Raspberry Pi SDR

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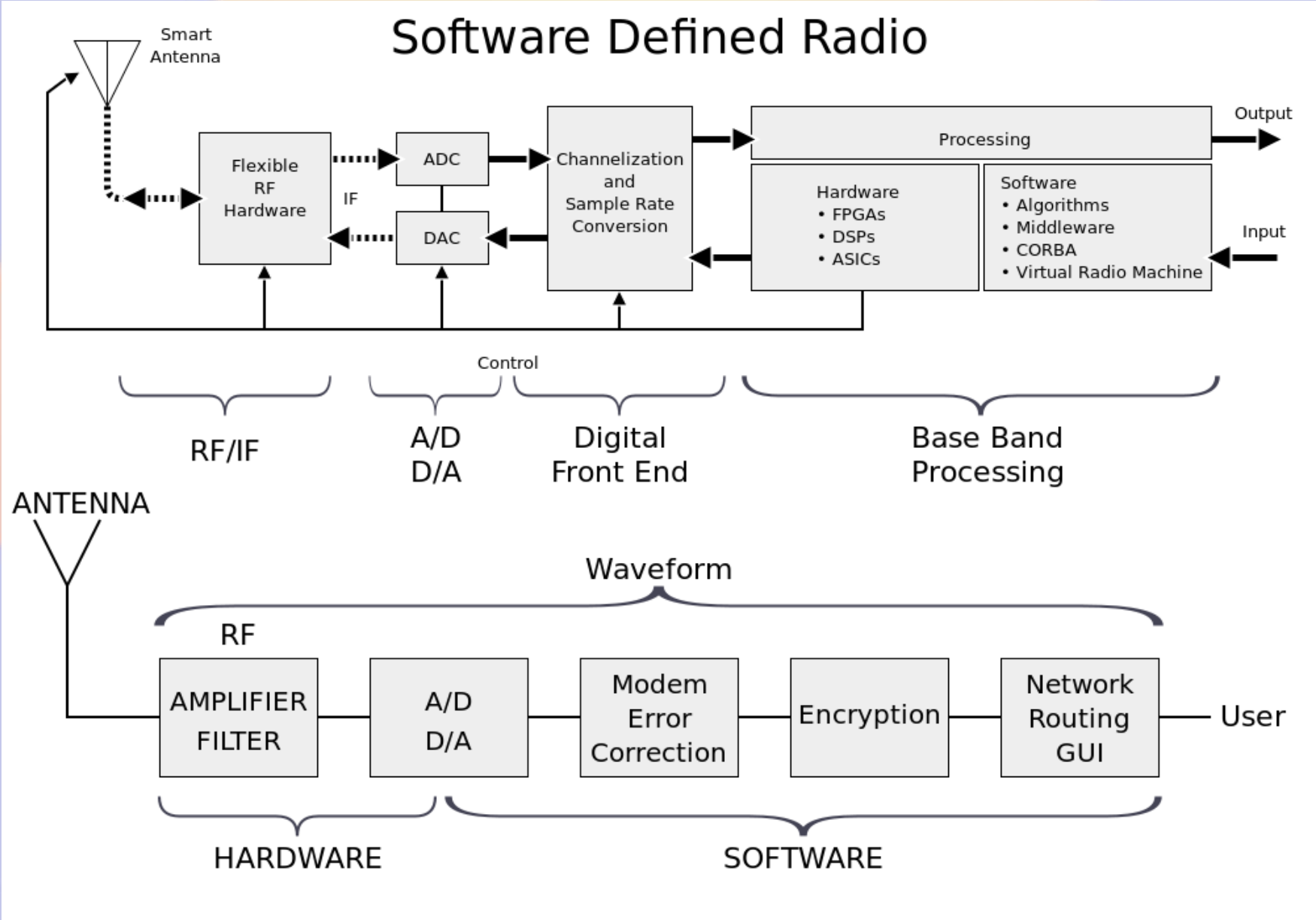
What is SDR?

- High speed analog to digital converter (A2D)
  - RF front end
- Digital Signal Processing (DSP)
  - Heavy duty filters, processes
- Digital to analog converter (D2A)
  - Audio out
- Control interface
  - Putting it all together

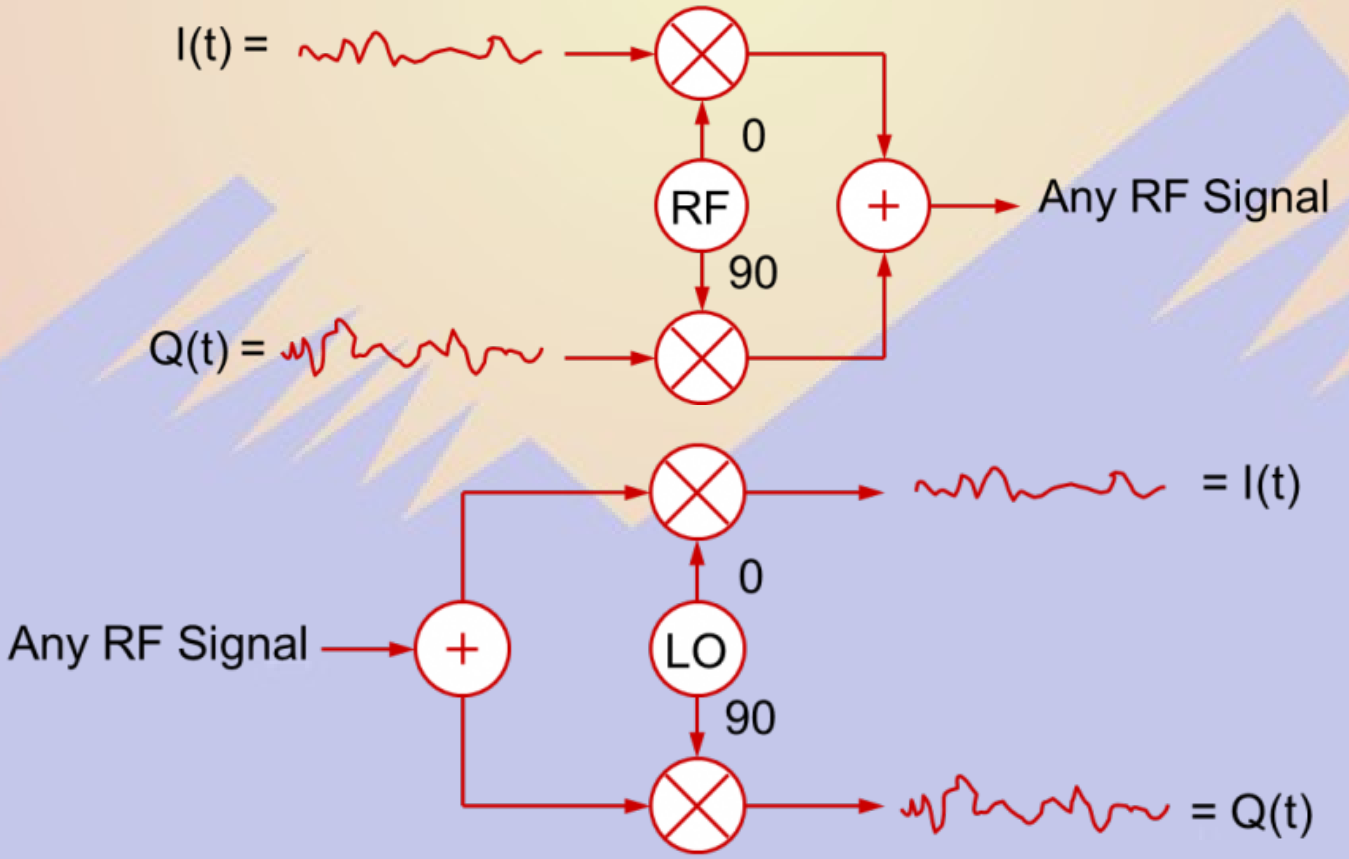

ICOM
POWER
REMOTE
LOCAL
P.LOCK
TIMER
PHONES
DIAL A
SCAN
PRIO
DIAL B
D-STAR
FIL3
P.AMP ATT10 IP+
11:32
D-STAR CALL CH
1295.300.000
AFC
MEMO
1999
AGC-F AN NR
MONI
64.5 dBμ
TS 10k
SPECTRUM SCOPE
CENTER
Grid 20k/10dB
-100k
+100k
-80 -60 -40 -20 0 +20 +40 +60 +80
< 1 >
SPAN
HOLD
CENT/FIX
EXPD/SET
IC-R8600
DIAL C
▲GRP
V/M
▼GRP
MW
RECEIVE
LOCK
M-CH DIAL
MENU
FUNCTION
M.SCOPE
QUICK
EXIT
SPEECH LOCK

Conceptual Block Diagram



In phase and Quadrature (IQ)

- $S(t) = I(t) \cos(2\pi f\, t) + Q(t) \sin(2\pi f\, t)$
- Complex numbers $x+iy$ makes the math elegant



Baseband SDR

- Baseband is the SDR equivalent of IF
  - Extracts a slice of spectrum
  - Center frequency +/- baseband bandwidth
  - Negative frequency is relative to center frequency
- Baseband bandwidth
  - Soundcard 48 kHz
    - Often analog
  - USB or IP 1-10 MHz
    - Limited by ADC speed and processor power

SDR Terminology

- Sample Rate = samples/sec
- Nyquist frequency = half the sample rate
  - Bandwidth given the sample rate
- Complex = IQ as complex numbers
- Decimation = reduce sample rate
- Interpolation = increase sample rate
- Resampling = Decimation or Interpolation
  - Rational = integer / integer
  - Fractional = decimal

Doing It Yourself

- RF front end and A2D converter
  - HackRF, SDR-IQ, RTL2832, FunCube, ...
- High speed CPU
  - A decent computer
- D2A converter
  - A sound card
- Control interface
  - rtl_fm, ...
  - SDR#, Gqrx, GNU Radio, ...

Why the Raspberry Pi?

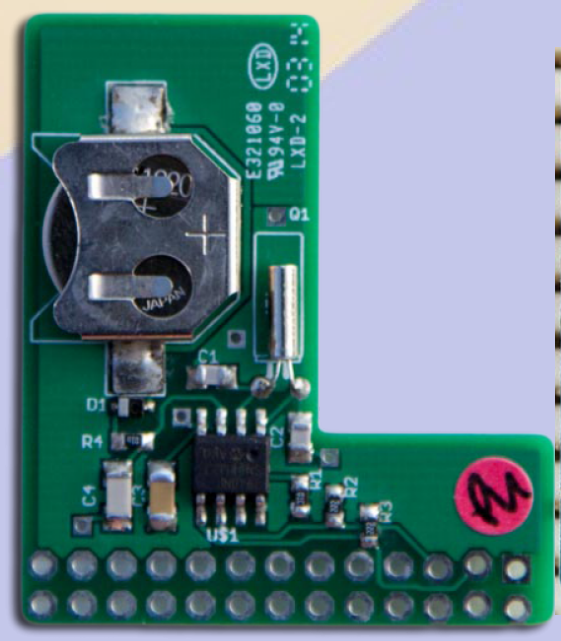
- Very well supported
- Fast enough to do serious work
- Full multi-tasking GNU/Linux OS
- Ethernet/Wifi connectivity
- Model 3B+ ($35)
- Model ZeroW ($10)

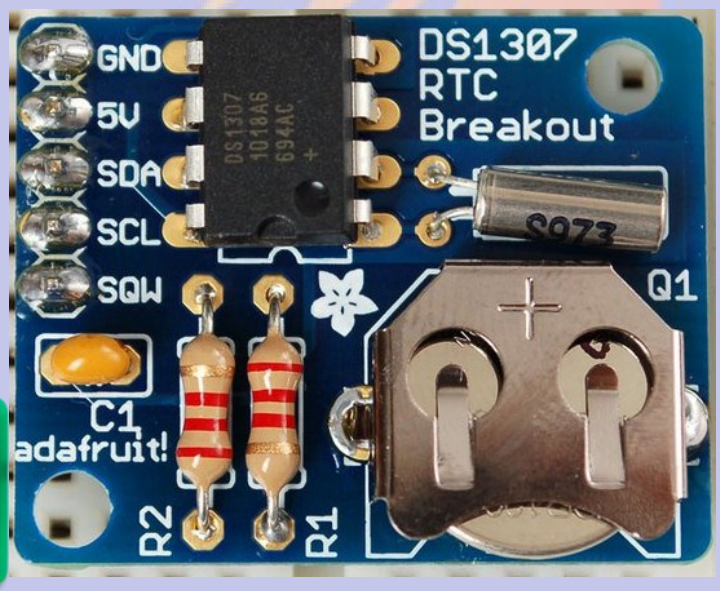
Raspberry Pi models

- Raspberry Pi
  - A/A+ 700 MHz CPU & 256MB SDRAM, 1xUSB
  - B 700 MHz CPU & 512MB SDRAM, 2xUSB, Ethernet
  - B+ 700 MHz CPU & 512MB SDRAM, 4xUSB, Ethernet
  - 2B 900 MHz Quad A7 & 1GB SDRAM, 4xUSB, Ethernet
  - 3B 1.2GHz Quad 64bit & 1GB SDRAM, 4xUSB, ether+wifi
  - 3B+1.4GHz Quad 64bit & 1GB SDRAM, 4xUSB, ether+wifi
- Pi Zero
  - 0 1GHz CPU & 512MB SDRAM, USB
  - 0W 1GHz CPU & 512MB SDRAM & Wifi

Must Have Accessories

- Micro SD card
  - Faster is better
    - Class 10
    - UHS 1
    - UHS 3
  - At least 4GB
    - 16GB is ample
  - SanDisk is reliable
- Real time clock
  - PiFace Shim RTC
  - Adafruit DS1307
  - Needed if no network (NTP)





Installing the OS

- Download raspbian and burn to SD card
  - dd if=raspbian*.img of=/dev/mmcblk0 bs=16M
- Enable remote ssh logins
  - touch .../boot/ssh
- Enable wifi of necessary
  - edit .../etc/wpa_supplicant/wpa_supplicant.conf

```
network={
    ssid="RMHAM-U"
    psk="guess1234"
    scan_ssid=1
}
```

Tips and Tricks

- Sudo elevates user permissions
  - sudo rtl_fm ….
- User must be in 'audio' group to play sound
  - sudo adduser *willem* audio
- ssh allows remote logins
  - ssh rtlpi3
    - log in to rtlpi3 as the same user
  - ssh pi@rtlpi3
    - log in to rtlpi3 as user pi

DVB-T USB

- Digital Video Broadcasting – Terrestrial
  - European digital television
- RF to USB A2D
  - MCX RF in
  - R820T tuner
  - RTL2832U demodulator
  - USB 2.0 output
- Cost about $20

NESDR SMArt

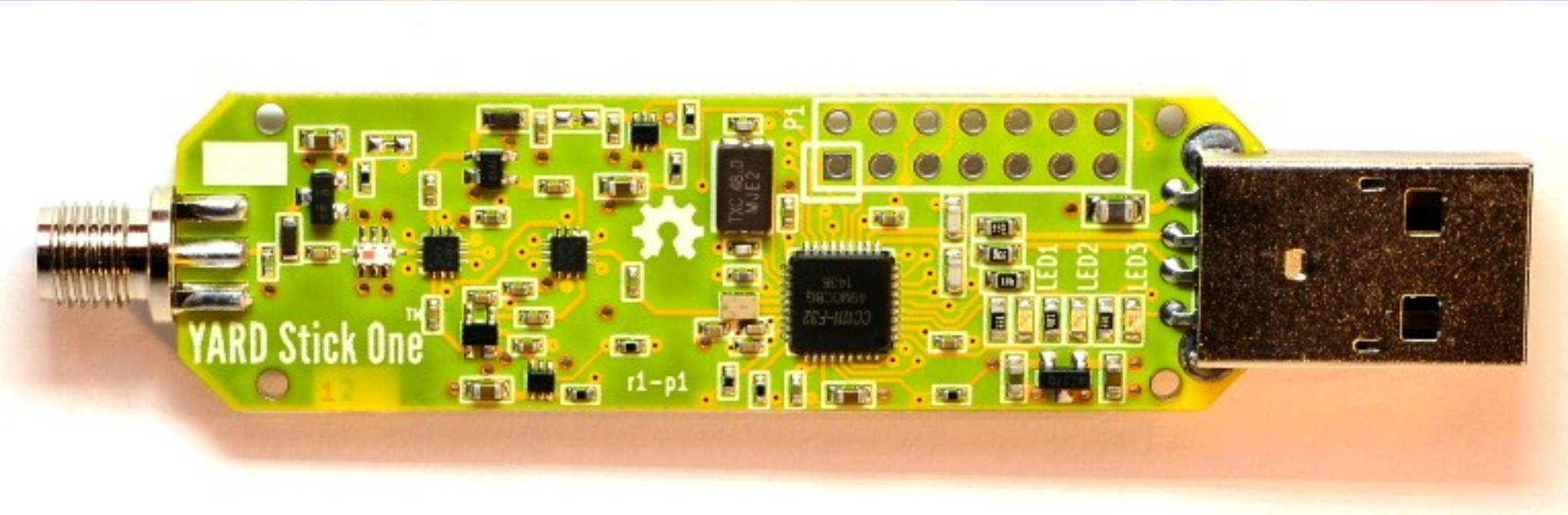
- Aluminum Enclosure
  - RFI protection
  - Heatsink
  - nano 3
- 0.5ppm TXCO
- SMA antenna
- Cost about $25

HackRF One

- High performance SDR
  - 20 million samples/sec
- Tx and Rx
- Open source hardware
- Expansion headers
- Headquartered in Evergreen
- Cost about $300

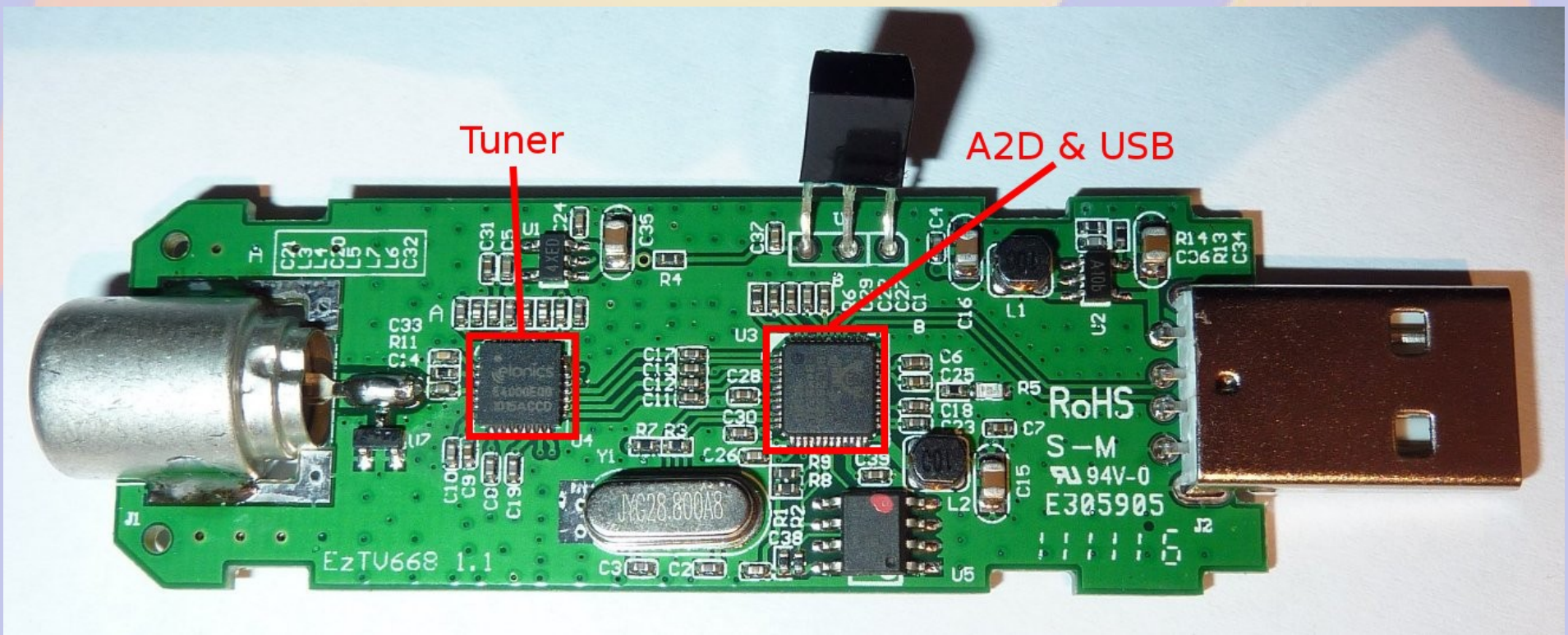
YARD Stick One

- Great Scott Gadgets
- Transceiver for 300-999 MHz
- $99



Inside the Dongle

- R820T or similar tuner
- RTL2832 A2D converter and USB



Raspberry Pi + DVB-T

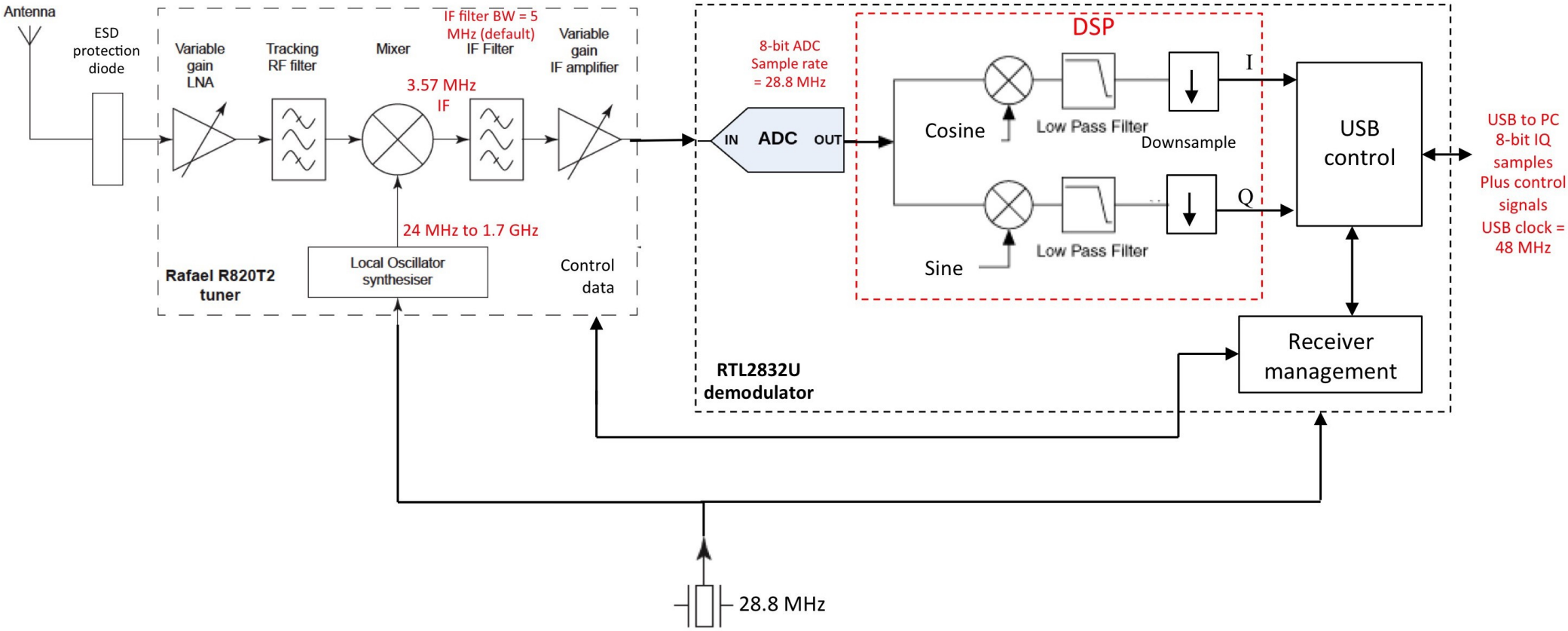
- Advantages
  - Simple to use
  - Widely supported
  - Can remotely mount DVB-T at antenna
  - Can stream audio or IQ data
- Disadvantages
  - Poor sensitivity and selectivity
- Chip temperature under load is a concern
- High RF environments require shielding

RTL-SDR

- Linux library and code to support DVB-T
- librtlsdr.a – library that supports hardware
- rtl_test – test hardware
- rtl_fm – simple FM receiver
- rtl_sdr – IQ stream
- rtl_tcp – IQ stream via TCP/IP
- *IQ (**I**n-phase and **Q**uadrature) is SDR speak for a data stream of complex numbers which is the discrete samples of the analog signal*

Block Diagram

Simplified Block Diagram of NooElec RTL-SDR



Installing RTL-SDR

- Install prerequisites
  - sudo apt-get install -y cmake pkg-config libusb-1.0
- Download RTL-SDR
  - git clone git://git.osmocom.org/rtl-sdr.git
- Build RTL-SDR
  - cd rtl-sdr
  - mkdir build
  - cd build
  - cmake ../ -DINSTALL_UDEV_RULES=ON
  - make
  - sudo make install
  - sudo ldconfig

Remove default modules

- Prevent built-in modules from loading
  - sudo cat <<EOF >>/etc/modprobe.d/blacklist-rtlsdr.conf
  - blacklist dvb_usb_rtl28xxu
  - blacklist rtl2832
  - blacklist rtl2830
  - EOF
- Reboot to clean out modules

Simple Local Receiver

- Connect speakers to rPi audio
- Run rtl_fm to demodulate to stdout
- Play using aplay from stdin

Broadcast radio KYGO

rtl_fm -f 98.5e6 -M wbfm -s 200k -r 44100 | aplay -r 44100 -f S16_LE

rtl_fm

- -f 98.5e6 frequency 98.5MHz
- -M wbfm wideband FM mode
- -s 200k sample rate (twice the bandwidth)
- -r 48k output rate

aplay

- -r 48k input rate
- -f S16_LE Signed 16bit little endian

Ham Radio 146.550

rtl_fm -f 146.550e6 -s12500 -Edeemp | aplay -r 12500 -fS16_LE

rtl_fm

- -f 146.550e6 frequency 146.550 MHz
- -s12500 sample rate (twice the bandwidth)
- -Edeemp deemphasis

aplay

- -r 12500 input rate
- -f S16_LE Signed 16bit little endian

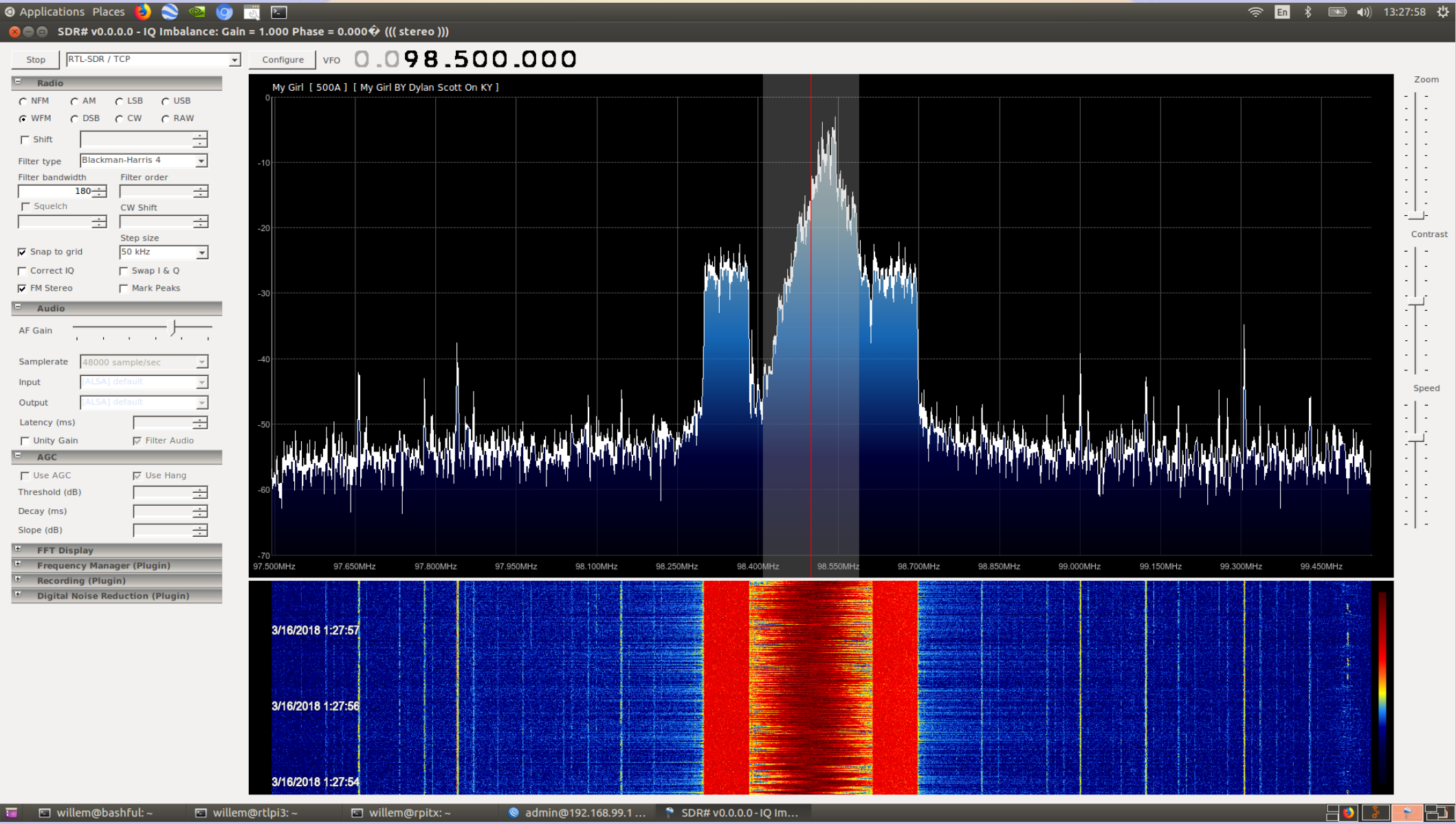
Remote IQ spectrum server

- rtl_tcp -a *ip-address*
  - Remote IQ server
  - Provide the local external IP address
    - Default 127.0.0.1
  - rtl_tcp -a 192.168.99.30
- Decode this using an SDR program
  - SDR#
  - Gqrx
  - gnu-radio
  - many others

SDR#

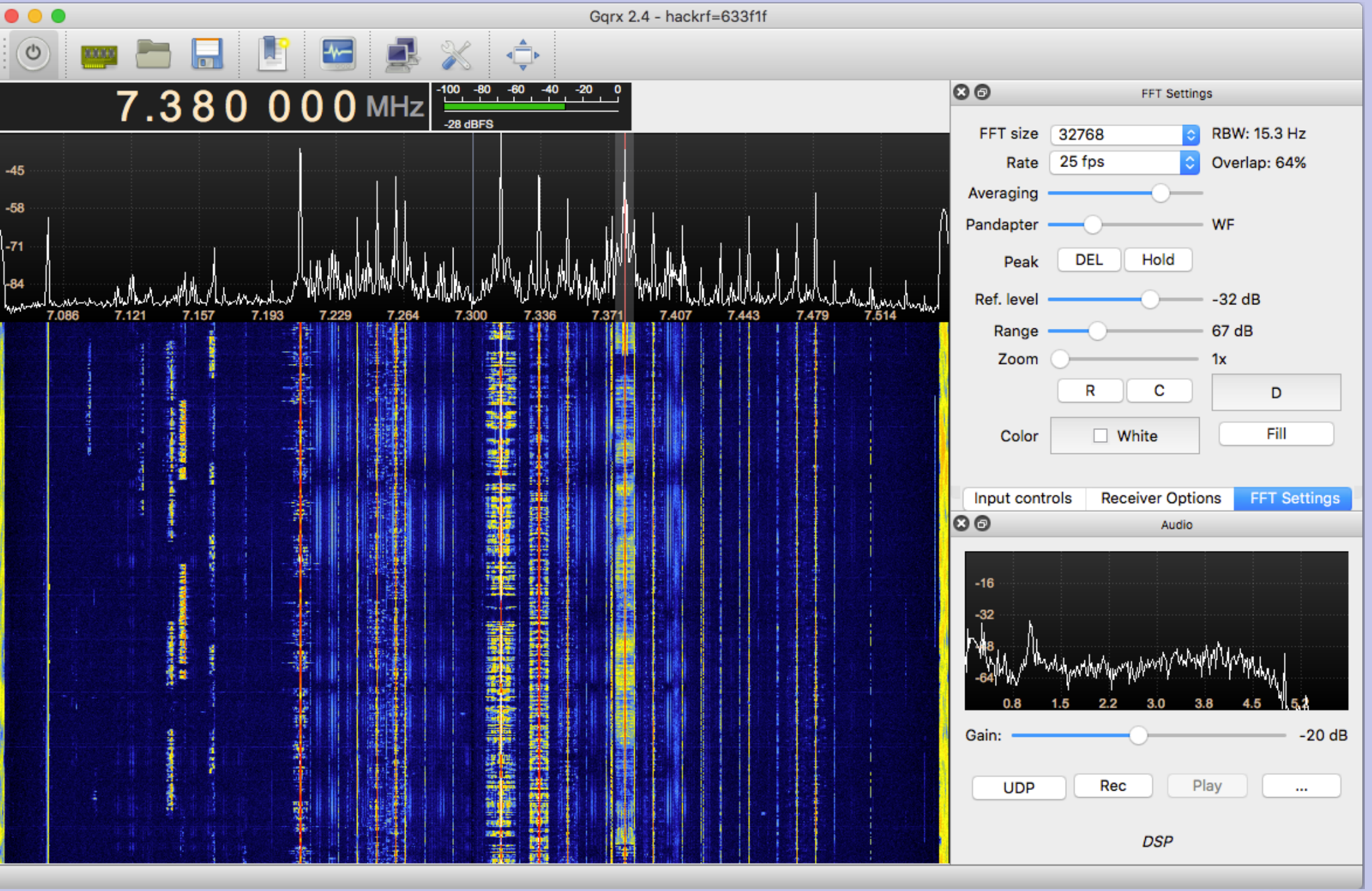
- Excellent SDR software
- Supports many hardware types
- Windows Only
  - runs on Linux using mono
- Easy to use but very powerful
- Free and extensible via plugins

SDR# Screen Shot KYGO



Gqrx

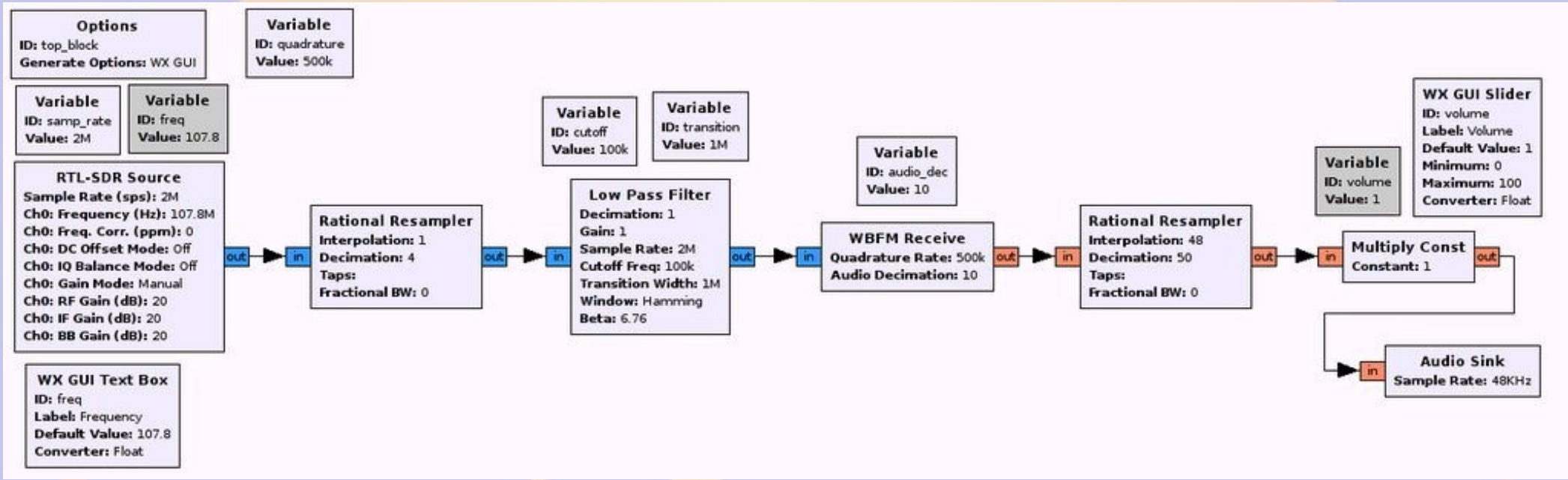
- Pretty good SDR
- Supports many hardware types
- Runs on all platforms
- Easy to use
- Free


Gqrx 2.4 - hackrf=633f1f
7.380 000 MHz
-100 -80 -60 -40 -20 0
-28 dBFS
-45
-58
-71
-84
7.086 7.121 7.157 7.193 7.229 7.264 7.300 7.336 7.371 7.407 7.443 7.479 7.514
FFT Settings
FFT size 32768
RBW: 15.3 Hz
Rate 25 fps
Overlap: 64%
Averaging
Pandapter
WF
Peak
DEL
Hold
Ref. level
-32 dB
Range
67 dB
Zoom
1x
R
C
D
Color
White
Fill
Input controls
Receiver Options
FFT Settings
Audio
-16
-32
-48
-64
0.8 1.5 2.2 3.0 3.8 4.5 5.2
Gain:
-20 dB
UDP
Rec
Play
...
DSP

GNU Radio

- Extremely powerful
- Supports many hardware types
- Runs on all platforms
- gnu-radio-companion makes it easier to use
  - Python wrapper to connect components
  - Heavy on processor demands
  - Can be run natively on the Raspberry Pi
- Free and extensible

gnu radio companion

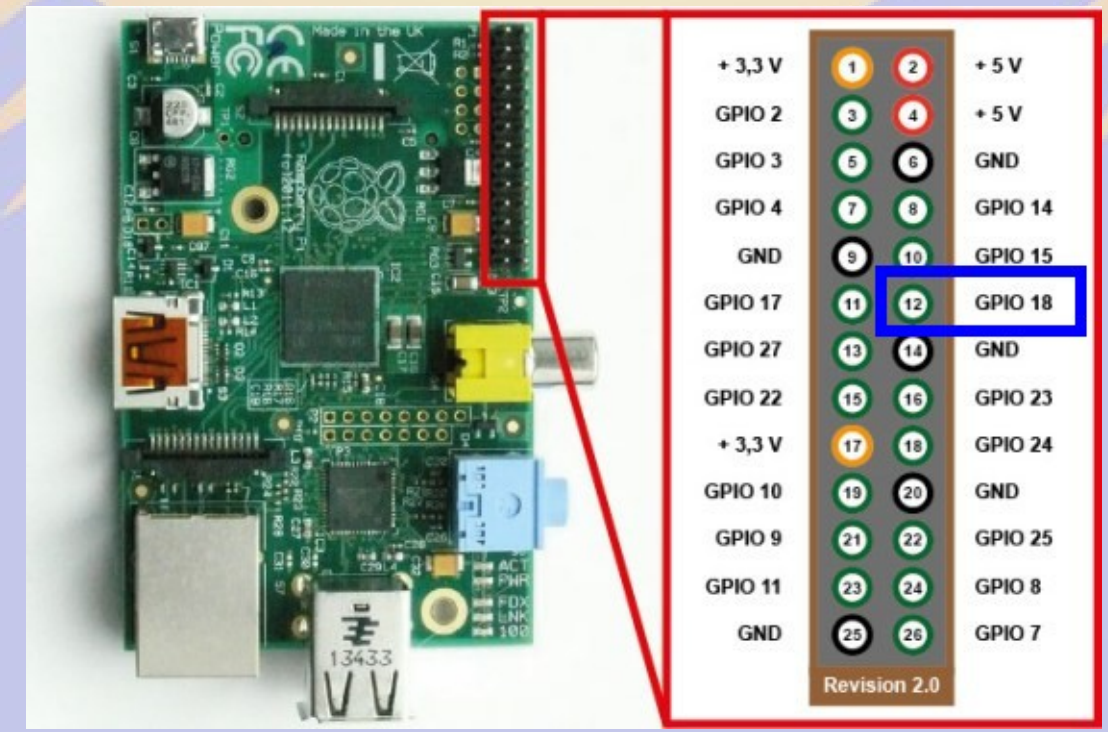


gnu radio hints

- Blue connectors = complex (IQ)
- Orange connectors = real
- Connectors speeds must match

Transmissing using **pitx**

- Several versions – use F5OEO for ham apps
- Takes IQ stream and transmits it
- Transmits on rPi GPIO pin 18



Filtering

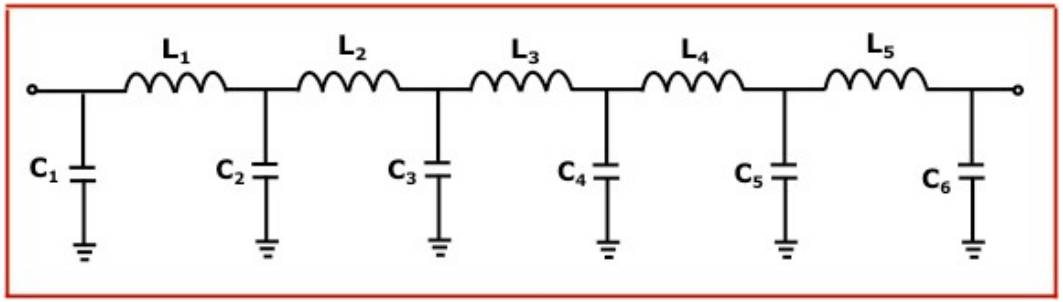
- FCC 97.307(e) [30-225 MHz]
  - … For a transmitter having a mean power of 25 W or less, the mean power of any spurious emission supplied to the antenna transmission line must not exceed 25 µW and must be at least 40 dB below the mean power of the fundamental emission, but need not be reduced below the power of 10 µW.
- Low pass filter LFCN-160+
  - 1/8 inch long
  - $3 each

Frequency (MHz)	Insertion Loss (dB)	VSWR (:1)
40	0.29	1.07
100	0.53	1.07
150	0.77	1.09
160	0.85	1.11
210	1.60	1.41
230	2.50	1.74
260	5.92	2.80
280	10.64	3.89
310	21.67	5.22
330	30.84	5.74
350	37.58	6.13
480	39.25	12.26
1000	54.13	59.91
2700	41.64	56.04
6100	20.85	27.59
9000	33.07	14.03
12000	19.52	4.50

Designing a Chebyshev Filter

http://www.calculatoredge.com/electronics/ch pi low pass.htm

Enter value, select unit and click on calculate. Result will be displayed.



Enter your values:

Cutoff Frequency:	160	MHz
Impedance Z_0:	50	ohm
Frequency Response Ripple:	0.01	db
Number of Components:	5	(1-11)

Calculate Clear

Results:

Inductance:		**Capacitance:**	
Unit :	nH	**Unit :**	pF
L_1:	64.90172	C_1:	15.04698
L_2:	64.90172	C_2:	31.37976
L_3:	0.000000	C_3:	15.04698

Designing an air core inductor

https://m0ukd.com/calculators/air-cored-inductor-calculator/

Input coil diameter, length & number of turns		
Coil Diameter	8	mm
Coil length	12	mm
Number of turns	4	t
Frequency (Not required, but used for calculating Q)		MHz

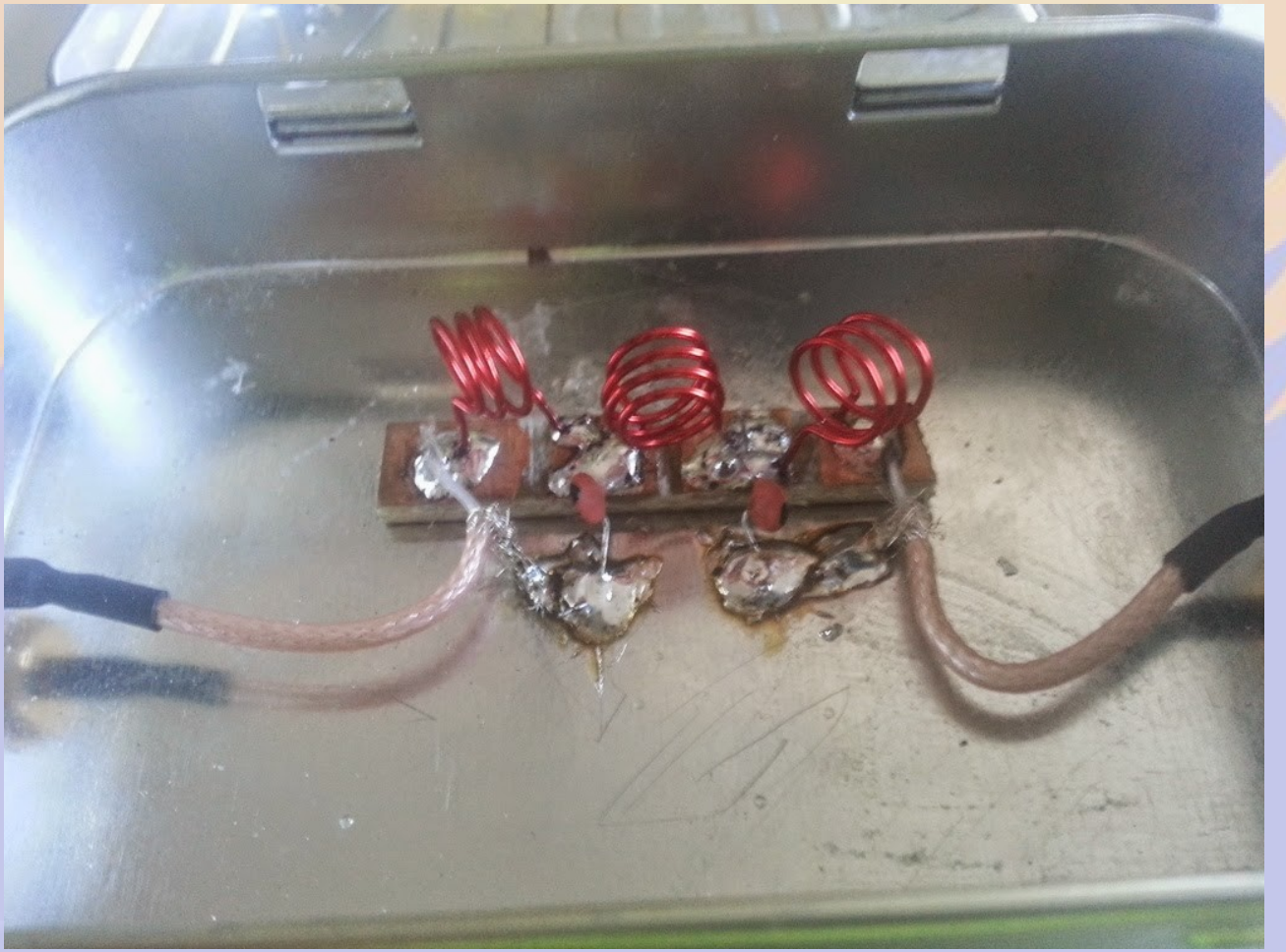
Calculate

Clear Fields

Calculated inductance, Q and wire length		
Nano H	64.841	nH

Low pass in an Altoids can

- http://blog.thelifeofkenneth.com/2015/02/designing-and-building-2m-low-pass.html



Installing **pitx**

- Download
  - git clone https://github.com/F5OEO/rpitx.git
- Build
  - cd rpitx
  - sudo install.sh
- Generate IQ
  - pisstv, pifm, piam, pissb, pifsq
- Transmit IQ
  - rpitx

Setting up to transmit

- Create IQ file
  - pifm ac0kq.wav ac0kq.ft
  - Input MUST be 48k mono
- Transmit the file
  - sudo rpitx -m RF -i ac0kq.ft -f 146550
- rpitx flag
  - -f frequency in kHz (130 to 750,000)
  - -i input file
  - -l loop
  -

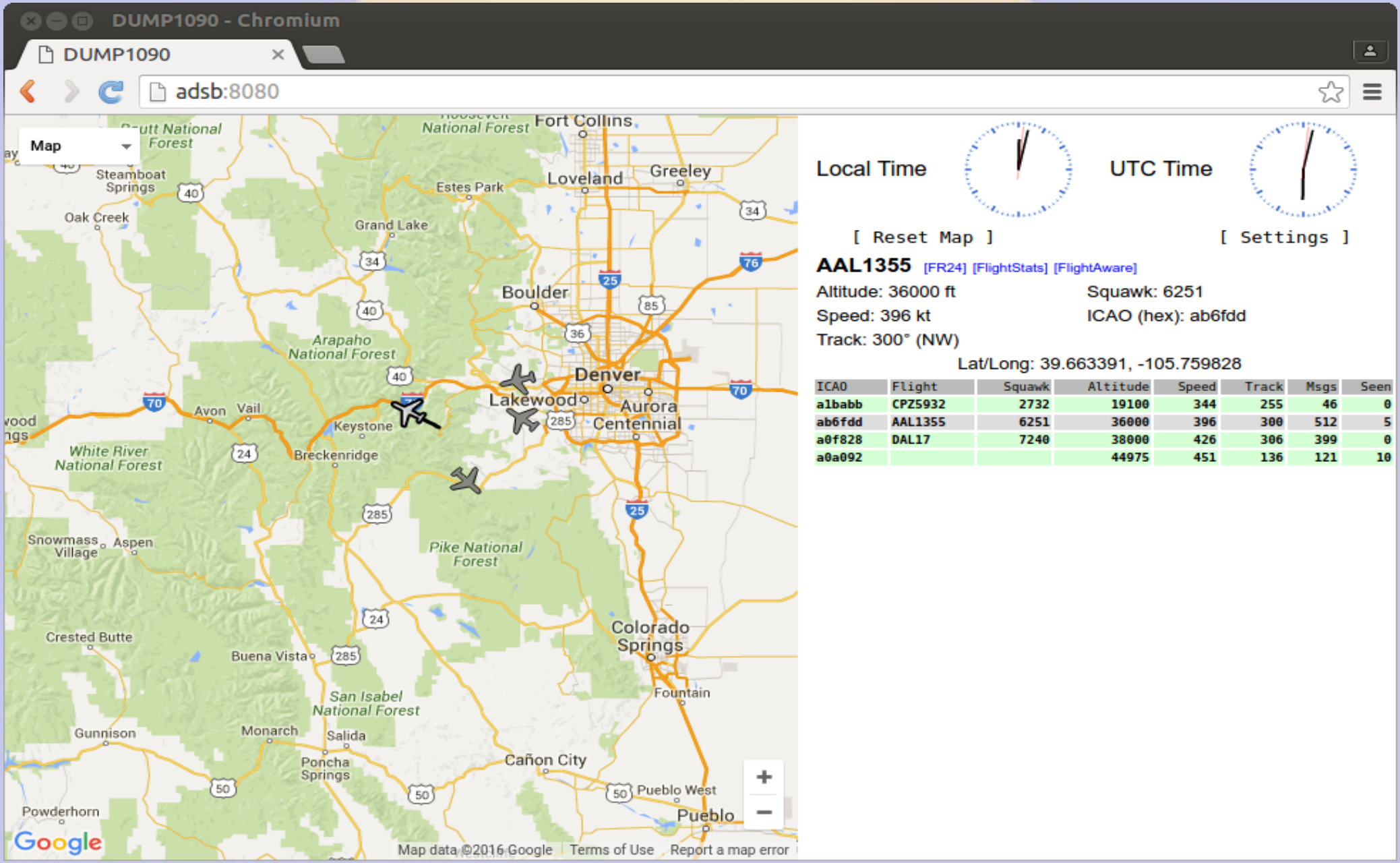
Where to go next

- Better hardware
  - Great Scott Gadgets HackRF
  - RFspace SDR-IQ
  - many others
- Specialized applications
  - ADSB
  - Freq Show

ADSB receiver

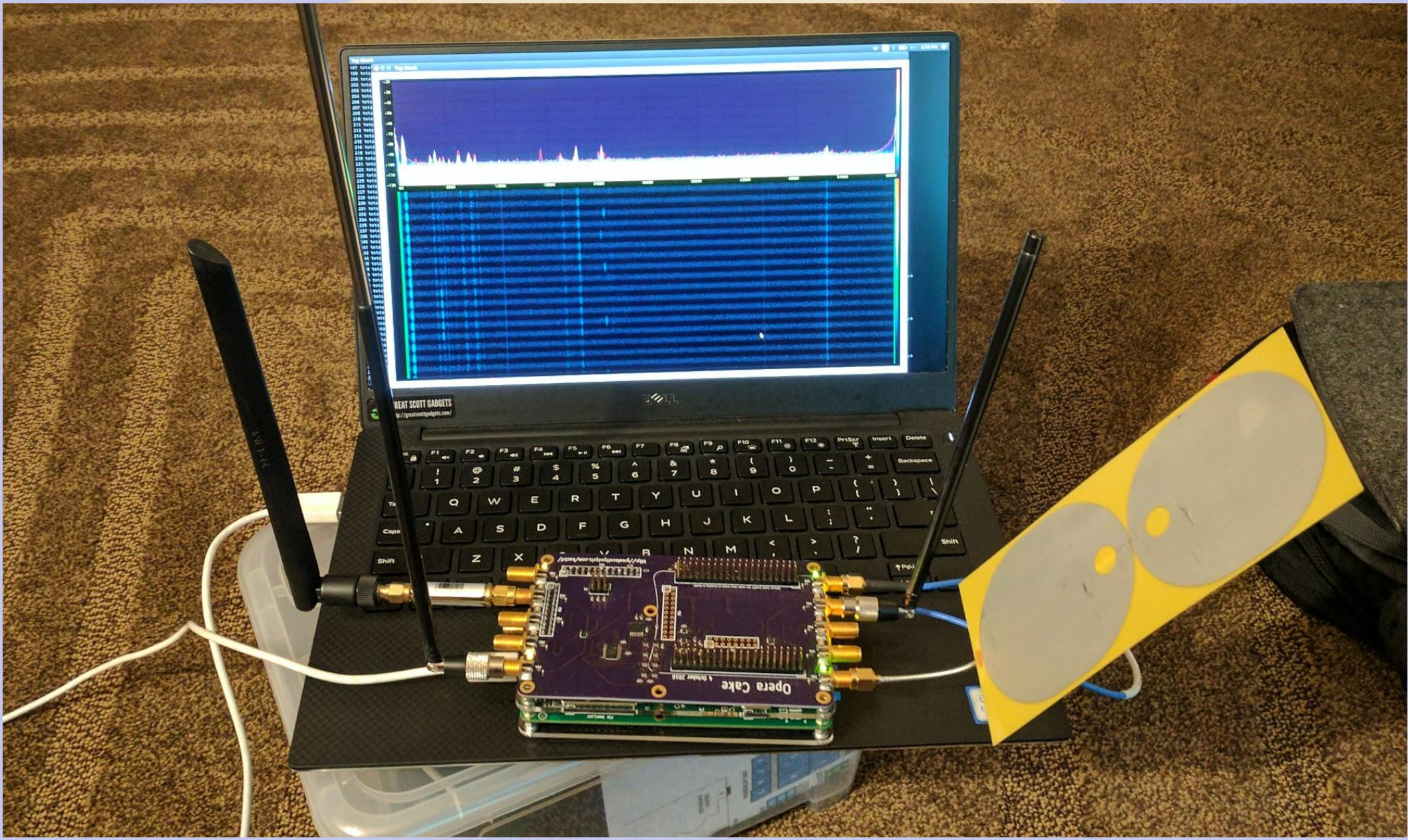
- Building the code
  - git clone git://github.com/MalcolmRobb/dump1090.git
  - cd dump1090
  - make
  - cd ..
- ./dump1090 --net --lon -105 --lat 39
  - --net enables web interface port 8080
  - --lon and –lat sets location

dump1090 ADSB web display



ICAO	Flight	Squawk	Altitude	Speed	Track	Msgs	Seen
a1babb	CPZ5932	2732	19100	344	255	46	0
ab6fdd	AAL1355	6251	36000	396	300	512	5
a0f828	DAL17	7240	38000	426	306	399	0
a0a092			44975	451	136	121	10

GSG Synchronized Antenna Switching



Show and Tell