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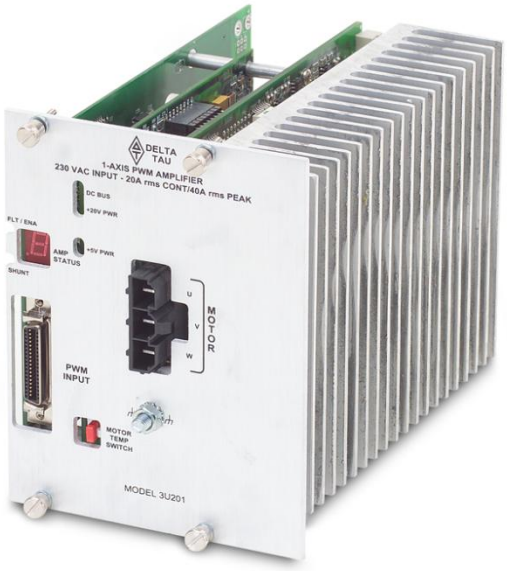
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USER MANUAL

Geo 3U Direct PWM Drives Family
3U081, 3U151 and 3U201



Geo 3U Direct PWM Drives Family

5xx-603555-xUxx

July 17, 2015

DELTA TAU
Data Systems, Inc.
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Operating Conditions

All Delta Tau Data Systems, Inc. motion controller products, accessories, and amplifiers contain static sensitive components that can be damaged by incorrect handling. When installing or handling Delta Tau Data Systems, Inc. products, avoid contact with highly insulated materials. Only qualified personnel should be allowed to handle this equipment.

In the case of industrial applications, we expect our products to be protected from hazardous or conductive materials and/or environments that could cause harm to the controller by damaging components or causing electrical shorts. When our products are used in an industrial environment, install them into an industrial electrical cabinet or industrial PC to protect them from excessive or corrosive moisture, abnormal ambient temperatures, and conductive materials. If Delta Tau Data Systems, Inc. products are directly exposed to hazardous or conductive materials and/or environments, we cannot guarantee their operation.

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IEC 364 resp. CENELEC HD 384 or DIN VDE 0100
IEC report 664 or DIN VDE 0110
National regulations for safety and accident prevention or VBG 4

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This product contains components that are sensitive to static electricity and can be damaged by incorrect handling. Avoid contact with high insulating materials (artificial fabrics, plastic film, etc.). Place the product on a conductive surface. Discharge any possible static electricity build-up by touching an unpainted, metal, grounded surface before touching the equipment.

Keep all covers and cabinet doors shut during operation. Be aware that during operation, the product has electrically charged components and hot surfaces. Control and power cables can carry a high voltage, even when the motor is not rotating. Never disconnect or connect the product while the power source is energized to avoid electric arcing.

After removing the power source from the equipment, wait at least 10 minutes before touching or disconnecting sections of the equipment that normally carry electrical charges (e.g., capacitors, contacts, screw connections). To be safe, measure the electrical contact points with a meter before touching the equipment.

The following text formats are used in this manual to indicate a potential for personal injury or equipment damage. Read the safety notices in this manual before attempting installation, operation, or maintenance to avoid serious bodily injury, damage to the equipment, or operational difficulty.



WARNING

A Warning identifies hazards that could result in personal injury or death. It precedes the discussion of interest.



Caution

A Caution identifies hazards that could result in equipment damage. It precedes the discussion of interest.



Note

A Note identifies information critical to the user's understanding or use of the equipment. It follows the discussion of interest.

REVISION HISTORY				
REV.	**DESCRIPTION**	**DATE**	**CHG**	**APPVD**
1	Updated for Power PMAC Deleted Bus Voltage feature in strobe word section (it does not work)	7/17/15	DCDP	SGM

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INTRODUCTION

This document provides technical data and support for all the 3U Geo Direct PWM drives: 3U081, 3U151 and 3U201 models brushless drive amplifier modules designed and manufactured by Delta Tau Data Systems, Inc.

These drive systems are designed to fit into a standard 3U (UMAC) rack. They are power amplifiers designed to drive AC Induction, permanent magnet brushless DC, linear and DC Brushed type motors from PWM (pulse width modulated) command signals. The 3U Geo Direct PWM drives will operate directly off the power mains wired to the backplane, typically 110 VAC or 230 VAC, three phase or single phase with appropriate derating. An external power supply of +24 VDC @ 1 A (regulated or unregulated) is required for logic power allowing the user to control motor power separately from control logic power. The amplifiers are interfaced to a PMAC controller via ACC-24E2, ACC-24E2M, ACC-8F or ACC-8FS.

These drive amplifiers are designed to receive logic-level direct digital PWM motor voltage command from the PMAC controller and convert them to high voltage for motor control. They provide the power conversion, motor current sense feedback to the PMAC controller, and comprehensive system protection. Each drive also accepts motor thermal overload sensors for drive shut down on motor overtemperature. The host controller provides all other motor control functions.

Product Features

- Simple wiring
- High power density
- Extensive fault protection
- Locking motor connectors
- Closed loop hall effect current sensors
- Direct line connection with Soft Start
- Separate logic and motor power control
- 3U format for small size and easy support
- Full isolation for PMAC and user interfaces
- Direct PWM control for best performance and cost
- Shunt Regulator (requires external Resistor) for Bus power control
- Auto ranging Shunt Regulator automatically selects for 115 or 230V operation

The 3U Geo Direct PWM drives consist of three basic components: the 3U format Drive Module, the backplane that gives access for the power supply, and the associated metal work with a fan for keeping the drive cool. Both the drive modules and backplane may be purchased separately as spares. This family of products is further supported with the availability of cable or connector kits and compatible shunt regulator resistor (regen resistor GARxx).

The amplifier has many protection features to ensure the proper operation and protection of all of the components connected to the unit. When the amplifier detects a fault, the unit will display a character indicating the type of fault. Even though backup protection is provided, the PMAC controller should have the I^2T protection variables set up to protect the amplifier from over current over time.

The following is a list of the faults detected by the logic of the amplifier:

- Instantaneous overcurrent
- Integrated current over time (I^2T)
- Motor over temperature (input from motor)
- Under voltage
- IGBT thermal failure
- PWM fault
- Over voltage
- Ground fault
- Minimum dead time protection
- Shoot through protection

The 3U Geo Direct PWM amplifiers are designed to work with a PMAC host controller. The PMAC interface through an ACC-24E2, ACC-24E2M, ACC-8F or ACC-8FS requires that the PMAC contain a PMAC GATE2-1D revision controller chip to read the motor current sensor signals accurately, or through a Gate3 IC when using ACC-24E3 with Power PMAC.



Note

The 3U drive products are available in kit-form. The electronics on these products are subject to damage by static electricity. Handle them as little as possible. Use ground wrist straps when handling. Do not allow static-charge holding materials (paper, plastic, etc.) to come in near proximity of the product.

SPECIFICATIONS

Environmental Specifications

Description	Unit	Specifications
Operating Temperature	°C	+0 to 45°C. Above 45°C, derate the continuous peak output current by 2.5% per °C above 45°C. Maximum Ambient is 55°C
Rated Storage Temperature	°C	-25 to +70
Humidity	%	10% to 90% non-condensing
Shock		Call Factory
Vibration		Call Factory
Operating Altitude	Feet (Meters)	Up to 3300 feet (~1000 meters). Derate the continuous and peak output current by 1.1% for each 330 feet (~100 meters) above the 3300 feet
Air Flow Clearances	in (mm)	3" (76.2mm) above and below unit for air flow

Electrical Specifications

	3U081	**3U151**	**3U201**
Output Circuits (axes)	1		
Nominal Input Voltage (VAC)	230		
Rated Input Voltage (VAC)	97-265		
Rated Continuous Input Current (A AC_{RMS})	5.28	9.9	13.2
Rated Input Power (Watts)	2103	3944	5259
Frequency (Hz)	50/60		
Phase Requirements	1Φ or 3Φ	3Φ	
Charge Peak Inrush Current (A)			
Main Bus Capacitance (µf), backplane board	1410		
Rated Output Voltage (V)	138		
Rated Cont. Output Current per Axis	8	15	20
Peak Output Current (A) for 2 seconds	16	30	40
Rated Output Power per Axis (Watts)	1912	3585	4780
Nominal DC Bus	325		
Over-voltage Trip Level (VDC)	410		
Under-voltage Lockout Level (VDC)	10		
Turn-On Voltage (VDC)	392		
Turn-Off Voltage (VDC)	372		
Maximum Current (A)			
Recommended Current (A)			
Minimum Resistance (Ohms)			
Maximum Power (W)			
Recommended Load Resistor (300 W Max.)	GAR78	GAR48	GAR48-3
Input Voltage (VDC)	20-27		
Input Current (A)	1		
Inrush Current (A)	2		
Resolution (bits)	12		
Full-scale Signed Reading (±A)	26.02	32.53	65.05
Maximum PWM Frequency (kHz) @ rated current	10	10	8
Minimum Dead Time (µs)	1		
Charge Pump Time (% of PWM period.)	5		

Recommended Fusing and Wire Gauge

Model	Recommended Fuse (FRN/LPN)	Recommended Wire Gauge*
3U081	20	12 AWG
3U151	20	10 AWG
3U201	25	10 AWG
* See local and national code requirements		

Wire Sizes

3U Geo Direct PWM Drive electronics create a DC bus by rectifying the incoming AC electricity. The current flow into the drive is not sinusoidal but rather a series of narrow, high-peak pulses. Keep the incoming impedance small so that these current pulses are not hindered. Conductor size, transformer size, and fuse size recommendations may seem larger than normally expected. All ground conductors should be 8 AWG minimum using wires constructed of many strands of small gauge wire. This provides the lowest impedance to high-frequency noises.

Physical Specifications

	3U081	3U151	3U201
Width (3U rack slots)	4 Slots	5 Slots	5 Slots
Weight: drive only with front panel (w/o backplane and side panels)	1.1 kg (2.3lbs)	1.3 kg (2.9 lbs)	1.3 kg (2.9 lbs)
Backplane	3UBP15A		
Backplane Width (3U rack slots)	4		
Backplane Weight	0.318 kg (0.7 lbs)		
Terminal Connections	Torque to 20 in-lb		

RECEIVING AND UNPACKING

Delta Tau products are thoroughly tested at the factory and carefully packaged for shipment. When the 3U Geo Direct PWM Drive is received, there are several things to be done immediately:

1. Observe the condition of the shipping container and report any damage immediately to the commercial carrier that delivered the drive.
2. Remove the device from the shipping container and remove all packing materials. Check all shipping material for connector kits, documentation, CD ROM, or other small pieces of equipment. Be aware that some connector kits and other equipment pieces may be quite small and can be accidentally discarded if care is not used when unpacking the equipment. You may retain the container and packing materials for future shipment.
3. Verify that the part number of the drive received is the same as the part number listed on the purchase order.
4. Inspect the drive for external physical damage that may have been sustained during shipment and report any damage immediately to the commercial carrier that delivered the drive.
5. Electronic components in this amplifier are design-hardened to reduce static sensitivity. However, use proper procedures when handling the equipment.
6. If the 3U Geo Direct PWM Drive is to be stored for several weeks before use, be sure that it is stored in a location that conforms to published storage humidity and temperature specifications stated in this manual.

Use of Equipment

The following restrictions will ensure the proper use of the 3U Geo Direct PWM Drive:

- The components built into electrical equipment or machines can be used only as integral components of such equipment.
- The 3U Geo Direct PWM Drives are to be used only on grounded three-phase industrial mains supply networks (TN-system, TT-system with grounded neutral point).
- The 3U Geo Direct PWM Drives must not be operated on power supply networks without a ground or with an asymmetrical ground.
- If the 3U Geo Direct PWM Drives are used in residential areas, or in business or commercial premises, implement additional filter measures.
- The 3U Geo Direct PWM Drives may be operated only in a closed switchgear cabinet, taking into account the ambient conditions defined in the environmental specifications.

Delta Tau guarantees the conformance of the 3U Geo Direct PWM Drives with the standards for industrial areas stated in this manual, only if Delta Tau components (cables, controllers, etc.) are used.

MOUNTING AND LAYOUT

The 3U Geo Direct PWM drives are designed to be installed in an enclosure whose ambient temperature does not exceed 55 °C. It must not be exposed to conductive dust or humidity in excess of 90% non-condensing. Corrosive gasses, corrosive dust, and other contaminants must be kept out of the drive enclosure.

3U081 Layout (Requires Four 3U-Rack Slots)

Dimensions are in inches

3U151 Layout and 3U201 Layout (Requires Five 3U-Rack Slots)

Dimensions are in inches

General Mounting Considerations

The drive rack should be mounted to a back panel. The back panel should be unpainted and electrically conductive to allow for reduced electrical noise interference. The back panel is machined to accept the mounting bolt pattern of the drive. Make sure that all metal chips are cleaned up before the drive is mounted so there is no risk of getting metal chips inside the drive.

The 3U rack is mounted to the back panel through 4 x 0.275” x 0.400” holes. The user needs to provide screws and internal-tooth lock washers to attach at the cabinet. It is important that the teeth break through any anodization on the drive's mounting gears to provide a good electrically conductive path in as many places as possible. Mount the 3U rack on the back panel so there is airflow (at least three inches) at both the top and bottom areas of the drive.

If multiple 3U Geo drives are used, they can be mounted side-by-side, leaving at least one-tenth of an inch clearance between drives in the 3U rack. It is extremely important that the airflow is not obstructed by the placement of conduit tracks or other devices in the enclosure.

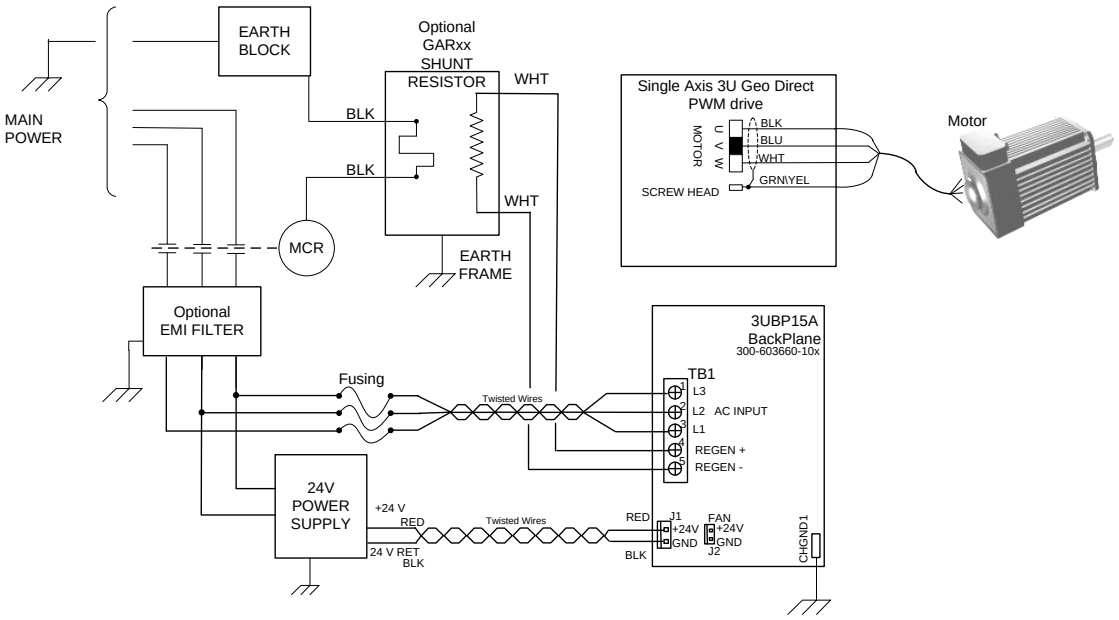


Units must be installed in an enclosure that meets the environmental IP rating of the end product (ventilation or cooling may be necessary to prevent enclosure ambient from exceeding 113° F [45° C]).

Caution

SYSTEM WIRING

Example Wiring Diagram





WARNING

Installation of electrical control equipment is subject to many regulations including national, state, local, and industry guidelines and rules. General recommendations can be stated but it is important that the installation be carried out in accordance with all regulations pertaining to the installation.

Safety Considerations

Fuse and Circuit Breaker Selection

In general, fusing must be designed to protect the weakest link from fire hazard. Each Geo drive is designed to accept more than the recommended fuse ratings. External wiring to the drive may be the weakest link as the routing is less controlled than the drive's internal electronics. Therefore, external circuit protection, be it fuses or circuit breakers, must be designed to protect the lesser of the drive or external wiring.

High peak currents and high inrush currents demand the use of slow blow type fuses and hamper the use of circuit breakers with magnetic trip mechanisms. Generally, fuses are recommended to be larger than what the rms current ratings require. Remember that some drives allow three times the continuous rated current on up to two axes of motion. Time delay and overload rating of protection devices must consider this operation.

Use of GFI Breakers

Ground Fault Interrupter circuit breakers are designed to break the power circuit in the event that outgoing currents are not accompanied by equal and opposite returning currents. These breakers assume that if outgoing currents are not returning, then there is a ground path in the load. Most circuit breakers of this type account for currents as low as 10 mA. PWM switching in servo drives coupled with parasitic capacitance to ground in motor windings and long cables generates ground leakage current. Careful installation practices must be followed. The use of inductor chokes in the output of the drive will help keep these leakage currents below breaker threshold levels.

Transformer and Filter Sizing

Incoming power design considerations for use with Geo Drives require some overrating. In general, it is recommended that all 3-phase systems using transformers and incoming filter chokes be allotted a 25% oversize to keep the impedances of these inserted devices from affecting stated system performance. In general, it is recommended that all single-phase systems up to 1 kW be designed for a 50% overload. All single-phase systems over 1 kW should be designed for a 200% overload capacity.

Noise Problems

When problems do occur often it points to electrical noise as the source of the problem. When this occurs, try to control the high-frequency current paths. If following the grounding instructions does not work, insert chokes in the motor phases. These chokes can be as simple as several wraps of the individual motor leads through a ferrite ring core (such as Micrometals T400-26D). This adds high-frequency impedance to the outgoing motor cable thereby making it harder for high-frequency noise to leave the control cabinet area.



Caution

Care should be taken to be certain that the core's temperature is in a reasonable range after installing such devices.

Operating Temperature

It is important that the ambient operating temperature of the 3U Geo Direct PWM drive be kept within specifications. The 3U Geo Direct PWM drive should be installed in an enclosure such as a NEMA spec. cabinet. The internal temperature of the cabinet must be kept under the Geo Drive Ambient Temperature specifications. It is sometimes desirable to roughly calculate the heat generated by the devices in the cabinet to determine if some type of ventilation or air conditioning is required. For these calculations the 3U Geo Direct PWM drive's internal heat losses must be known. Budget 100 W per axis for 1.5 A drives, 150 W per axis for 3 A drives, 200 W per axis for 5 A drives, 375 W per axis for 10 A drives, 500 W per axis for 15 A drives, and 650 W per axis for 20 A drives (all of these amperages are for continuous rating).

From 0°C to 45°C ambient temperature, no derating is required. Above 45°C, derate the continuous and peak output current by 2.5% per °C above 45°C. Maximum ambient is 55°C.

Amplifier Cooling Considerations

The drive amplifiers produce heat that must be removed. The installation requires that a fan blows air up through the vertical fins of the product's heat sink. The 3U Geo Direct PWM drive systems include the metal plates that go around the unit as part of the rack's metal panel work and a 24 VDC (2.6 W) fan. The fan must be positioned at the bottom side of the drive unit and attached to the fan connector, J1 on the backplane for power.



Caution

Do not operate the amplifier without an operational fan.

Do not impede airflow through the unit.

Single Phase Operation

Due to the nature of power transfer physics, it is not recommended that any system design attempt to consume more than 2 kW from any single-phase mains supply. Even this level requires careful consideration. The simple bridge rectifier front end of the Geo Drive, as with all other drives of this type, require high peak currents. Attempting to transfer power from a single-phase system getting one charging pulse each 8.3 milliseconds causes excessively high peak currents that can be limited by the power mains' impedances. The 3U Geo Direct PWM Drive output voltage sags, the input rectifiers are stressed, and these current pulses cause power quality problems on other equipment connected to the same line. While operating drives on single-phase power is possible, the actual power delivered to the motor must be considered. Never design expecting more than 1.5 HP total from any 115 VAC single-phase system and never more than 2.5 HP from any 230 VAC single-phase system.

Check the table below on how to calculate how to derate at single phase.

Drive	110 VAC Single Phase Derating Percentage	230 VAC Single Phase Derating Percentage
3U081	10%	Not needed
3U151	20%	10%
3U201	30%	20%
Note: Output Wattage derates when using single-phase power.		

Power Supply Considerations

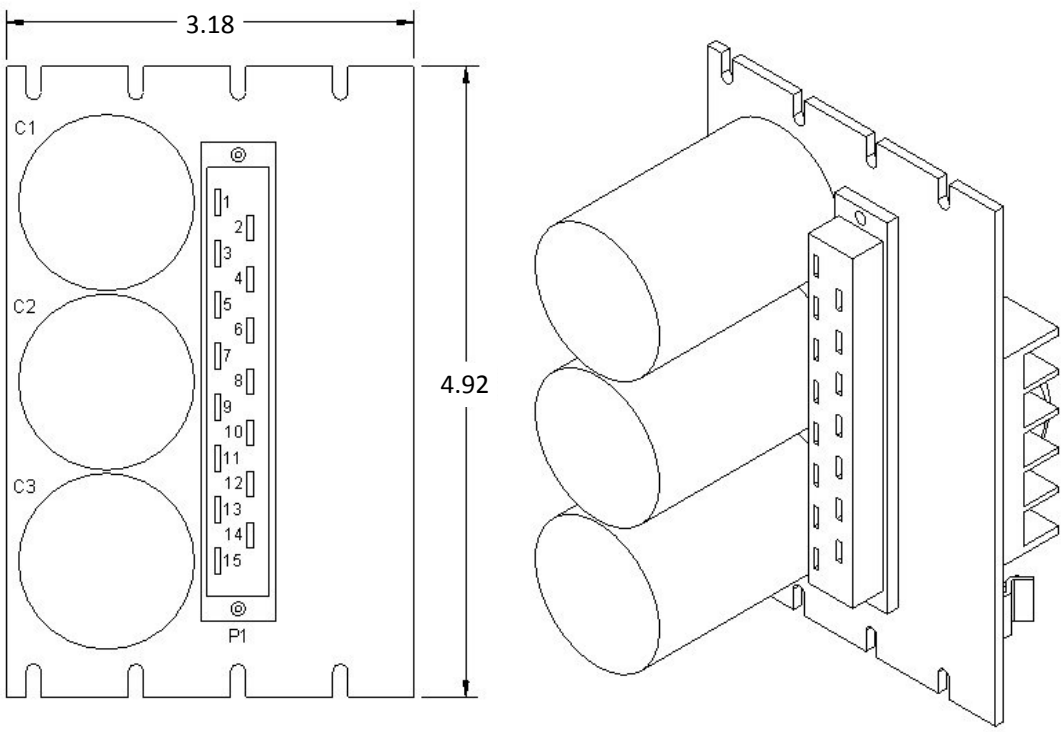
The 3U Geo Direct PWM Amplifiers require an external mains connection to the barrier block on the back side of the backplane to create the motor bus power. This connection can be single phase or three-phase AC power at 115 or 230 VAC. A single-phase system cannot provide more than 1500-2000 Watts. The form factor of the current becomes exaggerated perhaps allowing the internal rectifier bridge to be damaged and electrical noise to interfere with other electronic equipment. These connections must be fused with slow blow (i.e., FRN) fuses. Recommended fusing is 20 A for the 3U081 and 3U151, and 25 A for the 3U201.

The logic power for the amplifier is derived from a separate, external 24 VDC @ 1 A power supply. The 3U Drives have internal DC-to-DC converters that isolate the drive from this power supply and create all the internally required logic voltages. Startup current from this external power supply is isolated with a soft start circuit.

A Protective Earth Ground must be connected to the backplane (3UBP15A) and to the 3U rack itself. The ground should be a low impedance path directly returning to the main earth distribution block within the machine enclosure.

P1: Amplifier-to-Backplane Interface Connector

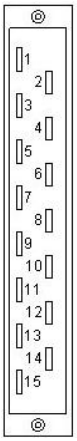
Below is a diagram of the front side of the amplifier backplane upon which P1 lies:



3U Servo Amplifier Backplane
Front View

All dimensions are in inches.

Below is a pinout of the connector into which the amplifier plugs:

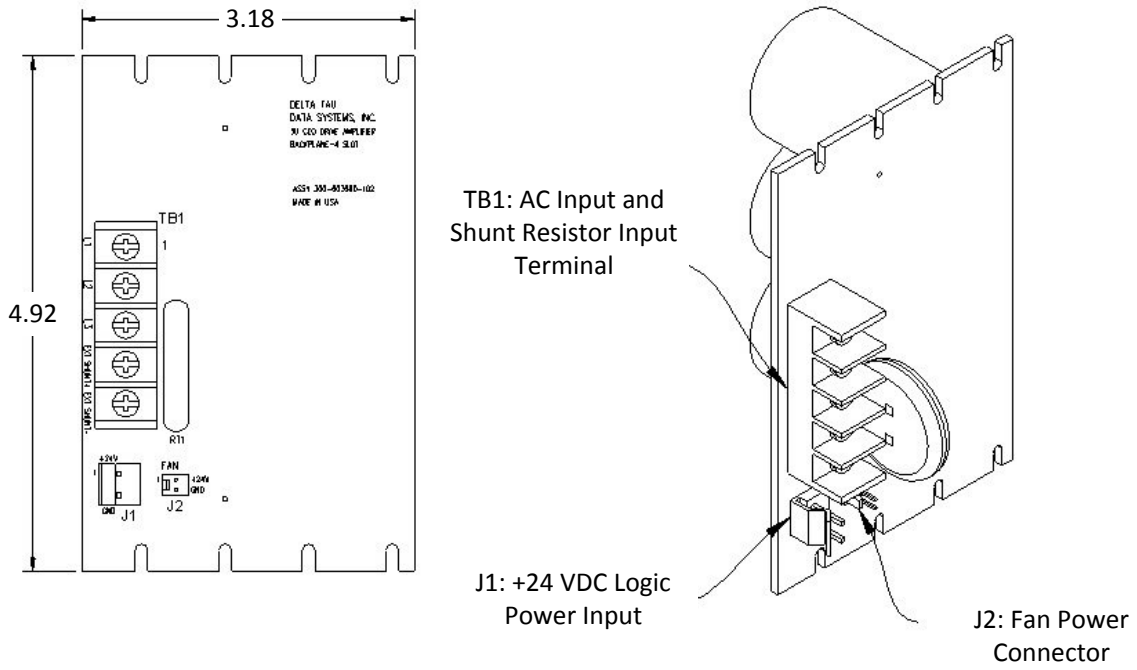
P1: 15-Pin Female **Mating: 15-Pin Male (on Rear of Amplifier)**	
Pin	**Description**
1	BUS-
2	L1 3-Phase AC input
3	BUS-
4	L2 3-Phase AC input
5	Line Voltage Sense
6	L3 3-Phase AC input
7	Gate Power from Drive
8	Rec+
9	Rec+
10	BUS+/Ext Shunt+
11	BUS+/Ext Shunt+
12	Ext Shunt-
13	Ext Shunt-
14	+24 VDC
15	+24VDC Return

Connectors on the Backplane (3UBP15A, 300-603660-10x)

This section describes all of the connectors located on the backplane which are necessary for the proper operation of the 3U amplifiers.

Rear of Backplane: TB1 and J1

Below is a diagram of the rear of the amplifier backplane, showing TB1, the connector for AC Power Input and the Regen (Shunt) Resistor, and J1, the +24 VDC Logic Power Input connector:



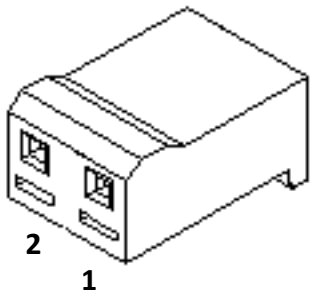
3U Servo Amplifier Backplane (3UBP15A, 300-603660-10x)
Rear View

All dimensions are in inches.

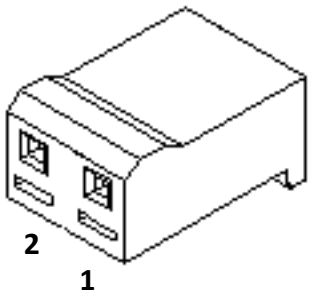
J1: 24 VDC Logic Supply Connector

An external 24 VDC power supply is required to power the logic portion of the 3U Geo Direct PWM drive. This power can remain on, regardless of the main AC bus input power, allowing the signal electronics to be active while the main motor power control is inactive. The 24 VDC must be wired to connector J1 on the 3UBP15A backplane board. The polarity of this connection is extremely important. Carefully follow the instructions in the wiring diagram at the start of this section. This connection can be made using 16 AWG wire directly from a protected power supply. In situations where the power supply is shared with other devices, it may be desirable to insert a filter in this connection.

The power supply providing this 24 VDC must be capable of providing an instantaneous current of at least 0.8 A to be able to start the DC-to-DC converter in the 3U Geo Direct PWM drive. In the case where multiple drives are driven from the same 24 VDC supply, it is recommended that each drive be wired back to the power supply terminals independently. It is also recommended that the power supply be sized to handle the instantaneous inrush current required to start up the DC-to-DC converter in the Geo drive.

J1: 2-Pin Male **Mating: 2-Pin Female**				
Pin #	**Symbol**	**Function**	**Description**	**Notes**
1	+24VDC	Input	Control power input	24 VDC ±10% @ 1 A
2	GND	Common	Control power return	
Note: This connector is located on the backplane, 3UBP15A, 300-603660-10x, not the drive. Delta Tau P/N: 200-C30F02-LHM Molex P/N: 10-01-3026 (housing, 0.100 spacing, 2 pins, white), 08-70-1028 (pins)				

J2: Fan Output

J2: 2-Pin Male **Mating: 2-Pin Female**	

Pin	**Description**
1	Fan+ (+24 VDC)
2	Fan- (GND)

Delta Tau P/N: 200-00F002-HSG

Molex P/N: 10-11-2023 (housing, 0.100 spacing, 2 pins, brown), 08-50-0114 (pins); use 22–28 AWG.

This is an output. Typically, you should plug your UMAC's amplifier fan into this connector.

TB1: AC Input and Regen (Shunt) Resistor

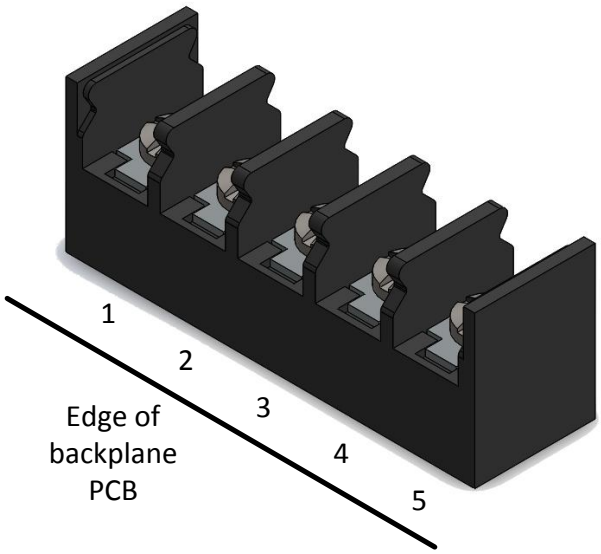
The main bus voltage supply must be brought to the Geo drive through connector TB1 on the backplane board. If single phase is used, derating needs to be calculated. It is acceptable to bring the single-phase power into any two of the three input pins on connector TB1. Higher-power drive amplifiers require three-phase input power. To provide fuse protection or overload protection to the input power to the Geo drive amplifier is extremely important. Typically, this is provided with fuses designed to be slow acting, such as FRN-type fuses. Due to the various regulations of local codes, NEC codes, UL and CE requirements, it is very important to reference these requirements before making a determination of how the input power is wired.

Additionally, many systems require that the power be able to be turned on and off in the cabinet. It is typical that the AC power runs through some kind of main control contact within the cabinet, through the fuses, and then to the Geo drive. If multiple Geo drives are used, it is important that each drive has its own separate fuse block.

Whether you are using single- or three-phase, it is important that the AC input wires be twisted together to eliminate noise radiation as much as possible. Additionally, some applications may have further agency noise reduction requirements that require that these lines be fed from an input filtering network.

The AC connections from the fuse block to the Geo drive are made via a cable that is connected at the backplane with screw terminals.

TB1: 5-Pin Screw Terminal Block



Pin #	Symbol	Function	Description	Notes
1	L1	Input	Line Input Phase 1	(Not used for single phase input)
2	L2	Input	Line Input Phase 2	
3	L3	Input	Line Input Phase 3	
4	EXT SHUNT+	Output	Shunt Resistor Output	
5	EXT SHUNT+	Output	Shunt Resistor Output	

Note: This connector can be found on the backplane, not on the drive itself.
Backplane part number: 3UBP15A, 300-603660-10x
If DC bus is used, use L3 for DC+ and L2 for DC return (check the enhanced node settings).

Regen (Shunt) Resistor Wiring

The regen circuit is also known as a shunt regulator. Its purpose is to dump power fed back into the drive from a motor acting as a generator. Excessive energy can be dumped via an external load resistor. The Geo product series is designed for operation with external shunt resistors of 48 Ω for the 10 A, 15 A and 20 A. These are available directly from Delta Tau, part numbers GAR48 and GAR78, respectively. These resistors are provided with preterminated cables that plug into the connector at the backplane.



Caution

The black wires are for the thermostat and the white wires are for the regen resistor on the external regen resistor (pictured in the Appendix). These resistors can get very hot. It is recommended that they be mounted away from other devices and near the top of the cabinet. Do not touch these resistors until they have cooled.

The regen resistors incorporate a thermal overload protection device available through the two black leads exiting the resistor. It is important that these two leads be wired in a safety circuit that stops the system from operating should the thermostat open.

Shunt Regulation

Regenerative deceleration is when the motor is used to slow the moving load. Under this operation, the motor is acting as a generator consuming energy from the load while passing the energy into the DC Bus's storage capacitors. Left unchecked, the DC Bus voltage can raise high enough to damage the drive. For this reason there are protection mechanisms built into the Geo Drive product such as shunt regulation and overvoltage protection.

The shunt regulator monitors the DC Bus voltage. If this voltage rises above a present threshold (the "Regen Turn On Voltage"), the Geo Drive will turn on a power device intended to place the externally mounted regen resistor across the bus to dump the excessive energy. The power device keeps the regen resistor connected across the bus until the bus voltage is sensed to be below the "Regen Turn Off Voltage," at which time the power device removes the resistor connection.

Minimum Resistance Value

The regen resistor selection requires that the resistance value of the selected resistor will not allow more current to flow through the Geo Drive's power device than specified.

Maximum Resistance Value

The maximum resistor value that will be acceptable in an application is one that will not let the bus voltage reach the drive's stated over voltage specification during the deceleration ramp time. The following equations defining energy transfer can be used to determine the maximum resistance value.

Energy Transfer Equations

Regen, or shunt, regulation analysis requires study of the energy transferred during the deceleration profile. The basic philosophy can be described as follows:

- The motor and load have stored kinetic energy while in motion.
- The drive removes this energy during deceleration by transferring to the DC bus.
- There are losses during this transfer, both mechanical and electrical, which can be significant in some systems.
- The DC bus capacitors can store some energy.
- The remaining energy, if any, is transferred to the regen resistor.

Kinetic Energy

The first step is to ascertain the amount of kinetic energy in the moving system, both the motor rotor and the load it is driving. In metric (SI) units, the kinetic energy of a rotating mass is:

$$E_K = \frac{1}{2} J\omega^2$$

where:
E_K is the kinetic energy in joules, or watt-seconds (J, W-s)
J is the rotary moment of inertia in kilogram-meter^2 (kg-m^2)
ω is the angular velocity of the inertia in radians per second (1/s)

If the values are not in these units, first convert them. For example, if the speed is in revolutions per minute (rpm), multiply this value by $2\pi/60$ to convert to radians per second.

When English mechanical units are used, there are additional conversion factors must be included to get the energy result to come out in joules. For example, if the rotary moment of inertia J is expressed in lb-ft-sec^2, the following equation should be used:

$$E_K = 0.678 J\omega^2$$

If the rotary moment of inertia J is expressed in lb-in-sec^2, the following equation should be used:

$$E_K = 0.0565 J\omega^2$$

In standard metric (SI) units, the kinetic energy of a linearly moving mass is:

$$E_K = \frac{1}{2} mv^2 ,$$

where:
E_K is the kinetic energy in joules (J)
m is the mass in kilograms (kg)
v is the linear velocity of the mass in meters/second (m/s)

Here also, to get energy in Joules from English mechanical units, additional conversion factors are required. To calculate the kinetic energy of a mass having a weight of W pounds, the following equation can be used:

$$E_K = 0.678 \frac{W}{g} v^2 = 0.0211 Wv^2 ,$$

where:
E_K is the kinetic energy in joules (J)
W is the weight of the moving mass in pounds (lb)
g is the acceleration of gravity (32.2 ft/sec^2)
v is the linear velocity of the mass in feet per second (ft/sec)

Energy Lost in Transformation

Some energy will be lost in the transformation from mechanical kinetic energy to electrical energy. The losses will be both mechanical due to friction and electrical due to resistance. In most cases, these losses will comprise a small percentage of the transformed energy and can be safely ignored especially because ignoring losses leads to a conservative design. However, if the losses are significant and the system should not be over-designed, calculate these losses.

In metric (SI) units, the mechanical energy lost due to Coulomb (dry) friction in a constant deceleration to stop of a rotary system can be expressed as:

$$E_{LM} = \frac{1}{2} T_f \omega t_d ,$$

where:
E_{LM} is the lost energy in joules (J)
T_f is the resistive torque due to Coulomb friction in newton-meters (N-m)
ω is the starting angular velocity of the inertia in radians per second (1/s)
t_d is the deceleration time in seconds (s)

If the frictional torque is expressed in the common English unit of pound-feet (lb-ft), the comparable expression is:

$$E_{LM} = 0.678 T_f \omega t_d$$

In metric (SI) units, the mechanical energy lost due to Coulomb (dry) friction in a constant deceleration to stop of a linear system can be expressed as:

$$E_{LM} = \frac{1}{2} F_f v t_d ,$$

where:
E_{LM} is the lost energy in joules (J)
T_f is the resistive force due to Coulomb friction in newtons (N)
v is the starting linear velocity in meters/second (m/s)
t_d is the deceleration time in seconds (s)

If the frictional force is expressed in the English unit of pounds (lb) and the velocity in feet per second (ft/sec), the comparable expression is:

$$E_{LM} = 0.678 F_f v t_d$$

The electrical resistive losses in a 3-phase motor in a constant deceleration to stop can be calculated as:

$$E_{LE} = \frac{\sqrt{3}}{2} i_{rms}^2 R_{pp} t_d ,$$

where:
E_{LE} is the lost energy in joules (J)
i_{rms} is the current required for the deceleration in amperes (A), equal to the required deceleration torque divided by the motor's (rms) torque constant K_T
R_{pp} is the phase-to-phase resistance of the motor, in ohms (Ω)
t_d is the deceleration time in seconds (s)

Capacitive Energy Stored in the Drive

The energy not lost during the transformation is initially stored as additional capacitive energy due to the increased DC bus voltage. The energy storage capability of the drive can be expressed as:

$$E_C = \frac{1}{2} C\left(V_{regen}^2 - V_{nom}^2\right),$$

where:
E_C is the additional energy storage capacity in joules (J)
C is the total bus capacitance in Farads
V_{regen} is the DC bus voltage at which the regeneration circuit would have to activate, in volts (V)
V_{nom} is the normal DC bus voltage, in volts (V)

Evaluating the Need for a Regen Resistor

Any starting kinetic energy that is not lost in the transformation and cannot be stored as bus capacitive energy must be dumped by the regeneration circuitry in to the regen (shunt) resistor. The following equation can be used to determine whether this will be required:

$$E_{excess} = E_K - E_{LM} - E_{LE} - E_C$$

If E_{excess} in this equation is greater than 0, a regen resistor will be required.

Regen Resistor Power Capacity

A given regen resistor will have both a peak (instantaneous) and a continuous (average) power dissipation limit. It is therefore necessary to compare the required peak and continuous regen power dissipation requirements against the limits for the resistor.

The peak power dissipation that will occur in the regen resistor in the application will be:

$$P_{peak} = \frac{V_{regen}^2}{R},$$

where:
P_{peak} is peak power dissipation in watts (W)
V_{regen} is the DC bus voltage at which the regeneration circuit activates, in volts (V)
R is the resistance value of the regen resistor, in ohms (Ω)

However, this power dissipation will not be occurring all of the time, and in most applications, only for a small percentage of the time. Usually, the regen will only be active during the final part of a lengthy deceleration, after the DC bus has charged up to the point where it exceeds the regen activation voltage. The average power dissipation value can be calculated as:

$$P_{avg} = P_{peak} \frac{\%on-time}{100},$$

where:
P_{avg} is average power dissipation in watts (W)
%on-time is the percentage of time the regen circuit is active



The Turn On voltage for the shunt circuitry for all Geo drives is 392V. There is a Hysteresis of 20V, so if the regen turns on @ 392V it will not turn off until it drops to 372V.

Note

Wiring Earth-Ground

Panel wiring requires that a central earth-ground location be installed at one part of the panel. This electrical ground connection allows for each device within the enclosure to have a separate wire brought back to the central wire location. Usually, the ground connection is a copper plate directly bonded to the back panel or a copper strip with multiple screw locations. The Geo drive should be brought to the earth-ground via a wire connected to the stud on the front panel through a heavy gauge, multi-strand conductor to the central earth-ground location.

Earth Grounding Paths

High-frequency noises from the PWM-controlled power stage will find a path back to the drive. It is best that the path for the high-frequency noises be controlled by careful installation practices. The major failure in problematic installations is the failure to recognize that wire conductors have impedances at high frequencies. What reads 0 ohms on a DVM may be hundreds of ohms at 30 MHz. Consider the following during installation planning:

1. Star point all ground connections. Each device wired to earth ground should have its own conductor brought directly back to the central earth ground plate.
2. Use unpainted back panels. This allows a wide area of contact for all metallic surfaces reducing high frequency impedances.
3. Conductors made up of many strands of fine wires outperform solid or conductors with few strands at high frequencies.
4. Motor cable shields should be bounded to the back panel using 360-degree clamps at the point they enter or exit the panel.
5. Motor shields are best grounded at both ends of the cable. Again, connectors using 360-degree shield clamps are superior to connector designs transporting the shield through a single pin. Always use metal shells.
6. Running motor armature cables with any other cable in a tray or conduit should be avoided. These cables can radiate high frequency noise and couple into other circuits.

Bonding

The proper bonding of shielded cables is imperative for minimizing noise emissions and increasing immunity levels. The bonding effect reduces the impedance between the cable shield and the back panel.

Power input wiring does not require shielding (screening) if the power is provided to the enclosure via a metal conduit. If metal conduit is not used in the system, shielded cable is required on the power input wires along with proper bonding techniques.

Filtering

CE Filtering

Apply proper bonding and grounding techniques, described earlier in this section, when incorporating EMC noise filtering components to meet this standard.

Noise currents often occur in two ways. The first is conducted emissions passed through ground loops. The quality of the system-grounding scheme inversely determines the noise amplitudes in the lines. These conducted emissions are of a common-mode nature from line-to-neutral (ground). The second is radiated high-frequency emissions that usually are capacitively coupled from line-to-line and are differential in nature.

When mounting the filters, make sure the enclosure has an unpainted metallic surface. This allows more surface area to be in contact with the filter housing and provides a lower impedance path between the housing and the back plane. The back panel should have a high frequency ground strap connection to the enclosure frame and earth ground.

Input Power Filtering



Caution

To avoid electric shock, do not touch filters for at least 10 seconds after removing the power supply.

The Geo Drive electronic system components require EMI filtering in the input power leads to meet the conducted emission requirements for the industrial environment. This filtering blocks conducted-type emissions from exiting onto the power lines and provides a barrier for power line EMI.

Adequately size the system. The type of filter must be based on the voltage and current rating of the system and whether the incoming line is single or three-phase. One input line filter may be used for multi-axis control applications. These filters should be mounted as close to the incoming power as possible so noise is not capacitively coupled into other signal leads and cables. Implement the EMI filter according to the following guidelines:

- Mount the filter as close as possible to the incoming cabinet power.
- When mounting the filter to the panel, remove any paint or material covering. Use an unpainted, metallic back panel.
- Filters are provided with a ground connection. All ground connections should be tied to ground.
- Filters can produce high leakage currents; they must be grounded before connecting the supply.
- Do not touch filters for a period of ten seconds after removing the power supply.

Motor Line Filtering

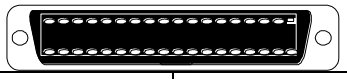
Motor filtering may not be necessary for CE compliance of Geo Drives. However, this additional filtering increases the reliability of the system. Nonmetallic enclosure surfaces and lengthy, unbonded (or unshielded) motor cables that couple noise line-to-line (differential) are some of the factors that may lead to the necessity of motor lead filtering.

Motor lead noise is either common-mode or differential. The common-mode conducted currents occur between each motor lead and ground (line-to-neutral). Differential radiated currents exist from one motor lead to another (line-to-line). The filtering of the lines feeding the motor provides additional attenuation of noise currents that may enter surrounding cables and equipment I/O ports in close proximity.

Differential mode currents commonly occur with lengthy motor cables. As the cable length increases, so does its capacitance and ability to couple noise from line-to-line. While every final system is different and every application of the product causes a slightly different emission profile, it may become necessary to use differential mode chokes to provide additional noise attenuation to minimize the radiated emissions. The use of a ferrite core placed at the Geo Drive end on each motor lead attenuates differential mode noise and lowers the frequency (30 to 60 MHz) of broadband emissions to within specifications. Delta Tau recommends a Fair-Rite P/N 263665702 (or equivalent) ferrite core.

Common mode currents occur from noise spikes created by the PWM switching frequency of the Geo Drive. The use of a ferrite or iron-powder core toroid places common mode impedance in the line between the motor and the Geo Drive. The use of a common mode choke on the motor leads may increase signal integrity of encoder outputs and associated I/O signals.

PWM Input Connector

P1: 36-Pin Mini-D Connector Mating: 36-Pin Mini-D Receptacle				
Pin #	**Symbol**	**Function**	**Description**	**Notes**
1	FC0	Feedback	1 of 4 fault code bits	
2	FC2	Feedback	1 of 4 fault code bits	
3	ADC_CLK1+	Command	A/D converter clock	
4	ADC_STB1+	Command	A/D converter strobe	
5	CURRENTA+	Feedback	Phase A actual current data	Serial digital
6	CURRENTB+	Feedback	Phase B actual current data	Serial digital
7	AENA1+	Command	Amplifier enable	High is enable
8	FAULT1+	Feedback	Amplifier fault	High is fault
9	PWMATOP1+	Command	Phase A top Cmd	High is on command
10	PWMABOT1+	Command	Phase A bottom Cmd	High is on command
11	PWMBTOP1+	Command	Phase B top Cmd	High is on command
12	PWMBBOT1+	Command	Phase B bottom Cmd	High is on command
13	PWMCTOP1+	Command	Phase C top Cmd	High is on command
14	PWMCBOT1+	Command	Phase C bottom Cmd	High is on command
15	GND	Common	Reference voltage	
16	+5V	Power	+5 VDC power	From controller
17	Reserved			
18	Reserved			
19	FC1	Feedback	1 of 4 fault code bits	
20	FC3	Feedback	1 of 4 fault code bits	
21	ADC_CLK1-	Command	A/D converter clock	
22	ADC_STB1-	Command	A/D converter strobe	
23	CURRENTA-	Feedback	Phase A actual current data	Serial digital
24	CURRENTB-	Feedback	Phase B actual current data	Serial digital
25	AENA1-	Command	Amplifier enable	Low is enable
26	FAULT1-	Feedback	Amplifier fault	Low is fault
27	PWMATOP1-	Command	Phase A top Cmd	Low is on command
28	PWMABOT1-	Command	Phase A bottom Cmd	Low is on command
29	PWMBTOP1-	Command	Phase B top Cmd	Low is on command
30	PWMBBOT1-	Command	Phase B bottom Cmd	Low is on command
31	PWMCTOP1-	Command	Phase C top Cmd	Low is on command
32	PWMCBOT1-	Command	Phase C bottom Cmd	Low is on command
33	GND	Common	Reference voltage	
34	+5V	Power	+5 VDC power	From controller
35	Reserved			
36	Reserved			

A Mini-D 36-pin connector for digital amplifier command outputs and current feedbacks. This connector provides the interface to a fully digital amplifier for one channel.
Note that current feedback data must be in serial digital form, already converted from analog in the amplifier.
For Cable Kits, see Appendix A.
There is one of these connectors for each axis on the drive.

Motor Output Connector

The cable wiring must be shielded and have a separate conductor connecting the motor frame back to the drive amplifier. The cables are available in cable kits (CABKITxx) from Delta Tau (see Appendix A)

Motor phases are conversed in one of three conventions. Motor manufacturers will call the motor phases A, B, or C. Other motor manufacturers call them U, V, W. Induction motor manufacturers may call them L1, L2, and L3. The drive's inputs are called U, V, and W. Wire U, A, or L1 to the drive's U terminal. Wire V, B, or L2 to the drive's V terminal. Wire W, C, or L3 to the drive's W terminal.

The motor's frame drain wire and the motor cable shield must be tied together at the mounting stud (which has a 5 mm thread) on the front of the Geo drive.

For 3U081, 3U151 and 3U201

Motor #1 Output Connector Pin-out

J2: 3-Pin Female **Mating: 3-Pin Male**				
Pin #	**Symbol**	**Function**	**Description**	**Notes**
1	U	Output	Axis 1/2 Phase 1	
2	V	Output	Axis 1/2 Phase 2	
3	W	Output	Axis 1/2 Phase 3	
Rake : Connect to motor frame and cable drain, Chassis Ground This connector is available in connector kit DT Part Number CONKIT3A or in cable kit CABKIT3B.				

Wiring the Motor Thermostats

Some motor manufacturers provide the motors with integrated thermostat overload detection capability. Typically, it is in one or two forms: a contact switch that is normally closed (i.e. when the motor is safely under-temperature) or a PTC. These sensors can be wired into the connector on the Geo drive's front panel labeled "MOTOR TEMP SWITCH" (refer to the "Mounting and Layout" section of the manual for an image).

Motor 1's thermostat should be wired to MTR1 PTC and MTR1 PTC RET. These contacts have to be low impedance for the drive to be operational.

If the motor overload protection is not required, these pins should be jumpered together to disable this function in the drive. Otherwise, the drive status display will show a fault code 5 for over temperature.

Motor Temperature Switch

Connector: 2-Pin Female Mating (on Front Panel of Drive): 2-Pin Female			
Pin	**Symbol**	**Function**	**Description**
1	MTR PTC	Input	If the motor does not have an overtemp sensor output, you must jump pin 1 to pin 2 (as sent from factory)
2	MOTOR PTC RET	Input	
Note: If the input is not used, then a regular jumper can be used. 2-pin Molex Connector 0.100" spacing, 22–28AWG Delta Tau Part Number: 200-00F002-HSG Molex Part Number: 10-11-2023 (housing), 08-50-0114 (pins)			

If not connecting an overtemperature switch to this connector, use a jumper to connect the pins. Below is an image of a typical jumper, commonly available from essentially any computer or electronics store:



POWER-ON PROCEDURE

This drive does not have its own ADC clock and therefore relies solely on the ADC clock and strobe word sent from PMAC in order to read the motor currents values (ADCs).

In Turbo PMAC, the DSPGates are up and running approximately within the first 200 msec of power up. This means that the ADC strobe and ADC clocks are established quickly. In addition, in previous generations of the PMAC (non-Power) the DSPGates were never reset other than under a watchdog event or loss of power. Power PMAC uses the reset line and actually resets all the hardware, including the DSPGates when a $$$ or a $$$*** command is issued. When the gates are reset, their software values and clock settings will be set to default values, until the project inside PMAC is loaded from flash memory into active memory and then loaded to Power PMAC. During this time period, the DSPGate runs based upon its default values.

In Geo Direct PWM drives, if the ADC strobe is changed, or the ADC clock is changed, since the firmware was not designed such that it can recognize these changes and exclusively looks at the ADC values it reads, different faults may be triggered even latching ones which can only be cleared by cycling the logic power on the amplifier.

In order to use the current drives, before we actually get to replacing them or updating the logic inside, we have to ensure of the following:

1. Power up the logic and line power of the drive from PMAC controlled I/Os. These I/Os should be

wired failsafe such that upon $$$, $$$*** and power cycle, the logic power and AC power is interrupted.

2. Make sure the logic is powered up first before the bus power is applied.
3. The bus power can be turned on and off while the logic is powered up. However, because of the

simple softstart circuitry in these drives, make sure:

   a. Apply the bus power for a while (1 to 2 seconds) before enabling any axis. This should allow the caps to charge up before pulling any currents through them.
   b. If the bus power is removed for any reason, it is necessary to keep the bus power off until the BUS LED is turned off. If the bus voltage is applied before the cap voltage is dropped below the threshold of 97 VDC, the soft start procedure will not start, permitting direct charging of the caps, which can cause them to explode.

4. The enhanced mode can be achieved using ACC-24E3 with proper strobe word settings; however, in case of a latching ADC reading, the drive will still do the same.



Note

After setting the drive to enhanced mode, leave it in enhanced mode. Do not set the mode back to default.

DIRECT PWM COMMUTATION CONTROLLER SETUP

The 3U amplifier must have the proper controller setup to command the amplifier/motor system. This section summarizes the key variables of both Turbo and Non Turbo PMAC2 controllers that must be modified for use with the amplifier. Delta Tau setup software (such as Turbo Setup) will help set these parameters for the system automatically. For details about direct commutation of brushless and induction motors, read the PMAC2 or Turbo PMAC2 User Manual. To find out the details about these variables, refer to the PMAC2 or Turbo PMAC2 Software Reference Manual.

Key Servo IC Variables

Non-Turbo	Turbo	Type	Description
I900	I7m00	Clock	Max phase clock setting
I901	I7m01	Clock Divisor	Phase clock divisor
I902	I7m02	Clock Divisor	Servo clock divisor
I903	I7m03	Clock	Hardware clock settings
I904	I7m04	Clock	PWM dead time
I905	I7m05	Strobe	DAC strobe word
*	I7m06	Strobe	ADC strobe word (Must be set to $3FFFFF for Geo drives.)
I9n0	I7mn0	Channel	Encoder decode for channel
I9n6	I7mn6	Channel	Output mode for channel (Must be set to 0.)

* To change the ADC strobe word for a non-Turbo PMAC2 controller, issue a write command directly to the memory location of the Gate array channel connected to the amplifier, I7m06. For non-Turbo PMAC2 channel 1-4, use memory location X:$C014. For non-Turbo PMAC2 channel 5–8, use memory location X:$C024.

For example: WX:$C014,$3FFFFF or I7m06=$3FFFFF for Turbo.

Key Motor Variables



Caution

The ADC Strobe Word, X:$C014 (non-Turbo) or I7m06 (Turbo), must be set to $3FFFFF for proper operation. Failure to set I7m06 equal to $3FFFFF could result in damage to the amplifier.

Non-Turbo	Turbo	Type	Description
Ix00	Ixx00	General	Motor enable
Ix01	Ixx01	General	Commutation enable
Ix25	Ixx24 Ixx25	General	Motor flag setup
Ix70	Ixx70	Commutation	Number of commutation cycles per Ix71
Ix71	Ixx71	Commutation	Counts per commutation cycle per Ix70
Ix72	Ixx72	Commutation	Commutation phase angle
Ix77	Ixx77	Commutation	Induction motor magnization current
Ix78	Ixx78	Commutation	Induction motor slip gain
Ix83	Ixx83	Commutation	On-going phase position
Ix61	Ix61	Current Loop	Current loop integrator gain
Ix62	Ix62	Current Loop	Current loop forward path proportional gain
Ix66	Ix66	Current Loop	PWM scale factor
Ix76	Ix76	Current Loop	Current loop back bath proportional gain
Ix82	Ix82	Current Loop	Current loop feedback address
Ix84	Ix84	Current Loop	Current loop feedback ADC mask word
Ix57	Ixx57	I^2T	Continuous limit for I2T
Ix58	Ixx58	I^2T	Integrated current limit

Example Setup for Motor 1 (DC Brushless Motor)

This example assumes that the user has a 3U081 drive with a DC Brushless motor as Motor 1, using a Turbo UMAC CPU in the same rack as the 3U081 drive, and an ACC-24E2.

```
// Set the clocks
I7200=3275 ; Servo IC2 Max Phase/PWM Frequency Control
I7201=0 ; Servo IC2 Phase Clock Frequency Control
I7202=3 ; Servo IC2 Servo Clock Frequency Control

I15=0 ; Trigonometric calculation in degrees
#define MaxPhaseFreq P8000 ; Max Phase Clock [KHz]
#define PWMClk P8001 ; PWM Clock [KHz]
#define PhaseClk P8002 ; Phase Clock [KHz]
#define ServoClk P8003 ; Servo Clock [KHz]
MaxPhaseFreq=117964.8/(2*I7000+3)
PWMClk=117964.8/(4*I7000+6)
PhaseClk=MaxPhaseFreq/(I7001+1)
ServoClk=PhaseClk/(I7002+1)

I7206=$3FFFFF ; Servo IC 2 ADC Strobe Word
I172=1365 ; Motor 1 Commutation phase angle

// Supposing that the drive's bus voltage > motor rated voltage
#define DCBusInput 170 ; DC Bus Voltage [VDC] = 1.414* 120 VAC -User Input
#define Mtr1Voltage 24 ; Motor 1 Rated Voltage [VDC] -User Input

I166=1.10*I7000*Mtr1Voltage/DCBusInput ; Motor 1 PWM Scale Factor

I182=$078206 ; Motor 1 Current Feedback Address

// Assuming a quadrature encoder is being used for this motor
I183=$078201 ; Motor 1 Commutation source address
I101=1 ; Motor 1 Commutation Enabled, from X-register
I100=1 ; Activate the motor

#define ContCurrent 3 ; Continuous Current Limit (here, from the motor) [Amps] -User Input
#define PeakCurrent 9 ; Instantaneous Current Limit (here, from the motor) [Amps] -User Input
#define MaxADC 26.02 ; =26.02 for 8/16A -User Input, see electrical specs
#define I2TOnTime 2 ; Time allowed at peak Current [sec] -User Input
I157=INT(32767*(ContCurrent*1.414/MaxADC)*cos(30))
I169=INT(32767*(PeakCurrent*1.414/MaxADC)*cos(30))
I158=INT((I169*I169- I157*I157)*ServoClk*1000*I2TOnTime/(32767*32767))

I170=2 // Motor has 2 pole pairs
I171=2000 // Motor has 2000 counts per revolution

// Current Loop Tuning
I162=1.0
I176=0.25
I161=.1

// Motor Phasing -- 2 Guess Method
I173=1200 ; Phase finding output value (adjustable) in units of 16-bit DAC
I174=12 ; Units of servo cycles (adjustable)
I180=4 ; 2-guess method, no absolute position read, no power-on phasing

// Servo Loop Tuning
I130=1000000 // Kp
I131=2000 // Kd
I132=2000 // Kvff
I133=100 // Ki
I134=1 // Integrate when desired velocity is zero
I135=10000 // Kaff
```

DC BRUSH MOTOR DRIVE SETUP WITH NON-TURBO PMAC

It is possible to use PMAC2's direct PWM and digital current loop for control of DC brush motors, both those with permanent-magnet fields, and those with wound fields. Because PMAC2's digital current loop and commutation algorithms are combined, it is necessary to activate PMAC2's commutation algorithm for the motor, even though it is not commutating the motor.

The sine-wave commutation is effectively disabled in this technique by telling PMAC2 that the motor has a commutation cycle of 1 count. Each of the counts received causes a 360^{o}e phase increment, leaving the phase angle constant at all times for DC control. With the phase angle always at zero, PMAC2's quadrature, or torque-producing, output voltage and feedback current are always equivalent to the motor's rotor, or armature, voltage and current. PMAC2's direct, or magnetization field, voltage and current are always equivalent to the motor's stator, or wound field, voltage and current (if any).

Hardware Connection

In this technique, the rotor (armature) current is commanded by PMAC2 phases A and C. The motor armature leads should be connected between the two half-bridges of the amplifier driven by PMAC2 phases A and C, together forming a full H-bridge.

The armature current sensor should feed an A/D converter that is connected to one of the serial ADC inputs for the channel on PMAC2. If there is a wound field, the armature current reading must be fed into ADC A and the field current reading must be fed into ADC B.

If there is a permanent magnet field only, the armature current reading can be fed into either ADC A or ADC B, with **Ix82** telling PMAC2 which one is used. If ADC A is used, the serial digital input for ADC B (+signal only) should be tied to GND so a zero feedback value is forced (alternately a background PLC can zero the direct current integrator register periodically). If ADC B is used, then PMAC uses the Compare A read/write register for the (non-existent) direct current feedback; in this case, a zero value should be written into this register on power-on/reset, and no other value should be written to it during the application.

If there is a wound field, it must be commanded from PMAC2's B phase, and the current feedback must be brought back into PMAC2's B-phase. If only unidirectional voltage and current are required for the field, the field windings can be commanded from a single half-bridge. If bidirectional voltage or current is required, a full H-bridge must be used, with PMAC2's B-phase commanding the two half bridges in anti-phase mode (also the command for the top of one half is used for the bottom of the other half).

I-Variable Setup

To set up a motor for this technique, the following I-variable settings must be made:

- **Ix00 = 1** to activate the motor
- **Ix01 = 1** to activate commutation algorithms
- **Ix02** should contain the address of the PWM A register for the output channel used (this is the default), just as for brushless motors
- **Ix70 = 4**, **Ix71 = 4**: This defines a commutation cycle size of 4/4 = 1 count. The use of 4/4 instead of 1/1 allows us to rotate the angle $\pm 90^{o}$ for test and tuning purposes.
- **Ix72 = 64** or **192** for 1/4 or 3/4 cycle between the armature (rotor) and field (stator). If a positive voltage output number creates a negative current feedback number, use **64**; otherwise use **192**.
- **Ix73 = 0**, **Ix74 = 0**: No power-on phase search will be required
- **Ix75 = 0**: Zero offset in the power-on phase reference
- **Ix77 = 0** for motors without wound field. With a wound field, **Ix77** determines the strength of the field; with field weakening functionality, **Ix77** will be a function of motor speed.
- **Ix78 = 0** for zero slip in the commutation calculations
- **Ix81 = $80770**: This tells PMAC2 to read the low 8 bits of Y:$0770 for the power-on phase position. This register is forced to zero on power-on/reset, so this setting forces the phase position to zero.
- **Ix82** should contain the address of ADC B register for the feedback channel used (just as for brushless motors) when the ADC A register is used for the rotor (armature) current feedback. If there is a wound field, the stator field current feedback should be connected to ADC B. If there is a permanent magnet field, there will be no feedback to ADC B.
- **Ix82** should contain the address one greater than that of the ADC B register for the feedback channel used when the ADC B register is used for the rotor (armature) current feedback. This is suitable for motors with only a permanent magnet field.
- **Ix83** does not really matter here, because the commutation position is defeated by the single-count cycle size. However, it is fine to use the default value.
- **Ix84** is set just as for brushless motors, specifying which bits the current ADC feedback uses.
- **Ix61**, **Ix62**, and **Ix76** current loop gains are set just as for brushless motors.

Example Setup for Motor 1 (DC Brush Motor)

This example assumes the user has a DC Brush motor with a Non-Turbo PMAC2.

```
I100=1 // Activate the motor
I101=1 // Activate commutation on the motor
I102=$C00A // Command output location (default)

// Define Commutation Size to be 1 count
I170=4
I171=4

I172=192 // Positive voltage output concurs with positive feedback values -User Input
I173=0 I174=0 // Do not use a power-on phase search method
I175=0 // Zero offset in the power-on phase reference
I177=0 // For motors without a wound field
I178=0 // For zero slip in the commutation calculations
I181=$80770 // Read the low 8 bits of Y:$0770 for power-on phase position. Doing this forces the
phase position to zero
I182=$C006 // ADC B Register for motor 1
I183=$C001 // Not used for brush motors; leave at default
I184=$FFF000 // Use the highest 12 bits of the ADC word

// Current loop
I161=0.001 // This is a starting value; can be adjusted to improve open-loop response
I162=0
I176=0
```

DC BRUSH MOTOR DRIVE SETUP WITH TURBO PMAC

Commutation Phase Angle: Ixx72

Ixx72 controls the angular relationship between the phases of a multiphase motor. When Turbo PMAC is closing the current loop digitally for Motor **xx**, the proper setting of this variable depends on the polarity of the current measurements as follows:

If the phase current sensors and ADCs in the amplifier are set up so that a positive PWM voltage command for a phase yields a negative current measurement value, **Ixx72** must be set to a value less than 1024: 683 for a 3-phase motor, or 512 for a DC brush motor.

If these are set up so that a positive PWM voltage command yields a positive current measurement value, **Ixx72** must be set to a value greater than 1024: 1365 for a 3-phase motor, or 1536 for a DC brush motor. The testing described below shows how to determine the proper polarity.

The direct-PWM algorithms in the Turbo PMAC are optimized for 3-phase motors and will cause significant torque ripple when used with 2- or 4-phase motors. Delta Tau has created user-written phase algorithms for these motors; contact the factory if interested in obtaining these.



Note

It is important to set the value of **Ixx72** properly for the system. Otherwise, the current loop will have unstable positive feedback and want to saturate. This could cause damage to the motor, the drive, or both, if overcurrent shutdown features do not work properly. If unsure of the current measurement polarity in the drive, consult the Testing PWM and Current Feedback Operation section of this manual.

For commutation with digital current loops, the proper setting of **Ixx72** is unrelated to the polarity of the encoder counter. This is different from commutation with analog current loops (sine-wave control), in which the polarity of **Ixx72** (less than or greater than 1024) must match the encoder counter polarity. With the digital current loop, the polarity of the encoder counter must be set for proper servo operation; with the analog current loop, once the **Ixx72** polarity match has been made for commutation, the servo loop polarity match is guaranteed.

Special Instructions for Direct-PWM Control of Brush Motors

Special settings are needed to use the direct-PWM algorithms for DC brush motors. The basic idea is to trick the commutation algorithm into thinking that the commutation angle is always stuck at 0 degrees, so current into the A phase is always quadrature (torque-producing) current. These instructions assume:

- The brush motor's rotor field comes from permanent magnets or a wound field excited by a separate means; the field is not controlled by one of the phases of this channel.
- The two leads of the brush motor's armature are connected to amplifier phases (half-bridges) that are driven by the A and C-phase PWM commands from Turbo PMAC. The amplifier may have an unused B-phase half-bridge, but this does not need to be present.

The following settings are the same as for permanent-magnet brushless servo motors with an absolute phase reference:

- **Ixx01 = 1** (commutation directly on Turbo PMAC) or **Ixx01=3** (commutation over the MACRO ring)
- **Ixx02** should contain the address of the PWM A register for the output channel used or the MACRO Node register 0 (these are the defaults), just as for brushless motors.
- **Ixx29** and **Ixx79** phase offset parameters should be set to minimize measurement offsets from the A and B-phase current feedback circuits, respectively.
- **Ixx61**, **Ixx62**, and **Ixx76** current loop gains are set just as for brushless motors.
- **Ixx73 = 0**, **Ixx74 = 0**: These default settings ensure that Turbo PMAC will not try to do a phasing search move for the motor. A failed search could keep Turbo PMAC from enabling this motor.
- **Ixx77 = 0** to command zero direct (field) current.
- **Ixx78 = 0** for zero slip in the commutation calculations.
- **Ixx82** should contain the address of ADC B register for the feedback channel used (just as for brushless motors) when the ADC A register is used for the rotor (armature) current feedback. The B register itself should always contain a zero or near-zero value.
- **Ixx81 > 0**: Any non-zero setting here makes Turbo PMAC do a "phasing read" instead of a search move for the motor. This is a dummy read, because whatever is read is forced to zero degrees by the settings of **Ixx70** and **Ixx71**, but Turbo PMAC demands that some sort of phase reference be done. (**Ixx81=1** is fine.)
- **Ixx84** is set just as for brushless motors, specifying which bits the current ADC feedback uses. Usually, this is **$FFF000** to specify the high 12 bits.

Special settings for brush motor direct PWM control:

- **Ixx70 = 0**: This causes all values for the commutation cycle to be multiplied by 0 to defeat the rotation of the commutation vector.
- **Ixx72 = 512** (90^{o}e) if voltage and current numerical polarities are opposite, **1536** (270^{o}e) if they are the same. If the amplifier would use 683 (120^{o}e) for a 3-phase motor, use **512** here; if it would use **1365** (240^{o}e) for a 3-phase motor, use **1536** here.
- **Ixx96 = 1**: This causes Turbo PMAC to clear the integrator periodically for the (nonexistent) direct current loop, which could slowly charge up due to noise or numerical errors and eventually interfere with the real quadrature current loop.

Settings that do not matter when using brush motors (not when using brushless motors):

- **Ixx71** (commutation cycle size) does not matter because an **Ixx70** setting of **0** defeats the commutation cycle.
- **Ixx75** (Offset in the power-on phase reference) does not matter because commutation cycle has been defeated. Leaving this at the default of **0** is fine.
- **Ixx83** (ongoing commutation position feedback address) does not matter, since the commutation has been defeated. Leaving this at the default value is fine.
- **Ixx91** (power-on phase position format) does not matter, because whatever is read for the power-on phase position is reduced to zero.

Example Setup for Motor 1 (DC Brush Motor)

Assumes the user has a DC Brush motor and a Turbo UMAC with ACC-24E2.

```
// Assumes Turbo UMAC with ACC-24E2
I100=1 // Activate motor
I101=1 // Commutate motor directly
I102=$78203

I173=0 I174=0 // Do not use power-on phasing
I177=0 // Zero direct (field) current
I178i=0 // Zero slip gain in commutation calculations

// Current Loop Tuning
I161=.001 // Acts like proportional gain - can be adjusted to get a better open-loop response
I176=0 // Acts like derivative gain
I162=0 // Acts like integral gain

I182=$078206 // Current Loop Feedback Address
I181=1 // Power-on phase position address, arbitrary for brush motor

I184=$FFF000 // Current ADC Mask Word for 12-bit ADCs

I170=0 // # of commutation cycles; =0 defeats rotation of the commutation vector
I172=1536 // Commutation angle; assumes the amplifier would use 1365 here normally
I196=1 // To clear the integrator periodically for the (nonexistent) direct current loop

I7210=0 // Output Mode: Outputs A and B are PWM; Output C is PWM
```

Testing PWM and Current Feedback Operation



WARNING

On many motor and drive systems, potentially deadly voltage and current levels are present. Do not attempt to work directly with these high voltage and current levels unless fully trained on all necessary safety procedures. Low-level signals on Turbo PMAC and interface boards can be accessed much more safely.

Most of the time in setting up a direct PWM interface, there is no need to execute all of the steps listed in these sections (or the Turbo Setup program will do them automatically). However, the first time this type of interface is setup, or there are problems, these steps will be of assistance.

For safety reasons, all of these tests should be done with the motor disconnected from any loads. All settings made as a result of these tests are independent of load properties, so will still be valid when the load is connected.

Before testing any of Turbo PMAC's software features for digital current loop and direct PWM interface, it is important to know whether the hardware interface is working properly. PMAC's M-Variables are used to access the input and output registers directly. The examples shown here use the suggested M-Variable definitions for Motor 1.

Purpose

The purpose of these tests is to confirm the basic operation of the hardware circuits on PMAC, in the drive, and in the motor, and to check the proper interrelationships. Specifically:

- Confirm operation of encoder inputs and decode
- Confirm operation of PWM outputs
- Confirm operation of ADC inputs
- Confirm correlation between PWM outputs and ADC inputs
- Determine proper current loop polarity
- Confirm commutation cycle size
- Determine proper commutation polarity

Preparation

First, define the M-Variables for the encoder counter, the three PWM output registers, the amplifier-enable output bit, and the two ADC input registers. Using the suggested definitions for Motor 1, utilizing Servo IC 0, Channel 1:

```
M101->X:$078001,0,24,S              ; Channel 1 Encoder position register
M102->Y:$078002,8,16,S              ; Channel 1 PWM Phase A command value
M104->Y:$078003,8,16,S              ; Channel 1 PWM Phase B command value
M107->Y:$078004,8,16,S              ; Channel 1 PWM Phase C command value
M105->Y:$078005,8,16,S              ; Channel 1 Phase A ADC input value
M106->Y:$078006,8,16,S              ; Channel 1 Phase B ADC input value
M114->X:$078005,14                  ; Channel 1 Amp Enable command bit
```



Note

The ADC values are declared as 16-bit variables even though typically, 12-bit ADCs are used; this puts the scaling of the variable in the same units as **Ixx69**, **Ixx57**, **Ixx29**, and **Ixx79**.

It is useful to monitor these values in the Watch window of the Executive program. Therefore, add the variable names to the Watch window which causes the program to repeatedly query Turbo PMAC for the values and display them. Then the hardware can be exercised with on-line commands issued through the Terminal window.

To prepare Turbo PMAC for these tests:

1. Set **I100** to **0** to deactivate the motor.
2. Set **I101** to **0** to disable commutation (This allows for manual use of these registers.)
3. Make sure that **I7000**, **I7004**, **I7016**, and **I7017** are set up properly to provide the PWM signals desired.
4. If the Amplifier Enable bit is 1, set it to zero with the command **M114=0**.
5. Set **Ixx00** and **Ixx01** for all other motors to zero.

Position Feedback and Polarity Test

If the PWM command values observed in the Watch window are not zero, set them to zero with the command:

```
M102=0 M104=0 M107=0
```

The motor can be turned (or pushed) freely by hand now. As the motor is turned, monitor the **M101** value in the Watch window. Look for the following:

- It should change as the motor is moved.
- It should count up in one direction, and count down in the other direction.
- It should provide the expected number of counts in one revolution or linear distance increment.
- As the motor is returned repeatedly to a reference position, it should report (approximately) the same position value each time.

If these things do not happen, check the encoder/resolver operation, its connection to Turbo PMAC and the Turbo PMAC decode variable **I7mn0**. Double-check that the sensor is powered. In addition, look at the encoder waveforms with an oscilloscope.

If the direction of motion to be the positive direction is known, check this here. If the direction is incorrect, invert it by changing **I7mn0**, usually from 7 to 3, or from 3 to 7. If the direction is not known, change it later, but make another change at that time to maintain the proper commutation polarity match; usually by exchanging two of the motor phase leads at the drive.



Note

Because **I100** has been set to **0**, and **I103** may not yet have been set properly, any change of position will not be reflected in the motor position window.

PWM Output and ADC Input Connection



WARNING

Make sure before applying any PWM commands to the drive and motor in this fashion that the resulting current levels are within the continuous current rating of both drive and motor.

First, enable the amp, then apply a very small positive command value to Phase A and a very small negative command value to Phase B with the on-line commands:

```
M114=1                                    ; Enable amplifier
M102=I7000/50 M104=-I7000/50 M107=0       ; A pos, B neg, C zero
```

This provides a command at 2% of full voltage into the motor, which should be well within the continuous current rating of both drive and motor. To make the sum of these commands equal to zero so as not to put a net DC voltage on the motor is a good idea. Furthermore, putting all three commands on one line causes the changes to happen virtually instantaneously.

With power applied to the drive and the amplifier enabled (**M114=1**), current readings should be received in the ADC registers as shown by the M-Variables **M105** and **M106** in the Watch window.

Since the M-Variables are defined as ±32,768 for full current range, which should correspond approximately to the instantaneous current limit. Make sure that the value read does not exceed the continuous current limit, usually which is about 1/3 of the instantaneous limit. If well below the continuous current limit, increase the voltage command to 5% to 10% of maximum. For example:

```
M102=I7000/10 M104=-I7000/10 M107=0       ; 10% of maximum
```

PWM/ADC Phase Match

Command values from Turbo PMAC's Phase A PWM outputs should cause a roughly proportionate response of one sign or the other on Turbo PMAC's Phase A ADC input (or whatever the phase is named in the motor and drive). The same is true for Phase B.

If no response is received on either phase, check the entire setup again, including answering the following questions:

- Is the drive properly wired to Turbo PMAC, either directly or through an interface board?
- Is the motor properly connected to the drive?
- Is the drive properly powered, both the power stage, and the input stage?
- Is the interface board properly powered?
- Is the amplifier enabled (**Mxx14=1** on Turbo PMAC and indicator ON at the drive)?
- Is the amplifier in fault condition? If so, why?

If only an ADC response is received on one phase, the phase outputs and inputs may not be matched properly. For example, the Phase B ADC may be reading current from the phase commanded by the Phase C PWM output. Confirm this by trying other combinations of commands and checking which ADC responds to which phase command. If there is not a proper match, change the wiring between Turbo PMAC and the drive. Changing the wiring between drive and motor will not help here.

Synchronous Motor Stepper Action

With a synchronous motor, this command should cause the motor to lock into a position, at least weakly, like a stepper motor. This action may be received temporarily on an induction motor, due to temporary eddy currents created in the rotor. However, an induction motor will not keep a holding torque indefinitely at the new location.

Current Loop Polarity Check

Observe the signs of the ADC register values in **Mxx05** and **Mxx06**. These two values should be of approximately the same magnitude, and must be of the opposite sign from each other. Again, remember that these readings may appear noisy. Observe the base value underneath the noise. If **Mxx05** is positive and **Mxx06** is negative, the sign of the PWM commands matches the sign of the ADC feedback values. In this case, the Turbo PMAC phase angle parameter **Ixx72** must be set to a value greater than 1024 (1365 for a 3-phase motor).

If **Mxx05** is negative and **Mxx06** is positive, the sign of the PWM commands is opposite that of the ADC feedback values. In this case, **Ixx72** must be set to a value less than 1024 (683 for a 3-phase motor).

Make sure your **I172** value is set properly before attempting to close the digital current loops on Turbo PMAC. Otherwise, positive feedback will occur, creating unstable current loops which could damage the amplifier and/or motor.

If **Mxx05** and **Mxx06** have the same sign, the polarities of the current sense circuitry for the two phases is not properly matched. In this case, something has been improperly wired in the drive or between Turbo PMAC and the drive to give the two phase-current readings opposite polarity. One of the phases will have to be fixed.

Do not attempt to close the digital current loops on Turbo PMAC until the polarities of the current sense circuitry for the two phases have been properly matched. This will involve a hardware change in the current sense wiring, the ADC circuitry, or the connection between them. As an extra protection against error, make sure that **Ixx57** and **Ixx58** are set properly for I^2T protection that will shut down the axis quickly if there is saturation due to improper feedback polarity.

Troubleshooting

If you are not getting the current readings expected, probe the motor phase currents on the motor cables with a snap-on hall-effect current sensor. If the current is not seen when commanding voltages, check for phase-to-phase continuity and proper resistance when the motor is disconnected.

SETTING I^2T PROTECTION (TURBO PMAC)

This section describes how to set I^2T protection for Turbo PMAC; for details on setting I^2T for Non-Turbo PMAC, see the PMAC User's Manual.

Setting the I^2T protection for the amplifier/motor system for PMAC2 direct PWM commutation is very important. Normally, an amplifier has internal I^2T protection because it is closing the current loop. When PMAC2 is closing the current loop, the amplifier cannot protect itself or the motor from overheating. Either set up the I^2T protection using one of the Setup Programs or manually set the **Ixx69**, **Ixx57** and **Ixx58** variables based on the following specifications:

Parameter	**Description**	**Notes**
MAX ADC Value	Maximum Current output of amplifier relative to a value of 32767 in Ixx69	3U081= 26.02 A 3U151= 48.7 9 A 3U201= 65. 05 A
Instantaneous Current Limit	The lower of the amplifier or motor system	RMS or Peak*
Continuous Current Limit	The lower of the amplifier or motor system	Usually RMS
I^2T protection time	Time at instantaneous limit	Usually two seconds
Magnetization Current	Ixx77 value for induction motors	Only for induction motors
Servo Update Frequency	Default is 2258 Hz.	
* If specification given in RMS, calculate this value by 1.41 to obtain peak current for calculations.		

Example Calculations for a Direct PWM commutated motor:
MAX ADC = 26.02 A (obtained from the specifications section of the amplifier's manual)
Instantaneous Current Limit = 16 A Peak
Continuous Current Limit = 8 A RMS
I^2T protection time = 2 seconds
Magnetization Current (**Ixx77**) = 0
Servo Update = 2.258 kHz

$$Ixx69 = \frac{\text{Instaneous Limit (Peak) RMS}}{\text{MAXADC}} \times 32767 \times \cos(30)$$

If the calculated **Ixx69** is greater than 32767, then **Ixx69** equals 32767.

$$Ixx57 = \frac{Continuous Limit}{Instantaneous Limit} x32767 xCos(30^\circ)$$

$$Ixx58 = \frac{Ixx69^2 - Ixx77^2 - Ixx57^2}{32767^2} \times ServoFrequency(Hz) \times Time(seconds)$$

Based on the above data and equations, the following results:

Ixx69=24675
Ixx57=14189
Ixx58=3669

For details about I^2T protection, refer to the safety sections of the User Manual. Details about the variable setup can be found in the Software Reference manual.

CALCULATING MINIMUM PWM FREQUENCY

The minimum PWM frequency requirement for a system is based on the time constant of the motor. Calculate the minimum PWM frequency to determine whether the amplifier will properly close the current loop. Systems with very low time constants need the addition of chokes or inline inductive loads to allow the PMAC to properly close the current loop of the system. In general, the lower the time constant of the system, the higher the PWM frequency must be.

Calculate the motor time constant by dividing the motor inductance by the resistance of the phases.

$$\tau_{motor} = \frac{L_{motor}}{R_{motor}}$$

The relationship used to determine the minimum PWM frequency is based on the following equation:

$$\tau > \frac{20}{2\pi \times PWM(Hz)}$$

$$\therefore PWM(Hz) = \frac{20}{2\pi\tau}$$

Example:

$$L_{motor} = 5.80 \text{ mH}$$

$$R_{motor} = 11.50\ \Omega$$

$$\tau_{motor} = \frac{5.80mH}{11.50\Omega} = 0.504m\,sec$$

Therefore, $PWM(Hz) = \frac{20}{2\pi \times (0.504m\,sec)} = 6316$ Hz.

Based on this calculation, set the PWM frequency to at least 6.32 kHz.

PWM DRIVE COMMAND STRUCTURE

The amplifier functions in two modes: Default and Enhanced.

Default Mode

Default Mode is the mode the amplifier is in when it is first powered on or the power is cycled for any reason. Default mode is compatible with all Delta Tau amplifiers and the A/D converters used on these amplifiers.

In this mode, the amplifier returns not only the currents for phases A and B but also the fault codes for the axes associated with those currents. The fault codes occupy the lower 12-bits on each phase.

For Default mode to work correctly, make sure that the A/D strobe word for the axis is set to the correct value for the A/D on the amplifier. For instance, the current Delta Tau amplifiers use a 12-bit Burr Brown part requiring a strobe word of $3FFFFF.

Set the amplifier into Default mode according to the following commands issued to PMAC:

PMAC Type	Command	Notes
Non-Turbo PMAC	`WX:$C014, $3FFFFF`	Directly writes to memory
Turbo PMAC	`I7m06=$3FFFFF`	Replace **m** with your Servo IC Number
Power PMAC with Gate1-Style Servo IC	`Gate1[i].AdcStrobe=$3FFFFF`	**i** is the card's index number based upon its base address.
Power PMAC with Gate3-Style Servo IC	`Gate3[i].AdcAmpCtrl=$FFFFFC02`	**i** is the card's index number based upon its base address.

This value can be saved to PMAC memory and sent to the amplifier on boot automatically.

Enhanced Mode

Enhanced mode is available on the Geo series of Delta Tau amplifiers and offers many more options than Default mode. Like the Default mode, Enhanced mode requires that a special strobe word be written to the amplifier, and like Default mode, this word may be saved to PMAC memory and issued upon each boot automatically. Enhanced mode axes and Default mode axes may not be mixed on the same amplifier; that is, all axes on the same amplifier must use the same mode.

Enhanced mode not only offers the fault codes associated with any axis on the lower 12 bits of current feedback A, but many other options, including reading and writing the on-board EEPROM, setting special SFRs for jumperless configuration of the amplifier, and reading both bus voltage and IGBT temperatures.

Use the following commands to set the strobe word:

PMAC Type	Command	Notes
Non-Turbo PMAC	`WX:$C014, $C00003`	Directly writes to memory
Turbo PMAC	`I7m06 = $C00003`	Replace **m** with your Servo IC Number
Power PMAC	`Gate1[i].AdcStrobe=$C00003` `Gate3[i].AdcAmpCtrl=$C0000204`	Use **Gate1[*i*].AdcStrobe** for Gate1-Style Servo ICs, or **Gate3[*i*].AdcAmpCtrl** for Gate3-Style Servo ICs, where ***i*** is the card's index number based upon its base address. Do not issue both commands.

When using Enhanced Mode with Power PMAC, there are three additional settings you must set:

1. Set **Motor[*x*].PhaseCtrl=4**.
2. Set **Gate3[*i*].Chan[*j*].PackInData=0**.
3. Set **Gate3[*i*].Chan[*j*].PackOutData=0**.

The above command is modal and subsequent communication will be in Enhanced Mode until the drive's power is cycled.

At present, the commands sent to axis one are active on all axes of the amplifiers. It is wise to code any software used to drive the amplifier so that the same command is sent to all axes, so that when independent control becomes available, the software will be both compatible and easily changed.



Note

After you have enabled Enhanced Mode, do not set the drive back to Default Mode.

Table of Enhanced Mode Features

Below is a table that summarizes commands you can issue to the drive via the Strobe Word.

Mode	Gate1 Strobe Word (I7m06, Gate1[*i*].AdcStrobe, or WX:$C014,{value})	Gate3 Strobe Control (Gate3[*i*].AdcAmpCtrl)
Default Mode	$3FFFFF	$FFFFFC02
Enhanced Mode	$C00003	$C0000204
Return IGBT Temperature	$800003	$80000204
Set shunt regulator control for 120 VAC input (3U042 only)	$A0000B	$A0000A04
Set PWM control for DC brush motors	$A00013	$A0001204
Turn Line Monitor Off	$A00023	$A0002204



Note

The above commands in blue can only be issued when you are using the drive in Enhanced Mode.



Note

If you want to set any of the above commands via a C program on Power PMAC, remember that **Gate1[*i*].AdcStrobe** is a 32-bit word, so you must first shift the value above in the "Gate1 Strobe Word" column left 8 bits before writing to the register. This is because the relevant values exist only in the top 24 bits of the register.

After issuing any of these commands, you may read the response in the phase B current register of motor 1, with the exception of reading the IGBT temperature, which is per axis. Below is a list of memory locations or parameters where this information can be found depending on which type of PMAC you have:

PMAC Type	**Memory Location**	**Note**
Non-Turbo	Suggested M-Variable **Mxx06** (**M106** for Motor 1)	Alternatively, read this memory location using the **RHY** command, e.g. **RHY$C006** for motor 1. Read **Mxx06** for IGBT temperature, **M106** for all other commands.
Turbo	Suggested M-Variable **Mxx06** (**M106** for Motor 1)	This memory location depends on the motor related to the IGBT temperature you want to read. Read **Mxx06** for IGBT temperature, **M106** for all other commands.
Power PMAC with Gate1-Style Axis Interface	**Gate1[*i*].Chan[*j*].Adc[1]**	***i*** is the index of your servo gate and ***j*** is the channel number**.** Change ***j*** appropriately when reading IGBT temperature, otherwise set ***j*=0** for all other commands.
Power PMAC with Gate3-Style Axis Interface	**Gate3[*i*].Chan[*j*].AdcAmp[1]**	***i*** is the index of your servo gate and ***j*** is the channel number. Change ***j*** appropriately when reading IGBT temperature, otherwise set ***j*=0** for all other commands.

TROUBLESHOOTING

Error Codes

In most cases, the Geo Drive communicates error codes with a text message via the serial port to the host. Some error codes are also transmitted to the Status Display. The same message is saved in the EEPROM under an error history log (FLTHIST, ERR) so nothing is lost when power is removed. Not all errors reflect a message back to the host. In these cases, the no-message errors communicate only to the Status Display.

The response of the Geo Drive to an error depends on the error's severity. There are two levels of severity:

1. Warnings (simply called errors and not considered faults and do not disable operation).
2. Fatal errors (fatal faults that disable almost all drive functions, including communications).

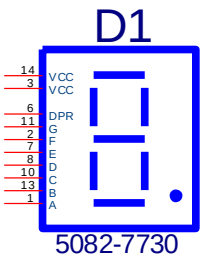


Note

The Geo Drive disables automatically at the occurrence of a fault.

3U Drive Status Display Codes

The 7-segment display on the current model (shown to the right), 16 numeric codes plus two decimal points, provides the following codes:



Display	Description	Cause
0	Normal operation	
1	Instantaneous over current	An internal timer has noticed that Axis 1 is taking more RMS current than the drive was designed to produce. Reduce loading.
2	Integrated current over time	Over current sensors have detected an excess of current through the motor leads. Typically, a shorted motor, shorted cable, extremely excessive current, or voltage commands from the controller through the power stage. The controller is the PMAC controller.
3	Over PWM fault – global	PMAC or UMAC setup is incorrect. The I-variables for the phase clock frequency and PWM frequencies should be adjusted under the Max PWM frequency
4	IGBT thermal failure	Heat sink temperature is above a factory pre-set range (approximately 75 ºC). Drawing excessive current through the amplifier, blocked airflow through the amplifier or operation in an ambient temperature above 45 ºC.
5	Motor over temp warning	Normally-closed input on the front of the Geo drive amplifier is detected in open circuit between pins 3 and 4.
b	Over voltage.	The bus voltage has exceeded a factor pre-set threshold of 820 V for 480 V drives or 420 V for 230 V drives. Lack of ability to dump the regenerated energy from the motor. A shunt regulator or dump resistor can help GAR 48 or GAR78. Another common cause can be excessively high input line voltage.
C	Under voltage	The DC bus internal to the Geo drive has decreased below a factory pre-set threshold of 16 to 30 VDC (no AC input power to the drive).
d	Shunt regulator fault	Fatal fault where the internal drive electronics for the power stage that controls the shunt regulator has failed. If unable to reset this fault, the unit needs to be returned to the factory for repair. A short in the shunt regulator or motor leads can cause this fault code. The output drive transistors have gone into a linear mode instead of a switching mode (DSAT).
E	Ground Fault	A short in the shunt regulator or motor leads can cause this fault code. The output drive transistors have gone into a linear mode instead of a switching mode (DSAT).
F	Gate drive power fault	Fatal fault where the internal drive electronics for the power stage that controls the six IGB outputs has failed. If unable to reset this fault, the unit needs to be returned to the factory for repair. A short in the shunt regulator or motor leads can cause this fault code. The output drive transistors have gone into a linear mode instead of a switching mode (DSAT).

Status LEDs

LED	Color	Description
FLT/ENA	Red/Green	Green when axis enabled. Red when drive is at fault. (Unlit does not necessarily mean fault.)
DC BUS	Red	Lit when bus powered.
SHUNT	Yellow	Lit when drive is attempting to dump power through the external shunt regulator regen resistor.
+5V PWR	Green	Lit when 5V logic has power.
20V PWR	Green	Lit when DC is on
For 3U081, 3U151 and 3U201		

Amplifier Stops and Displays a Code

Amplifier Fault

If a 3U amplifier displays a digit other than 0, please refer to the appropriate table from above for an explanation of fault codes.

Amplifier is Dark

If the amplifier status display, +5V, +12V, -12V, ENA1, and ENA2 are not illuminated, verify that 24VDC power is connected to the 3U amplifier.
If the condition described above is present, and the 3U amp is used in a UMAC rack along with a power supply, verify that the AC line is connected to the power supply.

Motor Does Not Move Upon a Command

Verify that PWM cables and motor leads are correctly connected to 3U amplifier.
Is the motor properly phased? Is the BUS voltage ON?

Cannot Phase a Motor

Verify that PMAC is properly configured and reads the motor's feedback. Power-cycle the drive and the controller.



Note

If a shunt (regen) resistor is required, use the shunt terminals on the backplane.

If the 3U amplifier is not used in Delta Tau UMAC rack, it is a user's responsibility to assure that the proper cooling is provided for the IGBTs. Delta Tau suggests a fan capable of at least 100 CFM placed as close to the heatsink as possible.

If the bus connection to the 3U amp is not done via Delta Tau backplane, a decoupling capacitor (about 120 μF) for positive (+) and negative (–) bus should be used.

APPENDIX A

PWM Cable Ordering Information

Cable	Length						Part Numbers
	600mm (24")	900mm (36")	1.5m (60")	1.8m (72")	2.1m (84")	3.6m (144")	
CABPWM-1	√						200-602739-024X
CABPWM-2		√					200-602739-036x
CABPWM-3			√				200-602739-060x
CABPWM-4				√			200-602739-072x
CABPWM-5					√		200-602739-084x
CABPWM-6						√	200-602739-144x

Mating Connector and Cable Kits

Cable sets can be purchased directly from Delta Tau to make the wiring of the system easier. Available cable kits (CABKITxx) are listed below.

However, for those who wish to manufacture their own cable sets, the table below provides Connector Kits to use with each drive. Connector Kits (CONKITxx) include the MOLEX connectors and pins for the motor outputs, and 24VDC power supply connector.

Cable kits have terminated cables on the drive end and flying leads on the other.

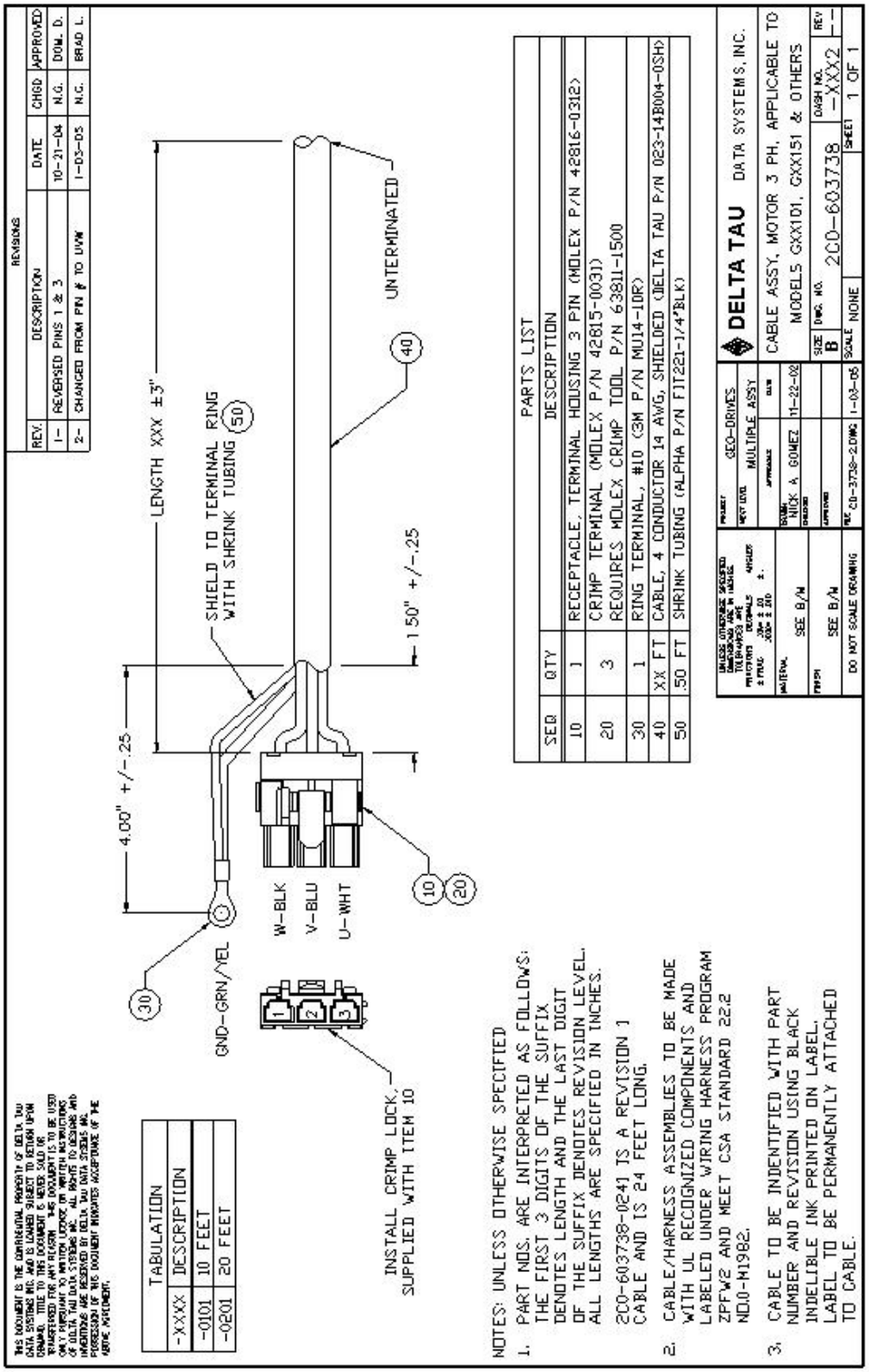
Kit Name	Description
CONKIT3A	Mating Connector Kit for drives minimum 5A up to 20A continuous rating : Includes Molex Connector kit for one motor, and 24V power connection for the backplane. For 3U081, 3U151 and 3U201 Requires Molex Crimp Tool for proper installation. Molex Part Number: 63811-0400 for the Motor Output
CABKIT3B	Includes Molex mating connectors pre-crimped for dual axis drives up to 5-amp continuous rated For 3U081, 3U151 and 3U201 (1) 3 ft. 24VDC Power Cable (1) 10 ft. shielded Motor Cable

Connector and Pins Part Numbers

CONKIT3A

Connector	D/T part number	D/T part number individuals	Molex part number
Motor (x1) 3-pins	200-H00F03-049	Housing: 014-H00F03-049 Pins: 014-042815-0031	42816-0312 42815-0031
24V 2-pins	200-C30F02-LHM	Housing: 014-C30F02-LHM Pins: 025-701030-MCT	10-01-3026 08-70-1030

Motor Cable Drawing (CABKIT3B)



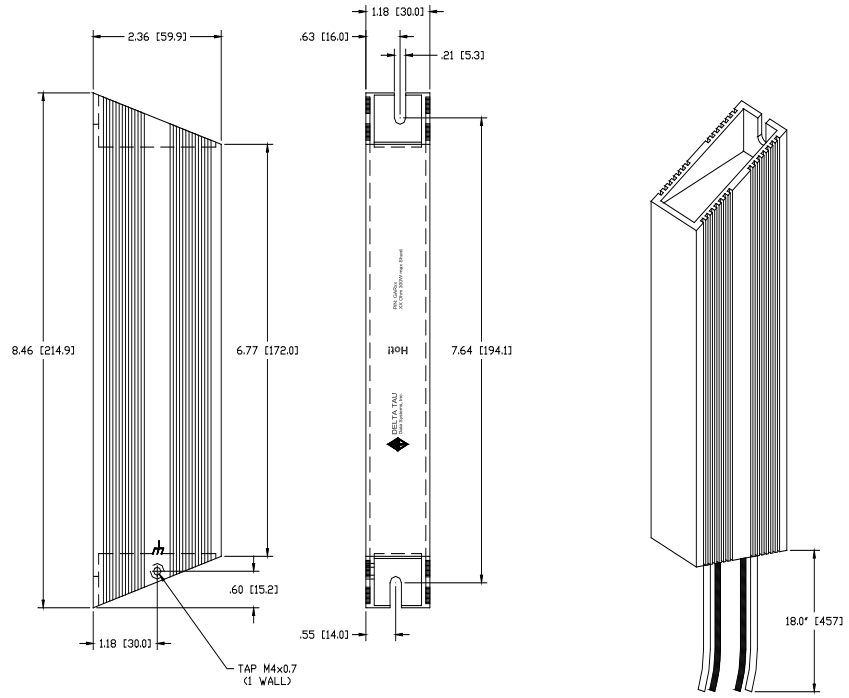
APPENDIX B

Regenerative Resistor: GAR78/48

Model	Description	1.5/4.5A	3/9A	5/10A	10/20A	15/30A	20/40A	30/60A
GAR78	300 W 78 OHM regenerative resistor with Thermostat protection. Includes 18 inch wire cable. Single or Dual Axis.	√	√	√				
GAR48	300 W 48 OHM regenerative resistor with Thermostat protection. Includes 18 inch wire cable. Single or Dual Axis.				√	√		
GAR48-3	300 W 48 OHM regenerative resistor with Thermostat protection. Includes 18 inch wire cable.						√	√

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REVISIONS				
REV.	DESCRIPTION	DATE	CHGD	APPROVED
--	NEW DRAWING RELEASE	2-04-03	N.G.	BILL K.



Specifications:

Continuous Wattage: 300 Watts
Hi Pot: 2500VAC 1 Second

Thermostat:
Normally Closed
115VAC, 1 Amp
Open at 227 +/- 11 degrees C.

Ohms:
008-0GAR48 is 48 ohms
008-0GAR78 is 78 Ohms

Leads:
Resistor: 18 inch High Temp, 14 AWG Min, White
Thermostat: 18 Inch High Temp, 16 AWG Min, Black

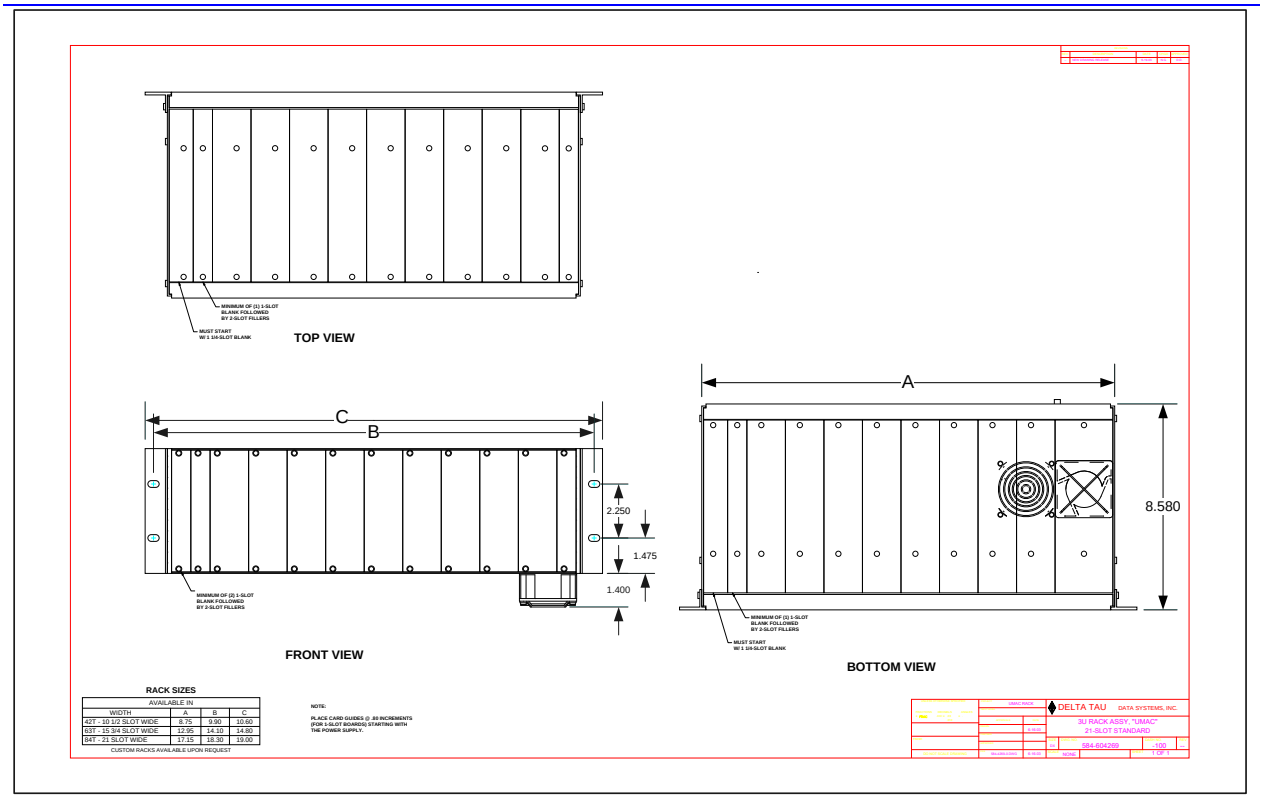
Vendor Reference Numbers:
008-0GAR48: SPR822-1
008-0GAR78: SPR822-2
IRV Series

NOTE:
1. SILKSCREEN SIDES SHOWN PER ARTWORK, 008-0GARxx-ART, USING BLACK EPOXY INK.

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ARE: FRACTIONS DECIMALS ANGLES .XX± .03 ±. .XXX± .010 ± FRAC	PROJECT	GEO-BOOK AMP	DELTA TAU DATA SYSTEMS, INC.
	NEXT LEVEL	MULTIPLE ASSY	RESISTOR, SHUNT REGULATOR, 48 & 78 Ohm 300W MAX
	APPROVALS	DATE	
MATERIAL SEE NOTES	DRAWN NICK A. GOMEZ	02-04-03	
FINISH SEE NOTES	CHECKED		SIZE C DWG. NO. 008-0GARXX DASH NO. -300 REV --
DO NOT SCALE DRAWING	APPROVED		SCALE NONE SHEET 1 OF 1
	FILE 008x0GARxx.DWG	02-04-03	

APPENDIX C

3U Rack DIMENSIONS



3U Rack Sizes			
Width	**A**	**B**	**C**
D1 - 10 ½ Slot wide	22.23 cm (8.75 in)	25.15 cm (9.9 in)	26.92 cm (10.6 in)
D2 – 15 ¾ Slot wide	32.89 cm (12.95 in)	35.81 cm (14.10 in)	37.60 cm (14.8 in)
D3 – 21 Slot wide	43.56 cm (17.15 in)	46.48 cm (18.30 in)	48.26 cm (19 in)
Note: All dimensions on the drawing are in inches			

APPENDIX D: FPGA COMMAND REGISTER

This section describes the commands given in the table above in more detail, and adds a few more commands.

The FPGA has a 4-bit command register located in the bits [22:19] of the strobe word. The strobe word can be located at the following memory locations depending on which type of PMAC you are using, according to the following table:

PMAC Type	Location	Notes
Non-Turbo PMAC	$C014	Write to this memory location using the **WX:$C014,value** command, where **value** is what you want to write to the strobe word
Turbo PMAC	**I7m06**	**m** is the Servo IC number of the Axis Interface gate as determined by the gate's base address
Power PMAC with Gate1-Style Axis Interface	**Gate1[i].AdcStrobe**	**i** is the index of the card as determined by the Axis Interface gate's base address.
Power PMAC with Gate3-Style Axis Interface	**Gate3[i].AdcAmpCtrl**	**i** is the index of the card as determined by the Axis Interface gate's base address.

These bits are used to read data from the drive as well as write data to the FPGA Control Registers and the drive's onboard EEPROM. The MSB (bit 23) of the strobe word must be a 1 since it is the start bit. In addition, the strobe word LSB and LSB+1 are stop bits and must both be set to 1.

All requested data is returned in the lower 12 bits of the phase B current feedback for each axis. Write command data is written to bits [10:3] of the strobe word.

Below is a table showing the effect of various commands:

Command	Strobe Word Bit Numbers	Value to Write to Strobe Word (Turbo/Non-Turbo)	Value to Write to Strobe Word (Power)
Return the IGBT Temperature (default in enhanced mode)	[22:19] = 0000	$800003	$80000204
Return the Bus Voltage	19	$880003	$88000204
Return the command value, RST Line Monitor Status and Control Register Value	20	$900003	$90000204
Return the Command Value, UART Received Data Bit Status and One-Wire Read Register Value	[20:19]	$980003	$98000204
Write a data word to the FPGA SFRs	21	$A00xxx*	$A00xxx04†
Write a data word to the UART transmitter	21 & 19	$A80xxx*	$A80xxx04†

* The lower three nibbles will vary depending on the data written since the data is contained in bits [10:3] of the strobe word. However, the LSB and LSB+1 are stop bits and must be set to 1.
† Bits [20:9] will vary depending on the data written since the data is contained in bits [18:11] of the strobe word.

Strobe Word

While in Default mode, the Control Word only sets up the operation of the A/D converter. In Enhanced mode, it takes on much more meaning. The significance of each Strobe Word bit is illustrated in the following figure:

23	22	21	20	19	18	17	16	15	14	13	12
Start bit	*CB[3]*	CB[2]	CB[1]	CB[0]	x	x	x	x	x	x	x

11	10	9	8	7	6	5	4	3	2	1	0
x	D[7]	D[6]	D[5]	D[4]	D[3]	D[2]	D[1]	D[0]	x	Stop bit	Stop bit



Note

To send a command (CB[3:0]), the start bit and the two stop bits must be set.

Command Register (CB[3:0]):

Setting bits [22:19] of the strobe word to the following settings has the following corresponding effects:

$00: Returns the axis IGBT temperature in lower 12-bits of the 24-bit word containing the phase B current for the particular axis.

$01: Returns the bus voltage in lower 12 bits of the 24-bit word containing the phase B current for the particular axis.

$02: Return the current command, the status of the three phase line and the value of the local control register in lower 12 bits of the 24-bit word containing the phase B current for the particular axis.

$03: Return the current command, the status of the UART received data bit and the value of the one-wire read register in lower 12 bits of the 24-bit word containing the phase B current for the particular axis.

$04: Write a data word (D[7:0]) to the local control register.

$05: Write a data word (D[7:0]) to the UART transmitter.

The result for any command is returned in the phase B current word, so for axis 1, the data will come back in Y-register $C006. The phase A current word will be unaffected and will continue to return phase A's current and the fault status word.

Any command remains in effect until the next command. Therefore, if the command to return the IGBT temperature is issued, the 24-bit word at Y:$C006 (axis 1) will contain two A/D conversions: the upper 12-bits will be phase B currents with the lower 12-bits carrying the IGBT temperature, and Y:$C006 will continue to return this data as long as the Strobe Word contains this command. Of course, the data is refreshed in real time.

In addition, a user's program can communicate directly with the embedded EEPROM on board using the UART built into the FPGA. Commands and a procedure for doing this are located in the documentation associated with the DS2480B modem chip (included with this document).

IGBT Temperature and Bus Voltage (Turbo/Non-Turbo)

To read the IGBT temperature for each IGBT block on the amplifier, write $800003 to the A/D strobe word. The 12-bit value of the IGBT temperature for each axis will be in the lower 12-bits of the register holding the phase B current for the axis.

For example, if looking at Axis 1, find the temperature in the lower 12-bits of:

Non-Turbo	**Turbo**	**Notes**
WX:$C014,$800003	I7m06=$800003	Command to send temperature (replace m with your Servo I.C. Number)
RHY$C006		Command to read temperature
Note: For motor 1, servo I.C. 0, M102 is defined as M102->Y:$78006,8,16,S.		

The same procedure will recover the Bus Voltage, the only difference being the command:

Non-Turbo	**Turbo**	**Notes**
WX$C014,$880003	I7m06=$880003	Command to send Bus Voltage (replace m with your Servo I.C. Number)
RHY$C006	M102	Command to read Bus Voltage
Note: For motor 1, servo I.C. 0, M102 is defined as M102->Y:$78006,8,16,S.		

Drive SFRs (Special Function Registers, Turbo/Non-Turbo)

The Drive has SFRs that are used to control various drive functions. To write to an SFR, the upper three nibbles of the strobe word should be $A00 and bits [10:3] of the strobe word are used to set the individual bits of each SFR. The table below outlines the SFRs and their functions.

Description	**Bit**	**Address, Non-Turbo**	**Address, Turbo**	**Value**
Set shunt regulator control for 120 VAC input (3U042 drives only)	3	WX:$C014	I7m06	$A0000B
Set PWM control for DC brush motors	4			$A00013
Turn off Line Monitor	5			$A00023

Once set, these bits remain set until reset with a write to the SFRs or power is cycled on the amplifier.

Shunt Regulator Control

This bit will set the shunt for either 230 V or 460 V operation on the Geo 3U amplifier.

Set PWM Control for DC Brush Motors

Setting this bit will reconfigure the amplifier to drive DC brush motors instead of 3-phase brushless motors. The number of DC brush motors that can be driven depends upon the number of axes available. For each 3-phase brushless axis, one DC brush axis is possible. Ensure that this bit is set as a configuration step only and not during operation.

Turn off Line Monitor

By default, the RST Line Monitor is active. This, however, is not convenient for test or maintenance purposes. Set this bit to disable the RST Line Monitor – the amplifier will no longer fault if a loss of phase occurs. The Line Monitor is re-activated when either the bit is explicitly set or power is cycled.

Reading and Writing the SFRs

Read the SFRs by writing $900003 to the Strobe Word: WX:$C014 (non-Turbo), I7m06 (Turbo). As an example, turn off the Line Monitor:

Non-Turbo	**Turbo**	**Notes**
WX$C014,$A00023	I7006=$A00023	Set bit
RHY:$C006	M102	Read line monitor
M102->Y:$78006,8,16,s		

The lower 12-bits of $C006/M102 will contain:

11	10	9	8	7	6	5	4	3	2	1	0
0	1	0	*2/3phase flag*	0	0	0	0	0	1	0	0

These 12-bits indicate that the current command is a read SFR command (bits 11:9), the status of the 3/3 phase flag (bit 8) and the status of the Line Monitor flag (bit 2).

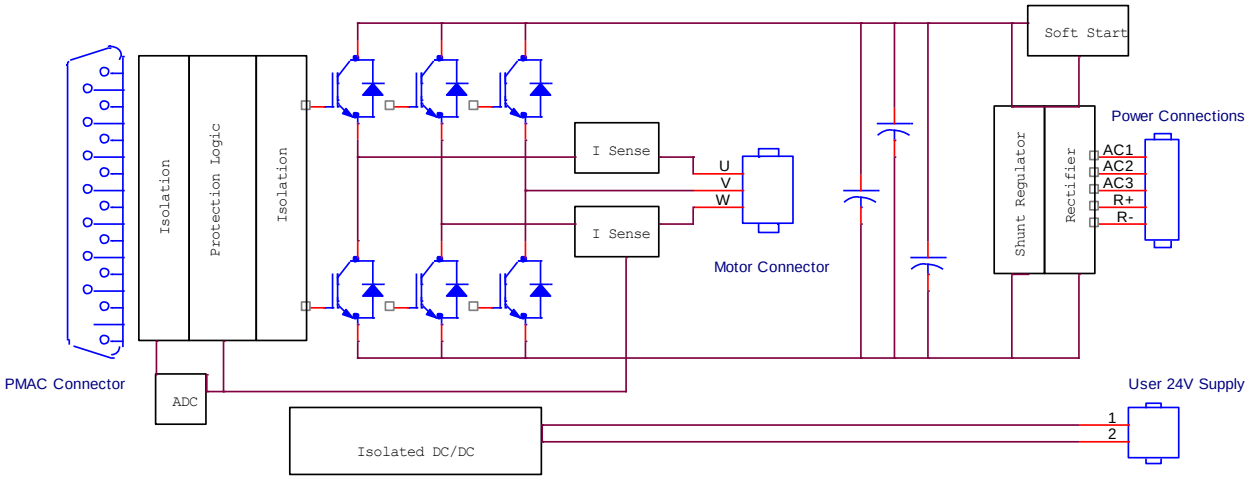


Note

Modifying the Control Register is a Read-Modify-Write procedure. To keep any previously set or cleared bits, first read the register, modify that value, and then write the register. Whatever is written to the Command Register is what is in the Command Register.

APPENDIX E: DIGITAL AMPLIFIER THEORY OF OPERATION

Below is a diagram roughly outlining the drive's internal schematic and connectors:



Block Diagram for 3U081 and 3U151 Amplifiers

These Servo Drive Amplifiers are based on Pulse Width Modulation (PWM), which is a technique employing both frequency and duty cycle to accurately create sinusoidal currents to control AC and DC motors. Each axis of the 3U Geo Direct PWM Amplifier uses a 3-½ H-bridge power output stage. Each leg employs top and bottom IGBT transistors. The motor windings are connected between the center points of top and bottom pairs. When two appropriate IGBT transistors in the bridge are turned on, voltage is applied to the two motor windings. Bridge transistors are turned on by logic from PMAC with no other conditioning necessary. The 3U Geo Direct PWM Amplifier performs no control functions itself other than self-protection; it simply accepts direct PWM commands from the controller. The controller requires the position feedback and the feedback about the current fed to the motors to commutate each controlled axis.

The current feedback is provided in digital form as a part of a serial data stream of 18 bits from the current feedback A/D converters, which are located in the 3U Geo Servo Drive Amplifier (12 bits report the current feedback and the remaining 6 bits report fault conditions). Each axis has its own mask word that tells the PMAC2 how many bits to expect from the A/D converter and must be masked to $3FFFFF. The clock and the strobe for the digital feedback are programmable at the PMAC2.

The main bus power supply connections are provided by adding the 3UBP8A (3U042) or 3UBP15A (3U081, 3U151 and 3U201) backplane for power supply. It is an unregulated rectifier-capacitor type with soft start circuitry. Power connection to the mains is made through the backplane and can be single or three phase 50/60Hz. Single-phase operation is not recommended for applications expecting to deliver more than 1400 Watts with 115 VAC input or more than 2000 Watts using 230 VAC input.

The 3U Geo Direct PWM amplifiers systems include an integrated shunt regulator circuitry. The purpose of the shunt regulator circuitry is to turn on an IGBT that dumps excess bus power (voltage) into an external resistor (Delta Tau part GARxx). Connect an external energy dump resistor (GARxx) to utilize this function at the appropriate connector of the backplane. On the 3UBP15A backplane connector is TB1, pins 4 and 5, while on the 3UBP8A the connector is TB2, pins 1 and 2, both have a line voltage monitor that automatically sets the shunt regulator trip point for proper operation of 115 VAC or 230 VAC operation.

Typically, the position feedback is fed to PMAC via ACC-24E2x, ACC-24E3 (Power PMAC only), ACC-24E2M, ACC-8F or ACC-8FS and is not part of the 3U drive amplifier**.** Thus, the position feedback is not to be connected to the amplifier in any way.

APPENDIX F: COMPATIBLE MOTORS

The 3U Geo Direct PWM product line is capable of interfacing to a wide variety of motors. The 3U Geo Direct PWM drives can be used with almost any type of three-phase brushless motor, including DC brushless rotary, AC brushless rotary, induction, and brushless linear motors. Motor selection for an application is a science in itself and cannot be covered comprehensively in this manual. However, some basic considerations and guidelines are offered here. Motor manufacturers include a host of parameters to describe their motor.

Some basic equations can help guide an applications engineer to mate a proper drive with a motor. A typical application accelerates a load to a speed, running the speed for a while and then decelerating the load back into position.

Maximum Speed

The motor's maximum rated speed should be given on the motor's data sheet. This speed may or may not be achievable in a given system. The speed could be achieved if enough voltage and enough current loop gain are available. Also, consider that the feedback device attached to the motor may add limitations to achievable speeds, especially if its update frequency is too low for your desired speed, or if the resolution is so high that PMAC's feedback registers saturate (this really only happens with very high-resolution encoders used on Non-Turbo or Turbo PMAC; Power PMAC will most likely never experience this problem). The load attached to the motor also may limit the maximum achievable speed. In addition, some manufacturers will provide motor data with their drive controller, which is tweaked to extend the operation range that other controllers may be able to provide. In general, the maximum speed can be determined by input voltage line-to-line divided by K_b (the motor's back EMF constant). To derate this a little for proper servo applications is wise.

Torque

The torque required for the application can be viewed as both instantaneous and average. Typically, the instantaneous or peak torque is calculated as a sum of machining forces or frictional forces plus the forces required to accelerate the load inertia. The machining or frictional forces on a machine must be determined by the actual application. The energy required to accelerate the inertia follows the equation: $t = JA$, where t is the torque in pound-feet required for the acceleration, J is the inertia in pound-feet-second squared, and A is in radians per second per second. The required torque can be calculated if the desired acceleration rate and the load inertia reflected back to the motor are known. The *t-JA* equation requires that the motor's inertia be considered as part of the inertia-requiring torque to accelerate.

Once the torque is determined, the motor's specification sheet can be reviewed for its torque constant parameter (K_t). The torque required at the application divided by the K_t of the motor provides the peak current required by the amplifier. A little extra room should be given to this parameter to allow for good servo control.

Most applications have a duty cycle in which the acceleration profile occurs repetitively over time. Calculating the average value of this profile gives the continuous rating required by the amplifier. Applications also concern themselves with the ability to achieve a speed. The requirements can be reviewed by either defining what the input voltage is to the drive, or defining what the voltage requirements are at the motor. Typically, a system is designed at a 230 or 480 V input line. The motor must be able to achieve the desired speed with this voltage limitation. This can be determined by using the voltage constant of the motor (K_b), usually specified in volts-per-thousand rpm. The application speed is divided by 1000 and multiplied by the motor's K_b. This is the required voltage to drive the motor to the desired velocity. Headroom of 20% extra voltage is suggested to allow for good servo control.

Peak Torque

The peak torque rating of a motor is the maximum achievable output torque. It requires that the amplifier driving it be able to output enough current to achieve this. Many drive systems offer a 3:1 peak-to-continuous rating on the motor, while the amplifier has a 2:1 rating. To achieve the peak torque, the drive must be sized to be able to deliver the current to the motor. The required current is often stated on the datasheet as the peak current through the motor. In some sense, it can also be determined by dividing the peak amplifier's output rating by the motor's torque constant (K_t).

Continuous Torque

The continuous torque rating of the motor is defined by a thermal limit. If more torque is consumed from the motor than this on average, the motor overheats. Again, the continuous torque output of the motor is subject to the drive amplifier's ability to deliver that current. The current is determined by the manufacturer's datasheets stating the continuous RMS current rating of the motor; it can also be determined by using the motor's K_t parameter, usually specified in torque output per Amp of input current.

Motor Poles

Usually, the number of poles in the motor is not a concern to the actual application. However, it should be noted that each pole-pair of the motor requires an electrical cycle. High-speed motors with high motor pole counts can require high fundamental drive frequencies that a drive amplifier may or may not be able to output. In general, drive manufacturers with PWM switching frequencies (16 KHz or below) would like to see commutation frequencies less than 400 Hz. The commutation frequency is directly related to the number of poles in the motor.

Motor Inductance

Typically, motor inductance of servomotors is 1 to 15 mH. The Geo drive product series can drive this range easily. On lower-inductance motors (below 1 mH), problems occur due to PWM switching where heating currents flow through the motor, causing excessive energy waste and heating. If an application requires a motor of less than 1mH, external inductors are recommended to increase that inductance. Motors with inductance in excess of 15 mH can still be driven, but are slow to react and typically are out of the range of high performance servomotors.

Motor Resistance

Motor resistance is not really a factor in determining the drive performance, but rather, comes into play more with the achievable torque or output horsepower from the motor. The basic resistance shows up in the manufacturer's motor horsepower curve.

Motor Back EMF

The back EMF of the motor is the voltage that it generates as it rotates. This voltage subtracts from the bus voltage of the drive and reduces the ability to push current through the motor. Typical back EMF ratings for servomotors are in the area of 8 to 200 volts-per-thousand rpm. The Geo drive product series can drive any range of back EMF motor, but the back EMF is highly related to the other parameters of the motor such as the motor's inductance and the motor K_t. The back EMF of the motor limits the maximum achievable speed and the maximum horsepower capability of the motor.

Motor Torque Constant

The motor's torque constant is referred to as K_t and usually it is specified in units of torque-per-Amp. This number is the most important for motor sizing. When the load that the motor will see and the motor's torque constant is known, the drive amplifier requirements can be calculated to effectively size a drive amplifier for a given motor. Some motor designs allow K_t to be non-linear, in which K_t will actually produce less torque per unit of current at higher output speeds. It is wise to derrate the system'ss torque producing capability by 20% to allow headroom for servo control.

Motor Inertia

Motor inertia comes into play when sizing motors because the torque required to accelerate the inertia of the motor is effectively wasted energy. Low inertia motors allow for quicker acceleration. However, consider the reflective inertia from the load back to the motor shaft when choosing the motor's inertia. A high ratio of load-to-motor inertia can cause limited gains in an application if there is compliance in the transmission system such as in belt-drive systems or rubber-based couplings to the systems. The closer the rotor inertia matches the load's reflected inertia to the motor shaft, the higher the achievable gains will be for a given system. In general, the higher the motor inertia, the more stable the system will be inherently. Mechanical gearing is often placed between the load and the motor in order to reduce the inertia reflected back to the motor shaft.

Motor Cabling

Motor cables are an integral part of a motor drive system. Several factors should be considered when selecting motor cables. First, the PWM frequency of the drive emits electrical noise. Motor cables must have a high-quality shield around them. The motor frame must also have a separate conductor connected back to the drive amplifier to help quench current flows from the motor due to the PWM switching noise. Both the motor drain wire and the cable shield should be tied at both ends to the motor and to the amplifier.

Another consideration in selecting motor cables is the conductor-to-conductor capacitance rating of the cable. A small capacitance is desirable. Longer runs of motor cable can add motor capacitance loading to the drive amplifier causing undesired spikes of current. It can also cause couplings of the PWM noise into the earth grounds, causing excessive noise as well. Typical motor cable ratings have 50 pf per foot maximum cable capacitance.

Another factor in picking motor cables is the actual conductor cross-sectional area. This refers to the conductor's ability to carry the required current to and from the motor. When calculating the required cable dimensions, consider agency requirements, safety requirements, maximum temperature that the cable will be exposed to, the continuous current flow through the motor, and the peak current flow through the motor. Typically, it is not suggested that any motor cable be less than 14 AWG.

The motor cable's length must be considered as part of the application. Motor cable's length affects the system in two ways. First, additional length results in additional capacitive loading to the drive. The drive's capacitive loading should be kept to no more than 1000 pf. Additionally, the length sets up standing waves in the cable, which can cause excessive voltage at the motor terminals. Typical motor cable length runs of 200 feet for 230 V systems and 50 feet for 480 V systems are acceptable. Exceeding these lengths may put other system requirements in place for either a snubber at the motor end or a series inductor at the drive end. The series inductor at the drive end provides capacitance loading isolation from the drive and slows the rise time of the PWM signal into the cable, resulting in less voltage overshoot at the motor.

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