Software Defined Radio in Ham Radio

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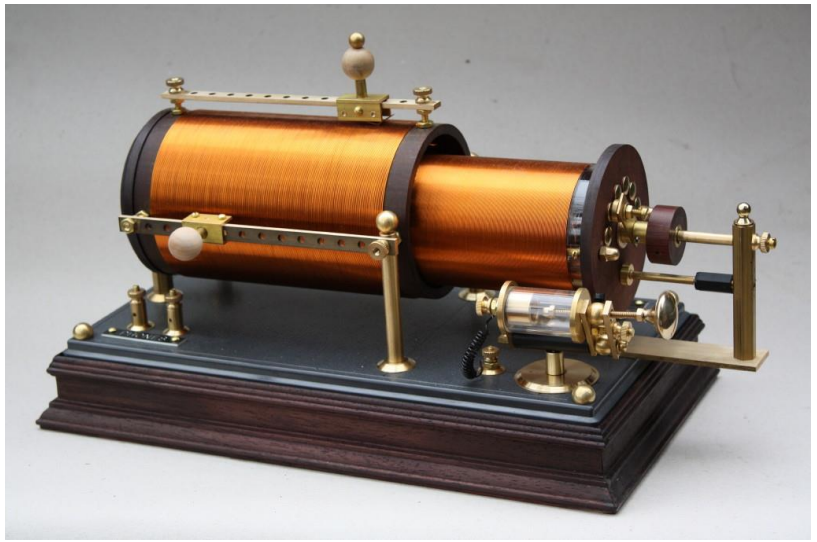
K3TU

SDR in HR

The *crystal radio* was once a simple introduction to radio electronics and Amateur Radio.



SDR in HR

The next early step was the simple transistor AM/FM broadcast band radio.

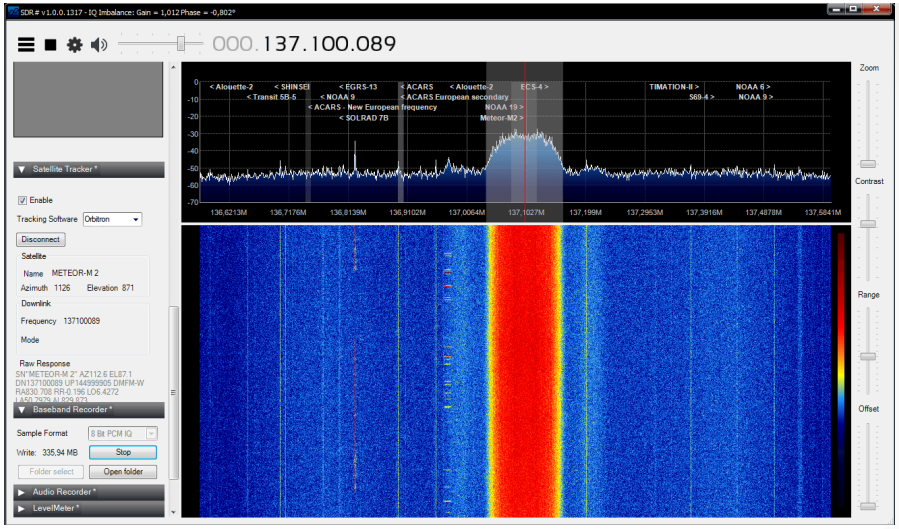
SDR in HR

Nowadays it seems that mobile robots and quadcopters are all the rage but they don't do much for *wireless technology* and HR.

SDR in HR

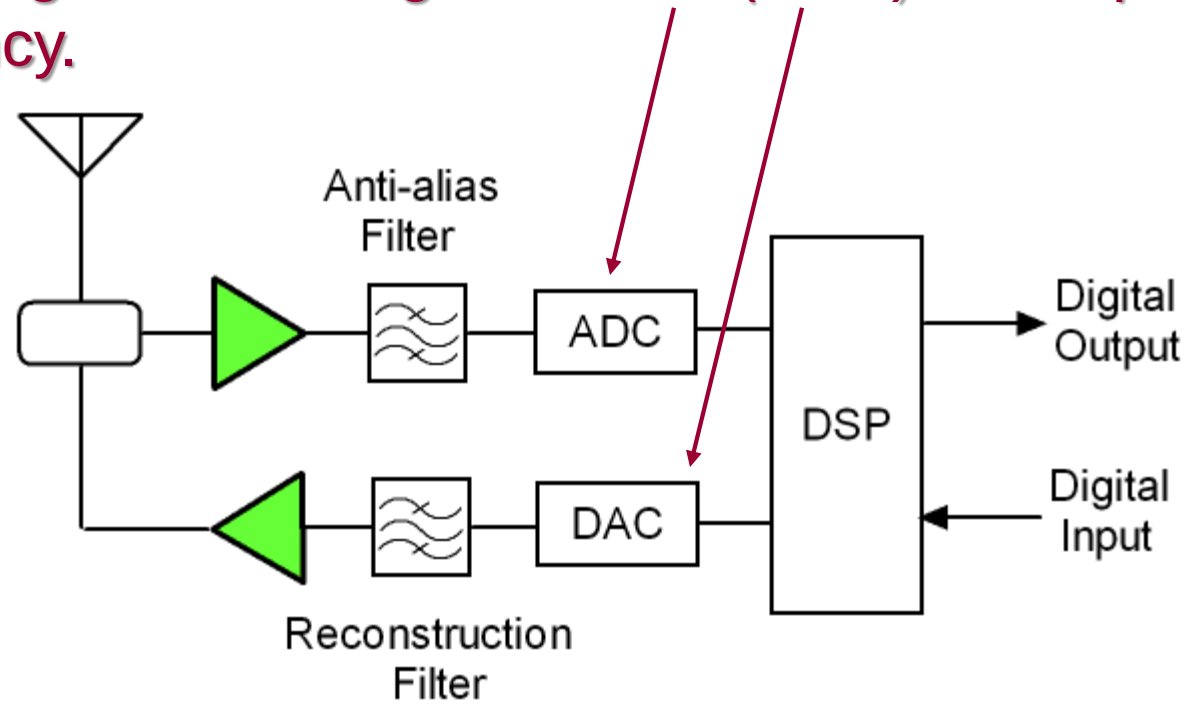
What is SDR?

Radio components that have been typically implemented in *hardware* (mixers, filters, amplifiers, modulators, demodulators, and detectors) are instead implemented in *software*.



SDR in HR

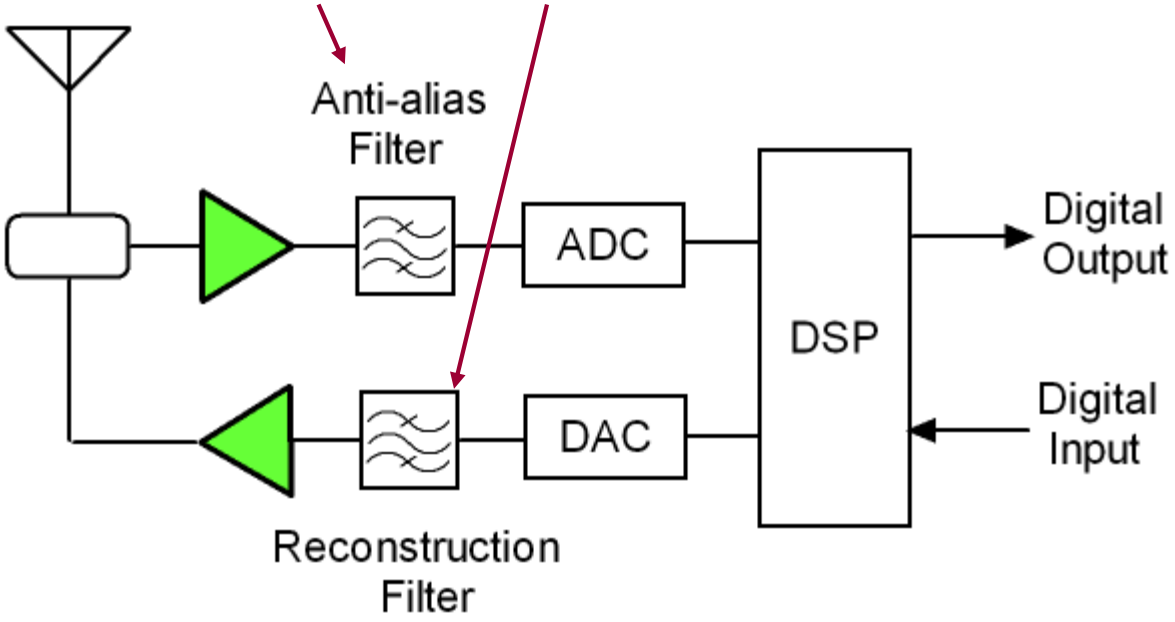
The ideal SDR would have a high speed (and expensive) analog-to-digital converter (ADC) for input and a high speed digital-to-analog converter (DAC) for output at RF frequency.



Ideal SDR Receiver and Transmitter

SDR in HR

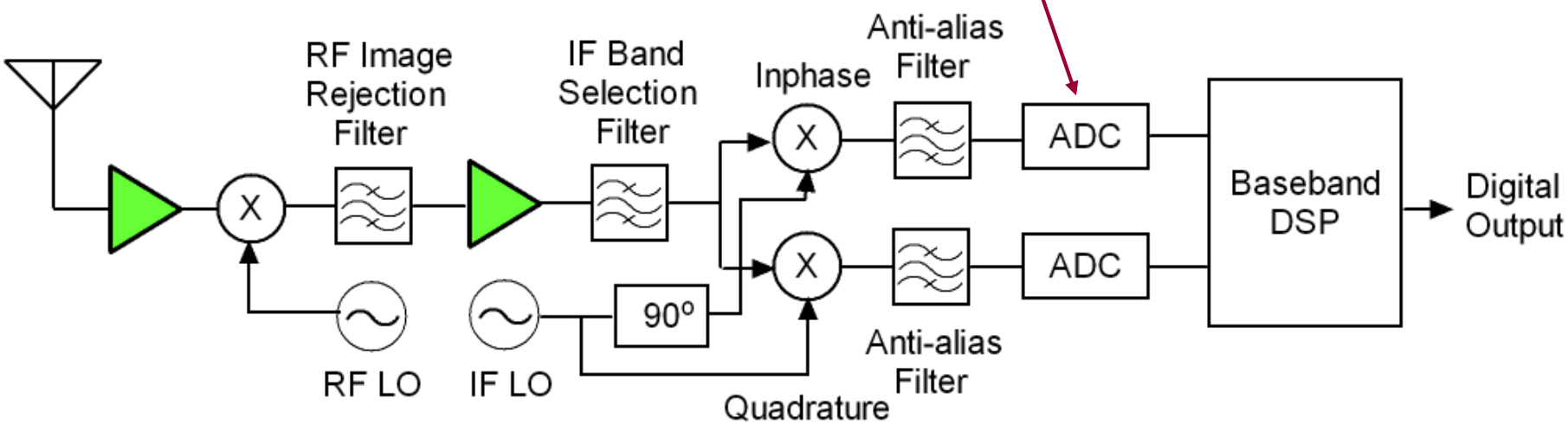
The anti-alias filter insures that unwanted signals which can caused interference are not processed by the SDR. The reconstruction filter smooths the output of the DAC and attenuates unwanted harmonics in the transmitted signal.



Ideal SDR Receiver and Transmitter

SDR in HR

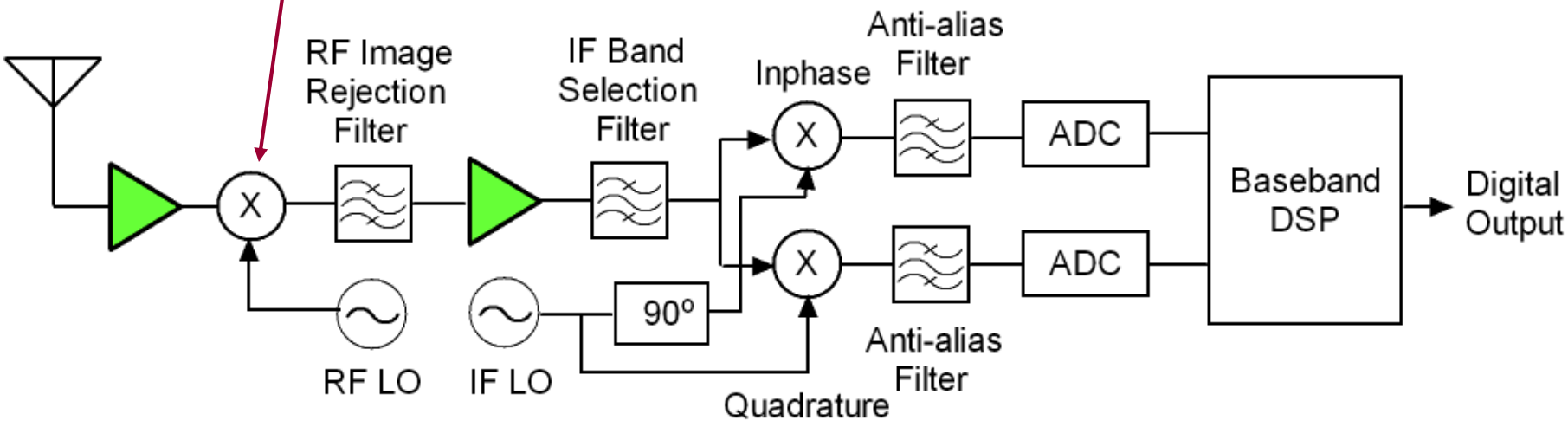
However, the first generation SDR receiver, circa mid-1990s, put the ADC far down the RF stages, essentially at *baseband* (low frequencies) and was less expensive.



First Generation SDR Receiver

SDR in HR

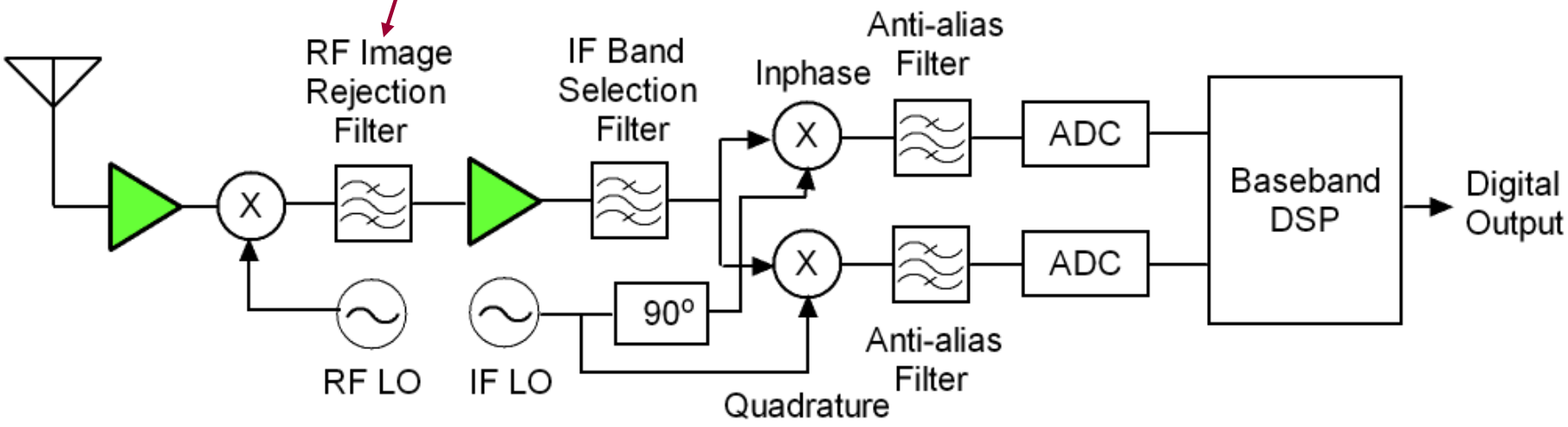
The first generation SDR receiver down-converted the RF signal to an IF with an RF LO. The multiplication in the mixer of the RF signal f_{RF} and the RF LO signal $f_{RF\ LO}$, results in the sum $f_{RF} + f_{RF\ LO}$ and difference $f_{RF} - f_{RF\ LO}$.



First Generation SDR Receiver

SDR in HR

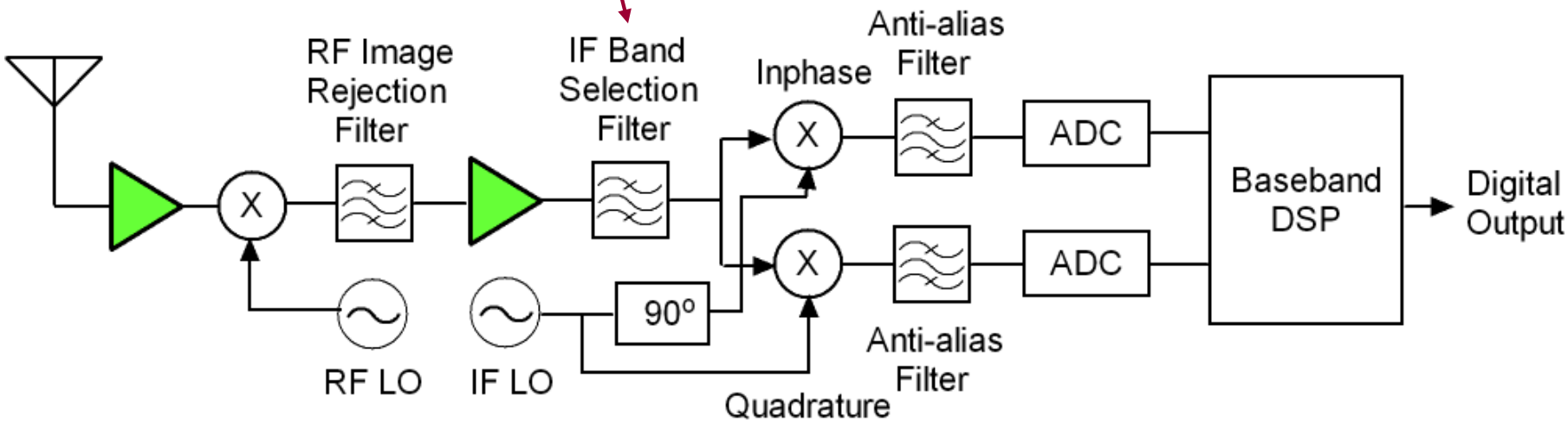
The RF image rejection analog filter passes $f_{RF} - f_{RF\ LO}$ or the IF signal f_{IF} and attenuates the high frequency image at $f_{RF} + f_{RF\ LO}$.



First Generation SDR Receiver

SDR in HR

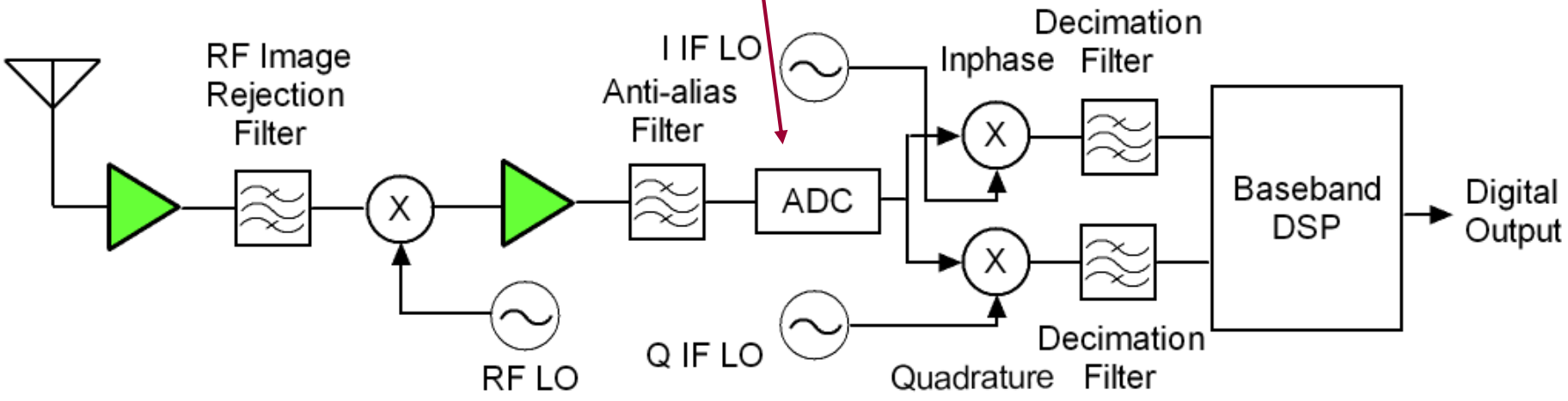
The IF band selection analog filter limits the bandwidth of the IF signal to the frequency range $f_{IF} + f_{data}$. The IF signal f_{IF} is then down converted to an inphase (I) and quadrature (Q) signal. The ADC sampling rate here is ~5 MHz.



First Generation SDR Receiver

SDR in HR

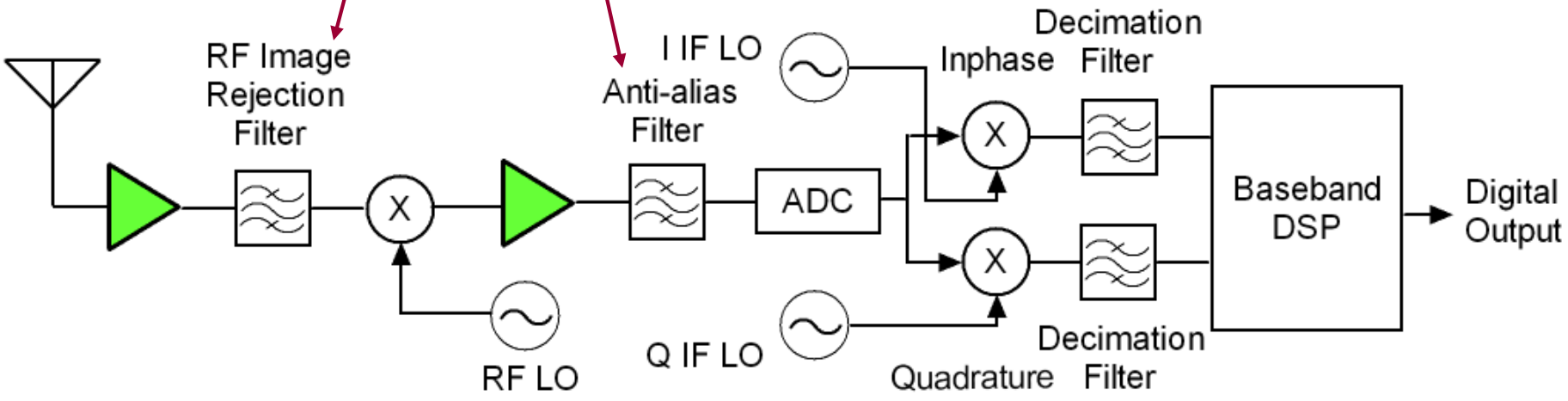
The second generation SDR receiver, circa the 2000s, put a faster ADC further up the RF stages for digital filtering at baseband.



Second Generation SDR Receiver

SDR in HR

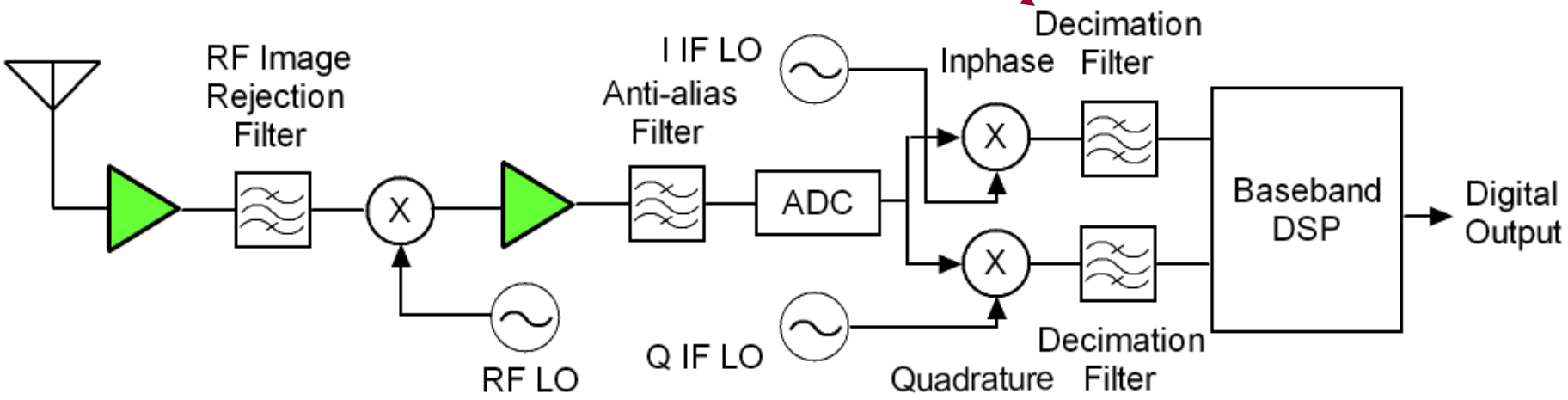
The RF image rejection analog filter now passes $f_{RF} - f_{data}$ and precedes the mixer stage using the RF LO signal $f_{RF\ LO}$. An anti-alias analog filter replaces the IF band selection filter before the ADC.



Second Generation SDR Receiver

SDR in HR

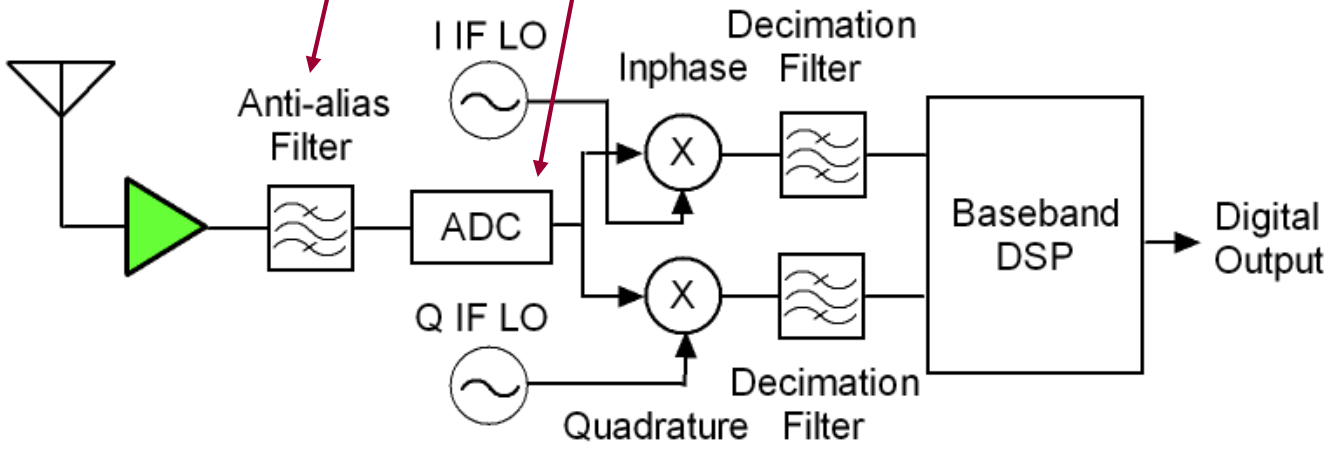
The decimation digital filter reduces the sampling rate of the sampled signal after the ADC and facilitates the use of a digital downconverter (DDC). The ADC sampling rate here is < 100 MHz.



Second Generation SDR Receiver

SDR in HR

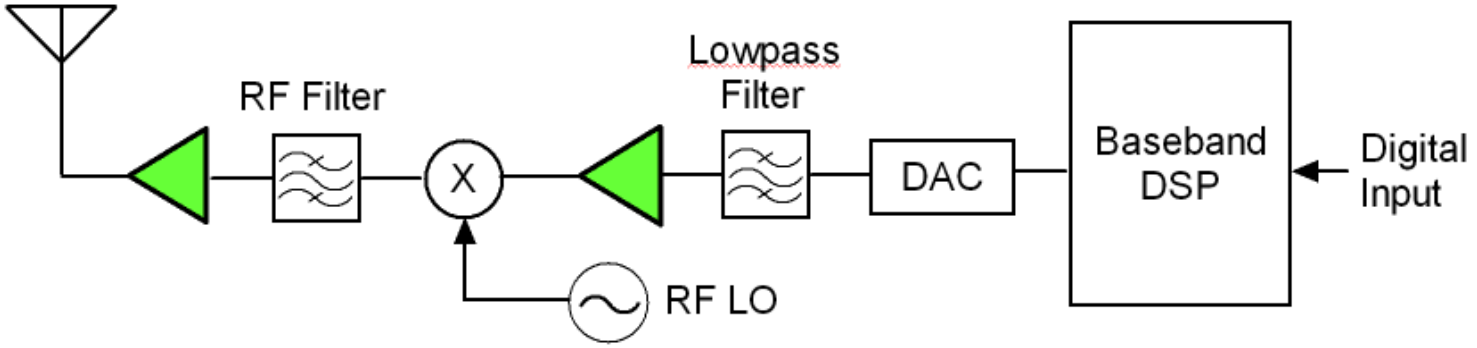
The third generation SDR receiver will be the ideal architecture. The anti-aliasing analog filter now attenuates signals beyond twice the sampling frequency and the ADC converter now samples data at a very high speed.



Third Generation SDR Receiver

SDR in HR

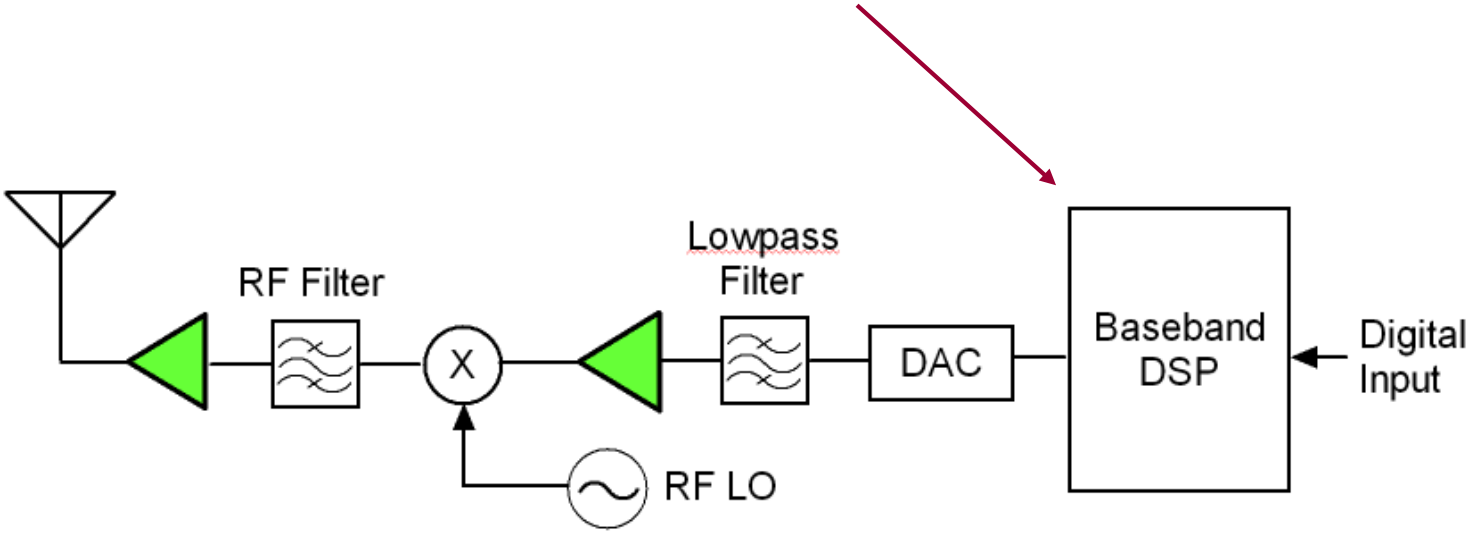
The generations of the SDR transmitter follow a similar development for the placement of DAC from the digital input and the configuration of the various analog filters and local oscillators.



Second Generation SDR Transmitter

SDR in HR

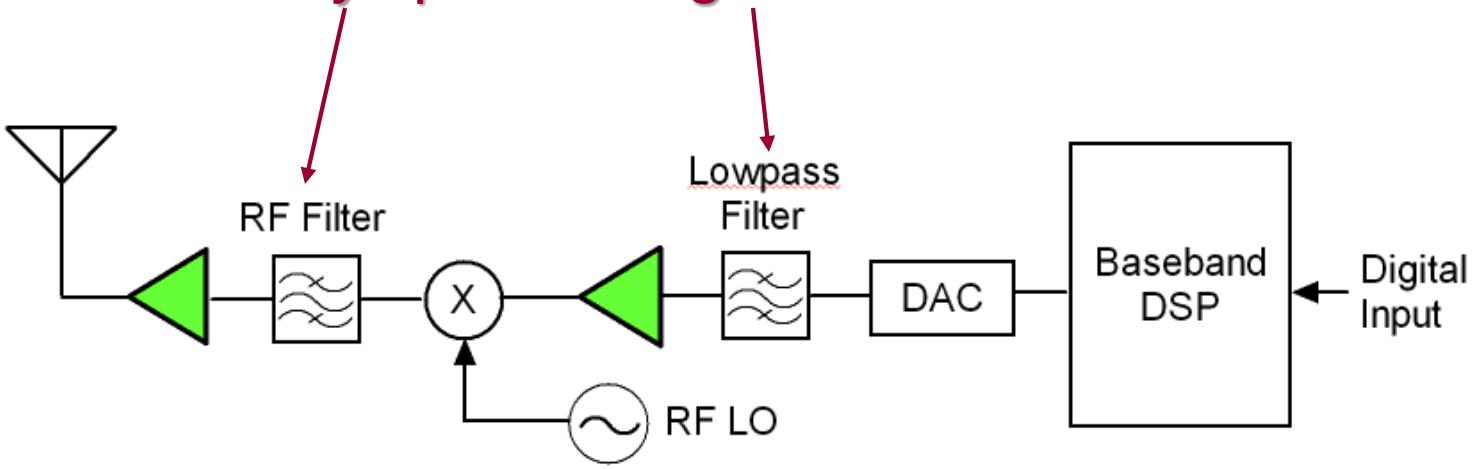
In the current second generation SDR transmitter a digital upconverter (DUC) converts the baseband signal to a modulated IF signal f_{IF} directly.



Second Generation SDR Transmitter

SDR in HR

The lowpass analog filter smooths the output of the DAC. The RF LO signal $f_{RF\,LO}$ and mixer outputs the transmitted signal $f_{RF\,LO} + f_{IF}$ and the RF analog filter attenuates any spurious signals.



Second Generation SDR Transmitter

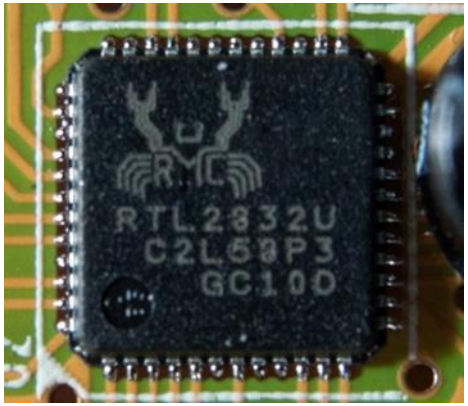
SDR in HR: Rx Only

The *receive only* SDRs are usually the least expensive but are very useful for HR.

SDR in HR: Rx Only

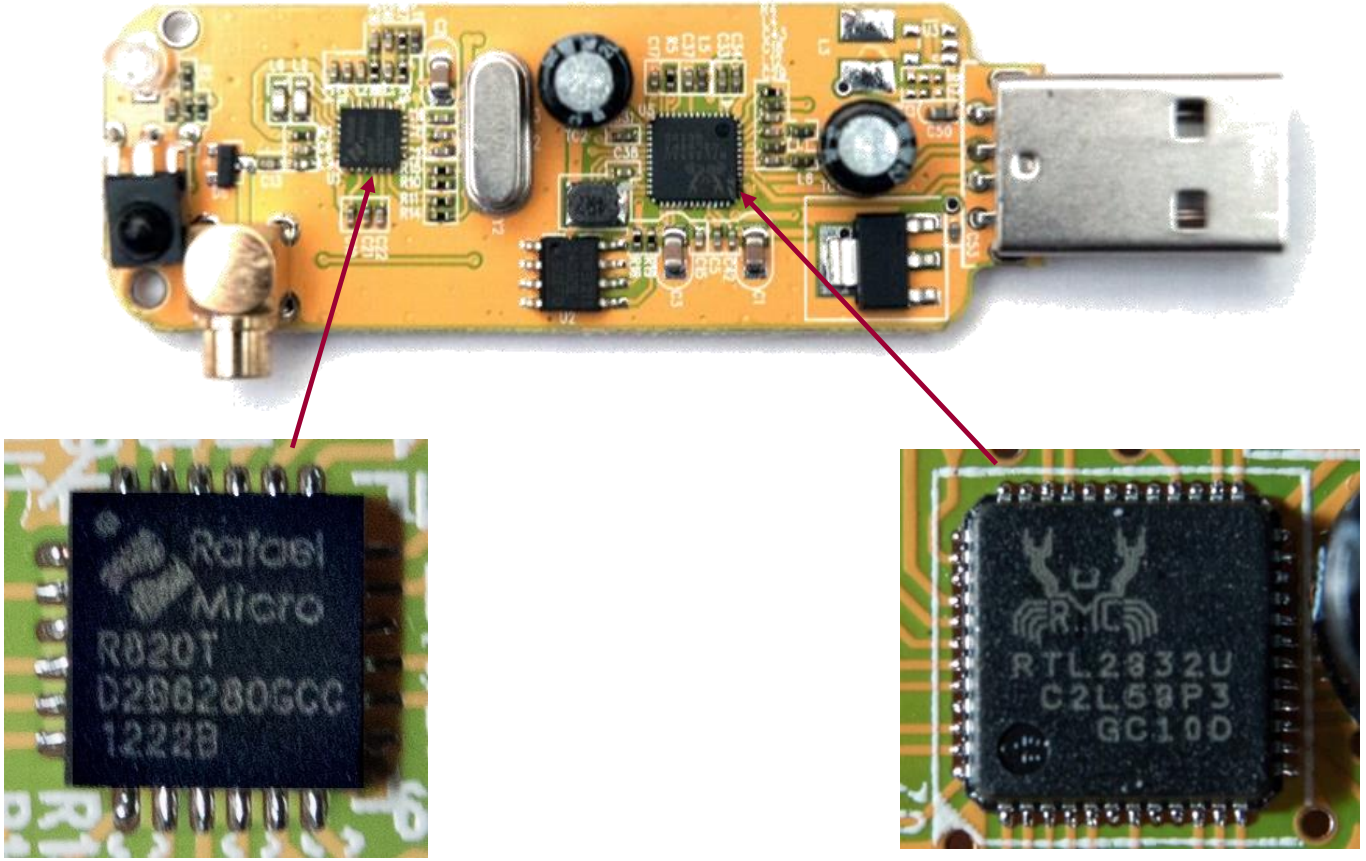
The ubiquitous RTL SDR and inexpensive (~$20) uses an RF tuner and receiver originally intended for decoding European HDTV broadcasts.

Host access to the raw data stream produced rapid development starting in 2010. Currently there are over 20 variants but all are based on the *Realtek RTL2832U* RF receiver.



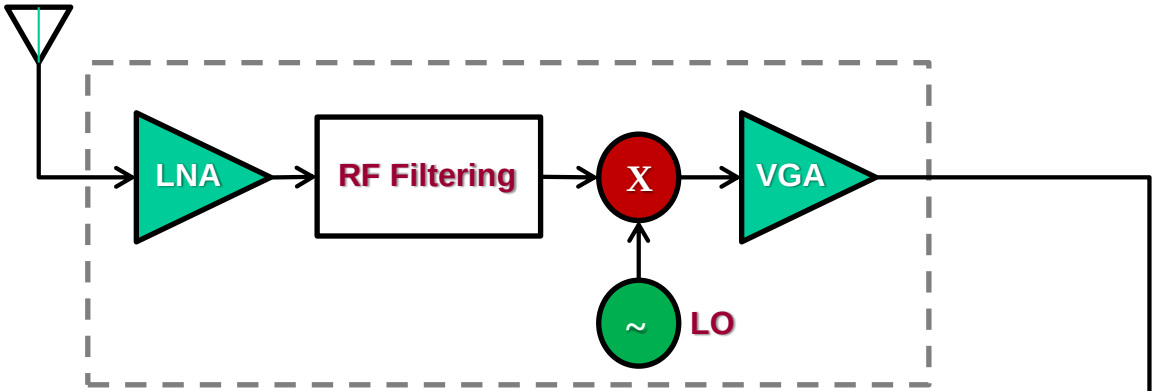
SDR in HR: Rx Only

Several different RF tuners can be use but the Rafael Micro 820T is the most common and versatile.

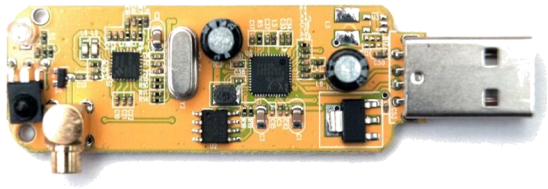


SDR in HR: Rx Only

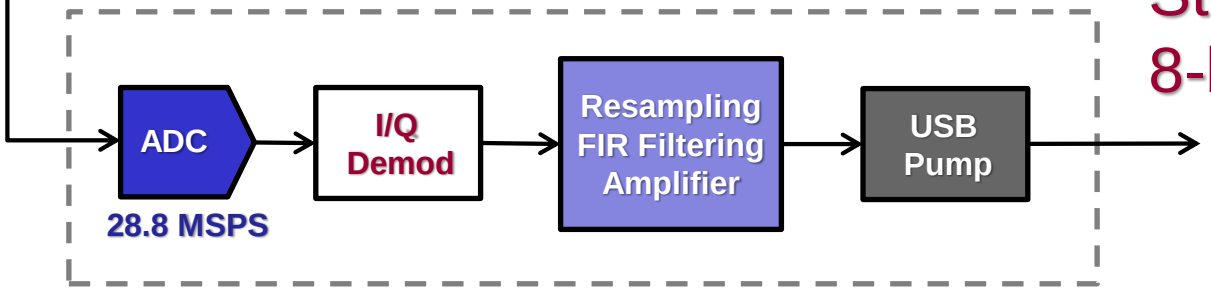
Block Diagram of an SDR *RTL USB Dongle*



Rafael Micro R820T



IF: 3.57 MHz
BW: ~6 MHz

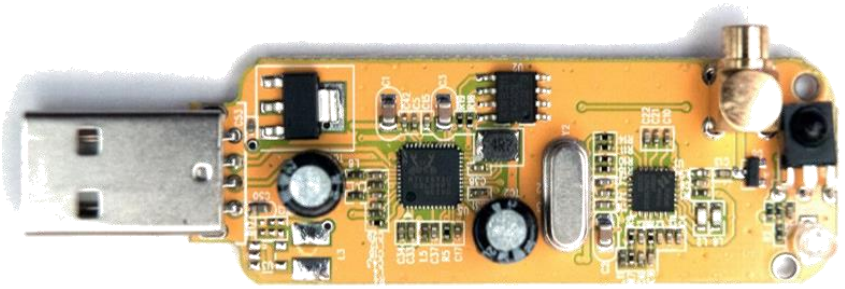


USB Data Stream 8-bit I/Q

Realtek RTL2832U

SDR in HR: Rx Only

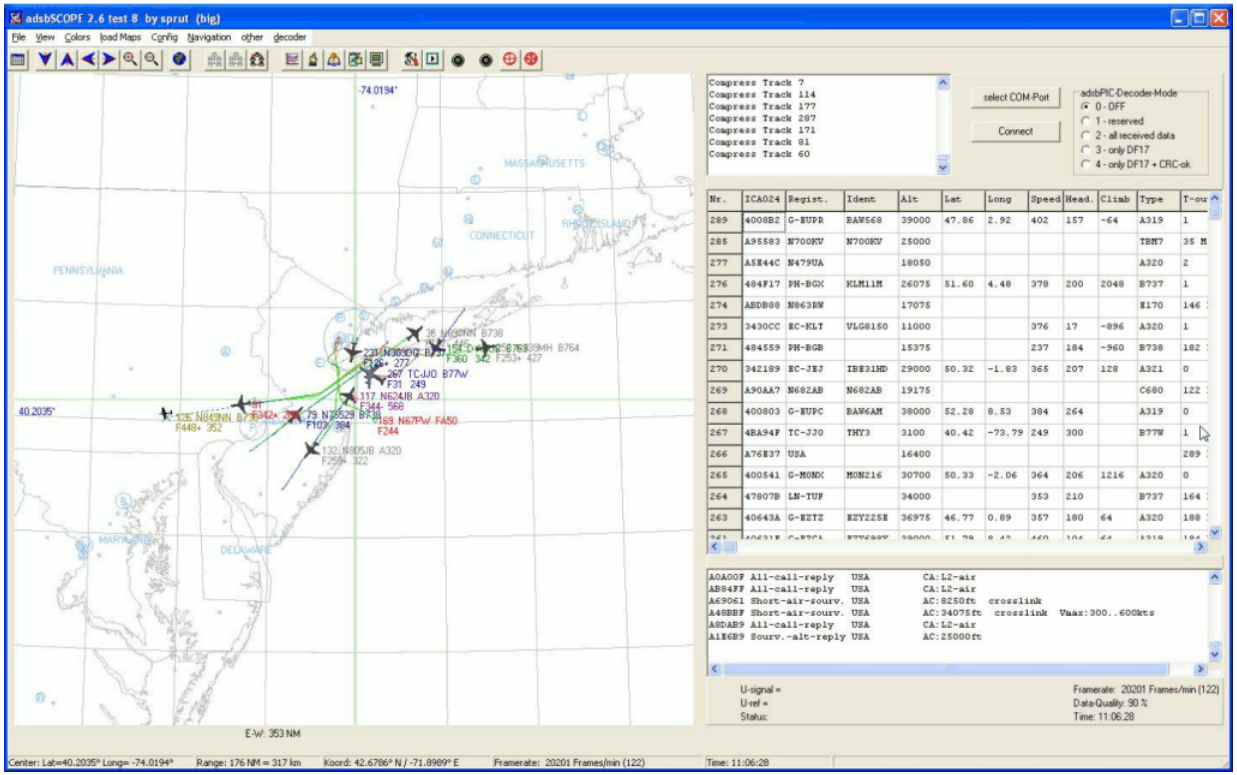
SDR RTL USB dongle specifications:



Specification	
Frequency range	24 MHz – 1766 MHz (R820T Tuner)
Noise figure	3.5 dB (R820T Tuner)
Gain Settings	0dB – 49.6dB (manual or AGC)
ADC Resolution	8-bit
Host Sample Rate*	Low speed: 225.001 to 300 kHz High speed: 900.001 kHz to 3.2 MHz
Maximum Bandwidth*	3.2 MHz
Data Interface	USB 2.0

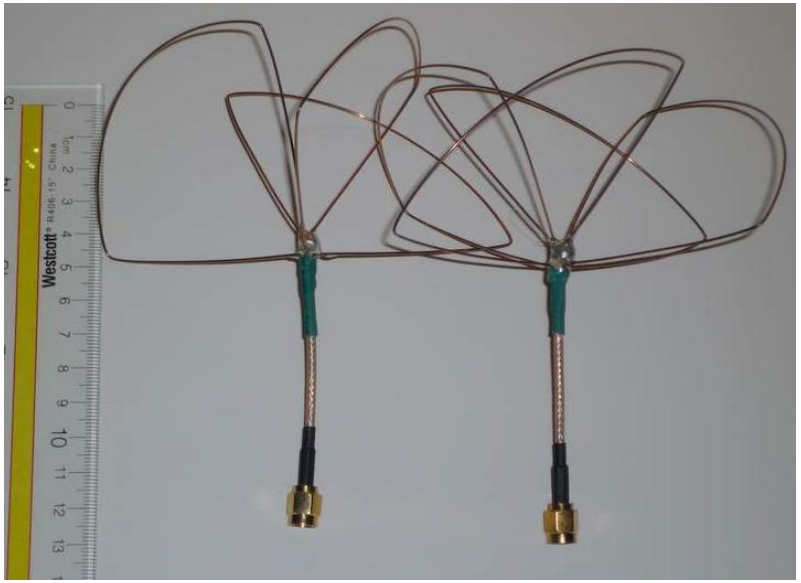
SDR in HR: Rx Only

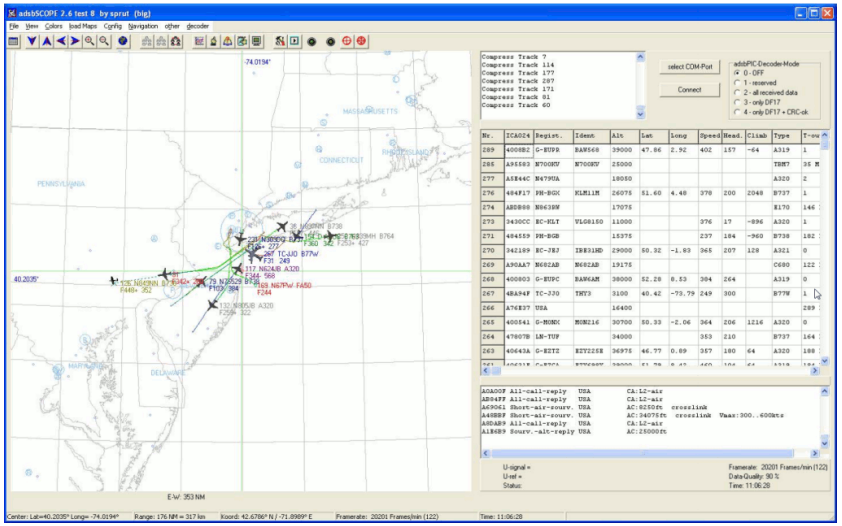
SDR RTL USB dongle applications: Tracking aircraft using the *Automatic Dependent Surveillance-Broadcast* (ADS-B) Mode-S transponder broadcasting location and altitude information to air traffic controllers at 1.09 GHz with freeware software.



SDR in HR: Rx Only

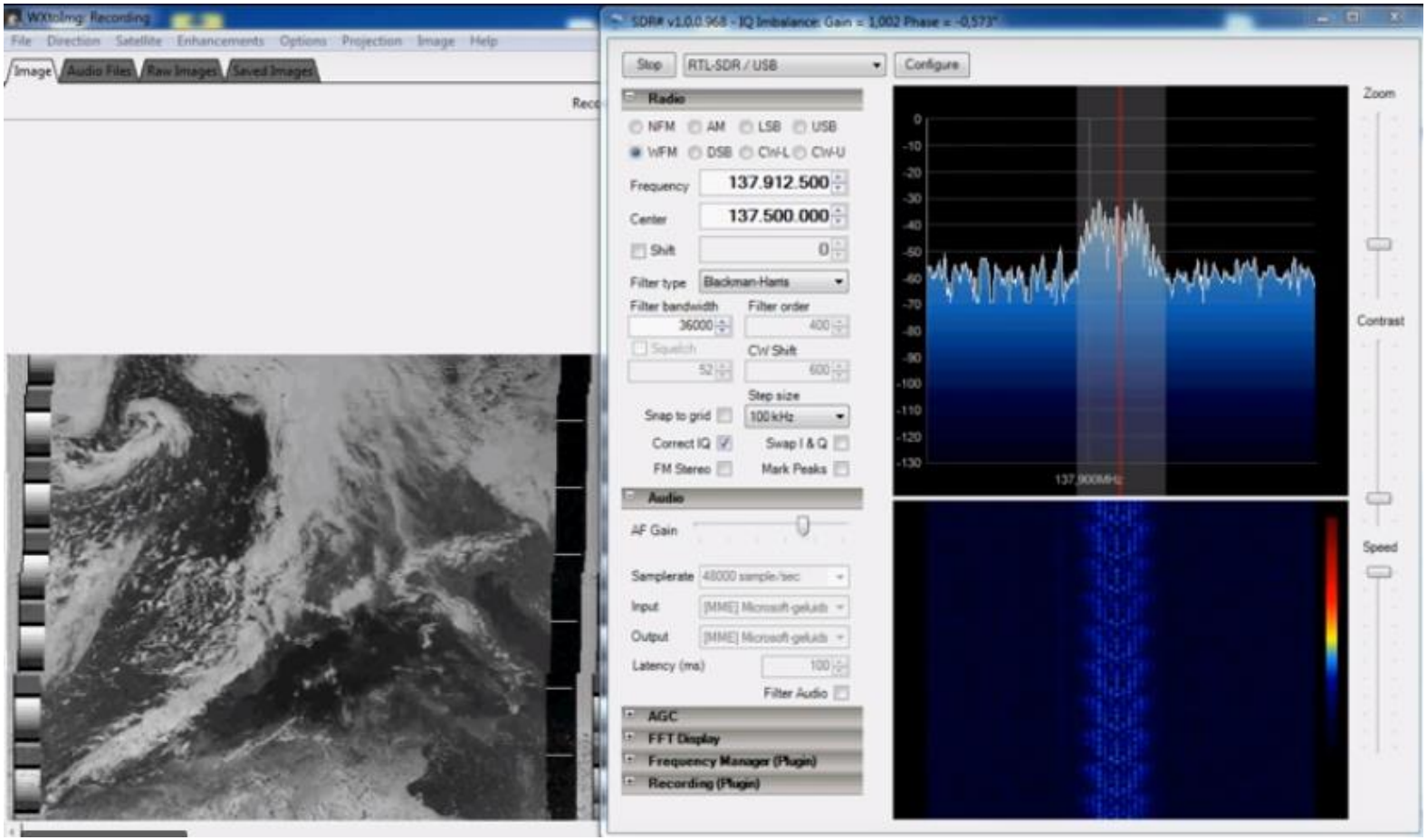
SDR applications: The antenna for the ADS-B Mode-S transponder at 1.09 GHz can even be a *homebrew.*





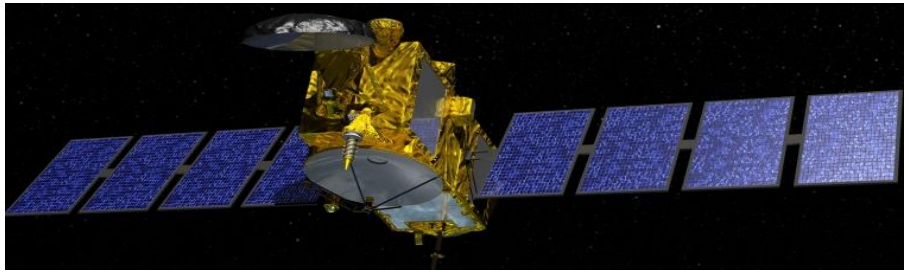
SDR in HR: Rx Only

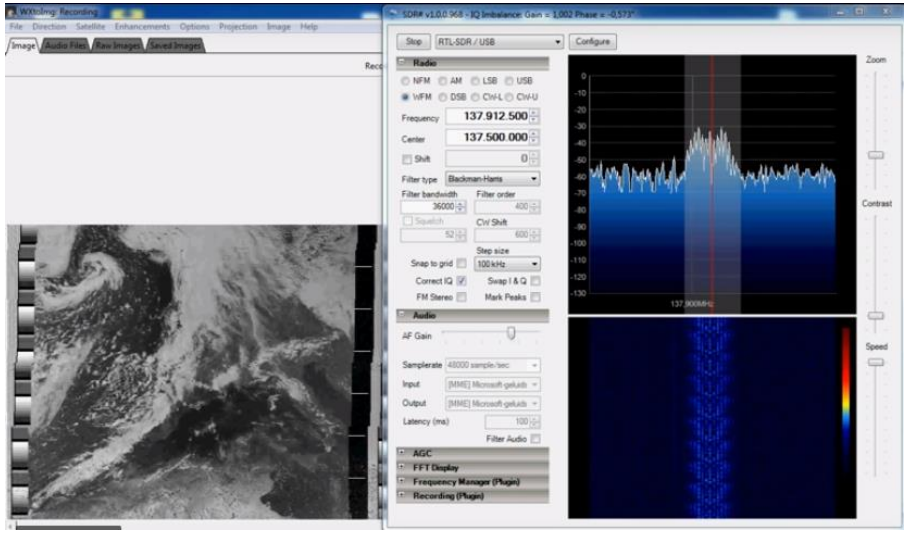
SDR RTL USB Dongle applications: NOAA weather satellite images at 137 MHz.

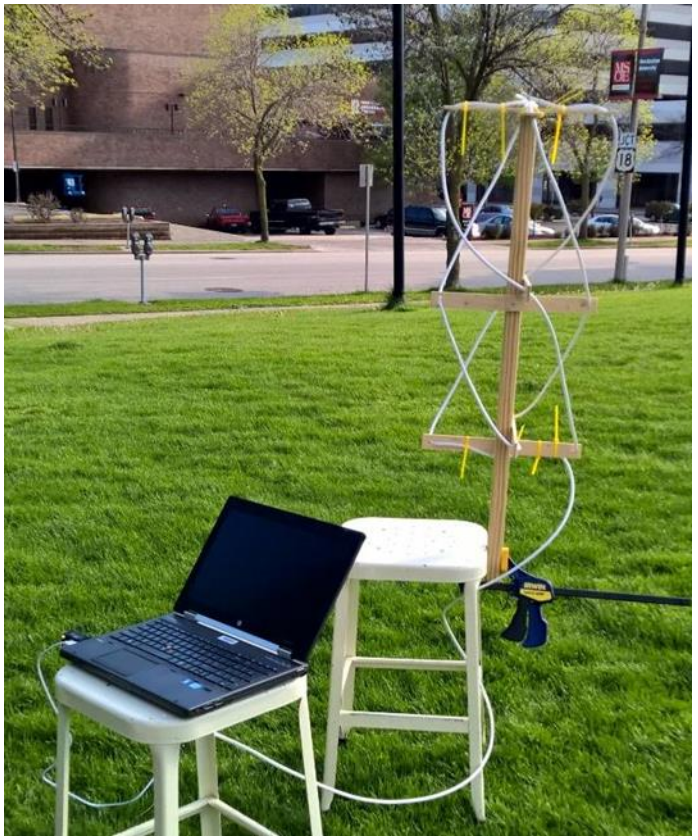


SDR in HR: Rx Only

SDR applications: The antenna for NOAA weather satellite images at 137 MHz can also be a *homebrew* quadrifilar helix antenna.

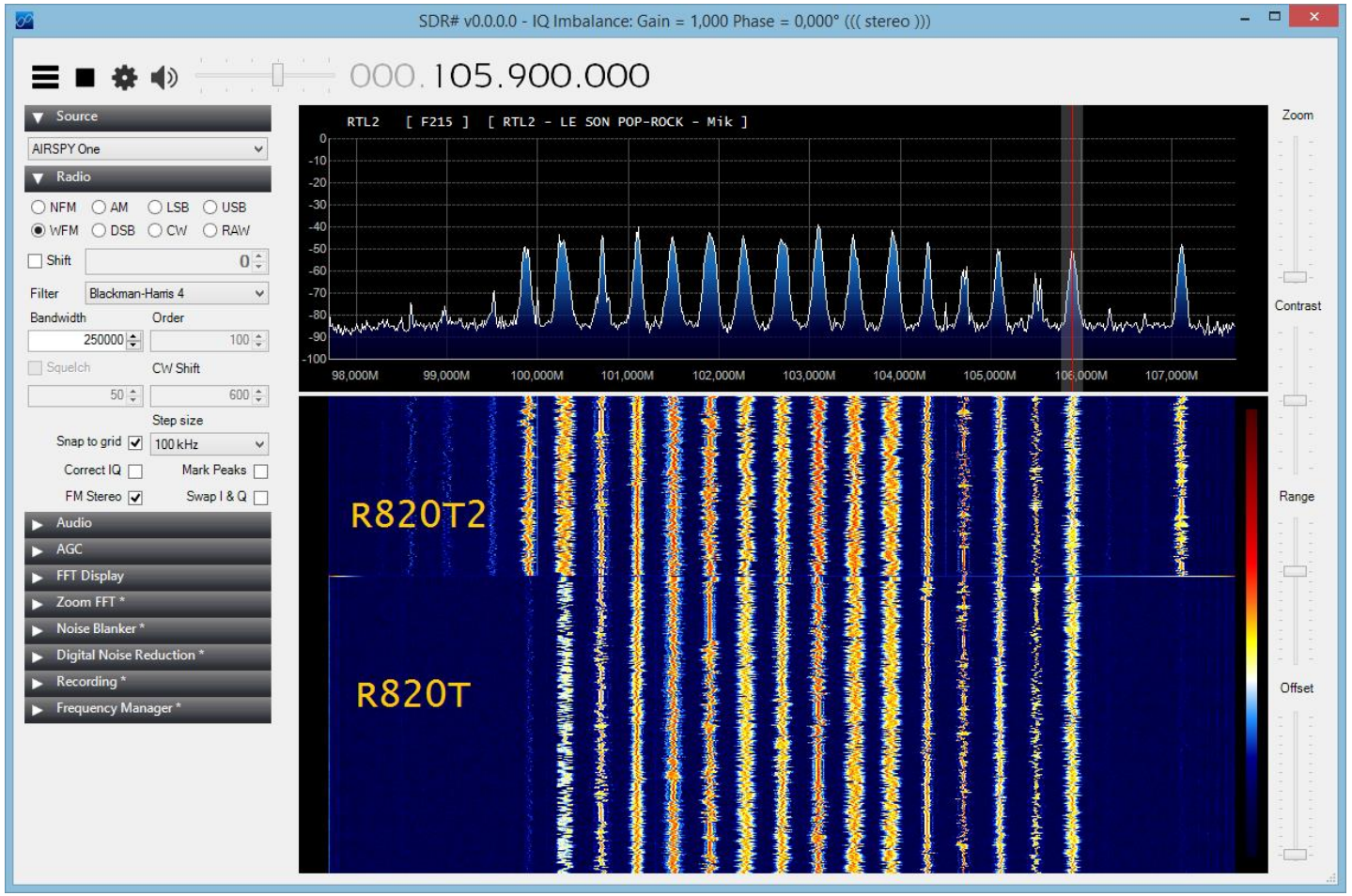






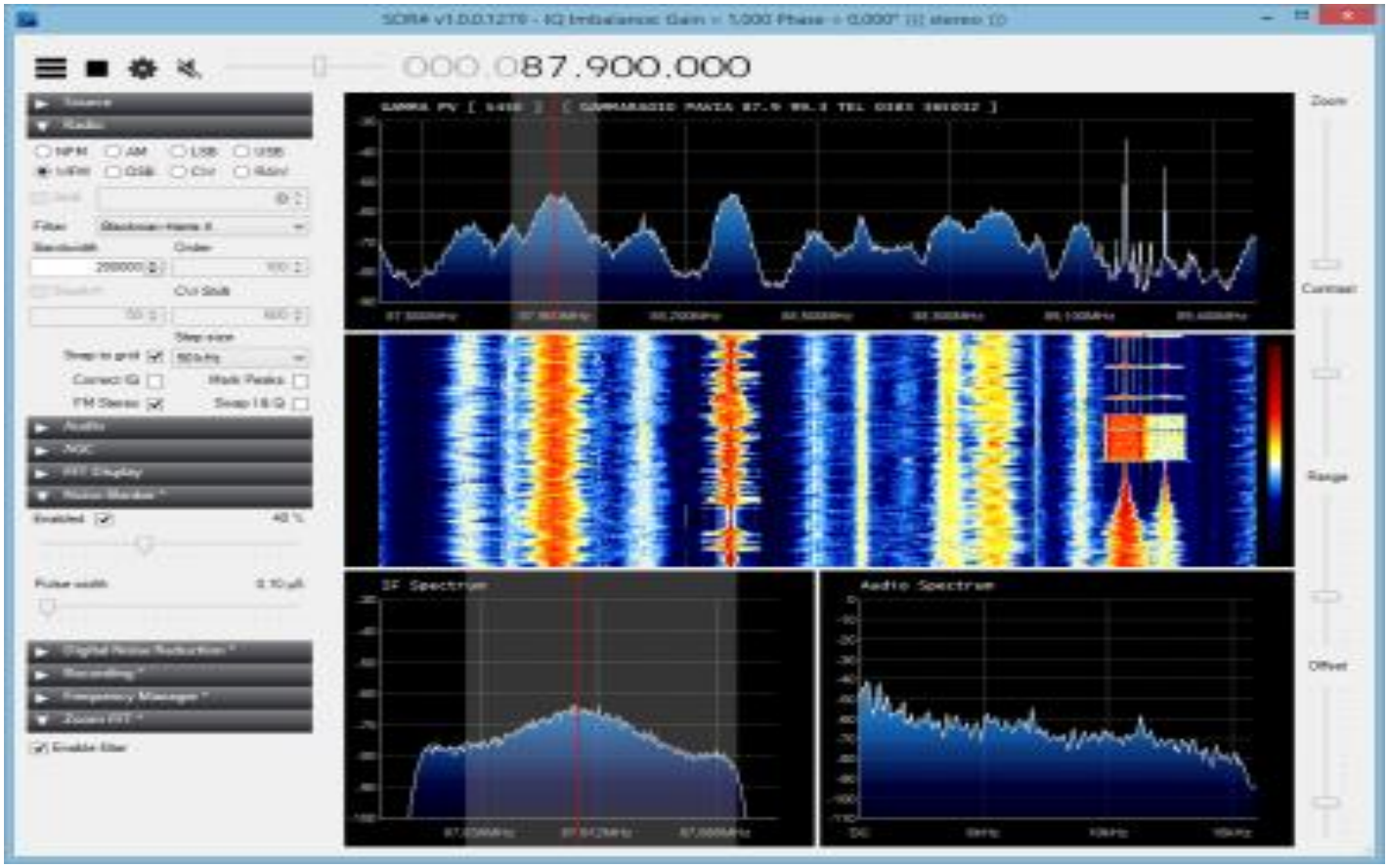
SDR in HR: Rx Only

SDR RTL USB dongle applications: analog FM broadcast reception



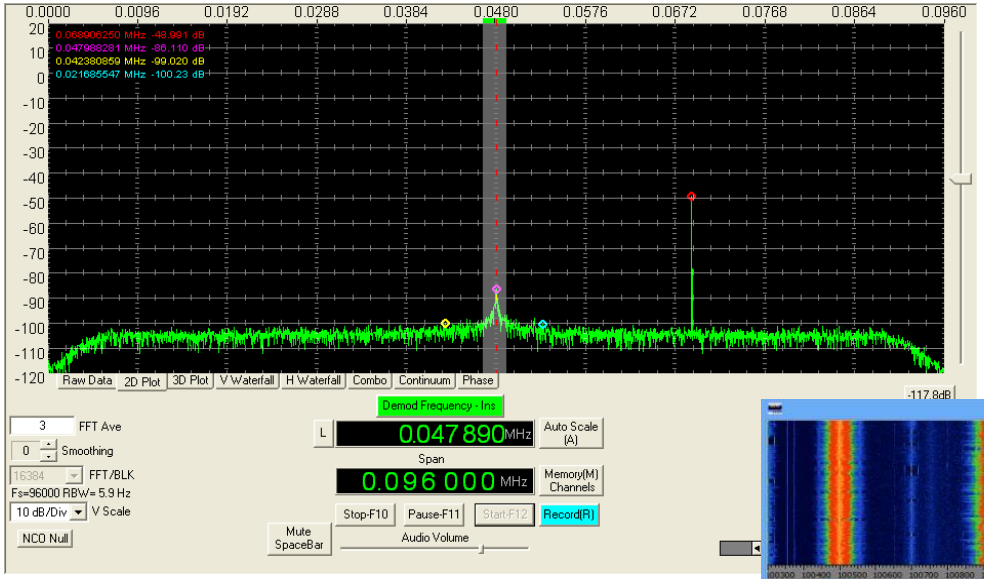
SDR in HR: Rx Only

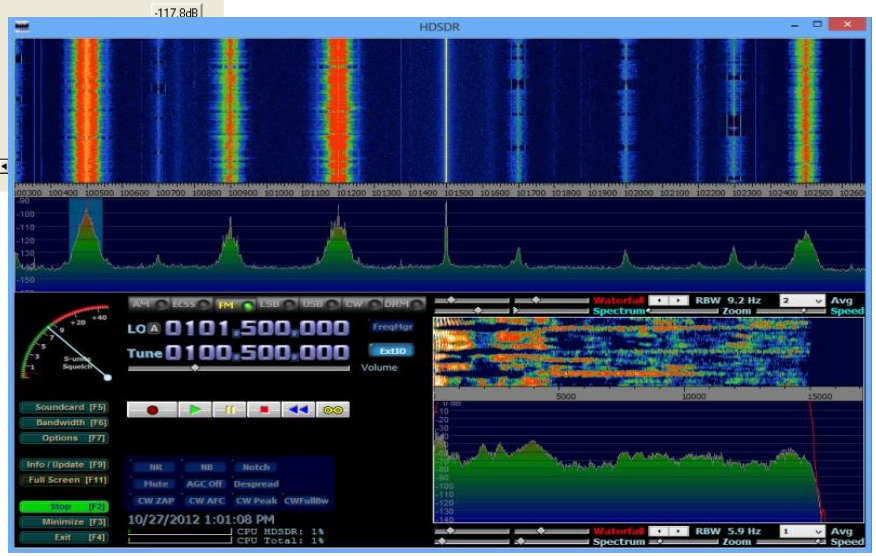
There are several freeware demodulation software for the SDR RTL USB dongle. SDR# is popular.



SDR in HR: Rx Only

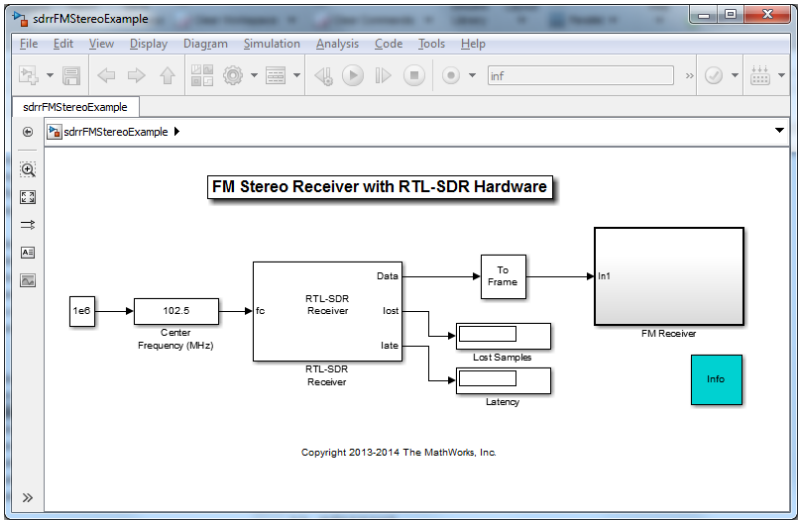
Other SDR freeware demodulation software include Spectravue and HDSDR.

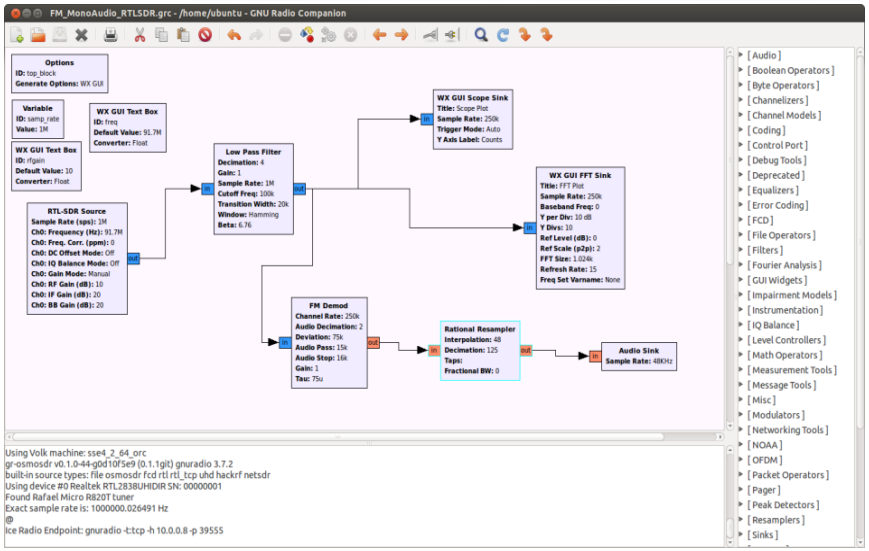




SDR in HR: Rx Only

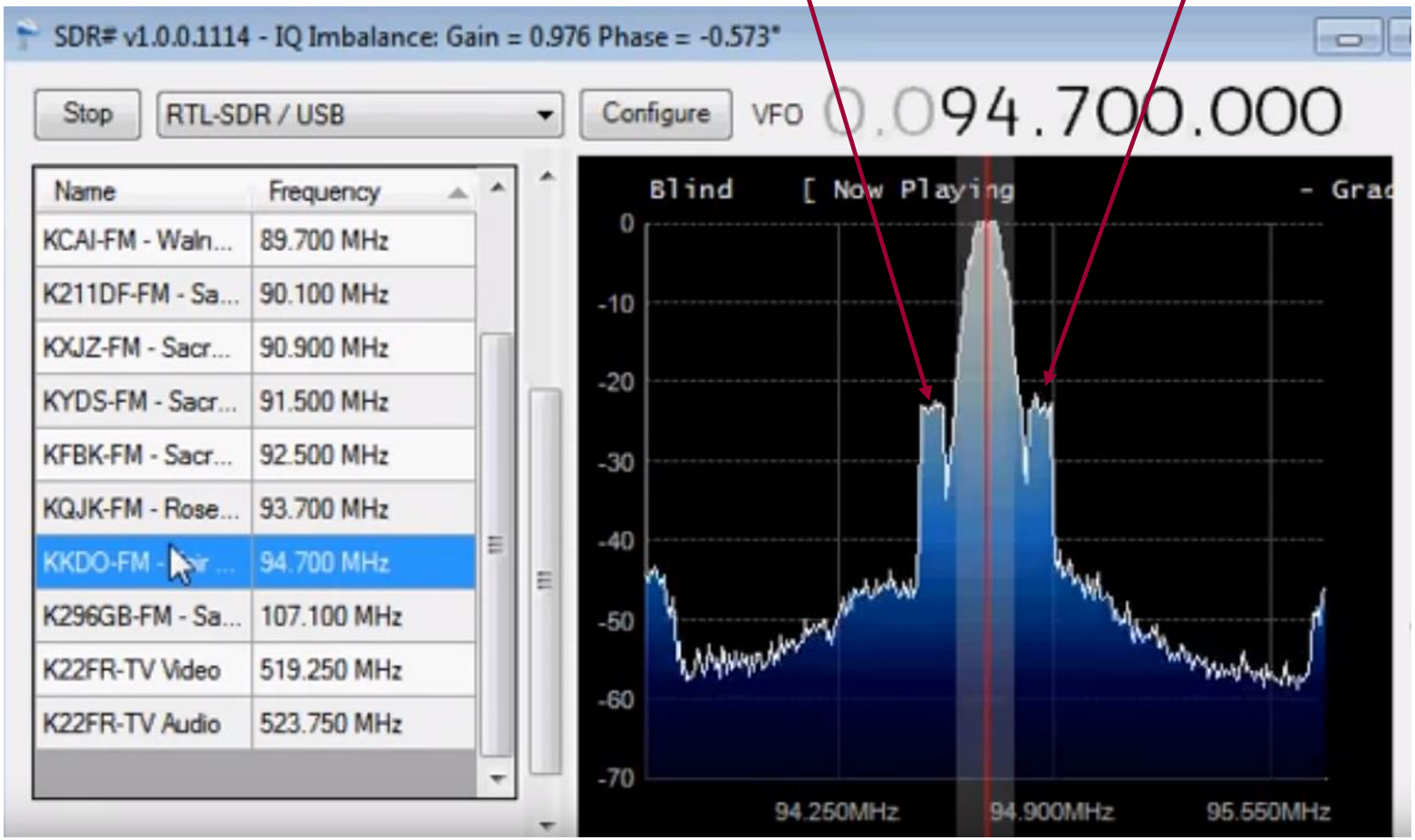
More complicated demodulation software for the SDR include MATLAB/Simulink and GNU radio.





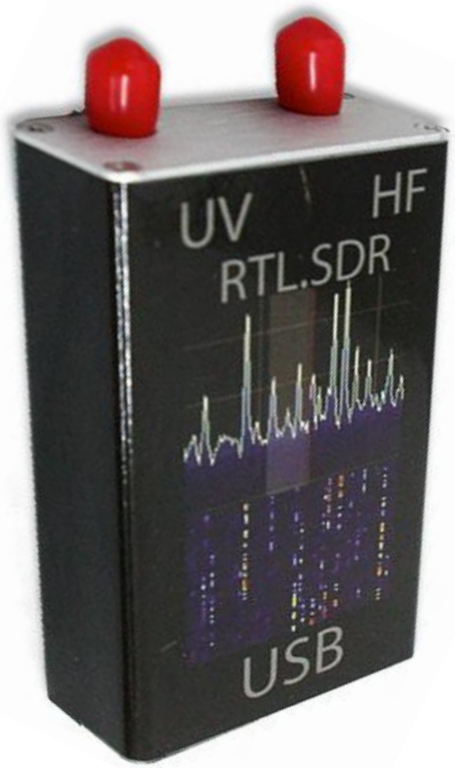
SDR in HR: Rx Only

SDR RTL USB dongle applications: Digital modulation sidebands on the analog FM broadcast band.



SDR in HR: Rx Only

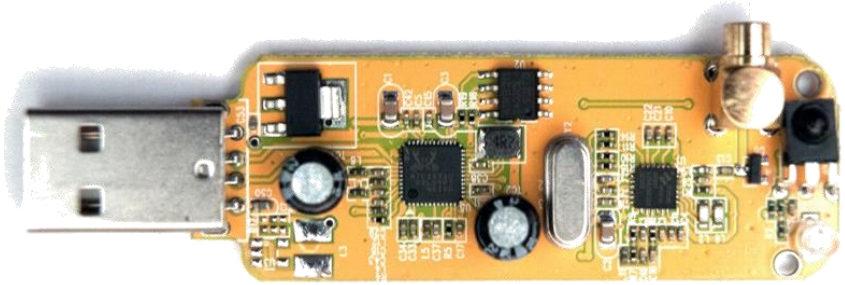
Although the lowest frequency of the Rafael Micro 820T RF tuner is 24 MHz, a *downconverter* can be added to lower the range to 100 kHz.

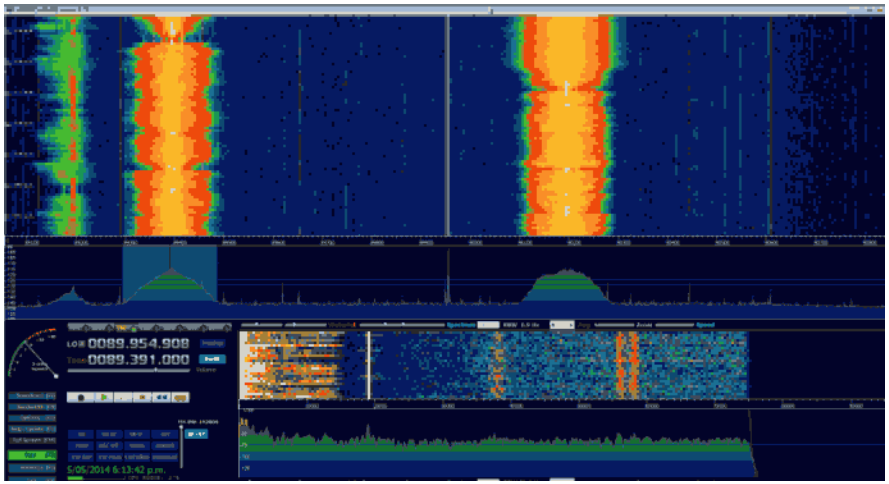


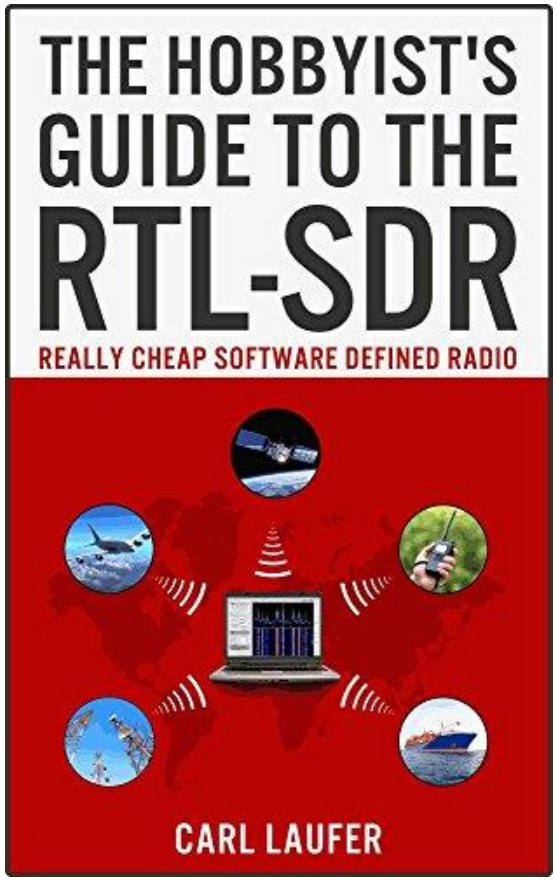
A low noise amplifier (LNA) can be added to improve signal reception in the UHF range.

SDR in HR: Rx Only

The support for SDR RTL USB dongle is immense but a comprehensive source is the inexpensive ($25) book:



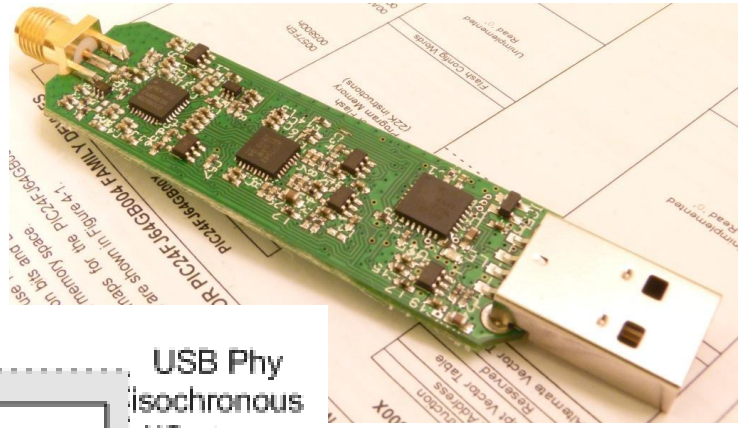


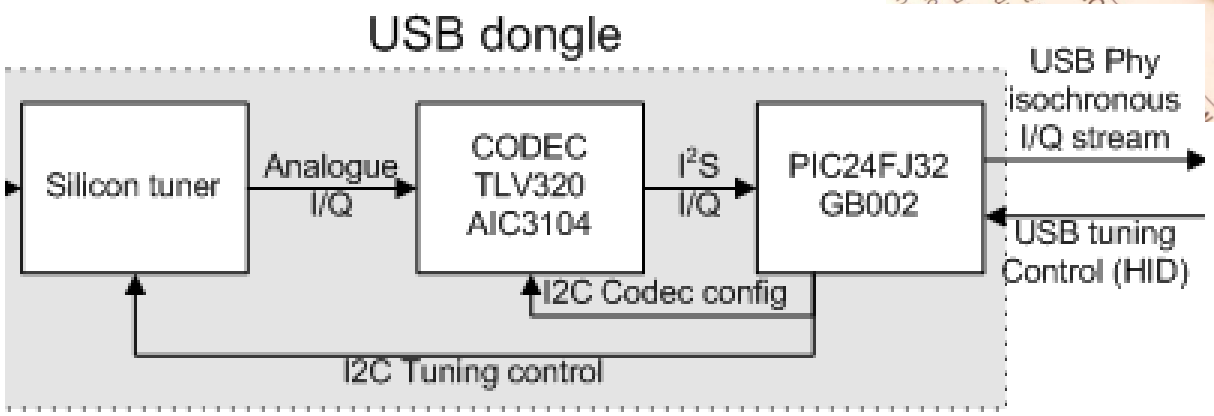


SDR in HR: Rx Only

One of the next levels of *receive only* SDR is the FUNcube project of the AMSAT-UK.

The FUNcube SDR dongle is more sophicated and sensitive than the RTL SDR.





SDR in HR: Rx Only

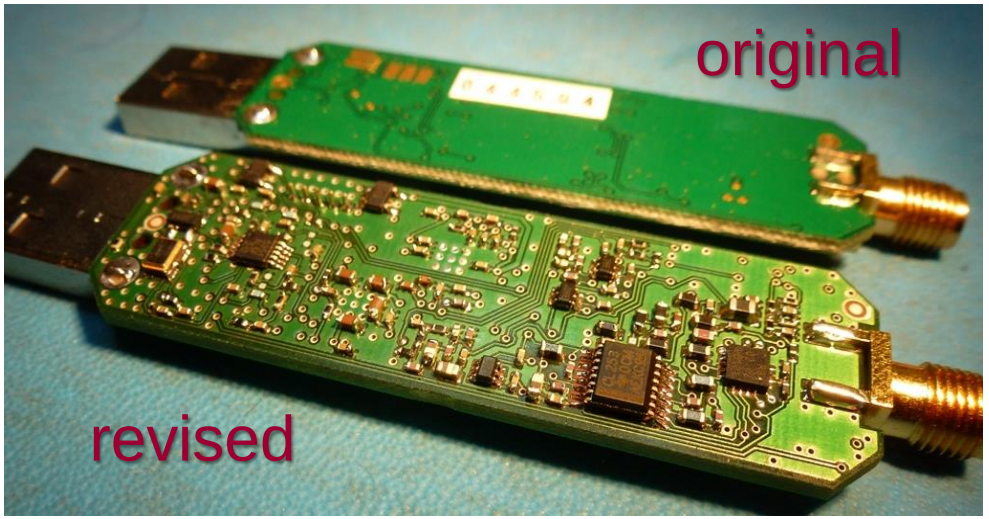
With continuous improvement there were two models of the FUNcube SDR dongle.

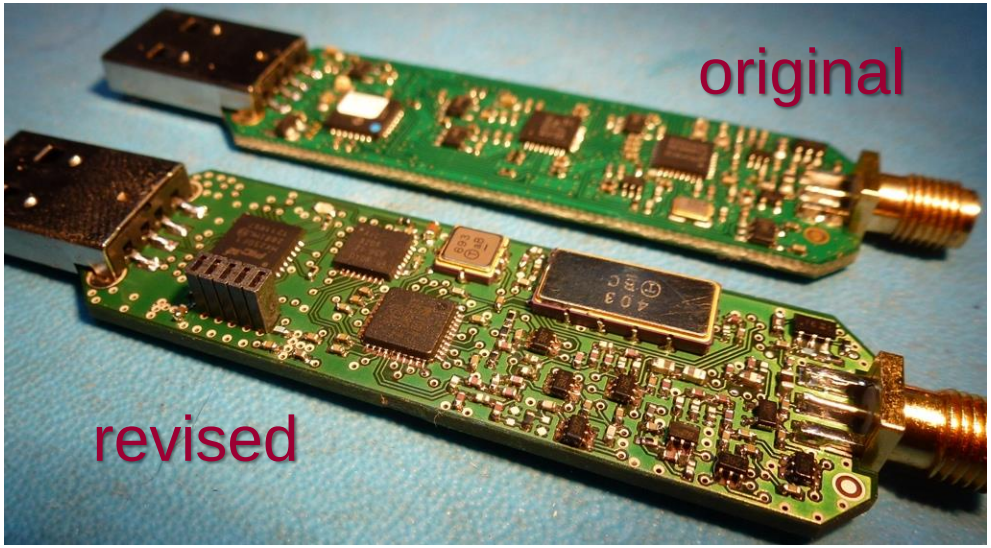
Frequency range:
- 150 kHz-240 MHz
- 420-1.9 GHz

Bandwidth: 160 kHz

Sensitivity:
- 0.15 µV 12 dB SINAD

Noise figure: 3 dB





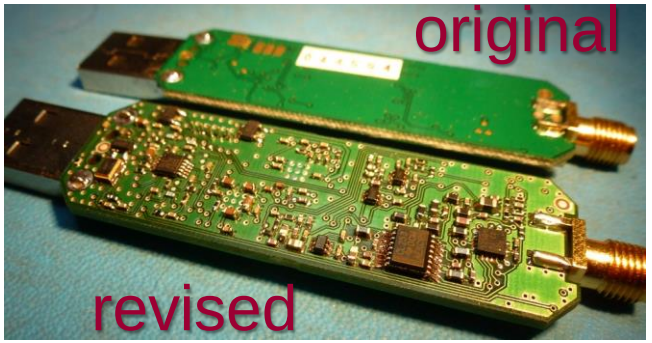
SDR in HR: Rx Only

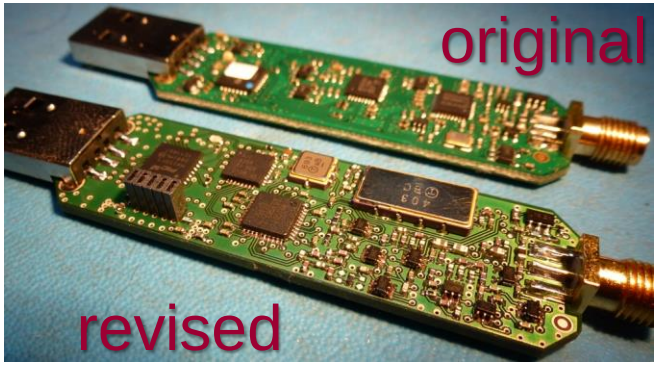
Hardware front end filters:

- 6 MHz 3dB bandwidth SAW filter for the 2m band.
- 20 MHz 3dB bandwidth SAW filter for the 70cm band
- Third- and fifth-order LC bandpass filters for other bands

Noise figures: 145 MHz 3.5dB
435 MHz 3.5dB
1296 MHz 5.5dB

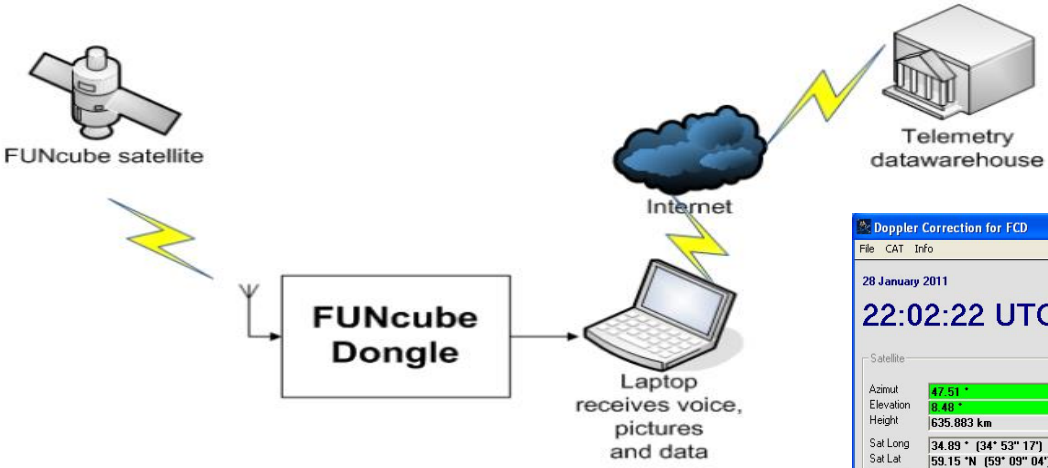
NFM 12dB SINAD: 145 MHz 0.15uV
435 MHz 0.15uV

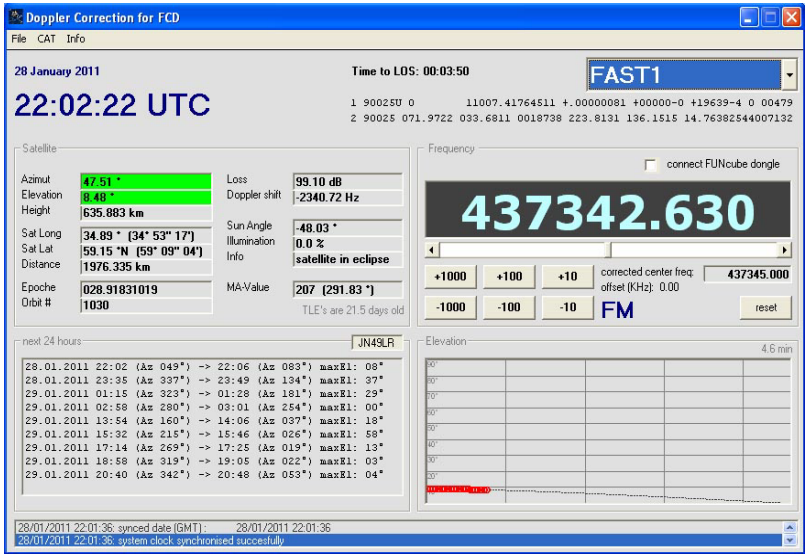




SDR in STEM Outreach

The FUNcube is used for a telemetry activity and LEO satellite signal acquisition and doppler shift correction.

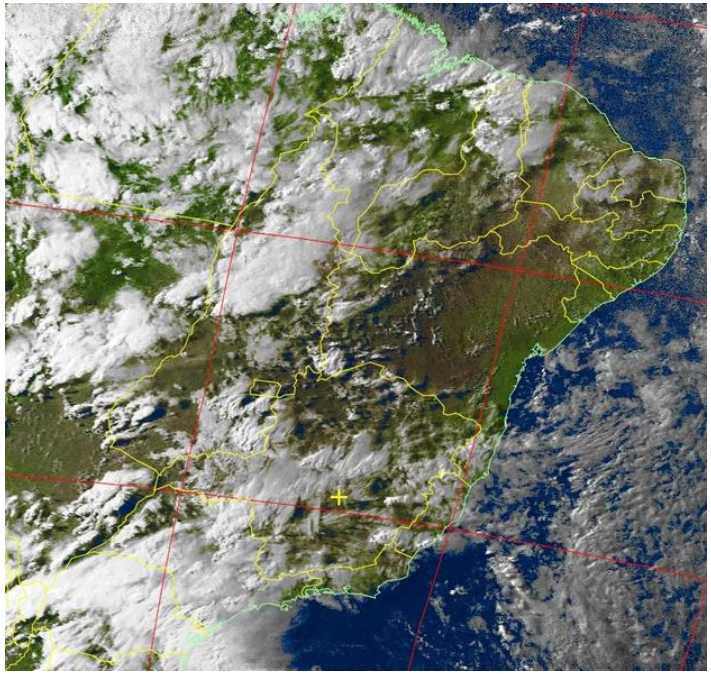




http://funcube.org.uk/

SDR in HR: Rx Only

The high performance FUNcube dongle capturing NOAA-15 weather images in color at TUARC K3TU with a wideband discone antenna.



SDR in HR: Rx Only

What? No PC? The RTL USB and the FUNcube dongle have been interfaced to a Raspberry Pi microcomputer (<$50) under Rasperian Linux.

Raspbian

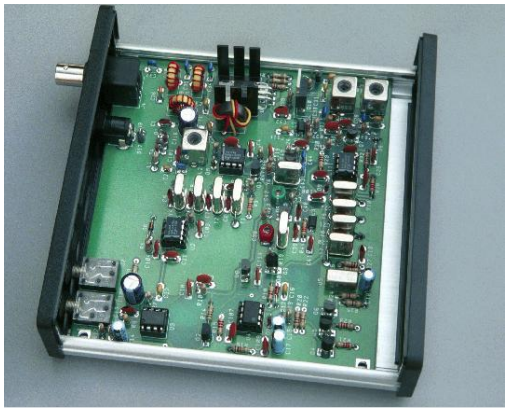
SDR in HR: Rx Only

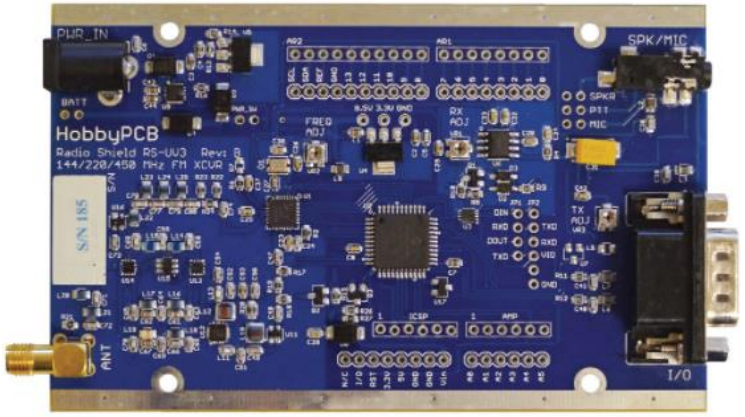
The FUNcube Dongle Pro used a BGA2717 LNA, E4000 silicon RF Tuner TLV320AIC audio coder-decoder (codec) and a 24FJ32 16-bit microcontroller.

The cost was ~$200 but this includes a sizeable donation to AMSAT-UK to support the FUNcube Amateur Radio LEO satellite program.

SDR in HR: Rx and Tx

The *receive and transmit* SDRs are often more expensive but are very useful for HR.

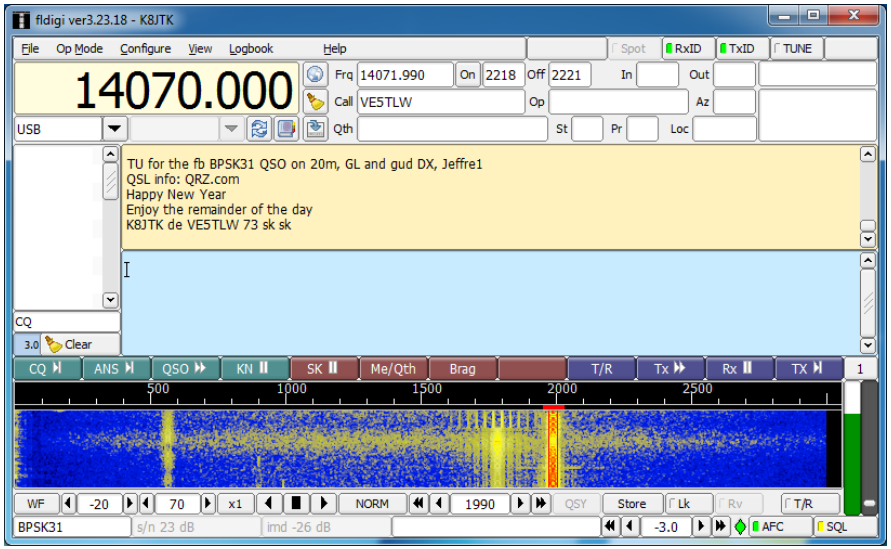


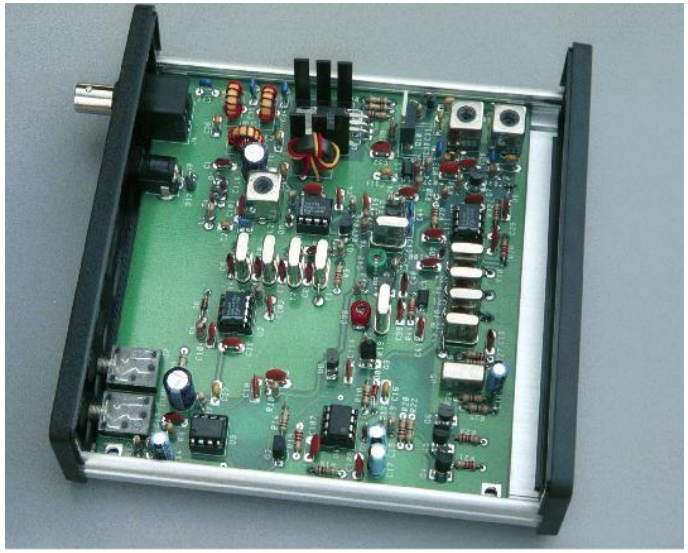


SDR in HR: Rx and Tx

Hams have embraced not only the receive capabilities but also the transmit capabilities of the SDR or the SDR/T. An early version was the PSK20, a 20 meter SDR/T for the keyboard PSK31 digital mode .

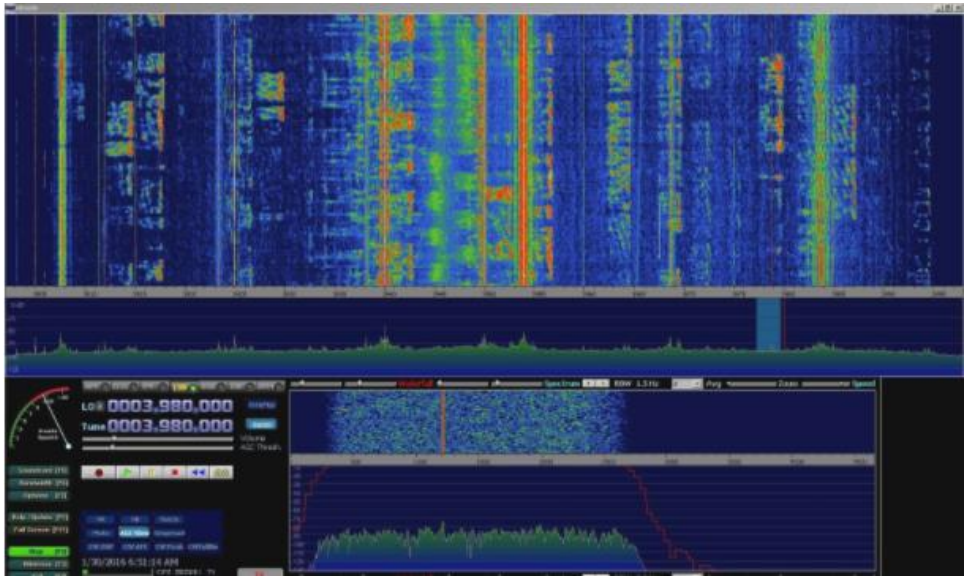
Unfortunately, no longer available!





SDR in HR: Rx and Tx

The HobbyPCB RS-HFIQ 5 W HF transceiver SDR/T is available.

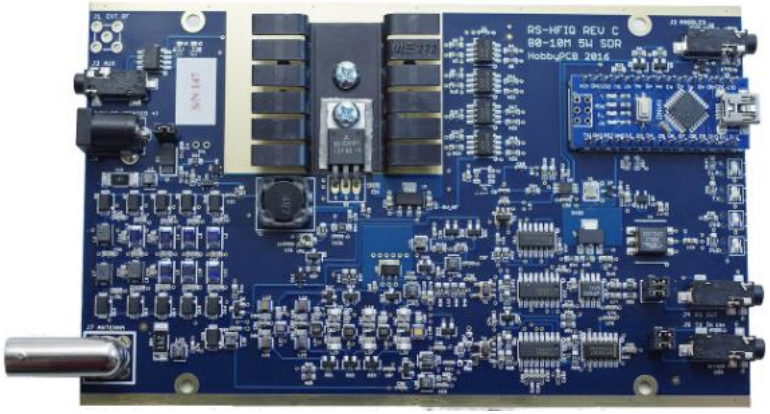


SDR in HR: Rx and Tx

The receiver in the RS-HFIQ consists of 5 band-pass filters to reject out-of-band signals, an LNA with frequency dependent gain and a conventional quadrature down-converter.

The transmitter in the RS-HFIQ uses a quadrature up-converter followed by the same band-pass filters used by the receivers, a 5W power chain and a low-pass filter bank.

HobbyPCB

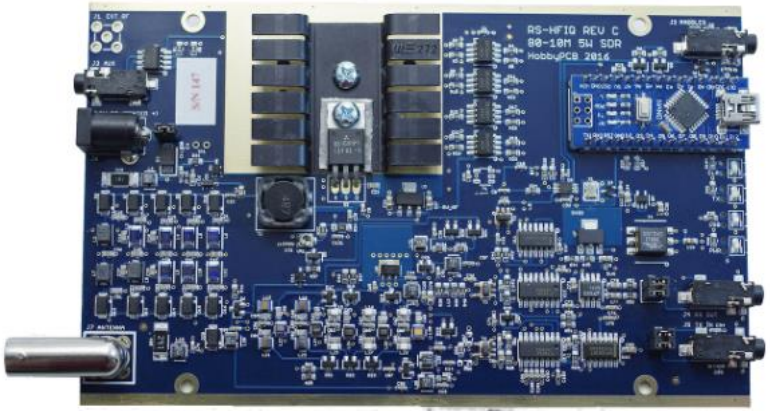


SDR in HR: Rx and Tx

HobbyPCB RS-HFIQ 5 W HF transceiver:

Frequency Range: 3-30 MHz
Minimum Detectable Signal: < -128 dBm on 80 M to |
    < -135 dBm on 10 M
Tx Power: 5W typical, 4W minimum
LO Feed-through: < -50 dBc at 5W output
Spurious and Harmonics: < -50 dBc typical

HobbyPCB



SDR in HR: Rx and Tx

The HobbyPCB RS-HFIQ 5 W HF transceiver has an accessory 50 W power amplifier and antenna tuning unit.

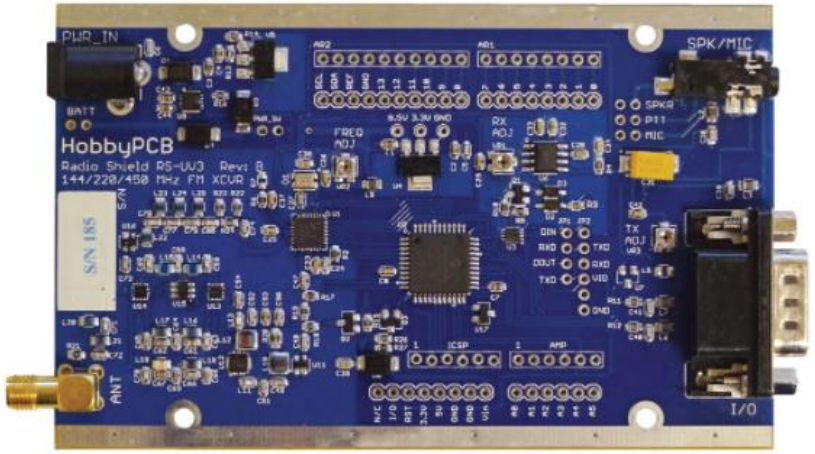
HobbyPCB

SDR in HR: Rx and Tx

The HobbyPCB RS-UV3 radio module is a 144/220/450 MHz FM transceiver board.

The RS-UV3 is a low cost transceiver solution for Packet Radio, repeaters, Echolink stations, base, link and mobile applications..

HobbyPCB

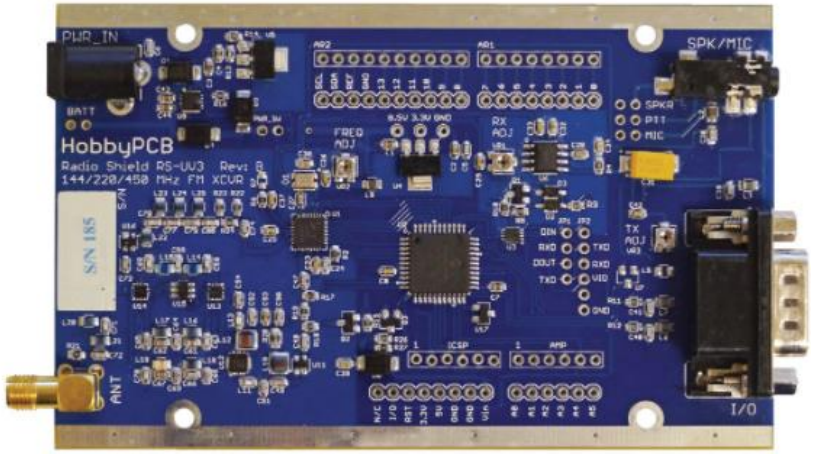


SDR in HR: Rx and Tx

The HobbyPCB RS-UV3 VHF/UHF FM transceiver:

Frequency range: 144-148, 220-225, 420-450 MHz
Sensitivity: −120 dBm for 12 dB SINAD
Tx Power: 23 dBm ± 1dB (0.2 W)
Spurious Emissions: −60 dB or lower

HobbyPCB



SDR in HR: Rx and Tx

The RS-UV3 transceiver has an accessory 5 W power amplifier and enclosure.

HobbyPCB

SDR in HR: Rx and Tx

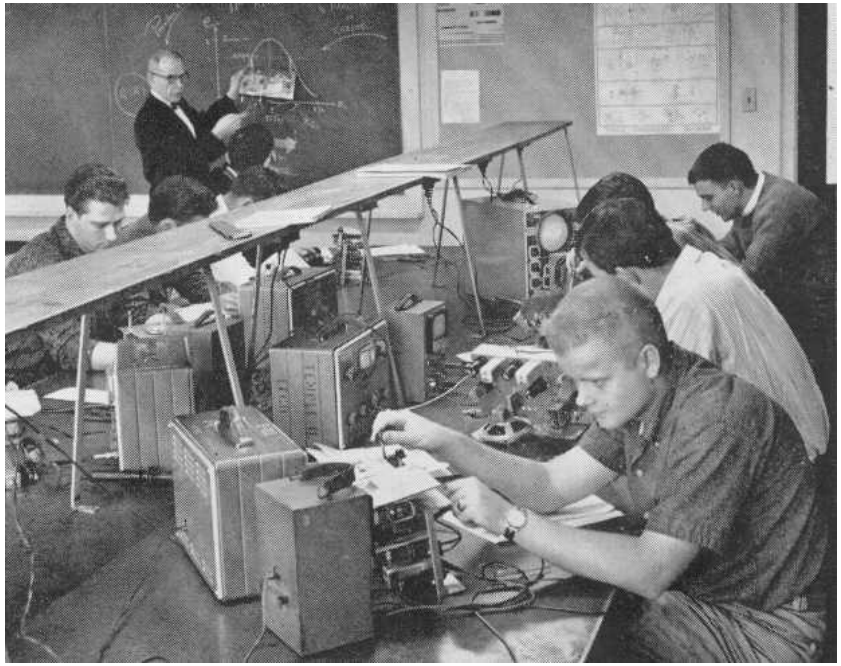
The very top of the range for SDR/T is the FlexRadio.

FlexRadio Systems®
Software Defined Radios

SDR in EE Education

The SDR/T has a role in modern EE education.

Temple Technical Institute
Analog Communications Laboratory
1962



TEMPLE UNIVERSITY
Of The Commonwealth System Of Higher Education

SDR in EE Education

The Analog Devices ADALM-Pluto is inexpensive (~$100) SDR/T.

The impact of this low-cost SDR/T is not only for HR but for EE education.

Current most college labs, as is Temple ECE, are equipped with an SDR/T like the NI USRP-2900 (~$700) or the NI USRP-2920 (~$2400).

SDR in EE Education

The ADALM-Pluto is based on The AD9363 - Highly Integrated RF Agile Transceiver and the Xilinx Zynq Z-7010 system-on-chip.

RF coverage is from 70 MHz to 3.8 GHz with up to 20 MHz of bandwidth using 12-bit ADC and DAC.

ANALOG DEVICES

AHEAD OF WHAT'S POSSIBLE™

ADALM-PLUTO | Software-Defined Radio Active Learning Module

SDR in EE Education

The ADALM-Pluto has one transmitter and one receiver for half or full duplex.

The antennas provided though are for the 2.4 GHz ISM band. There is no antenna switch or duplexer.

RX noise figure: <3.5 dB Tx Power: 7 dBm (5 mW)

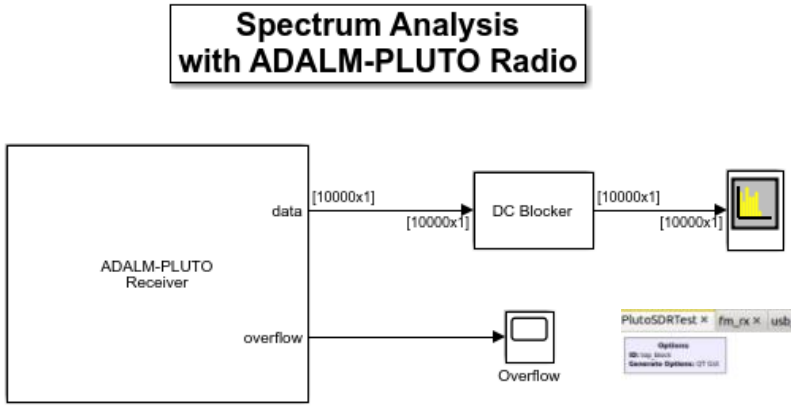
ANALOG DEVICES

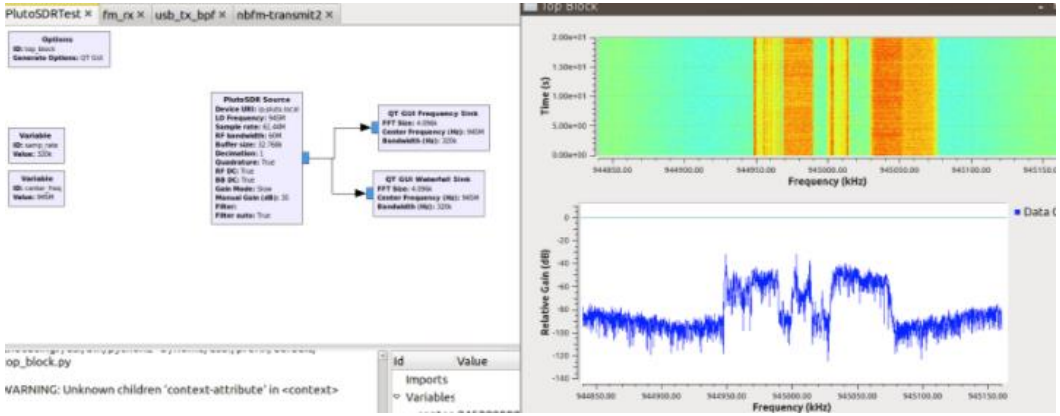
AHEAD OF WHAT'S POSSIBLE™

ADALM-PLUTO | Software-Defined Radio Active Learning Module

SDR in EE Education

The ADALM-Pluto is programmed in MATLAB/Simulink or GNU radio





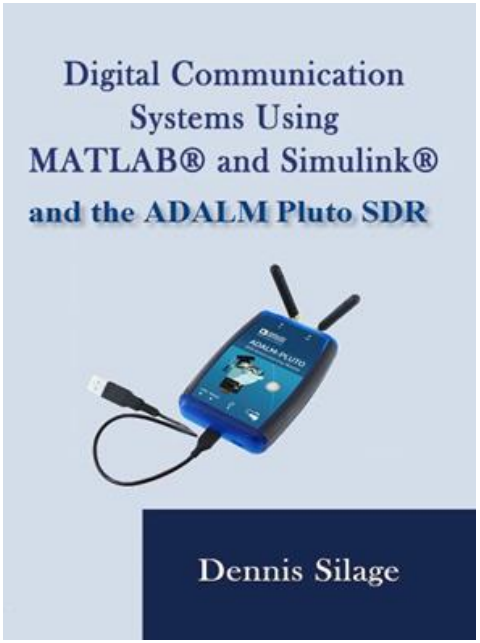
ANALOG DEVICES

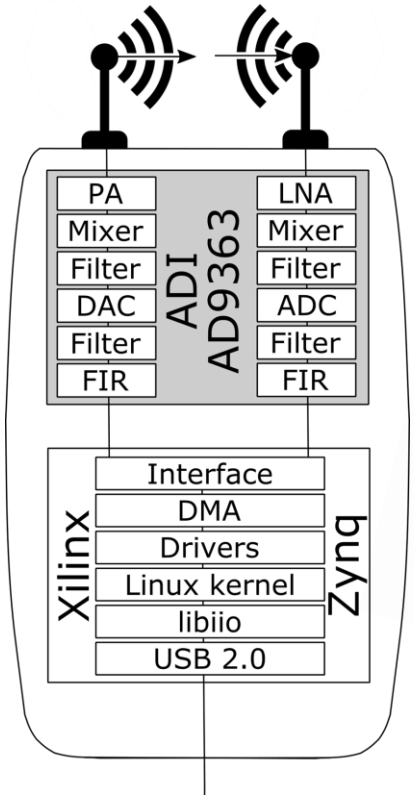
AHEAD OF WHAT'S POSSIBLE™

ADALM-PLUTO | Software-Defined Radio Active Learning Module

SDR in EE Education

However, the ADALM-Pluto will be quite useful for EE education.





Software Defined Radio in Ham Radio

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