Multi-Rotor 35
Brushless DC Speed Control

1 DESCRIPTION

The Castle Creations Multi-Rotor 35 Electronic Speed Controllers (ESCs) are self-contained sensorless brushless DC (BLDC) motor controllers, designed for use in high performance multi-rotor aircraft.

The Multi-Rotor 35 ESCs contain all the necessary hardware and software to drive three phase BLDC motors given input power and a control signal. Extremely low internal resistance and a unique Adaptive Timing System maximize efficiency and power output across the entire throttle range for maximized power and flight times. The output power resolution is extremely fine with exceptional linearity between throttle input and power output. Throttle latency is minimal, which when combined with the Adaptive Timing System provides superior input signal to output power response for improved vehicle stability.

The ESCs provide a number of programmable settings to allow tuning for various setups. With the use of a Castle Link USB adapter or Castle Field Link settings can be easily changed through the receiver wire on the ESC. The firmware can also be updated allowing for future support and feature updates. Throttle calibration and motor rotation settings can also be easily configured in the field allowing without additional hardware for very quick vehicle setup.

1.1 FEATURES

- Wide input voltage range (6.0-25.2V)
- High Maximum electrical RPM (300,000 eRPM)
- Adaptive Timing System for Increased Power and Efficiency
- Low Internal Resistance for Maximum Efficiency (1.40 mΩ phase resistance)
- Low Latency Throttle Response (< 75 µs)
- Auto Detecting Servo PWM, OneShot (>600 Hz), and OneShot 125 (4000 Hz) input options
- Very Linear Throttle Response
- Active Braking
- Programmable via Castle Link USB Adapter
- Throttle Calibration and Motor Direction can be easily configured in the field without additional hardware
- Two versions: one with a low noise 5.6V 6A switching Battery Eliminator Circuit (BEC), and one with no BEC to reduce weight

1.2 TARGET APPLICATIONS

- FPV Racing Drones
- Battle Drones
- Large Camera-Carrying Multi-Rotors
- Large Payload-Carrying Multi-Rotors

FIGURE 1: MULTI-ROTOR 35 W/BEC

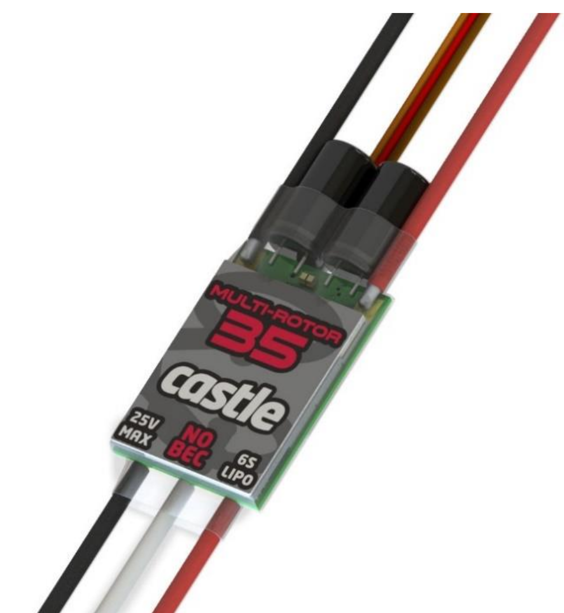

FIGURE 2: MULTI-ROTOR 35 NO BEC

2 CONTENTS

3 Technical Specifications

3.1 Absolute Max Ratings

Characteristic	Min	Max	Unit
Maximum Input Voltage	-0.3	30	V
Heatsink Temperature	-25 (-13)	130 (266)	°C (°F)
BEC Line Voltage (w/BEC)[1]	-0.3	Min(8.5, V_{in} + 0.3)	V
BEC Line Voltage (No BEC)[2]	-0.3	12	V

[1]Specification only applies to the Multi-Rotor 35 w/BEC units.
[2]Specification only applies to the Multi-Rotor 35 "NO BEC" units.

3.2 Electrical Specifications

Characteristics at 25°C (77°F) unless stated otherwise.

Characteristic	Minimum	Typical	Maximum	Unit
Operating Input Voltage	6.0		25.2	V
BEC Output Voltage (w/ BEC)[1]		5.6		V
BEC Output Peak Current (w/ BEC)[1]			7.0	A
BEC Output Continuous Current (w/ BEC)[1]			5.0	A
Operating BEC Input Voltage (No BEC)[2]	4.5		8.0	V
BEC Input Current @ 12V, 100,000 eRPM (No BEC)[2]		58.2		mA
Current @ 5 mph (8 km/h) airflow[3]			35.0	A
Current @ 40 mph (64 km/h) airflow[3]			50.0	A
Fundamental Frequency[4]			300 000	eRPM
PWM Switching Frequency		8-16, Dynamic		kHz
MOSFET Resistance[5]		0.94		mΩ
MOSFET Bank Resistance[6]		0.94		mΩ
ESC Phase Resistance[7]		1.40		mΩ
ESC Loop Resistance[8]		2.80		mΩ

[1]Specification only applies to the Multi-Rotor 35 w/BEC units.
[2]Specification only applies to the Multi-Rotor 35 "NO BEC" units. "NO BEC" units require a BEC supply voltage in order to operate. It is recommended to use the supply from a Multi-Rotor 35 "w/BEC" unit to power Multi-Rotor 35 "NO BEC" units.
[3]Current is specified as the maximum value the ESC can handle at full throttle for the duration of a single 4,000 mAh battery pack with the ESC in the specified speed of 25°C (77°F) or cooler airflow. Controller temperature must never exceed 100°C (212°F). Exceeding current or temperature ratings may damage components and may shorten the life of the ESC. Always verify system current draw at full-throttle. Decrease load or increase airflow to decrease the ESC's operating temperature.
[4]Electrical RPM (eRPM) is the equivalent fundamental driving frequency of a 2 pole motor running at the specified RPM. To calculate eRPM use the following equation: eRPM = [Motor RPM] * [Number of Motor Poles] / 2.
[5]Drain to source resistance of single MOSFET contained within one of the six MOSFET banks when fully enhanced.
[6]Drain to source resistance of one of the six MOSFET banks when fully enhanced.
[7]Average resistance from Vin to phase output or Gnd to phase output when MOSFET banks are fully enhanced.
[8]Average resistance from Vin to Gnd when phase outputs are shorted and MOSFET banks are fully enhanced.

3.3 Physical Specifications

Characteristic	Value	Unit
Mass with wires (w/BEC)[1]	25.2 (0.889)	g (oz)
Mass without wires (w/BEC)[1]	13.1 (0.462)	g (oz)
Mass with wires (No BEC)[2]	24.2 (0.854)	g (oz)
Mass without wires (No BEC)[2]	12.1 (0.427)	g (oz)
Width	22.4 (0.88)	mm (in)
Length	49.0 (1.93)	mm (in)
Depth	8.4 (0.33)	mm (in)

[1]Specification only applies to the Multi-Rotor 35 w/BEC units.
[2]Specification only applies to the Multi-Rotor 35 "NO BEC" units.

3.4 Communication Specifications

Characteristic	Value	Unit
Input Signal Logic Level High	2.53	V
Input Signal Logic Level Low	0.614	V
Input Signal Minimum Low Time[1]	12	µs
Maximum Input Signal Frequency (Standard Servo Signal)[2]	490	Hz
Maximum Input Signal Frequency (OneShot)[2]	>600	Hz
Maximum Input Signal Frequency (OneShot125)[2]	4000	Hz
Typical Signal Latency @ 100,000 eRPM[3]	< 75	µs

[1] Minimum logic low level time required between input pulses.
[2] Signals outputting at maximum input signal frequency must conform to the signal minimum low time specification.
[3] Mean time between signal falling edge and controller output power adjustment

3.5 Temperature Specifications

Characteristic	Value	Unit
Over-Temperature Warning Threshold	95.0 (203.0)	°C (°F)
Max Operating Temperature	105.0 (221.0)	°C (°F)
Shutdown Temperature	115.0 (239.0)	°C (°F)

4 MOTOR DRIVE FEATURES

4.1 ELECTRICAL RPM

Some BLDC motors, for example those used in FPV Racing Drones, have high Kv values and high magnetic pole counts. These factors lead to extremely high electrical RPMs (eRPMs) and commutation rates. These high eRPMs leave very little time for the ESC to perform processing and make motor tracking difficult. The Castle Multi-Rotor ESC's are able to operate up to 300,000 eRPM while maintaining precise motor timing. At eRPMs above 300,000 the firmware will begin to pull back power to prevent motor tracking issues. To calculate the unloaded eRPM use the formula below.

Max eRPM = (Motor Kv) * (Max Battery Voltage) * (Number of Motor Poles) / 2

Before flying you should ensure that your setup is running below 300,000 eRPM under load. If the motors go above 300,000 eRPM in flight the ESC will pull back power which may create vehicle instability.

4.2 ADAPTIVE TIMING SYSTEM

The Castle Creations Adaptive Timing System dynamically adjusts the motor timing during operation to keep the motor operating at peak efficiency. Traditionally, ESC's use a fixed motor timing that is set by the user. With a fixed motor timing operation can be optimized for a specific RPM and load but not for the entire operational envelope. By using hardware and software to monitor and adjust the timing dynamically the Adaptive Timing System is able to keep the motor operating at peak efficiency at any RPM or load. This leads to an increase in flight times and overall power output compared to a fixed motor timing. This also reduces the amount of ESC tuning required.

4.3 PWM FREQUENCY

ESCs control the speed of a motor by varying the duty cycle of the voltage applied to the motor. The PWM pulses are typically applied at a fixed frequency. The PWM frequency can often resonate with the commutation frequency of the motor creating a nonlinear throttle response. This can lead to decreased system efficiency and vehicle stability. Castle Multi-Rotor ESCs negate this problem by varying the modulation frequency across a broad spectrum, creating an extremely linear throttle curve and also reducing the audible noise of the system. This linearity significantly improves flight stability, simplifies flight controller PID tuning, and increases flight times and efficiency.

5 SAFETY FEATURES

5.1 ARMING SEQUENCE

All Castle ESCs feature an arming sequence intended to prevent accidental startups. The ESC will power-up in a disarmed state and remain at idle until the throttle signal goes below the motor start endpoint for one second, upon which the ESC will chime to indicate it is armed and ready to start the motor. Some error conditions will disarm the ESC. In this case, the ESC will remain disarmed until the throttle briefly returns to idle. The green LED will remain lit while the ESC is armed.

5.2 LOW VOLTAGE CUTOFF

When this feature is enabled in Castle Link, the ESC will reduce output power once the input voltage falls below the set threshold. If the “Soft Cutoff” option is selected, the ESC will gradually reduce power to a minimum of 50% power output. The ESC will continue to apply reduced power, allowing the operator to safely land the aircraft before battery damage occurs. If the “Hard Cutoff” option is selected, the ESC will stop applying power to the motor and disarm until the throttle returns to idle. This setting is not generally recommended for typical multi-rotor applications.

5.3 SIGNAL LOSS FAILSAFE

If the ESC does not receive a valid throttle signal for 1.0 seconds, it will stop applying power to the motor and enter a failsafe mode. To exit this mode, the ESC must receive eight (8) valid signal pulses, after which the ESC will rearm once the throttle signal is at idle for 200ms. This lockout procedure is intended to prevent the ESC from interpreting noise caused by faulty equipment and/or poor connections as valid throttle signals. Do not connect or disconnect throttle cables while the ESC is powered.

5.4 EXCESSIVE TEMPERATURE PULLBACK

The ESC will trigger an over-temperature warning if the ESC temperature exceeds the over-temperature warning threshold. This does not affect flight behavior, but the motor will emit an over-temperature beep code after the flight to indicate that the ESC approached the max operating temperature. If the ESC continues to increase in temperature it will start to decrease power output to the motor. As the ESC exceeds its maximum operating temperature, it reduces its output power linearly with temperature to enable a safe, non-catastrophic landing. Finally, if the ESC continues to increase in temperature, it will disarm once the temperature exceeds the ESC’s rated absolute maximum temperature. These over-temperature protection features are illustrated in Figure 3. The temperature specifications can be found in section 3.5.

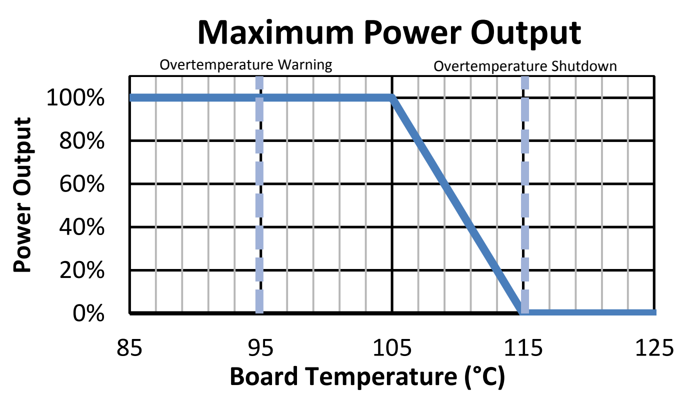

FIGURE 3: EXCESSIVE TEMPRATURE PULLBACK

5.5 Error Codes

In the event of a pullback or shutdown the ESC will produce an error code for trouble shooting. The ESC uses the motor to produce beep codes and must have a motor connected for them to be audible. The red LED will also blink out the error codes for a visual cue. Refer to the table below for error code meanings. A dot (•) stands for a short beep and a dash (–) stands for a long beep.

Tone	Meaning	Description
•	ESC ready to run motor	ESC beeps motor every 20 seconds to remind user that power is connected to the ESC. This notice may be disabled in Castle Link.
• •	Start Fail	ESC was unable to start the motor.
• -	Low Voltage Cutoff	Main battery voltage dropped below the cutoff value (disabled by default).
• • •	Propeller Strike/ Motor Anomaly/ Motor Desync Detected	ESC detected a sudden mechanical interruption of the motor's rotation.
• • -	Radio Glitch	ESC detected unusual signals or loss of signal on receiver lead.
• - •	Over-Temperature	ESC reached an over-temperature condition when operated under too high a load, operated without proper cooling airflow.

6 COMMUNICATION

The Castle Multi-Rotor series is compatible with the standard servo PWM protocol, OneShot, and OneShot125. The controller will automatically detect which protocol the flight control is using, and then internally latch this setting until the next reset so as to reject any extraneous signals caused by noise on the communications line. Refer to section 3.4 for communication tolerances.

6.1 SERVO PWM

Figure 4 shows the servo PWM signal traditionally used in hobby applications. The flight controller varies the pulse width of the signal between 1.0 ms (0% throttle) and 2.0 ms (100% throttle). Traditionally, the frequency of this signal is 50Hz, but can be increased to up to 490 Hz by shortening the off-time between pulses.

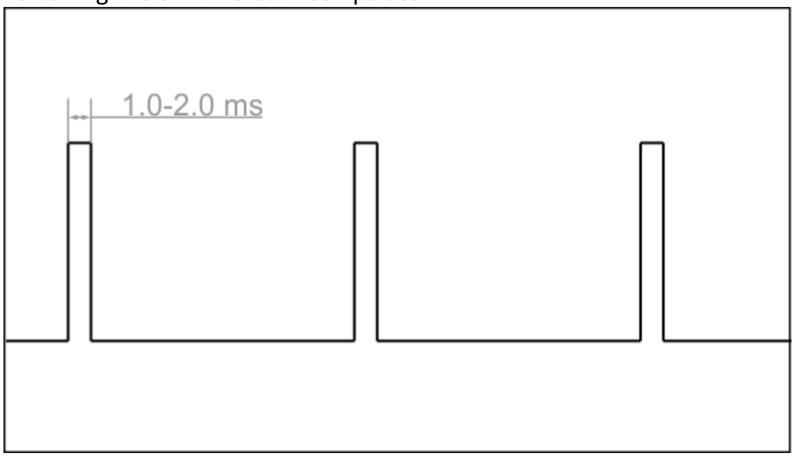

FIGURE 4: SERVO PWM

6.2 ONESHOT

Figure 5 shows a OneShot signal. The flight controller varies the pulse width of the signal between 1.0 ms (0% throttle) and 2.0 ms (100% throttle). OneShot allows the flight controller to transmit a throttle pulse as soon as the flight controller has new data to transmit to the ESC. Because the signal low-time is not defined, the signal frequency can vary from throttle pulse to throttle pulse. With this protocol, the signal frequency can exceed 600 Hz depending on throttle level and calibration.

Signals outputting at maximum input signal frequency must conform to the signal minimum low time specification from section 3.4.

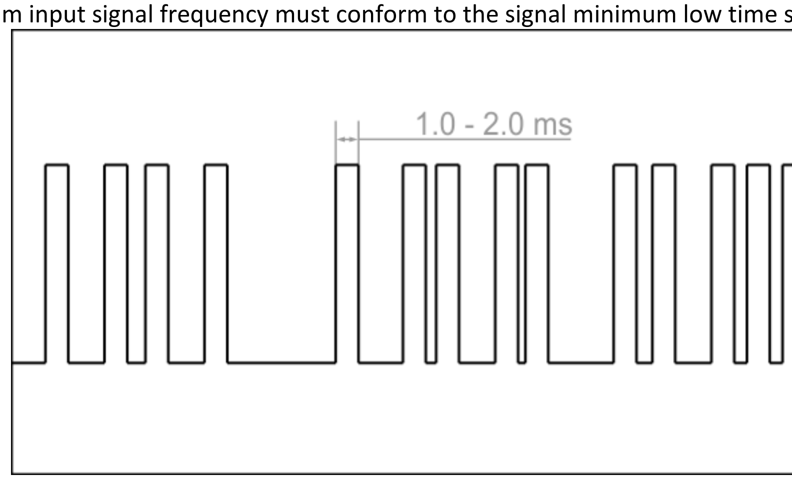

FIGURE 5: ONESHOT

6.3 ONESHOT125

Figure 6 shows a OneShot125 signal. OneShot125 is a modification of OneShot designed to improve system stability and responsiveness by reducing the delay between the flight controller and the ESC. OneShot125 scales down the OneShot signal by a factor of eight (8), reducing the endpoints to 125 µs (0% throttle) and 250 µs (100% throttle). Like OneShot, the signal low-time and frequency are not specified. A new pulse is transmitted as soon as the flight controller has data to transmit. With this protocol, the signal frequency can exceed 4000 Hz depending on throttle level and calibration.

Signals outputting at maximum input signal frequency must conform to the signal minimum low time specification from section 3.4.

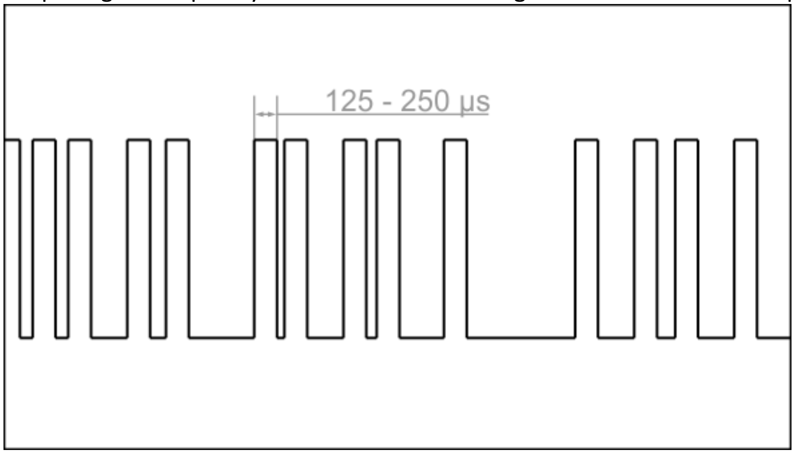

FIGURE 6: ONESHOT 125

6.4 Calibration Procedure

The throttle endpoints and motor direction can be easily configured during a calibration procedure. Due to possible differences in oscillator accuracy between ESCs and the flight control, it is recommended that calibration is performed with all ESCs in a system before the first flight. The calibration can generally be performed on all the ESCs in a system simultaneously. The following procedure will teach the ESC the endpoints and desired motor direction:

1. Remove propellers from all motors
2. Configure the flight controller to produce a full throttle signal
3. Connect a battery or power supply to the ESC
4. The motor should chime and begin to repeatedly beep indicating the ESC has recognized the full endpoint
5. Reduce the throttle signal to the minimum
6. The motor will chime again. The start endpoint will be set to 5% of the range between the maximum and minimum signals; i.e. [Start Endpoint] = ([High Signal] - [Low Signal]) * 5% + [Low Signal].
7. Throttle calibration data has now been saved. Continue to step 8 to program the direction of rotation. Otherwise disconnect power from the ESC.
8. Briefly spin motor in the desired direction of rotation
9. The motor will beep twice when the ESC has detected motor rotation
10. Spin the motor in the same direction to confirm the direction
11. The motor will beep four times confirming the setting
12. Disconnect power from the ESC to exit calibration

The throttle endpoints and motor direction can also be accessed and adjusted through the Castle Link application settings detailed in section 7.

7 Programmable Settings

The Castle Multi-Rotor series offers a variety of programmable settings which can be changed by connecting the ESC to a Windows PC via the Castle Link USB adapter. Users can configure ESC settings, save and load settings profiles, and upgrade ESC firmware by simply connecting the Castle Link USB adapter to the receiver wire of an ESC. The Castle Link settings page can be seen in Figure 7 and descriptions are listed below:

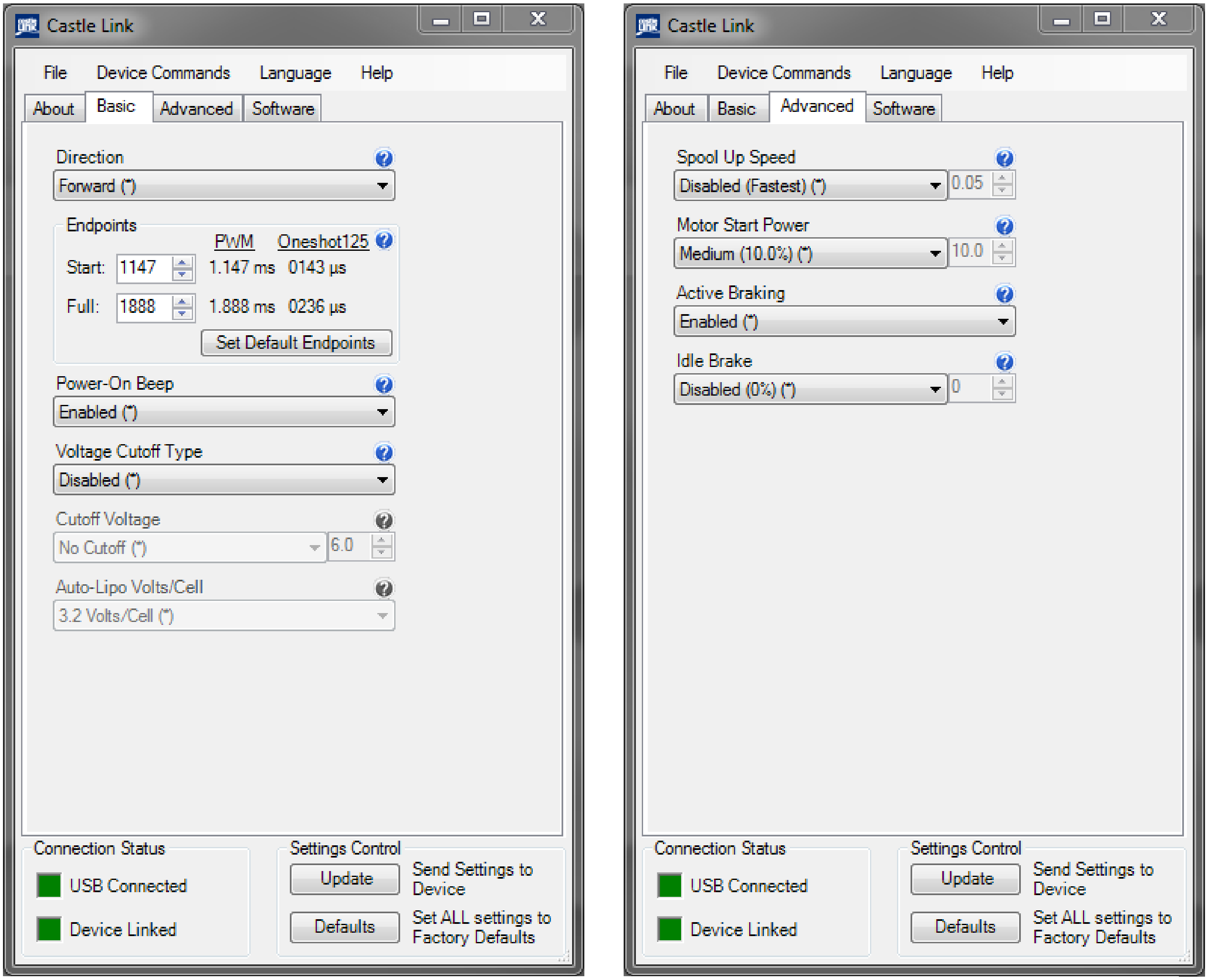

FIGURE 7: MULTI-ROTOR 35 CASTLE LINK SETTINGS

7.1 Direction

The Motor Direction setting allows you to reverse the direction of rotation on your motor. The actual direction will be determined by the motor and how the wires are connected.

7.2 Endpoints

The user may configure the ESC's throttle endpoints. These endpoints represent the boundaries of the ESC's input throttle measured in microseconds. If using OneShot125, simply enter the desired pulse width multiplied by 8. The values entered here should closely match those in the flight controller's configurator.

7.3 Power-On Beep

When this setting is enabled and the throttle is at idle, the ESC will beep every twenty seconds to alert the user that power is still connected.

7.4 Voltage Cutoff Type

When enabled, this setting adjusts how the ESC responds when the input voltage drops below the cutoff voltage.

7.5 Cutoff Voltage

The ESC will enter Low-Voltage Cutoff when the input voltage drops below this value.

7.6 Auto-LiPo Volts/Cell

This setting adjusts the per-cell cutoff voltage when using Auto-LiPo cutoff. The ESC will enter Low-Voltage Cutoff when the average cell voltage drops below this value.

7.7 Spool Up Speed

When enabled, the ESC will smoothly increase power after startup at the selected rate until the applied power matches the throttle signal. After the motor has spooled up, the ESC will respond normally until the throttle returns to idle. The value displayed in Castle Link represents the time required to accelerate to 25% power.

7.8 Motor Start Power

This setting adjusts the power applied to the motor during startup.

7.9 Active Braking

When enabled, the ESC will apply regenerative braking to the motor when throttle is reduced. This will cause the motor speed to respond more quickly to decreases in throttle and may affect system efficiency.

7.10 Idle Brake

This setting adjusts the regenerative braking force applied when the throttle is at idle or disconnected.

8 Graphs

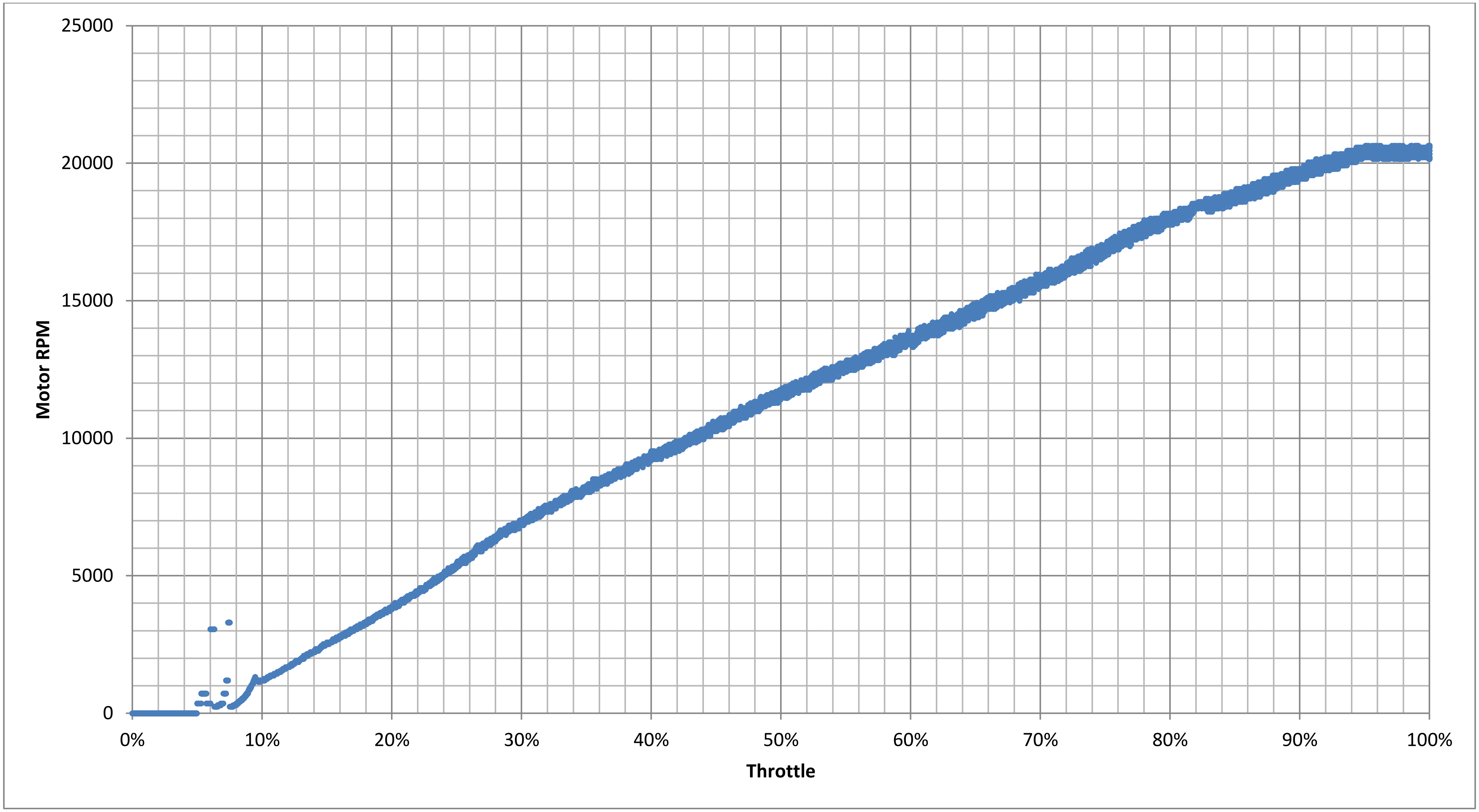

FIGURE 8: THROTTLE LINEARITY – ACTIVE BRAKE ENABLED, 2300KV MOTOR WITH 5X3 PROPELLER @ 12V

9 Technical Drawings

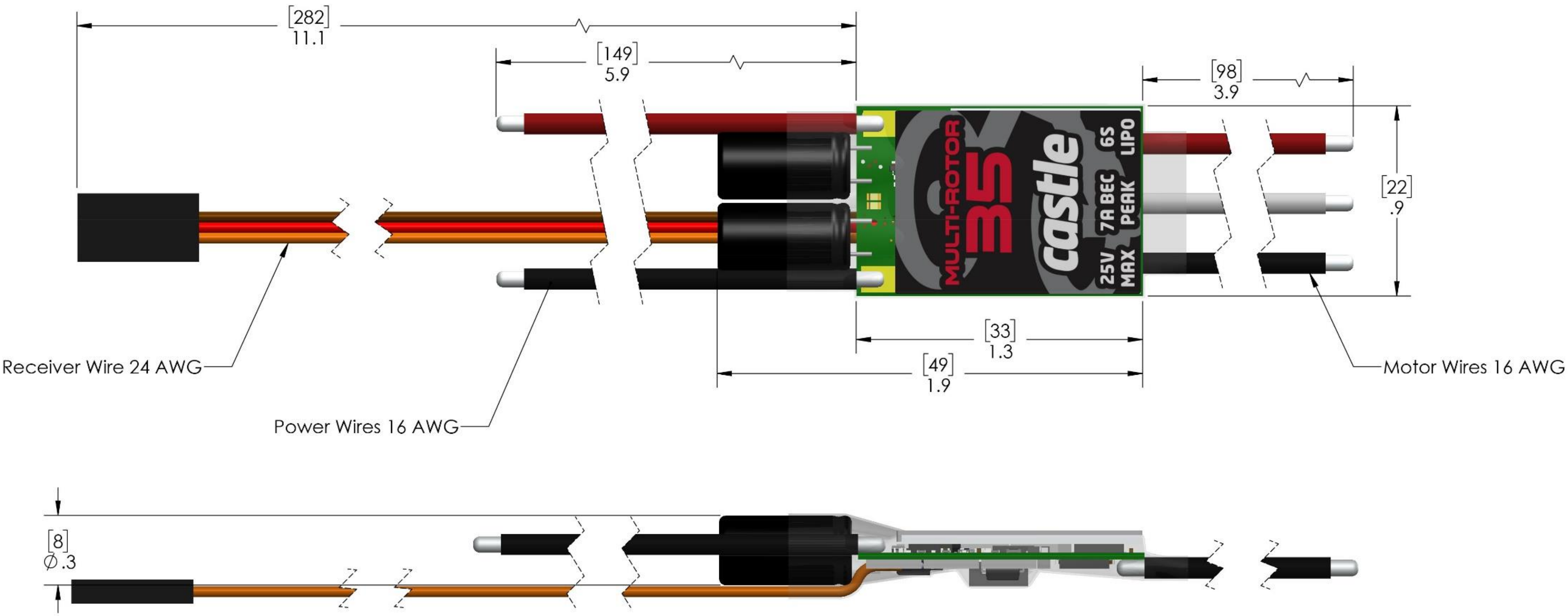

FIGURE 9: MULTI-ROTOR 35 DIMENSIONS [MILLIMETERS] INCHES

10 Wiring and Mounting Recommendations

For optimal efficiency the input power and motor wires should be kept as short as possible. On “NO BEC” versions of the Multi-Rotor 35 the red receiver wire must be connected to a voltage source that is able to supply the voltage and current specified in section 3.2. It is recommended to use the BEC output of a “w/BEC” unit to supply the BEC input on “NO BEC” units. Refer to figures Figure 10 and Figure 11 for wire designations.

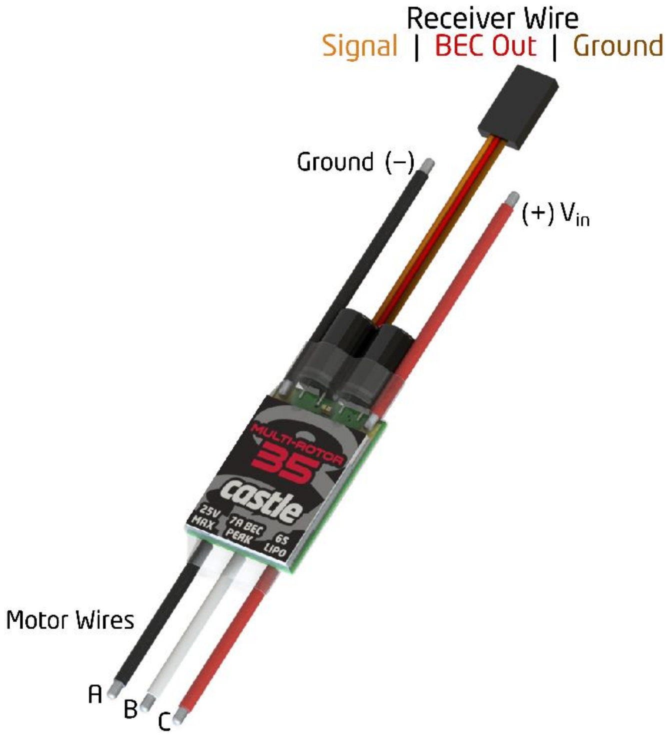

FIGURE 10: MULTI-ROTOR 35 W/BEC WIRE DESIGNATIONS

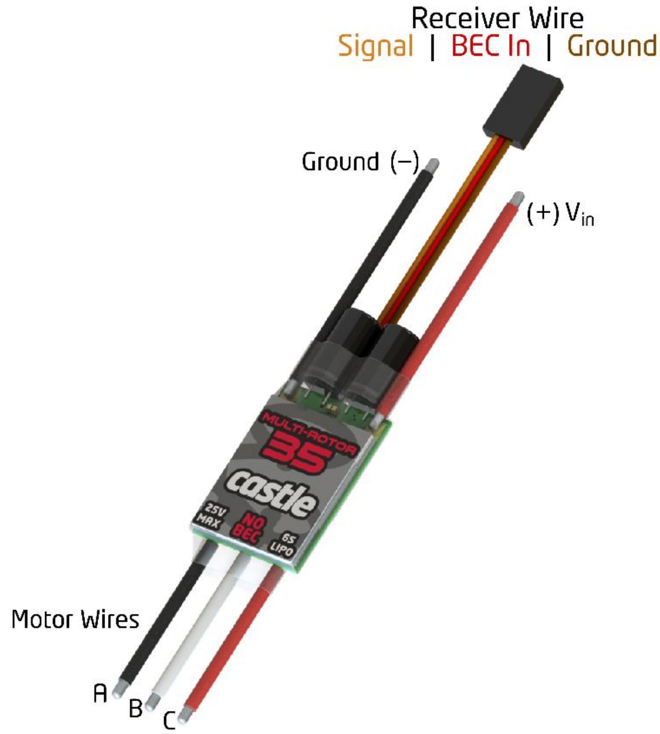

FIGURE 11: MULTI-ROTOR 35 NO BEC WIRE DESIGNATIONS

Castle Creations recommends placing a piece of foam at least 1/8” thick under each ESC before securing it to the aircraft. If cable ties are used to secure the ESC, do not cinch the cable tie down directly on the board as this may damage components on the underside of the device. Place the ESC in a location with adequate airflow.

11 Support Information

All Castle Creations ESCs are warranted for one (1) year[1] from date of purchase to be free from manufacturing and component defects. This warranty does not cover damages caused to the controller from abuse. Abuse includes, but is not limited to: exceeding specifications listed in this document, incorrect wiring, over-voltage, overloading, improper motor and/or propeller selection, incorrect controller settings, insufficient batteries, or inadequate connectors.

[1]Customer may have additional warranty rights under the laws of certain nations or states.

12 Contact Information

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13 Revision History

Date	Revision
7/14/2016	Initial Release
7/18/2016	Corrected current maximums in section 3.2 Electrical Specifications

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