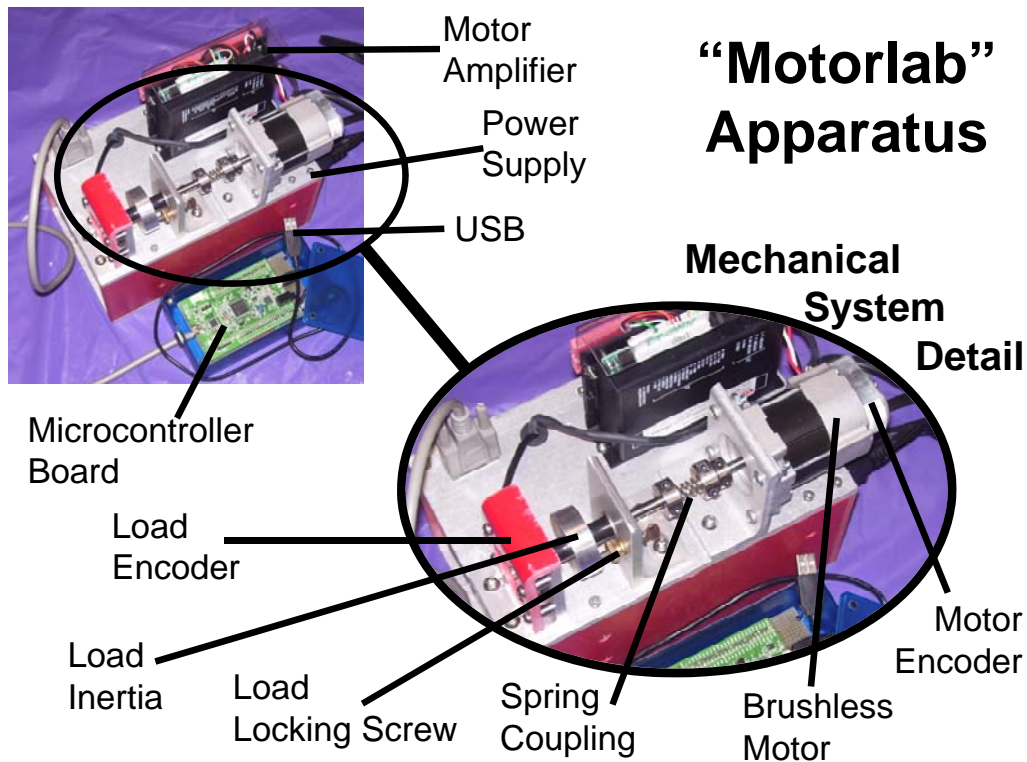
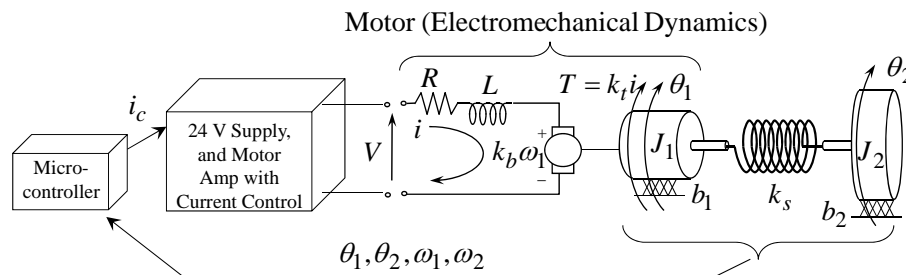


# “Motorlab” Dynamics and Controls System

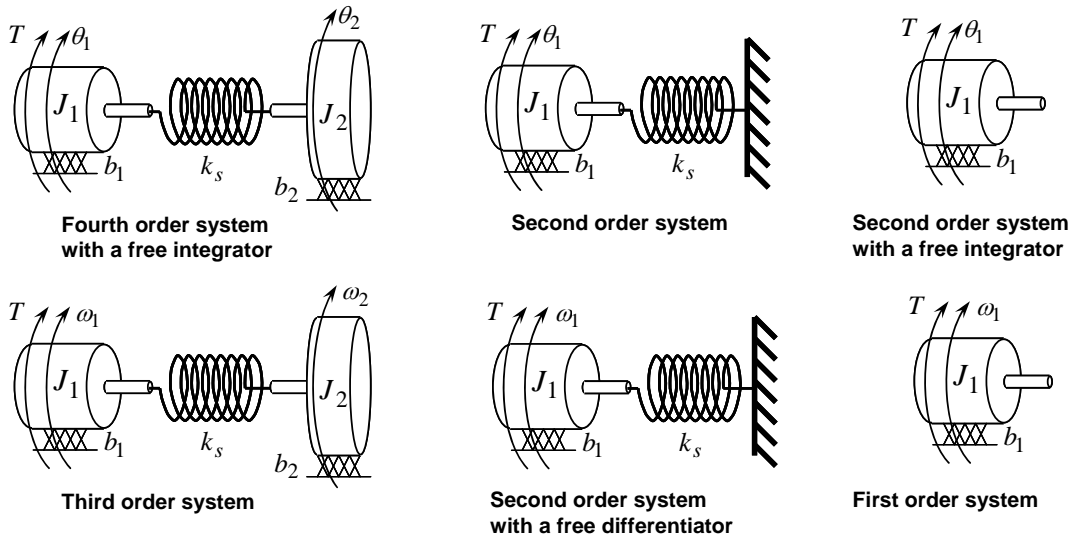


## System Description

Below is a schematic representation of the Motorlab system in a closed-loop position or speed control configuration. There are two position sensors on the apparatus, a motor encoder and a load encoder. The speeds of the two inertias are measured by numerically differentiating the position signals in the computer controlling the system (microcontroller). The motor amplifier has a control loop that measures and controls the electric current in the motor windings. This results in what is commonly known as a “torque controlled” motor, since the magnetic torque is proportional to the current in the windings. The microcontroller is interfaced to the motor amplifier through a  $\pm 10V$  analog signal. By varying the magnitude of this voltage the microcontroller can change the current in the motor. This voltage, which is proportional to the controlled current, serves as a current command (desired current) for the current control loop in the amplifier. An additional sensor, not shown below, is the current sensor in the amplifier used to implement the current control. The signal from this sensor is also read by the microcontroller, using an analog to digital converter. Although this signal is not used in the control loops on the microcontroller, it is recorded for data analysis.



Several different configurations of the system can be utilized in experiments. Either sensor, the motor or load encoder, can be used for the feedback of the control loop. The selection is made in the software interface. The motor encoder is known as a “collocated” sensor since it is co-located with the input to the mechanical system, the motor torque. The load sensor is separated from the input to the system by a spring and is therefore known as a “non-collocated” sensor. In addition to varying which sensor is used, the mechanical system can be changed with the lock down screw and the spring coupling. Also, a choice can be made between velocity control or position control by selecting the appropriate control program. Any of the following mechanical models may be realized using the Motorlab hardware and software.

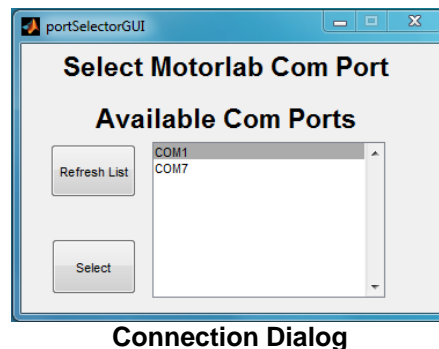


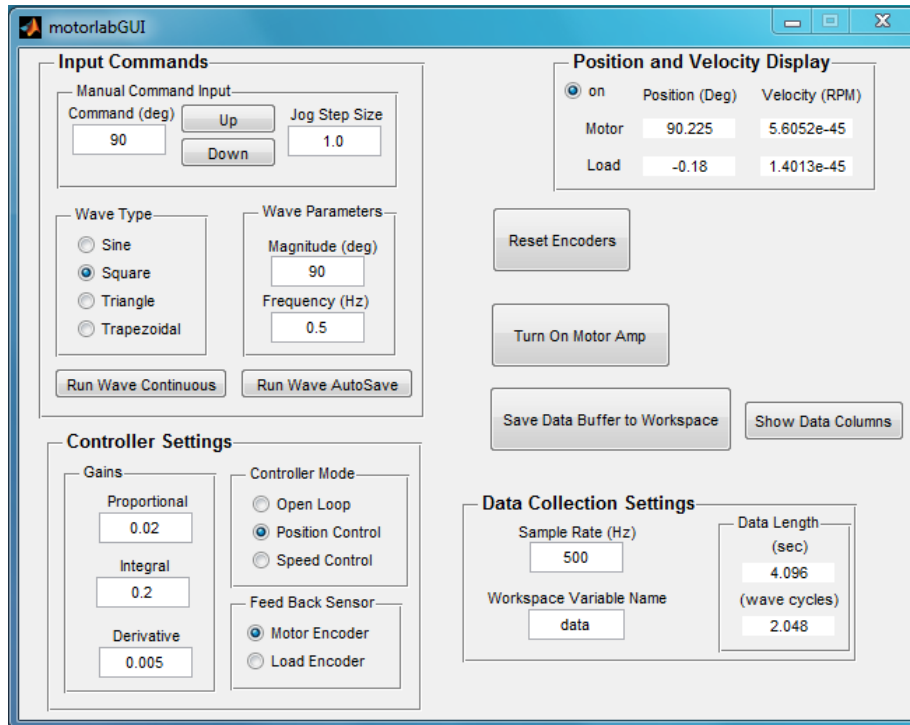
## Software

The software for the system can be found in the “c:\Motorlab” directory on the laboratory machines. All the needed Matlab functions can be found there. The software that is on the microcontroller is included in this directory in the motorlabRepo.zip file. This program is burned into the flash memory of the microcontroller and runs on power up. The software that runs on the PC is a GUI written in Matlab (“motorlabGUI.m”). There are additional m-files in the “Motorlab” directory that can be used to plot data from the system.

### User Interface

To run the Motorlab GUI you must open Matlab and add the “c:\Motorlab” directory to the Matlab path or set this directory as the current directory. Normally you will add it to the path and set the current directory to the location where you are storing your files. The microcontroller should be plugged into USB. In the Matlab command window type “motorlabGUI.” The opening dialog (below) asks you to select the communication port for the microcontroller. If more than one port is listed you should be able to detect which is the Motorlab by unplugging the USB or powering it down and then clicking the “Refresh List” button. The GUI should open after selecting the com port.





**Motorlab GUI**

### Data Acquisition

The microcontroller stores data in a circular buffer that is 2048 data samples in length with 9 variables in each sample. After 2048 sample periods the buffer begins to be overwritten with the more recent data. At any time the buffer contains the most recent 2048 samples. Pressing the "Save Data Buffer to Workspace" button will write this data to a 2048x9 matrix in the Matlab workspace. Pressing the "Run Wave AutoSave" button starts the wave type selected and then writes the data to the Matlab workspace once the buffer has filled with new data. The time length of the data depends on the sample rate. If for example the sample rate is set to 500 Hz, then the last 4.096 seconds (2048/500) of data will be saved in the buffer.

The data matrix saved in the Matlab workspace contains 9 variables (columns). The ninth column is reserved. The other eight are listed below. Note that the variable in the second column changes. It depends on the "Controller Mode" chosen at the time of the data storage.

Column	1	2	3	4	5	6	7	8
<b>Description</b>	Time	Command	Motor Encoder	Load Encoder	Motor Speed	Load Speed	Current Command	Motor Current
<b>Variable</b>	$t$ (sec)	$\theta_c$ (deg), $\omega_c$ (rpm), $i_c$ (Amp)	$\theta_1$ (deg)	$\theta_2$ (deg)	$\omega_1$ (rpm)	$\omega_2$ (rpm)	$i_c$ (Amp)	$i$ (Amp)

### M-files for plotting

There are m-files provided in the "c:\Motorlab" directory that can be used to plot the data from the Motorlab. Although you will frequently want the access the data with your own m-files, these files are useful for quickly viewing the data after acquiring it. There is one file for each of the "Controller Mode" settings.

**File: mlolplots.m** function: mlolplots(data,Iscale); Uses data generated by the Motorlab in open loop control. If an "Iscale" argument is supplied then the commanded current values are scaled by the Iscale value in the plots.

example: mlolplots(data); Does not scale the current command.

example: mlolplots(data,Iscale); Multiplies commanded current values by Iscale.

**File: mlposplots.m** function: mlposplots(data); Uses data generated by the Motorlab position control mode.  
example: mlposplots(data);

**File: mlspeedplots.m** function: mlspeedplots(data); Uses data generated by the Motorlab velocity control mode.  
example: mlvelplots(data);

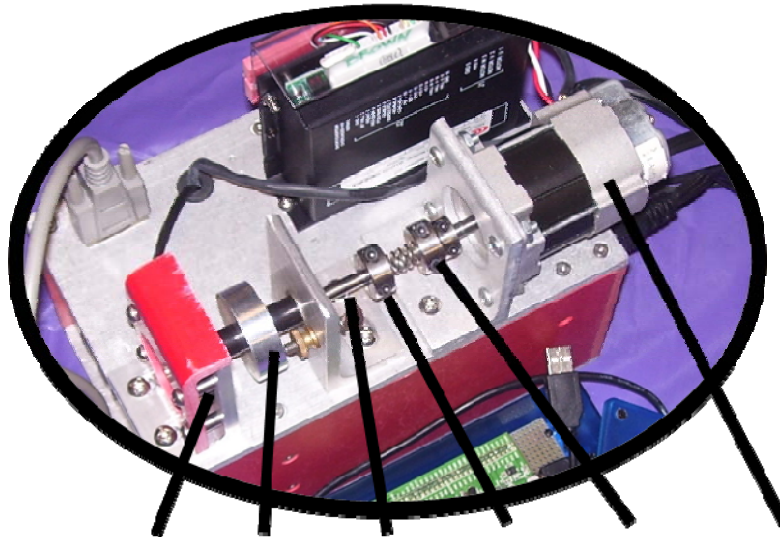
**File: trapprof.m** function: [x,v,t]=trapprof(DX,Vmax,Amax,DT) Trapezoidal-velocity motion profile generation  
Outputs: x=position vector, v=trapezoidal velocity vector, t=time vector  
Inputs: DX=distance to move, Vmax=maximum velocity, Amax=maximum acceleration, DT=time step for outputs  
example: [x,v,t]=trapprof(DX,Vmax,Amax,DT)

## Hardware Specifications

### Important Scaling Considerations

- Motor Amplifier Scaling = 1 Amp/Volt. Therefore, one Volt output from the microcontroller corresponds to a one Amp command to the current control loop in the motor amplifier. The plotting routines provided take this scaling into consideration.
- Position is measured in degrees and velocity is measured in RPM. The output of the control algorithm in the microcontroller is measured in Volts. Therefore, for example, the units of the proportional and derivate gains in the position controller would be Volts/deg and Volts\*sec/deg, respectively. When multiplied by the amplifier scaling (1 Amp/Volt) these gains become Amp/deg and Amp\*sec/deg. The units of the proportional gain in the velocity controller would be Volts/RPM (or Amp/RPM if amplifier scaling is included).

### Inertias



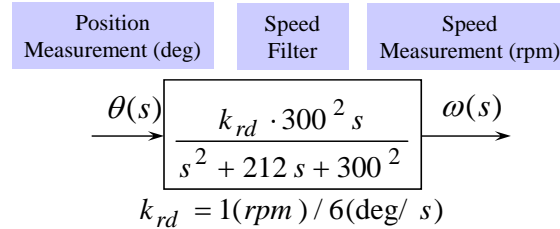
Object	Load Encoder	Load Wheel	Load Shaft	Single Shaft Collar	Double Shaft Collar	Motor Rotor and Motor Encoder
Inertia(g-cm <sup>2</sup> )	0.8	82	1.4	15	19	110

### A Few Other Details

- Max Data Acquisition Sample Rate = 10 kHz (the control update rate of the microcontroller software)
- Motor Encoder Resolution = 360 deg/1600 counts = 0.225 deg/count
- Load Encoder Resolution = 360 deg/2000 counts = 0.18 deg/count
- Max motor velocity with the 24 Volt power supply is about 4000 rpm

## Speed Measurement

The two speeds measured by the Motorlab system are found using a discrete time approximation (i.e. computer code) of a derivative with a low pass filter. The continuous time transfer function for this filter is given below. It uses the encoder position measurement for input. Note the free  $s$  in the numerator performs the differentiation and the filter with a cutoff frequency of 300 rad/s helps to filter spikes in the speed measurement caused by differentiating the discrete steps inherent in an encoder position measurement.



## Specs from Motor Manufacturer's Data Sheet

<b>LA052-040E Motor Dynamic Specs From Shinano Kenshi</b>		
	UNITS	Value
RATED POWER	W	40
RATED VOLTAGE	VDC	24
RATED SPEED	rpm	3,000
RATED TORQUE	N-cm	12.7
	kgf-cm	1.3
RATED CURRENT	A	2.5
TORQUE CONSTANT	N-cm/A	5.0
	kgf-cm/A	0.51
BACK EMF CONSTANT	V/krpm	5.2
PHASE RESISTANCE	Ohm	1.18
PHASE INDUCTANCE	mH	4.4
INSTANTANEOUS PEAK TORQUE	N-cm	38.2
MAX SPEED	rpm	5,000
ROTOR INERTIA	g-cm <sup>2</sup>	110
POWER RATE	kW/s	1.48
MECHANICAL TIME CONSTANT	ms	5.2
ELECTRICAL TIME CONSTANT	ms	3.7
MASS	kg	0.6

## Current Control Loop Model

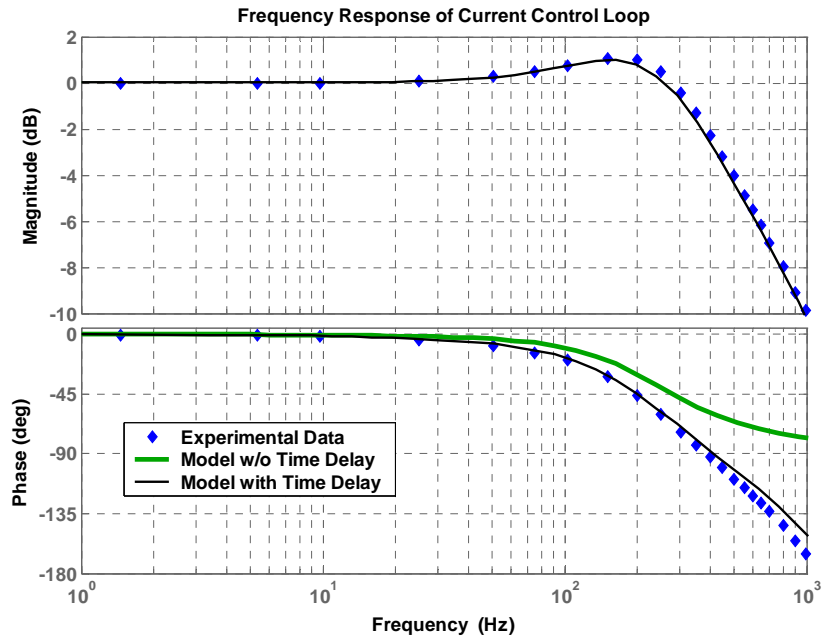
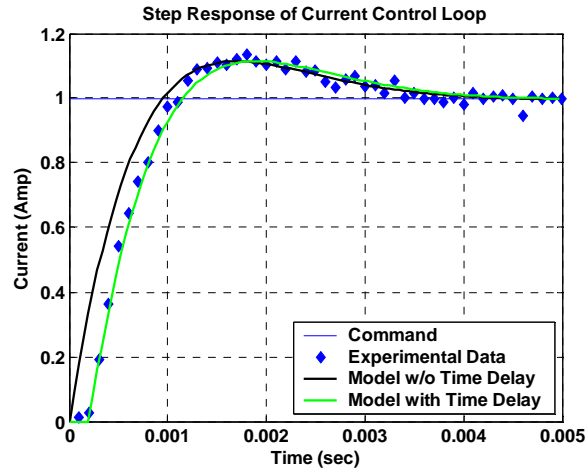
The motor amplifier has a current control loop. As configured in the Motorlab apparatus this loop has a bandwidth of approximately 400 Hz. Using data acquired from step and sinusoidal responses the following two closed loop transfer functions have been identified as approximate models for the closed-loop current control dynamics.

$$T_i = \frac{\omega_n^2 (s+z)}{z(s^2 + 2\zeta\omega_n s + \omega_n^2)} \text{ or } \begin{cases} T_{idelay} = \frac{\omega_n^2 (s+z)}{z(s^2 + 2\zeta\omega_n s + \omega_n^2)} e^{-t_d s} \\ T_{ipade} = \frac{\omega_n^2 (s+z)}{z(s^2 + 2\zeta\omega_n s + \omega_n^2)} \cdot \frac{s^2 - 6s/t_d + 12/t_d^2}{s^2 + 6s/t_d + 12/t_d^2} \end{cases}$$

**where :**  
 $z = 170 \cdot 2\pi \text{ (rad/sec)}$   
 $\omega_n = 230 \cdot 2\pi \text{ (rad/sec)}$   
 $\zeta = 0.8$   
 $t_d = 0.0002 \text{ (sec)}$

Two of the models above contain a time delay while the other does not. One model with the time delay uses the exponential (exact) representation with the delay, while the other uses a second order Pade' approximation of the

delay. In the following two figures the responses of these two models are compared with actual data acquired from one of the Motorlab systems. Both the step response and the frequency response models are shown.



# ***Motor Amplifier Manual***



## FEATURES

- *CE Compliance to 89/336/EEC*
- *Recognized Component to UL 508C*
- Complete torque ( current ) mode functional block
- Drives motor with 60° or 120° Halls
- Single supply voltage 18-55VDC
- 5A continuous, 10A peak more than double the power output of servo chip sets
- Fault protected  
**Short-circuits from output to output, output to ground**  
**Over/under voltage**  
**Over temperature**  
**Self-reset or latch-off**
- 2.5kHz bandwidth
- Wide load inductance range 0.2 to 40 mH.
- +5, +15V Hall power
- Separate continuous, peak, and peak-time current limits
- Surface mount technology

## APPLICATIONS

- X-Y stages
- Robotics
- Automated assembly machinery
- Component insertion machines

## THE *OEM* ADVANTAGE

- **NO POTS: Internal component header configures amplifier for applications**
- Conservative design for high MTBF
- Low cost solution for small brushless motors to 1/3 HP



## PRODUCT DESCRIPTION

Model 503 is a complete pwm servoamplifier for applications using DC brushless motors in torque ( current ) mode. It provides six-step commutation of three-phase DC brushless motors using 60° or 120° Hall sensors on the motor, and provides a full complement of features for motor control. These include remote inhibit/enable, directional enable inputs for connection to limit switches, and protection for both motor and amplifier.

The /Enable input has selectable active level ( +5V or gnd ) to interface with most control cards.

/Pos and /Neg enable inputs use fail-safe (ground to enable) logic. Power delivery is four-quadrant for bi-directional acceleration and deceleration of motors.

Model 503 features 500W peak power output in a compact package using surface mount technology.

An internal header socket holds components which configure the various gain and current limit settings to customize the 503 for different loads and applications.

Separate peak and continuous current limits allow high acceleration without sacrificing protection against continuous overloads. Peak current time limit is settable to match amplifier to motor thermal limits.

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

Package design places all connectors along one edge for easy connection and adjustment while minimizing footprint inside enclosures.

High quality components and conservative ratings insure long service life and high reliability in industrial installations.

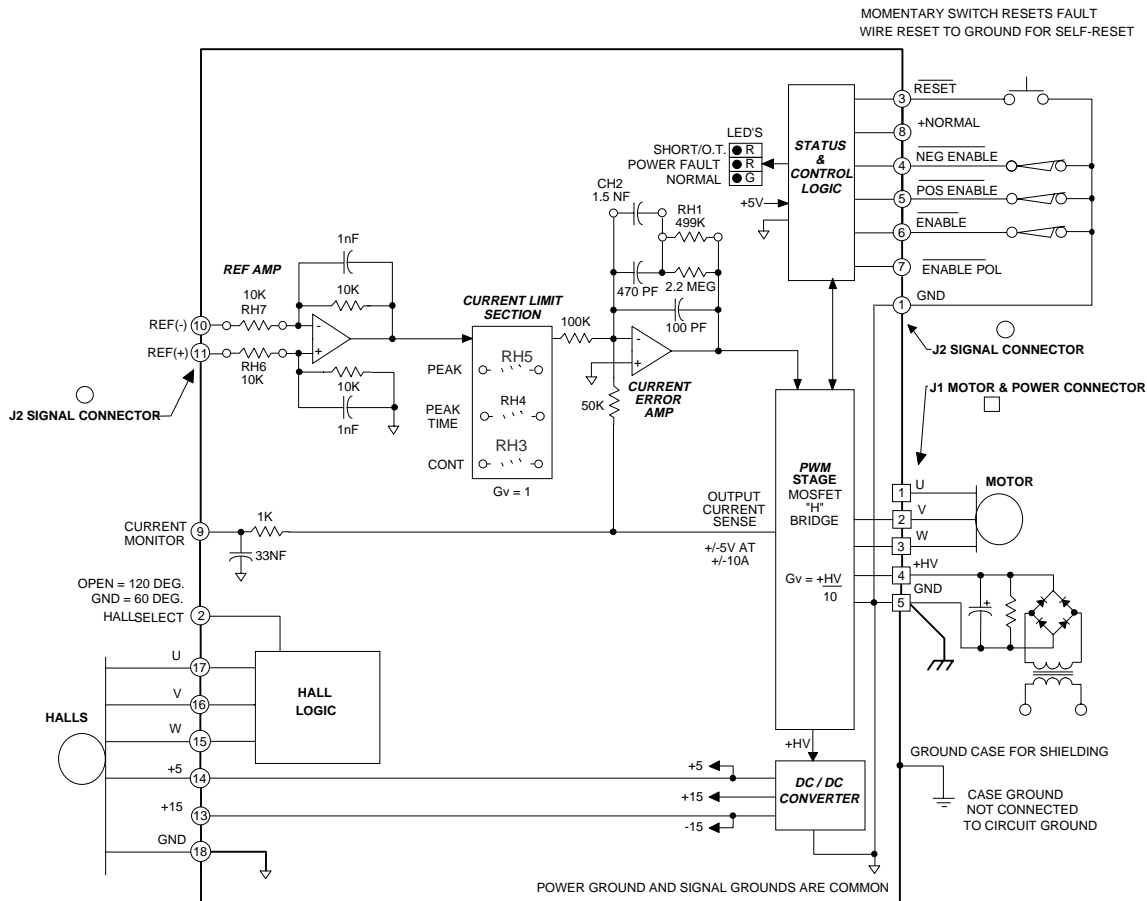
A differential amplifier buffers the reference voltage input to reject common-mode noise resulting from potential differences between controller and amplifier grounds.

Output short circuits and heatplate overtemperature cause the amplifier to latch into shutdown. Grounding the reset input will enable an auto-reset from such conditions when this feature is desired.

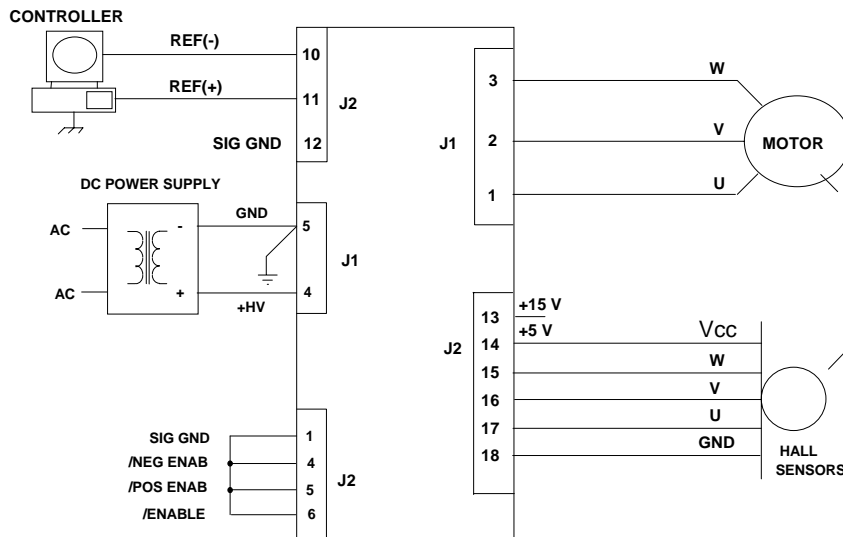


# Model 503 DC Brushless Servo Amplifier

## FUNCTIONAL DIAGRAM



## TYPICAL CONNECTIONS



**APPLICATION INFORMATION**

To use the model 503 set up the internal header with the components that configure the transconductance, current limits, and load inductance. Current-limits and load inductance set up the amplifier for your particular motor, and the transconductance defines the amplifiers overall response in amps/volt that is required by your system.

**COMPONENT HEADER SETTINGS**

Use the tables provided to select values for your load and system. We recommend that you use these values as starting points, adjusting them later based on tests of the amplifier in your application.

**LOAD INDUCTANCE (RH1,CH2)**

Maximizes the bandwidth with your motor and supply voltage. First replace CH2 with a jumper (short). Adjust the value of RH1 using a step of 1A or less so as not to experience large signal slew-rate limiting. Select RH1 for the best transient response ( lowest risetime with minimal overshoot). Once RH1 has been set. choose the smallest value of CH2 that does not cause additional overshoot or degradation of the step response.

**TRANSCONDUCTANCE (RH6,7)**

The transconductance of the 503 is the ratio of output current to input voltage. It is equal to  $10k\Omega/RH6$  (Amps/Volt). RH6, and RH7 should be the same value and should be 1% tolerance metal film type for good common-mode noise rejection.

**CURRENT LIMITS (RH3, 4, & 5)**

The amplifier operates at the 5A continuous, 10A peak limits as delivered. To reduce the limit settings, choose values from the tables as starting points, and test with your motor to determine final values. Limit action can be seen on current monitor when output current no longer changes in response to input signals. Separate control over peak, continuous, and peak time limits provides protection for motors, while permitting higher currents for acceleration.

**SETUP BASICS**

1. Set RH1 and CH2 for motor load inductance (see following section).
2. Set RH3, 4, & 5 if current limits below standard values is required.
3. Ground the /Enable (/Enable Pol open), /Pos Enable, and /Neg Enable inputs to signal ground.
4. Connect the motor Hall sensors to J2 based on the manufacturers suggested signal names. Note that different manufacturers may use A-B-C, R-S-T, or U-V-W to name their Halls. Use the required Hall supply voltage (+5 or +15V). *Note that there is a 30 mA limit at +5V. Encoders that put-out Hall signals typically consume 200-300 mA, so if these are used, then they must be powered from an external power supply.*
5. Connect J1-4,5 to a transformer-isolated source of DC power, +18-55V. Ground the amplifier and power supply with an additional wire from J1-5 to a central ground point.

6. With the motor windings disconnected, apply power and slowly rotate the motor shaft. Observe the Normal (green) led. If the lamp blinks while turning then the 60/120° setting is incorrect. If J2-2 is open, then ground it and repeat the test. In order to insure proper operation, the correct Hall phasing of 60° or 120° must be made.
6. Turn off the amplifier and connect the motor leads to J1-1,2,3 in U-V-W order. Power up the unit. Apply a sinusoidal reference signal of about 1 Hz. and 1Vrms between Ref(+) and Ref(-), J2-10,11.

7. Observe the operation of the motor as the current monitor signal passes through zero. When phasing is correct the speed will be smooth at zero crossing and at low speeds. If it is not, then power-down and re-connect the motor.

There are six possible ways to connect the motor windings, and only one of these will result in proper motor operation. The six combinations are listed in the table below. Incorrect phasing will result in erratic operation, and the motor may not rotate. When the correct combination is found, record your settings.

	J1-1	J1-2	J1-3
#1	U	V	W
#2	V	W	U
#3	W	U	V
#4	U	W	V
#5	W	V	U
#6	V	U	W

**GROUNDING & POWER SUPPLIES**

Power ground and signal ground are common ( internally connected ) in this amplifier. These grounds are isolated from the amplifier case which can then be grounded for best shielding while not affecting the power circuits.

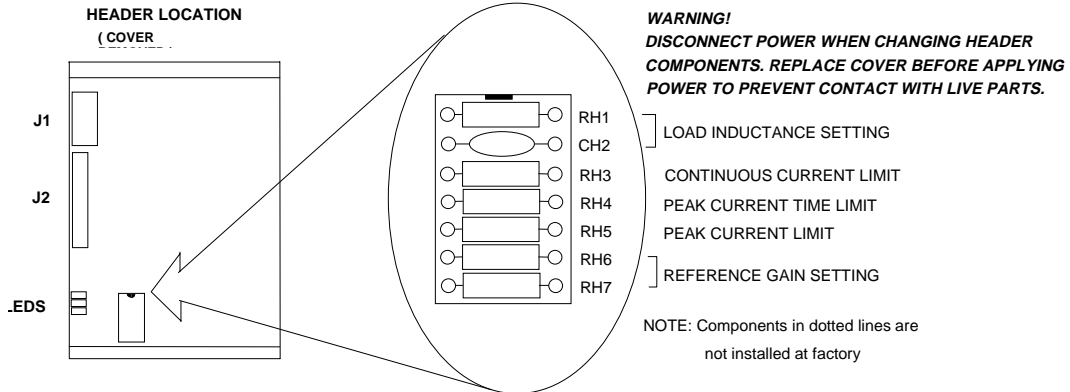
Currents flowing in the power supply connections will create noise that can appear on the amplifier grounds.

This noise will be rejected by the differential amplifier at the reference input, but will appear at the digital inputs. While these are filtered, the lowest noise system will result when the power-supply capacitor is left floating, and each amplifier is grounded at its power ground terminal ( J1-5 ). In multiple amplifier configurations, always use separate cables to each amplifier, twisting these together for lowest noise emission. Twisting motor leads will also reduce radiated noise from pwm outputs. If amplifiers are more than 1m. from power supply capacitor, use a small (500-1000µF.) capacitor across power inputs for local bypassing.



**APPLICATION INFORMATION (CONT'D)**

**COMPONENT HEADER**



**CONTINUOUS CURRENT LIMIT (RH3)**

$I_{cont}$ (A)	RH3 ( $\Omega$ )
<b>5</b>	<b><i>open</i></b> *
4	20k
3	8.2k
2	3.9k
1	1.5k

**INPUT TO OUTPUT GAIN SETTING ( RH6, RH7 )**

Note 1

Example: Standard value of RH6 is 10k $\Omega$ , thus  $G = 1 A/V$

**PEAK CURRENT LIMIT (RH5) Note 3**

$I_{peak}$ (A)	RH5 ( $\Omega$ )
<b>10</b>	<b><i>open</i></b> *
8	12k
6	4.7k
4	2k
2	750

**LOAD INDUCTANCE SETTING (RH1 & CH2) Note 2**

Load (mH)	RH1	CH2
0.2	49.9 k	1.5 nF
1	150 k	1.5 nF
<b>3</b>	<b><i>499 k</i></b>	<b><i>1.5 nF</i></b> *
10	499 k	3.3 nF
33	499 k	6.8 nF
40	499 k	10 nF

**PEAK CURRENT TIME-LIMIT (RH4) Note 4**

$T_{peak}$ (s)	RH4 ( $\Omega$ )
<b>0.5</b>	<b><i>open</i></b> *
0.4	10 M
0.2	3.3 M
0.1	1 M

Times shown are for 10A step from 0A

Notes: \* **Standard values installed at factory are shown in italics.**

1. RH6 & RH7 should be 1% resistors of same value.
2. Bandwidth and values of RH1, CH2 are affected by supply voltage and load inductance. Final selection should be based on customer tests using actual motor at nominal supply voltage.
3. Peak current setting should always be greater than continuous current setting.
4. Peak times will double when current changes polarity. Peak times decrease as continuous current increases.

## TECHNICAL SPECIFICATIONS

Typical specifications @ 25°C ambient, +HV = +55VDC. Load = 200µH. in series with 1 ohm unless otherwise specified.

### OUTPUT POWER

Peak power	±10A @ 50V for 0.5 second, 500W
Unidirectional	
After direction change	±10A @ 50V for 1 second, 500W
Continuous power	±5A @ 50V, 250W

### OUTPUT VOLTAGE

Vout = 0.97HV -(0.4)(Iout)

### MAXIMUM CONTINUOUS OUTPUT CURRENT

Convection cooled, no conductive cooling	±2A @ 35°C ambient
Mounted on narrow edge, on steel plate, fan-cooled 400 ft/min	±5A @ 55°C

### LOAD INDUCTANCE

Selectable with components on header socket	200 µH to 40mH (Nominal, for higher inductances consult factory)
---	--

### BANDWIDTH

Small signal	-3dB @ 2.5kHz with 200µH load
Note: actual bandwidth will depend on supply voltage, load inductance, and header component selection	

### PWM SWITCHING FREQUENCY

25kHz

### ANALOG INPUT CHARACTERISTICS

Reference	Differential, 20K between inputs with standard header values
-----------	--

### GAINS

Input differential amplifier	X1 as delivered. Adjustable via header components RH6, RH7
PWM transconductance stage	1 A/V ( output vs. input to current limit stage )

### OFFSET

Output offset current ( 0 V at inputs )	20 mA max. ( 0.2% of full-scale )
Input offset voltage	20 mV max ( for 0 output current, RH6,7 = 10kΩ )

### LOGIC INPUTS

Logic threshold voltage	HI: ≥ 2.5V , LO: ≤1.0V, <b>+5V Max on all logic inputs</b>
/Enable	LO enables amplifier (/Enable Pol open) , HI inhibits; 50 ms turn-on delay
/POS enable, /NEG enable	LO enables positive and negative output currents, HI inhibits
/Reset	LO resets latching fault condition, ground for self-reset every 50 ms.
/Enable Pol (Enable Polarity)	LO reverses logic of /Enable input only (HI enables unit, LO inhibits)

### LOGIC OUTPUTS

+Normal	HI when unit operating normally, LO if overtemp, output short, disabled, or power supply (+HV) out of tolerance HI output voltage = 2.4V min at -3.2 mA max., LO output voltage = 0.5V max at 2 mA max. <b>Note: Do not connect +Normal output to devices that operate &gt; +5V</b>
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### INDICATORS (LED's)

Normal (green)	ON = Amplifier enabled, no shorts or overtemp, power within limits
Power fault (red)	ON = Power fault: +HV <18V OR +HV > 55V
Short/Overtemp (red)	ON = Output short-circuit or over-temperature condition

### CURRENT MONITOR OUTPUT

±5V @ ±10A (2A/volt), 10kΩ, 3.3nF R-C filter

### DC POWER OUTPUTS

+5VDC	30mA (Includes power for Hall sensors)
+15VDC	10mA
Total power from all outputs not to exceed 200mW.	

### PROTECTION

Output short circuit (output to output, output to ground)	Latches unit OFF (self-reset if /RESET input grounded)
Overtemperature	Shutdown at 70°C on heatplate (Latches unit OFF)
Power supply voltage too low (Undervoltage)	Shutdown at +HV < 18VDC (operation resumes when power >18VDC)
Power supply voltage too high (Overvoltage)	Shutdown at +HV > 55VDC (operation resumes when power <55VDC)

### POWER REQUIREMENTS

DC power (+HV)	+18-55 VDC @ 10A peak.
Minimum power consumption	2.5 W
Power dissipation at 5A output, 55VDC supply	10W
Power dissipation at 10A output, 55VDC supply	40W

### THERMAL REQUIREMENTS

Storage temperature range	-30 to +85°C
Operating temperature range	0 to 70°C baseplate temperature

### MECHANICAL

Size	3.27 x 4.75 x 1.28 in. (83 x 121 x 33mm)
Weight	0.52 lb (0.24 kg.)

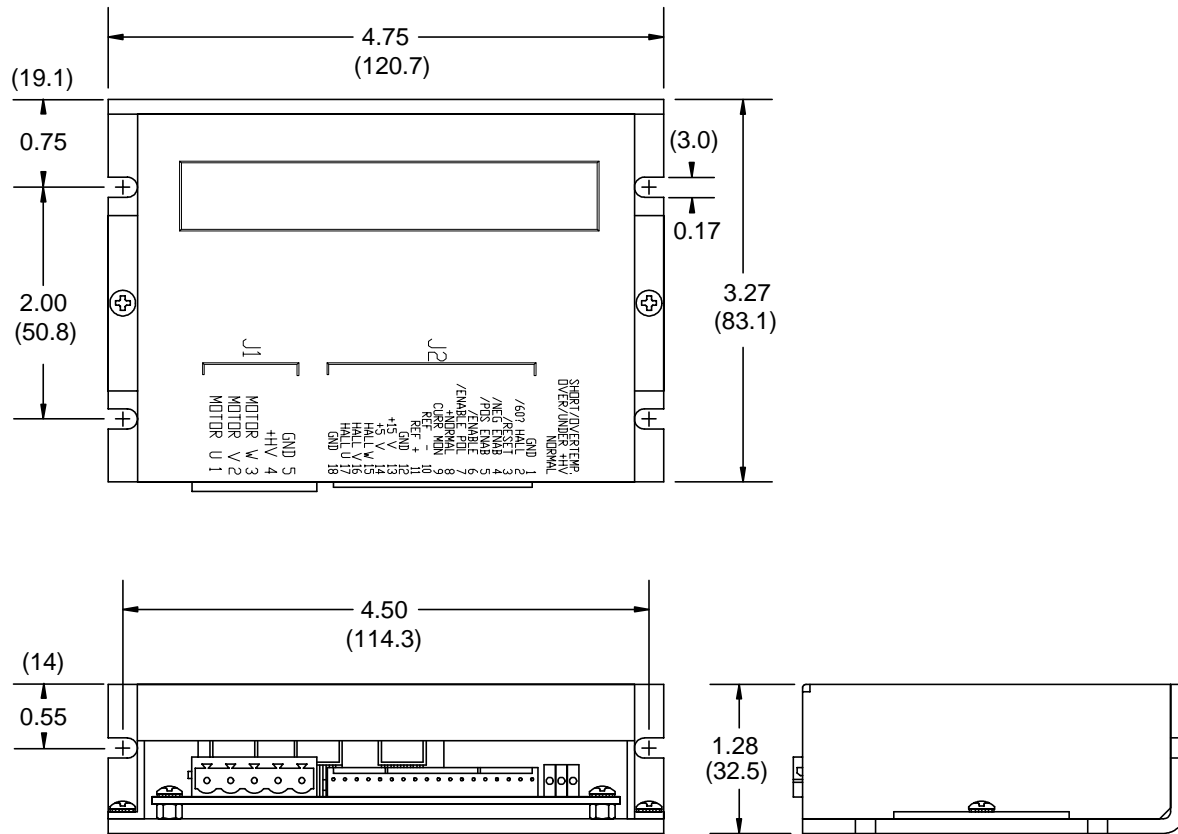
### CONNECTORS

Power & motor	Weidmuller: BL-125946; Phoenix: MSTB 2.5/5-ST-5.08
Signal & Halls	Molex: 22-01-3167 housing with 08-50-0114 pins

# Model 503 DC Brushless Servo Amplifier

## OUTLINE DIMENSIONS

Dimensions in inches (mm.)



## ORDERING GUIDE

Model 503	5A Continuous, 10A Peak, +18-55VDC Brushless Servoamplifier
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## OTHER BRUSHLESS AMPLIFIERS

- Model 505** Same power output as 503. Adds Hall / Encoder tachometer feature for velocity loop operation.
- 5001 Series** Six models covering +24-225VDC operation, 5-15A continuous, 10-30A peak. With optional Hall / Encoder tachometer, and brushless tachometer features.
- Model 513R** Resolver interface for trapezoidal-drivemotors. Outputs A/B quadrature encoder signals and analog tachometer signal for velocity loop operation. +24-180VDC operation, 13A continuous, 26A peak.

***Excerpt of Data Sheet for the  
STM32F4 Microcontroller***

## STM32F4DISCOVERY STM32F4 high-performance discovery board

### Introduction

The STM32F4DISCOVERY helps you to discover the STM32F4 high-performance features and to develop your applications. It is based on an STM32F407VGT6 and includes an ST-LINK/V2 embedded debug tool interface, ST MEMS digital accelerometer, ST MEMS digital microphone, audio DAC with integrated class D speaker driver, LEDs, pushbuttons and an USB OTG micro-AB connector.

Figure 1. STM32F4DISCOVERY

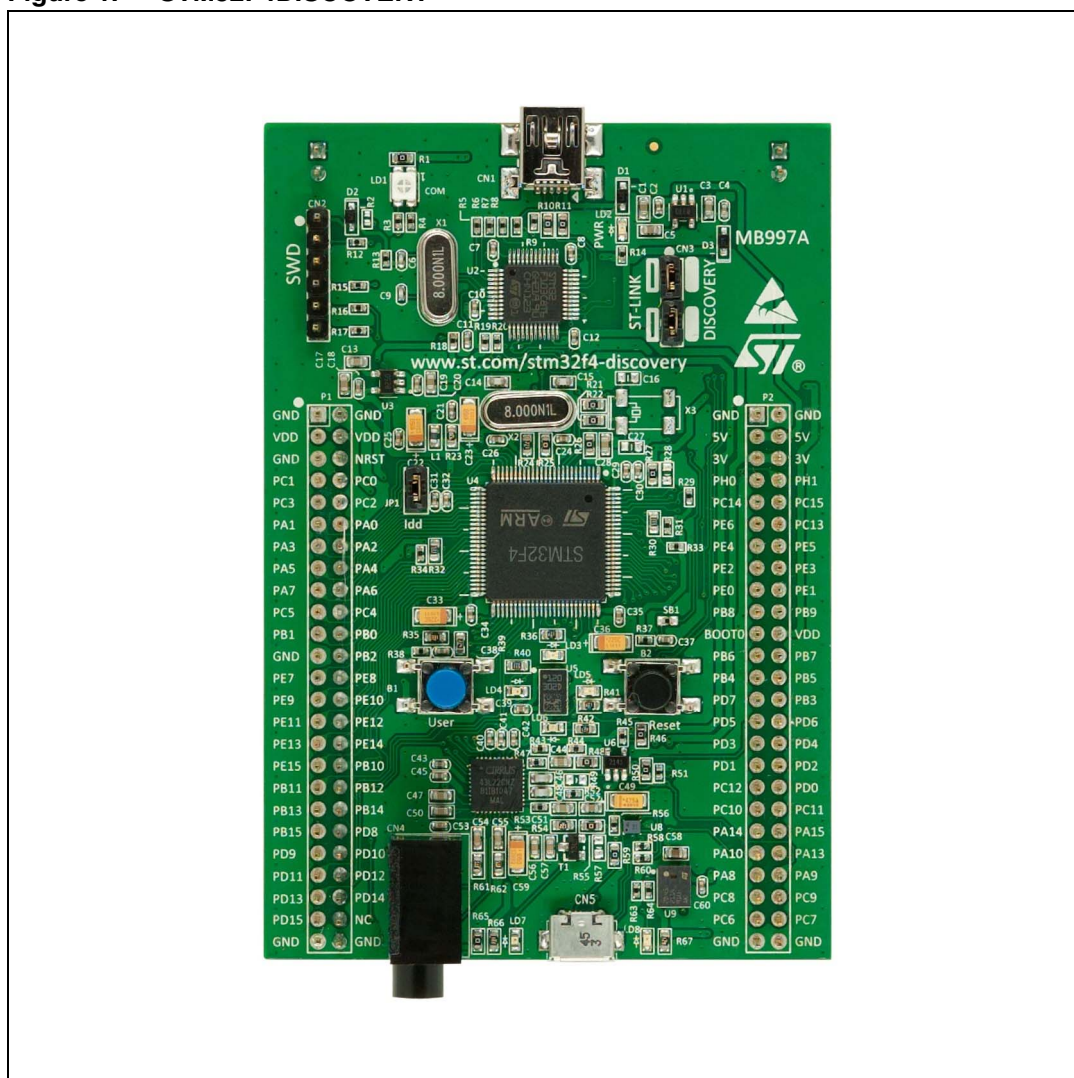
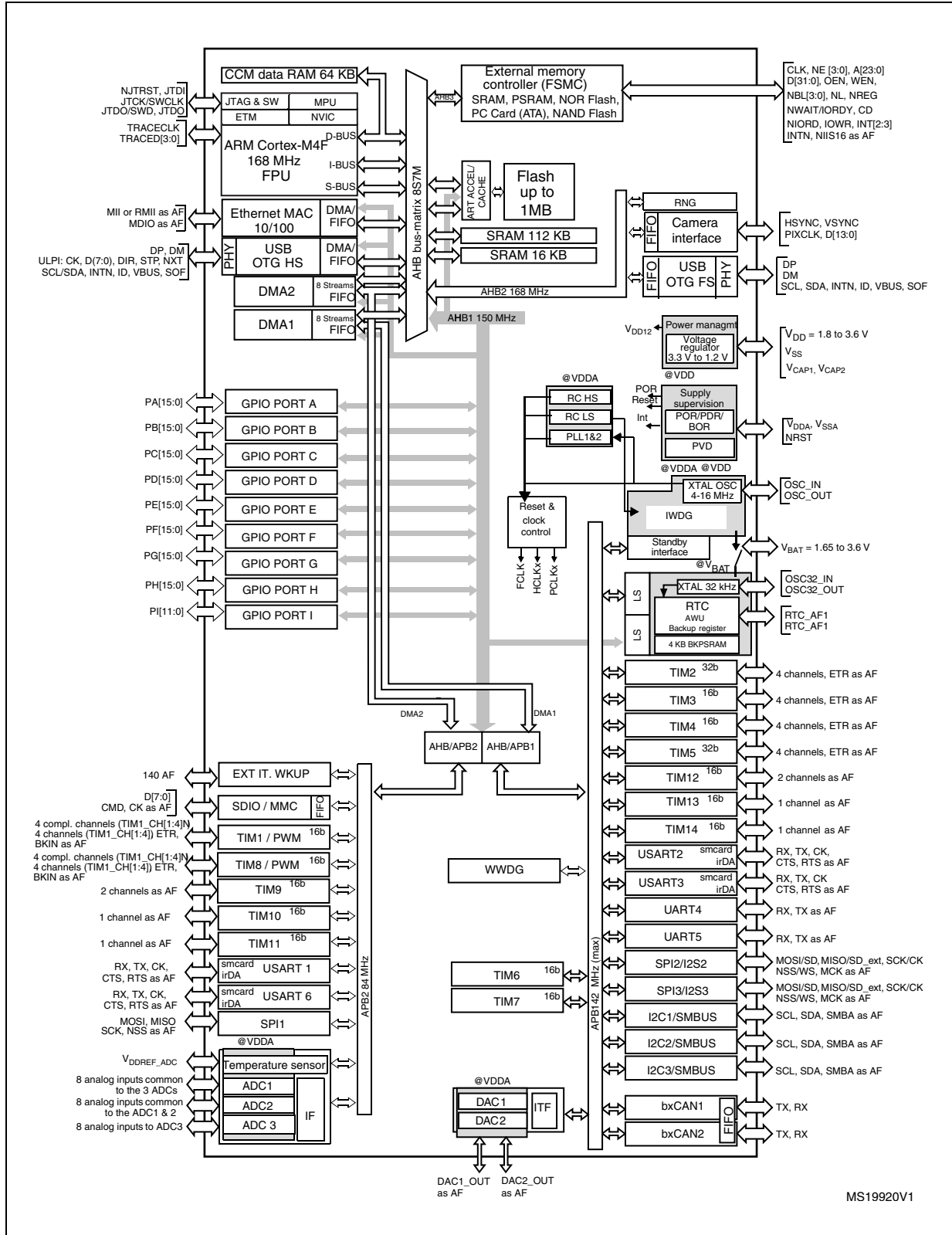




Figure 6. STM32F407VGT6 block diagram

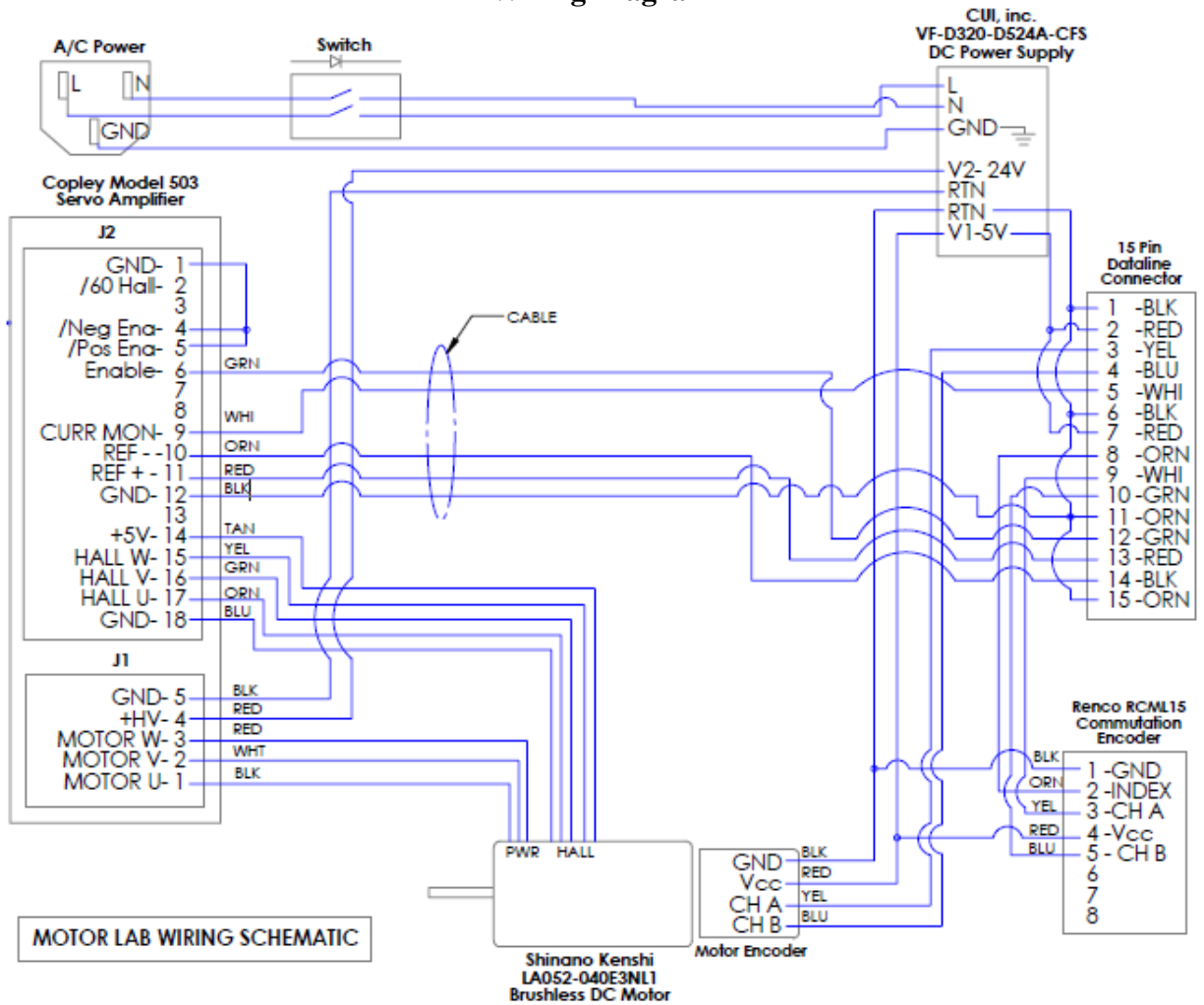


## ***Wiring for the “Motorlab” Apparatus***

### 15 Pin Microcontroller Connections

Amp J2	Hardware Wire Color	15pin Connector	Function	15pin Cable	STM32f4 Discovery
	Black	1 Black	Motor Encoder Ground	1 Black	GND
	Red	2 Red	+5V Power	2 Brown	Voltage Regulator
	Yellow	3 Yellow	Motor Encoder Channel A	3 Red	PE9 (TIM1-Ch1)
	Blue	4 Blue	Motor Encoder Channel B	4 Orange	PE11 (TIM1-Ch2)
Curr Mon	9 White	5 White	Current Monitor	5 Yellow	PB0 (ADC1-Ch8) thru resistor network
	Black	6 Black	Inertia Encoder Ground	6 Green	GND
	Red	7 Red	+5V Power	7 Blue	Voltage Regulator
	Orange	8 Orange	Inertia Encoder Index	8 Purple	--
	Yellow	9 White	Inertia Encoder Channel A	9 Gray	PA15 (TIM2-Ch1)
	Blue	10 Green	Inertia Encoder Channel B	10 White	PA1 (TIM2-Ch2)
GND	12 Black	11 Orange	Amp Signal Ground	11 Pink	GND
Enable	6 Green	12 Green	Amp Signal (Amp Enable)	12 Light Green	PB11 (Digital Out)
Ref+	11 Red	13 Red	Current Command +	13 Black-White	PB4 (TIM3-Ch1)
Ref-	10 Orange	14 Black	Current Command -	14 Brown-White	PB5 (TIM3-Ch2)
GND	12 Black	15 Orange	GND	15 Red-White	--

### Wiring Diagram



# STM32F4Discovery Host Board

