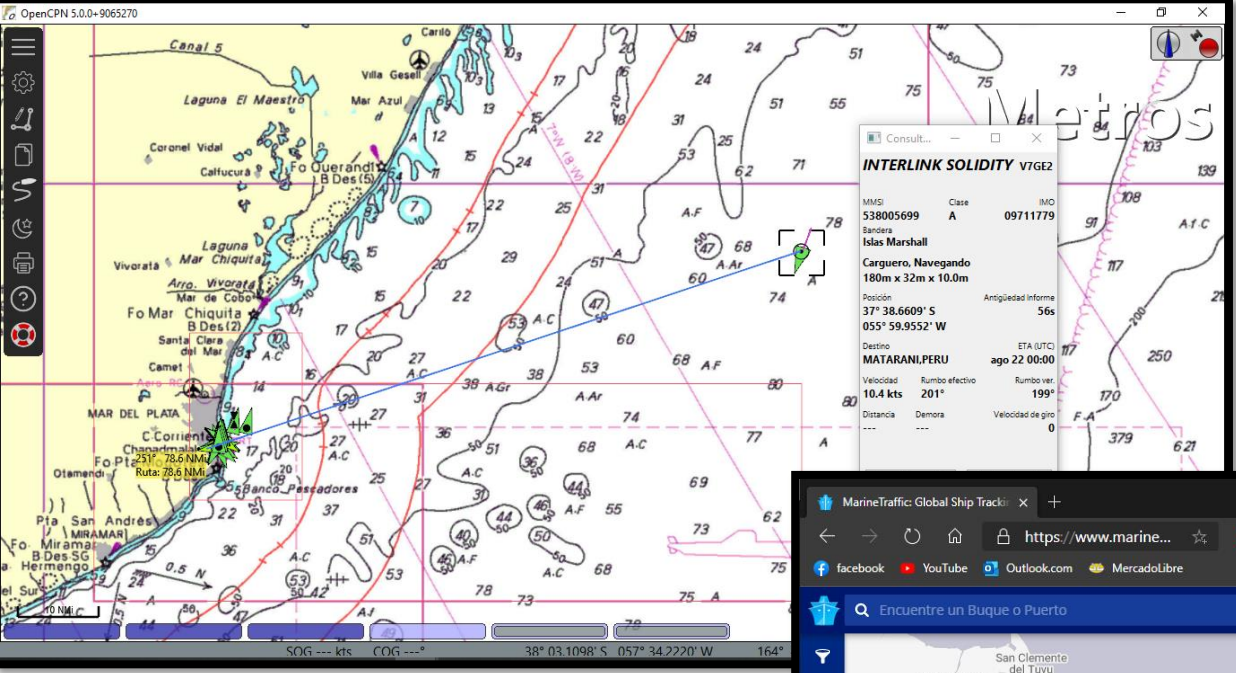


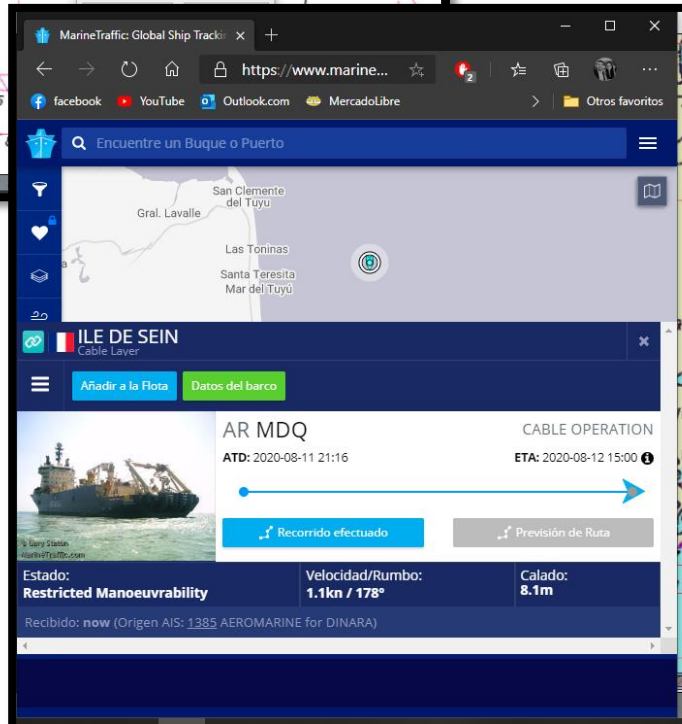
Captura del sitio https://marinetraffic.com

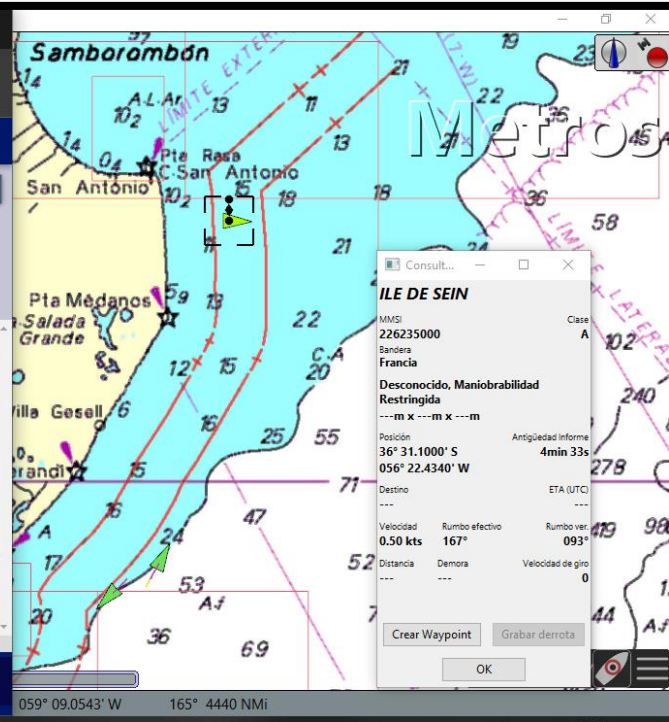
Ejemplo avanzado: Receptor AIS

Basado en Receptor RTL-SDR




OpenCPN 5.0.0+9065270
Canal 5
Villa Gesell
Laguna El Maestro
Mar Azul
Coronel Vidal
Calfucurá
Laguna Mar Chiquita
Vivorata
Arro. Vivorata
Fo Mar Chiquita
B Des (2)
Santa Clara del Mar
Camet
MAR DEL PLATA
C Corrientes
Fo Pta
Otamendi
Ruta: 78.6 NMi
Banco Pescadores
Pta San Andres
MIRAMAR
Fo Miramar
B Des Sg
Hermengo
Consult...
INTERLINK SOLIDITY V7GE2
MMSI 538005699
Clase A
IMO 09711779
Bandera Islas Marshall
Carguero, Navegando
180m x 32m x 10.0m
Posición 37° 38.6609' S 055° 59.9552' W
Antigüedad informe 56s
Destino MATARANI,PERU
ETA (UTC) ago 22 00:00
Velocidad 10.4 kts
Rumbo efectivo 201°
Rumbo ver. 199°
Distancia ---
Demora ---
Velocidad de giro 0
SOG --- kts
COG ---°
38° 03.1098' S 057° 34.2220' W
164°
Metros


MarineTraffic: Global Ship Tracki
https://www.marine...
facebook
YouTube
Outlook.com
MercadoLibre
Otros favoritos
Encuentre un Buque o Puerto
San Clemente del Tuyú
Gral. Lavalle
Las Toninas
Santa Teresita
Mar del Tuyú
ILE DE SEIN
Cable Layer
Añadir a la Flota
Datos del barco
AR MDQ
CABLE OPERATION
ATD: 2020-08-11 21:16
ETA: 2020-08-12 15:00
Recorrido efectuado
Previsión de Ruta
Estado:
Restricted Manoeuvrability
Velocidad/Rumbo:
1.1kn / 178°
Calado:
8.1m
Recibido: now (Origen AIS: 1385 AEROMARINE for DINARA)

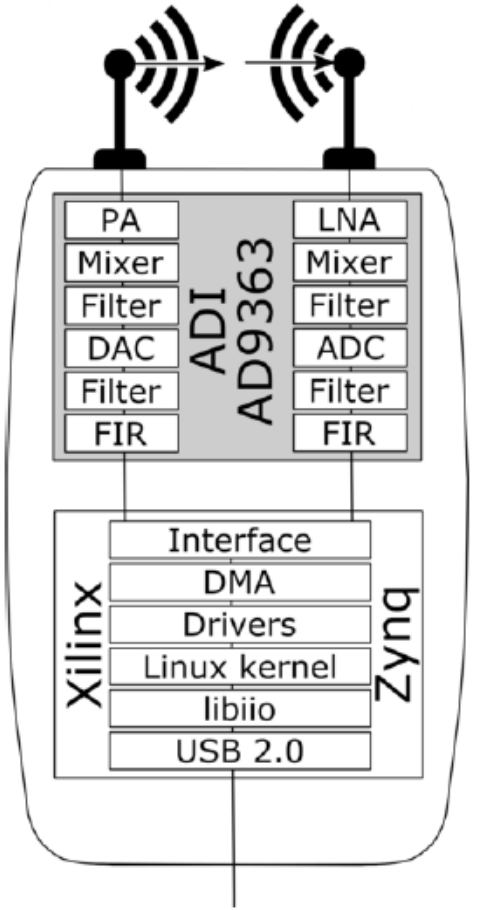

Samborombón
Pta Rasa
C San Antonio
San Antonio
Pta Medanos
Salada Grande
Villa Gesell
Consult...
ILE DE SEIN
MMSI 226235000
Clase A
Bandera Francia
Desconocido, Maniobrabilidad Restringida
---m x ---m x ---m
Posición 36° 31.1000' S 056° 22.4340' W
Antigüedad informe 4min 33s
Destino ---
ETA (UTC) ---
Velocidad 0.50 kts
Rumbo efectivo 167°
Rumbo ver. 093°
Distancia ---
Demora ---
Velocidad de giro 0
Crear Waypoint
Grabar derrota
OK
059° 09.0543' W
165° 4440 NMi
Metros

ADALM PLUTO

- **Full duplex / Half duplex.**
- **325MHz - 3,8GHz (extendible a 60MHz - 6GHz)**
- **ADC/DAC Sample Rate 65.2 kSPS to 61.44 MSPS**
- **ADC/DAC Resolution 12 bits**
- **Frequency Accuracy ±25 ppm**
- **RBW= máximo 20MHz (puede estar limitado a máx 5MHz).**
- **Impedancia de entrada de 50 Ohms.**

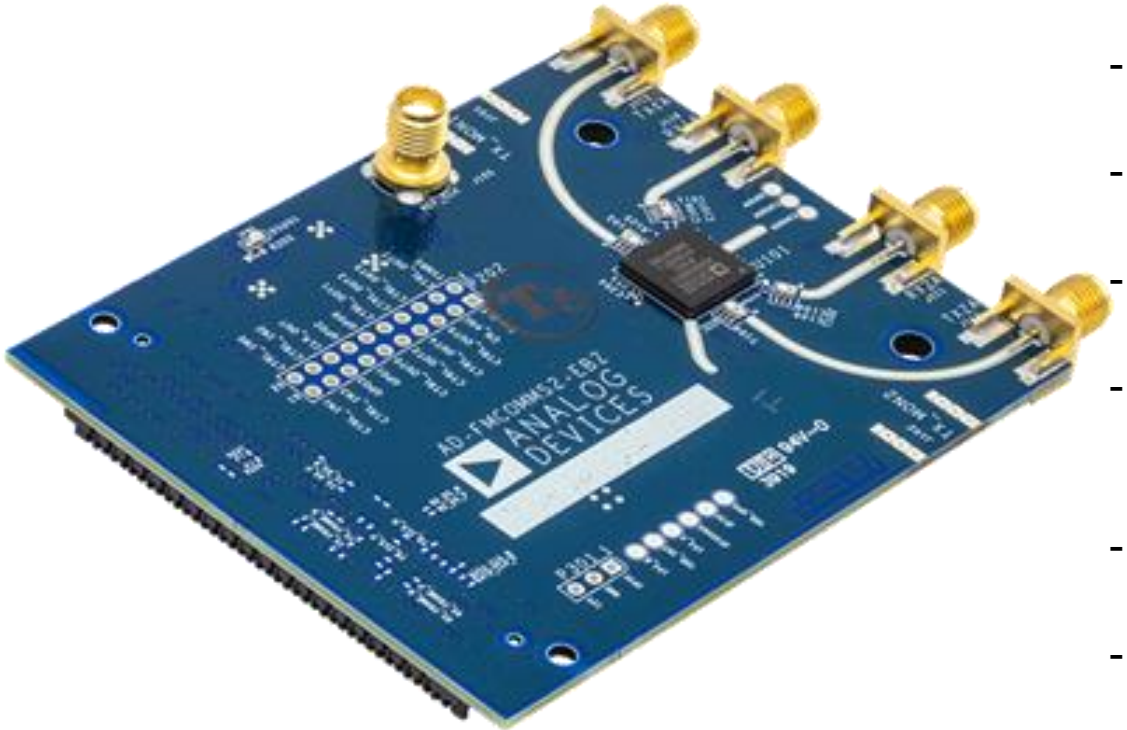
https://media.digikey.com/pdf/Data%20Sheets/Analog%20Devices%20PDFs/ADALM-PLUTO_Prod_Highlight.pdf

ADALM PLUTO



- Runs Linux inside the device
- Uses Linux's IIO framework to expose I/Q data and control
- Multi-Function Device
  - Native IIO over USB
  - Serial over USB
  - Ethernet over USB
  - Mass Storage
  - Device Firmware Update
- Host
  - USB dongles

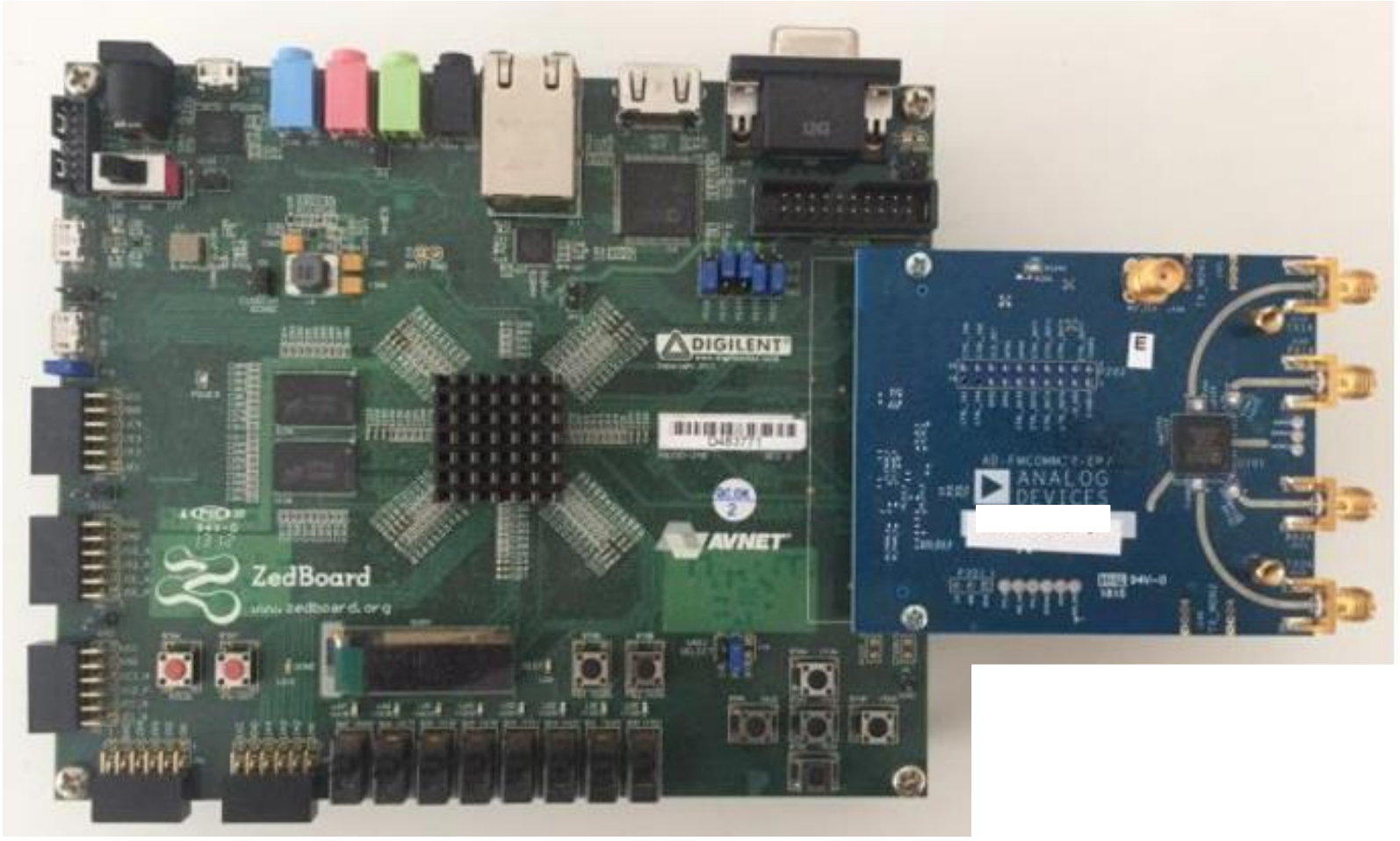
FSCOMMS4



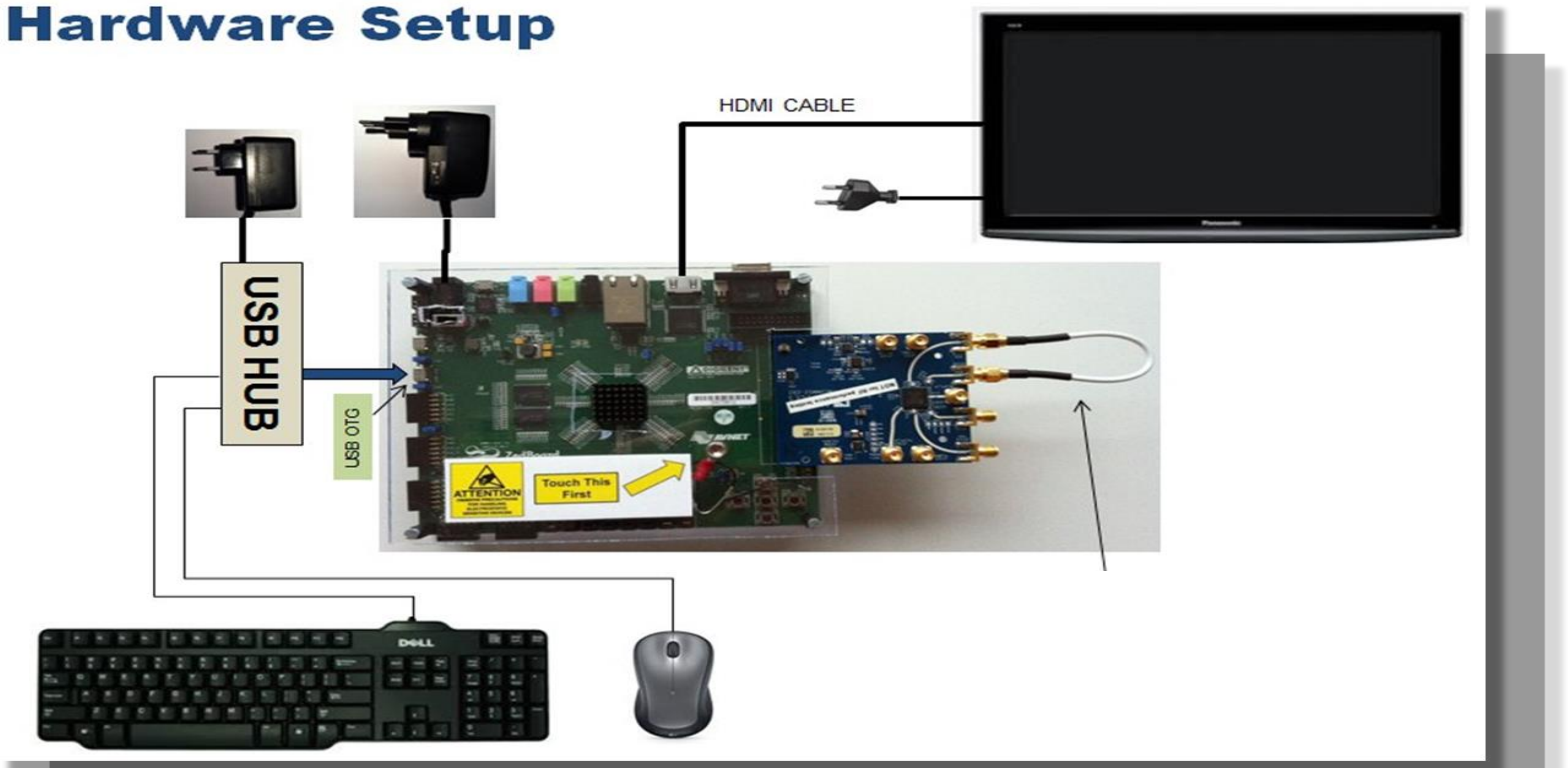
- **Dos salidas y dos entradas full duplex**
- Rango de operación: 70 MHz – 6,0 GHz)
- **RBW=** <200 kHz to 56 MHz
- **12 bits de resolución**
- **Superior receiver sensitivity with a noise figure < 2.5 dB**
- **RX gain control**
- **Real-time monitor and control signals for manual gain**
- **Independent automatic gain control**

https://www.analog.com/en/products/ad9364.html#product-overview

FSCOMMS2 + Zedboard



Plataforma SDR: Xilinx Zedboard + Analog Devices FSCOMMS4 (60MHz - 6GHz)



RTL2832U

- **Solo recepción.**
- **Rango de operación: 35MHz - 1,8GHz**
- **RBW=**
- **8 bits de resolución**

- Encapsulado de aluminio (disipador pasivo)

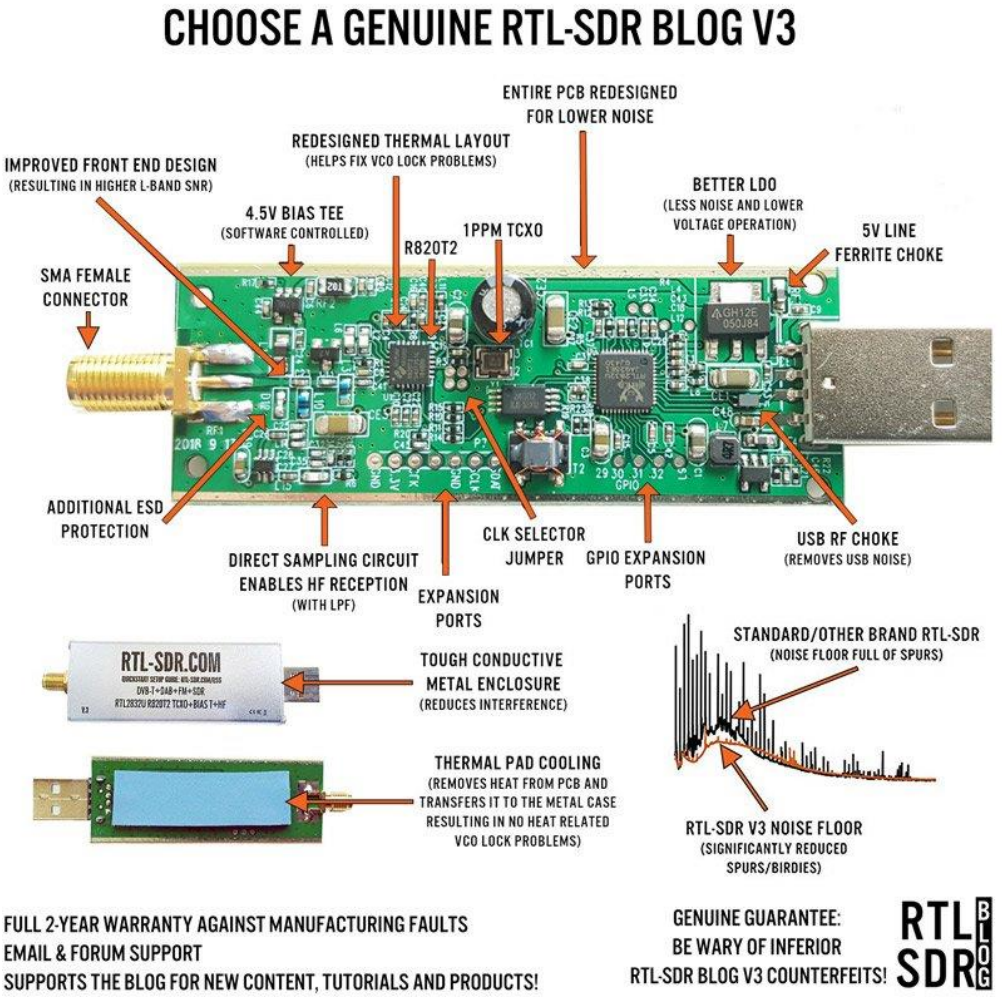
- Disponible con impedancia de entrada de 50 Ohms y de 75 Ohms.

- <1 PPM temperature compensated oscillator (TCX)

https://www.rtl-sdr.com/

RTL2832U

https://www.rtl-sdr.com/



Original RTL-SDR Blog V3
-Rounded enclosure
-Full website URL written on body
-Two diagonally offset screws on each side
-Newer units have logo on the back
-Green PCB with thermal pad on bottom
-NSY production QC sticker on back
-Newer units say R860 instead of R820T

Fake RTL-SDR Blog V3 Clones:
-Flat enclosure
-May say “RTL.SDR”, “RTL-SDR V3 Pro”, or be unmarked
-Four screws per side panel
-May not have bias tee, HF or TCXO features despite advertising
-No SMA nut, or nut without washer
-PCB sits loosely inside enclosure
-May have significantly more spurs + noise
-No logo on the back
-Yellow double stacked PCB, or blue PCB
-May not have thermal pad
-Signals may be distorted with mysterious high pitched whine in the audio spectrum

Clone sellers may also use images of the original
Please try to order from repurable sellers if not ordering directly from our stores.

New Sophisticated Fake V3 Clones
-Looks exactly like an original V3 except for minor differences
-Side panel screws are not diagonally offet
-No NSY QC sticker
-Listings may use our original graphics

https://www.rtl-sdr.com/

Hack RF ONE

- 1 MHz to 6 GHz operating frequency

- Half-duplex transceiver

- Up to 20 million samples per second

- 8-bit quadrature samples (8-bit I and 8-bit Q)

- SMA female antenna connector

- SMA female clock input and output for synchronization

Especificaciones relevantes

- Frecuencia mínima y máxima de operación.
- Solo recepción, half- duplex o full-duplex.
- Ancho de banda de tiempo real (RBW).
- Candidad de bits ADC/DAC.
- Conectores de entrada y salida de RF.
- Encapsulado.