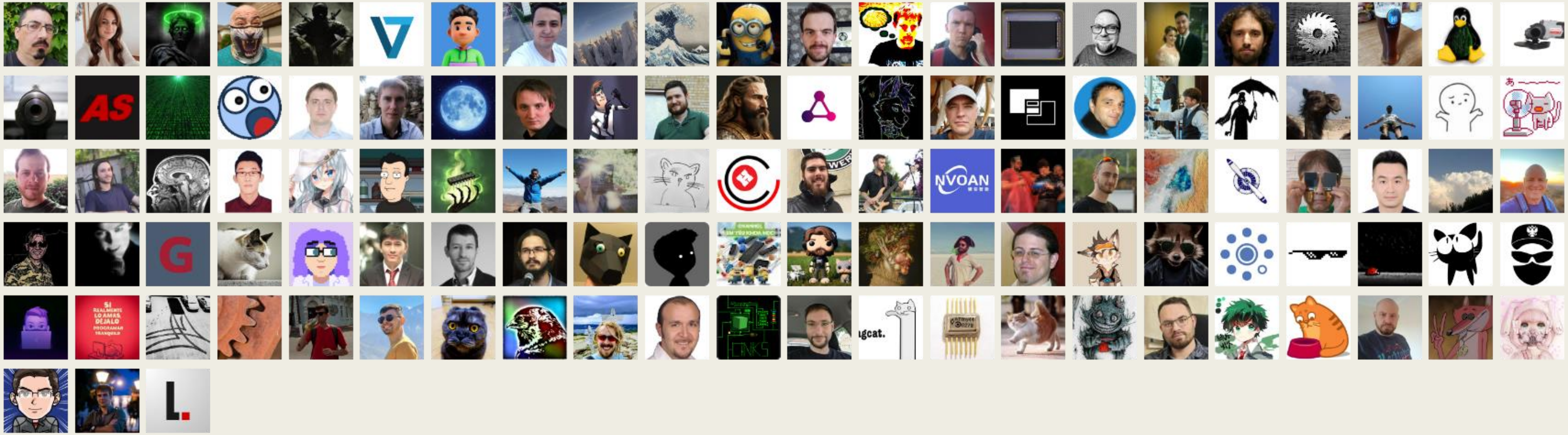
ДИЗАЙН И ЭВОЛЮЦИЯ OPEN SOURCE СИСТЕМ БЕСПРОВОДНОЙ ПЕРЕДАЧИ ВИДЕО

Ильин Дмитрий

By standing upon the shoulders of giants*

*Isaac Newton

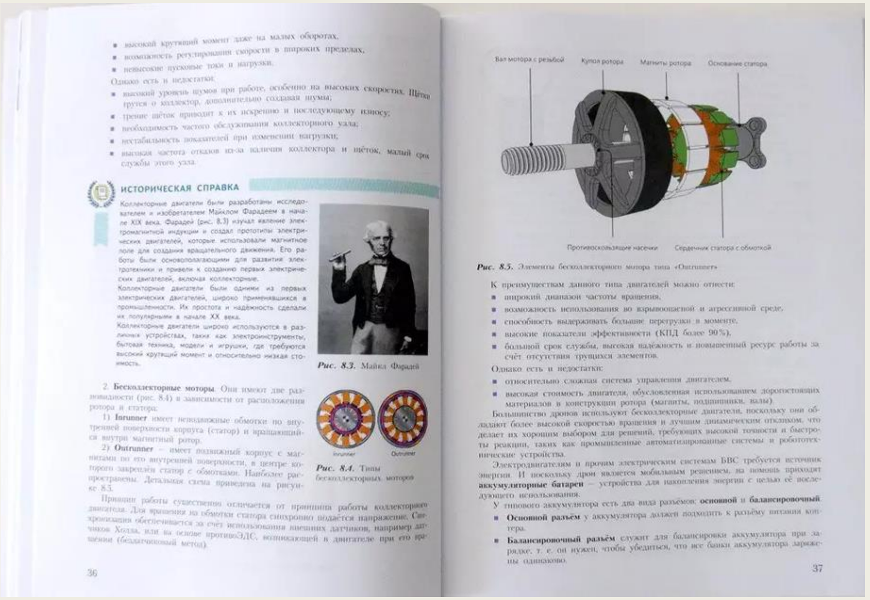


Снова в школу

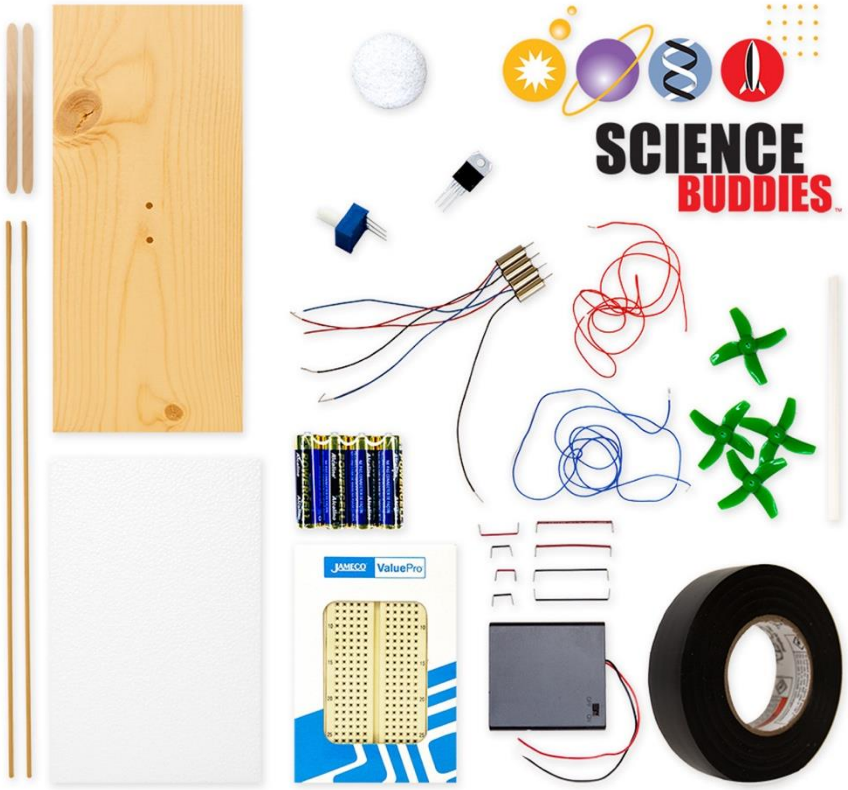
Наши дни

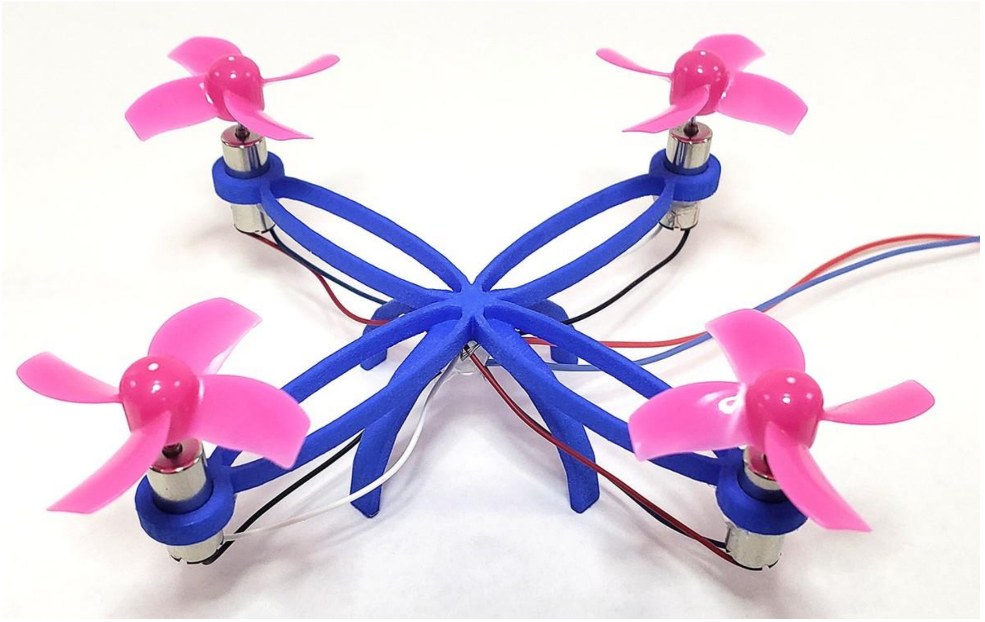

ТРУД
ТЕХНОЛОГИЯ
БЕСПИЛОТНЫЕ
ЛЕТАТЕЛЬНЫЕ
АППАРАТЫ
8-9


Подвес и крепления к раме посадочного шасси


ИСТОРИЧЕСКАЯ СПРАВКА

DIY





Попробуем передать видео по Wi-Fi

Что внутри Wi-Fi адаптера

3.1. 11ac Dual-Band 2x2 RF Application

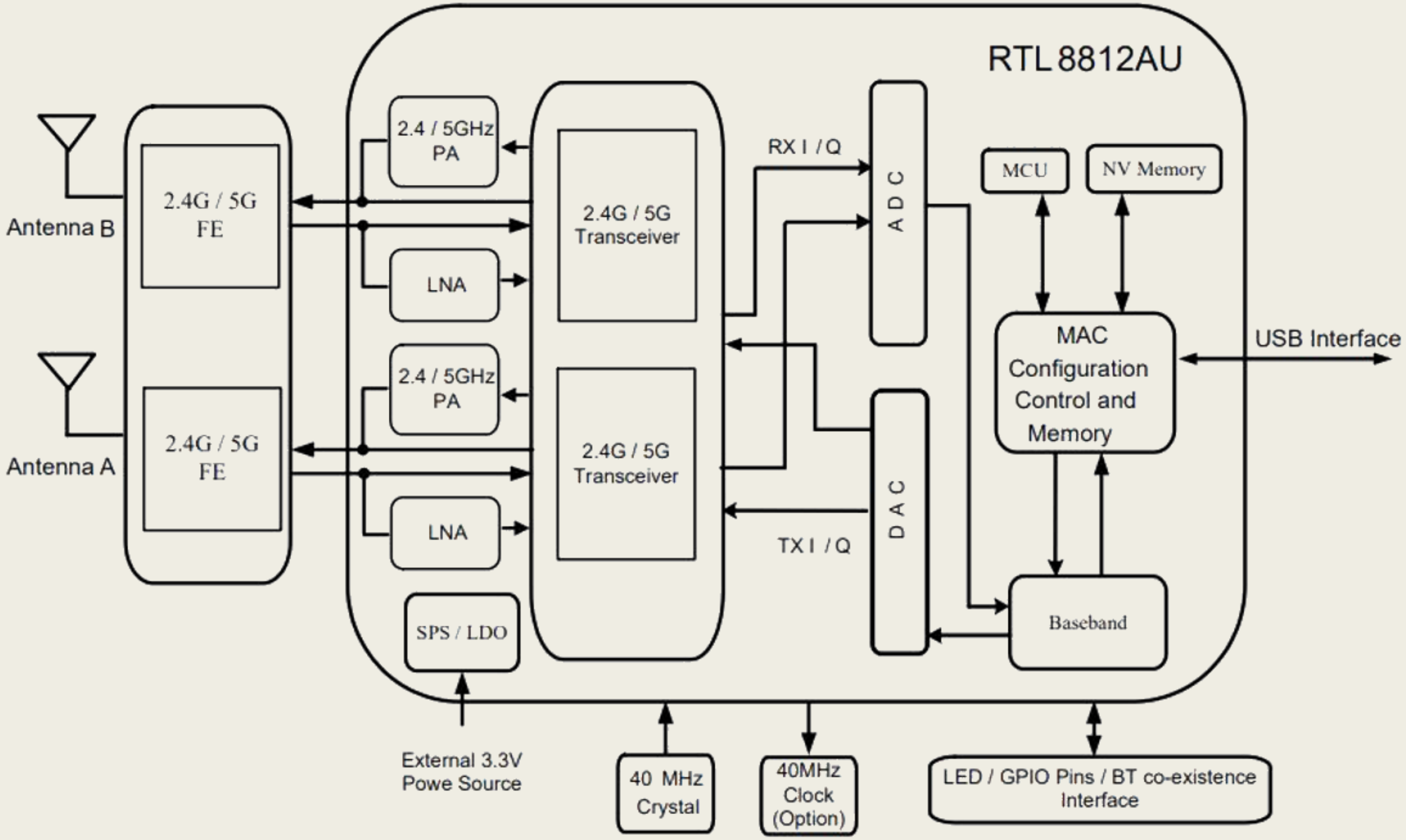
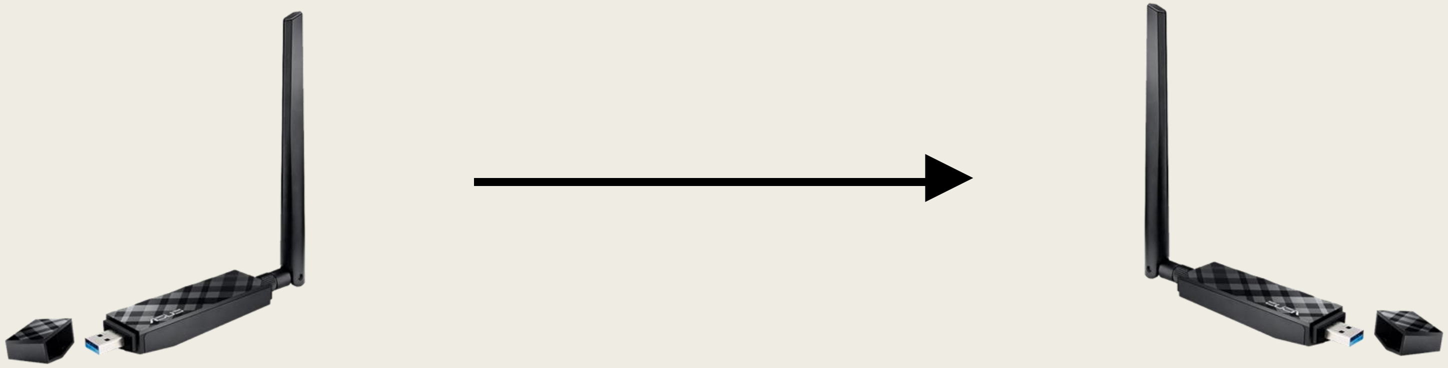


Figure 1. Dual-Band MIMO 2x2 Solution – RTL8812AU-CG (11ac 2x2 MAC/BB/RF + PA)

Простейший беспроводной линк

Передатчик

Приемник



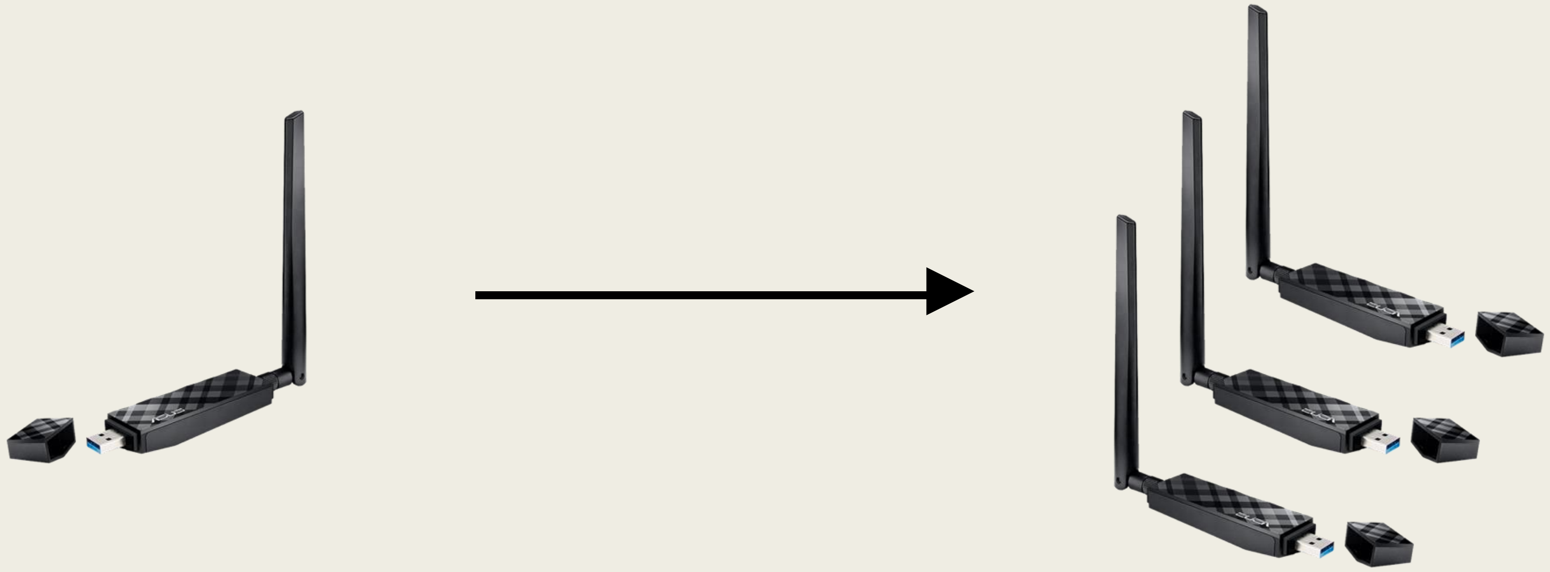
Injection mode

Monitor mode

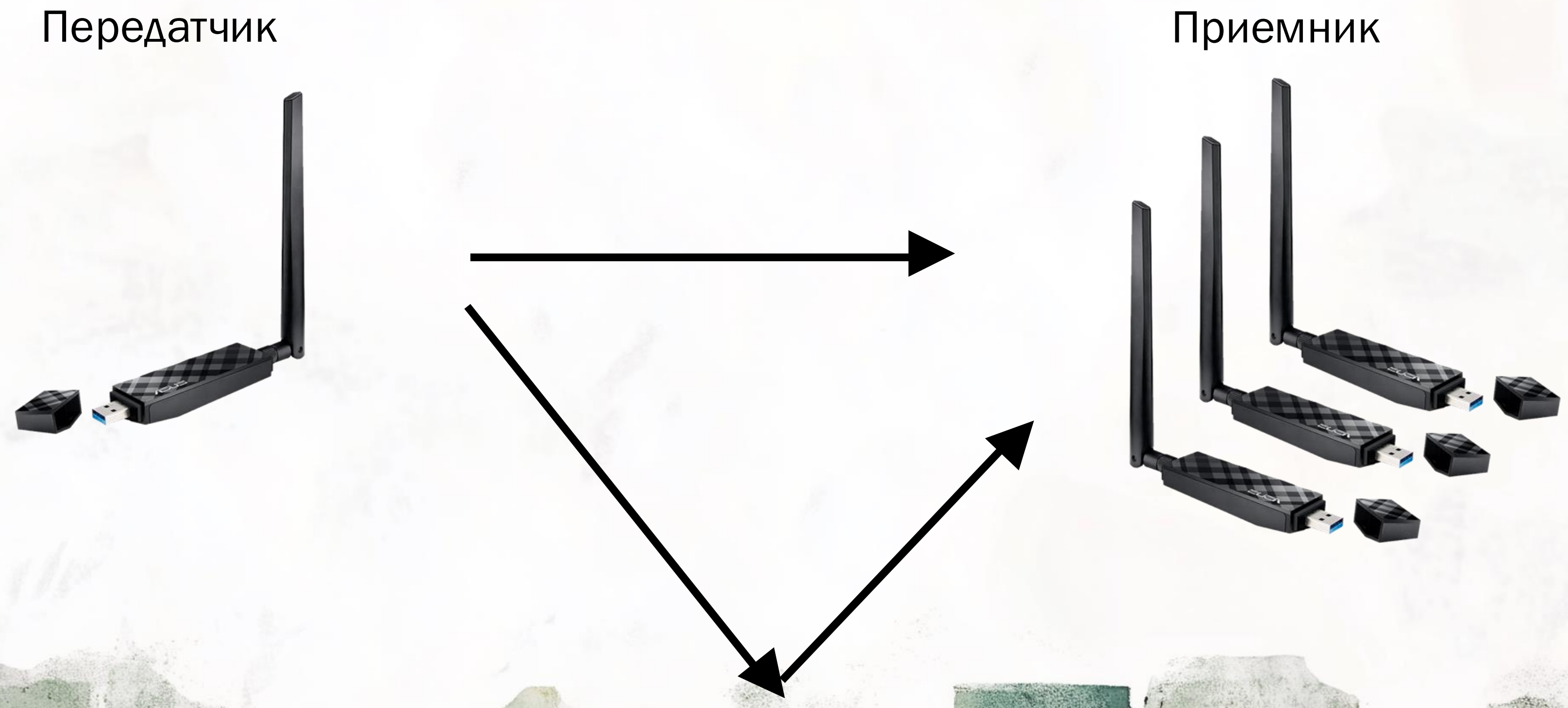
Множественный прием

Передатчик

Приемник



Интерференция

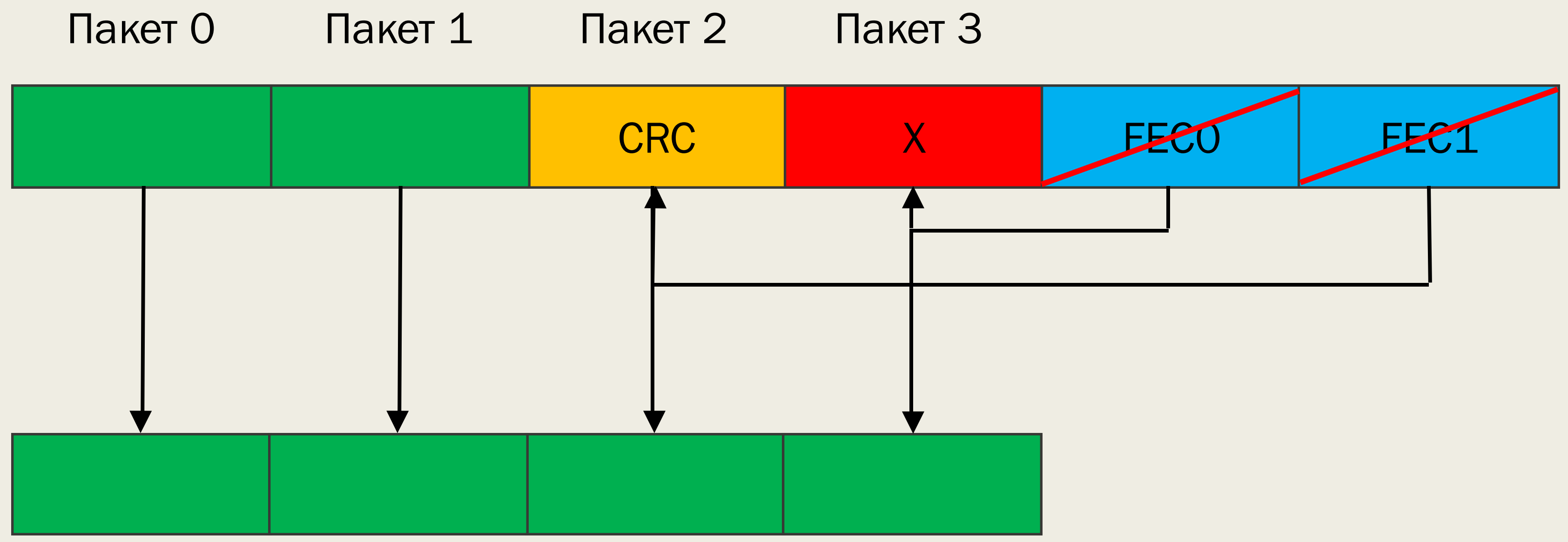



TURBOWING
TURBOWING
RADIOMASTER
TX12
EdgeTX - ELRS

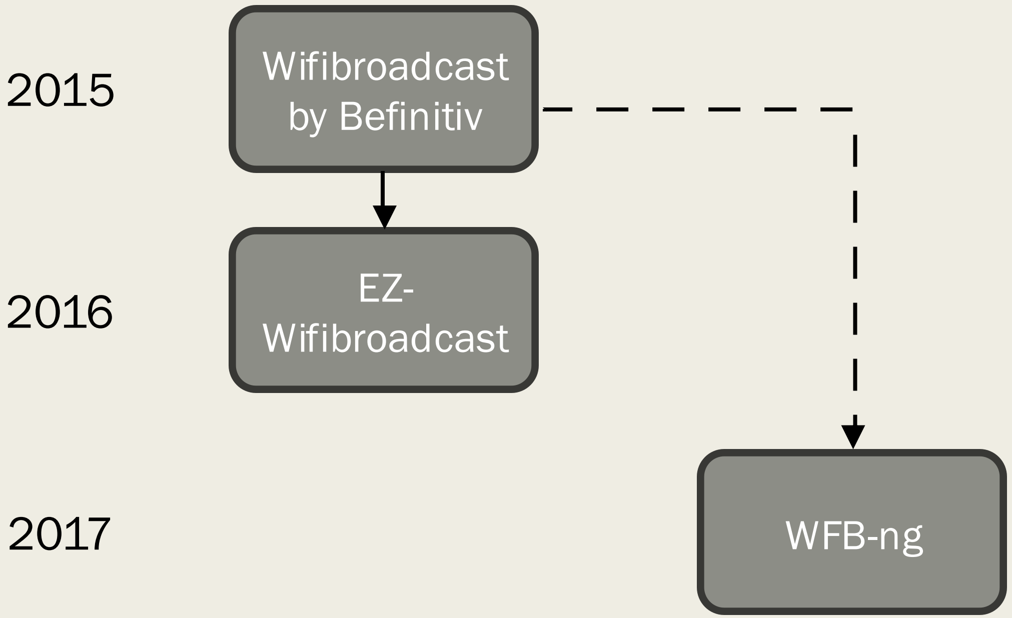
Множественный прием

	Пакет 1	Пакет 2	Пакет 3	Пакет 4
Карта 0	CRC		CRC	X
Карта 1		CRC	X	X
Карта 2		X	CRC	X
Объединение			CRC	X

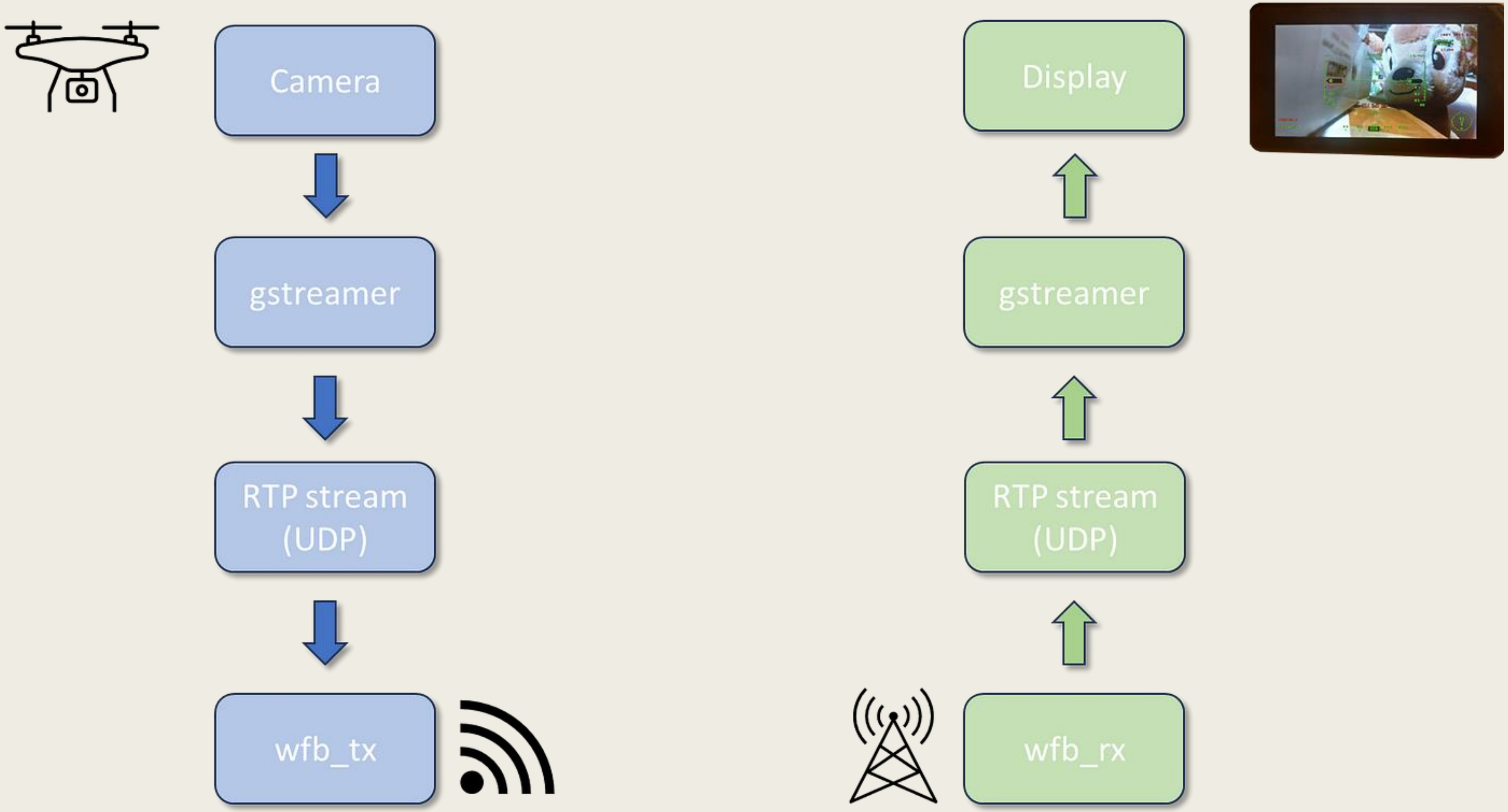
Предварительная работа над ошибками (FEC)



Эволюция идеи



WFB-ng


Camera
gstreamer
RTP stream
(UDP)
wfb_tx
Display
gstreamer
RTP stream
(UDP)
wfb_rx


OpenGL renderer
N
042
3
60
E
H-
01:08:10
ARMED
H: 19m
ALTCTL
GS
REL
30
20
10
0.2
150
140
130
123
110
100
PT 0
RL 0
THR 44%
[km/h]
[m]
60% 3D-10
15.3V 37.523787
-1.0A -122.255150
WFB -25 F6 L0
GCS connection regained
Armed by external command
Takeoff detected

WFB-ng_24.5.20.74460 @drone wlan1 [default]

WFB-ng

```
[TX: drone video]
      pkt/s pkt        Flow: 953 kbit/s -> 1.7 mbit/s
sent    193 90525
udp     128 60061      [ANT] pkt/s      Injection [us]
fec_t     0 0           00XX   193      4 <   20 <   89
drop      0 0
trunc     0 0
```

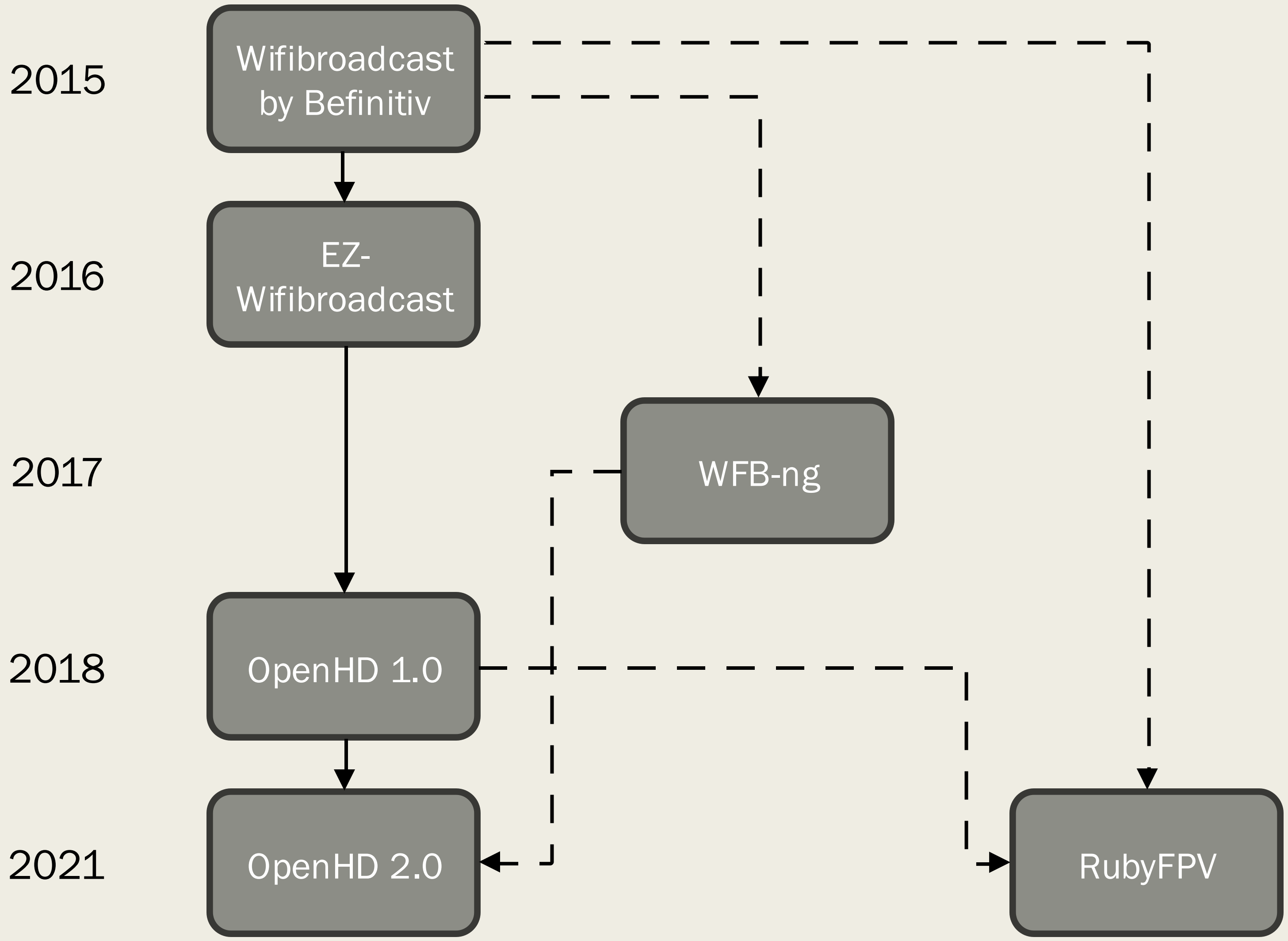
```
[RX: drone mavlink]
     pkt/s pkt       Flow: 1.5 kbit/s -> 0.2 kbit/s  FEC: 1/4
recv       4 173
udp        1 35      Freq MCS BW [ANT] pkt/s     RSSI [dBm]        SNR [dB]
fec_r      0 3       5805   1 20  0000     4  -22 < -21 < -18   22 <  23 <  25
lost       0 3       5805   1 20  0001     4  -30 < -29 < -28   22 <  23 <  25
d_err      0 26
bad        0 0
```

```
[TX: drone mavlink]
      pkt/s pkt        Flow: 144 kbit/s -> 295 kbit/s
sent     27 11519
udp      13 5546       [ANT] pkt/s      Injection [us]
fec_t     0 0           00XX    27      7 <   37 <  119
drop      0 0
trunc     0 0
```

```
[RX: drone tunnel]
     pkt/s pkt       Flow: 1.1 kbit/s -> 0.0 kbit/s  FEC: 1/2
recv       3 861
udp        1 357     Freq MCS BW [ANT] pkt/s     RSSI [dBm]        SNR [dB]
fec_r      0 12      5805   1 20  0000     3  -22 < -19 < -18   19 <  20 <  22
lost       0 31      5805   1 20  0001     3  -30 < -29 < -28   19 <  20 <  22
d_err      0 0
bad        0 0
```

```
[TX: drone tunnel]
      pkt/s pkt        Flow: 0.0 kbit/s -> 0.4 kbit/s
sent      2 1300
udp       1 523        [ANT] pkt/s      Injection [us]
fec_t     0 0           00XX     2     16 <   60 <  105
drop      0 0
trunc     0 0
```

Эволюция идеи



Ruby

Radio Links and Video Links management in Ruby

Ruby continuously tracks the radio link quality by measuring dbm signal, radio ping quality, retransmissions, lost packets, interferences in order to compute a global more accurate Radio Link Quality indicator

Best Radio Link Conditions

Radio Link Quality

Worst Radio Link Conditions

Based on radio link conditions, the following parameters are continually adjusted with the single purpose to maintain a consistent video link (albeit with a lower quality or increased latency) even in the worst radio conditions:

Highest Radio Modulation Scheme

Radio Modulation Scheme

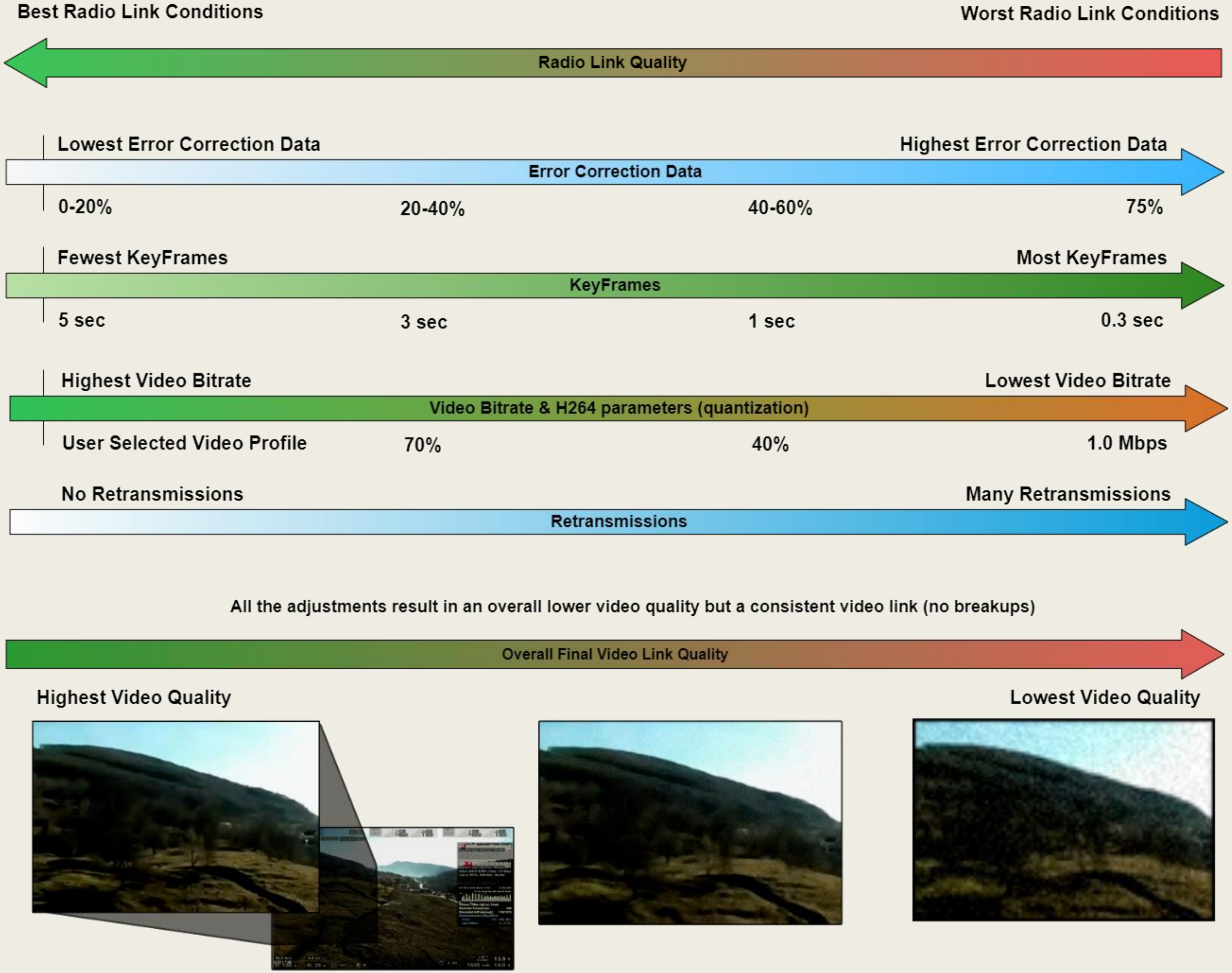
Lowest Radio Modulation Scheme

QAM-16 QAM-4 QPSK BPSK

802.11ac - VHT MCS, SNR and RSSI

VHT MCS	Modulation	Coding	20MHz				40MHz				80MHz				160MHz			
			Data Rate		Min. SNR	RSSI	Data Rate		Min. SNR	RSSI	Data Rate		Min. SNR	RSSI	Data Rate		Min. SNR	RSSI
			800ns	400ns			800ns	400ns			800ns	400ns			800ns	400ns		
1 Spatial Stream																		
0	BPSK	1/2	6.5	7.2	2	-82	13.5	15	5	-79	29.3	32.5	8	-76	58.5	65	11	-73
1	QPSK	1/2	13	14.4	5	-79	27	30	8	-76	58.5	65	11	-73	117	130	14	-70
2	QPSK	3/4	19.5	21.7	9	-77	40.5	45	12	-74	87.8	97.5	15	-71	175.5	195	18	-68
3	16-QAM	1/2	26	28.9	11	-74	54	60	14	-71	117	130	17	-68	234	260	20	-65
4	16-QAM	3/4	39	43.3	15	-70	81	90	18	-67	175.5	195	21	-64	351	390	24	-61
5	64-QAM	2/3	52	57.8	18	-66	108	120	21	-63	234	260	24	-60	468	520	27	-57
6	64-QAM	3/4	58.5	65	20	-65	121.5	135	23	-62	263.3	292.5	26	-59	526.5	585	29	-56
7	64-QAM	5/6	65	72.2	25	-64	135	150	28	-61	292.5	325	31	-58	585	650	34	-55
8	256-QAM	3/4	78	86.7	29	-59	162	180	32	-56	351	390	35	-53	702	780	38	-50
9	256-QAM	5/6			31	-57	180	200	34	-54	390	433.3	37	-51	780	866.7	40	-48

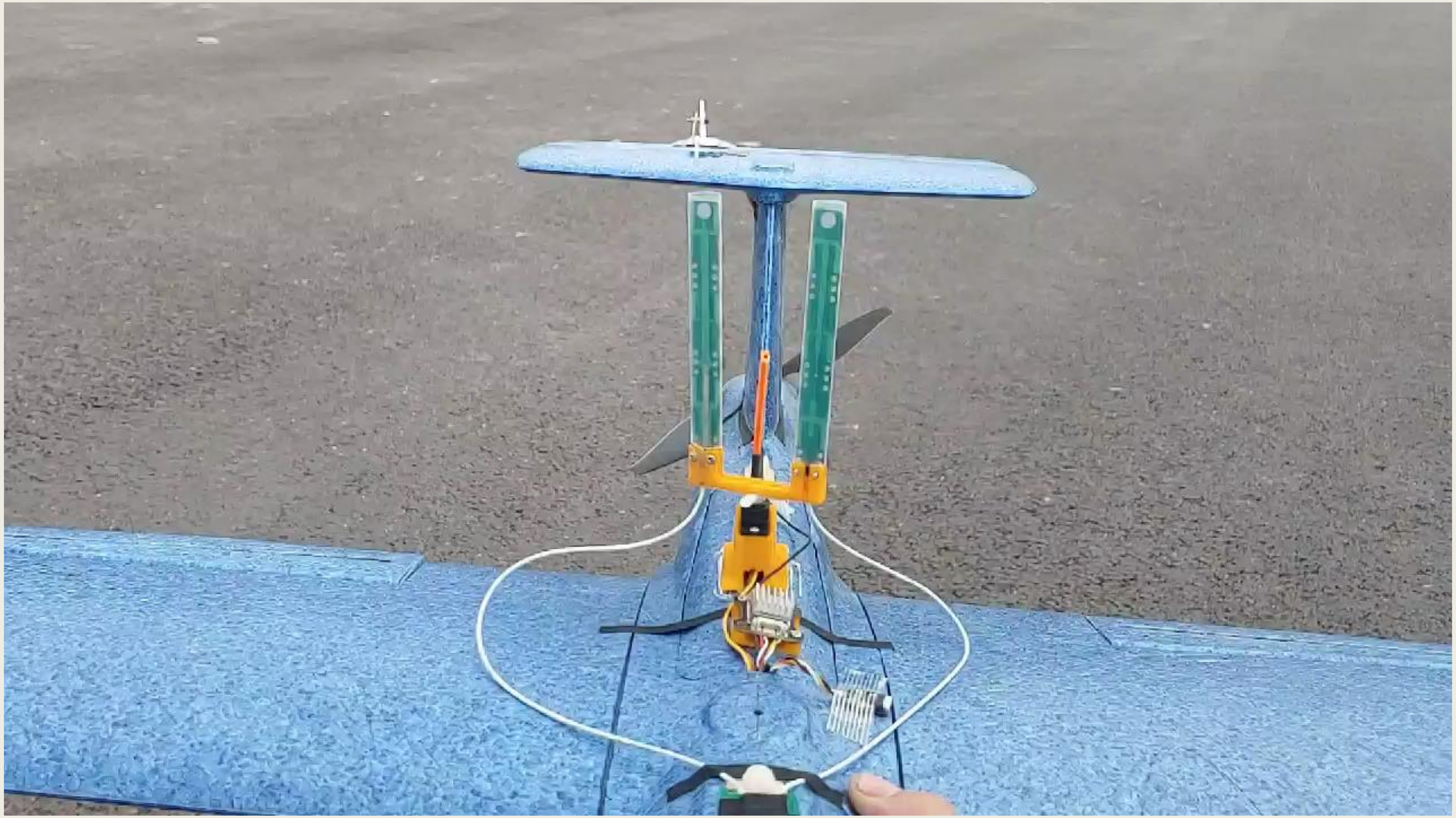
Ruby



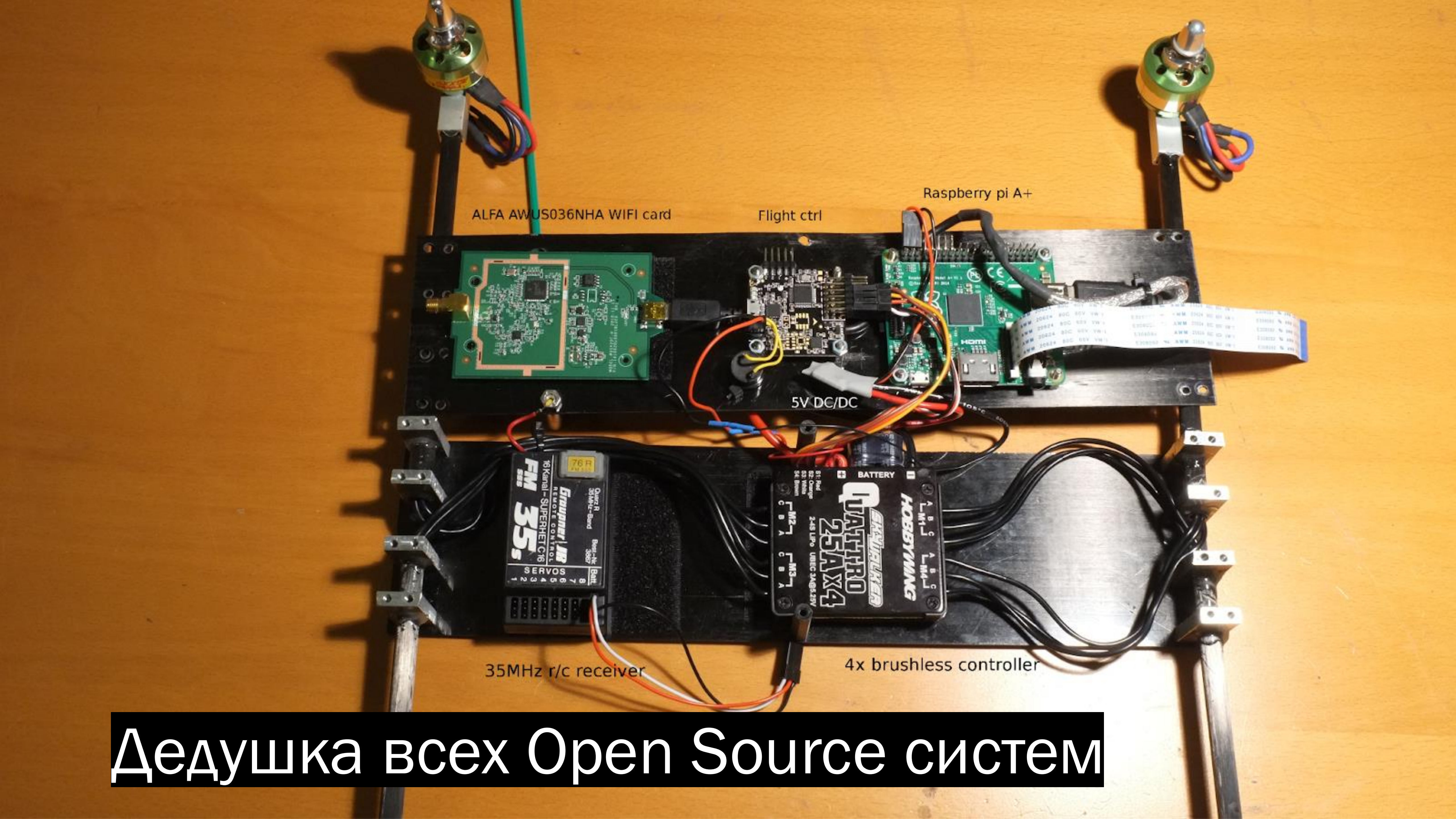
Best Radio Link Conditions
Worst Radio Link Conditions
Radio Link Quality
Lowest Error Correction Data
Highest Error Correction Data
Error Correction Data
0-20%
20-40%
40-60%
75%
Fewest KeyFrames
Most KeyFrames
KeyFrames
5 sec
3 sec
1 sec
0.3 sec
Highest Video Bitrate
Lowest Video Bitrate
Video Bitrate & H264 parameters (quantization)
User Selected Video Profile
70%
40%
1.0 Mbps
No Retransmissions
Many Retransmissions
Retransmissions
All the adjustments result in an overall lower video quality but a consistent video link (no breakups)
Overall Final Video Link Quality
Highest Video Quality
Lowest Video Quality


3D 12
HDOP 0.8
CRUS
25 : 39
-54 dbm A: RX
-56 dbm B: RX/TX
-40 dbm S2: RX
5320 Mhz
0.0 Mbps
13 % 1200 Mhz 34 C
6 % 1200 Mhz 13 C
30 40 NE 50 60 70 80 E 100 110 120 130
080
80
70
(km/h) SPD(A) 61.7
50
GS: 95.0 km/h
D: 21614 m
080
15 10 5 0 -5 -10
1980
1967 (m) ALT
1960
1950
Radio Link 99%
Link delay: 10 ms
Data: 8 kbps
A: RX -54 dbm 99% 12.2 Mbps
B: RX/TX -56 dbm 90% 11.9 Mbps
S2: RX -40 dbm 0% 0 kbps
A 5320 Mhz
B 5320 Mhz
S2 5320 Mhz
Video Decoder
Stream: 1920x1080, 30 fps 10 key
Params: HQ / R/1/[250-26]
EC: 5/1/1300 / 10/2 ms
1.2 seconds 30 ms/bar
Max lost gap packets: 3
Max lost gap time: 6 ms
Packets/sec out: 1090
Blocks/sec out: 181
Received retrans: 11540
Bad blocks (discarded): 155
Unrecoverable packets: 381
S2: RX, -40 dbm
B: RX/TX, -56 dbm
A: RX, -54 dbm
Efficiency Stats
mA/km: 164
mA/h: 11023
95.0 km/h
1.8 m/s
Total: 28 km
D: 21614 m
H: 1967 m
080°
Pitch: 2
92%
3.33 V (4 cells)
5341 mAh
13.3 V
17.2 A

Направленные антенны

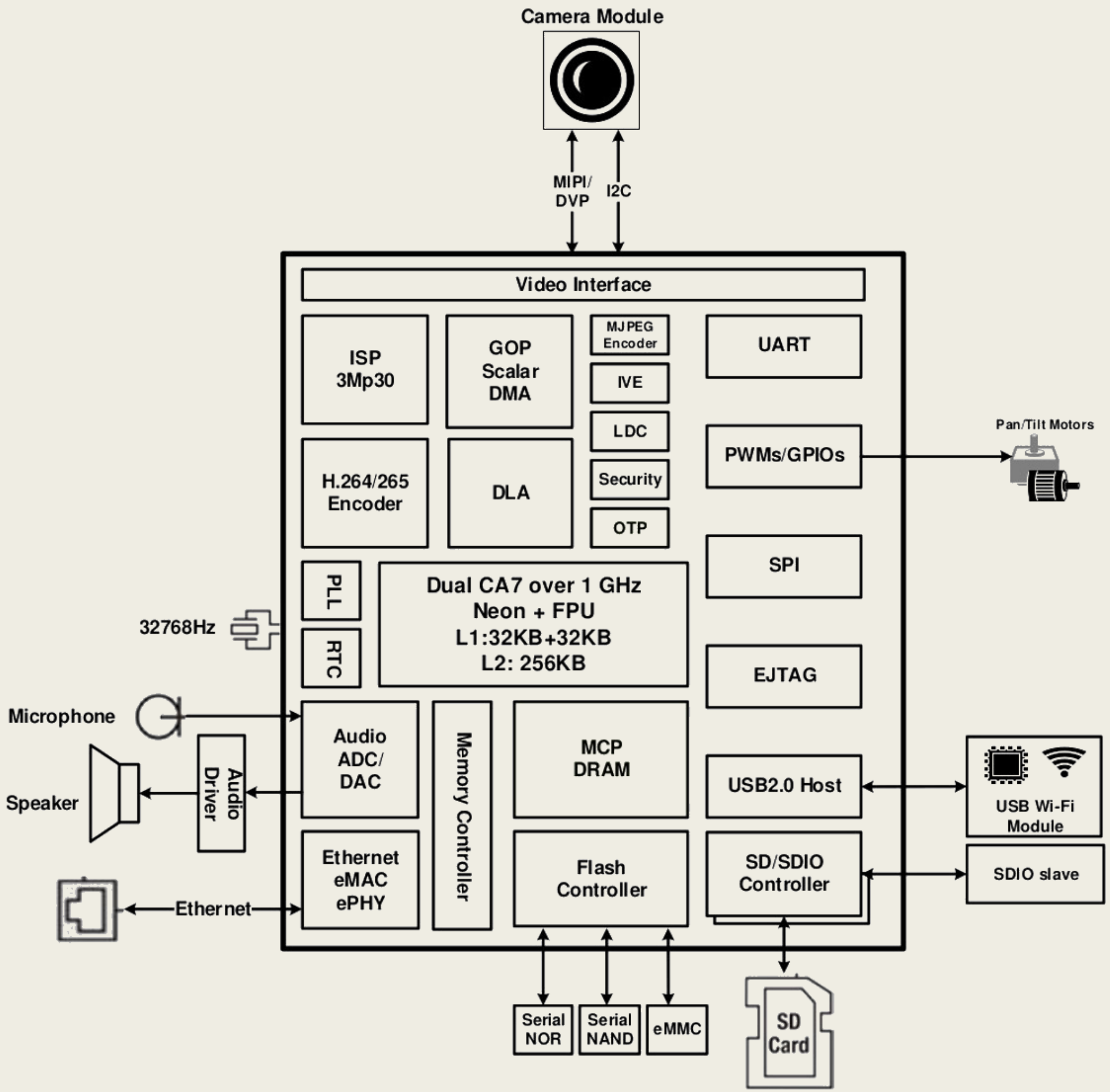



RX1: 1 %
14478 mAh
-88dBm
-88dBm [155751]
-90dBm [81712]
46°
W N E S
BATT 0%
70
59.3
km/h
50
40
10
10
10
10
20
0 %
17.01 V
2.42 A
AUTO
121.1km

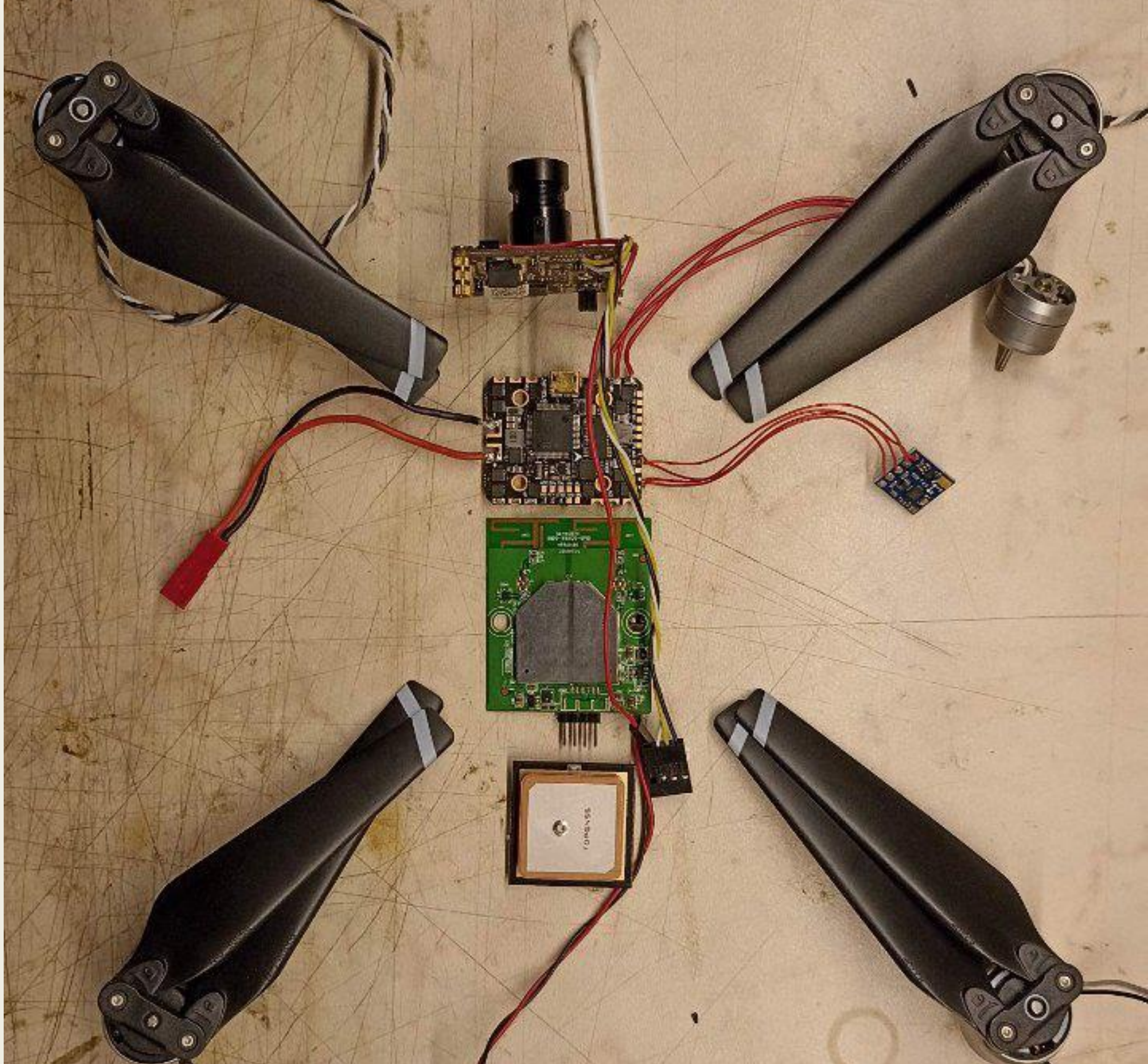


Дедушка всех Open Source систем

Что такое CCTV IP камера?



Современный вариант

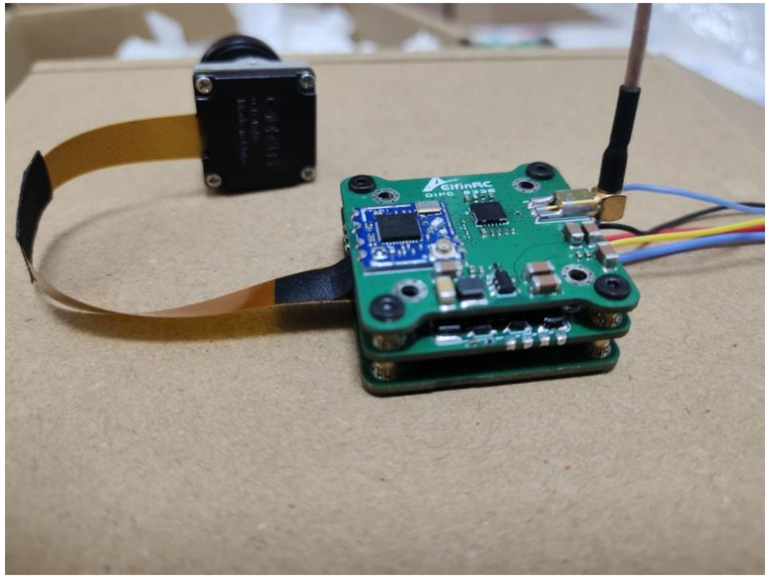


OpenIPC AIO (all-in-one)

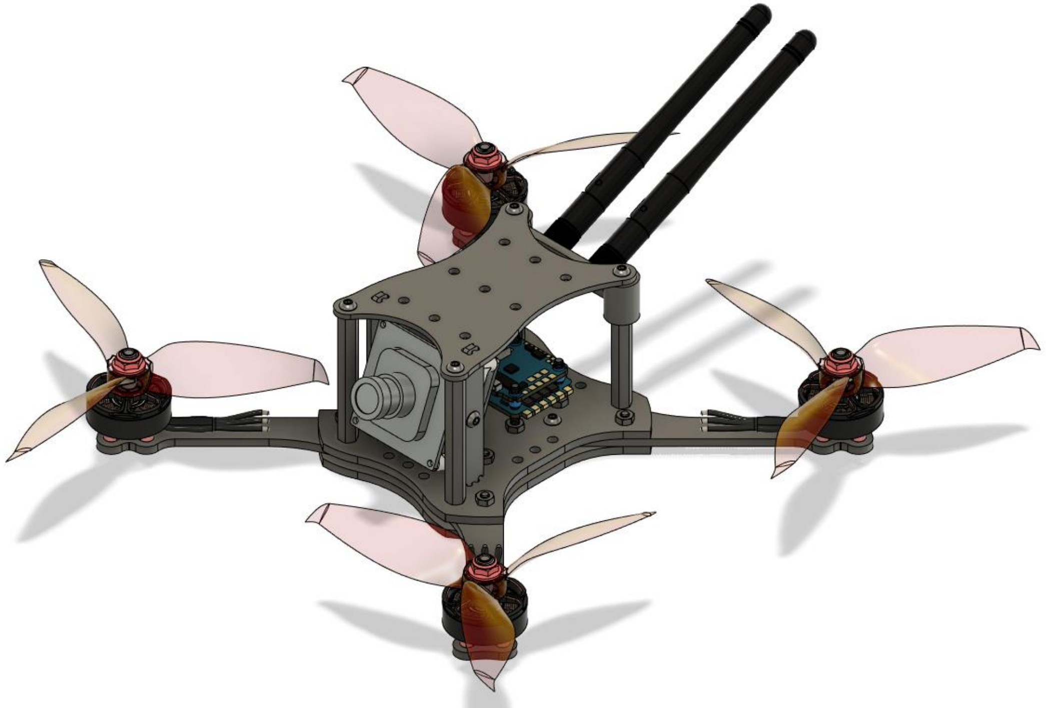
Open~~WRT~~IPC

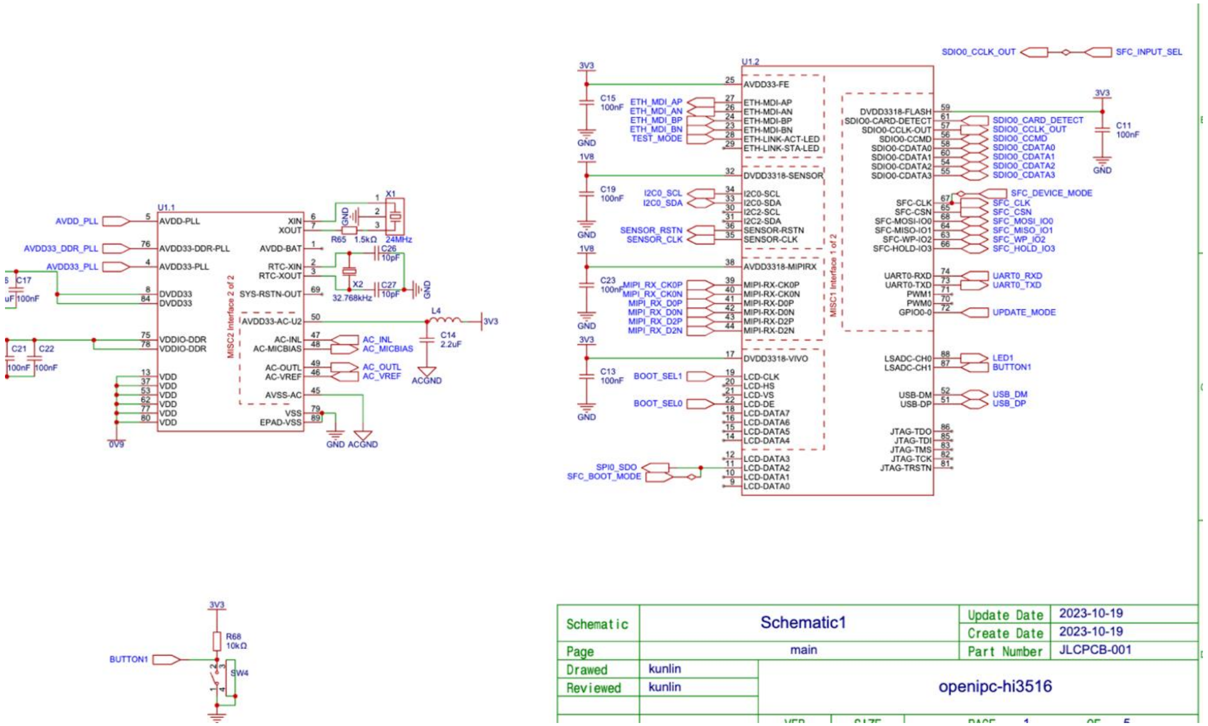
RunCam®
Born for RC Fanatics

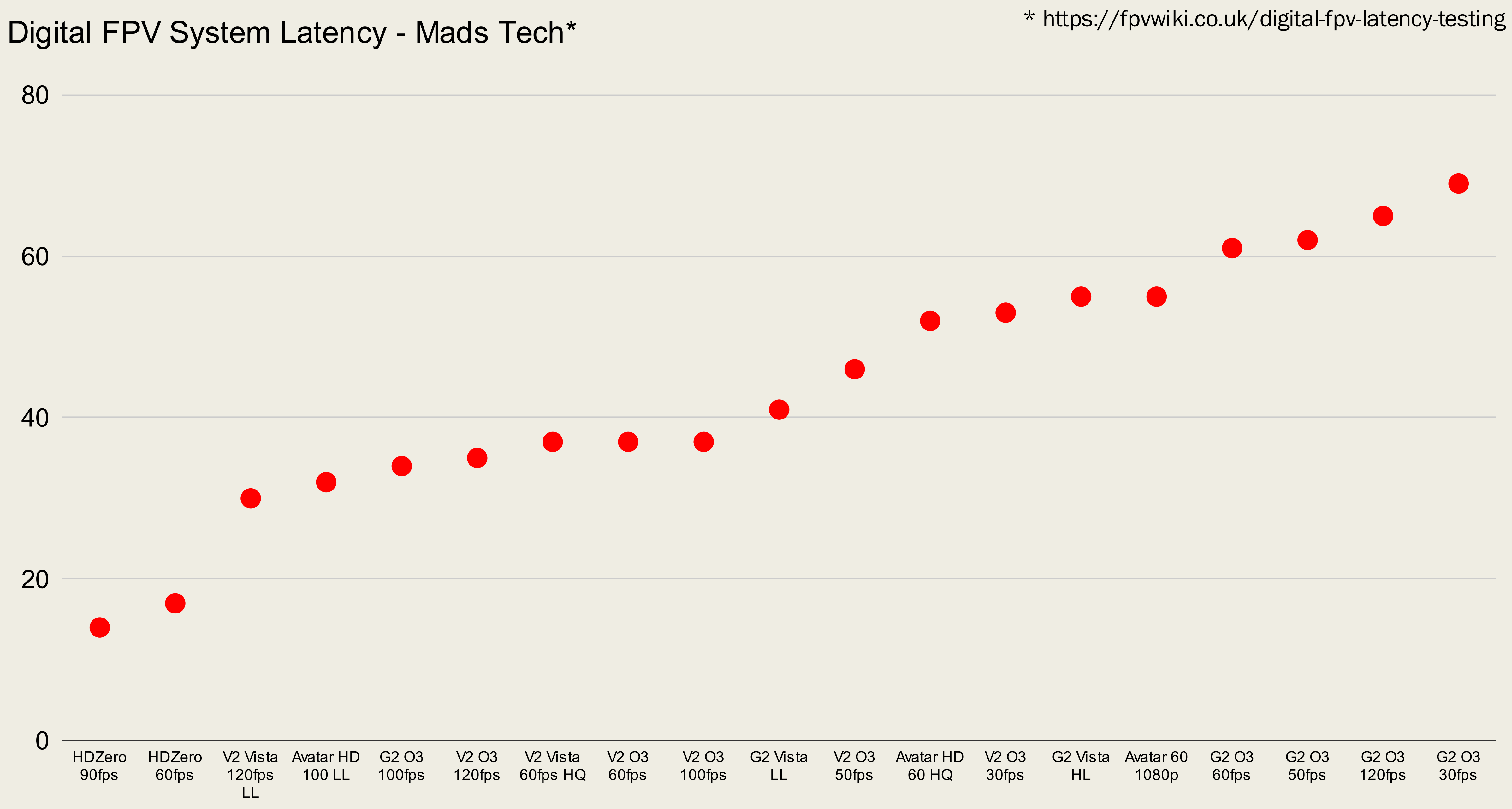
EMAX



Open hardware

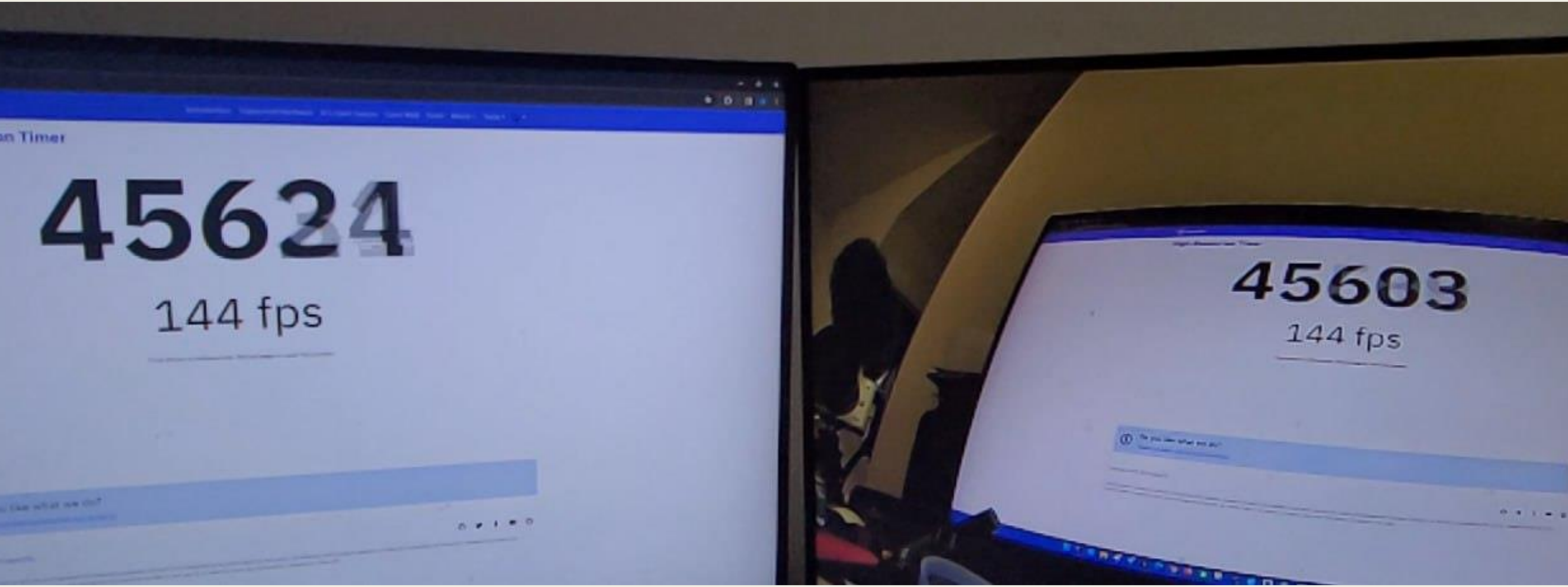






Digital FPV System Latency - Mads Tech*
* https://fpvwiki.co.uk/digital-fpv-latency-testing
80
60
40
20
0
HDZero 90fps
HDZero 60fps
V2 Vista 120fps LL
Avatar HD 100 LL
G2 O3 100fps
V2 O3 120fps
V2 Vista 60fps HQ
V2 O3 60fps
V2 O3 100fps
G2 Vista LL
V2 O3 50fps
Avatar HD 60 HQ
V2 O3 30fps
G2 Vista HL
Avatar 60 1080p
G2 O3 60fps
G2 O3 50fps
G2 O3 120fps
G2 O3 30fps

G2G latency тесты



Тюнинг кодека

- H.265 со слайсами
  - *Мы хотим отправлять в сеть данные пока идет readout сенсора*
- 60/90/120 fps (240 fps для гонок)
  - *Обязательный тюнинг драйверов сенсоров и ISP*
- FEC
  - *Например, восстанавливает 4 пакета из блока 12*
- Битрейт кодека зависит от кейса
  - *Минимум для гонок*

Видеоочки

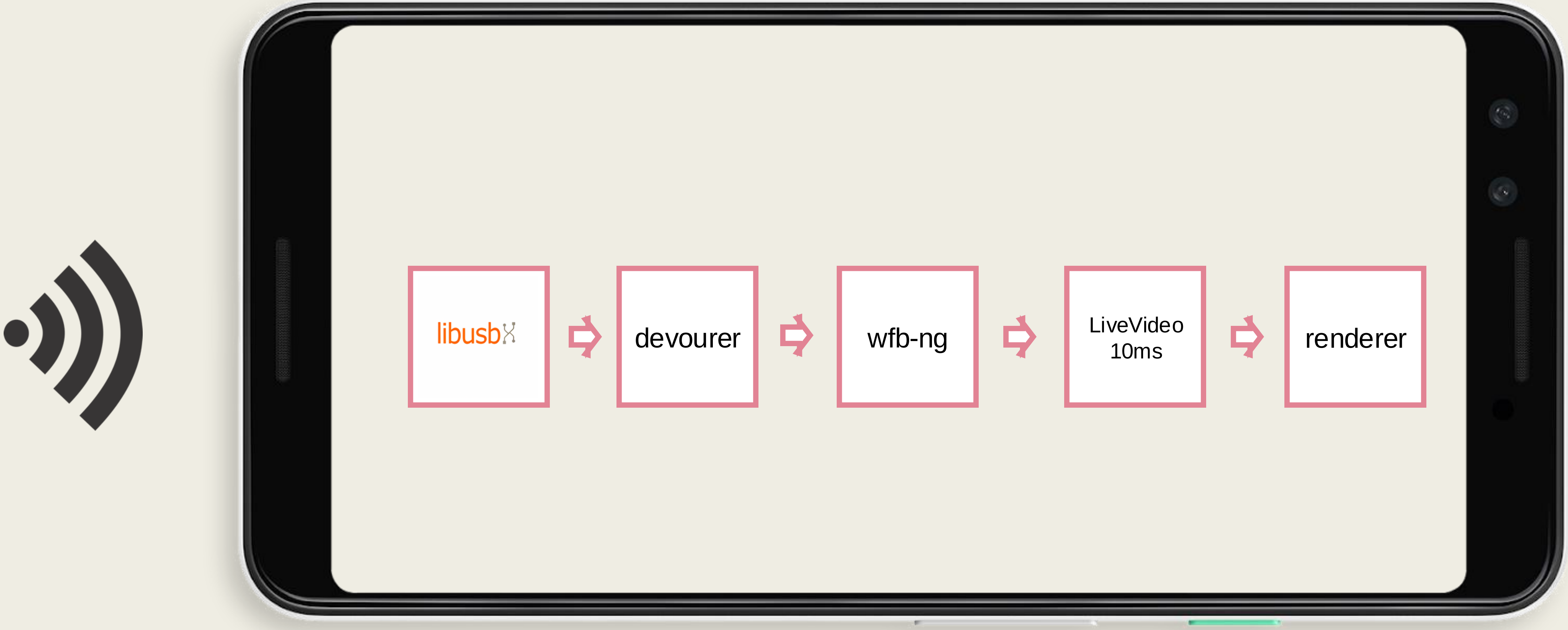
Android как GroundStation

USB + Android

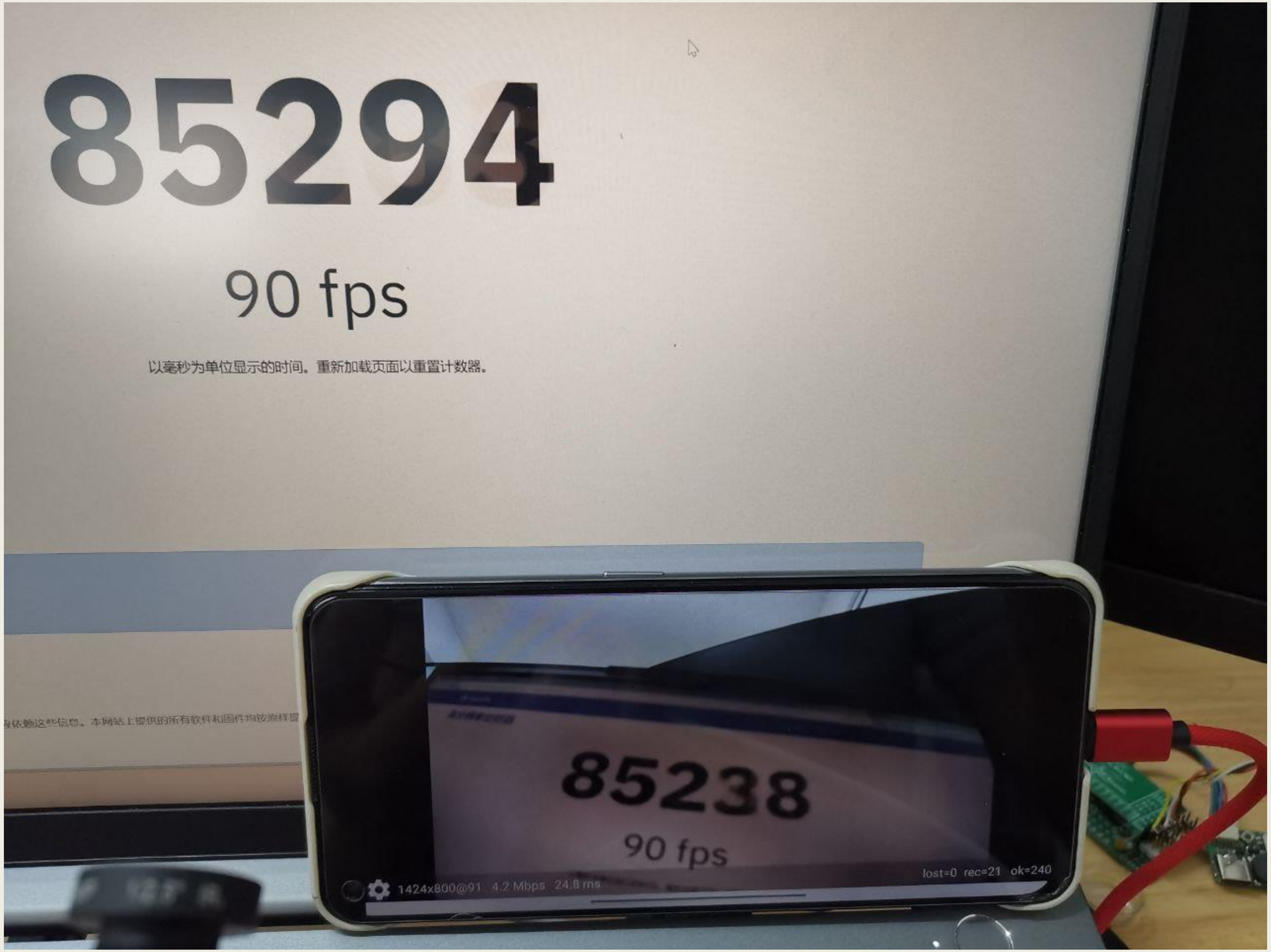
activity_main.xml | MainActivity.java | AndroidManifest.xml | device_filter.xml | UsbManager.java

```java

    @Override
    protected void onCreate(Bundle savedInstanceState) {
        super.onCreate(savedInstanceState);

        UsbManager manager = (UsbManager) getSystemService(Context.USB_SERVICE);

        for (UsbDevice usbDevice: manager.getDeviceList().values()) {
            String deviceName = usbDevice.getDeviceName();

            Log.e(TAG, msg: "DeviceName " + usbDevice.getDeviceName());
            Log.e(TAG, msg: "ManufacturerName " + usbDevice.getManufacturerName());
            Log.e(TAG, msg: "ProductName " + usbDevice.getProductName());

            UsbInterface usbInterface = findInterface(usbDevice);

            UsbEndpoint mOutEndpoint = null, mInEndpoint = null ;

            for (int nEp = 0; nEp < usbInterface.getEndpointCount(); nEp++) {
                UsbEndpoint tmpEndpoint = usbInterface.getEndpoint(nEp);

                Log.e(TAG, msg: "endpoint = " + tmpEndpoint);

                if (tmpEndpoint.getType() != UsbConstants.USB_ENDPOINT_XFER_BULK) continue;

                if ((mOutEndpoint == null)
```

FPVue



G2G latency с userspace драйвером



VR видео

Video
8K60 decode, 8K30 encode, low-latency slice-based decoding
AVC, HEVC, VP9, and AV1 decode


FPVue
1280x720 116 fps 3.90 MB/s 8.1 ms
CH 149
err=311 lost=0 recovered=968 ok=12376
9:25

Open Source community

- github.com/orgs/OpenIPC/repositories
- github.com/svpcom/wfb-ng
- github.com/PetruSoroaga/RubyFPV
- github.com/gehee

С чего начать?

- Aliexpress.com
- Ozon.ru
- ....

Что дальше?

- Стереоскопическое видео
- Замена Wi-Fi на 5G
- Тюнинг современных кодеков AV1 и H.266
- Железо: адаптивный подход к потреблению мощности
- MIMO everywhere
- Софт: использование дополнительной hw акселерации

Q&A
session

Если ли жизнь после Wi-Fi?