



## **USER'S MANUAL**

### **WaveSculptor 200 Motor Drive**

TRI74.021 ver 5  
31 August 2015

# **WaveSculptor 200 Motor Drive User's Manual**

**31 August 2015**

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Brisbane, Australia

<http://www.tritium.com.au>



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## TABLE OF CONTENTS

<b>1</b>	<b>Introduction.....</b>	<b>5</b>
<b>2</b>	<b>Getting Started.....</b>	<b>6</b>
<b>3</b>	<b>Unpacking &amp; Preparation.....</b>	<b>6</b>
<b>4</b>	<b>Controller Function.....</b>	<b>7</b>
4.1	Overview.....	7
4.2	A Note on Motor and Battery Currents.....	7
<b>5</b>	<b>Mounting.....</b>	<b>7</b>
5.1	Choosing A Location.....	7
5.2	Environmental.....	8
5.3	Dimensions & Tolerances.....	8
<b>6</b>	<b>Accessing the Controller.....</b>	<b>9</b>
6.1	Safety.....	9
6.2	Inspection Cover.....	9
6.3	Enclosure.....	9
<b>7</b>	<b>Cooling.....</b>	<b>10</b>
7.1	Liquid Cooling Overview.....	10
7.2	WaveSculptor Waterblock.....	10
7.3	Radiator.....	10
7.4	Pump.....	11
7.5	Reservoir.....	11
7.6	Tubing.....	11
7.7	Coolant.....	12
7.8	Bleeding.....	12
<b>8</b>	<b>CAN Bus and Low Voltage.....</b>	<b>12</b>
8.1	CAN BUS Topology.....	12
8.2	CAN Wiring.....	13
8.3	CAN Connector.....	13
8.4	CAN Shielding.....	14
8.5	CAN Termination.....	14
8.6	Communications.....	14
8.7	Power Supply.....	15
8.8	Driver Controls.....	15
8.9	System Expansion.....	15
8.10	Multiple Motors.....	15
<b>9</b>	<b>PC Software.....</b>	<b>16</b>
9.1	Ethernet Bridge Installation.....	16
9.2	PC Software.....	16
9.3	Low Voltage & CAN Bus Testing.....	16



## USER'S MANUAL

### WaveSculptor 200 Motor Drive

TRI74.021 ver 5  
31 August 2015

<b>10</b>	<b>Driver Controls.....</b>	<b>16</b>
<b>11</b>	<b>Motor Sense Connections.....</b>	<b>16</b>
11.1	Overview.....	16
11.2	Connector Pinout.....	17
11.3	Motor Position Sense.....	18
11.4	Motor Temperature Sense.....	18
<b>12</b>	<b>High Power Connections.....</b>	<b>18</b>
12.1	Cable.....	19
12.2	Motor Inductance.....	20
12.3	High Power Connections.....	20
12.4	Testing.....	20
12.5	Precharge.....	20
12.6	Fusing.....	21
12.7	HV Isolation.....	21
<b>13</b>	<b>Motor Setup &amp; Testing.....</b>	<b>21</b>
13.1	Low Power Setup.....	21
13.2	PhasorSense – BLDC Motors.....	22
13.3	IMExtract – Induction Motors.....	22
13.4	Low Power Testing – PC Control.....	22
13.5	Low Power Testing – Driver Controls Hardware.....	23
<b>14</b>	<b>High Power Testing.....</b>	<b>24</b>
14.1	Connections.....	24
14.2	PC Software Control.....	24
14.3	Driver Controls.....	24
<b>15</b>	<b>Driving.....</b>	<b>24</b>
15.1	Warnings.....	24
15.2	Procedure.....	25
15.3	On Road Testing.....	25
<b>16</b>	<b>Appendix A – Recommended Component Sources.....</b>	<b>26</b>
16.1	CAN cabling & Low Voltage Connectors.....	26
16.2	High power cabling & Connectors.....	26
16.3	Cooling System Components.....	26
<b>17</b>	<b>Appendix B – Guide to Successful Crimping.....</b>	<b>28</b>
17.1	Molex MicroFit 3.0.....	28
17.2	High Power Bolt Lugs.....	28
<b>18</b>	<b>Appendix C – CAN Communications Protocol.....</b>	<b>31</b>
18.1	Overview.....	31
18.2	Drive Commands.....	32
18.3	Drive Command Examples.....	33
18.4	Motor Controller Broadcast Messages.....	33



## USER'S MANUAL

### WaveSculptor 200 Motor Drive

TRI74.021 ver 5  
31 August 2015

18.5	Configuration Commands.....	38
<b>19</b>	<b>Revision Record.....</b>	<b>38</b>



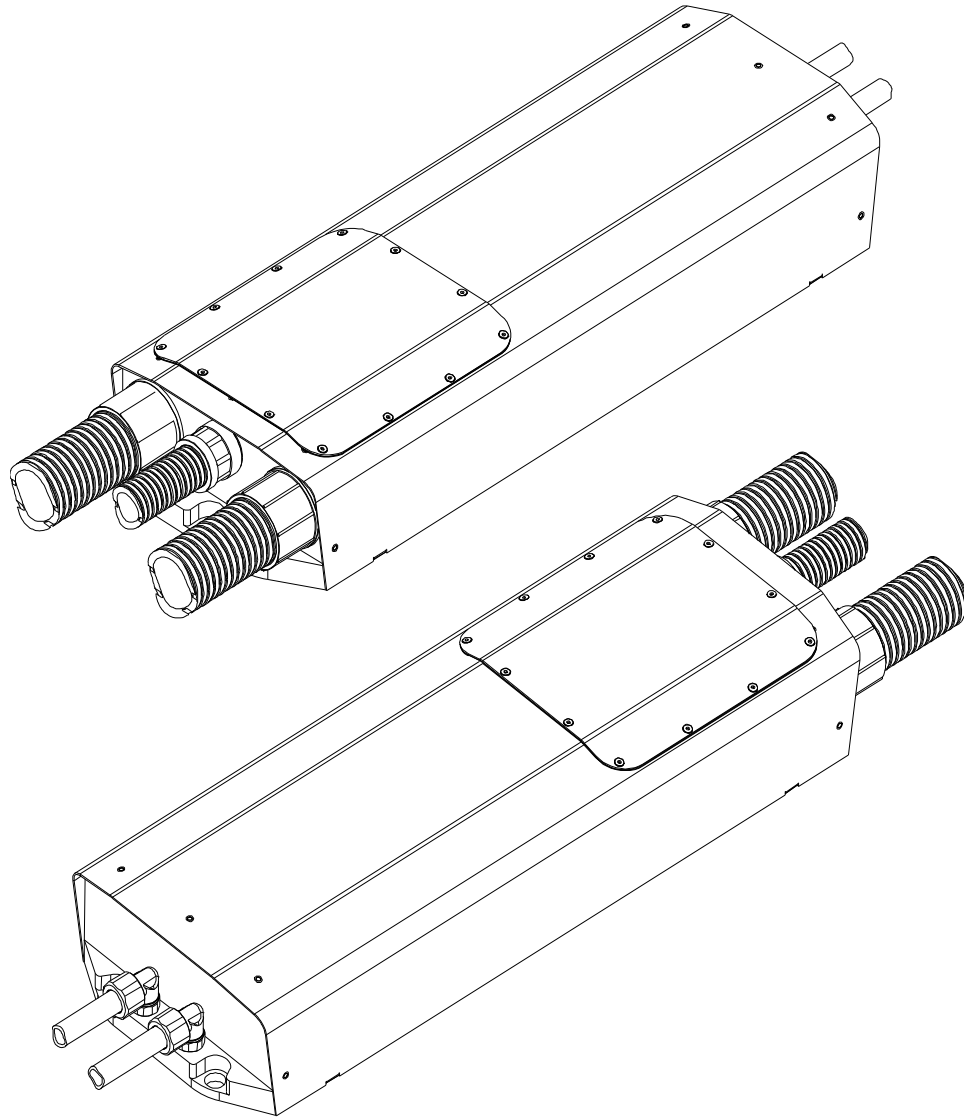
## USER'S MANUAL

### WaveSculptor 200 Motor Drive

TRI74.021 ver 5  
31 August 2015

## **1 INTRODUCTION**

This document describes the operation, connections, mounting, communications, cooling and how to get started with and use the Tritium WaveSculptor 200 Motor Controller.



**This product processes and uses potentially lethal voltages and currents. Do not provide power or operate with the cover removed.  
To be opened and connected to by authorised personnel only.**



## **2 GETTING STARTED**

Work through this manual in sequence, using this checklist as you go.

- [ ] Items arrived in good condition
- [ ] Read and understood the datasheet
- [ ] Read and understood this document
- [ ] A good mounting location chosen
- [ ] Cooling system installed and purged of air
- [ ] Controller mounted into place
- [ ] CAN Bus & 12V supply wiring installed
- [ ] PC software installed
- [ ] 12V supply and CAN communications functioning
- [ ] Motor sense connections completed
- [ ] Motor phase cables connected
- [ ] Precharge system working
- [ ] HV DC cables connected
- [ ] PhasorSense or RotorSense routines run and saved
- [ ] Motor test at low voltage, wheels off ground, using PC software
- [ ] Motor test at low voltage, wheels off ground, using driver controls hardware
- [ ] Motor test at high voltage, wheels off ground, using PC software
- [ ] Motor test at high voltage, wheels off ground, using driver controls hardware
- [ ] Private road test
- [ ] On-road vehicle test

## **3 UNPACKING & PREPARATION**

Check that all items on the packing list are in the box and undamaged. Contact the shipping company and Tritium if there is obvious outer box damage during transport. Contact Tritium immediately if there is a discrepancy with the items or other damage.

You will require the following specialised tools for installing the WaveSculptor motor controller:

- Allen (hex) keys
- Molex MicroFit crimp tool
- Cable cutters
- Hex lug or hydraulic crimp tool
- Various electronics hand tools for low power cable cutting & stripping



## **4 CONTROLLER FUNCTION**

### **4.1 OVERVIEW**

As a high-level description, the WaveSculptor takes high voltage DC from a battery pack, and converts it to a lower voltage 3-phase AC to drive a motor.

Power flow is bi-directional, so it can also perform regenerative braking (regen) where power flows from the motor back into the batteries. It is a four-quadrant device, which means that it can drive or regen in both forwards and reverse directions.

Ignoring the losses in the system (refer to the datasheet for efficiency curves for the WaveSculptor), total power through the motor controller is conserved. It does not create energy, it just converts it from one form (DC) to another (AC).

### **4.2 A NOTE ON MOTOR AND BATTERY CURRENTS**

Motor current is proportional to *torque*, whereas battery current is proportional to *power*.  $\text{Power} = \text{Torque} \times \text{speed}$ . The effect of this is that battery current will only approach motor current as the motor speed approaches 100%. At low motor speeds, the *battery* current will also be low, regardless of what the *motor* current is.

This applies to most motor controllers, but with DC motor systems (where efficiency is much more variable) the effect is not usually as noticeable. So, when reading this document (and the datasheet) make sure to note if the specification is talking about motor current or battery current. They are very different quantities.

## **5 MOUNTING**

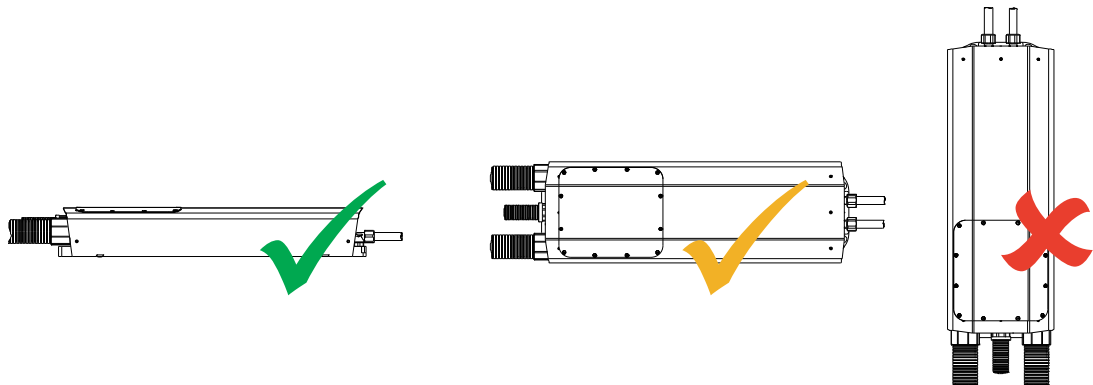
### **5.1 CHOOSING A LOCATION**

Careful attention should be paid to positioning the WaveSculptor correctly, to ensure optimum performance.

The main criteria for choosing a good mounting location are vibration, water spray, cooling layout, and cable positioning.

Although the Tritium WaveSculptor is rated for use in water spray environments, it is preferable to locate the controller in an area that won't be directly impacted with water jets coming in through the grille of your car at highway speeds. Locating the WaveSculptor in the engine bay area is fine, but try to keep it out of the most exposed areas.

The Wavesculptor should ideally be mounted in a horizontal position, but vertical mount is also acceptable if the long axis of the controller is horizontal. Do not mount the controller with the long axis vertical (ie, conduit exiting top or bottom) as water may pool in the end areas of the controller and eventually seep into the interior. This position will also trap air in the cooling system.



The Cooling section of this document has further details, but as an overview the controller should not be the highest point in the liquid cooling system, or bleeding the cooling system of air bubbles will be difficult. Keep this in mind when choosing a location.

The WaveSculptor has been designed with all cables and connections to the device at one end, to allow simplified positioning in your vehicle. The 40mm orange conduit that contains the motor and battery cabling can be quite stiff, and has a minimum bend radius of around 250mm. Make sure your chosen position allows room at the connection end of the controller for conduit and cooling connections.

## 5.2 ENVIRONMENTAL

The WaveSculptor is rated to withstand water spray from any angle. Meeting this rating requires permanently gluing the motor, battery and CAN bus conduit into their fittings in the end panel of the motor controller using standard plumbing PVC pipe cement.

If the conduit is not glued, then a reduced environmental rating applies, where the controller is immune to low velocity splashing water only. This may be acceptable if a mounting location is chosen carefully.

## 5.3 DIMENSIONS & TOLERANCES

Before final mounting of the controller in the vehicle, connect and fill the liquid cooling system as shown in the next section of this document. The controller needs to be tilted to fully bleed air bubbles from the system.

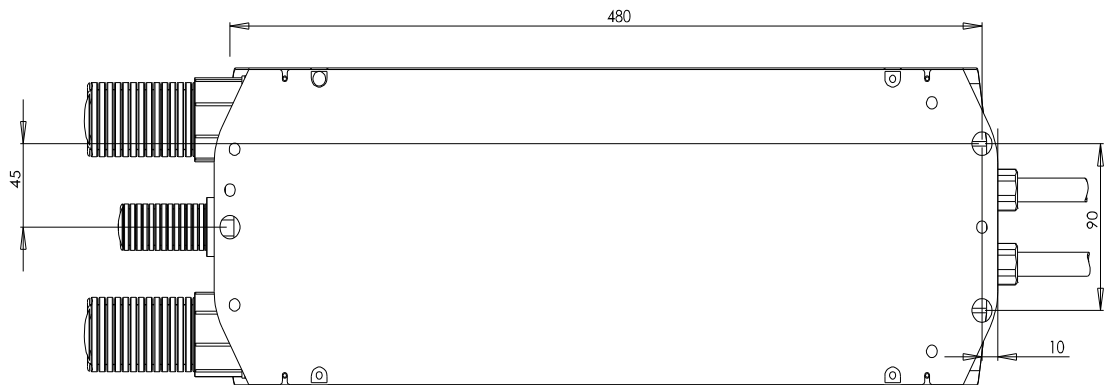
The Wavesculptor is mounted with a three-point mount using rubber standoffs to help isolate vehicle vibration from the controller electronics. Refer to the drawing below for mounting hole locations, which should be fitted with an M6 insert or nut.





## WaveSculptor 200 Motor Drive

TRI74.021 ver 5  
31 August 2015



Three M6 thread shoulder screws and washers are provided with the controller for mounting purposes, and the shoulder design means that when fully tightened, the rubber grommet compression is correct – the shoulder on the screw prevents over-compressing the grommet. Tighten these screws to 10Nm, using Loctite 243 or similar retaining compound to prevent them working loose.

## 6 ACCESSING THE CONTROLLER

### 6.1 SAFETY

Opening the cover on the WaveSculptor will expose the connections for the CAN bus and motor sense, and high power terminals for battery and motor phase connections. High voltages may be present inside this cover. Before opening, make sure that the battery contactors are dis-engaged, so that high voltage is not present at the motor controller. Allow 10 minutes for the internal capacitors to discharge before working on the controller.

### 6.2 INSPECTION COVER

The inspection cover is held closed against a sealing gasket with stainless steel M3 countersunk hex head screws. Use a 2mm allen (hex) key to loosen and remove all twelve screws.

Lift off the inspection cover and set it aside. Use a multimeter to check across the battery connection terminals for high voltage. If more than a few volts are present, wait additional time for the capacitors to discharge to a safe level.

Be extremely careful to not drop loose fasteners into the motor controller, as they may move around while driving and short out the battery or motor phase connections.

When finished working inside the WaveSculptor, replace the inspection cover and insert and tighten all 12 screws in an even pattern. It is mandatory to use a small amount of Loctite 243 or similar threadlocking compound to seal the threads of the screws against moisture. Failure to apply locking compound will reduce the environmental rating of the controller.

### 6.3 ENCLOSURE

The main enclosure is bonded in place and not removable by the end user. Doing so will void the controller warranty.

## **7 COOLING**

### **7.1 LIQUID COOLING OVERVIEW**

The liquid cooling system consists of four main components. They are:

- WaveSculptor 200 waterblock
- Pump
- Radiator
- Reservoir

They should be connected as shown below. Tracing the liquid flow path around the circuit, the pump should be directly after the reservoir, to minimise dry running the pump when installing the system. The radiator should be directly after the WaveSculptor, to cool the liquid as soon as possible and minimise the temperature that the pump is exposed to.

Additional components can be added to the system. Recommended items are:

- Flow sensor somewhere in the loop
- Level sensor in the reservoir

Having both of these extra items wired to an alarm/fault signal will guarantee that the motor controller is not operated without coolant flowing.

It is important to make sure that all items exposed to the coolant loop are either plastic or aluminium. Using dissimilar metals (especially copper) in different parts of the cooling loop will result in corrosion and pitting of various items in the loop, with quite rapid failure likely.

The coolant system should be operated non-pressurised. A breather hole or an air space of at least 25mm (1") should be left at the top of the reservoir to allow coolant expansion and contraction without pressure buildup.

### **7.2 WAVESCUPTOR WATERBLOCK**

The coolant flow path inside the WaveSculptor is a 'U' shape along one side from the inlet to the far end of the controller, across at the end, and back along the other side to the outlet.

When mounted horizontally, it does not matter which way coolant flows in the waterblock, so connect the inlet and outlet in the way that simplifies the tube routing in your vehicle.

When mounted vertically (the middle picture in the "Choosing a Location" section) then the inlet should be below the outlet. Doing this will simplify bleeding air from the system.

### **7.3 RADIATOR**

Tritium recommends an aluminium radiator of at least 120 x 360mm dimensions, such as Koolance part number HX-1020 and a pair of nozzles NZL-V10P or NZL-L10P, for vertical or right-angle hose attachment. This will need to be used with three 120mm fans, which should be rated for use in wet environments, as they will be exposed to road grime and spray.



The radiator should be mounted in the airflow path through the front of the car, to help with cooling. If thermostatically controlled fans are used, a carefully chosen mounting location will minimise the time the fans are required to operate, therefore saving power.

#### 7.4 PUMP

Tritium recommends using a Koolance part number PMP-400 pump. The specifications on this pump are 8.7 litres/min and 7m head (0.68 Bar, 68 kPa), and a 50,000 hour rated lifetime. This pump is a good match for the pressure drop through the WaveSculptor water block, radiator, and several metres of 10mm ID tubing.

A quality installation will use some form of monitoring on the pump speed feedback signal, to flag a fault in the event of slow or stalled operation.

It is important to never run the pump without coolant in the system, as dry operation for even a few seconds will dramatically reduce the lifespan of the pump. This constraint means that the pump should be located below the level of fluid in the reservoir.

The PMP-400 pump does not require additional nozzles, having moulded push-fit barbs as part of the pump. Make sure to secure the tubing to the barbs using cable ties or hose clamps. Do not over-tighten if using hose clamps, as the pump barbs are plastic.

#### 7.5 RESERVOIR

A reservoir is necessary to allow for coolant contraction and expansion as the system heats and cools. It also allows for time to notice and correct any leaks in the system before running the pump dry.

The reservoir should be the highest component in the system, so that any air bubbles from other components will collect in the reservoir, not inside the waterblock or radiator.

Tritium recommends building a reservoir using Koolance parts COV-TKBTM (base), BDY-TK200 (body), COV-TKTOP (top lid), and a pair of nozzles either NZL-L10P or NZL-V10P. This reservoir holds more liquid than strictly necessary, but this allows for easier filling and air bleeding when installing the system. Using a reservoir with a large top opening allows you to add coolant quickly as the pump sucks it from the reservoir when filling the system for the first time, without having to stop and start the pump.

A second option is a combined reservoir and pump, saving some space, fittings and tubing. This can be constructed using Koolance parts COV-RP400, PMP-400, BDY-TK200, COV-TKTOP & either NZL-V10P or NZL-L10P.

#### 7.6 TUBING

Tritium recommends using high quality 10mm ID / 13mm OD tubing, such as Koolance part number HOS-10CL. This is also available in a range of colours. High quality tubing will be far less likely to kink than standard cheap PVC tube, and also has less problems with softening at higher temperatures. If a tight bend radius is required, consider using a spring wrap such as Koolance part SPR-10BK, which helps stop the tube kinking.

## **7.7 COOLANT**

The coolant used in the system is critical for its longevity. A quality coolant designed for this application is required, to help with corrosion, foaming, heat transfer, and biological growth. Automotive coolant fulfils the first three requirements, but not the last, as it gets hot enough in a vehicle engine to kill any bacteria, so a biocide is not required. If using automotive coolant in your system, an additional biocide will have to be added manually.

Tritium recommends using Koolance liquid LIQ-702BU-B, which meets all requirements for the system. This is also available in a range of colours.

## **7.8 BLEEDING**

It is important to bleed all air from the system. The pump and radiator are mostly self-bleeding, but the waterblock on the WaveSculptor requires some intervention by the user..

The coolant flow path inside the WaveSculptor is a 'U' shape along one side from the inlet to the far end of the controller, across at the end, and back along the other side to the outlet.

With the coolant filled and the reservoir close to full, start the pump. Tilt the WaveSculptor by around 30° to allow air bubbles near the inlet to move to the far end of the controller. Next, tilt it to the side, so that the air trapped at the far end moves to the outlet side of the waterblock. Now, tilt the controller so the far end is down, and the air moves along the outlet side of the controller and exits through the outlet tubing. Repeat this circular tilting motion until air stops exiting the controller. You may need to top up the reservoir during this process, depending on how much air is purged from the waterblock.

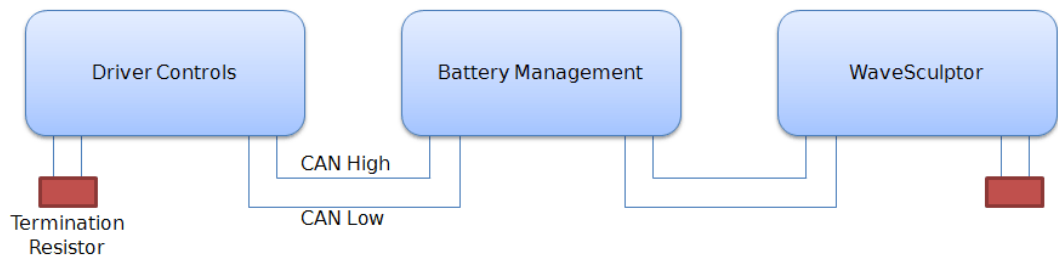
You may also need to perform a similar process with the radiator, depending on its mounting location and position relative to the other components in the system.

# **8 CAN BUS AND LOW VOLTAGE**

## **8.1 CAN BUS TOPOLOGY**

The CAN bus is structured as a linear network, with short stubs branching from 'T' connectors on the main bus backbone to each device. The CAN bus data lines must be terminated at each end of the main bus with 120 ohm resistors between the CAN-H and CAN-L signals.

In the range of Tritium EV products, including the WaveSculptor 200, EV Driver Controls, and BMS Pack Master, the CAN connections are implemented with an 'in' and an 'out' connector, therefore placing the 'T' on the device, resulting in a very short fixed-length stub on the circuit board of each device. This is ideal from a signal integrity and network performance point of view.



Therefore, a basic system consists of three major components:

1. WaveSculptor motor controller
2. Driver controls interface to pedals, switches & gauges
3. Power supply (nominally 12V DC) to operate the system

Other components can also be added to the network. Items typically found in a electric vehicle would include:

4. LCD and other driver information displays
5. Battery management system
6. Multiple motor controllers
7. Datalogging

## 8.2 CAN WIRING

The CAN data lines (CAN-H and CAN-L) must be implemented with twisted-pair wire for proper data integrity. The wire should have a characteristic impedance of 120 ohms.

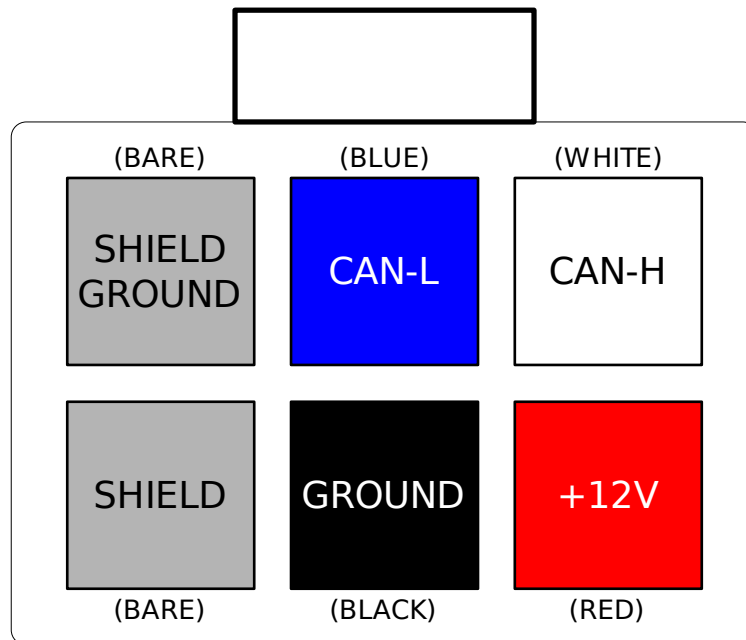
Power should also be provided along the CAN cable, ideally with another twisted pair to minimise noise pickup. An overall shield can also be advantageous.

From a performance perspective, the optimal choice of cable is 7mm Devicenet CANbus 'thin' cable, with 24AWG (data) + 22AWG (power) twisted pairs and a braided shield. Using this cable will result in a robust installation. However, it is not cheap, and using it for a large network with many devices will quickly add up to a significant cost.

For those on a budget, standard CAT5 network cabling (which has an impedance of 100 ohms) can be used, but may become unreliable in longer networks or in the presence of electrical noise from DC/DC converters and other electrical devices in the system – use this type of cable at your own risk.

## 8.3 CAN CONNECTOR

The connector used on the WaveSculptor200 and other Tritium devices is a 6-way 3mm pitch Molex MicroFit connector. The pinout is shown below, as viewed from the wire side – as you would look at it while inserting crimps. The colours shown match those in the standard DeviceNet CAN cabling pairs. Please refer to Appendix B for an overview of correct crimping technique, as poor crimps will cause unreliable operation.



### 8.4 CAN SHIELDING

If the recommended braided shield is used in the cable, then terminate it to the SHIELD pin (lower-left corner on the connector) on both CAN IN and CAN OUT connectors on each device.

On **one device only** in the network, instead of using the SHIELD pin, terminate the shield to the SHIELD GROUND pin (upper-left corner on the connector) on both CAN IN and CAN OUT connectors, to ground the shield for the entire network at this single point. The usual place to do this is where power is fed into the network, typically at Tritium's EV Driver Controls product.

### 8.5 CAN TERMINATION

To implement the required 120 Ohm termination resistor at each end of the CAN bus, plug a connector into the unused CAN connector on the last device at each end of the network with a resistor crimped into the appropriate locations. Leave the power, ground and shield pins unconnected.

### 8.6 COMMUNICATIONS

The CAN standard does not specify high-level message protocols. Tritium devices use a custom protocol, outlined in the communication specification document for each device.

By default, each device operates at 500 kbits/second, one step below the maximum possible data rate of 1 Mbit/second, and comes programmed from the factory with a CAN base address that will allow it to work without problems with other Tritium devices. Using the Windows PC interface program and the Tritium CAN-Ethernet bridge, both the data rate and the base address can be programmed to suit your network.

WaveSculptor controllers also have a second programmable base address that



they watch for command messages. This should be set to whatever base address is used by the driver controls node on the network.

The WaveSculptor motor controller expects regular messages from the driver controls device. If a message is not received within a set timeout period (refer to the communications specification in Appendix A for the exact value) then the controller will change to a safe mode and will stop driving the motor until a valid message is received again. This protects against faults where either a connector is loose or broken, the cable has been damaged, or the driver controls have failed.

## 8.7 POWER SUPPLY

Each Tritium device expects a DC supply on the CAN bus connection of between 9 and 15V. 13.8V from a small lead-acid battery charged by your vehicle's DC/DC converter is ideal. Refer to each device's datasheet for CAN bus current consumption values, and make sure that the total is less than the rating on your chosen cable.

Tritium's EV Driver Controls product provides a means to connect power from the battery into the CAN bus, to power other devices on the network. It can switch power to the CAN bus based on the state of the ignition key.

## 8.8 DRIVER CONTROLS

Tritium can provide a CAN bus driver controls device. This interfaces to pedals and switches, and provides the messages required to operate a WaveSculptor controller. The firmware for this device is open-source, allowing it to be easily customized to suit your vehicle.

As the communications specification is open, the WaveSculptor can also be operated from custom driver controls hardware specific to your vehicle, or from a Windows PC running either the provided Tritium software, or custom software of your choice.

Please refer to the driver controls datasheet and user's manual on our website for further details.

## 8.9 SYSTEM EXPANSION

Tritium can provide a CAN bus LCD display capable of showing up to four different telemetry values (one at a time) on a 3.5 digit sunlight-readable screen. Multiple displays can be used if desired.

## 8.10 MULTIPLE MOTORS

Multiple motors/controllers are accommodated easily with the CAN bus system. All that is required is for each WaveSculptor controller to be programmed to receive messages from the same *driver controls* base address, and then to run the vehicle in current-control mode (the default setup). Each motor will now operate at the same current, thus giving automatic wheel speed differences for cornering, with the system acting as an electronic differential.

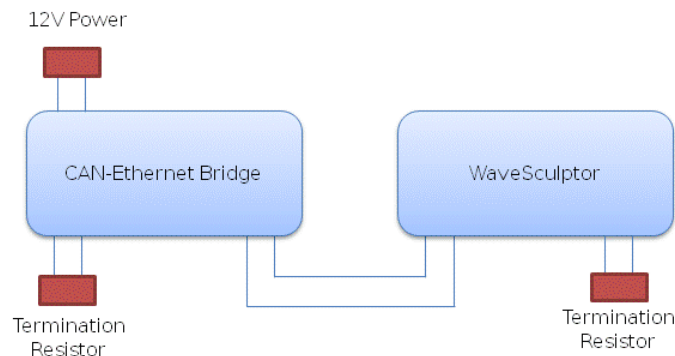
The base address of *each WaveSculptor controller* should be programmed to a different value. This allows viewing of separate telemetry data from each controller on the LCD displays or other telemetry systems in the vehicle.

## **9 PC SOFTWARE**

### **9.1 ETHERNET BRIDGE INSTALLATION**

Refer to the CAN-Ethernet bridge User's Manual for installation and setup of this piece of hardware.

Connect the Ethernet bridge via a CAN bus cable to the WaveSculptor. Use 120 ohm termination resistors between the CAN-H and CAN-L lines at both items.



Refer to the Software Download section on the WaveSculptor 200 product page for the Configuration & Setup software tool download.

Refer to the Software User's Manual for installation and usage instructions.

### **9.3 LOW VOLTAGE & CAN BUS TESTING**

Provide 12V DC to the CAN bus adapter at the CAN-Ethernet Bridge, to power up both the Ethernet Bridge and the WaveSculptor control electronics.

If everything is connected correctly, you should see telemetry values appearing and updating several times per second in the PC software window.

## **10 DRIVER CONTROLS**

Wire and install the hardware driver controls as described in the Driver Controls User's Manual.

Test the driver controls as described in the User's Manual.

## **11 MOTOR SENSE CONNECTIONS**

### **11.1 OVERVIEW**

The WaveSculptor200 requires a position sensor to be able to control the motor. It can also measure the temperature of the motor, and gradually reduce the motor current if this temperature rises towards a user-programmable threshold.

Since there are a large variety of possible combinations of position and temperature sensors, Tritium has implemented the interface on the motor controller in a generic manner. Small adapter circuit boards, suitable for mounting directly inside the motor terminal box, are used to adapt the sensors in



that motor to the interface required by the WaveSculptor200. This also provides a robust signalling mechanism (isolated, differential) for the longest length of cable possible.

It is expected that the motor sense adapter board will be located inside the motor terminal box, and connect to the WaveSculptor200 via a twisted-pair cable routed along the conduit with the motor phase wiring.

The WaveSculptor provides isolated, regulated +5V and +12V DC to power the external adapter. Refer to the datasheet for specifications on these supplies.

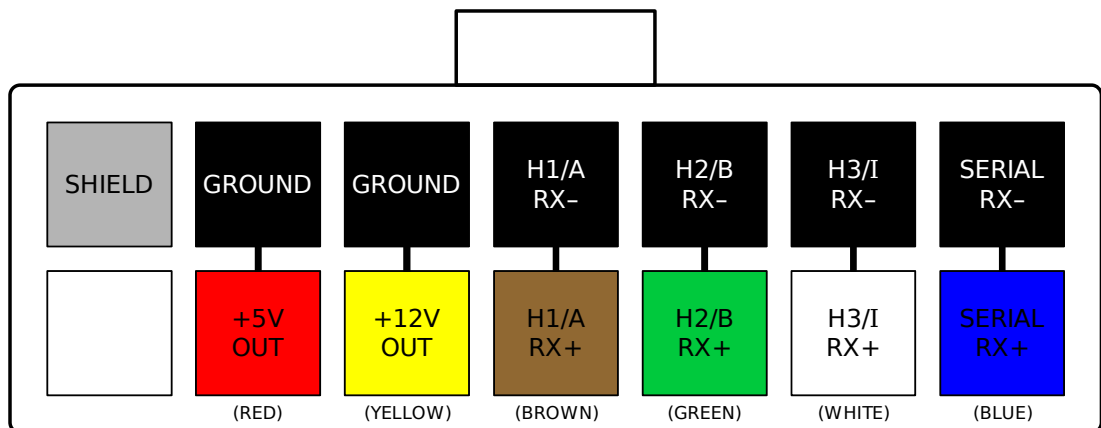
The WaveSculptor provides four isolated differential inputs for information from the motor. Three of these are routed to timer/capture peripherals in the main processor, and are normally used for three Hall-effect position sensors, or the A, B and Index channels of a quadrature encoder. The fourth channel is routed to a UART serial receiver, and expects digital data. Depending on the adapter board, this data may contain temperature, position, velocity, or a combination of all three.

A brief datasheet for each adapter option is available on the Tritium website. If your motor requires an adapter that is not yet available, please contact Tritium to enquire about development, as new adapters are simple and low-cost to design.

## 11.2

### CONNECTOR PINOUT

The connector used on the WaveSculptor200 for the connection to the motor sense adapter board is a 14-way 3mm pitch Molex MicroFit connector. The pinout is shown below, as viewed from the wire side – as you would look at it while inserting crimps. Please refer to Appendix B for an overview of correct crimping technique, as poor crimps will cause unreliable operation.



The wiring for this connector should be implemented with twisted pairs, as the signal inputs are differential. Tritium recommends using Belden 9506 type cable (shielded 6 pair) for this connection, with suggested cable colours shown above.

Make sure to wire the cable with the pair orientation correct, with each + and - signal (eg Serial RX+ and Serial RX-) twisted together.



## 11.3 MOTOR POSITION SENSE

### 11.3.1 BLDC Motor

For operating Brushless DC (BLDC) and Permanent Magnet Synchronous (PMSM) type motors, the WaveSculptor requires three motor position sensing inputs, commonly provided using Hall-effect switches embedded in the motor.

Please note that the relation between each Hall-effect input and a motor output phase, as well as the polarity of the Hall-effect input signal, does not matter. The WaveSculptor will detect these relationships when running its initial setup and configuration routine (PhasorSense). The only requirement for these signals is that they have a fixed alignment (ideally, a 0° offset) with the zero-crossing point of the back-EMF waveform of the motor, and that the signals are offset from each other by 120°. This is where most motors will be configured by default.

### 11.3.2 Induction Motor

For operating Induction motors, the WaveSculptor requires a quadrature (A + B channel) indexed (+ I channel) incremental encoder. If you have purchased your motor through Tritium, this encoder will already be fitted in place.

The encoder must be chosen to give enough speed resolution to operate successfully. This can depend somewhat on your expected operating rpm, but as a good all-round solution a 256 count encoder will be suitable.

### 11.3.3 IPM Motor

For operating Interior Permanent Magnet motors, as well as some types of BLDC motors, a resolver is a suitable position sensor. Tritium can provide a motor adapter suitable for driving and interpreting data from this type of sensor.

## 11.4 MOTOR TEMPERATURE SENSE

Tritium's motor adapters are currently available for use with NTC thermistor and Pt100 temperature sensor elements. Variations are possible to accommodate thermocouple and LM35-type semiconductor sensors also.

## 12 HIGH POWER CONNECTIONS

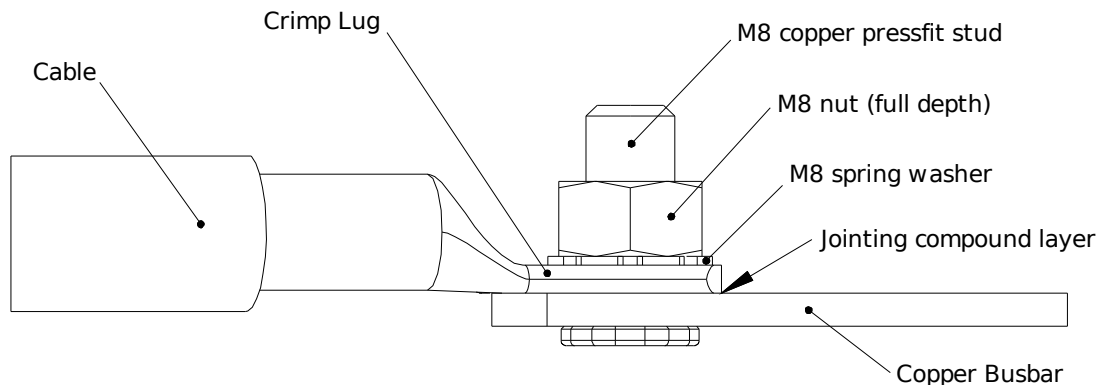
It is important to correctly terminate the high power wiring for successful long-term operation of the controller. DC battery and AC motor phase connections should be crimped to bolt lug crimp terminals. The copper studs in the busbars of the WaveSculptor have a metric M8 thread, so use a lug designed for this size bolt, with an 8.5mm hole.

High power connections should not be soldered for vehicle applications, as the solder wicks up inside the copper strands and creates a stress point, which can fatigue and break due to the vibration present in a vehicle.

For a guide to good quality crimping of the high power connections, please read Appendix B of this document.

Copper oxidation is a threat to the long-term reliability of both the crimp and the bolted joint to the controller. Use a thin smear of anti-oxidation electrical jointing compound between the busbar and the crimp lug when bolting the cable to the controller, as shown in the diagram below. A small amount has already been

applied in the factory to minimise corrosion in the time between manufacture and first assembly of the unit in your vehicle.



The copper pressfit studs are permanently attached to the busbars. To assemble the bolted joint follow these steps:

- Apply a thin smear of electrical jointing compound to the busbar
- Route the cable in through the conduit fitting and locate the crimp lug down over the stud
- Place a plain (flat) washer and a spring washer on top of the lug
- Thread a nut over the stud
- Use a torque wrench to tighten the nut to 10Nm (7.5 ft.lbs)

### 12.1 CABLE

The cable used to connect to the high power terminals must be rated for the full DC battery voltage as a minimum. 600/1000V cable is suitable.

The current rating of the cable will depend on your expected load and duty cycle for your driving habits in your vehicle. The WaveSculptor bolt terminal area is designed to accept up to 35mm<sup>2</sup> cable with an outside diameter of up to 13.5mm. Tritium suggests the use of at least 110°C rated PVC cable (note that standard PVC is 90°C rated) to allow a longer duration of peak power output without exceeding the cable temperature rating.

The cable should have orange coloured insulation. This is required by the NCOP14 standard for EV conversions in Australia, but is a good idea in any case. This is what is used in the Prius and other hybrid vehicles, and emergency response personnel are trained to not cut through orange cables. Use a short piece of red or black insulation at the ends of the orange cable to indicate polarity.

Use of flexible cable with a high number of fine strands is advised, to help with cable routing and reduce strain and fatigue on the terminations. Tritium recommends using "ZDFX" double-insulated 0.6/1kV 110°C rated cable from Tycab Australia, which is made with 1120x 0.2mm strands, resulting in a flexible cable. It is available in orange insulation. Similar cable will be available from alternative suppliers in other countries.

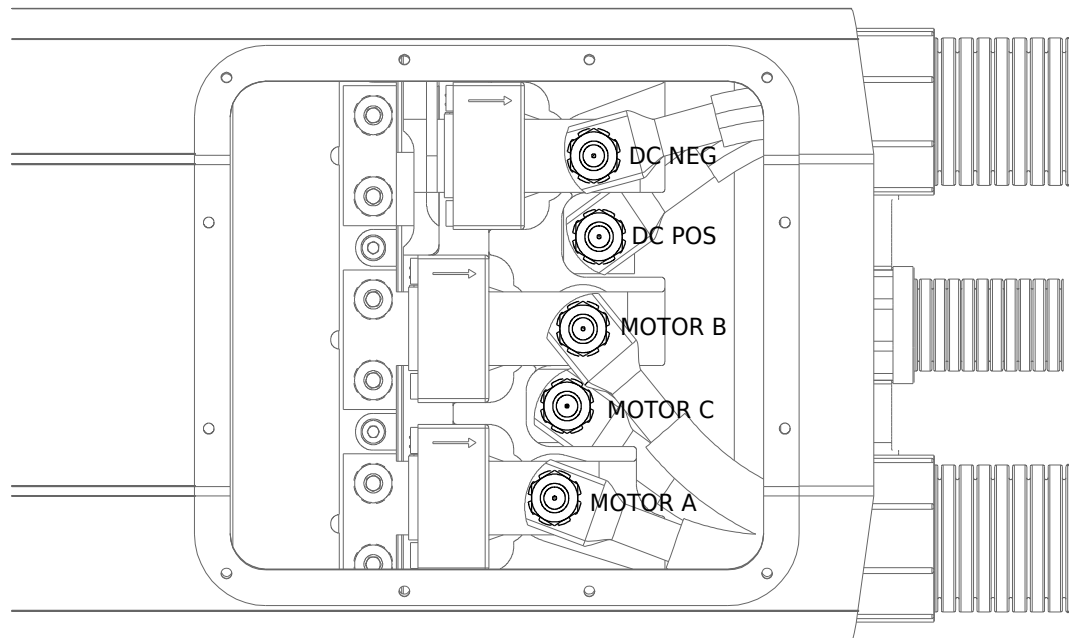
### 12.2 MOTOR INDUCTANCE

The WaveSculptor requires a minimum of 50 $\mu$ H inductance (phase – neutral) per phase to operate correctly. Please ensure that sufficient external inductance has been added if your motor does not have at least this amount of inductance already. External inductors will most likely only be required on ultra-high efficiency ironless BLDC type motors.

These external inductors must be rated to the full motor current and have windings insulated to the full DC bus voltage.

### 12.3 HIGH POWER CONNECTIONS

The positions of the busbars for the various connections are shown in the diagram below. The recommended cable assembly order, to make cable routing inside the controller as easy as possible, is MOTOR C, MOTOR B, MOTOR A, DC POS, DC NEG.



At this point, do not connect the other end of the high power DC NEG and DC POS cables to your precharge circuit or batteries. You will need to connect them to a low-voltage supply of power for initial testing, which is detailed in the “Motor Setup & Testing” section of this document.

### 12.5 PRECHARGE

The WaveSculptor has 800 $\mu$ F of extremely low-impedance capacitance across the DC bus input connections. An external precharge circuit is mandatory.

When not driving a motor, the WaveSculptor draws minimal power from the DC bus, with only a high-value discharge resistor to bleed charge. Therefore, careful attention should be given when working on the controller to ensure that the capacitors have been discharged first. Note that these capacitors hold over 80 Joules of energy and take up to 10 minutes to discharge to safe levels.

Tritium can provide a circuit to implement the precharge function, as part of our Pack-Master BMS system. Please refer to the product webpage for more information. There are a variety of other ways to implement precharge but many do not automatically check for faults and may overheat themselves in the event of a problem.

## **12.6 FUSING**

At least one appropriately rated fuse must be installed in the high voltage DC circuit. This fuse must be rated to the highest expected DC voltage. AC rated fuses are not appropriate, unless they have a DC rating as well.

Choosing the current rating of the fuse depends on your expected load, the maximum fault current in the battery system, duration of loads, cable sizes, and several other factors. It is beyond the scope of this document to detail fuse selection for your vehicle.

Note that the WaveSculptor can be programmed to limit the current it draws from the DC bus connection, which may simplify fuse, contactor and wiring selection. However, this will also have the effect of limiting total system power throughput, so be aware that when setting it to less than 100% that you may compromise your vehicle performance.

## **12.7 HV ISOLATION**

The WaveSculptor has an isolation barrier rated to 1kV continuously between the CAN bus, the DC bus, and the Motor position connection. This helps minimise damage in the event of a fault, and also allows safe connection of the high voltage battery pack.

Tritium recommends that the CAN bus be operated at the system ground potential, with CAN Ground connected to the vehicle chassis at some point in your system.

The battery ground, high-voltage DC connections, and motor phases should be isolated from the vehicle chassis. This is so that a single fault anywhere in the high voltage system will not result in a high voltage potential being present between any wiring and the chassis of the vehicle.

Please refer to any relevant regulations governing this type of connection, such as (in Australia) the NCOP14 standard for EV conversions.

## **13 MOTOR SETUP & TESTING**

### **13.1 LOW POWER SETUP**

At this stage, put the car on a vehicle lift, or use a secure method to lift the drive wheels from the ground. If your vehicle is equipped with a manual gearbox, putting the gearbox in neutral may be an adequate substitute.

A low voltage supply should be connected to perform the next stage of testing. Note that if it is necessary to run these tests again later, they may be run from the high voltage pack – it is not necessary to disconnect everything and use a low voltage setup. At this point however, the low voltage supply should be used as a safer option until it is known that everything in the system is working correctly.

A suitable low voltage supply is a pair of 12V batteries in series. Make sure to



fuse them correctly, and use your precharge circuit. A power supply with current limiting is the best option if one is available.

Run the PC software, and provide 12V along the CAN cable to power up the motor controller electronics. You should see telemetry values updating on the PC. Connect the 24V to the high power section of the motor controller. You should see the reported battery voltage on the PC show the correct value.

### 13.2 PHASORSENSE - BLDC MOTORS

If you are using a BLDC or other permanent magnet motor, **refer to the software user's manual for the procedure to run PhasorSense**. This routine identifies the relationship between motor phases and hall position sensors.

Next, run the parameter extraction routine, which calculates motor parameters. Save the results into one of the ten available motor configuration slots. In the general configuration screen, set this motor slot as the "Active Motor".

For bench testing with an unloaded motor, set the vehicle mass in the config screen to 30kg. Using the actual vehicle mass when running with an unloaded motor will cause the velocity control loop to overshoot and oscillate around the setpoint.

### 13.3 IMEXTRACT - INDUCTION MOTORS

If you are using an induction motor, **refer to the software user's manual for the procedure to run ImExtract**. This routine calculates motor parameters. Save the results into one of the ten available motor configuration slots. In the general configuration screen, set this motor slot as the "Active Motor".

For bench testing with an unloaded motor, set the vehicle mass in the config screen to 30kg. Using the actual vehicle mass when running with an unloaded motor will cause the velocity control loop to overshoot and oscillate around the setpoint.

### 13.4 LOW POWER TESTING - PC CONTROL

This test will check that the motor spins and is configured correctly.

Open the controls screen in the PC software (View → Controls). There are three sliders, setting Motor Current, Motor Velocity, and Bus (battery) current respectively. The motor controller will use up to whatever motor current you have set to try and achieve the requested velocity. The motor current will be limited if the battery current reaches the bus current setpoint.

If using batteries as the power source, regenerative braking (regen) can also be tested. Do NOT test regen braking if using a power supply for the 24V source, as you will force current back into the supply and damage it.

The motor controller will regen if the velocity is set to a lower speed than the motor is actually moving, and motor current is above zero.

To stop without regen braking:

1. Zero the motor current, then
2. Zero the velocity



To stop with regen braking:

1. Set motor current to your desired regen current, then
2. Zero the velocity

Now that the motor is configured correctly, set the Bus Current to 100%, if it is not already. Change the Velocity slider to around 10%. Now, gradually increase the Motor Current slider, and the motor should smoothly accelerate to a moderate speed.

Zero the motor current, then zero the velocity, and the motor should smoothly coast to a stop.

Now set the velocity slider to 100%. Once again, gradually increase the motor current. The motor should smoothly accelerate to a faster speed than before. Zero the motor current, then zero the velocity.

If using batteries, now test regen braking. Set velocity to 100%. Gradually increase motor current. Now, with the motor spinning, set motor current to around 10%. Zero the velocity. The motor will regen brake to a halt. Since it does not have the mass of a vehicle to damp the system, it may then oscillate slightly forwards and backwards – this should be relatively minimal if the vehicle mass was set to 30kg as outlined in the previous section. Zero the motor current when near zero speed to stop this happening.

## 13.5

### LOW POWER TESTING - DRIVER CONTROLS HARDWARE

Remove the CAN cable and termination resistor from the CAN-Ethernet bridge, and connect them both to the EV Driver Controls hardware.

Provide 12V power to the driver controls. Go through the startup sequence as described in the Driver Controls User's Manual. Depending on the exact firmware you have this will usually involve turning the key to the start position, and selecting forward gear in the driver controls.

Use the accelerator (gas) pedal to run the motor. Complete the following checks:

- [ ] Driving forwards
- [ ] Car coasts to a stop when accelerator pedal is lifted
- [ ] Driving in reverse
- [ ] Car coasts to a stop when accelerator pedal is lifted
- [ ] Appropriate action happens when brake pedal is pushed
- [ ] If your driver controls is configured to use regen, it works correctly in forwards
- [ ] If your driver controls is configured to use regen, it works correctly in reverse
- [ ] Selecting Neutral on the driver controls makes the car coast to a stop
- [ ] Turning off the key makes the car coast to a stop



## **14 HIGH POWER TESTING**

### **14.1 CONNECTIONS**

Make sure your precharge circuit, contactors, and fusing are in place. Check the polarity of the supply cables to the WaveSculptor. Take all appropriate safety precautions when working on the HV circuitry. Depending on the legislation in your country, you may require a licensed electrician to work on the high voltage parts of the system.

Making sure that all contactors are off, in the safe state, make the bolt connections to the DC POS and DC NEG terminals of the WaveSculptor.

### **14.2 PC SOFTWARE CONTROL**

Move the CAN cable and termination resistor from the hardware driver controls and reconnect it to the CAN-Ethernet bridge. Run the PC software. Run through the same checks as outlined in the previous 24V low voltage testing section.

### **14.3 DRIVER CONTROLS**

Reconnect the CAN cable and termination resistor to the hardware driver controls. Run through the same checks as listed above in the 24V driver controls hardware testing.

Test at least the following functionality:

- [ ] Driving forwards
- [ ] Car coasts to a stop when accelerator pedal is lifted
- [ ] Driving in reverse
- [ ] Car coasts to a stop when accelerator pedal is lifted
- [ ] Appropriate action happens when brake pedal is pushed
- [ ] If your driver controls is configured to use regen, it works correctly in forwards
- [ ] If your driver controls is configured to use regen, it works correctly in reverse
- [ ] Selecting Neutral on the driver controls makes the car coast to a stop
- [ ] Turning off the key makes the car coast to a stop

## **15 DRIVING**

### **15.1 WARNINGS**

Perform the following tests in a location off public roads, in an area free of obstructions. Take all appropriate safety precautions when performing this testing.

Using the Windows configuration software, set the vehicle mass to the actual mass of the vehicle, so that the velocity control loop will be tuned optimally.





## 15.2 PROCEDURE

Perform the same checks that were performed with the vehicle off the ground.

- [ ] Driving forwards
- [ ] Car coasts to a stop when accelerator pedal is lifted
- [ ] Driving in reverse
- [ ] Car coasts to a stop when accelerator pedal is lifted
- [ ] Appropriate action happens when brake pedal is pushed
- [ ] If your driver controls is configured to use regen, it works correctly in forwards
- [ ] If your driver controls is configured to use regen, it works correctly in reverse
- [ ] Selecting Neutral on the driver controls makes the car coast to a stop
- [ ] Turning off the key makes the car coast to a stop

## 15.3 ON ROAD TESTING

After meeting all the relevant regulations in your country for vehicle registration and safety checks, you should be ready to drive your car out in the real world! We suggest gradually building up your confidence in the new drive system with a series of tests, at increasing speeds and power levels.



## 16 APPENDIX A - RECOMMENDED COMPONENT SOURCES

<b>Part Description</b>	
Manufacturer	Manufacturer Part Number
Suggested Supplier	Supplier Part Number

### 16.1 CAN CABLING & LOW VOLTAGE CONNECTORS

<b>DeviceNet Cable (per metre)</b>	
Lapp Cable	2170343
Farnell	161-7915

<b>6 way MicroFit connector housing (CAN connectors)</b>	
Molex	43025-0600
Digikey	WM1785-ND

<b>14 way MicroFit connector housing (Motor Sense connector)</b>	
Molex	43025-1400
Digikey	WM2489-ND

<b>MicroFit crimps (20-24 AWG)</b>	
Molex	43030-0007
Digikey	WM1837-ND

### 16.2 HIGH POWER CABLING & CONNECTORS

<b>Motor Temperature Sensor - 100k 25°C NTC thermistor</b>	
BethTherm	10KD6A372I
Farnell	970-7298

<b>High power 35mm² M8 bolt lug connections</b>	
Cabac	CAA 35-8
Local electrical supplier	-

<b>High power cabling - 35mm² high temp orange</b>	
Tycab Australia	ZDFX1112102-OR
Local electrical supplier	-

### 16.3 COOLING SYSTEM COMPONENTS

<b>Radiator - Aluminium core 3x 120mm size</b>	
Koolance	HX-1020 plus either NZL-V10P or NZL-L10P



## USER'S MANUAL

### WaveSculptor 200 Motor Drive

TRI74.021 ver 5  
31 August 2015

<b><i>Pump - Magnetically coupled 12V</i></b>	
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Koolance	PMP-400
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<b><i>Reservoir - 200mm long acrylic</i></b>	
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Koolance	COV-TKBTM plus BDY-TK200 plus COV-TKTOP plus either NZL-L10P or NZL-V10P
----------	---

<b><i>10mm ID / 13mm OD tubing - per foot (up to 10 feet required, depends on vehicle)</i></b>	
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Koolance	HOS-10CL
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<b><i>Coolant - 700ml bottle, Blue (probably two bottles required, depends on vehicle)</i></b>	
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Koolance	LIQ-702BU-B
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## **17 APPENDIX B - GUIDE TO SUCCESSFUL CRIMPING**

### **17.1 MOLEX MICROFIT 3.0**

At the bare minimum, use a quality hand crimp tool such as Molex part number 0638111000, available at a reasonable price from Digikey, part WM9999-ND. The tool must be shaped to fold the crimp ears around and down through the centre of the wire conductor bundle - crimping with pliers or an 'automotive' barrel type crimp tool will not give a satisfactory result.

Refer to the Molex "Quality Crimping Handbook":

[http://www.molex.com/pdm\\_docs/ats/TM-638000029.pdf](http://www.molex.com/pdm_docs/ats/TM-638000029.pdf)

Note the pictures in the "Troubleshooting" section for the visual differences between a good and a bad crimp.

For higher volumes, the extra expense of a dedicated MicroFit hand tool such as Molex part number 63819-0000 may be appropriate, but this tool is probably not worth the cost for a one-off vehicle conversion. This tool is available from Digikey, part WM9022-ND. Be aware that this tool does provide far superior results compared to the generic crimp tool

### **17.2 HIGH POWER BOLT LUGS**

It is important to crimp the high power connections properly so that they remain reliable and low-resistance for a long time. High power connections should not be soldered for vehicle applications, as the solder wicks up inside the copper strands and creates a stress point, which can fatigue and break due to the vibration present in a vehicle.

Follow the steps below for a successful crimp

**Step 1** - Cut the cable square and neatly, with no loose strands. The best tool to use is a parrot-beak cable cutter, available at electricians supply stores.



**WaveSculptor 200 Motor Drive**TRI74.021 ver 5  
31 August 2015

**Step 2** - Strip the insulation to the correct distance for the crimp you are using. When inserted into the crimp, the insulation should touch the barrel of the crimp with no large gaps and you should be able to see the ends of the copper strands through the inspection hole next to the lug of the crimp.

**Step 3** - Put a small blob (6mm or 1/4" diameter) of electrical jointing compound into the barrel of the crimp. This compound prevents oxygen and moisture from getting into the crimp later on, and keeps it in good condition for a long time.



**Step 4** - Insert the wire into the crimp. Hold your finger over the inspection hole to stop the jointing compound coming out, therefore forcing it up between the wire strands. Push the wire all the way into the crimp barrel, so that the wire insulation touches the end of the barrel with no large gaps.



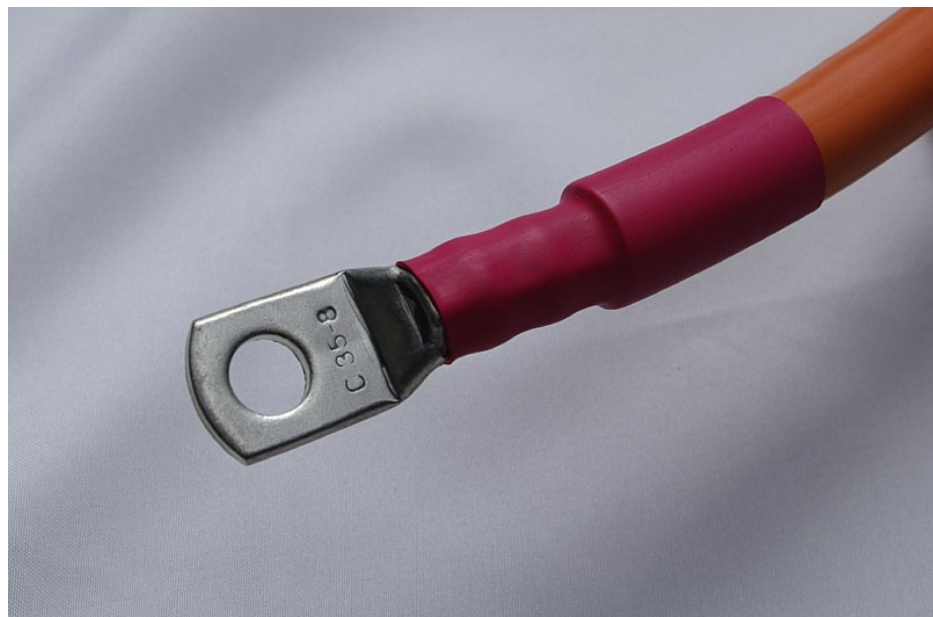
**WaveSculptor 200 Motor Drive**TRI74.021 ver 5  
31 August 2015

**Step 5** - Set your hex crimp tool to the same size as the crimp lug. In the example photos here, we have used 35mm<sup>2</sup> cable, lugs, and crimp tool. To crimp with the proper force, you will need either a 'bolt cutter' type crimp tool, as shown in the photo above, with handles around 600mm (2') long, or a hydraulic tool with an appropriate crimp die set.



**Step 6** - Crimp the barrel of the crimp. For the tool used in these photos, it can be crimped three times along the length of the barrel. A hydraulic tool may be similar. A high volume tool will probably only require a single action.

**Step 7** - Heatshrink both ends of the orange cable with red or black heatshrink to indicate DC polarity. Red and Black cable should be reserved for low voltage (12V) wiring in the car. Use other colour heatshrink for the motor phases.



## 18 APPENDIX C - CAN COMMUNICATIONS PROTOCOL

### 18.1 OVERVIEW

#### 18.1.1 Hardware

The CAN hardware interface used is compatible with the CAN 2.0B standard. The supported bit rates (bits per second) are 1 Mbps, 500 kbps (default), 250 kbps, 125 kbps, 100 kbps and 50 kbps.

#### 18.1.2 Software

The CAN protocol uses data frames for most communication. Remote frames are also enabled. The identifier field uses the standard frame definition length of 11 bits, with identifiers 0x7F0 to 0x7FF reserved for use by the WaveSculptor bootloader. The bootloader will send a message with identifier 0x7F1 at 500kbit after a system reset. All measurement data is transmitted using IEEE single-precision 32-bit format (IEEE 754) with most significant byte (MSB) sent first.

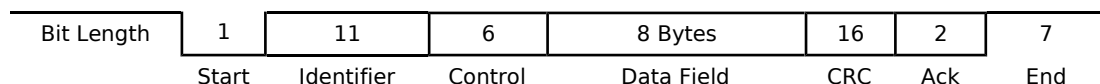


Figure 1. CAN data frame

#### 18.1.3 Identifier

The identifier field has been split into two sections for Tritium devices. Bits 10-5 contain the device identifier and bits 4-0 contains the message identifier associated with that device, as shown in Figure 2. This means that there is a maximum of 63 Tritium device that can be on the CAN bus at any one time. The 64th location is reserved for the bootloader. Each Tritium device can have 31 different types of messages. The first message identifier is used by the device identification message. Two device slots could be used if more messages per device were required, however this has not been required yet.

The term Base Address is used instead of Device Identifier in the Windows configuration program. Base Address is simply the Device Identifier multiplied by 32. Using this term makes it more obvious what range of CAN identifiers have been used. As an example, there may be a Tritium driver controls at base address 0x400, a left wheel WaveSculptor motor controller at 0x420 and a right wheel WaveSculptor motor controller at 0x440. So, address range 0x400 – 0x45F would be used by this Tritium system.

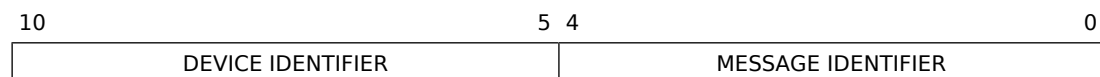


Figure 2. CAN device identifier address format

#### 18.1.4 Data Field

The data field in all frames is fixed at 8 bytes (64 bits) which allows space for two IEEE 754 32-bit floating point variables as shown in Figure 3. The data field is sent and expected to be received least significant byte first. This allows a direct overlay of a float[2] array and char[8] array on a little endian processor, such as an Intel x86, the TI DSP in the WaveSculptor, or the MSP430 micro in the driver controls product.

## WaveSculptor 200 Motor Drive

TRI74.021 ver 5  
31 August 2015

High float	Low float
s eeeeeeee mmmmmmmmmmmmmmmmmmmmm ^ ^ ^ ^ ^ 63 62 55 54 32	s eeeeeeee mmmmmmmmmmmmmmmmmmmmm ^ ^ ^ ^ ^ 31 30 23 22 0

Figure 3. Format of the data field in a data frame

### 18.1.5 Units

Please note that variables described in the following packets with units of percent “%” should be sent with a minimum floating-point value of 0.0 and a maximum value of 1.0. Do not send 100.0 as the maximum value.

## 18.2 DRIVE COMMANDS

These are data frames broadcast from the driver controls to any listening motor controller. These commands contain desired set points for the control software to operate the controller. The commands are sent as required, however there is a maximum permissible delay between consecutive Motor Drive commands.

The identifier of a received command will contain the base address of the device from which the message was sent and a message identifier offset. The base address of the sending device is a preset value stored in internal memory, which can be set during initial configuration of the motor controller using the configuration utility.

### 18.2.1 Motor Drive Command

**ID:** Driver Controls Base Address + 0x01

<b>Variable</b>	<b>Bits</b>	<b>Units</b>	<b>Description</b>
Motor Current	63 .. 32	%	Desired motor current set point as a percentage of maximum current setting.
Motor Velocity	31 .. 0	rpm	Desired motor velocity set point in rpm

The WaveSculptor motor controller must receive a Motor Drive Command frame at least once every 250ms. If this does not occur, the controller will assume that communications have failed and will halt all motor control functions, placing the system into neutral and coasting until another valid command is received.

### 18.2.2 Motor Power Command

**ID:** Driver Controls Base Address + 0x02

<b>Variable</b>	<b>Bits</b>	<b>Units</b>	<b>Description</b>
Bus Current	63 .. 32	%	Desired set point of current drawn from the bus by the controller as a percentage of absolute bus current limit.
Reserved	31 .. 0	–	–



### 18.2.3 Reset Command

**ID:** Driver Controls Base Address + 0x03

<i>Variable</i>	<i>Bits</i>	<i>Units</i>	<i>Description</i>
Unused	63 .. 32	-	-
Unused	31 .. 0	-	-

Send a command from this address to reset the software in the WaveSculptor.

## 18.3 DRIVE COMMAND EXAMPLES

Ignoring the added complexity of bus and thermal limiting, the WaveSculptor operates such that it will use the maximum available current (torque) to try and achieve the desired velocity. This is true for both accelerating and decelerating operation, i.e. the WaveSculptor will automatically regneratively brake if a setpoint velocity is provided that is slower than the current speed.

Two main drive modes will be used in a normal vehicle setup: torque control; and velocity (cruise) control. A conventional vehicle runs in torque control mode, where the position of the accelerator (gas) pedal controls the amount of torque produced by the engine. In an electric system, the motor current is proportional to torque, and can be easily regulated, as can the velocity.

To run the motor in torque control mode, set the velocity to an unobtainable value such as 20000rpm. Set the current to a value that is proportional to your accelerator pedal position. If you wish to drive in reverse, set the velocity to -20000rpm. The motor will operate the same as a normal car, and will coast down to a stop if the driver removes their foot from the pedal.

To run the motor in velocity (cruise) control mode, set the current to your maximum desired acceleration force (usually 100%), and set the velocity to the desired speed. The WaveSculptor will use the setpoint current to keep the vehicle at the setpoint speed, and will use both drive and regenerative braking to do so. Use this mode to regeneratively brake to a halt by setting current to your desired braking force, and setting velocity to zero.

## 18.4 MOTOR CONTROLLER BROADCAST MESSAGES

Data frames containing telemetry values are periodically broadcast onto the bus by the WaveSculptor. Broadcast of these values can be individually enabled and disabled via the Windows configuration software.

Any of these telemetry values can be requested at any time (no matter if enabled or disabled) by sending the appropriate RTR packet on the CAN bus. For example, with a WaveSculptor200 configured at base address 0x400, your device should send an empty packet onto the CAN bus with an ID of 0x402 and the RTR bit set. The WaveSculptor200 will reply immediately with a packet from ID 0x402 containing the latest bus voltage and current readings.

### 18.4.1 Identification Information

**ID:** Motor Controller Base Address + 0x00

**Interval:** 1 second

Variable	Bits	Type	Description
Serial Number	63 .. 32	Uint32	Device serial number, allocated at manufacture.
Tritium ID	31 .. 0	Uint32	Device identifier. 0x00004002

The periodic broadcast of this message cannot be disabled. It is needed to find the motor controller on the network if the base address is lost or mis-configured.

### 18.4.2 Status Information

**ID:** Motor Controller Base Address + 0x01

**Interval:** 200 ms

Variable	Bits	Type	Description
Receive error count	63..56	Uint8	The DSP CAN receive error counter (CAN 2.0)
Transmit error count	55 .. 48	Uint8	The DSP CAN transmission error counter (CAN 2.0)
Active Motor	47 .. 32	Uint16	The index of the active motor currently being used.
Error Flags	31 .. 16	Uint16	Flags indicate errors:
			<b>Bits</b> <b>Parameter</b>
			15 .. 9      Reserved
			8      Motor Over Speed (15% overshoot above max RPM)
			7      Desaturation fault (IGBT desaturation, IGBT driver UVLO)
			6      15V rail under voltage lock out (UVLO)
			5      Config read error (some values may be reset to defaults)
			4      Watchdog caused last reset
			3      Bad motor position hall sequence
			2      DC Bus over voltage
1      Software over current			
0      Hardware over current			
Limit Flags	15 .. 0	Uint16	Flags indicate which control loop is limiting the output current of the motor controller:
			<b>Bits</b> <b>Parameter</b>
			15 .. 7      Reserved
			6      IPM Temperature or Motor Temperature
			5      Bus Voltage Lower Limit
			4      Bus Voltage Upper Limit
			3      Bus Current
			2      Velocity
			1      Motor Current
			0      Output Voltage PWM

### 18.4.3 Bus Measurement

**ID:** Motor Controller Base Address + 0x02

**Interval:** 200 ms

<i>Variable</i>	<i>Bits</i>	<i>Units</i>	<i>Description</i>
Bus Current	63 .. 32	A	Current drawn from the DC bus by the controller.
Bus Voltage	31 .. 0	V	DC bus voltage at the controller.

### 18.4.4 Velocity Measurement

**ID:** Motor Controller Base Address + 0x03

**Interval:** 200 ms

<i>Variable</i>	<i>Bits</i>	<i>Units</i>	<i>Description</i>
Vehicle Velocity	63 .. 32	m/s	Vehicle velocity in metres / second.
Motor Velocity	31 .. 0	rpm	Motor angular frequency in revolutions per minute.

### 18.4.5 Phase Current Measurement

**ID:** Motor Controller Base Address + 0x04

**Interval:** 200 ms

<i>Variable</i>	<i>Bits</i>	<i>Units</i>	<i>Description</i>
Phase C Current	63 .. 32	A <sub>rms</sub>	RMS current in motor Phase C.
Phase B Current	31 .. 0	A <sub>rms</sub>	RMS current in motor Phase B.

While the motor is rotating at speed these two currents should be equal. At extremely low commutation speeds these two currents will only match in one third of the motor position, the other two thirds will involve current also flowing in Phase A.

### 18.4.6 Motor Voltage Vector Measurement

**ID:** Motor Controller Base Address + 0x05

**Interval:** 200 ms

<i>Variable</i>	<i>Bits</i>	<i>Units</i>	<i>Description</i>
Vd	63 .. 32	V	Real component of the applied non-rotating voltage vector to the motor.
Vq	31 .. 0	V	Imaginary component of the applied non-rotating voltage vector to the motor.

### 18.4.7 Motor Current Vector Measurement

**ID:** Motor Controller Base Address + 0x06

**Interval:** 200 ms

<i>Variable</i>	<i>Bits</i>	<i>Type</i>	<i>Description</i>
Id	63 .. 32	A	Real component of the applied non-rotating current vector to the motor. This vector represents the field current of the motor.
Iq	31 .. 0	A	Imaginary component of the applied non-rotating current vector to the motor. This current produces torque in the motor and should be in phase with the back-EMF of the motor.

### 18.4.8 Motor BackEMF Measurement / Prediction

**ID:** Motor Controller Base Address + 0x07

**Interval:** 200 ms

<i>Variable</i>	<i>Bits</i>	<i>Type</i>	<i>Description</i>
BEMFd	63 .. 32	V	By definition this value is always 0V.
BEMFq	31 .. 0	V	The peak of the phase to neutral motor voltage.

### 18.4.9 15V Voltage Rail Measurement

**ID:** Motor Controller Base Address + 0x08

**Interval:** 1 second

<i>Variable</i>	<i>Bits</i>	<i>Type</i>	<i>Description</i>
15V supply	63 .. 32	V	Actual voltage level of the 15V power rail.
Reserved	31 .. 0	-	-

### 18.4.10 3.3V & 1.9V Voltage Rail Measurement

**ID:** Motor Controller Base Address + 0x09

**Interval:** 1 second

<i>Variable</i>	<i>Bits</i>	<i>Type</i>	<i>Description</i>
3.3V supply	63 .. 32	V	Actual voltage level of the 3.3V power rail.
1.9V supply	31 .. 0	V	Actual voltage level of the 1.9V DSP power rail.

### 18.4.11 Reserved

**ID:** Motor Controller Base Address + 0x0A

**Interval:** -

<i>Variable</i>	<i>Bits</i>	<i>Type</i>	<i>Description</i>
Reserved	63 .. 32	-	-
Reserved	31 .. 0	-	-



### 18.4.12 IPM Phase A & Motor Temperature Measurement

**ID:** Motor Controller Base Address + 0x0B

**Interval:** 1 second

<i>Variable</i>	<i>Bits</i>	<i>Type</i>	<i>Description</i>
IPM Phase A Temp	63 .. 32	°C	Internal temperature of phase A in main IPM.
Motor Temp	31 .. 0	°C	Internal temperature of the motor.

### 18.4.13 IPM Phase B & DSP Board Temperature Measurement

**ID:** Motor Controller Base Address + 0x0C

**Interval:** 1 second

<i>Variable</i>	<i>Bits</i>	<i>Type</i>	<i>Description</i>
IPM Phase B Temp	63 .. 32	°C	Internal temperature of phase B in main IPM.
DSP Board Temp	31 .. 0	°C	Temperature of the DSP board.

### 18.4.14 IPM Phase C Temperature Measurement

**ID:** Motor Controller Base Address + 0x0D

**Interval:** 1 second

<i>Variable</i>	<i>Bits</i>	<i>Type</i>	<i>Description</i>
IPM Phase C Temp	63 .. 32	°C	Internal temperature of phase C in main IPM.
Reserved	31 .. 0	°C	-

### 18.4.15 Odometer & Bus AmpHours Measurement

**ID:** Motor Controller Base Address + 0x0E

**Interval:** 1 second

<i>Variable</i>	<i>Bits</i>	<i>Type</i>	<i>Description</i>
DC Bus AmpHours	63 .. 32	Ah	Charge flow into the controller DC bus from the time of reset.
Odometer	31 .. 0	m	Distance the vehicle has travelled since reset.

### 18.4.16 Slip Speed Measurement

**ID:** Motor Controller Base Address + 0x17

**Interval:** 200 ms

<i>Variable</i>	<i>Bits</i>	<i>Type</i>	<i>Description</i>
Slip Speed	63 .. 32	Hz	Slip speed when driving an induction motor.
Reserved	31 .. 0	°C	-



## 18.5 CONFIGURATION COMMANDS

### 18.5.1 Active motor change

**ID:** Motor Controller Base Address + 0x12

<i>Variable</i>	<i>Bits</i>	<i>Units</i>	<i>Description</i>
Active Motor	63 .. 48	WORD	Desired active motor (0 to 9)
Configuration Access Key	47 .. 0	ASCII	Must spell "ACTMOT" in ASCII (0x54 4F 4D 54 43 41)

Send this command to change the active motor. Note that the controller will save the active motor to the EEPROM config memory, so what you send will survive a reset. This has a downside that you don't want to be sending it constantly, as you'll wear out the EEPROM.

Example to set the active motor to motor slot 5:  
CAN ID = 0x412, Data = 0x00 05 54 4F 4D 54 43 41

## 19 REVISION RECORD

<i>REV</i>	<i>DATE</i>	<i>CHANGE</i>
1	21 April 2010	Document creation (JMK)
2	28 November 2010	Updated for v2 (production) hardware (JMK)
3	15 February 2011	Updated Koolance part numbers for cooling system (JMK)
4	18 April 2012	Clarified broadcast and reset messages. Clarified error descriptions (AKR)
5	31 August 2015	Updated Configuration commands and added extra error definitions (AKR)