FEATURES

- Complete servo amplifier for dc brushless-motors with 60° or 120° Halls
- Wide power supply range
  +24 to +225VDC
  ±5 to ±15A continuous
  ±10 to ±30A peak
- *+5V @ 200mA* powers motors with "commutating encoders"
- *VELOCITY MODE OPTIONS*
  Hall or encoder tach
  Brushless tachometer
- *BRAKE* feature with current-limiting
- *FAIL-SAFE ENABLE INPUT* with ground or +5V active level selection
- *FAULT PROTECTIONS*
  Short-circuits
  output to output
  output to gnd
  Over / under voltage
  Over temperature
  Self-reset or latch-off
- 3kHz Bandwidth
- Wide load inductance range 0.2 to 40 mH.
- Independent settings for continu ous and peak current, and peak-time
- Surface mount technology

APPLICATIONS

- X-Y stages
- Robotics
- Automated assembly machinery

THE OEM ADVANTAGE

- Conservative design for high MTBF
- Flexibility: internal header config ures amp for wide range of applications

MODEL	POWER	I-CONT (A)	I-PEAK (A)
5121	+24 to +90 VDC	10	20
5131	+24 to +90 VDC	15	30
5211	+24 to +180 VDC	5	10
5221	+24 to +180 VDC	10	20
5231	+24 to +180 VDC	15	30
5321	+24 to +225 VDC	10	20

FEATURES

The 5xx1 models are third-generation amplifiers for Hall commutated dc brushless motors. Operating from +24 to +225 VDC transformer-isolated unregulated power supplies, models output peak currents from ±10 to ±30A, and continuous currents of ±5 to ±15A.

Built with surface-mount technology, these amplifiers offer a full complement of features for DC brushless motor control. Torque-mode operation is standard, and there are three choices for velocity-loop operation. Brush tachometers can be used with the standard amplifier. Brushless tachometers are supported with the "U" option. Frequency to voltage conversion of Hall or encoder signals gives tachless velocity-loop operation with the "V" option.

Torque mode is used typically with digital controllers that calculate position and velocity from the motors encoder. Velocity loops using brush or brushless tachometers give the best low-speed control. Hall tach operation works well for high speed applications such as spindles. Encoder tach velocity loops give a wide speed range and lower ripple near zero velocity.

Separate current-limits provide protection for motors while optimizing acceleration characteristics. Peak current, continuous current, and peak-time are individually settable.

The /Enable input active logic-level is switch-selectable to ground or +5V to interface with all types of control cards. Fail-safe operation in either polarity results from an internal jumper that selects the default input level so that the amplifier shuts down with no input.

An active brake feature decelerates the motor to zero velocity with current-limiting and adjustable gain.

Mosfet H-bridge output stage delivers four-quadrant power for bi-directional acceleration and deceleration of motors.

An internal 40-pin solderless socket lets the user configure the various gain and current limit settings to customize the amplifiers for a wide range of loads and applications.

Header components permit compensation over a wide range of load inductances to maximize bandwidth with different motors.

All models are protected against output short circuits (output to output and output to ground) and heatplate overtemperature. With the /Reset input open the amplifier will latch off until powered-down or the /Reset input is toggled. The amplifier will reset itself automatically from faults if the /Reset input is wired to GND.

Typical at 25°C ambient, Load = 200µH. in series with 1 Ω.

TECHNICAL SPECIFICATIONS

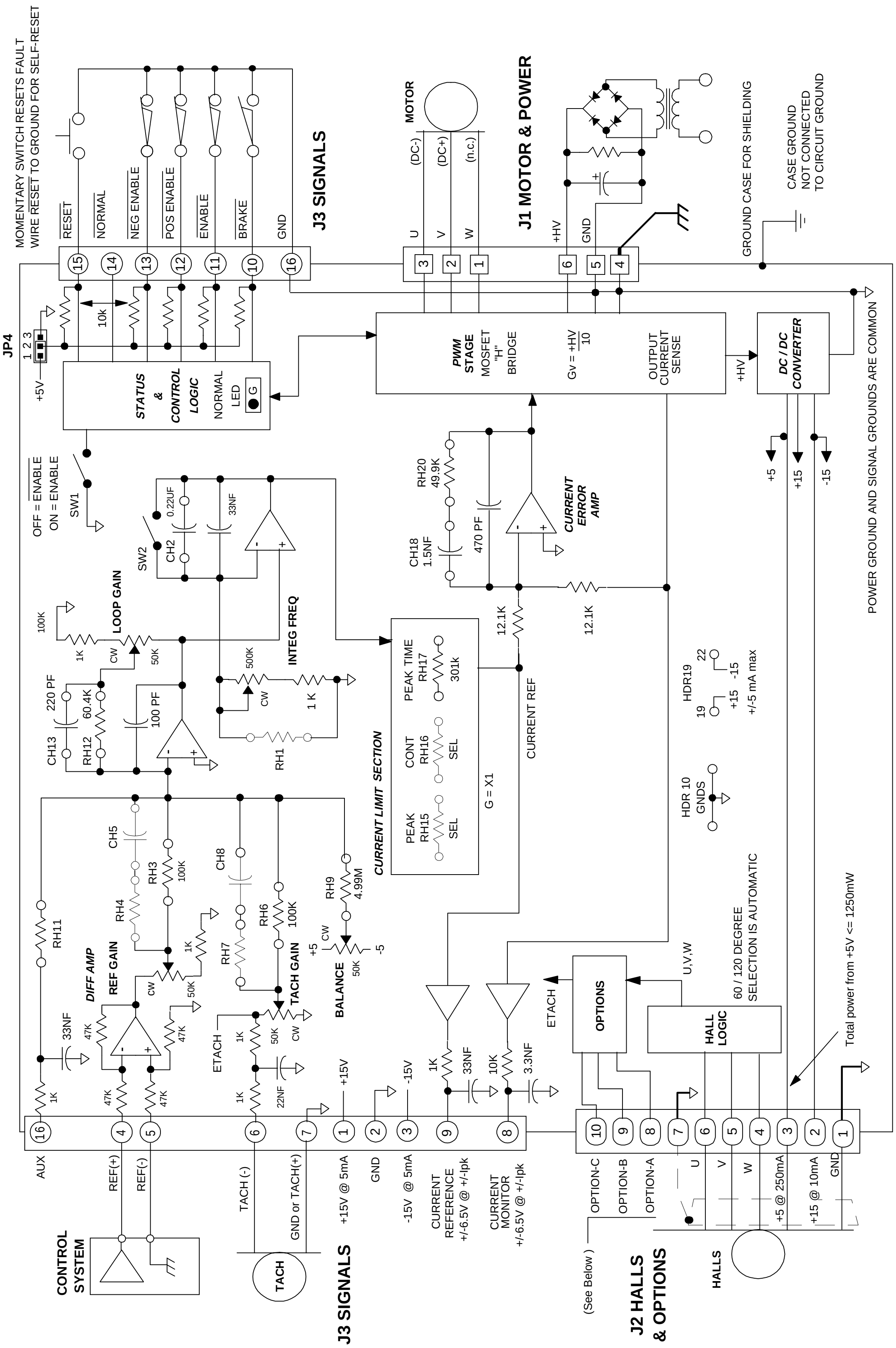
MODEL		5121	5131	5211	5221	5231	5321
OUTPUT POWER							
	Peak power	±20A @ ±83V	±30A @ ±83V	±10A @ ±171V	±20A @ ±171V	±30A @ ±172V	±20A @ ±214V
	Peak time	1 sec at peak power or 2 secs. after polarity reversal					
	Continuous power	±10A @ ±85V	±15A @ ±85V	±5A @ ±173V	±10A @ ±173V	±15A @ ±173V	±10A @ ±216V
OUTPUT VOLTAGE		±Vout = (±HV)×(0.97) - (Ro)×(Io)					
		Ro = 0.2	Ro = 0.15	Ro = 0.4	Ro = 0.2	Ro = 0.1	Ro = 0.2

LOAD INDUCTANCE		200 µH to 40mH typical. Selectable with components on header socket	
BANDWIDTH	Small signal	-3dB @ 3kHz with 200µH load at maximum supply voltage, varies with load inductance and RH20, CH18 values	
PWM SWITCHING FREQUENCY		25kHz	
REFERENCE INPUT		Differential, 94KΩ between inputs, ±20V maximum	
GAINS	Input differential amplifier	X1	(Volt / Volt)
	PWM transconductance stage	Ipeak / 6V	(Amps / Volt)
POTS	Ref Gain	Default = CW	CCW attenuates Reference input from x1 to 0
	Tach Gain	Default = CCW	CW increases speed (decreases feedback from tachometer). Note: fully CW = open-loop
	Loop Gain	Default = CCW	CW increases loop gain in velocity mode, current gain in torque mode
	Integ Freq	Default = CCW	Integrator zero-gain frequency in velocity mode. CW increases stiffness
	Balance/Test	Default = center	Use to set output current or rpm to zero; or use as ±10V test input if RH9 set to 50kΩ
DIP SWITCHES	S1: /Enable input active level	Default = OFF	GND enables, open or >2.5V inhibits (*Note: S1 has no effect on /Pos or /Neg enables*)
		ON	Open or >2.5V enables, GND inhibits
	S2: Integrator control	Default = ON	Integrator disabled for torque mode
		OFF	Integrator enabled for velocity mode
LOGIC INPUTS			
	/Enable	Default = GND	GND enables amplifier, open or >2.5V inhibits with S1 OFF. If S1 ON then GND inhibits
	/POS enable, /NEG enable	Default = GND	GND enables, open or >2.5V inhibits positive/negative output currents (S1 has no effect)
	/Brake	Default = OPEN	GND brakes motor. (Wire to +5V for brake-OFF condition if J4 is jumpered to GND)
	/Reset	Default = OPEN	GND resets latching fault condition, ground for self-reset every 50 ms.
	Input resistance	10kΩ (Jumper J4 selects connection to +5V or ground), R-C filters on inputs	
	Logic threshold voltage		2.5V (Schmitt trigger inputs with hysteresis, 74HC14)
	Input voltage range		0V to +32VDC
FAIL-SAFE OPERATION			
	Internal jumper J4 selects +5V or GND connection for input pull-up resistors to /Enable, /Pos Enable, /Neg Enable, /Reset, and /Brake so that amplifier will default to *disabled* condition if inputs are open-circuit, or wires are broken. (See Applications section for details)		
LOGIC OUTPUT			
	+Fault (/Normal)		LO (current sinking) when Normal LED is ON; HI when LED is OFF
	HI output voltage		+5V (no load). Output is N-channel mosfet drain terminal with10kΩ pullup resistor to +5V
	LO output voltage		1.25V @ max output current of 250mA. On resistance Ro = 5Ω, max voltage = 50VDC
INDICATORS (LED's)			
	Normal (Green)	ON = Amplifier enabled AND HV within normal limits AND NOT Fault (overtemp or output short circuits)	
	Power OK (Green)	ON = Power OK (+HV >24V AND +HV < 92V for 51x1, or <182V for 52x1, or <230V for 5321)	
	Fault (Red)	ON = Output short-circuit or over-temperature condition	
MONITOR OUTPUTS	Current Ref	Demand signal to PWM stage: ±6V = ±Ipeak	
	Current Monitor	Response from motor: ±6V @ ±Ipeak (1kΩ, 33nF R-C filter)	
DC POWER OUTPUTS		+15VDC @ 5 mA (J2-2, J3-1, and internal header at position 19) -15VDC @ 5mA (J3-3, and internal header at position 22) +5V @ 250 mA max (J2-3) Note: maximum power from all dc outputs not to exceed 1.4W	
PROTECTIVE FEATURES			
	Short circuit (output to output, output to ground)	Latches unit OFF (Power off/on, or ground at /Reset input resets)	
	Overtemperature	Latches unit OFF at 70°C on heatplate (Power off/on, or ground at /Reset input resets) *Wire /Reset input to ground for automatic reset after latching fault*	
	Undervoltage	Shutdown at +HV < 22VDC	
	Overvoltage	Shutdown at +HV > 92VDC(51x1), or +HV > 182VDC (52x1), or +HV >230VDC (5321) (Amplifier operation resumes when power is NOT undervoltage or NOT overvoltage)	
	Current-limiting (foldback)	Output current set by header components (peak, continuous, & peak-time)	

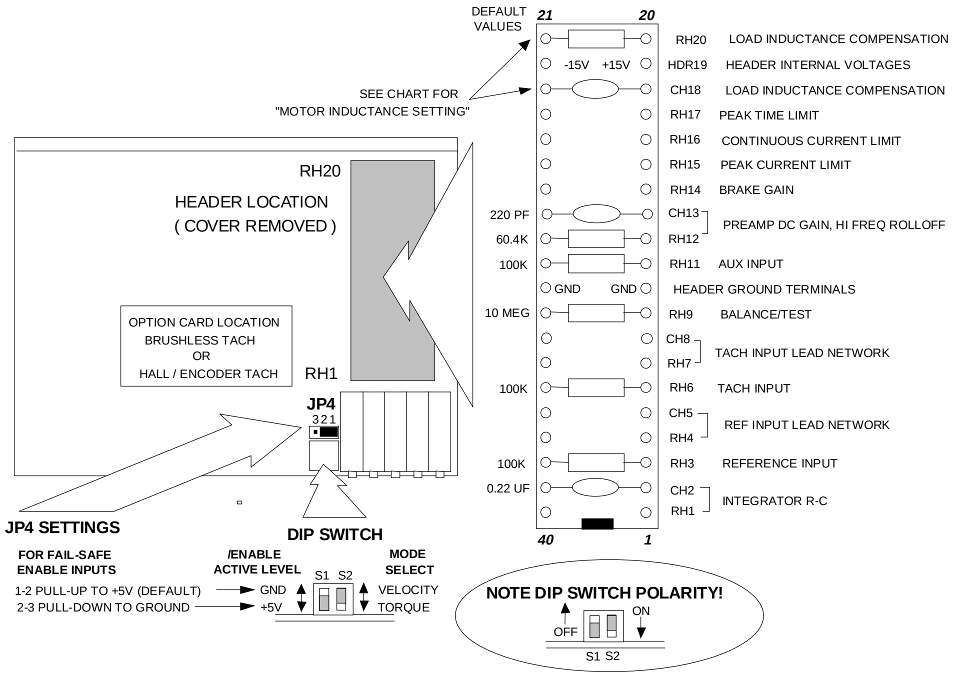
POWER REQUIREMENTS							
	DC power (+HV)	+24 to +90VDC (51x1), +24 to +180VDC (52x1), +24 to +225VDC (5321) Transformer isolated					
	Watts minimum	2.5W	2.7W	2.5W	3W	4W	4W
	Watts @ Icont	25W	41W	20W	54W	53W	50W

THERMAL REQUIREMENTS		Storage temperature range -30°C to +85°C Operating temperature range 0° to 70°C baseplate temperature
MECHANICAL	Size	3.82 x 6.57 x 1.37 in. (97 x 167 x 34.8 mm.) without optional heatsink 3.82 x 6.57 x 2.9 in. (97 x 167 x 74 mm.) with optional heatsink mounted
	Weight	1.1 lb (0.48 kg.) without optional heatsink. Add 1.0 lb (0.45 kg) for heatsink.

FUNCTIONAL DIAGRAM



COMPONENT HEADER



MOTOR INDUCTANCE SETTING

Model	5121		5131		5211		5221		5231		5321	
Load (mH)	C	R	C	R	C	R	C	R	C	R	C	R
0.2 to 0.5		20k		30k		10k		10k		15k		10k
0.6 to 1.9	**6.8**	**68k**	**6.8**	**68k**	**6.8**	**15k**	**6.8**	**30k**	**6.8**	**30k**	**6.8**	**40.2k**
2 to 5.9		100k		150k		47k		68k		68k		82k
6 to 19		220k		220k		68k		150k		150k		150k
20 to 40		330k		470k		150k		220k		330k		300k

Note: Values in ***bold & italics*** are factory default values. R = RH20 resistance in Ω, C = CH18 capacitance in nF. Values shown are for 90V (5121, 5131), 180V (5211, 5221, 5231), and 225V (5321). At lower supply voltages RH20 may be increased and CH20 decreased. Test for best results: short CH18, select RH20 for best step response in current-mode, next test CH18 for lowest value that does not degrade step response.

PEAK CURRENT TIME-LIMIT

Tpeak (s)	RH17 (Ω)
1.5	***open*** [1]
1.0	2M
0.5	560k

Times shown are for 100% step from 0A

1. Values in ***bold & italics*** are factory default values.
2. Peak times double after polarity reversal.
3. Peak current limit should always be set greater than or equal to continuous current limit

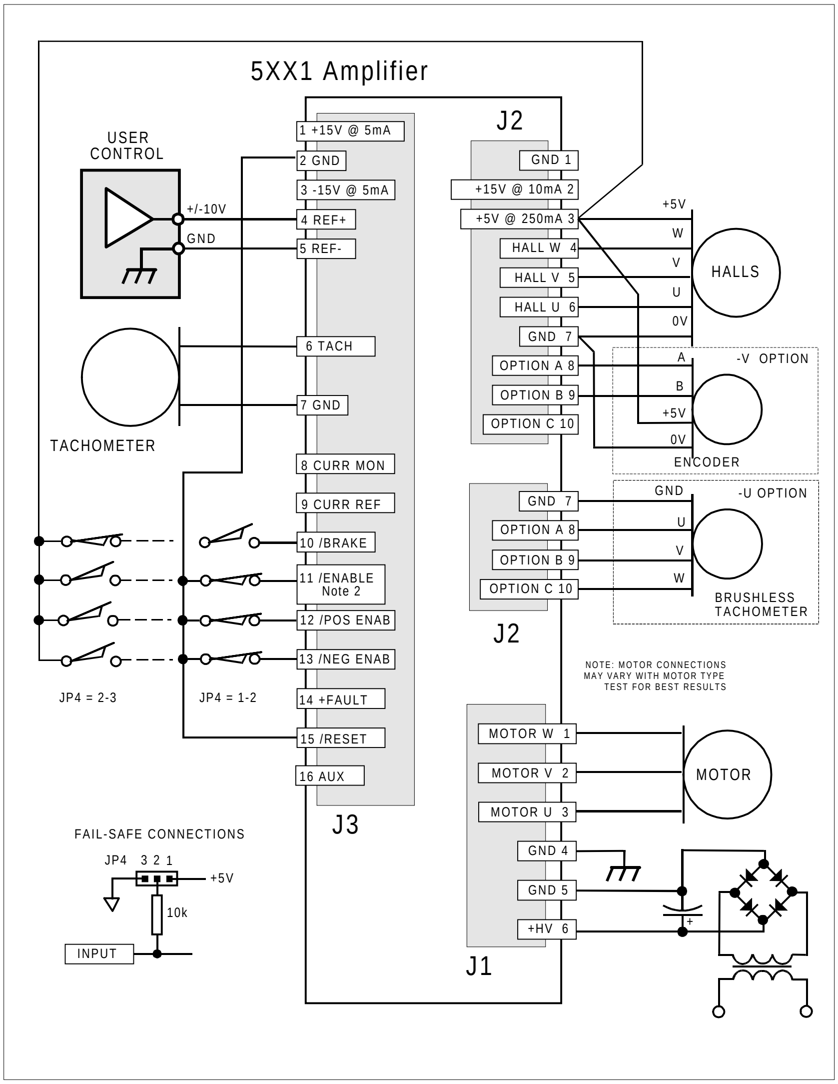
PEAK CURRENT LIMIT

Ipeak (%)	RH15 (Ω)
100	***open*** [1]
80	20k
60	9.1k
40	4.3k
20	1.5k

CONTINUOUS CURRENT LIMIT

Icont (%)	RH16 (Ω)
100	***open*** [1]
80	47k
60	20k
40	6.8k
20	510

AMPLIFIER CONNECTIONS



Notes
1. All amplifier grounds are common (J1-3,4 & J2-2,7)
   Case/heatplate is isolated from amplifier grounds.
2. /Enable input is ground active with S1 in the OFF (default) position: GND will enable the amplifier.
   For +5V active enables, set S1 ON (open inputs will enable amplifier via internal pullups to +5V).
3. For best noise immunity, use twisted shielded pair cable for reference and tachometer inputs.
   Twist motor and power cables and shield to reduce radiated electrical noise from pwm outputs.

SWITCH AND POTENTIOMETER SETTINGS (SEE APPLICATION SECTION FOR DETAILS)

	TORQUE MODE	**Default**	**VELOCITY MODE**
S2	ON	ON	OFF for operation, ON for initial setup (see Integ Freq Pot below)
Ref Gain pot	Sets current-gain	CW	RPM/Vref ratio, use after tach-loop settings are complete CCW reduces speed
Tach Gain pot	n/a	CCW	Begin full CCW, adjust CW to increase speed. Sets Vtach/Vref ratio. Re-adjust Loop Gain, Integ. Freq pots after changing
Loop Gain Pot	CCW	CCW	CW until oscillation, then back off 1-2 turns
Integ. Freq Pot	n/a	CCW	Adjust Loop-Gain pot with S2 ON, then with S2 OFF, adjust CW for best stiffness without oscillation

APPLICATION INFORMATION

INTRODUCTION

Operating from transformer-isolated DC power supplies, the 5xx1 family of amplifiers has been designed to drive three-phase DC (permanent-magnet) brushless motors in either torque or velocity mode. Hall detectors mounted in the motor provide commutation information for 'trapezoidal' or 6-step drive. Adjustable current limits for peak, continuous, and peak time provide protection for smaller motors. The "U" option supports motors using brushless tachometers for velocity loop operation. And, the "V" option uses frequency to voltage conversion techniques to deliver velocity loop operation from A/B channel digital encoders, or the motors own Hall signals. The sections that follow describe the initial setup of the amplifier and connection to power sources, as well as the operation of the amplifiers with their options.

POWER SUPPLIES & GROUNDING

Transformer-isolated power supplies are required, and in most cases these are unregulated power supplies consisting of transformer, rectifier, and filter capacitor. The choice of power supply voltage should take into consideration the variation in the mains voltage, and the no-load to full-load change in power supply output voltage. For example: common 120VAC lines may vary from 105 to 132VAC, and power supply output may change from 5 to 10% from the no-load condition The goal then becomes to find a power supply voltage that is adequate to power the motor at full load at low-line conditions, and that will not cause the amplifier to shutdown for overvoltage fault under high-line and no-load conditions. This equation is a shortcut way to find the highest power supply voltage where:

VDC = Power supply full load output voltage
MaxBuss = amplifier maximum power supply rating
Vmains:High = Maximum mains voltage
Vmains:Low = Minimum mains voltage
%Reg = power supply regulation in percent:

Example: Find the highest voltage for a model 5121 power supply operating from 120V mains. The amplifiers normal operating range is +24 to +90VDC, the mains voltage is 132V maximum and 105V minimum, and the supply regulation will be 5%.. Solving this equation gives 68V. Note that this does not reflect any tolerance for "pump-up" of the power supply due to regenerative power transfer during deceleration of heavy loads.
Higher voltages could be used, but you would need some assurance that the AC mains would stay within a narrower margin at your site if you want to be prepared for the worst-case conditions.

AMPLIFIER WIRING & CABLING

Power supply and motor connections should be done with wire that has a rating to support the amplifiers continuous current ratings. AWG 14 wire will support all amplifiers in this series.
To minimize noise radiation from motor and power cabling, wires should be twisted, and shielded if possible.
Hall and encoder signals are frequently routed near to motor phase winding cables. To minimize coupling of PWM noise, Hall wiring should be multiple-conductor shielded cable. Grounding the motor case will also reduce coupling between motor windings and Hall and/or encoder.

If amplifiers are more than 1m. from power supply capacitor, use a small (500-1000µF.) capacitor between the +HV and Gnd inputs for local bypassing.

GROUNDING

Power ground and signal ground are common (internally connected) in these amplifiers. All grounds are isolated from the amplifier case which can then be grounded for best shielding while not affecting the power circuits.
Currents flowing in the power supply connections create noise that appears on the amplifier grounds. To minimize this cable noise, the best approach is to ground the amplifiers at J1-4, and to leave the minus side of the power supply capacitor floating.
Wiring noise will be rejected by the differential amplifier at the reference input, but will appear at the digital inputs. These are filtered, but this noise must be considered when multiple amplifiers are mounted more than 1-2 m from the power supply.

MULTIPLE AMPLIFIER CONNECTIONS

When installing multiple amplifiers, each amplifier should have its own twisted-pair cable running to terminals of the power supply filter capacitor. Don't "daisy-chain" cables from one amplifier to the next. This will aggravate cable noise and cause the noise from amplifiers to add to each other. The "star" wiring configuration will minimize wiring noise.

MOTOR HALL SIGNAL CONNECTIONS

Different manufactures use various naming conventions for the Halls and motor phase windings. Copley uses the U-V-W convention, but you may also see R-S-T, A-B-C or others. In all cases there are three Hall signals and three motor phase wires.
Most Halls operate from +5V. This, and +15V is available at J2. Connect the Hall power & ground, and then wire the Hall signals to the U-V-W inputs in the same order (i.e., R-S-T, A-B-C).
Use shielded cable if possible, grounding the shield at the amplifier and letting the motor end float. Once wired, you will not have to change these connections during the *phasing* process.
Regardless of the order in which the Halls are connected, the motor windings can be phased correctly. We take the approach that wires the Halls first, and then changes the motor windings as needed simply because the motor connections are screw terminals and are easily changed.

MOTOR PHASE CONNECTIONS

Connect the motor phase windings in the same U-V-W order to begin the phasing process. Some motors are set up to work well with this wiring scheme. If it is not the right one, then there are only five other possible combinations of wiring remaining, and one of these will be the right one.

AMPLIFIER CONTROL SIGNALS

Two type of controls signals are used: analog and digital. The reference input(s) (one input, two wires in differential mode, see following) is an analog input that takes the industry-standard ±10V to control motor torque or velocity. Digital signals connect to the /Enable, /Pos Enable, /Neg Enable, /Reset, and /Brake inputs to control these functions in an ON/OFF mode. These signals can be TTL, CMOS, or relays, but all share the characteristic that they are two-state signals (HI/LOW, ON/OFF, 0/+5V, open/closed contact, etc.).

REFERENCE INPUTS

The reference input is the input for the “command” signal to the amplifier. There are two reference inputs (Ref(+) and Ref(-)), and *both should be used*.

A differential amplifier operates like a voltmeter, measuring the voltage *between* two points. In the case of a servo amplifier, the voltage to be measured is typically the output of a control system. You may think that your control card has a single output, ±10V, for example, but that voltage is *relative* to the ground at the control card. In practice this ground may be at a different potential than the ground at the amplifier (see the previous section about wiring and cabling).

By connecting the Ref(+) input to the output of the control card, and Ref(-) to ground *at the control card*, the amplifier will correctly measure the cards output and reject any noise between the grounds.

Do nott connect Ref(-) to the amplifier signal ground, and Ref(+) to the control card output. This connection will now measure not only the cards output voltage, but will also pick up as an input any noise that exists between card and amplifier grounds! This can cause oscillation or erratic operation.

/ENABLE INPUT

This input functions as the “ON/OFF” switch for the amplifier. Without removing DC power from the amplifier, this signal will completely disable the amplifier outputs, and reset the integrators in the PWM and preamplifier stages so that the amplifier will re-enable without jerking. When the amplifier is disabled, the Normal LED will turn off, switching of the PWM outputs will stop, and the +Fault output will go HI. The mosfets in the output bridge are all off, so the motor can be moved as if it were not connected to the amplifier.

Note: the back-emf of the motor can cause the diodes that are part of the mosfets to conduct if the motor voltage exceeds the power supply. But, for small motions, the motor will “coast” when the amplifier is disabled.

/ENABLE INPUT ACTIVE LEVEL SELECTION

The default operation for this signal is *ground-active*. That is, grounding the input will enable the amplifier, and when the signal is open (or greater than +2.5V), the amplifier will be disabled. This type of operation is also *fail-safe* in that a broken wire will cause the amplifier to disable (default setting of JP4 on pins 1-2 connects pullup resistors to +5V).

For control cards that output +5V (or open-collector) to enable the amplifier, dip switch S1 should be turned ON. Now, grounding the input will disable (inhibit) the amplifier and +5V (or open-circuit) will enable it. But, simply changing this switch alone has eliminated the fail-safe feature: a broken wire will produce an open input, and the amplifier can operate.

FAIL-SAFE OPERATION FOR /ENABLE INPUT

Fail-safe operation means that the amplifier will be disabled if the wire to the /Enable input is broken (or the input is open-circuit). In order to provide fail-safe operation with +5V active Enable (S1 ON) an internal jumper JP4 is on the pc board that changes the connection for the “pull-up” resistors for the Enable input, as well as the /Pos & /Neg Enable, /Brake and /Reset inputs.

When this is moved to position 2-3, the input resistors are connected to ground. Now, if the wire to the /Enable input is broken, the input will be “pulled-down” to ground, inhibiting the amplifier.

DIGITAL INPUT PULL-UP/PULL-DOWN RESISTORS (JUMPER JP4)

This is a three pin jumper with a shorting plug found just behind the LED’s on the pc board. The default position is between pins 1-2, which connects the input resistors for the enable inputs (and others, see above) to +5V. When the position is changed to pins 2-3, the resistors become “pull-downs” and the inputs will be grounded with no signals attached. Used in conjunction with S1, this jumper can be used for *fail-safe* operation so that broken wires shut down the amplifier. The effect on inputs other than the /Enable input is described below.

/POS & /NEG ENABLE INPUTS

THESE TWO INPUTS ARE ALWAYS GROUND-ACTIVE AND MUST BE GROUNDED FOR THE AMPLIFIER TO OPERATE.
THE SETTING OF S1 HAS NO EFFECT ON THEIR OPERATION.

These inputs function as direction-sensitive enable/disables and are normally used with limit switches so that torque is inhibited when the motor drives into the limit, but is available to back-out of the limit.

With JP4 in the default position, these inputs are pulled-up to +5V and are typically grounded through normally closed limit switches. When the switches open, the inputs pull-up to +5V and the torque will be inhibited.

If JP4 is in position 2-3, for fail-safe /Enable operation from cards that output +5V to run the amplifier, then normally-open limit switches connected to +5V should be used. When a limit switch is hit, the switch will pull-up to +5V and torque will be inhibited.

/BRAKE INPUT

This input overrides the signal at the reference inputs and drives the motor to a stop at a rate determined by the amplifier current-limits and the value of header part RH14. If the amplifier is simply disabled, the outputs stop switching and the motor coasts to a stop with no power applied. Note that if JP4 is in the 2-3 position, that the /Brake input must be wired to +5V to operate the amplifier (brake off).

The brake feature senses the motor back-emf and actively drives it to zero, which corresponds to zero rpm. When this feature is active the signals at the reference inputs are internally disconnected from the PWM stage, and the output voltage is fed-back through the current limit circuit in such a way that the output voltage is driven to zero while maintaining the current-limits set on the component header.

Header component RH14 controls the gain of the brake function. It should be chosen based on the application and will vary according to the amplifier tuning, load inertia, and motor characteristics. In practice, choose a value that will drive the amplifier into current-limiting and does not produce oscillation or noise at a standstill.

/RESET INPUT

Overtemperature and output short circuits are called *latching* faults because they cause the amplifier to turn off and stay off (like a latching switch that stays where you left it).

These faults can be reset by turning the +HV off and back on, or by grounding the /Reset input when the amplifier is under power.

If an auto-reset from these conditions is desired, the /Reset input can be wired to ground. In this case, the amplifier will “try” to reset every 50mS. after a fault occurs, and if the cause of the fault has been removed, operation will resume.

If jumper JP4 has been moved to position 2-3 for fail-safe operation from HI active /Enable input then the amplifier will always auto-reset unless the /Reset input is jumpered to +5V.

SETTINGS FOR THE MOTOR

INDUCTANCE COMPENSATION

Armature inductance compensation maximizes the bandwidth for your motor and supply voltage. Values for CH18, RH20 from the table (page 4) work well for most instances. To optimize: first replace CH18 with a jumper (short), then use a 50Hz, 1V peak-to-peak square wave input and select RH20 for the best step response (lowest risetime with minimal overshoot). Next install CH18 and choose the smallest value that does not result in excessive ringing on the current waveform.

CURRENT LIMITS

The Current Reference signal provides a way to customize these settings without driving the motor at high current levels. This signal is the output of the servo preamplifier stage and current limit section. It has the same scale factor as the current monitor:
±6V will demand ±Peak current from the amplifier. In terms of amps/volts the scale factor is Ipeak / 6V. So, for a model 5221 with a peak output current of 20A, the Current Ref scale factor would be 20A / 6V or 3.33A/V. Using this you can calculate the effects of header component changes on the actual current to the motor. In use, a test signal is inputted to the amplifiers reference inputs, and the response can be observed at the Current Ref output.

CONTINUOUS CURRENT LIMIT

Select RH16 using manufacturers specification for your motor. This keeps the motor within its thermal limits. Table values give basic settings. Note that this limit measures average current and will not work on symmetrical wave-forms such as might occur during system oscillation. Input a square wave reference signal of ±10V with a very slow (1/4 Hz) frequency. This will allow the 2 s. peak time after polarity reversals, and time for the current to settle to the continuous value. Calculate the current by multiplying the observed voltage by the scale factor, and adjust the value of RH16 for the desired current.

PEAK CURRENT LIMIT

Amplifiers are shipped with no part installed in RH15, which delivers the amplifiers peak rated current. For lower settings use values from the table. This setting is of importance when a motor can be demagnetized by currents that are within the peak-current capability of the amplifier. Peak limits “clamp” motor current at the set value and are not affected by the waveform.
Using the same ±10V square wave, select RH15 for the desired output current as described above.

PEAK CURRENT TIME-LIMIT

Using the bipolar reference input, the observed peak times will double, and will typically be 2s. after polarity reversals. This is the maximum peak time that the amplifier can deliver, and is 2X the unipolar peak time when driving from 0V input to the maximum of +10 or -10V. For shorter peak times, test values of RH17 that give the desired result. Note that peak times are also affected by the DC level of the current that precedes the peak demand. So, peak times will be less than 1s if preceded by currents of the same polarity that are near to the continuos current level.

PHASING THE MOTOR

Power up the amplifier with the reference voltage set to zero. Apply a small voltage (about 0.5 to 1V) between the reference inputs. This should produce enough torque to spin the motor. Watch what happens, and then reverse the polarity of the reference. If the motor is phased properly, it will rotate with little torque to the maximum speed permitted by the power supply. You may be able to slow it with your hands (be careful). Proper phasing will be evident by smooth rotation in both directions, and smooth torque at low speeds. For a sensitive test of phasing, input a small (±0.5 to ±1V) reference signal at about 1Hz. Hold the motor shaft and feel the torque in your hand. A properly phased motor will feel as if someone was twisting the shaft with their hands, the force will change smoothly as the direction moves from CW to CCW. If the phasing is wrong the motor may twist in one direction, but there will be a lag after changing directions, and it may jump after a pause. Or, it may not move at all. Of the six combination, the right one should be quite obvious. As a check when you think that you have got it right, change the windings: the motor shouldn’t be good now at all.

If the first try doesn’t work, then there are five other possible connections of the three motor wires remaining and one of these must be the right one. Of the six possible connection combinations, three of these will result in rotation that is the opposite of the Hall signal rotation pattern and will not work at all. Of the other three, one will be the correct connection, one will run the motor at reduced torque and with uneven low-speed operation, and the third will not turn the motor at all, but will drive current through the windings and produce no torque. The chart below lists all six of the combinations to make it easy to try them without missing one:

TRY	J1-3	J1-2	J1-1	DIR
#1	U	V	W	
#2	V	W	U	CW
#3	W	U	V	
#4	U	W	V	
#5	W	V	U	CCW
#6	V	U	W	

Note that combinations 1-2-3 all represent the same direction of rotation. The thing that changes is the phasing of the leads. If you read from left-to-right, beginning with U, all of the first three are in U-V-W order. For combinations 4-5-6, note that W and V are reversed. But again, all of these read in the same order U-W-V, and differ only in phasing. If you start up your motor and it turns at all, even roughly, then you probably have the correct *direction* of rotation and should now try the other combinations in the same rotation group. E.g., if you wired it up U-V-W and it ran roughly, then try #2, or #3. If you get no rotation at all, and turning the shaft by hand makes it jump backwards, then you’re probably in the wrong rotation group, and should go to the opposite group.

Remember that when the drive is operating in torque mode, that the speed of the motor will only be controlled by the load, or friction torque so typically small currents will accelerate an unloaded motor to high speeds.

AMPLIFIER OPERATING MODES

TORQUE MODE OPERATION

Use this mode with microprocessor control cards that take encoder signals, compute position *and velocity*, and output a torque-control command to the amplifier.
Transconductance (amps output vs. volts at Ref input) equals Ipeak / 10V.

Settings

Ref Gain pot	fully CW
Tach Gain pot	n/a (no function)
Loop Gain pot	fully CCW
Integ Freq pot	n/a (no function)
Balance pot input	adjust for zero torque at zero
S2	ON (disables integrator)

BRUSH TACHOMETER OPERATION

Disconnect the motor from the load for this procedure! If tachometer phasing is reversed, motor may 'run-away' at high speed damaging equipment or causing injury!

Begin with these settings:

Ref Gain pot	fully CW (default)
Tach Gain pot	fully CCW (default)
Loop Gain pot	fully CCW (default)
Integ Freq pot	fully CCW (default)
Balance pot input	adjust for zero torque at zero
S2	ON (disables integrator)

Select a value for RH6 based on this equation, use a standard value resistor closest to the solution:

$$RH6 = \left(\frac{HV \times Kg}{Ke}\right)\left(\frac{RH3}{10V}\right)$$

HV = power supply voltage
Kg = tachometer gradient (usually volts / krpm)
Ke = motor back-emf constant (volts / krpm)
RH3 = reference input scaling resistor(default = 100K)
10V = maximum reference input voltage (typical)

DYNAMIC ADJUSTMENTS

Connect motor and tachometer. Power-up the amplifier and rotate the shaft slightly. If the tachometer is phased wrong the motor will "run-away". If this occurs, reverse tachometer connections. When the phasing is correct, the motor will show some resistance to rotation and will not run away.

Set reference voltage to zero and turn the LOOP GAIN pot CW until tach oscillation occurs and then back-off until it goes away, giving 1 or 2 additional turns CCW. Set S2 OFF. With the INTEG FREQ pot fully CCW apply a step input. Observe the tach signal and adjust INTEG FREQ in a CW direction until some overshoot appears after the step. Adjusting INTEG FREQ pot CW will increase stiffness. At some point a strong oscillation will occur. Maximum stiffness occurs just before oscillation, so adjust pot carefully.

TACH GAIN POT

Always begin with the Tach Gain pot in the fully CCW (default) position. Fully CCW gives maximum feedback, and minimum rpm. Fully CW gives *no feedback*, and uncontrolled rpm.

With the Ref Gain pot fully CW, the tach/ref voltage ratio will be set by the header components as described above. Turning the Ref Gain pot CCW will *reduce* motor speed, and turning the Tach Gain pot CW will *increase* motor speed.
Adjusting the Tach Gain pot to change the motor speed will also change the loop-gain of the servo loop, and thus alter the bandwidth and risetime of the motor. For this reason, we prefer to set the value of RH6 so that the motor goes a bit faster than the ideal, and thereafter use the Ref Gain pot to reduce the motor speed to the optimal value. The reason for this is that changes in the Ref Gain pot will not affect the adjustments of the Loop Gain and Integrator Frequency pots, or the servo loop dynamics.

"V" OPTION: FREQUENCY TO VOLTAGE TACHOMETER FROM HALL SIGNALS OR QUADRATURE ENCODER

FUNCTIONAL DIAGRAM (SEE PG. 201)

OPTION BOARD LAYOUT (SEE PG. 201)

HALL TACH OPERATION (default)
ENCODER TACH OPERATION

***** Position of jumper J1-A sets polarity of tach signal. This may change with selection of Hall or encoder connections.
All other jumpers must be set as shown.

"V" OPTION SPECIFICATIONS

ENCODER INPUTS

Encoder type: 2-channel, 90° quadrature, incremental, digital single-ended outputs (+5V logic , open-collector, TTL, cmos, or line-driver.)
Inputs: Logic threshold voltage 2.5V. RC filter to 74HC14 Schmitt inverters.
Encoder power: +5V @ 200mA max. available at J2-3; +15V @ 10mA available at J2-2 (Halls use power from same pins).
Maximum frequency: 600,000 f/v pulses/sec, or 150,000 encoder lines/sec (each encoder line decodes to 4 f/v pulses)

HALL INPUTS

Hall type: Three-channel, digital, +5V or +15V power, 60° or 120° electrical phase separation.
Inputs: Logic threshold voltage 2.5V. RC filter to 74HC14 Schmitt inverters.
Hall power: +5V @ 200mA max. Available at J2-3; +15V @ 10mA available at J2-2 (Encoder uses power from same pins).
Maximum frequency: 600,000 f/v pulses/sec, or 100,000 Hall cycles/sec (each Hall cycle decodes to 6 f/v pulses. Motor poles/2 = Hall cycles per rev)

F/V TACH OUTPUT

±5V typical, ±10V maximum; connects to amplifier at Tach Gain potentiometer (see Functional Diagram)

LOW-PASS FILTER

Filter type: Two-pole active filter. Voltage gain = 1:1. Filter type and frequency variable with component selection on header.
Default values CH3, CH4 = 0.1µF for Hall tach mode. For encoder tach mode, remove CH3 & CH4 (see text for details)

F/V ONE-SHOTS (MONOSTABLE MULTVIBRATORS)

IC type: 74HCT4538
Pulse width: 700ns minimum with CH1, CH2 = 100pF, 7ms with 1µF. Pulse width ≈ 0.7 X CH1 X 10kΩ (CH1 and CH2 must be same)
Default values CH1, CH2 = 33nF for Hall tach mode. For encoder tach mode, select values for application (see text for details)

ABOUT F/V CONVERSION

F/V, or *frequency to voltage* conversion is a technique that takes a digital pulse train of some *frequency* and converts it to an analog *voltage*, with the *amplitude* of the analog signal proportional to the *frequency* of the digital signal.

As implemented in the 5xx1 series amplifiers, the "V" option is a small pc board that is inside the amplifier case.

It uses a digital A/B channel encoder connected to the Option A & B inputs on J2, or the Hall signals as the digital signal source, and converts it to a ±10V analog signal that feeds back to the amplifier through the Tach Gain potentiometer. This is shown as the ETACH signal on the functional diagram.

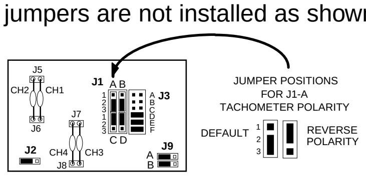
Where the reference input commanded an analog voltage from a brush tachometer in an analog velocity loop, it now commands a *frequency* from the digital encoder. As encoders are manufactured with so many lines per revolution, specifying a line frequency means specifying a motor rpm, or revs per second.

In operation, the encoder or Hall signals are first decoded. Each encoder line decodes into four states, and for every pair of motor poles there is one Hall cycle, and each cycle has six states. Each time there is a transition from one state to the next, a monostable multivibrator, or one-shot is fired and produces a pulse. The width of the pulses depends on the settings of CH1 and CH2 and is selected so that the duty-cycle at top speed is about 50%. This sequence of pulses from the one-shots is then sent through a low-pass filter where it becomes an analog ±5V signal. The amplitude of the voltage is proportional to the frequency of the pulse-train, and the polarity depends on the direction of rotation of the motor. You can observe this signal with an oscilloscope at the Tachometer Input pin J3-6.

HALL TACHOMETER OPERATION

OPTION CARD JUMPER SETTINGS

First remove the cover and check the jumper positions on the option card. Hall tachometer is the default configuration. If the jumpers are not installed as shown, set them up now.



The default values for the components are:
CH1, CH2 = 33nF
CH3, CH4 = 0.1µF

These values are for a 4-pole motor turning 10,000 rpm maximum in Hall tach mode, with a low-pass filter frequency of 15.9Hz.

POT AND SWITCH SETTINGS

The sections that follow give setup details for the options. Before proceeding with these instructions, the amplifier must first be set up and operating correctly in *torque mode*. That is, the motor and Halls must be correctly phased, current limits set, and inductance compensation set up. To adjust these with the option card installed, first make these settings:

Ref Gain pot	fully CW
Tach Gain pot	fully CW
Loop Gain pot	fully CCW
Integ Freq pot	n/a (no function)
Balance pot	adjust for zero torque at zero input
S2	ON (disables integrator)

The amplifier is now in *torque mode*, with no velocity feedback. You can now proceed with the instructions in previous sections about current-limiting, phasing, and so forth.

When you have completed torque mode setup, rotate the Tach Gain pot fully CCW.

MAXIMUM F/V RATE CHECK

Next, check to see if your maximum motor speed is within the range of the f/v converter. Enter the number of *poles* in the motor, and maximum anticipated rpm into this equation:

$$\text{Fmax} = \frac{\text{Poles X rpm}}{20}$$

The result should be less than 600,000. This will typically be much lower than the 600,000 when operating in Hall mode.

If it is more, then you must reduce the maximum rpm.

ONE-SHOT CAPACITOR SELECTION

Select the values of CH1 & CH2 (they should always be the same) based on this equation:

$$\text{CH1} = \text{CH2} = \frac{1400}{\text{Poles X rpm}} \quad (\text{uF})$$

Use the standard capacitor value that is closest to the result you get from this calculation. Final speed adjustments will be made using Ref Gain and Tach Gain pots, so exact capacitor selection is not necessary.

After you have selected CH1 & CH2, install these in the sockets on the option board. Begin your testing with the motor disconnected from the load.

TACHOMETER SIGNAL POLARITY

Check the setting of J1-A first. This jumper controls the polarity of the tachometer signal. This should always be such that the tach signal is *negative feedback*. If the polarity is reversed, the tach signal becomes *positive feedback*, and the motor will speed up uncontrollably. The alternate positions are on pins 1-2, or pins 2-3. With the amplifier powered-up and enabled, turn the motor shaft slightly. If the motor ‘runs-away’, change the jumper to the alternate position. Try again, the motor shaft should now resist rotation as you turn it. If the jumper has no effect, check again the position of the Tach Gain pot, and be sure that it is in the fully CCW position. With feedback enabled and J1-A set properly you should have a velocity loop

DYNAMIC ADJUSTMENTS

LOOP GAIN

Next, adjust the Loop Gain. Use a function generator and apply a square-wave to the reference inputs of about ±5V and 1/2Hz. This will cause the motor to step to 1/2 of the top speed in both directions. Without the integrator, speed regulation (the shape of the flat-top portion of the square wave) may be poor, but concentrate instead on the edges of the waveform. Connect an oscilloscope to the tach signal at J3-6, and adjust the Loop Gain pot to get a good quality step-response. If the gain is too high (pot CW) there will be overshoot and/or ringing on the edge of the step. Turn the pot CCW until the step-edge shows a clean response in the minimum time. Note that the Hall tach mode will produce a noisy tach signals at low speeds, so the Loop Gain should be adjusted with the motor turning more rapidly.

INTEGRATOR

Next, adjust the integrator. Set switch S2 OFF, this will enable the integrator. Again, using the ±5V, 1/2Hz waveform and monitoring the Tach signal, turn the Integ Freq pot in a CW direction. The best adjustment for the integrator will be found when there is some overshoot (10-20%), and settling without undershoot and ringing. If the pot is turned too far CW, the integrator will produce very strong oscillation at low frequencies. If this occurs, disable the amplifier immediately, turn the pot 2-3 turns CCW, and try again. If you can load the motor while it is turning, then apply and remove the load and adjust the Integ Freq pot for the best speed regulation that does not ring or 'hunt' when the load is removed and applied.

MOTOR TOP-SPEED

To make adjustments of the top speed. Apply a 10V signal to the reference inputs. You can measure the top speed by monitoring any Hall signal and measuring its *period*. The jumpers at J3-D, E, or F are good points to probe to see these signals. The motor speed in *rpm* will be:

Adjusting the Ref Gain pot CCW will reduce the speed, and adjusting the Tach Gain pot CW will increase it. The Ref Gain pot will not affect the dynamic behavior of the velocity loop. But, large adjustments of the Tach Gain pot will affect the loop gain and may require re-tuning of the Loop Gain and Integ Freq pots.

LOW PASS FILTER

The default values for CH3 & CH4 are 0.1µF giving a low-pass filter frequency of 16Hz. We have found this to be a good starting point for Hall tach operation. The Hall tach pulse-train will be at a much lower frequency than with an encoder, and typically Hall tach operation will be for high speed applications such as spindles or pumps. This can lead to very rough operation at lower speeds. So, begin with the default values and then increase or decrease as needed.

ENCODER TACHOMETER OPERATION

ENCODER CONNECTIONS

Use shielded cable for the encoder signals, if possible. Grounding the motor case and encoder cable shield will give maximum noise immunity from the PWM signals in the motor power cabling. Encoder power is available at J2-3. The +5V supply has a 200mA rating and will drive "commutating" encoders that output the A/B signals as well as the Hall signals.

Connect the A and B channel encoder signal to the option "A" and "B" inputs (J2-8 & J2-9). J2-1 is the ground pin for encoder signal ground, another ground pin (J2-7) makes it easy to connect the cable shield to ground.

OPTION CARD JUMPER SETTINGS

This diagram shows the positions of the jumpers and capacitors on the option card. Note that only the jumpers on J3 have changed from the default Hall tachometer settings. J1-B, C, and J1-D remain in their default positions. J1-A may change position depending on the polarity of the tach signal required.

POT AND SWITCH SETTINGS

The sections that follow give setup details for the options. Before proceeding with these instructions, the amplifier must first be set up and operating correctly in *torque mode*. That is, the motor and Halls must be correctly phased, current limits set, and inductance compensation set up. To adjust these with the option card installed, first make these settings:

Ref Gain pot	fully CW
Tach Gain pot	fully CW
Loop Gain pot	fully CCW
Integ Freq pot	n/a (no function)
Balance pot	adjust for zero torque at zero input
S2	ON (disables integrator)

The amplifier is now in *torque mode*, with no velocity feedback. You can now proceed with the instructions in previous sections about current-limiting, phasing, and so forth.

When you have completed torque mode setup, rotate the Tach Gain pot fully CCW.

MAXIMUM F/V RATE CHECK

An f/v pulse train is generated that is 4X the encoder line frequency (lines / second). The maximum f/v clock rate for the option is 600kHz. First check to make sure that your f/v pulse-train will be within the options limits.

If the rate is greater than 600kHz, then the maximum rpm or encoder line count must be reduced to stay within the option specifications.

ONE-SHOT CAPACITOR SELECTION

If the rate is acceptable, select the f/v capacitors CH1 & CH2 as follows (Note C = CH1 and CH2, both should be the same):

$$C = \frac{1 \times 10e9}{Lines \times rpm} \quad (C = pF)$$

TACHOMETER SIGNAL POLARITY

Check the setting of J1-A first. This jumper controls the polarity of the tachometer signal. This should always be such that the tach signal is *negative feedback*. If the polarity is reversed, the tach signal becomes *positive feedback*, and the motor will speed up uncontrollably. The alternate positions are on pins 1-2, or pins 2-3. With the amplifier powered-up and enabled, turn the motor shaft slightly. If the motor 'runs-away', change the jumper to the alternate position. Try again, the motor shaft should now resist rotation as you turn it. If the jumper has no effect, check again the position of the Tach Gain pot, and be sure that it is in the fully CCW position. With feedback enabled and J1-A set properly you should have a velocity loop

DYNAMIC ADJUSTMENTS

Begin with the switches and pots set like this:

Ref Gain pot	fully CW
Tach Gain pot	fully CCW
Loop Gain pot	fully CCW
Integ Freq pot	fully CCW
Balance pot	adjust for zero torque at zero input
S2	ON (disables integrator)

Next, enable the amplifier and turn the motor slightly. Observe whether or not the motor 'runs-away'. If it does, reverse the position of jumper J1-A. The loop should be stable before you proceed. When this is complete, input a reference signal of a square-wave of ±1V at a frequency of 1Hz. This will let you see the step response of the velocity loop at the Tach input at J3-6.

LOOP GAIN

Adjust the Loop Gain pot CW until the response to the step overshoots and then back off for the cleanest response. This will optimize the loop gain. If you turn the pot CW too far, you may get oscillation. Again, turn the pot CCW until this disappears and you get the cleanest & fastest response without ringing.

INTEGRATOR

Now, set switch S2 OFF, this will enable the integrator.

With the motor at a standstill you can turn the shaft by hand and feel the 'stiffness'. Rotating the Integ Freq pot CW will increase the stiffness. Too far and there will be violent oscillation, so be ready to turn the power off, or disable the amplifier. At the point of best stiffness without oscillation, if you input the square wave you should see some overshoot on the tach signal that settles without excessive undershoot to the steady-state value. Changes in load should cause an increase in current such that the speed remains constant.

These adjustments are made simpler by using switch S2 so that you can turn the integrator on and off to make the loop-gain and stiffness adjustments separately.

MOTOR TOP SPEED

When these adjustments are complete, input a 10V DC signal, to drive the motor to top speed. Clip the oscilloscope probe to the jumper at location J2. The metal part of the jumper should be accessible. Here you can monitor the train of pulses coming from the one-shots. The duty cycle of these should be about 50%, typically. The quality of the encoder will determine the consistency of the pulse train. The important thing is that the pulses never overlap, as this would cause a sudden change in the tach voltage. Also, if the pulses overlap, then the tach voltage would 'saturate', or remain unchanged as the speed changes. This would open the velocity loop and the motor would spin uncontrollably. If you're getting pulse overlap at the desired top speed of the motor, the solution is to change to a smaller value capacitor for CH1 & CH2 to make a narrower pulse. You will have to re-adjust either the Tach Gain pot or header resistor RH6 to re-set the top speed if this is the case.

LOW-PASS FILTER

CH3 and CH4 form a two-pole low-pass filter. The cut-off frequency of the filter is approximately (assume CH3 = CH4):

This frequency has a large effect upon the operation of the velocity loop. As the frequency goes down, low-speed ripple is less, and the *range* of operation increases. At the same time the bandwidth of the velocity loop decreases, and its response-time increases. As the frequency of the filter increases, the velocity loop bandwidth increases with it, but low-speed ripple will be greater. So, in practice the choice of the filter is made on the basis of each application and its individual requirements. There will always be a tradeoff between low-speed velocity ripple and bandwidth.

When choosing a filter frequency for encoder operation, we generally start with the CH3 & CH4 parts removed. This approach works well for encoders with 500 lines or greater.

After top speed and velocity-loop adjustments are complete, capacitance can be added as necessary to smooth out low-speed operation. The option card default components are set for Hall tach operation, and the low-pass filter frequency is 16Hz. This is usually much too low for encoder operation. This low frequency is chosen because the frequency of the Hall signals is so much lower than the typical encoder frequency that Hall operation is typically used only for high-speed operation such as spindle drives. These applications do not typically require fast response times.

For encoder tach operation we have found that removing CH3 & CH4 works for top speed and dynamic setup. Then, rotate the motor at your lowest anticipated speed and check the velocity ripple. If it is objectionable, then add capacitance at CH3 & CH4 until it affects the overall tuning and retest at low speed. If you want smoother operation than you observe, you will have to sacrifice some bandwidth by lowering the filter frequency and re-tuning the velocity loop with the new values.

U" OPTION: BRUSHLESS TACHOMETER ADAPTER

FUNCTIONAL DIAGRAM (SEE PG. 201)

OPTION CARD LAYOUT (SEE PG. 201)

CH1 & CH2 control low-pass filter. RH1, 2, & RH3 control tachometer scaling. J3-A controls tachometer polarity, J3-B no function

"U" OPTION SPECIFICATIONS

TACHOMETER INPUTS		
	Type	3-phase Wye-connected with grounded center tap
	Scaling	Adjustable with socketed components
	Voltage range	tbd VAC maximum
OUTPUT VOLTAGE		Analog, ±10V typical with tachometer at maximum motor rpm
BANDWIDTH	Settable with low-pass filter components	
PROTECTION	Amplifier is reset when ETACH signal is >+12V or <-12V. This will cause a 50ms. shutdown, disabling output stages and effectively limiting motor speed under closed-loop conditions.	

BRUSHLESS TACHOMETER OPERATION

The "U" option is an interface that mounts inside the amplifier case and is powered from the main board. A brushless tachometer connects to the J2 connector at the Option A, B, and C pins (and ground). The three AC waveforms from the tachometer are converted by the option card into a DC voltage that is proportional to the motor rpm in magnitude, and to the motor direction in polarity. Input scaling resistors are chosen so that the output of the option board is ±10V at the maximum speed that the motor can achieve with a particular motor and power supply combination. This signal is fed back to the amplifier via the tachometer gain potentiometer (see ETACH on amplifier functional diagram). Thus the tachometer input pin (J3-6) can be used to monitor the ETACH signal, and the Tach Gain pot can be used to adjust the motor speed. The result is that the motor and amplifier form a 'velocity loop' that controls motor speed in response to a reference voltage input.

BRUSHLESS TACHOMETER CONNECTIONS

For best results, shielded cable should be used to connect the tach signals from motor to amplifier. In addition, it is recommended that the motor frame be grounded to add shielding between the motor phase windings and the tachometer. Tachometer signal currents are negligible, so the choice of cable should be based on adequate mechanical strength, ability to flex, insulation breakdown appropriate to tach voltages anticipated, and shielding.

POT AND SWITCH SETTINGS

The sections that follow give setup details for the options. Before proceeding with these instructions, the amplifier must first be set up and operating correctly in *torque mode*. That is, the motor and Halls must be correctly phased, current limits set, and inductance compensation set up. To adjust these with the option card installed, first make these settings:

Ref Gain pot	fully CW
Tach Gain pot	fully CW
Loop Gain pot	fully CCW
Integ Freq pot	n/a (no function)
Balance pot	adjust for zero torque at zero input
S2	ON (disables integrator)

The amplifier is now in *torque mode*, with no velocity feedback. You can now proceed with the instructions in previous sections about current-limiting, phasing, and so forth.

When you have completed torque mode setup, leave the Tach Gain pot fully CW. Before the velocity loop can be closed, the tach signal must be tested for correct phasing!

SCALING FOR MAXIMUM TACHOMETER VOLTAGE

The maximum motor speed will occur under no-load conditions and will be a function of the motor back-emf and power supply voltage. Scaling is the process of selecting resistors so that the peak voltage at the tachometer switching matrix does not exceed ±10V (7VACrms) under these conditions. This is important because signals greater than this may cause the processing circuit to 'saturate', opening the velocity loop and causing the motor to spin uncontrollably.

You can calculate the values of these resistors by using the following formulae. Your motor datasheet may define the tachometer output in either volts 'peak' (VDC) or in volts 'rms' (VAC) per thousand revolutions per minute. This is typically expressed as "V/krpm". Use the formula that matches the units in your motor datasheet, and calculate Vpeak or Vrms based on the power supply voltage, and the motor back-emf constant:

$$\text{Vpeak} = \text{KgDC}\left(\frac{+\text{HV}}{\text{KeDC}}\right)$$

Vpeak = DC peak tach voltage at maximum motor rpm
KgDC = tachometer gradient (Vpeak/krpm)
KeDC = motor back-emf constant (Vpeak/krpm)

$$\text{Vrms} = \text{KgAC}\left(\frac{+\text{HV}}{1.4\ \text{KeAC}}\right)$$

Vrms = AC peak tach voltage at maximum motor rpm
KgAC = tachometer gradient (Vrms/krpm)
KeAC = motor back-emf constant (Vrms/krpm)
+HV = Maximum DC power supply voltage

After you have calculated the maximum DC or AC tach voltage, now find the values for the scaling resistors. The "Rx" in the formulae refers to resistors RH1, RH2, and RH3, which must all be the same value.

$$\text{Rx} = \frac{\text{Vpeak}}{2} - 5 \qquad \text{Rx} = \frac{\text{Vrms}}{1.4} - 5$$

(Rx = k ohms)

TACHOMETER SIGNAL PHASING

The previous adjustments should have left the amplifier in torque mode, properly phased, with no tach signal feedback (Tach Gain pot fully CW). Apply a small reference input to rotate the motor at a low speed. Monitor the tach signal at J3-6. If the tachometer phasing is correct, the signal will like a DC signal that follows the motor speed directly. If phasing is not correct, there will be large dropouts, ripple, or polarity reversals. If this occurs, try the other five combinations of U-V-W tachometer signals that are possible. Only one will be correct. When you think that you have found it, reverse the reference voltage polarity to rotate the motor in the opposite direction. The tach signal should change to the opposite polarity in response to the change in the motor direction.

TACHOMETER SIGNAL POLARITY

The polarity of the ETACH signal must be opposite to the polarity of the reference signal in order for the loop to be stable. To check for this without producing uncontrolled speed, spin the motor under a small reference input in torque mode, as described previously. Measure the polarity of the Current Reference signal at J3-9. Next measure the polarity of the ETACH signal at J3-6. *Both must be the same polarity*. If they are opposite polarity, change the position of jumper J3-A to the alternate position. This will reverse the polarity of the ETACH signal so that is now should be the same as the Current Reference signal.

When the tachometer is properly phased, and the jumper is set for the correct polarity, rotate the Tach Gain potentiometer fully CCW. This will close the velocity loop.

DYNAMIC ADJUSTMENTS

Begin with the switches and pots set like this:

Ref Gain pot	fully CW
Tach Gain pot	fully CCW
Loop Gain pot	fully CCW
Integ Freq pot	fully CCW
Balance pot	adjust for zero torque at zero i nput
S2	ON (disables integrator)

LOOP GAIN

Use a function generator and apply a square-wave to the reference inputs of about ±5V and 1/2Hz. This will cause the motor to step to 1/2 of the top speed in both directions. Without the integrator, speed regulation (the shape of the flat-top portion of the square wave) may be poor, but concentrate instead on the edges of the waveform. Connect an oscilloscope to the tach signal at J3-6, and adjust the Loop Gain pot to get a good quality step-response. If the gain is too high (pot CW) there will be overshoot and/or ringing on the edge of the step. Turn the pot CCW until the step-edge shows a clean response in the minimum time.

INTEGRATOR

Next, adjust the integrator. Set switch S2 OFF, this will enable the integrator. Again, using the ±5V, 1/2Hz waveform and monitoring the Tach signal, turn the Integ Freq pot in a CW direction. The best adjustment for the integrator will be found when there is some overshoot (10-20%), and settling without undershoot and ringing. If the pot is turned too far CW, the integrator will produce very strong oscillation at low frequencies. If this occurs, disable the amplifier immediately, turn the pot 2-3 turns CCW, and try again. If you can load the motor while it is turning, then apply and remove the load and adjust the Integ Freq pot for the best speed regulation that does not ring or 'hunt' when the load is removed and applied.

LOW-PASS FILTER

CH3 and CH4 form a two-pole low-pass filter. The cut-off frequency of the filter is approximately (assume CH3 = CH4):

This frequency has a large effect upon the operation of the velocity loop. The default frequency is 159Hz, a good starting point for a wide range of applications.

If you application demands a faster velocity loop response, begin by removing the filter capacitors CH3 & CH4. Then, tune your velocity loop for the fastest response time that you can achieve using the Loop Gain and Integ Freq pots. If you want to smooth the response a bit, you can now add capacitance at CH3 and CH4 that just begins to affect the step response, and then back off of the Loop Gain pot for best results.

Other applications may demand a slower response. In this case, increase the capacitance until the desired risetime is achieved.

FINDING THE BEST VALUES DEPENDS HEAVILY ON THE APPLICATION, MOTOR AND LOAD INERTIA, AND QUALITY OF MOTION DESIRED.

A VISUAL GUIDE TO TUNING THE AMPLIFIER

The waveforms for the current monitor in torque mode operation, and the tachometer for velocity-loop operation are very similar. Both involve a gain-stage and an integrator function, and in both cases, these adjustments are made separately. Here is a quick overview to support the explanations in the Applications section.

LOAD INDUCTANCE COMPENSATION

Important: always power-down when changing components in the header socket.

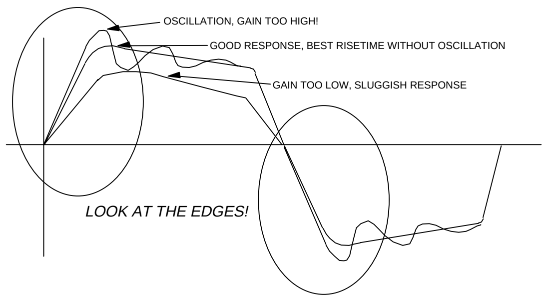
1. Use a square-wave test waveform of ±0.5. Set the power supply to the anticipated operating voltage.
2. Replace the compensation capacitor CH18 with a shorting jumper. This turns the integrator OFF.
3. Observing the signal at the current monitor, select a value for RH20 that gives a clean step response.
   Observe the edges of the waveform, do not consider the 'flat-top' portion.
4. Install CH18. This turns the integrator ON. Select the smallest value that does not result
   in excessive (>10%) overshoot and/or oscillation while observing the flat-top portion of the waveform.
5. Switch to a sine-wave signal of the same amplitude. Sweep the frequency over the range of interest and note the frequency at which amplitude drops to 0.707 of the amplitude at 100Hz. This is the 'bandwidth' of the current loop.

VELOCITY LOOP TUNING (BRUSH & BRUSHLESS TACHOMETER, HALL OR ENCODER TACHOMETER)

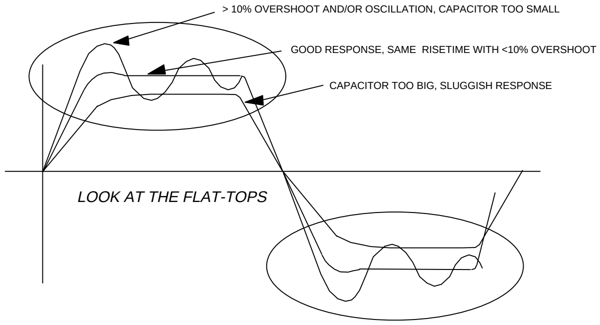
The principles of velocity loop tuning remain the same even though the source of the tachometer signal may vary.

1. Use a square-wave test waveform of ±0.5. Set the power supply to the anticipated operating voltage.
2. Set dip switch S2 ON. This will disable the integrator.
3. Observe the tach signal at J3-6. Adjust the Loop Gain pot for the best step response observing the edges of the tachometer signal.
4. Set dip switch S2 OFF. This turns the integrator ON. Adjust the Integ Freq pot in a CW direction until some overshoot occurs, but the signal settles cleanly without undershooting excessively. Too much CW rotation will produce undershoot and ringing, or even violent oscillation. If the pot cannot be adjusted over its range, increase or decrease CH1 to scale the frequency range up or down until the pot has a range of adjustment that produces the best stiffness.
5. Switch to a sine-wave signal of the same amplitude. Sweep the frequency over the range of interest and note the frequency at which amplitude drops to 0.707 of the amplitude at 100Hz. This is the 'bandwidth' of the velocity loop.

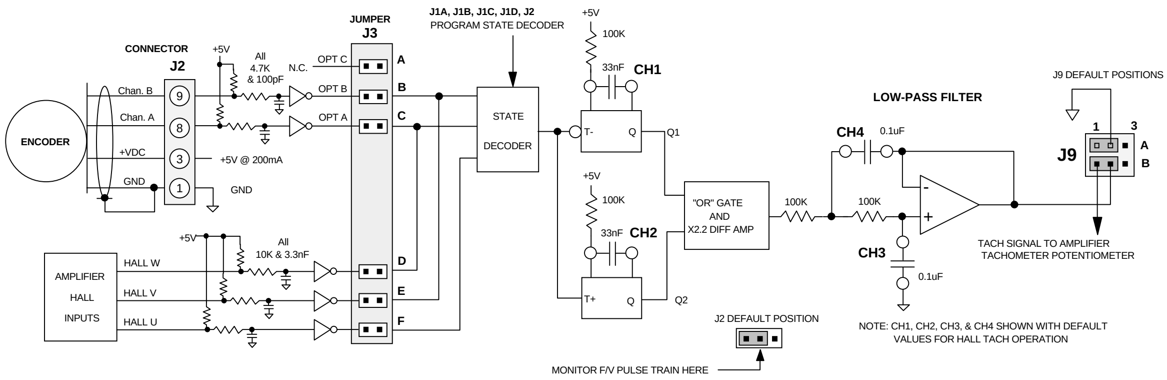
INTEGRATOR OFF



INTEGRATOR ON

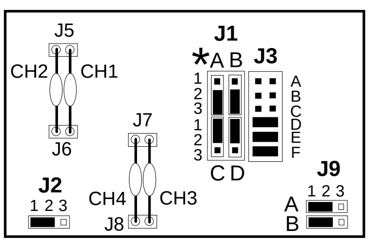


FUNCTIONAL DIAGRAM (“V”- OPTION)

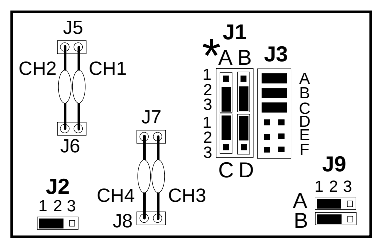


OPTION BOARD LAYOUT (SEE PG. 193)

HALL TACH OPERATION (default)



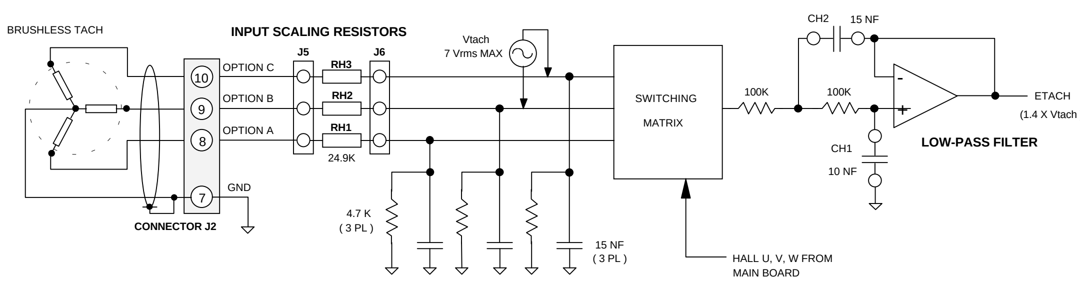
ENCODER TACH OPERATION



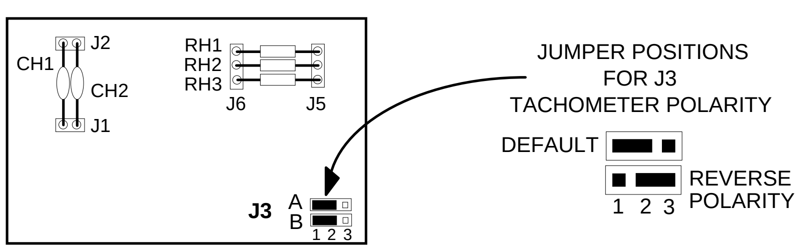
***** Position of jumper J1-A sets polarity of tach signal. This may change with selection of Hall or encoder connections.

All other jumpers must be set as shown.

FUNCTIONAL DIAGRAM (“U”- OPTION)



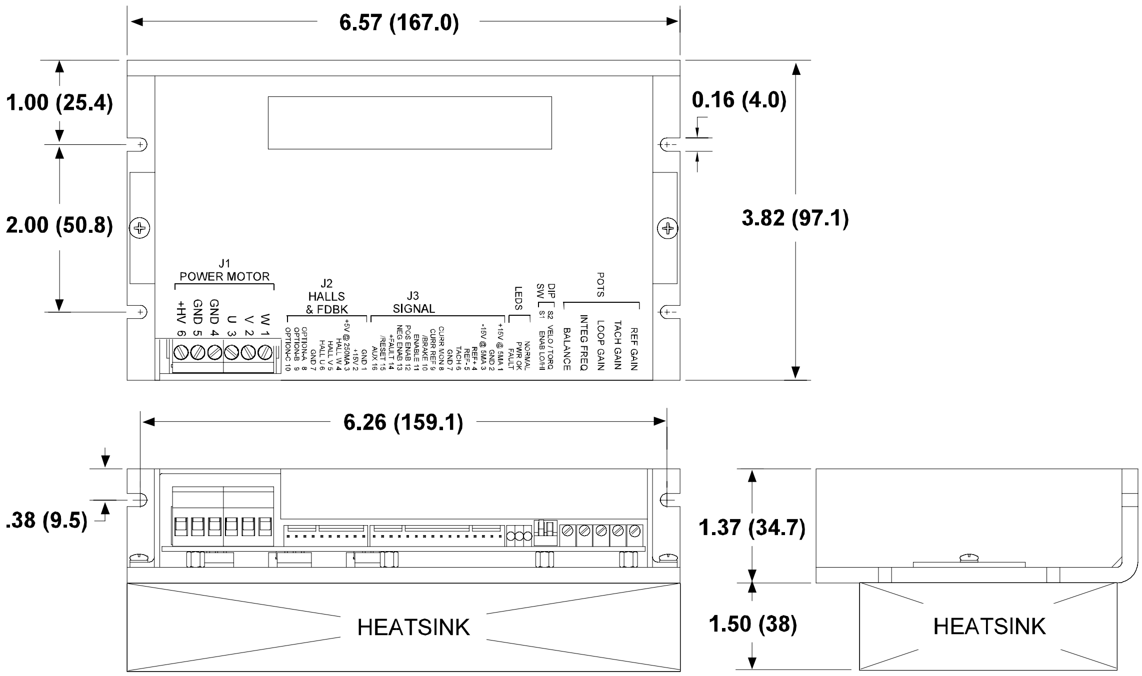
OPTION CARD LAYOUT



CH1 & CH2 control low-pass filter. RH1, 2, & RH3 control tachometer scaling. J3-A controls tachometer polarity, J3-B no function

OUTLINE DIMENSIONS

Dimensions in inches (mm.)



WEIGHT 1.1 lb (0.48 kg) for amplifier. Add 1.0 lb (0.46 kg) for heatsink option

CONNECTORS
J1: Power & motor — 6 position compression-connector (Phoenix MKDS-5.08) AWG 24-12 (0.2 to 2.5 mm^2), 30A max.
J2: Halls / Options — 10-position housing (Molex 22-01-3107) with ten AWG 30-22 contacts (Molex 08-50-0114)
J3: Signal — 16-position housing (Molex: 22-01-3167) with sixteen AWG 30-22 contacts (Molex 08-50-0114)

ORDERING GUIDE

Model 5121	20A peak, 10A continuous, +24 to +90 VDC brushless motor amplifier
Model 5131	30A peak, 15A continuous, +24 to +90 VDC brushless motor amplifier
Model 5211	10A peak, 5A continuous, +24 to +180 VDC brushless motor amplifier
Model 5221	20A peak, 10A continuous, +24 to +180 VDC brushless motor amplifier
Model 5231	30A peak, 15A continuous, +24 to +180 VDC brushless motor amplifier
Model 5321	20A peak, 10A continuous, +24 to +225 VDC brushless motor amplifier

Notes:
1. Add “U” to model number to specify brushless tachometer option
2. Add “V” to model number to specify Hall / Encoder tachometer option
3. Add “H” to model number to specify heatsink option.
Examples: 5121U for model 5121 with brushless tach option; 5321VH for 5321 with Hall / Encoder tach & heatsink.

OTHER DC BRUSHLESS AMPLIFIERS

Model 503 Torque-mode brushless amplifier. +18 to +55VDC, 5A continuous, 10A peak.

Model 505 Same power output as 503. Adds Hall / Encoder tachometer feature for velocity loop operation.

Model 513R Resolver interface for trapezoidal-drive motors. Outputs A/B quadrature encoder signals and analog tachometer signal for velocity loop operation. +24 to +180VDC operation, 13A continuous, 26A peak.

Model 5421AC and 5321AC
Operation directly from 120VAC or 240VAC mains.

Copley Controls Corp.
Corporate Offices: 20 Dan Road
Canton, MA 02021
Telephone: (781) 828-8090
Fax: (781) 828-6547
E-mail: sales@copleycontrols.com
www.copleycontrols.com