Aerial Robotics

FLEXIPILOT 1.35

Installation: connectors, mounting and layout

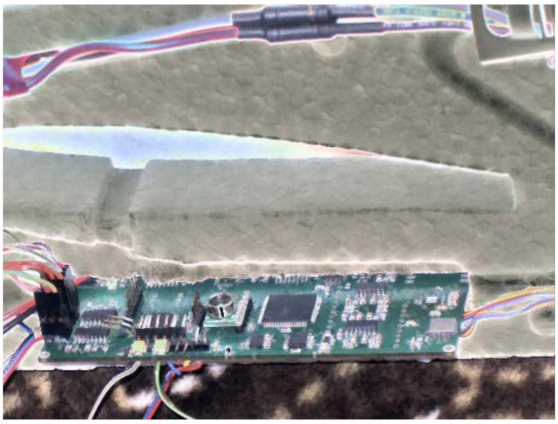
The document depicts placement of the connectors, mounting issues and vibration testing, power supply and status LEDs. Also, the electronic components interaction is discussed.

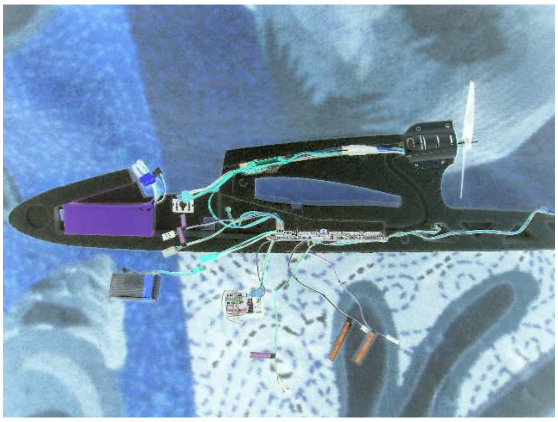
Components

The functional autopilot control system contains the following components:

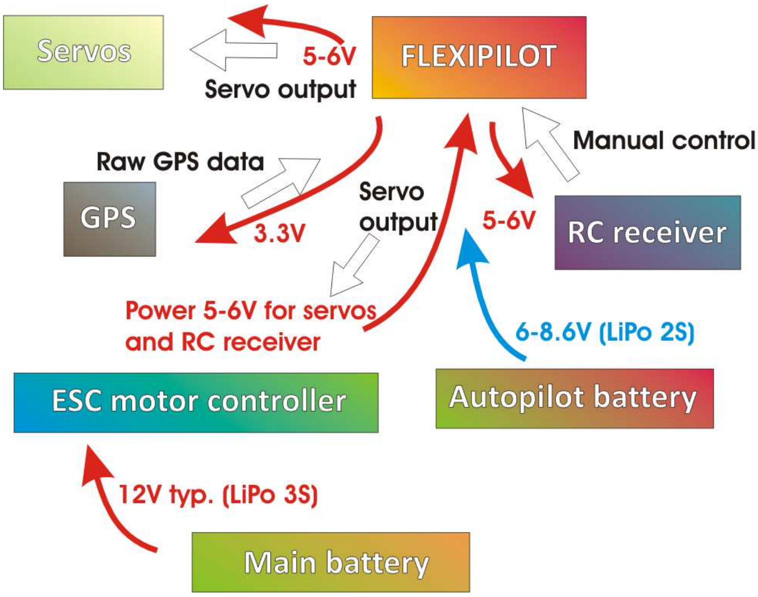
- FLEXIPILOT PCB
    - 120x50x14mm size with airspeed sensor, 10mm height without.
    - Typical power consumption 140mA @ 6V (840mW total)
    - Weight 55g including connectors and GPS module
- Supplied, external GPS module 30x30x5mm
- Supplied, external USB-A connector
- User's external RC receiver around 55x30x20mm
- Optional external Pitot tube with silicon tubing 5mm dia.

The receiver is supplied by the user as country-specific frequency is necessary. The receiver must support fail-safe settings (digital PCM receivers are best). The airspeed sensor and Pitot tube is optional.





Power connections



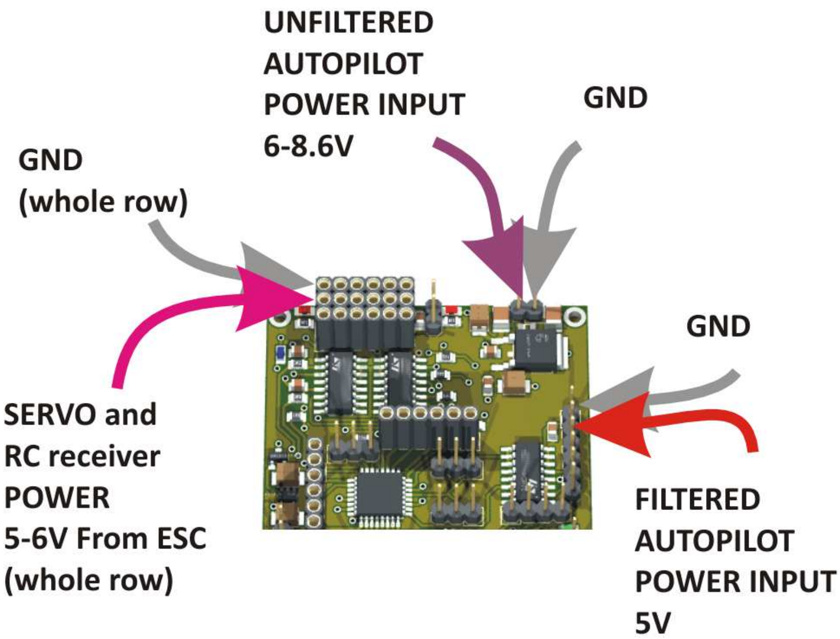
In order to save weight, remove autopilot battery, and use step-down switching converter between Main battery and autopilot Unfiltered Power Input, providing at least 6V. This will be efficiently filtered by linear low-drop regulator onboard the autopilot and the operation is 100% safe, also step-down regulator is very efficient in suppressing motor noise, not letting it enter the autopilot. Use voltages slightly above 6V for power usage efficiency.
The autopilot nominally could be powered from up to 13V power supply however the PCB would heat by a few degrees during flight resulting in worse barometric pressure sensor accuracy.
Also, external switching voltage regulator from LiPo 3S voltage ranges (9…12.6V) to 6V filters out engine noise.

It is impossible to protect systems against reverse polarity power while conserving power efficiency which is at premium in aerial vehicles. The autopilot power input is protected against overvoltage and reverse voltage with 13.8V Zener diode that will TYPICALLY become shorted (and destroyed) after applying reverse polarity. This however almost guarantees the destruction of the external power supply if reverse voltage is applied to the autopilot, but in most cases the components on the autopilot board will survive. Therefore, always use polarized connectors that cannot be reversed (Deans T-shaped connectors are preferred over JST due to better holding force).

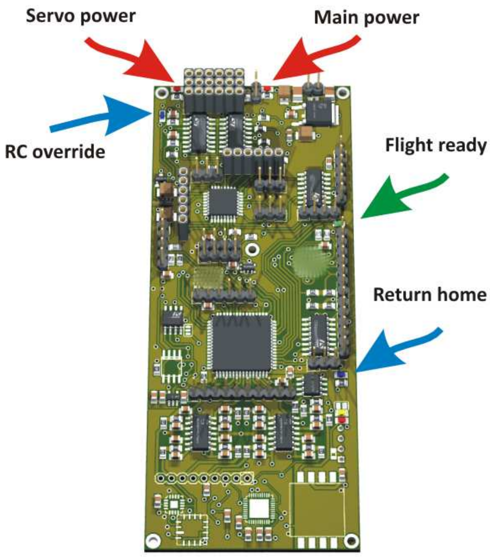
Popular T-shaped connector protecting from reversed polarity

You cannot power the FLEXIPILOT from either 4x NiMh batteries (only 4.8V) nor the servo power rail (sudden voltage drops to 4V under load that cannot be filtered with low capacity power supplies that would fit on the FLEXIPILOT board). You can use 5x NiMh batteries, as they provide 6V.

Attention: the choice which cable is – and which is + varies between battery manufacturers. It could happen that your battery is using T-shaped connector, but the cables are soldered exactly the opposite way. Resolder all cables in order to maintain consistent polarity for all your equipment. Usually, the **BLACK cable** is **-** or **GND** while **RED cable** is **+**.



Status LEDs



Servo power indicates 5-6V on the power supply rail coming from ESC Motor Controller. This is totally independent from the remaining autopilot power.
Main power is indicating healthy main autopilot power, 5.35-8V

Flight ready is **blinking at fast rate** when the barometric altimeter is calibrating. This can take up to 15s.
It is **blinking in slow rate** when GPS lock is being acquired. This can take 5-30s.
LED lit then fast_blinking alternating indicates IMU problem and the inspection using UAVStation is necessary, as described in ‘Weather conditions and IMU calibration’.
Only **when the light is steady, you are free to takeoff**. During tossing the light might change its status due to the sudden acceleration on the IMU, but the whole flight will be perfectly normal. The flight in manual mode is always possible regardless on autopilot readiness, but the automatic logging will not start.

LED status (1s period being shown)	Situation
*_*_*_*_*_*_*_*_*_*_*_*_*_*_*_*_	Altitude sensor calibrating! Wait 15s.
*_*_*****_*_****________________	Setup errors are present!
********________********________	GPS sensor searching sats (5-120s)
*_*_*_*_*_*_*_*_*_*_*_*_*_*_*_*_	Automatic takeoff: Voltage is being analyzed, wait.
*_*_*_*_*_*_*****_*_*_*_*_****	IMU not calibrated! Wait up to 60s then inspect.
--------************************	Other error, inspect setup.
********************************	Ready for takeoff
--------------------------------	Automatic takeoff: pre-takeoff procedure successful or in flight.
--------------------------------	Manual takeoff: in flight.

RC override indicates that RC override channel on the RC receiver has been activated.

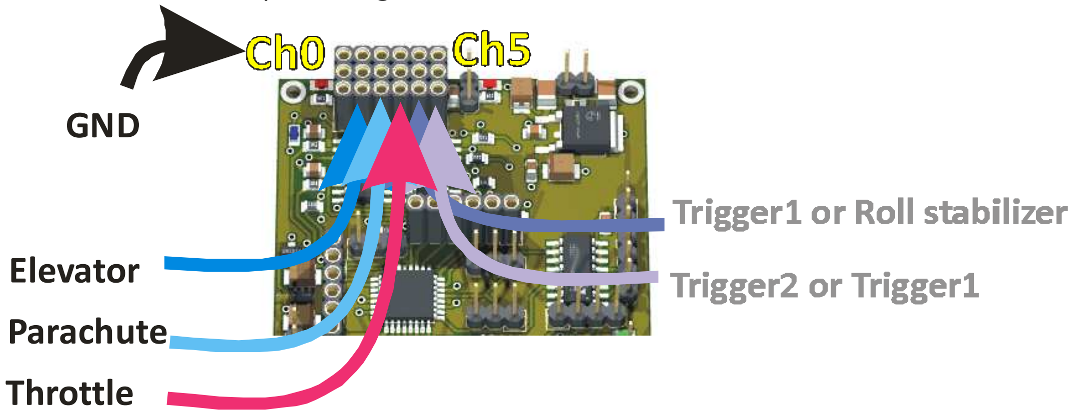
----------------	Autopilot is in control
****************	Manual control (RC override)

Return home when stable indicates that the mission has ended, RETHOME failsafe condition has been activated or the MODE_CHANNEL is active in return home mode. When blinking, indicates that the autopilot is navigating and that the main processor is functional.

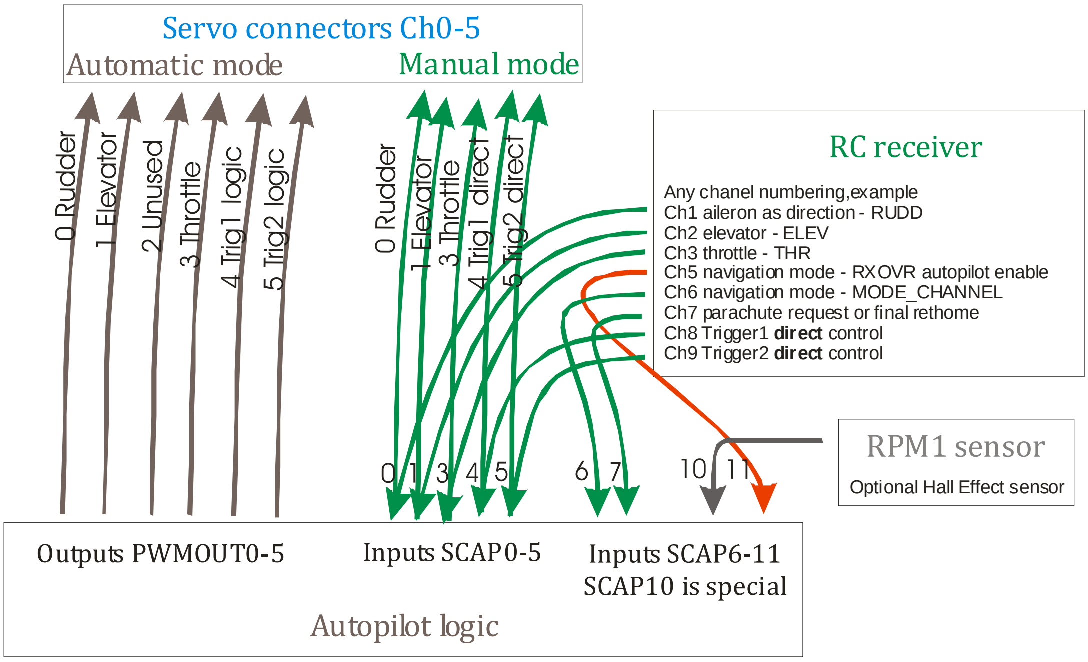
----------------	Manual mode
*_*_*_*_*_*_*_*_	Autopilot is in control (opposite to RC override)
*********_*_*_*_	Autopilot returning home

Servo output connectors

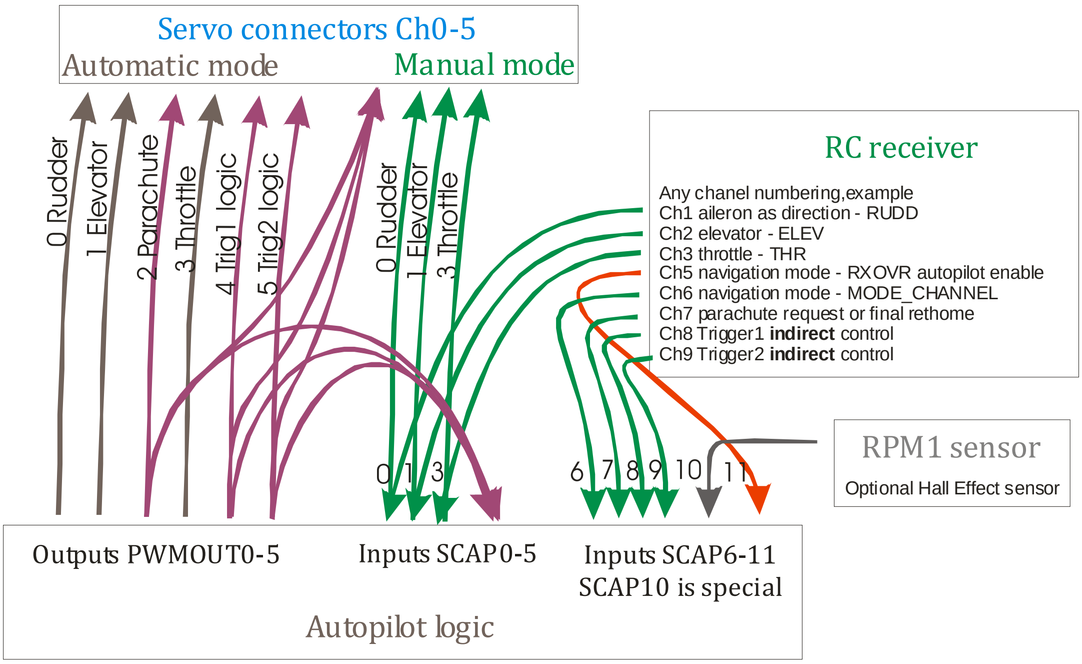
FLEXIPILOT features filtered, amplified and overload protected servo output signals with 20mA collective output rating.



The autopilot processor output is not connected physically to the output pins UNTIL the autopilot is enabled. In manual mode (called RC OVERRIDE) the output channels 0-5 are multiplexed (connected physically) to servo capture inputs ch0-5.
Note: in some installations Ch2, Ch4 and Ch5 are always connected to the autopilot (providing constant parachute management or continuous roll stabilization).
Trigger connectors can be unused. The servo output status on the autopilot processor side can be viewed on the console using **Y/y** command. It will show the autopilot digital output.
Typical output:
`10576 14304 0 0 20000 20000`
Shows output channel value in order:
Ch0 - rudder
Ch1 - elevator
Ch2 - parachute
Ch3 - throttle
Ch4 - trigger 1
Ch5 - trigger 2
10000 correspond to 1ms active PWM pulse duty or servo minimal position.
20000 correspond to 2ms active PWM pulse duty or servo maximal position.
The outputs are protected against issuing invalid range i.e 2.5ms by the autopilot, which would damage the servos.
It the channel is disabled, i.e before takeoff, it can assume 0 value (low signal). For trigger action values 0 and 1 are also possible, where 1 assumes high TTL level (+5V).

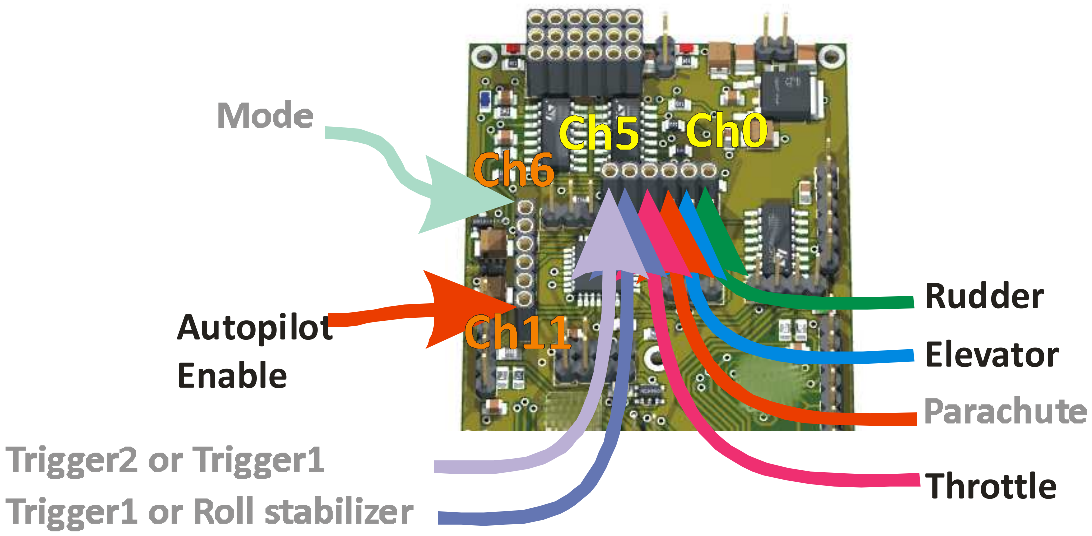


Autopilot Multiplexer Wiring A (default, with sample installation):
Ch0-5 is strictly multiplexed between autopilot and RC receiver,
either the autopilot or the RC receiver controls all,
autopilot always surveys receiver state and is fully aware of flying passively.



Autopilot Multiplexer Wiring B (custom wiring):
Ch0,1,3 is strictly multiplexed between autopilot and RC receiver,
Autopilot always surveys receiver state and is fully aware of flying passively.
Ch2,4,5 are always connected to autopilot output,
Which also simulates RC receiver readings on those channels for itself.
Parachute, Trig1and Trig2 outputs are repereresenting any functionality
and can be interchanged or left unused.

Servo capture connectors – inputs from the remote control



The autopilot has 12 input channels, 6 of them are multiplexed (optionally connected) to the RC receiver (Ch0-5).
The remaining 6 input channels can trigger various autopilot software actions (when appropriately configured):
-Autopilot Enable is connecting/disconnecting the signals from RC to output (default)
-in special autopilot makes, some outputs can be wired permanently to autopilot (usually triggers, stabilization and parachute)
-repetitive trigger actions can influence upon any of the output channels, when configured
-Parachute can be deployed by specific logic at input channel
-navigation/return home can be affected using input channels (Mode)
-it is possible to adjust tuning parameters in flight

Observe that by default Trigger1, 2 positions are commanded directly from the RC receiver when flying in manual mode (Autopilot disabled – RC override enabled).
You can change the assignment and role of any of the 6 input channels; you can also use a separate receiver for them.

The minimal servo input consists of:
Ch0 – Rudder
Ch1 – Elevator
Ch3 – Throttle
Ch11 – Autopilot enable
This allows basic autopilot flying.

It is recommended to add for enhanced safety:
Ch6 – Mode (MODE_CHANNEL), used for selecting actions during advanced tuning modes or magnet-home function
Ch7 – Return home failsafe channel or Parachute

For remote triggering of photo shooting in autopilot mode
(those triggers enable and disable trigger sequencers) use:
Ch8 – Trigger1 Input
Ch9 – Trigger2 Input

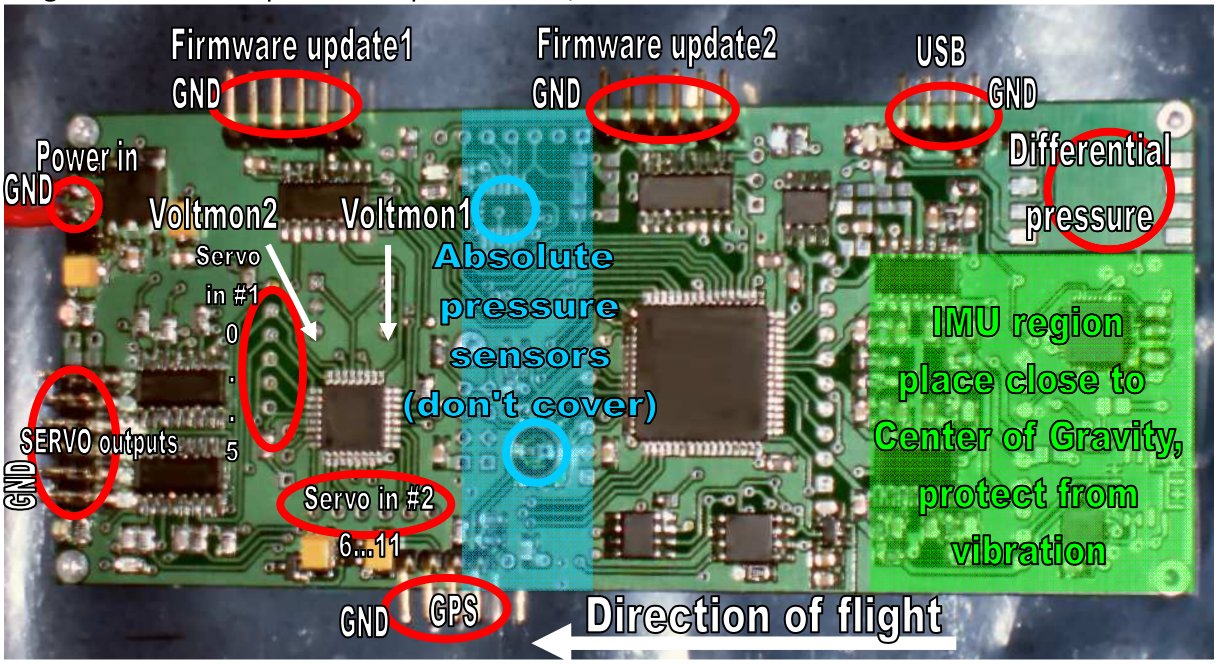
The servo input status can be viewed on the console using **S/s** command.
The display is cycling between off, servo capture display, and voltage/current display.

Servo capture display:
13742 13379 9617 11014 0 0 0 15175 9692 0 0 0 56084
Shows output channel value in order:
Ch0 – Ch11,
'live timer' counting 0-65535

Voltage/current display:
467 15 11.101V 0.074V 0.000A 0.516A 0.000Ah 0.001Ah 5.708W 12300RPM
(RAW ADC VOLTAGE1/RAW ADC AMP1) then (RAW ADC VOLTAGE2/RAW ADC AMP2)
Scaled voltage
Current scaled from voltage
Total consumed current
Power calculated from VOLTAGE1*AMP2
Motor RPM (if connected, uses SCAP10)

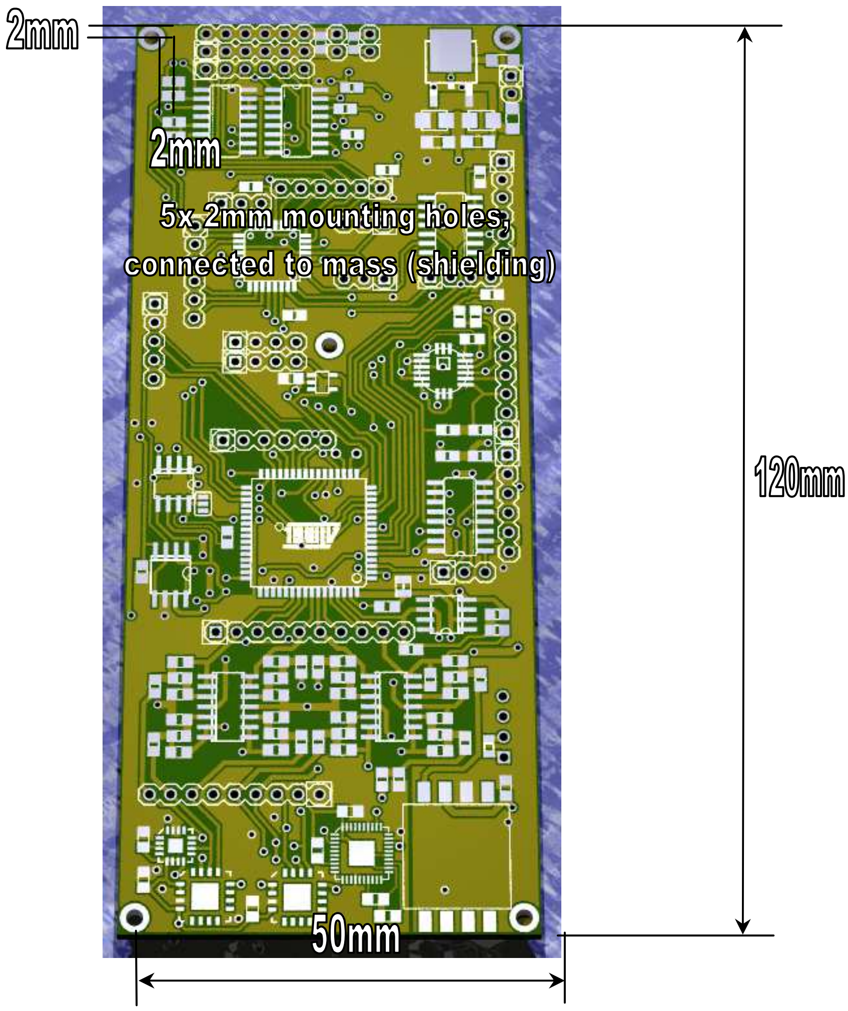
Dimensions and mounting

The autopilot board has dimension 50x120mm,
height 14mm with optional airspeed sensor, 10mm without.



For simplicity, it is best to mount it as in the following picture. Reversed mounting (upside-down or back-to-front) is possible, but tilted installation is not possible. There are offset parameters expressed as Euler angles, but the deviation from the flat installation by more than a few degrees is not recommended.

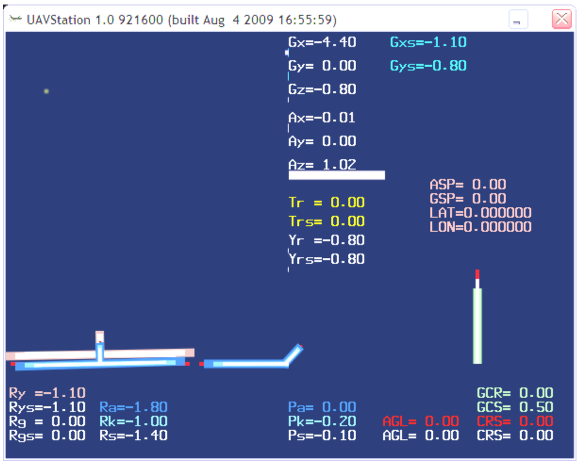
FLEXIPILOT uses carefully selected accelerometers in order to reduce vibration impact on the IMU, but as a rule the motor mount (even if electric) must be suspended using rubber spacers and the autopilot should be mounted between 2 layers of 1cm thick vibration-insulating foam. You should not cover absolute pressure sensors with the insulation. Using mounting holes is possible to the custom box, but the box itself has to be insulated from vibration.

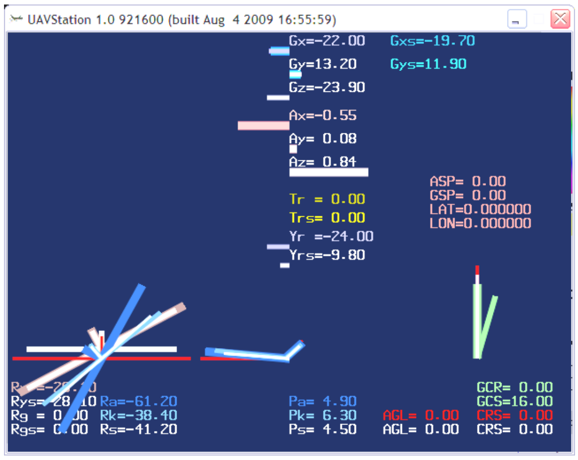


Testing vibration impact on the IMU

IMU stands for Inertial Measurement Unit and is the most important component of the autopilot as it allows orientation in the 3D space. All commercially available IMU autopilots are sensitive to airplane vibration. This requires modifications and testing of the RC flying models before converting them into automated devices.

Launch the UAVStation, use **I/i** in order to toggle IMU debug output:





Test the engine using RC receiver and the autopilot inactive (in manual mode).
Hold the plane firmly in a horizontal position on the ground. Increase the throttle slowly, from minimum to max RPM. Observe if the pitch and roll are stable within a few degrees (under full throttle the plane will likely to change its inclination). It could happen that at some throttle (usually in the middle position) the reading of one or several of the accelerometer axes will change its readings by up to 30% for no apparent reason. This indicates vibration corresponding to MEMS sensors resonant frequency and must be eliminated before flying.
Add insulating foam, reduce engine vibration, and balance the propeller in order to resolve the problem.

Configuring voltage monitoring

NOTE: the analog voltage inputs accept voltages 0-5V, therefore it is necessary to use external voltage divider before connecting to the autopilot. The inputs have built-in analog filter and adjustable digital IIR filter.

Depending on installation, it is possible to use 2 voltage monitoring inputs dedicated for monitoring propulsion and/or autopilot power supply.
Voltage is calculated using the formula:
SCAP_VOTLAGEn=IIRfilter(ADC_RAW*SCAP_VOLTSCALEn, SCAP_VOLTALPHAn)
The ADC input is filtered with 1^{st} order analog RC filter with 16Hz lowpass freq.
On top of it, the IIRfilter is calculated at 20Hz frequency.

SCAP_VOLTSCALE1
SCAP_VOLTSCALE2
Default: 5V/1024counts
Possible values: 0-1e6
The input to a voltage measurement point is scaled by external voltage divider so that the input never exceeds 5V.

SCAP_VOLTALPHA1
SCAP_VOLTALPHA2
Default: 1 (immediate update)
Possible values: 0.00-1.00
Defines filtering of the measured voltage in order to filter out voltage transients due to servo power consumption or throttle change. 1 is immediate update, 0 is no update, update rate is 20Hz.

VOLTAGE_MOTORCUT1
VOLTAGE_MOTORCUT2
Default: 0 (disabled)
Possible values: 0-32V
It is recommended to set the value around 3.1V per LiPo cell

VOLTAGE_SYSTEMLOW1
VOLTAGE_SYSTEMLOW2
Default: 0 (disabled)
Possible values: 0-32V
It is recommended to set the value around 6V which is minimal safe operational input for the autopilot . This will shut down most servos, abort mission and shut down motor.

VOLTAGE_MIN2TAKEOFF1
VOLTAGE_MIN2TAKEOFF2
Default: 0 (disabled)
Possible values: 0-32V
Defining a safe margin for flying comfortably a mission in fully automatic mode.

Must provide enough power to climb to a loiter point or parachute deployment altitude.

Related variables:
(navigation)
RETHOME_VOLTMIN1
RETHOME_VOLTMIN2

Configuring amperage monitoring and battery management

You can use 2 existing voltage inputs in many ways:
-as 2 voltage monitors for battery
-as 2 voltage monitors calibrated for amperage monitoring
-Recommended for single motor use:
VOLT1 as voltage monitoring and VOLT2/AMP2 as current monitoring

Amperage is calculated using the following formula:
SCAP_AMPn=SCAP_VOLTAGEn* SCAP_AMPSCALEn + SCAP_AMPOFFSETn
Therefore, the value is subject to the same filtering as SCAP_VOLTAGEn, because it is calculated from it.

SCAP_MODE
Default: 0
Possible values: 0…3
Flags:
1 – Reset AHCONSUMED1 during takeoff
2 – Reset AHCONSUMED2 during takeoff
The internal counter related to RETHOME_AHBATCAP1 and/or 2 can be reset during takeoff. This allows keeping the UAV powered up for a long time before takeoff without triggering false 'battery empty' alarm. It should be noted that scaled battery consumption has residual current indication typically above 0A, what leads to internal worst-case current consumption estimation, gradually reducing estimated remaining battery energy even if the UAV stays on the ground.

SCAP_AMPSCALE1
SCAP_AMPSCALE2
Default: 0
Possible values: 0…100.0[A/V]
The value is multiplied by corresponding voltage value producing current value.

SCAP_AMPOFFSET1
SCAP_AMPOFFSET2
Default: 0
Possible values: -10.0…10.0[A]
Defines an offset added to amperage value.
The resulting current is clamped to nonnegative values, not less than SCAP_AMPMINn.

SCAP_AMPMIN1
SCAP_AMPMIN2
Default: 0
Possible values: 0.0…100.0[A]
Calculated amperage is never lower than this value.
Used for correcting ampmeter nonlinearity, assuring the consumption is never underestimated. Also allows using RETHOME_AHBATCAPn without actual Amp meter connected, enter typical current consumption in this case.

SCAP_AMP1_AVGALPHA
SCAP_AMP2_AVGALPHA
Default: 0.001 (slow update)
Possible values: 0.00-1.00
Smoothing of averaged current consumption during automatic flight, used for AHRESERVE and WHRESERVE RETHOME conditions (estimating battery reserve to return to base).
1 is immediate update, 0 is no update, update rate is 20Hz. Typical value 0.01.

Related variables:
(navigation)
RETHOME_AHBATCAP1
RETHOME_AHBATCAP2

Calibrating amperage measurement

1. Make sure that SCAP_VOLTALPHA2 is >0 (1 is immediate value update, filtering off).
2. Connect amperage probe that outputs 0-5V to VOLT2
3. Measure reference voltage of the main rail, say 5.01V.
4. Set SCAP_VOLTSCALE2 =5.01/1024. After reset, VOLT2 should show directly the voltage on probing wire.
5. Measure current consumption using AMP meter for 1, 2, 3, and other values of amperage. Note the SCAP2 voltage output in volts. Using Excel, fit linear equations and find coefficients AMP2=coeff1*VOL2+coeff2. coeff1 is SCAP_AMPSCALE2, coeff2 is SCAP_AMPOFFSET2.
6. Since the current sensor is typically under/overestimating current consumption below 1A, measure it directly with servo steady and propeller stopped, enter SCAP_AMPMIN2
7. Make a test flight, find how much Ah you can pull from your typical battery and enter RETHOME_AHBATCAP2. you can use RETHOME_WHBATCAP2 instead of AHBATCAP. You can also enter RETHOME_AMPMAX2 as protection against failed motor/propeller. Set RETHOME_WATTMAX2 following engine power dissipation rating.
8. Check by double pressing ‘S’ on the console that voltage, amperage and wattage display is correct.

WARNING: if you connect the wire to the wrong ping, swapping channels, you will see the same measured value on inputs. This is because voltage measurement works like railroad switch, leaking a few values from connected wire to unconnected pin during periodic switching. When you see abnormal and 'lazy update' readings check the channel you are actually connected to.

Configuring RPM measurement

If the RPM measurement is supported, SCAP10 servo input channel is reserved for calculating a period of a signal. This allows measuring RPM between 60 and 60000. If there is no reading for 0.5s (less than 60RPM), the RPM is 0. If the motor starts or stops spinning, it is possible to get transient, accurate measurements of RPM below 60. The numbers minimal numbers above assume one 'rpm counter event' per revolution. Because there might be many magnets/diodes/events per revolution, scaling factor allows adjustment.
The system counts on rising edge signal, TTL (0-5V, 3V logic compatible), without any additional analog filtering.
Resolution is 2 events, as the number sent is the number of events divided by two.
Measurement delay is 0.5s.

RETHOME logic monitors MIN and MAX RPM if the following preconditions are satisfied:

- The plane is in autonomous mode and after takeoff
- The throttle is ordered to operate (when using electrical motors, they can be suppressed for optimized propeller folding, when high above target etc, at those moments RPM is not monitored)
- The logic requests throttle above specified threshold: RPM1_THRMIN

Then, if actual RPM falls OUTSIDE RETHOME_RPM1MIN... RETHOME_RPM1MAX, RPM1 is marked as failed and the plane returns home.
Besides that, depending on FB_THR_MODE and FB_THRB_MODE, any of the 2 motors can be either permanently disabled or enabled as a result of this event. Since a selected subset of RETHOME conditions assumes NOCLIMB condition, and the electric motor can recover operating, the consequences are different for gas an electric engines:
Electric engines:
RPM1 dead may or may not cut off the motor forever, depending on FB_THR_MODE and FB_THRB_MODE. If it was a temporary ESC overhead, the plane will navigate applying cruise throttle, slowly loosing altitude.
Gas engines:
RPM1 dead means the motor will not recover, but the gas servo will remain around cruise throttle position. The plane will simply glide home.

This logic allows the following safety and current conservation protections:
-starting a motor if the other one has failed
-stopping a motor if it is blocked and cannot spin
-stopping a motor if it has lost a propeller and is spinning too fast
(either because of stopping or over-rpm due to lost propeller)

SCAP_RPM1_SCALE
Default: 1
Possible values: 0…100.0
0 disables readings, but is not disabling RPM alarm (see RETHOME)
Typical values:

- 2 magnets: 2 events per rotation, raw number already divided by 2, SCAP_RPM1_SCALE=1
- 14-pole outrunner has 7 state switches using magnetic probe, since the raw number is divided by 2, SCAP_RPM1_SCALE= 0.285714 //=2/7
- 1 magnet per revolution or optical probe mounted on engine axis: SCAP_RPM1_SCALE=2
- 1 laser finder illuminating 3-blade propeller: SCAP_RPM1_SCALE=0.666667 //=2/3

Related variables:
(navigation)
RETHOME_RPM1MIN
RETHOME_RPM1MAX
RETHOME_RPM1MIN_THRMIN
RETHOME_RPM1MIN_THRBMIN

Configuring airspeed sensor

When enabled, the airspeed value is used for:
- cruise speed estimation allowing more precise wind estimation (also when flying in one direction for a long time) what might result in more precise navigation against wind
- improving IMU accuracy in turns
- it is possible to setup airspeed feedback loop acting on elevator
- MIXOUT gyro dampers are scaled for airspeed
- RUDD and ELEV feedback loops are scaled for airspeed
- True airspeed is available in log data even if it is not used for feedback control

The autopilot is designed for function without airspeed sensor. The failure of airspeed sensor is always dangerous as it will introduce oscillatory control surface behavior and deepen achieved roll angles by a factor of about 2, often exceeding aircraft stability limits. The sensor can be used in passive mode when ASP_CONFIG=0.

In order to configure the sensor:
- Initialize variables:

ASP_CONFIG=0 (logging only)
ASP_KMH_ALPHA=1 (immediate update)
ASP_PRES_ALPHA=1 (immediate update)
ASP_ADCFLOOR= the value of ADC input on channel 0 (press A/a, first column)
ASP_KMH_SCALE=4 as first guess
ASP_PRES_SCALE=2 as first guess
- Compare pressure output

- Fly a mission with several circular patterns and determine scaling factor for airspeed using groundspeed as reference
- Adjust filtering ALPHA based on logs
- Use N/n display in order to verify ASP (immediate) value and ASPs (smoothed) value

- Setup feedback
* The value of airspeed dynamic pressure is
sqrt(ADC_RAW- ASP_ADCFLOOR)* ASP_PRES_SCALE
This pressure can be used as input feedback for elevator and multiplied by FB_FF_PRES2ELEV_COEFF.

- The value of airspeed can be used as input feedback for elevator
  using the arguments FB_FF_ASP_MIN… FB_FF_ASP_MAX
  and output range FB_FF_ASP2ELEV_OUTPUT_MIN… FB_FF_ASP2ELEV_OUTPUT_MAX

-Evaluate physical properties:
Max airspeed: sqrt(1024**-** ASP_ADCFLOOR)*ASP_PRES_SCALE in km/h,
Example: using typical SCALE=5, 108km/h max with floor =560
Example: using typical SCALE=5, 158km/h max with floor =24
Smallest measurable speed: sqrt(1)* ASP_PRES_SCALE
Noise level around one unit:
+/- 5km/h at 0km/h;
+/-0.61km/h at 20km/h
+/-0.25km/h at 50km/h
+/-0.125km/h at 100km/h

-Above measureable speed, the GPS groundspeed is used with gradual fade between the two measurements. Max GPS measureable speed is 515m/s=1854km/h. GPS is never used if its measurement indicates slower speed than sensed pressure-airspeed.

ASP_CONFIG
Default: 0 (not used, only stored)
Possible values: 0..7
0 – Pitot tube airspeed is only stored internally in logs
Add 1 – Pitot tube will be used for IMU pitch improvement
Add 2 – Pitot tube will be used for feedback/airspeed control (FB_ parameter)
(otherwise airspeed control is off)
Add 4 – Pitot tube will be used for airspeed broadcasting via OSD and modem
Options 0 and 4 are safe in case of Pitot tube breakdown.

ASP_KMH_ALPHA
ASP_PRES_ALPHA
Possible values: 0…1
Amount of filtering for the dynamic pressure and airspeed

ASP_ADCFLOOR
Default: 0
Possible values: 0…1023
Typical value: 0-300
ADC floor level when not moving

ASP_KMH_SCALE
ASP_PRES_SCALE
Default: 0
Possible values: 0…100
Scaling factors for airspeed in km/h and dynamic pressure (preferred unit: Pascals).

Configuring servo output mixers and feedback control

There are 6 output servo channels (PWMOUT).

The servo output channel value can come from any of the following sources:

- RC receiver (in manual mode)
- Parachute
- Trigger1 or 2
- Stabilized head axis Stab1, 2, 3.
- THR throttle control logic
- THRB secondary throttle control logic
- RUDD generalized direction control logic (Ailerons and rudder, mixed)
- ELEV generalized elevation control logic
- Any axis gyroscope (X,Y,Z) control logic

PWMOUT3 (4^{th} connector) is for throttle only and is a result only of throttle logic.
PWMOUT2 (3^{rd} connector) is for throttleB only (if enabled, FB_THRB_MODE=1).

Besides the two mentioned exceptions, you can setup a channel to be a mixture of any of the mentioned control logic. In practice, this allows ailerons action slaved to RUDD, with asymmetric travel, V-tail any other very exotic control mechanisms like bi-directional fans or brakes.

When flying in manual mode, each channel learns its stable, central position used as anchor point for feedback deflections.

Besides learning the central position with fixed rate, the user can adjust the speed of learning the neutral point for gyroscopes. That way, you can assign high-pass filtered gyroscope signal to any control surface. This is as supplement to RUDD and ELEV control logic, which in itself uses full IMU model but is typically set up with much smoother output curves. Also note that ELEV control is related to pitchrate over the horizon, while the gyro mixers are in plane's reference.

Correspondingly, RUDD logic depends either on pure roll+rollrate on turnrate measured flat over the horizon (depending on actual choice of PID family), while gyro logic that you can feed to any output channel is always in possible on top of RUDD.

Calibrate barometer

While the barometer has internal temperature compensation, it is possible to adjust its readout for the actual pressure.
It is not important for flying itself, but affects:

- RETHOME condition: flight level
- Density altitude (OSD meteo report and logs)
- Standard altitude (OSD meteo report and logs, stratospheric altitude temperature model)
- Local absolute pressure (OSD meteo report and logs)

ALTI_PRESCORR
Default: 0
Possible values: -20000…20000 Pa
Typically -1000…1000Pa.
Scaling factors for airspeed in km/h and dynamic pressure (preferred unit: Pascals).
Turn on 'H' display on the console, compare to local pressure (subtract around 1hP per floor you live in when compared on ground-level weather station).

Calibrate temperature and humidity sensors

If Humidity sensor is installed, it allows accurate calculation of Relative Humidity, DewPoint, FrostPoint, Cloudbase Altitude, Frost Altitude, Density Altitude and precise measurement of Outside Air Temperature (OAT). In its absence, all the variables above are calculated using HUMI_RHGUESS and HUMI_OATDELTA.

HUMI_RHGUESS
Default: 40
Values: 0…100 %
Relative humidity value as percents, used in absence of external humidity sensor.

HUMI_OATDELTA
Default: -6.0
Values: -20.0..20.0 Celsius or Kelvin
In absence of humidity sensor it is supposed that
OAT=InternalTemperature + HUMI_OATDELTA

Those values can be set interactively using
@@@SETOATGUESS T T[C]=-55…125
(the command is ignored Ii HUMI_OATDELTA would exceed valid range)
and
@@@SETHUMIGUESS h h[%]=0…100

Configuring servo update rate

PWMOUT_MODE
Default: 0
Values:
0 – all channels analog
1 – PWMOUT0..2 (RUDD, ELEV, THRB, PARA or other) digital
2 – PWMOUT3..5 (THR, others) digital
3 – PWMOUT 0-5 digital
You can select between analog (60Hz) and digital (300Hz) update rate for each triplet of servo outputs separately.
Danger: digital update rates will burn analog servos!

Configuring throttle control

FB_THR_MODE
Default: 1
Values:
0 or 1 – THR is always enabled (PWMOUT3 used)
2 – Disable THR engine (throttle low) if RPM1 failure detected
4 –Force enabled THR engine (throttle control active) if RPM1 failure is detected
Note: RPM sensor can monitor **secondary** or gas engine.
This way you can use electric THR engine as a backup.
Throttle low condition is subject to 1s dead-counter.
Once detected, the system stays in RPM1-fail state (non-recovering).

FB_THRB_MODE
Default: 0
Values:
0 – THRB disabled
1 – THRB enabled (PWMOUT2 used)
2 – Disable THRB engine (throttle low) if RPM1 failure detected
4 –Force enabled THRB engine (throttle control active) if RPM1 failure is detected
Note: RPM sensor can be set up by installation to monitor primary electric or gas engine.
This way you can use electric THRB engine as a backup.
Throttle low condition is subject to 1s dead-counter.
Once detected, the system stays in RPM1-fail state (non-recovering).

FB_THR_DIRECT
Default: 0
Values:
0 –disabled
1 –enabled
Enables direct RC control over THR and THRB in all phases of flight.
Note: @@@SERVODIRECT command enables direct control
over all PWMOUT channels in autopilot mode, until RESET.

Configuring feedback control logic

FB_RUDDCONTROL
Default: 0
Values:
0 – none
1 – rudd2roll, roll2head
2 – rudd2turn, turn2head
The control methods can be mixed.

FB_ELEVCONTROL
Default: 0
Values:
0 – none
1 – elev2pitchrate
2 – elev2pitch, pitch2alti
3 – elev2climb, climb2alti
8 – elev2alti
The control methods can be mixed.

SCAP_RUDD_ALPHA
SCAP_ELEV_ALPHA
Values: 0..1
Neutral position learning rate for RUDD and ELEV.
Set to 0 if RUDD and ELEV are mixed channels.

FB_RUDD_ALPHA
FB_ELEV_ALPHA
FB_THR_ALPHA_UP
FB_THR_ALPHA_DOWN
FB_THRB_ALPHA_UP
FB_THRB_ALPHA_DOWN
Values: 0..1
Filtering of direction, elevation and throttle control logic. Throttle filtering is asymmetric and can be adjusted to flying style. Throttle slew rate should be adjusted directly by slew rate limiter of a given PID, those filters only smooth the output.

Configuring the gyroscope control layer

MIXOUT_GROLLNEUT_ALPHA
MIXOUT_GPITCHNEUT_ALPHA
MIXOUT_GYAWNEUT_ALPHA
Default: 1
Possible values: 0…1
Typical value: 0.001-0.1
Define high-pass filter: how fast to learn the central gyro value (1 is immediate, 0 is never), based on IIR filter with 20Hz update rate.

MIXOUT_GROLLAMP
MIXOUT_GPITCHAMP
MIXOUT_GYAWAMP
Default: 0
Possible values: -10000…10000
Typical value: 10 (each deg/s of rotation is multiplied by 10 then added to the output)

Configuring per-channel mixers

Since there are 6 output channels, there are 6 MIXOUT modules: MIXOUT0…MIXOUT5.
The channels define amount of each logics to be mixed into servo output.
For example, *POS value of 56 means that for positive values of given logic (i.e. positive roll rates after scaling, or if RUDD/ELEV deflections are greater than its central value) the output will be multiplied by 56%.

MIXOUTn_MODE
Values:
0 – no output in autopilot mode
1 – direct RC control (copy the RC input, can affect autopilot navigation)
2 – fix position to learned neutral position (learning during manual flight)
3 – full mixer logic
add 32 – given control surface will not learn its central position when in manual mode, useful for flaps or airbrakes
add 64 – given control surface deflection would not be scaled using IDLEGAIN settings, what corresponds to this surface being away from propwash (dependent only on airspeed, not thrust).
add 128 – output is photo-lockable: frozen if photo-lock is active

Note: throttle control has special safety and cutoff logic, therefore use MIXOUTn_MODE=0 for THR and THRB channels. It can be difficult to find correct multipliers that replicate the same idle position following THR logic as it would be using fully manual control, therefore a mistake will result in throttle spinning when switching between automatic and manual mode.
@@@MIXOUT2_MODE=0

MIXOUTn_MINOUT
MIXOUTn_MAXOUT
Values: 8000...24000
Define the range of servo deflection.

MIXOUT0_RUDDPOS
MIXOUT0_RUDDNEG
MIXOUT0_ELEVPOS
MIXOUT0_ELEVNEG
MIXOUT0_THRPOS
MIXOUT0_THRNEG
MIXOUT0_THRBPOS
MIXOUT0_THRBNEG
MIXOUT0_GROLLPOS
MIXOUT0_GROLLNEG
MIXOUT0_GPITCHPOS
MIXOUT0_GPITCHNEG
MIXOUT0_GYAWPOS
MIXOUT0_GYAWNEG
Values: -125..125 %
Default: 0
Defines amount of deflection for given output channel as a response to selected input:
PIDs: RUDD (general direction), ELEV (general elevation), THR, THRB
GYRO rates: rollrate, pitchrate, yawrate

MIXOUTn_ARMRATIO
Values: 0.2..10
Default: 1
Ratio of arm length: control surface arm to servo arm. For example if control surface arm is two times longer than servo arm, put 2. Supposing infinite pushrod length, this ratio allows correcting for large deflection angle when arm length are being changed, without affecting the PIDs. The corrector action besides correcting for mechanically changed servo setup from one installation to another, has different amplification depending on deflection angle if the ratio is not 1.
1 is neutral (corrector mathematically disabled, assuming equal arm lengths).

Examples

The simplest case, unmixed rudder:

```
@@@MIXOUT0_MODE=3
@@@MIXOUT0_RUDDPOS=100  <- RUDD positive output is 100% positive deflection
@@@MIXOUT0_RUDDNEG=-100 <- RUDD negative output is 100% positive deflection
@@@MIXOUT0_ELEVPOS=0
@@@MIXOUT0_ELEVNEG=0
@@@MIXOUT0_THRPOS=0
@@@MIXOUT0_THRNEG=0
@@@MIXOUT0_THRBPOS=0
@@@MIXOUT0_THRBNEG=0
@@@MIXOUT0_GROLLPOS=0
@@@MIXOUT0_GROLLNEG=0
@@@MIXOUT0_GPITCHPOS=0
@@@MIXOUT0_GPITCHNEG=0
@@@MIXOUT0_GYAWPOS=0
@@@MIXOUT0_GYAWNEG=0
@@@MIXOUT0_MINOUT=10000
@@@MIXOUT0_MAXOUT=20000
@@@MIXOUT0_ARMRATIO=1
```

Unmixed elevator:

```
@@@MIXOUT1_MODE=3
@@@MIXOUT1_RUDDPOS=0
@@@MIXOUT1_RUDDNEG=0
@@@MIXOUT1_ELEVPOS=100
@@@MIXOUT1_ELEVNEG=-100
@@@MIXOUT1_THRPOS=0
@@@MIXOUT1_THRNEG=0
@@@MIXOUT1_THRBPOS=0
@@@MIXOUT1_THRBNEG=0
@@@MIXOUT1_GROLLPOS=0
@@@MIXOUT1_GROLLNEG=0
@@@MIXOUT1_GPITCHPOS=0
@@@MIXOUT1_GPITCHNEG=0
@@@MIXOUT1_GYAWPOS=0
@@@MIXOUT1_GYAWNEG=0
@@@MIXOUT1_MINOUT=10000
@@@MIXOUT1_MAXOUT=20000
@@@MIXOUT1_ARMRATIO=1
```

Complex case: right aileron on PWMOUT5, asymmetric deflection slaved to RUDD (direction control) stabilized by roll gyro with asymmetric travel:

```
@@@//AILR
@@@MIXOUT5_MODE=3
@@@MIXOUT5_RUDDPOS=-70 <-RUDD negative (turn left)
                         is mixed into 70% deflection down (entering turn)
@@@MIXOUT5_RUDDNEG=100 <-RUDD positive (turn right)
                         is mixed into 100% deflection up (entering turn)
@@@MIXOUT5_ELEVPOS=0
@@@MIXOUT5_ELEVNEG=0
@@@MIXOUT5_THRPOS=0
@@@MIXOUT5_THRNEG=0
@@@MIXOUT5_THRBPOS=0
@@@MIXOUT5_THRBNEG=0
@@@MIXOUT5_GROLLPOS=-70 <- roll gyro positive is deflection down (counteracting)
@@@MIXOUT5_GROLLNEG=100 <- roll gyro positive is deflection up (counteracting)
@@@MIXOUT5_GPITCHPOS=0
@@@MIXOUT5_GPITCHNEG=0
@@@MIXOUT5_GYAWPOS=0
@@@MIXOUT5_GYAWNEG=0
```

```
@@@MIXOUT5_MINOUT=10000
@@@MIXOUT5_MAXOUT=20000
@@@MIXOUT5_ARMRATIO=1
```

Complex case: left Vtail slaved to RUDD and ELEV on PWMOUT3:

```
@@@//RUDL
@@@MIXOUT1_MODE=3
@@@MIXOUT1_RUDDPOS=-100
@@@MIXOUT1_RUDDNEG=100
@@@MIXOUT1_ELEVPOS=100
@@@MIXOUT1_ELEVNEG=-100
@@@MIXOUT1_THRPOS=0
@@@MIXOUT1_THRNEG=0
@@@MIXOUT1_THRBPOS=0
@@@MIXOUT1_THRBNEG=0
@@@MIXOUT1_GROLLPOS=0
@@@MIXOUT1_GROLLNEG=0
@@@MIXOUT1_GPITCHPOS=0
@@@MIXOUT1_GPITCHNEG=0
@@@MIXOUT1_GYAWPOS=0
@@@MIXOUT1_GYAWNEG=0
@@@MIXOUT1_MINOUT=10000
@@@MIXOUT1_MAXOUT=20000
@@@MIXOUT1_ARMRATIO=1
```

Configuring IMU orientation

IMU_GEOMETRY_CONFIG
Values: (0…127)
0 – default geometry
1 – AccelX reverse
2 – AccelY reverse
4 – AccelZ reverse
8 – GyroX reverse
16 – GyroY reverse
32 – GyroZ reverse
64 – Swap X and Y axis
128 – Swap X and Z axis
256 – Swap Y and Z axis
512 – Ignore Z accelerometer (climbing or descending flight only)
1024 – ignore IMU corrections assuming coordinated turns by the airplane

The autopilot can be installed upside-down or flipped 180deg relative to any axis of symmetry (X/Y/Z). In this case, accelerometer and gyro calibration stays the same.

Also, it is possible to swap X/Y axis, for example putting the IMU part inside the wing, while keeping servo outputs in the fuselage. However, swapping the axis, the user must remember to swap accelerometer and gyro calibration values, namely:
IMU_ACCELX_MIN and IMU_ACCELY_MIN
IMU_ACCELX_MAX and IMU_ACCELY_MAX
IMU_GYROX_CENTER and IMU_GYROY_CENTER
IMU_GYROX_SENSITIVITY and IMU_GYROY_SENSITIVITY
IMU_GYROX_MINOUT and IMU_GYROY_MINOUT
IMU_GYROX_MAXOUT and IMU_GYROY_MAXOUT
IMU_GYROX_TEMPADC and IMU_GYROY_TEMPADC
IMU_GYROX_TEMPCOEFF and IMU_GYROY_TEMPCOEFF

Because of a specific choice of IMU hardware, it is not possible to place the autopilot vertically (Z axis must remain vertical).

IMU_MOUNT_OFFSET_X
Default: 0m (-2…2m)
Amount of displacement of the IMU section behind the center of gravity, along the wings.
0.1is 10cm to the right -1 is one meter to the left.
This setting only affects agile platforms achieving high angular rates.

IMU_MOUNT_OFFSET_Y
Default: 0m (-2…2m)
Amount of displacement of the IMU section behind the center of gravity, along the fuselage.
0.1is 10cm behind, -1 is one meter in front.
This setting only affects agile platforms achieving high angular rates.

IMU_MOUNT_OFFSET_Z

Default: 0m (-2…2m)

Amount of displacement of the IMU section above/below the center of gravity.
0.1 is 10cm above, -1 is one meter below.
This setting only affects agile platforms achieving high angular rates.

IMU_MOUNT_OFFSET_ROLL_DEG

Default: 0deg (-30..30deg)

Amount of roll angle to be added to IMU orientation. Affects all feedback loops and turning, stabilized head. The angle should be small, typically a few degrees max in order to not introduce nonlinear cross-coupling in IMU tuning.
For autopilot tilted 5.2 deg to the right, use -5.2.

IMU_MOUNT_OFFSET_PITCH_DEG

Default: 0deg (-30..30deg)

Amount of pitch angle to be added to IMU orientation. Affects all feedback loops, airspeed and altitude hold, stabilized head. The angle should be small, typically a few degrees max in order to not introduce nonlinear cross-coupling in IMU tuning.
For autopilot tilted 8.1 deg up, use -8.1.

IMU_MOUNT_OFFSET_YAW_DEG

Default: 0deg (-30..30deg)

Amount of yaw angle to be added to IMU orientation. Affects all feedback loops, altitude hold in turns, stabilized head. The angle should be small, typically a few degrees max in order to not introduce nonlinear cross-coupling in IMU tuning.
For autopilot turned clockwise 12.3 deg, use -12.3.

Data filtering: the use of ALPHA variables

Analog ADC outputs are filtered using second order Bessel filter.
Cutoff frequencies are 16Hz on all inputs except 1Hz for the airspeed sensor.
This means, for regular ADC inputs, all input signals of the frequency 16Hz are already attenuated by 3dB (half of the signal power, 71% of the amplitude) with additional 20dB attenuation per decade (precisely 12dB per octave, 20dB attenuation for 160Hz signals).

On top of that, there are several places when ALPHA variables are used. Those are first order IIR filters, with infinite memory, 10dB falloff per decade (precisely 6dB per octave).

The formula used for filtering is:

$$value_t = measurement \cdot ALPHA + (1 - ALPHA) \cdot value_{t-1}$$

Obviously 1 means no filtering (immediate update), 0 means no update.

The following formula relates cutoff frequency F_{CUT}, filter update rate F_{UP} (autopilot or feedback loop frequency) and ALPHA value:

$$dt = \frac{1}{F_{UP}}$$

$$RC = \frac{1}{2 \cdot \pi \cdot F_{CUT}}$$

$$ALPHA = \frac{dt}{RC + dt}$$

However, in order to make easier transition to lower or higher frequencies in the autopilot in the future, the ALPHA parameter is stored as if F_{UP} would be 20Hz.
The actual frequency of your autopilot edition (F_{UP}) may differ, be it 48, 32, 25, 24 or 16Hz.
System variables FB_HZ and IMU_HZ reflect this.

For this reason the ALPHA parameter written in autopilot setting files must be renormalized for 32Hz frequency with the formula below:

$$ALPHA_{32} = 1 - (1 - ALPHA)^{\frac{F_{UP}}{32}}$$

Reverse formula for convenience:

$$ALPHA = 1 - (1 - ALPHA_{32})^{\frac{32}{F_{UP}}}$$

By choosing the $ALPHA_{32}$ value from the following table you can obtain desired cutoff frequencies:

Cutoff Freq[Hz]	0.5	1	2	4	5	8
ALPHA32	0.088132	0.160043	0.270799	0.415708	0.466134	0.571384

Cutoff Freq[Hz]	10	12	16	24	32	64
ALPHA32	0.618803	0.655551	0.709129	0.774442	0.813391	0.884387

In other words, when working with alpha values you assume as if the autopilot would be working at 32Hz update rate.

Connection failures and fail-safe behavior

Applying reverse supply voltage will damage the autopilot, always use polarized connectors that will not disconnect in vibrating environment or due to high acceleration during the launch. A good example is T-shaped Deans connector. When using JST connector, apply additional protection against disconnection (good adhesive tape or latches).

If the GPS connector is failing before the takeoff, the TAKEOFF-READY LED will not lit. When GPS data is not detected for more than 2s during the flight, the RETHOME condition is triggered, the event is logged in TRACE and the plane returns home using inertial measurements with about 20-30deg heading accuracy. It is your obligation to intercept the plane with your receiver and bring it down as it will not be able to calculate the distance in the presence of wind.

If any of the ***RC input signals*** other than the ***RC override signal*** are disconnected while the autopilot is in manual mode, the consequences are the same as for any other RC model – loss of one of the control surfaces. However, if the RC receiver is still powered and the ***RC override signal*** is disabled (the autopilot engaged), the autopilot maintains normal control and continues the mission.

If ***MODE_CHANNEL*** is defined but disconnected or not readable, it defaults to magnet-home.
If the RC receiver is simply powered down (***RC override signal*** not present) the autopilot engages immediately and executes same decision set as above (concerning ***MODE_CHANNEL*** and ***RETHOME_CHANNEL***) in order to return home or to continue programmed mission.
In case of failure of ***MODE_CHANNEL*** or ***RC override signal*** the autopilot will head home.

If ***RETHOME_CHANNEL*** is defined to a valid, fixed region (like 12000-15000) the disconnected RC receiver will trigger home condition, log the event in TRACE and return home automatically.

RC receiver channel malfunctions and autopilot action:

RUDD, THR, ELEV channels	**RXOVR Channel #1**	**MODE Channel #2**	**RC disable generated by RXOVR_MODE**	**RETHOME Channel #3**	**Action**
All valid	Low	any	RC Enabled	undefined/OK	Manual control
All valid	High	Low	RC Enabled	undefined/OK	Autopilot enabled, normal navigation
All valid	High	High	RC Enabled	undefined/OK	Autopilot enabled, magnet home, waypoints ignored
All valid	High	Invalid	RC Enabled	undefined/OK	Autopilot enabled, magnet home, waypoints ignored
Invalid	Low	any	RC Enabled	undefined/OK	Manual control, control surface lost
Invalid	High	any	RC Enabled	undefined/OK	Autopilot enabled, manual terrain avoidance not possible
any	Invalid	any	RC Enabled	undefined/OK	Autopilot enabled, magnet home, waypoints ignored
any	any	any	RC Disabled	undefined/OK	Autopilot enabled, normal navigation
any	any	any	any	Invalid	The autopilot cancels navigation, when ON will head home

#1: RXOVR=RC override signal set High is Autopilot Enable

#2: If MODE_CHANNEL is defined as -1, the function is disabled and only 'any' values are applicable
#3: If RETHOME_CHANNEL is defined as -1 or is valid (within defined range), the RETHOME function will not trigger. This works only after takeoff, but once enabled, guarantees non-cancellable return home no matter the other settings

The USB connector has no impact on flight reliability.

The servo signal outputs are protected against overload without negatively affecting their neighbors. However their power supply is shared (typically comes from the ESC). You can consider using separate power supply for trigger servos if they are particularly strong, in order to not overload the ESC thus disabling the power for flight control servos.

When main autopilot power fails, the RC override switches are no longer operational and piloting in manual mode is not possible.

When servo power fails, the autopilot remains fully functional and continues logging using its separate battery source. When ESC is overheated because of the high engine throttle (or extremely hot weather) and badly matched ESC-battery-motor, the linear regulator powering the servos and RC receive which is effectively placed on the same PCB as the ESC might overheat as well, causing temporary servo and RC receiver power shutdown (which will take a several seconds to restore because of regulator thermal protection hysteresis). This will not affect the autopilot, only the control surfaces.

When main power battery for the electric engine is depleted, the ESC is responsible for cutting down the throttle. The autopilot returns home based on flight time or altitude band (see navigation manual - Return-home emergency management).

The order in which the power supplies are being plugged is not important:
-if the main autopilot is being powered before the motor ESC+servos, it outputs the servo signals but the servos are not powered
-if the ESC+servos are powered (using main battery) and the autopilot power input is not powered, the servos are powered but they signal lines are not physically connected to the receiver, hence they will not move (the ESC might emit warning sounds about lost signal in this case).
-it is possible to power both from the same LiPo 3S battery provided that the autopilot power comes from switching regulator (6V output) and the ESC+electric motor noise impact on the system has been tested.