Applications

- Electric Vehicles
- Drones
- Research programs
- Industrial Machinery

Features

- Hardware-based overcurrent, overvoltage, overtemperature trips and more
- Open Source platform[1]
- Full isolation from powerstage for improved noise immunity
- Perfect match for EconoDual/17mm IGBT modules, proven for high power, high performance applications
- Resolver/Encoder support
- Field Oriented Control for advanced torque control and performance
- Isolated CAN bus interface
- Extensive fault reporting

Block Diagram

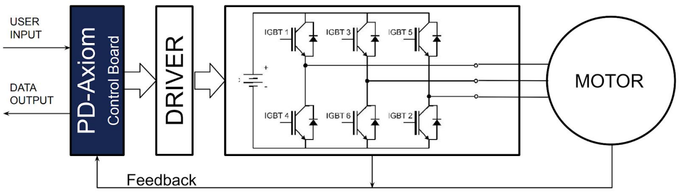


Figure1: Simplified system block diagram

Product Summary

At the heart of the electric vehicle is the motor controller capable of delivering torque quickly and precisely over a wide speed range, on demand set by the driver or the vehicle control system.

The controller's ability to provide constant motor position tracking without delay, ultra fast response to system or load disturbance and to otherwise deliver, intelligently, peak torque at all moments means maximum torque from the motor to the wheels. Maximum torque is achieved at low speed, even zero speed for electric vehicles and continues through the normal speed range. Operation of the motor and controller over the whole speed range is managed at high efficiency and high reliability.

The motor controller supports permanent magnet AC synchronous motors such as BLDC and SPM.

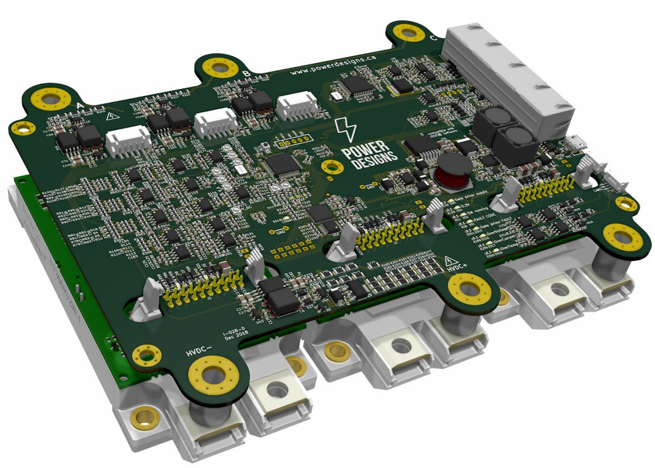


Figure 2: Control Board with IGBTs
(IGBT modules and gate drivers sold separately)

[1] Firmware and GUI released under GPLv3, schematics released under Creative Commons Attribution Share-Alike license

Absolute Maximum Ratings (1)

Parameter		Min	Max	Unit
Vdc_{IN}	Low voltage supply	0	30	Vdc
$HVDC_{IN}$	High Voltage DC sense (traction pack)	0	800	Vdc
T_s	Storage temperature	-40	85	°C

subject to change without notice

(1) Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. These are stress ratings only and functional operation of the device at these or any other conditions beyond those indicated under Recommended Operating Conditions is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

Recommended Operating Conditions

Parameter		Min	Typ(2)	Max	Unit
T_a	Ambient temperature	-40		60	°C
Vdc_{IN}	Low voltage supply	9	12	28	Vdc
Vdc_{CANbus}	CANbus supply	4.5		5.5	Vdc
$HVDC_{IN}$	High voltage supply (traction pack)(3)	72		410	V
f_{base}	AC frequency			1000	Hz

(2) All typical values are at 25°C with a 12V supply.
(3) Operation at higher voltages is possible with custom sensing gain, see Applications Information

Isolation ratings

Parameter	Min	Max	Unit
HVDC to control logic isolation	1500		Vrms
High Voltage to Chassis	1500		Vrms
CANbus rated isolation	400		Vrms

The control board has not been tested to any industrial standard.

Supply Current

Over recommended operating conditions (unless otherwise noted)

Parameter		Test Conditions	Min	Typ	Max	Unit
I_{CC}	Supply current	Vdc_{IN} = 12Vdc, I_{GATE_DRV}=0A		390		mA
I_{CC}	Supply current	Vdc_{IN} = 12Vdc, I_{GATE_DRV}=1A		1.4A		A

Gate Driver Supply Electrical Characteristics

Over recommended operating conditions (unless otherwise noted)

Parameter		Test Conditions	Min	Typ	Max	Unit
I_{GATE_DRV}	Gate Driver Supply Current(4)	Vdc_{IN} = 12Vdc			1	A
V_{GATE_DRV}	Gate Driver Supply Voltage(5)	Vdc_{IN} = 12Vdc	12	15	24	Vdc

(4) The Gate Driver DC/DC supplies all 6 gate drivers.
(5) Hardware changes are required for Gate Driver Supply voltage above or below 15V. Contact technical@powerdesigns.ca for more information

Analog Inputs(5)

Over recommended operating conditions (unless otherwise noted)

Parameter		Test Conditions	Min	Typ	Max	Unit
V_{AN}	Analog Input Voltage		0		5	V
f_{cutoff}	Filter cutoff frequency			TBD		kHz

(5) ACCEL1, ACCEL2 and ADC7 are buffered and protected.

General Purpose I/O(6)

Over recommended operating conditions (unless otherwise noted)

Parameter		Test Conditions	Min	Typ	Max	Unit
V_{OD}	Open Drain Voltage	Mode:Open Drain Output	0	12	14	V
I_{OD}	Open Drain Current Sink	Mode:Open Drain Output			200	mA

(6) PA7, PC13 and PC15 are by default configured as open drain outputs, intended for relays to drive a fan or pump. By changing resistors they can be reconfigured as 0-5Vdc inputs.

CANbus Interfaces

Over recommended operating conditions (unless otherwise noted)

Parameter		Test Conditions	Min	Typ	Max	Unit
Vcc_{CANbus}	CANbus Supply Voltage		0	5	5.5	V
I_{CANbus}	CANbus current draw			TBD		mA
	Data Rate				500	kbps

Resolver Interface

Over recommended operating conditions (unless otherwise noted)

Parameter		Test Conditions	Min	Typ	Max	Unit
V_{EXC}	Resolver Excitation Voltage			12		Vpp
I_{CANbus}	Sin/Cos Input Voltage				3.15	Vpp
f_{EXC}	Excitation Frequency(7)			20		kHz

(7) Excitation frequency is programmable with 0603 jumpers to 10 kHz, 12 kHz, 15 kHz, or 20 kHz .

BiSS Encoder Interface(8)

Over recommended operating conditions (unless otherwise noted)

Parameter		Test Conditions	Min	Typ	Max	Unit
Vcc_{BiSS}	BiSS Encoder Supply Voltage			5		Vdc
	Data Rate			TBD		kHz

(8) Firmware support under development

Current Sensor Inputs

Over recommended operating conditions (unless otherwise noted)

Parameter		Test Conditions	Min	Typ	Max	Unit
Vcc_{ISENSE}	Current Sensor Supply Voltage(8)			5		Vdc
Icc_{ISENSE}	Current Sensor Supply Current (per Channel)				150mA	mA
f_{cutoff_ISENSE}	Filter cutoff frequency			200		kHz

(8) Current Sensors Supply Voltage can be set at 3.3Vdc with 0805 jumpers

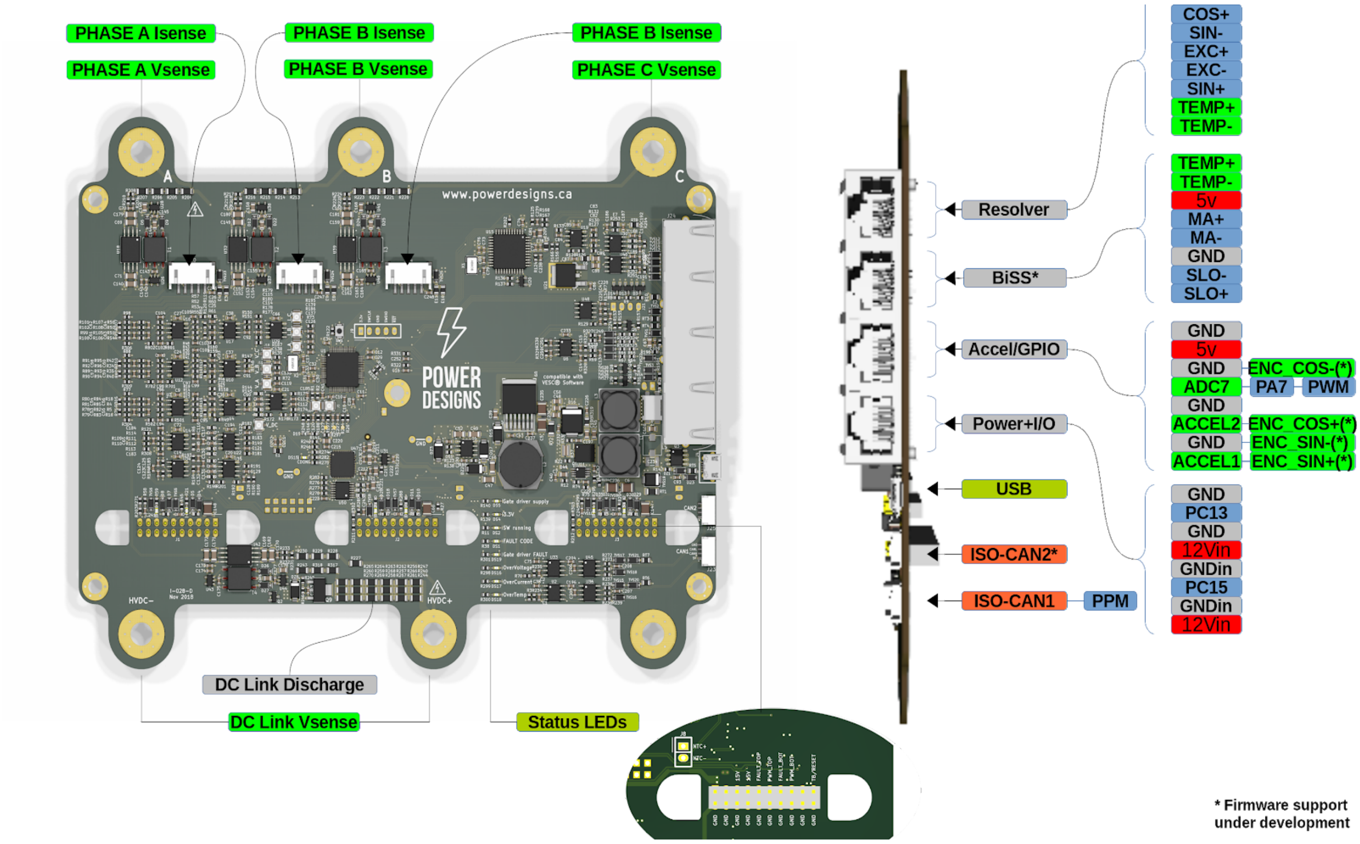
If using current sensors with weak REF output/input, install 100 Ohm resistors in R311 to R316 (x6) to provide a stronger voltage reference

High Voltage Sensor Inputs

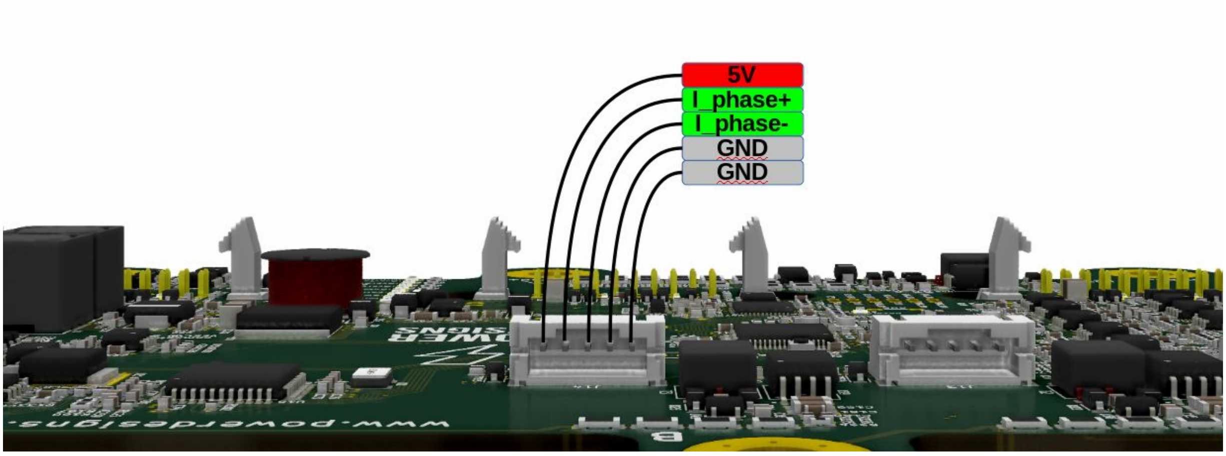
Over recommended operating conditions (unless otherwise noted)

Parameter		Test Conditions	Min	Typ	Max	Unit
$HVDC_{SENSE}$	High Voltage Battery Sense Range		0		610	V
HV_{SENSE}	High Voltage Phase Sense Range		-600		600	V
f_{cutoff_ISENSE}	Filter cutoff frequency			200		kHz

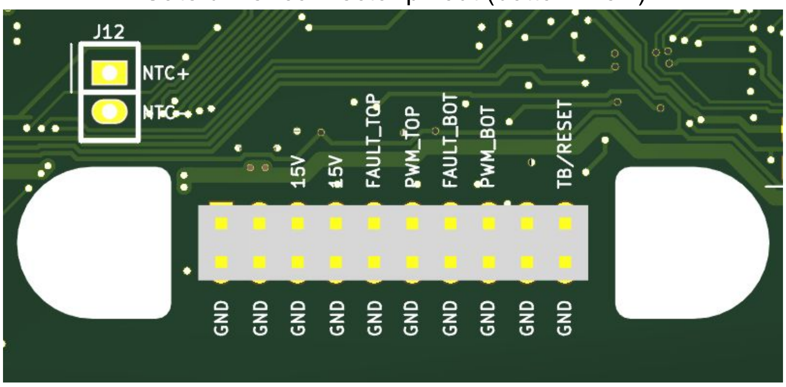
Pinout information



* Firmware support under development



Gate driver connector pinout (bottom view)

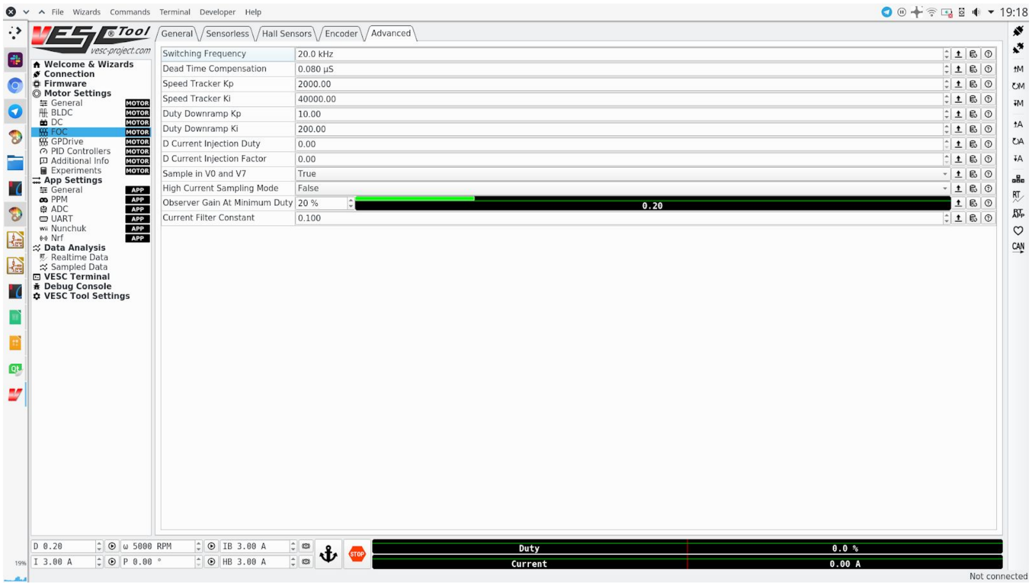


Connectors

- Board supply input: Standard RJ45 (port 1)
- Analog/GPIO inputs: Standard RJ45 (port 2)
- BiSS Encoder: Standard RJ45 (port 3)
- Resolver: Standard RJ45 (port 4)
- Current sensor connector: S5B-PH-SM4-TB(LF)(SN). Mates with housing **455-1163-ND** and wires **ASPHSPH24K152**.
- USB: Standard micro USB
- CANbus: Standard UAVCAN connector SM04B-GHS-TB(LF)(SN)-. Mates with JST housing **GHR-04V-S** and wires **AGHGH28K305**.

User Interface

Download VESC_tool graphical user interface from *https://vesc-project.com/vesc_tool*
This is open source software (GPLv3) and runs on Windows and most linux flavors.



User manuals are located at https://vesc-project.com/node/178

VESC Software Features

- Current and voltage measurement on all phases for superior performance
- Regenerative braking
- Sensored, sensorless and hybrid mode
- Configurable RPM, current, voltage and power limits
- Input sources:
  - Dual CANbus (VESC and UAVCAN protocols)
  - Dual Analog input
  - PPM (optional)
- Communication ports:
  - USB
  - CANbus
- Rotor position sources:
  - Resolver
  - Encoder (absolute)

- Throttle curve and ramping in all input sources
- Seamless 4-quadrant operation
- Motor revolution, Amp hour, Watt hour counting
- Real time data analysis and read out via communication ports
- Adjustable protection against:
  - Low HVDC voltage
  - High HVDC voltage
  - High motor current
  - High input current
  - High regenerative braking current
  - High RPM (separate limits for each direction)
  - Over temperature
- Traction control of dual drives over CANbus

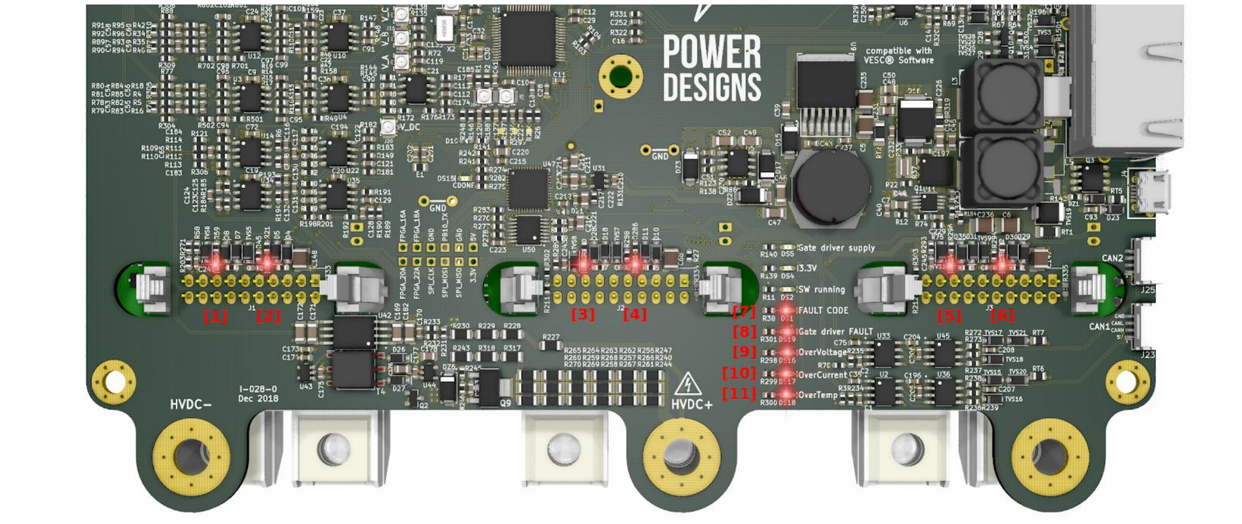
Fault Reporting

One of the biggest challenges when it comes to setup and tune a motor drive is how difficult is to identify the failures and its root causes. To ease the job of the tuner, these boards come with several ways to identify a fault origin.

- VESC Tool interface (software trips)
  Current Fault is displayed in the real time tab.
  Clicking Tools->Print faults will show all the faults that occurred since the last reset along with the conditions when it happened.

  As of v3.55, this is the list of possible faults
  1. ***FAULT_CODE_OVER_VOLTAGE***
  2. ***FAULT_CODE_UNDER_VOLTAGE***
  3. ***FAULT_CODE_DRV***
  4. ***FAULT_CODE_ABS_OVER_CURRENT***
  5. ***FAULT_CODE_OVER_TEMP_FET***
  6. ***FAULT_CODE_OVER_TEMP_MOTOR***
  7. ***FAULT_CODE_GATE_DRIVER_OVER_VOLTAGE***
  8. ***FAULT_CODE_GATE_DRIVER_UNDER_VOLTAGE***
  9. ***FAULT_CODE_MCU_UNDER_VOLTAGE***
  10. ***FAULT_CODE_BOOTING_FROM_WATCHDOG_RESET***
  11. ***FAULT_CODE_ENCODER_SPI***
  12. ***FAULT_CODE_ENCODER_SINCOS_BELOW_MIN_AMPLITUDE***
  13. ***FAULT_CODE_ENCODER_SINCOS_ABOVE_MAX_AMPLITUDE***
  14. ***FAULT_CODE_FLASH_CORRUPTION,***
  15. ***FAULT_CODE_HIGH_OFFSET_CURRENT_SENSOR_1,***
  16. ***FAULT_CODE_HIGH_OFFSET_CURRENT_SENSOR_2,***
  17. ***FAULT_CODE_HIGH_OFFSET_CURRENT_SENSOR_3,***
  18. ***FAULT_CODE_UNBALANCED_CURRENTS***

- LEDs on the control board (hardware trips)



1. FAULT on LEG A, IGBT Bottom(1)
2. FAULT on LEG A, IGBT Top(1)
3. FAULT on LEG B, IGBT Bottom(1)
4. FAULT on LEG B, IGBT Top(1)
5. FAULT on LEG C, IGBT Bottom(1)
6. FAULT on LEG C, IGBT Top(1)
7. General FAULT asserted. This is an MCU output, and will blink if any hardware or software fault is asserted.
8. One or more of the 6 gate drivers asserted a fault
9. OverVoltage fault in phase or battery
10. OverCurrent fault in one or more phases
11. OverTemperature fault

(1) *With most gate drivers it means either a gate driver undervoltage or a short-circuit trip, also known as desaturation protection.*

We have extensive math support for precisely tune the trips thresholds of our hardware. This (link) is an example of such math support. Contact us if you want us to tune your voltage, current, temp trips, etc.

- Faults can be retrieved over the CANbus interface

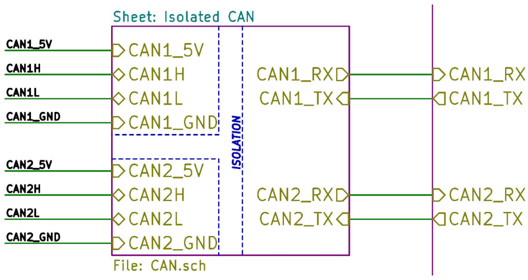
Safety Features

This device integrates several safety mechanisms to prevent human injury and severe property damage.

- DC Link Discharge. When the Control Board supply drops out, the energy stored in the DC Link capacitor (650uF at 400V) is dissipated on a resistor to achieve safe voltage levels in less than 30 seconds
- FPGA-based logic is continuously monitoring all fault inputs. If any fault is asserted, all PWM activity is shut down. An FPGA reset is required to overcome this state.
- FPGA supervises the PWM generated by the MCU. If a shoot-through command is detected, PWM activity is shut down with the following logic:

INPUTS (MCU PWM pins)			OUTPUTS (To Gate Driver)		Notes
PWM_xT	**PWM_xB**	**ENABLE**	**PWM_GxT**	**PWM_GxB**	
X	X	0	0	0	A Fault clears EN signal. Disable outputs
0	0	1	0	0	Safe state
0	1	1	0	1	
1	0	1	1	0	
1	1	X	0	0	Shoot-through detected. Disable outputs

- All hardware faults are latched. In order to recover from a hardware fault, the board needs to be either reset or an explicit command (`palta_reset_oc`) needs to be sent using VESC Terminal.
- Reinforced isolation between traction pack and control logic for safety and noise immunity
- Basic isolation on CANbus interfaces for extra system safety and more reliable operation



- Hardware trips ensure safe system shutdown even in cases of firmware errors.
- Plenty of software-configurable limits.
- Continuous monitoring of resolver and encoder signal quality.
- Software watchdog timers for broad coverage of firmware errors.
- Source code publicly available for review.

Layout/Wiring Requirements

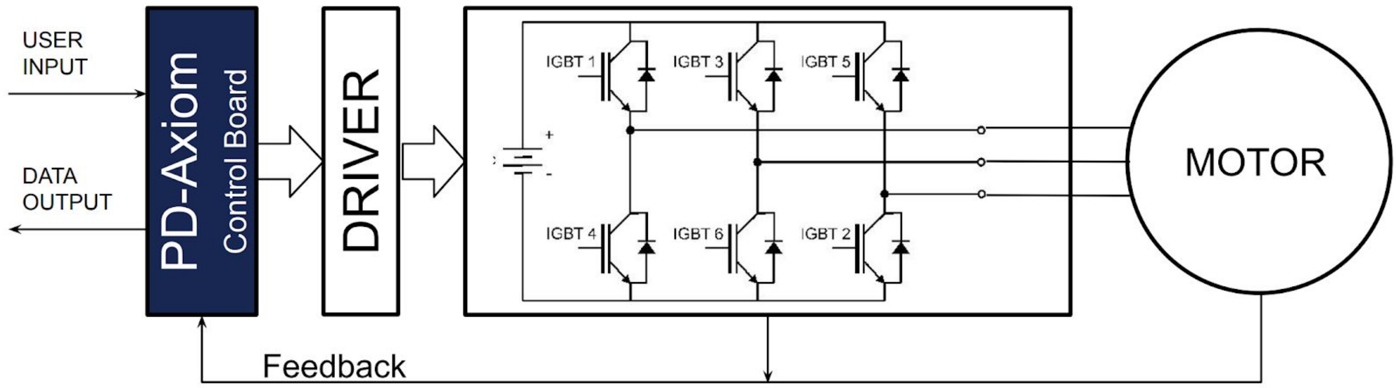
In high power applications it is mandatory to minimize the EMI impact of the inverter layout. The following rules must be followed while building an inverter:

- The DC Link capacitor is a critical piece of the inverter. Minimal ESL is mandatory, along with adequate ripple current capability and capacitance. Contact us if you need support selecting it.
- Keep the gate driver cables short (<10cm) and signals tightly coupled to the GND return. A long cable exposes PWM signals and GND reference to severe transients that can affect the control quality.
- Current sensor cables should have minimal length, and use twisted pair wiring (gnd with 5v, I+ with I-) and shielded cables. These cables can be zip tied or glued down to avoid vibrations. Current sensor connectors have 2 GND pins, one for the signal return path, the other to ground the cable shielding.
- A metal shield between control board and powerstage can reduce noise. This shield should be grounded to chassis.
- All RJ45 ports have been defined in a way that allows all the signals to travel differentially through twisted pairs within CAT5 cables. This improves the signal quality in noisy environments, and should be used.
- If shielded CAT5 cable is used, ground the shield to chassis, do not connect it directly to MCU GND.

Keep us in the loop while going through your build to avoid issues early in the process.

Application Information

A typical application of the PD-Axiom motor control board for a high performance Electric Vehicle would be based on the following system block diagram



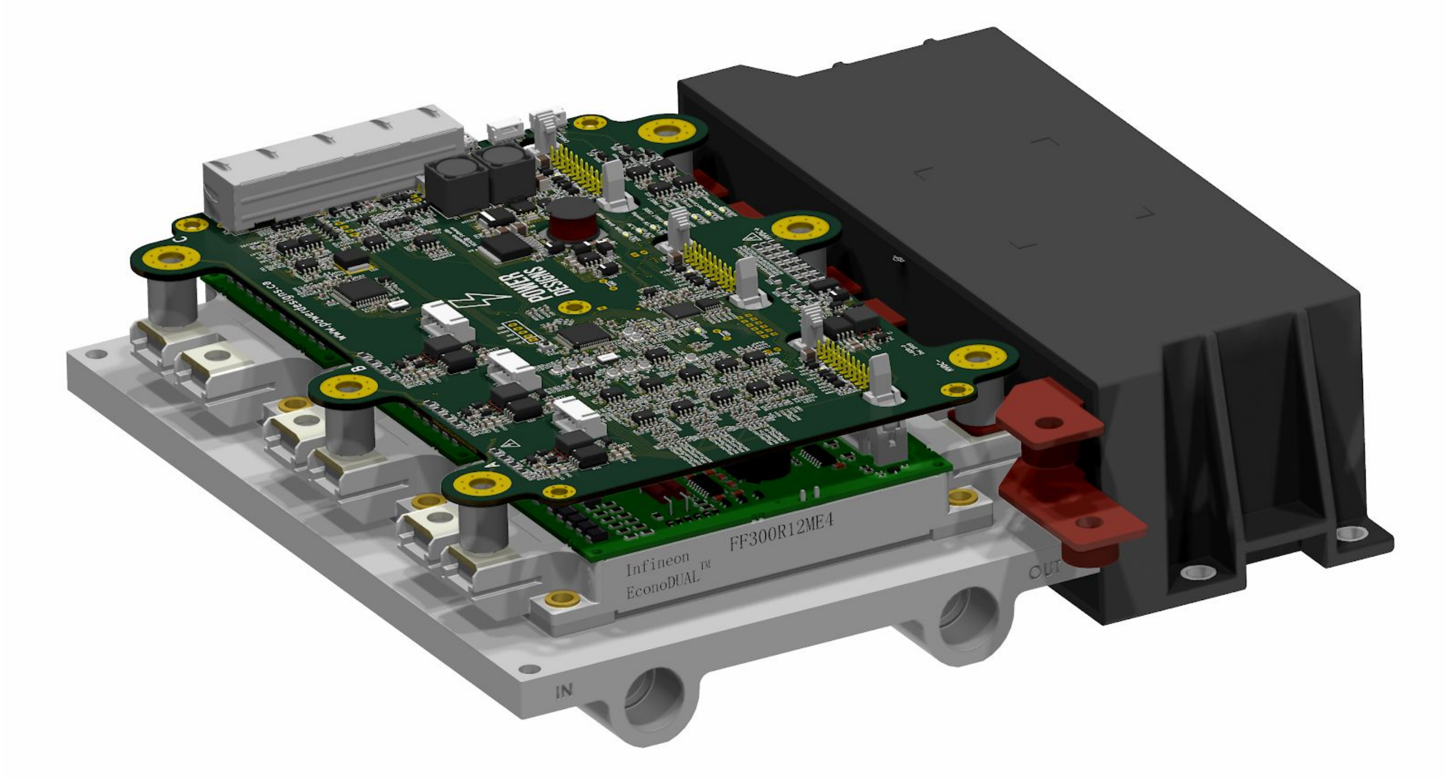
The system designer selects the power switch module (IGBT or Mosfet) and other necessary components to suite the intended application. The PD-Axiom can be paired with many different IGBT or Mosfet modules, this example uses three Econodual Package FF600R07ME4B11 from Infineon for the following application:

- Fully electric sports car
- Power: 80kW continuous, 120kW peak for 5 seconds.
- Battery voltage: 400Vdc
- Surface permanent magnet 3-phase motor
- Liquid cooling

Other motor controller components selected:

- Liquid cooled cold plate, 3000 Series from MicroCool
- DC Link capacitor, supplied by Power Designs (contact sales@powerdesigns.ca for more information)
- Gate driver (x3) 2SP0115T2A0-06 by Power Integrations
- Current sensor (x3) HTFS 800-P by LEM or ISB-425-A-802 by ICE Components

Assembly Notes:
400Vdc is properly handled by a 650V IGBT switch in Econodual Package, mated to a 600V DC Link capacitor with <15nH ESL.
An appropriate thermal interface material must be applied between the IGBT and the cold plate (or heatsink) according to IGBT manufacturer direction.
More information about IGBT mounting can be found here:
https://www.infineon.com/dgdl/Infineon-AN2006_05_Mounting_Instructions_EconoDUAL_3-AN-v2.1-en.pdf?fileId=db3a304412b407950112b40ecdaf1288
Miscellaneous hardware is needed to complete the assembly.

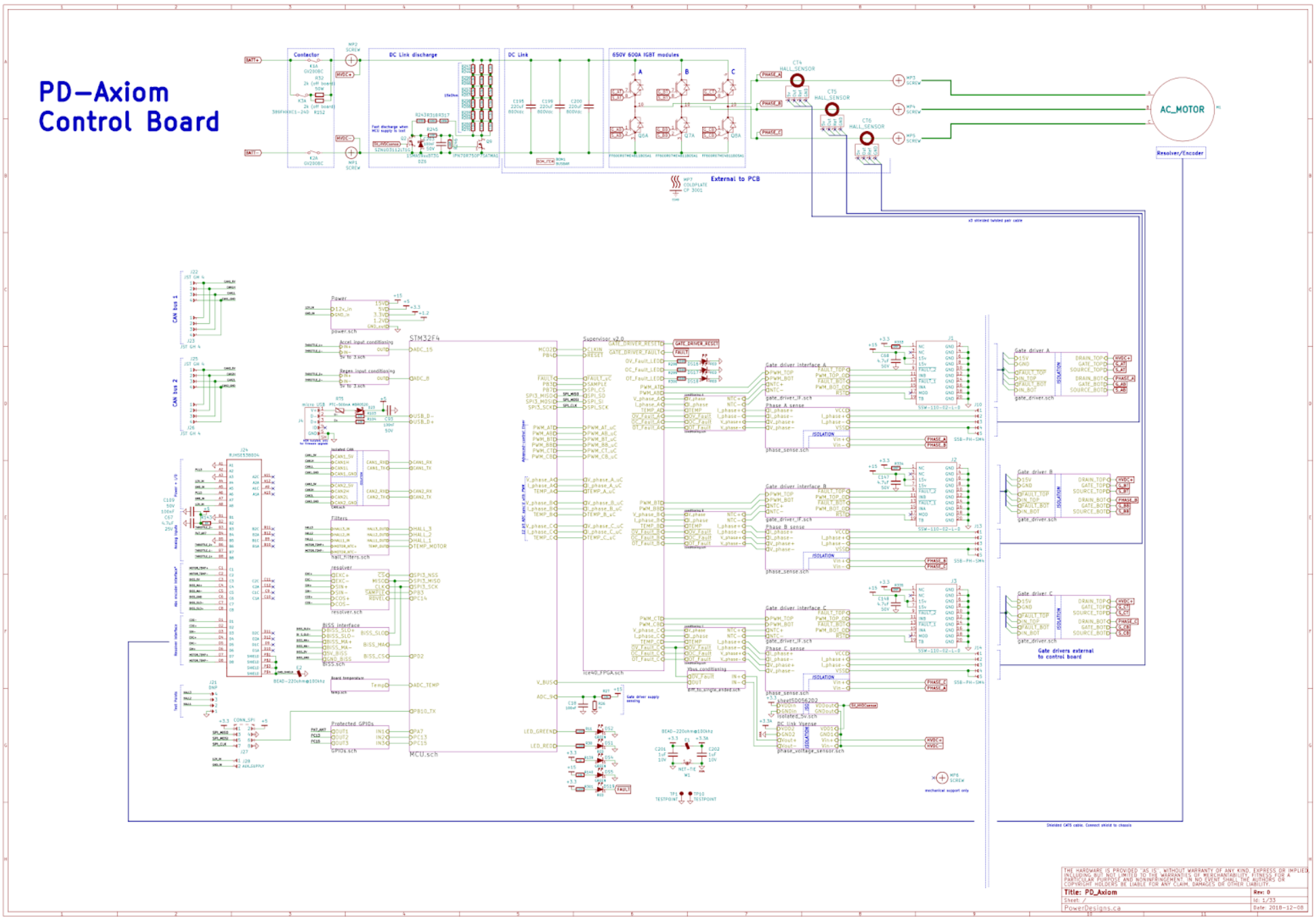


Contact us for help dimensioning your motor drive to optimize your investment and ensure reliability by calculating phase current ratings, overvoltage and overcurrent tripping points, overtemperature and motor parameter detection.

Contact sales@powerdesigns.ca for IGBTs, gate drivers, DC Link capacitor, current sensors, cooling options or other application-specific requirements.

Schematic

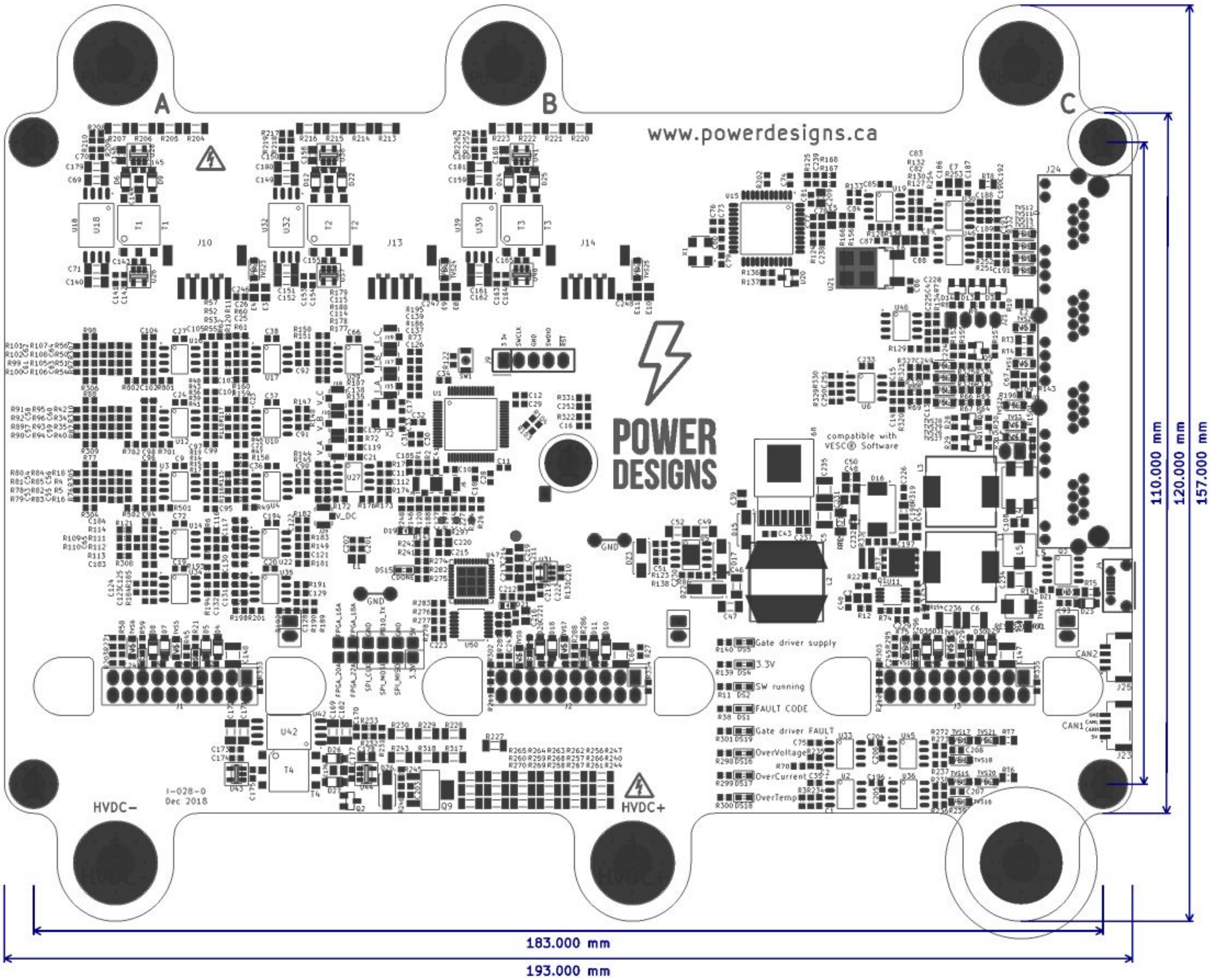
Top level shown for reference. For the complete schematic in PDF format visit www.powerdesigns.ca.



Mechanical

The following list provides the mechanical specifications for the PD-Axiom:

- PCB size: 4.6" x 2.8" x 0.75" (193 mm x 157 mm x 19 mm)
- No heat sink necessary
- IGBT connections: M6 x6
- Mounting points: M3 x5
- 3D model (.step) available on request.



Additional Information

Contact us at sales@powerdesigns.ca.

Terms And Conditions

PowerDesigns controllers are experimental systems designed to develop and test electrical systems incorporating electric motors or actuators. Electrical systems can cause danger to humans, property and nature; therefore precautions shall be taken to avoid any risk. Under no circumstances shall the hardware be used where humans or property are put to risk without a qualified professional thoroughly validating and testing the whole system. Software and hardware interact in various ways, and software developers cannot foresee all possible combinations of hardware used together with their software, nor problems that can occur in these different combinations. Things that can happen, even when using the correct settings, are:

- Electrical failure
- Fire
- Electric shock
- Hazardous smoke
- Overheating motors and actuators
- Overstrained power sources, causing fire or explosions (e.g. Lithium Ion Batteries)
- Motors or actuators stopping from spinning/moving
- Motors or actuators locking in, acting like a brake (full stop)
- Motors or actuators losing control over torque production (uncontrolled acceleration or braking)
- Interferences with other systems
- Other unforeseeable behavior of the system

VESC Tool and the VESC firmware are developer tools that for safety reasons may only be used by experts and experienced users, knowing exactly what they do. Following safety standards applicable in the area of usage. under safe conditions where software or hardware malfunction will not lead to death, injuries or severe property damage. Keeping in mind that software and hardware failures can happen. Although we design our products to minimize such issues, you should always operate with the understanding that a failure can occur at any point of time and without warning. As such, you shall take the appropriate precautions to minimize danger in case of failure.