Software Defined Radio Demystified

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Tech Saturday – January 10 2026

Overview

- SDR Concepts
- SDR Uses
- SDR Devices
- SDR Software
- Remote SDR access
- Work session

NotebookLM Presentation

SDR_Your_Shack_s_New_Superpower.pdf

What is an SDR

Unlocking the Airwaves: A Beginner's Guide to Software Defined Radio (SDR)

What is Software Defined Radio?

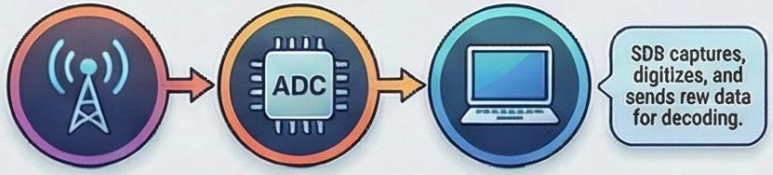
Radio Controlled by Circuits
Fixed analog hardware handles signal processing.

Radio Controlled by Software
Flexible software on a computer, FPGA, or GPU processes signals.

The RTL-SDR Revolution

Inexpensive TV tuners act as wideband receivers, democratizing SDR for around $30.

How it Works: From Antenna to Application



Capture Spectrum → **Digitize Signal** → **Software Decodes**

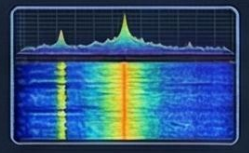
SDB captures, digitizes, and sends rew data for decoding.

What Can You Do With an SDR? (Popular Projects)

Track Live Aircraft
Create your own live flight tracker map using ADS & signals.

Download Weather Satellite Images
Receive real-time images from polar orbiting NDAA and Meteor satellites.

Decode Satellite Telemetry
Capture health and status information from amateur satellites.



Create a Panadapter for Your Transceiver
Add a real-time spectrom display to view entire band activity.

Listen to Digital Communications
Decode unencrypted digital voice transmissions (e.g., P2S, DMR) using software.

Ham Transceiver
Decode unencrypted digital voice transmissions (e.g., P21, RMR) using software.

Explore the Airwaves
Use as a general purpose scanner for FM radio, air traffic, maritime, and more.

Choosing Your First SDR: A Comparison

Device	Price Range	Key Features	Best For
RTL-SDR	$30+	Receive only 8-bit ADC, 2.4 MHz bandwidth	Beginners, listening, and simple projects.
ADALM-Pluto	$250+	Transmit & Receive (Full-duplex), 12-bit ADC, 20 MHz bandwidth	Students, learners, and transmitting experiments.
HaskRF One	$300+	Transmit & Receive (Half-duplex), 5-bit ADC, 20 MHz bandwidth, 1 MHz & GHz	Security research, RF hacking, general experimentation.
LimeSDR / USRP	$700 - $2000+	Pro-level features, 12-bit ADC, +60 MHz bandwidth, MIMO support	Academic research, professionals, complex systems.

The Software Ecosystem

General Receiver Software
User-friendly interfaces with spectrum displays (SDRX, GQRX, SDR Console).

Specialized Decoding Tools
Specific software for decoding data like weather images or digital voice.

Advanced Frameworks: GNU Radio
Open-source toolkit for building custom radio applications by connecting blocks.

Remote SDR & Dedicated Projects

The Raspberry Pi: A Perfect SDR Companion
Low power, dedicated receiver for optimal reception locations.

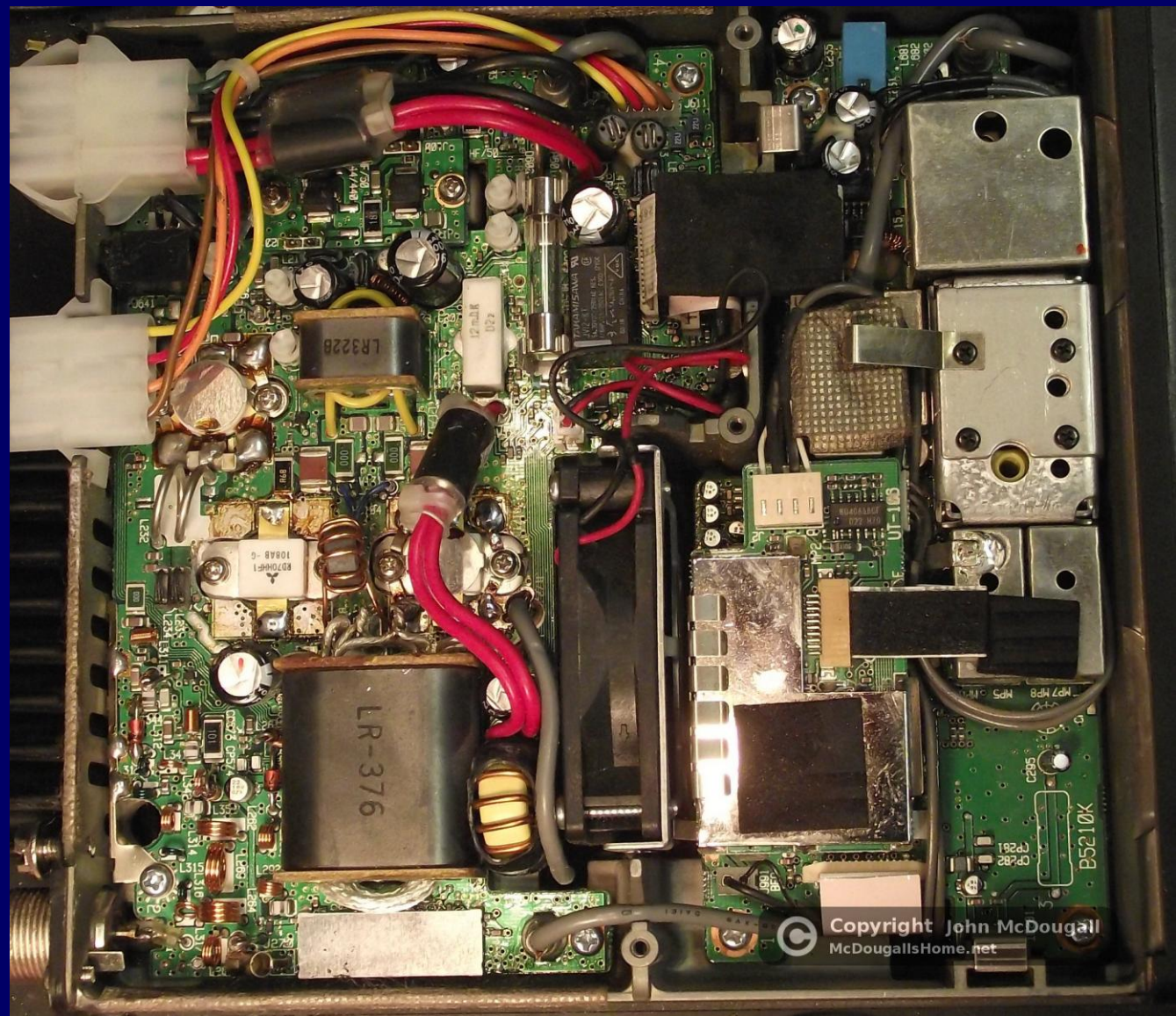
Network Streaming with Spyserver
Stream raw digital data over the network for processing on powerful PCs.

Web-Based Radio with OpenWebRX
Set up a web server for browser based access from anywhere.

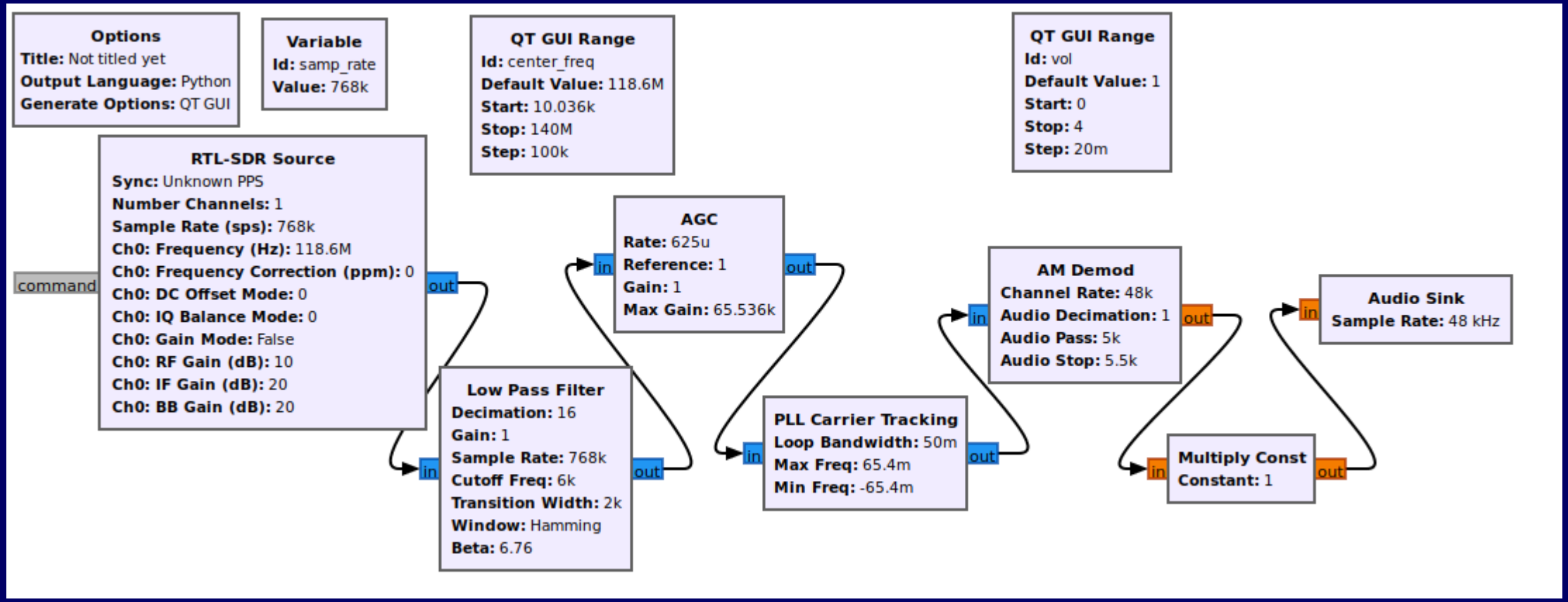

RTL-SDR.COM
QUICKSTART SETUP GUIDE: RTL-SDR.COM/QSG
DVB-T+DAB+FM+SDR
RTL2832U R820T2 TCXO+BIAS T+HF
V.3

Traditional Radios

Radio functions implemented with discrete electronics components

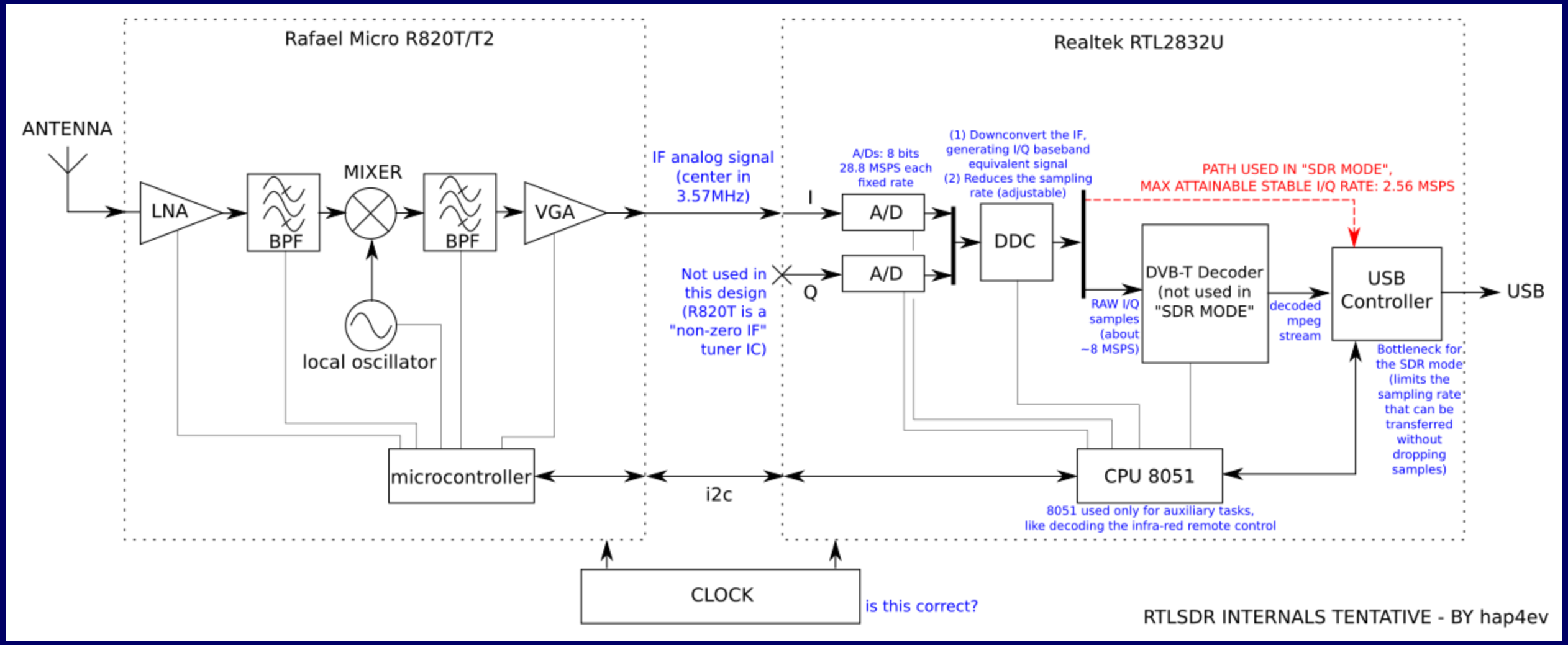


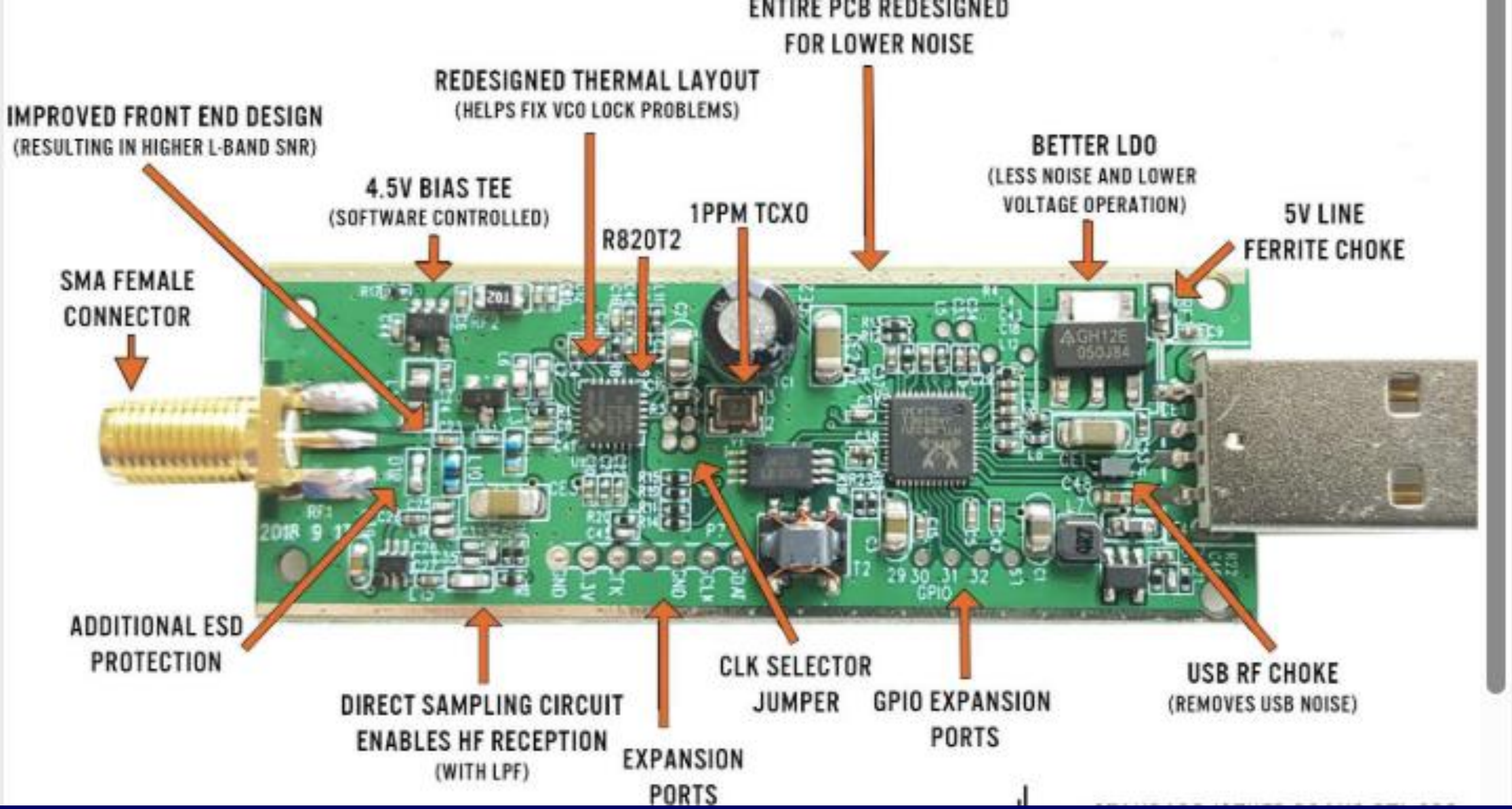
SDR in Gnu Radio



Radio functions implemented in computer programming

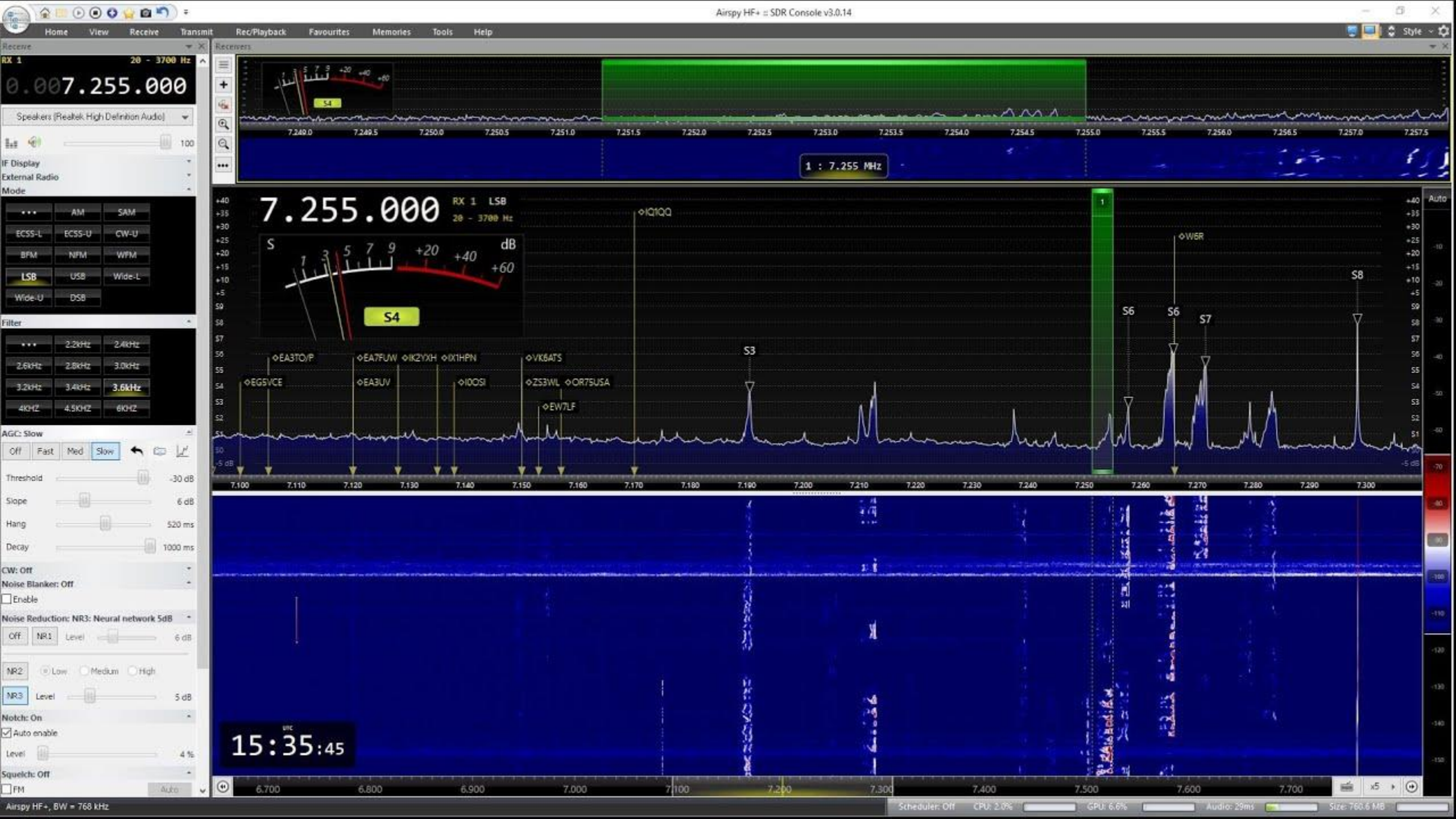
RTL-SDR


Rafael Micro R820T/T2
Realtek RTL2832U
ANTENNA
LNA
BPF
MIXER
BPF
VGA
local oscillator
microcontroller
IF analog signal (center in 3.57MHz)
Not used in this design (R820T is a "non-zero IF" tuner IC)
I
Q
A/Ds: 8 bits 28.8 MSPS each fixed rate
A/D
A/D
(1) Downconvert the IF, generating I/Q baseband equivalent signal
(2) Reduces the sampling rate (adjustable)
DDC
PATH USED IN "SDR MODE", MAX ATTAINABLE STABLE I/Q RATE: 2.56 MSPS
RAW I/Q samples (about ~8 MSPS)
DVB-T Decoder (not used in "SDR MODE"
decoded mpeg stream
USB Controller
USB
Bottleneck for the SDR mode (limits the sampling rate that can be transferred without dropping samples)
i2c
CPU 8051
8051 used only for auxiliary tasks, like decoding the infra-red remote control
CLOCK
is this correct?
RTLSDR INTERNALS TENTATIVE - BY hap4ev


ENTIRE PCB REDESIGNED
FOR LOWER NOISE
REDESIGNED THERMAL LAYOUT
(HELPS FIX VCO LOCK PROBLEMS)
IMPROVED FRONT END DESIGN
(RESULTING IN HIGHER L-BAND SNR)
BETTER LDO
(LESS NOISE AND LOWER
VOLTAGE OPERATION)
4.5V BIAS TEE
(SOFTWARE CONTROLLED)
1PPM TCXO
R820T2
5V LINE
FERRITE CHOKE
SMA FEMALE
CONNECTOR
ADDITIONAL ESD
PROTECTION
DIRECT SAMPLING CIRCUIT
ENABLES HF RECEPTION
(WITH LPF)
EXPANSION
PORTS
CLK SELECTOR
JUMPER
GPIO EXPANSION
PORTS
USB RF CHOKE
(REMOVES USB NOISE)

Simplest implementation

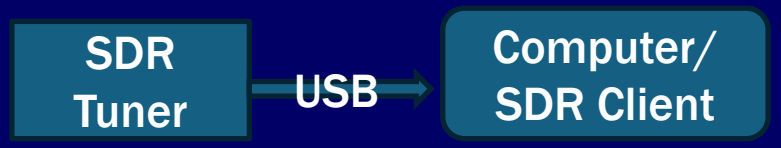
What do I see?


Airspy HF+ :: SDR Console v3.0.14
Home View Receive Transmit Rec/Playback Favourites Memories Tools Help
Receive
RX 1 20 - 3700 Hz
0.007.255.000
Speakers (Realtek High Definition Audio)
IF Display
External Radio
Mode
AM SAM
ECSS-L ECSS-U CW-U
BFM NFM WFM
LSB USB Wide-L
Wide-U DSB
Filter
2.2kHz 2.4kHz
2.6kHz 2.8kHz 3.0kHz
3.2kHz 3.4kHz 3.6kHz
4KHZ 4.5KHZ 6KHZ
AGC: Slow
Off Fast Med Slow
Threshold -30 dB
Slope 6 dB
Hang 520 ms
Decay 1000 ms
CW: Off
Noise Blanker: Off
Enable
Noise Reduction: NR3: Neural network 5dB
Off NR1 Level 6 dB
NR2 Low Medium High
NR3 Level 5 dB
Notch: On
Auto enable
Level 4 %
Squelch: Off
FM
Receivers
1 : 7.255 MHz
7.255.000
RX 1 LSB
20 - 3700 Hz
S4
IQ1QQ
W6R
S8
S6
S6
S7
S3
EA3TO/P
EG5VCE
EA7FUW
EA3UV
IK2YXH
IOOSI
OX1HPN
VK6AT5
ZS3WL
OR7USA
EW7LF
15:35:45
Auto
Airspy HF+, BW = 768 kHz
Scheduler: Off
CPU: 2.0%
GPU: 6.6%
Audio: 29ms
Size: 760.6 MB

How can I use it?

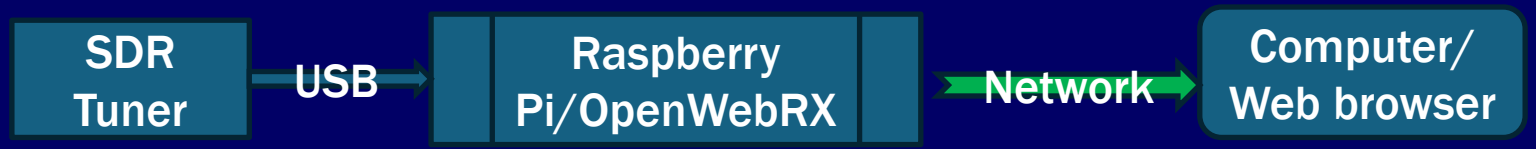
- Operating
  - As a receiver for QSOs
  - To listen to any frequency within the SDR's range
  - To pipe audio into other programs (WSJT, FL-Digi) to decode
  - As a panadapter to view large freq spans
- Experimenting
  - Listening to new stations
  - Trying new modes
- Single-Purpose Reporting (with Raspberry Pi)
  - ADS-B aircraft
  - ABS ships
  - GOES
  - Satnogs

Typical SDR Configurations

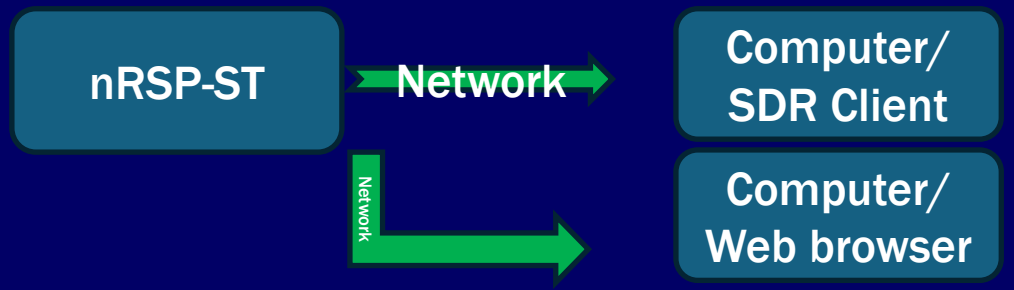


Typical application

Spyserver – Discovery dish or remote radio



OpenWebRX

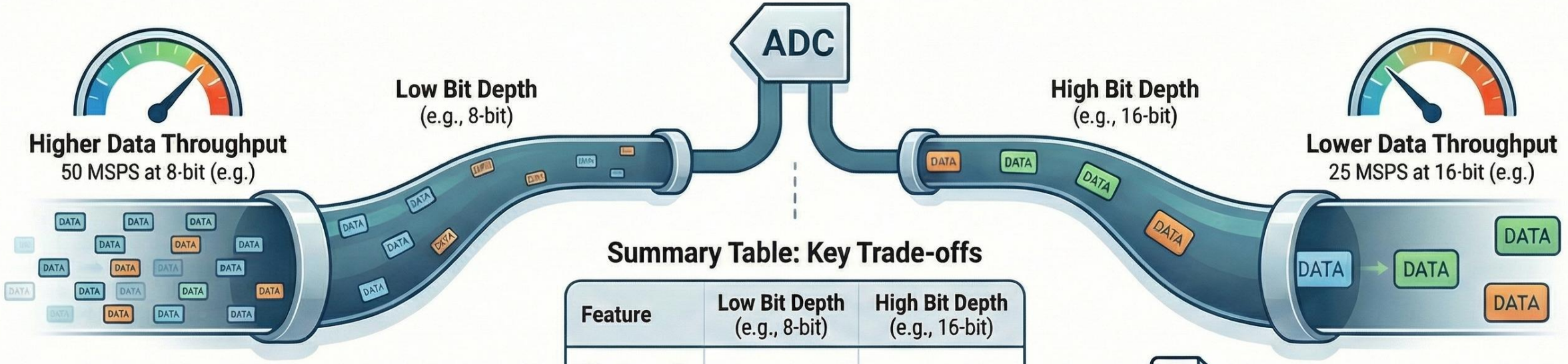


nRSP-ST SDR Network Server

SDR Radio Characteristics

- ADC resolution
- Bandwidth – the breadth of frequencies that can be viewed in one time.
- Frequency coverage – the range of frequencies that can be received
- Filtering – the ability of the radio to reject strong and unwanted adjacent signals
- Inputs – the number of antenna inputs on the device

SDR Performance: The **Bit Depth Difference**



Summary Table: Key Trade-offs

Feature	Low Bit Depth (e.g., 8-bit)	High Bit Depth (e.g., 16-bit)
Max Sample Rate	Higher	Lower
Data/File Size	Smaller	Larger
Dynamic Range	Lower	Higher
Best For...	High-speed scanning, streaming	Weak signal analysis, high-fidelity recording

Smaller Data Footprint

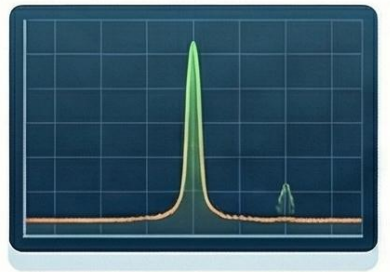
Reduces storage needs and network bandwidth, ideal for streaming applications.

Limited Dynamic Range

A higher intrinsic noise floor can obscure weak signals, especially near strong ones.

Larger Data Footprint

A 16-bit I/Q sample pair is double the size of an 8-bit pair, requiring more storage.



Superior Dynamic Range

A lower noise floor allows for the detection of very faint signals.

Why ADC Bit Depth Matters

- 8-bit: 256 steps -distortion
- 14-bit: 16,384 steps -DX through broadcast
- 16-bit: 65,536 steps -contest-grade
- Image: Stair-step graphic

Bandwidth Considerations

- SDR bandwidths are much larger than entire ham bands
- May be needed for experimental work
- Larger bandwidth = more CPU and network utilization
- Use only what you need

Bandwidth = Your Instant View

- RTL-SDR: 2-3 MHz
- SDRplay/Airspy: 8-10 MHz
- Ettus/Lime: 30-56 MHz
- Wider bandwidth = more CPU & network load

When Wide Bandwidth Wins

- Full 6 m sporadic-E watch
- Wide satellite transponders
- UHF DATV (2-8 MHz signals)
- Microwave beacon surveys
- Software decimation lets you zoom in

Leveling Up: A Guide to Your Next SDR

	 **RTL-SDR Blog V4**	 **SDRplay RSPdx**	 **Airspy R2**	 **HackRF One**
Bandwidth (Wider View)	~2.4 MHz **Like a porthole on the RF spectrum.**	~10 MHz **Like a panoramic window.**	~10 MHz	~20 MHz
Bit Depth (More Detail)	8-bit **Laptop's built-in mic.**	14-bit **Professional studio mic. Hear weak signals next to strong ones.**	12-bit	8-bit
Filtering (Less Noise)	Basic	✔ Excellent ✔	✔ Excellent ✔	Good
Transmit?	No (RX only)	No (RX only)	No (RX only)	Yes (TX/RX)

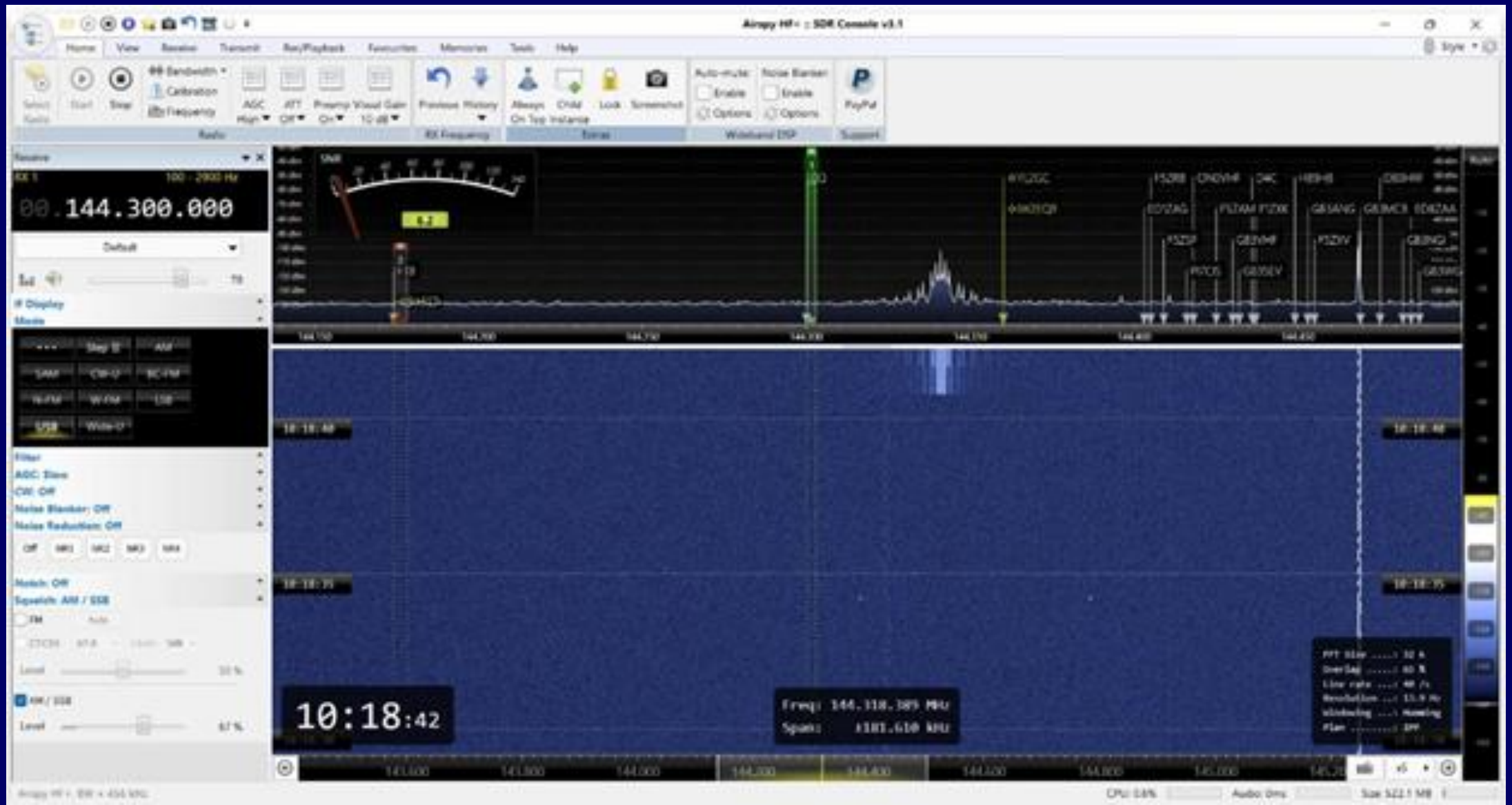
Hardware & Software Are Interchangeable

- RTL today, Pluto tomorrow -same software!
- Open libraries: SoapySDR, libiio
- Exceptions: Proprietary (Flex SmartSDR)
- Image: Device icons â†’ SDR software logos

SDR Software - Two Camps

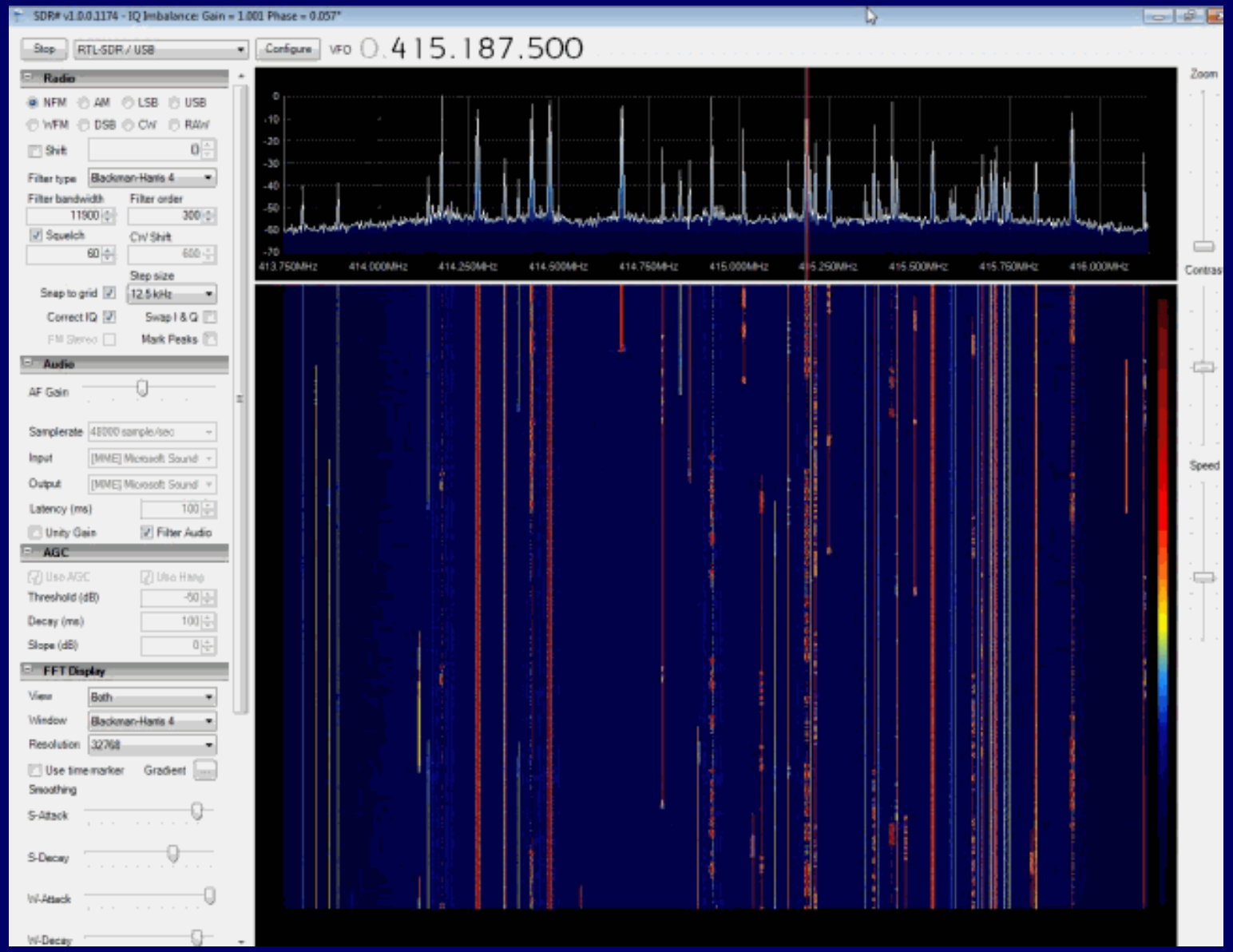
- Operating-focused: QSO audio & logging
- Experiment-focused: decoders, transmit, analysis
- Image: Split icons

SDR Console

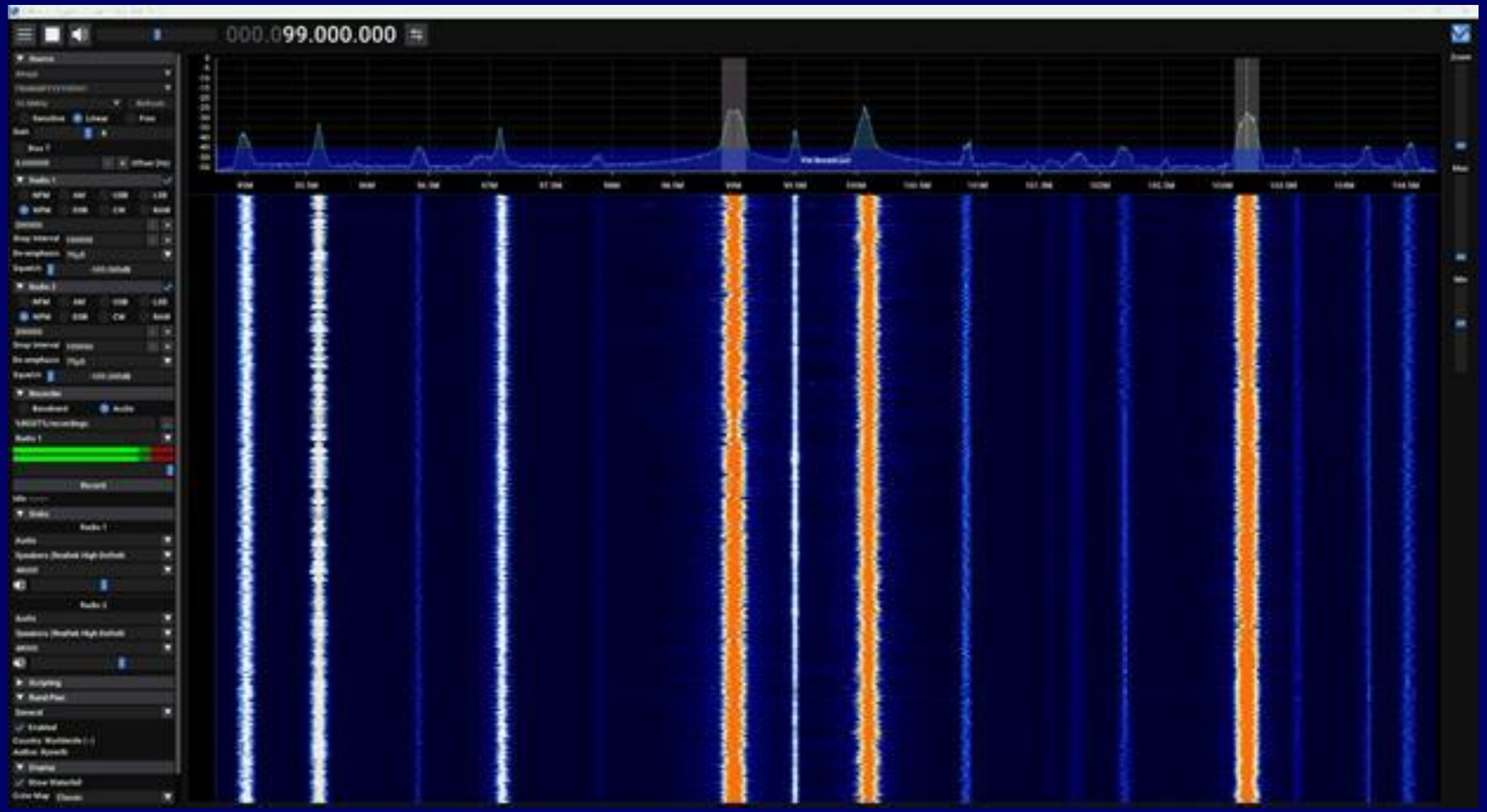


SDR#

- Fastest & lightest
- Huge plugin ecosystem

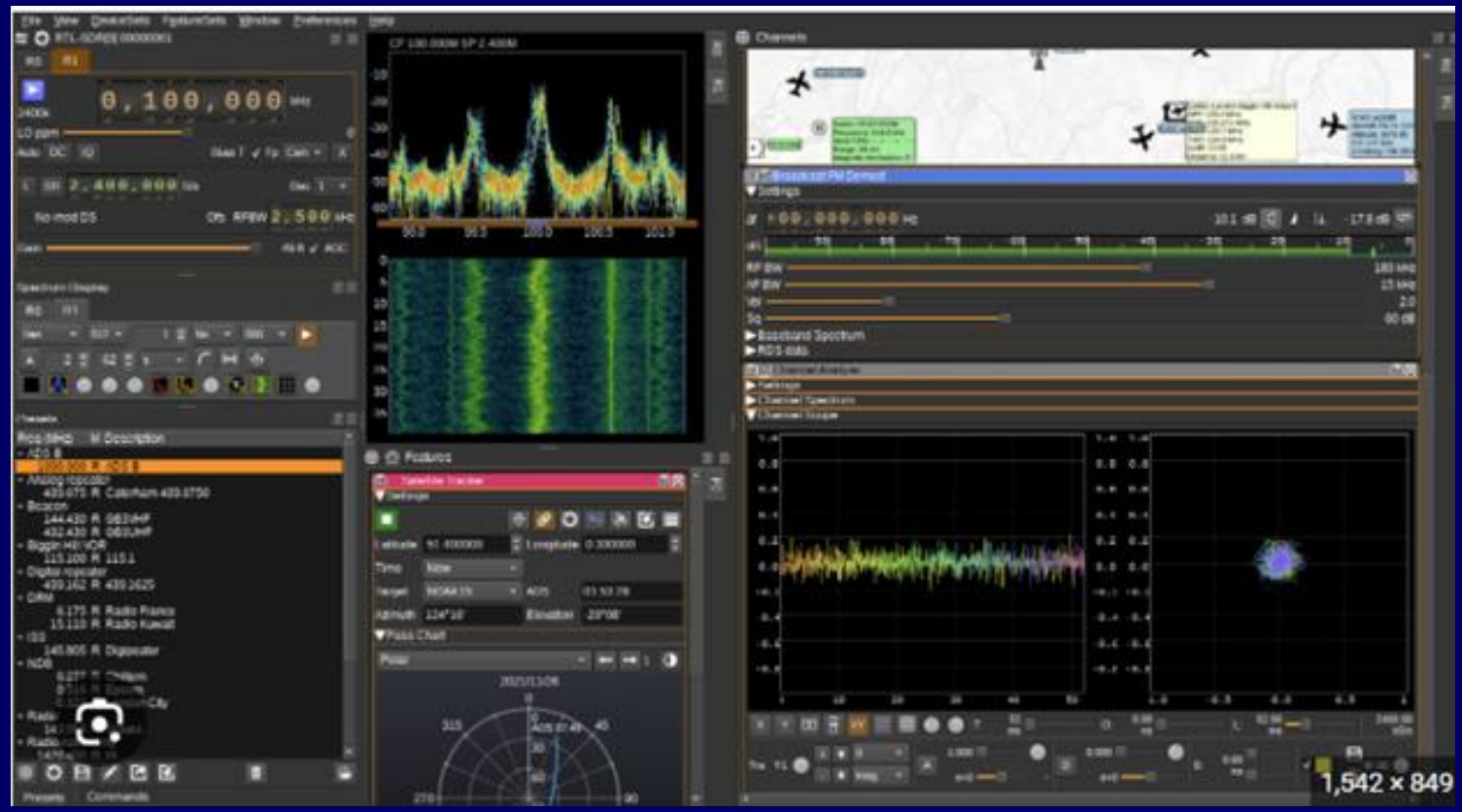


SDR++



SDR Angel

- Transmit support (Pluto, HackRF)
- Multiple VFOs, built-in decoders
- Satellite tracking



The “Language” of SDR – the “IQ Stream”

Comment: According to Jeff Long: “This is a great thing to try to figure out. If we can come up with an answer that gives someone a feel for why I/Q is used in SDR in 10 minutes, and does not include

- phasors,
- exponentials to a complex power,
- a derivation of any equation,
- the concept of orthogonality,

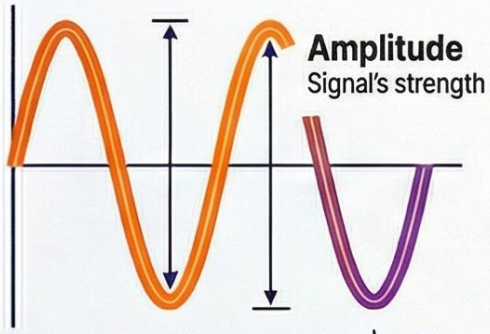
etc., … it will win a Nobel prize in education.”

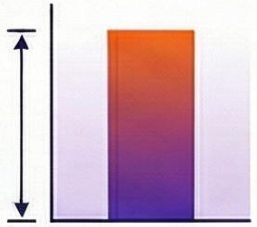
It is a stream of digital data containing pairs of numbers (the I and the Q component) that describe a radio signal. It’s sent from the SDR Device to the SDR Software

Decoding the Ether: What's Inside an I/Q Signal?

The Challenge:
A One-Dimensional View is Not Enough

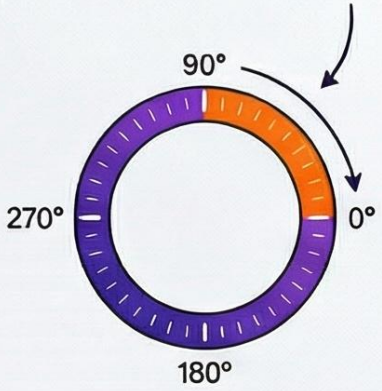
Radio Waves Have Two Key Properties





A Single Measurement Can Be Deceiving

Simply measuring a signal's strength (amplitude) loses all its critical phase information.

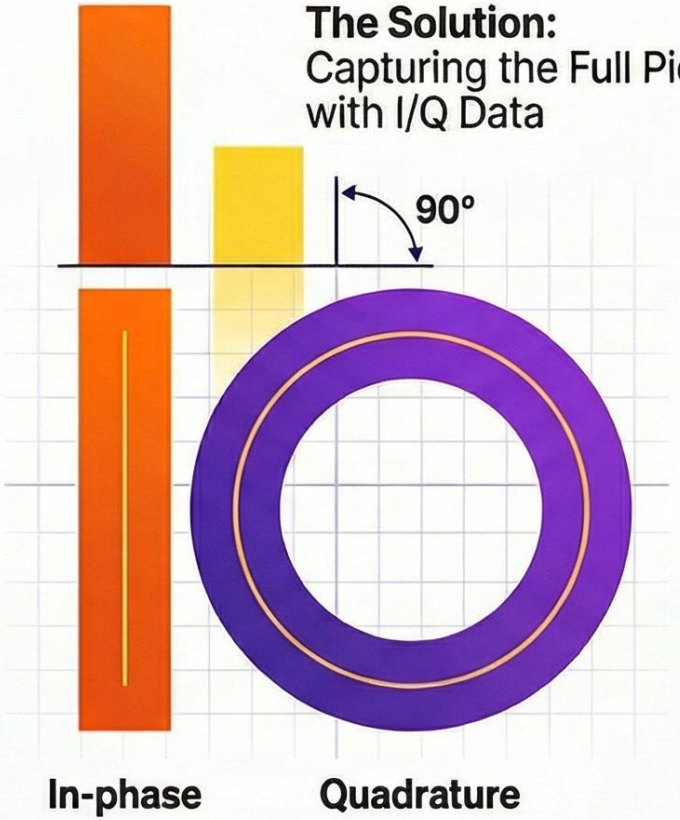


Phase
Position within repeating cycle

Phase Blindness Hides Information

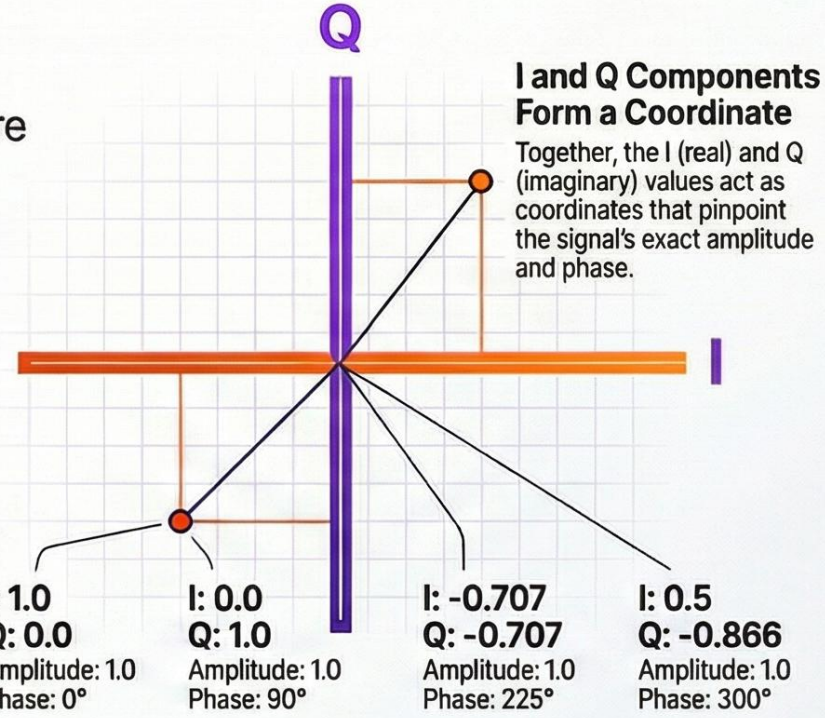
Many modern digital signals (like PSK) encode data by changing the phase, which is invisible to a simple amplitude-only measurement.

The Solution:
Capturing the Full Picture with I/Q Data



I/Q Data Splits the Signal into Two Orthogonal Components

This creates a 2D representation using an In-phase (I) component and a Quadrature (Q) component, which is offset by 90°.



I and Q Components Form a Coordinate

Together, the I (real) and Q (imaginary) values act as coordinates that pinpoint the signal's exact amplitude and phase.

A Stream of I/Q Samples Represents the Live Signal

Raw signal recordings are binary files containing an alternating sequence of I and Q values (IQIQIQ...).

How the IQ Stream is used

- Directly from the SDR Device to the SDR Software (USB connection)
- Indirectly thru a network connection
- Can be recorded and played back allowing active retuning

Why Record Raw I/Q (Not Audio)

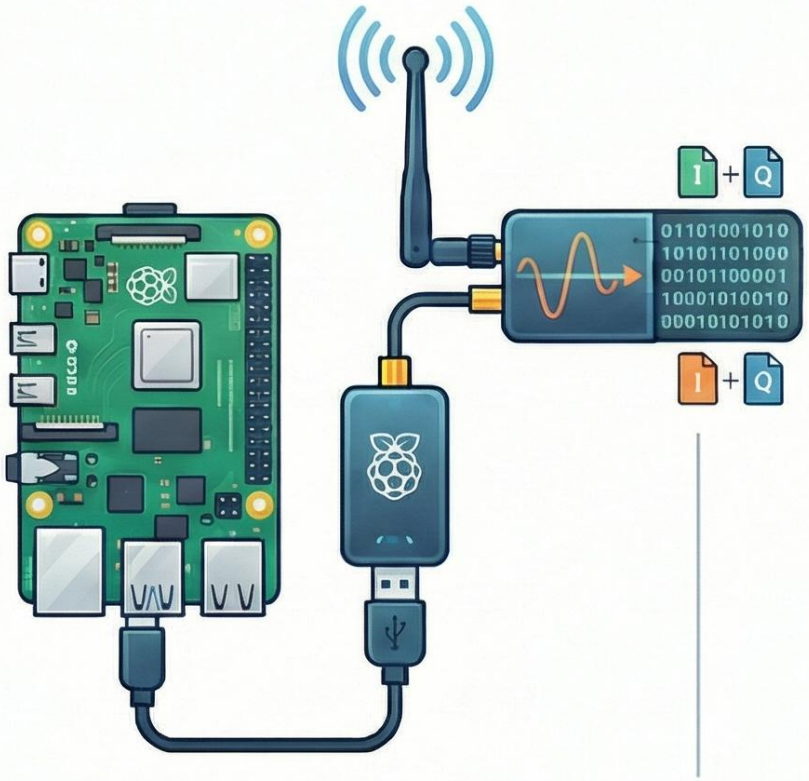
- Retune, filter, slow down after recording
- Replay missed callsign/telemetry
- One good pass = hundreds of practice decodes
- Image: Audio vs. I/Q playback

IQ Stream Limitations

- Affected by:
  - Signal bandwidth
  - “Decimation” – intentionally regularly dropping observations
- Limitations
  - Computer speed
  - USB port speed
  - Network speed (if using network)

Remote SDR

Access Your SDR from Anywhere with SpyServer



1. Server Setup: Raspberry Pi + SDR

A Software Defined Radio (SDR) dongle is connected via USB to a Raspberry Pi.

2. Capture & Digitize

The SDR captures analog radio signals and converts them into digital I/Q data streams.

3. Stream Over Network

SpyServer software running on the Pi streams the I/Q data over the local network or internet.

4. Client Software

A user on a separate computer runs an SDR client application like SDR Console.

5. Connect to Server

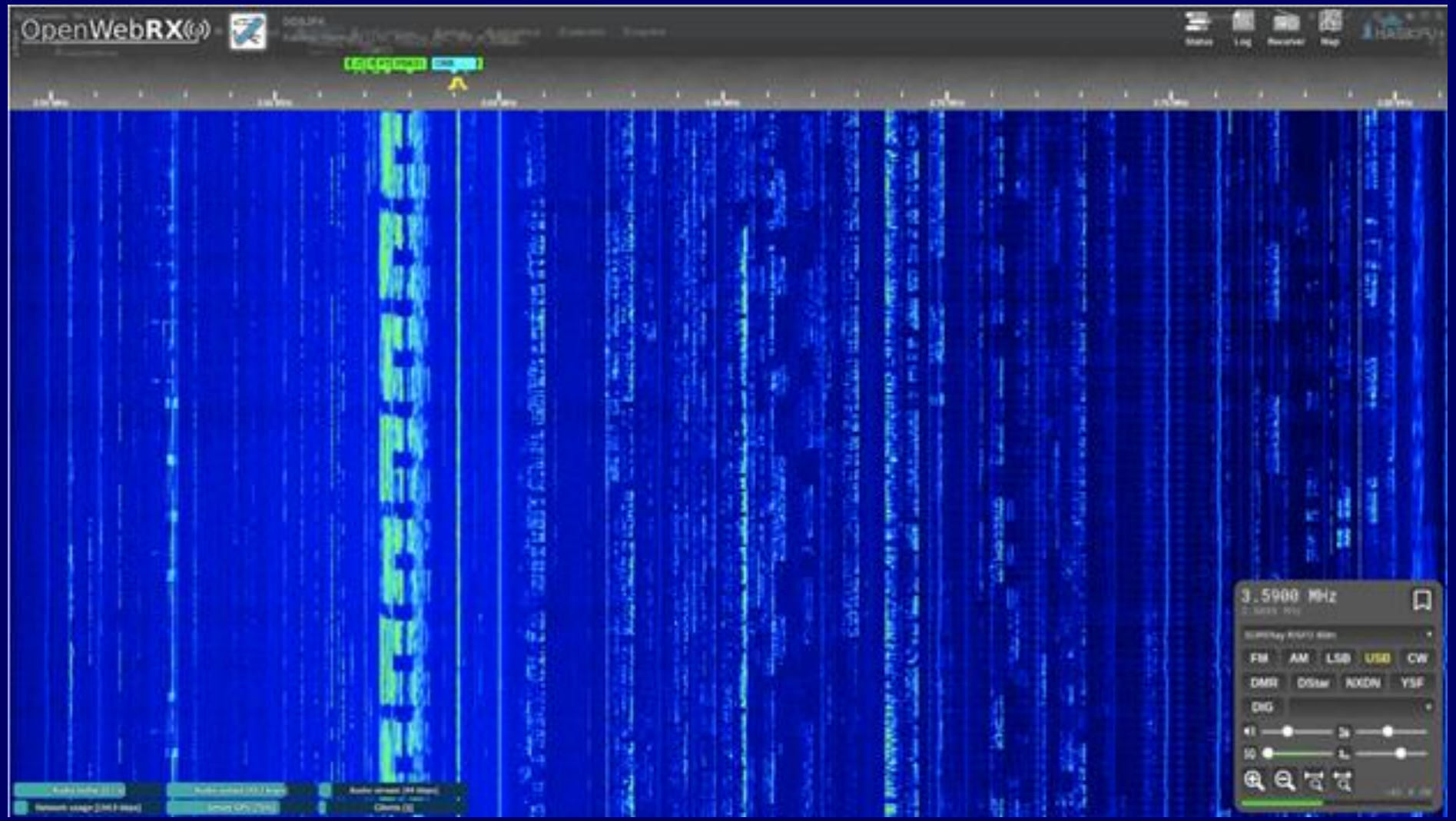
In the client, "SpyServer" is selected as the source, using the Raspberry Pi's IP address.

6. Remote Control & Listen

The client receives the I/Q stream, displaying the spectrum and playing audio as if the SDR were local.

SpyServer on Discovery Dish Post

OpenWebRX



How a Raspberry Pi SDR Station Tracks Aircraft

1. Aircraft Broadcasts Flight Data

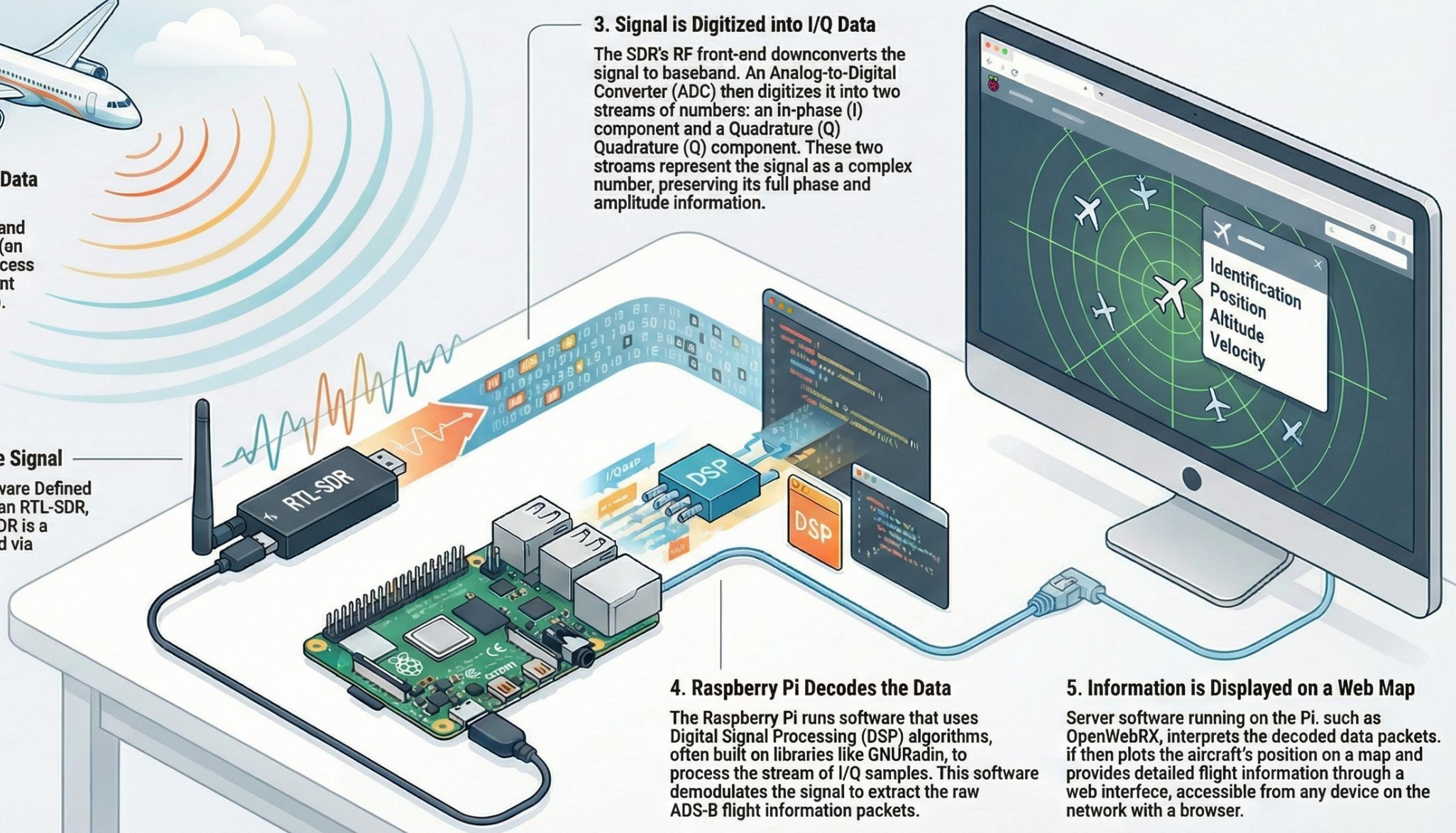
An aircraft in flight transmits its identification, position, altitude, and velocity as a digital radio signal (an electromagnetic wave). This process is known as Automatic Dependent Surveillance–Broadcast (ADS-B).

2. SDR Receiver Captures the Signal

An antenna connected to a Software Defined Radio (SDR) peripheral, such as an RTL-SDR, captures the radio waves. The SDR is a small, versatile device connected via USB to a Raspberry Pi.

3. Signal is Digitized into I/Q Data

The SDR's RF front-end downconverts the signal to baseband. An Analog-to-Digital Converter (ADC) then digitizes it into two streams of numbers: an in-phase (I) component and a Quadrature (Q) Quadrature (Q) component. These two stroams represent the signal as a complex number, preserving its full phase and amplitude information.

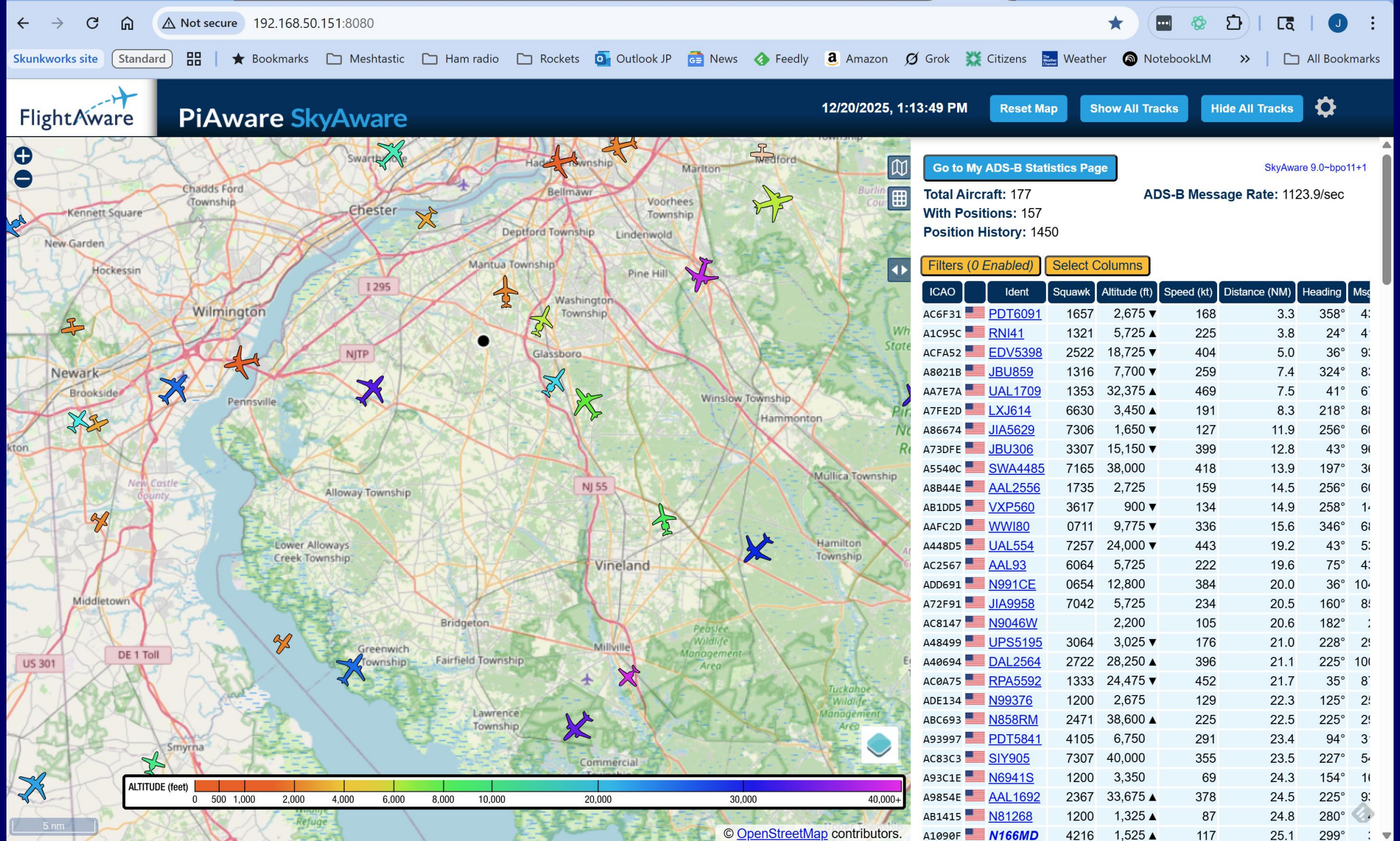


4. Raspberry Pi Decodes the Data

The Raspberry Pi runs software that uses Digital Signal Processing (DSP) algorithms, often built on libraries like GNURadin, to process the stream of I/Q samples. This software demodulates the signal to extract the raw ADS-B flight information packets.

5. Information is Displayed on a Web Map

Server software running on the Pi. such as OpenWebRX, interprets the decoded data packets. if then plots the aircraft's position on a map and provides detailed flight information through a web interfece, accessible from any device on the network with a browser.


Not secure
192.168.50.151:8080
Skunkworks site
Standard
Bookmarks
Meshtastic
Ham radio
Rockets
Outlook JP
News
Feedly
Amazon
Grok
Citizens
Weather
NotebookLM
All Bookmarks
FlightAware
PiAware SkyAware
12/20/2025, 1:13:49 PM
Reset Map
Show All Tracks
Hide All Tracks
Go to My ADS-B Statistics Page
SkyAware 9.0~bpo11+1
Total Aircraft: 177
With Positions: 157
Position History: 1450
ADS-B Message Rate: 1123.9/sec
Filters (0 Enabled)
Select Columns
ICAO | Ident | Squawk | Altitude (ft) | Speed (kt) | Distance (NM) | Heading
AC6F31 PDT6091 1657 2,675 ▼ 168 3.3 358°
A1C95C RNI41 1321 5,725 ▲ 225 3.8 24°
ACFA52 EDV5398 2522 18,725 ▼ 404 5.0 36°
A8021B JBU859 1316 7,700 ▼ 259 7.4 324°
AA7E7A UAL1709 1353 32,375 ▲ 469 7.5 41°
A7FE2D LXJ614 6630 3,450 ▲ 191 8.3 218°
A86674 JIA5629 7306 1,650 ▼ 127 11.9 256°
A73DFE JBU306 3307 15,150 ▼ 399 12.8 43°
A5540C SWA4485 7165 38,000 418 13.9 197°
A8B44E AAL2556 1735 2,725 159 14.5 256°
AB1DD5 VXP560 3617 900 ▼ 134 14.9 258°
AAFC2D WWI80 0711 9,775 ▼ 336 15.6 346°
A448D5 UAL554 7257 24,000 ▼ 443 19.2 43°
AC2567 AAL93 6064 5,725 222 19.6 75°
ADD691 N991CE 0654 12,800 384 20.0 36°
A72F91 JIA9958 7042 5,725 234 20.5 160°
AC8147 N9046W 2,200 105 20.6 182°
A48499 UPS5195 3064 3,025 ▼ 176 21.0 228°
A40694 DAL2564 2722 28,250 ▲ 396 21.1 225°
AC0A75 RPA5592 1333 24,475 ▼ 452 21.7 35°
ADE134 N99376 1200 2,675 129 22.3 125°
ABC693 N858RM 2471 38,600 ▲ 225 22.5 225°
A93997 PDT5841 4105 6,750 291 23.4 94°
AC83C3 SIY905 7307 40,000 355 23.5 227°
A93C1E N6941S 1200 3,350 69 24.3 154°
A9854E AAL1692 2367 33,675 ▲ 378 24.5 225°
AB1415 N81268 1200 1,325 ▲ 87 24.8 280°
A1090F N166MD 4216 1,525 ▲ 117 25.1 299°
ALTITUDE (feet)
0 500 1,000 2,000 4,000 6,000 8,000 10,000 20,000 30,000 40,000+
5 nm
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Questions and Demos