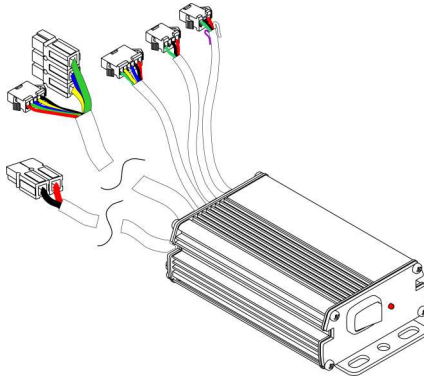




The Grinfineon Motor Controller

User Manual - Rev 1.0



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1 Introduction

The Grinfineon controller is based around the popular Infineon series of ebike motor controllers which we've adapted with custom firmware and custom cable harnesses to be broadly useful in aftermarket and DIY ebike applications. With the exception of some high RPM geared motors, it should work well with a large majority of brushless motors on the market in the 500-3000 watt power range.

1.1 Key Features

Here are some of the features that make this controller stand out which you won't usually find with most 3rd party ebike motor controllers

- Long phase leads (140cm)
- On/Off Switch
- Proportional Regenerative Braking
- Fwd/Rev Control
- Plug and Play Automatic Hall Mapping
- LED Status Indicator
- Watertight Enclosure
- CA-DP Plug
- User Crimpable Connectors (JST-SM and Anderson Powerpoles)

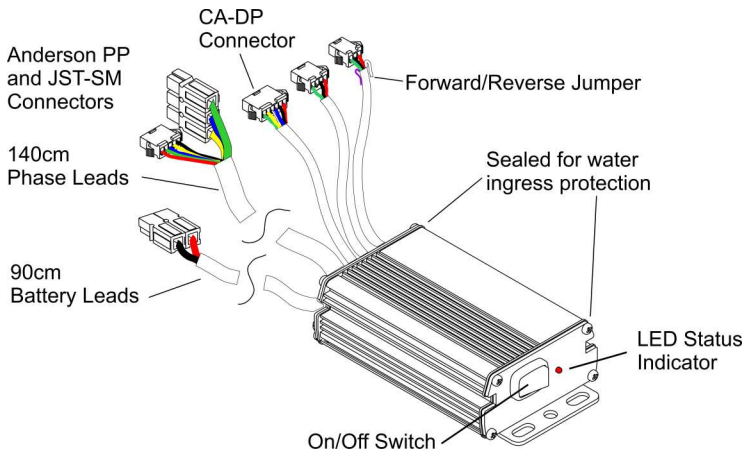


Figure 1: Key Controller Features

2 Installation and Hookup

The motor controller end plates have a flange with holes to facilitate securing to the vehicle. We recommend locating it in place where the ON/OFF switch is accessible and where it still has good exposure to air flow. Common bicycle locations include on the front of the rear rack support, between the seat tube and the rear wheel, or on the top tube with front motors.

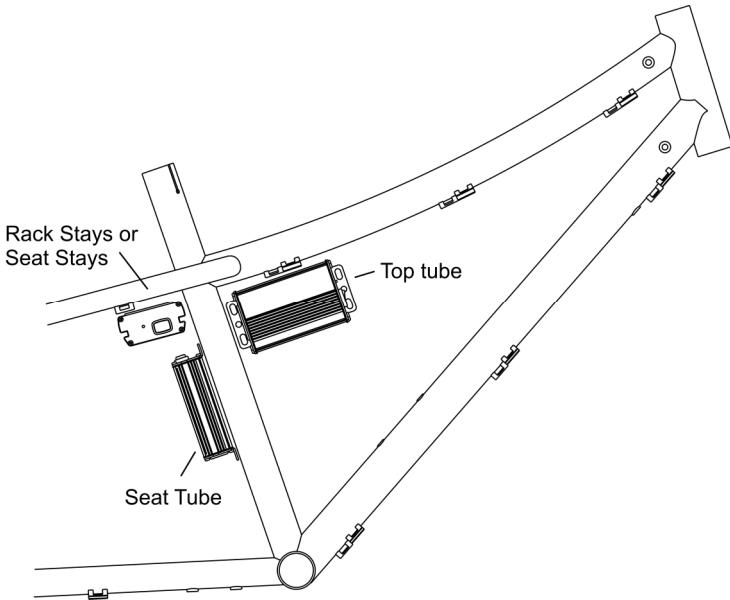


Figure 2: Common mounting locations and orientations

Although it is tempting, we do not recommend putting the controller inside a bag or enclosure box that blocks exposure to air flow, as it will be more susceptible to overheating. The silicone grommets on the controller end plates do an excellent job of keeping water out, so there is little concern about having the controller exposed to the elements, and the orientation of the installed controller does not matter.

2.1 Basic Hookup

The controller has 6 cables coming out of it: Battery, Motor Phase, Motor Hall, Throttle, Ebrake, and Cycle Analyst. At the bare minimum, the controller just needs a throttle, battery pack, and motor connection in order to work:

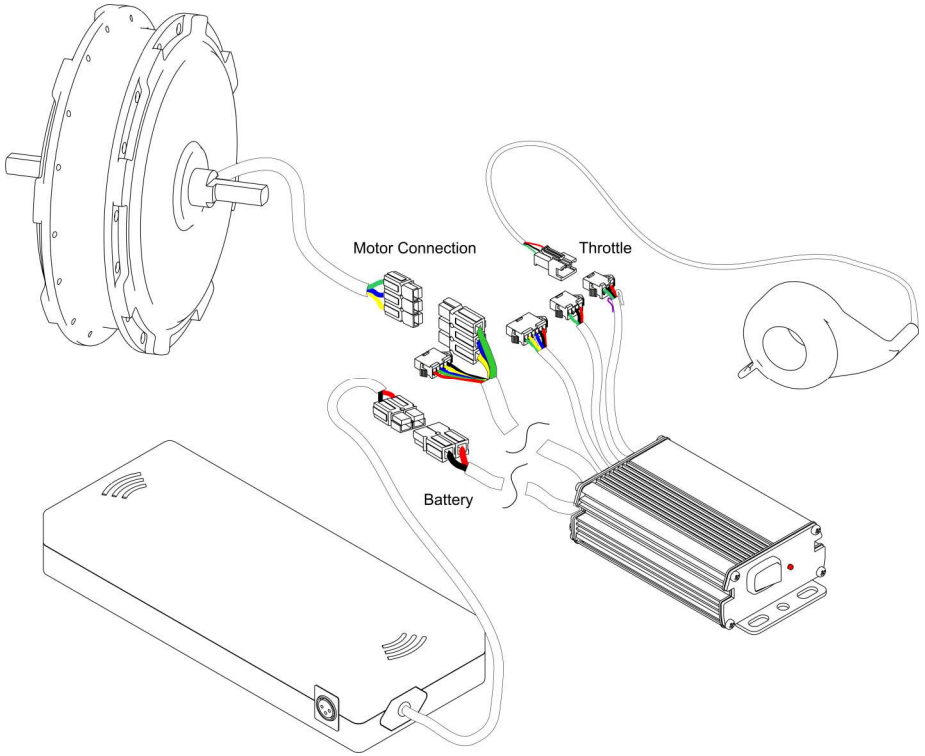


Figure 3: Basic hookup diagram

The throttle is a 3-pin JST-SM plug intended for Hall Effect throttle devices. It supplies 4.3V to power the throttle plug and expects a signal of 0.9V - 3.6V as the throttle is twisted. Throttle signal voltages higher than 3.9V are considered a fault condition, so if a potentiometer based throttle is used then appropriate resistors are needed to keep the voltage swing within range.

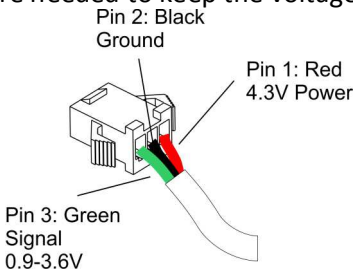


Figure 4: Controller Throttle Pinout

The brushless hub motor will have 3 phase wires that need to terminate with the 3 controller wires. Typically these are green, yellow, and blue, but many other possibilities exist and the exact pairing does not matter. When you first plug in the motor and press the throttle, the motor should start spinning in sensorless mode. If the motor is spinning backwards, then simply swap any pair of the phase wire connections in order to switch the direction.

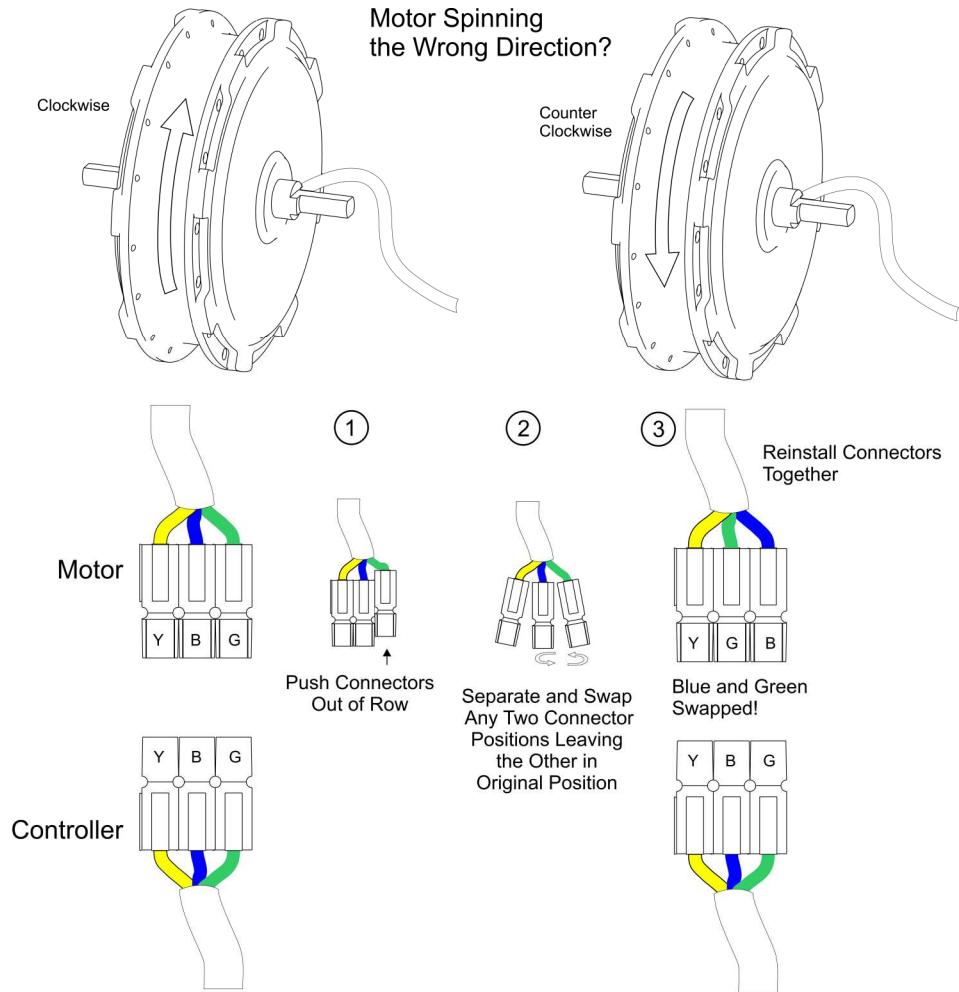


Figure 5: Motor Direction Change by Swapping Phase Wires

If you want regenerative braking in a basic setup, then you can connect either an ebrake cutoff lever or other momentary push switch to the 4-pin ebrake plug.

2.2 Cycle Analyst Hookup

You can also add a V2 Cycle Analyst to this basic setup in order to have an informative display of all your vehicle and battery stats. The system still responds the same way to your throttle, but the V2 Cycle Analyst has the ability to override and limit the throttle signal if you are exceeding the CA's programmed current limit, speed limit, or battery low voltage cutoff.

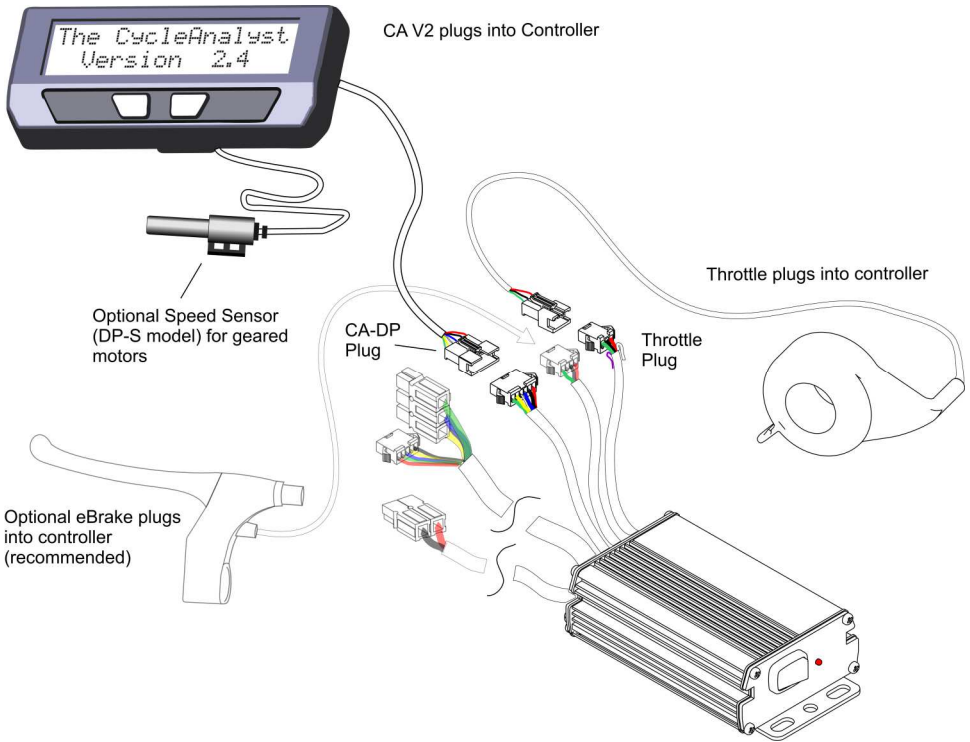


Figure 6: CA V2 Hookup. Throttle and eBrake Plug into Controller

Finally, if you are using a V3 Cycle Analyst, then your throttle and ebrake signals will connect to the Cycle Analyst rather than to your motor controller. Only the 6-pin CA-DP plug of the controller is used.

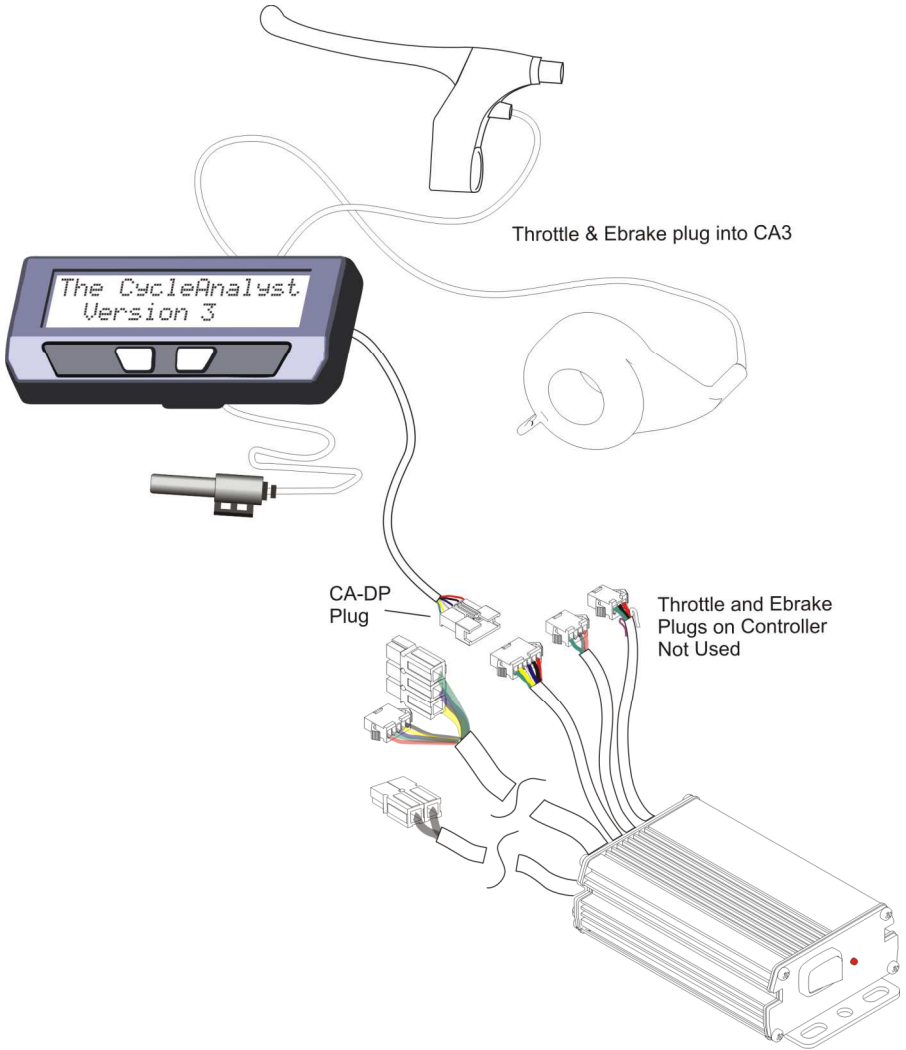


Figure 7: CA V3 Hookup. Throttle and eBrake Plug into CA (not controller)

The V3 Cycle Analyst is useful when much more advanced control features are desired, like PAS operation, motor over-temperature protection, torque sensing pedelec, mode presets etc.

2.3 *Sensored vs. Sensorless*

While the Grinfineon controller will work sensorless with the hall connector unplugged, there are several limitations to this mode.

- Starting from a standstill can be a little bit jerky while the controller attempts to self start the wheel.
- The maximum electrical commutation frequency is lower (13000 eRPM), which can limit its use with geared motor drives, and
- When using a Cycle Analyst, you won't have the option of picking up the speed signal from the motor hall line and will require an external speedo sensor and spoke magnet (i.e. CA-DPS or CA3-DPS).

If the motor has hall sensor wires, then we recommend connecting them to the controller as well so that you can benefit from sensed operation. The hall sensor plug has 5 wires, red and black supply power to the hall sensors in the motor, and the yellow, green, and blue wires carry the resulting hall signals.

2.4 *Hall Mapping Procedure*

Traditionally, figuring out the proper hall/phase pinout between a given motor and controller was a tedious process of trial and error, with 36 possible hall and phase pinout combinations only 3 of which would spin the motor correctly in the right direction. With the Grinfineon controllers, this hall pinout can be mapped automatically by the controller.

To do this, first power up and run the controller with the halls *unplugged* and with the motor off the ground. You should notice that the controller LED flashes in a rapid 2 Hz blinking pattern while the motor is spinning, which indicates that it is in sensorless mode. Running sensorless like this clears out any previous hall mapping from the controller memory.

Next, connect the hall plug between the controller and motor. Now run the motor again, and apply and release the throttle several times. When the controller has determined that a valid set of hall signals is present, then the LED will switch from a rapid 2Hz blinking pattern to being steady ON when the motor is running. This confirms that the controller has mapped and is using the hall sensors for commutating.

Hall Sensor Mapping

With Phase Wires Connected to Motor Controller
Be sure that the motor can spin freely!

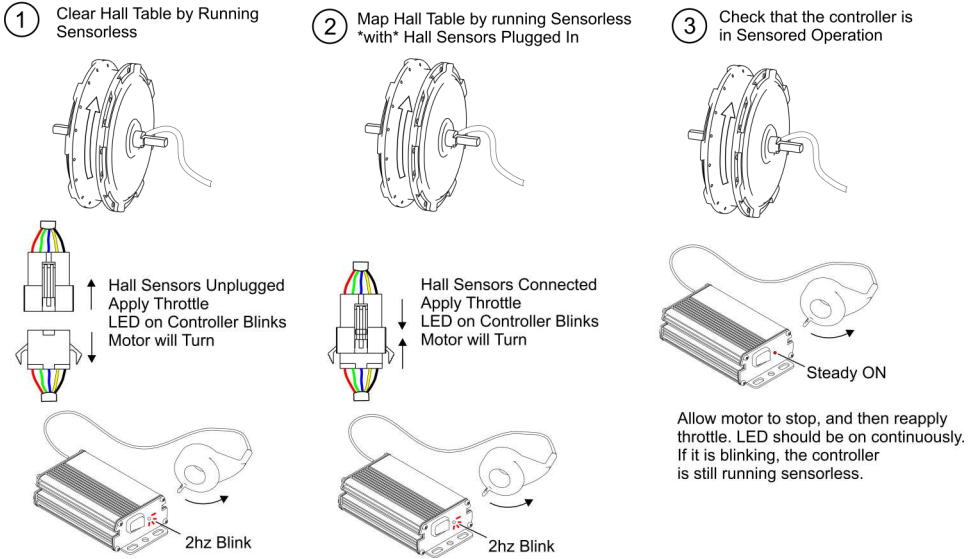


Figure 8: Hall Sensor Mapping Procedure

Note that the controller LED will always blink slowly at 0.8 Hz when the throttle is off and everything is otherwise OK. It is only when you have the throttle pressed and the motor turning that you will see the steady ON led indicating sensored mode.

If your motor is spinning the wrong direction, follow the phase-wire swapping procedure in Figure 5 and then follow the hall mapping procedure described above.

3 Core Features

3.1 LED Indicator

The LED status indicator lets you know if the controller is powered up, what state it's in, and most importantly if there are any fault conditions that would cause things not to work. The following are normal operating modes:

LED Off	No power to controller (either battery is disconnected, or ON/OFF switch is OFF)
LED Slow Flash	Controller powered up, throttle is not pressed
LED Fast 2Hz Flash	Controller is running the motor in sensorless mode
LED Steady On	Controller is running the motor in sensed mode

The following state flash signals occur with quick blinks and then a pause:

1 Blink	Brake cutoff is engaged
2 Blinks	Regenerative Braking is engaged
3 Blinks	Battery voltage below low voltage cutoff
4 Blinks	Motor has stalled
5 Blinks	Throttle voltage was high when controller turned on

Additional fault conditions exist in which the LED will blink staying on for a long time and then only briefly flashing off.

1 Long Blink	Motor short circuit protection engaged
2 Long Blinks	15V regulator is damaged
3 Long Blinks	Throttle too high signal fault (>3.9V)
5 Long Blinks	Microprocessor is damaged

3.2 On/Off Switch

The included ON/OFF toggle switch on the controller end plate allows for conveniently switching your ebike on and off without disconnecting the main battery pack. When the switch is off, both the Controller and the Cycle Analyst (if attached) will power down and cease drawing current from the battery.

If you want the switch to be accessible from the handlebars or mounted on a dashboard, then it is possible to remove it from the end plate and extend the wires up to your desired switch location and then seal the hole with a grommet. The wire gauge can be fairly thin, but if it is being used with a Cycle Analyst with light or other accessories powered from the DC jack, then we recommend using at least 20g.

3.3 Regenerative Braking

The Grinfineon controllers have proportional regenerative braking enabled, allowing you to use the hub motor as a brake and return kinetic energy back into the battery pack. There are two basic methods of activating regen:

3.3.1 Ebrake Input

In the first method, you connect an ebrake cutoff lever or other momentary switch between pins 2 and 4 of the 4-pin ebrake plug. When the ebrake signal is pulled to ground, then the controller switches to a baseline level of regenerative braking, putting drag on the wheel and a small amount of current in the battery pack.

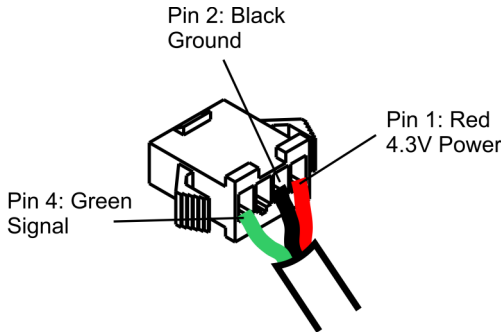


Figure 9: eBrake Connector. 5V+ for Hall Brakes

If you then press the throttle while the regen lever is activated, the amount of braking force and regen current will increase, with full throttle giving maximum regen. This way you can modulate the intensity of the braking with the standard

throttle already on your bike. The only thing to be careful about is releasing the throttle before you let go of the brake lever once you come to a stop.

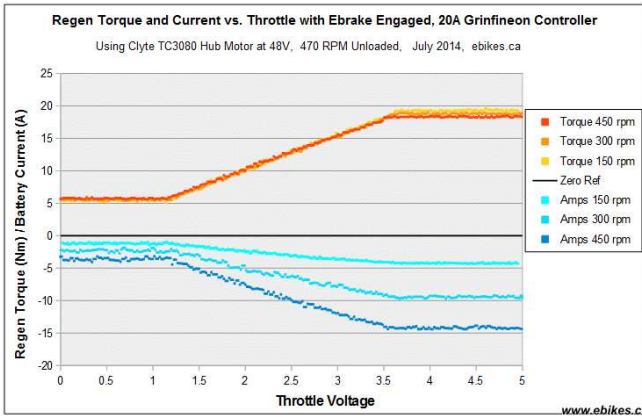


Figure 10: Throttle Voltage and Regen Intensity while eBrake is Active

3.3.2 0-0.8V Throttle Signal

The second method to engage regen is with a throttle signal that is less than 0.8 Volts. Normally a hall effect throttle will only swing from 0.9V to about 3.6V, leaving the range of 0.0-0.9V unused. In the Grinfineon controllers, this unused range is mapped to regenerative braking, with regen starting at 0.8V and then increasing to a maximum as the throttle signal goes down to 0.0V.

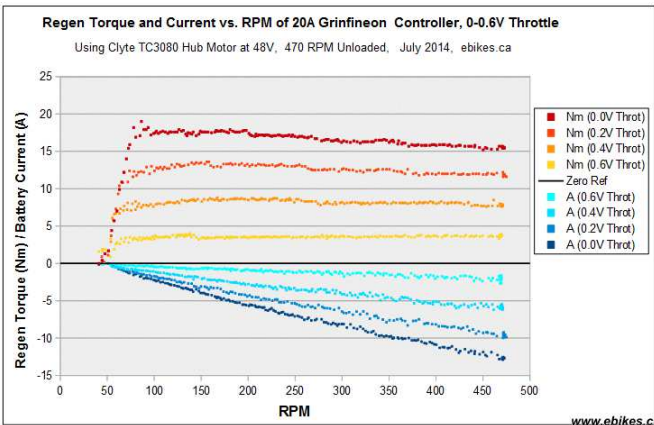


Figure 11: Regen intensity for throttle 0V-0.8V

This throttle mapped regen is handy since it allows for variable braking without any additional wires to the controller, and in principle a small bidirectional throttle

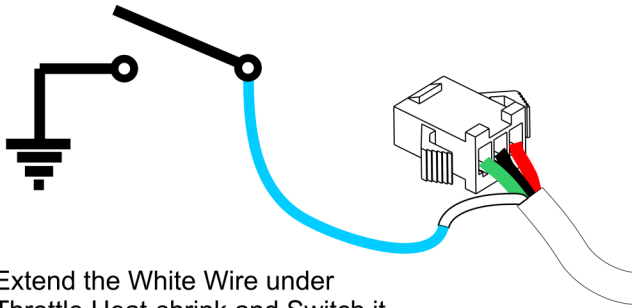
would allow you to both accelerate and slow down without the need for any kind of brake sensors. It is also how regenerative braking is activated with the V3 Cycle Analyst, which can send any signal to the throttle line.

If you have a geared motor or mid-drive motor, then the regen won't have much effect. It will cause the motor to quickly stop spinning when you squeeze the brakes, but it won't be able to help slow the bike down due to the intrinsic freewheel of these systems.

3.4 Additional Features

3.4.1 Fwd / Rev

If you have an application where the motor direction needs to be reversed at times, as is handy with trike and quad applications, then there is an additional white forwards/reverse direction wire that is tucked under the throttle heatshrink. If this wire is exposed and then connected via a switch to ground, it will enable you to change the motor direction on the fly without swapping the motor phase leads.



Extend the White Wire under Throttle Heat-shrink and Switch it to Ground to Change the Motor Direction

Figure 12: FWD/REV switch schematic

Note that there is also a purple wire under the shrink wrap too. This is reserved for future functionality and is not a ground wire. Connecting the white to purple will not change direction; you must connect it to a black (ground) wire.

3.4.2 Disabling Regen

If you don't want regenerative braking with a direct drive hub motor but you still want to have ebrakes to cut off the motor power, then it is possible to fully disable regen as well. This is done by opening up the motor controller and soldering a short wire between the pad labeled TA and any nearby ground pin.

Bottom View of Controller Board

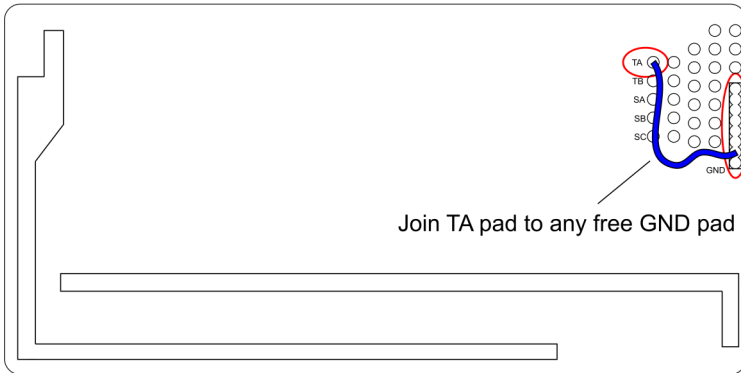


Figure 13: Disable Regen by Jumping TA to GND with Wire

With Regen disabled, the ebrake signal will now act just as a motor cutoff, and applying a throttle voltage between 0-0.8V will have no effect.

4 Limitations

Although we tried to make this controller fairly universal, there are also more than a few limitations that can affect its use in some applications.

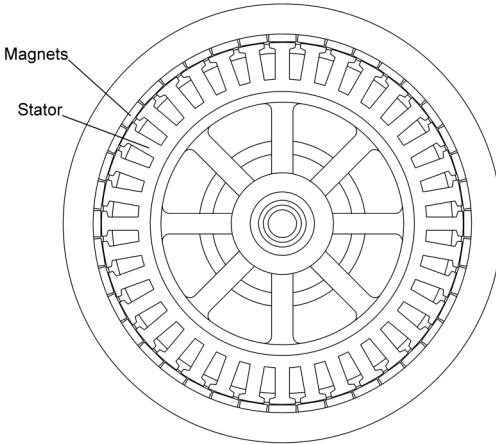
4.1 eRPM Sensorless & Sensored

The maximum commutation frequency in sensorless mode is about 13000 eRPM. The electrical RPM is easy to calculate by taking the mechanical RPM of the motor, multiplying it by the number of magnetic pole pairs in rotor, and then again by the gear ratio if it is a geared hub.

For instance, below is a diagram of a direct drive motor with 40 magnets. That means there are 20 magnetic pole pairs. A 13000 eRPM would correspond to a 650 maximum mechanical RPM at the wheel, which is much faster than you would have on a bicycle (200-300 rpm is more common); therefore this hub would have no problem running sensorless at bicycle RPMs.

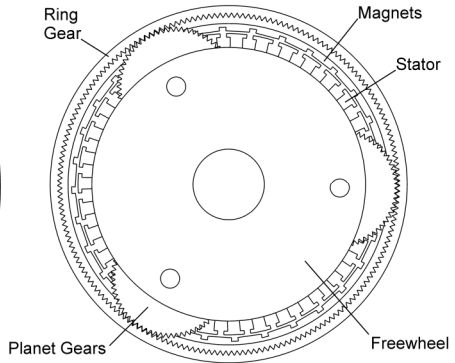
The motor below has 32 magnets and a 7:1 gear reduction. In this case, the maximum RPM in sensorless mode would be $13000 \text{ eRPM} / (16 * 8) = 116 \text{ rpm}$. This would not work on a standard bicycle wheel, unless it was a fairly low speed system.

Direct Drive Hub Motor



40 Magnets = 20 Pole Pairs
 13000 eRPM / 20 Pole Pairs = 650 RPM max

Geared Hub Motor



32 Magnets = 16 Pole Pairs
 7:1 Gear Ratio
 13000 eRPM / (16 Pole Pairs x 7:1 Gear Ratio) = 116 RPM max

Figure 14: Direct Drive and Geared Hub Motor eRPM examples

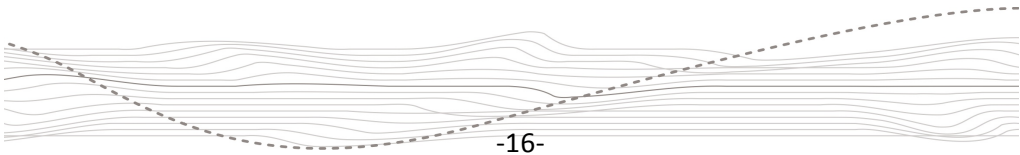
The maximum RPM when running with hall sensors is much higher, but at values over 40,000 eRPM the commutation timing can be off and motor performance will suffer.

4.2 Low Impedance Hubs (Sensored or Sensorless)

There can also be problems even below the eRPM limit when running hub motors with very low winding resistance and winding inductance. We don't have exact values, but high speed and high power geared hub motors (such as low turn count MAC motors, and the 350 rpm eZee hubs) will often fall in this category, and lead to erratic controller behavior and cutouts.

4.3 60 Degree Hall Timing

Most brushless motors use 120 degree hall timing, where at any given point there is always at least 1 hall signal that is high, and 1 hall signal that is low. But some motors use 60 degree hall spacing, where 000 and 111 are also valid hall patterns.



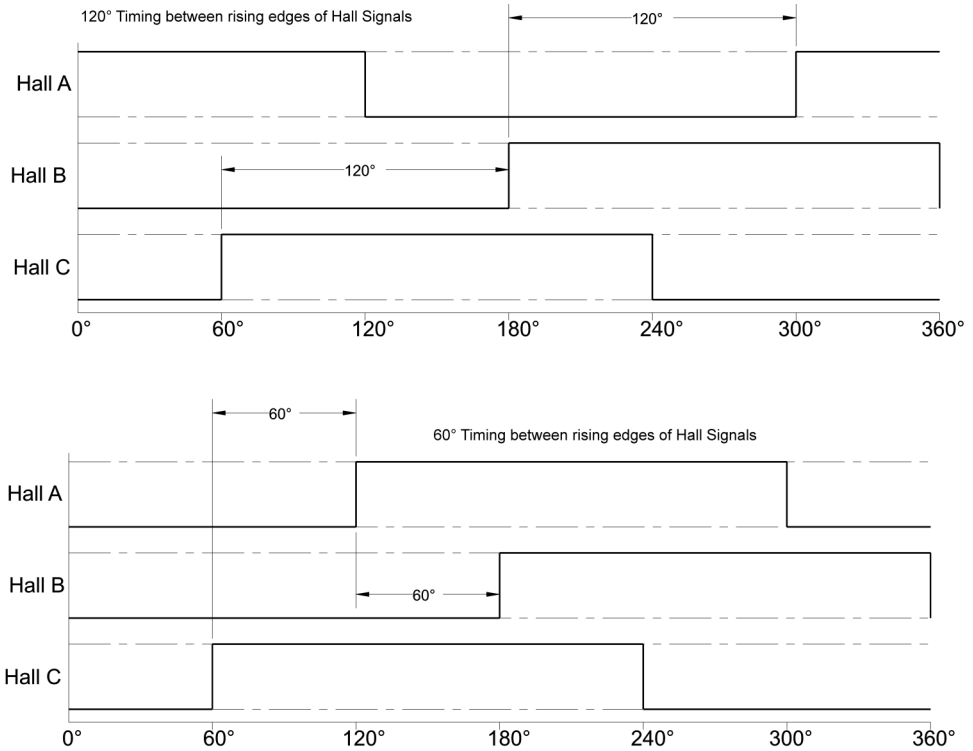


Figure 15: Hall Timing Diagram

The Grinfineon controller will map to 60 degree hall timing, but once this is done it is tricky to reset the mapping for it to run sensorless as having the halls unplugged will produce what appears to be a valid hall signal.

4.4 Trapezoidal Drive

The controller output is trapezoidal, not sinusoidal. For motors with trapezoidal back-emf waveforms this will result in smooth and silent operation. If the motor has a sinusoidal winding, then it will still work fine but there may be some audible buzzing from the current harmonics.

4.5 No Change to Internal Settings

For a number of reasons the controller's internal settings for low voltage cutoff, battery and phase current limits, max regen current etc. are fixed in the controller IC and can't be reprogrammed by the user. The fixed values are sensibly chosen to be around the maximum allowable range for flexibility while keeping the controller in a conservative operating area.

If you want to further limit these settings for custom low voltage rollbacks or current/power limits, then either a V2 or V3 Cycle Analyst will provide that functionality and a lot more just via modulation of the throttle signal.

4.6 Max Regen Voltage

The maximum regen voltage is set to ~58V for the 24-48V controllers and ~88V for the 36-72V controllers. This upper voltage regen cutoff is critical to prevent damage to the controller if ever the battery is disconnected during regenerative braking, since the regen will stop abruptly before the voltage has a chance to spike.

It is also higher than the full charge voltage on most battery packs you would use, and there can be a possibility of overcharging a battery if you start with a full charge at the top of a hill and your battery's BMS circuit does not have an overvoltage cutoff. In that scenario it is prudent to have a Cycle Analyst or other volt meter to keep an eye on the battery voltage level. In practice you will almost always consume many more amp-hours than you put back in while braking and overcharging from regen is not much of a concern.

4.7 Won't Show CA Accessory Current Draw

The CA-DP plug on the motor controller is wired up so that it will show the current draw of the motor and controller, but not the current draw of any other devices (like front lights) that are plugged into the CA's power tap. If you want the Cycle Analyst to show auxiliary device current, then the device can be opened up and the black wire from the CA-DP cable moved from the - side of the shunt (adjacent to the blue wire) to the + side of the shunt (adjacent to white wire).
Specifications

5 Specifications





5.1 Electrical

	C3620	C7225	C3635	C7240
Battery Current (A, +/- 10%)	19	23	33	38
Phase Current Limit (A +/- 10%)	40	50	70	80
Nominal Battery Voltage (VDC)	24-48	36-72	24-48	36-72
MOSFETs	6x		12x	
	AOT460	IRFB4110	AOT460	IRFB4110
Max Regen Voltage (VDC)	58	88	58	88
Low Voltage Cutoff (VDC)	19	29	19	29
Control Chip	Infineon XC836			
eRPM Limit Sensorless	~13,000			
eRPM Limit Sensored	~40,000			

5.2 Mechanical

	C3620	C7225	C3635	C7240
Dimensions (mm)	110x71x34		154x87x46	
Weight (kg)	0.47	0.49	0.75	0.78
Chassis Material	Extruded Aluminum			
DC Battery Connector	Genuine Anderson Power Poles			
Motor Phase Connector	Genuine Anderson Power Poles			
Hall Sensor Connector	JST-SM Series			
Other I/O Connectors	JST-SM Series			
Waterproofing	Gasketed at end plates and wire exits, sealed switch			

5.3 Connector Pinout

	<p>Throttle*: 1=4.3V 2=Gnd 3=Signal:1-3.6V</p>
	<p>Ebrake: 1=5V 2=Gnd 3=NC 4=Ebrake</p>
	<p>Hall Sensor**: 1=Gnd 2=Yellow 3=Blue 4=Green 5=5V</p>
	<p>Cycle Analyst***: 1=Vbatt 2=Gnd 3=-Shunt 4=+Shunt 5=Hall 6=Throt</p>

* White wire in sheath is for FWD/REV - Jump to GND to enable

** When running sensorless LED Flashes 2Hz on throttling

*** **Do not use with old Small Screen Cycle Analysts**