Getting Started with
ST Drone Kit

Adriano Basile

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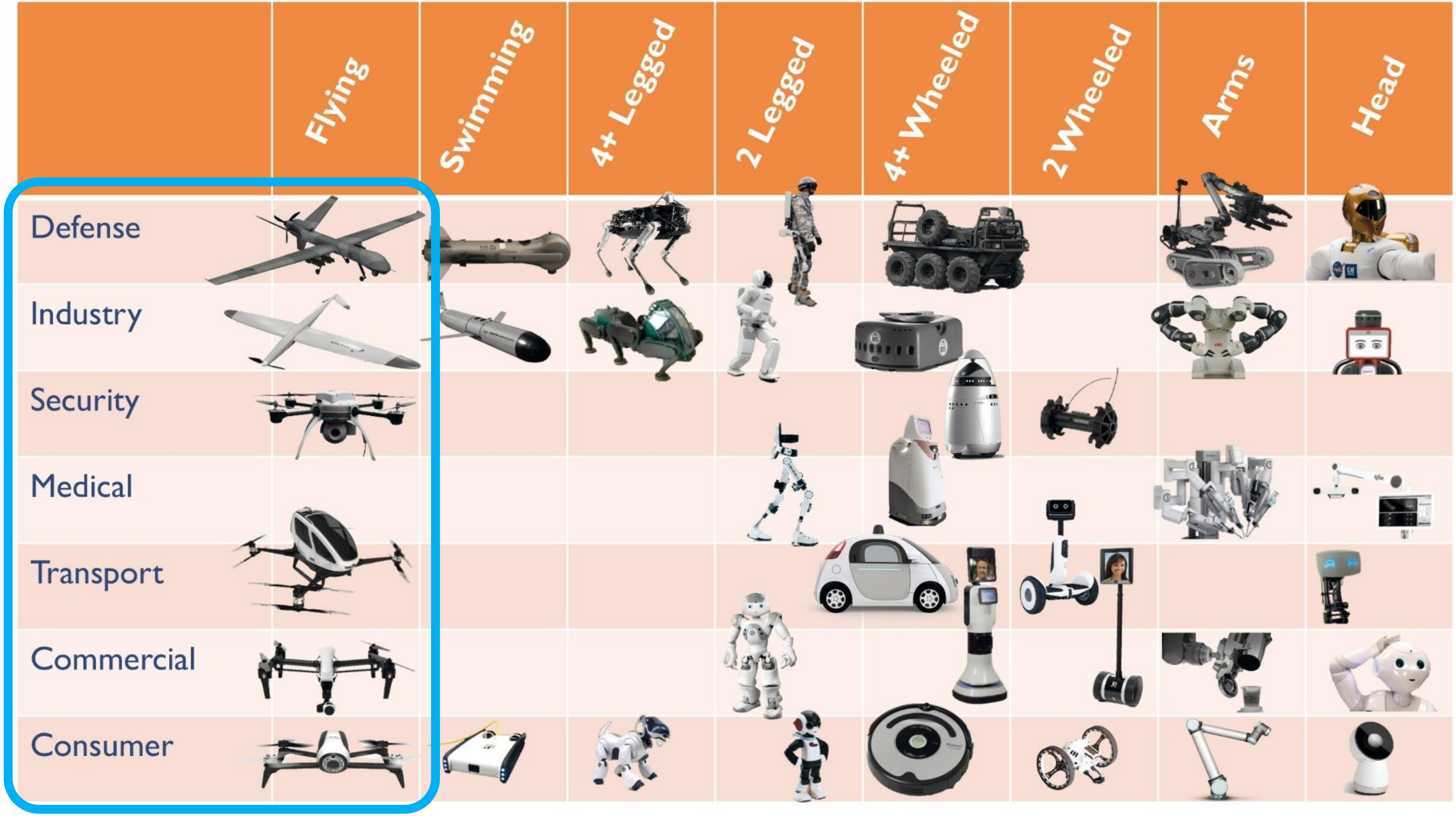
v.0.97

Drones

Robots across segments…



Source: YOLE

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Drones - Segmentation

Definition of Drone Segments: By ASP, Functions and Dimensions

Toy/Mini Drones

- **Not Restricted by the Regulation**
- **ASP:** [0 .. $300]
- **Weight:** ~< 500g
- **Motors:**
  - DC Brushed Motors(Main Stream)
  - BLDC
- **HW Requirements:**
  - ESC, Flight Control
- **Main Functions:**
  - Camera (optional)
  - GPS (optional)

Consumer/Commercial Drones

- **Not Restricted by the Regulation**
- **ASP:** < [$300 .. $3000]
- **Weight:** ~<7-10 Kg
- **Motors:**
  - BLDC Motors (>= 4)
- **HW Requirements:**
  - ESC, Flight control,
  - Gimbal board, GPS
- **Main Functions:**
  - Camera
  - Gimbal (optional)
  - Vision (optional)

Prosumer/Industrial Drones

- **Restricted by the Regulation**
- **ASP:** > $3000
- **Weight:** >10Kg
- **Motors:**
  - BLDC Motors (>= 4)
- **HW Requirements:**
  - ESC, Flight control, Gimbal board, GPS
- **Main Functions:**
  - Carry on packages
  - Gimbal
  - Camera
  - Collision avoidance
  - Long distance

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Drone Kit


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STEVAL-DRONE01
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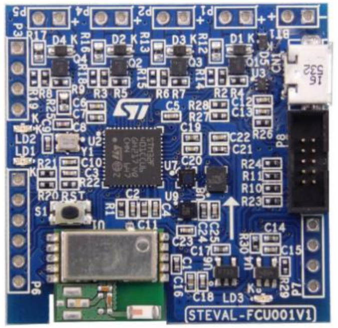
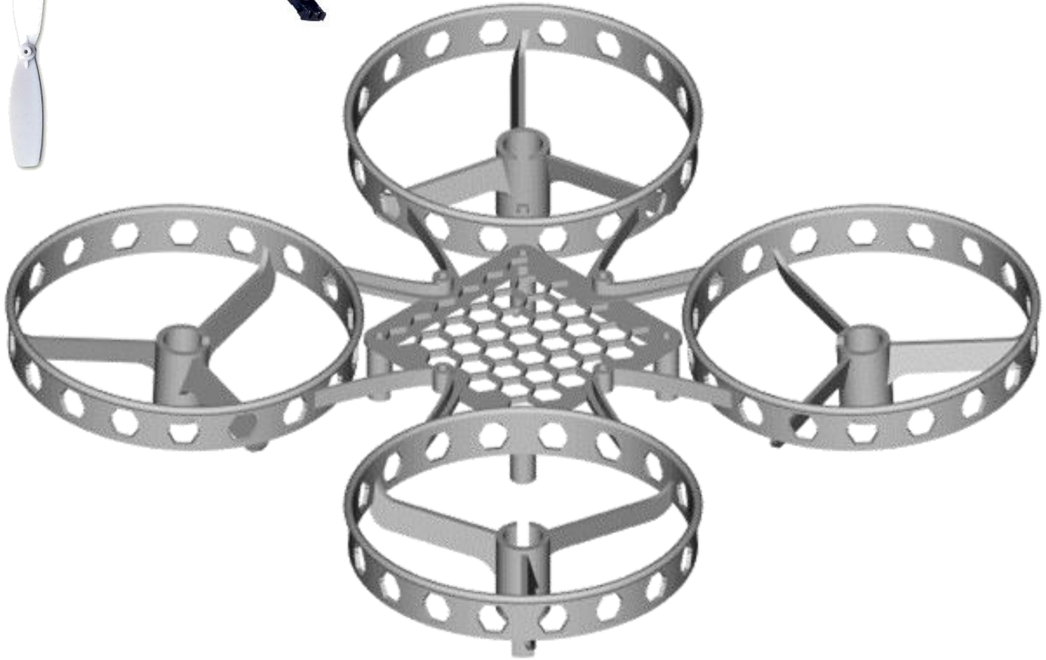

STEVAL-FCU001V1



Overview

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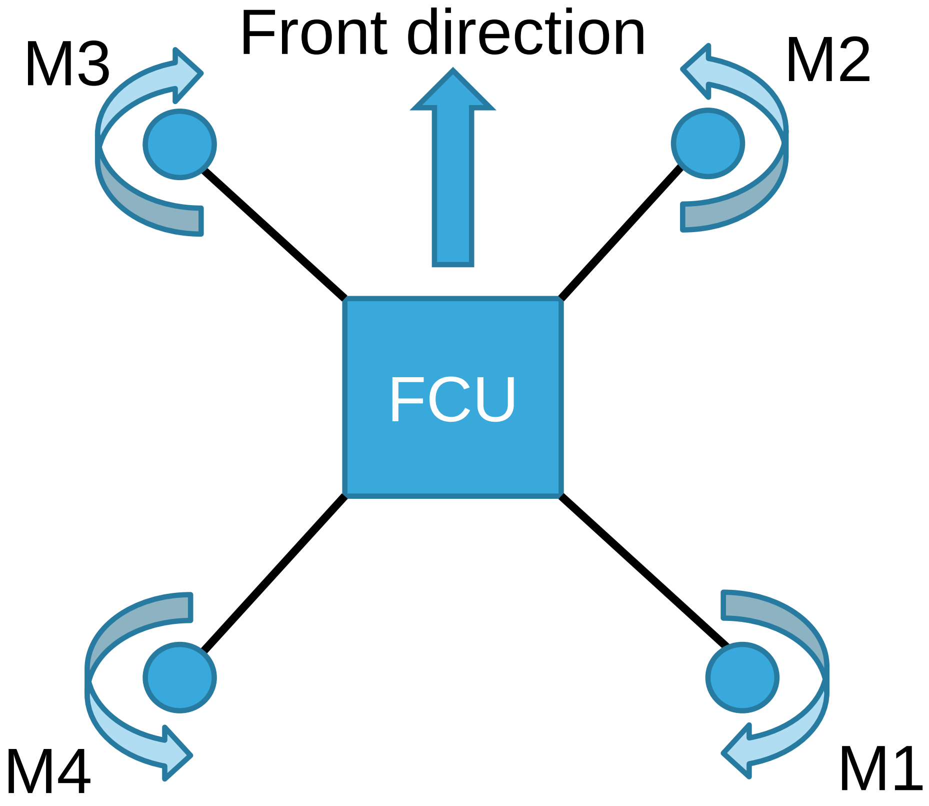
Definition of UAS, drone, multicopter

An *UAS (Unmanned Aircraft System)*, sometimes called a *drone*, is an aircraft without a human pilot on-board; instead, the UAS is controlled from an operator on the ground.

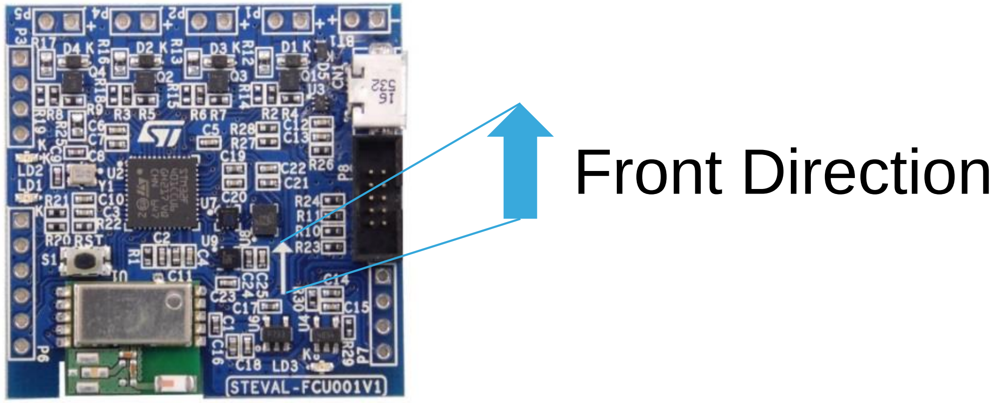
A *multicopter* or *multirotor* is a rotorcraft with more than two rotors. While single (and double) rotor helicopters are more complex to build because they need variable pitch rotors whose pitch varies as the blade rotates for flight stability and control, multicopters use fixed-pitch blades. Control of the multicopter is achieved by varying the relative speed of each rotor to change the thrust and torque produced by each.

A *quadcopter* is a 4-rotor multicopter. In this document we will also use the more popular term, *drone*.

Quadcopter basics: flight control dynamics

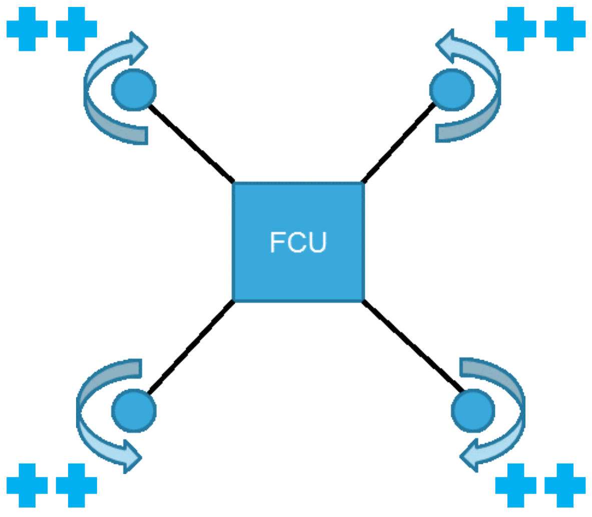


Each rotor produces both a thrust and a torque about its center of rotation. If all rotors are spinning at the same angular velocity, with M1 and M3 rotating CW and M2 and M4 rotating CCW, the angular acceleration about the yaw axis is exactly zero (so there is no need for a tail rotor like on conventional helicopters).

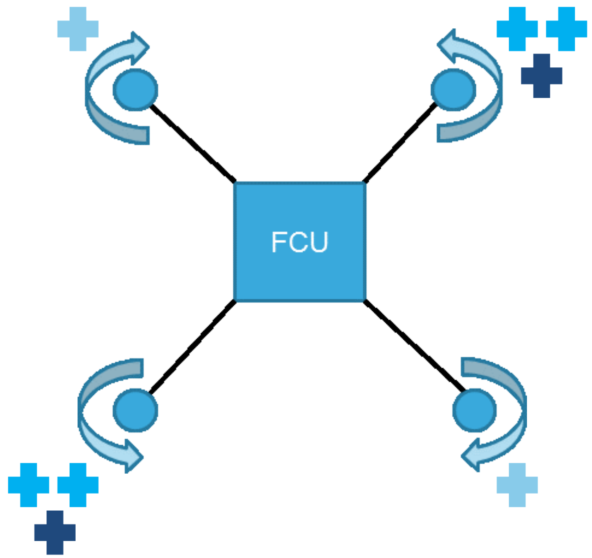


FCU: Flight Control Unit

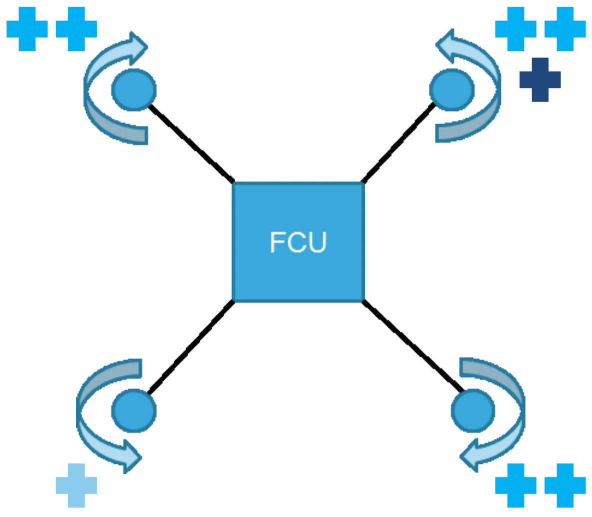
Quadcopter basics: flight control dynamics



A quadcopter *hovers* or *adjusts its altitude* by applying equal thrust to all 4 rotors.



A quadcopter *adjusts its yaw* by applying more thrust to rotors rotating in the same direction.



A quadcopter *adjusts its pitch or roll* by applying more thrust to one rotor and less thrust to its diametrically opposite rotor.

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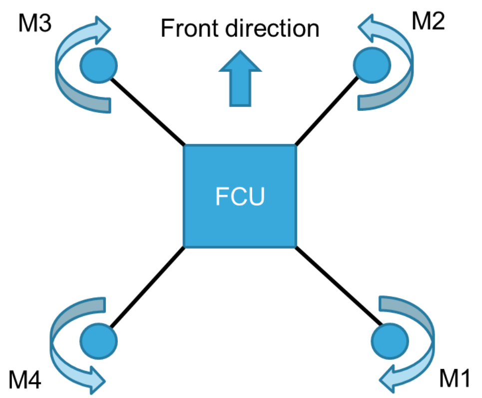
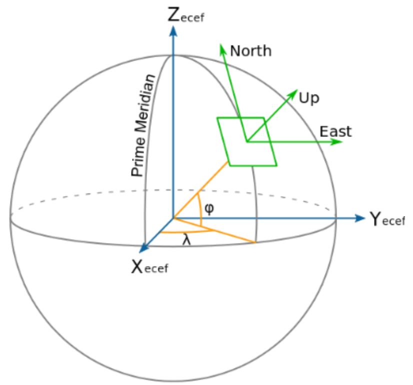
Quadcopter basics: flight control dynamics



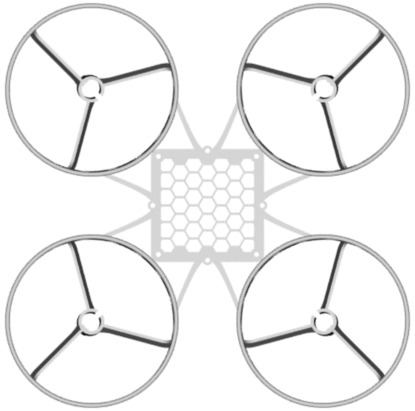
- Coordinate System: ENU
- Frame Type: X-type
- 4 x Motor, rotation direction as shown
- Movement:
  - Forward / Backward (Pitch)
  - Left / Right (Roll)
  - Turn Left / Right (Yaw)
  - Up / Down



Motor / Action	1	2	3	4	Note
Pitch (x)	Slow **(Fast)**	**Fast** (Slow)	**Fast** (Slow)	Slow **(Fast)**	Move Backward (Forward)
Roll (y)	Slow **(Fast)**	Slow **(Fast)**	**Fast** (Slow)	**Fast** (Slow)	Move Right (Left)
Yaw (z)	**Fast** (Slow)	Slow **(Fast)**	**Fast** (Slow)	Slow **(Fast)**	Heading Left (Right)
Up / Down	**Fast** (Slow)	**Fast** (Slow)	**Fast** (Slow)	**Fast** (Slow)	Move Up (Down)

ENU: East North Up

Quadcopter basics: mechanical structure

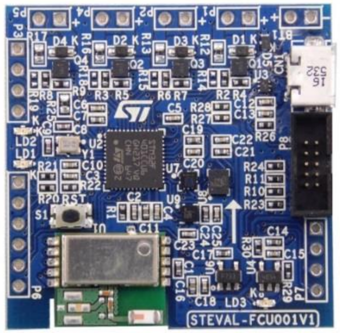


Frame: there are several frames of different size and materials available on the market. For simplest control algorithm (reference FW available with STEVAL-FCU001V1) the motors and propellers should be placed at equidistant intervals.

Motors: for small drones, *DC coreless motors* are usually used, while for bigger frames, *3-ph DC brushless* motors are preferred. The choice of the motor must be made together with the frame and propeller selection. Please be aware that some motors are designed to be used only in CW or CCW direction (especially DC brushed).

Propellers: are a type of fan that convert rotational motion into thrust. There is a wide choice with 2, 3, and 4 blades, different materials and shapes.

Quadcopter basics: electronics



FCU (Flight Controller Unit): the main algorithm for flight control usually runs on a *32-bit microcontroller*, which also controls the speed of each motor by directly controlling them (*DC motor*) or by sending a signal to an external *ESC* (*Electronic Speed Controller for 3-ph DC brushless*). In order to stabilize the drone, data from *accelerometer* and *gyroscope* sensors are analyzed, while a *pressure sensor* may be used for altitude control.

Remocon and RX receiver: it is possible control drones with Smartphones and/or remocons specific for multicopters, these are generally preferred from users because they offer better flight control sensitivity, meanwhile smartphone App is cheaper. Each remocon has an RX unit that must be connected to the FCU.

Battery: for multicopters *LiPo (Lithium Polymer) batteries* are commonly used. Depending on the size of the drone and motors, 1-, 2- or 3-cell batteries are selected, with different current capabilities and sizes. This kind of battery must be used with particular care because they can be damaged (and even explode) if overcharged or short-circuited.

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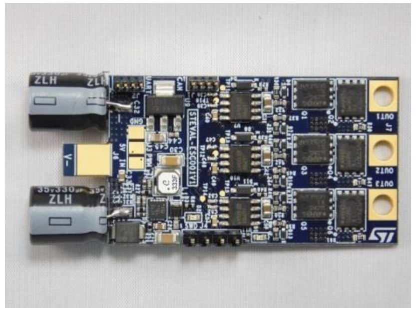
Quadcopter basics: electronics

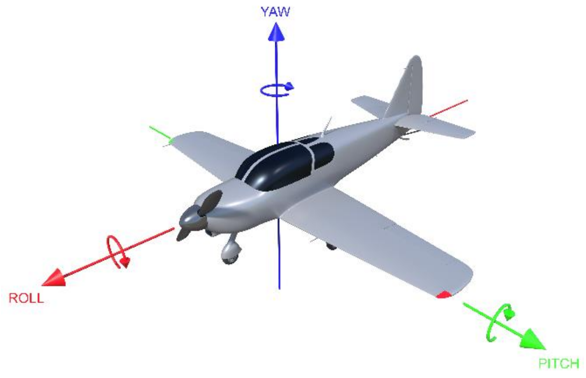


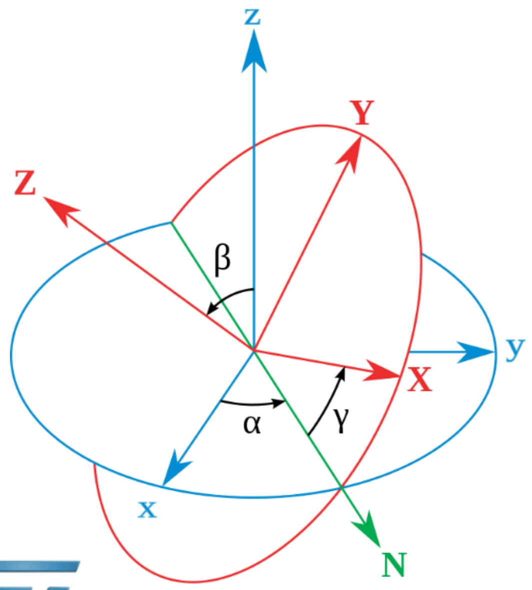
STEVAL-ESC001V1

ESC (Electronic speed controller): is used to drive a 3-ph DC brushless motor in sensorless mode. Generally, it receives an input signal up to 500Hz PWM from the FCU, with a pulse width varying from 1 ms (motor off) to 2 ms (motor full speed). The ESC is also connected directly to the battery, representing the Vbus for driving the motor.

Most of them incorporate a so-called *BEC (battery eliminator circuit)*: basically a DCDC converter to give the supply voltage to the FCU.

Quadcopter basics: Euler angles





Euler angles – The fixed system (*xyz*) is in blue, while the rotating system (*XYZ*) is in red. In green are the line of nodes (*N).* The Euler angles are:

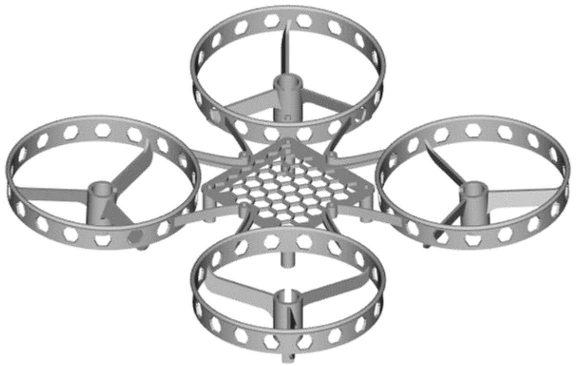
- $\boldsymbol{\alpha}$ is the angle between x axis and line of nodes N.
- $\boldsymbol{\beta}$ is the angle between *z* and *Z* axis.
- $\boldsymbol{\gamma}$ is the angle between line of nodes N and X axis.

The Euler angles are very useful to represent the inclination of a quadcopter (or other flying vehicle) moving in space and will be used for the basic PID control algorithm.

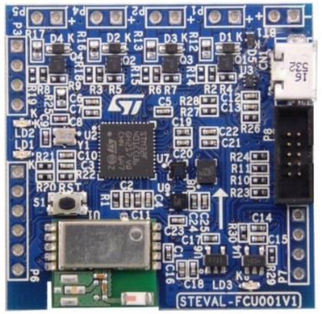
Overview

Assemble the items: mechanical structure

The items below represent possible assembly items for a small drone and have already been tested with the current FW version, demonstrating stable flight performance.



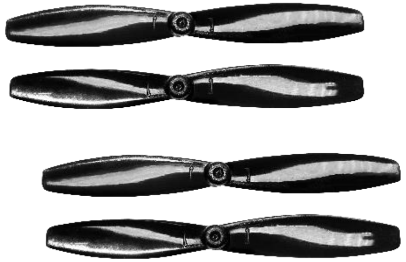
3D mechanical frame



STEVAL-FCU001V1 board

1-cell battery 3.7V 600mAh 30C

2 x CW, 2 x CCW coreless DC motor 8.5x20mm



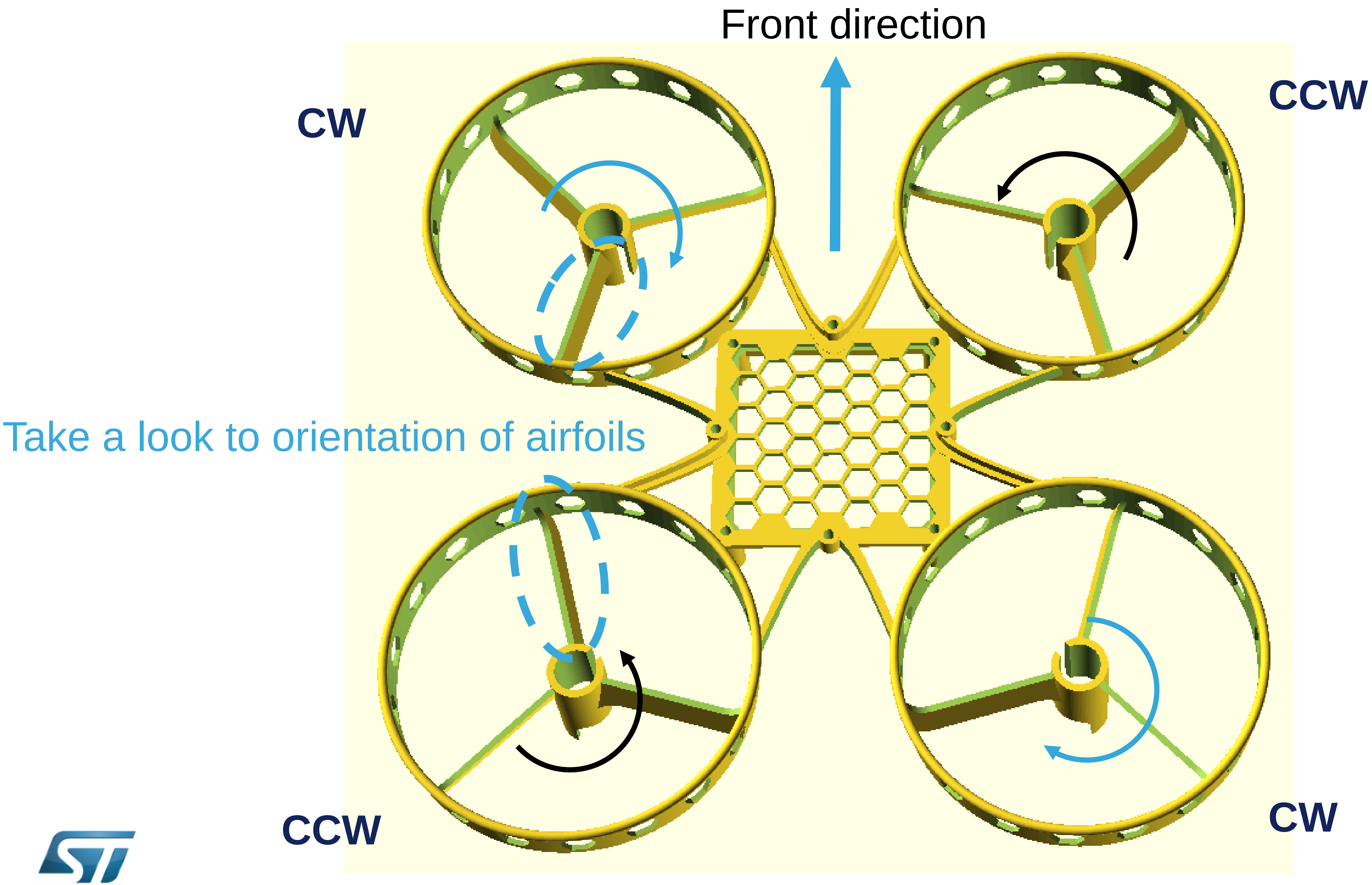
4 x 65mm propellers

Remote Controller or Smartphone App

Mechanical structure of STEVAL-DRONE01

The drone frame is one of the critical part of drone because its size, weight and material impact on the flight capability. In the kit, it has been included a good tradeoff between weight and easy replicability, in fact the frame has been made with a 3D printer: the STL file could be downloaded by the product folder.

In order to support the air flow for clockwise and counterclockwise motors, the three arms to sustain the motors have been designed as airfoils, see Figure on next slide.



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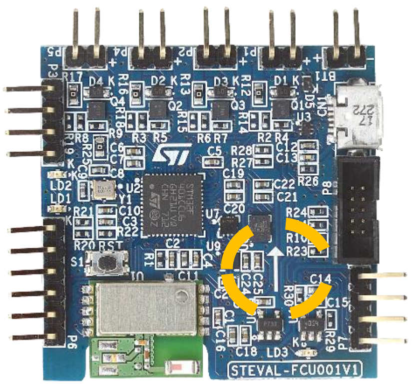
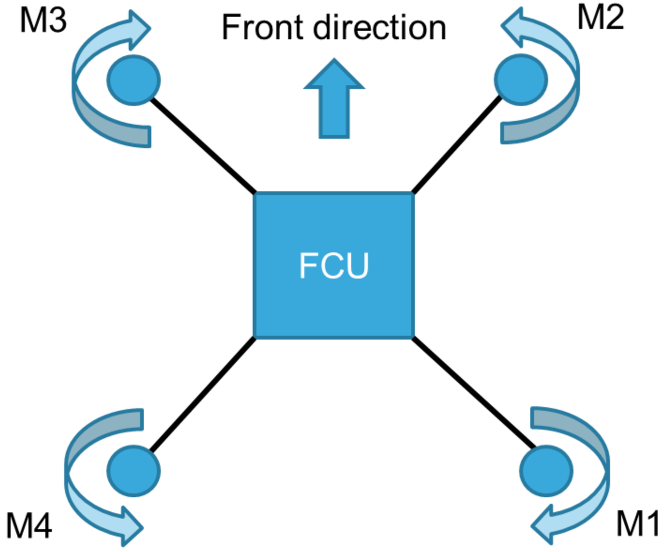
Step 1: mounting STEVAL-FCU001V1 board on frame





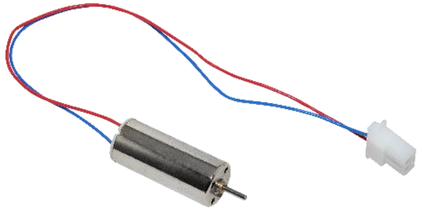
- The STEVAL-FCU001V1 must be mounted in the center of the drone, equidistant from the four motors.
- Front direction is indicated on the STEVAL-FCU001V1 by a **small arrow**. Take care about frame orientation (see figure on left).
- The board must be mounted as flat as possible and well anchored to the frame.
- You can use an adhesive sponge between the frame and the FCU board to minimize mechanical vibration from motors.
- Current FW supports the common "x" configuration shown here. To use a "+" configuration, some modifications to the FW are needed (*).

(*) Please refer to the FW explanation session for more details.

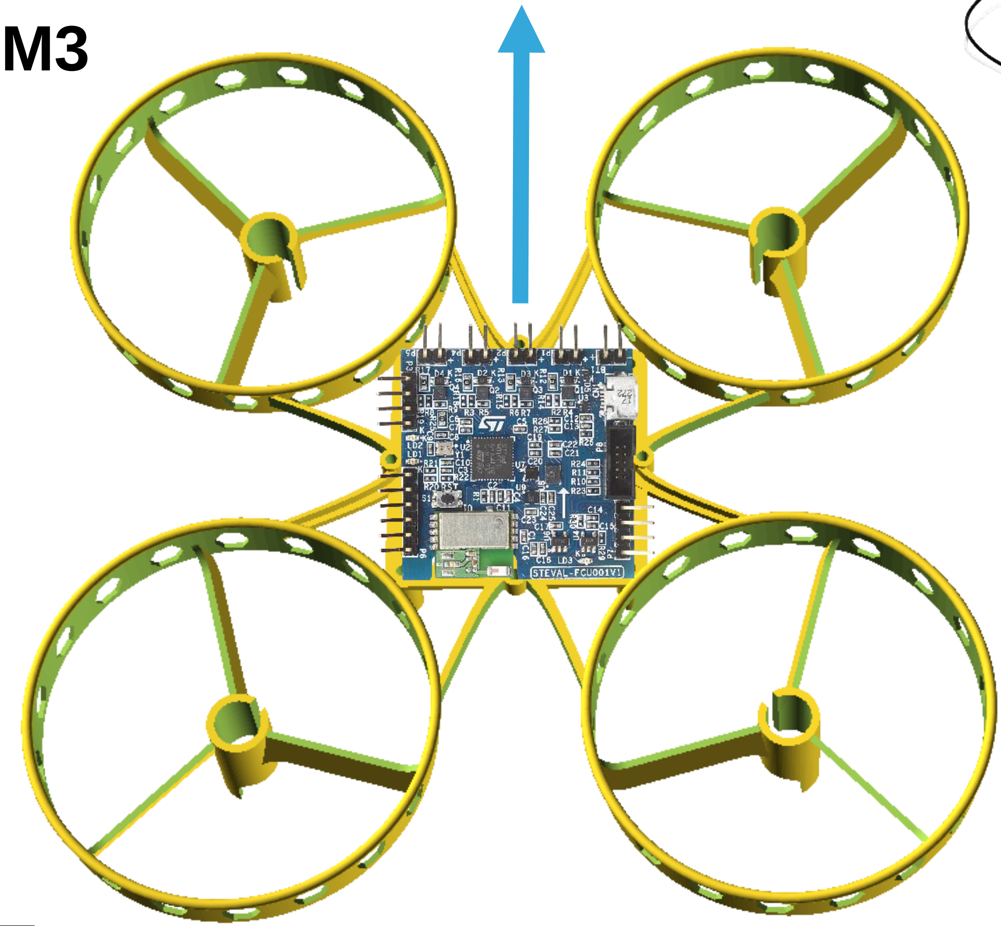
Step 2: mounting motors in the Frame

Front direction

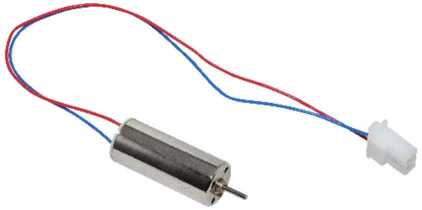
M3



ClockWise: Blue(-)/Red(+)



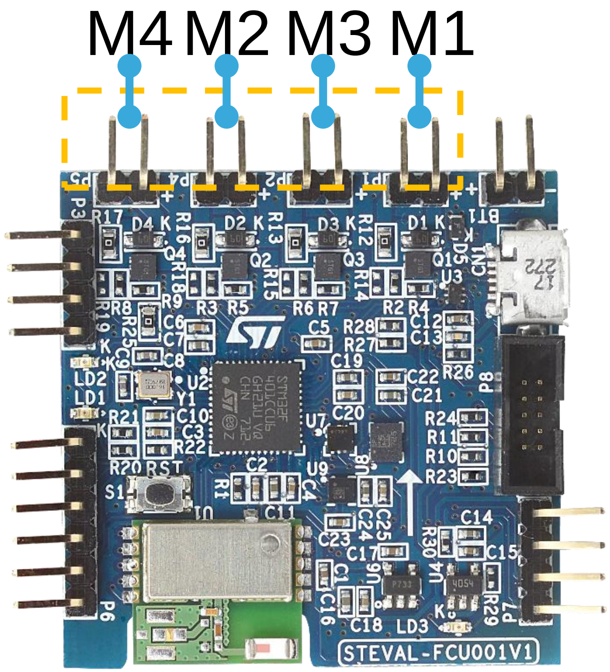
CounterClockWise: Black(-)/White(+)



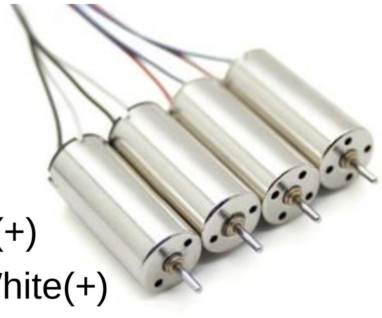
ClockWise: Blue(-)/Red(+)

CounterClockWise: Black(-)/White(+)

Step 3: motor connection on the board



DC motors should be connected to P5, P4, P2 and P1 connectors following the sequence in the figure.



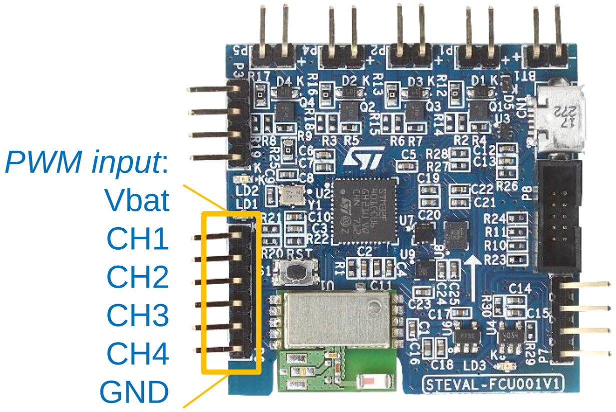
CW: Blue(-)/Red(+)

CCW: Black(-)/White(+)

Note: This configuration is valid also for 3-ph DC brushless motors connected through external ESC

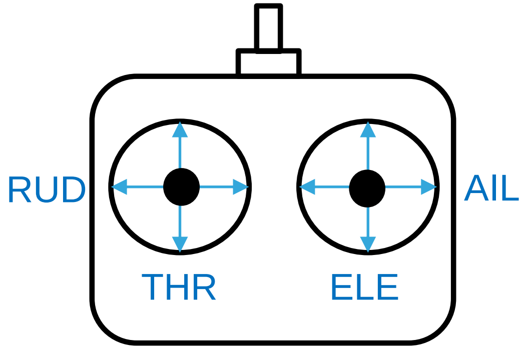
Warning: A CW DC motor can rotate in CCW direction if "+" and "-" are reversed, but the brushes are designed for CW rotation and prolonged use in the opposite direction may reduce its lifetime

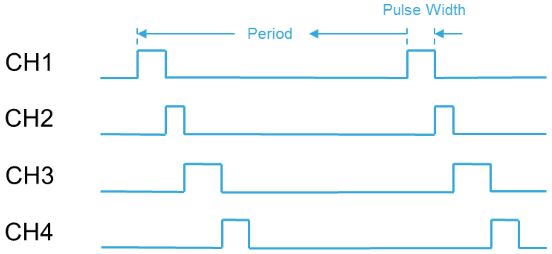
Step 4: (optional) Remocon RX module connection



- RX module should be connected to the PWM input connector.
- You should verify that transmitter is programmed in order to have the 4 RC channels assigned as per the table below.
- Current FW is compatible with PPM (Pulse Period Modulation) receiver.

Channel	Control	Function	Position	L / D	M	R / U
CH1	AIL	Roll	R: LR	2ms	1.5ms	1ms
CH2	ELE	Pitch	R: UD	1ms	1.5ms	2ms
CH3	THR	Thrust	L: UD	1ms	-	2ms
CH4	RUD	Yaw	L: LR	2ms	1.5ms	1ms





Period: ~5..20ms
(50..200Hz)
Pulse Width: 1~2ms

Note: The above figure refers to a Type2 remocon, commonly used for quadcopters. In case of Type1, the commands are switched.

L: Left R: Right U: Up D: Down

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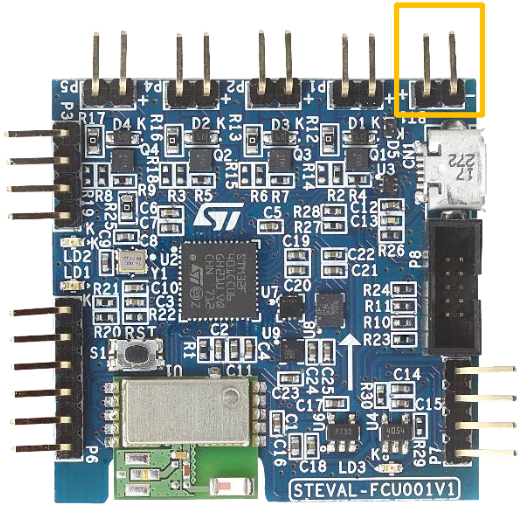
Step 5: Battery connection

BT1 connector
BAT input



A LiPO 1-cell battery can be connected directly to connector BT1 on STEVAL-FCU001V1 board and battery can be charged via USB thanks to the on-board charger.

In case of 2-cell or 3-cell, the battery should be connected to the ESC and Vbat should be connected to the 5V (max input voltage 5.5V) generated by the BEC of the ESC.

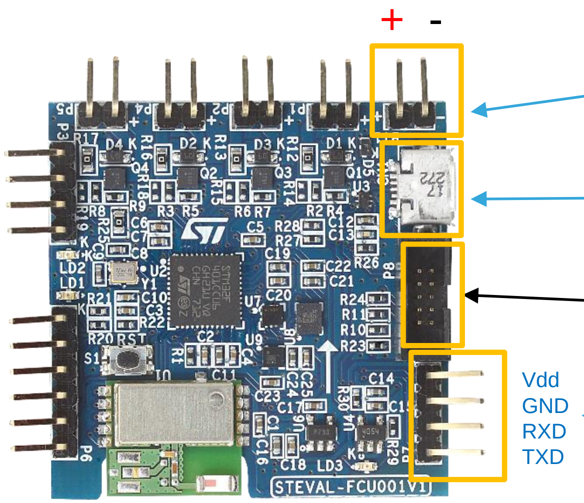
Warning: a reverse battery protection diode is not mounted, check carefully before connecting the battery!

Warning: LiPO batteries can be damaged and even explode if they are short-circuited or overcharged. They should also always be kept in a safe bag when not used or during charging. Please read detailed information from battery maker or on the Internet before handling a LiPO battery.

Warning: as soon as the battery is discharged after a flight (when there is not enough power to make the drone fly), disconnect the battery from the board immediately. If the battery remains connected and is completely discharged, it will be damaged and you will no longer be able to recharge.

Step 6: JTAG connection and SW download

To download and debug the FW on the STM32F401 MCU, a JTAG with micro connector (SWD) should be connected, and a voltage should be supplied to the board through a 1S LiPo battery (3.7V).



1-cell battery (or 3.7V supply voltage by external power supply) must be connected.

Connect microUSB cable to avoid to discharge the battery.

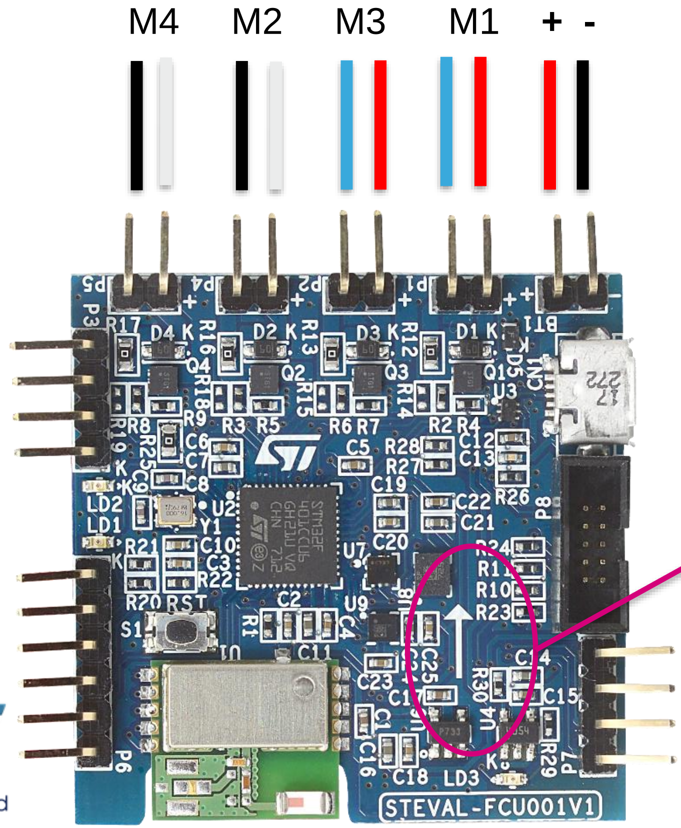
Cable for ST-Link/V2 included in the STEVAL-FCU001V1 package.

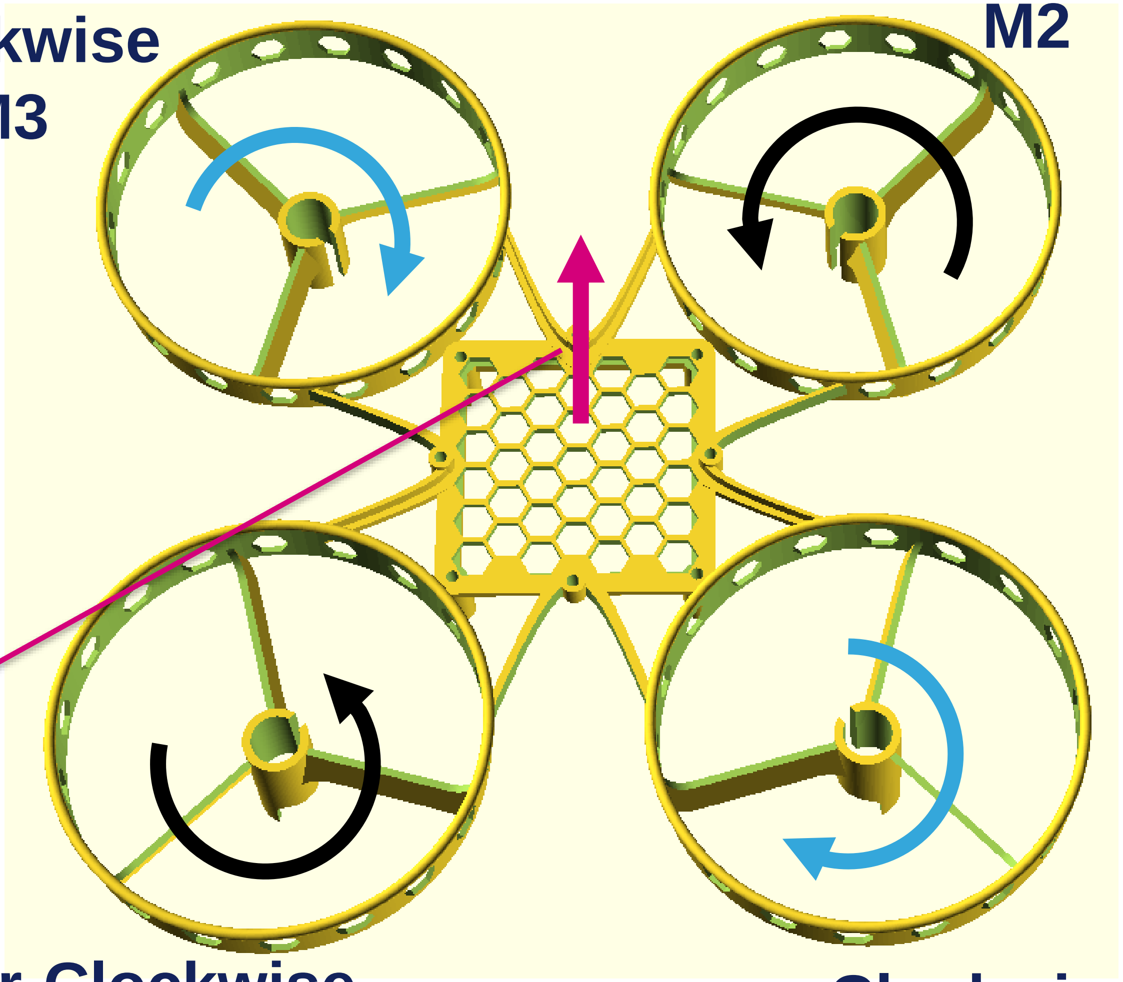
(optionally) UART can be used for debug and datalog

Note: if only the microUSB cable is connected with no battery or supply voltage connected to the BT1 connector, the STM32 supply voltage may be unstable and not work properly in debugging.

Note: In order to avoid complete LiPo battery discharge during a debugging session, always connect the microUSB cable (connected to PC or charger) to keep charging the battery.

Resume: Motor and Battery connections





Step 7: Calibration procedure

After startup (with STEVAL-FCU001V1 already mounted on the quadcopter), it is necessary to run a sensor calibration procedure. Place the quadcopter on a flat surface, press the reset button and move the remocon control levers to the positions shown in the figure below or act on the Smartphone App.

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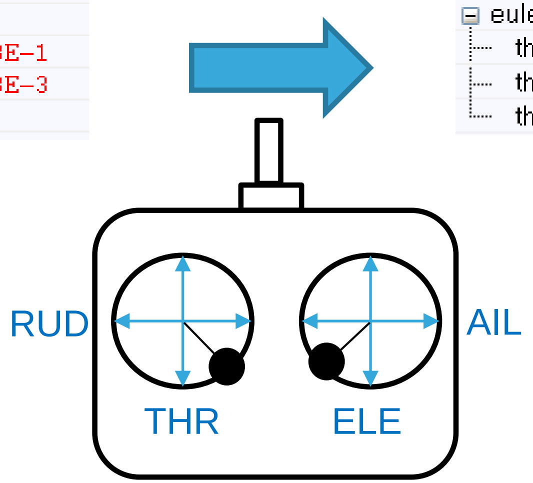
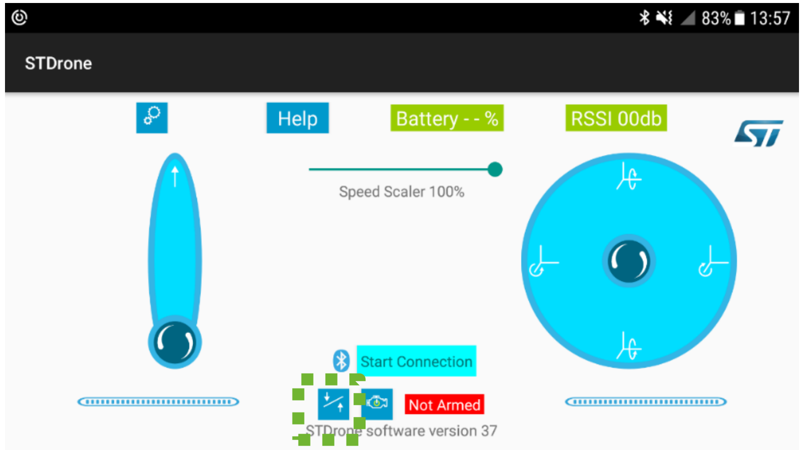
thx	2.7870795133E-1
thy	7.9544568433E-3
thz	0.0



euler_ahrs	<struct>
thx	4.0701283144E-3
thy	-3.6119404833E-4
thz	0.0

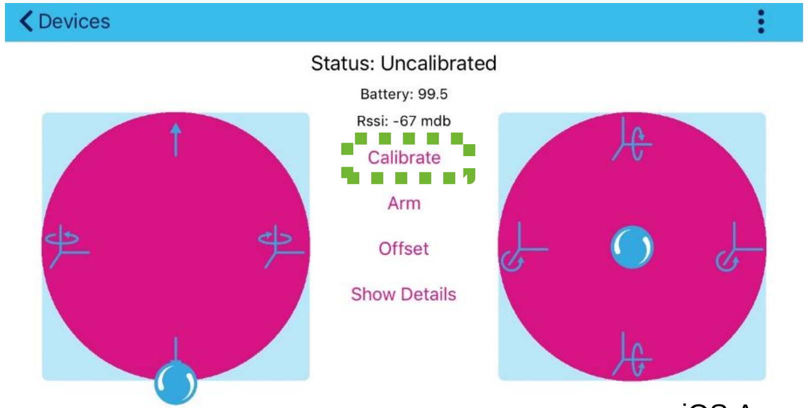


Android App

Note: The STEVAL-FCU001V1 will take the flat surface as reference and determine any offsets for the AHRS Euler angle.

Note: by using the Smartphone App there is a different behavior in Android or iOS:

- [*Android*] tap for few seconds the button… until it become **GREEN**
- [*iOS*] tap the button and wait few seconds until it appears **Calibrated**



iOS App

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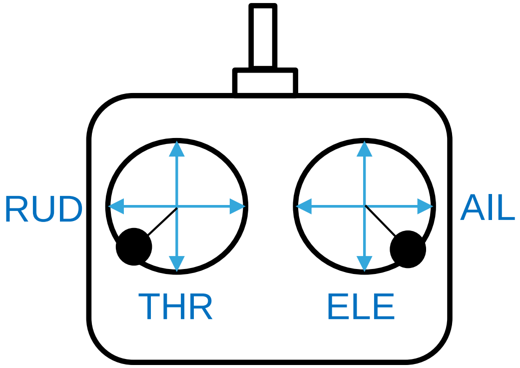
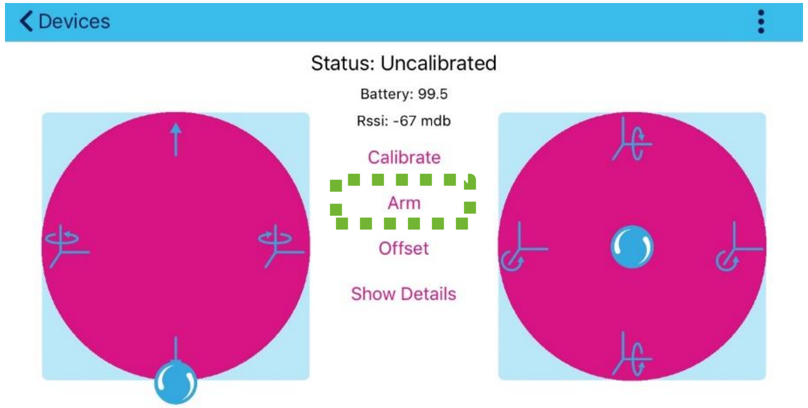
Step 7: Arming procedure

The first operational tests should be performed without the propellers mounted to verify that connections are correct, the motors function and the remocon connection is established.

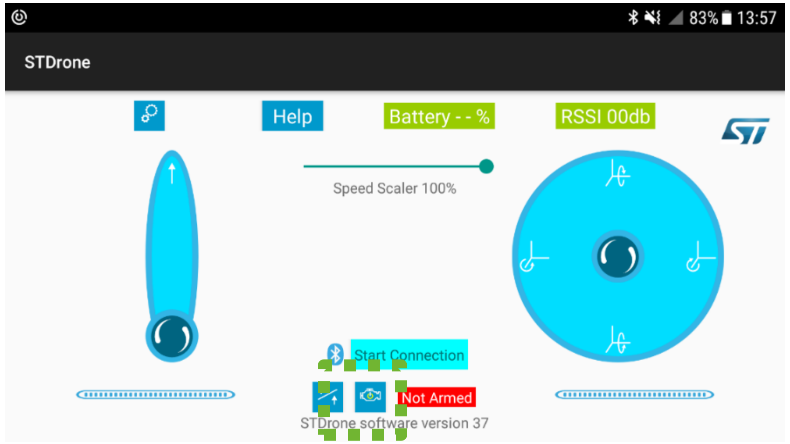
For safety reasons, the drone is initially *Disarmed*: even if connection with Remocon TX is established and throttle is at full scale, the motors are intentionally *not driven* (red LED on the STEVAL-FCU001V1 blinks).

To allow flight, you must perform an *Arming* procedure: in the current FW implementation, arming is achieved by moving the remocon levers to the positions shown in the figure below for at least 2 seconds (the red LED will stop blinking and remain ON) or by tapping the button on the Smartphone App.





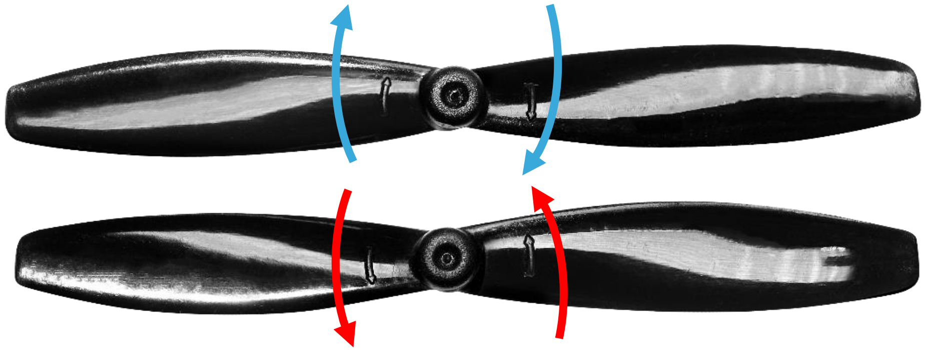
iOS App



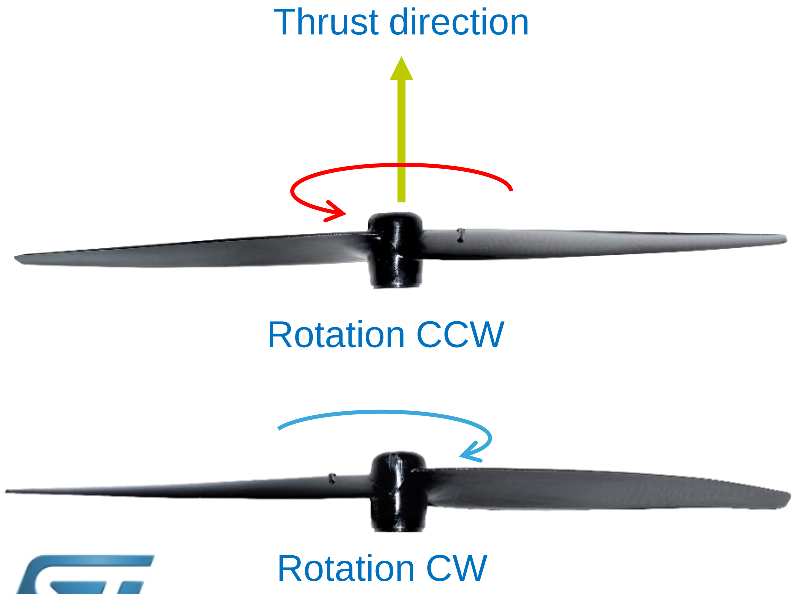
Android App

Note: by using the Smartphone App tap the button… you will see **Armed message**

Step 8: mounting the propeller



Care must be taken to mount the propeller blades correctly: the propeller is designed according to Bernoulli's principle, where a positive thrust perpendicular to the rotation axis is achieved when the top advances in the sense of rotation.



Some propeller vendor add an **arrow** to indicate CW or CCW orientation or **F** or **R** respectively for CW or CCW.

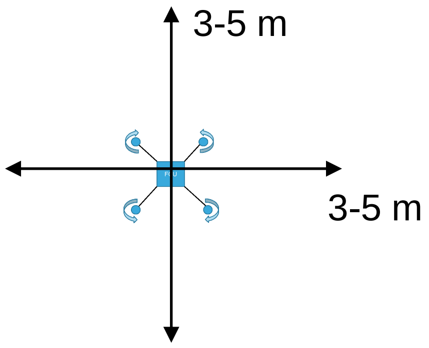
Warning: Before mounting the propellers, disconnect the battery for safety.

Warning: if you mount CW propellers on a CCW motor or viceversa, your quadcopter will not fly.

Step 9: first test flight

Proceed with your first test flight in an open area with no one in the immediate vicinity after you have followed all the safety procedures during setup and have completed the arming procedure.

- First make the drone hover at 2m altitude and ensure that it remains stable.
- Then proceed with simple flight maneuvres like forming a cross at 2-3 m altitude.



Troubleshooting: if the drone seems unstable and starts to oscillate, try reducing the PID proportional gain, refer to the FW description section and PID tuning tutorials on the Internet.

Overview

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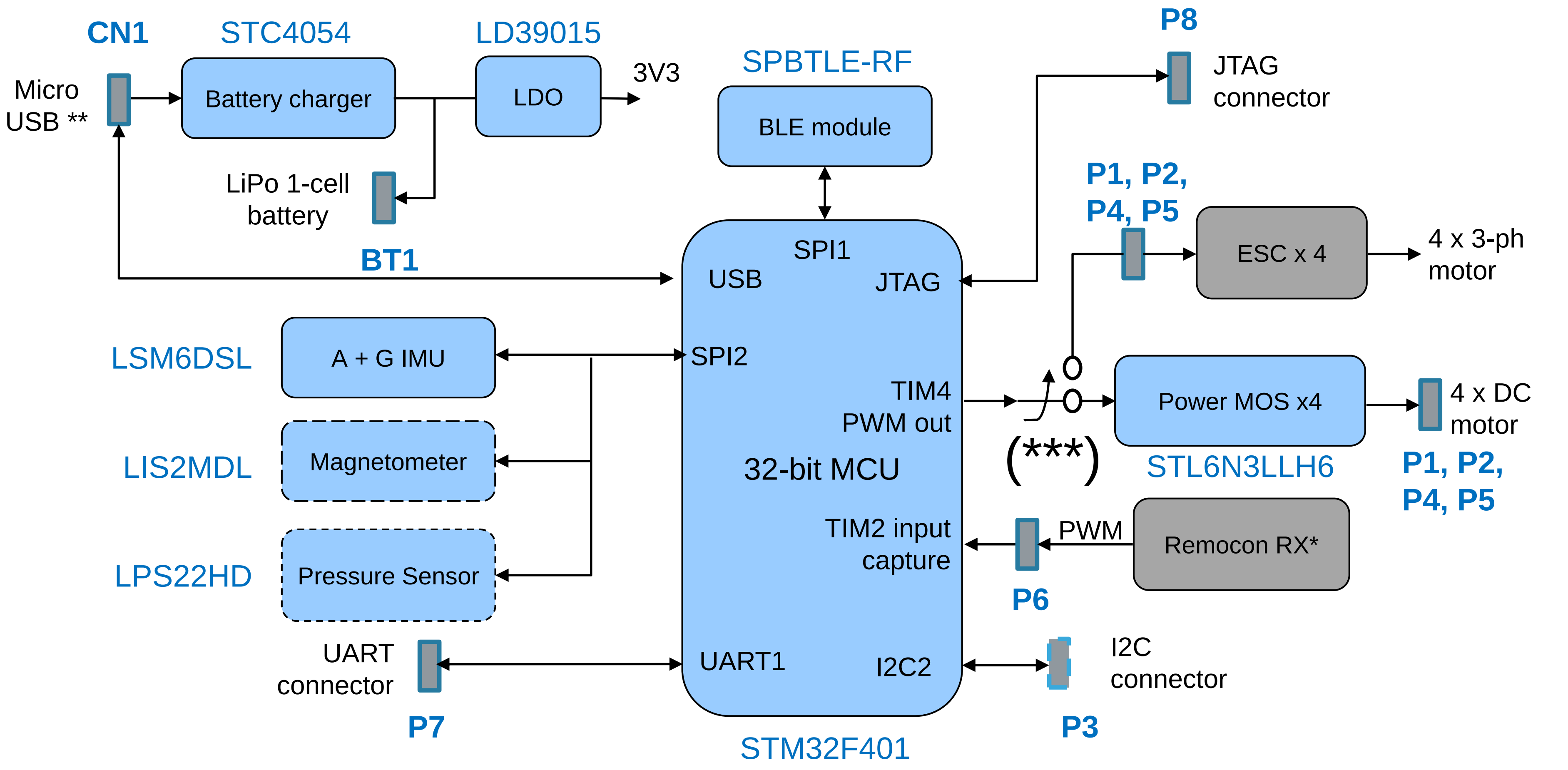
STEVAL-FCU001V1 block diagram



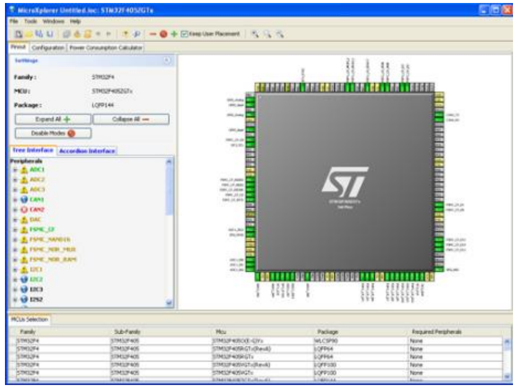
Block present on the board but not exploited in current FW version. HW available for customer use.

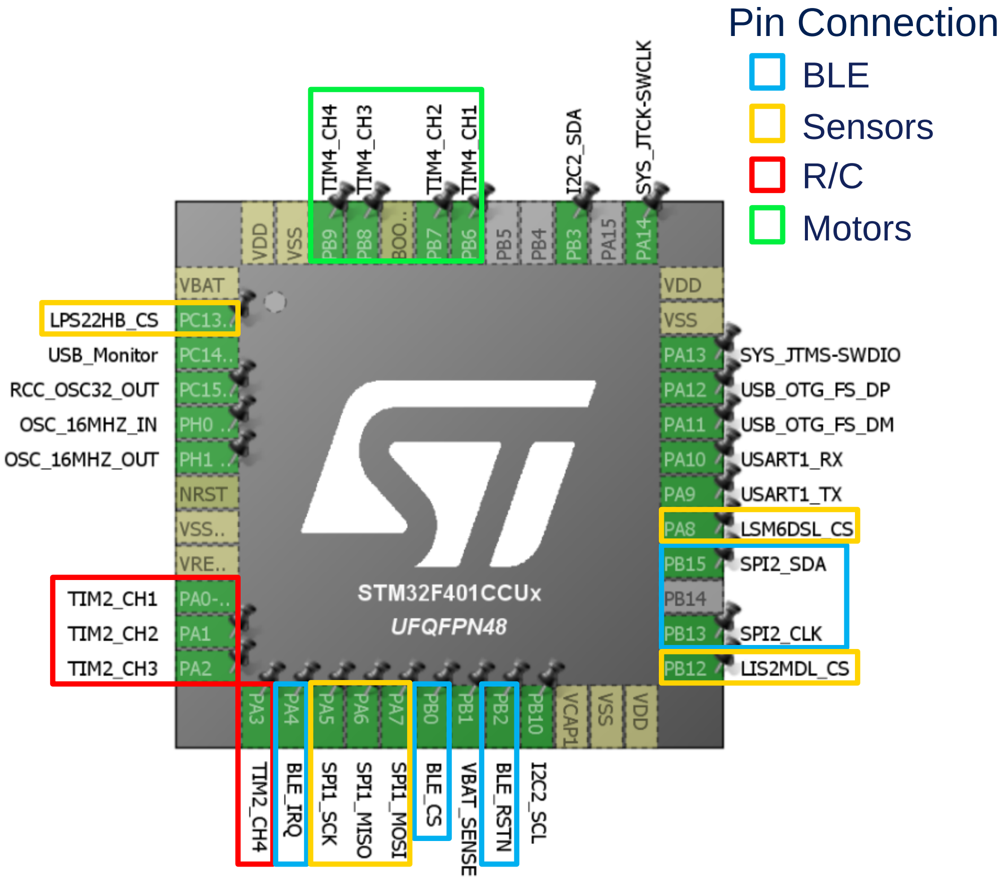
(*) RX module should be paired with Remocon TX.
(**) MicroUSB connector used only for battery charger purpose. USB Data line connected to the MCU but USB driver not included in current FW version.
(***) This switch is based on Zero Ohm Resistors, see next pages for detail

STM32F401 connections

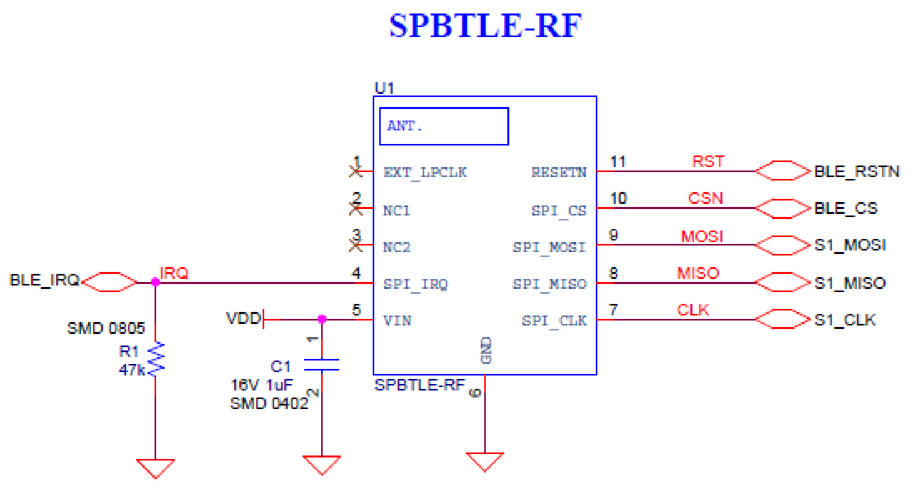
STM32CubeMX:

- It is a graphic interface for configuring the STM32 peripherals and generating the relative source code
- It contains embedded STM32Cube libraries
- STM32CubeF4 is designed to be used with the STM32F4 family

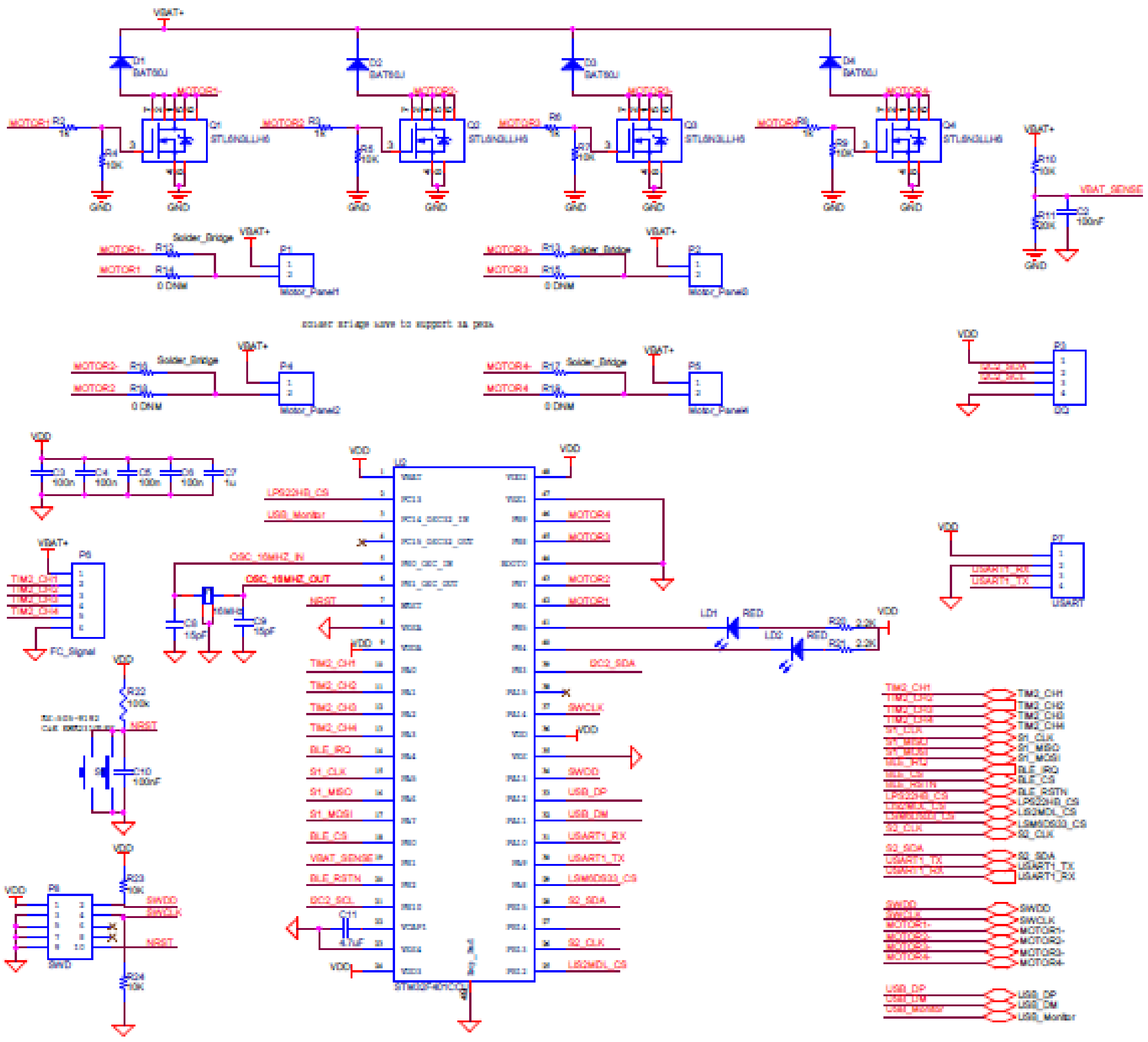




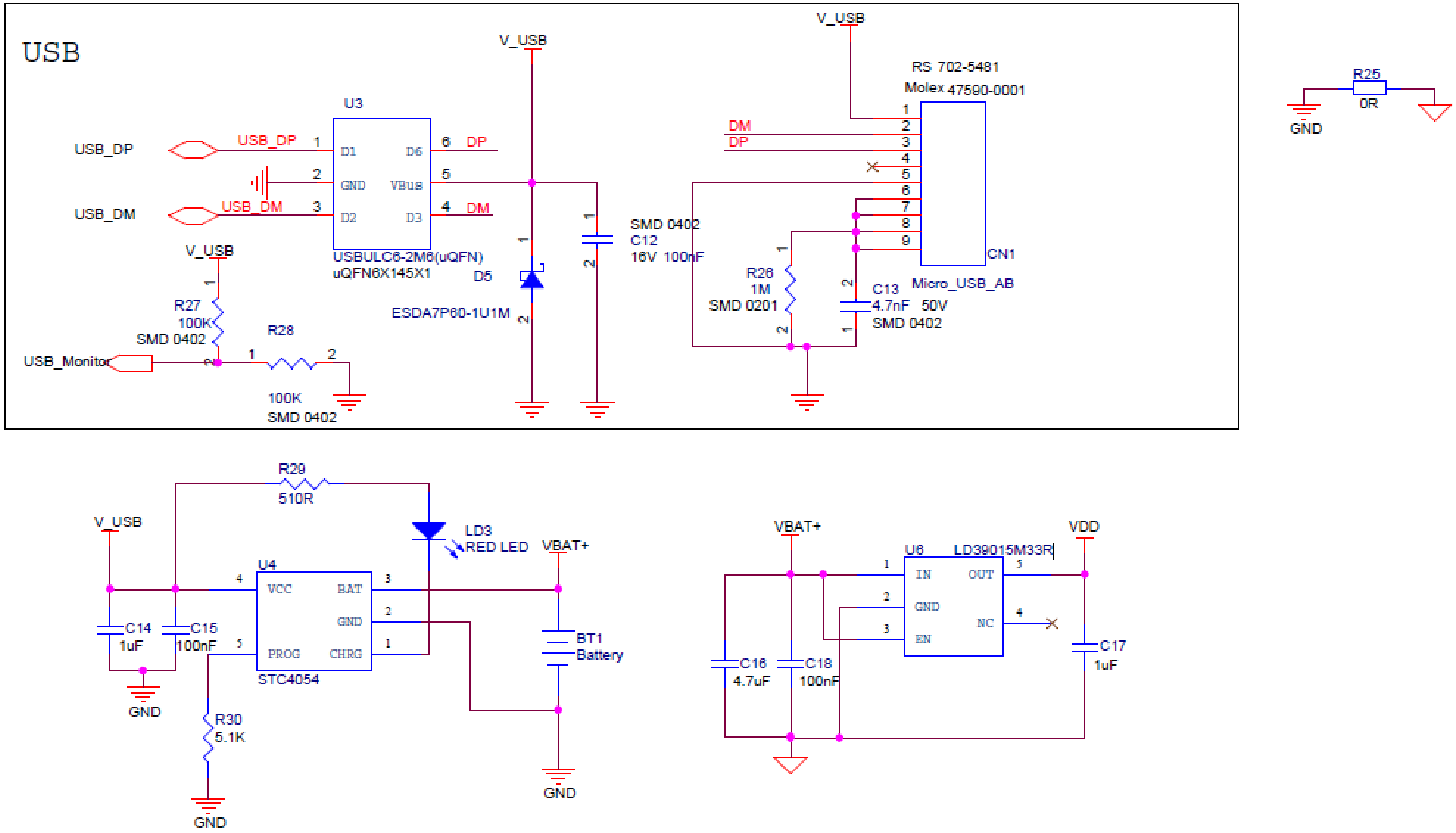
STEVAL-FCU001V1 schematics (1/4)



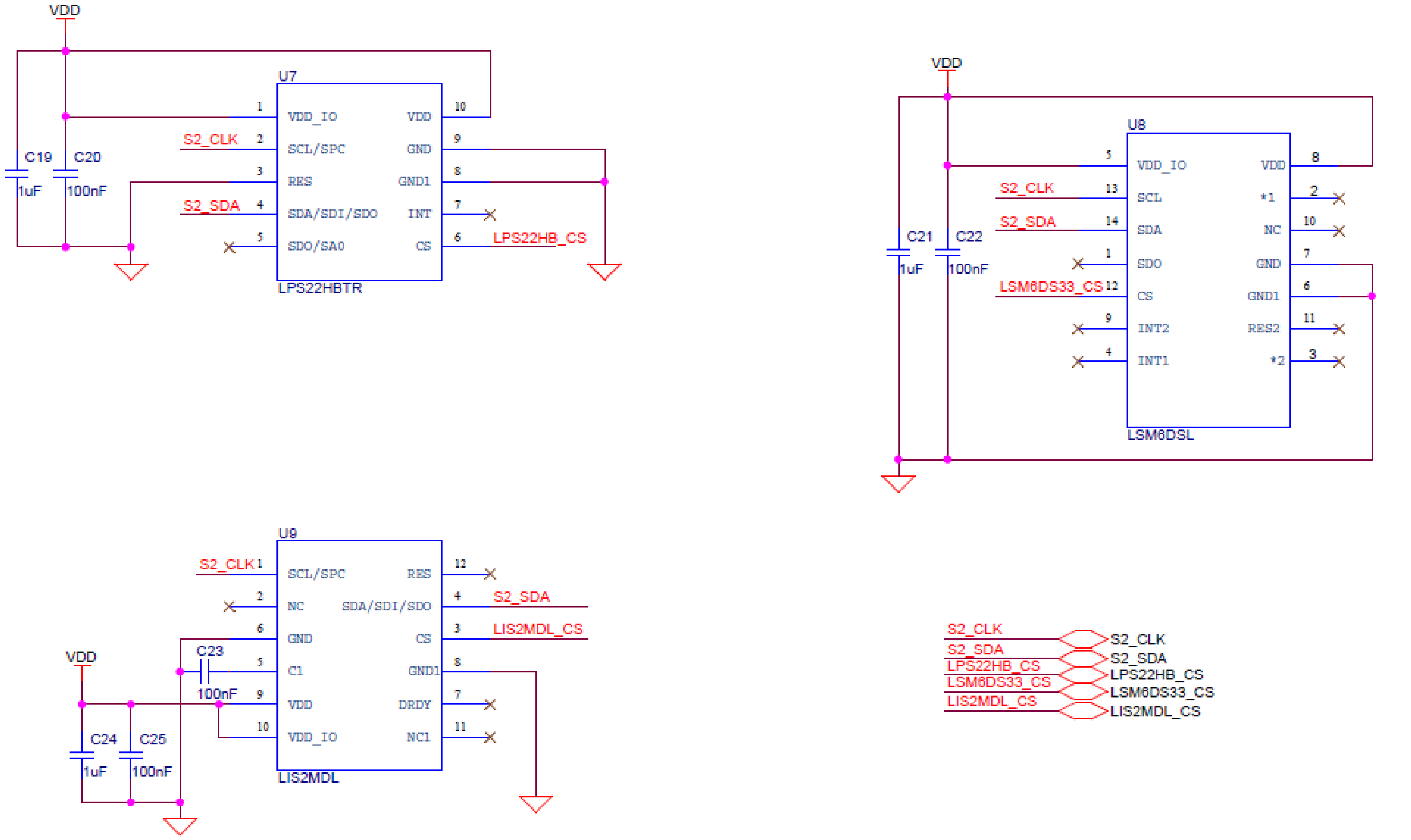
STEVAL-FCU001V1 schematics (2/4)



STEVAL-FCU001V1 schematics (3/4)



STEVAL-FCU001V1 schematics (4/4)



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STEVAL-FCU001V1 BOM

Item	Reference	Part / Value	Voltage / Watt / Ampere	Type / TECNOLOGY informations	Tolerance	Package	Manufacturer
1	BT1	Battery Connector		Strip Line male 1X2 pitch 2,54mm		siptm2002	ANY
2	CN1	Micro_USB 2,0 Female SMt				microusb7025481	Molex
3	C1,C7,C14,C16,C17,C19,C21,C24	1uF	16V	Capacitor Ceramic XR7	10%	smc0402	ANY
4	C2,C3,C4,C5,C6,C10,C12,C15,C18,C20,C22,C23,C25	100nF	16V	Capacitor Ceramic XR7	10%	smc0402	ANY
6	C8,C9	15pF	16V	Capacitor Ceramic XR7	10%	smc0402	ANY
7	C11	4.7uF	16V	Capacitor Ceramic XR7	10%	smc0402	ANY
8	C13	4.7nF	16V	Capacitor Ceramic XR7	10%	SMC0402	ANY
9	D1,D2,D3,D4	BAT60J	10v-3A	Signal Schottky Diode		sod323	STM
10	D5	ESDA7P60-1U1M		Voltage Suppressor		SMD1610	STM
11	LD1,LD2,LD3	RED LED		LED RED SMD		smd0603	OSRAM Opto
12	L1	2.2uH	1,4A Rcc 140mOhm	SMD Inductor		sml0805	WURTH
13	P1	Motor_Panel1		Strip Line male 1X2 pitch 2,54mm		siptm2002	ANY
14	P2	Motor_Panel3		Strip Line male 1X2 pitch 2,54mm		siptm2002	ANY
15	P3	i2Q		Strip Line male 1X4 pitch 2,54mm		siptm4004	ANY
16	P4	Motor_Panel2		Strip Line male 1X2 pitch 2,54mm		siptm2002	ANY
17	P5	Motor_Panel4		Strip Line male 1X2 pitch 2,54mm		siptm2002	ANY
18	P6	FC_Signal		Strip Line male 1X6 pitch 2,54mm		siptm6006	ANY
19	P7	USART		Strip Line male 1X4 pitch 2,54mm		siptm4004	ANY
20	P8	SWD		Connector 2X5 pitch 1,27mm		Ampmode10X1M27	SAMTEC
21	Q1,Q2,Q3,Q4	STL6N3LLH6		Power Mosfet		powerFLAT2X2	STM
22	R1	47k	1/16W	SMD Thick Film Resistor	1%	smr0402	ANY
23	R2,R3,R6,R8	100	1/16W	SMD Thick Film Resistor	1%	smr0402	ANY
24	R4,R5,R7,R9,R10	10K	1/16W	SMD Thick Film Resistor	1%	smr0402	ANY
25	R11	20K	1/16W	SMD Thick Film Resistor	1%	smr0402	ANY
26	R12,R13,R16,R17,R25	0	1/16W	SMD Thick Film Resistor	1%	smr0603	ANY
27	R14,R15,R18,R19,R23,R24	NA	1/16W	SMD Thick Film Resistor	1%	smr0402	ANY
28	R20,R21	2.2K	1/16W	SMD Thick Film Resistor	1%	smr0402	ANY
29	R22,R27,R28	100K	1/16W	SMD Thick Film Resistor	1%	smr0402	ANY
30	R26	1M	1/16W	SMD Thick Film Resistor	1%	SMR0402	ANY
31	R29	510R	1/16W	SMD Thick Film Resistor	1%	smr0402	ANY
32	R30,R31,R32	5.1K	1/16W	SMD Thick Film Resistor	1%	smr0402	ANY
33	S1	Reset		Push Botton		PushKMR22	C&K
34	U1	SPBTLE-RF				spbtrfle	STM
35	U2	STM32F401CCU				UFQFPN48X7X7	STM
36	U3	USBULC6-2M6(uQFN)				uQFN6X145X1	STM
37	U4	STC4054				SOT23L5	STM
38	U5	STOD1812				DFN10L3X3X075	STM
39	U6	LD39015M33R				sot23l5	STM
40	U7	LPS22HBTR				HLGA10X2X2X07	STM
41	U8	LSM6DSL				lga14X2m5X3X086	STM
42	U9	LIS2MDL				lga12X2X2X1	STM
43	Y1	16MHz		Quarzo	15ppm	quarzonx2520sa	NDK

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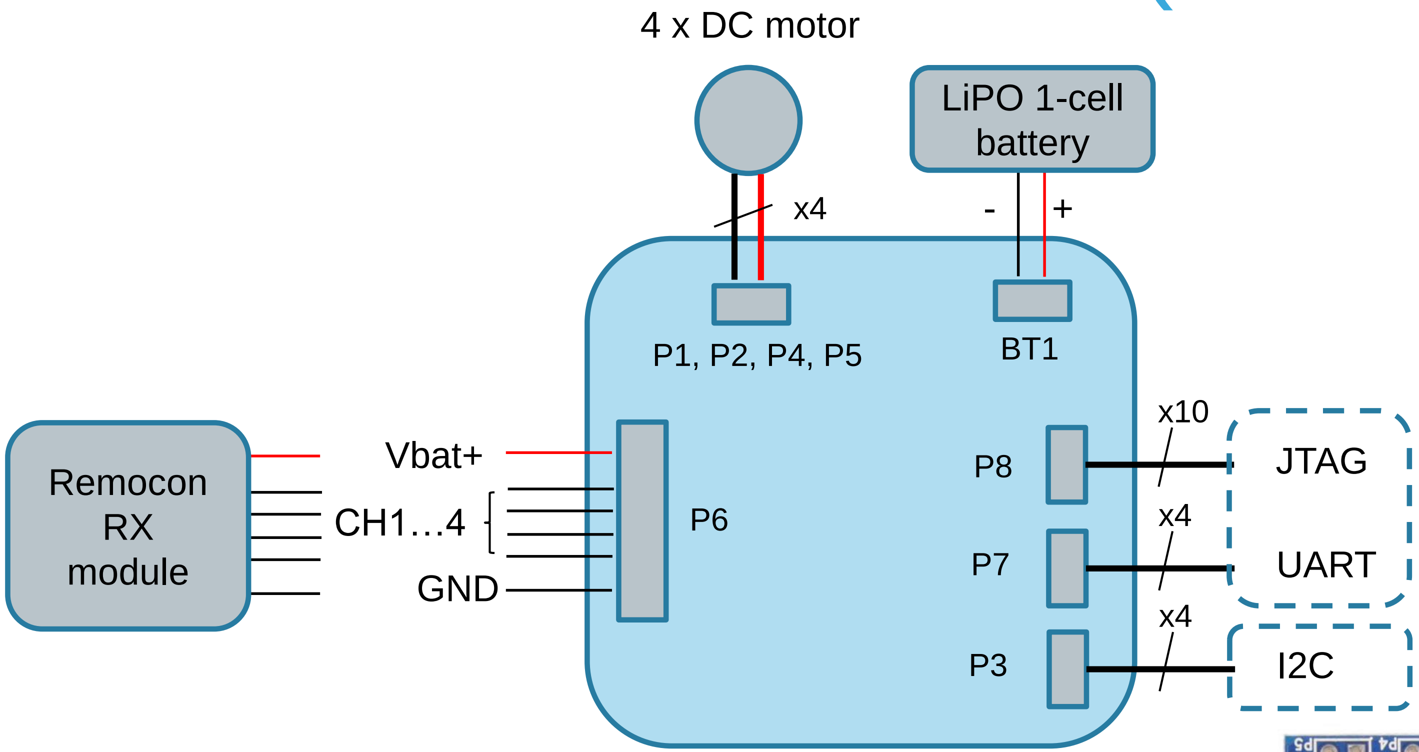
STEVAL-FCU001V1 application connection (3.7V DC motors)

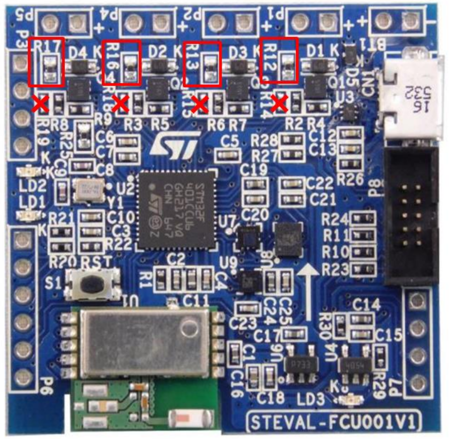


Used only for debug purposes

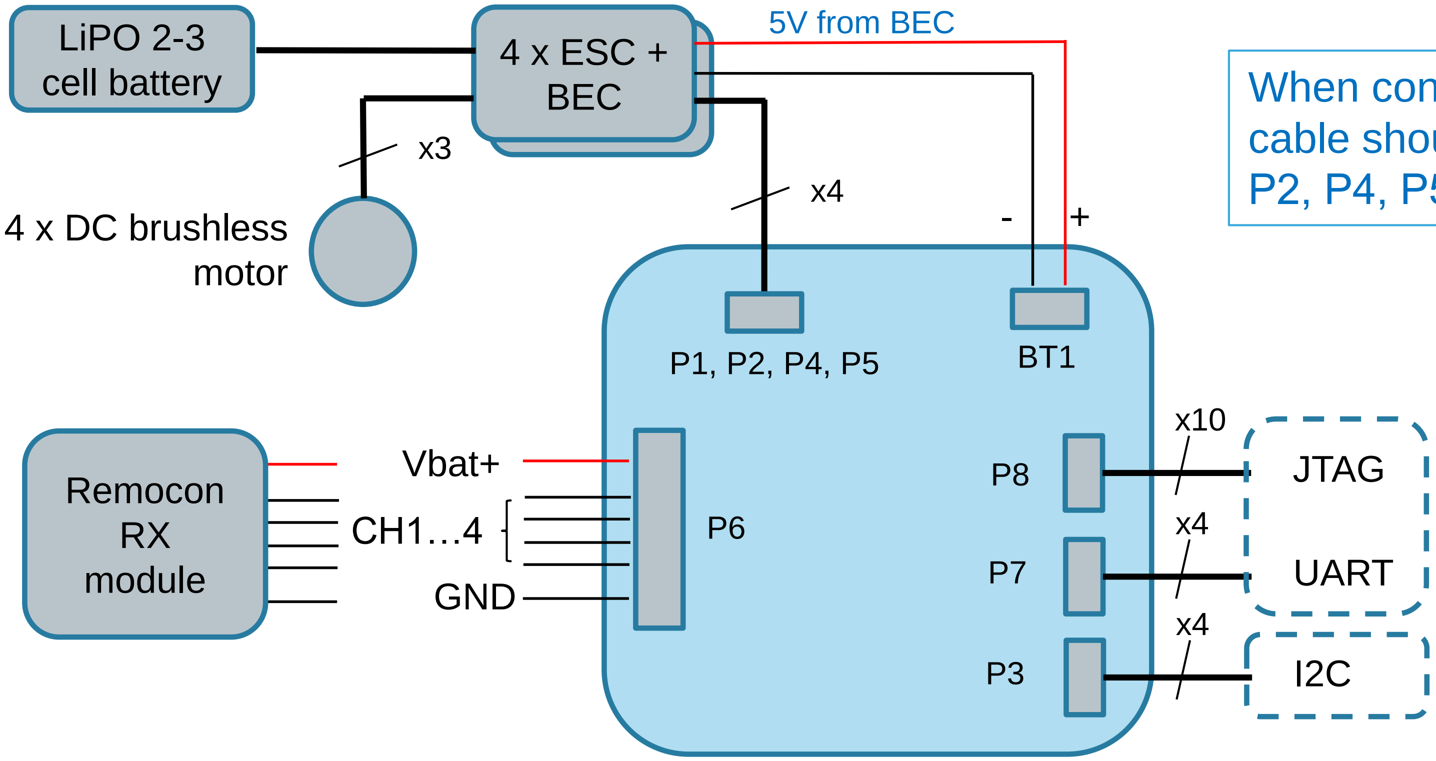
Available for future use

Note: this is the Out of the Box configuration

Resistor Configuration	R12, R13, R16, R17 mounted R14, R15, R18, R19 NOT mounted



STEVAL-FCU001V1 application connection (External ESC for DC brushless motors)

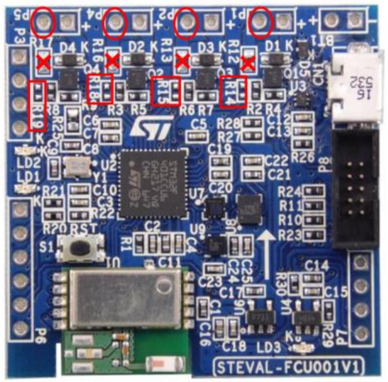


When connecting the ESC the PWM signal cable should be connected to pin2 of P1, P2, P4, P5 connectors (not the "+" pin).

Used only for debug purposes

Available for future use

STEVAL-FCU001V1



Resistor Configuration

R12, R13, R16, R17 NOT mounted
R14, R15, R18, R19 mounted

Overview

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STEVAL-FCU001V1 FW download

The source code of the STEVAL-FCU001V1 can be downloaded at the following link (or QR code):

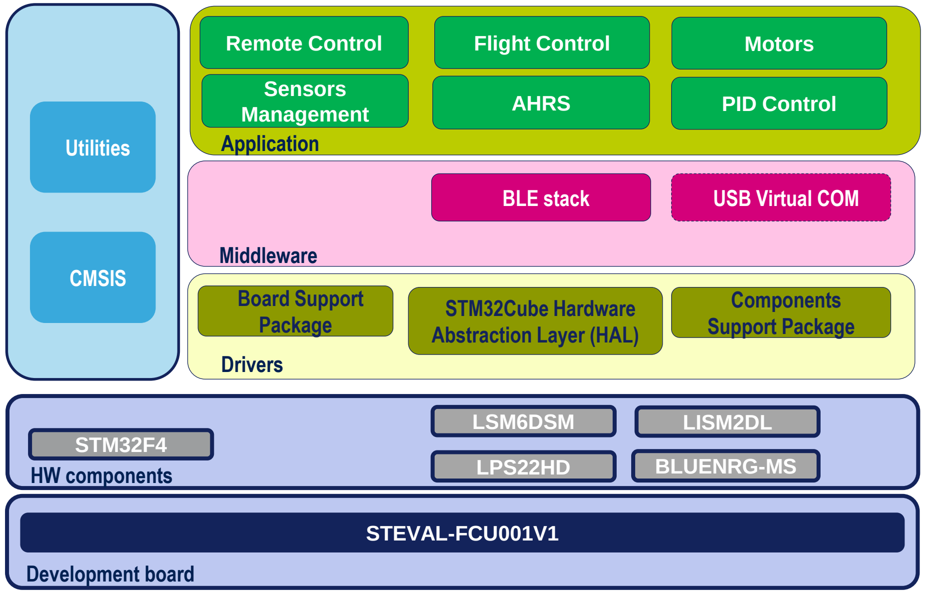
https://github.com/STMicroelectronics-CentralLabs/ST_Drone_FCU_F401

Warning: The source FW code is intended to be used for evaluation of the board, and must be used or modified by experts. The FW is not designed and tested for commercial use and for the mass production of commercial products.

FW Architecture

- The firmware is structured in different levels:
  - ***Application***: contains all the functions developed for the user to control the flight of the drone.
  - ***Middleware***: libraries to manage connectivity (USB and BLE).
  - ***Drivers***: the level nearest to the HW with all the functions managing the sensors and peripherals of the microcontroller.

- The *Utilities* and *CMSIS are functions directly related to the* STM32 architecture and corresponding Cortex-M4.



Module not yet implemented in current FW implementation.

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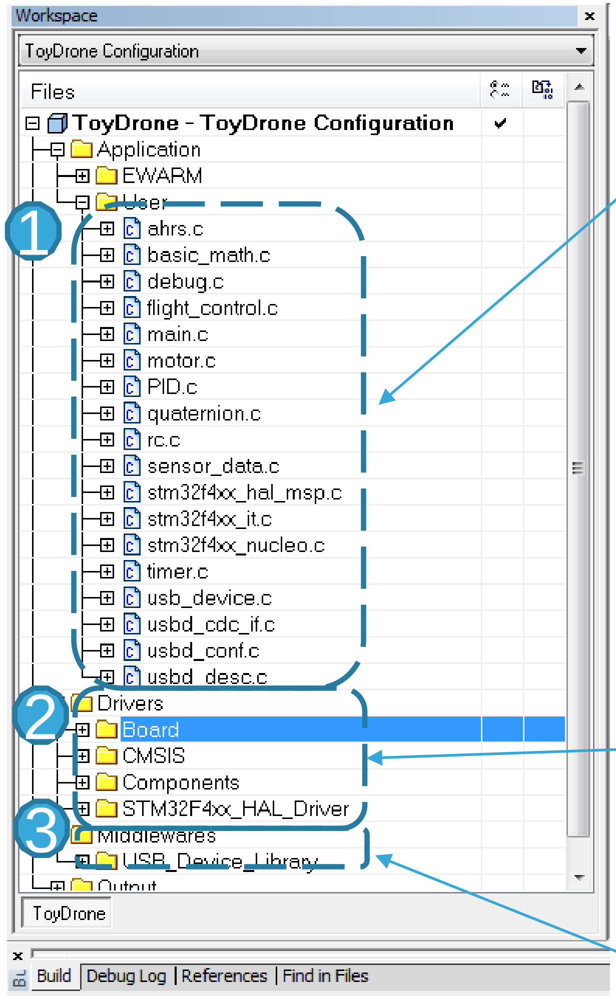
FW Project folder (1/2)

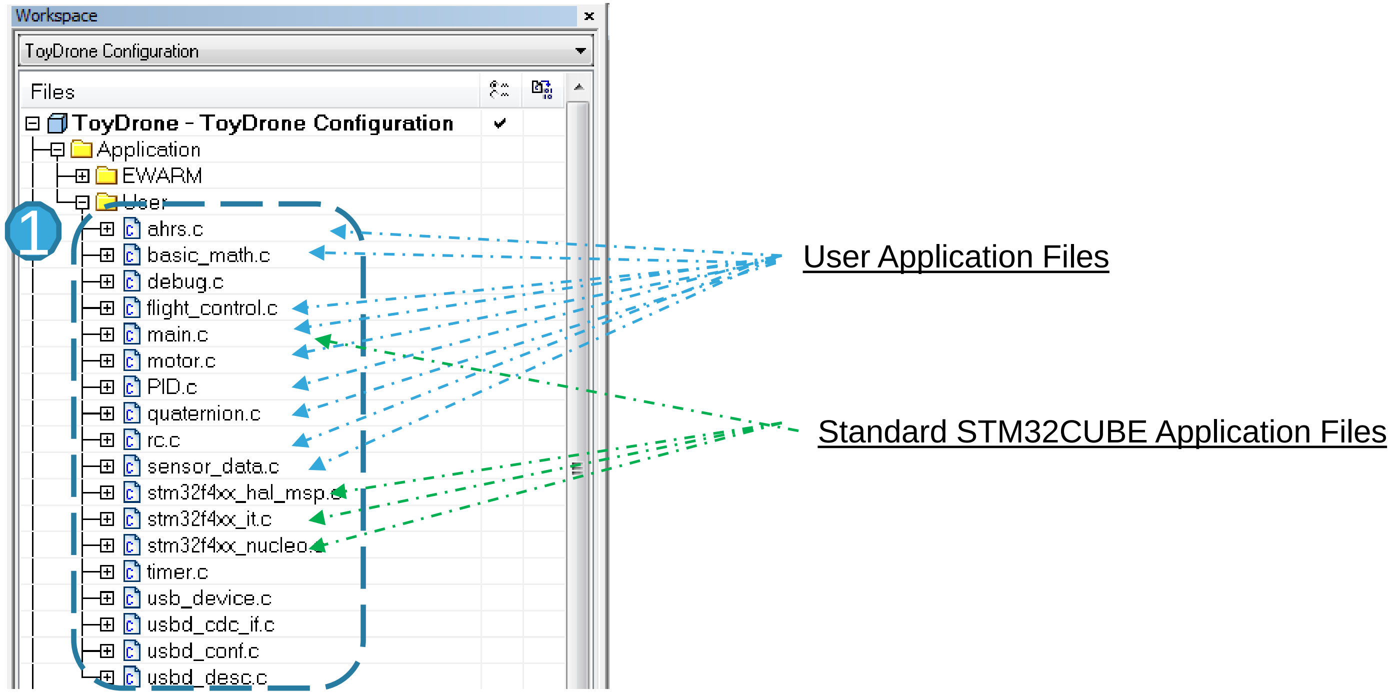


Main user application.
The main part of the FW project. The description of the FW implementation is focused on this section.

Device drivers and Board configuration

Middleware USB library. Not used at application level in this FW implementation.

FW Project folder (2/2)



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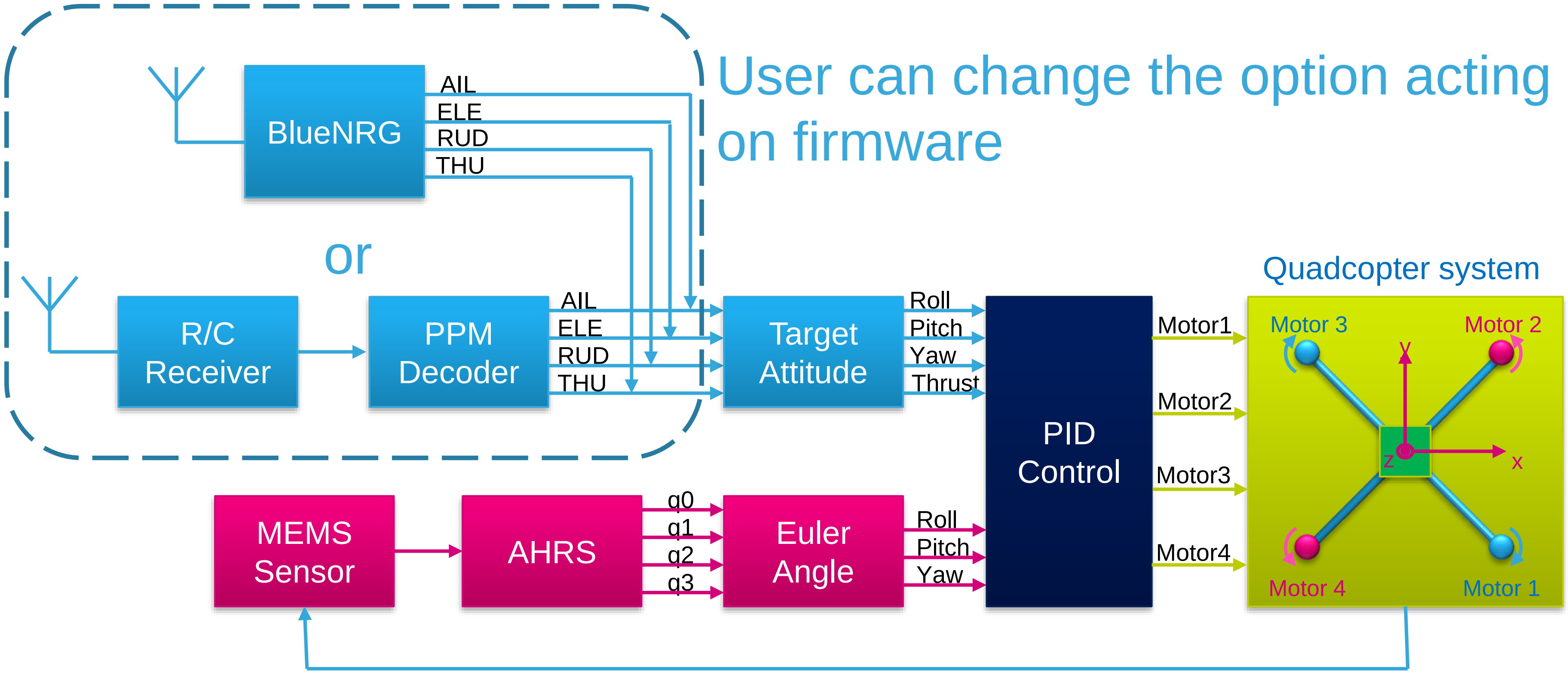
Overall FW block diagram

User can change the option acting on firmware



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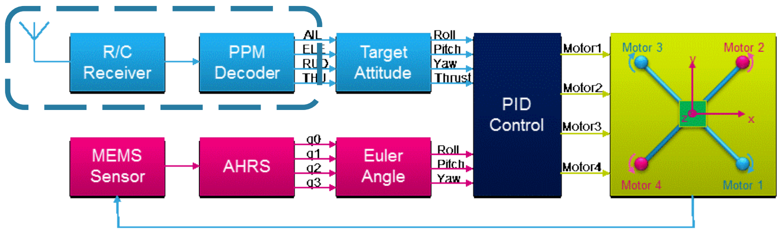
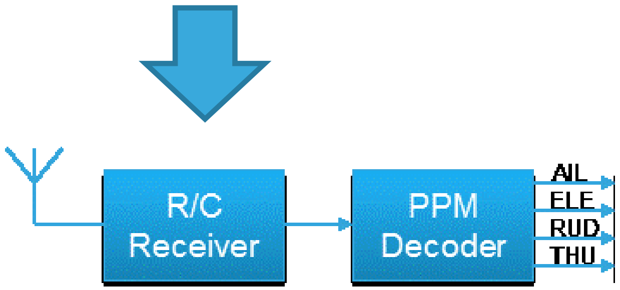
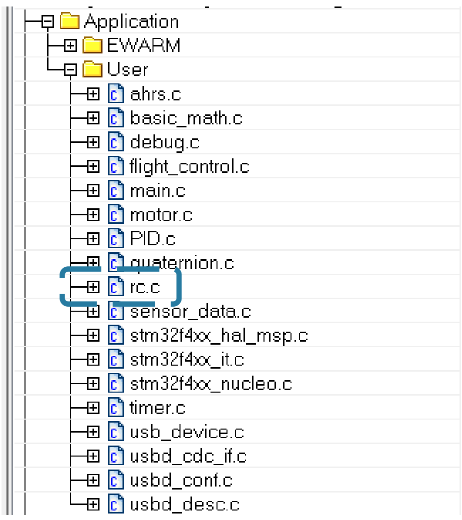
R/C receiver and PPM decoder







R/C Receiver and PPM decoder functions are implemented in *rc.c*. TIM2 (4 channels) input capture mode is used to calculate the pulse width of each PPM signal.
The pulse width is then decoded and the following R/C global variables are updated:

```
int16_t gAIL, gELE, gTHR, gRUD.
```

gAIL, gELE and gRUD are 0 centered (+/-0.5ms with 0.25us/LSB). gTHR is 0~1ms with 0.25us/LSB.

For details of TIM2 PPM decoding and data filtering, refer to the functions:

```
void HAL_TIM_IC_CaptureCallback(TIM_HandleTypeDef *htim)
void update_rc_data(int32_t idx)
```

Other variables that may be used to check remocon connection:

```
volatile int rc_timeout;
char rc_connection_flag;
```

>> R/C timeout counter
>> R/C connection status

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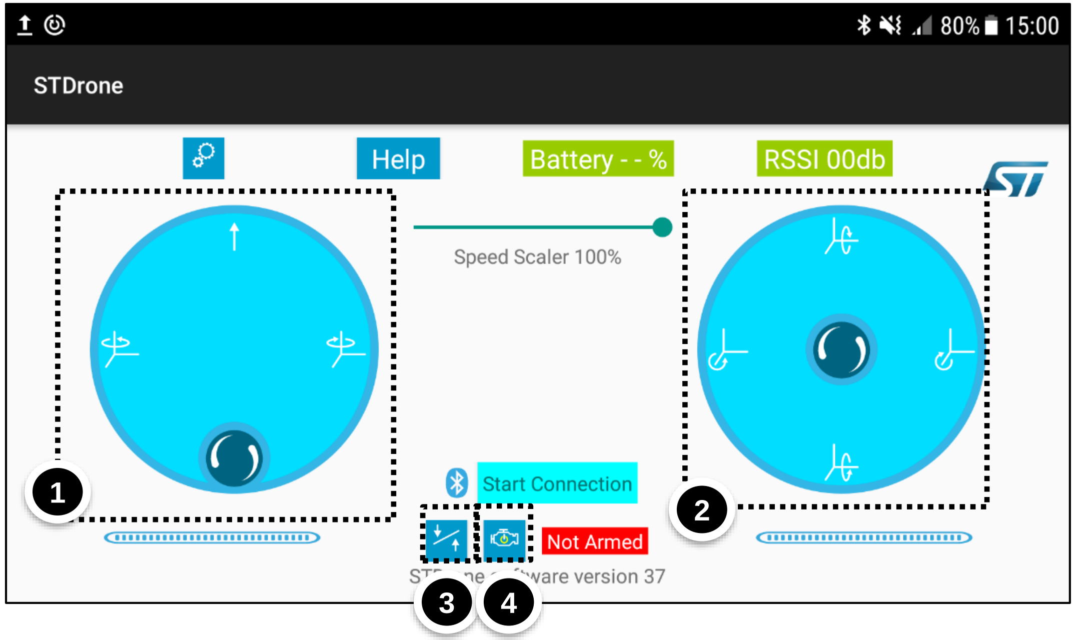
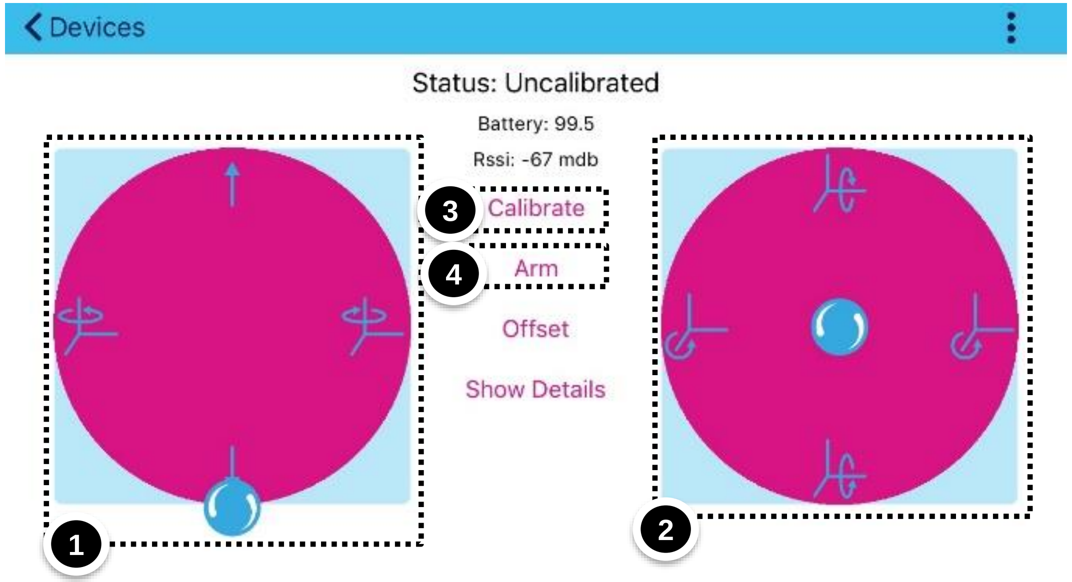
Smartphone Apps





1. Left joystick(THR, RUD)
2. Right joystick (ELE, AIL)
3. Calibrate button
4. ARM button

GET IT ON Google Play

https://play.google.com/store/apps/details?id=com.st.STDrone

Download on the App Store

https://apps.apple.com/it/app/st-ble-drone/id1471332188

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Bluetooth ST AppDrone

- When using BLE to control the drone, the difference is in the presence of the BLE stack to manage the communication, and in the absence of the PPM Decoder, since the values are given directly by the BLE module with the variables:

```
int16_t gAIL, gELE, gTHR, gRUD.
```

- To switch from the R/C to the BLE app configuration, simply change a `define` in the file «`rc.h`»:

```
//#define REMOCON_PWM // Remocon RX 4 channel PWM
#define REMOCON_BLE  // BLE Remocon App
```

Overview

Appendix A
ST Support and Community

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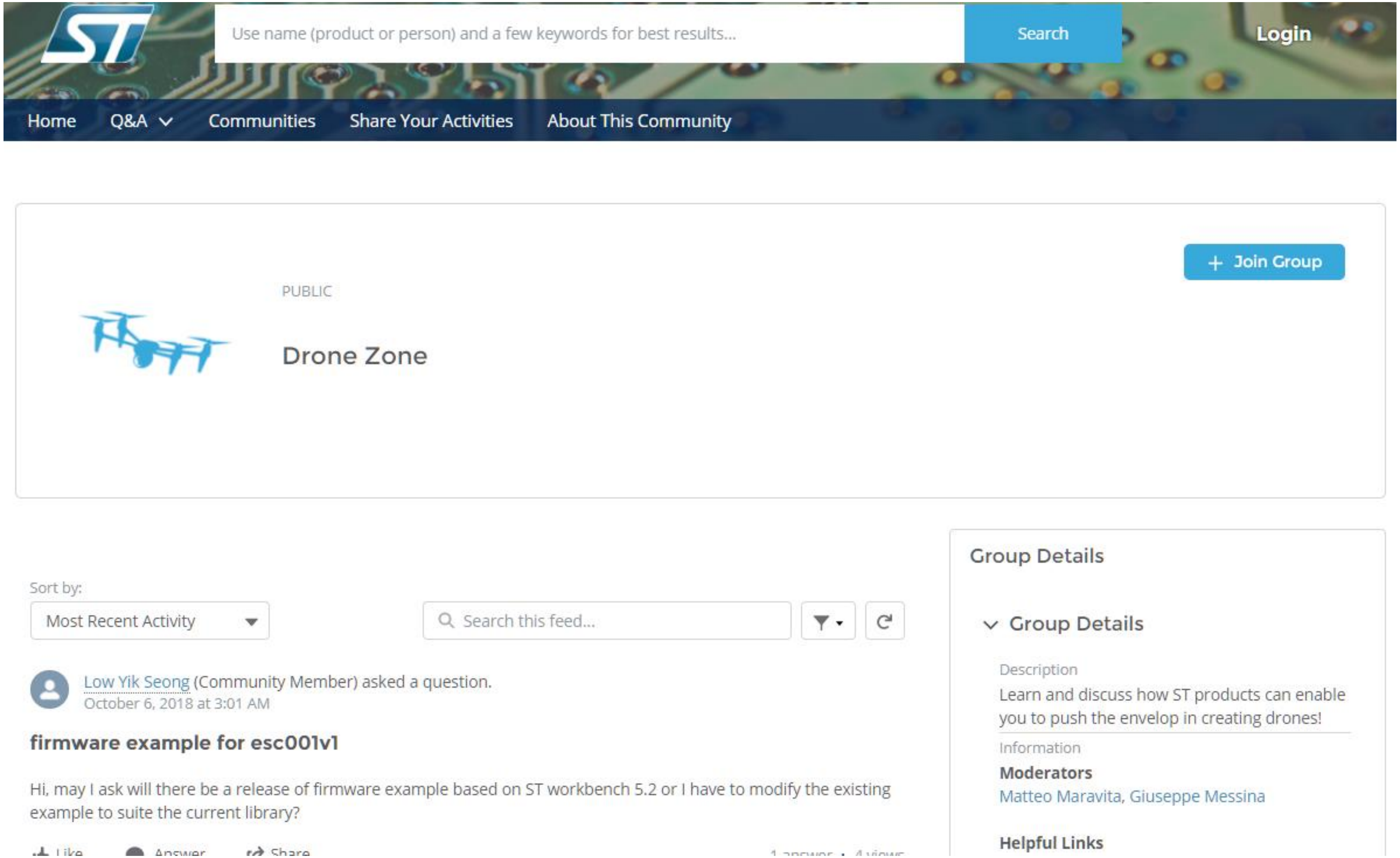
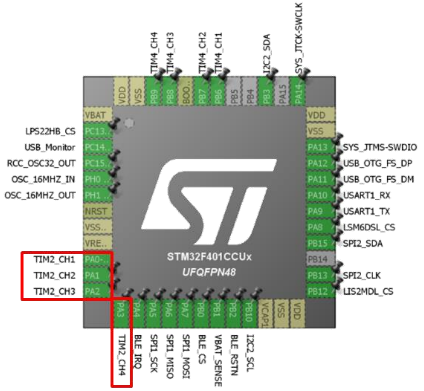


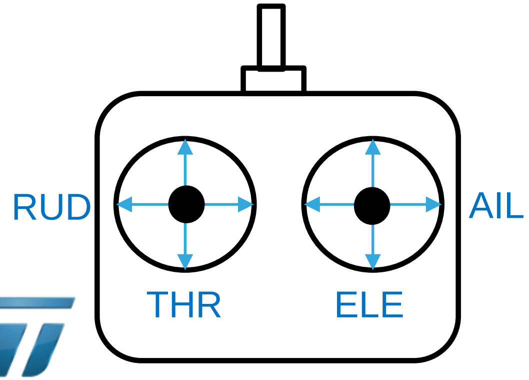
community.st.com/dronezone

Appendix B
Fine Tuning of the Firmware

R/C channels and R/C calibration



Channel	Control	GPIO
CH1	AIL	PA0
CH2	ELE	PA1
CH3	THR	PA2
CH4	RUD	PA3



The RC channels are mapped in the file *config_drone.h*, where it is also possible to define the timeout interval (if no signal from remocon motor OFF):

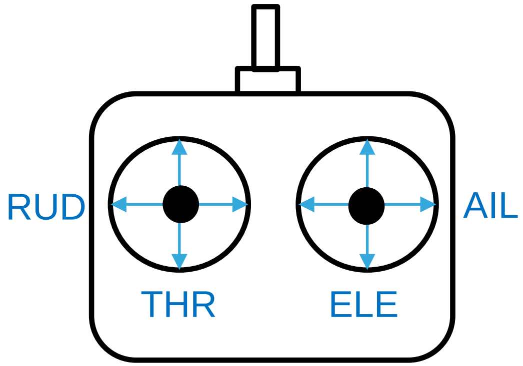
```
#define RC_TIMEOUT_VALUE    30
// Define the GPIO port for R/C input capture channels
#define RC_CHANNEL1_PORT    GPIOA
#define RC_CHANNEL1_PIN     GPIO_PIN_0
…
```

You can also calibrate the Remocon by fine tuning certain parameters (center and full scale positions, arming threshold) in *rc.h*:

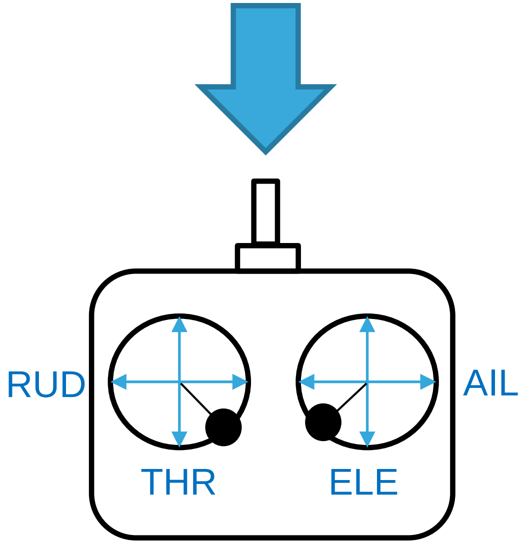
```
// Definition for AIL(Roll) Channel
#define AIL_LEFT     7661
#define AIL_MIDDLE   6044
#define AIL_RIGHT    4434
…

#define RC_FULLSCALE        1500
#define RC_CAL_THRESHOLD    1200
```

Sensor calibration procedure



“Standby”



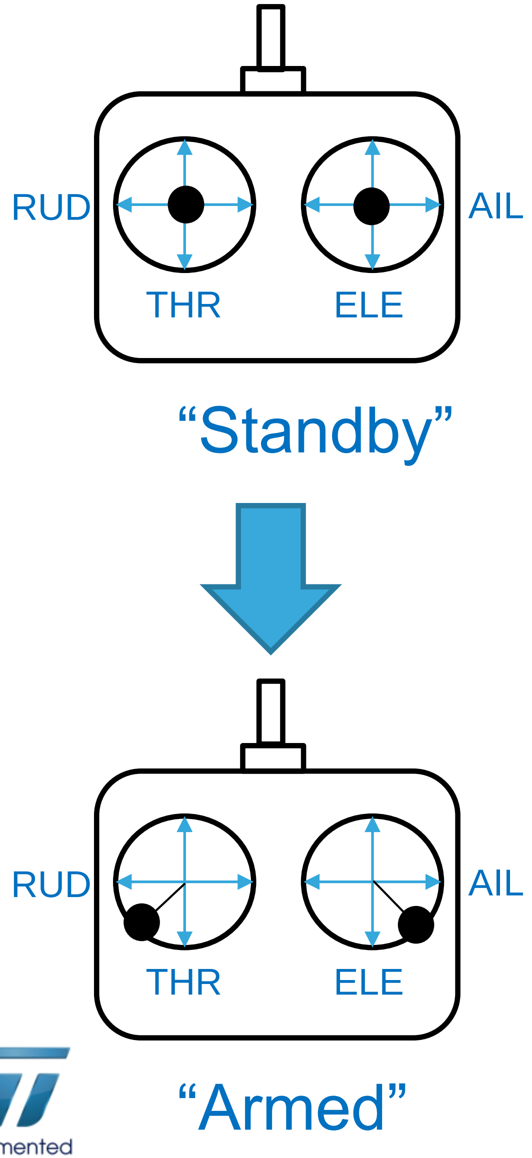
“Calibration”

If the battery is applied to the FCU (or reset button pushed) when the quadcopter is not on a flat surface (or the FCU not mounted flat on the frame), the AHRS Euler angle will have an offset. To eliminate it, run a simple calibration procedure through the remocon after startup.

Calibration procedure may be customized in the function *update_rc_data*:

```
if ( (gTHR == 0) && (gELE < -RC_CAL_THRESHOLD) && (gAIL > 
RC_CAL_THRESHOLD) && (gRUD < -RC_CAL_THRESHOLD))
  {
     rc_cal_flag = 1;
  }
```

Motor arming procedure



For safety reasons (in order to avoid any damage or injury when the quadcopter battery is inserted and remocon is switched ON), an *Arming* procedure is always implemented: motors are switched off until a certain sequence of commands on remocon is applied.

Arming procedure may be customized in the function *update_rc_data*:

```
if ( (gTHR == 0) && (gELE < - RC_CAL_THRESHOLD) && (gAIL < -
RC_CAL_THRESHOLD) && (gRUD > RC_CAL_THRESHOLD))
  {
    rc_enable_motor = 1;
    fly_ready = 1;
  }
```

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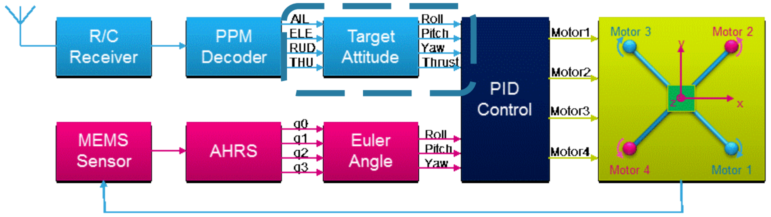
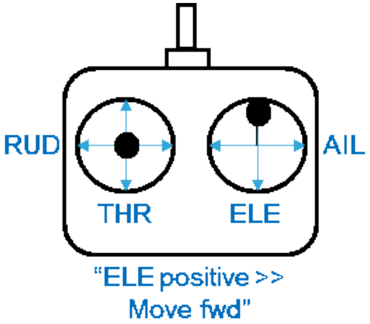
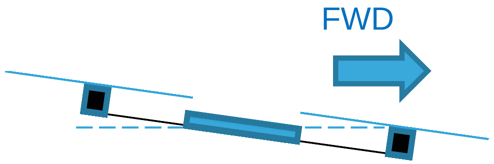
Target attitude







Conversion from Remocon Euler angle to AHRS Euler angle (needed for setting the target of the PID control loop) is implemented in the *rc.c* file in the function:

void GetTargetEulerAngle(EulerAngleTypeDef *euler_rc, EulerAngleTypeDef *euler_ahrs)

The data from the Remocon (i.e. `gELE`) is normalized to the full scale value and converted in angle:

```
 t1 = gELE;
    if (t1 > RC_FULLSCALE)
        t1 = RC_FULLSCALE;
    else if (t1 < -RC_FULLSCALE)
        t1 = - RC_FULLSCALE;
euler_rc->thx = -t1 * max_pitch_rad / RC_FULLSCALE;
const float max_pitch_rad = I*PITCH_MAX_DEG/180.0;
```

The change of sign (`-t1`) is related to the fact than increasing ELE (plus compared to Mid level) to move forward, corresponds to a negative target angle for pitch.

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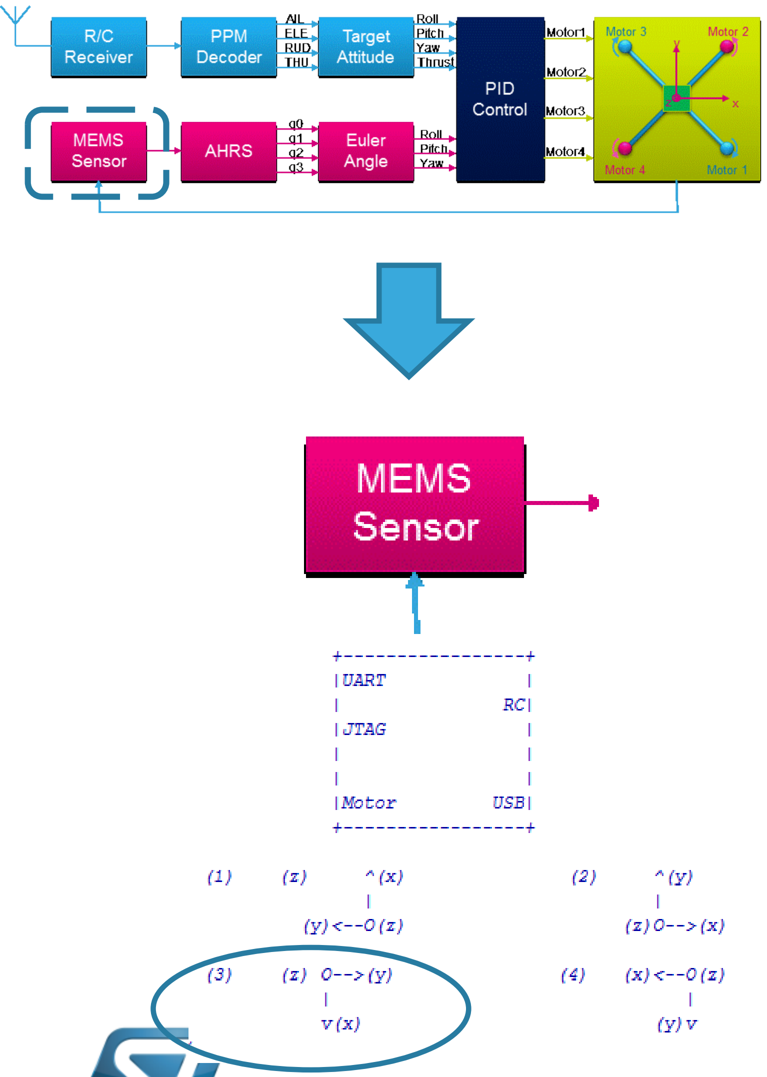
MEMS sensor



The main sensors used for flight stabilization are the accelerometer and gyroscope (LSM6DSL device). Sensor drivers are implemented in the function *lsm6dsl.c*.

In the FW project there are also drivers for magnetometer and pressure sensors (*lis2mdl.c* and *lps22hb.c*), but they are not used in the current FW implementation.

Initialization of the sensors is performed in the following function in the *board.c* file:

```
IMU_6AXES_StatusTypeDef BSP_IMU_6AXES_Init(void)
```

RAW data from 6-axis acc+gyro sensors are then converted into [*mg]* and [*mdps]* units and translated to the coordinate system used (orientation of FCU board vs motor configuration) in *sensor_data.c*. Default Coordinate system that corresponds to configuration described in previous assembling description is #3.

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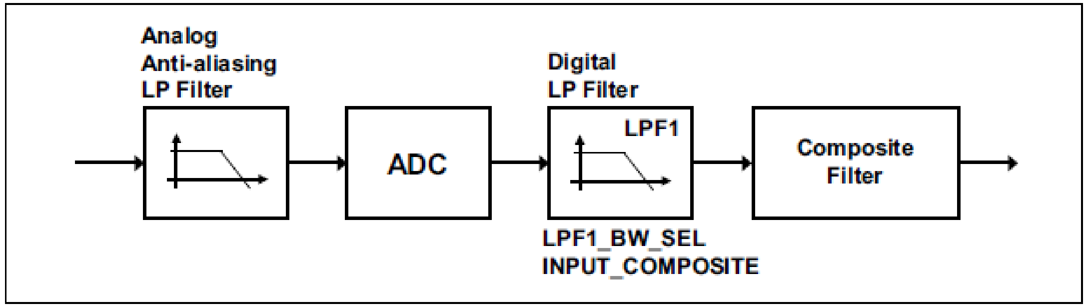
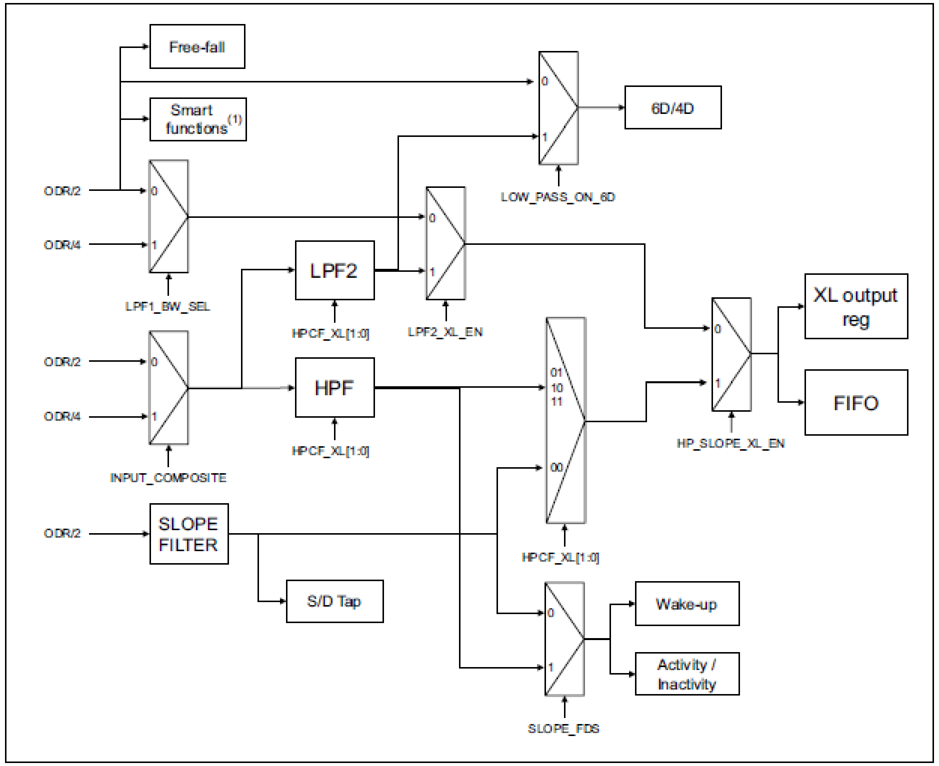
Accelerometer and gyroscope sensor setup





The Flight control algorithm is based on the data generated by accelerometer and gyroscope sensors. It is important to ensure that sensors are well tuned. It is especially important that RAW data coming from sensors are not impacted by mechanical noise generated by the vibration of the motors and propagated through the frame.

In the figure block diagram of the LSM6DSL accelerometer chain.

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Accelerometer sensor setup

Accelerometer key parameter settings:

- Accelerometer full-scale selection FS ***default ±2g >> set to ±4g***
- Analog Filter Bandwith ***default 1.5KHz >> keep default***
- Output data rate and power mode selection ODR ***default Power down mode >> set to 1.6kHz***
- Composite filter input selection ***default ODR/2 >> keep default***
- Accelerometer low-pass filter LPF2 selection ***default >> set to Low pass filter enabled @ ODR/50 or ODR/100 depending on mechanical vibration noise***

```
BSP_ACCELERO_Set_ODR_Value(LSM6DSL_X_0_handle, 1660.0);       /* ODR 1.6kHz */

BSP_ACCELERO_Set_FS(LSM6DSL_X_0_handle, FS_MID);                   /* FS 4g */

LSM6DSL_ACC_GYRO_W_InComposit(LSM6DSL_X_0_handle, LSM6DSL_ACC_GYRO_IN_ODR_DIV_2);   /* ODR/2 low pass filtered sent to composite filter */

LSM6DSL_ACC_GYRO_W_LowPassFiltSel_XL(LSM6DSL_X_0_handle, LSM6DSL_ACC_GYRO_LPF2_XL_ENABLE); /* Enable LPF2 filter in composite filter block */

LSM6DSL_ACC_GYRO_W_HPCF_XL(LSM6DSL_X_0_handle, LSM6DSL_ACC_GYRO_HPCF_XL_DIV100); /* Low pass filter @ ODR/100 */

uint8_t tmp_6axis_reg_value;

BSP_ACCELERO_Read_Reg(LSM6DSL_X_0_handle, 0x10, &tmp_6axis_reg_value);

tmp_6axis_reg_value = tmp_6axis_reg_value & 0xFE;  /* Set LSB to 0 >> Analog filter 1500Hz*/

BSP_ACCELERO_Write_Reg(LSM6DSL_X_0_handle, 0x10, tmp_6axis_reg_value);
```

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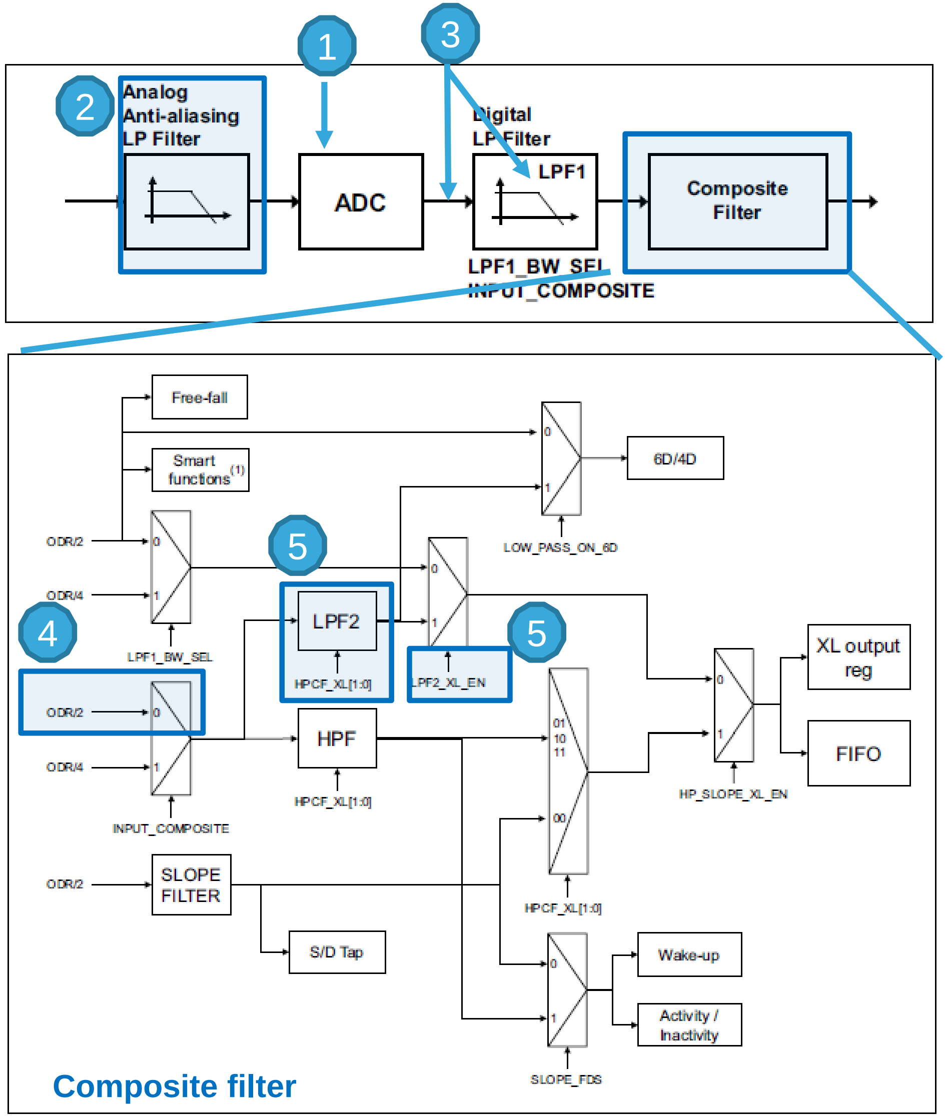
Accelerometer sensor setup



1. Full-scale selection FS ***±4g***
2. Analog Filter Bandwith ***1.5KHz***
3. Output data rate ODR ***1.6kHz***
4. Composite filter input selection ***ODR/2***
5. Low-pass filter LPF2 selection ***enabled @ ODR/50 or ODR/100***

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Gyroscope sensor setup

- Gyroscope key parameter settings:
  - Gyroscope Full Scale selection ***default 245 dps >> set to 2000dps***
  - Gyroscope output data rate selection ODR ***default power down >> set to 104Hz***
  - Gyroscope's low-pass filter bandwidth selection LPF1 FTYPE ***>> set to Narrow (10b)***

```
BSP_GYRO_Set_FS(LSM6DSL_G_0_handle, FS_HIGH);  /* Set FS to 2000dps */

BSP_GYRO_Set_ODR(LSM6DSL_G_0_handle, ODR_HIGH);  /* Set ODR to 104Hz */

LSM6DSL_ACC_GYRO_W_LP_BW_G(LSM6DSL_G_0_handle,
LSM6DSL_ACC_GYRO_LP_G_NARROW); /* LPF1 FTYPE set to 10b */
```

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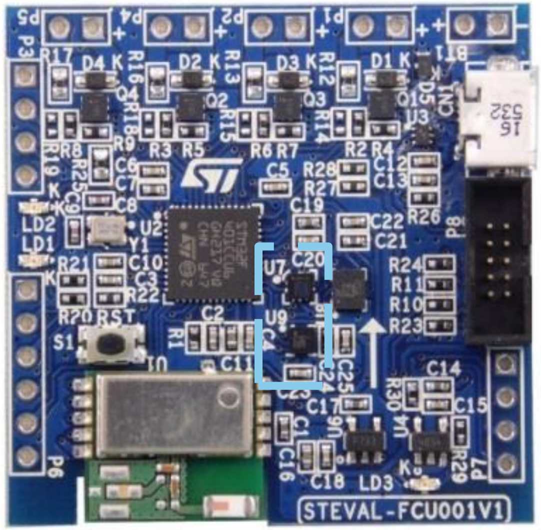
Use of Pressure sensor and Magnetometer



To use the Pressure sensor (for altitude estimation) and Magnetometer (for Compass), it is necessary to enable the sensors in the *config_drone.h*.

```
// Use magnetic sensor or not 1 = use
#define USE_MAG_SENSOR      0
// Use presure sensor or not 1 = use
#define USE_PRESSURE_SENSOR  0
```

The data from sensors are updated at the rate of 800Hz (using Timer9 interrupt):

```
ReadSensorRawData(&acc, &gyro, &mag, &pre);
```

So if it’s needed for example to display the data on UART with a printf for debugging purpose:

```
PRINTF("Pressure [atm] = %f\n\n",pre);
PRINTF("Magnetometer X = %d\tY = %d\tZ = %d\n\n", mag.AXIS_X, mag.AXIS_Y, mag.AXIS_Z);
```

Note Pressure data are expressed in *atmospheres*, while magnetometer data in *degrees* (from north magnetic pole).

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Sensor calibration after startup (1/2)

After inserting the battery, it is important to put the quadcopter on a flat surface and press the reset button. In fact, just after the reset, if the quadcopter has a certain inclination, there will be an offset in the *euler_ahrs* coordinates.

This happens because an automatic sensor calibration is performed immediately following startup.

Expression	Value	Location
pre	1.03042163E+3	0x20000B38
p_id	Error (col 1): Un...	
mag	<struct>	0x200009F8
VBAT_Sen...	Error (col 1): Un...	
VBAT	Error (col 1): Un...	
gELE	-1	0x20000B54
gAIL	-422	0x20000B52
gRUD	199	0x20000B58
gTHR	0	0x20000B56
motor_pwm	<struct>	0x2000097C
motor1_p...	0.0	0x2000097C
motor2_p...	0.0	0x20000980
motor3_p...	0.0	0x20000984
motor4_p...	0.0	0x20000988
euler_ahrs	<struct>	0x200009C8
thx	4.57809686E-1	0x200009C8
thy	-1.09683387E-2	0x200009CC
thz	0.0	0x200009D0
ahrs	<struct>	0x2000094C
pid	<struct>	0x20000498

WRONG

Inclined position at startup >> euler_ahrs.thx = 0.457 * 53 = 24.2 deg

Expression	Value	Location
pre	1.03048217E+3	0x20000B38
p_id	Error (col 1): Un...	
mag	<struct>	0x200009F8
VBAT_Sen...	Error (col 1): Un...	
VBAT	Error (col 1): Un...	
gELE	0	0x20000B54
gAIL	-422	0x20000B52
gRUD	199	0x20000B58
gTHR	0	0x20000B56
motor_pwm	<struct>	0x2000097C
motor1_p...	0.0	0x2000097C
motor2_p...	0.0	0x20000980
motor3_p...	0.0	0x20000984
motor4_p...	0.0	0x20000988
euler_ahrs	<struct>	0x200009C8
thx	-7.1783561722E-4	0x200009C8
thy	-6.69909815E-4	0x200009CC
thz	0.0	0x200009D0
ahrs	<struct>	0x2000094C
pid	<struct>	0x20000498

CORRECT

Flat position at startup >> euler_ahrs.thx = -0.0371 * 53 = -1.96 deg

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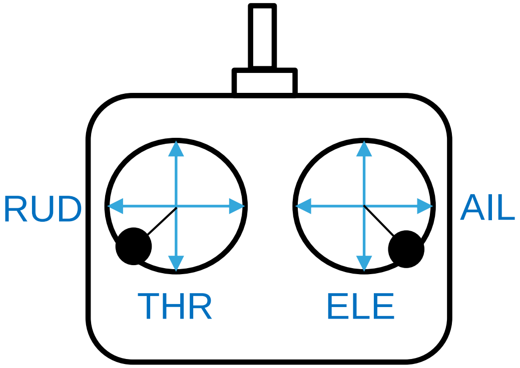
Sensor calibration after startup (2/2)


```
if(sensor_init_cali == 0)
  {
    sensor_init_cali_count++;
    if(sensor_init_cali_count > 800)
    {
      // Read sensor data and prepare for specific coodinate system
      ReadSensorRawData(&acc, &gyro, &mag, &pre);
      acc_off_calc.AXIS_X += acc.AXIS_X;
      acc_off_calc.AXIS_Y += acc.AXIS_Y;
      acc_off_calc.AXIS_Z += acc.AXIS_Z;
      gyro_off_calc.AXIS_X += gyro.AXIS_X;
      gyro_off_calc.AXIS_Y += gyro.AXIS_Y;
      gyro_off_calc.AXIS_Z += gyro.AXIS_Z;
      if (sensor_init_cali_count >= 1600)
      {
        acc_offset.AXIS_X = acc_off_calc.AXIS_X * 0.00125;
        acc_offset.AXIS_Y = acc_off_calc.AXIS_Y * 0.00125;
        ...
        sensor_init_cali_count = 0;
        sensor_init_cali = 1;
      }
    }
```



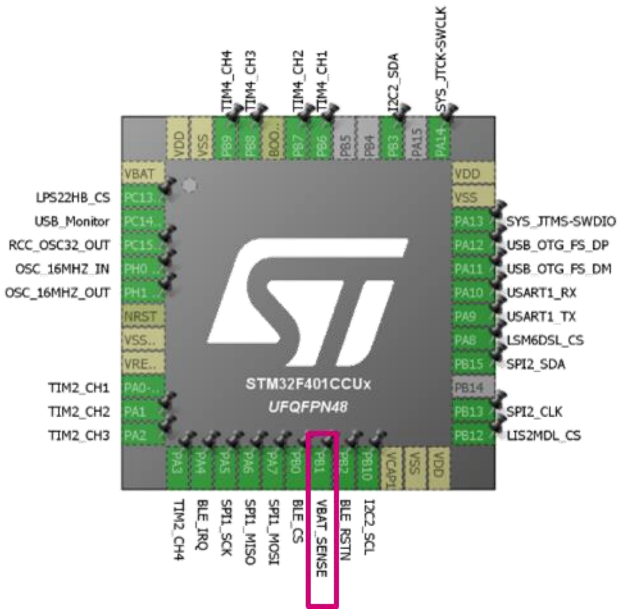
“Sensor calibration”

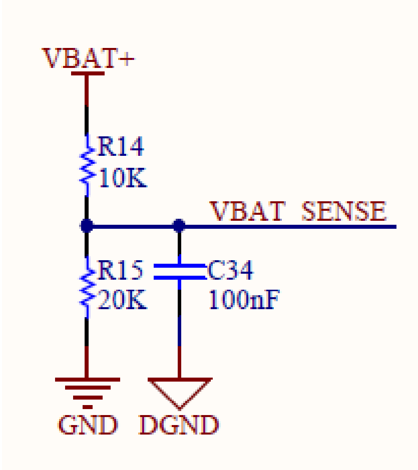
Looking into detail, in the *HAL_TIM_PeriodElapsedCallback* function, both the accelerometer and gyroscope are calibrated:

1. When the *sensor_init_cali* variable is 0, just after the system startup (battery inserted or reset button pushed).
2. When the *rc_cal_flag* variable is 1, manual calibration launched before the motors are armed if the sticks are in a certain position (check *update_rc_data* function in *rc.c* file):

```
if ( (gTHR == 0) && (gELE < - RC_CAL_THRESHOLD) &&
        (gAIL > RC_CAL_THRESHOLD) && (gRUD < -
        RC_CAL_THRESHOLD)) {
            rc_cal_flag = 1;
          }
```

Battery voltage monitoring





It is sometimes important to monitor the level of the battery for telemetry purposes, or to trigger certain actions (stop the motor, sound alarm, …).

For this reason, the ADC1 channel 9 (PB1) is connected to Vbat through a resistor partition. For debug purposes, a simple code fragment is inserted in the *main.c* to perform a single ADC reading(*) and send the data converted to UART:

```
HAL_ADC_Start(&hadc1);
if (HAL_ADC_PollForConversion(&hadc1, 1000000) == HAL_OK)
   {
        VBAT_Sense = HAL_ADC_GetValue(&hadc1);
        VBAT = (((VBAT_Sense*3.3)/4095)*(BAT_RUP+BAT_RDW))/BAT_RDW;
            PRINTF("Battery voltage = %fV\r", VBAT);
   }
   HAL_ADC_Stop(&hadc1);
```

(*) It may eventually be possible to use the ADC with direct conversion to DMA, without launching the ADC conversion each time.

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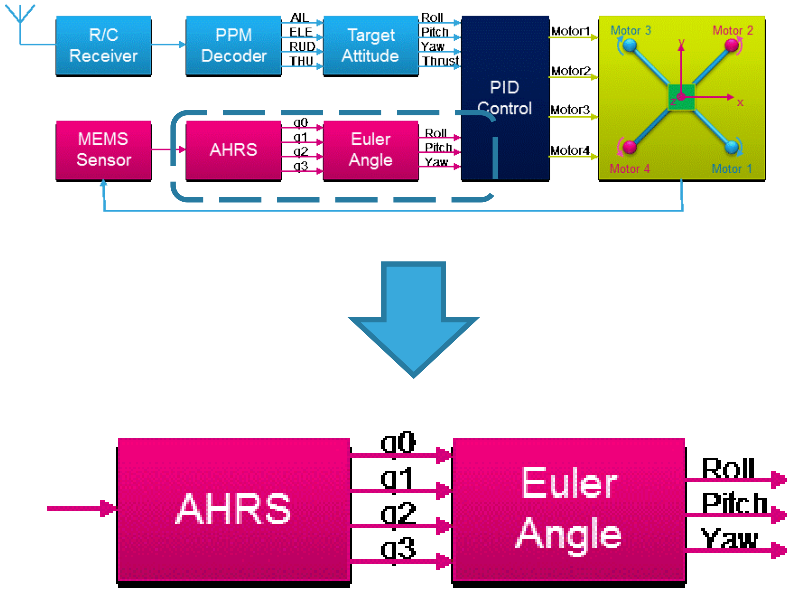
Attitude Heading Reference System



The RAW data from the Accelerometer and Gyroscope are passed to the AHRS algorithm:

```
ahrs_fusion_ag(&acc_ahrs, &gyro_ahrs, &ahrs);
```

function present in the *ahrs.c.*

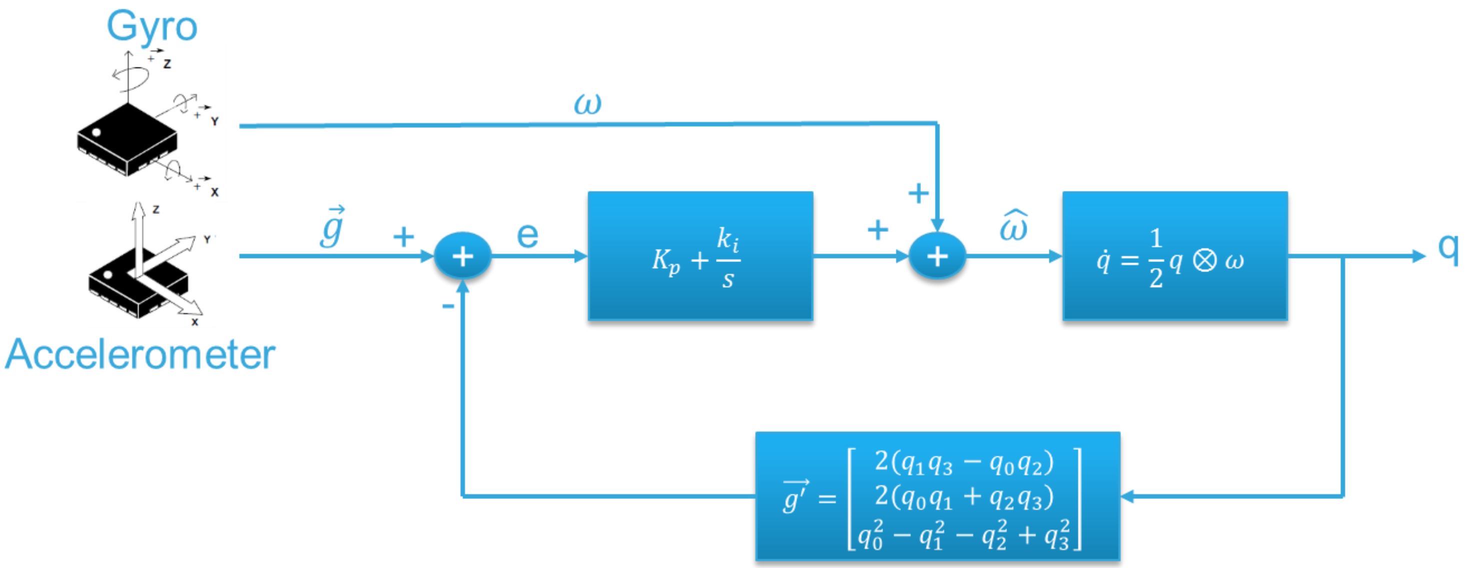
In order to perform the stabilization algorithm for the drone, data from AHRS quaternion must be translated to Euler angle:

```
QuaternionToEuler(&ahrs.q, &euler_ahrs);
```

function present in *quaternion.c*

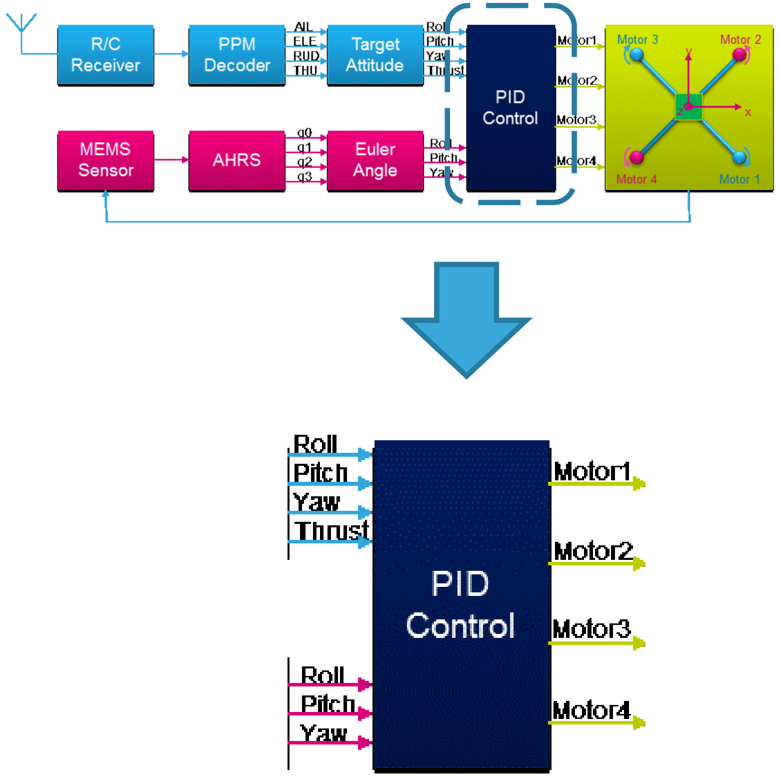
Attitude & Heading Reference System (AHRS) is the key algorithm for a UAV system. The algorithm chosen for the current FW of STEVAL_DRONE01 board is the "Complementary filter".

AHRS - Complementary Filter



- Accelerometer and gyroscope can calculate the attitude independently.
- Accelerometer is always influenced by high-frequency noise, and gyroscope has a low-frequency offset.
- Gyroscope results are accurate in short-term, but will generate an offset over time. Acc is not accurate in short-term because of noise, but is reliable over time.
- Based on Mahoney. Use the gyroscope to get the attitude, use the acc to calibrate the attitude (the accel. Measurement of gravity is used to estimate the gyro drift on pitch and roll).

Flight PID Control



The stabilization algorithm is performed with PID control. Target for the PID is given by the Euler angle imposed by the Remocon, which is compared to the Euler angle of the actual drone position.

```
FlightControlPID_OuterLoop(&euler_rc_fil, &euler_ahrs, &ahrs, &pid);
```

function present in *flight_control.c*.

The output of the PID is the value of the 4 motors’s speed (PWM HW signal for ESC or Mosfet driving) for the quadcopter:

```
motor_pwm->motor1_pwm = motor_thr - pid->x_s2 - pid->y_s2 + pid->z_s2 + MOTOR_OFF1;
  motor_pwm->motor2_pwm = motor_thr + pid->x_s2 - pid->y_s2 - pid->z_s2 + MOTOR_OFF2;
  motor_pwm->motor3_pwm = motor_thr + pid->x_s2 + pid->y_s2 + pid->z_s2 + MOTOR_OFF3;
  motor_pwm->motor4_pwm = motor_thr - pid->x_s2 + pid->y_s2 - pid->z_s2 + MOTOR_OFF4;
```

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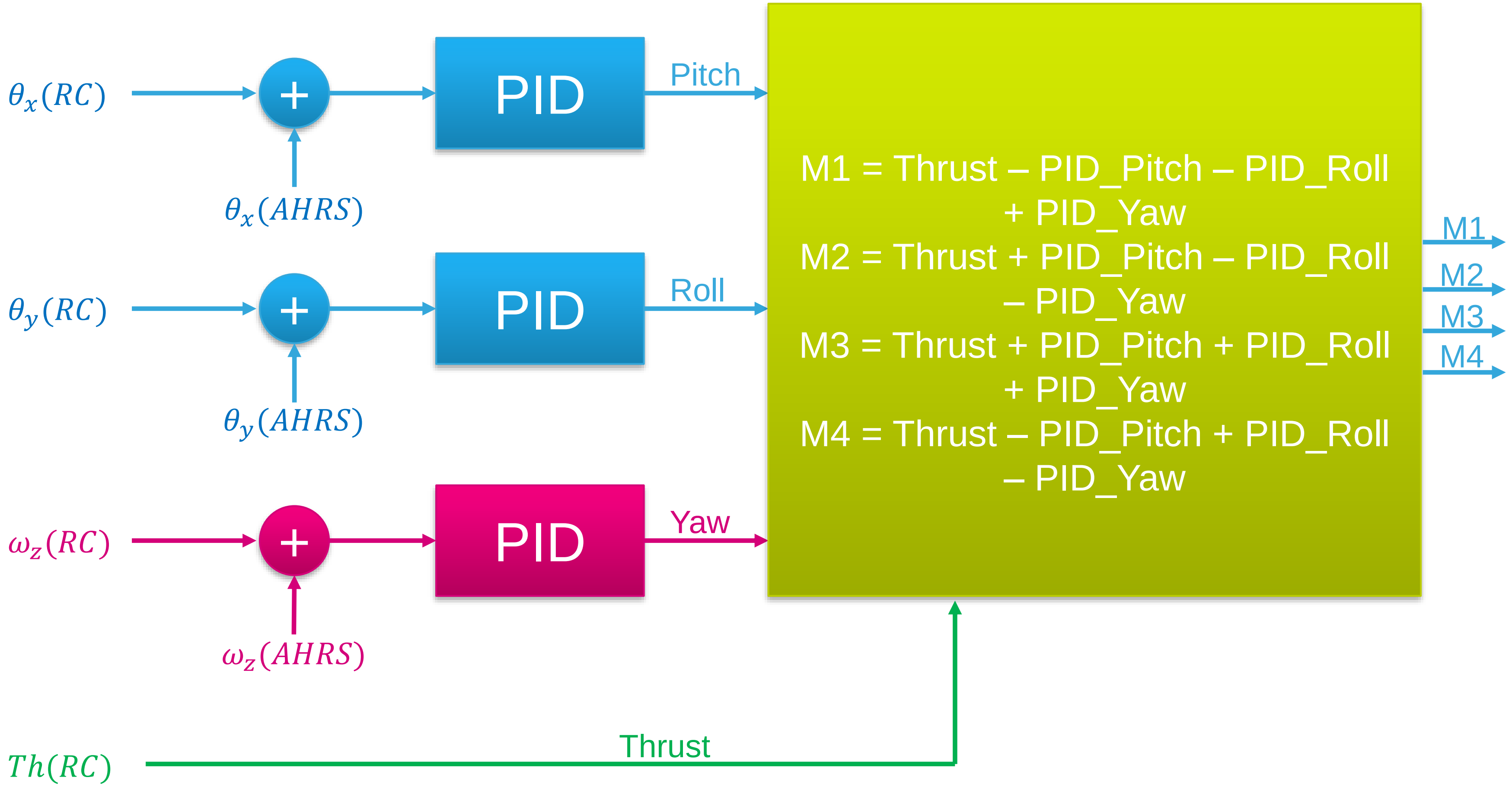
Flight PID Control



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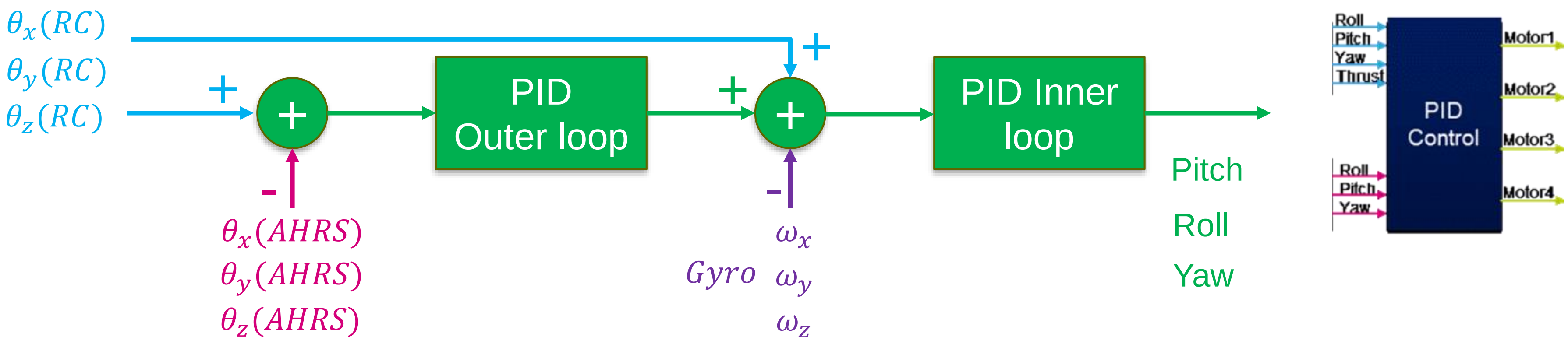
Flight PID Control



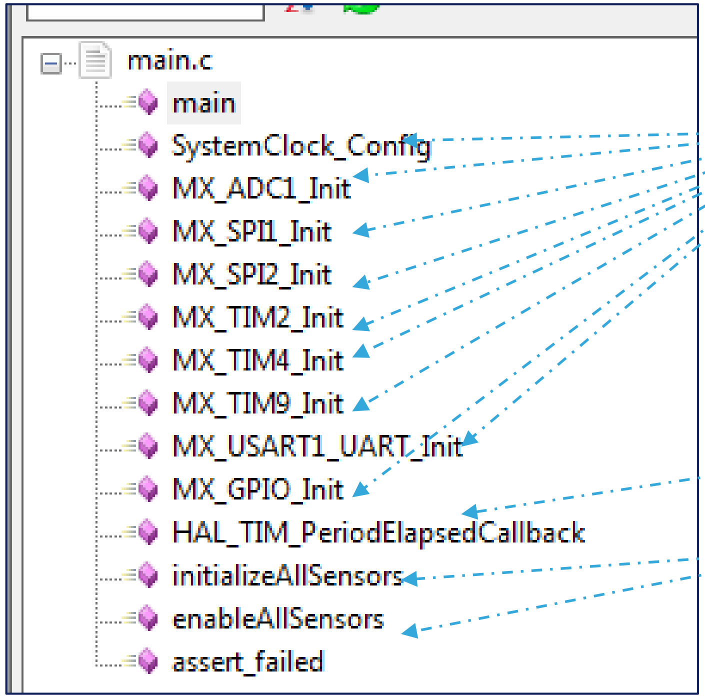
PID control is performed in two separate stages:

- *PID Outer loop*: comparing the target Euler angles given by Remocon and the Euler angles of the AHRS system, it controls the incline angle
- *PID Inner loop*: used to track the angular rate.

Using a mathematical model of the drone system, it is almost impossible to make the system stable in a single loop. The inner loop has to be added to the outer loop in order to stabilize the system. The relative functions are present in *flight_control.c*:

```
void FlightControlPID_OuterLoop(EulerAngleTypeDef *euler_rc, EulerAngleTypeDef *euler_ahrs, AHRS_State_TypeDef *ahrs,
P_PI_PIDControlTypeDef *pid);
void FlightControlPID_innerLoop(EulerAngleTypeDef *euler_rc, Gyro_Rad *gyro_rad, AHRS_State_TypeDef *ahrs,
P_PI_PIDControlTypeDef *pid, MotorControlTypeDef *motor_pwm);
```

FW Project Main Folder



Initialization of GPIO, SPI, UART, Timers, ADC, Clock

Sensors calibration after start up

Initialization and enabling of sensors

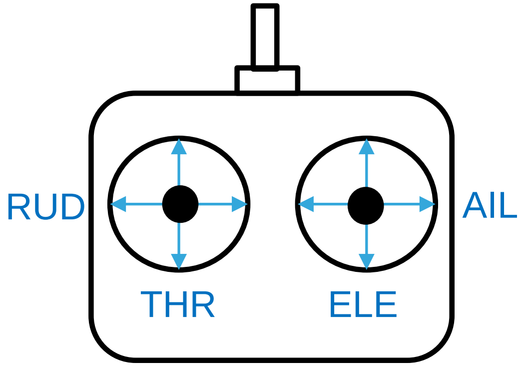
STEVAL-FCU001V1 FW

Flow Diagram from Code...

```
 /* USER CODE BEGIN 1 */
MCU Configuration
/* Reset of all peripherals, Initializes the Flash interface and the Systick. */
/* Configure the system clock */
 /* Initialize all configured peripherals */
//  Initialize Onboard LED
 /* Configure and disable all the Chip Select pins for sensors on SPI*/
/* Initialize and Enable the available sensors on SPI*/
/* Initialize settings for 6-axis MEMS Accelerometer */
 /* Initialize settings for 6-axis MEMS Gyroscope */
 /* Initialize settings for Magnetometer settings (By default after reset is in in
idle mode) */
 /* Initialize Remote control*/
 /* Initialize TIM2 for External Remocon RF receiver PWM Input*/
 /* Initialize TIM4 for Motors PWM Output*/
 /* Initialize General purpose TIM9 50Hz*/
 /* Initialize PID and set Motor PWM to zero */
 /* Setup a timer with 5ms interval */

Infinite loop
// AHRS update, quaternion & true gyro data are stored in ahrs
 // Calculate euler angle drone
 // Get target euler angle from remote control
FlightControlPID_OuterLoop
```

R/C calibration (1/2)



After connecting a new Remocon receiver to the FCU, one of the first operations to perform is to check if the channels are connected correctly and then calibrate the offset for each channel.

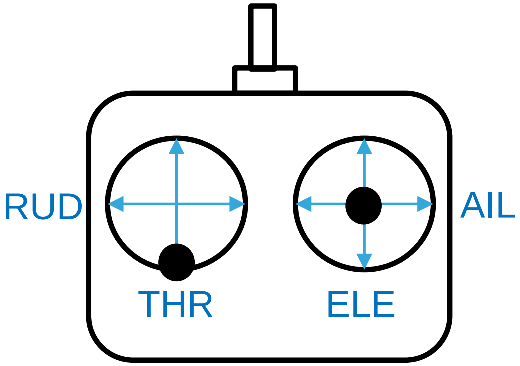
Channel	Control	GPIO
CH1	AIL	PA0
CH2	ELE	PA1
CH3	THR	PA2
CH4	RUD	PA3

1) ***Remocon TX and RX binding***: at first it is better to ensure that the TX and RX *binding* operation is successful, otherwise no signals will be generated by RX receiver to the FCU. For this operation, please refer to the remocon manufacturer instructions.
2) ***Channels connection***: after connecting the RX receiver to the FCU, you must verify that the channel connections: by moving the joysticks, verify that the THR, RUD, … are in line with the variables gAIL, gELE, gTHR, gRUD (in *rc.c*). In case of incorrect connections, it is possible to modify the HW connection or by SW(*) in the function:

```
void update_rc_data(int32_t idx)
```

(*) Some remoconds also allow you to set the channel assignments.

R/C calibration (2/2)

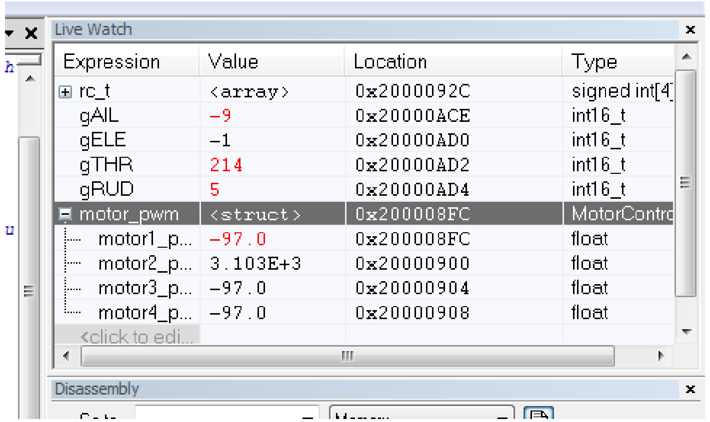


3) ***Channels offset calibration***: it is necessary to adjust the offset for each channel(*).
   a. Position the left joystick to the center-bottom
   b. Position the right joystick in the center
   c. Take note of the values of the variables gAIL, gELE, gTHR, gRUD (in *rc.c*). If the remocon is calibrated correctly, each value should be *close to zero*.
   d. If values are not close to zero, adjust the offset by modifying the value of the following constants in *rc.h*:

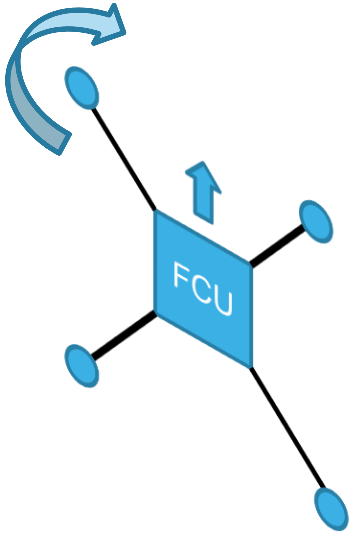
```
#define AIL_MIDDLE  6269
#define ELE_MIDDLE  6051
#define RUD_MIDDLE  5949
#define THR_BOTTOM  4437
```

(*) This operation is usually done by the PC GUI of commercial FCU available in the market.

Motor connection check



Wrong connection situation.



It is easy to connect the motors to the FCU incorrectly (correct configuration described in "*Step2 – DC motor connection*" section).

This can be verified by increasing the Throttle value (just enough to spin the motor but not to lift the quadcopter), and forcing an inclination. The figure shows what happens when there is a *wrong* connection: the motor in lower position is stopped while the one in higher position is spinning >> it should be opposite to stabilize the drone.

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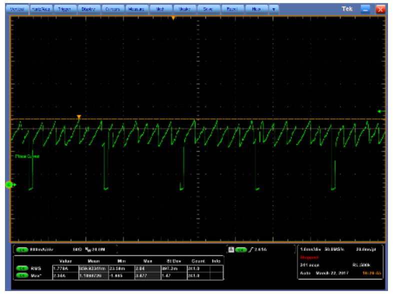
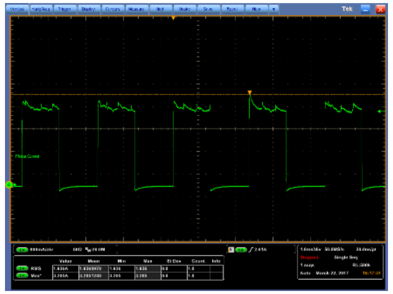
DC motor configuration – MOS Current



DC motor current Full Throttle (Rg = 1Kohm)



DC motor current Full Throttle (Rg = 0ohm)

It may be necessary to perform a small adjustment to the gate resistor to MOSFET according to the DC motor used.

If Rg is too large, the MOSFET may not switch on properly and available current for DC motor may be sufficient to lift the quadcopter.

At the same time, the current capability to switch on the MOS is linked to the STM32 GPIO current capability.

Note that the current needed may vary with the DC motor used, size of propeller and overall weight of the drone. For a small minidrone frame, a default Rg of 100 ohm is the preferred all-round value.

Stabilization PID tuning


```
#define ROLL_PID_KP1       3
#define ROLL_PID_KI1       0
//#define ROLL_PID_KP2     800 /* default */
#define ROLL_PID_KP2       100 /* test minidrone */
//#define ROLL_PID_KI2     400 /* default */
#define ROLL_PID_KI2       100 /* test minidrone */
#define ROLL_PID_KD2       10
…

#define PITCH_PID_KP1      ROLL_PID_KP1
#define PITCH_PID_KI1      ROLL_PID_KI1
#define PITCH_PID_KP2      ROLL_PID_KP2
#define PITCH_PID_KI2      ROLL_PID_KI2
#define PITCH_PID_KD2      ROLL_PID_KD2
```

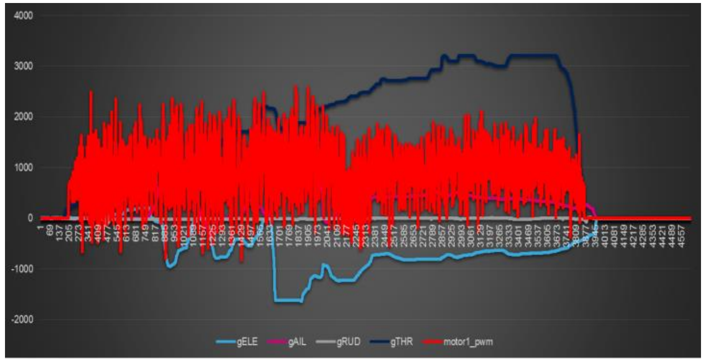
For every configuration of quadcopter frame/motor/FCU, it is necessary to fine tune the PID parameters (in *flight_control.h*) to find the best settings that allow the drone to fly with good stability and responsiveness.

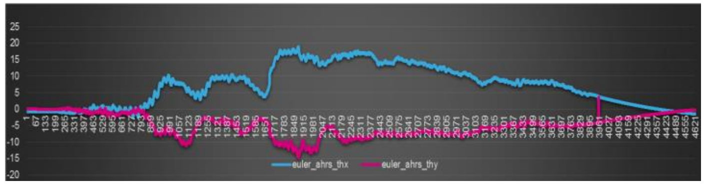
You must first check that the drone *hovers* (only Throttle command applied from Remocon) without any oscillations.

1. start with low value of KP (same value for x and y axis if quadcopter design is symmetrical and mechanically well balanced, as in most cases) and smaller value of KI.
2. Increase KP without experiencing oscillations.
3. Increase KI value without experiencing oscillations.
4. You should keep the same PID value for roll and pitch in most cases.

Note: In most of use cases (except racing drones in which very high response is needed) it is better to keep the KD value at zero to ensure good stability.

Datalog with UART



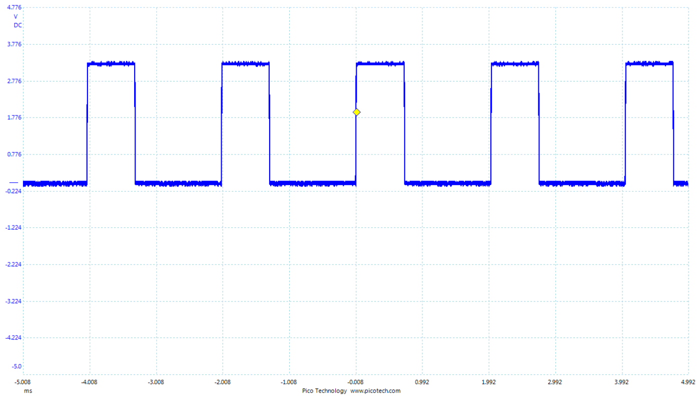


During test and debugging, could be useful to make a data log and plot of certain variables like Remocon input, MEMS raw data, Euler angle, Motor PWM, …

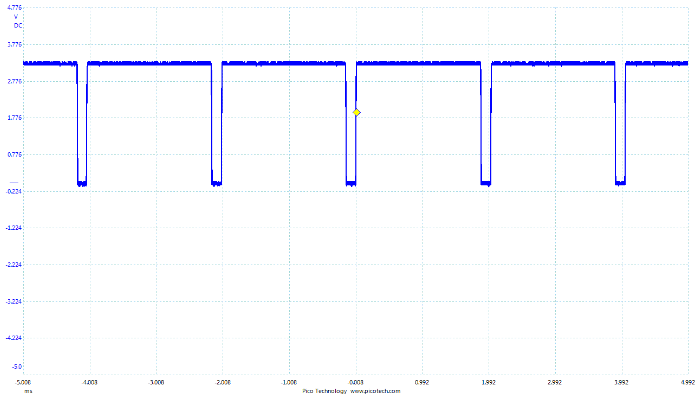
There are three way to do this:

1. Connect the board to a PC through an USB to UART converter (namely Virtual COM port). There is an UART on the board, see Step 5 in Assembly Section.
2. By using a `printf` within the code and using the console offered by IDE. Note: this could introduce a delay in the program flow impacting the performance (please refer to Timings in the Total Data Flow diagram).
3. Use the on-board BLE module, but the user should add a telemetry to the actual communication protocol.

External ESC FW fine tuning



Motor PWM on pin2 or P1, P2, P4, P5
(THR to minimum value)



Motor PWM on pin2 or P1, P2, P4, P5
(THR to maximum value)

With an external ESC, a few modifications may be necessary to ensure that the PWM output signal for each motor is compatible with ESC input signal.

Most ESCs accept an input signal with frequency varying from 50 to 400Hz, and the Ton time of the PWM is proportional to the motor speed. The *minimum Ton time* for which the ESC is *armed* (when not armed usually the ESC emits a particular alarm beep) must also be checked.
It may be necessary to adjust the following variables:

- MIN_THR (*flight_control.h*)
- MOTOR_MIN_PWM_VALUE (*motor.h*)
- MOTOR_MAX_PWM_VALUE (*motor.h*)
- htim4.Init.Prescaler (*main.c*)

Accelerometer sensor fine tuning – Low vibration frame

If the frame does not experience high vibration from the motors, it is also possible to use alternative settings for the MEMS accelerometer:

- Accelerometer full-scale selection FS ***default ±2g >> set to ±4g***
- Analog Filter Bandwidth ***default 1.5KHz >> set to 400Hz***
- Output data rate and power mode selection ODR ***default Power down mode >> set to 1.6kHz***
- Composite filter input selection ***default ODR/2 >> set to ODR/4***
- Accelerometer low-pass filter LPF2 selection ***default >> set to Low pass filter enabled @ ODR/50***

```
BSP_ACCELERO_Set_ODR_Value(LSM6DSL_X_0_handle, 1660.0);       /* ODR 1.6kHz */
BSP_ACCELERO_Set_FS(LSM6DSL_X_0_handle, FS_MID);                   /* FS 4g */
LSM6DSL_ACC_GYRO_W_InComposit(LSM6DSL_X_0_handle, LSM6DSL_ACC_GYRO_IN_ODR_DIV_4);
/* ODR/4 low pass filtered sent to composite filter */
LSM6DSL_ACC_GYRO_W_LowPassFiltSel_XL(LSM6DSL_X_0_handle, LSM6DSL_ACC_GYRO_LPF2_XL_ENABLE);
/* Enable LPF2 filter in composite filter block */
LSM6DSL_ACC_GYRO_W_HPCF_XL(LSM6DSL_X_0_handle, LSM6DSL_ACC_GYRO_HPCF_XL_DIV4);
/* Low pass filter @ ODR/50 */

uint8_t tmp_6axis_reg_value;
BSP_ACCELERO_Read_Reg(LSM6DSL_X_0_handle, 0x10, &tmp_6axis_reg_value);
tmp_6axis_reg_value = tmp_6axis_reg_value | 0x01;
/* Set LSB to 1 >> Analog filter 400Hz*/
BSP_ACCELERO_Write_Reg(LSM6DSL_X_0_handle, 0x10, tmp_6axis_reg_value);
```

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Fine tuning for sport/racing use

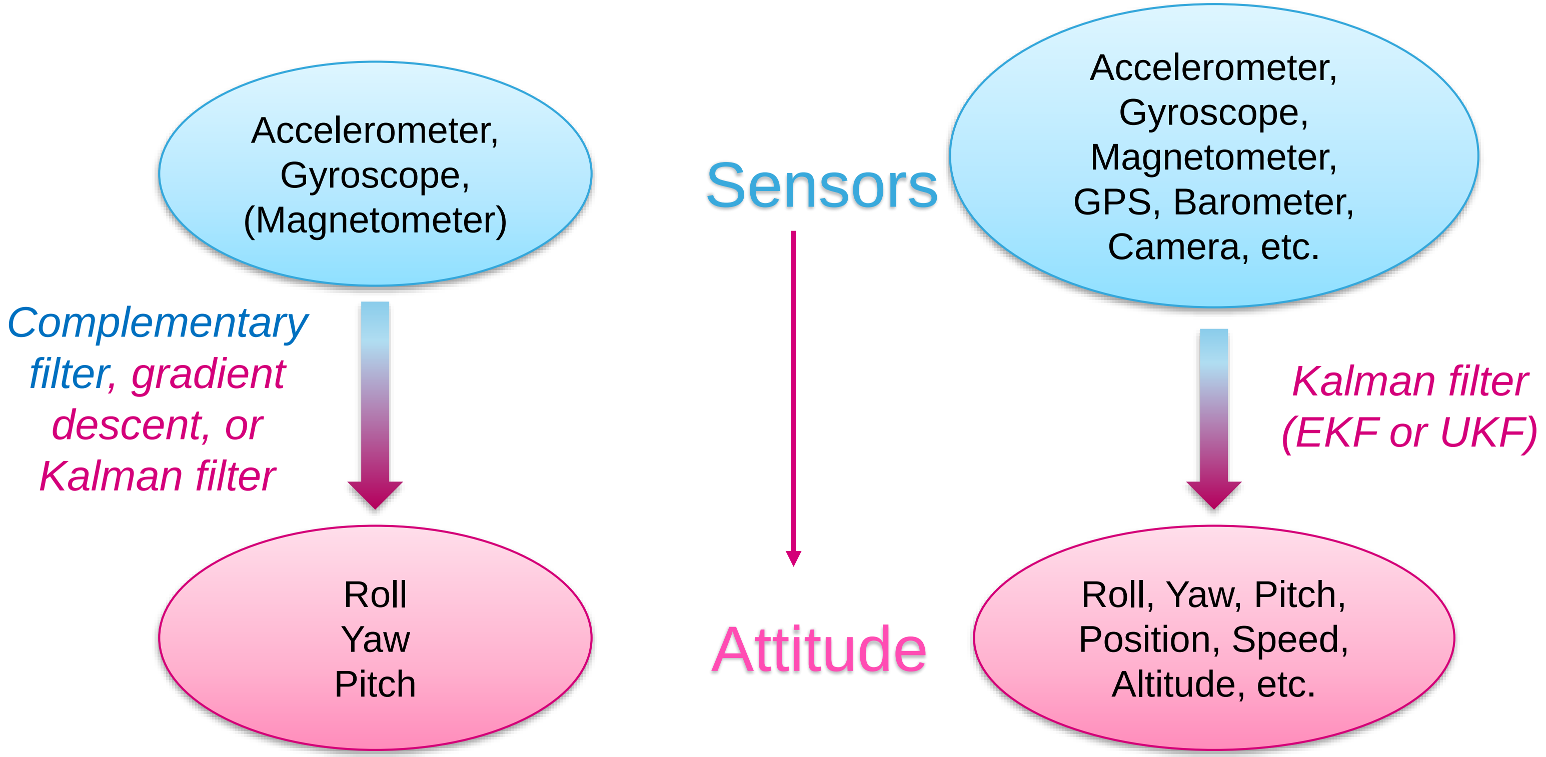
- In the default settings, the maximum PITCH and ROLL angles are limited to 20 degrees, while the maximum YAW is limited to the max rotation speed of 100 deg/s. These values are good for beginners to gain confidence with the quadcopter.

- For more expert pilots (and for racing/sport use), it is possible to increase these values in the rc.h:

```
/ Maximum roll/pitch 20deg
#define PITCH_MAX_DEG   20
/* change to 45 (angle degree) for higher forward/backward speed */
#define ROLL_MAX_DEG    20
/* change to 45 (angle degree) for higher right/left speed */
#define YAW_MAX_DEG     (60.0*SENSOR_SAMPLING_TIME)
/* change to 120 or 180 for higher rotation speed */
#define YAW_MIN_RAD     0.0872
#define EULER_Z_TH      600
```

Appendix C
AHRS Formula details

AHRS Algorithm



Toy Level
(Simply, Resource limited)

Professional Level
(Accurate, Performance)

AHRS - EKF (1)

- 13 States, 3 Measurements
- Gyro data is G input, Accelerometer data A is the measurement

State: $x = \begin{bmatrix} Q \\ G_{off} \end{bmatrix}$, where
$Q = [q_0 \quad q_1 \quad q_2 \quad q_3]^T$ is the quaternion;
$G_{off} = [g_{x\_off} \quad g_{y\_off} \quad g_{z\_off}]^T$ is the gyro bias error

Measurement: $z = [A]$, where
$A = [a_x \quad a_y \quad a_z]^T$ is the gravity measured by accelerometer

State Equation

$$\hat{x}_{k+1} = \begin{bmatrix} \hat{Q}_{k+1} \\ \hat{G}_{off\ k+1} \end{bmatrix} = \begin{bmatrix} Q_k + \frac{1}{2} Q_k \otimes (G_k - G_{b\ k}) \cdot T \\ G_{off\ k} \end{bmatrix}$$

Measurement Equation

$$\hat{z}_{k+1} = \hat{Q}^*_{K+1} \begin{bmatrix} 0 \\ 0 \\ 0 \\ 1 \end{bmatrix} \hat{Q}_{K+1}$$

State Update

$$x_{k+1} = \hat{x}_{k+1} + K_{k+1}(z_{k+1} - \hat{z}_{k+1})$$

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AHRS - EKF (2)

- 13 States, 3 Measurements
- Gyro data is G input, Quaternion from accelerometer & magnetometer data $Z_k = Q_M$ is the measurement

State: $x = \begin{bmatrix} Q \\ G_{off} \\ M_e \\ M_{off} \end{bmatrix}$, where $Q = [q_0 \quad q_1 \quad q_2 \quad q_3]^T$ is the quaternion;

$G_{off} = [g_{x\_off} \quad g_{y\_off} \quad g_{z\_off}]^T$ is the gyro bias error; $M_e = [m_x \quad m_y \quad m_z]^T$ is true earth magnetic field measured in body frame; $M_{off} = [m_{x_{off}} \quad m_{y_{off}} \quad m_{z_{off}}]^T$ is the hard iron offset

Measurement: $z = [q]$, where $A = [q_0 \quad q_1 \quad q_2 \quad q_3]^T$ is the quaternion estimated by gravity & magnetic field

State Equation $\hat{x}_{k+1} = \begin{bmatrix} \hat{Q}_{k+1} \\ \hat{G}_{b\ k+1} \\ M_{e\ k+1} \\ M_{off\ k+1} \end{bmatrix} = \begin{bmatrix} Q_k + \frac{1}{2} Q_k \otimes (G_k - G_{b\ k}) \cdot T \\ G_{b\ k} \\ M_{e\ k} - T\Omega_k M_{e\ k} \\ M_{off\ k} \end{bmatrix}$

Measurement Equation $\hat{z}_{k+1} = \hat{Q}_{k+1}$

State update $x_{k+1} = \hat{x}_{k+1} + K_{k+1}(z_{k+1} - \hat{z}_{k+1})$

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Appendix D
On board Battery charger for LiPO

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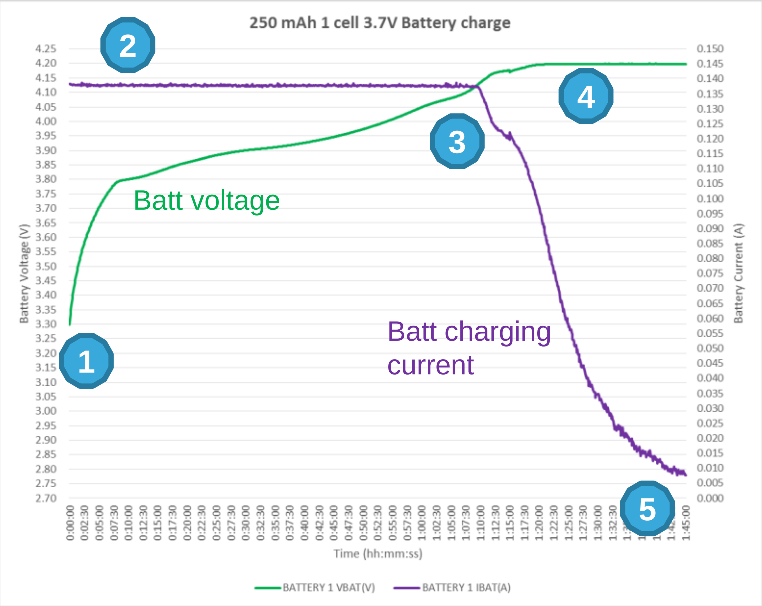
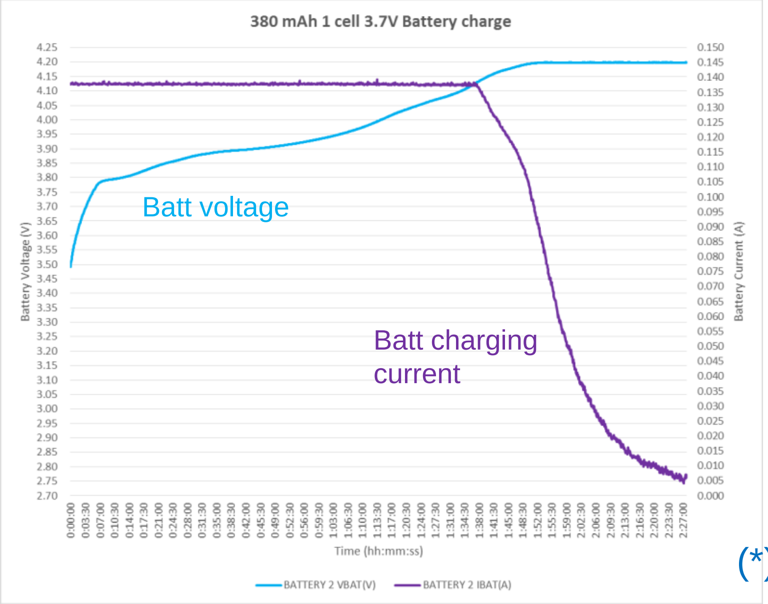
Charge of a LiPO battery





The diagram shows a typical charging curve for a LiPo battery. It consists of the following steps:

1. Battery discharged at cutoff voltage (2.7V).
2. Charge current set to ~135mA (*).
3. When Battery voltage reaches ~4.1V the charging switches from constant current mode to constant voltage mode. Battery voltage increases slowly till 4.2V and Charging current decrease.
4. 4.2V voltage at maximum charge
5. Charge current reached termination (1/10 of charging current) value, it just keeps battery charge.

The two diagrams are relative to 2 different batteries:

- 250mAh battery >> ~1h 25m from full discharge to full charge
- 380mAh battery >> ~2h from full discharge to full charge

(*) Charge current can be changed by the resistor connected to PROG pin of STLC4054.

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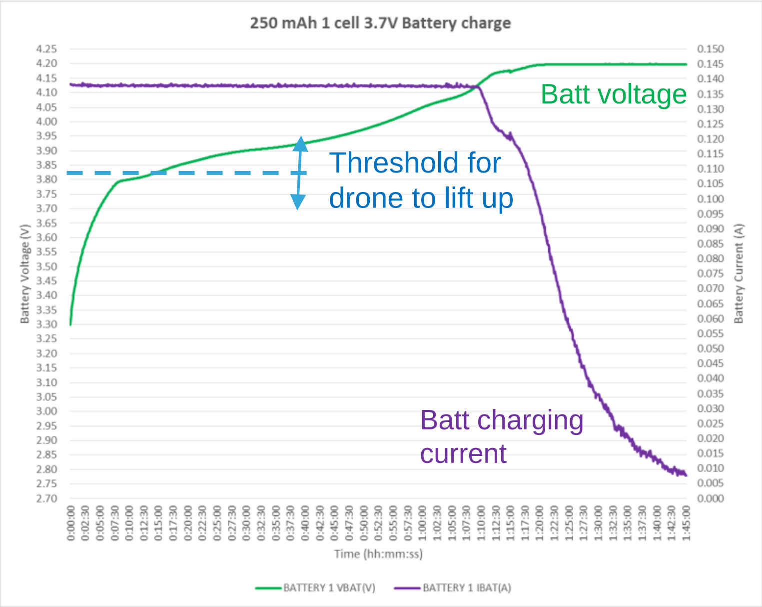
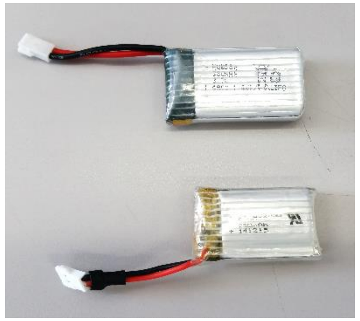
Use of LiPO battery in drone application





380mAh 1 cell Batt >> 11g

250mAh 1 cell Batt >> 8g

Note the following tips when using a LiPO Battery in the application:

1. Depending on several factors (drone total weight, motors and propeller used, …), the drone may not be able to lift (or just hovering at few cm from ground) at a voltage greater than full discharge value (i.e. 3.5V or 3.6V). It will be necessary to charge the battery from this voltage level, it will shorten battery charging time.

2. Choosing a larger battery will increase flight time, but attention must be paid to the trade off with the total weight.

3. After flight, battery should be immediately disconnected from FCU board. If it remains connected for a long time and battery voltage drops below 2.7V, there is the risk of permanently damaging the battery to the point that it can no longer be charged.

4. It is recommended that charge current should not exceed ~1/3 of maximum capacity (i.e. 380mAh >> charging current 130mA).

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