

## 1 General Description

The Millswood Engineering UAV Engine Starter is designed to start internal combustion engines up to 150cc in size. It is small, lightweight, and delivers rapid and reliable engine starting without the use of decompression valves.

The engine starter drives the BLDC alternator as a motor in order to start the engine. Once the engine is running the starter disconnects itself from the BLDC alternator to allow electrical power generation. A suitable BLDC alternator fitted with Hall sensors is required.

Engine starting is initiated locally by push-button or remotely using CAN or RS232 commands. In-flight restarts are possible with CAN or RS232 commands.

## 2 Features

- Rapid and reliable starting – 1500RPM is typically achieved in under 0.5 Seconds.
- Maximum torque available from standstill.
- Operates from battery voltages of 20 to 55VDC. Tolerates generated 3-phase voltages up to 140VAC.
- CAN, RS232 and USB connectivity.
- Comprehensive front-panel diagnostics to aid integration and commissioning.
- User-friendly configuration software, with integrated graphing and logging to optimise and verify performance.
- Weight: 190 grams (6.7 ounces).
- Dimensions: 93.5 x 80.5 x 20mm.



Figure 1 – UAV Engine Starter

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## 4 Operation

The Engine Starter allows a 3-phase BLDC alternator to be used as a motor to start an internal combustion engine. It requires a source of power capable of delivering high-current, and a BLDC alternator fitted with Hall sensors. When requested to do so, the starter energises the windings of the BLDC alternator to accelerate the engine up to starting speed. Once the engine starts, the starter disconnects itself electrically from the BLDC alternator. This allows the engine to spin freely and the BLDC alternator to generate electrical power without interference from the starter.

## 5 Wiring Diagram

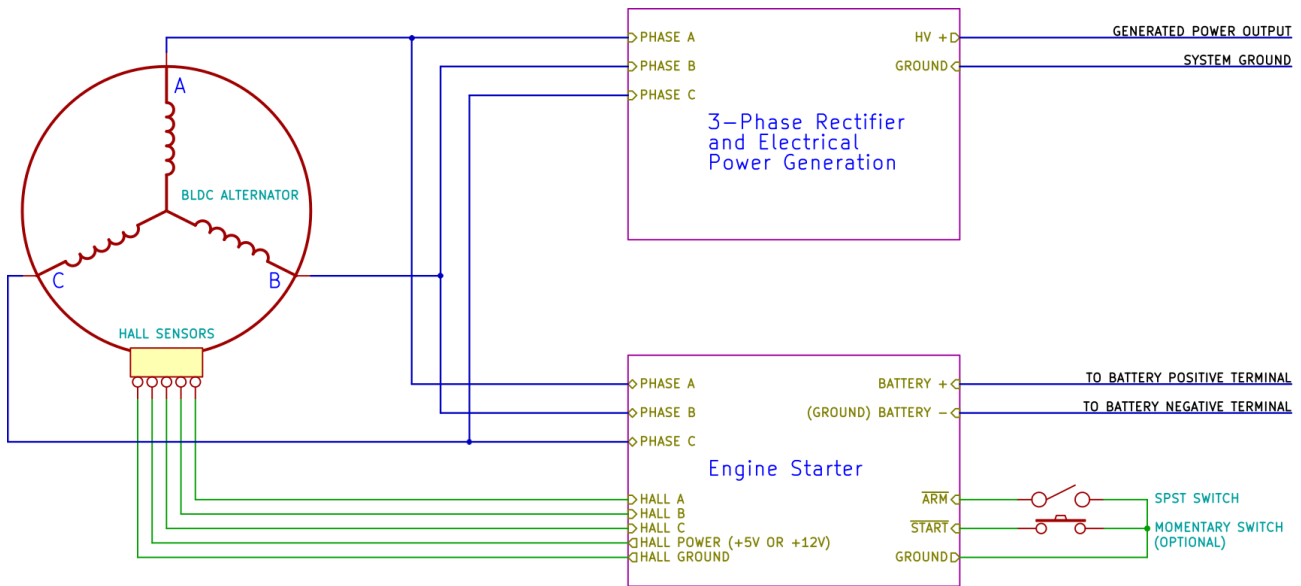


Figure 2 – Wiring diagram

Referring to Figure 2 above:

- High-current wiring is shown in blue, small-signal wiring is shown in green.
- CAN, RS232 and USB omitted for clarity.
- The negative battery input to the engine starter is its ground reference. This may be tied to system ground.
- If the BLDC alternator is star connected and exposes its neutral, this must be left unconnected. Do not connect it to ground.

During starting, the engine starter will energise the 3 phases with battery voltage modulated with 20kHz PWM. Most rectifiers tolerate this without problems, but it is worth disabling electrical power generation during starting so as to not burden the starter unnecessarily.

If colour-coding the high-current wiring, the following colours are suggested:

Connection	Colour	Part number	Online distributors
Battery +	Red	Mueller Electric Coolflex 45 WI-M-10-10-2	Digi-Key 314-1241-ND Mouser 548-WI-M-10-10-2
Battery -	Black	Mueller Electric Coolflex 45 WI-M-10-10-0	Digi-Key 314-1240-ND Mouser 548-WI-M-10-10-0
Phase A	Yellow	Mueller Electric Coolflex 45 WI-M-10-10-4	Digi-Key 314-1498-ND Mouser 548-WI-M-10-10-4
Phase B	Green	Mueller Electric Coolflex 45 WI-M-10-10-5	Digi-Key 314-1499-ND Mouser 548-WI-M-10-10-5
Phase C	Blue	Mueller Electric Coolflex 45 WI-M-10-10-6	Digi-Key 314-1500-ND Mouser 548-WI-M-10-10-6

Table 1 – High-current wiring suggested colour-coding scheme

## 6 Initial setup and test

This section outlines an initial setup and test procedure using the minimum possible number of connections.

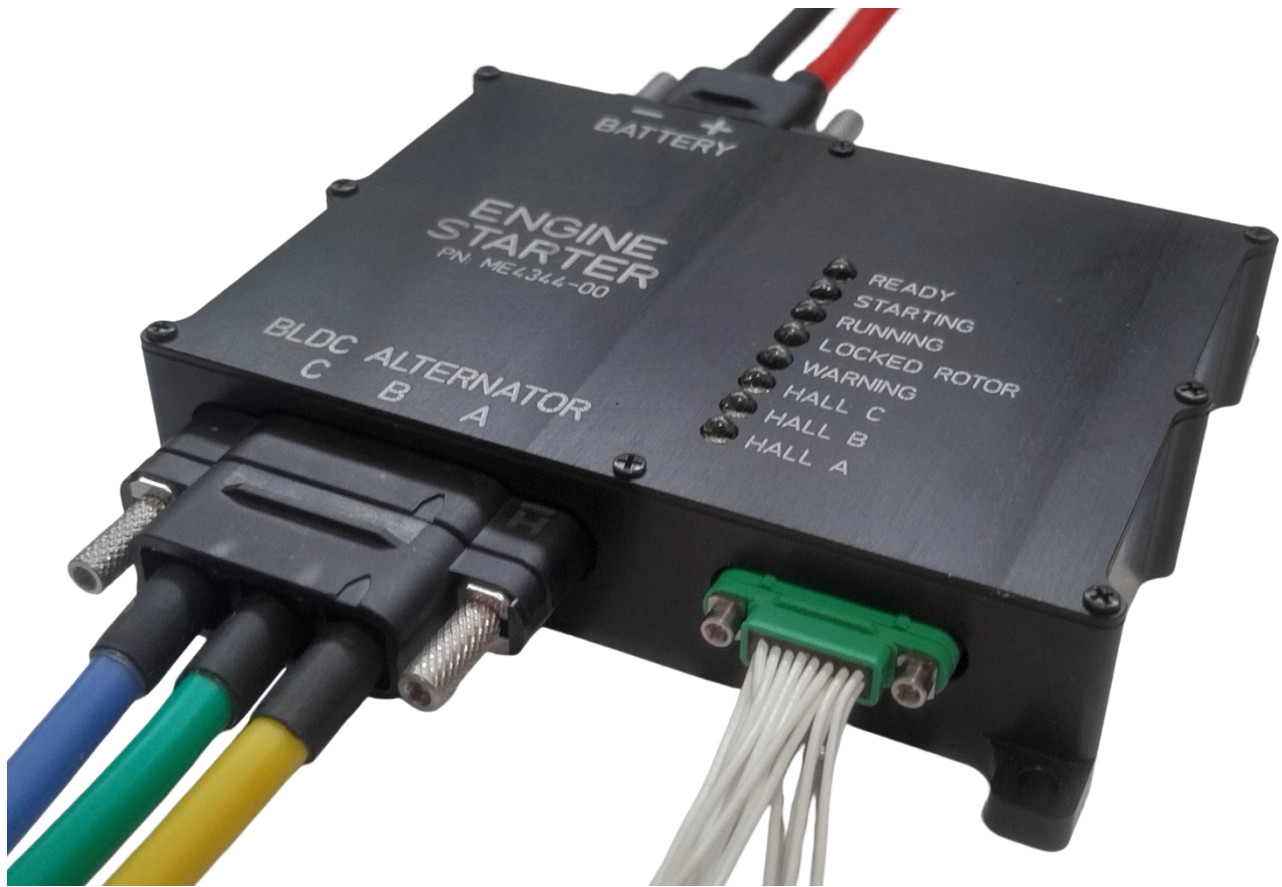


Figure 3 – Engine Starter with its main cables plugged in

### 6.1 Setup

Make the following connections to the starter:

#### 6.1.1 Battery

Connect a battery or power supply (see section 9.1 for details). Take care not to reverse the polarity.

#### 6.1.2 BLDC alternator

Connect phases A, B and C to the BLDC alternator (see section 9.2 for details).

#### 6.1.3 Hall sensors

5 wires need to be connected – Hall power, Hall ground, and the 3 Hall sensor signals. All of these connections are located on the 16-way Harwin Gecko connector (see section 9.3 for details).

The 3 Hall sensor signals may need swapping around, so keep these connections accessible during initial setup and testing.

#### 6.1.4 Arm input

Wire a switch between the Arm input and signal ground – both of these connections are located on the 16-way Harwin Gecko connector (see section 9.3 for details).

### 6.1.5 USB

Use a standard micro-USB cable to connect the starter to a PC. **A galvanically-isolated USB interface is strongly recommended if there is any possibility of a ground loop forming.**

## 6.2 Test

Run the configuration software, press the "Open" button to connect to the starter via USB, and check that reading parameters from the starter works.

Apply battery voltage and check that this is being reported correctly on the "Diagnostics" tab.

Turn the Arm switch on and off and check that this is being reported correctly (also on the "Diagnostics" tab).

Rotate the BLDC alternator by hand and check that the blue Hall sensor LEDs (on the starter itself) illuminate in order. There should always be one or two blue LEDs on, and they should appear to "flow" from one end to the other and wrap around as the alternator is rotated. All Hall LEDs on or all LEDs off are illegal states and should never happen. Do not proceed if illegal states are observed.

### 6.2.1 Hall sensor check

Go to the "Wiring Check" tab. With battery voltage applied and the Arm switch closed press each of the buttons to check that the correct LED illuminates. Swap Hall sensor wires as required until all 3 Hall sensors are correct (see section 8.6 for further details).

### 6.2.2 Cranking the engine

Go to the "Engine Starting" tab and check that the BLDC pole count parameter is set correctly. Change it if necessary and write out the new value to the starter. With spark plugs removed attempt to crank the engine by pressing the "Start" button.

The default parameters are generally insufficient to crank the engine successfully, and a "locked rotor" condition will be the result. This is completely normal.

Increase the "Initial PWM duty cycle" and "PWM ramp rate" parameters (on the "Engine Starting" tab), write the new values out to the starter and try again. Keep going until the engine can be cranked successfully and reach the chosen target speed (see section 8.1 for further details). This is an empirical trial-and-error process.

**Keep an eye on the BLDC alternator winding temperature – repeatedly energising a stalled rotor will heat up the windings.**

Once the engine is able to be cranked reliably without spark plugs, fit the spark plugs and continue testing, increasing the initial PWM duty cycle and PWM ramp rate as required.

For reference, the following settings have been found to work well on a 150cc twin-cylinder engine (simultaneous compression, no decompression valves), with the starter powered from a 12S LiPo:

- Cranking current limit: 67 Amps
- Initial PWM duty cycle: 50%
- PWM ramp rate: 250%

These settings give a typical engine start time of less than 400ms. Even more aggressive starting is possible by increasing the initial PWM duty cycle.

## 7 Communications

The Engine Starter has USB, RS232 and CAN interfaces. They are largely independent and may be used concurrently. There is no requirement for any of the communications interfaces to be used operationally – once configured, the starter is capable of operating with no communications at all.

### 7.1 USB

The USB interface is designed to provide easy initial access to the starter, accelerating the process of setup and testing. It is not intended to be used operationally (in flight).

When a PC is connected to the starter via the USB interface, the configuration software can communicate directly with the starter, allowing access to all of the starter's configurable parameters, internal status registers, measured values and a host of other diagnostic information. Data logging, graphing, statistics and Hall sensor alignment checking are also available from the configuration software.

### 7.2 RS232

The RS232 interface provides identical functionality to USB, but has superior noise margins and uses a more reliable connector and is therefore suitable for operational use in flight. The Baudrate may be set to any of the standard rates from 9600 to 115,200 Baud.

The RS232 protocol is given in Appendix 1 – RS232 protocol.

### 7.3 CAN

The CAN interface provides a subset of the functionality available in the USB and RS232 interfaces, but is faster and more reliable. The bitrate may be set to 125kb/s, 250kb/s, 500kb/s or 1Mb/s. The CAN bus is not terminated internally.

The CAN protocol is given in Appendix 2 – CAN protocol.



## 8 Configuration software

Download the Windows configuration application from [www.millswoodeng.com.au/resources.html](http://www.millswoodeng.com.au/resources.html). Connect the starter to a PC via a micro-USB cable and run the configuration software. The starter will power itself from the USB connection.



Figure 4 – UAV Engine Starter configuration utility

Parameters may be read from and written to the starter. All parameters are stored in non-volatile memory. The starter also maintains a small database of statistics internally, also stored in non-volatile memory. This allows performance to be assessed and optimised.



## 8.1 Engine Starting parameters

Exercise caution when initially configuring the starter. The starter is a high-power device with a low-impedance output stage and is easily capable of destroying a BLDC alternator. In particular, monitor the BLDC alternator's winding temperature with repeated failed start attempts. Failed start attempts tend to heat the windings more than successful ones.

Once successful starting is achieved, winding temperature rise tends to be minimal – even with repeated starts – because the starting process is extremely fast and the total energy lost to winding resistance is low.

It is recommended that the spark plugs be removed for initial testing.

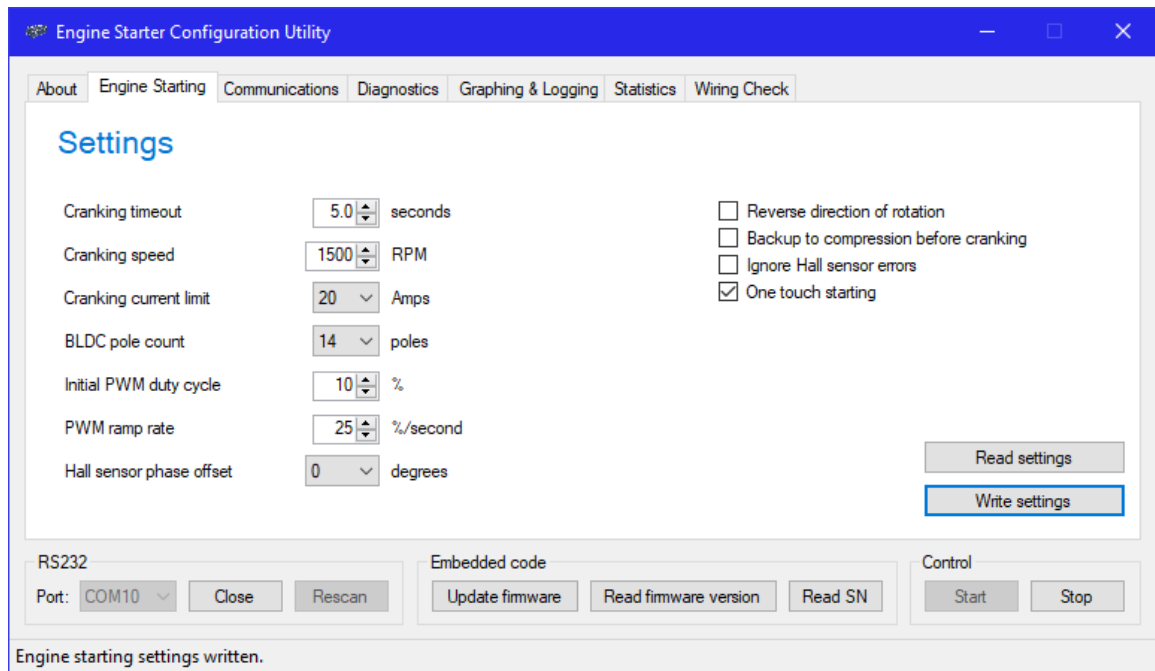


Figure 5 – Engine Starting parameters

### 8.1.1 Cranking timeout

Can be set from 1.0 to 8.5 seconds. Intended to prevent overheating the BLDC alternator's windings when an engine can be cranked but is failing to start.

The starter also implements locked rotor protection with a fixed timeout of 0.5 seconds. During the initial setup of a new engine, the locked rotor timeout and associated LED will probably trip many times, helping to prevent the BLDC alternator windings from overheating. Once the system is optimised, locked rotor protection should rarely, if ever, trip.

### 8.1.2 Cranking speed

Can be set from 500 to 5000 RPM. The starter will attempt to crank the engine at this speed until either the engine starts or the cranking timer expires.

### 8.1.3 Cranking current limit

Can be set from 20 to 200 Amps. Intended to prevent damage to the starter's output stage if there is a short-circuit. Should be set one or two levels above the point where current limiting events happen occasionally.

When current limiting occurs the warning LED illuminates briefly. Current limiting may only be detectable by a worsening in starting performance as the limit is reduced.

Empirically it has been found that a 150cc 2-cylinder engine requires about 50 Amps to start (initial PWM duty cycle = 50%, PWM ramp rate = 250%/s), and so a current limit of 67 Amps is appropriate in this case.

### 8.1.4 BLDC pole count

Can be set from 2 to 32 poles. This is the number of magnetic poles, not electrical poles (count the magnets, not the windings). This setting can be verified by measuring the speed of the engine and comparing with the starter's estimate of the speed. If the number of poles has been set correctly, these two numbers will match.

### 8.1.5 Initial PWM duty cycle

Can be set from 10 to 90%. This will determine the initial current the starter will draw, and therefore the torque that is applied initially. Higher values will result in faster but more violent engine starting.

Do not set this parameter up too high initially, and only increase it incrementally. This is the parameter that will break stuff and ruin your day. 25% is suggested as a reasonable initial value.

### 8.1.6 PWM ramp rate

Can be set from 25 to 250%/s. This sets an upper limit on the acceleration of the system. The higher this value is, the faster the engine can reach its target cranking speed, but the starter will draw more current in doing so.

Do not set this parameter up too high initially. 50%/s is suggested as a reasonable initial value.

### 8.1.7 Hall sensor phase offset

Can be set from -180 to +180 degrees in 60 degree steps. The main intended use for this parameter is to correct for Hall sensor misalignment. Usually a +60 or -60 degree offset is all that is required.

A secondary use for this parameter is to correct for inverted Hall sensors. Setting this parameter to either +180 or -180 degrees is equivalent to inverting the sense of the Hall sensor signals.

### 8.1.8 Reverse direction of rotation

Spin the BLDC alternator in the opposite direction.

### 8.1.9 Backup to compression before cranking

Rotate backwards until compression is found, before attempting to start in the correct direction.

### 8.1.10 Ignore Hall sensor errors

Starting is normally aborted if the Hall sensor error rate exceeds 2 errors per 100ms. Sometimes it is useful to turn this error checking off. The warning LED will still flash whenever Hall sensor errors are detected, but the start attempt will proceed regardless.

### 8.1.11 One touch starting

If enabled, a single press of the start button is all that is required to start the engine. If one touch starting is not enabled, releasing the start button will cause the start attempt to be abandoned.

## 8.2 Communications parameters

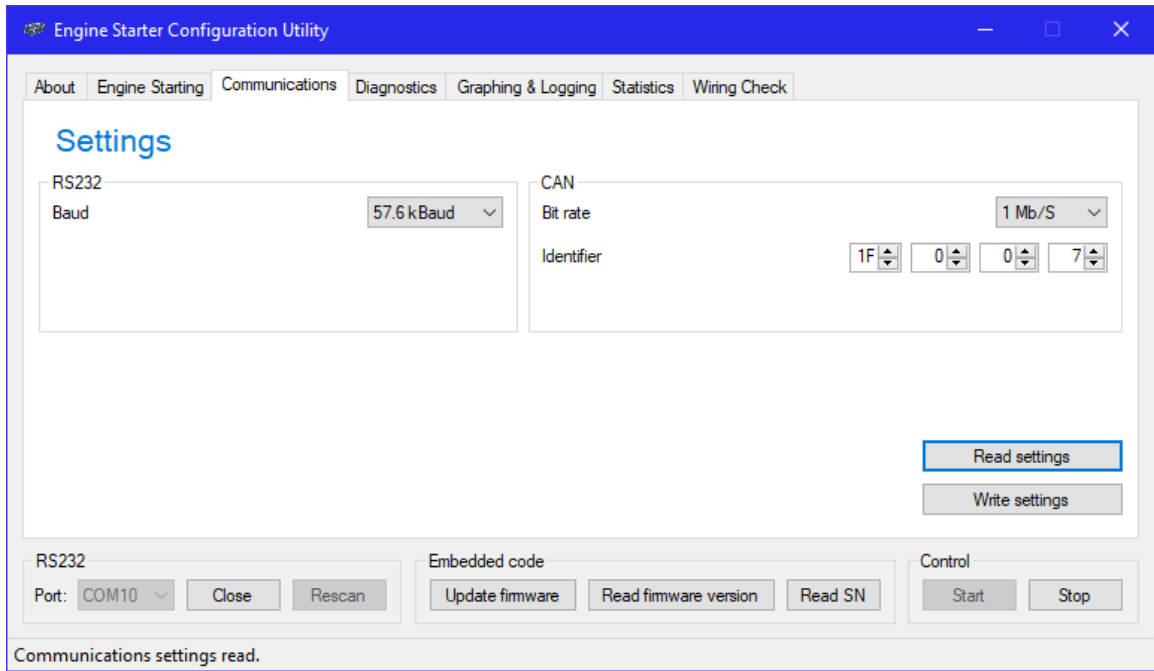


Figure 6 – Communications parameters

The RS232 and CAN communications protocols are given in the appendices to this document.

## 8.3 Diagnostics

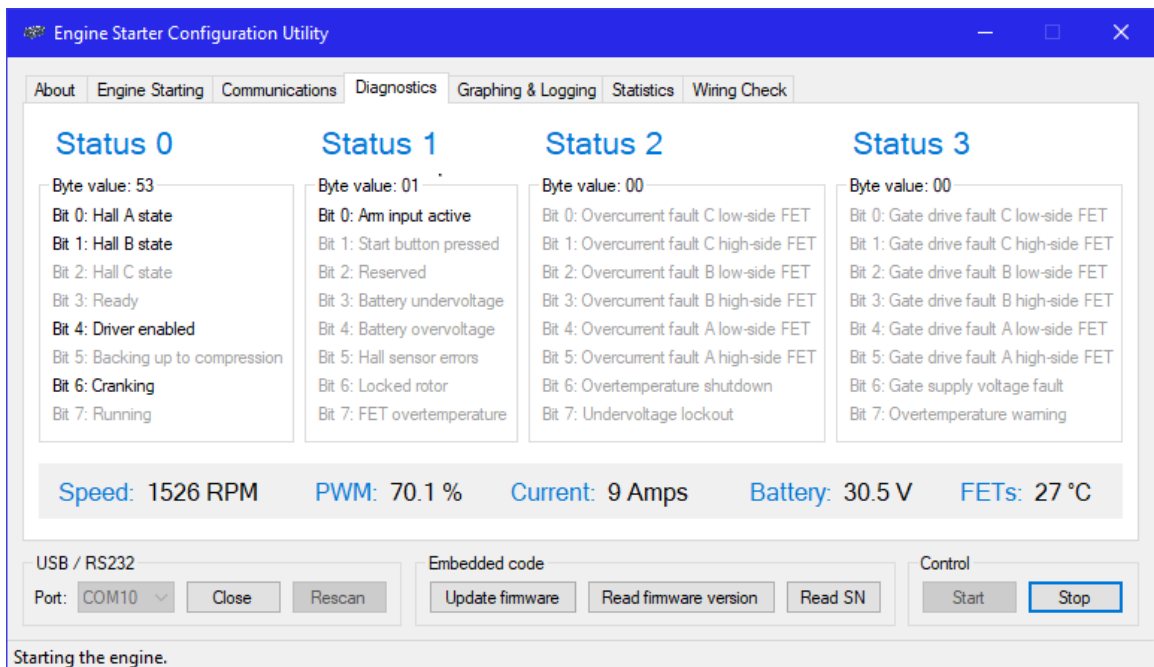


Figure 7 – Diagnostics

Status registers 0 and 1 contain useful information about the starter's internal state. Status registers 2 and 3 contain information about the 3-phase FET driver and can generally be ignored.

8.4 Graphing & Logging

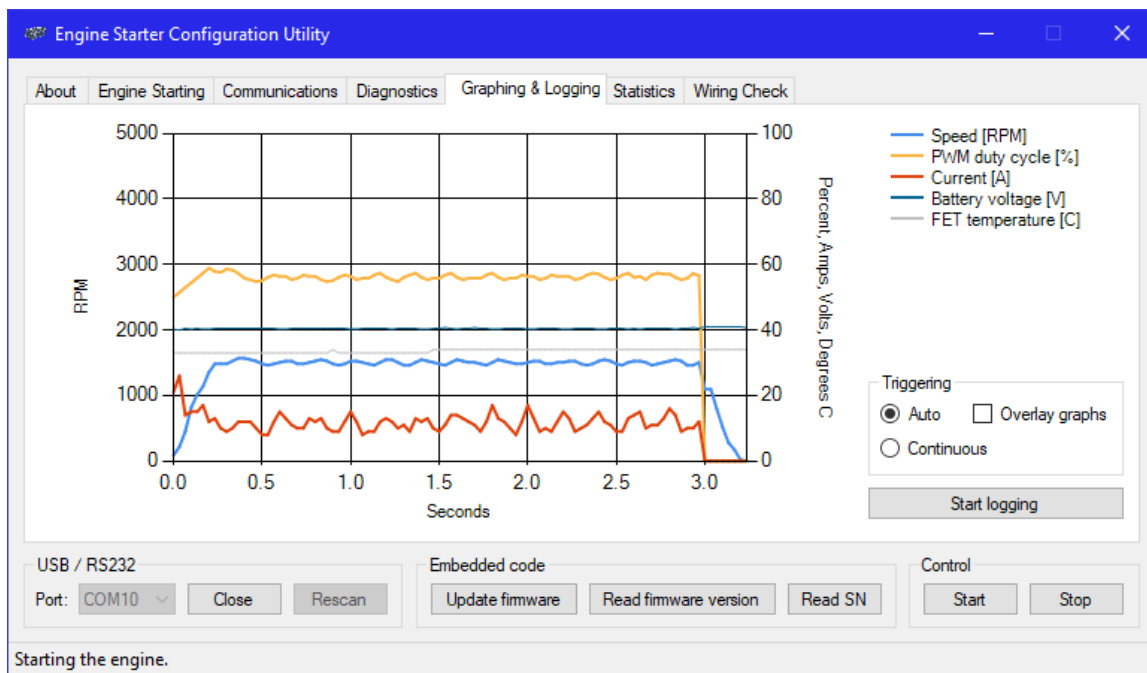


Figure 8 – Graphing & Logging

Graphs are created dynamically in real-time. Data is recorded at 30Hz. Data can be written to a CSV file by clicking the “Start logging” button prior to starting the engine. Don’t forget to turn logging off when finished.

Current is the peak phase current; this is higher than the DC link (battery or supply) current by a factor of approximately  $100 / \text{PWM duty cycle}$ .

Temperature is that of the output FETs.

### 8.5 Statistics

The starter records some basic statistics into non-volatile memory. This allows the last start to be analysed, as well as the longer-term performance of the system.

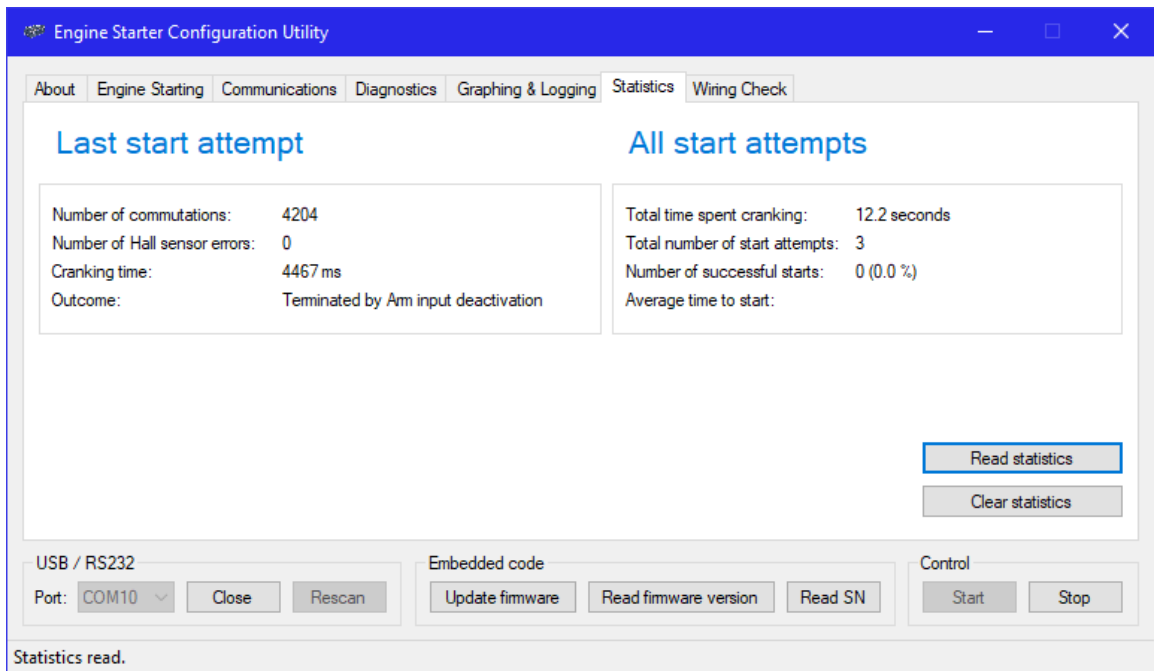


Figure 9 – Statistics

## 8.6 Wiring Check

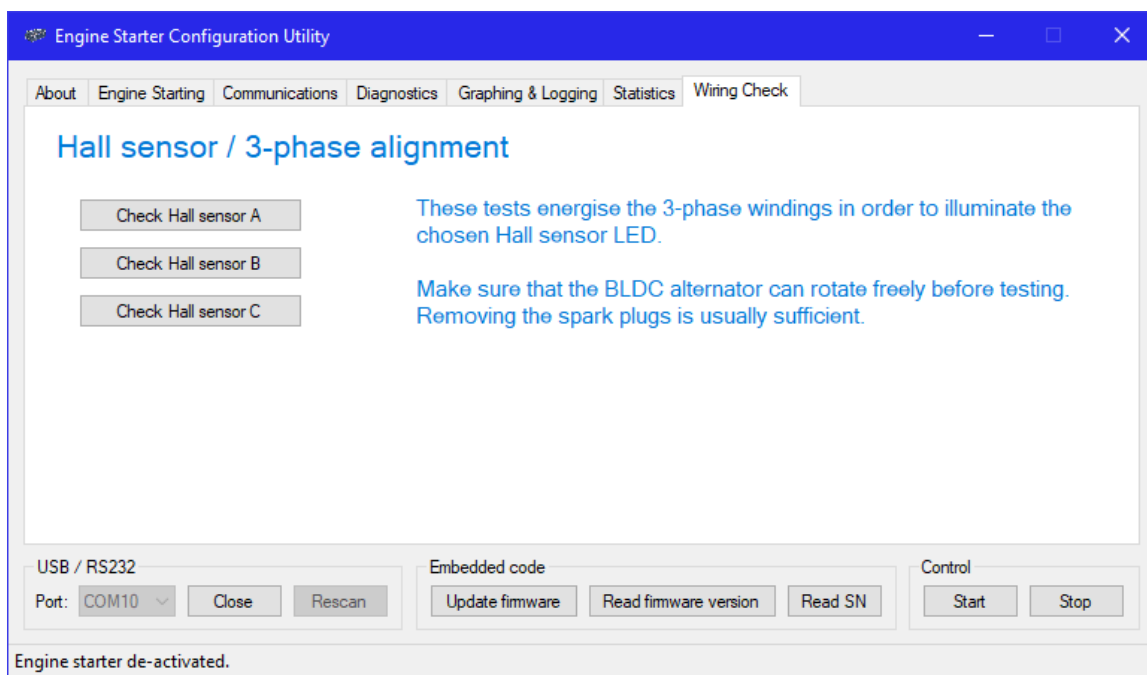


Figure 10 – Wiring Check

The wiring check allows the alignment between the alternator windings and the Hall sensors to be checked. Pressing one of the buttons energises the windings so that the specified Hall LED turns on. The amount of power applied to the windings in this test is limited to avoid overheating the windings, and the resulting torque is therefore quite low. If the BLDC alternator cannot rotate freely it may be necessary to nudge it by hand to find the null. For each test, once the BLDC alternator is centred on the null, only one blue LED should be illuminated.

The locked rotor LED illuminates during this test.

Press the “Stop” button to end each test.

If necessary, swap the Hall sensor wires until the correct LED for each test illuminates.

**If the nulls correspond to two Hall LEDs illuminating for all three tests:**

This means that the outputs of the Hall sensors are inverted. In this case, swap the Hall sensor wires to align the nulls with the LEDs that are off, and set the Hall sensor phase offset (in the “Engine Starting” tab) to + or -180 degrees.

**If the nulls correspond to a mix of one and two LEDs illuminating:**

This means that the Hall sensors are misaligned. It may be possible to compensate for the misalignment by adjusting the Hall sensor phase offset (in the “Engine Starting” tab), but this is a trial and error process with no guarantee of success. A better solution is to correct the physical locations of the Hall sensors.

Once the wiring is correct, it is worth assessing how well the Hall sensors are aligned. After centring each Hall sensor at its null, de-energise the windings and then move the rotor in each direction by hand (away from the null) until a second LED illuminates. For a well-aligned Hall sensor, this should be approximately equal in both directions.

It does not need to be perfect, but if it is consistently off-centre for all 3 Hall sensors, then performance might be improved by adjusting the Hall sensor phase offset to + or -60 degrees.

## 9 Connectors

The starter has four connectors: one each for Battery, BLDC alternator and interfacing, plus the USB connector for initial setup and testing. Mating connector part numbers for the three main connectors are listed in Table 2 below. The USB connector is a standard micro-USB type.

Connector	Part number	Online distributors
<b>Battery</b>	Harwin Kona KA1-2010298F1	Mouser 855-KA1-2010298F1 Digi-Key 952-KA1-2010298F1-ND element14 3765273
<b>BLDC alternator</b>	Harwin Kona KA1-2010398F1	Mouser 855-KA1-2010398F1 Digi-Key 952-KA1-2010398F1-ND element14 3765274
<b>Contacts for above (5 required)</b>	Harwin Kona KA1-0400005	Mouser 855-KA1-0400005 Digi-Key 952-KA1-0400005-ND element14 3765279
<b>Interface (150mm cable assembly)</b>	Harwin Gecko G125-FC11605F1-0150L	Mouser 855-G125FC1165F1150L Digi-Key 952-4238-ND element14 3755609
<b>Interface (450mm cable assembly)</b>	Harwin Gecko G125-FC11605F1-0450L	Mouser 855-G125FC1165F1450L Digi-Key 952-4240-ND element14 2965928

Table 2 – Mating connector part numbers

Kona connector housings are sold separately from their contacts. A total of 5 contacts are required (2 for the battery and 3 for the BLDC alternator). Kona connectors are designed for 8AWG wire, although 10AWG can be used with careful soldering. The maximum diameter of the insulation should not exceed 7.5mm. Wires should be stripped by 7mm prior to soldering.

Gecko connectors are also available as housing and crimps, but it is more convenient and reliable to use Harwin’s pre-assembled cables. These cables come with the rear of the connector already potted for strain relief. Only one cable is required, but two different lengths are available.

### 9.1 Battery

The battery connector requires a low-impedance source of power with a voltage between 20 and 55VDC. It is not recommended to mate this connector with live terminals because of the risk of contact damage from arcing. A high-current switch or sacrificial connector in series with the positive lead is recommended.



Take care not to reverse the polarity – a very large current will flow and potentially damage the starter, the wiring and the battery.

Try to keep the cable as short as possible – less than 30cm is recommended.

### 9.2 BLDC alternator

Connect the BLDC alternator to the BLDC alternator terminals, observing the correct phasing.

It is preferable to route the 3-phase connections separately to the Hall sensor signals. The 3-phase wires carry high current switched at 20kHz – they will radiate electrical noise when starting the engine.



Try to keep this cable as short as possible – less than 40cm is recommended.



### 9.3 Interface

The interface connector carries the Hall sensor signals, RS232, CAN and Arm and Start inputs.

Two power supply voltages are provided for the Hall sensors: +5V and +12V. Most Hall sensors tolerate either. The Hall sensor inputs are filtered to reduce the 20kHz noise coupled in from the 3-phase cable, but it better to avoid coupling signals into these lines in the first place by routing the cables separately.



The RS232 signals are at true RS232 signal levels, not TTL.

The CAN bus is not terminated internally.

The four ground pins are internally connected to the negative battery terminal.

Pin	Name	Type	Description
1	Hall A	Input	Normally connects to an open-collector or open-drain output. Internally pulled up to +5V via a 1k resistor.
2	Hall B	Input	Normally connects to an open-collector or open-drain output. Internally pulled up to +5V via a 1k resistor.
3	Hall C	Input	Normally connects to an open-collector or open-drain output. Internally pulled up to +5V via a 1k resistor.
4	Start	Input	Active low with internal pull-up. Short to ground to start. If used, this pin is usually connected to a momentary push-button switch.
5	Spare	I/O	Leave unconnected.
6	RS232 Rx	Input	Leave unconnected if not used.
7	Ground	Ground	
8	CAN H	I/O	Leave unconnected if not used.
9	+12V	Output	Intended as Hall sensor power supply.
10	+5V	Output	Intended as Hall sensor power supply.
11	Ground	Ground	
12	Arm	Input	Active low with internal pull-up. Short to ground to enable the starter. This is implemented in hardware for safety.
13	Ground	Ground	
14	RS232 Tx	Output	Leave unconnected if not used.
15	Ground	Ground	
16	CAN L	I/O	Leave unconnected if not used.

Table 3 – Interface connector pin descriptions

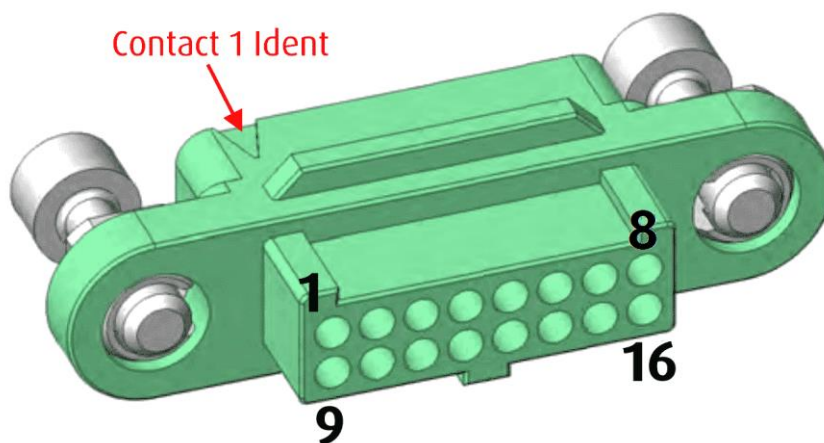


Figure 11 – Interface connector pin numbering

## 10 Visual indicators

There are 8 LEDs on the front panel: 3 green, 2 red and 3 blue.

- The 3 green LEDs indicate progress through the process of starting the engine.
- The 2 red LEDs indicate possible problems.
- The 3 blue LEDs indicate the Hall state.

Name	Interpretation when illuminated
<b>Ready</b>	The starter will crank the engine if requested to do so. For this LED to illuminate the following conditions must be met: <ul style="list-style-type: none"> <li>(a) Arm pin low, and</li> <li>(b) Battery voltage within upper and lower limits, and</li> <li>(c) FET temperature below upper limit, and</li> <li>(d) Engine not spinning.</li> </ul>
<b>Starting</b>	The starter is cranking the engine.
<b>Running</b>	The engine is spinning without assistance from the starter.
<b>Locked rotor</b>	The last start attempt was unsuccessful due to the rotor becoming stuck. This is usually the result of: <ul style="list-style-type: none"> <li>(a) Insufficient initial PWM duty cycle, or</li> <li>(b) Insufficient PWM ramp rate, or</li> <li>(c) Current limit set too low, or</li> <li>(d) One or more phases not connected.</li> </ul>
<b>Warning</b>	Illuminates whenever: <ul style="list-style-type: none"> <li>(a) Battery is under-voltage, or</li> <li>(b) Battery is over-voltage, or</li> <li>(c) FETs are over-temperature, or</li> <li>(d) Hall sensor error is detected, or</li> <li>(e) Current limiting event occurs, or</li> <li>(f) 3-phase FET driver fault occurs.</li> </ul>
<b>Hall C</b>	Hall sensor C output is switching low.
<b>Hall B</b>	Hall sensor B output is switching low.
<b>Hall A</b>	Hall sensor A output is switching low.

Table 4 – Visual indicator interpretation

When the locked rotor LED is on this indicates that the last start attempt was aborted due to a locked rotor condition. If the ready LED is on then further starts are permitted, despite a red LED being on. Sending a "Stop" command to the starter will turn the locked rotor LED off, if having a red LED on is undesirable.

When the Hall sensors are working correctly, one or two of the blue Hall state LEDs should be on. Having zero or three blue LEDs on constitutes an illegal Hall state and should never happen.

## 11 Specifications

### 11.1 Absolute Maximum Ratings *Note 1*

Symbol	Parameter	Min	Max	Unit
$V_{BLDC}$	BLDC alternator voltage, phase-to-phase	-140	+140	$V_{PP}$
$V_{BLDC}$	BLDC alternator voltage with respect to battery ground	-1	+140	$V_{DC}$
$V_{BAT}$	Battery voltage <i>Note 2</i>	-1	+60	$V_{DC}$
$V_{RS232\_I}$	RS232 input voltage	-25	+25	$V_{DC}$
$V_{RS232\_O}$	RS232 output voltage	-13.2	+13.2	$V_{DC}$
$V_{CAN\_L}$ , $V_{CAN\_H}$	CAN L and H voltage	-58	+58	$V_{DC}$
$V_{DIG}$	Digital inputs (Arm, Start)	-3	+30	$V_{DC}$
$V_{HALL}$	Hall sensor inputs (device not powered)	-10	+10	$V_{DC}$
$V_{HALL}$	Hall sensor inputs (device powered)	-5	+15	$V_{DC}$
$V_{HALL\_+5V}$	+5V Hall power output <i>Note 3</i>	-12	+35	$V_{DC}$
$V_{HALL\_+12V}$	+12V Hall power output <i>Note 3</i>	-12	+42	$V_{DC}$
$T_{AMB}$	Storage temperature	-55	+125	$^{\circ}C$

Table 5 – Absolute Maximum Ratings

*Note 1: Absolute maximum ratings are those values beyond which damage to the product may occur. Functional operation under these conditions is not implied (or recommended).*

*Note 2: The battery input is not reverse polarity protected. Applying reverse polarity will cause parasitic diode conduction within the starter, and with a low-impedance power source such as a battery this will result in a very large reverse current. Damage to the starter and external wiring are both possible outcomes.*

*Note 3: Pin protected from negative voltage by resettable fuse.*

### 11.2 Recommended Operating Conditions

Symbol	Parameter	Min	Max	Unit
$V_{BAT}$	Battery voltage	20	55	$V_{DC}$
$V_{CAN\_L}$ , $V_{CAN\_H}$	CAN L and H voltage	-12	+12	$V_{DC}$
$T_{AMB}$	Operational temperature	-40	+85	$^{\circ}C$

Table 6 – Recommended Operating Conditions

### 11.3 Electrical Specifications (-40 to +85°C, typical values given for +25°C)

#### 11.3.1 Hall sensor power outputs

	Min	Typ	Max	Unit
<b>+5V</b>				
Output voltage	4.25	4.75	5.25	V <sub>DC</sub>
Continuous output current capability	60			mA <sub>DC</sub>
<b>+12V</b>				
Output voltage	11.5	12.0	12.5	V <sub>DC</sub>
Continuous output current capability	60			mA <sub>DC</sub>

Table 7 – Hall sensor power outputs

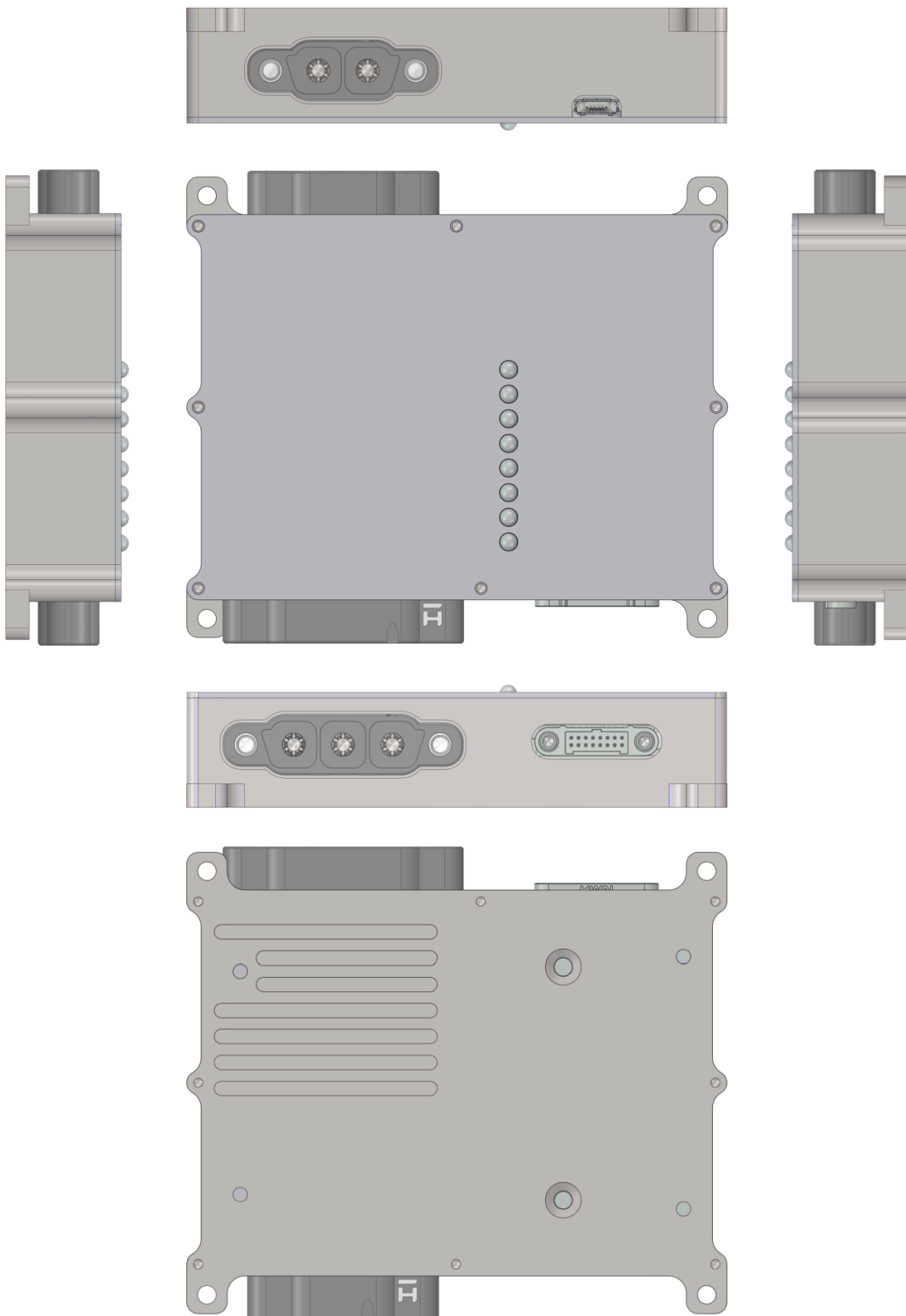
Current capability specifications give the minimum current that an output is guaranteed to be able to deliver across the operating temperature range.

#### 11.3.2 Monitoring

	Min	Typ	Max	Unit
<b>Update rate</b>			30	Hz
<b>Battery voltage monitoring</b>				
Accuracy		±0.25	±0.75	V <sub>DC</sub>
Range	0		62.5	V <sub>DC</sub>
<b>Current monitoring</b>				
Accuracy		±1	±3	A <sub>DC</sub>
Range	0		100	A <sub>DC</sub>
<b>FET temperature monitoring</b>				
Accuracy (-40 to +105°C)		±1	±3	°C
Range	-55		+125	°C
<b>BLDC speed monitoring</b>				
Accuracy (2 pole BLDC)		±150	±300	RPM
Accuracy (8 pole BLDC)		±38	±76	RPM
Accuracy (14 pole BLDC)		±22	±44	RPM
Accuracy (20 pole BLDC)		±15	±30	RPM
Accuracy (26 pole BLDC)		±12	±24	RPM
Accuracy (32 pole BLDC)		±10	±20	RPM
Range	0		30,000	RPM

Table 8 – Monitoring

11.4 Mechanical Characteristics



Dimensions: 93.5 x 80.5 x 20mm  
Mass: 190g (excluding mating harnesses)

### 11.4.1 Mounting

There are 2 options for mounting the starter. The simplest approach is to secure the starter to a flat surface using 4 x M3 bolts inserted through the M3 clearance holes in the corners. Alternatively, there are 8 x M2 tapped holes on the underside of the starter. The relative positions of the mounting holes are shown in Figure 12 below:

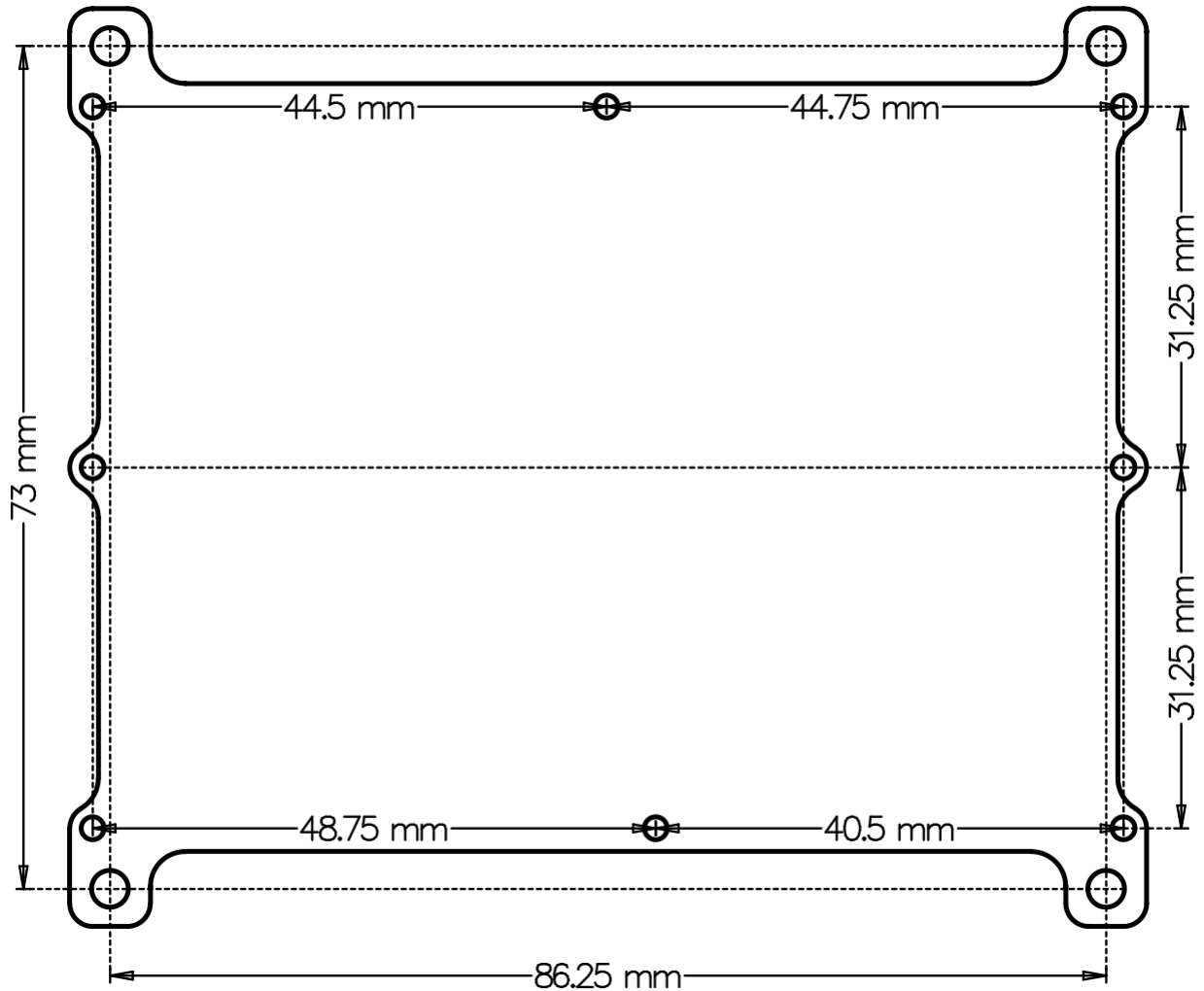


Figure 12 – Mounting hole locations (viewed from above)

Be careful not to distort the enclosure by mounting to a warped surface. The M2 holes on the underside of the starter are tapped to a depth of approximately 6mm.

## 12 Document version history

## 13 Appendix 1 – RS232 protocol

### 13.1 Hardware layer

Full-duplex bidirectional UART operating at RS232 voltage levels. Baud rate configurable to any standard rate from 9600 to 115200 Baud. Data formatted to 8N1.

### 13.2 Command protocol

Commands may be sent to the engine starter using the following structure:

First byte:	Synchronisation	Always FEh
Second byte:	Command	Ranges from 00h to 7Fh
Third byte:	Payload byte count	Ranges from 0 to 255
Fourth and subsequent bytes:	Payload	Number of bytes specified

Some commands return a response, some do not. Responses have the same structure as commands, except that the most significant bit of the command byte is set.

Malformed and undefined commands are ignored. If insufficient payload bytes are specified the command is ignored. Extra payload bytes are tolerated (the command is still processed and actioned), but the surplus bytes are ignored.

There is no timeout on command reception. Commands are processed and actioned once all required bytes are received, regardless of how long that takes.

There is no need for a gap between commands; one command may be followed immediately by the next.

Multi-byte payload values are little-endian unless specified otherwise.



### 13.3 Command summary

Command name	Command byte	Payload size	Payload	Response payload
<b>Start</b>	00h	0	No payload	No response
<b>Stop</b>	01h	0	No payload	No response
<b>Align</b>	02h	2	1 PWM duty cycle in %, 10 to 30 2 Hall LED to illuminate, 0 to 2 <i>Note 1</i>	No response
<b>Reset</b>	03h	0	No payload	No response
<b>Get Status Registers</b>	04h	0 or 1	If payload size = 1, then payload specifies the interval between streamed responses in increments of 33.333ms. A payload size of zero, or payload value of zero terminates this stream of data.	1 Status register 0 <i>Note 2</i> 2 Status register 1 <i>Note 2</i> 3 Status register 2 <i>Note 2</i> 4 Status register 3 <i>Note 2</i>
<b>Get Measurements</b>	05h	0 or 1	If payload size = 1, then payload specifies the interval between streamed responses in increments of 33.333ms. A payload size of zero, or payload value of zero terminates this stream of data.	1 Speed in RPM (low byte) 2 (high byte) 3 PWM duty cycle in increments of 0.1% (low byte) 4 (high byte) 5 Current in Amps 6 Battery voltage in increments of 0.25V 7 FET temperature in °C (signed byte)
<b>Get Statistics</b>	06h	0	No payload	1 Number of commutations (low byte) 2 (high byte) 3 Number of Hall sensor errors detected (low byte) 4 (high byte) 5 Outcome, 0 to 11 <i>Note 3</i> 6 Time spent cranking in increments of 33.333ms 7 Total time spent cranking in increments of 33.333ms (low byte) 8 (high byte) 9 Number of start attempts (low byte) 10 (high byte) 11 Time spent cranking during successful start attempts in increments of 33.333ms (low byte) 12 (high byte) 13 Number of successful start attempts (low byte) 14 (high byte)

<b>Get Engine Starting Parameters</b>	07h	0	No payload	<ol style="list-style-type: none"> <li>1 Cranking timeout in increments of 33.333ms, 30 to 255 (1.0 to 8.5 seconds)</li> <li>2 Cranking speed in increments of 100RPM, 1 to 50 (100 to 5000 RPM)</li> <li>3 Cranking current limit, 0 to 9 <i>Note 4</i></li> <li>4 BLDC pole count, 2 to 32 (even numbers only)</li> <li>5 Initial PWM duty cycle in %, 10 to 90</li> <li>6 PWM ramp rate in %/s, 25 to 250</li> <li>7 Control flag register <i>Note 5</i></li> <li>8 Hall sensor phase offset, 0 to 6 <i>Note 6</i></li> </ol>
<b>Get Communications Parameters</b>	08h	0	No payload	<ol style="list-style-type: none"> <li>1 RS232 Baudrate, 0 to 7 <i>Note 7</i></li> <li>2 CAN bitrate, 0 to 7 <i>Note 8</i></li> <li>3 CAN flag register <i>Note 9</i></li> <li>4 CAN ID (least-significant byte)</li> <li>5 CAN ID (byte 2)</li> <li>6 CAN ID (byte 3)</li> <li>7 CAN ID (most significant byte)</li> </ol>
<b>Get Serial Number</b>	09h	0	No payload	<ol style="list-style-type: none"> <li>1 Serial number (low byte)</li> <li>2 (high byte)</li> </ol>
<b>Get Firmware Version</b>	0Ah	0	No payload	<ol style="list-style-type: none"> <li>1 Firmware version number (minor)</li> <li>2 (major)</li> </ol>
<b>Reserved for future use</b>	0Bh			
<b>Clear Statistics</b>	0Ch	0	No payload	<ul style="list-style-type: none"> <li>• If successful, returns new values read from non-volatile memory.</li> <li>• If unsuccessful, returns null response (payload size of zero).</li> </ul>
<b>Set Engine Starting Parameter</b>	0Dh	8	<ol style="list-style-type: none"> <li>1 Cranking timeout in increments of 33.333ms, 30 to 255 (1.0 to 8.5 seconds)</li> <li>2 Cranking speed in increments of 100RPM, 1 to 50 (100 to 5000 RPM)</li> <li>3 Cranking current limit, 0 to 9 <i>Note 4</i></li> <li>4 BLDC pole count, 2 to 32 (even numbers only)</li> <li>5 Initial PWM duty cycle in %, 10 to 90</li> <li>6 PWM ramp rate in %/s, 25 to 250</li> <li>7 Control flag register <i>Note 5</i></li> <li>8 Hall sensor phase offset, 0 to 6 <i>Note 6</i></li> </ol>	<ul style="list-style-type: none"> <li>• If successful, returns new values read from non-volatile memory.</li> <li>• If unsuccessful, returns null response (payload size of zero).</li> </ul>

<b>Set Communications Parameters</b>	0Eh	7	1 RS232 Baudrate, 0 to 7 <sup>Note 7</sup> 2 CAN bitrate, 0 to 7 <sup>Note 8</sup> 3 CAN flag register <sup>Note 9</sup> 4 CAN ID (bits 0 – 7) 5 CAN ID (bits 8 – 15) 6 CAN ID (bits 16 – 23) 7 CAN ID (bits 24 – 28)	<ul style="list-style-type: none"> <li>• If successful, returns new values read from non-volatile memory.</li> <li>• If unsuccessful, returns null response (payload size of zero).</li> </ul>
<b>Do not use</b>	0Fh			

Table 9 – RS232 command summary

Note 1: Hall LED to illuminate: 0=A, 1=B, 2=C.

Note 2: Status register bit definitions as per Diagnostics tab in configuration software.

Note 3: Outcome: 0=unknown, 1=success, 2=timeout, 3=battery under-voltage, 4=battery over-voltage, 5=Hall sensor errors, 6=locked rotor, 7=FET over-temperature, 8=stop command, 9=reset command, 10=arm pin inactive, 11=start button released.

Note 4: Cranking current limit: 0=20A, 1=23A, 2=27A, 3=30A, 4=33A, 5=67A, 6=100A, 7=133A, 8=167A, 9=200A.

Note 5: Control flag register: bit 7=Reverse direction of rotation, bit 6=Backup to compression before cranking, bit 5=Ignore Hall sensor errors, bit 4=One touch starting, bits 3 to 0=X (don't care).

Note 6: Hall sensor phase offset: 0=-180°, 1=-120°, 2=-60°, 3=0°, 4=+60°, 5=+120°, 6=+180°.

Note 7: RS232 Baudrate: 0=115200, 1=76800, 2=57600, 3=38400, 4=28800, 5=19200, 6=14400, 7=9600.

Note 8: CAN bitrate: 0=1Mb/s, 1=500kb/s, 3=250kb/s, 7=125kb/s.

Note 9: CAN flag register: Reserved for future use.

## 14 Appendix 2 – CAN protocol

### 14.1 Hardware layer

Unterminated. Bitrate configurable to 125kb/s, 250kb/s, 500kb/s or 1Mb/s.

### 14.2 Command protocol

The CAN protocol uses a single extended ID (29 bits) for all communications. This ID is configurable to any value.

For transmissions directed at the starter, the ID must match and at least one data byte must be present. The first data byte is interpreted as a command byte; any additional data bytes are ignored.

The starter may perform an action in response to receiving a command, or it may send a response on the CAN bus. Responses use the same CAN ID. The command byte is returned as the first data byte with its most significant bit set. The remaining data bytes are used for actual data as required.

### 14.3 Command summary

Command name	Command byte	Response payload
Start	00h	No response
Stop	01h	No response
Reset	03h	No response
Get Status Registers	04h	0 84h 1 Status register 0 <i>Note 1</i> 2 Status register 1 <i>Note 1</i> 3 Status register 2 <i>Note 1</i> 4 Status register 3 <i>Note 1</i>
Get Measurements	05h	0 85h 1 Speed in RPM (low byte) 2 (high byte) 3 PWM duty cycle in increments of 0.1% (low byte) 4 (high byte) 5 Current in Amps 6 Battery voltage in increments of 0.25V 7 FET temperature in °C (signed byte)
Get Statistics	06h	0 86h 1 Number of commutations (low byte) 2 (high byte) 3 Number of Hall sensor errors detected (low byte) 4 (high byte) 5 Outcome, 0 to 11 <i>Note 2</i> 6 Time spent cranking in increments of 33.333ms

Table 10 – CAN command summary

*Note 1: Status register bit definitions as per Diagnostics tab in configuration software.*

*Note 2: Outcome: 0=unknown, 1=success, 2=timeout, 3=battery under-voltage, 4=battery over-voltage, 5=Hall sensor errors, 6=locked rotor, 7=FET over-temperature, 8=stop command, 9=reset command, 10=arm pin inactive, 11=start button released.*