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# MANUAL

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**CURTIS**PMC

MODEL **1208C**

**MOTOR CONTROLLER**

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DESIGN OF CURTIS PMC 1200 SERIES  
CONTROLLERS PROTECTED BY U.S.  
PATENT NO. 4626750.

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## 1

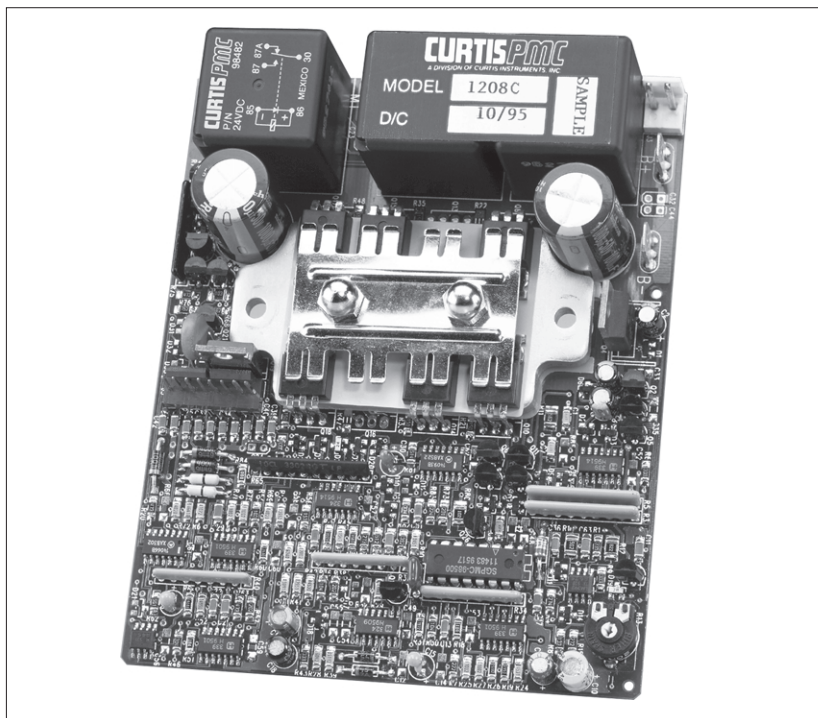
## OVERVIEW

The Curtis PMC 1208C electronic DC motor speed controller is designed for permanent magnet motor applications in mobility aids, scrubbers, sweepers, AGVs, etc. It offers smooth, silent, cost-effective control of motor speed and torque.

The 1208C controller adds extended fault detection and other product improvements to the 1208 design, while maintaining the same mechanical dimensions. The 1208C can provide all the features and fault checks required to meet TÜV regulations, and the TÜV models have been formally TÜV-approved by a certified agency.

**Fig. 1** Curtis PMC 1208C electronic motor controller, shown here with an 8-pin low power connector. The 8-pin connector is required on TÜV models.

The standard low power connector for the 1208C is a 6-pin connector, with 7-pin and 8-pin options also available.



Like all Curtis PMC motor controllers, the 1208C offers superior operator control of the vehicle's motor drive speed. **Features include:**

- ✓ Power MOSFET design, providing
  - infinitely variable drive and brake control
  - silent high-frequency operation
  - high efficiency (for reduced motor and battery losses)

*More Features* ➞

- ✓ Circuitry protected by precision current-limit setting—rated to 70 amps (24V controllers)
- ✓ Wide range of symmetric and asymmetric acceleration/deceleration rates
- ✓ Reduced reverse speed (full-speed reverse also available)
- ✓ Externally adjustable top speed (via potentiometer or switch with resistor)
- ✓ Improved anti-rollback circuitry sets brake delay according to speed and direction
- ✓ High pedal disable function monitors status of throttle during turn-on and prevents operation until throttle has been returned to neutral
- ✓ Neutral throttle (default braking) brakes motor during hands off or power off
- ✓ Current-limited brake driver protects the controller from shorts in the brake or its wiring
- ✓ Missing brake detection feature inhibits controller operation if the electromagnetic brake becomes disconnected for any reason
- ✓ Fault checking circuitry looks for neutral throttle demand vs. controller output and inhibits controller operation if a fault is detected
- ✓ EMI susceptibility minimized through the use of surface mount technology and advanced component layout
- ✓ Throttle buffer improves consistency in reduced throttle throw applications
- ✓ Improved undervoltage cutback function protects against low battery voltages, including those caused by external loads
- ✓ Polarity protected battery input
- ✓ Simple installation with no adjustments required
- ✓ Quick connect power terminals
- ✓ Plug-in connectors for control wiring.

*Additional features of TÜV models:*

- ★ Fully TÜV approved
- ★ Main relay weld check performed at power-up to ensure proper relay action
- ★ Throttle pot fault detection compliant with ISO 7176 requirements
- ★ Diagnostic and fault information provided via LED
- ★ Brake driver protected against overtemperature and overcurrent.

Familiarity with your Curtis PMC controller will help you to install and operate it properly. We encourage you to read this manual carefully. If you have questions, please contact the Curtis office nearest you.

## 2

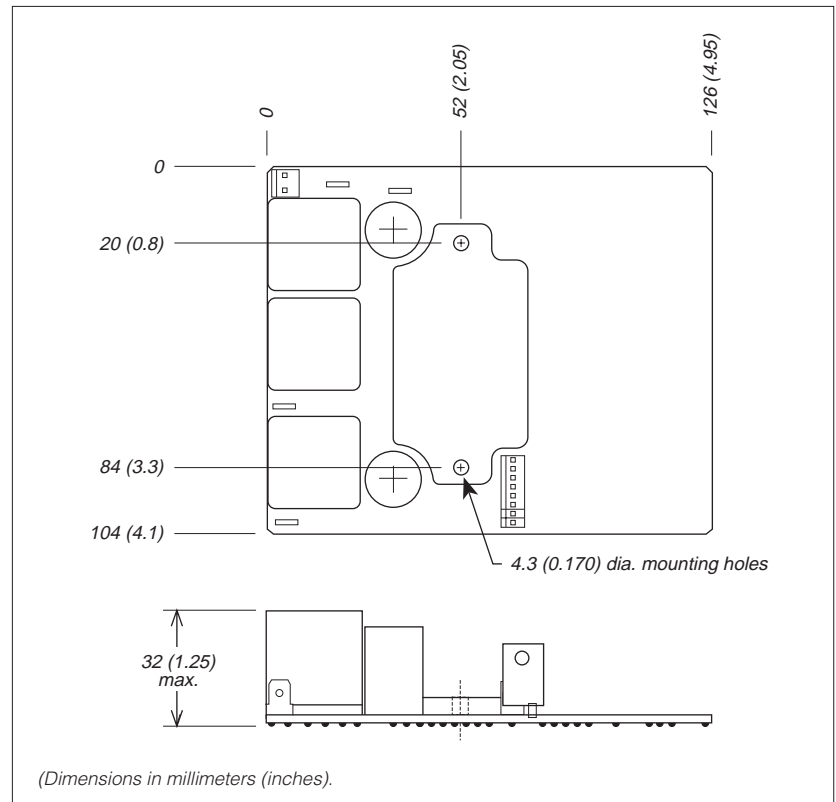
## INSTALLATION AND WIRING

## MOUNTING THE CONTROLLER

The controller can be oriented in any position, but **the location should be carefully chosen to keep the controller clean and dry and protect it from mechanical abuse.** If a clean, dry mounting location cannot be found, a cover must be used to shield the controller from water and contaminants.

The outline and mounting dimensions for the 1208C controller are shown in Figure 2. The circuit board can be mounted from either the top or bottom, using aluminum spacers to conduct heat from the on-board mounting plate to the installation heatsink (wall, bulkhead, etc.). The minimum required heatsink to meet the 30-second current rating is a 4"×5" by 1/8" thick aluminum plate, mounted with 3/8" diameter by ≤1" long aluminum spacers.

**Fig. 2** Mounting dimensions for Curtis PMC 1208C controller.



## CONNECTORS

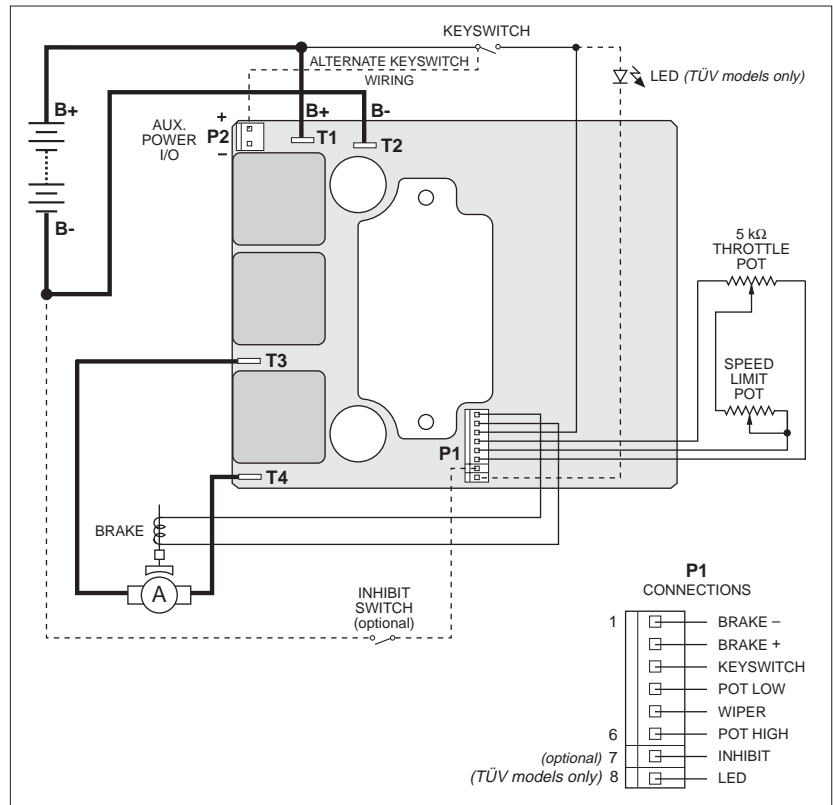
The main power connections to the controller use 1/4" quick connect terminals (**T1**, **T2** for the battery; **T3**, **T4** for the motor). The other connections use 0.100" (**P1**) and 0.156" (**P2**) center-to-center connectors. 1208C controllers have either 8-pin, 7-pin, or 6-pin **P1** connectors, depending on whether they include the optional features. Several manufacturers' connectors will mate with the on-board connectors with options of crimp or insulation displacement terminals and wires straight out or at right angles to the connector shells. See Appendix C for a list of available connectors.

## WIRING

### Standard Wiring: Potentiometer Throttle

The 1208C controller is designed to use a 3-wire, 5k $\Omega$  potentiometer as a wigwag throttle input, as shown in the basic wiring diagram (Figure 3). The wigwag

**Fig. 3** Basic wiring configuration for Curtis PMC 1208C controller.





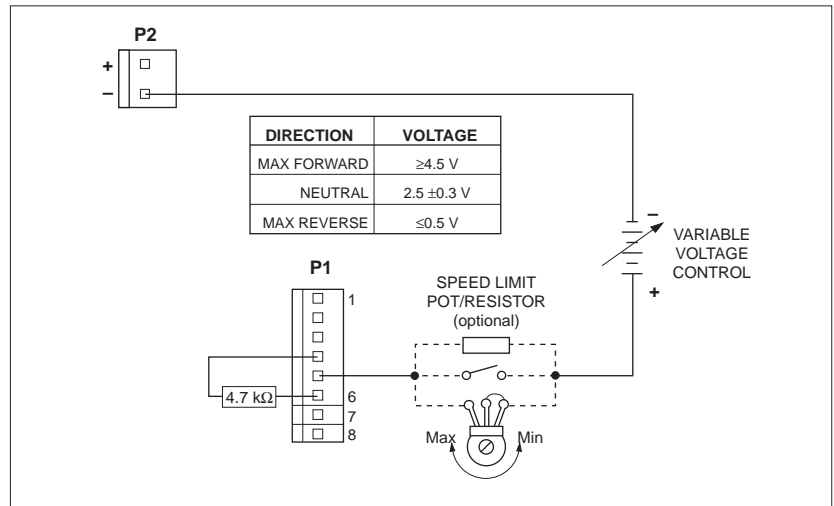
throttle provides a neutral window in the center of its travel range, from approximately 2.2 k $\Omega$  to 2.8 k $\Omega$ , to allow for variations in centering. Throttle inputs greater than 2.8 k $\Omega$  select the forward direction, with increasing resistance corresponding to faster speed. Throttle inputs less than 2.2 k $\Omega$  select the reverse direction, with decreasing resistance corresponding to faster reverse speed.

### Voltage Throttle

A 0–5V variable voltage can also be used as a throttle input to the 1208C controller, as shown in Figure 4. This 0–5V signal is in reference to B-. When using a voltage input, a 4.7 k $\Omega$  resistor must be connected between pot low and pot high (P1 Pins 4 and 6) to simulate a throttle potentiometer and prevent the pot fault circuitry from disabling the controller. Neutral is 2.5  $\pm$ 0.3 volts, maximum forward is  $\geq$ 4.5 volts, and maximum reverse is  $\leq$ 0.5 volts.

Because the throttle input voltage is referenced to B- and no throttle connections are made to the pot high and pot low inputs, throttle fault protection is lost with 0–5V throttles. The only throttle fault that will be detected by the controller is a broken wire to the pot wiper input (P1 Pin 5), which will cause a normal deceleration to zero speed. The controller will not recognize out of range throttle inputs as faults, and applying excessive voltages to the throttle wiper input may damage the controller. **It is the responsibility of the vehicle manufacturer to provide throttle fault detection for 0–5V throttles.**

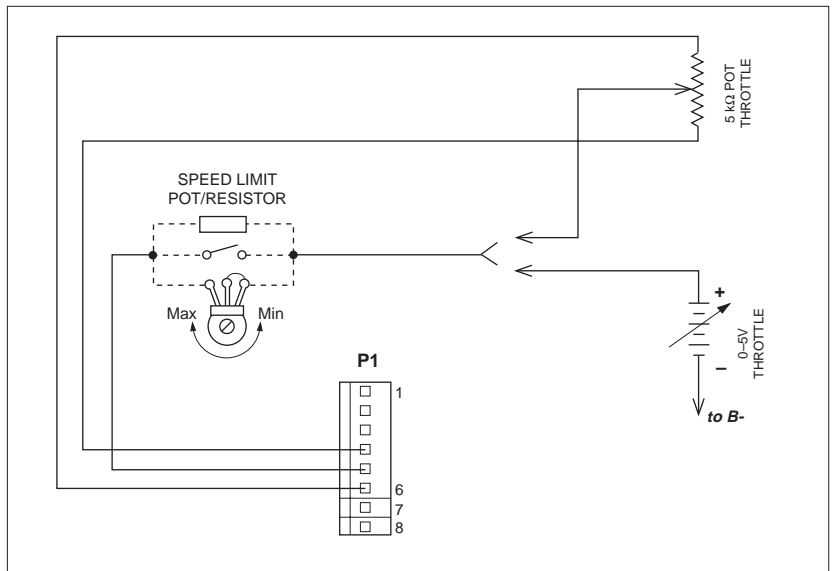
**Fig. 4** Variable voltage throttle input.



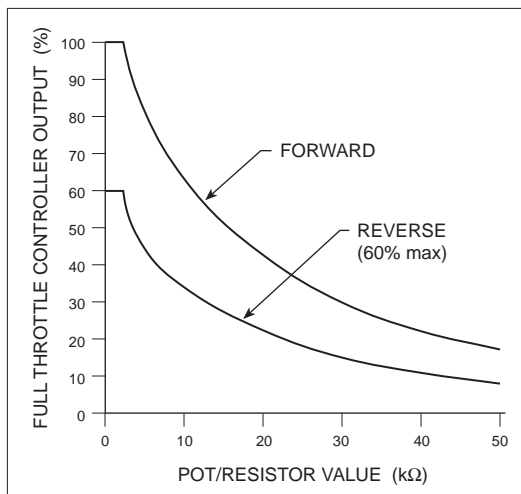
### Maximum Speed Limiting

If desired, an optional speed limit potentiometer/resistor in series with the throttle wiper wire can be used to limit maximum speed. This pot/resistor can be used with both 0–5V variable voltage throttles and 5 k $\Omega$  potentiometer throttles, and should be wired as shown in Figure 5. The full throttle output vs. the maximum speed pot/resistor value is shown on the graph in Figure 6.

**Fig. 5** Wiring for speed limit pot/resistor.



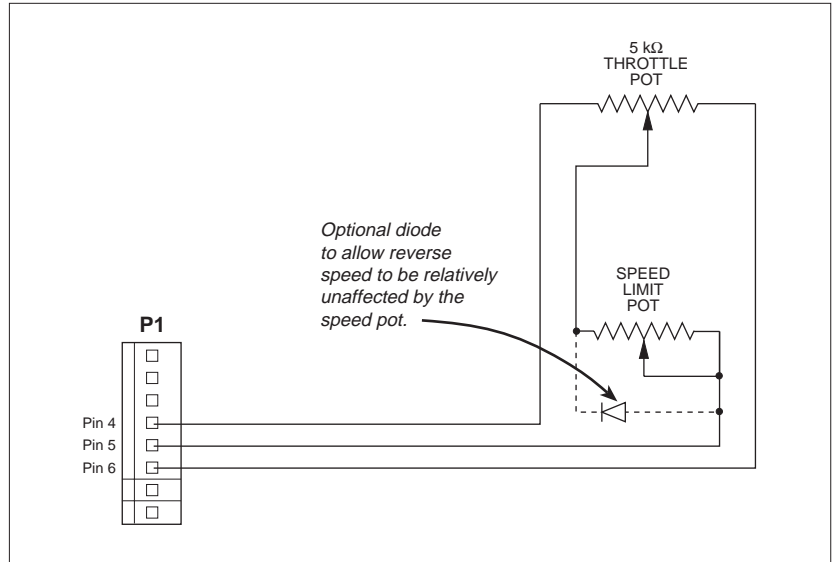
**Fig. 6** Maximum speed limiting.



A 50 k $\Omega$  potentiometer allows continuous adjustment of the output range down to 20%. The pot can be used for continuously variable maximum speed control or it can be used to experimentally “dial in” various speeds and then be replaced by a fixed value resistor once the desired vehicle maximum speed is determined.

The maximum speed pot/resistor will affect both forward and reverse speed. To allow reverse speed to be relatively unaffected when using a maximum speed pot/resistor, a diode can be placed across it as shown in Figure 7.

**Fig. 7** *Wiring to reduce effect of maximum speed potentiometer/resistor on reverse speed.*

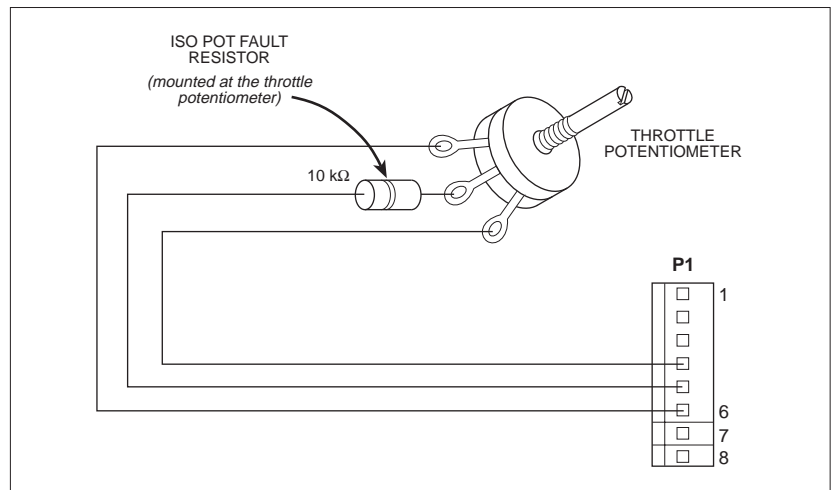


### ISO Pot Fault

The 1208C controller is available with a throttle option that meets International Standard ISO 7176 requirements for control systems. The ISO pot fault circuitry detects any combination of open or shorted throttle wires and shuts down the controller. NOTE: The standard (window) pot fault circuitry protects only against open throttle wires.

The ISO pot fault option requires an external 10 k $\Omega$  resistor, in addition to specifying the ISO pot fault option for the controller. This resistor **must** be added at the throttle control source in the wiper lead in order to meet the ISO 7176 requirements. (NOTE: Placing the resistor in the wiring harness or at the controller input **will not** meet the ISO 7176 requirements.) The proper wiring configuration for the ISO pot fault option is shown in Figure 8.

**Fig. 8** *Wiring for ISO pot fault option.*



### Keyswitch

The vehicle should have a master on/off keyswitch to turn the system off when not in use. The keyswitch provides logic power for the controller and precharges the internal capacitors when power is initially applied. The keyswitch should be sized to carry 200 mA of current continuously (controller logic and LED drive current) and a 1.2 amp inrush current for 0.5 seconds during precharge. NOTE: The circuitry is not designed for cycling times of  $\leq 0.5$  seconds.

### Electromagnetic Brake

The electromagnetic brake driver (**P1** Pins 1, 2) is rated at 2 amps and is protected against short circuits and thermal overload.

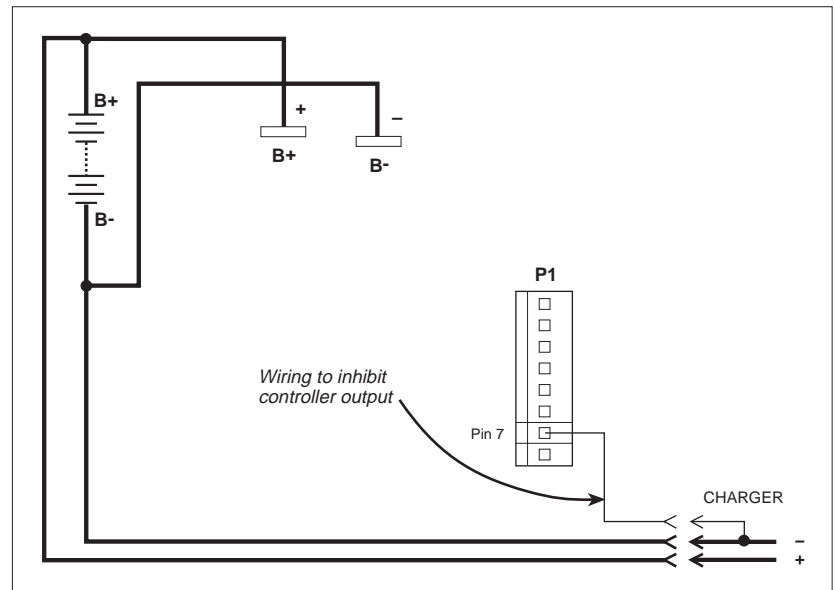
The brake driver circuitry will also detect if the brake is “missing” or not wired into the circuit, and will inhibit operation until the brake is properly wired. In order for the controller to operate if an electromagnetic brake is not used, either the missing brake fault detect feature must be disabled at the factory or an appropriate resistor ( $10\text{k}\Omega$ ,  $0.25\text{W}$  or greater) must be wired across Pins 1 and 2. An electromagnetic brake is required to meet TÜV regulations.

### Inhibit

Wiring for the inhibit feature is represented by a dashed line in the basic wiring diagram (Figure 3). For 1208C controllers with the inhibit option, the standard 6-pin connector is replaced with a 7-pin or 8-pin connector.

Pin 7 is the inhibit input. Inhibit is active (no controller output) for applied voltages less than  $\approx 9\text{ V}$  at Pin 7. Opening the inhibit input (letting the inhibit pin “float open”) or maintaining a voltage higher than  $10\text{ V}$  allows normal controller operation. Typical wiring to inhibit controller output during battery charging is shown in Figure 9.

**Fig. 9** Typical wiring to inhibit operation during battery charging.



### LED Driver

With the optional 8-pin connector, the 1208C controller can include an LED driver to provide diagnostics and fault information. The driver is rated at 15 mA and pulls down to B- via **P1** Pin 8. The LED is wired as shown in Figure 3. When the controller is powered on and no faults exist, the LED is lit steadily.

The following fault conditions will cause the LED to flash:

- pot fault
- missing brake
- welded main relay
- precharge failure
- controller output at neutral throttle
- HPD fault

### Auxiliary Power Input/Output

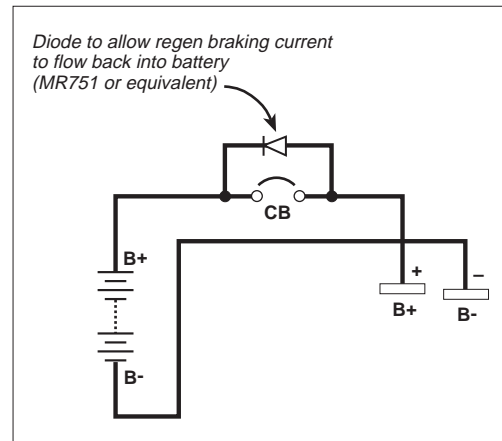
Connector **P2** is an auxiliary connection that can be used as a power source for the keyswitch input or for vehicle accessories such as lights or a horn. It can also be used as a connection point for the battery charger. The connector is rated to carry 7 amps of current continuously.

If **P2** is used, the mating connector, pins, and wire must sized to carry the desired load (up to 7 amps).

### Main Circuit Breaker or Fuse

A circuit breaker or fuse is recommended to interrupt all power from the battery to the controller, including the keyswitch (see Figure 10). If a circuit breaker or fuse is used, a power diode should be connected across it to allow regenerative braking current to flow into the battery in the event the breaker or fuse becomes

**Fig. 10** *Wiring of main circuit breaker.*



open. If this diode is not included, braking current has no place to go and may cause abnormal operation. The diode should be rated to carry at least 6 amps of continuous current and have a reverse breakdown voltage of at least 100 V. For a more detailed discussion, please refer to Curtis PMC Application Note "Safety Disconnects—Breaking the Battery Line on 1208s and 1203As" (available from Curtis).

# 3

## OEM-SPECIFIED PARAMETERS

*The following items specify various operating characteristics of the 1208C controller. These parameters should be determined by working with Curtis PMC Applications Engineers. A worksheet is included for your convenience; see page 15.*

### Acceleration/Deceleration Rate

The 1208C is available with a wide range of symmetrical and asymmetrical acceleration/deceleration rates. A symmetrical acceleration/deceleration rate has the same rate, or time, for both acceleration and deceleration. An asymmetrical rate typically has a shorter time for deceleration than for acceleration.

The acceleration and deceleration rates can be independently specified to values between 0.05 seconds and 2.5 seconds. The actual time for a particular vehicle to accelerate and decelerate is a function of the vehicle load, gearing, and vehicle dynamics. NOTE: The deceleration rate will affect vehicle stopping distance. The maximum allowed vehicle stopping distance is defined by TÜV requirements and may also be defined by local regulations.

### Brake Delay

The maximum brake delay can be specified to any value between 1 second and 3 seconds. The value chosen should be the time required for the vehicle to stop when decelerating from full forward speed to neutral on a flat surface. The standard value is 1.5 seconds. The anti-rollback and anti-roll-forward functions will automatically reduce the brake delay as appropriate (see below and Appendix A: Glossary).

### Anti-Roll-Forward / Anti-Rollback

The anti-roll-forward feature prevents a vehicle that is traveling downhill in forward or reverse from rolling downhill excessively when the throttle is released. The anti-roll-forward parameter specifies how much the brake delay is reduced as a function of applied throttle. If the throttle is returned to neutral from its maximum speed position, the brake delay will be as specified; that is, it will not be modified by the anti-roll-forward function. If the throttle is released to neutral from a less-than-maximum-speed position, the anti-roll-forward function will reduce the brake delay time accordingly.

The anti-roll-forward parameter can be specified between 1 and 3.5, with 1 applying the least modification to the brake delay and 3.5 the most aggressive. More aggressive anti-roll-forward values will result in jerkier stops but will minimize the distance the vehicle can roll before the brake is engaged.

The anti-rollback feature prevents a vehicle that is traveling uphill in forward or reverse from rolling back downhill when the throttle is released. The anti-rollback value is factory-set to optimize its performance.

### Reduced Reverse Speed (% of maximum speed)

The 1208C controller can be specified with a reduced maximum reverse speed. This is a safety feature designed to prevent full speed in reverse where vehicle control may be restricted. A 60% maximum reverse speed setting is typical and is a good compromise between performance and control in reverse.

If an external speed limit pot/resistor is used, it will also reduce vehicle speed in reverse. See Section 2, page 6, for a discussion of the effects of a speed limit pot/resistor on reverse speed.

### Inhibit

The inhibit feature is typically used to prevent controller operation (and hence vehicle operation) during battery charging.

### Overvoltage

The 1208C controller's internal circuitry self-protects during short-term overvoltage conditions. The overvoltage circuitry can be specified to either short the motor or open the motor connection (letting the vehicle coast).

If the short option is specified, the motor will be braked to a stop so that the vehicle can no longer travel while the overvoltage condition exists. Because the motor is actually shorted, the braking effect may be significant. This is the recommended option for all 1208C controllers, and is required to meet TÜV regulations.

If the coast option is specified, the motor will freewheel during overvoltage and will coast as long as the overvoltage condition exists. The “coast” option is not appropriate for manned vehicles, because the controller cannot influence the vehicle's travel while freewheeling.

**NOTE:** The overvoltage protection circuitry is designed to protect the controller during brief periods of overvoltage. These conditions may exist if the batteries become disconnected or any circuit protection devices open. Attempts to operate the vehicle for extended periods in an overvoltage condition—such as trying to drive the vehicle with the charger attached and charging—will damage the controller.



### High Pedal Disable (HPD)

High Pedal Disable (HPD) is a safety feature that prevents inadvertent vehicle operation. If the keyswitch is turned on with greater than  $\approx 15\%$  throttle applied, the controller will be inhibited until the throttle is returned to neutral. At this point, throttle can be re-applied and the vehicle will operate normally. The HPD feature operates with either potentiometer or voltage throttles. The HPD feature is required in order to meet TÜV requirements.

### Fault Detection

Circuitry that provides fault detection for welded main relay, controller output during neutral throttle, and missing brake conditions is required in order to meet TÜV requirements.

Each of these fault detect features is available as an option for the 1208C controller; see Appendix A: Glossary.

### Throttle Pot Fault

Window pot fault and TÜV-compliant ISO 7176 pot fault options are available for 1208C controllers. The ISO pot fault circuitry detects any combination of open and shorted throttle wires and shuts down the controller; window pot fault circuitry protects only against open throttle wires. Wiring for the ISO option is described in Section 2, page 8.

### EMI Immunity

Noise filtering at internal integrator nodes and power supply inputs gives the 1208C controller improved EMI immunity over its predecessor, the 1208. EMI is nevertheless strongly influenced by controller mounting, wiring, and vehicle construction, and attaining the desired level of EMI immunity may require repositioning the controller or rerouting the control wiring; see Appendix B. An external metal box or other enclosure is required for the controller to meet TÜV system susceptibility requirements. Additional application-specific improvements are possible. Contact Curtis PMC for solutions available for specific EMI problems.

### Compliance with TÜV Requirements (Summary)

*The parameters discussed in this section must be configured as follows to meet all the TÜV requirements for mobility aid vehicle traction control.*

**Deceleration Rate:** Must be set to a value that stops the vehicle within the TÜV-required distance. Stricter requirements may be established by local governing bodies.

**Overvoltage:** “Short” option.

**High Pedal Disable (HPD):** Active.

**Fault Detection:** Must include fault detection for welded main relay, controller output at neutral throttle, and missing brake.

**Throttle Pot Fault:** ISO 7176.

**EMI Immunity:** Must have at least the basic EMI filtering option. An external metal box or other enclosure is required for the controller to meet TÜV requirements for system susceptibility. Additional incoming signal filtering may also be necessary. Actual shielding requirements will be application-specific.

## 1208C CONTROLLER WORKSHEET



VEHICLE PARAMETERS				UNITS	DESCRIPTION	
Application				—	3-wheel scooter, 4-wheel scooter, sweeper, AGV, etc.	
Gross Weight				kg/lbs	Vehicle weight plus max. load.	
Drive Wheels				—	Front or rear wheel drive; number of drive wheels.	
Drive Type				—	Transaxle, chain, belt, or direct drive from motor.	
E/M Brake				amps	Electro-mechanical brake current, if used.	
MOTOR PARAMETERS				UNITS	DESCRIPTION	
Power				kW/HP	Size of motor and power rating.	
Resistance				mΩ	Armature resistance (Ra).	
Stall Current				amps	Max. locked rotor stall current.	
CONTROLLER PARAMETERS		RANGE	STD.	DESIRED	UNITS	DESCRIPTION
Current Limit	20 – 70	60			amps	Main current limit.
MOSFET Quantity	2x2, 3x3, 4x4	3x3			each	MOSFET's split for Drive and Regen functions.
Throttle Type	5kΩ or 5V	5kΩ			Ω or V	Type of wigwag throttle to be used: resistance or voltage.
Throttle Pot Fault	Std/ISO	Std			—	Standard throttle pot option <i>or</i> ISO pot fault (ISO pot fault option meets ISO 7176*)
Acceleration/Deceleration	0.05 – 2.5	accel: 1.2 decel: 0.6	accel: decel:		sec.	Time required for PWM output to go from zero to full output (acceleration) and from full output to zero (deceleration).
Maximum Reverse Speed	30 – 100	60			%	Max. speed in reverse as a percentage of forward.
Maximum Brake Delay	0 – 3	1.5			sec.	Max. brake delay. Anti-rollback will shorten this delay.
Anti-Roll-Forward	1 – 3.5	3.5			sec.	Modifies the brake delay as a function of throttle position to minimize vehicle rolling distance before the E/M brake is engaged. Higher values will reduce the brake delay time more aggressively.
Anti-Rollback	Yes/No	Yes			—	Engages brake when vehicle moves in opposite direction.
Inhibit	Yes/No	No			—	Inhibits controller when Pin 7 input is less than 9 volts.
High Pedal Disable (HPD)	Yes/No	Yes			—	Inhibits controller if throttle is applied before KSI.
Output Fault Detect at Neutral Throttle	Yes/No	Yes			—	Prevents errant PWM output from being transferred to the motor in the event of a failure.
Welded Main Relay Fault Detect	Yes/No	No			—	Inhibits controller if fault is detected.
Missing Brake Fault Detect	Yes/No	No			—	Inhibits controller if fault is detected.
External LED Driver	Yes/No	No			—	Causes LED to flash in response to specified faults.
Oversvoltage Option	coast/short	short			—	Opens or shorts motor during oversvoltage.

\*ISO Pot Fault requires an external 10kΩ resistor in series with the pot wiper.

Signature: \_\_\_\_\_ Date: \_\_\_\_\_

# 4

## SAFETY CONSIDERATIONS

*The following safety considerations are important when installing and using the 1208C controller in mobility aid scooters.*

### Controller Location

The controller must be installed so that under normal use the operator will not come into contact with it.

### Power Switch

The main power switch should be mounted in a location readily accessible to the operator under all conditions.

### Diagnostic LED

The external diagnostic LED must be connected. It should be a color other than red, and it should be mounted in a location readily visible to the operator under all conditions.

### Acceleration and Deceleration Settings

The deceleration rates should be specified so that with the heaviest specified operator the following maximum braking distances are not exceeded on a flat, level surface:

<i>Speed (km/hr)</i>	4	5	6	7	8	9	10	11	12	13	14	15
<i>Braking distance (m)</i>	0.6	0.8	1.0	1.2	1.5	1.7	2.0	2.2	2.5	2.8	3.2	3.5

The acceleration rates should be specified so that with the lightest specified operator, the acceleration on a flat, level surface does not exceed  $4 \text{ m/sec}^2$ . The maximum speed should be specified so as not to exceed 15 km/hr.

### Circuit Protection

An appropriately sized fuse or circuit breaker must be provided in series with the battery. The time-current characteristic of the protective device should be chosen to ensure that it will not open when passing the rated current of the controller for 1.5 minutes, and that it will open when continuously subjected to 1.5 times the rated current.

### Unpowered Condition

This family of controllers uses a half-bridge FET power stage to drive the motor, which means there are direction relays to short the motor when the controller is unpowered. The controller is designed to operate a normally engaged electromagnetic brake. The brake should be sized so that with the heaviest specified operator the scooter will stop on the maximum specified slope without assistance from a shorted motor. In applications without an electromagnetic brake, it is solely the responsibility of the vehicle manufacturer to provide other means to ensure that the unpowered state is safe.

### Environmental Protection

The installation should provide environmental protection to at least class IP-54 of IEC 519.

### Radiated Immunity

When tested in a 1.3 mm aluminum case measuring 127 mm × 178 mm × 51 mm and with a 25 mm OD, 13 mm ID, 28 mm long cylindrical ferrite core (Fair-Rite type 43 material) around the control cable, the controller meets the EMC requirements of ISO 7176. The installation should provide an equivalent or greater degree of electromagnetic shielding.

### User Documentation

The documentation provided to the user of the scooter must include the following information:

- If, except on a down-slope, motion continues for more than 6 seconds after the throttle has been returned to neutral, or if the scooter moves from a standstill without the throttle being applied, the main power switch must be turned off. The scooter must not be used again until it has been repaired.
- Every time the scooter is turned on, and before operating the throttle, the operator should observe the external diagnostic LED for at least 5 seconds to ensure that it is steadily illuminated. If it is not, the scooter must not be used again until it has been repaired.
- The high pedal disable (HPD) feature is designed to prevent activation of the scooter motor if the keyswitch is turned On with more than ≈15% throttle applied. The following 4-step test must

be performed at least once a day to determine whether the HPD feature is functioning properly. Before starting the test, jack the scooter up to get the drive wheels off the ground; this is important because if the HPD feature is not functioning, the scooter may suddenly lurch forwards or backwards.

#### **Daily HPD Test Procedure**

Step 1. Apply more than 50% throttle in the Forward direction, and then turn the keyswitch On. The motor should not engage.

Release the throttle back to neutral.

Turn the keyswitch Off.

Step 2. Apply more than 50% throttle in the Reverse direction, and then turn the keyswitch On. The motor should not engage.

Release the throttle back to neutral.

Leave the keyswitch On.

Step 3. Apply more than 50% throttle in the Forward direction. The motor should engage and the drive wheels should be rotating.

Release the throttle back to neutral.

Step 4. Apply more than 50% throttle in the Reverse direction. The motor should engage and the drive wheels should be rotating.

Turn the keyswitch Off.

If the drive wheels are rotating in Step 1 or 2, or if they are not rotating in Step 3 or 4, the scooter must not be used again until it has been repaired.

# APPENDIX A

## GLOSSARY OF FEATURES AND FUNCTIONS

### **Acceleration rate**

The acceleration rate defines the time required for the controller to increase from 0 to 100% output. A larger value represents a longer acceleration time and a gentler start. The acceleration rate can be specified by the OEM—*see Section 3, page 11.*

### **Anti-rollback**

The anti-rollback feature prevents a vehicle that is traveling uphill in forward or reverse from rolling back downhill when the throttle is released. It overrides the brake delay and engages the electromagnetic brake as soon as the vehicle begins to roll back down the incline.

### **Anti-roll-forward**

The anti-roll-forward feature prevents a vehicle that is traveling downhill in forward or reverse from rolling downhill excessively when the throttle is released. It modifies the brake delay time proportional to the estimated speed at the time the neutral throttle request is detected. This reduces “coasting” downhill when the throttle is released during low speed operation.

The value of the anti-roll-forward parameter can be specified by the OEM—*see Section 3, page 11.*

### **Brake delay time**

The brake delay time defines when the controller engages the electromagnetic brake after the throttle is returned to neutral. This time delay, specified for a throttle change from 100% to 0% output, is set to be long enough to allow full deceleration without jerking the vehicle to a stop yet short enough so that the brake is engaged immediately after the vehicle comes to a stop. The brake delay time can be specified by the OEM—*see Section 3, page 11.*

The anti-rollback and anti-roll-forward features override the brake delay to prevent excessive travel on inclines when the throttle is released to neutral.

### **Controller output fault detect at neutral throttle**

The controller output fault detect at neutral throttle prevents errant PWM output from being transferred to the traction motor in the event of a failure. If, for any

reason, the controller's power section provides output to the motor when the throttle is in neutral, the controller automatically drops both direction relays—thus shorting the motor and braking the vehicle to a stop. This fault detect feature is required by TÜV regulations, and is standard on all 1208C controllers. However, the controller can be specified without this feature for applications where it is not desired.

### **Current limiting**

Curtis PMC controllers limit the motor current to a preset maximum. This feature protects the controller and motor from damage that might result if the current were limited only by motor demand. PWM output to the power section is reduced until the motor current falls below the set limit level.

In addition to protecting the controller, the current limit feature also protects the rest of the system. By eliminating high current surges during vehicle acceleration, stress on the motor and batteries is reduced and their efficiency enhanced. Similarly, there is less wear and tear on the vehicle drivetrain.

### **Current multiplication**

During acceleration and during reduced speed operation, the Curtis PMC controller allows more current to flow into the motor than flows out of the battery. The controller acts like a dc transformer, taking in low current and high voltage (the full battery voltage) and putting out high current and low voltage. The battery needs to supply only a fraction of the current that would be required if a resistive controller were used. The current multiplication feature gives vehicles using Curtis PMC controllers dramatically greater driving range per battery charge.

### **Deceleration rate**

The deceleration rate defines the time required for the controller to decrease from 100% output to zero. A larger value represents a longer deceleration time and a gentler stop. The deceleration rate affects the vehicle stopping distance. The maximum allowed vehicle stopping distance may be defined by local regulations.

The deceleration rate can be specified by the OEM—see *Section 3, page 11*.

**Fault detect options** (*see Controller output fault detect at neutral throttle, Missing brake fault detect, Throttle pot fault protection, and Welded main relay fault detect*)



### **High-pedal-disable (HPD)**

The HPD feature prevents controller output if the controller is turned on when the throttle is not in neutral. If the operator attempts to start the vehicle when the throttle is already applied, the controller output will remain off. For the vehicle to start, the controller must receive an input to KSI before receiving a throttle input. In addition to providing routine smooth starts, HPD also protects against accidental sudden starts if problems in the throttle linkage (e.g., bent parts, broken return spring) give a throttle input signal to the controller even with the throttle released.

The HPD feature is optional for 1208C controllers, but is required by TÜV regulations—*see Section 3, page 13.*

### **Inhibit**

The inhibit input is used to put the vehicle in a safe, non-drivable state during battery charging or under other conditions where this precaution is desired—*see Section 2, page 9.*

The inhibit feature is optional for 1208C controllers—*see Section 3, page 12.*

### **ISO pot fault** (*see Throttle pot fault protection*)

### **KSI**

KSI (Key Switch Input) provides power to the controller's logic board, and initializes and starts diagnostics. The keyswitch functions as a master switch for the vehicle, to turn the system off when not in use.

### **LED**

The 1208C controller, when specified with an 8-pin low power connector, can provide a low-side driver for a Light Emitting Diode (LED). The driver will provide up to 15 mA of current through the LED. An appropriately rated LED should be selected to provide the desired illumination at that current. The LED indicates whether the controller is powered on, and also provides system fault information—*see Section 2, page 10.*

### **Missing brake fault detect**

The missing brake fault detect inhibits controller output if it does not sense an electromagnetic brake connected at **P1** Pin 1. This fault detect feature prevents

operation under conditions which would allow the vehicle to roll uncontrolled because of a nonfunctional electromagnetic brake or faulty brake wiring. The missing brake fault detect feature continues to inhibit the controller's output until the brake or its wiring is repaired.

The missing brake fault detect feature is optional, but is required by TÜV regulations.

## **MOSFET**

A MOSFET (metal oxide semiconductor field effect transistor) is a type of transistor characterized by its fast switching speeds and very low losses.

## **OEM (= Original Equipment Manufacturer)**

**Overtemperature** (*see Temperature effects*)

## **Overvoltage protection**

The overvoltage protection feature shuts down the regenerative current path to the controller if the voltage exceeds the factory-set limit. Controller operation resumes when the voltage is brought within the acceptable range. The cutoff voltage and re-enable voltage are percentages of the battery voltage, and are set at the factory. The controller can be configured to short the motor (required by TÜV regulations) or to let it coast in the event of overvoltage—*see Section 3, page 12*.

The overvoltage threshold is set at 42 volts for 24V controllers and 50 volts for 36V controllers.

## **PWM**

Pulse width modulation (PWM), also called “chopping,” is a technique that switches battery voltage to the motor on and off very quickly, thereby controlling the speed of the motor. Curtis PMC 1200 series controllers use high frequency PWM—15 kHz—which permits silent, efficient operation.

## **Regenerative braking**

The 1208C controller uses regenerative braking to slow the vehicle to a stop and to reduce speed when traveling downhill. Regenerative braking means that the energy used to slow the vehicle is channeled back into the batteries, resulting in longer vehicle range between charges.

### **Smooth, stepless operation**

Like all Curtis PMC 1200 Series controllers, the 1208C allows superior operator control of the vehicle's drive motor speed. The amount of current delivered to the motor is set by varying the "on" time (duty cycle) of the controller's power MOSFET transistors. This technique—pulse width modulation (PWM)—permits silent, stepless operation.

### **Temperature effects**

The 1208C controller does not employ active temperature compensation or protection circuitry. Therefore, variations in ambient and operating temperatures will affect controller performance.

Increasing MOSFET temperatures increase the MOSFET on-resistance. As the on-resistance increases, less current is required to create an equivalent voltage drop across the MOSFETs. Curtis PMC controllers use this MOSFET voltage drop to determine the current flowing in the controller's power section. Consequently, as the MOSFETs heat up, the maximum current allowed to flow in the motor (i.e., the current limit value) decreases due to the increased on-resistance. Therefore, the 30-second current limit rating will vary as a function of temperature and the actual measured value may be more or less than the specified limit. Good heatsinking and maximized airflow to remove heat from the controller and heatsink will minimize this effect.

The reduction in current limit as a function of increasing MOSFET temperature provides an inherent level of overtemperature protection. Because the current allowed to flow in the controller decreases as the MOSFET temperature increases, the chance of thermal runaway within the MOSFET is reduced.

### **Throttle pot fault protection**

There are two types of throttle pot fault protection: window and ISO. The 1208C controller can be specified to provide either type.

#### Window pot fault protection

Window pot fault protection shuts down the controller output in the event of an open circuit condition in the throttle pot or the throttle wiring. Window pot fault is engaged when the resistance between the pot high and pot low inputs (P1 Pins 4, 6) is outside the acceptable range (4.5 k $\Omega$  to 7.5 k $\Omega$ ). If the wiper input to Pin 5 breaks or is disconnected, the controller output will be shut down and the vehicle will decelerate to zero speed.

### ISO pot fault protection

ISO pot fault protection meets all the requirements of the ISO 7176 specification. In addition to the protection provided by the window pot fault, the ISO pot fault inhibits controller output for any combination of shorted pot wires including shorts to B+ or B-. An additional 10k $\Omega$  resistor is required in the throttle wiper wiring to complete the ISO fault detect requirements. This resistor must be wired close to the actual throttle pot wiper pin to be effective (see Figure 7, page 7).

### **Undervoltage protection**

The control circuitry requires a minimum battery voltage to function properly. The controller is therefore designed so its output is gradually reduced if the battery voltage falls below a certain level. Cutback voltages for the various models are listed in the specifications (Appendix C). Reducing the output to the motor allows the battery voltage to recover, and an equilibrium is established in which the battery supplies as much current as it can without falling below the cutback voltage.

### **Welded main relay fault detect**

If the welded main relay fault detect is specified, the controller checks for a welded main relay at startup. If a fault is detected, the controller forces the throttle input to neutral to inhibit controller output. The welded main relay fault detect feature is optional, but is required by TÜV regulations.

## APPENDIX B

### ELECTROMAGNETIC COMPATIBILITY (EMC)

Electromagnetic compatibility (EMC) encompasses two areas: emissions and immunity. *Emissions* are radio frequency (rf) energy generated by a product. This energy has the potential to interfere with communications systems such as radio, television, cellular phones, dispatching, aircraft, etc. *Immunity* is the ability of a product to operate normally in the presence of rf energy.

EMC is ultimately a system design issue. Part of the EMC performance is designed into or inherent in each component; another part is designed into or inherent in end product characteristics such as shielding, wiring, and layout; and, finally, a portion is a function of the interactions between all these parts. The design techniques presented below can enhance EMC performance in products that use Curtis PMC motor controllers.

#### *Decreasing Emissions*

Motor brush arcing can be a significant source of rf emissions. These emissions may be reduced by installing bypass capacitors across the motor wires and/or between each motor wire and the motor frame. If the latter approach is used, the voltage rating and leakage characteristics of the capacitors must be adequate to meet any safety regulations regarding electrical connections between a battery operated circuit and the chassis. The bypass capacitor should be installed as close to the motor as possible, or even inside it, to provide the best performance. Alternatively a ferrite bead can be installed on the wires, as close as possible to the motor. In some instances, capacitors and ferrite beads may both be appropriate. Another option is to choose a motor with a brush material that will result in less arcing to the commutator. Brushes that have been run in for approximately 100 hours will typically generate lower emissions than new brushes because there is less arcing after they are properly seated.

The motor drive output from Curtis PMC controllers can also make a contribution to rf emissions. This output is a pulse width modulated square wave with rather fast rise and fall times that are rich in harmonics. The impact of these switching waveforms can be minimized by making the wires from the controller to the motor as short as possible. Ferrite beads installed on the drive wires can further reduce these emissions. For applications requiring very low emissions, the solution may involve enclosing the controller, interconnect wires, and motor together in one shielded box. The motor drive harmonics can couple to battery supply leads and throttle circuit wires, so ferrite beads may also be required on these other wires in some applications.

### *Increasing Immunity*

Immunity to radiated electric fields can be achieved either by reducing the overall circuit sensitivity or by keeping the undesired signals away from this circuitry. The controller circuitry itself cannot be made less sensitive, since it must accurately detect and process low level signals from the throttle potentiometer. Thus immunity is generally achieved by preventing the external rf energy from coupling into sensitive circuitry. This rf energy can get into the controller circuitry via conducted paths and via radiated paths.

Conducted paths are created by the wires connected to the controller. These wires act as antennas and the amount of rf energy coupled into these wires is generally proportional to their length. The rf voltages and currents induced in each wire are applied to the controller pin to which the wire is connected. Curtis PMC motor controllers include bypass capacitors on the printed circuit board's throttle wires to reduce the impact of this rf energy on the internal circuitry. In some applications, ferrite beads may also be required on the various wires to achieve desired performance levels.

Radiated paths are created when the controller circuitry is immersed in an external field. This coupling can be reduced by enclosing the controller in a metal box. Some Curtis PMC motor controllers are enclosed by a heat sink that also provides shielding around the controller circuitry, while others are unshielded. In some applications, the designer will need to mount the controller within a shielded box on the end product. The box may be constructed of just about any metal, although steel and aluminum are most commonly used.

Most coated plastics do not provide good shielding because the coatings are not true metals, but rather a mixture of small metal particles in a non-conductive binder. These relatively isolated particles may appear to be good based on a dc resistance measurement but do not provide adequate electron mobility to yield good shielding effectiveness. Electroless plating of plastic will yield a true metal and can thus be effective as an rf shield, but it is usually more expensive than the coatings.

A contiguous metal enclosure without any holes or seams, known as a Faraday cage, provides the best shielding for the given material and frequency. When a hole or holes are added, rf currents flowing on the outside surface of the shield must take a longer path to get around the hole than if the surface was contiguous. As more "bending" is required of these currents, more energy is coupled to the inside surface, and thus the shielding effectiveness is reduced. The reduction in shielding is a function of the longest linear dimension of a hole rather than the area. This concept is often applied where ventilation is necessary, in which case many small holes are preferable to a few larger ones.

Applying this same concept to seams or joints between adjacent pieces or segments of a shielded enclosure, it is important to minimize the open length of these seams. Seam length is the distance between points where good ohmic

contact is made. This contact can be provided by solder, welds, or pressure contact. If pressure contact is used, attention must be paid to the corrosion characteristics of the shield material and any corrosion-resistant processes applied to the base material. If the ohmic contact itself is not continuous, the shielding effectiveness can be maximized by making the joints between adjacent pieces overlapping rather than abutted.

The shielding effectiveness of an enclosure is further reduced when a wire passes through a hole in the enclosure. RF energy on the wire from an external field is re-radiated into the interior of the enclosure. This coupling mechanism can be reduced by filtering the wire at the point where it passes through the boundary of the shield. Given the safety considerations involved with connecting electrical components to the chassis or frame in battery powered vehicles, such filtering will usually consist of a series inductor (or ferrite bead) rather than a shunt capacitor. If a capacitor is used, it must have a voltage rating and leakage characteristics that will allow the end product to meet applicable safety regulations.

The B+ (and B-, if applicable) wires that supply power to the throttle control panel—such as for the keyswitch—should be bundled with the remaining throttle wires so that all these wires are routed together. If the wires to the control panel are routed separately, a larger loop area is formed. Larger loop areas produce more efficient antennas which will result in decreased immunity performance.

Electrostatic discharge (ESD) immunity is achieved either by providing sufficient distance between conductors and the outside world so that a discharge will not occur, or by providing an intentional path for the discharge current such that the circuit is isolated from the electric and magnetic fields produced by the discharge. In general the guidelines presented above for increasing the radiated immunity will also provide increased ESD immunity.

It is usually easier to prevent the discharge from occurring than to divert the current path. A fundamental technique for ESD prevention is to provide adequately thick insulation between all metal conductors and the outside environment so that the voltage gradient does not exceed the threshold required for a discharge to occur. If the current diversion approach is used, all exposed metal components must be grounded. The shielded enclosure, if properly grounded, can be used to divert the discharge current; it should be noted that the location of holes and seams can have a significant impact on the ESD suppression. If the enclosure is not grounded, the path of the discharge current becomes more complex and less predictable, especially if holes and seams are involved. Some experimentation may be required to optimize the selection and placement of holes, wires, and grounding paths. Careful attention must be paid to the control panel design so that it can tolerate a static discharge.

## APPENDIX C

### SIGNAL AND AUXILIARY CONNECTOR SUPPLIERS

#### SIGNAL CONNECTOR: P1

*(mating connectors are all available for 22–30 AWG wire)*

MANUFACTURER	PART NUMBER	NOTES
Molex	22-01-3067	6-pin, locking, polarized, crimp terminals
AMP	643813-6	6-pin, locking, polarized, insulation displacement
Methode	1300-106-422	6-pin, locking, polarized, insulation displacement
Molex	22-01-3077	7-pin, locking, polarized, crimp terminals
AMP	643813-7	7-pin, locking, polarized, insulation displacement
Methode	1300-107-422	7-pin, locking, polarized, insulation displacement
Molex	22-01-3087	8-pin, locking, polarized, crimp terminals
AMP	643813-8	8-pin, locking, polarized, insulation displacement
Methode	1300-108-422	8-pin, locking, polarized, insulation displacement

Standard 1208C PC board header is Molex 22-03-2061.

#### AUXILIARY POWER CONNECTOR: P2

*(mating connectors are all available for 18–26 AWG wire;  
not all connectors will provide full 7 amp capability)*

MANUFACTURER	PART NUMBER	NOTES
Molex	09-50-3021	Locking, crimp terminals
Methode	3300-102-218	Locking, insulation displacement
AMP	640426-2	Locking, insulation displacement, right angle
Panduit	CE156F18-2	Locking, insulation displacement, right angle

Standard 1208C PC board header is AMP 640445-2 or Methode 3100-8-102-02.



## APPENDIX D

### SPECIFICATIONS

Nominal input voltage	24 V and 36 V
Maximum operating voltage	125% of nominal voltage
Minimum operating voltage	16.5 V at 24 V; 27.5 V at 36 V
Nominal current limit	45–70 amps at 24 V; 25–45 amps at 36 V
Time/current rating	may be held at full current for 30 seconds (continuous current rating depends on mounting; 25 amps typical)
Nominal frequency of operation	15 kHz
Speed control signal	5k $\Omega$ , 3-wire pot; or 0–5V throttle
Neutral	2.5 k $\Omega$ $\pm$ 300 $\Omega$ ; or 2.5 V $\pm$ 0.3 V
Maximum forward	$\geq$ 4.8 k $\Omega$ ; or $\geq$ 4.5 V
Maximum reverse	$\leq$ 200 $\Omega$ ; or $\leq$ 0.5 V
Weight	0.23 kg (0.5 lb)
Dimensions	104 $\times$ 126 $\times$ 32 mm (4.10" $\times$ 4.95" $\times$ 1.25")

MODEL NUMBER	NOMINAL BATTERY VOLTAGE (volts)	FET COMP	* CURRENT LIMIT 30 SEC RATING (amps)	MAX. ALLOW BRAKING CURRENT (amps)	MIN. ALLOW MOTOR RESISTANCE (m $\Omega$ )	TYPICAL VOLTAGE DROP @20 A (volts)	UNDER VOLTAGE CUTBACK (volts)
22XX	24	2/2	45	40	400	0.35	16.5
23XX	24	3/3	60	50	250	0.30	16.5
24XX	24	4/4	70	50	200	0.25	16.5
32XX	36	2/2	25	25	800	0.35	27.5
33XX	36	3/3	45	35	500	0.30	27.5
34XX	36	4/4	45	35	400	0.25	27.5

\* Actual value of 30-second rating depends on MOSFET heating (see "Temperature effects" in Appendix A: Glossary).