Operation manual for BLHeli Atmel Rev14.x

BLHeli firmware is designed for use in brushless ESCs in helicopters, multirotors, planes and more.

The firmware supports a multitude of ESC hardware.

There are three versions of the code:
- Main: Intended for helicopter main motor, and supports:
  - Soft spoolup
  - Governor
  - Low voltage limiting
- Tail: Intended for helicopter tail motor, and supports:
  - Rapid throttle response
  - Idling (the motor runs a few seconds after throttle is zeroed, in order to avoid stops in the air)
  - Bidirectional operation
- Multi: Intended for multirotor motors, and supports:
  - Rapid throttle response
  - Closed loop operation
  - Bidirectional operation

All codes run the motor smoothly and with good throttle linearity.

All codes support a damped light mode (on hardware that support it).
Damped light does braking, causing very fast motor retardation, and inherently does active freewheeling.

All codes support features to prevent sync loss. This is mostly required in multirotor applications. There are tuneable parameters that can make the code run well with almost any motor.

All codes support 1kHz, 2kHz, 4kHz, 8kHz and 12kHz PWM input signal in environments where the ESC takes its input from a source that would normally drive a brushed motor. The code also supports regular 1-2ms pulse width PPM input or OneShot125 (125-250us), at a rate up to almost 1kHz. The input signal is automatically detected by the ESC upon power up.

All codes support a beacon functionality, where the ESC will start beeping after a given time of zero throttle. This can be very useful for finding lost crafts.

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	**1.00**	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	**1.00**	1.5	2.0	3.0	4.0	6.0	8.0
3 - Governor mode	**Tx**	Arm*	Setup	Off	-	-	-	-	-	-	-	-	-
4 - Governor range	**High**	Middle	Low	-	-	-	-	-	-	-	-	-	-
5 - Low voltage limit (/cell)	Off	3.0V	3.1V	**3.2V**	3.3V	3.4V	-	-	-	-	-	-	-
6 - Startup power**	0.031	0.047	0.063	0.094	0.125	0.188	0.25	0.38	0.50	0.75	1.00	1.25	1.50
7 - Commutation timing	Low	MediumLow	**Medium**	MediumHigh	High	-	-	-	-	-	-	-	-
8 - Pwm frequency	High	**Low**	DampedLight	-	-	-	-	-	-	-	-	-	-
9 - Demag compensation	**Off**	Low	High	-	-	-	-	-	-	-	-	-	-
10 - Rotation direction	**Normal**	Reversed	-	-	-	-	-	-	-	-	-	-	-
11 - Input pwm polarity	**Positive**	Negative	-	-	-	-	-	-	-	-	-	-	-

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

**: Default startup power varies by ESC. Generally the default power is lower for larger 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 tail:

Function	1	2	3	4	5	6	7	8	9	10	11	12	13
1 - Tail gain	0.75	0.88	**1.00**	1.12	1.25	-	-	-	-	-	-	-	-
2 - Tail idle speed	Low	MediumLow	Medium	**MediumHigh**	High	-	-	-	-	-	-	-	-
3 - Startup power**	0.031	0.047	0.063	0.094	0.125	0.188	0.25	0.38	0.50	0.75	1.00	1.25	1.50
4 - Commutation timing	Low	MediumLow	**Medium**	MediumHigh	High	-	-	-	-	-	-	-	-
5 - Pwm frequency	**High**	Low	**DampedLight***	-	-	-	-	-	-	-	-	-	-
6 - Pwm dither	Off	7	**15**	31	63	-	-	-	-	-	-	-	-
7 - Demag compensation	**Off**	Low	High	-	-	-	-	-	-	-	-	-	-
8 - Rotation direction	**Normal**	Reversed	Bidirectional	-	-	-	-	-	-	-	-	-	-
9 - Input pwm polarity	**Positive**	Negative	-	-	-	-	-	-	-	-	-	-	-

*: Only enabled for some ESCs.
**: Default startup power varies by ESC. Generally the default power is lower for larger 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 - Closed loop P gain	0.13	0.17	0.25	0.38	0.50	0.75	1.00	1.5	**2.0**	3.0	4.0	6.0	8.0
2 - Closed loop I gain	0.13	0.17	0.25	0.38	0.50	0.75	1.00	1.5	**2.0**	3.0	4.0	6.0	8.0
3 - Closed loop mode	HiRange	MidRange	LoRange	**Off**	-	-	-	-	-	-	-	-	-
4 - Multi gain	0.75	0.88	**1.00**	1.12	1.25	-	-	-	-	-	-	-	-
5 - Startup power**	0.031	0.047	0.063	0.094	0.125	0.188	0.25	0.38	0.50	0.75	1.00	1.25	1.50
6 - Commutation timing	Low	MediumLow	**Medium**	MediumHigh	High	-	-	-	-	-	-	-	-
7 - Pwm frequency	**High**	Low	DampedLight*	-	-	-	-	-	-	-	-	-	-
8 - Pwm dither	Off	7	**15**	31	63	-	-	-	-	-	-	-	-
9 - Demag compensation	Off	**Low**	High	-	-	-	-	-	-	-	-	-	-
10 - Rotation direction	**Normal**	Reversed	Bidirectional	-	-	-	-	-	-	-	-	-	-
11 - Input pwm polarity	**Positive**	Negative	-	-	-	-	-	-	-	-	-	-	-

*: Only enabled for some ESCs.

**: Default startup power varies by ESC. Generally the default power is lower for larger 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 middle range, throttle values from 25% to 100% will lead to governor targets from 39000 to 156000 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.
Low voltage limiting can also be disabled.

Programming parameters for multi:

In the closed loop mode, the throttle value while running sets the rpm target of the motor.

Closed loop P gain sets the proportional gain for the rpm control loop.
This setting controls the gain from speed error to motor power.

Closed loop I gain sets the integral gain for the rpm control loop.
This setting controls the gain from integrated speed error (summed over time) to motor power.

Closed loop mode sets the range of speeds that the control loop can operate on.
- For the high range, throttle values from 0% to 100% linearly correspond to rpm targets from 0 to 200000 electrical rpm
- For the middle range, throttle values from 0% to 100% linearly correspond to rpm targets from 0 to 100000 electrical rpm
- For the low range, throttle values from 0% to 100% linearly correspond to rpm targets from 0 to 50000 electrical rpm

When closed loop mode is set to off, the control loop is disabled.

Programming parameters for tail/multi:

Tail/multi gain scales the power applied to the motor for a given input. Note that this is only for PWM input, for PPM input it has no effect.
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.

Rotation direction can be set to "bidirectional" for tail and multi codes.
In this mode, center throttle is zero and above is fwd rotation and below is reverse rotation.
Bidirectional operation is only supported for PPM input signal.
When bidirectional operation is selected, programming by TX is disabled.
Motor rotation performance can be somewhat controlled by startup power. Higher startup power can give faster reversal, but at some point it can also lead to motor occasionally stalling.

Pwm dither is a parameter that adds some variation to the motor pwm off cycle length. This can reduce problems (like throttle steps or vibration) in rpm regions where the pwm frequency is equal to harmonics of the motor commutation frequency, and it can reduce the step to full throttle. It is primarily beneficial when running damped light mode. Dither is not applied in closed loop mode.

Programming parameters for main/tail/multi:

Startup is always done with the direct startup method, which 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. Beware that setting startup power too high can cause excessive loading on ESC or motor!

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

High pwm frequency is around 16kHz, and low pwm frequency is around 8kHz.
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 light mode adds loss to the motor for faster retardation. Damped light mode always uses high pwm frequency.
In damped light mode, two motor terminals are shorted when pwm is off.
The damped light mode is only supported on some ESCs (where fet switching is sufficiently fast).

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.

Demag compensation is a feature to protect from motor stalls caused by long winding demagnetization time after commutation. The typical symptom is motor stop or stutter upon quick throttle increase, particularly when running at a low rpm. As described earlier, setting high commutation timing normally helps, but at the cost of efficiency.

The demag compensation is an alternative way of combating the issue. First of all, it detects when a demag situation occurs.
- In this situation, there is no info on motor timing, and commutation proceeds blindly with a predicted timing.
- In addition to this, motor power is cut off some time before the next commutation.

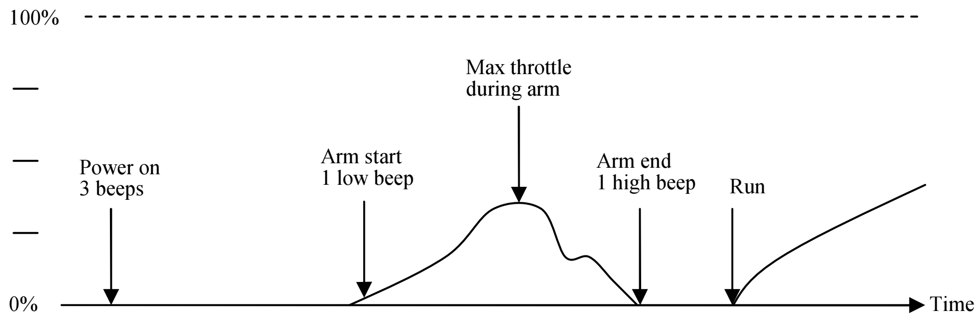
A metric is calculated that indicates how severe the demag situation is. The more severe the situation, the longer power is cut off.
When demag compensation is set to off, power is never cut.
When setting it to low or high, power is cut. For a high setting, power is cut more aggressively.

Generally, a higher value of the compensation parameter gives better protection.
If demag compensation is set too high, maximum power can be somewhat reduced.

Programming parameters that can only be accessed from configuration software (BLHeliSuite):
- Throttle minimum and maximum values for PPM input (will also be changed by doing a throttle calibration).
- Throttle center value for bidirectional operation with PPM.
- Main motor spoolup time. Legal range is 1 to 17, values outside are clipped.
- 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).
- High/low BEC voltage for ESCs that support it (default is low).
- Thermal protection can be enabled or disabled (default is disabled).
- PWM input can be enabled or disabled (default is disabled). If disabled, only 1-2ms PPM and 125-250us OneShot125 are accepted as valid input signals. Set to disabled if using OneShot125 with looptimes below 1100.
- Power limiting for low RPMs can be enabled or disabled (default is enabled). Disabling it can be necessary in order to achieve full power on some low kV motors running on a low supply voltage. However, disabling it increases the risk of toasting motor or ESC.

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.
Then, when or if throttle is zero, 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.

The main motor has a soft spoolup of some 3-10 seconds for full power. The spoolup is done in three phases, in order to be soft enough for the heli not to move, particularly before tail rpm is high enough to give some tail authority. In the first phase power is limited to the startup power for about one second. Then the power limit is slowly increased over the next three seconds. And in the final phase the power limit is increased more rapidly, until full power is available.

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

Auto bailout (for main):

The auto bailout function works as described below.

The first start after powerup will always have a soft spoolup.
When the motor is fully spooled up, auto bailout is armed.
When auto bailout is armed, spoolup will be faster, with about 2 seconds for full power.
If then throttle is at a low non-zero value bailout remains armed. Even if the motor stops at times.
If a zero throttle value is seen, auto bailout is disarmed immediately, and the next spoolup will be soft.

Auto bailout only works for governed main motor operation.
For non-governed main motor operation, throttle response is always fast after spoolup is done.

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 12kHz, 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.

OneShot125 mode works just the same as PPM mode, the only difference is that all timing is divided by 8.
Most Atmel based ESCs can not measure the input signal pulse length by HW. This means that the pulse length measurement will have some variation, that will show up as somewhat uneven running, particularly at low rpms.
Afros and a few other ESCs use the ICP1 pin for signal input. This enables use of HW for measuring input pulse length, and therefore they run more smooth with OneShot125 input signal.

Thermal protection:

The ESC measures temperature limits motor power if the temperature is too high.
Motor power is limited in four steps:
- If the temperature is above 140^0C, motor power is limited to 75%.
- If the temperature is above 145^0C, motor power is limited to 50%.
- If the temperature is above 150^0C, motor power is limited to 25%.
- If the temperature is above 155^0C, motor power is limited to 0%.

Not all ESCs have the hardware required for temperature measurement.

Stall protection:

From rev 14.2, the code also provides stall protection.
If the motor has attempted to start but not succeeded for a few seconds, it will stop attempting and wait for throttle to be zeroed before attempting again.

Braking / active freewheeling:

Damped light mode is implemented by doing braking, and inherently active freewheeling is also implemented.
Then losses due to braking are counteracted by the reduced losses of active freewheeling.

Maximum speeds:

From rev 14.2, the code also provides overspeed protection.
Maximum speed is limited to 250k eRPM, at which point power to the motor is limted.

The maximum speed can be lower if running closed loop.

Beeps - Normal operation:

This procedure is used for PWM input signal.

Power up:

Once

Throttle up detected (arming sequence start):

Once

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

Zero throttle detected (arming sequence end):

Once

After this, the motor will run.

Beeps - Normal operation:

This procedure is used for PPM input signal.

Power up:

Once

Throttle signal detected (arming sequence start):

Once

Zero throttle detected (arming sequence end):

Once

After this, the motor will run.

Beeps - Entering programming mode:

This procedure is used for PWM input signal.

Power up:

Once

Throttle up detected (arming sequence start):

Once

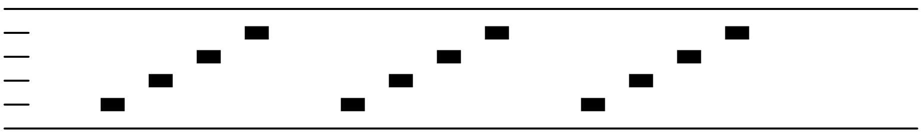
Full throttle detected (start of entering programming mode):

Infinite

Zero throttle detected (continue entering programming mode):

Infinite

Full throttle detected (programming mode entered):



Once

The above description is for main or multi.
For the tail, follow the same sequence, but use right rudder as full throttle and left rudder as zero throttle.

Beeps - Throttle calibration and entering programming mode:

This procedure is used for PPM input signal.

Power up:

Once

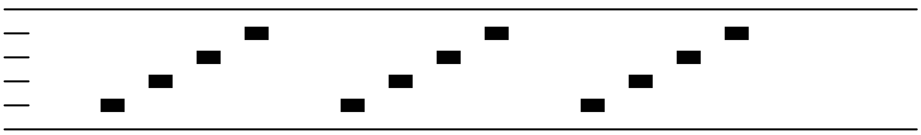
Throttle signal detected (arming sequence start):

Once

When throttle is above midstick (measuring max throttle):

While measuring

If throttle is above midstick for 3 seconds:



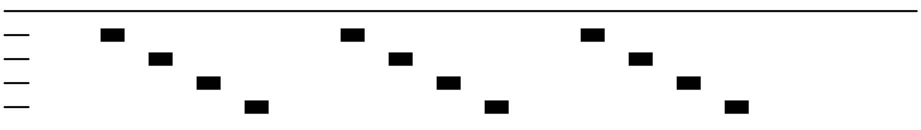
Once

This beep sequence indicates that max throttle has been stored

When throttle is below midstick (measuring min throttle):

While measuring

If throttle is below midstick for 3 seconds:

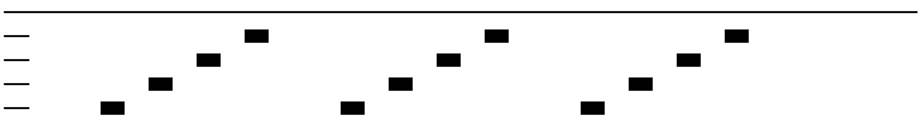


Once

This beep sequence indicates that min throttle has been stored

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:

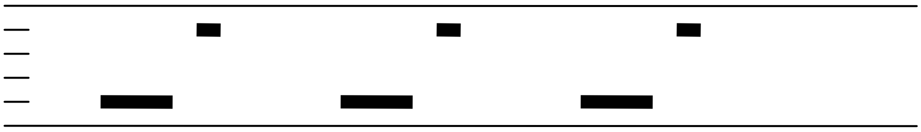


Once

This beep sequence indicates that programming mode is entered

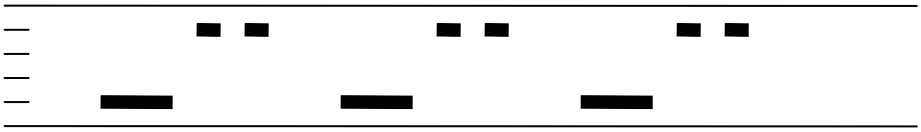
Beeps - Programming mode:

Function 1, parameter value 1



Once

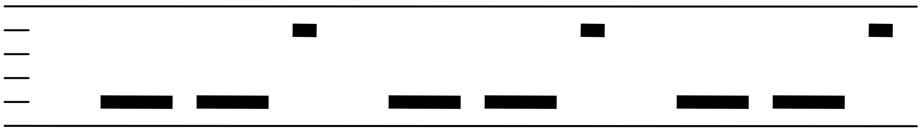
Function 1, parameter value 2



Once

…etc…

Function 2, parameter value 1

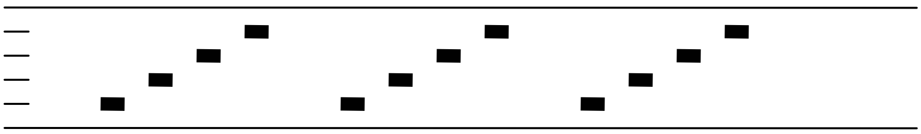


Once

…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



Once

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 load the defaults and then reset itself after the last parameter value of the last function. This is a convenient way of setting all parameters to defaults.

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

Revision history:

- Rev11.2 Ported from the SiLabs version
- Rev12.0 Added programmable main spoolup time
  Added programmable temperature protection enable
  Bidirectional mode stop/start improved. Motor is now stopped before starting
  Power is limited for very low rpms (when BEMF is low), in order to avoid sync loss
  Damped light mode is made more smooth and quiet, particularly at low and high rpms
  Comparator signal qualification scheme is changed
  Demag compensation scheme is significantly changed
  Increased jitter tolerance for PPM frequency measurement
  Fully damped mode removed, and damped light only supported on damped capable ESCs
  Default tail mode changed to damped light
  Miscellaneous other changes
- Rev12.1 Fixed bug in tail code
  Improved startup for Atmel
  Added support for multiple high BEC voltages
  Added support for RPM output
- Rev12.2 Improved running smoothness, particularly for damped light
  Avoiding lockup at full throttle when input signal is noisy
  Avoiding detection of 1-wire programming signal as valid throttle signal
- Rev13.0 Removed throttle change rate and damping force parameters
  Temperature protection default set to off
  Added support for OneShot125
  Improved commutation timing accuracy
- Rev13.1 Removed startup ramp for MULTI
  Improved startup for some odd ESCs
- Rev13.2 Still tweaking startup to make it more reliable and faster for all ESC/motor combos
  Increased deadband for bidirectional operation
  Relaxed signal detection criteria
  Miscellaneous other changes

- Rev14.0 Improved running at high RPMs and increased max RPM limit
  Improved reliability of 3D (bidirectional) mode and startup
  Avoid being locked in bootloader (implemented in Suite 13202)
  Smoother running and greatly reduced step to full power in damped light mode
  Removed low voltage limiting for MULTI
  Added pwm dither parameter
  Added setting for enable/disable of low RPM power protection
  Added setting for enable/disable of PWM input
  Better AFW and damping for some ESCs (that have a slow high side driver)
  Miscellaneous other changes
- Rev14.1 Fixed max throttle calibration bug (for non-oneshot)
  Fixed some closed loop mode bugs
  Relaxed signal jitter requirement for looptimes below 1000
  Added skipping of damping fet switching near max power, for improved high end throttle linearity, using the concept of SimonK
  Improved sync hold at high rpms
- Rev14.2 Improved quality of comparator reading, giving better bemf detection (for improved startup amongst others)
  Removed mechanism where some ESCs could reset upon starting motor (due to ADC being read)
  Added stalled motor shutoff after about 10 seconds (for tail and multi code with PPM input)
  Greatly increased maximum rpm limit, and added rpm limiting at 250k erpm
  Improved bidirectional operation
- Rev14.3 Moved reset vector to be just before the settings segment, in order to better recover from partially failed flashing operation
  Shortened stall detect time to about 5sec, and prevented going into tx programming after a stall
  Optimizations of software timing and running reliability