Introduction to the RTL-SDR

Dayton Software Defined Radio Meetup
March 7, 2016

Welcome to Our First Meetup!

- Goal: Discuss interesting topics related to software defined radios and signal processing.
- Plan on hosting monthly meetings.
  - Possibly also host a special meeting during Hamvention week in May
- Looking for feedback:
  - What kinds of topics would you like to see presented?
  - What meeting time works best?
- Introductions
- Have an interesting topic or demo that you'd like to share? Please e-mail bhart@pretalen.com .

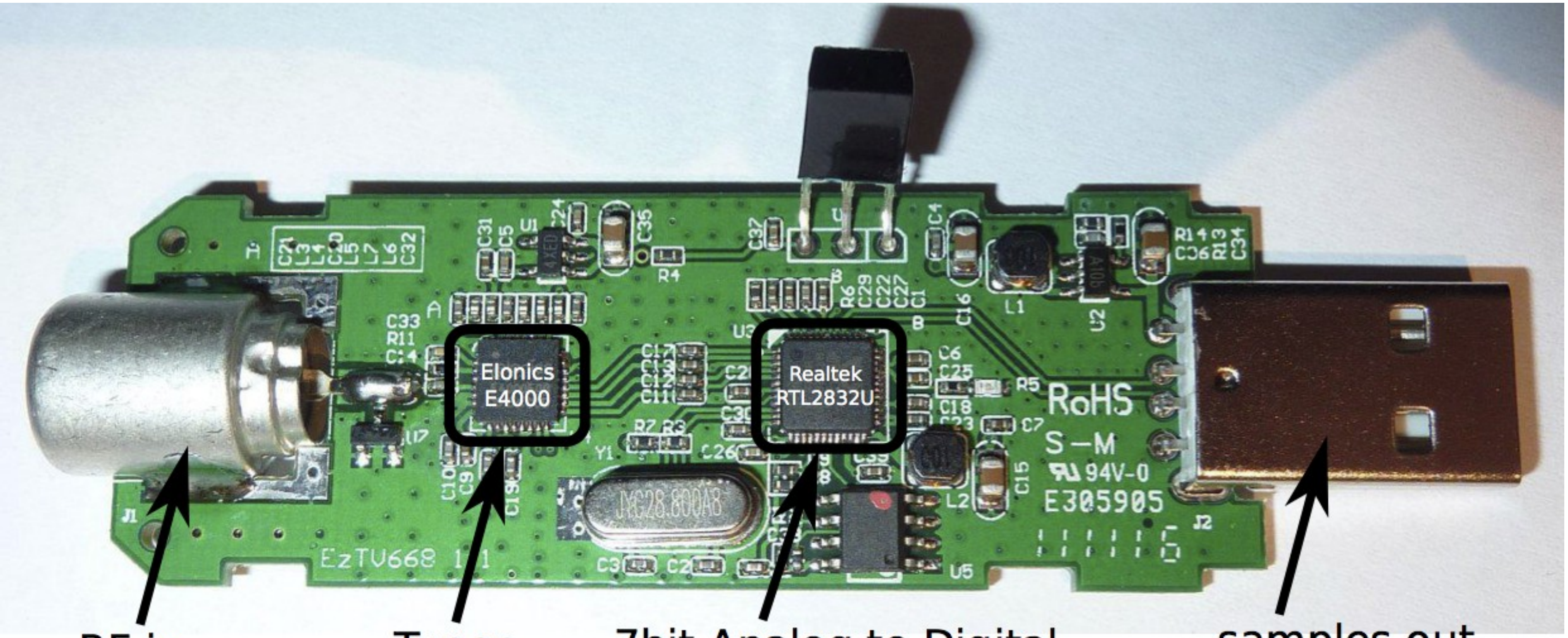
Meetup Sponsor -- PreTalen

- Thank you to our sponsor PreTalen for paying our group hosting fees, providing food and allowing us to use the office!
- If you are interested in signal processing and software defined radio PreTalen is currently looking to hire engineers in our Dayton office.
- Great opportunity to join a fast growing company with amazing benefits.
- Visit http://www.pretalen.com/careers for more information or see me after the meeting if you are interested in learning more.

What is an RTL-SDR anyway?

- Originally created as a low cost DVB-T receiver in a USB device
  - DVB-T is the TV transmission standard for Europe, Asia (except China), Australia and Africa
- Hobbyists discovered general purpose capabilities
- Using custom software, device can tune to other frequencies.
- Chipset is readily available to
- overseas manufacturers

Circuit Board



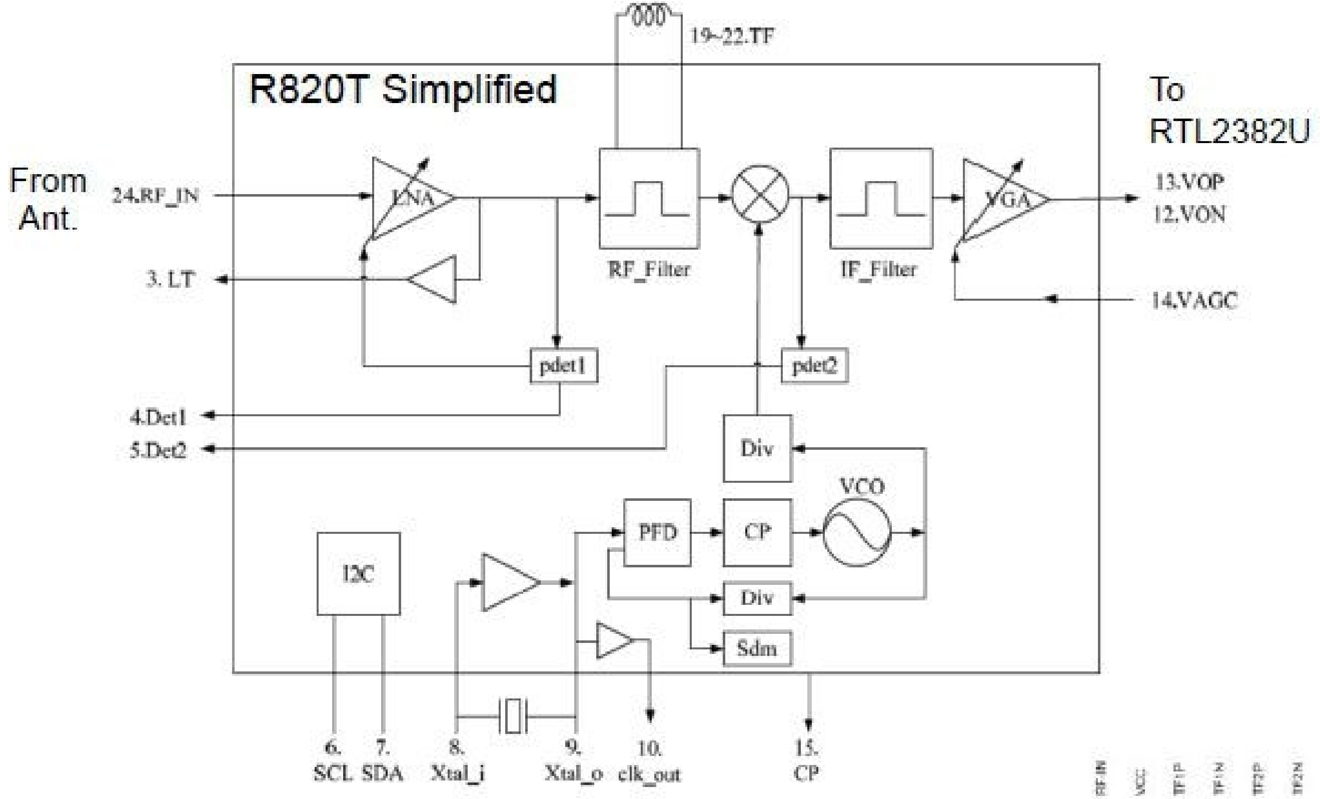
RF in

Tuner

7bit Analog to Digital

samples out

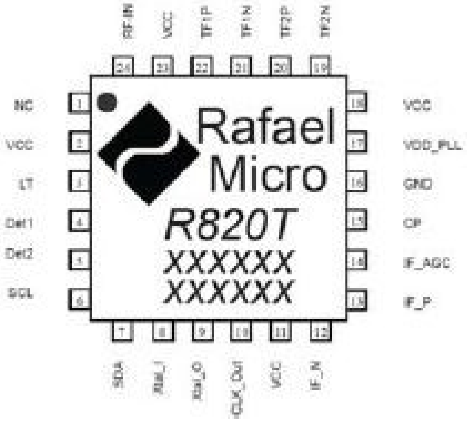
Tuner Component



Typical figures

■ Frequency range:	42 to 1002 MHz
■ Noise figure :	3.5 dB @ RF_IN
■ Phase noise:	-98 dBc/Hz @ 10 kHz
■ Current consumption:	< 178 mA @ 3.3V power supply
■ Max input power:	+10 dBm
■ Image rejection:	65 dBc

note: [dBm]=[dBuV on 75Ω] -108.75dB



Features of the RTL-SDR

- Low cost – less than $20 on Amazon
- Wide tuning range – 24 MHz to 1.7 GHz
- Instantaneous bandwidth of up to 3.2 MHz
- Works with almost any computer
    - Windows and Linux compatible
- Open source software
- Small and easy to use -- plugs into any USB 2.0 port on your computer

Limitations of the Hardware

- Cheap oscillator
  - Frequencies are inaccurate (up to +/- 70 ppm error)
  - Drifts with temperature
  - Phase noise
- Limited dynamic range
  - Only an 8 bit ADC
  - Roughly 45 dB of SFDR
- Cheap antenna
- No shielding

Setting Up the RTL-SDR on Linux

- Install GNURadio (recommended):

```
sudo apt-get install gnuradio-dev
```

- Install RTL-SDR library:

```
•    git clone https://github.com/balint256/gr-baz
•    cd gr-baz
•    sh bootstrap
•    ./configure
•    make
•    sudo make install
•    sudo ldconfig
```

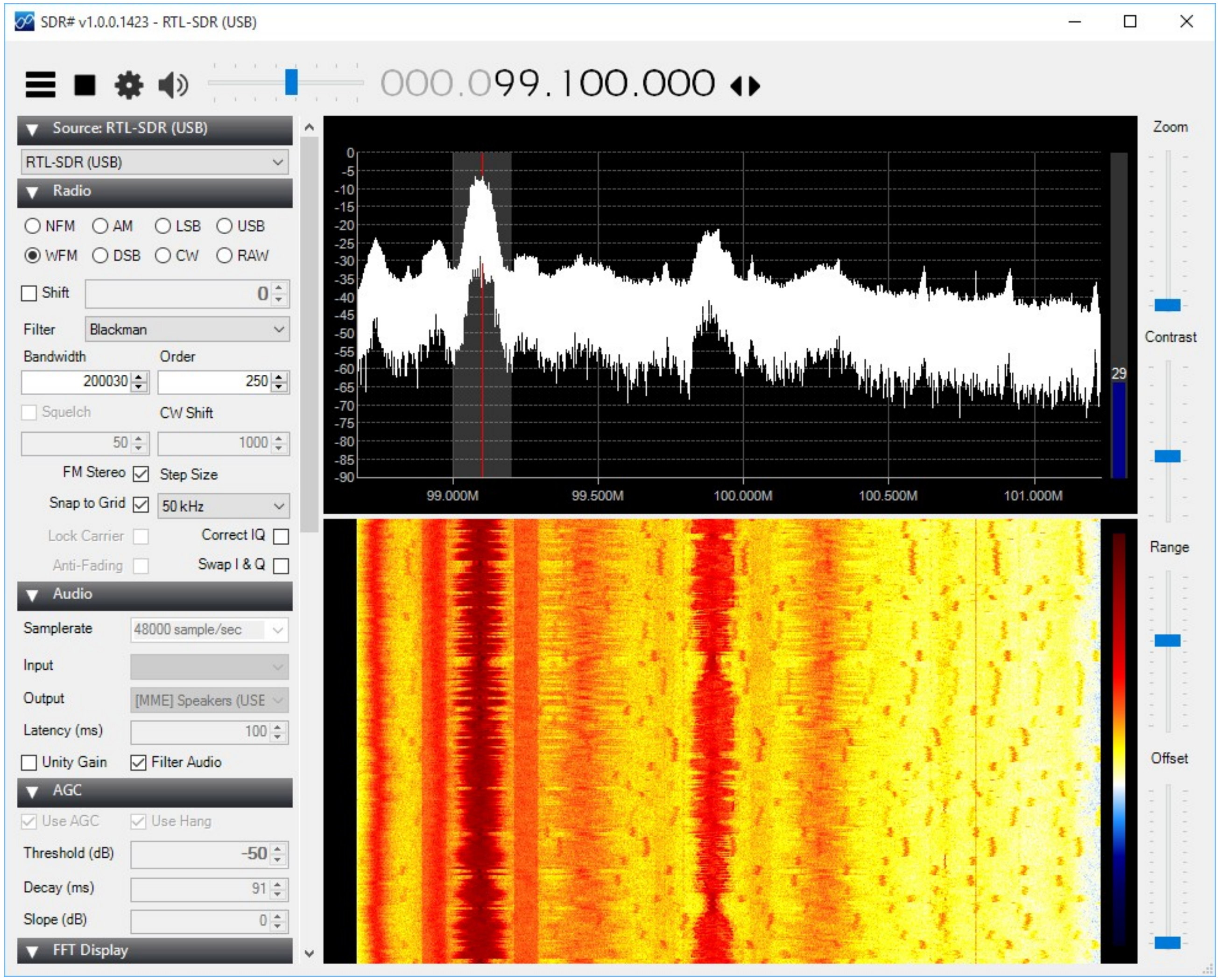
Install GQRX:

```
•    sudo apt-get install gqrx-sdr
```

Blacklist Incompatible Driver

- dvb_usb_rtl28xxu module is incompatible with driver for RTL-SDR
- Need to add to blacklist
- Edit /etc/modprobe.d/rtlsdr.conf
- Add the following line and reboot:
  - blacklist dvb_usb_rtl28xxu
- Can also run (if module is not locked):
  - rmmod dvb_usb_rtl28xxu

SDRSharp for Windows



SDR# v1.0.0.1423 - RTL-SDR (USB)

000.099.100.000

Source: RTL-SDR (USB)

RTL-SDR (USB)

Radio

○ NFM ○ AM ○ LSB ○ USB

● WFM ○ DSB ○ CW ○ RAW

□ Shift 0

Filter Blackman

Bandwidth 200030 Order 250

□ Squelch 50 CW Shift 1000

FM Stereo ☑ Step Size

Snap to Grid ☑ 50 kHz

Lock Carrier □ Correct IQ □

Anti-Fading □ Swap I & Q □

Audio

Samplerate 48000 sample/sec

Input

Output [MME] Speakers (USE

Latency (ms) 100

□ Unity Gain ☑ Filter Audio

AGC

☑ Use AGC ☑ Use Hang

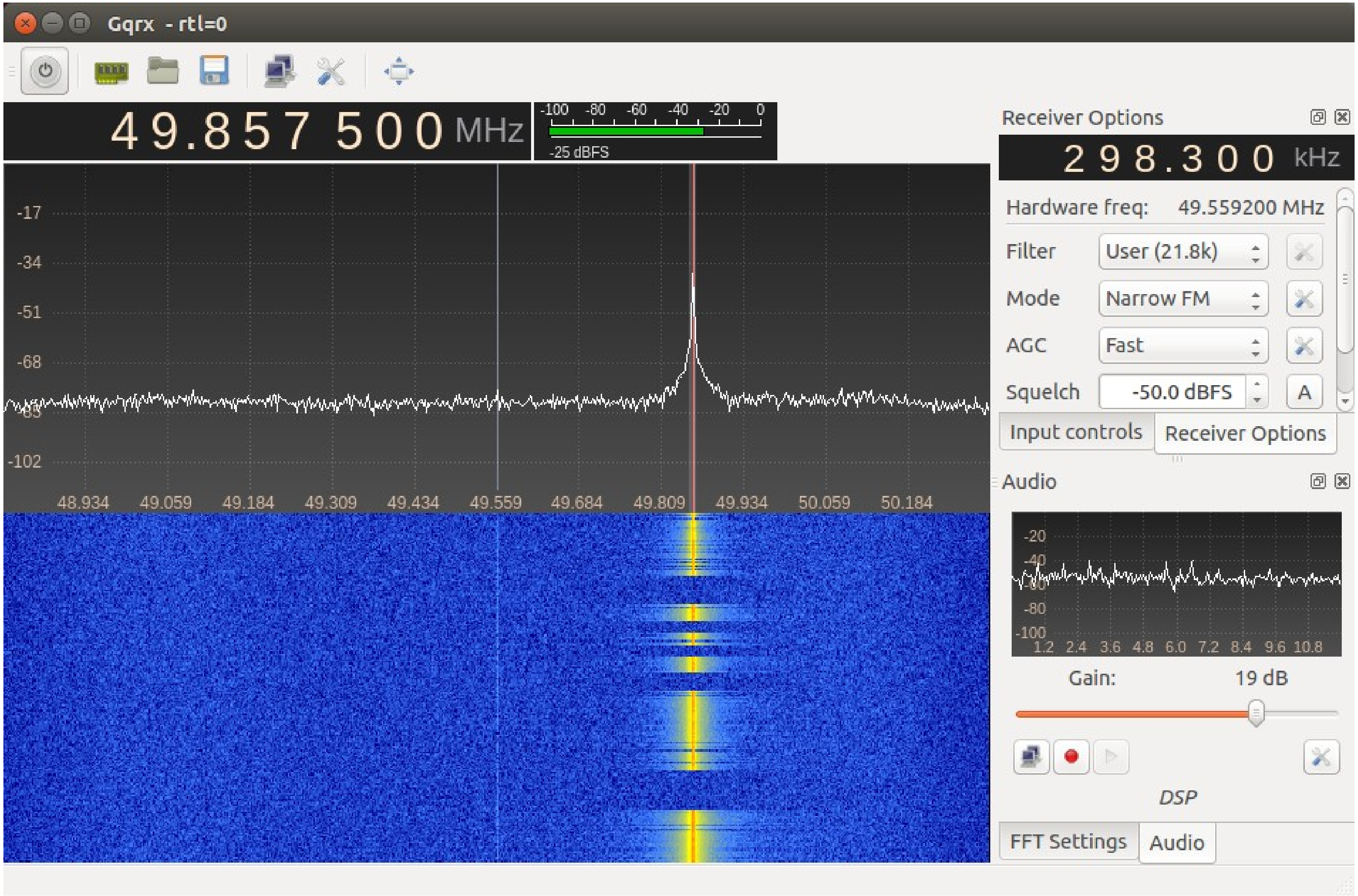
Threshold (dB) -50

Decay (ms) 91

Slope (dB) 0

FFT Display

GQRX for Linux



Gqrx - rtl=0

49.857 500 MHz

-25 dBFS

Receiver Options

298.300 kHz

Hardware freq: 49.559200 MHz

Filter: User (21.8k)

Mode: Narrow FM

AGC: Fast

Squelch: -50.0 dBFS

Gain: 19 dB

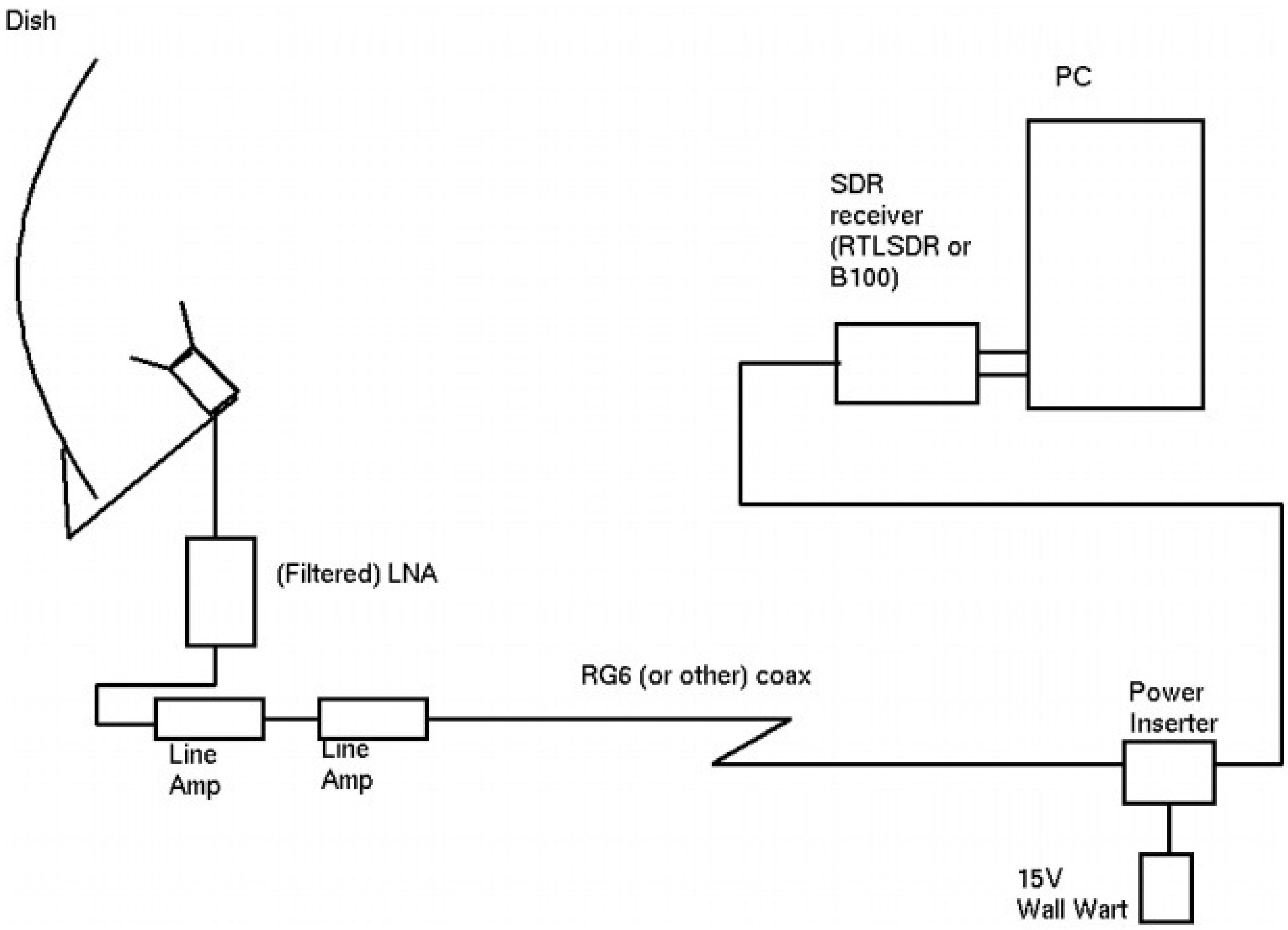
GQRX Demo

- This demo will show the GQRX software in action.

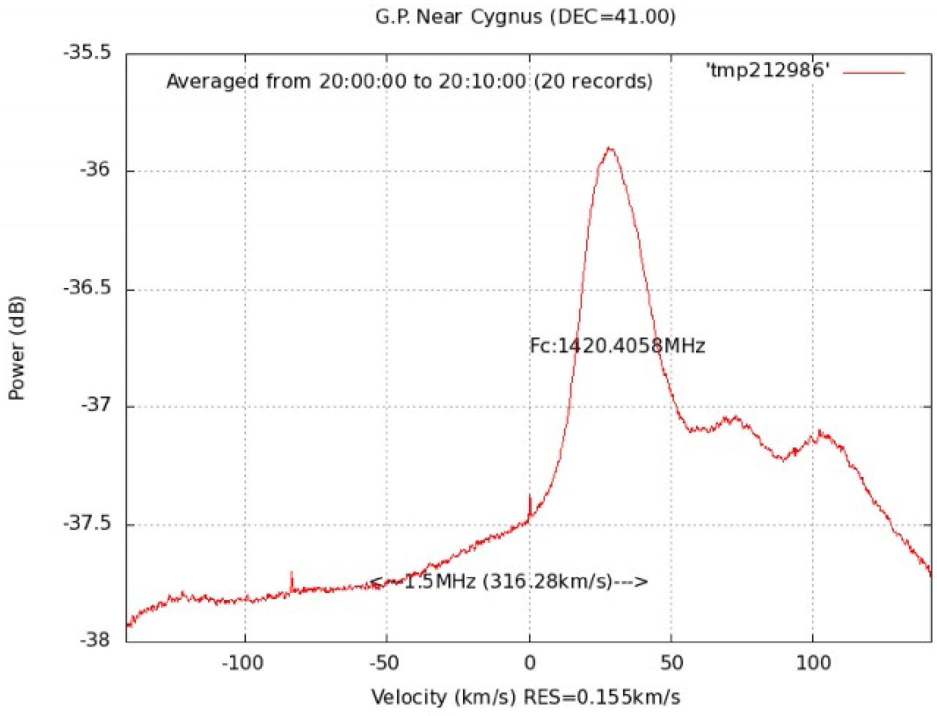
- FM radio stations:
  - 107.7 MHz
  - 103.9 MHz
  - 104.7 MHz
  - 88.1 MHz

- ADS-B/Mode S – 1090 MHz
- Verizon LTE – 746 – 757 MHz, 776-787 MHz
- WHIO TV – 633.25 MHz
- NOAA Weather Radio – 162.475 MHz (NFM)

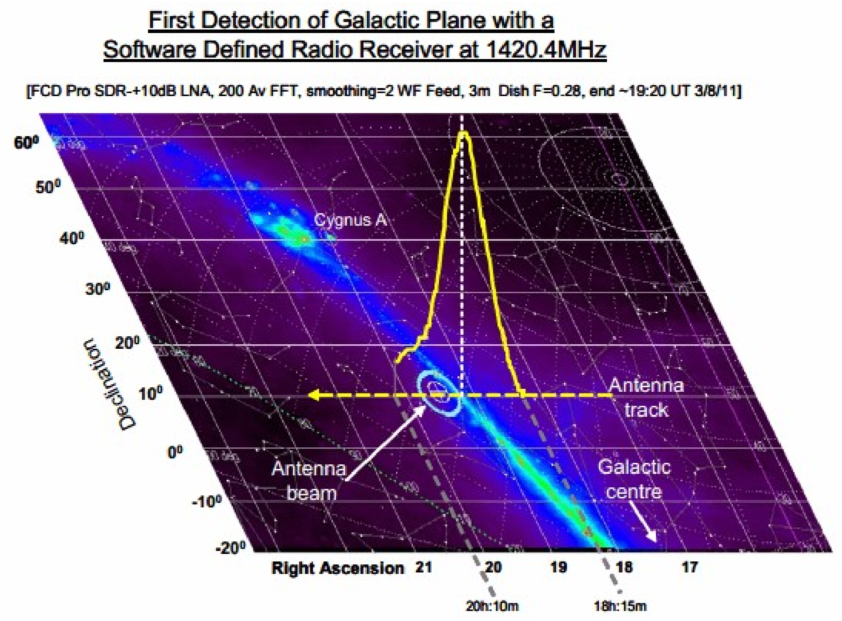
Cool Application – Radio Telescope



Radio Telescope Results



G.P. Near Cygnus (DEC=41.00)

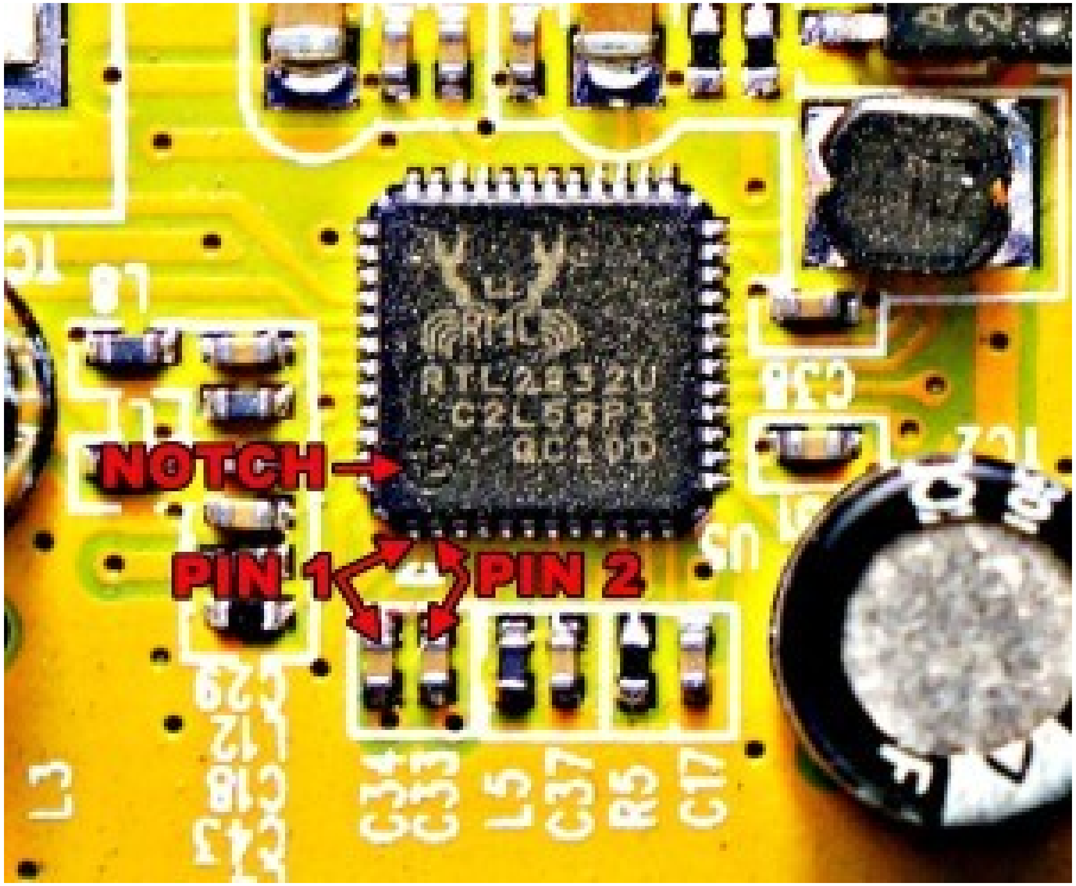


First Detection of Galactic Plane with a Software Defined Radio Receiver at 1420.4MHz

[FCD Pro SDR-+10dB LNA, 200 Av FFT, smoothing=2 WF Feed, 3m Dish F=0.28, end ~19:20 UT 3/8/11]

Hardware Modification – Lower Tuning Range

- Solder a wire to pin 1 or pin 2 of the RTL chip

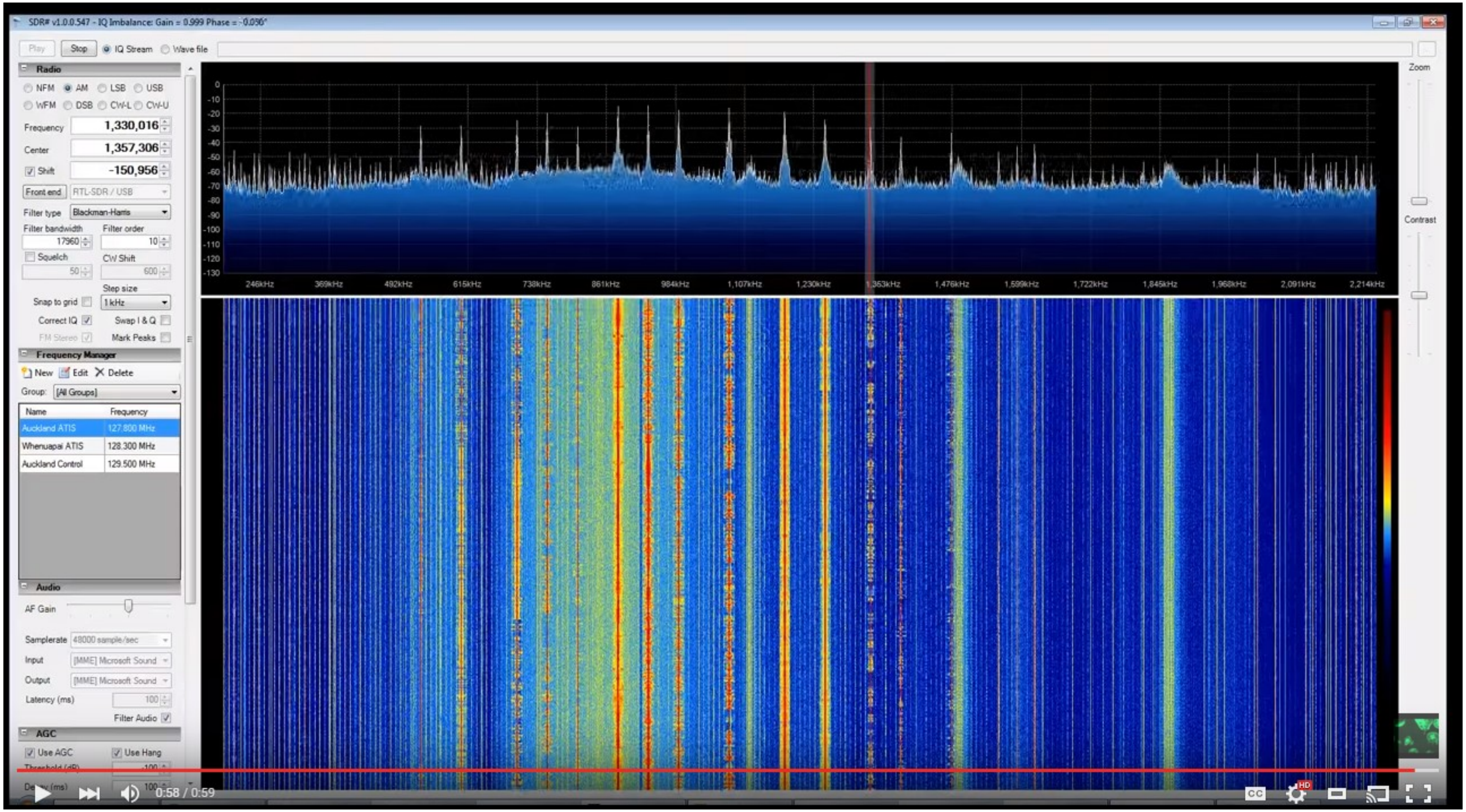


Hardware Modification – Lower Tuning Range

- How does the modification work?
- Wire acts as an antenna – bypasses tuner and goes directly into ADC
- Receives signals from 0-14.4 MHz
- Can also receive image from 14.4-28 MHz if band pass filter is used
- FM interference can be a problem – filtering is recommended
- Matching transformer for differential input can also improve the reception at low frequencies
- More information: http://www.rtl-sdr.com/rtl-sdr-direct-sampling-mode/

AM Radio Demo with Low Frequency Mod

- https://www.youtube.com/watch?v=JCE9SeQ3dJQ



SDR# v1.0.0.547 - IQ Imbalance: Gain = 0.999 Phase = -0.096°

Play | Stop | ● IQ Stream | ○ Wave file

Radio

○ NFM ● AM ○ LSB ○ USB

○ WFM ○ DSB ○ CW-L ○ CW-U

Frequency 1,330,016

Center 1,357,306

☑ Shift -150,956

Front end: RTL-SDR / USB

Filter type: Blackman-Harris

Filter bandwidth 17960

Filter order 10

□ Squelch 50

CW Shift 600

Step size 1 kHz

Snap to grid □

Correct IQ ☑

Swap I & Q □

FM Stereo ☑

Mark Peaks □

Frequency Manager

New | Edit | Delete

Group: [All Groups]

Name	Frequency
Auckland ATIS	127.800 MHz
Whenuapai ATIS	128.300 MHz
Auckland Control	129.500 MHz

Audio

AF Gain

Samplerate 48000 sample/sec

Input [MME] Microsoft Sound

Output [MME] Microsoft Sound

Latency (ms) 100

Filter Audio ☑

AGC

☑ Use AGC ☑ Use Hang

Threshold (dB) -100

Decay (ms) 100

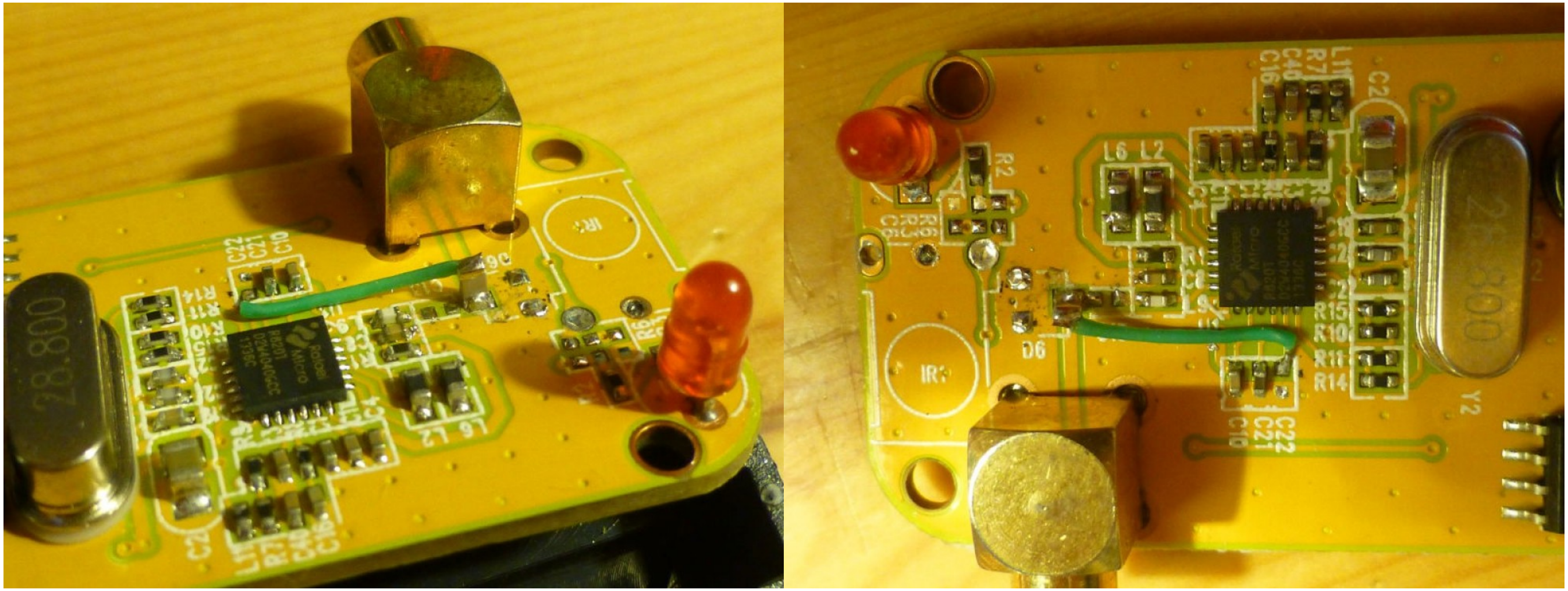
Hardware Modification – Tone Transmission

- Possible to use the hardware to transmit tones.

- Be careful! Could violate FCC regulations if transmitting in regulated bands.

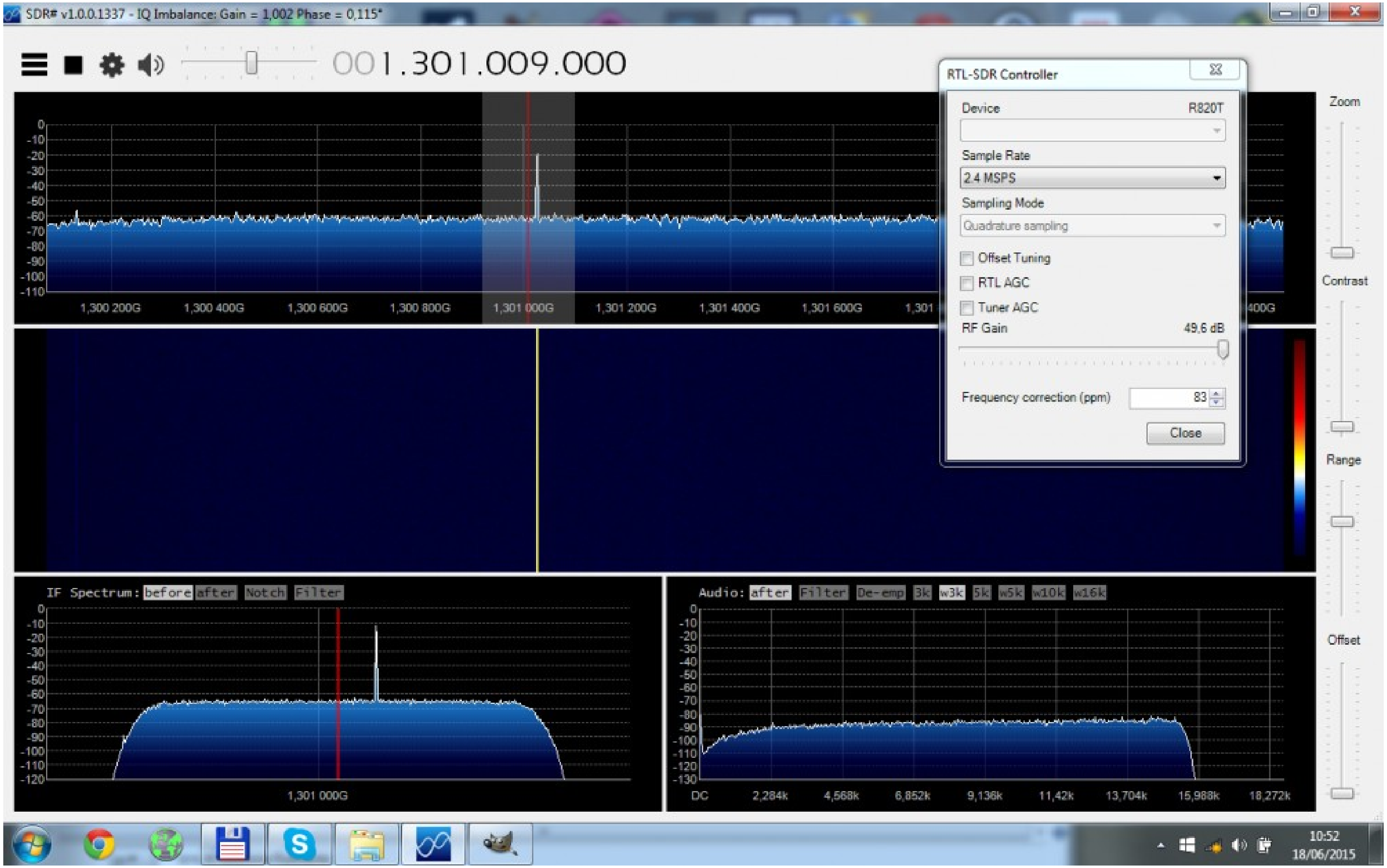
- Hardware mod steps:
  - Remove the input capacitor C13 ;
  - Remove the bypass capacitor C22 ;
  - Remove the protection diode D6 ;
  - Wire a capacitor 100pF connecting the Antenna input (D6 pad) to the pin 5 of R820T (ex C22 pad).

Hardware Modification – Tone Transmission



http://www.steila.com/SDR/RFgenmod/index.html

Tone Transmission



SDR# v1.0.0.1337 - IQ Imbalance: Gain = 1,002 Phase = 0,115°

001.301.009.000

RTL-SDR Controller

Device R820T

Sample Rate: 2.4 MSPS

Sampling Mode: Quadrature sampling

□ Offset Tuning

□ RTL AGC

□ Tuner AGC

RF Gain 49,6 dB

Frequency correction (ppm) 83

Close

RTL-SDR in GNURadio

- RTL-SDR can act as a source directly in GNURadio
- Makes it easy to tune and acquire samples
- Simple to do things like:
  - Record data to a file
  - Demodulate signals to audio
  - Filtering of signal data
  - Plot signal waterfall or frequency spectrum
- GNURadio companion exposes GNURadio components as drag and drop blocks

RC Car Controller Demonstration

- Goal: Demonstrate decoding an RF protocol using the RTL-SDR
- Something different than online tutorials
- More interesting than broadcast AM/FM station
- Selected an RC car controller:
  - 49 MHz center frequency
  - RF protocol is unknown – need to use GNU radio to analyze and build decoder
  - 8 different commands : up, down, left, right, up+left, up+right, down+left, down+right

RC Signal Analysis

- Plotted data -- hard to see in real time
- Used GNURadio to write samples to a file
- Discovered the signal is pulsed CW
  - Also called on-off keying (OOK) or binary keying
- Simple signal – easy to generate with cheap electronics
- Single frequency – avoids intermod products on cheap amplifier

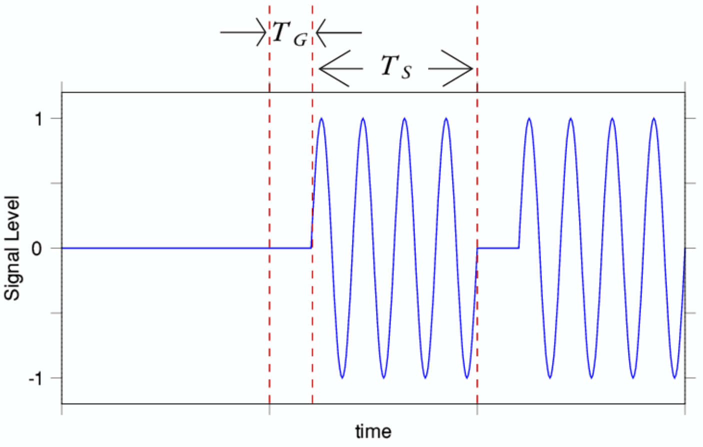
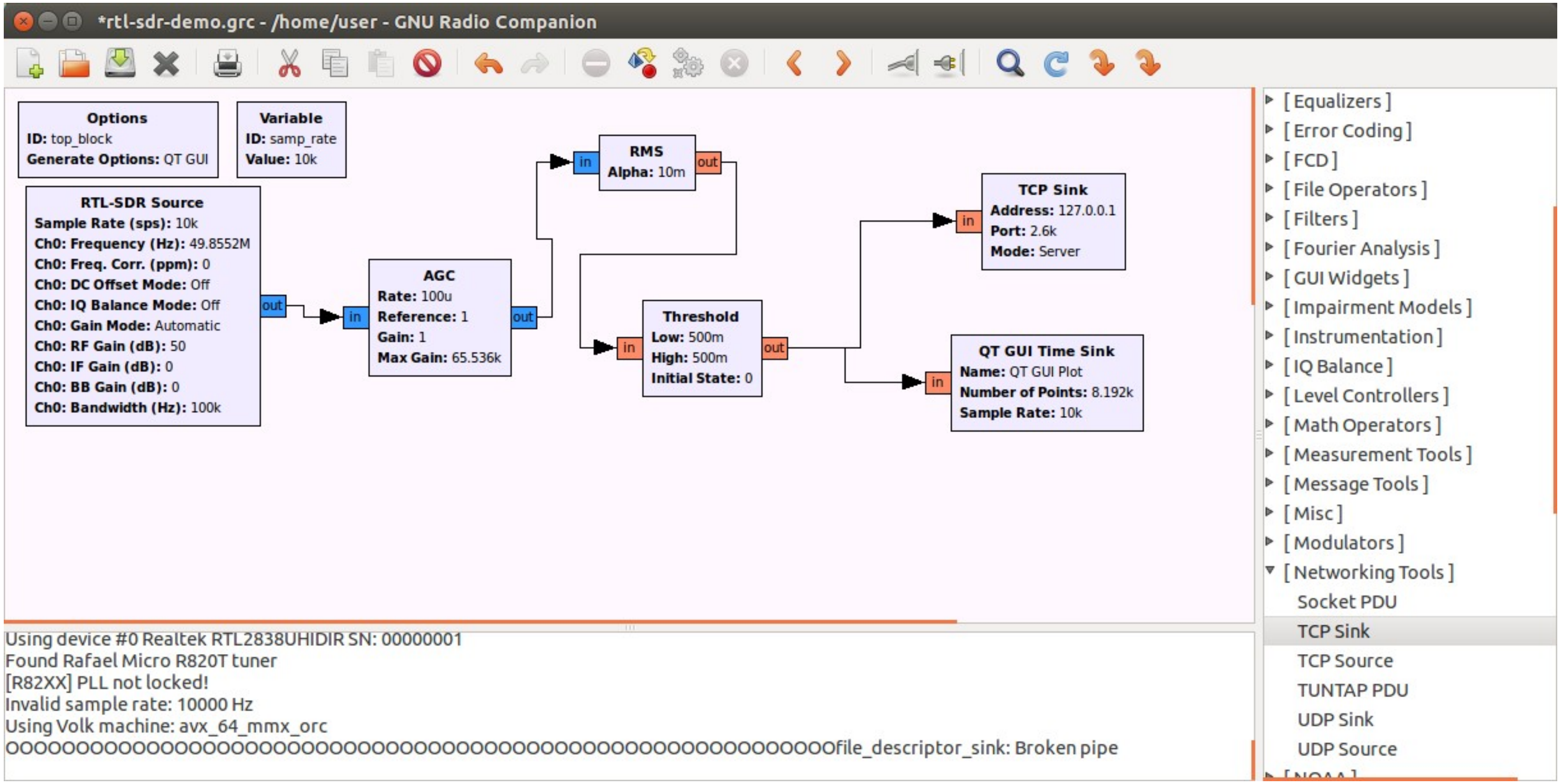


Fig 19.2 Symbol and Guard durations.

Signal Decoder

- Demodulation is pretty simple: the goal is to get the envelope of the function and then decode the bit sequence
- Process: filter on the center frequency, take the root mean squared of the signal
- Signal can only take on two values: on or off
- Use thresholding to convert to on-off values
- How to decode the bit sequence?
  - Captured all commands to data files
  - Wrote a C++ program to analyze the data

Block Diagram of Receiver



Options
ID: top_block
Generate Options: QT GUI

Variable
ID: samp_rate
Value: 10k

RTL-SDR Source
Sample Rate (sps): 10k
Ch0: Frequency (Hz): 49.8552M
Ch0: Freq. Corr. (ppm): 0
Ch0: DC Offset Mode: Off
Ch0: IQ Balance Mode: Off
Ch0: Gain Mode: Automatic
Ch0: RF Gain (dB): 50
Ch0: IF Gain (dB): 0
Ch0: BB Gain (dB): 0
Ch0: Bandwidth (Hz): 100k

AGC
Rate: 100u
Reference: 1
Gain: 1
Max Gain: 65.536k

RMS
Alpha: 10m

Threshold
Low: 500m
High: 500m
Initial State: 0

TCP Sink
Address: 127.0.0.1
Port: 2.6k
Mode: Server

QT GUI Time Sink
Name: QT GUI Plot
Number of Points: 8.192k
Sample Rate: 10k

```
Using device #0 Realtek RTL2838UHIDIR SN: 00000001
Found Rafael Micro R820T tuner
[R82XX] PLL not locked!
Invalid sample rate: 10000 Hz
Using Volk machine: avx_64_mmx_orc
OOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOOfile_descriptor_sink: Broken pipe
```

Bit Sequence

- Controller sends two types of pulses: short pulse (3 ms) and long pulse (8.25 ms)

- Used a 5 ms cutoff to separate short and long pulses

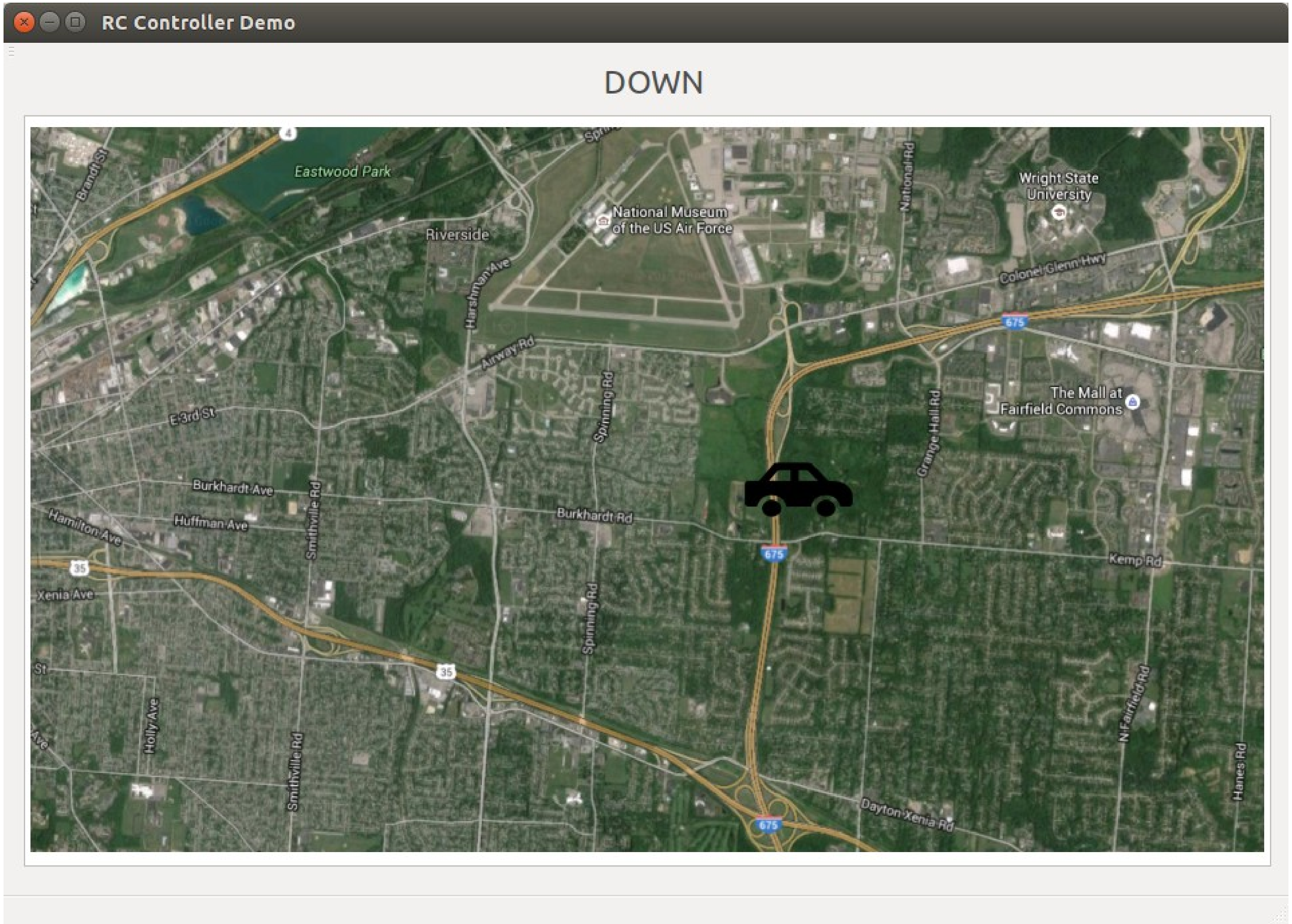
- Command always starts with four long pulses followed by a series of short pulses:

UP	10 pulses	DOWN	40 pulses
LEFT	58 pulses	RIGHT	64 pulses
DOWN + LEFT	52 pulses	UP + LEFT	28 pulses
DOWN + RIGHT	46 pulses	UP + RIGHT	34 pulses

Bit Decoder

- GNURadio feeds output over a local TCP socket to a custom Qt application
- Application uses a simple state machine to determine command:
  - Short pulses increment a counter
  - Long pulses reset the counter, execute commands
- When command is decoded, car icon is moved around on the screen
- Qt signals and slots approach makes it easy to buffer up TCP data and process periodically

Qt Software Demonstration



DOWN

Thank You!

- Questions?
- Next Meetup: April 4th
  - An Introduction to GNURadio
- Feedback on what you’d like to see from the group:
  - Email bhart@pretalen.com
- Invite your friends. We are trying to grow this group over time.
- Any interest in online streaming of meetings?
- Presentations are available on the Meetup site:

http://www.meetup.com/Dayton-Area-Software-Defined-Radio-Meetup/files/

- Software demonstration files are available on GitHub:
  - https://github.com/brucehart/dayton-sdr