

MODELS 5121, 5131, 5211, 5221, 5231, 5321

DC BRUSHLESS SERVO AMPLIFIERS

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-ground
Over / under voltage
Over temperature
Self-reset or latch-off
- 3kHz Bandwidth
- Wide load inductance range
0.2 to 40 mH.
- Independent settings for continuous and peak current, and peak-time
- Surface mount technology

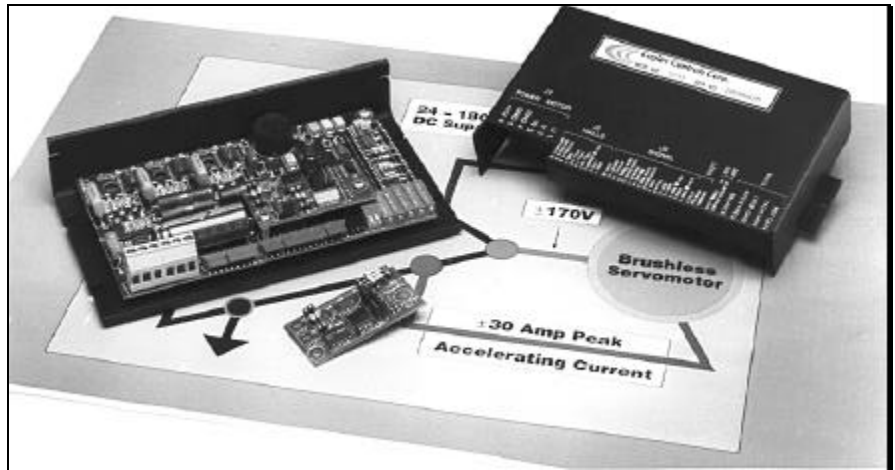
APPLICATIONS

- X-Y stages
- Robotics
- Automated assembly machinery

THE OEM ADVANTAGE

- Conservative design for high MTBF
- Flexibility: internal header configures 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



PRODUCT DESCRIPTION

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

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automatically from faults if the /Reset input is wired to GND.

TECHNICAL SPECIFICATIONS

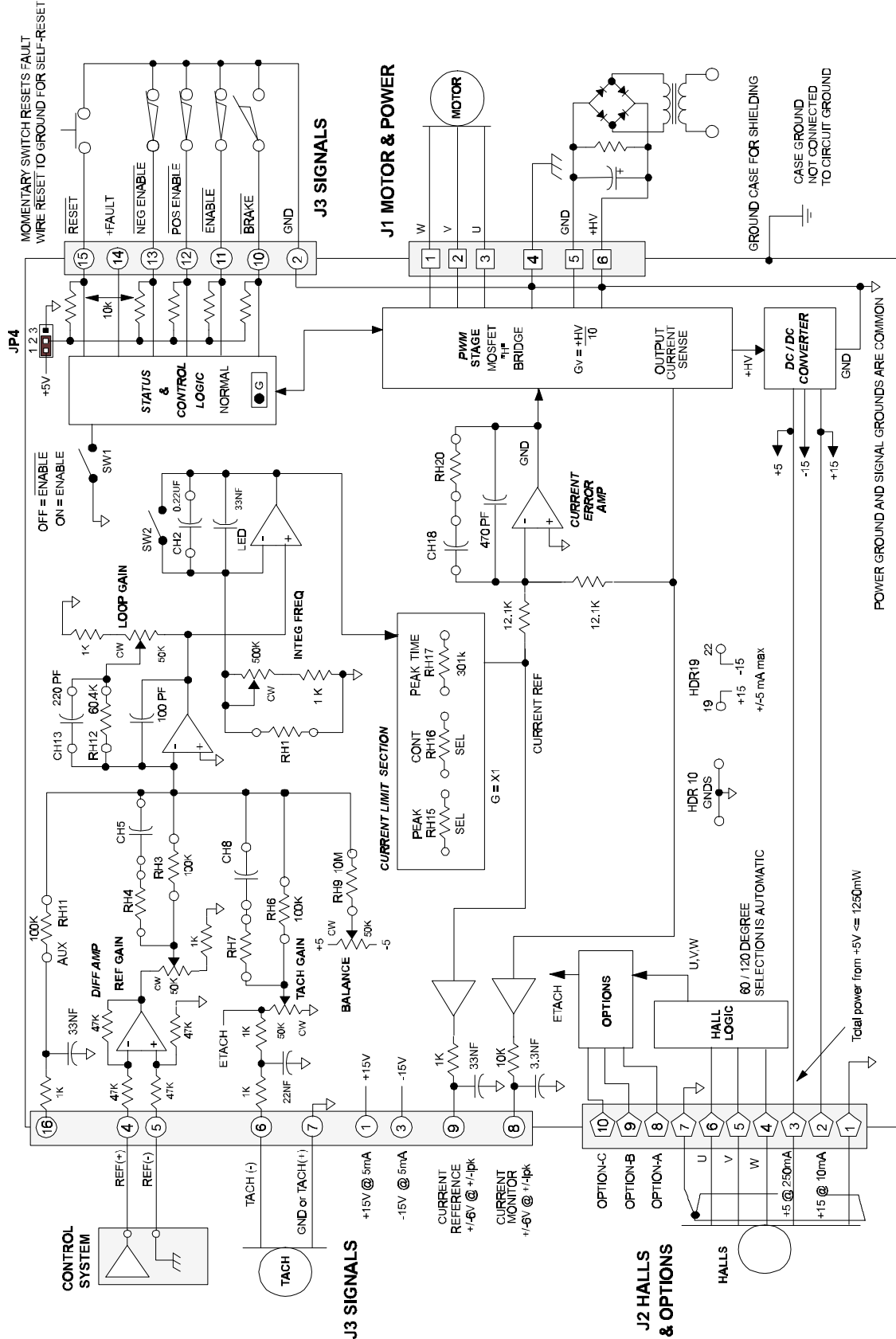
Typical at 25°C ambient, Load = 200μH. in series with 1 Ω.

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						
	Ro = 0.2	Ro = 0.15	$\pm V_{out} = (\pm HV) \times (0.97) - (Ro) \times (I_o)$		Ro = 0.2	Ro = 0.1
			Ro = 0.4			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)		
POTENTIOMETERS						
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 JP4 is jumpered to GND)			
/Reset	Default = OPEN		GND resets latching fault condition, ground for self-reset every 50 ms.			
Input resistance	10kΩ (Jumper JP4 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 JP4 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 <i>disabled</i> 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 with 10kΩ 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 (Model 51x1), or +HV > 182VDC (Model 52x1), or +HV > 230VDC (Model 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 (Model 51x1), +24 to +180VDC (Model 52x1), +24 to +225VDC (Model 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.					
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	Molex: 22-01-3107 ten-position housing with 08-50-0114 contacts (AWG 30-22)					
J3: Signal	Molex: 22-01-3167 sixteen-position housing with 08-50-0114 contacts (AWG 30-22)					

FUNCTIONAL DIAGRAM

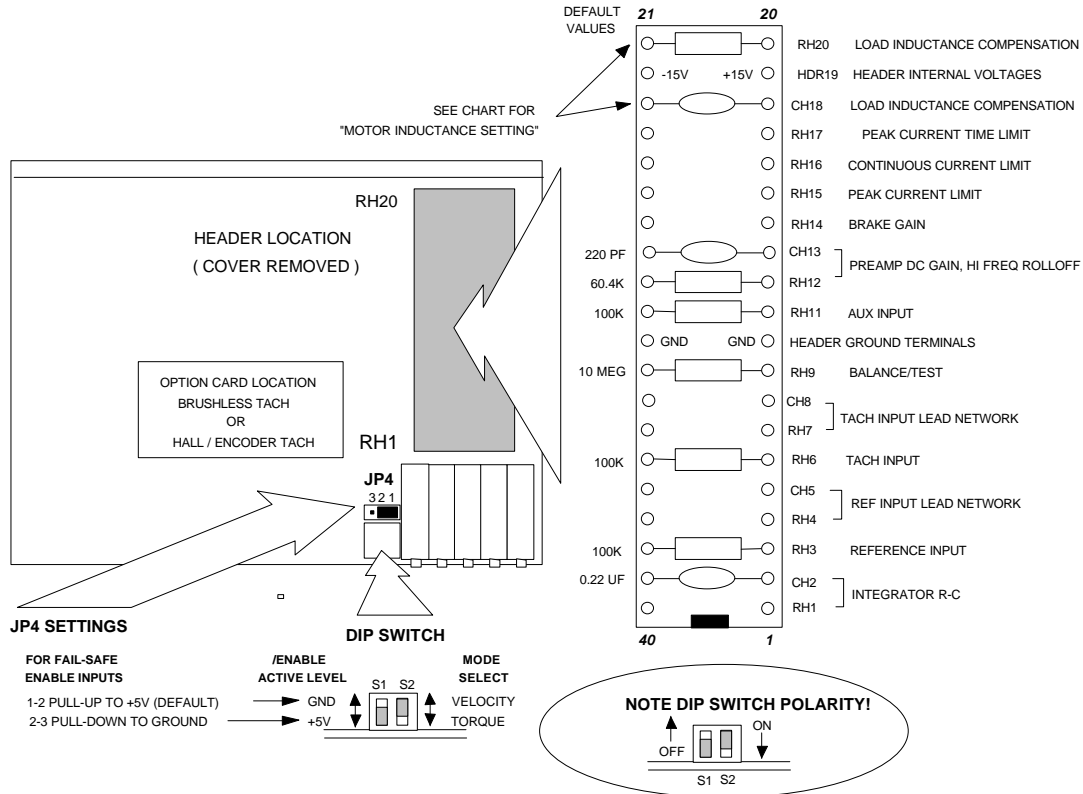
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COMPONENT HEADER

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MOTOR INDUCTANCE SETTING

Model Load (mH)	5121		5131		5211		5221		5231		5321	
	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 LIMIT

I _{peak} (%)	RH15 (Ω)
100	open
80	20k
60	9.1k
40	4.3k
20	1.5k

CONTINUOUS CURRENT LIMIT

I _{cont} (%)	RH16 (Ω)
100	open
80	47k
60	20k
40	6.8k
20	510

PEAK CURRENT TIME-LIMIT

T _{peak} (s)	RH17 (Ω)
1.5	open
1.0	2M
0.5	560k

Times shown are for 100% step from 0A

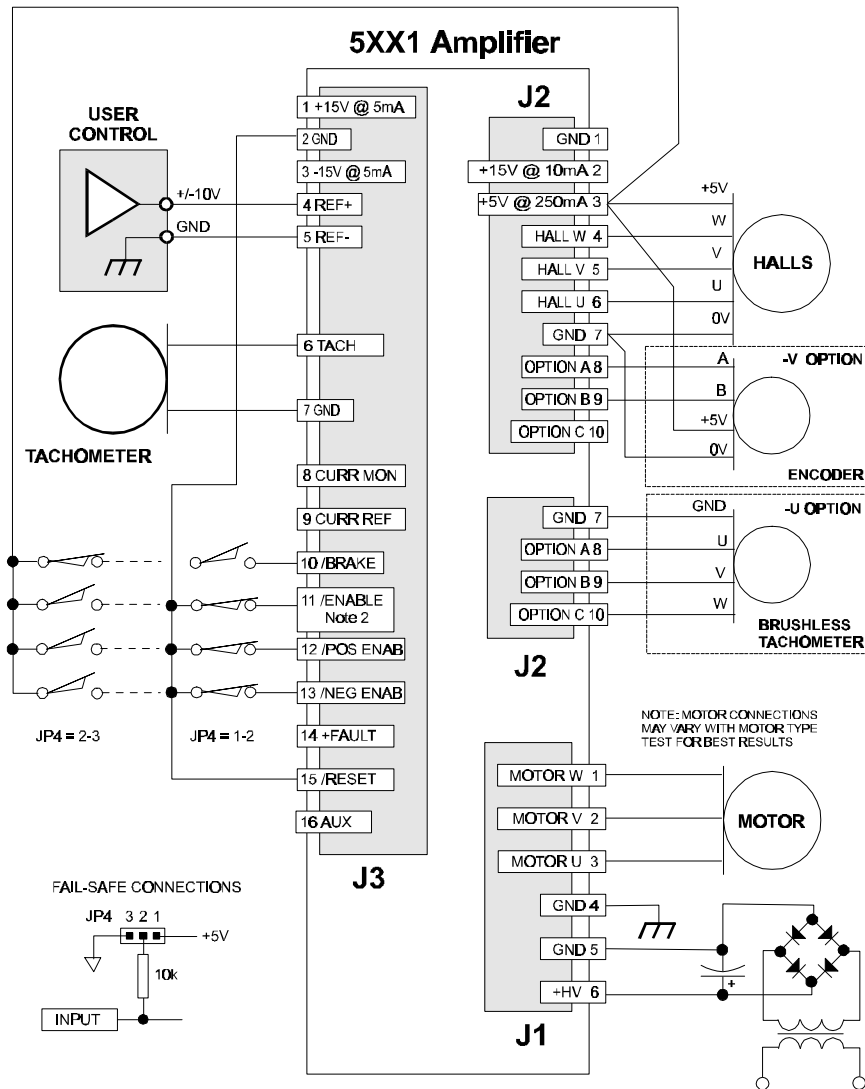
Notes on Current Limits:

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.

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AMPLIFIER CONNECTIONS



- Notes
1. All amplifier grounds are common (J1-4,5 & 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 below)
Ref Gain	Sets current-gain	CW	RPM/ref ratio, use after tach-loop settings are complete CCW reduces speed
Tach Gain	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	CCW	CCW	CW until oscillation, then back off 1-2 turns
Integ. Freq	n/a	CCW	Adjust Loop-Gain with S2 ON, then with S2 OFF, adjust CW for best stiffness without oscillation
Balance	Balance	Center	Adjust for 0 Volts @ current monitor

APPLICATION INFORMATION

INTRODUCTION

Operating from transformer-isolated DC power supplies, the Model 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. 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, 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:

$$VDC = \frac{MaxBuss}{\left(\frac{Vmains:High}{Vmains:Low} \right) (1 + \%Reg)}$$

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 some assurance is necessary to insure the AC mains would stay within a narrower margin - the on-site user should be prepared for 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 1meter 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 ungrounded. 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 R-S-T, A-B-C or others may be seen. 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, these connections will not have to change 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.).

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5XX1 AMPLIFIER TRUTH TABLE

With jumper **JP4** in **FAIL-SAFE LO (DEFAULT)** position on pins 1-2. Input resistors pulled-up to +5V.

SIGNAL ->	ENABLE INPUT J3-11	/POS ENABLE INPUT J3-12	/NEG ENABLE INPUT J3-13	/BRAKE INPUT J3-10	+FAULT OUTPUT J3-14	AMPLIFIER RESULT
SW1 OFF (Default)	OC-HI	X	X	OC-HI	HI	Disabled; outputs OFF; Fail-Safe Disable
	VLO	VLO	VLO	OC-HI	LO	Enabled: outputs ON
	VLO	OC-HI	VLO	OC-HI	LO	Enabled; CW rotation inhibited (Note 2)
	VLO	VLO	OC-HI	OC-HI	LO	Enabled; CCW rotation inhibited (Note 2)
	VLO	OC-HI	OC-HI	OC-HI	LO	Enabled; CW & CCW rotation inhibited (Note 2)
SW1 ON	VLO	VLO	VLO	VLO	LO	Enabled; braking mode active.
	VLO	X	X	X	HI	Disabled; outputs OFF
	OC-HI	VLO	VLO	HI	LO	Enabled: outputs ON
	OC-HI	HI	VLO	HI	LO	Enabled; CW rotation inhibited (Note 2)
	OC-HI	VLO	HI	HI	LO	Enabled; CCW rotation inhibited (Note 2)
	OC-HI	HI	HI	HI	LO	Enabled; CW & CCW rotation inhibited (Note 2)
	OC-HI	VLO	VLO	VLO	LO	Enabled; braking mode active.

With jumper **JP4** in **FAIL-SAFE HI** position on pins 2-3. Input resistors pulled-down to ground.

SIGNAL ->	ENABLE INPUT J3-11	POS ENABLE INPUT J3-12	NEG ENABLE INPUT J3-13	BRAKE INPUT J3-10	+FAULT OUTPUT J3-14	AMPLIFIER RESULT
SW1 ON	OC-LO	X	X	X	HI	Disabled; outputs OFF; Fail-Safe Disable
	VHI	OC-LO	OC-LO	VHI	LO	Enabled: outputs ON
	VHI	VHI	OC-LO	VHI	LO	Enabled; CW rotation inhibited (Note 2)
	VHI	OC-LO	VHI	VHI	LO	Enabled; CCW rotation inhibited (Note 2)
	VHI	VHI	VHI	VHI	LO	Enabled; CW & CCW rotation inhibited (Note 2)
SW1 OFF (Default)	VHI	OC-LO	OC-LO	OC-LO	LO	Enabled; braking mode active.
	VHI	X	X	X	HI	Disabled; outputs OFF
	OC-LO	OC-LO	OC-LO	VHI	LO	Enabled: outputs ON
	OC-LO	VHI	OC-LO	VHI	LO	Enabled; CW rotation inhibited (Note 2)
	OC-LO	OC-LO	VHI	VHI	LO	Enabled; CCW rotation inhibited (Note 2)
	OC-LO	VHI	VHI	VHI	LO	Enabled; CW & CCW rotation inhibited (Note 2)
	OC-LO	OC-LO	OC-LO	OC-LO	LO	Enabled; braking mode active.

Notes:

- VLO = grounded or connection to voltage source 0 to +0.7 VDC, *not open-circuit*
VHI = connection to voltage source +3.4 to +24VDC, *not open-circuit*
OC-LO = open-circuit or connection to voltage source 0 to +0.7VDC
OC-HI = .open-circuit or connection to voltage source +3.4 to +24VDC.
- CW and CCW are given as rotation conventions only. Actual direction of rotation will depend on motor mounting and phasing.

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 card. If the control card has a single output, $\pm 10V$, 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 not connect Ref(-) to the amplifier signal ground, and Ref(+) to the control card output. This connection will 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 may 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.

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.

/RESET INPUT

Overtemperature and output short circuits are called *latching* faults because they cause the amplifier to turn off and stay off.

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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 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: $\pm 6V$ will demand \pm Peak current from the amplifier. In terms of amps/volts the scale factor is $I_{peak} / 6V$. So, for a Model 5221 with a peak output current of 20A, the Current Ref scale factor would be $20A / 6V$ or $3.33A/V$.

The user can calculate the effects of header component changes on the actual current to the motor. In use, a test signal is applied 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 the 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 waveforms such as might occur during system oscillation. Input a square wave reference signal of $\pm 10V$ 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 $\pm 10V$ 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 continuous current level.

MODELS 5121, 5131, 5211, 5221, 5231, 5321

DC BRUSHLESS SERVO AMPLIFIERS

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. 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. 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 combinations, the right one should be quite obvious. As a check, change the windings: the motor shouldn't be good at all.

If the first try doesn't work, then there are five other possible connections of the three motor wires remaining. 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	CW
#2	V	W	U	
#3	W	U	V	
#4	U	W	V	CCW
#5	W	V	U	
#6	V	U	W	

Note that combinations 1-2-3 all represent the same direction of rotation. What changes is the phasing of the leads. Reading 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 the motor turns at all, even roughly, then the *direction* of rotation is probably correct, and the other combinations in the same rotation group should be tried. E.g., if it is wired up U-V-W and it ran roughly, then try #2, or #3. If there is no rotation at all, and turning the shaft by hand makes it jump backwards, then it is probably wired 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	fully CW
Tach Gain	n/a (no function)
Loop Gain	fully CCW

Integ Freq	n/a (no function)
Balance	adjust for zero torque at zero input
S2	ON(disables integrator)

BRUSH TACHOMETER OPERATION

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

Begin with these settings:

Ref Gain	fully CW (default)
Tach Gain	fully CCW (default)
Loop Gain	fully CCW (default)
Integ Freq	fully CCW (default)
Balance	adjust for zero torque at zero input
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)

BRUSH-TACH 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 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 fully CCW apply a step input. Observe the tach signal with an oscilloscope and adjust INTEG FREQ in a CW direction until some overshoot appears after the step. Adjusting INTEG FREQ CW will increase stiffness. At some point a strong oscillation will occur. Maximum stiffness occurs just before oscillation, therefore, adjust the potentiometer carefully.

TACH GAIN POTENTIOMETER

Always begin with the Tach Gain 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 fully CW, the tach/ref voltage ratio will be set by the header components as described above.

Turning the Ref Gain CCW will *reduce* motor speed, and turning the Tach Gain CW will *increase* motor speed.

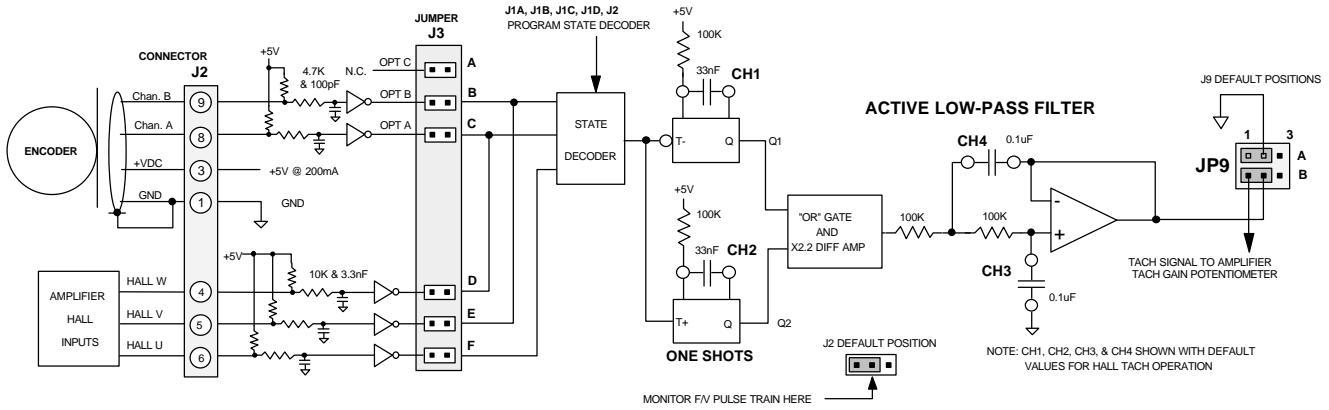
Adjusting the Tach Gain to change the motor speed will also change the loop-gain of the servo loop, and thus alter the bandwidth and risetime of the motor. For this reason, we prefer to set the value of RH6 so that the motor goes a bit faster than the ideal, and thereafter use the Ref Gain to reduce the motor speed to the optimal value. The reason for this is that changes in the Ref Gain will not affect the adjustments of the Loop Gain and Integrator Frequencies, or the servo loop dynamics.

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

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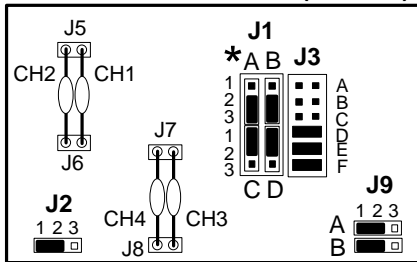
DC BRUSHLESS SERVO AMPLIFIERS

FUNCTIONAL DIAGRAM

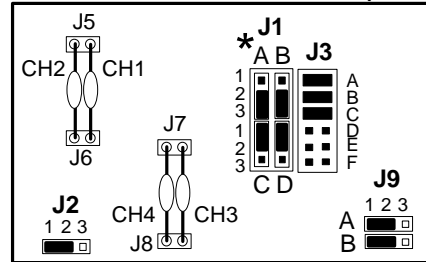


OPTION BOARD LAYOUT

HALL TACH OPERATION (default)



ENCODER TACH OPERATION (default)



* 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.

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DC BRUSHLESS SERVO AMPLIFIERS

“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”

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 Model 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.

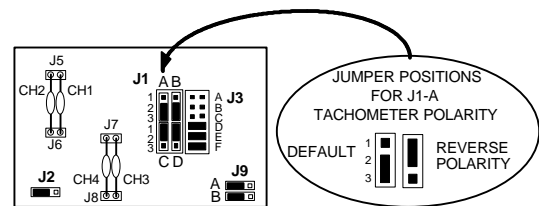
Where the reference input commanded an analog voltage from a brush tachometer in an analog velocity loop, it now commands a *frequency* from the digital encoder. As encoders are manufactured with so many lines per revolution, specifying a line frequency means specifying a motor rpm, or revs per second.

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 triggered 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. 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 16Hz.

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

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

Upon completion of torque mode setup, rotate the Tach Gain fully CCW.

MAXIMUM F/V RATE CHECK

Next, check to see if 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:

$$f_{\max} = \frac{\#Poles \times rpm}{20}$$

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DC BRUSHLESS SERVO AMPLIFIERS

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 the maximum rpm must be reduced.

ONE-STEP CAPACITOR SELECTION

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

$$CH1 = CH2 = \frac{1400}{(\# \text{ poles})} (\text{uF}) (\text{rpm})$$

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

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

TACHOMETER SIGNAL POLARITY (J1)

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. If the jumper has no effect, check again the position of the Tach Gain, and be sure that it is in the fully CCW position. With feedback enabled and J1-A set properly, a velocity loop should be the result.

DYNAMIC ADJUSTMENTS

LOOP GAIN

Use a function generator and apply a square-wave to the reference inputs of about $\pm 5V$ 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 to get a good quality step-response. If the gain is too high (CW) there will be overshoot and/or ringing on the edge of the step. Turn the 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.

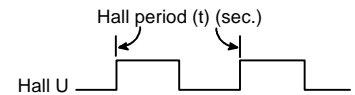
INTEGRATOR

Set switch S2 OFF, this will enable the integrator. Again, using the $\pm 5V$, $1/2Hz$ waveform and monitoring the Tach signal, turn the Integ Freq 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 potentiometer is turned too far CW, the integrator will produce very strong oscillation at low frequencies. If this occurs, disable the amplifier immediately, turn the potentiometer 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 for the best speed regulation that does not ring or 'hunt' when the load is removed and applied.

MOTOR TOP-SPEED

In order to make adjustments to the top speed, apply a 10V signal to the reference inputs. 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:

$$RPM = \frac{120}{(\text{Hall period}) (\# \text{ poles})}$$



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

Gain potentiometer fully CCW.

LOW PASS FILTER

The default values for CH3 & CH4 are 0.1 μ F 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.

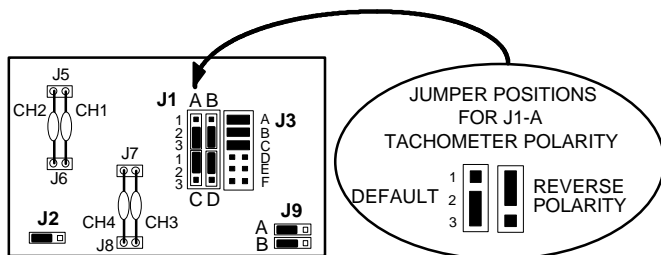
ENCODER TACHOMETER OPERATION

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.



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

The amplifier is now in *torque mode*, with no velocity feedback. Proceed with the instructions in previous sections about current-limiting, phasing, and so forth. Upon completion of *torque mode setup*, rotate the Tach

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DC BRUSHLESS SERVO AMPLIFIERS

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 f/v pulse-train will be within the options limits.

$$f/v \text{ Encoder} = \frac{\text{Lines} \times \text{rpm}}{15}$$

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-STEP 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):

$$C = \frac{1 \times 10^9}{\text{Lines} \times \text{rpm}} \quad (C = \text{pF})$$

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 it is turned. If the jumper has no effect, check again the position of the Tach Gain, and be sure that it is in the fully CCW position. With feedback enabled and J1-A set properly, a velocity loop should be the result.

DYNAMIC ADJUSTMENTS

Begin with the following switches and potentiometers settings:

Ref Gain	fully CW
Tach Gain	fully CCW
Loop Gain	fully CCW
Integ Freq	fully CCW
Balance	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 proceeding. When this is complete, input a reference signal of a square-wave of $\pm 1V$ at a frequency of 1Hz. This will display the step response of the velocity loop at the Tach input at J3-6.

LOOP GAIN

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

INTEGRATOR

Set switch S2 OFF, this will enable the integrator. With the motor *at a standstill*, the shaft may be turned by hand to feel the 'stiffness'. Rotating the Integ Freq 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, allowing the installer to 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. 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 pulse overlap is observed 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. Re-adjust either the Tach Gain 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):

$$f = \frac{1}{2 \pi RC} \quad \begin{array}{l} \pi = 3.14 \\ R = 100k \text{ ohms} \\ C = \text{CH3 or CH4} \end{array}$$

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.

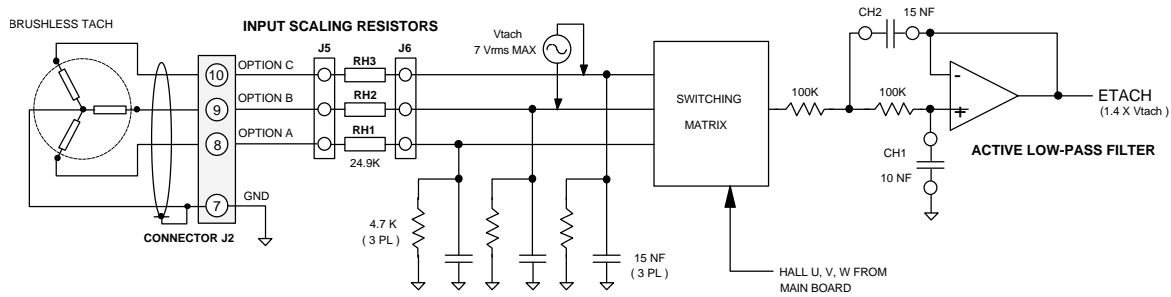
For encoder tach operation we have found that removing CH3 & CH4 works for top speed and dynamic setup. Then, rotate the motor at the lowest anticipated speed and check the velocity ripple. If it is objectionable, then add capacitance at CH3 & CH4 until it affects the overall tuning and retest at low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

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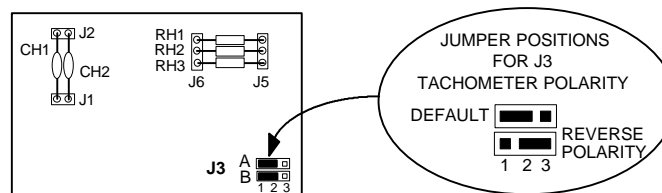
U" OPTION: BRUSHLESS TACHOMETER ADAPTER

FUNCTIONAL DIAGRAM



OPTION CARD LAYOUT

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, $\pm 10V$ 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 $\pm 10V$ 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 on page 3). Thus the tachometer input pin (J3-6) can be used to monitor the ETACH signal, and the Tach Gain 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.

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

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

Having completed torque mode setup, leave the Tach Gain potentiometer 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

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DC BRUSHLESS SERVO AMPLIFIERS

power supply voltage. Scaling is the process of selecting resistors so that the peak voltage at the tachometer switching matrix does not exceed $\pm 10V$ ($7V_{ACrms}$) 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.

Calculate the values of these resistors by using the following formulae. The motor datasheet may define the tachometer output in either volts 'peak' (V_{DC}) or in volts 'rms' (V_{AC}) 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 V_{peak} or V_{rms} based on the power supply voltage, and the motor back-emf constant:

$$V_{peak} = K_{gDC} \left(\frac{+HV}{K_{eDC}} \right)$$

V_{peak} = DC peak tach voltage at maximum motor rpm
 K_{gDC} = tachometer gradient ($V_{peak}/krpm$)
 K_{eDC} = motor back-emf constant ($V_{peak}/krpm$)

$$V_{rms} = K_{gAC} \left(\frac{+HV}{1.4 K_{eAC}} \right)$$

V_{rms} = AC peak tach voltage at maximum motor rpm
 K_{gAC} = tachometer gradient ($V_{rms}/krpm$)
 K_{eAC} = motor back-emf constant ($V_{rms}/krpm$)

+HV = Maximum DC power supply voltage

After calculating 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 RH2, which must all be the same value.

$$R_x = \frac{V_{peak}}{2} - 5 \quad R_x = \frac{V_{rms}}{1.4} - 5$$

($R_x = k$ ohms)

TACHOMETER SIGNAL PHASING

The previous adjustments should have left the amplifier in torque mode, properly phased, with no tach signal feedback (Tach Gain potentiometer 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. Once discovered, 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 potentiometers set like this:

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

LOOP GAIN

Use a function generator and apply a square-wave to the reference inputs of about $\pm 5V$ 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 to get a good quality step-response. If the gain is too high (CW) there will be overshoot and/or ringing on the edge of the step. Turn the potentiometer 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 $\pm 5V$, $1/2Hz$ waveform and monitoring the Tach signal, turn the Integ Freq 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 potentiometer is turned too far CW, the integrator will produce very strong oscillation at low frequencies. If this occurs, disable the amplifier immediately, turn the potentiometer 2-3 turns CCW, and try again. If the motor can be loaded while it is turning, then apply and remove the load and adjust the Integ Freq 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):

$$f = \frac{1}{2 \pi RC} \quad \pi = 3.14$$

$R = 100k$ ohms
 $C = CH3$ or $CH4$

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 the application demands a faster velocity loop response, begin by removing the filter capacitors CH3 & CH4. Then, tune the velocity loop for the fastest response time that can be achieved using the Loop Gain and Integ Freq potentiometers. If still smoother response is still desired, add capacitance at CH3 and CH4 that just begins to affect the step response, and then back off of the Loop Gain 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

MODELS 5121, 5131, 5211, 5221, 5231, 5321 DC BRUSHLESS SERVO AMPLIFIERS

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 (Figure 1), 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.

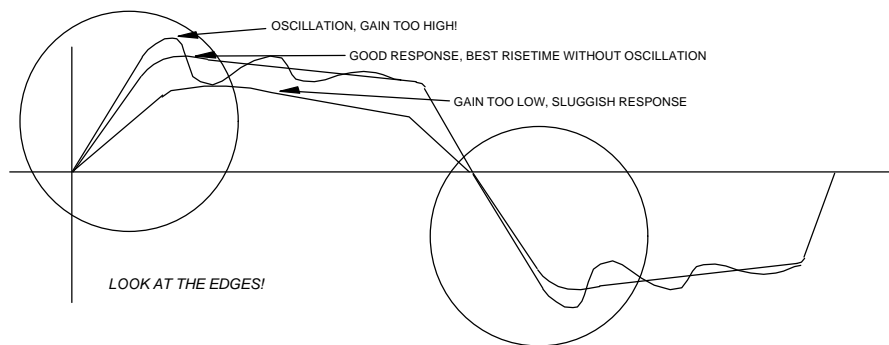
VELOCITY LOOP TUNING (BRUSH & BRUSHLESS TACHOMETER, HALL OR ENCODER TACHOMETER)

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

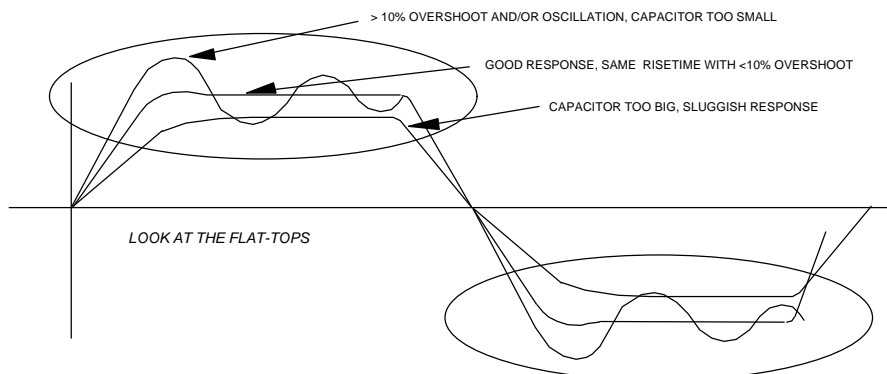
1. Use a square-wave test waveform of ± 0.5 . Set the power supply to the anticipated operating voltage.
2. Set dip switch S2 ON. This will disable the integrator.
3. Observe the tach signal at J3-6. Adjust the Loop Gain potentiometer for the best step response observing the edges of the tachometer signal.
4. Set dip switch S2 OFF. This turns the integrator ON. Adjust the Integ Freq 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 potentiometer cannot be adjusted over its range, increase or decrease CH1 to scale the frequency range up or down until the potentiometer 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.

TYPICAL WAVEFORMS (FIGURE 1)

INTEGRATOR OFF



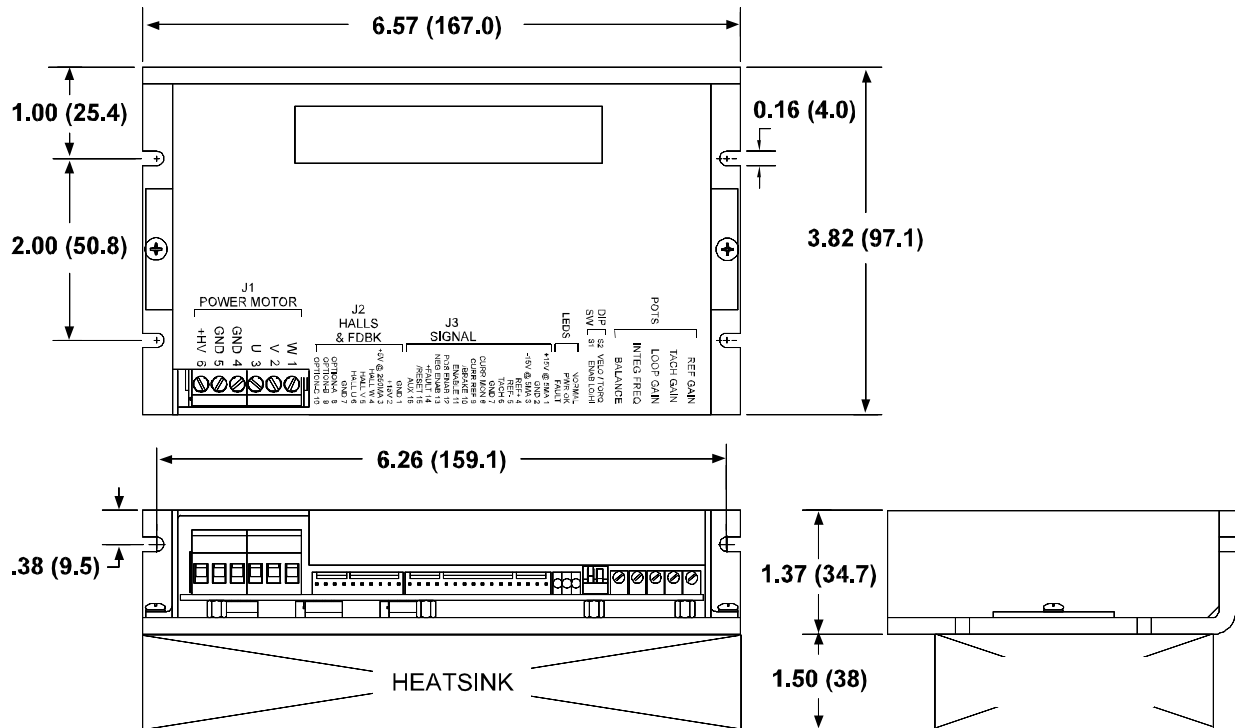
INTEGRATOR ON



MODELS 5121, 5131, 5211, 5221, 5231, 5321 DC BRUSHLESS SERVO AMPLIFIERS

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.



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