UAV Components Part 2 (advanced)

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Autonomian

Multirotors

Applications review

Military
Commercial
Healthcare
Communication
Police
Agriculture
Maps and GISes
SAR
Meteorology
Delivery
R&D
Illegals

Applications review

- Military
    - Surveillance and battlefield recognition, offensive/defensive UCAVs - (unmanned combat aerial vehicle, i.e. Hermes 900)
    - armor delivery drones and UGVs
        - Big Dog (Boston Dynamics), hard to classify... UGV? UWV?
    - Border monitoring and smuggling prevention
- Commercial
    - With video cameras: weddings, fun flights, area and crowd monitoring, access control, civil engineering (progress, statistics)
    - With sensor sets (utilities): pollution monitoring and environmental protection tasks

Applications review

- Healthcare
  - Automated External Defibrillator (AED) tested in Dubai and Sweden
  - Rapid medical samples transportation
- Communication
  - Air taxi
- Police
  - Search and observation, monitoring (human crowd) danger evaluation.

Applications review

- Agriculture
  - Fertilising, in particular fluid based
  - Crop monitoring and estimation
  - Precise agriculture and forestry
- Earth Sciences
  - Photogrammetry
  - 2D and 3D mapping
  - Cadastral systems
- Crisis management
  - Damage assessment and identification of the needs
  - Search for victims

Applications review

- Meteorology
  - Storm hunters
- Deliver of the goods
  - This is supposed to be most valuable and profitable drone applications in the feature
- R&D
  - Data collection
- Illegals
  - Drugs smuggling
  - Terrorist attacks
  - Robbery

Multirotors

Advanced properties of the electric propulsions

Brushless DC motors in details

ESCs

Configurations

Brushless DC electric motors

Inner construction of the brushless DC motor

Thrust to weight ratio

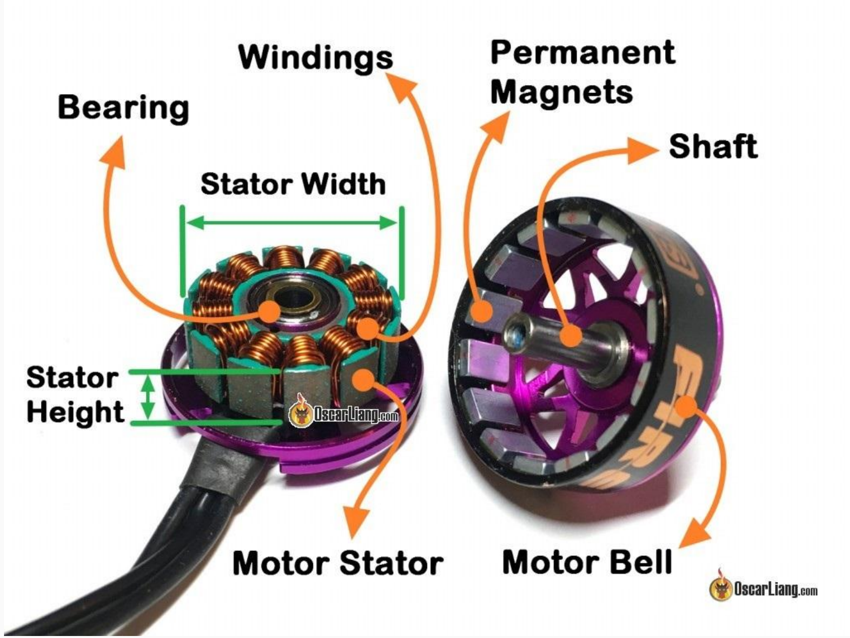
Applications

Additionals

Mechanical features

Inner construction of the brushless DC motor

- Stator
  - Bearing
  - Windings
  - Stator Width / Height
- Rotor (Motor Bell)
  - Shaft
  - Permanent Magnets
- Number of windings != number of magnets!



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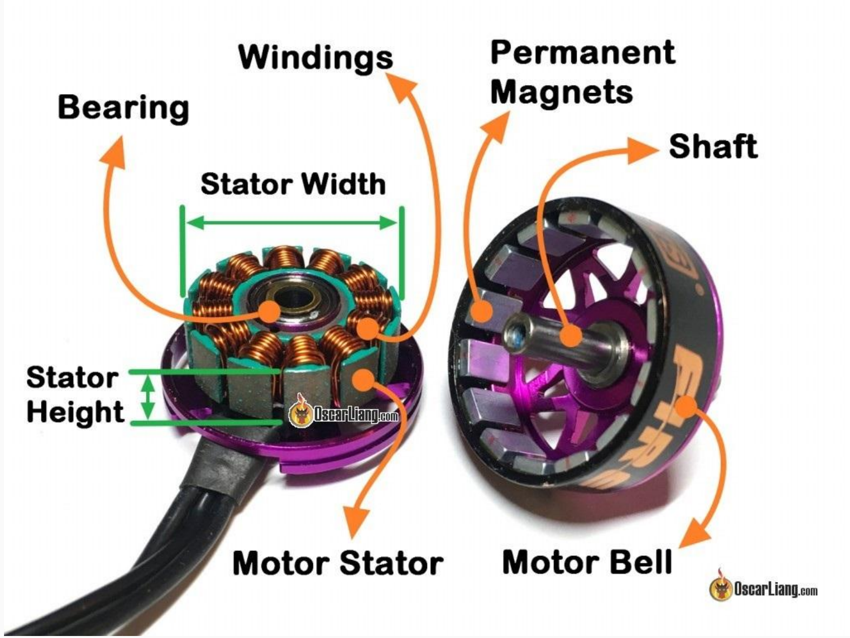
Inner construction of the brushless DC motor

- Physics:
    - Motor is controlled with 3-phase via ESC
        - Number of windings in the statue must be a multiply of 3 then.
    - Stator: N-pole, rotor: S(P) pole
    - Common configuration is 12N14P, as on the photo.
    - More domains (windings magnets), smoother the operation and higher the power.



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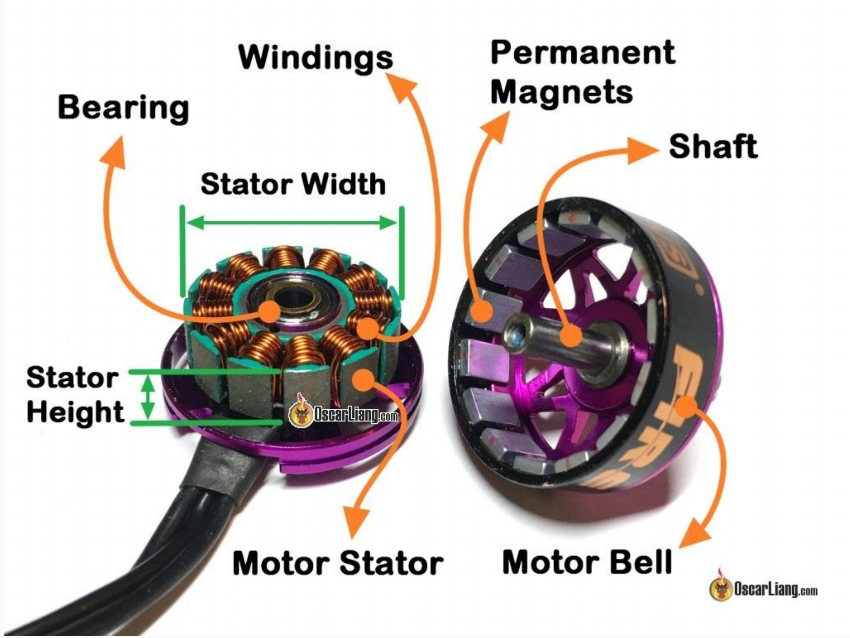
Brushless DC motor properties

- Features:
  - Motors that present longer (higher) construction with lower diameter present better heat dispersion and higher KV.
    - They work better in higher RPM.
  - Flat (so called “sandwich”) motors with higher diameter present higher torque and better energy efficiency



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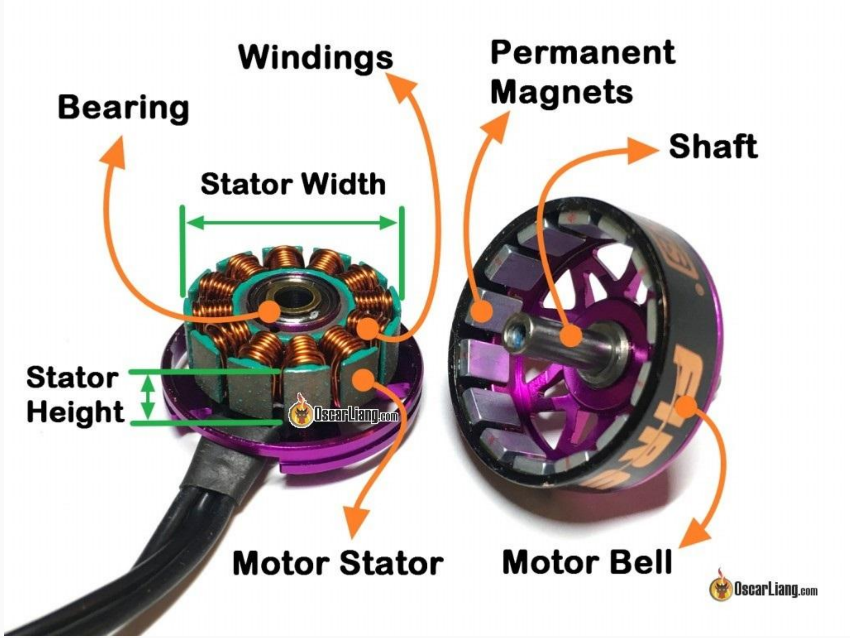
Brushless DC motor propertieso

- Stator coils in short:
  - shorter = higher KV (lower resistance)
  - longer = lower KV

  - Single wire coil windings = higher wire diameter = better hear dispersion (5S-6S).
  - Triple wiring coil windings (3 wires, parallel) = better allocation = smaller motor = higher energy efficiency, higher magnetic field generated inside.



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Motor thrust

- Motors are described (among others) with their max thrust
- It is provided for particular propeller and voltage (powering).
  - It strictly relates to the “S” value and propeller used.

Motor thrust

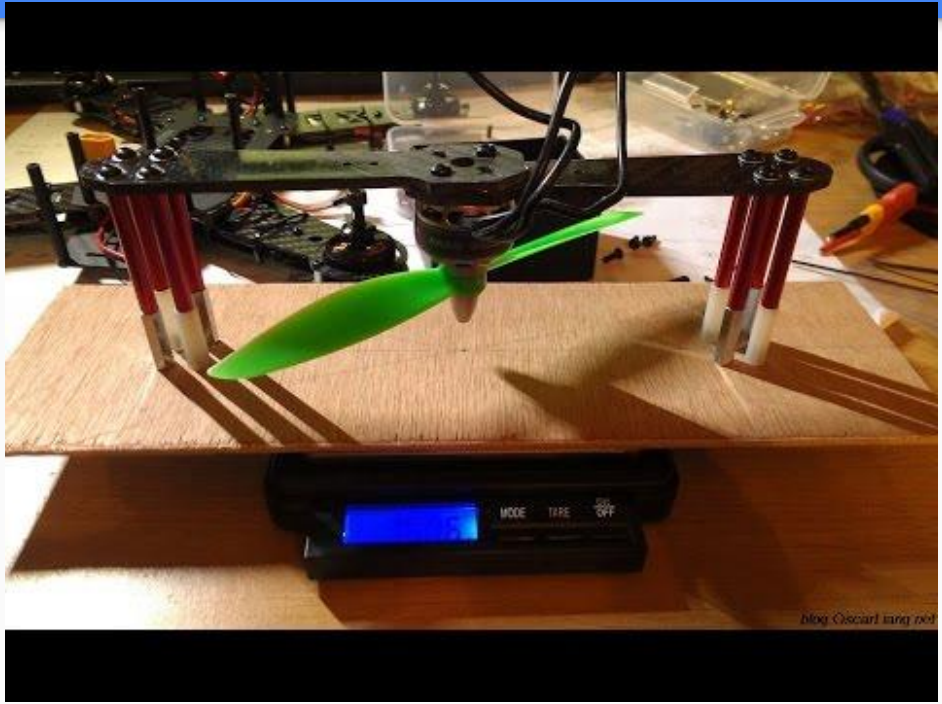
- What impacts thrust?
- Motor construction, as follows:
    - Size, in general, the bigger the motor, the more thrust it generates
        - It is stator size that defines the thrust
    - Type o magnets used in their construction
    - Copper wire used for coils, its quality, organisation, number of wires in the wind.
    - Number of magnets (related to the number of winds)
    - And even depends on the air-gap (a gap between rotor and stator, the lower, the higher magnetic field = higher thrust but also lower head dispersion).

Motor thrust

- In case of the active generation of the lift force (multirotors, VTOLs, helis) total thrust must be higher (usually significantly higher) than MTOM.
  - It is important to remember that current Take-Off Mass can vary by utility and payload.
- Total thrust is slightly lower than simple multiplication of the individual thrust times number of motors: it is because of airflow is disturbed by nearby propellers.
- Thrust is provided in ‘g’ (gram) for small motors and in ‘kg’ for large ones.

Motor thrust measurement

- It is possible to build a device to measure thrust quite simply
    - Use weight to find the difference when motor is off and when it is on with full / partial power.



Thrust to weight relation

- Rule of thumb says, thrust:mass should be at least as 2:1
  - It it is going to be lower, then it will be hard to control drone, it is no going to respond to your requests as needed and will drain battery quickly
  - Take-off will take time and ascend will be slow, eventually impossible
  - In critical situation when thrust:mass ratio is lower than 1, drone will start to descend uncontrolled way.
- If ratio is too high (far too high, i.e. 20:1) you will struggle to control the UAV at all:
  - Minimal throttle lever change will cause huge thrust change: your drone may disappear in the sky. Similarly it applies to the roll, pitch and yaw - you may won't be able to do a precise move at all.

Thrust:weight ratio - sample applications

- Photo and video footage drone:
  - Thrust / mass: from 3:1 to 4:1
- Racing drone:
  - At least 5:1
  - Common is 10:1 and even 13:1

Some considerations about electric motors and propulsion

- In theory:
  - The higher the KV, the lower the torque, the lower the KV the higher the torque (assuming same power consumption).
  - It is a rule of thumb but in reality... KV is not so directly bound to the thrust, because:
    - Electric DC brushless motors presenting high KV present low resistance (shorter coil windings) that simply means the maximum voltage is lower as current is high. Assuming P=U*I, those engines are limited with maximum power that is related to the heat dispersion capabilities.
  - It is common assumption that motors with different KV but same internal construction, present ability to generate pretty same maximum thrust:
    - In case of the motor with lower KV you need to apply higher voltage to achieve same rotation speed.

Some considerations about electric motors and propulsion

- Because o aforementioned relation, it is not always true, that the motor with higher KV will present better thrust:mass ratio. Rule is not so straightforward as it may look.

Some considerations about electric motors and propulsion

- Electric brushless DC motor is controlled with 3 phase = there are 3 wires
- Exchanging any of 2 wires will change its rotation direction
- Why there are CW and CCW motors on the market?
  - The reason is “self-locking” mechanism on the motors shaft in case of use of the threaded propeller mount.

Some considerations about electric motors and propulsion

- In case of the drones where thrust:mass ratio is high (i.e. FPV racing drones) that use high KV motors there is known problem with oscillations and resonance, hard to be removed / compensated.
    - For this reason, FC (problem affects IMU readings) is commonly mounted on the dumpers.

Mechanical motor mounts

- In case of majority of the racing drones, motor to frame mount is using standardised templates:
  - 12x16mm
  - 16x16mm
  - 16x19mm

ESCs

Microcontrollers and firmware

Communication protocols

ESC microcontrollers and their firmware

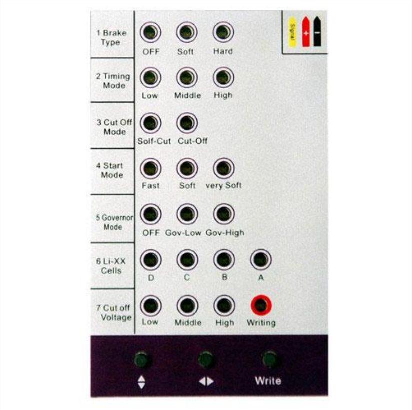
- Indeed, even simplest ESC has a built in MCU! It is 8 bit one, usually.
  - Lates solutions employ 32-bit microcontrollers.
- If there is an MCU, then there is a firmware
  - Majority is based on the open source:
    - SimonK
    - BLHeli
    - BLHeli_S
    - BLHeli_32
  - Or closed:
    - KISS ESC Firmware

ESC microcontrollers and their firmware

- Most common MCUs include:
  - ATMEL 8-bit (SimonK or BLHeli firmware)
  - SILABS 8-bit (BLHeli or BLHeli_S firmware)
    - SILABS F330 i F39X
      - Currently used
        - BusyBee1 – BB1 (EFM8BB10F8)
        - BusyBee2 – BB2 (EFM8BB21F16)
  - Atmel ARM Cortex 32-bit (BLHeli_32 firmware)
    - Most common is STM32 F0

ESC microcontrollers and their firmware

- It means, ESCs are “programmable”:
  - Programming here means configuration, and it is done via so called “cards”, separate (serial) port, eventually via PWM change sequence.
  - Configuration includes: rotation direction change, motor timing, IDLE mode power, block/coast on idle, battery type, and many other.
    - Motor timing it is a moment of time when coil (wing) generates highest electromagnetic field. One can tune it against magnets position to achieve slightly better KV value (motor tuning).



ESC control protocols

- It regards communication in between ESC and FC.
- Protocol has specific features, its timing defines responsiveness.
- In the order of the development (oldest first):
  - Standard PWM - up to 2ms delay
  - Oneshot125
  - Oneshot42
  - Multishot
  - DShot (DShot150, DShot300, DShot600, DShot1200)
  - ProShot - 5-25us delay

Configurations

How to build a multirotor from scratch?

Configurations

- Order of configuring a new drone and selecting components (this process is to be repeated in the loop, if finally battery mass is inadequate):
  Frame -> Propellers -> Motors -> ESC -> Battery

Frame size (mm)	Propeller size (inch)	Motor type (size)	KV
<=150 mm	3” lor smaller	1105 - 1306	>=3000KV
180 mm	4”	1806, 2204	2600KV - 3000KV
210 mm	5”	2205 - 2208, 2305 - 2306	2300KV - 2600KV
250 mm	6”	2206 - 2208, 2306	2000KV - 2300KV
350 mm	7”	2506 - 2508	1200KV - 1600KV
450 mm	8”, 9”, 10” and larger	26XX and bigger	<=1200KV

Multirotors

FPV gear

Cameras

Transmitters

Cameras

Sizes

Sensors

Ratios

FOV

Lenses

Recording type PAL/NTSC

Resolutions and latency

Configurations and summary

Camera size

- In FPV world when using component-based build, camera size is usually standardised to:
    - 28mm - standard (so called “full size” camera)
    - 21mm - mini
    - 19mm - micro
    - 14mm - nano
- There are AIO solutions, integrating antenna with transmitter.
- Weight
    - Usually in between 4 and 20g
        - Popular action cameras are not suitable here as they are far more heavy

Sensors

- CCD
  - Global snapshot when taking photo - full sensor content is collected at once
  - Lower resolutions comparing to the CMOS
  - Image colours seem more neutral
  - Image dynamics range is acceptable but worse than CMOS
  - Usually higher contrast than CMOS
- CMOS
  - Lower latency than CCD
  - Higher resolution and image sharpness than CCD
  - Flowing snapshot: line by line, causing “jello” effect.

Ratios

- Common ratios are (horizontal:vertical):
  - 4:3
  - 16:9
- It is important to fit it to the display equipment (LCD monitor, FPV goggles).
  - Standard “analogue” transmission is fixed 4:3 both for PAL and NTSC.
  - Analogue photo SLR camera is 3:2 and digital SLR is 4:3.

FOV

- Field of view:
  - Large (shorter focal) = wide angle,
    - It enables you to see almost around in wide perspective but due to the low resolution there are no details visible
  - Small (longer focal) = wide angle,
    - It enables you to see details but there is no wide context
- In some cameras, focal can be changed with interchangeable lenses or zoom lenses (driven by separate channel, usually servo or brushless motor):
  - In general, in FPV cameras zoom is not used because of the weight and complex mechanics

Focal length	FOV (degrees)
1.8 mm	160-170
2.1 mm	150-160
2.3 mm	140-150
2.5 mm	130-140
2.8 mm	120-130
3.0 mm	110-120

FOV is calculated for typical ⅓" sensor and 4:3 ratio. Sensor change impacts FOV with preselected focal length

FOV

- Depends on the utility and individual preferences but common starting point is about 150 degrees, giving it good situation overview with acceptable details recognition possibility
  - Flight speed and drone construction impacts on the FOV selection.

Lenses

- In majority of the cameras, lens can be unscrewed and replaced "wykręcić".
  - Moving the lens forth and back changes focus point. While wide lens is barely affected, narrow lens requires precise calibration, otherwise image will be unsharp and blurry!
- For standard and mini camera sizes:
  - Lens mount is M12 (12mm diameter - thread=12mm)
- For smaller than mini camera sizes:
  - Lens mount is M8 (8mm diameter - thread=8mm)
- "Lens glass" (it is usually plastic, however, to save on its weight) is frequently larger than aforementioned thread (8/12mm) and stick out.

Analogue video transmission standards

- In general, there are two standards in the world, related to the AC frequency (½ of it):
  - PAL: 576 lines (720x576px), 25fps - mainly used in Europa, Africa i China, India and Australia, also partially in South America.
  - NTSC: 480 lines (720x480px), 30fps - slightly smoother image, mainly used in USA and Japan.
- Mentioned above are transmission, not camera standards

Resolutions and latency

- Analogue cameras’ resolution is specified by TVL (number of TV lines that the sensor can record:
  - TVL is a number of alternating black and white lines that camera sensor can register, theoretically.
- Common TVL values are:
  - 600, 700, 800 and 1200.
- Because of the analogue transmission limitations, it is not rule that higher TVL camera brings better image. Transmission limits impact final result significantly.

Resolutions and latency

- Transmission latency is crucial in high speed missions, in particular, FPV racing:
  - I.e. if drone moves forwards with constant speed of 120km/h, assuming transmission latency is 50ms, the error when approaching the obstacle is 1.6m. You're already 1.6 closer to the obstacle when you notice the obstacle in your googles (or on the monitor).

Camera configurations

- Minimalistic set it when camera is directly bound to the RF video transmitter (video downlink).
- Common set includes intermediate image processing, so called OSD (part of FC, or a separate module interfacing with FC), where number of information is overlaid on the video stream. Cameras used to provide configuration channel that one can change their parameters, even during flight, directly via some uplink or indirectly via FC, such as:
  - white balance
  - contrast, brightness, gamma,
  - sensor sensitivity (ISO)
  - other

Camera configurations

- To register analogue signal it is common to use A/D converters (recorders) that record to the flash memory, commonly TF card:
  - it can be located locally in the drone:
    - Dedicated or integrated with the camera / video transmitter
    - FC integrated
  - or it can be located in the ground section:
    - In RC receiver or FPV goggles,
    - As dedicated DVR device
- As analogue transmission is more vulnerable to the interference, it is better to record “in drone”, to achieve higher image quality.

Radio transmission

Components

Theoretical model

External factors and their impact on the transmission range and efficiency

RF transmission components in general

- In the physical layer it is FM transmission
- Video downlink (FPV) is composed of (at least):
    - Camera
    - **Transmitter**
    - **TX antenna**
    - **Air**
    - **RX antenna**
    - **Receiver / decoder**
    - Display

RF transmission physics

- Radio signal level can be measured with dB.
  - It is logarithmic scale, so:
    - Change by 3dB equals twice as much (or less) the signal to become.
- Each of the aforementioned (underlined) components of RF transmission solution has its own sensitivity and amplification, as measured in dB.
- Their total relation impacts theoretical transmission range.
  - In practice, variety of other factors impacts transmission range.

RF transmission simplified model

- Link budget represent effective gain given in “dB” (summarising amplifications and losses).
  - The higher the link budget, the longer the range.
  - In theory, link budget drop to zero (or any other minimum value required for reliable connectivity) defines maximum range.
    - In practice, video stream is no longer delivered, telemetry and RC is down and there is no control over the UAV, thus reaching this limit is very dangerous.

RF transmission simplified model

- In case of the analogue FPV video transmission, link budget is calculated as follows:
  - Sum of gains of the sender and the receiver antennas
    - Measured in the isotropic decibel (dBi = related to the “ideal antenna”)
  - Transmitter power
    - Given in dBm (decibel related to the transmission power), calculated following way
      1 dBm = 10*log10(mW)
      1 mW = 10^(dBm/10)
    - For typical, max allowed, 200 m transmitter, it is 23.01 dBm
  - Receiver sensitivity
    - Provided as “negative” (below zero) dB, usually around -85dB up to -90dB
      - Majority of receivers present this sensitivity and it is not very frequently specified in the documentation, so it is reasonable to assume -90dB as common.

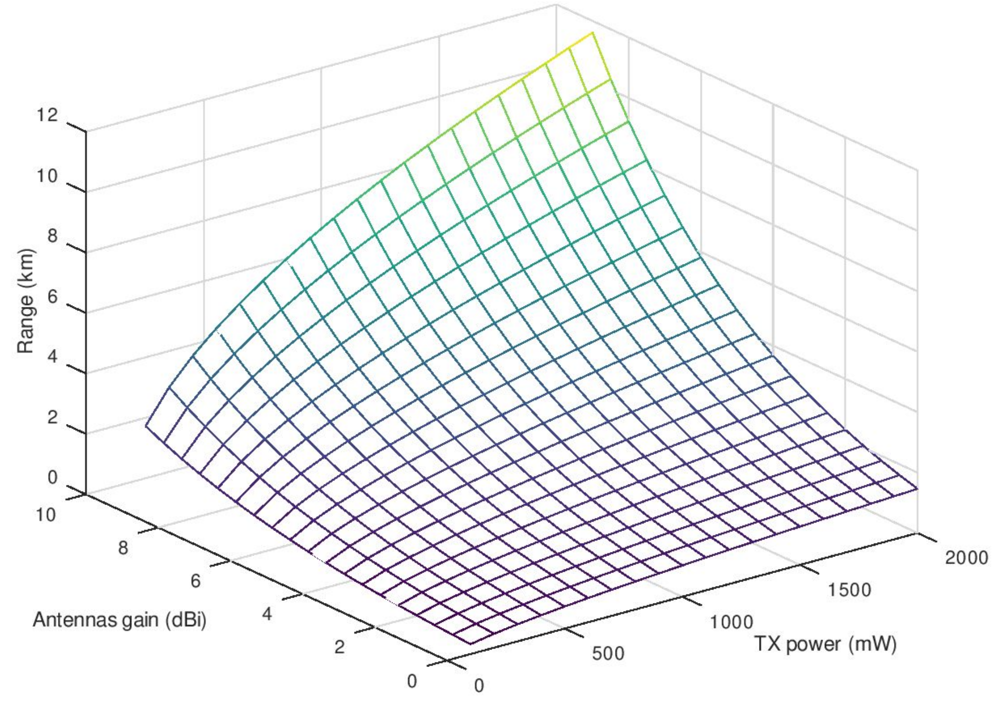
RF transmission simplified model

- How to estimate range then?
  - First of all, we assume a "link margin", about 12dB (*LM*) - a value that presents reasonable approach to the margin for transmission fluctuations regarding other factors. Below this value, transmission of the video may still be possible but video stream may be broken, noisy and disappear.
  - *Range = 10^(((X-LM-32.44)-20*log10(f))/20)*
    - Whereas X is calculated as a sum of the:
      X = aRXGain+aTXGain + TXP - RXS , where:
      - *aRXGain, aTXGain* present antenna gain (receiver and transmitter, respectively),
      - *TXP* power transmission (**in dBm, not in mW!**),
      - *RXS* - receiver sensitivity
    - f - Video link frequency in MHz (usually 5800 = 5.8GHz, but there are others)

Video link transmission range regarding power and gain

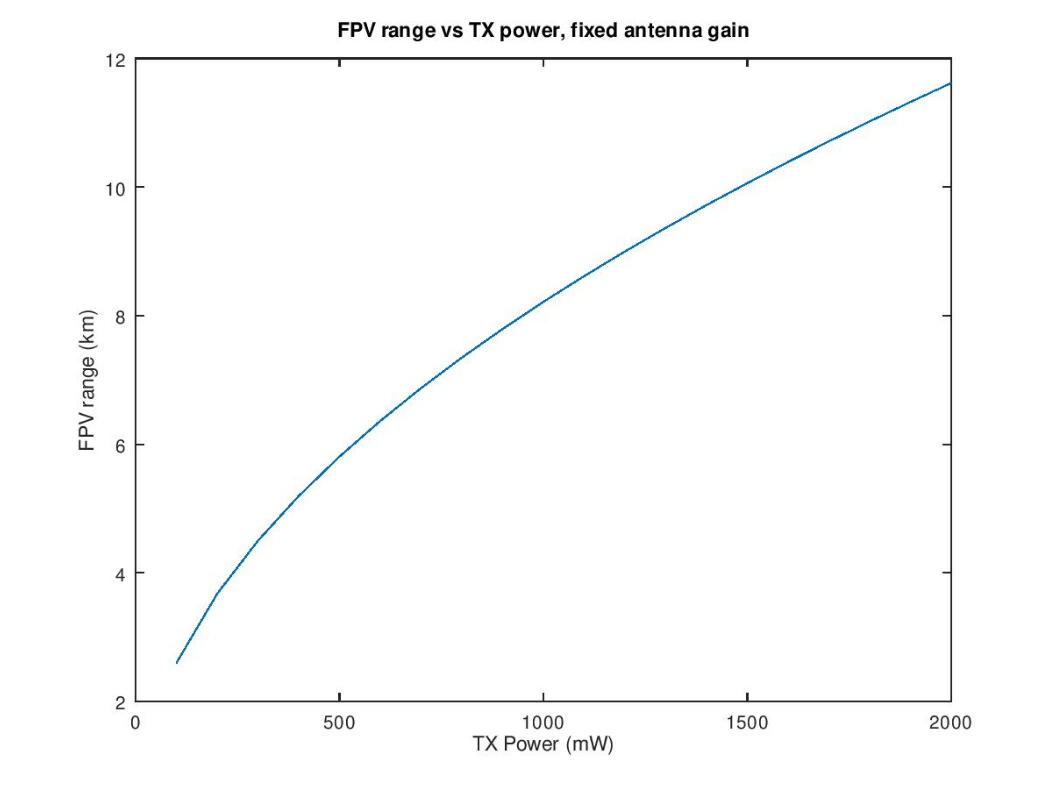
Relation between antennas summary gain and transmission power.

As one can observe, it is antenna gain that brings better result than increasing transmission power.



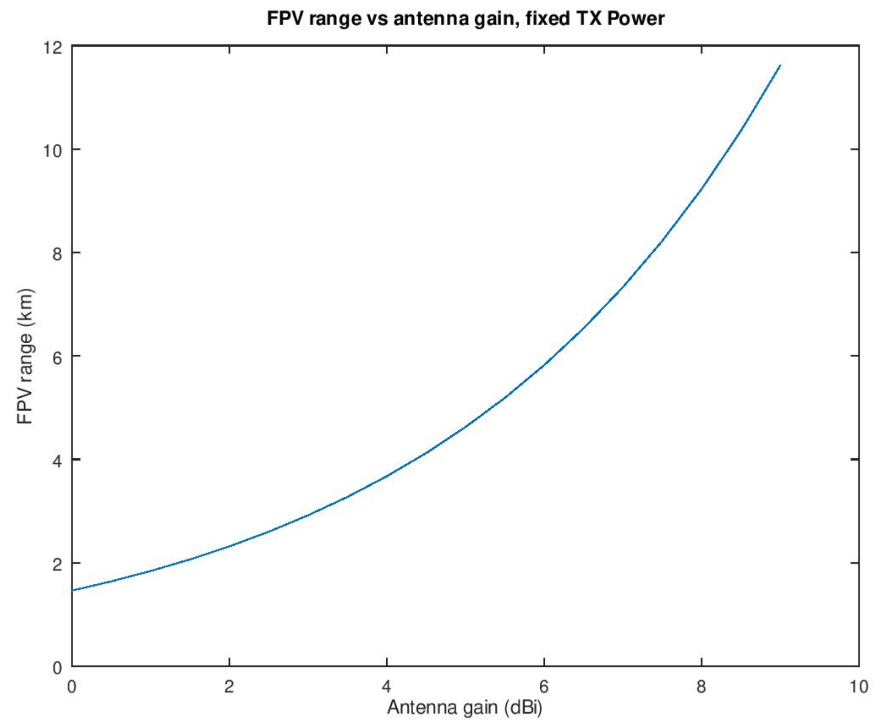
Video link transmission range regarding power and gain

Relation between transmission power and fpv transmission range, assuming fixed hardware configuration.



Video link transmission range regarding power and gain

Relation between FPV range and antenna gain, regarding fixed transmission power

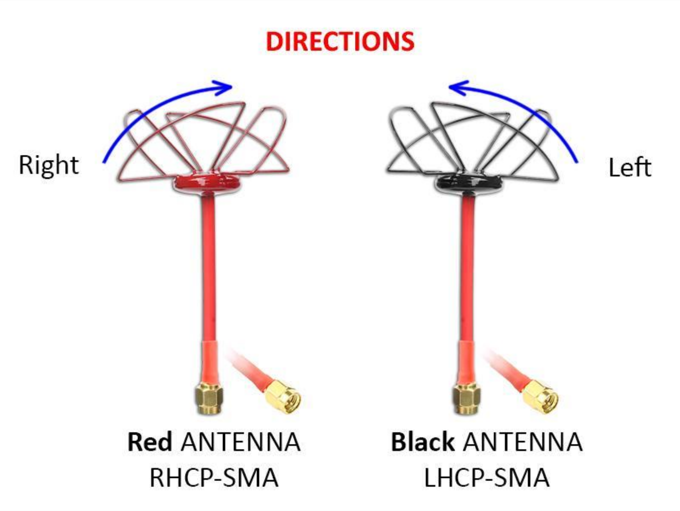


External factors affecting transmission range

- Radio interferences from other transmitters (also from other frequencies via resonation).
- TXP (transmission power) drops with transmitter overheating
- Physical relation between transmitter and receiver antennas (as for simple wire/monopole antenna):
    - 45 degrees unalignment -> about -3dB
    - 90 degrees unalignment -> about -20dB !!!!!!
    - Two monopole antennas pointing one to another (common mistake for beginners): **-30dB**

External factors affecting transmission range - polarisation conversion

- Polarisation conversion:
  - Linear to coaxial -> about -3dB
  - Right coaxial to left coaxial -20dB



100%

Koniec wykładów