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5210 Driver

Instruction Manual

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Table of Contents

1 Overview of 5210

In this Chapter

This chapter introduces the 5210 stepper motor driver. Topics covered are:

- 5210 definition
- Other system components
- How to use this manual
- Warranty

1.1 5210 Definition

The Pacific Scientific 5210 stepper motor driver is an electronics package that converts step and direction inputs to motor winding currents to control a two-phase bipolar stepper motor.

The output current of the 5210 ranges from 1 to 3 amps/phase with a 44V maximum dc bus.

Standard features

- Short circuit protection
- High-frequency chopper control of motor current (17 kHz)
- Overtemperature protection
- Full, half-step or wave drive operation
- TTL/CMOS compatible inputs
- Selectable motor current (3A max)
- PC board mountable

1.1.1 Short Circuit Protection

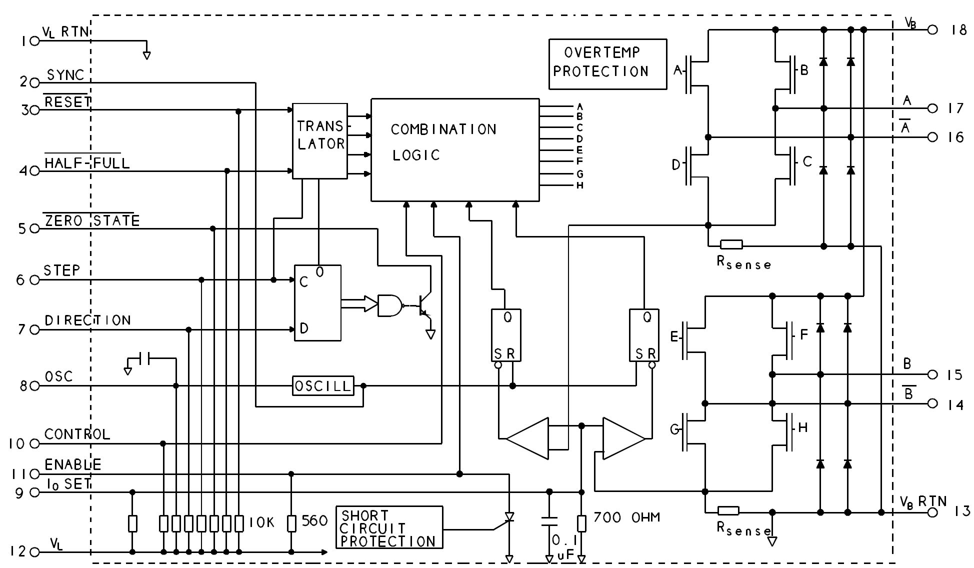
The module short circuit protection is implemented by an internal SCR latch on the Enable input (pin 11). Circuitry senses if there is an overcurrent condition phase-phase, phase-bus supply, or phase-bus Rtn and triggers the SCR. The SCR short circuits the Enable input (pin 11) which shuts off the module output transistors.

The enable input is available for external use with an open collector driver. The input is pulled up to V_L via a 560 Ω resistor.

To reset short circuit protection

The short circuit protection can be reset by cycling power to the module, or by pulling the Enable input (pin 11) to below 0.4V.

1.1.2 Block Diagram



1.2 Other System Components

Overview

The other components that, along with the driver comprise a complete motor control system are:

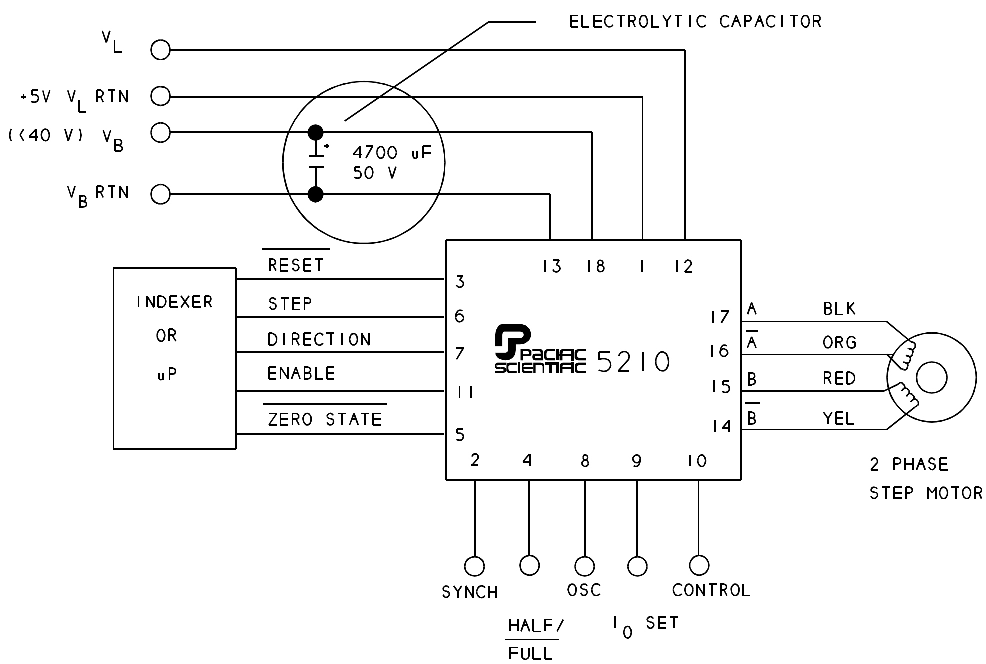
- Indexer or step source
- Motor

Selection and installation guidelines for these components are described in Chapter 2, "Installing the 5210 Series".

1.2.1 External Capacitor

One external capacitor is required with the 5210 module. This capacitor is shown in the diagram below.

Connection diagram



An aluminum electrolytic capacitor must be provided across the Bus Supply (pins 13 and 18). This capacitor is required to handle the ripple currents generated by the switch mode operation.

Note: *The capacitor ripple current rating should be 3.0 A rms at 120 Hz or greater.*

The total lead length between the capacitor and the module must be 6 inches or less, i.e. the capacitor is 3 inches or less from the module.

Suggested supplier

Sprague's model 80D472P050MB2 (4700 µF, 50V) aluminum electrolytic capacitor will provide the required performance.

1.3 How to Use this Manual

This manual contains information and procedures to install, set up, and troubleshoot the 5210 stepper motor driver.

The most effective way to use the manual is to follow the instructions in Chapter 2, "Installing the 5210", and Chapter 3, "Powering Up the 5210".

1.4 Warranty

The Pacific Scientific 5210 stepper motor driver has a **two year warranty** against defects in material and assembly. Products that have been modified by the customer, physically mishandled, or otherwise abused through miswiring, incorrect switch settings, and so on, are exempt from the warranty plan.

2 Installing the 5210 Series

In this Chapter

This chapter explains how to install the 5210 stepper motor driver. Topics covered are:

- Unpacking and inspecting the 5210
- Selecting other system components
- 5210 safety guidelines
- Mounting the 5210 in your installation
- Pin functions
- Motor current regulation
- Output current programming
- Chopper frequency programming
- Multiple module applications

2.1 Unpacking and Inspecting the 5210

Unpacking procedure

1. Remove the 5210 from the shipping carton. Make sure all packing materials are removed from the unit.
2. Check the items against the packing list. A label located on the pin side of the unit identifies the unit by model number, serial number and date code.

Inspection procedure

Inspect the unit for any physical damage that may have been sustained during shipment.

If you find damage, either concealed or obvious, contact your buyer to make a claim with the shipper. Do this as soon as possible after receipt of the unit.

Storing the unit

After inspection, store the 5210 in a clean, dry place. The storage temperature must be between -40 degrees C and 85 degrees C. To prevent damage during storage, replace the unit in the original shipping carton.

2.2 Selecting Other System Components

Selecting an indexer

The 5210 requires step, direction and enable inputs. Select an indexer that provides, as a minimum, these commands. A compatible indexer will provide the capability to drive the input circuits shown in the pinout table (page 2-5).

Selecting a motor

The 5210 is designed for use with Pacific Scientific's line of hybrid stepper motors. The driver works with either the standard line or the enhanced high performance line of stepper motors. The motor winding current rating must be compatible with the output current of the driver package (up to 3.0 A peak).

Refer to the Torque/Speed curves in the Pacific Scientific "Motion Control Solutions Catalog" or contact your local Pacific Scientific distributor for sizing and motor compatibility assistance.

2.3 5210 Safety

Your responsibility

As the user or person applying this unit, you are responsible for determining the suitability of this product for any application you intend. In no event will Pacific Scientific Company be responsible or liable for indirect or consequential damage resulting from the misuse of this product.

Note: *Read this manual completely to effectively and safely operate the 5210 unit.*

Safety guidelines

To avoid possible injury whenever you are working with the 5210:

- Always remove power before making or removing connections from the unit.
- Do not use the enable input as a safety shutdown. Always remove power to the drive for a safety situation.

2.4 Mounting the 5210 in Your Installation

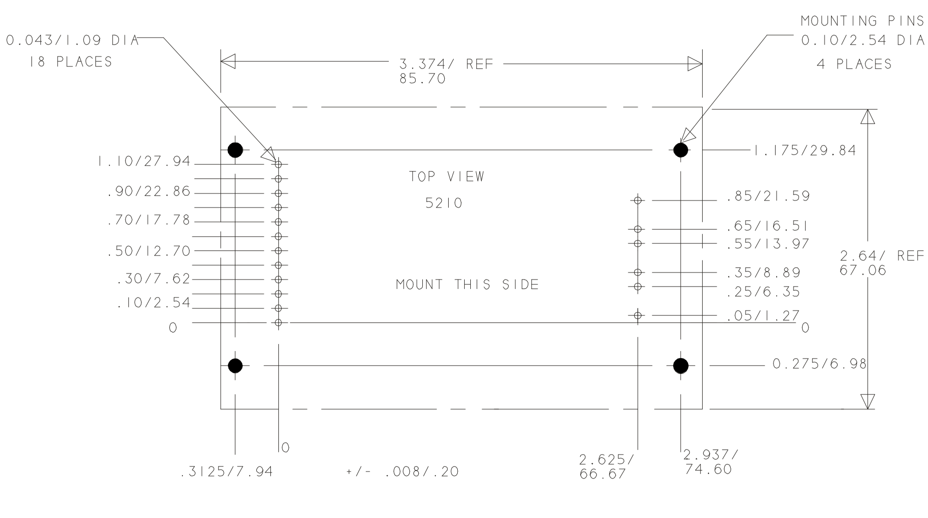
The figure below shows the mechanical outline of the 5210. The unit is designed to be mounted on a PC board.

Caution

The unit should not be subjected to excessive vibration or shock. The environment should be free of corrosives, moisture and dust.

Mounting dimensions

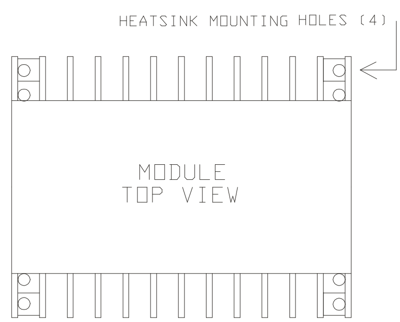
Prepare the PC board for the 5210 using the dimensions in inches or millimeters as shown below. Pin lengths are compatible with PC board thickness of 0.093" or less. The four 0.1" diameter corner pins provide secure mounting to the PC board.



2.4.1 Optional Heatsink

An optional heatsink kit, available form Pacific Scientific (Order number 106-521001-01) may be required for operation at ambient temperatures above 35^{o}C, output current above 2A or bus voltage higher than 35 VDC. If any of these conditions are true, refer to Appendix B, “Thermal Operating Conditions”, to determine if a heatsink is required.

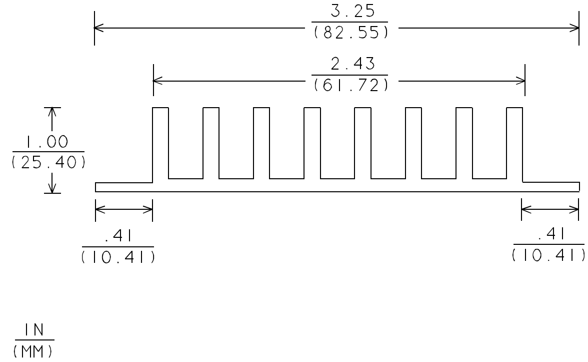
The heatsink is mounted to the top of the 5210 using four self-tapping screws which are threaded into the four holes at the outside corners of the driver module as shown.



Note: *Assembly of the self-tapping screws is eased if the diameter of the four mounting holes is increased slightly using a Number 37 drill bit.*

The screws and a Sil-pad, which provides better thermal contact between the module and heatsink, are included in the heatsink kit. Heatsink dimensions are shown below.

Heatsink dimensions

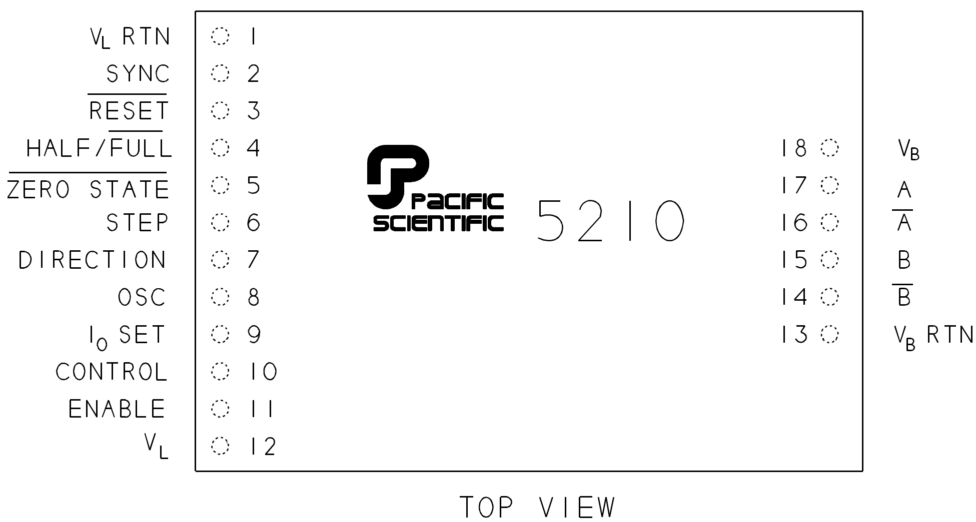


2.5 Pin Functions

Introduction

There are 18 pinouts associated with the 5210 stepper motor driver. Refer to the diagram and table for location and functionality information.

Pinout diagram



Pinout table

Pin	Name	Function
1	V_LRTN	Return for the low power logic supply voltage. This pin is internally tied to pin 13.
2	SYNC	Output of the module chopper oscillator. For multi-axis applications, the choppers of several modules can be synchronized to avoid noise and beat frequencies. Also, the module can be operated from an external chopper oscillator by injecting a frequency signal in this pin. See Section 2.9, "Multiple Module Applications".
3	$\overline{\text{RESET}}$	This input produces an asynchronous reset. A low state on this pin will force the module to the Zero state output: * $\overline{\text{A}}$A, $\overline{\text{B}}$B
4	HALF/$\overline{\text{FULL}}$	This input selects full-step or half-step mode of operation. A high or unconnected state on this input will place the module in half-step mode. Full-step mode or Wave drive mode is set by forcing this input low. **Note:** *Do NOT change the state of this input while the module outputs are changing since the full-step or wave drive mode selection is dependent upon the state of the outputs when this input is forced low. See Appendix D.*
5	$\overline{\text{ZERO STATE}}$	This output indicates that the module output state is: * $\overline{\text{A}}$A, $\overline{\text{B}}$B
6	STEP	A pulse on this input will increment the motor one step. The step motion will occur on the rising edge of this input signal.

* The designation $\overline{\text{A}}$A means current travels in through $\overline{\text{A}}$ and out from A.

Pin	Name	Function
7	DIRECTION	This input selects the direction of motor rotation. A high or unconnected input will cause clockwise motor rotation. A low input will cause counterclockwise rotation.
8	OSC	The module chopper frequency is set at 17 kHz nominal. The chopper frequency can be increased by connecting a resistor between this pin and V_L. It can be decreased by connecting a capacitor between this pin and V_LRTN. This pin is also the input for the chopper frequency SYNCH signal in multi-axis configuration. See Section 2.9, "Multiple Module Applications".
9	I_oSET	The module current is set at 2 A per phase. The phase current can be decreased by connecting a resistor between this pin and V_LRTN or can be increased by connecting a resistor between this pin and V_L. Scale factor is 1 A/0.17V on this pin. See Section 2.7. **Note:** *The minimum output current for a 5210 is 1A. The maximum recommended operating current is 2.5A.*
10	CONTROL	This input defines the module switching mode. • A low input places the module in a non-recirculating or fast decay mode. • An unconnected or high input places the module in a recirculating or slow decay mode. See Section 2.6, "Motor Current Regulation".

Pin	Name	Function
11	ENABLE	This input enables the module when it is high or unconnected. A low input will inhibit both phase currents.
12	V_L	The 5 VDC logic supply power is applied to this input.
13	V_BRTN	Return for the high power bus voltage supply. This pin is internally tied to pin 1.
14	$\overline{B}$	Motor Phase $\overline{B}$ output (Phase B return)
15	B	Motor Phase B output.
16	$\overline{A}$	Motor Phase $\overline{A}$ output (Phase A return).
17	A	Motor Phase A output.
18	V_B	The high power bus supply is applied to this input. The maximum voltage on this input must not exceed 44 VDC.

2.6 Motor Current Regulation

Motor phase currents are controlled by two switch mode (chopper), MOSFET, full-bridges. Pulse-width-modulation (PWM) switching provides efficient and precise current control to obtain good torque-speed characteristics from the stepping motor.

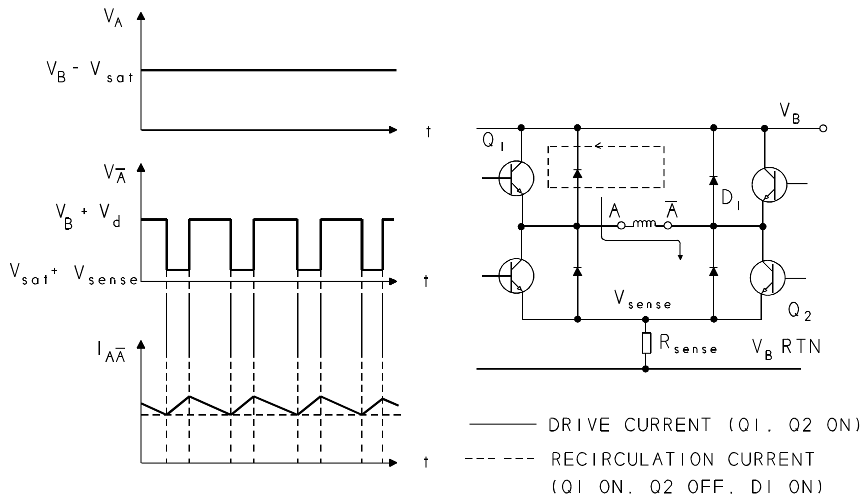
Recirculating mode

The recirculating mode is obtained by pulling the CONTROL input high or leaving it unconnected.

An internal PWM oscillator supplies pulses at a fixed frequency (17 kHz nominal) to a pair of flip-flops. The flip-flops turn on a pair of transistors in each bridge. In the recirculation diagram, transistors Q1 and Q2 are turned on to obtain a phase current of $A\overline{A}$.

Note: *The other pair would be turned on if phase current of A*A was required.

Recirculation mode diagram

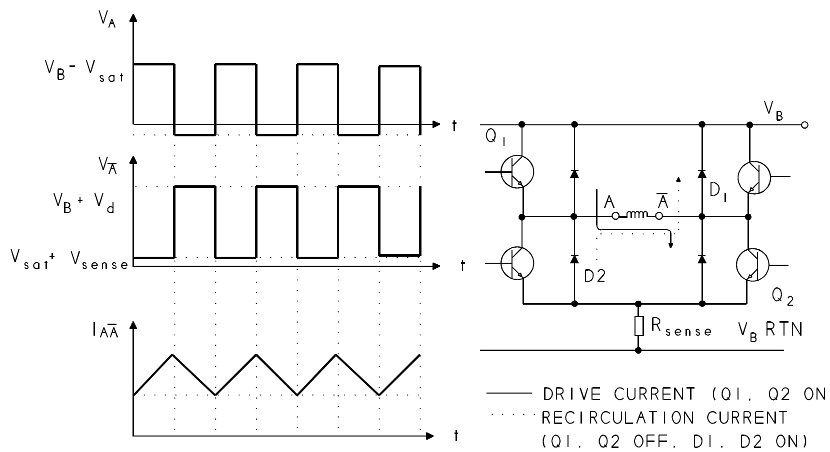


The phase current ramps up in the motor winding inductance until the current sensed by resistor R_{sense} equals the current defined by I_oSET. At this point the flip-flop is toggled which turns transistor Q2 off and causes the current to recirculate through transistor Q1 and diode D1. The current decays slowly in this recirculation path because the voltage across the motor winding inductance is only a diode drop (D1) plus V_{sat} of Q1. The next PWM oscillator pulse toggles the flip-flop and turns Q2 back on causing the current to start ramping back up.

Non-recirculating mode

The second mode of operation is non-recirculating. This mode is obtained by pulling the CONTROL input low. Operation in this mode is identical to that of the recirculating mode except that when the current sensed by resistor R_{sense} equals the current defined by I_oSET, transistors Q1 and Q2 are both turned off. This causes the current to flow through diodes D1 and D2 as shown in the non-recirculation diagram. Rather than recirculating locally through just the motor phase winding, the current flows back through the Bus supply. The voltage across the motor inductance is therefore equal to the Bus voltage plus two diode drops causing the current to decay rapidly.

Non-recirculatin
g diagram



The current decays until the next PWM oscillator pulse turns transistors Q1 and Q2 back on.

In most applications, recirculation mode is preferred. The power losses in the module and stepping motor are lower in the recirculation mode due to the lower amplitude ripple current. This mode should be used whenever possible.

For some applications, it may be necessary to use the non-recirculation mode. While this mode introduces higher module and motor losses due to higher ripple currents, it reduces the modules sensitivity to back EMF from the motor. This improved back EMF rejection reduces mid-range stability problems. Mid-range stability problems are inherent in any stepping motor system and can cause the motor to fall out of synch due to the parametric oscillation of the motor current resulting in a reduction of torque at mid-range speeds. Using the non-recirculation mode will reduce the systems susceptibility to mid-range instability.

2.7 Output Current Programming

The module output current level can be re-programmed with the addition of an external resistor to the I_oSET input. The module output current is set to 2 A when I_oSET is not connected.

Adding a resistor between I_oSET (pin 9) and V_LRTN (pin 1) will reduce the output current level below 2 A. The resistor necessary to set the module to a reduced current level is defined by the following formula:

$$R = \frac{1}{(0.59(\frac{V_L}{I_O}) - 1.47)}$$

Where: I_o = Desired Output Current (< 2 A), A
V_L = Logic Supply, V
R = Current Setting Resistor, kΩ

Note: *The minimum output current is 1.0 Amp.*

Adding a resistor between I_oSET (pin 9) and V_L (pin 12) will increase the output current level above 2 A. The resistor necessary to set the module to an increased current level is defined by the following formula:

$$R = \frac{10(\frac{V_L}{I_O}) - 1.7}{2.44 - (\frac{V_L}{I_O})}$$

Where: I_o = Desired Output Current (2 A < I_O < 3 A), A
V_L = Logic Supply, V
R = Current Setting Resistor, kΩ

Note: *The minimum value for resistor R is 19.7 kΩ* which will set the output current at 3 A with V_L *= 5 VDC.*

2.8 Chopper Frequency Programming

The chopper or PWM frequency is set at 17 kHz nominal. This frequency can be changed by the addition of an external component to the OSC input.

To reduce the chopper frequency, connect a capacitor between OSC (pin 8) and V_LRTN (pin 1). The capacitor necessary to reduce the chopper frequency is defined by:

$$C = \left(\frac{80{,}515}{f_c}\right) - 4700$$

Where: f_c = Desired chopper frequency, (< 17 kHz), kHz
C = Frequency setting capacitor, pF

To increase the chopper frequency, connect a resistor between OSC (pin 8) and V_L (pin 12). The resistor necessary to increase the chopper frequency is defined by:

$$R = \frac{18}{\left(\frac{f_c}{17}\right) - 1}$$

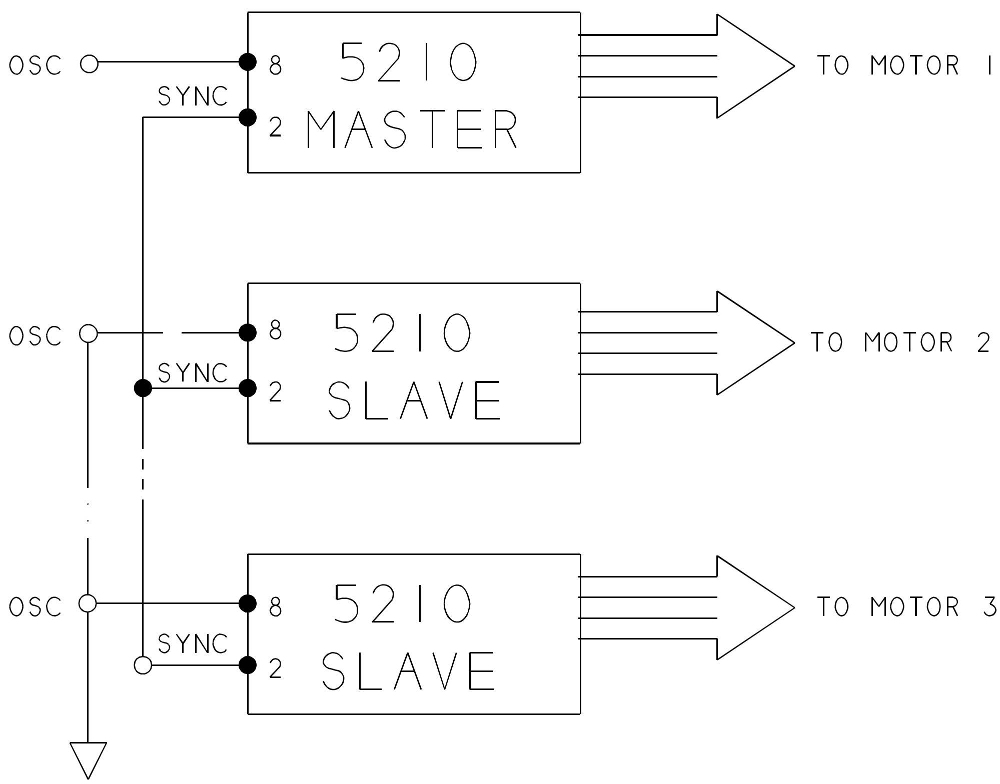
where f_c = Desired chopper frequency (> 17 kHz), kHz
R = Frequency setting resistor, kΩ

Note: *The minimum value for resistor R is 18 k*Ω which will double the chopper frequency to 34 kHz.

2.9 Multiple Module Applications

In multi-axis systems, each stepping motor must be driven by a 5210 module. To avoid problems caused by noise and beat frequencies, it is sometimes necessary to synchronize the choppers.

The figure below shows the interconnection wiring for synchronizing the choppers of multiple modules.



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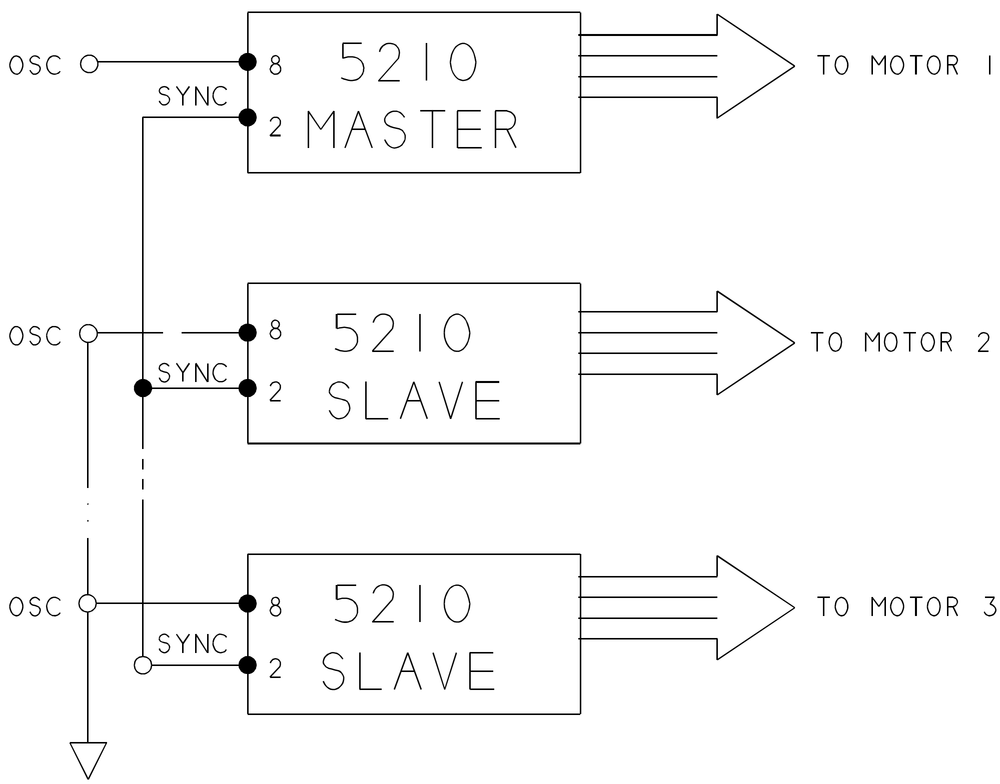


3 Powering up the 5210

In this Chapter

This chapter explains how to power up the 5210 stepper motor driver after installation.

3.1 Testing the Installation

Background

Perform the following test procedure to verify that the 5210 is installed properly and that it was not damaged internally during shipment.

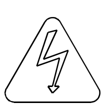
Configuration

The installation test power-up procedure requires a motor and indexer (or step and direction source) to test the functionality of the 5210.

Procedure

After performing the installation per the guidelines given in Chapter 2, “Installing the 5210 Series”, test your installation as follows.

Warning



Perform this initial power-up with the motor shaft disconnected from the load. Improper wiring or undiscovered shipping damage could result in undesired motor motion. Be prepared to remove power if excessive motion occurs.

3.1.1 Connections Test

Introduction

Before beginning the connections test, please check the following:

- all wiring and mounting to verify correct installation
- specifications to make sure that voltages being applied do not exceed the voltages specified

Test procedure

Notes: 1. *Be prepared to turn power OFF at any time when performing the test procedure.*

2. *No load should be connected to the motor shaft.*

3. *Connect motor chassis to Ground (pin 13).*

1. Ensure the power is OFF.
2. Connect the motor phase A, $\overline{A}$ to pins 17, 16 and motor phase B, $\overline{B}$ to pins 15, 14.
3. Apply power to the 5210.
4. Check the presence of the holding torque on the motor shaft.
5. Input a step command to pin 6.

   - The motor should move clockwise.
6. Turn power Off.
7. Connect direction input (pin 7) to Ground (pin 1).
8. Apply power again, then input a step command to pin 6.

   - The motor should move counterclockwise.
9. Turn power OFF.
10. Connect enable input (pin 11) to Ground (pin 1).
11. Apply power to the 5210.

    - The motor shaft should be free to move.
12. Turn power OFF.
13. Remove connection from pin 11 to pin 1 (enable input).

If the 5210 does not pass all the above steps, refer to Section 2.5, “Pin Functions” and Section 4.2, “Troubleshooting”.

Getting help

If you need further help with your installation, contact your local distributor for assistance.

4 Maintaining/Troubleshooting

In this Chapter

This chapter covers maintenance and troubleshooting of the 5210 stepper motor driver.

4.1 Maintaining the 5210

Introduction

The 5210 module is designed for minimum maintenance. The following cleaning procedures performed as needed will minimize problems due to dust and dirt build-up.

Procedures

Remove superficial dust and dirt from the module using clean, dry, low-pressure air.

4.2 Troubleshooting the 5210

Introduction

A table of problems, causes and appropriate actions is provided to help in the troubleshooting of your 5210 module.

Symptom	Problem	Possible Solution
Motor has no holding torque with power applied to the driver.	Driver is disabled.	Enable input (pin 11) should be high.
^	Motor is cross wired with each winding connected to both Phase A and Phase B.	Reconnect motor windings to the corresponding phase terminals.
^	Driver output short circuited.	Remove short circuit. Check motor windings for phase-to-phase or phase-to-ground shorts.

Symptom	Problem	Possible Solution
Motor has holding torque but will not step.	Step pulse absent at pin 6.	Check pulse input with an oscilloscope. If the pulse train is absent, troubleshoot stepping source and interconnection wiring.
^	Loss of phase current in one winding.	Check phase current in both phases by placing an ammeter in series with each winding. If not present, check for open circuit in motor phase winding by measuring the resistance.
^	One motor phase not wired correctly at stepping motor.	Check stepping motor wiring.
^	Input frequency too high.	Lower input frequency and apply frequency ramping if necessary.
Motor steps in wrong direction.	Incorrect motor phase winding connection.	Reverse connections of one phase.
^	Incorrect direction input.	Reverse polarity of direction input.

Symptom	Problem	Possible Solution
Motor misses steps.	Fault in driver logic or power translator circuit. To evaluate, perform the following test: Pulse motor one step. (Motor should move one step) Repeat this procedure for eight steps in both directions.	Replace driver module.
^	Incorrect ramp time.	Adjust acceleration/ deceleration ramp time.
^	Intermittent connection in pin 6.	Repair faulty connection.
^	Incorrect step pulse magnitude.	Troubleshoot step pulse generator.
Motor operation is rough or erratic.	Operation is on resonance region of torque/speed curve.	Change frequency of applied stepping logic pulses.
^	Improper phase sequencing (faulty drive).	Replace driver.

If 5210 is defective

If you cannot correct the problem, return the module to Pacific Scientific for replacement.

Return procedure

1. Call Danaher Motion Customer Support (815) 226-3100 from 8 am to 6 pm Eastern Standard Time to receive a Returned Materials Authorization Number (RMA#) and the current address to ship the unit. Be sure to include the RMA# on the outside of the package.

   Note: *Do not attempt to return the stepper driver or any other equipment without a valid RMA#. Returns received without a valid RMA# will not be accepted and will be returned to the sender.*

2. Pack the driver in its original shipping carton. Pacific Scientific is not responsible or liable for damage resulting from improper packaging or shipment.

Shipment of your driver or motor to Pacific Scientific constitutes authorization to repair the unit. Refer to Pacific Scientific's repair policy for standard repair charges. Your repaired unit will be shipped via UPS Ground delivery. If another means of shipping is desired, please specify this at the time of receiving an RMA#.

Appendix A Specifications

General

Input power	12 - 40 VDC, 5 VDC logic
Output current per phase	2.5 A maximum. (Optional heatsink required for current above 2.0A or temperature above 35^{o}C.) adjustable to below 2.5A with addition of a resistor - contact factory
Output voltage	12 - 40 VDC
Input format (step & direction)	TTL/CMOS compatible
Maximum input pulse rate	full step - 20,000 pulses/sec half step - 20,000 pulses/sec
Minimum input pulse width	500 nS
Motor current enable input	Connecting ENABLE (pin 11) to V_LRTN (pin 1) shuts down the output
PWM chopping frequency	17 kHz (inaudible)

Parameter specifications

Note: *T_{amb} = 25°C unless otherwise specified.*

Parameter		Test Conditions	Min	Typ	Max	Unit
V_B	Bus supply voltage	Pin 18	12		40	V
V_L	Logic supply voltage	Pin 12	4.75	5	5.25	V
I_B	Quiescent bus supply current	Pin 18 Pin 11 = low I_{OUT} = 0 V_B = 42V	15			mA
I_L	Quiescent logic supply current	Pin 12 All inputs high I_{OUT} = 0 V_L = 5V		60		mA
V_i	Input voltage	Pin 3,4,6,7,10 low high	V_LRTN -.5 2.0		0.8 V_L	V V
I_i	Input current	Pin 3,4,6,7,10 V_i = low V_i = high			-0.6 10	mA µA
V_{en}	Enable input voltage	Pin 11 low high	V_LRTN -.5 2.0		0.8 V_L	V V
I_{en}	Enable input current	Pin 11 V_{en} = L V_{en} = H			-10 10	mA µA
V_{ZS}	Zero state output voltage	Pin 5 low I_{ZS} = 5 mA high	V_LRTN -.5 2.0		0.4 V_L	V V
R_{DS}(ON)	On resistance	Pin 14,15,16,17		0.3	0.45	Ω
V_{DS}(ON)	Saturation voltage	Pin 14,15,16,17 I_o = 1A I_o = 3A		0.3 0.9	0.45 1.35	V V
f_c	Chopper frequency			17		kHz
V_D	Diode voltage	Pin 14,15,16,17			1	V
t_{clk}	Stepclk width	Pin 6 See Figure A	0.5			µs

Parameter		Test Conditions	Min	Typ	Max	Unit
t_s	Set up time	See Figure A	1.0			µs
t_b	Hold time	See Figure A	1.0			µs
t_R	Reset width	See Figure B	1.0			µs
t_{Rclk}	Reset to STEP set up time	See Figure B	1.0			µs

Figure A

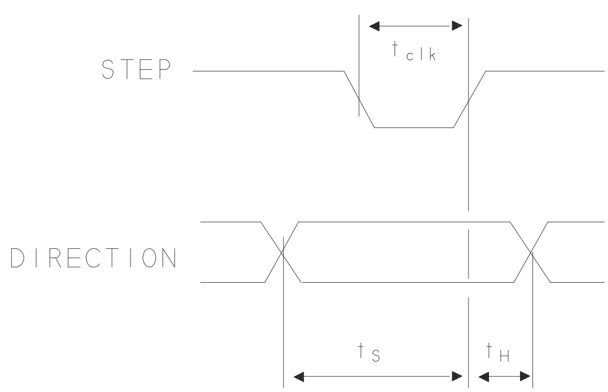
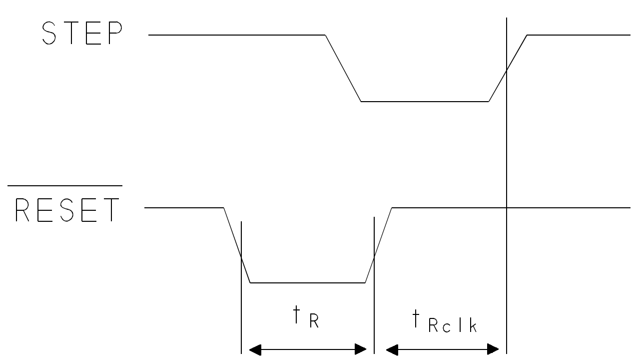


Figure B



Operating temperature	0^oC to 50^oC ambient (heatsink required for operation above 35^oC. See Appendix B "Thermal Operating Conditions")
Storage temperature	-40^oC to 85^oC
Relative humidity	10% to 90% (non-condensing)

Appendix B Thermal Operating Conditions

Introduction

The 5210 is designed to operate at 2 A per phase with a 35 VDC bus supply in a 35^{o}C ambient temperature with natural convection cooling and no additional heatsink. If any of these parameters is above the values given, the analysis described in this appendix should be carried out to see if an external heatsink is required.

The power losses in the module are a function of the output current, bus supply voltage, duty cycle, commutation mode and PWM mode.

The following parameters must be defined to calculate the thermal operating conditions of the module:

Parameter	Definition
V_B	Bus supply voltage, V
V_L	Logic supply voltage, V
I_O	Output current, A
T_A	Ambient temperature, ^{o}C
R_M	Motor resistance, Ω
Commutation mode	Full step, half step, wave drive
PWM mode	Recirculation, non-recirculation

The module power losses are divided into two parts:

- Quiescent
- Output stage

Quiescent power losses

The quiescent losses are static and are not dependent upon the output current level. These losses are composed of control logic losses and leakage current losses.

The following formula is used to calculate quiescent power losses in the module:

$$P_Q = V_L I_L + V_B I_B$$

Output stage power losses

The output stage losses are a function of PWM duty cycle (D.C.) which can be calculated from the following formula:

Mode	Formula
Recirculation	$D.C. = \frac{(R_M I_O)}{V_B}$
Non-recirculation	$D.C. = 0.5\left(\left(\frac{R_M I_O}{V_B}\right) + 1\right)$

PWM mode

The output stage power losses are also a function of the PWM mode selected. Use the appropriate formula.

Mode	Formula
Recirculation	$P_O = 1.1[2(D.C.)R_{DS} I_O^2 + (R_{DS} I_O^2 + V_D I_O)(1 - D.C.)] + 0.3(D.C.) I_O^2$
Non-recirculation	$P_O = 1.1[2(D.C.)R_{DS} I_O^2 + 2 V_D I_O (1 - D.C.)] + 0.3 I_O^2$

Note: R_{DS} and V_D are given in Appendix A, “Specifications”.

Commutation mode

The total module power losses depends upon the commutation mode used. The appropriate formula should be used.

Mode	Formula
Full step or Half step	$P_M = P_Q + 2P_O$
Wave Drive	$P_M = P_Q + P_O$

Maximum module operating temperature

Using the calculated total module power loss, a maximum operating temperature for the application can be derived. The formula below calculates the maximum module ambient temperature for a given total module power loss.

$$T_A = T_C - P_M R_{CA}$$

where T_C = maximum case temperature, 85°C

R_{CA} = module case ambient thermal resistance, 5°C/W

Example

V_B = 35 V	I_L = 60 mA = 0.06 A
V_L = 5 V	I_B = 15 mA = 0.015 A
I_O = 2.5 A	R_{DS} = .45 Ω
R_M = 4 Ω	V_D = 1 V
T_A = 50°C	

Commutation mode

Full step

PWM mode

Recirculation

$P_Q = V_L I_L + V_B I_B = (5)(.06) + (35)(.015) = .83$ W

$$D.C. = \frac{(RM\ IO)}{VB} = \frac{(4)(2.5)}{35} = .29 \text{ (Recirculation)}$$

Recirculation mode

$$PQ = 1.1\left[2(D.C.)R_{DS} I^2 O + \left(R_{DS} I^2 O + V_D I_O\right)(1 - D.C.)\right] + 0.3(D.C.)I^2 O$$

$$= 1.1\left[2(.29)(.45)(2.5)^2 + \left(.45(2.5)^2 + 1(2.5)\right)(1 - .29)\right] + 0.3(.29)(2.5)^2$$

$= 6.48$ W

Full step or half step mode

$P_M = P_Q + 2P_O = .83\ 2(6.48) = 13.79$ W

$T_A = T_C - P_M R_{CA} = .85 - 13.79(5) = 16.1°C$

The calculations indicate that under these conditions, the module can only be operated in an ambient temperature up to 16.1°C.

A heatsink can be added to the module to reduce the case ambient thermal impedance and increase the operating ambient temperature. For example, the optional heatsink available from Pacific Scientific has a thermal impedance of 3°C/W and can be used with the 5210. This impedance would be in parallel with the case-ambient impedance.

$$R_{CAS} = \frac{\left(R_{CA} R_{HS}\right)}{\left(R_{CA} + R_{HS}\right)} = \frac{(5 * 3)}{(5 + 3)} = 1.88^{\circ}\ C/W$$

Recalculating the operating ambient temperature:

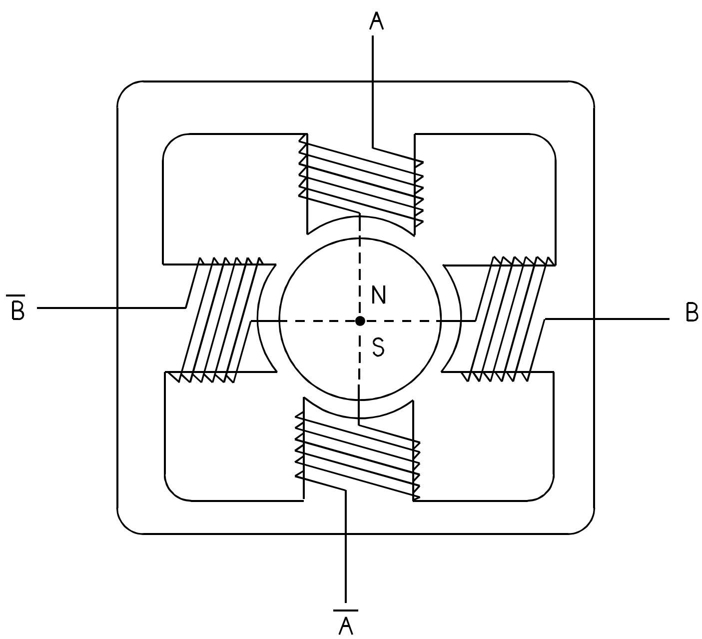
$T_A = T_C - P_M R_{CAS} = 85 - 13.79(1.88) = 59.1°C$

Note: The addition of a heatsink has increased the operating ambient temperature to an acceptable level. For information on ordering a heatsink, please refer to Section 2.4, “Mounting the 5210”.

Appendix C Stepping Motor Basics

Hybrid stepping motor

A hybrid stepping motor can be simplified to the diagram shown below:



The stator consists of two-phase windings and the rotor is a permanent magnet. The rotor aligns itself with the magnetic field created by the stator windings. By controlling the winding currents in the proper sequence, torque is produced and the rotor will rotate in the desired manner. The phase currents are bidirectional and sequencing of these phase currents is termed commutation. There are three basic types of stepping motor commutation possible with the 5210 module.

- One-phase-on Drive or Wave Drive
- Full-step Drive
- Half-step Drive

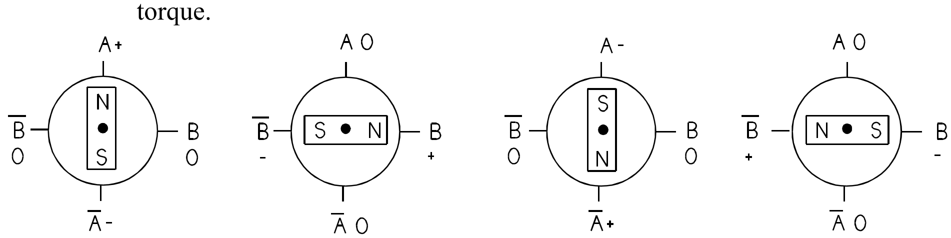
One-Phase-On Drive or Wave Drive

In this type of commutation, only one phase of the stepping motor is on at any given time. Phases are energized in the following sequence.

$$\rightarrow A\overline{A} \text{ —- } B\overline{B} \text{ —- } \overline{A}A \text{ —- } \overline{B}B$$

Note: *AA* means that the phase current is flowing from A to *A*.

The figure below shows the commutation sequence for clockwise rotation of a stepping motor with wave drive commutation. The rotor is simplified to a bar magnet with North and South poles. This type of commutation is typically not used since Full-step drive provides equivalent step resolution with 1.4 times more torque.



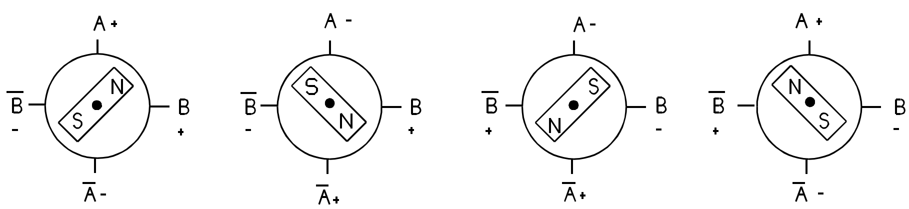
This type of commutation is selected by applying power to the module with the HALF/$\overline{\text{FULL}}$ input high or unconnected. This will set the module for Half-step operation starting in the Zero state. Input one pulse into the STEP input. This will force the outputs to one of the Wave Drive commutation states. Now, force the HALF/$\overline{\text{FULL}}$ input into the low state. The module will be set for Wave Drive operation. The Full-step wave drive mode can be set with the output disabled (enable line pulled low) so that the motor will not move during wave drive selection.

Note: *Do NOT change the state of the HALF/FULL* input state during operation since the Full-step or Wave Drive mode is selected based upon the state of the module outputs when the HALF/*FULL* input is pulled low.

Full-Step Drive

In this type of commutation both stepping motor phases are energized at all times. The commutation sequence is:

The following figure shows this commutation sequence for clockwise motor rotation.

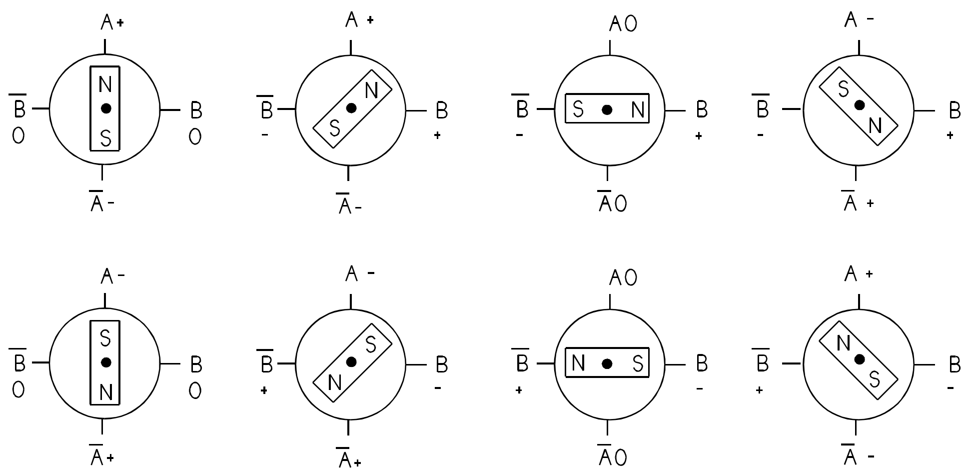


This type of commutation is selected by forcing the HALF/$\overline{\text{FULL}}$ input low prior to applying power to the module and keeping the input low. The module is now set for Full-step operation. Do NOT change the state of the HALF/$\overline{\text{FULL}}$ input state during operation since the Full-step or Wave drive mode is selected based upon the state of the module outputs when the HALF/$\overline{\text{FULL}}$ input is pulled low.

Half-Step Drive

This type of commutation alternates between one phase energized and two phases energized. This halves the step size (doubles step resolution) but gives irregular torque. The torque with two phases energized is 1.4 times higher than that produced with one phase energized. The commutation sequence is:

AA —- AA&BB —- BB —- BB&AA —- AA —- AA&BB —- BB —- BB&AA



The figure below shows the half-step drive sequence.

This type of commutation is selected by forcing the HALF/$\overline{\text{FULL}}$ input high or leaving it unconnected when applying power to the driver. Do NOT change the state of the HALF/$\overline{\text{FULL}}$ input state during operation since the Full-step or Wave Drive mode is selected based upon the state of the module outputs when the HALF/$\overline{\text{FULL}}$ input is pulled low.

Note: *All figures are simplified and show a stepping motor with a 90^o full-step or 45^o half-step commutation. Pacific Scientific stepping motors are designed with a 1.8^o full-step or 0.9^o half-step commutation.*

Appendix D Series/Parallel Connections

Introduction

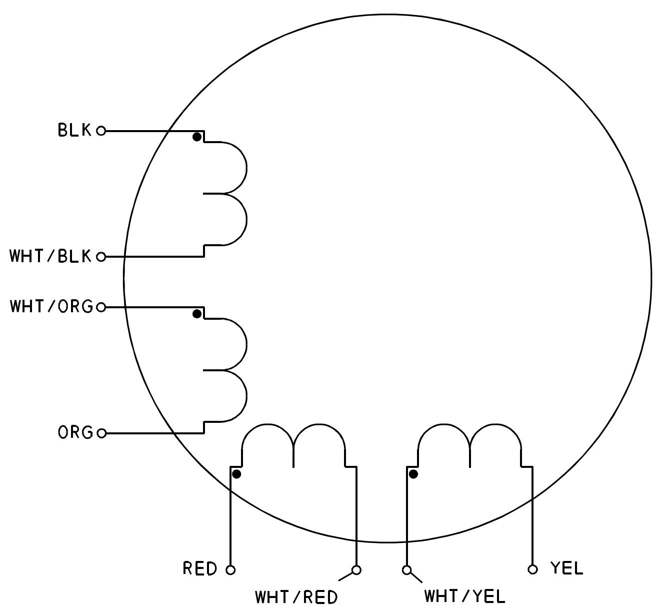
Several motor connections are possible when using a bipolar drive.

- 8-lead motor
- 6-lead motor
- 4-lead motor

The various connection schemes produce different torque/speed characteristics. They also affect the current rating in the motor.

8-lead motor

The 8-lead motor is the most versatile configuration. It can be connected by the user in either an 8-lead, 4-lead (series or parallel) or 6-lead configuration.



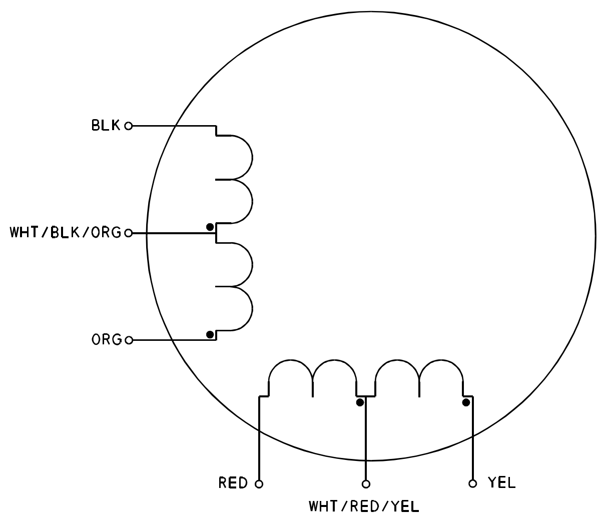
Connection table

Refer to the table below for detailed connection information.

Connection	Terminal #	Lead Color	Driver Connection
4-lead bipolar series	1	Black (Blk)	A
^	3	Orange (Org)	$\overline{A}$
^	2	Red	B
^	4	Yellow (Yel)	$\overline{B}$
^	6 & 5	Wht/Blk & Wht/Org	
^	7 & 8	Wht/Red & Wht/Yel	
4-lead bipolar parallel	1 & 5	Blk & Wht/Org	A
^	3 & 6	Org & Wht/Blk	$\overline{A}$
^	2 & 7	Red & Wht/Yel	B
^	4 & 8	Yel & Wht/Red	$\overline{B}$
6-lead unipolar	1	Black (Blk)	A
^	3	Orange (Org)	$\overline{A}$
^	2	Red	B
^	4	Yellow (Yel)	$\overline{B}$
^	6 & 5	Wht/Blk & Wht/Org	none
^	7 & 8	Wht/Red & Wht/Yel	none

6-lead motor

The 6-lead motor is normally used with unipolar drives. In some cases, the 6-lead motor can be used in a 4-lead series configuration for use with bipolar drives.

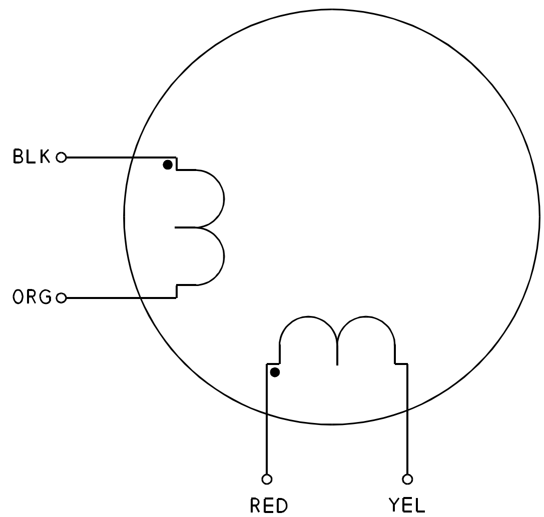


Connection table

Refer to the table below for detailed connection information.

Connection	Terminal #	Lead Color	Driver Connection
6-lead unipolar	1	Black (Blk)	A
^	3	Orange (Org)	$\overline{A}$
^	2	Red	B
^	4	Yellow (Yel)	$\overline{B}$
^	5	Wht/Blk/Org	open
^	6	Wht/Red/Yel	open

4-lead motor The 4-lead motor is for use only with bipolar drives.



Connection table Refer to the table below for detailed connection information.

Connection	Terminal #	Lead Color	Driver Connection
4-lead bipolar	1	Black (Blk)	A
	2	Orange (Org)	$\overline{A}$
	3	Red	B
	4	Yellow (Yel)	$\overline{B}$

Note: *Terminals 5, 6, 7 and 8 are not used.*

Winding Connections

Series

Connecting both halves in series results in the drive current flowing through twice as many turns compared with using one half-winding only. For identical currents, this doubles the "amp-turn" and produces a corresponding increase in torque. In practice, the torque increase is seldom 100% due to the non-linearity of the magnetic material. Equally, the same torque will be produced at half the drive current when the windings are in series.

Doubling the effective number of turns in the windings means that the inductance increases by a factor of four. This causes the torque to drop off much more rapidly as speed increases. As a result, the series mode is only useful at low speeds. The maximum shaft power obtainable in series is typically half that available in parallel using the same current setting on the drive.

Conversely, connecting the windings in series will double the total resistance and the current rating is reduced by a factor of 1.4. The provides a safe current of 3.5 amps for a 50 amp motor series.

Parallel

Winding can be connected in parallel is either an 8-lead motor of 6-lead motor.

8-lead

Connecting the two half-windings of an 8-lead motor in parallel allows the current to divide itself between the two coils. It does not change the effective number of turns and therefore the inductance remains the same. At a given drive current, the torque characteristics will be the same for the two half-windings in parallel as it is for one of the windings on its own.

Connecting the windings of an 8-lead motor in parallel has the same effect as halving the total resistance. For the same power dissipation in the motor, the current may now be increased by 40%. Therefore, the 5 amp motor will accept 7 amps with the winding in parallel. This provides a significant increase in the available torque.

6-lead

"Parallel" in a 6-lead motor refers to the use of one half-winding only. The current rating of a stepper motor is determined by allowable temperature rise. Unless the motor manufacturer's data states otherwise, the rating is a "unipolar" value and assumes both phases of the motor are energized simultaneously. Therefore, a current of 5 amps means that the motor will accept 5 amps flowing in each half-winding.

Summary

As a general rule, parallel connection is preferred over the other options. It produces a flatter torque curve and greater shaft power. Series connection is useful when a high torque is required at low speeds. It allows the motor to produce full torque at low speeds from lower current drives.

Care should be taken to avoid overheating the motor using series connection since its current rating is lower in this mode. Series connection also carries a greater likelihood of resonance problems due to high torque produced in the low speed region.

Appendix E Phasing Sequencing

Introduction

This appendix provides information on phase sequencing for the following set ups:

- Bipolar half-step
- Bipolar full-step

Use the following key to interpret sequence tables:

Phase Sequencing Key	
0	Off or Open
+	Current in to winding
-	Current out of winding

Bipolar Half-step

The table below shows phase sequencing for bipolar half-step motors.

Step	A	A	B	B
1	+	-	0	0
2	+	-	+	-
3	0	0	+	-
4	-	+	+	-
5	-	+	0	0
6	-	+	-	+
7	0	0	-	+

Bipolar Full-step

The table below shows phase sequencing for bipolar full-step motors.

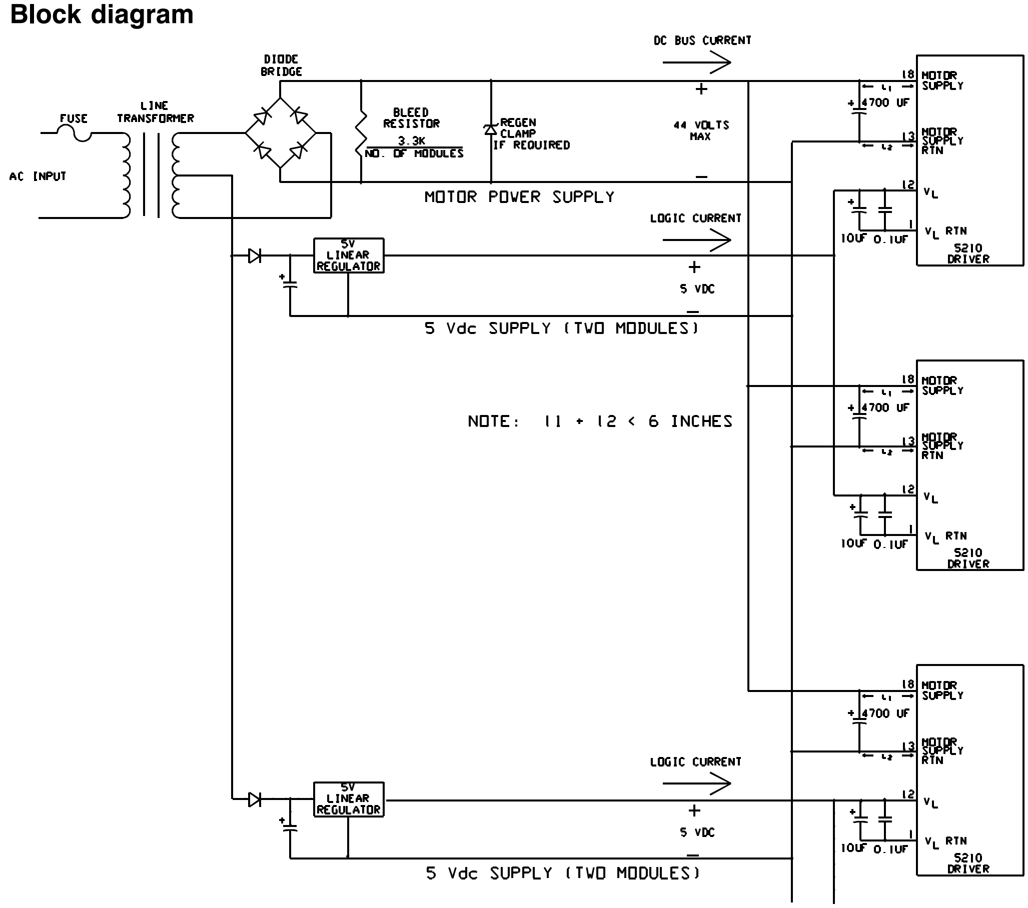
Step	A	A	B	B
1		-	-	
2	-		-	
3	-			-
4		-		-
1		-	-	

Appendix F Power Supply Considerations

F.1 Motor Power Supply

The figure below shows the full-wave-bridge, capacitor-input configuration most commonly used to power one or more 5210 driver modules. One line transformer and bridge rectifier are used. To minimize voltage spikes, separate “bus” capacitors are located close to each module such that the total lead length between each capacitor and its associated module is six inches or less (See figure).

Block diagram



Warning

Power supply design must insure that the voltage between module pins 18 and 13 never exceeds 44 volts <u>under any operating conditions</u>. These include high line voltage, transformer regulation effects, voltage spiking due to current switching within the module, and regeneration. Failure to do this can result in permanent damage to the 5210.

F.1.1 Line Transformer Selection

Primary voltage and frequency rating

Make sure that the transformer is guaranteed to operate at the highest line voltage combined with the lowest line frequency that will ever be used to power your system. Failure to do so can result in saturation, large current increases and winding failure.

Secondary voltage rating

Maximum motor speed performance will be achieved by using as high a Motor Supply voltage as possible **without ever exceeding 44 volts**. Of course lower voltages can also be used (so long as the voltage is greater than the minimum specified value of 12 volts) but motor torque will drop more rapidly as speed increases.

The peak bus voltage (excluding any spiking due to current switching in the driver module or any regeneration effects) is approximately equal to:

(1.414 * **Actual** Secondary rms voltage) - 1.5

If, for example, the secondary rms voltage is 24 VAC, the peak bus voltage will be 1.414 * 24 - 1.5 = 32.4 volts. A transformer with 115 VAC primary and 24 VAC secondary would produce 32.4 volts peak bus voltage under nominal line conditions and at rated loading.

However if the line voltage increases 10%, the peak bus voltage increases to:

(1.414 * 1.1 * 24) - 1.5 = 35.8 volts

at rated transformer loading.

Load regulation must also be accounted for when selecting the transformer. Transformers are designed to produce their specified secondary voltage when loaded by their rated current. **For currents less than rated, the secondary voltage will increase**. Signal Transformer gives the following load regulation data for its line of rectifier transformers[1]:

VA Rating	Load Regulation
1 - 100	10%
100 - 350	8%
500	5% or less

This means that the secondary voltage of a 100 VA transformer will increase 10% over the specified voltage if the load current is reduced from rated current to zero. Since the stepper driver(s) might sometimes be disabled, the full regulation effect as well as maximum line voltage should be considered when selecting the transformer.

Based upon these considerations, the table below gives the highest allowable rated secondary voltage when using a line with +10% voltage tolerance:

Transformer VA Rating	Maximum Rated Secondary Voltage
1 - 100	26.5 VAC
100 - 350	27.0 VAC
500	27.8 VAC

1 The VA product is obtained by multiplying the specified secondary voltage (Volts rms) by the rated secondary current (Amps rms). \~For example, a 24 VAC transformer with a rated secondary current of 1 Amp has a VA of 24.

Current Rating

The average motor supply current into a 5210 is approximately equal to the output phase current[2]. If the default output current setting of two amps is selected, then the average motor supply current will be two amps. The average transformer secondary current equals the sum of the average module currents. Because the transformer supplies pulses of current to charge the "bus" capacitor(s) on the other side of the diode bridge, the rms current is higher than the average current. The transformer should have a rated secondary rms current of 1.8 times the average current or higher.

Example

The transformer used to supply three 5210 driver modules, each set for a phase current of 2 amps should have a rated secondary rms current of 1.8 * (2 + 2 + 2) = 10.8 amps or greater.

Note: *It is generally* <u>*not*</u> *advisable to significantly oversize the transformer because this will increase rectifier surge current during turn on, rectifier rms current (for a given average current) during normal operation, and capacitor ripple current.*

Typical performance curve

The following graph shows the measured output voltage vs. load current of a motor power supply built using a 100 VA transformer. The transformer is rated at 24 VAC secondary voltage at 4 A rms with 115 VAC primary voltage (actual primary voltage during test was 120 VAC). The curve shows the average voltage as well as the minimum and the maximum voltages occurring over a charging cycle (1/120 second). The drop in average voltage with increasing load is due to the poor regulation typical of such a small transformer as well as voltage ripple which increases the load.

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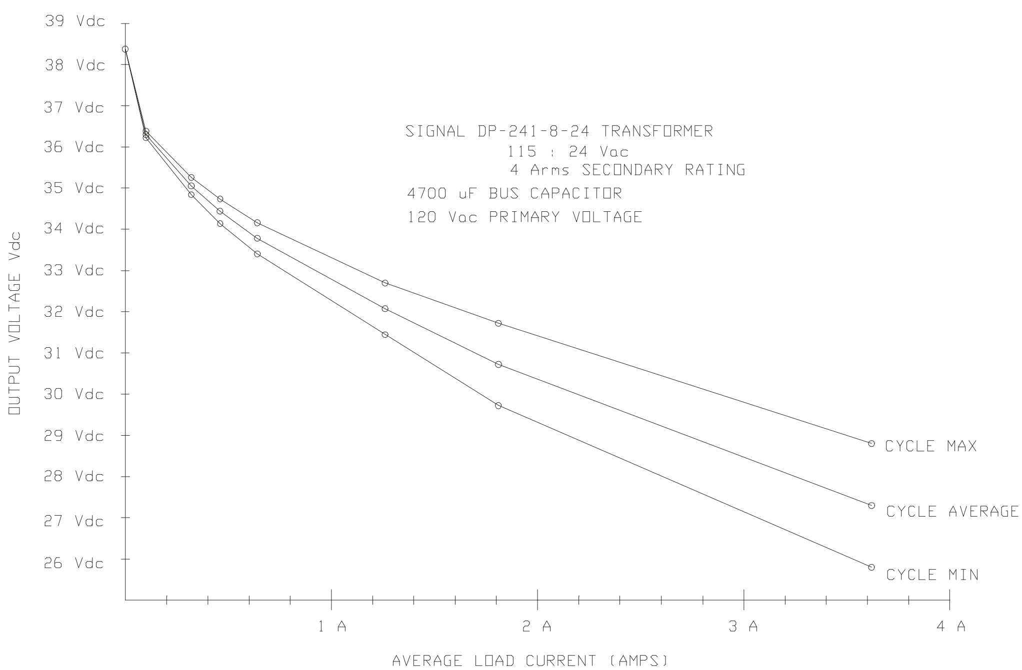
2 The supply current is a function of the motor used as well as motor speed torque. \~The actual supply current may be less than the phase current. \~To optimize the design, the supply current can be measured when the motor is producing the highest shaft power. \~Otherwise, assume it equals the phase current. \~When power is first applied to the 5210, motor supply current may briefly reach twice the phase current but will drop when the input voltage reaches 12 VDC, the minimum specified operating voltage. \~The brief surge does not affect transformer sizing.

Power supply output voltage vs. Load current



F.1.2 Rectifier Diode Selection

Voltage Rating For the bridge rectifier configuration shown, the peak inverse voltage (PIV) equals 1.414 times the secondary rms voltage. For example, a 24 Vrms secondary will develop 1.414 * 24 = 33.9 PIV across the rectifier diodes. To allow for line variation and spiking allow at least a 50% safety factor in the diode rating. Therefore, **the PIV rating of the rectifier diodes should be at least twice the rated secondary rms voltage.**

Current Rating Since each diode conducts only on alternate cycles, the average diode current will be between half the average DC current load on the supply. When power is first applied, there is a surge of current to charge the capacitor(s) which must be less than the diode's peak one cycle surge current (I_{FSM}) rating. Typically, diodes are chosen with an average current rating of at least twice the average current load of the supply. It is often advisable to select diodes with an even greater average current rating because they have lower thermal resistance between junction and case and hence ease heat sinking requirements. It is good design practice to limit the maximum junction temperature to 125^{o}C. Testing should be done to insure the power-on surge current is within the diodes I_{FSM} rating.

F.1.3 Capacitor Selection

As described earlier, separate capacitors should be used for each module to minimize lead length between the capacitor and the modules. The 4700 uf capacitor shown in the diagram will result in approximately 3 volts peak-to-peak voltage ripple at the input to the module. If less ripple is required, a correspondingly larger valued capacitor should be used. The capacitor's voltage rating should be at least twice the transformer's rated secondary rms voltage and its rated ripple current must be at least three Amps rms at 120 Hz.

F.1.4 Fusing

A line fuse should be included in series with the transformer primary to protect against short circuits.

Current Rating The fuse rms current rating should be approximately twice the transformer's primary rms current during normal operation. Based upon the foregoing:

Fuse Current Rating (Amps rms) =

$$3.6 * \# \text{ of 5210s} * \text{5210 Phase Current} * \frac{(\text{Transformer Secondary Voltage})}{(\text{Transformer Primary Voltage})}$$

5210 Index

Example If three 5210s with phase current set at the default value of 2 A are driven by a transformer with primary voltage of 115 VAC and secondary voltage of 24 VAC, the fuse should have an rms current rating of 3.6 * 3 * 2 * (24 / 115) = 4.5 Arms.

Voltage Rating A voltage rating of 250 Volts is suitable for use with both 115 and 230 VAC lines.

Type The fuse must handle the high inrush current when power is first applied (BUS MDA line of fuses or equivalent is recommended).

F.1.5 Regeneration Considerations

The motor power supply voltage can be "pumped up" when the motor and load are decelerated by the driver. In effect the motor becomes a generator converting mechanical energy stored in the spinning motor and load inertia into electrical energy. If the mechanical energy is less than the losses in the driver and motor the supply voltage does not increase but if it is greater than these losses the supply voltage will increase (be pumped up).

The mechanical energy of a spinning inertia is given by:

$$\text{Energy} = 3.87 * 10^{-5} * J * V^2$$

where: E = kinetic energy (joules)
J = inertia in oz-in-sec^2
V = speed in rpm

If any of this energy is converted to electrical energy in the form of charge on the bus capacitor(s), the voltage supply voltage is:

$$V = \sqrt{Vo^2 + \frac{2E}{C}}$$

where: V is the final voltage (after energy transferred to capacitor(s))
V_o is the initial voltage
C is the total capacitance in micro-farads
E is the initial kinetic energy in joules

Example

If an E32 motor (rotor inertia = .0170 oz-in-sec^2) is rotating at 1000 rpm, the stored energy is:

$$3.87 * 10^{-5} * .0170 * 1200^2 = .947 \text{ joules}$$

If this energy is transferred to a 4700 uf capacitor, initially charged to 40V, the voltage on the capacitor after the transfer is equal to 44.8 volts.

Note: *This exceeds the 44 volt maximum specification of the 5210 driver.*

In practice, most or all the kinetic energy is dissipated in the motor windings or in the driver power circuitry so that voltage pump-up is not a problem. However, in systems running at high speeds and having large load inertia, the voltage might be pumped up significantly and circuitry must be added to insure that the 44 volt limit is never exceeded.

Note: *Regeneration effects should be considered in the presence of high line conditions.*

To find out if regenerative energy is a problem, run the system while monitoring the supply voltage with an oscilloscope (a storage type is preferable). Start the system with slow deceleration rates and monitor the motor power supply to see if the voltage rises during deceleration. Slowly increase the deceleration rate (shorten deceleration time) while monitoring the voltage. If regeneration causes the supply voltage to exceed 44 VDC peak, a clamping circuit is required.

Note: *Be sure to add the effect of high line voltage when evaluating this test.*

Clamping Circuit

If a clamp is required, a power zener diode can be used as shown in the figure. The maximum zener clamp voltage must not exceed 44 volts. A 39 volt ±10% or 43 volt ±2% zener can be used.

Caution

If a clamp is required, the transformer secondary voltage must be re-checked to insure that the minimum clamp voltage is not exceeded under high line and low load conditions when there is no regeneration. Otherwise, the zener might overheat and fail.

To determine the required diode power rating, start with a 5W device and monitor the zener current with a current probe. Power (in watts) is the average current (in amps) times the zener voltage. Estimate the average current from the oscilloscope trace and compute the power. Select a zener rated slightly higher than the measured power.

F.2 +5 VDC Supply

A 5 volt ±5% (±0.25 volt) at 60 mA per driver module supply is required for the low voltage supply. An economical solution is shown in the block diagram at the beginning of this appendix. Diodes from a center tap of the transformer used for the motor power supply charge capacitors at the input of linear regulators. For reasons given below, the recommended approach is to use separate supplies for every two 5210 modules.

F.2.1 Capacitor Selection

The voltage at the input to the regulator is approximately half the motor supply voltage. Good design practice allows for at least a one-cycle dropout of the AC line before the low voltage supply drops out of regulation. Using this requirement and assuming the regulator requires at least three volts, select the capacitor at the input to the regulator as follows:

1. Measure the average motor supply voltage for maximum load current and minimum line voltage. Define this voltage as V_{mtr}.
2. The required capacitance at the regulator's input is given by:

$$C(uF) = 30{,}000 * [\ I_{load} / (V_{mtr} / 2 - 8)]$$

For example, if the measured motor supply voltage (minimum line voltage and maximum current load) is 30 volts and the supply is to drive on 5210 module (load current = 60 ma, the capacitor should be at least:

$$30,000 * [0.06 / ((15 - 8)] = 257 \text{ uF}$$
(use 270 uF)

If the supply is to drive two 5210 modules, then the capacitor should be:

$$30,000 * [0.12 / (15-8)] = 514 \text{ uF}$$
(use 680 uF)

Obviously, if riding through a longer dropout is required, a larger capacitor must be used. The rms ripple current rating of the capacitor should be two to three times higher than the load current.

F.2.2. Diode Selection

Average diode current equals the load current (60 mA for one 5210, 120 mA for two 5210s). Again, it is advisable to use an oversized diode to minimize thermal problems. The diode's voltage rating is half that required for the motor supply rectifier diodes. Testing to insure the power-on surge current is within the diodes IFDS rating.

Regulator Considerations

Power dissipation in the regulator is the voltage across it times the load current. For an input voltage of 20 volts (40 volt motor power supply voltage), the regulator's power dissipation will be (20-5) * .06 = .9 Watts for one 5210 and 1.8 Watts for two 5210s. Both can be handled using a TO-220 regulator with clip-on heat sink. Therefore, the recommended approach is to use a separate T0-220 regulator, as well as separated input and output capacitors, for every pair if 5210s as shown in the diagram.

To prevent voltage spikes at the low voltage supply input to the driver modules, a 10 uf Tantalum capacitor paralleled with a 0.1 uF ceramic capacitor should be located close to each module such that the total lead length between the capacitor and module is less than 6 inches.