# Signal SAFARI

MWR LABS

BSidesNYC 2018

# Welcome!

- Curious about RF?
- Looking for awesome new projects?
- Seeking adventure?

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## Agenda

- RF Overview / Exploration
  - GQRX
- Light Switch Reversing
  - RTL_433
- Fan Controller
  - GNU Radio Companion (GRC)
- Signal Security
- Continuing the Adventure

## Safari Guide

Katie Knowles, @_sigil

- Security Consultant, MWR InfoSecurity
- RF Enthusiast
- Infosec Explorer

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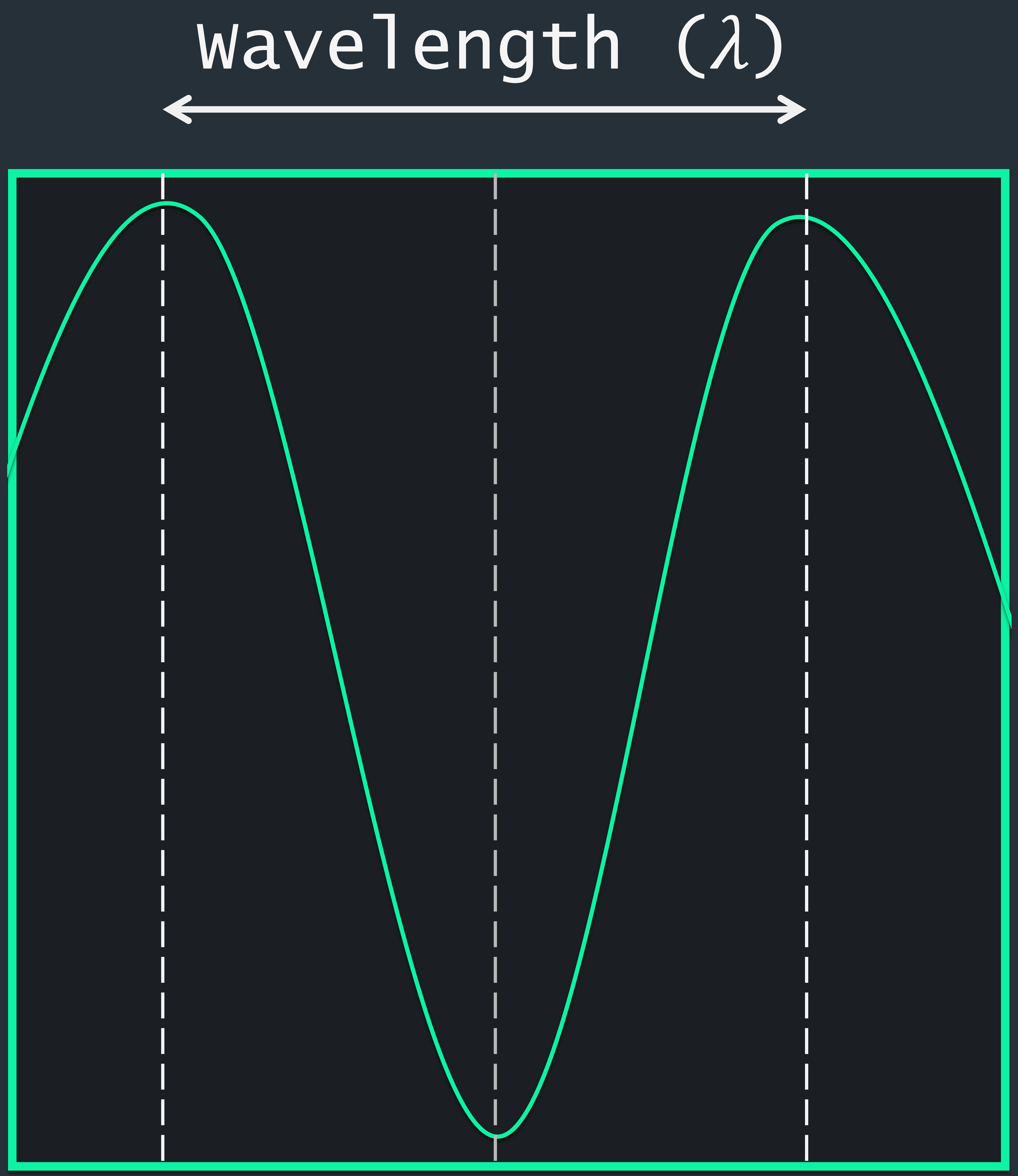
## Fundamentals



- RF travels as electromagnetic (EM) waves
- EM waves travel at the speed of light ($c$)
- Wavelength ($\lambda$): The length of the wave
- Frequency ($f$): How many wavelengths happen in a unit of time, based on the wave's speed
- Multiplying Wavelength ($\lambda$) by Frequency ($f$) will always equal the speed of light ($c$)

$$c = 3 * 10^8\, m/s = f * \lambda$$

# Investigating Unknown Signals:

RTL-SDR.COM
QUICKSTART SETUP GUIDE: RTL-SDR.COM/QSG
DVB-T+DAB+FM+SDR
RTL2832U R820T2 TCXO+BIAS T+HF
V.3

RTL-SDR

*(~$30)*

+

Linux

*(Free)*

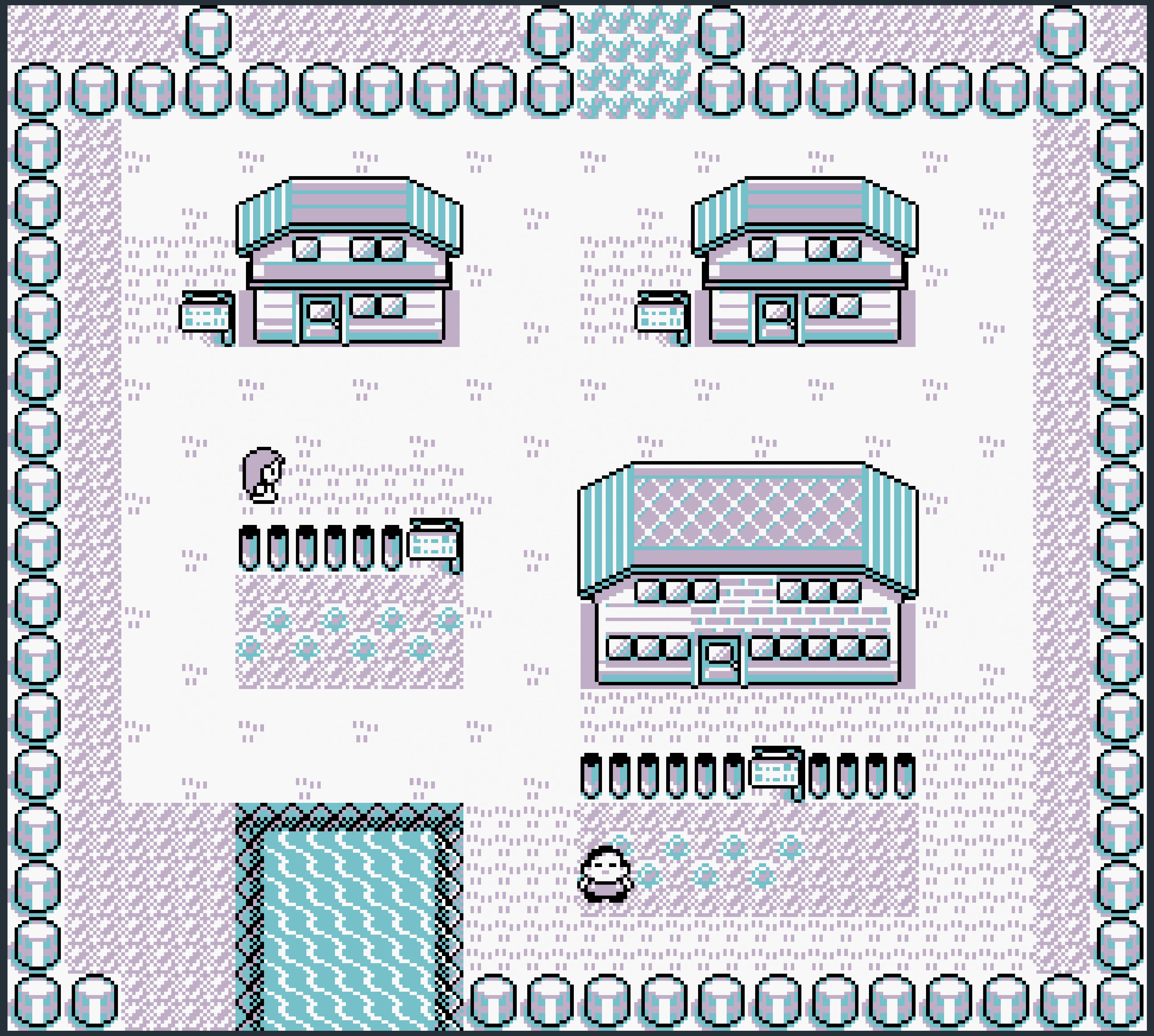
=

✨

MAGIC!

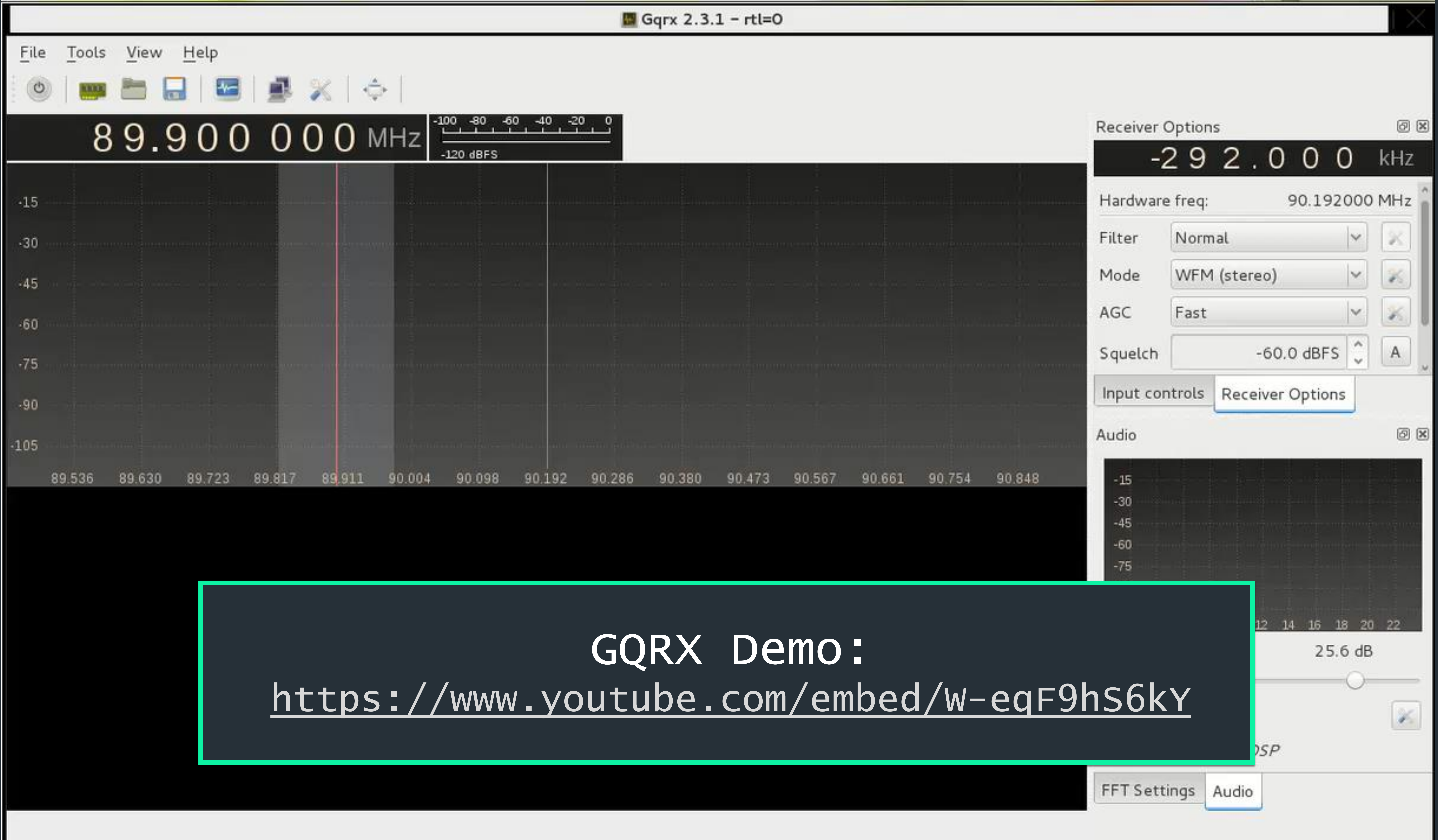
*(Priceless)*

# First Steps with GQRX



- Simple program for tuning Software Defined Radios (SDRs)
- “Waterfall” view of activity at different frequencies over time
- Frequency range limited based on hardware of SDR in use

http://gqrx.dk/



89.900 000 MHz

-292.000 kHz

Hardware freq: 90.192000 MHz

Filter: Normal

Mode: WFM (stereo)

AGC: Fast

Squelch: -60.0 dBFS

## GQRX Demo:

https://www.youtube.com/embed/W-eqF9hS6kY

# Signal Safari

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AM Radio

525-1705 kHz

“Ham” Radio

FM Radio

88-108 MHz

Television

54-88 MHz

174-216 MHz

480-806 MHz

WiFi

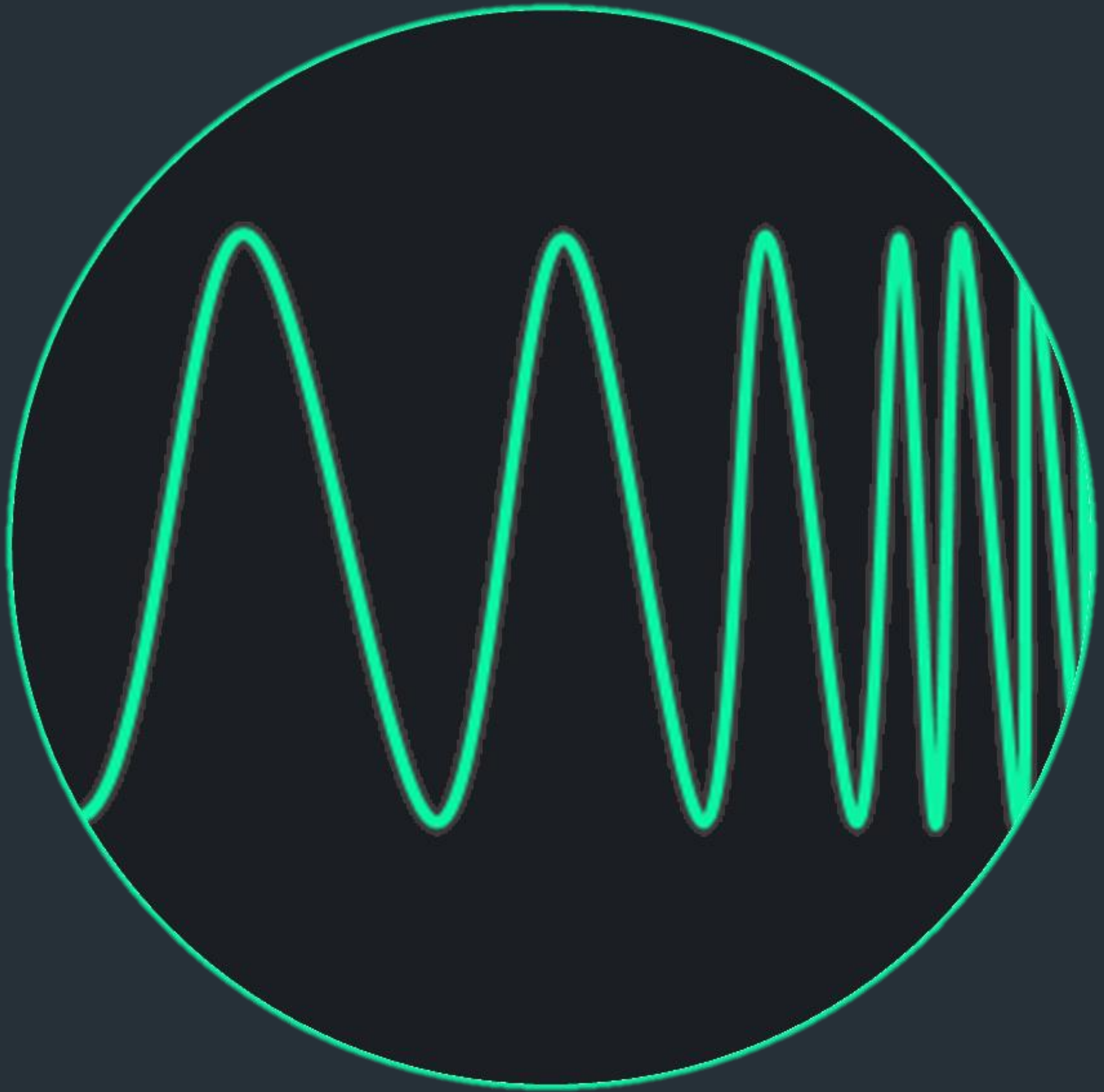
2.4 GHz

5 GHz

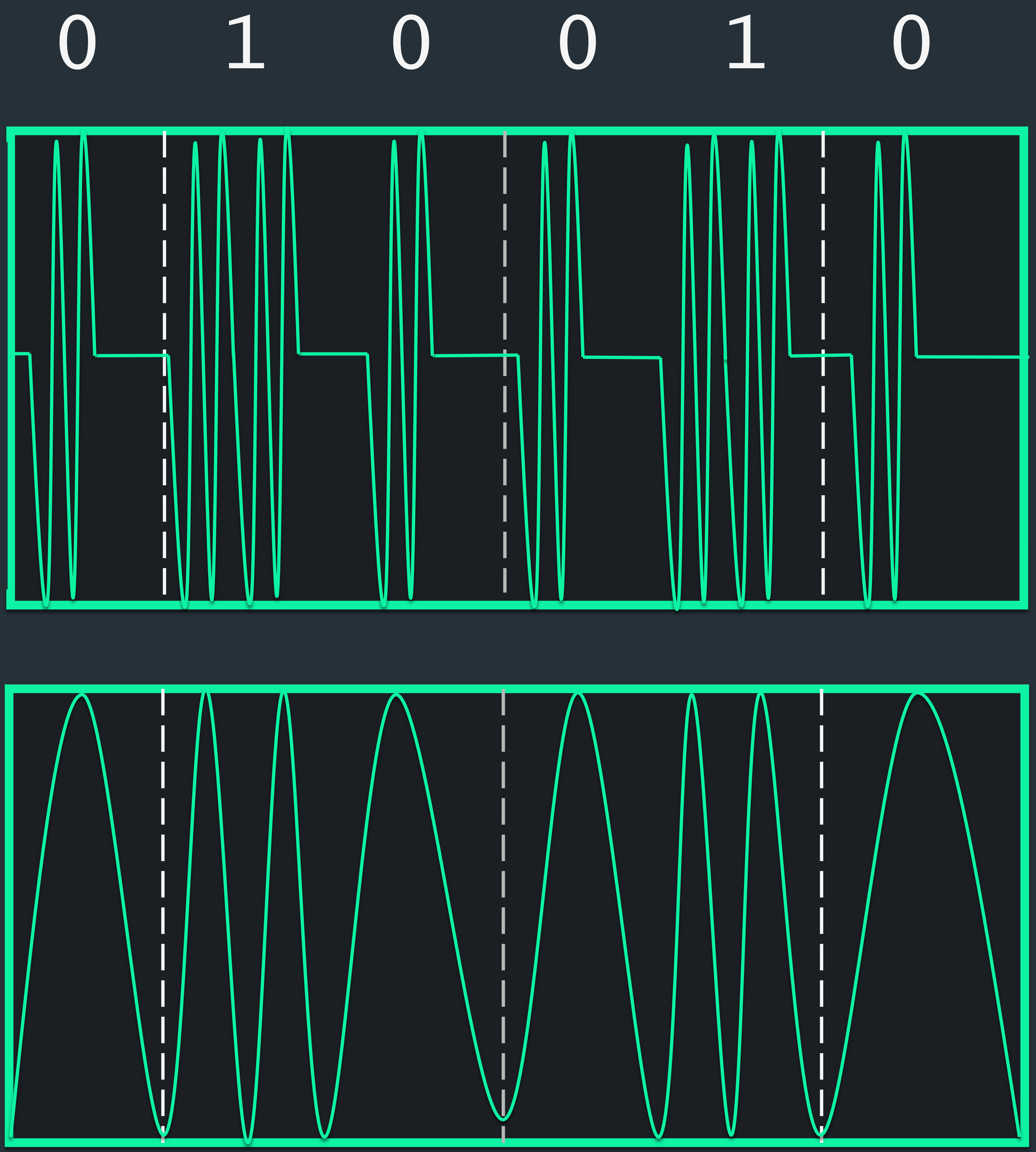
Cell

MF
HF
VHF
UHF
SHF
300 kHz
3 MHz
30 MHz
300 MHz
3 GHz

# Short-Range Device Frequencies



| Center $f$ | Starts at: | Ends at: | Type |
|---|---|---|---|
| 433 MHz | 433.05 MHz | 434.79 MHz | ISM |
| 915 MHz | 902 MHz | 928 MHz | ISM |
| 2.45 GHz | 2.4 GHz | 2.5 GHz | ISM |
| 5.8 GHz | 5.725 GHz | 5.875 GHz | ISM |
| 315 MHz | 285 MHz | 322 MHz | Unlicensed |



# Simple Control Signals

## + ASK: Amplitude-Shift Keying

Amplitude (strength) of signal communicates 1 or 0.

*Pictured: A short pulse is 0, and a long pulse is 1. Also known as On-Off Keying (OOK).*

## + FSK: Frequency-Shift Keying

Frequency ($f$) of signal communicates 1 or 0.

*Pictured: A low frequency is 0, and a high frequency is 1.*

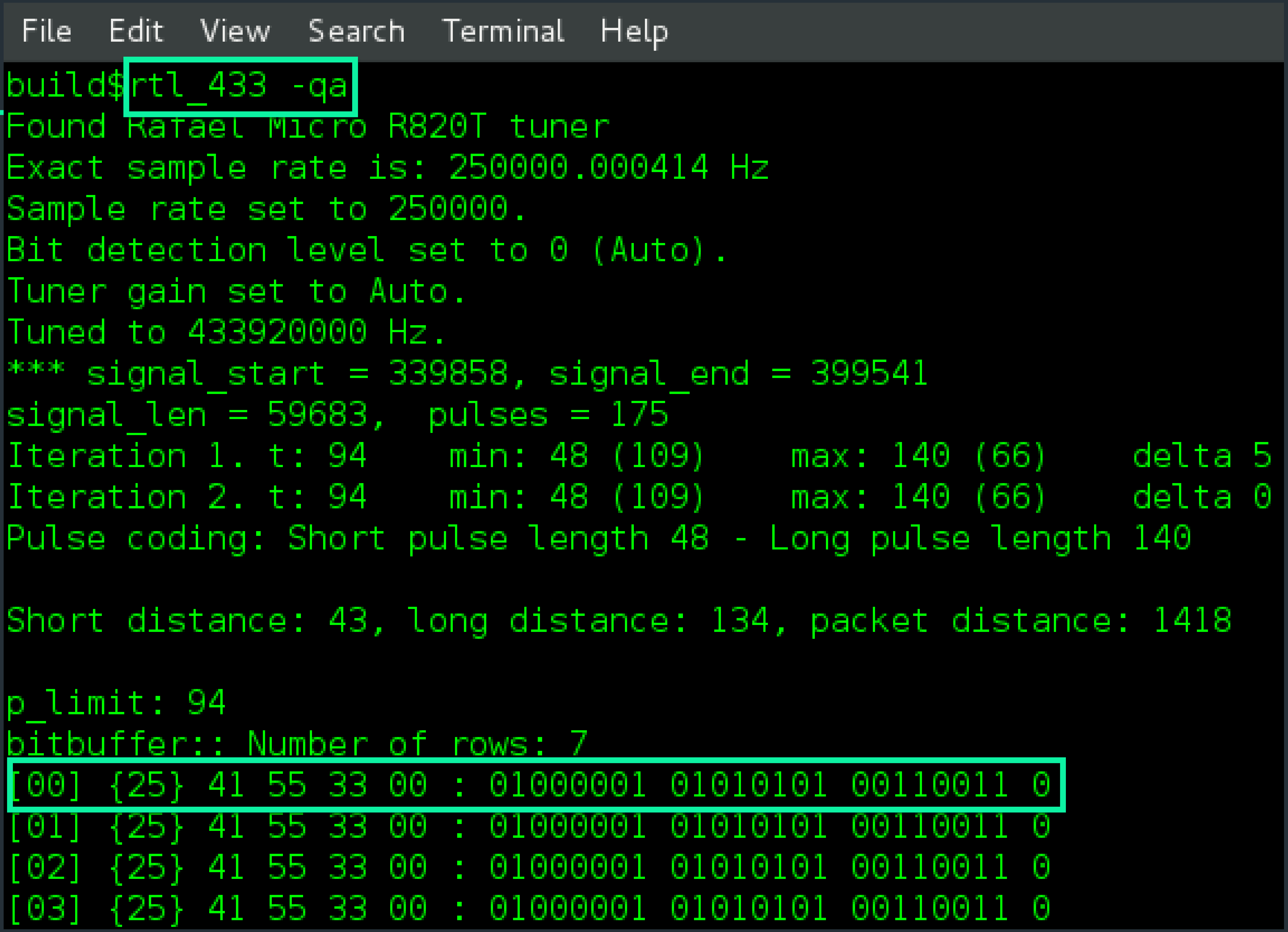
# MYSTERY SIGNAL!

Signal Safari

If only we had a tool...

SIGNAL FOUND:

010000010101010100111100

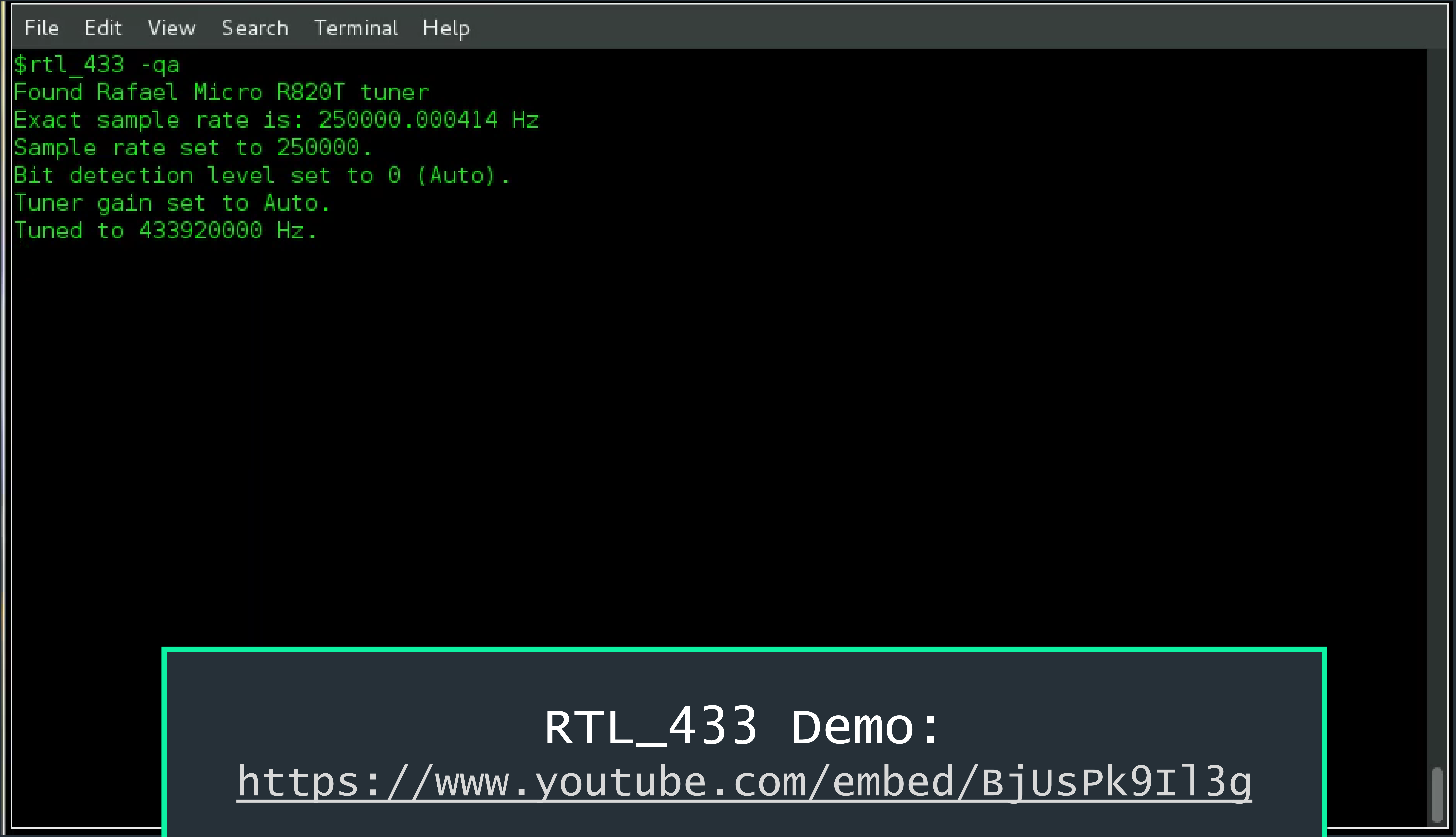


```
build$rtl_433 -qa
Found Rafael Micro R820T tuner
Exact sample rate is: 250000.000414 Hz
Sample rate set to 250000.
Bit detection level set to 0 (Auto).
Tuner gain set to Auto.
Tuned to 433920000 Hz.
*** signal_start = 339858, signal_end = 399541
signal_len = 59683,  pulses = 175
Iteration 1. t: 94    min: 48 (109)    max: 140 (66)    delta 5
Iteration 2. t: 94    min: 48 (109)    max: 140 (66)    delta 0
Pulse coding: Short pulse length 48 - Long pulse length 140

Short distance: 43, long distance: 134, packet distance: 1418

p_limit: 94
bitbuffer:: Number of rows: 7
[00] {25} 41 55 33 00 : 01000001 01010101 00110011 0
[01] {25} 41 55 33 00 : 01000001 01010101 00110011 0
[02] {25} 41 55 33 00 : 01000001 01010101 00110011 0
[03] {25} 41 55 33 00 : 01000001 01010101 00110011 0
```

https://github.com/merbanan/rtl_433

## RTL_433

- Command-line
- Identifies unknown signals
- Focused on 433 MHz range
- Can be tuned to search at specific frequencies and other ranges



```
$rtl_433 -qa
Found Rafael Micro R820T tuner
Exact sample rate is: 250000.000414 Hz
Sample rate set to 250000.
Bit detection level set to 0 (Auto).
Tuner gain set to Auto.
Tuned to 433920000 Hz.
```

RTL_433 Demo:

https://www.youtube.com/embed/BjUsPk9Il3g

# Command Map

| Switch | State | RF Command |
|---|---|---|
| 1 | On | 0100000101 01 01010011 0011 |
| 1 | Off | 0100000101 01 01010011 1100 |
| 2 | On | 0100000101 01 01011100 0011 |
| 2 | Off | 0100000101 01 01011100 1100 |
| 3 | On | 0100000101 01 01110000 0011 |
| 3 | Off | 0100000101 01 01110000 1100 |
| 4 | On | 0100000101 01 11010000 0011 |
| 4 | Off | 0100000101 01 11010000 1100 |
| All | On | 0100000101 11 01010000 0011 |
| All | Off | 0100000101 11 01010000 1100 |

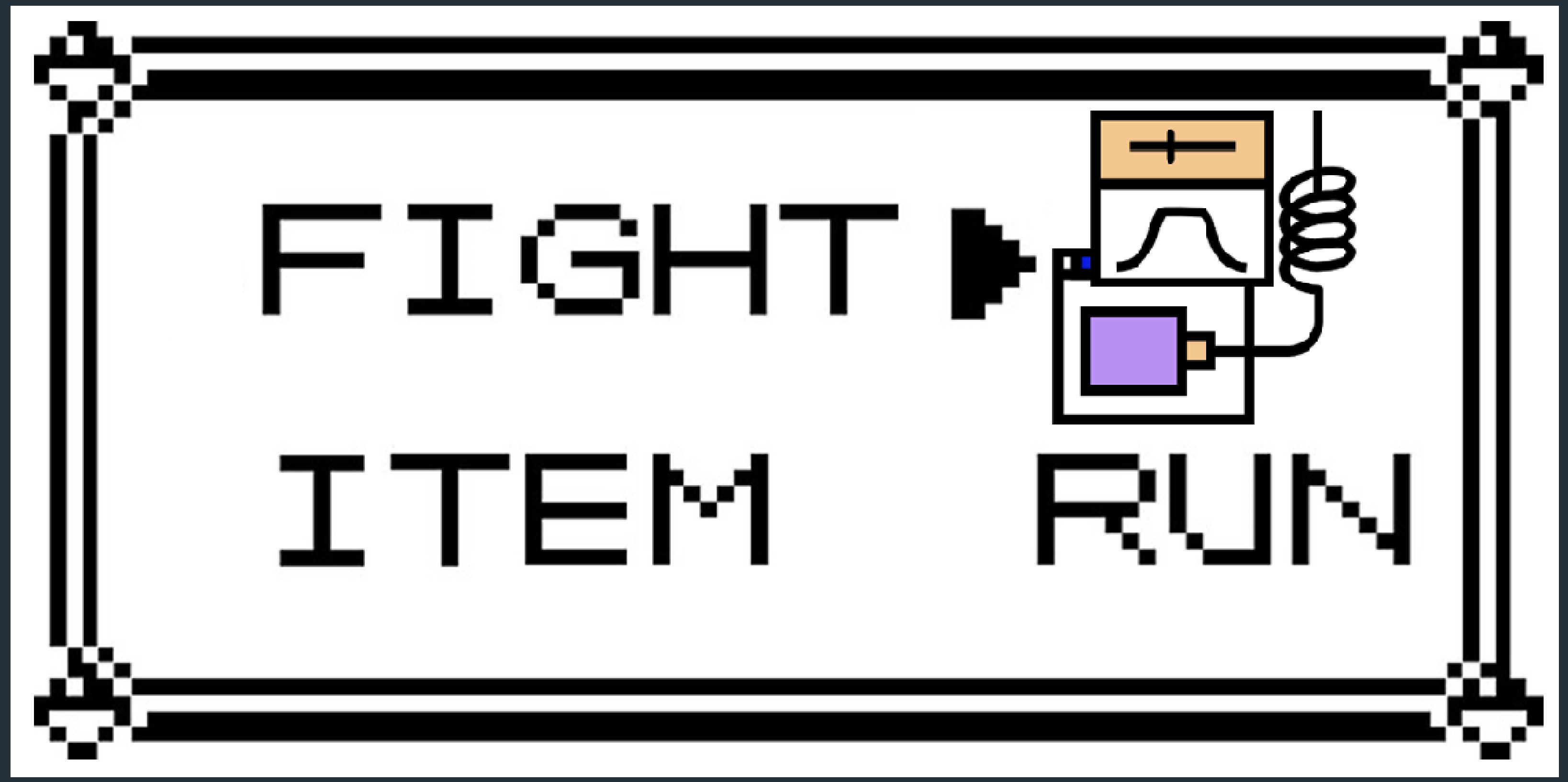
| 10 bits | 2 bits | 8 bits | 4 bits |
|---|---|---|---|
| “Preamble” | All or One? | Switch # | On/Off |

$$\underbrace{0100000101}_{\text{Remote ID}}\ \underbrace{01}_{\text{One Light}}\ \underbrace{01011100}_{\text{Switch 2}}\ \underbrace{0011}_{\text{On}}$$

“This is Remote 0100000101.
Turn Switch 2 on.”

MYSTERY SIGNAL!

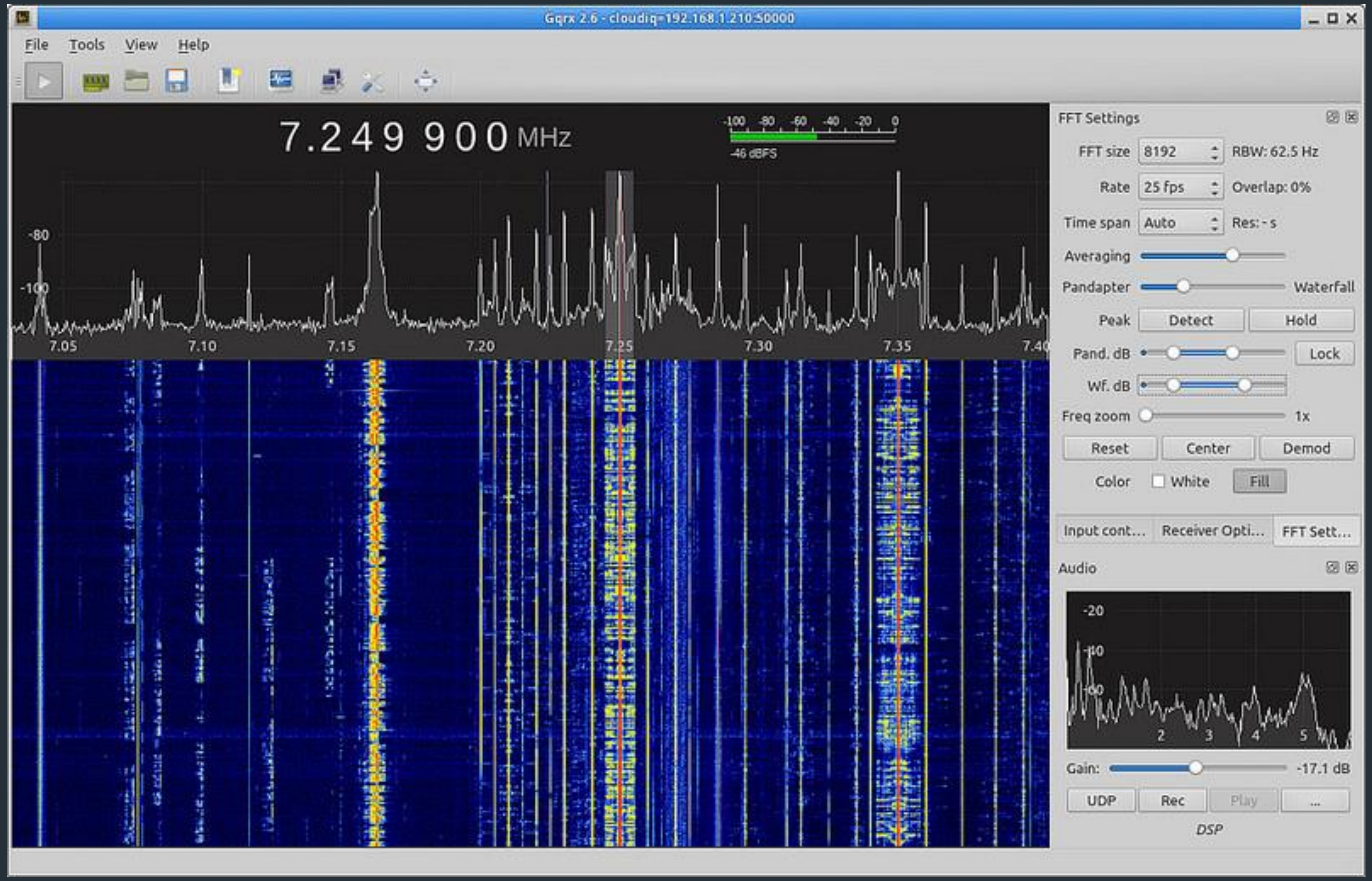
# New Challenges, New Tools



- RTL_433 won’t discover signals without a “nearby” frequency to look at
- GQRX is good for tuning, but has limited features and views
- GNU Radio Companion (GRC) can create software radio systems
- Simple, block-based design generates code using GNU Radio in Python

https://wiki.gnuradio.org/index.php/GNURadioCompanion

## GQRX



FFT Settings

FFT size 8192 RBW: 62.5 Hz

Rate 25 fps Overlap: 0%

Time span Auto Res: - s

Averaging

Pandapter Waterfall

Pand. dB

Wf. dB

Freq zoom 1x

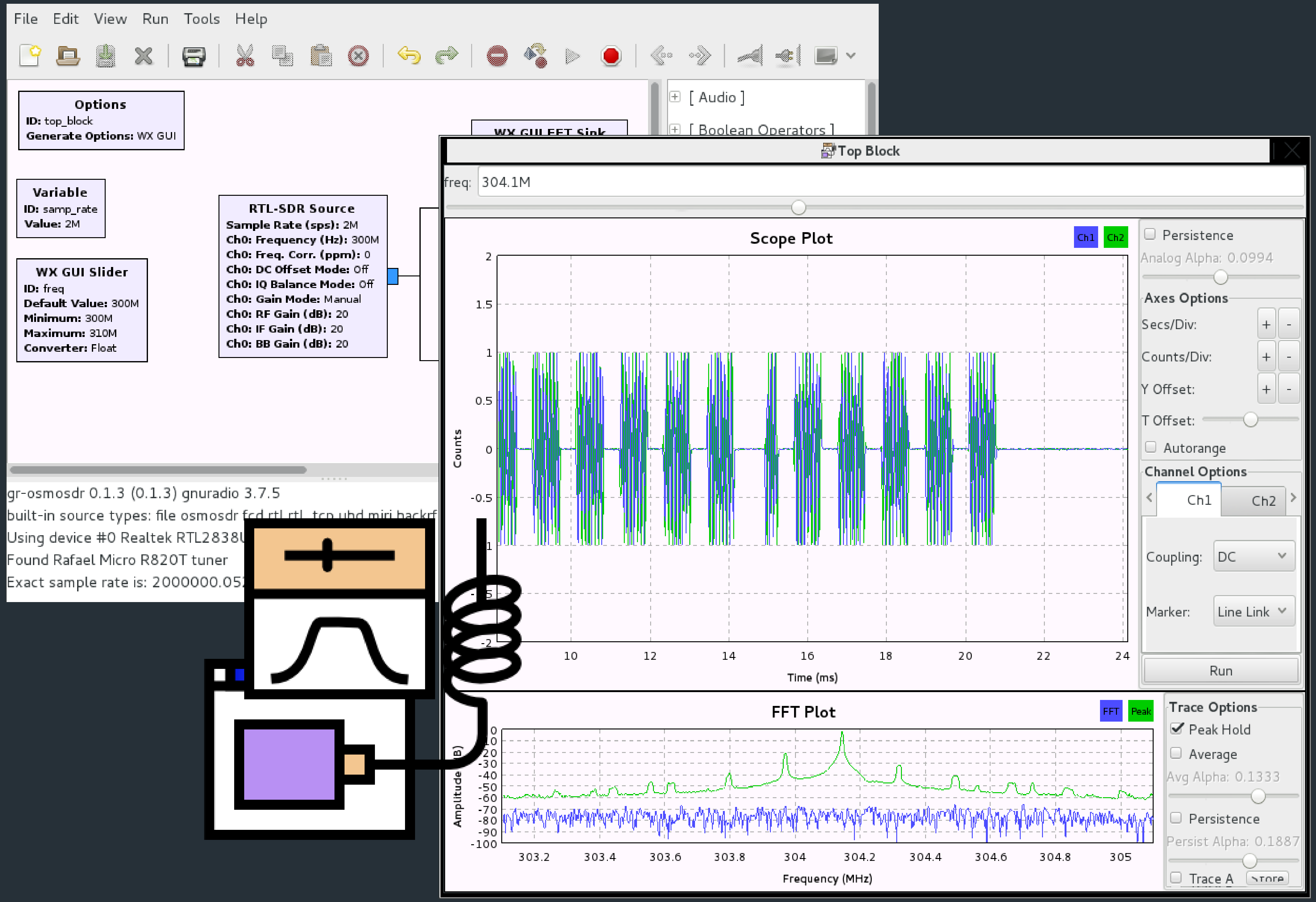
Color □ White

Audio

Gain: -17.1 dB

Tool that uses GNURadio

## GRC



**Options**
ID: top_block
Generate Options: WX GUI

**Variable**
ID: samp_rate
Value: 2M

**WX GUI Slider**
ID: freq
Default Value: 300M
Minimum: 300M
Maximum: 310M
Converter: Float

**RTL-SDR Source**
Sample Rate (sps): 2M
Ch0: Frequency (Hz): 300M
Ch0: Freq. Corr. (ppm): 0
Ch0: DC Offset Mode: Off
Ch0: IQ Balance Mode: Off
Ch0: Gain Mode: Manual
Ch0: RF Gain (dB): 20
Ch0: IF Gain (dB): 20
Ch0: BB Gain (dB): 20

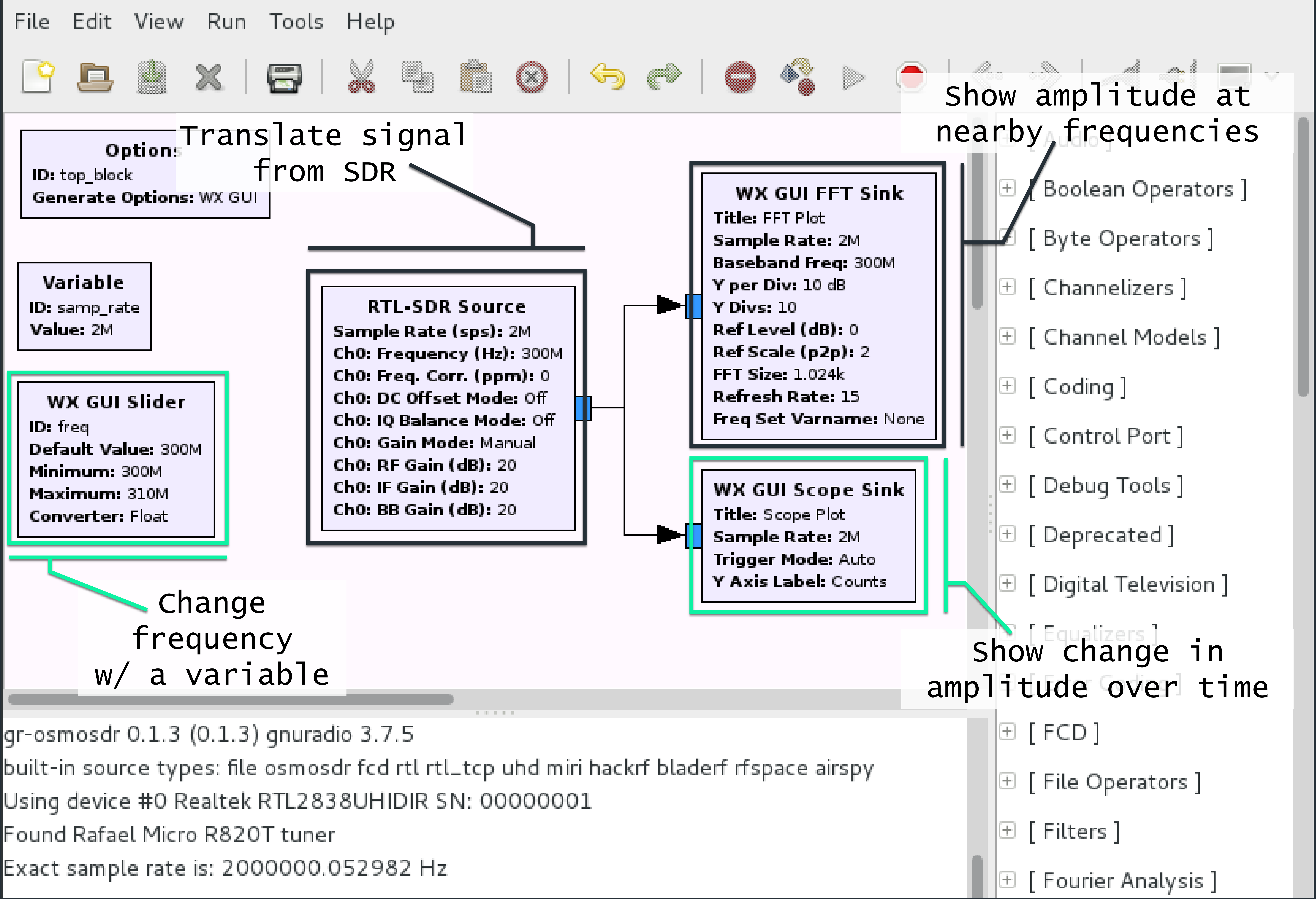
```
gr-osmosdr 0.1.3 (0.1.3) gnuradio 3.7.5
built-in source types: file osmosdr fcd rtl rtl_tcp uhd miri hackrf
Using device #0 Realtek RTL2838U
Found Rafael Micro R820T tuner
Exact sample rate is: 2000000.05
```

freq: 304.1M

□ Persistence
Analog Alpha: 0.0994
Axes Options
Secs/Div:
Counts/Div:
Y Offset:
T Offset:
□ Autorange
Channel Options
Ch1 Ch2
Coupling: DC
Marker: Line Link

Trace Options
☑ Peak Hold
□ Average
Avg Alpha: 0.1333
□ Persistence
Persist Alpha: 0.1887
□ Trace A

Builds tools that use GNURadio



Translate signal from SDR

Show amplitude at nearby frequencies

Change frequency w/ a variable

Show change in amplitude over time

**Options**
**ID:** top_block
**Generate Options:** WX GUI

**Variable**
**ID:** samp_rate
**Value:** 2M

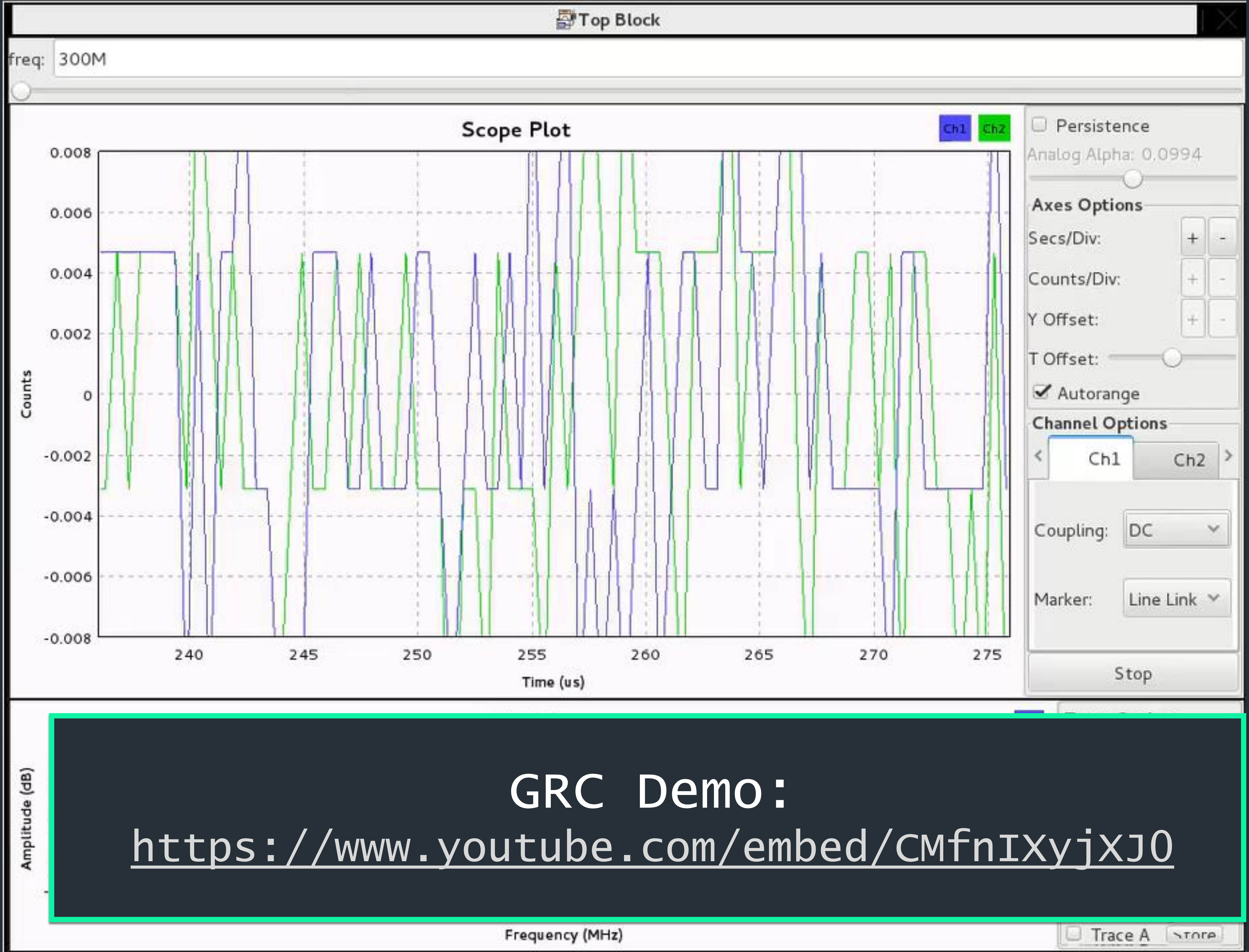
**WX GUI Slider**
**ID:** freq
**Default Value:** 300M
**Minimum:** 300M
**Maximum:** 310M
**Converter:** Float

**RTL-SDR Source**
**Sample Rate (sps):** 2M
**Ch0: Frequency (Hz):** 300M
**Ch0: Freq. Corr. (ppm):** 0
**Ch0: DC Offset Mode:** Off
**Ch0: IQ Balance Mode:** Off
**Ch0: Gain Mode:** Manual
**Ch0: RF Gain (dB):** 20
**Ch0: IF Gain (dB):** 20
**Ch0: BB Gain (dB):** 20

**WX GUI FFT Sink**
**Title:** FFT Plot
**Sample Rate:** 2M
**Baseband Freq:** 300M
**Y per Div:** 10 dB
**Y Divs:** 10
**Ref Level (dB):** 0
**Ref Scale (p2p):** 2
**FFT Size:** 1.024k
**Refresh Rate:** 15
**Freq Set Varname:** None

**WX GUI Scope Sink**
**Title:** Scope Plot
**Sample Rate:** 2M
**Trigger Mode:** Auto
**Y Axis Label:** Counts

```
gr-osmosdr 0.1.3 (0.1.3) gnuradio 3.7.5
built-in source types: file osmosdr fcd rtl rtl_tcp uhd miri hackrf bladerf rfspace airspy
Using device #0 Realtek RTL2838UHIDIR SN: 00000001
Found Rafael Micro R820T tuner
Exact sample rate is: 2000000.052982 Hz
```



Top Block

freq: 300M

□ Persistence

Analog Alpha: 0.0994

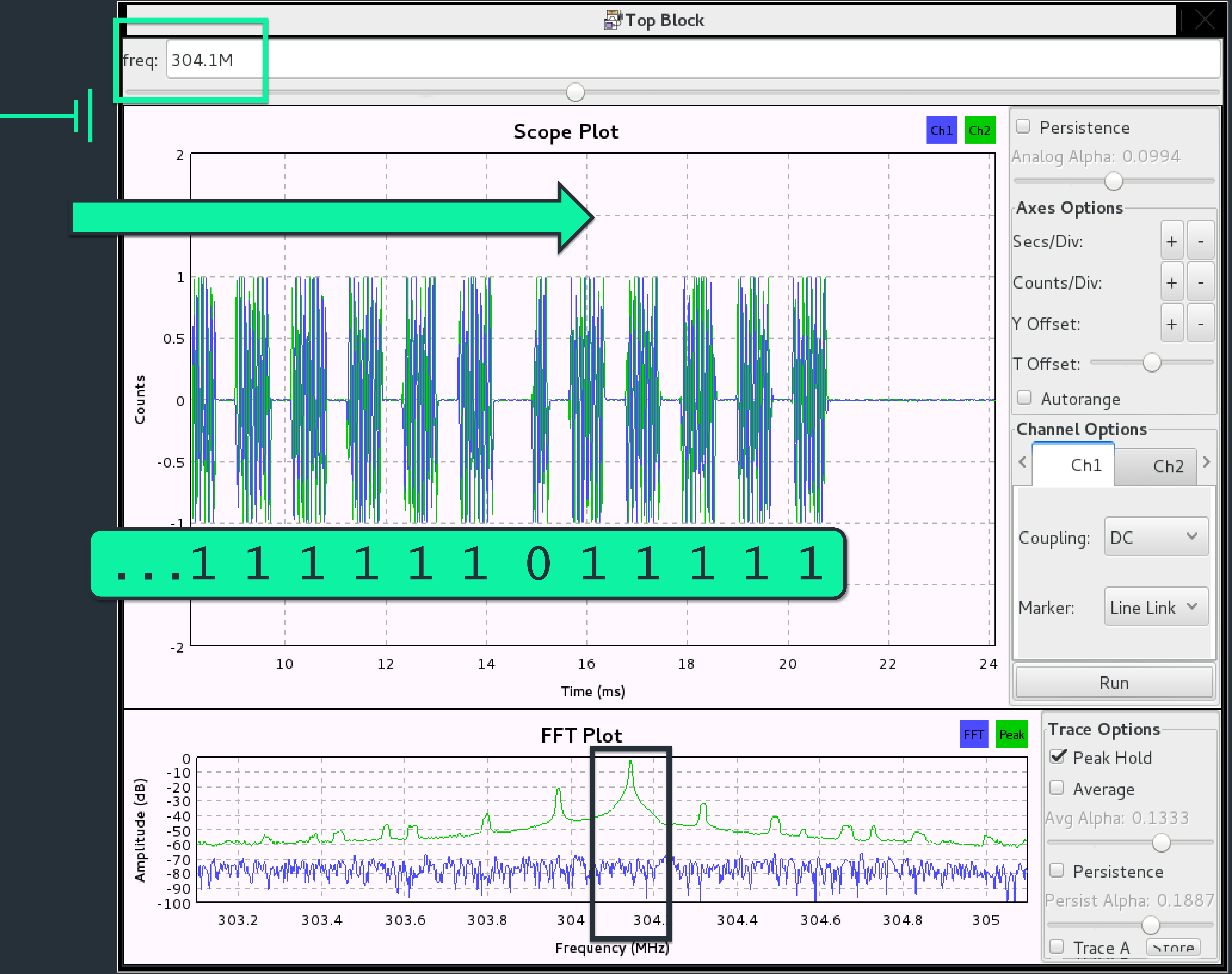
☑ Autorange

Coupling: DC

Marker: Line Link

GRC Demo:

https://www.youtube.com/embed/CMfnIXyjXJ0



freq: 304.1M

Analog Alpha: 0.0994

Coupling: DC

Marker: Line Link

Avg Alpha: 0.1333

Persist Alpha: 0.1887

...1 1 1 1 1 1 0 1 1 1 1 1

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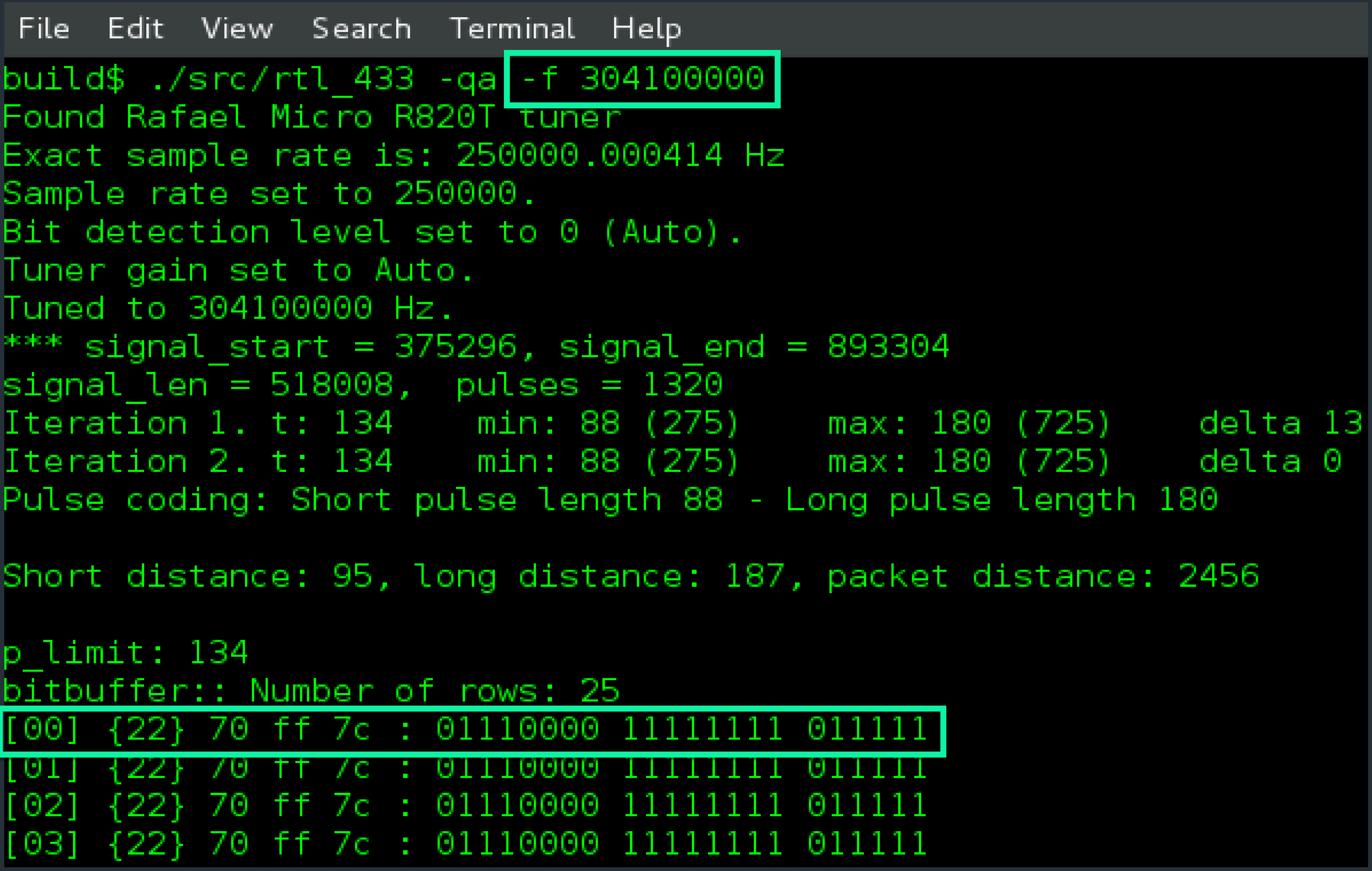
- Slider for *freq* variable tunes from 300–310 MHz
- FFT sink plot shows highest signals near current center frequency
- GUI scope plot shows signal strength at center frequency over time

With *f* known, RTL_433 can handle the rest...



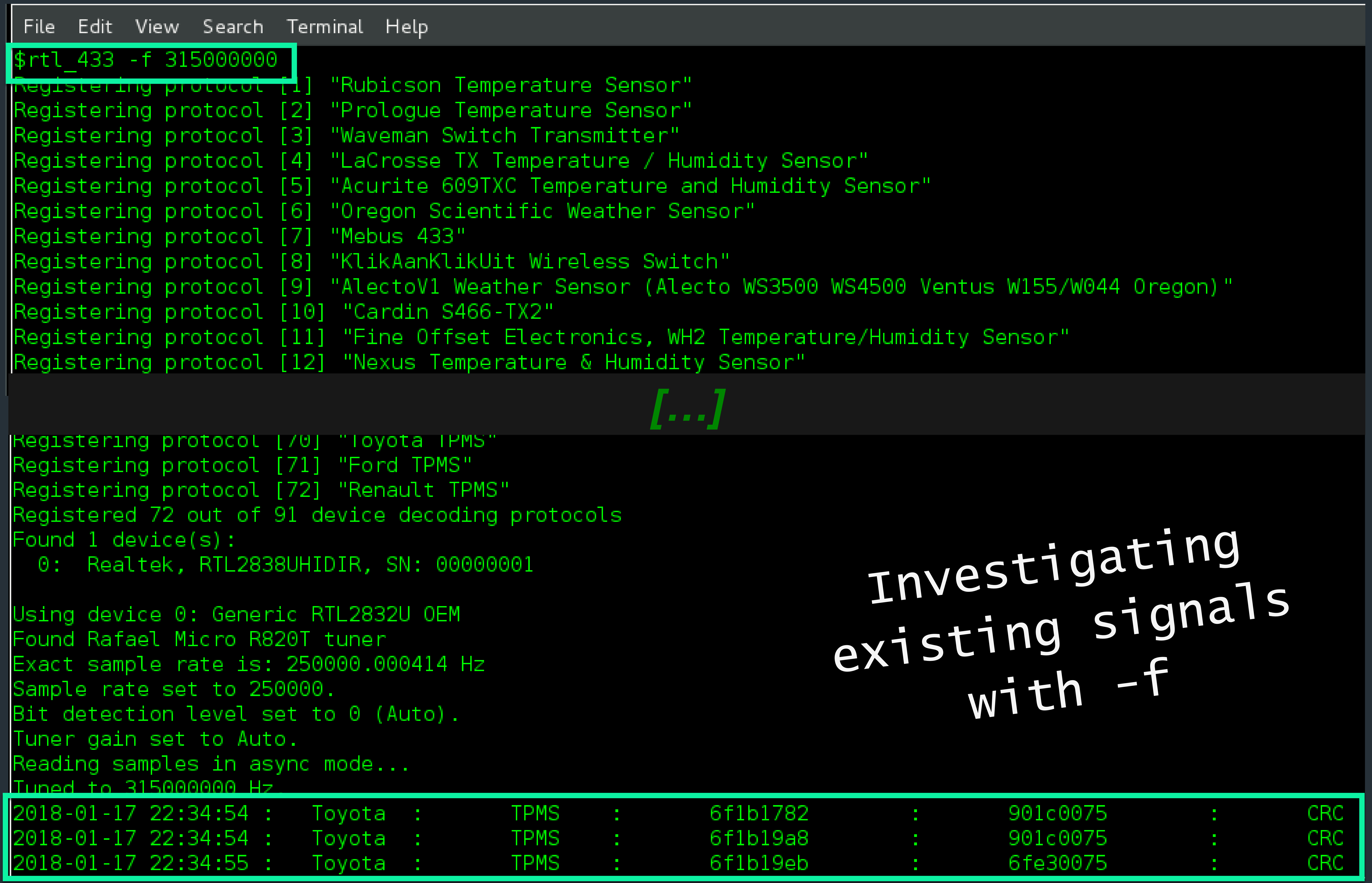
```
build$ ./src/rtl_433 -qa -f 304100000
Found Rafael Micro R820T tuner
Exact sample rate is: 250000.000414 Hz
Sample rate set to 250000.
Bit detection level set to 0 (Auto).
Tuner gain set to Auto.
Tuned to 304100000 Hz.
*** signal_start = 375296, signal_end = 893304
signal_len = 518008,  pulses = 1320
Iteration 1. t: 134    min: 88 (275)    max: 180 (725)    delta 13
Iteration 2. t: 134    min: 88 (275)    max: 180 (725)    delta 0
Pulse coding: Short pulse length 88 - Long pulse length 180

Short distance: 95, long distance: 187, packet distance: 2456

p_limit: 134
bitbuffer:: Number of rows: 25
[00] {22} 70 ff 7c : 01110000 11111111 011111
[01] {22} 70 ff 7c : 01110000 11111111 011111
[02] {22} 70 ff 7c : 01110000 11111111 011111
[03] {22} 70 ff 7c : 01110000 11111111 011111
```

# MYSTERY SIGNAL!

File Edit View Search Terminal Help

```
User cancel, exiting...
$rtl_433 -qa -f 315000000
Found Rafael Micro R820T tuner
Exact sample rate is: 250000.000414 Hz
Sample rate set to 250000.
Bit detection level set to 0 (Auto).
Tuner gain set to Auto.
Tuned to 315000000 Hz.
*** signal_start = 291725, signal_end = 405307
signal_len = 113582,  pulses = 582
Iteration 1. t: 116    min: 80 (540)    max: 153 (42)    delta 8
Iteration 2. t: 116    min: 80 (540)    max: 153 (42)    delta 0
Distance coding: Pulse length 116

Short distance: 66, long distance: 140, packet distance: 1928

p_limit: 116
bitbuffer:: Number of rows: 2
[00] {290} 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 03 88 40 22 10 05 4e 48 48 a2 00
[01] {290} 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 03 88 40 22 10 05 4e 48 48 a2 00
*** signal_start = 470452, signal_end = 584008
signal_len = 113556,  pulses = 580
Iteration 1. t: 116    min: 80 (536)    max: 153 (44)    delta 8
Iteration 2. t: 116    min: 80 (536)    max: 153 (44)    delta 0
Distance coding: Pulse length 116

Short distance: 66, long distance: 140, packet distance: 1903

p_limit: 116
bitbuffer:: Number of rows: 2
[00] {289} 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 03 88 40 04 42 24 aa 61 4a 44 00
[01] {289} 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 00 03 88 40 04 42 24 aa 61 4a 44 00
*** signal_start = 653918, signal_end = 767543
```

Receiving unlock code with known device *f*



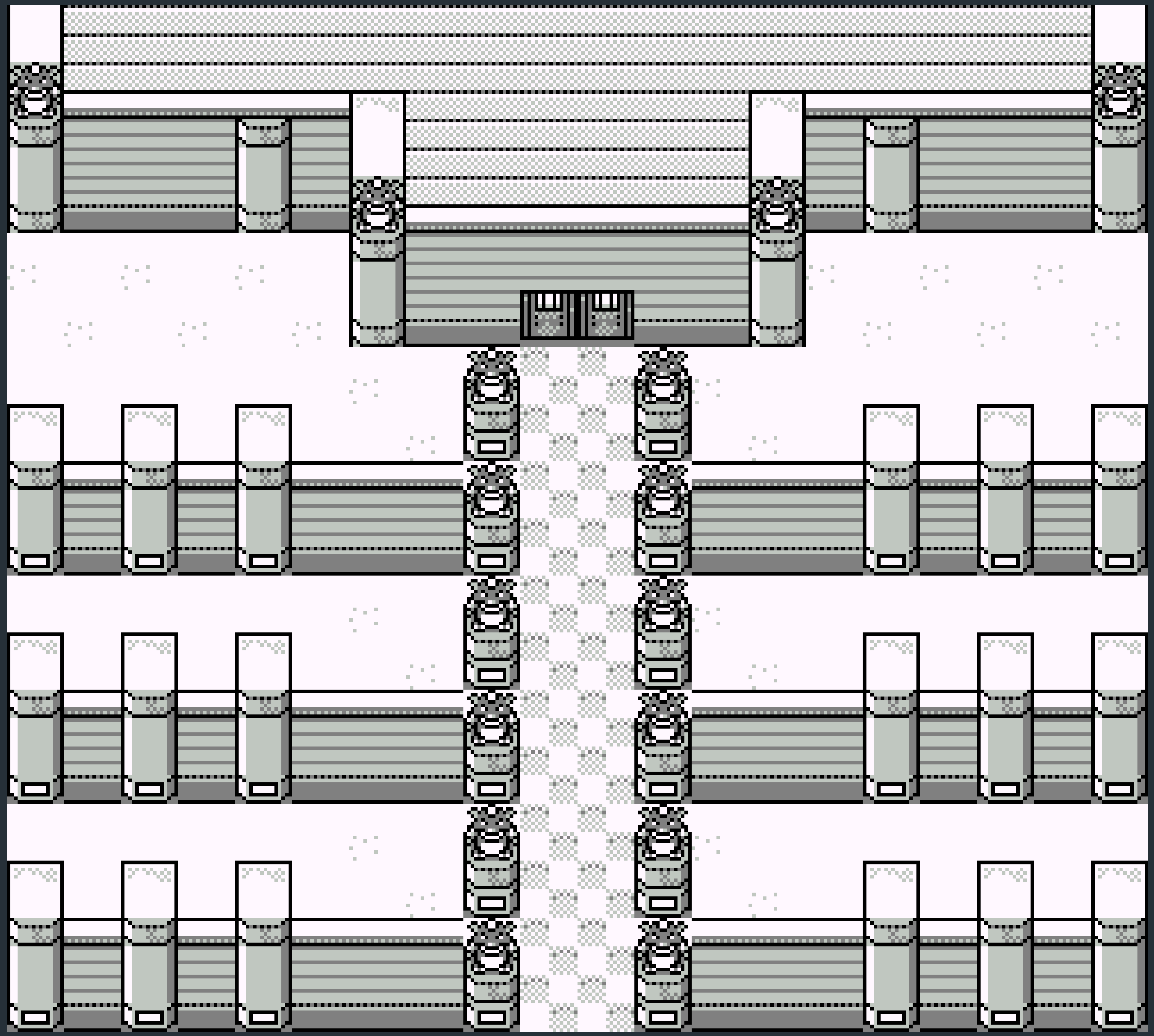
```
$rtl_433 -f 315000000
Registering protocol [1] "Rubicson Temperature Sensor"
Registering protocol [2] "Prologue Temperature Sensor"
Registering protocol [3] "Waveman Switch Transmitter"
Registering protocol [4] "LaCrosse TX Temperature / Humidity Sensor"
Registering protocol [5] "Acurite 609TXC Temperature and Humidity Sensor"
Registering protocol [6] "Oregon Scientific Weather Sensor"
Registering protocol [7] "Mebus 433"
Registering protocol [8] "KlikAanKlikUit Wireless Switch"
Registering protocol [9] "AlectoV1 Weather Sensor (Alecto WS3500 WS4500 Ventus W155/W044 Oregon)"
Registering protocol [10] "Cardin S466-TX2"
Registering protocol [11] "Fine Offset Electronics, WH2 Temperature/Humidity Sensor"
Registering protocol [12] "Nexus Temperature & Humidity Sensor"
```

[...]

```
Registering protocol [70] "Toyota TPMS"
Registering protocol [71] "Ford TPMS"
Registering protocol [72] "Renault TPMS"
Registered 72 out of 91 device decoding protocols
Found 1 device(s):
  0:  Realtek, RTL2838UHIDIR, SN: 00000001

Using device 0: Generic RTL2832U OEM
Found Rafael Micro R820T tuner
Exact sample rate is: 250000.000414 Hz
Sample rate set to 250000.
Bit detection level set to 0 (Auto).
Tuner gain set to Auto.
Reading samples in async mode...
Tuned to 315000000 Hz
2018-01-17 22:34:54 :   Toyota  :       TPMS    :       6f1b1782        :       901c0075        :       CRC
2018-01-17 22:34:54 :   Toyota  :       TPMS    :       6f1b19a8        :       901c0075        :       CRC
2018-01-17 22:34:55 :   Toyota  :       TPMS    :       6f1b19eb        :       6fe30075        :       CRC
```

Investigating existing signals with -f

# RF Signal Security



- Securing RF systems can be tricky
- Hardware design, limited resources make improvements difficult
- Things are (slowly) improving
- Each niche in security offers its own unique  challenges. Don’t be afraid to explore!

**More Curiosity => More Solutions**

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# Continue Your Safari:

**Flavio D. Garcia:**

USENIX Security '16,
"Lock It and Still Lose It: On the (In)Security of Automotive Remote Keyless Entry Systems"

**Samy Kamkar:**

DC 23,"Drive It Like You Hacked It"

Digital Ding Dong Ditch
https://github.com/samyk/dingdong

**Michael Ossman:**

Software Defined Radio with HackRF
https://greatscottgadgets.com/sdr/

**FCC ID Search:**
https://www.fcc.gov/oet/ea/fccid

Browse new registrations:
https://fccid.io/#fccid-today

**ARRL, Amateur Radio:**
https://www.arrl.org/

# Questions?

Reach out at:

🐦 @_sigil

✉ Katie.Knowles@mwrinfosecurity.com