

# Operation manual for BLHeli SiLabs Rev7.x

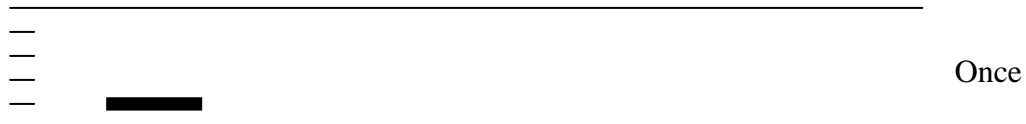
## Normal operation:

This procedure is used for PWM input signal.

Power up:



Throttle up detected (arming sequence start):



The maximum throttle in this interval sets the "arm" target for the governor.

Zero throttle detected (arming sequence end):

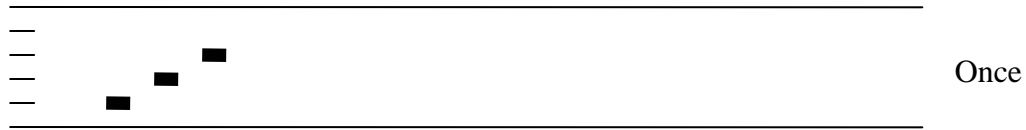


After this, the motor will run.

## Normal operation:

This procedure is used for PPM input signal.

Power up:



Throttle signal detected (arming sequence start):



Zero throttle detected (arming sequence end):

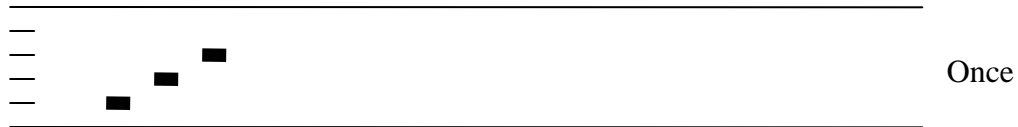


After this, the motor will run.

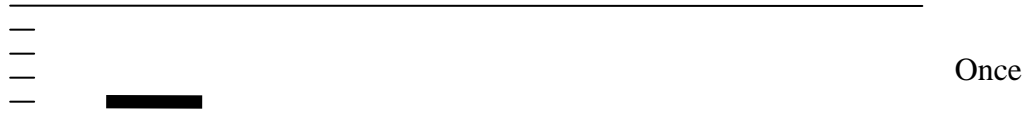
## Entering programming mode:

This procedure is used for PWM input signal.

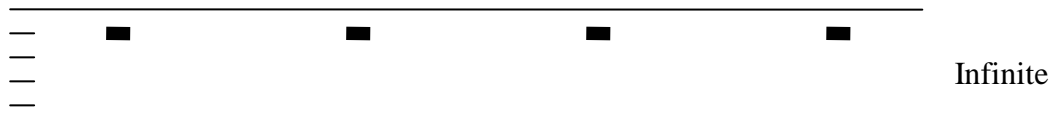
Power up:



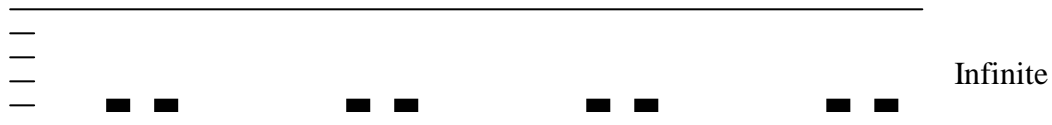
Throttle up detected (arming sequence start):



Full throttle detected (start of entering programming mode):



Zero throttle detected (continue entering programming mode):



Full throttle detected (programming mode entered):



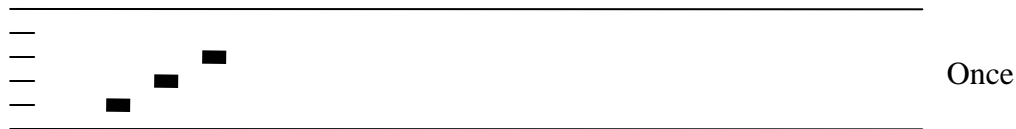
The above description is for main.

For the tail, follow the same sequence, but use right rudder as full throttle and left rudder as zero throttle.

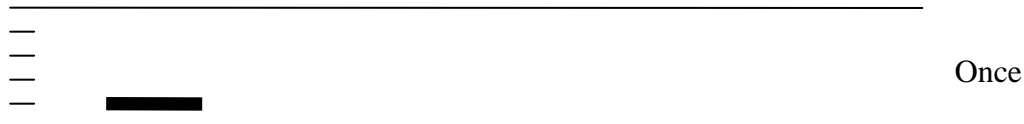
# Throttle range calibration and entering programming mode:

This procedure is used for PPM input signal.

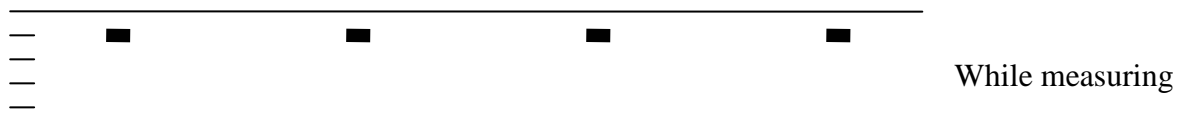
Power up:



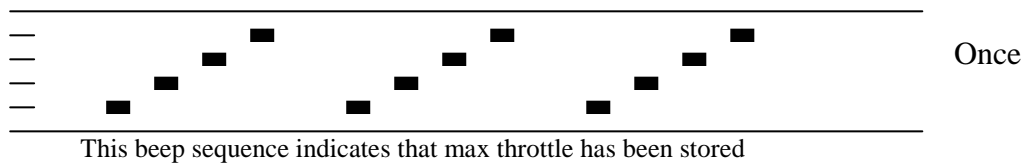
Throttle signal detected (arming sequence start):



When throttle is above midstick (measuring max throttle):



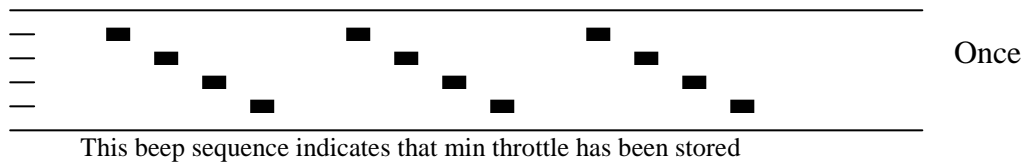
If throttle is above midstick for 3 seconds:



When throttle is below midstick (measuring min throttle):

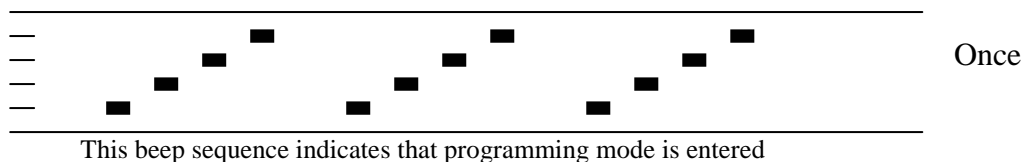


If throttle is below midstick for 3 seconds:



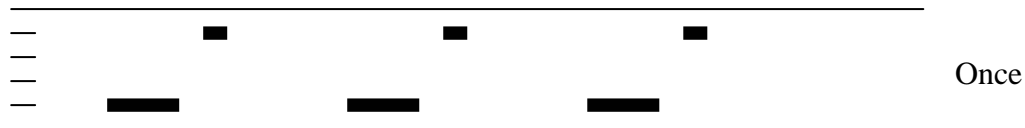
At this point throttle calibration values are stored. You may remove power from the ESC, if you just wanted to do a throttle calibration and not enter programming mode.

Full throttle detected:



## Programming mode:

Function 1, parameter value 1



Function 1, parameter value 2



...etc...

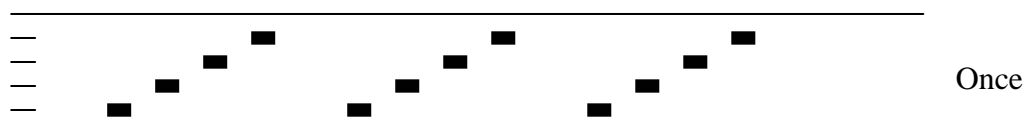
Function 2, parameter value 1



...etc...

If the throttle stick is moved to zero during one of the above sequences, the parameter value of that function is selected and stored. And you will hear this sound:

Parameter value stored



The ESC then resets itself.

If the throttle stick is moved below max (but not to zero), the current parameter will be skipped, and programming will proceed to the next parameter. This way it is possible to access the later parameters without going through all the beeps.

It is generally a good idea to go to full throttle again before selecting a parameter, to make sure you have selected the right parameter.

Throttle is read in the 1 second pause between the function/parameter beeps.

If the throttle stick is never moved to zero, the ESC will reset itself after the last parameter value of the last function. Then no changes are done to the programmed values.

If power is disconnected during the programming sequence, then no changes are done to the programmed values.

## Programming functions and parameter values:

Programming parameter value table main:

Function	1	2	3	4	5	6	7	8	9	10	11	12	13
1 - Governor P gain	0.13	0.17	0.25	0.38	0.50	0.75	<b>1.00</b>	1.5	2.0	3.0	4.0	6.0	8.0
2 - Governor I gain	0.13	0.17	0.25	0.38	0.50	0.75	<b>1.00</b>	1.5	2.0	3.0	4.0	6.0	8.0
3 - Governor mode	<b>Tx</b>	Arm*	Setup	Off	-	-	-	-	-	-	-	-	-
4 - Governor range	<b>High</b>	Low	-	-	-	-	-	-	-	-	-	-	-
5 - Low voltage limit	3.0V/cell	3.1V/cell	<b>3.2V/cell</b>	3.3V/cell	3.4V/cell	-	-	-	-	-	-	-	-
6 - Startup method	<b>Stepped</b>	Direct	-	-	-	-	-	-	-	-	-	-	-
7 - Startup power	0.50	0.75	<b>1.00</b>	1.25	1.50	-	-	-	-	-	-	-	-
8 - Startup rpm	0.67	0.80	<b>1.00</b>	1.25	1.50	-	-	-	-	-	-	-	-
9 - Startup acceleration	<b>0.4</b>	0.7	1.0	1.5	2.3	-	-	-	-	-	-	-	-
10 - Commutation timing	Low	MediumLow	<b>Medium</b>	MediumHigh	High	-	-	-	-	-	-	-	-
11 - Throttle change rate	2	3	4	6	8	12	16	24	32	48	64	128	<b>255</b>
12 - Damping force	<b>VeryLow</b>	Low	MediumLow	MediumHigh	High	-	-	-	-	-	-	-	-
13 - Pwm frequency	High	<b>Low</b>	DampedLight	-	-	-	-	-	-	-	-	-	-
14 - Voltage compensation	<b>Off</b>	On	-	-	-	-	-	-	-	-	-	-	-
15 - Rotation direction	<b>Normal</b>	Reversed	-	-	-	-	-	-	-	-	-	-	-
16 - Input pwm polarity	<b>Positive</b>	Negative	-	-	-	-	-	-	-	-	-	-	-

\*: Governor arm mode is only supported with PWM input signal

Default values are marked in bold **green**.

If for some reason there is an error in the eeprom/flash write operation (e.g. due to loss of power or low voltage), defaults will be loaded.

Programming parameter value table tail:

Function	1	2	3	4	5	6	7	8	9	10	11	12	13
1 - Tail gain	0.75	0.88	<b>1.00</b>	1.12	1.25	-	-	-	-	-	-	-	-
2 - Tail idle speed	Low	MediumLow	Medium	<b>MediumHigh</b>	High	-	-	-	-	-	-	-	-
3 - Startup method	<b>Stepped</b>	Direct	-	-	-	-	-	-	-	-	-	-	-
4 - Startup power	0.50	0.75	<b>1.00</b>	1.25	1.50	-	-	-	-	-	-	-	-
5 - Startup rpm	0.67	0.80	<b>1.00</b>	1.25	1.50	-	-	-	-	-	-	-	-
6 - Startup acceleration	0.4	0.7	1.0	1.5	<b>2.3</b>	-	-	-	-	-	-	-	-
7 - Commutation timing	Low	MediumLow	<b>Medium</b>	MediumHigh	High	-	-	-	-	-	-	-	-
8 - Throttle change rate	2	3	4	6	8	12	16	24	32	48	64	128	<b>255</b>
9 - Damping force	VeryLow	Low	MediumLow	MediumHigh	<b>High</b>	-	-	-	-	-	-	-	-
10 - Pwm frequency	High	Low	<b>DampedLight</b>	<b>Damped*</b>	-	-	-	-	-	-	-	-	-
11 - Voltage compensation	<b>Off</b>	On	-	-	-	-	-	-	-	-	-	-	-
12 - Rotation direction	<b>Normal</b>	Reversed	-	-	-	-	-	-	-	-	-	-	-
13 - Input pwm polarity	<b>Positive</b>	Negative	-	-	-	-	-	-	-	-	-	-	-

\*: Only enabled for some ESCs.

Default values are marked in bold **green**.

If for some reason there is an error in the eeprom/flash write operation (e.g. due to loss of power or low voltage), defaults will be loaded.

Programming parameter value table multi:

Function	1	2	3	4	5	6	7	8	9	10	11	12	13
1 - Multi gain	0.75	0.88	<b>1.00</b>	1.12	1.25	-	-	-	-	-	-	-	-
2 - Low voltage limit	3.0V/cell	3.1V/cell	<b>3.2V/cell</b>	3.3V/cell	3.4V/cell	-	-	-	-	-	-	-	-
3 - Startup method	Stepped	<b>Direct</b>	-	-	-	-	-	-	-	-	-	-	-
4 - Startup power	0.50	0.75	<b>1.00</b>	1.25	1.50	-	-	-	-	-	-	-	-
5 - Startup rpm	<b>0.67</b>	0.80	1.00	1.25	1.50	-	-	-	-	-	-	-	-
6 - Startup acceleration	0.4	0.7	1.0	1.5	<b>2.3</b>	-	-	-	-	-	-	-	-
7 - Commutation timing	Low	MediumLow	<b>Medium</b>	MediumHigh	High	-	-	-	-	-	-	-	-
8 - Throttle change rate	2	3	<b>4</b>	6	8	12	16	24	32	48	64	128	<b>255</b>
9 - Damping force	VeryLow	<b>Low</b>	MediumLow	MediumHigh	High	-	-	-	-	-	-	-	-
10 - Pwm frequency	<b>High</b>	Low	DampedLight	Damped*	-	-	-	-	-	-	-	-	-
11 - Voltage compensation	<b>Off</b>	On	-	-	-	-	-	-	-	-	-	-	-
12 - Rotation direction	<b>Normal</b>	Reversed	-	-	-	-	-	-	-	-	-	-	-
13 - Input pwm polarity	<b>Positive</b>	Negative	-	-	-	-	-	-	-	-	-	-	-

\*: Only enabled for some ESCs.

Default values are marked in bold **green**.

If for some reason there is an error in the eeprom/flash write operation (e.g. due to loss of power or low voltage), defaults will be loaded.



## **Programming parameters for main:**

In the governor “tx” mode, the throttle value while running sets the speed target for the governor.

In this mode, the throttle curve when flying should be flat.

In the governor “arm” mode the maximum throttle seen during the arming sequence will set the speed target for the governor.

Note that governor “arm” mode is not supported for PPM input signal.

In the governor “setup” mode the governor target is stored in the ESC. It’s default value is 70% (about 4800rpm on mCPX with a 6pole motor and an 8T pinion). The value can be changed with configuration software.

In governor “arm” and “setup” modes, the throttle curve when flying does not influence headspeed.

Throttle curve can be set to a V-curve for the desired main to tail mix (this mix is in the mCPX 3in1).

Throttle must be above 20% in these modes. Values below 20% will cause spooldown.

Governor P gain sets the proportional gain for the governor.

This setting controls the gain from speed error to motor power.

Governor I gain sets the integral gain for the governor.

This setting controls the gain from integrated speed error (summed over time) to motor power.

Governor range sets the available range of speeds that the governor can operate on.

- For the high range, throttle values from 25% to 100% will lead to governor targets from 70000 to 208000 electrical rpm

- For the low range, throttle values from 25% to 100% will lead to governor targets from 20000 to 89000 electrical rpm

The low range is primarily intended for low pole count motors (e.g. 2-pole inrunners).

The low voltage limit sets the voltage at which motor power is reduced.

Motor power is reduced while at this voltage, but only temporarily, and full power is resumed if the voltage rises again.

### **Programming parameters for tail/multi:**

Tail/multi gain scales the power applied to the motor for a given input.  
Beware that a low tail/multi gain will also limit the maximum power to the motor.

Tail idle speed is the speed of the motor during the delayed stop.

### **Programming parameters for main/tail/multi:**

The startup method selects which method is used to start the motor.

Stepped method first runs the motor as a stepper motor at a given power, rpm and acceleration. This is done for an rpm range selected by the rpm parameter. Normal running begins after this.

Direct startup method runs the motor using back emf detection from the very start. In this mode power is given by the throttle used, but limited to a maximum level. This maximum level can be controlled with the startup power parameter.

Startup power, rpm and acceleration are parameters that control the startup of the motor for the first initial rotations only (about a second or less).

Startup power sets the power applied to the motor in this phase.

Startup rpm is used for stepped method only, and sets the rotational speed with which the motor is started.

Startup acceleration is used for stepped method only, and sets the rate at which the motor is accelerated.

If required, these parameters can be used to optimize motor startup for different motors and loads.

Commutation timing can be adjusted in three steps. Low is about 0°, mediumlow 8°, medium 15°, mediumhigh 23° and high 30°.

Typically a medium setting will work fine, but if the motor stutters it can be beneficial to change timing.

Some motors with high inductance can have a very long commutation demagnetization time. This results in motor stop or stutter upon quick throttle increase, particularly when running at a low rpm. Setting timing to high will allow more time for demagnetization, and often helps.

The throttle change rate parameter is an additional mechanism to avoid demagnetization problems. Setting this parameter to a low value will result in slow changes in motor power. Which of course is not desirable in order to have a responsive motor, but in some cases it can be required. This parameter determines how many steps motor power is allowed to increase for each new received input pulse. Full motor power is 255 steps.

So, e.g. for a 400Hz input rate and a throttle change rate setting of 2, motor power can change 2 steps every 2.5ms. Which means that zero to full power will take  $(255/2)*2.5\text{ms}=319\text{ms}$ , which is really slow. On the other hand, the default setting of 255 means that motor power can change from zero to full power instantly.

High pwm frequency is around 20-25kHz, and low pwm frequency is around 8-12kHz.

One benefit of using a low pwm frequency is that the step from almost full power to full power becomes smaller. On the other hand, 8kHz is in the audible frequency range, and also there is a step in power when the motor rotation frequency is equal to the pwm frequency.

Pwm damped mode adds loss to the motor for faster retardation. Damped mode always uses high pwm frequency.

In full damped mode, all three motor terminals are shorted when pwm is off, while in damped light mode, two motor terminals are shorted.

The full damped mode is only supported on some ESCs (where fet switching is sufficiently fast).

If one of the damped modes is selected, then the damping strength can be varied.

If damping is high, loss is added in 7 out of 9 pwm cycles.

If damping is medium high, loss is added in 3 out of 5 pwm cycles.

If damping is medium low, loss is added in 2 out of 5 pwm cycles.

If damping is low, loss is added in 1 out of 5 pwm cycles.

If damping is very low, loss is added in 1 out of 9 pwm cycles.

Damped mode may result in uneven running at low speeds on some motor/ESC/voltage combinations.

This can be seen on high electrical rpm systems, with high damping force and an ESC with slow switching fets.

If this is a problem, reduce the damping force or use an ESC with faster switching fets.

Voltage compensation is a feature whereby the voltage is measured and used to compensate motor power. This can have a beneficial effect on governor speed accuracy. And possibly also tail accuracy.

The rotation direction setting can be used to reverse motor rotation.

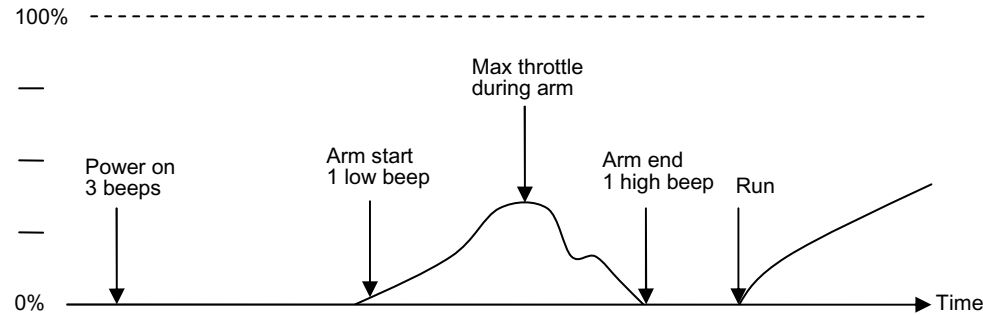
The input pwm polarity setting can be used to inverse the throttle behaviour. This is intended to be used with receivers that provide negative pwm (at least some Walkeras do). When using PPM input it must be set to positive.

**Programming parameters that can only be accessed from configuration software (BLHeliSetup, BLHeliTool):**

- Throttle minimum and maximum values for PPM input (will also be changed by doing a throttle calibration).
- Governor setup mode rpm target.
- Beep strength, beacon strength and beacon delay.
- Programming by TX. If disabled, the TX can not be used to change parameter values (default is enabled).
- Re-arming every start. If enabled, a new arming sequence will be required for every startup, not just the first after poweron (default is disabled).

## Arming sequence:

The figure below shows an example of throttle value versus time.



At power on, the ESC beeps 3 beeps.

For PWM input, the following applies:

When throttle is raised above zero, it beeps one low tone beep. This signals the start of the arming sequence.

When throttle is reduced to zero again, it beeps one high tone beep. This signals the end of the arming sequence.

For PPM input, the following applies:

When throttle signal is detected, it beeps one low tone beep. This signals the start of the arming sequence.

When throttle is reduced to zero again, it beeps one high tone beep. This signals the end of the arming sequence.

For a main motor esc running with PWM input, throttle is monitored during the arming sequence. The maximum value of throttle is recorded.

If governor arm mode is selected, this value will be used as the governor speed target when the motor starts running.

When running, the throttle input has no effect, as long as it is not below 20%.

Also, if 100% throttle is detected during the arming sequence, the ESC starts entering programming mode.

When restarting main motor after a stop, there is a 3 second delay from motor stop has been initiated until a new start can commence.

The main motor has a soft spoolup of about 8 seconds for full power.

If the esc is armed and sees zero throttle for a given time, it beeps beacon beeps, which are about 1 beep per second

## Input signal:

The ESC accepts both positive and negative PWM, as well as PPM as input signal.

The type of input signal is auto detected during the arming sequence.

The only input signal that requires changing the default parameters, is negative PWM.

PWM is accepted as 8kHz (mCPX v1), 4kHz, 2kHz (several Walkeras) and 1kHz (mCPX v2).

PPM has a default throttle range of 1150us-1830us, and accepts rates from the normal 50Hz up to several hundred Hz.

Available throttle calibration range for PPM is from 1000us to 2000us, and the difference between minimum and maximum throttle must be more than 520us. If a calibration is done where the difference is less than 520us, the maximum will be shifted so that the difference is 520us.

## Thermal protection:

The ESC measures temperature within the MCU and limits motor power if the temperature is too high.

Motor power is limited in four steps:

- If the temperature is above 140<sup>0</sup>C, motor power is limited to 75%.
- If the temperature is above 145<sup>0</sup>C, motor power is limited to 50%.
- If the temperature is above 150<sup>0</sup>C, motor power is limited to 25%.
- If the temperature is above 155<sup>0</sup>C, motor power is limited to 0%.

Note: The above is valid for rev4.1 and up. For rev4.0, these limits were 85<sup>0</sup>C to 130<sup>0</sup>C

## Revision history:

- Rev1.0: Initial revision based upon BLHeli for AVR controllers
- Rev2.0: Changed "Eeprom" initialization, layout and defaults
  - Various changes and improvements to comparator reading. Now using timer1 for time from pwm on/off
  - Beeps are made louder
  - Added programmable low voltage limit
  - Added programmable damped tail mode (only for 1S ESCs)
  - Added programmable motor rotation direction
- Rev2.1: (minor changes by 4712)
  - Added Disable TX Programming by PC Setup Application
  - therefore changed EEPROM\_LAYOUT\_REVISION = 8
  - Added Vdd Monitor as reset source when writing to "EEProm"
  - Changed for use of batch file to assemble, link and make hex files
- Rev2.2: (minor changes by 4712)
  - Added Disable Throttle Re-Arming every motor start by PC Setup Application
- Rev2.3: (minor changes by 4712)
  - Added bugfixed (2x CLR C before j(n)c operations)thx Steffen!
- Rev2.4: Revisions 2.1 to 2.3 integrated
- Rev3.0: Added PPM (1050us-1866us) as accepted input signal
  - Added startup rpm as a programming parameter
  - Added startup acceleration as a programming parameter
  - Added option for using voltage measurements to compensate motor power
  - Added governor target by setup as a governor mode option
  - Governor is kept active regardless of rpm
  - Smooth governor spoolup/down in arm and setup modes
  - Increased governor P and I gain programming ranges
  - Increased and changed low voltage limit programming range
  - Disabled tx programming entry for all but the first arming sequence after power on
  - Made it possible to skip parameters in tx programming by setting throttle midstick
  - Made it default not to rearm for every restart
- Rev3.1: Fixed bug that prevented chosen parameter to be set in tx programming
- Rev3.2: ...also updated the EEPROM revision parameter
- Rev3.3: Fixed negative number bug in voltage compensation

- Fixed bug in startup power calculation for non-default power
- Prevented possibility for voltage compensation fighting low voltage limiting
- Applied overall spoolup control to ensure soft spoolup in any mode
- Added a delay of 3 seconds from initiation of main motor stop until new startup is allowed
- Reduced beep power to reduce power consumption for very strong motors/ESCs
- Rev3.4: Fixed bug that prevented full power in governor arm and setup modes
  - Increased NFETON\_DELAY for XP\_7A and XP\_12A to allow for more powerful fets
  - Increased initial spoolup power, and linked to startup power
- Rev4.0: Fixed bug that made tail tx program beeps very weak
  - Added thermal protection feature
  - Governor P and I gain ranges are extended up to 8.0x gain
  - Startup sequence is aborted upon zero throttle
  - Avoided voltage compensation function induced latency for tail when voltage compensation is not enabled
  - Improved input signal frequency detection robustness
- Rev4.1: Increased thermal protection temperature limits
- Rev5.0: Added multi(copter) operating mode. TAIL define changed to MODE with three modes: MAIN, TAIL and MULTI
  - Added programmable commutation timing
  - Added a damped light mode that has less damping, but that can be used with all escs
  - Added programmable damping force
  - Added thermal protection for startup too
  - Added wait beeps when waiting more than 10 sec for throttle above zero (after having been armed)
  - Modified tail idling to provide option for very low speeds
  - Changed PPM range to 1150-1830us
  - Arming sequence is dropped for PPM input, unless it is governor arm mode
  - Loss of input signal will immediately stop the motor for PPM input
  - Bug corrected in Turnigy Plush 6A voltage measurement setup
  - FET switching delays are set for original fets. Stronger/doubled/tripled etc fets may require faster pfet off switching
  - Miscellaneous other changes
- Rev6.0: Reverted comparator reading routine to rev5.0 equivalent, in order to avoid tail motor stops
  - Added governor range programmability
  - Implemented startup retry sequence with varying startup power for multi mode
  - In damped light mode, damping is now applied to the active nfet phase for fully damped capable ESCs
- Rev6.1: Added input signal qualification criteria for PPM, to avoid triggering on noise spikes (fix for plush hardware)
  - Changed main and multi mode stop criteria. Will now be in run mode, even if RC pulse input is zero



Fixed bug in commutation that caused rough running in damped light mode

Miscellaneous other changes

- Rev7.0 Added direct startup mode programmability

Added throttle calibration. Min $\geq$ 1000us and Max $\leq$ 2000us. Difference must be  $>520$ us, otherwise max is shifted so that difference=520us

Added programmable throttle change rate

Added programmable beep strength, beacon strength and beacon delay

Reduced power step to full power significantly

Miscellaneous other changes