

# FPV HAT manual V1.2

This manual is valid for the following SKUs:

FPVHAT433

FPVHAT868

FPVHAT915

**PLEASE NOTE: We recommend that only Raspberry Pi 3's or 2's are used in connection with our FPV HAT.** The original Raspberry Pi cannot be used with our HATs as its 26 pin GPIO connector does not fit the 40 pin GPIO connector mounted on the FPV HAT. Raspberry Pi Zero, A+ and B+ *can* be used with our HATs but at reduced transfer rates. Raspberry Pi Zero e.g. approx. 420 kbit @ 4GFSK and only in role as sender (too slow as receiver at any bitrate). When we say reduced transfer rates we mean a transfer rate where end-to-end low latency of continuous data transfer is maintained. You may be able to set a somewhat higher data rate for discontinuous data / burst transfers on these slower boards. But for maximum data rate for continuous data transfer we recommend using only the Raspberry Pi 2 or 3.

**PLEASE NOTE: Keep antennas attached to the SMA antenna connector on both transmitting and receiving Pi+HAT at all times when these are powered on!**

**DISCLAIMER: WE CANNOT BE HELD LIABLE FOR ANYTHING THAT HAPPENS IN CONNECTION WITH THE USE OF OUR PRODUCTS. ALL LEGAL ISSUES ARISING FROM THE IMPORT, POSSESSION OR USE OF OUR PRODUCTS ARE THE SOLE RESPONSIBILITY OF THE IMPORTER, BUYER OR USER.**

## FPV HAT Specifications:

- Built-in RF amplifier frequency ranges:
  - 433 Mhz version: 410-450 Mhz,
  - 868 Mhz version: 863-873 Mhz,
  - 915 Mhz version: 905-925 Mhz.
- 1 watt max transmit power.
- Max data rate 500 kbit.
- Software supports AES-256 symmetric key encryption option (via OpenSSL).
- HAT conforms to Raspberry Pi Foundation 2014 HAT standard, incl. EEPROM.
- SMA female antenna connector. 50 Ohms impedance.
- Powered from Rpi 40-pin GPIO and draws 550-600 miliamperes at max. transmit power (1 watt max). Can also be powered via +5VDC and GND pins on HAT. NOTE that you will power both HAT and Pi via this option and that you must provide stable 5V +/-0.25V. No USB power cable must be attached to the Pi. This is an experimental option only.
- Software supports 2FSK, 2GFSK, 4FSK and 4GFSK modulations. Max data rates are approx. 300 kbit for 2FSK/2GFSK and 500 kbit for 4FSK/4GFSK. 2FSK/2GFSK takes up approx 300 khz bandwidth centered on the selected or default frequency. 4FSK/4GFSK approx 600 Khz (including some of the side- band).
- Software has experimental support for 4/8 FEC (Forward Error Correction).
- Transmit and receive frequencies can be set in software in 500 Khz increments above base frequency (which will be 433/868/915mhz depending on version). Setting the frequency below base frequency is not implemented yet but is coming in future software releases.
- The FPV HAT hardware wireless RF link latency alone is <1 ms
  - BUT please note that raspivid h.264 minimum video latency is approx 100-150ms. This is mainly due to the design of the encoding pipeline in the Raspberry Pi Broadcom h.264 hardware video encoder. The latency is also strongly dependent on e.g. Raspivid h.264 bitrate, fps, quantization and other parameters and can increase dramatically above 150ms if too bandwidth-demanding raspivid options are set. TFT displays also have varying latencies which can add to the final camera-to-screen latency as well.

## Summary:

Thanks for purchasing our FPV HAT for Raspberry Pi.

This manual describes physical installation and software setup for our FPV HAT.

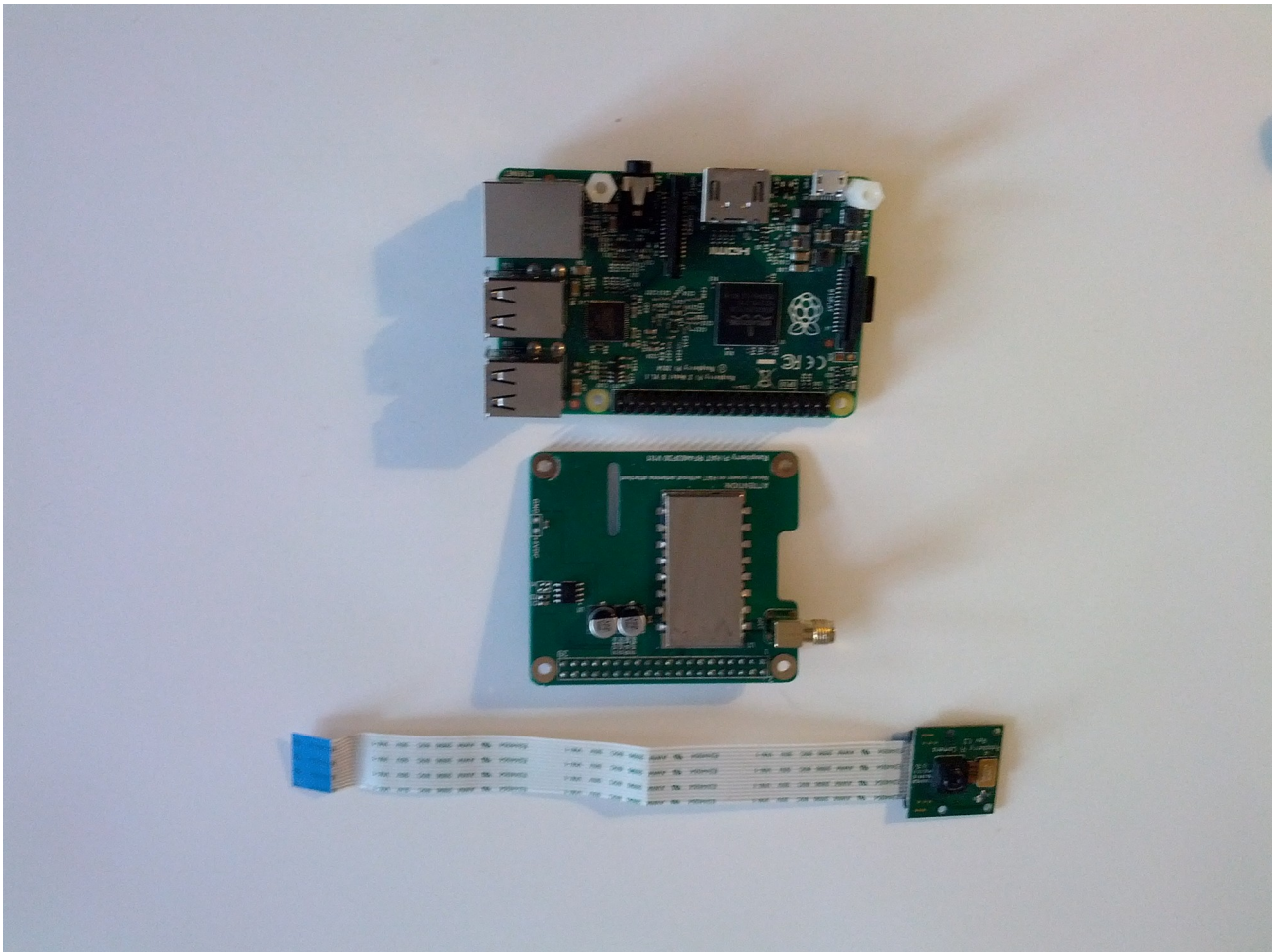
Please note that the software in its current form is **a one-way system**. I.e. data is transmitted from sender Pi to receiving Pi and no data goes the other way. This has enabled us to remove almost all protocol overhead and any possible delays in switching from RX to TX in hardware and software.

All publicly available software related to this project is GPLv3 licensed.

Thanks to Befinitiv and his wifibroadcast system for inspiration!

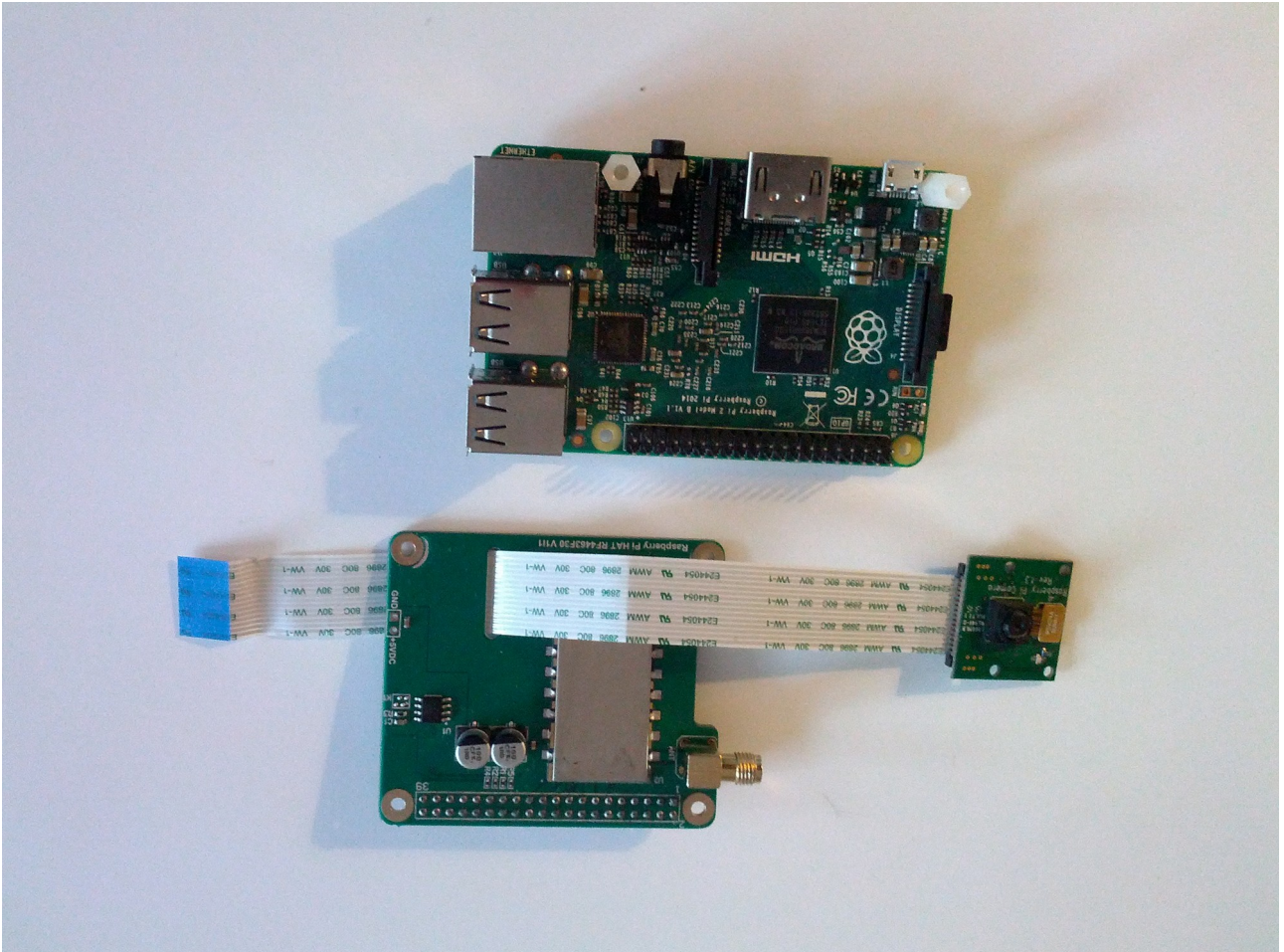
## Physical assembly:

On (video) transmitter side you should add both our FPV HAT and the Raspberry Pi Camera (or equivalent compatible camera) to a Raspberry pi board:



Please note that due to the lack of flow-control and protocols, the receive Pi should be equal to or faster than the sending Pi to avoid data buffer "overflow" on receive Pi side. E.g. use a Pi2 as sender and a Pi3 as receiver. Or just use two Pi3's (the built-in WIFI on the Pi3 is very useful for remote setup via ssh). Future versions of the FPV HAT will probably require only Pi3's anyway.

First, the camera ribbon cable is passed through the rectangular hole in the FPV HAT:



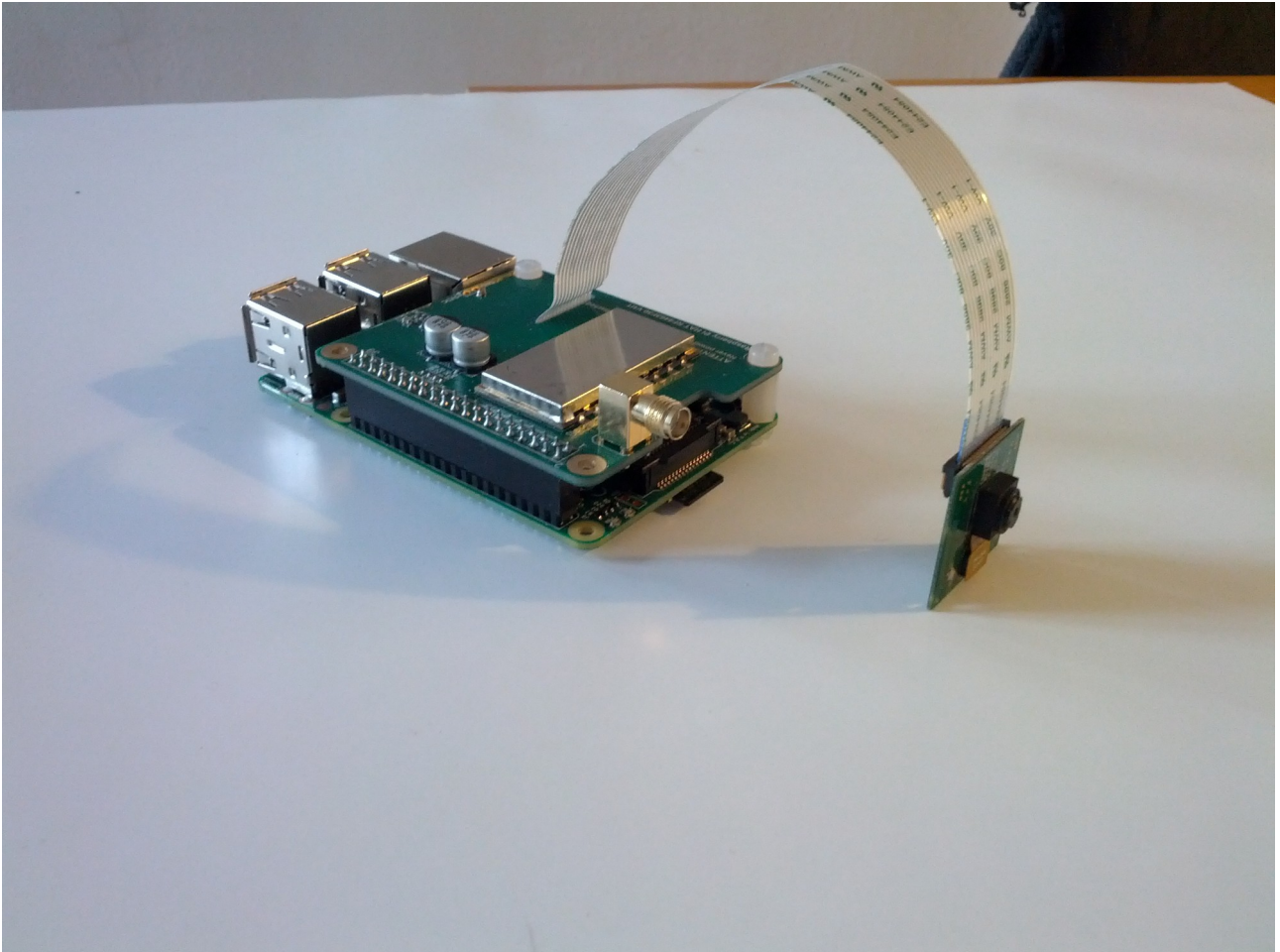
Then the camera ribbon cable is attached to the camera CSI connector on the Raspberry Pi board while at the same time holding the FPV HAT board.

Make sure the the ribbon cable is fully inserted and that the ribbon cable-end is level with the surface of the Raspberry Pi board before pressing hard on the camera connector fastener.

After fastening the camera ribbon cable please align the FPV HAT 40 pin connector with the 40 GPIO pins on the Raspberry Pi board. Then carefully but firmly press the FPV HAT onto the Pi board.



After which it should look like this:



PS: The plastic stand-offs visible in the pictures are not included but are recommend for long term use. Especially if any kind of vibration or physical movement of the transmitter board+pi is expected. I.e. when in use as a FPV solution on RC plane/car/robot/etc or similar.

Repeat the same process on receive Pi side, except for not adding a camera.

Lastly, please attach you antennas to the SMA connectors on the FPV HATs.  
DO NOT turn on the Pi's before attaching the antennas!

## Software installation:

This software installation guide assumes that you have 2 working Raspberry Pi's already set up, each with internet access. One of these Pi's should also have a Raspberry Pi Camera attached. The Pi with the camera will be the "transmitting pi" and the one without will be the "receiving Pi". You should also have some sort of display. Either a local display connected directly to the receiving Pi. Or a separate pc+monitor or laptop when using mplayer for video display. See display options below.

Make sure that you have some additional free space on your Pi's SD card ('df') and that your Raspbian installation is up-to-date (by running 'sudo apt-get update' and 'sudo apt-get install') Make sure that you have the full version Raspbian installed and not e.g. the lightweight version. The current full versions of Raspbian have all necessary libraries etc., such as wiring pi, included.

Enter Raspi-config:

`sudo raspi-config`

Make sure that you have SPI enabled on both Pi's.

Enable camera on the Pi which will be used as video transmitter.

Disable any overlocks you might have previously set. Especially on transmitting Pi as the FPV HAT board will emit some extra heat to the air in close proximity to the Pi CPU during transmit.

While you're at it in raspi-config, it is recommended to enable sshd so that remote login on your Pi is possible. It is highly convenient when experimenting with- and setting up our FPV HAT to work on both Pi's via SSH over WIFI from terminals on e.g. a desktop or laptop PC.

Install the necessary OpenSSL library:

`sudo apt-get install libssl-dev`

If you haven't already have done so, please install the git utility package:

`sudo apt-get install git`

Download the software for the FPV HAT onto your Pi:

`git clone https://github.com/FernRF/FPV-HAT.git`

Change directory to the video-transfer directory:

`cd FPV-HAT/src`

Set correct version to be compiled – this depends on which version you have purchased.

For 868 Mhz version it would be:

`git checkout 868mhz`

For 433 Mhz version it would be:

`git checkout master`

For 915 Mhz version it would be:

`git checkout 915mhz`

Compile:

`make`

(Or if you compiled already and made some mistake, e.g. forgot to checkout the correct branch, and must redo this step:)

```
make clean all
```

Please change to test dir:

```
cd test
```

Test to see if FPV HAT is alive and well:

```
sudo ./info
```

This command prints version info from the radio module on the HAT. If you have attached and installed everything correctly in previous steps - and your HAT is working correctly and/or is undamaged - you should always be able to print this info via the ./info command.

If you feel that the radio module on the FPV HAT board gets too hot while idling, you can use this command to put the board to sleep (it will automatically wake up when receiving or transmitting):

```
sudo ./sleep
```

On a fresh Rasbian install the hello\_pi utilities must be compiled in order to utilize the hello\_video.bin h.264 hardware decoder (this is the up-to-date alternative to otherwise use the supplied hello\_video\_old.bin binary. This is used in the receive command line example below):

```
cd /opt/vc/src/hello_pi/
```

```
./rebuild.sh
```



## Transmitting / receiving video.

Assuming that all steps above were carried out correctly you should now be ready to transmit video using raspivid.

Before running the sender or receive apps you should shut down any graphical interface (X11/Wayland) running on both Pi's to free up CPU and GPU resources.

### Transmitting video:

The command line on the transmitting Pi could be something like this:

```
sudo stdbuf -o 0 raspivid -n -t 0 -vf -hf -w 512 -h 288 -fps 48 -g 72 -b 440000 --flush -a 512 -pf high -ih -o - | sudo ./sender -m 4 -P 20 -f -
```

To explain each part of this rather long command line:

sudo	executes the following commands with as superuser
stdbuf	
-o 0	sets stream buffering to zero (to avoid possible latency due to Pi system buffers).
raspivid	The Raspberry Pi h.264 hardware encoder app.
-n	No preview.
-t 0	No timeout on video stream.
-vf	Vertically flip image – depends on your physical camera position/set-up.
-hf	Horizontally flip image.
-w 512	512 pixels video width. This may seem very low but remember that our bandwidth is limited to max. 500 kbit on the FPV HAT. This number should also be divisible by 16 due to h.264 macroblock size of 16. You may have to experiment to find a resolution that scales nicely on your display.
-h 288	288 pixels video height. Same considerations as above. 512x288 pixels also corresponds to the 16:9 aspect ratio of most modern displays.
-fps 48	Frame rate set to 48 frames per second. The higher the frame rate the lower the (camera) latency. It also makes motion seem more fluid and pleasant to watch. Please note that image quality is reduced above 49 fps. If you have the RaspberryPi Camera V.2, you can increase -fps to 60.
-g 72	This sets the intra-refresh rate of the Pi h.264 hardware encoder to 72. I.e for every 72 frames an I-frame is sent. With a frame rate of 48 hz this equals an I-frame per 1½ second approx. The I-frame is a self-contained full frame that will correct previous errors accumulated during transmit of B- or P frames. Decrease this number to prevent errors but be aware that this increases the data rate and that the h.264 encoder lowers image quality correspondingly to try and stay within the set -b bit rate.
-b 440000	This is the selected bit rate. The FPV HAT can transfer a maximum of approx. 500 kbit (500000). Please note that the higher the bit rate the shorter the range, and vice versa. A good high data rate which will also give some range is 440 kbit. NB: The spec sheet for the si4463 module mentions 1 mbit as max. bit rate. It may be that the hardware is capable of this but SiLabs EZRadioPro software (used to generate

	initialization bytes for radio module) only allows a max. setting of 500 kbit anyhow.
-flush	Flush h.264 encoder buffers. May reduce latency.
-a 512	Adds a frame counter to video output.
-pf high	Video quality and compression profile. High is best in most cases.
-ih	Extra headers on frames. Necessary in case of restart of receiver and/or hello_video.
-o -	Send output video stream to stdout (and pipe).
	Unix pipe
sender	Our sender app which takes video stream input from pipe or file and sends it to/via radio module on board
-m 4	4GFSK. Together with 4FSK this is the fastest modulation type available on the FPV HAT. For really long range projects -m 1 (2FSK) or -m 2 (2GFSK) should be set. Max. data rate for -m 1 and -m 2 is approx. 300 kbit. Again, set raspivid -b bit rate option a tad lower at, say, 280 kbit, for better reception/range. -m 3 (4FSK) option works best with the 433 Mhz version of this board. Use -m 4 (4GFSK) on 868/915 Mhz versions for max. Bit rate.
-P 20	Transmit power option. Range between 1 and 127. Above 80-90 produces a lot more heat, relatively speaking, as the rf power output curve is not flat. 127 should give around 1 watt at 5V. Start out low and see how much you need.
-f -	Sends video stream to stdin/out

**NB:** You will probably notice some stutter in the video stream each time an I-frame is transmitted. If you or your application is sensitive to this, the raspivid options -g 0 and -if cyclic can be used. This eliminates I-frame stutter but the -if cyclic option does not transmit SEI NAL information with each I-frame. This will prevent hello\_video from restarting the video stream correctly if signal was lost or hello\_video was restarted, thus making the video link much less robust.

Mplayer is not affected by the absence of SEI NAL information and will happily resume displaying video even after a complete signal loss. Which obviously makes it the better choice for displaying stutter-free fluent FPV video.

**NB:** If your video freezes in mid stream it might be because of sender module overheating. Check that you are using a correct antenna for your selected branch and frequency. Or it may be that your transmitting Pi stopped sending video data for some other reason. Power issues or system instability e.g.

## Receiving and displaying video via hello\_video / hdmi screen on receiving Pi: (skip to next page for true FPV display setup using mplayer)

Hello\_video is a handy test app included with Raspberry Pi Rasbian. It is somewhat simple and not very robust when handling errors and video stream losses or stream interruptions. But its useful if your application for the FPV HAT does not require lowest latencies and/or you want to use a local hdmi screen connected directly to the receiving Pi for video output.

NB: Newer versions of hello\_video do not allow piping directly to hello\_video app and will only display files. In this case you can use our patch for hello\_video to enable piping.

```
cd FPV-HAT (if you're not already there)
```

```
git checkout 868mhz (or "master" for 433 mhz or "915mhz")
```

```
cp video.c.patch /
```

```
cd /
```

```
sudo patch -p1 < video.c.patch
```

```
cd /opt/vc/src/hello_pi
```

```
sudo ./rebuild.sh
```

Test piping to hello\_video like this:

```
cat test.h264 | ./hello_video.bin
```

On receive side a command compatible with the above transmit command could be:

```
sudo stdbuf -o 0 ./receiver -m 4 -f - | ./opt/vc/src/hello_pi/hello_video/./hello_video.bin
```

receiver                      Our receive app which takes wireless data from radio module and outputs it to a unix pipe or file.

hello\_video                  A Raspberry Pi built-in h.264 hardware decoded video player

Almost same options as in tx/transmit app used. No points for guessing what they do here;) It is important to specify the same -m (modulation) parameter for both sender and receiver apps.

NB: If your using raspivid -g 0 and if cyclic options with hello\_video you MUST start the receiving command line first, before starting the transmitting command line.

## Displaying video using mplayer on a separate Ubuntu Linux pc/laptop:

For lowest latencies (approx. 100 msec is possible!) and maximum robustness versus stream errors and interruptions you should use a separate quad-core pc or laptop running Ubuntu Linux and mplayer app to display the received video. Furthermore the receiving Pi should be connected to the Ubuntu pc via an ethernet cable (and not wifi, although this is a less robust alternative possibility). Unlike hello\_video, mplayer is a sophisticated and mature video renderer application which is very error tolerant.

On your Ubuntu pc or laptop you most likely have some kind of wifi setup already. In order to use wifi for internet and an ethernet cable for receiving-Pi-connection concurrently, you need to do a little tweak:

Go to your Network Connections page Then click Wired connection 1 -> Edit -> IPv4 Settings -> Method: Shared to other computers

That will tell ubuntu to stop looking for an internet connection there and expect a device instead. Then restart Ubuntu.

Install mplayer on your ubuntu system:

```
sudo apt-get install mplayer
```

Install netcat (nc) on both ubuntu system and receiving Pi:

```
sudo apt-get install netcat
```

The sequence when starting these apps is "backwards" in that you must start nc+mplayer on ubuntu system first, then nc+rx app on receiving Pi and lastly raspivid+tx app on transmitting Pi:

On receiving Pi and ubuntu system you need to do the following:

Make a netcat pipe to mplayer. The netcat app (plus mplayer) will listen on port 5000 to incoming connections and must therefore be started before the receiving pi starts forwarding received video data:

```
nc -l -p 5000 | mplayer -fps 64 -nocache -demuxer h264es -
```

Start forwarding received video data from receiving Pi to ubuntu system:

```
sudo ./rx -m 4 -f - | nc [eth0 ipv4 adress of ubuntu system] 5000
```

And lastly start transmitting stutter-free video using -g 0 and -if cyclic options, i.e.:

```
sudo stdbuf -o 0 raspivid -n -t 0 -vf -hf -w 640 -h 480 -fps 48 -g 0 -b 440000 --flush -a 512 -pf high -if cyclic -ih -o - | sudo ./sender -m 4 -P 20 -f -
```

NB: If you use the Raspberry Camera V2, you can set -fps option to 60 for a higher frame rate.

## All sender app options:

915 MHz version, usage:

`./sender [cspgizhrmfFESkK]`

SPI configuration:

- c [0|1] defines SPI channel
- s [500..10000] defines SPI bus speed, kHz

GPIO configuration:

- p PIN defines RPi pin connected to power down control GPIO pin
- g PIN defines RPi pin connected to GPIO1 of Si4463
- i PIN defines RPi pin connected to interrupt output pin

Radio configuration:

- r CHANNEL defines radio channel
- m [1,4] defines modulation type, supported 2fsk (1), 2gfsk (2), 4fsk(3) or 4gfsk (4)
- P level defines power level (1..127)

Encryption:

- E use encryption
- S session ID
- k define key as hex string, key should be 256 bits
- K define salt as hex string

Miscellaneous:

- F use FEC
- q COUNT defines max available packets in incoming queue, packets exceeding the queue size will be dropped
- f FILE defines input/output file, use '-' for stdin/stdout
- u FILE defines console input file
- U FILE creates FIFO to be used as console input file

Help:

- h shows this help

The -r channel option is only usable above default frequencies (433/868/915 Mhz). It is set in increments of 500 Khz. E.g. -r 10 adds 5 Mhz to default frequency. On a 433 Mhz version this would result in setting a frequency of 438 Mhz.

It is not possible to go below the default frequency at the moment.

The -F FEC (Forward Error Correction) option uses 4/8 FEC. Meaning 4 FEC bits for every 8 data bits. I.e. using 33 pct of available bandwidth for error correction.

The -u and -U options can be used to create a separate data stream, alongside the video stream. I.e. for autopilot telemetry or similar. Please note that this is also a one-way stream from transmitter to receiver so it cannot completely replace a conventional two-way telemetry radio link.



## All receiver app options:

915 MHz version, usage:

`./receiver [kKcsSpgirfmFhE]`

SPI configuration:

- `-c [0|1]` defines SPI channel
- `-s [500..10000]` defines SPI bus speed, kHz

GPIO configuration:

- `-p PIN` defines RPi pin connected to power down control GPIO pin
- `-g PIN` defines RPi pin connected to GPIO1 of Si4463
- `-i PIN` defines RPi pin connected to interrupt output pin

Radio configuration:

- `-r CHANNEL` defines radio channel
- `-m [1,4]` defines modulation type, supported 2fsk (1), 2gfsk (2), 4fsk (3) or 4gfsk (4)

Encryption:

- `-E` use encryption
- `-S` session ID
- `-k` define key as hex string, key should be 256 bits
- `-K` define salt as hex string

Miscellaneous:

- `-F` use FEC
- `-f FILE` defines input/output file, use '-' for stdin/stdout
- `-u FILE` defines console output file
- `-U FILE` creates FIFO to be used as console output file

Help:

- `-h` shows this help

## Additional documentation for other raspivid options:

<https://www.raspberrypi.org/documentation/raspbian/applications/camera.md>

## H.264 video compression:

[https://en.wikipedia.org/wiki/H.264/MPEG-4\\_AVC](https://en.wikipedia.org/wiki/H.264/MPEG-4_AVC)

## Mplayer video player for Ubuntu Linux:

<https://help.ubuntu.com/community/MPlayer>