CAN Precharge Controller User's Manual

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http://www.tritium.com.au

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1 INTRODUCTION

This document details the interface, installation, and usage requirements for the Tritium CAN precharge product. It also provides information on programming the device to implement custom functionality.

The precharge controller provides an easy way to connect the high voltage power connections between a battery pack and a Tritium WaveSculptor motor controller (or other capacitive device requiring precharging) without the risk of dangerous currents, contact welding, or sparks.

The precharge controller comes programmed from the factory configured with sensible default values that will work in a plug-and-play manner with a motor controller and Tritium CAN bus driver controls.

The microcontroller firmware for the device (in 'C') is available on the Tritium website under an open-source license, as are the hardware schematics and component overlays.

For further details on overall system configuration, please refer to the Wiring Engineering Reference document (TRI50.010), available on the Tritium website.

2 DEVICE OVERVIEW

The precharge controller provides two basic functions:

1) Charges the DC bus capacitors in the motor controller in a controlled manner to avoid high inrush currents on startup.
2) Discharges the DC bus capacitors in the motor controller on shutdown, to avoid a shock hazard when disconnecting the motor controller or working on the vehicle electrical systems.

Both functions are accomplished by connecting the motor controller to either the batteries (precharge) or ground (discharge) via an external high power resistor. The precharge controller takes care of all connections and sequencing involved in the operation, and reports it's progress and status on the front panel LEDs and also on the CAN bus communications interface.

The precharge controller also protects itself, and the external resistor, in the event of a fault. Over temperature, voltages not meeting expectations, and other faults are all detected and result in a shutdown of the precharge system, to avoid any risk of a fire or other undesirable event.

The precharge controller provides an interface between the CAN bus used by the WaveSculptor system, the high-voltage power connections, and the low-voltage emergency shut-down circuit. Inputs are provided for:

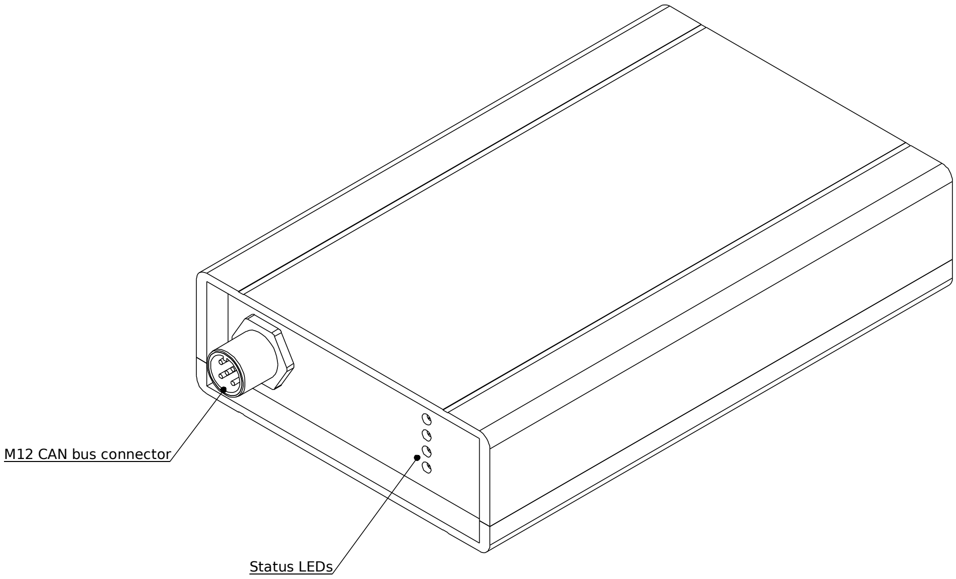
- CAN Bus and 12V device power
- 12V power for contactor outputs
- Two contactor drive outputs
- High voltage sensing
- Precharge / Discharge resistor and associated temperature sensor

Communications with the vehicle is via a CAN bus running at 1 Mbit/second, using a fixed base address of 0x540. Alteration of either the bit rate or the base address currently requires reprogramming the microcontroller, although hardware support does exist to allow remote configuration in the future.

Four LEDs are provided on the front panel of the device to indicate status.

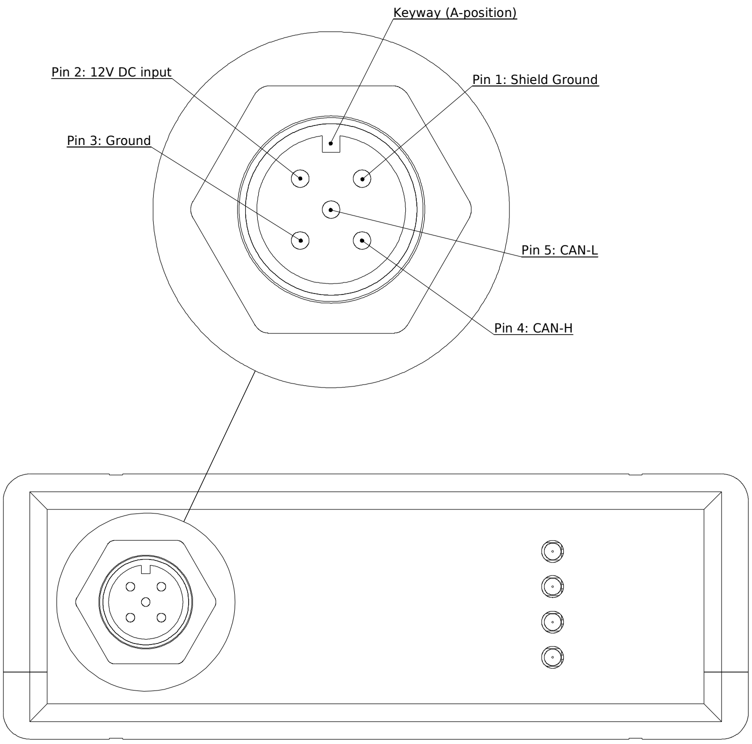
3 FRONT PANEL

The following illustration shows the connections and indicators on the front panel of the precharge controller. A CAN bus connection and four status LEDs are present on this panel.



3.1 CONNECTOR

The CAN bus connector is a male 5-pin M12 screw locking industrial standard DeviceNET connector. The pinout is shown below:



3.2 LEDS

The precharge controller shows the following information on the front panel LEDs:

LED label	***Colour***	***Function***
CAN Activity	Green	Flashes on CAN activity associated with the device (Tx & Rx)
Contactor 12V OK	Green	Solid when the 12V supply for the contactors is present
Precharge / Discharge	Yellow	Solid when precharging, flashes when discharging
HV Live	Red	Solid when output is live, flashes on errors

3.3 DEVICE POWER INPUT

Summary

Power for the precharge controller circuitry must be supplied along the CAN bus cable. The CAN bus is isolated from both the 12V contactor power and the high voltage sense connections. The precharge controller contains an internal switch-mode supply and will operate successfully within the specified operating range.

Specifications

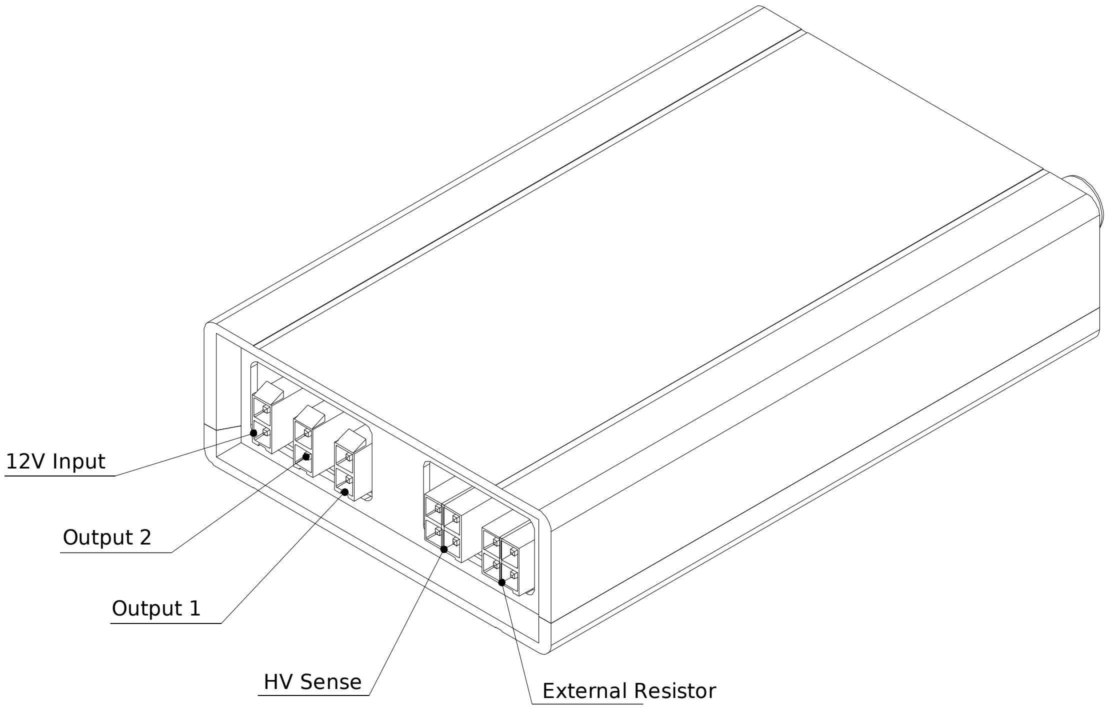
Supply voltage nominal:	13.8	V	(Note 1)
Supply voltage minimum:	9	V	(Note 1)
Supply voltage maximum:	15	V	(Note 1)
Circuit supply current maximum:	55	mA	(Note 2)
Circuit supply current typical:	40	mA	
Isolation voltage:	500	V	(Note 3)

Notes:

1. The input voltage operates the internal circuitry of the precharge controller, but not the contactors themselves.
2. The supply current drawn by the precharge controller electronics only, and will vary with output and status LED states. This figure does not include power drawn by the contactor output section or the contactors themselves.
3. Please refer to the Isolation section of the Wiring Engineering Reference document (available on the Tritium website) for more information regarding recommended earthing and connection practices for the entire vehicle system.

4 REAR PANEL

The rear panel of the device contains the connections for the contactors, the precharge/discharge resistor, and the high-voltage sense circuitry. These are shown in the following illustration.



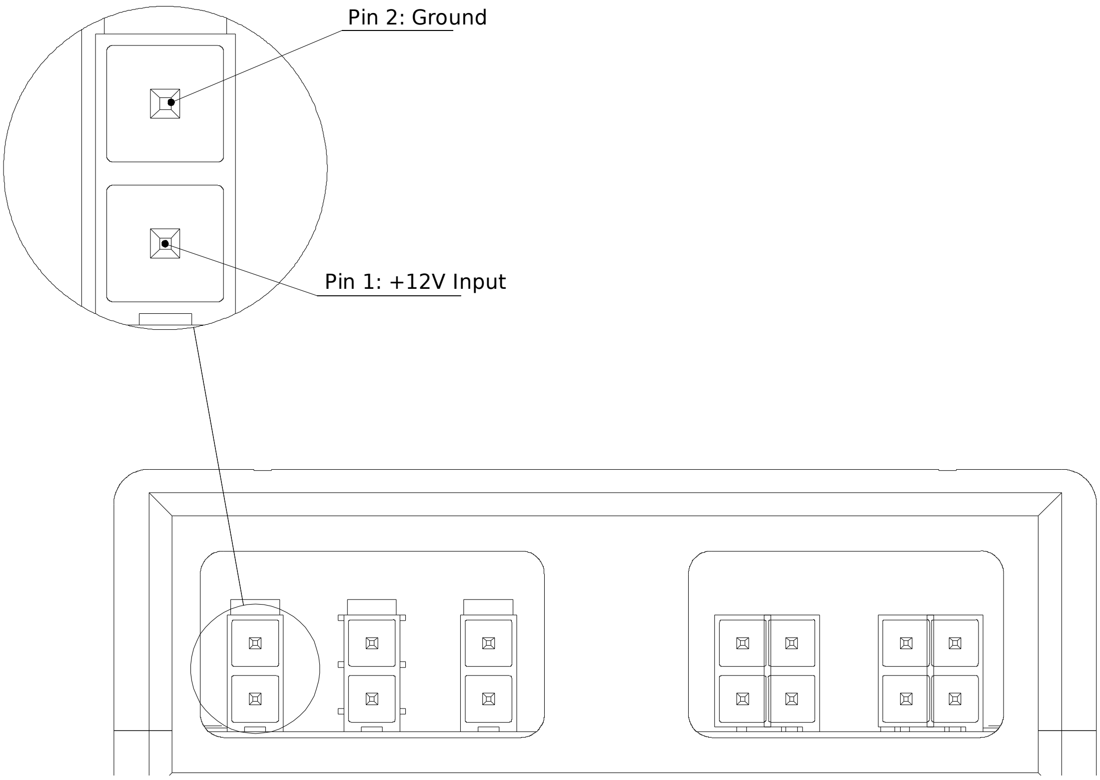
4.1 CONTACTOR POWER INPUT

Summary

Power for the contactors needs to be supplied on the 2-pin +12V input connector. This circuit is isolated from both the CAN bus and the high voltage sense connections.

Allowance must be made on this supply for the power consumed by the external contactors, which can be significant. Large inrush currents can also be drawn by the contactors during turn-on, so wiring to the +12V input should be of low impedance. The precharge controller contains sufficient internal capacitance to source the demand from an EV200 type contactor (Kilovac / Tyco), but extra external capacitance may need to be added near the precharge controller for higher power contactors and/or long supply wiring.

This supply is expected to be connected to a low voltage battery or power supply via the vehicle ignition switch and any emergency shutdown switches or circuits. If this supply is not present, the contactors will open and remove the high voltage connection between the battery pack and any connected circuitry.



Specifications

Supply voltage nominal:	13.8	V	(Note 4)
Supply voltage minimum:	9	V	(Note 4)
Supply voltage maximum:	15	V	(Note 4)
Circuit supply current:	5	mA	(Note 5)
Isolation voltage:	500	V	(Note 6)

Notes:

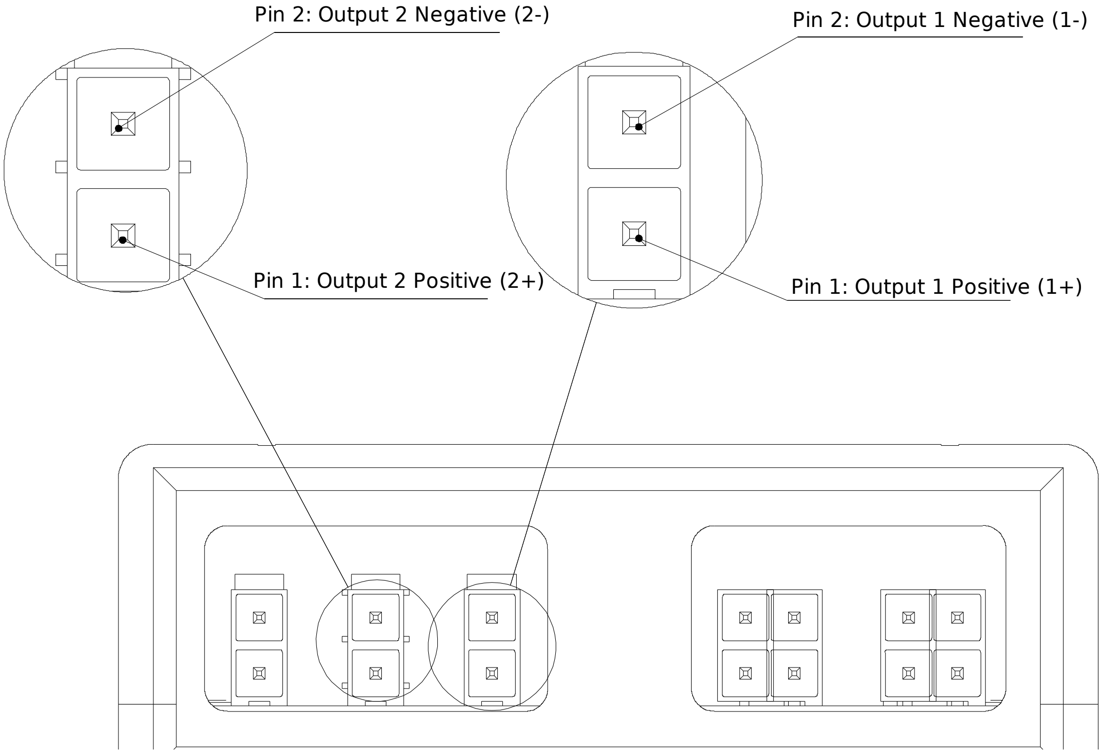
4. The input voltage operates the switching section of the internal circuitry, but is also switched through the control circuits in the precharge controller and is output on the contactor control outputs. Please choose an operating voltage that will allow correct operation of your chosen contactors.
5. The supply current drawn by switching section diagnostics circuitry only. Allow extra current capability on this input for whatever power is drawn by the external contactors. Please note that several models of contactor have large inrush (turn-on) surges, and the impedance of the input supply connection should be kept low. Use short wiring and add external capacitors if needed.
6. Please refer to the Isolation section of the Wiring Engineering Reference document (available on the Tritium website) for more information regarding recommended earthing and connection practices.

4.2 CONTACTOR DRIVE OUTPUTS

Summary

Two 2-pin outputs are provided on the rear of the precharge controller for operating external high-voltage contactors, such as the EV200 type from Kilovac / Tyco. These outputs are labelled as OUT1 and OUT2, and should be connected as shown in the Connections section later in this document.

The output voltage present when this output is active will be whatever voltage is applied to the 12V contactor power connector.



Specifications

Switching current peak (per output):	6.5	A	(Note 7)
Switching current continuous (per output):	2	A	(Note 8)

Notes:

7. The outputs are switched via an Infineon Smart High-Side MOSFET switch, which will current limit and indicate a fault if this current level is exceeded.
8. The switch will thermally limit and indicate a fault if this current level is exceeded on a continuous basis.

4.3 PRECHARGE / DISCHARGE RESISTOR

Summary

The precharge controller uses an external resistor to precharge the load capacitance. This same resistor is also used to discharge the capacitance to a safe voltage level when the device is commanded to shut down.

A 4-pin connector is provided on the rear panel for a high-power resistor used to perform the precharge and discharge functionality. This resistor should be sized such as to limit the current when precharging to the acceptable limit of the device, which will result in the fastest possible precharge time. Alternatively, choosing a higher resistance value will result in a longer precharge time, but a smaller physical size and cost for the resistor.

The wiring for the precharge resistor should be rated to the full battery voltage expected in the high-voltage pack, and also rated for the maximum expected fault current, which is the maximum HV battery voltage divided by the precharge resistor value.

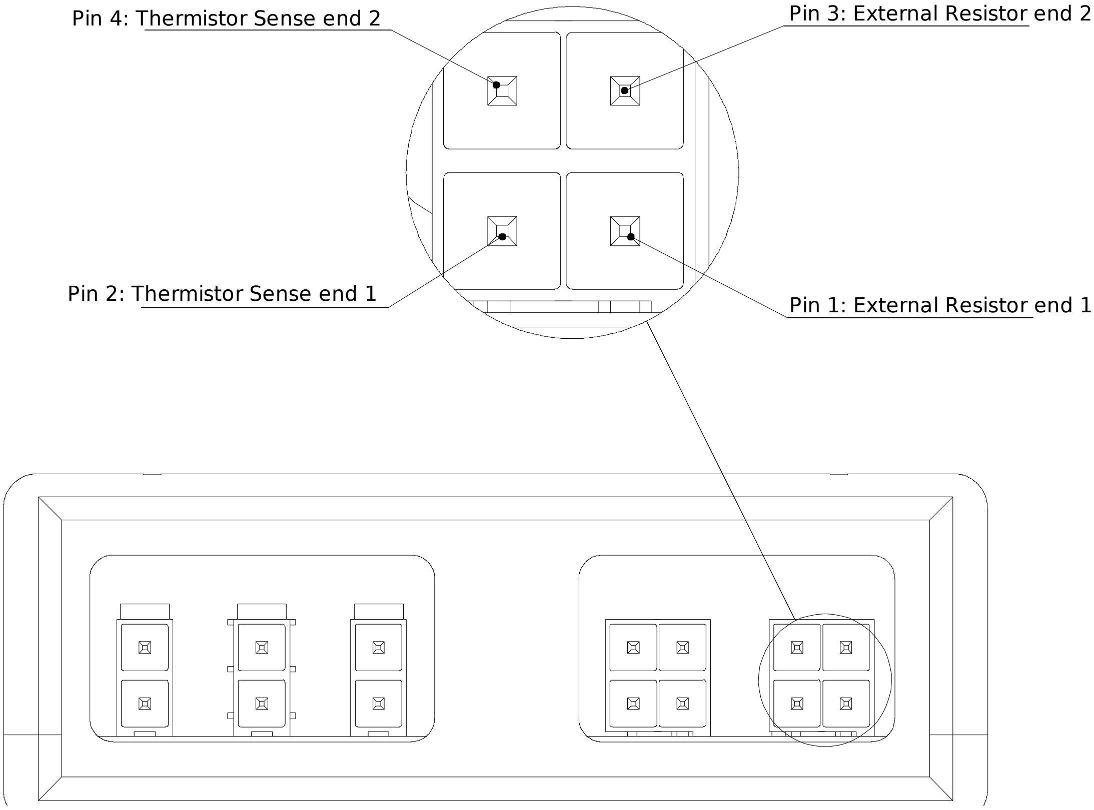
The connector also contains a connection for an external NTC thermistor, to sense the temperature of the high-power precharge resistor. This is required as a safety measure for the fault scenario of a short-circuit fault in the device being precharged, leading to much greater than expected power dissipation in the precharge resistor. Use of the NTC thermistor to sense temperature allows the precharge controller to halt operations in the event of a fault, to avoid the possibility of fire or other resistor failure scenarios.

Specifications

Resistor temperature maximum:	85	°C	(Note 9)
Internal circuit temperature maximum:	65	°C	(Note 9)
Precharge current maximum:	4	A	(Note 10)
Precharge voltage maximum:	500	V	(Note 10)

Notes:

9. Reaching this temperature will result in the precharge controller transitioning to an ERROR state, and disconnecting both contactors to open the high-voltage circuit of the vehicle.
10. Exceeding these voltage and current ratings may destroy the internal MOSFETs used to control the precharge and discharge actions. This could result in an unsafe voltage being present at the output of the device in a state where no voltage should be present.



4.4 HIGH VOLTAGE SENSE

Summary

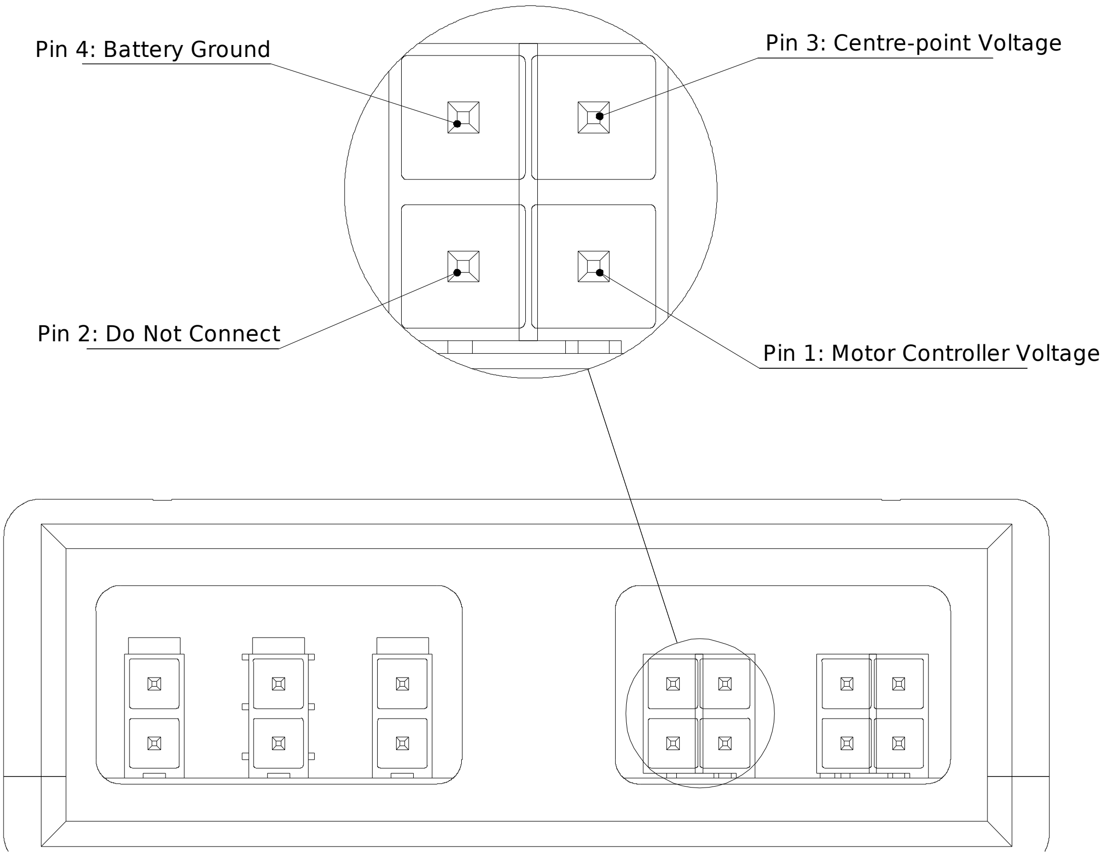
A 4-pin connector is provided on the rear panel for sensing the voltage present on either side of the precharge contactor (Contactor 2 as shown in section 7.1). When both sides are within the acceptable matching limit (ie, precharge has finished), then the contactor can be closed by the controller, to complete the high-power circuit and allow operation of the motor controller.

The wiring on this connection is used to source and sink power via the precharge resistor during both precharging and discharging phases of operation. As such, the wiring for the high-voltage sense should be rated to the full battery voltage expected in the high-voltage pack, and also rated for the maximum expected fault current, which is the maximum HV battery voltage divided by the precharge resistor value.

To protect against faults with the internal semiconductor switches, a fuse should be placed inline with the Centre-point voltage (pin 3). This fuse should be rated for the maximum expected precharge current (normally, 4A) and maximum expected battery voltage.

Specifications

Current maximum:	4	A	(Note 10)
Voltage maximum:	500	V	(Note 10)



5 PROGRAMMING

5.1 OVERVIEW

Programming is not required to use the device – it is supplied from the factory as a working unit, with sensible default values.

The precharge controller is based around a Texas Instruments (TI) MSP430 16-bit embedded low-power microcontroller, operating from a 4 MHz clock as default. Operation at 2 or 8 MHz is also possible. CAN bus support is provided via a Microchip MCP2515 CAN controller and TI SN65HVD234 CAN transceiver. The precharge controller is isolated from the CAN network.

5.2 SCHEMATICS & SOURCE CODE

Schematics and PCB component position overlays in PDF format are available for download on the Tritium website. A zip file is also provided containing the default source code for the microcontroller, written in 'C' and available under a BSD open-source license.

Please refer to these references if developing custom firmware for the driver controls.

5.3 TOOLCHAIN

The example default code provided is configured to work with the freely-available open-source MSP430 GCC toolchain, which provides a command-line driven compiler, binutils, download, and real-time debug capability through a JTAG header present on the precharge controller PCB. Please refer to the README file with the source code for download and installation instructions.

An adapter is provided with every precharge controller product that converts the TI standard 14-pin JTAG debug header to the smaller 8-pin flexible printed circuit (FPC) header used on Tritium devices. Tritium recommends the use of the USB programmer part number MSP-FET430 UIF available from TI or their distributors, although lower cost and slower performance parallel-port devices are also usable.

5.4 CODE DOWNLOAD

Connect the 8-pin FPC ribbon to the header on the precharge controller PCB, with the Pin 1 indication arrows matching on both the precharge controller and the adapter board.

Follow the instructions in the README file to compile your 'C' source, produce an object file for loading into the microcontroller, and download the new firmware to flash memory in the microcontroller. Please feel free to email any questions or comments to James Kennedy, james@tritium.com.au.

6 MECHANICAL FORM FACTOR

The precharge controller is packaged in an ABS plastic enclosure. Adhesive rubber feet are supplied, or the box may be mounted using a user-supplied velcro strip on the base.

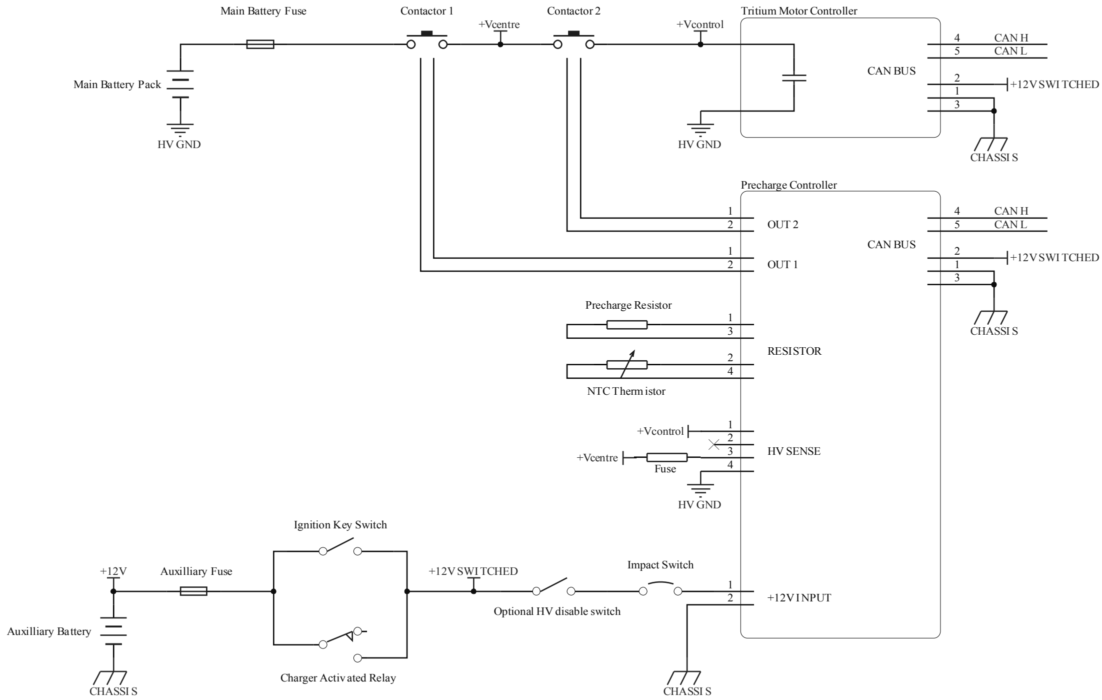
Enclosure length:	133	mm	(Note 11)
Enclosure width:	85	mm	
Enclosure height:	30	mm	
Enclosure mass:	160	grams	

Notes:

11. Enclosure length only. Please allow extra room for connector bodies and wiring harnesses at both ends of the enclosure. Recommended minimum allowance is 50mm per end, more if shielded (non-flexible) CAN bus cabling is used.

7 CONNECTIONS FOR USING THE PRECHARGE CONTROLLER

7.1 OVERVIEW



7.2 CONNECTORS

Due to the possibility of the customer using various different wire sizes, Tritium does not supply mating housings or crimps for the connectors on the precharge controller. The following part numbers (from Digikey, with indicative pricing) are suitable. These parts are also commonly available from other catalogue suppliers such as Farnell.

For reliable connections, please use one of the recommended crimp tools – do NOT use pliers.

Description	***Order Code***	***Approx Price***
18-24 AWG Mini-Fit Jr Female crimp (MOQ = 10)	WM2501-ND	$0.10
22-28 AWG Mini-Fit Jr Female crimp (MOQ = 10)	WM2503-ND	$0.07
2 way crimp housing	WM3700-ND	$0.46
4 way crimp housing	WM3701-ND	$0.61
Mini-Fit Jr dedicated prototype crimp tool	WM9996-ND	$243
Generic Molex crimp tool	WM9999-ND	$50

7.3 CAN BUS

The precharge controller should be supplied with 13.8V (or 12V) DC along the CAN cable. This power supply should already be present in the system to operate other devices on the CAN bus such as the Tritium CAN bus Driver Controls, and WaveSculptor motor controllers.

7.4 RESISTOR

Each end of the precharge resistor should be wired directly to its respective terminal on the Precharge Resistor Connector (pins 1 and 3). No wiring to other points in the system is necessary. The precharge controller determines what points in the circuit the resistor is connected to, allowing it to control precharge, idle, and discharge modes automatically.

A 10k @ 25°C NTC thermistor should be thermally connected to the precharge resistor casing to enable the precharge controller to sense the precharge resistor temperature. The thermistor should be wired directly to the two dedicated terminals on the Precharge Resistor Connector (pins 2 and 4). This is necessary as a safety measure, as the precharge resistor is never rated for continuous operation at the power level present in a fault situation. Neglecting to connect the thermistor could result in a situation leading to the precharge resistor catching fire. As a backup failsafe, this situation is also minimised by only operating the precharge resistor for a predetermined amount of time.

7.5 HV SENSE

Three connections need to be made between the HV Sense Connector and various parts of the vehicle system. They are Centre-point voltage (pin 3), Battery Ground (pin 4), and Motor Controller voltage (pin 1). Pin 2 is not connected. Pin 3 must be fused with a user-supplied external fuse rated for the expected precharge current and battery voltage.

The Motor Controller voltage can be most easily connected to using the main high-current output bolt terminal of Contactor 2, where the wire to the motor controller terminates.

The Centre-point voltage can be most easily connected to using the main high current input bolt terminal of Contactor 2, where the wire to Contactor 1 (or the HV battery pack, depending on configuration) terminates.

HV Battery Ground should be connected wherever is convenient in the system. Note that in a proper isolated vehicle setup, the HV Battery Ground and the Vehicle Chassis are NOT connected together. In a system configured this way, do NOT use the chassis as the ground sense point for this connector.

8 HIGH-CURRENT CONFIGURATION

Tritium recommends the use of Tyco EV200-AAA-NA contactors, available from Newark, order code 09J3878, rated to 500A carry current, 2000A break current, and up to 900V operating voltage, for typical EV and solarcar applications with the precharge controller and Tritium motor controllers.

Two configurations are possible with this system, referred to as a Type 1 and a Type 2 system.

8.1 TYPE 1 CIRCUIT

A type 1 circuit is the recommended configuration for using the precharge controller. It provides the best possible safety and reliability, however this comes at a slightly higher cost, weight and complexity than a type 2 circuit. A type 1 circuit is configured as shown in the figure in Section 7.1, above.

When the precharge circuit is off (either via removal of the 12V input, or from a CAN bus command) then Contactor 1 is open, and there is no connection whatsoever between the HV battery pack positive and the remainder of the vehicle.

8.2 TYPE 2 CIRCUIT

A type 2 circuit sacrifices some safety for cost and weight reduction. Tritium does not recommend using this option in electric vehicle applications.

A type 2 circuit is identical to a type 1 circuit, but with the omission of Contactor 1. Nothing should be connected to the OUT1 connector on the precharge controller.

The precharge and discharge function will still operate using the resistor and Contactor 2, however, when the system is off, there is a potential connection between the HV battery pack positive and the remainder of the vehicle, via the precharge controller sense circuitry. A type 2 circuit relies on the integrity of the precharge controller to guarantee safety – if the precharge controller has had multiple internal component failures, then high voltage may be present on the output of the system, even when it is expected to be in a safe state.

8.3 PRECHARGE RESISTOR SELECTION

Selection of the external precharge/discharge resistor is critical for correct and long-term reliable operation of the precharge circuit. A judgement must be made by the designer of the vehicle power system to the tradeoff between resistor size, cost and weight, and expected precharge time. A slower time can use a smaller, cheaper resistor, but taking too long to precharge will be annoying to the end user of the vehicle. An aluminium-cased wirewound resistor is the most commonly chosen type of resistor.

The shortest precharge time is limited by the acceptable precharge current. See Section 4.3 for the maximum permissible current. As an example, the calculations for a typical solarcar system are shown as follows:

System battery voltage maximum = **150V**

Motor controller (Tritium Wavesculptor 20kW) capacitance = **10,000µF**

Maximum charge current = **4A**

Therefore, the minimum resistance (fastest precharge) will be 150V / 4A = 37.5 Ohms. Choose **40 Ohms** as the next highest common value. Peak power dissipation in the resistor is therefore 150*150/40 = **563W**.

The expected precharge time is given by the time constant TAU = R (Ohms) * C (Farads), where the voltage on the capacitor should change by 63% of the difference each TAU time interval. Precharge should be within 95% of the initial value within 4 TAU, and to 99% within 5 TAU intervals, as an exponential decay. For the example system, TAU = 400ms, so the expected precharge time of 5 TAU = **2 seconds**.

Choosing a >500W resistor is unnecessary, as this rating is only needed for a short amount of time during normal operation. However, the resistor cannot be too small, as if a fault situation occurs, such as a short circuit in the motor controller, then this power will be dissipated continuously for the entire expected precharge time, until the precharge controller realises that precharging has not occurred properly and goes into an error state. For safety, the resistor in the example system should be chosen to tolerate a one-off event, starting at the expected maximum ambient temperature, of 563W for 2 seconds.

Searching through available off-the-shelf options from Digikey, the RH series from Vishay is chosen as a likely candidate. According to the datasheet located at http://www.vishay.com/docs/50013/rh.pdf , for short time overloads, a power rating of 12x the nominal power is acceptable for a 2 second duration. Using a 50W resistor, this equates to an overload rating of 600W, starting at an ambient of 25°C.

Therefore, our initial choice is acceptable for the external resistor in this application based on maximum fault power, and at US$4.63 and 30 grams should be suitable for most solarcar type vehicles.

As a further check, during normal operation, the capacitors contain a charge of 1.5C, giving an energy storage of **112 Joules**. Note that this is a lethal amount of energy. During an RC precharge type event, the same amount of energy that is eventually stored in the capacitor is also dissipated in the resistor. 112 Joules in 2 seconds is an average power dissipation in the resistor of **56W**, well under the acceptable limit. If not mounted on any additional thermal mass, and assuming that 20g of the resistor's total mass is aluminium (specific heat = 0.897 J/g°C), 112 Joules will give a temperature rise of $\Delta T = Q/mc$ = **6.2°C**, also well within limits.

The maximum acceptable operating voltage for the 50W resistor is 1285V, so our maximum of 150V is also well within limits.

Therefore, a **40 ohm, 50W, RH series wirewound aluminium resistor** would be a suitable choice of external resistor for this application of precharging **10000uF to 150V in 2 seconds**.

Note that the precharge controller <u>must</u> be programmed with the correct resistance and capacitance values, so as to determine the expected precharge time. If this is not done, then the precharge controller will either expect precharge to have finished when it has not, resulting in an error state, or it will expect precharge to take much longer than it really does, resulting in a potential overload and a fire in the external resistor if there is a system fault and the external thermistor is also faulty.

9 OPERATION

The precharge controller operates using a software state machine, observing different voltages, commands, status lines and timers, to determine the correct sequence of operations. Normal operation proceeds as follows:

1) 12V power is applied along the CAN bus. The precharge controller electronics begin operating, and transmitting and receiving CAN bus packets. The precharge controller will report its status as “ERROR”, as no power is currently present on the contactor supply input.
2) 12V power is applied to the contactor supply connection via the ignition switch (turned to the “Accessories” position) and other safety interlocks in the vehicle. The precharge controller will report its status as “IDLE”, indicating that it is ready for operation.
3) The driver controls device on the CAN bus reports that the ignition switch has been turned to the “ON” position, via a bit in the Switch Position Packet. The precharge controller observes this transition, and begins the precharge sequence.
4) The precharge controller energizes OUT1, to turn on Contactor 1. It reports its status as “MAIN”, indicating that the main battery contactor (Contactor 1) is closed.

5) The precharge controller waits for 250ms, to allow the centre-point voltage (ie, the connection between the two contactors) to rise to a stable level, equal to the HV battery voltage. At the end of the 250ms interval, the precharge controller saves the voltage measurement value into memory.
6) The precharge controller connects the external precharge resistor between the centre-point and the motor controller. This begins charging the capacitors in the motor controller, through the resistor. It reports its status as “PRECHARGE”, indicating that precharging is occurring.
7) The precharge controller waits for the expected time to elapse that would result in a 95% precharge (ie, no more than a 5% difference between centre and controller voltages). At the end of this interval, the controller checks that the motor controller voltage is within 5% of the value stored in step 5. See Section 8.3 for more detail on expected precharge times.
8) If the two voltages are within the expected range, then OUT2 is energized, to turn on Contactor 2 and complete the high-current circuit in the vehicle. The external resistor is disconnected. The precharge controller reports its status as “RUN”, indicating that it is fully operational and the vehicle is ready to operate.
9) The vehicle is operational and driving
10) The driver controls on the CAN bus reports that the ignition switch is no longer in the “ON” position. The precharge controller observes the transition, and begins the discharge sequence.
11) OUT1 and OUT2 are de-energized, opening both contactors. The external resistor is connected between the motor controller and ground, beginning to discharge the capacitors in the motor controller. The precharge controller reports its status as “IDLE”.
12) The external resistor remains in the discharge position for as long as the motor controller voltage is above the safety threshold. The default safety threshold voltage is 10V.

At any time, if the external resistor or internal circuit board rise above the acceptable operating temperature, or 12V contactor power is removed, or a fault in the OUT channel drivers is detected, then the precharge controller moves to the “ERROR” state, and disconnects both contactors. If the resistor is within acceptable temperature, it will also commence discharge operations if the motor controller voltage is above the safety threshold.

To exit the “ERROR” state, the ignition key must be moved away from the “ON” position, and all error conditions cleared (ie, within temperature, voltage present, etc). Once all of these conditions are met, the controller will report its status as “IDLE”, and once again be ready for normal operation.

10 SAFETY

Always treat any high voltage connection as potentially live. Do not rely on the LED indicators of the precharge controller for notification of a live connector, as a LED or part of the circuit responsible for driving it may have failed.

11 REVISION RECORD

REV	***DATE***	***CHANGE***
1	6 February 2009	Document creation (JMK)