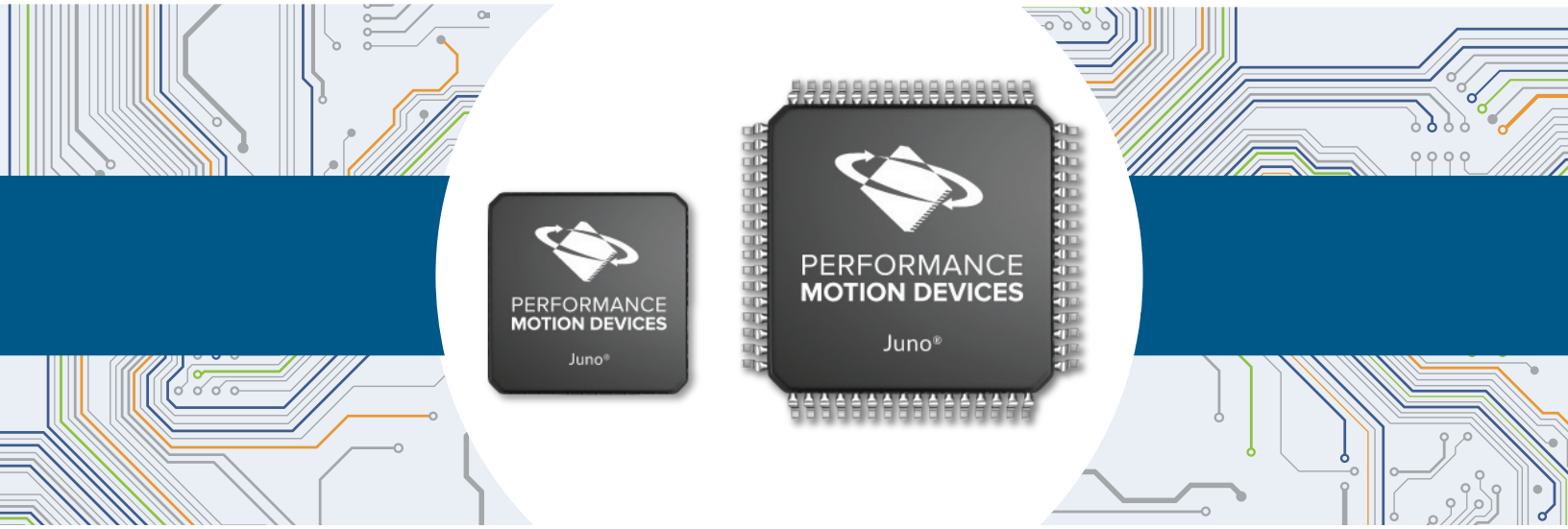
PERFORMANCE MOTION DEVICES

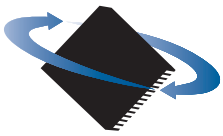
MOTION CONTROL AT ITS CORE



Juno® Torque Control IC

User Guide

Juno Torque Control IC
User Guide



PERFORMANCE
MOTION DEVICES

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Related Documents

DK78113 Developer Kit User Manual

How to install and configure the DK78113 Developer Kit. This developer kit supports all 64-pin TQFP Juno ICs including MC71112, MC73112, MC71113, MC73113, MC71112, MC73112, and MC78113.

DK73112N Developer Kit User Manual

How to install and configure the DK73112N Developer Kit. This developer kit supports the 56-pin VQFN Juno torque control ICs including MC71112N and MC73112N.

Juno Velocity & Torque Control IC User Guide

Complete description of the Juno Velocity & Torque Control IC family features and functions with detailed theory of operations.

Juno Velocity & Torque Control IC Programming Reference

Description of all Juno family IC commands, with coding syntax and examples, listed alphabetically for quick reference.

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1. The Juno IC Family

In This Chapter

- Introduction
- Family Overview
- Juno IC Developer Kits

1.1 Introduction

This manual describes the MC71112, MC71112N, MC73112, and MC73112N ICs from Performance Motion Devices, Inc. These devices comprise the torque control ICs of PMD Corp.'s Juno Velocity & Torque Control IC family. Additional members of the family are the MC71113, MC73113, and MC78113 ICs for velocity control of DC Brush and Brushless DC motors, and the MC74113, MC74113N, MC75113, and MC75113N ICs for control of step motors.

PMD Corp.'s Juno ICs are ideal for a wide range of applications including precision liquid pumping, laboratory automation, scientific automation, flow rate control, pressure control, high speed spindle control, and many other robotic, scientific, and industrial applications.

The Juno family provides full four quadrant motor control and directly inputs quadrature encoder, index, and Hall sensor signals. It interfaces to external bridge-type switching amplifiers utilizing PMD Corp.'s proprietary current and switch signal technology for ultra smooth, ultra quiet motor operation.

Juno ICs can be pre-configured via NVRAM for auto power-up initialization and standalone operation with SPI (Serial Peripheral Interface), direct analog, or pulse & direction command input. Alternatively Juno can interface via SPI, point-to-point serial, multi-drop serial, or CANbus to a host microprocessor.

Internal profile generation provides acceleration and deceleration to a commanded velocity with 32-bit precision. Additional Juno features include performance trace, programmable event actions, FOC (field oriented control), microstep signal generation, and external shunt resistor control.

All Juno ICs are available in 64-pin TQFPs (Thin Quad Flat Packages) measuring 12.0 mm x 12.0 mm including leads. The step motor control ICs and torque control ICs are also available in 56-pin VQFN (Very thin Quad Flat Non-leaded) packages measuring 7.2 mm x 7.2 mm. These VQFN parts are denoted via a "N" suffix in the part number.

1.2 Family Overview

The following table summarizes the operating modes and control interfaces supported by the Juno IC family:

Note that the MC78113 IC allows the motor type to be selected by the user. It provides all of the operating modes indicated for the MC71113, MC73113, and MC74113 Juno ICs.

	MC74113 MC74113N MC75113 MC75113N MC78113	MC71112 MC71112N	MC71113 MC78113	MC73112 MC73112N	MC73113 MC78113
Motor Type & Control Mode					
Motor Type	Step motor	DC Brush	DC Brush	Brushless DC	Brushless DC
Velocity			✓		✓
Torque/current	✓	✓	✓	✓	✓
Position & outer loop			✓		✓
Host Interface					
Serial point-to-point	✓	✓	✓	✓	✓
Serial multi-drop			✓		✓
SPI			✓		✓
CANbus			✓		✓
Command Input					
Analog velocity or torque		✓	✓	✓	✓
SPI velocity or torque		✓	✓	✓	✓
Pulse & direction	✓		✓		✓
SPI position increment	✓				✓
Motion I/O					
Quadrature encoder input	✓ (MC74113 & MC74113N only)		✓	✓	✓
Hall sensor input				✓	✓
Tachometer input			✓		✓
AtRest input	✓				
FaultOut output	✓	✓	✓	✓	✓
HostInterrupt output	✓	✓	✓	✓	✓
Amplifier Control					
PWM High/Low	✓	✓	✓	✓	✓
PWM Sign/Magnitude	✓	✓	✓		
DC Bus & Safety					
Shunt		✓	✓	✓	✓
Overcurrent detect	✓	✓	✓	✓	✓
Over/undervoltage detect	✓	✓	✓	✓	✓
Temperature input	✓	✓	✓	✓	✓
Brake	✓	✓	✓	✓	✓

1.3 Juno IC Developer Kits

Three different Juno developer kits are available. All of the 64-pin TQFP package Juno ICs are supported via the DK78113 developer kit board. The DK part numbers differ in the specific type of Juno IC that is installed.

Developer Kit P/N	Juno IC Installed	Motor supported	Comments
DK71112	MC71112	DC Brush	Torque control
DK71113	MC71113	DC Brush	Velocity & torque control
DK73112	MC73112	Brushless DC	Torque control
DK73113	MC73113	Brushless DC	Velocity & torque control
DK74113	MC74113	Step Motor	Provides quadrature encoder input
DK75113	MC75113	Step Motor	No quadrature encoder input
DK78113	MC78113	Multi-motor (Brushless DC, DC Brush, Step Motor)	Velocity & torque control with user-settable motor type

The 56-pin VQFN IC package step motor ICs are supported by the DK74113N developer kit board. The DK part numbers differ in the specific type of Juno IC that is installed.

Developer Kit P/N	Juno IC Installed	Motor Supported	Comments
DK74113N	MC74113N	Step Motor	Provides quadrature encoder input
DK75113N	MC75113N	Step Motor	No quadrature encoder input

The 56-pin VQFN IC package torque control ICs are supported by the DK73112N developer kit board. The DK part numbers differ in the specific type of Juno IC that is installed.

Developer Kit P/N	Juno IC Installed	Motor Supported	Comments
DK71112N	MC71112N	DC Brush	Torque control
DK73112N	MC73112N	Brushless DC	Torque control

Each developer kit includes:

- Standalone board with easy to access connectors for fast setup and testing
- Pro-Motion autotuning and axis wizard setup software
- Complete Juno manuals or PDFs
- Extensive application schematic examples

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2. Functional Characteristics

In This Chapter

- Configurations, Parameters, and Performance
- Physical Dimensions, 64-PIN TQFP Package
- Physical Dimensions, 56-PIN VQFN Package
- Absolute Maximum Environmental and Electrical Ratings

2.1 Configurations, Parameters, and Performance

Control command sources	AnalogCmd	Torque command is provided via external direct analog input
	SPI	Torque command is provided via external SPI (Serial Peripheral Interface) direct input
	Internal profile	Torque command is provided via internal profile generator function
	Motor Command Resistor	Torque command is provided via host command to a 16-bit register.
Host communication modes	Point to point asynchronous serial	
Serial port baud rate range	1,200 baud to 460,800 baud (1,200, 2,400, 9,600, 19,200, 57,600, 115,200, 230,400, 460,800)	
Motor output modes	PWM High/Low	Individual high and low drive signals for each bridge switch
	Sign/Magnitude PWM	Sign and magnitude drive signals for an H-bridge.
Commutation rate	39.06 kHz	
Current loop rate	19.53 kHz	
Current measurement resolution	12 bits	
PWM resolution & rates	1:1,536 @ 20 kHz 1:768 @ 40 kHz 1:384 @ 80 kHz 1:256 @ 120 kHz	
DC Bus & safety signals	*Brake, BusVoltage, BusCurrentSupply, Temperature, Shunt*	
Amplifier output signals	*AmplifierEnable, PWMHighA, PWMLowA, PWMHighB, PWMLowB, PWMHighC, PWMLowC*	
Serial communication signals	*SrlXmt, SrlRcv*	
Analog command signals	*AnalogCmd*	
SPI command signals	*SPIXmt, SPIRcv, SPIClk, SPIEnable*	
SPI frequency range	1.0 MHz - 10.0 MHz	
Encoder input signals	*QuadA, QuadB, Index*	
Position range	-2,147,483,648 to +2,147,483,647 counts	
Hall sensor signals	*Hall A-C*	
Miscellaneous control signals	*Enable, FaultOut, HostInterrupt, Reset*	

Drive safety functions	Over current detect, over temperature detect, over voltage detect, under voltage detect, I^2t current foldback
Brake input modes	Passive braking, full disable
Output limiting	I^2t, current, and voltage limit
Maximum encoder rate	40 Mcounts/sec
Cycle time range	102.4 microseconds to 1.114 seconds
Position-capture triggers	*Index* signal
Internal RAM	6,144 16-bit words
Maximum number of simultaneous trace variables	4
NVRAM storage size	1,024 16-bit words

2.2 Physical Dimensions, 64-PIN TQFP Package

All dimensions are in millimeters.

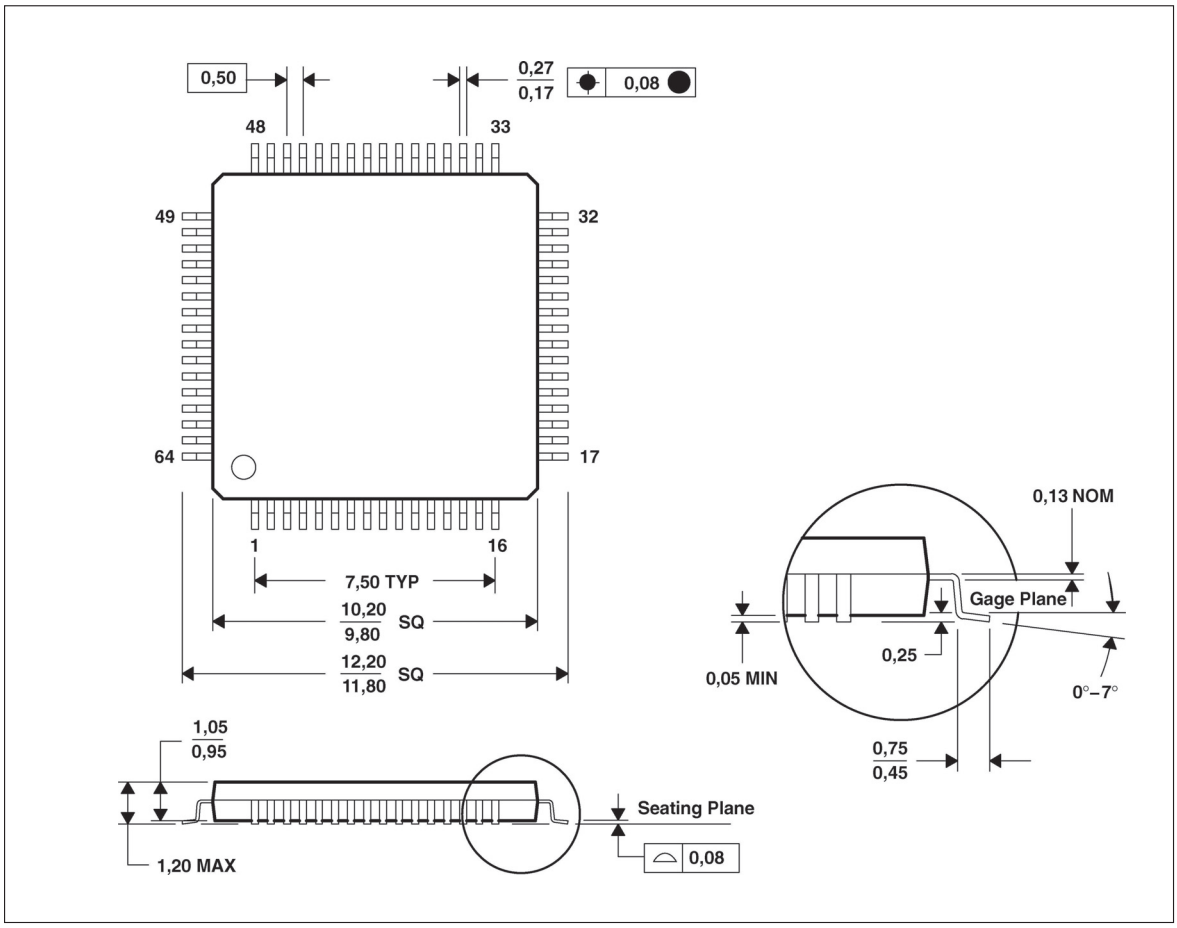


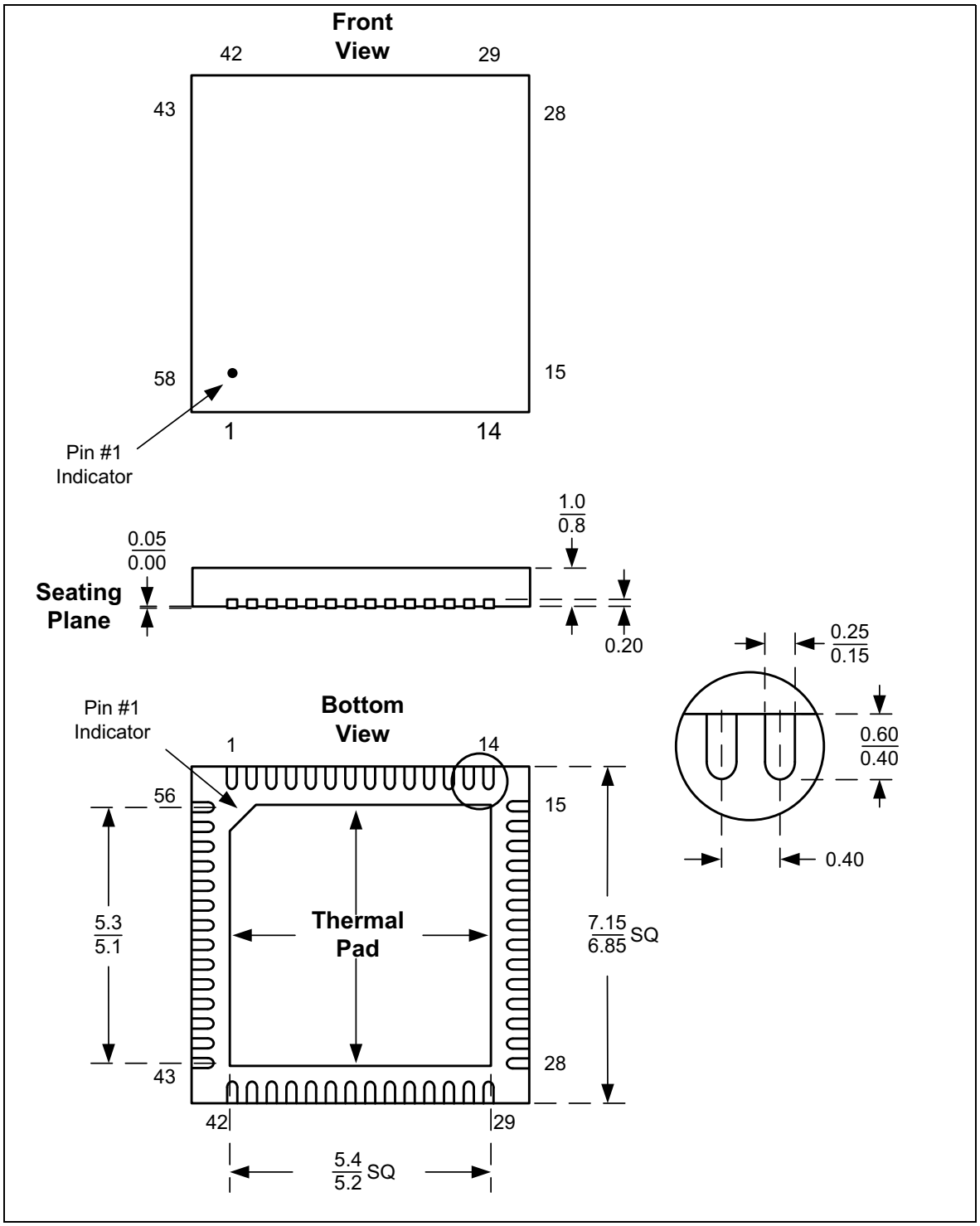
Figure 2-1: 64-Pin TQFP Physical Dimensions

Notes:

1. *Juno IC is RoHS compliant and free of Bromine and Antimony based flame retardants.*
2. *Moisture sensitive level: MSL 3*

2.3 Physical Dimensions, 56-PIN VQFN Package

Figure 2-2: 56-Pin VQFN Physical Dimensions



Notes:

1 *Juno IC is RoHS compliant and free of Bromine and Antimony based flame retardants.*

2 *Moisture sensitive level: MSL 3*

2.4 Absolute Maximum Environmental and Electrical Ratings[1]

Supply voltage (Vcc)	-0.3V to +4.6V
FltCap pin voltage range	-0.3V to 2.5V
Analog voltage range with respect to AnalogGND (AnalogVcc)	-0.3V to +4.6V
Input voltage (Vi)	-0.3V to +4.6V
Output voltage (Vo)	-0.3V to +4.6V
Input clamp current (Ii,clamp), peak:	+/-20 mA
continuous:	+/-2 mA
Output clamp current (Io,clamp)	+/-20 mA
Package thermal impedance, 64-pin TQFP package (θ_{JA})	56.5°C/W
Package thermal impedance, 56-pin VQFN package (θ_{JA})	34.8°C/W
Junction temperature range (Tj)(2)	-40°C to 150°C
Storage temperature range (Ts)	-65°C to 150°C
Nominal clock frequency (Fclkin)	10.0 MHz

(1) Unless otherwise noted, all voltages are with respect to GND
(2) Please refer to "Design tips" section for more information

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3. Electrical Characteristics

In This Chapter

- DC Characteristics
- AC Characteristics

3.1 DC Characteristics

(Vcc and Ta per operating ratings, Fclkin=10.0MHz)

Symbol	Parameter	Minimum	Maximum	Conditions
V_{cc}	Supply voltage	2.97V	3.63V	With respect to GND
I_{dd}	Supply current		115 mA	All I/O pins are floating
AnalogV_{cc}	Analog input supply voltage	2.97V	3.63V	With respect to AnalogGND
AnalogI_{dd}	Analog supply current		18 mA	
T_a	Operating free-air temperature	-40°C	105°C	Note 2
T_j	Operating junction temperature	-40°C	150°C	
Input Voltage				
V_{ih}	Logic 1 input voltage	2.0V	Vcc+0.3V	
V_{il}	Logic 0 input voltage	-0.3V	0.8V	
Output Voltage				
V_{oh}	Logic 1 Output Voltage	2.4V		Io=-4 mA
		Vcc-0.2V		Io=-50 μA
V_{ol}	Logic 0 Output Voltage		0.4V	Io=4 mA
Other				
I_{out}	Tri-state output leakage current	-2 μA	2 μA	Vo=0 or Vcc
I_{in}	Input current	2 μA	-205 μA	Vcc=3.3V with internal pullup
$I_{in,\sim RESET}$	Input current for ~RESET pin	2 μA	-375 μA	Vcc=3.3V
C_i	Input capacitance		2 pF	typical
V_{fltcap}	FltCap voltage		1.9V	typical
V_{reset}	Vcc BOR trip point	2.50V	2.96V	Falling Vcc
$V_{reset,hys}$	Vcc BOR hysteresis		35 mV	typical
T_{reset}	BOR reset release delay time	400 μs	800 μs	Time from removing reset to ~RESET release
Analog Input				

Symbol	Parameter	Minimum	Maximum	Conditions
V_{analog}	Analog input voltage range	0	3.3V	With respect to AnalogGND
C_{ai}	Analog input capacitance		5 pF	typical
E_{dnl}	Differential nonlinearity error. Difference between the step width and the ideal value. No missing codes.	-1	1	LSB
E_{inl}	Integral nonlinearity error. Maximum deviation from the best straight line through the ADC transfer characteristics, excluding the quantization error.	-4	4	LSB
E_{zo}	Zero-offset error	-4	4	LSB

Notes:
(1) V_{cc} and AnalogV_{cc} should be within 0.3V from each other.
(2) Please refer to design tips in the Application Notes of this manual for thermal design considerations.

3.2 AC Characteristics

Refer to Chapter 4, *Timing Diagrams*, for timing diagrams.

3.2.1 Quadrature Encoder Input

Timing Interval	No.	Min	Max
Encoder pulse width	T4	33.3 nSec	
Dwell time per state	T5	16.7 nSec	
~Index active pulse time	T6	33.3 nSec	

Notes:
(1) ~Index is defaulted as active low, which is shown here. It can be configured to be active high.

3.2.2 SPI

Timing Interval	No.	Min	Max
SPIClock clock cycle time	T23	80 nSec	
Pulse duration, SPIClock high	T24	33 nSec	
Pulse duration, SPIClock low	T25	33 nSec	
~SPIEnable low to first SPIClock high	T26	25 nSec	
SPIClock high to SPIXmt valid delay time	T27		21 nSec
SPIXmt data valid time after SPIClock low	T28	T25	
SPIRcv setup time before SPIClock low	T29	25 nSec	
SPIRcv valid time after SPIClock low	T30	25 nSec	
Last SPIClock low to ~SPIEnable high	T31	25 nSec	

3.2.3 Power-on Reset

Timing Interval	No.	Min	Max
Power on pulse duration driven by device (typical)	T32		600 µSec
Device ready/ outputs initialized (typical)	T33		2 mSec

Note: The device will generate a *~Reset* pulse upon power on. An external *~Reset* signal is optional.

3.2.4 Warm Reset

Timing Interval	No.	Min	Max
~Reset low duration for warm reset	T35	570 nSec	

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4. Timing Diagrams

4

In This Chapter

- Quadrature Encoder Input
- SPI Timing
- Power On Timing
- Warm Reset

For the values of *Tn*, please refer to the table in Section 3.2, "AC Characteristics" for more information

4.1 Quadrature Encoder Input

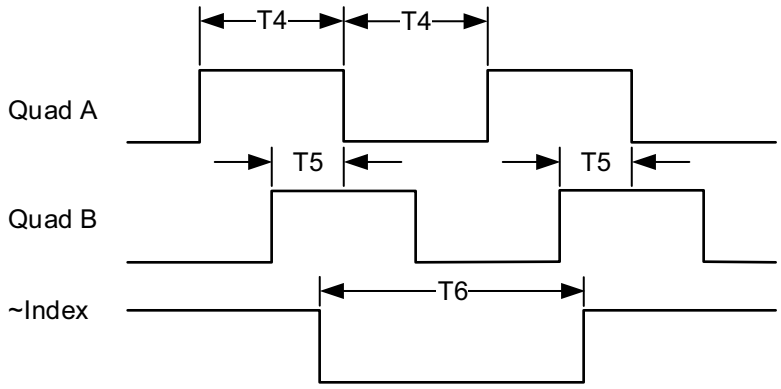
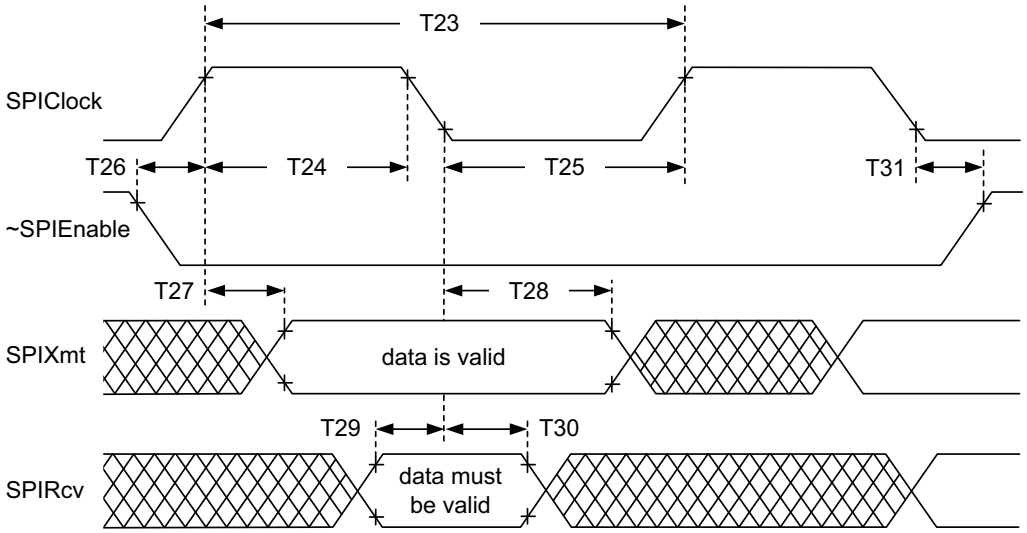


Figure 4-1: Quad Encoder Timing

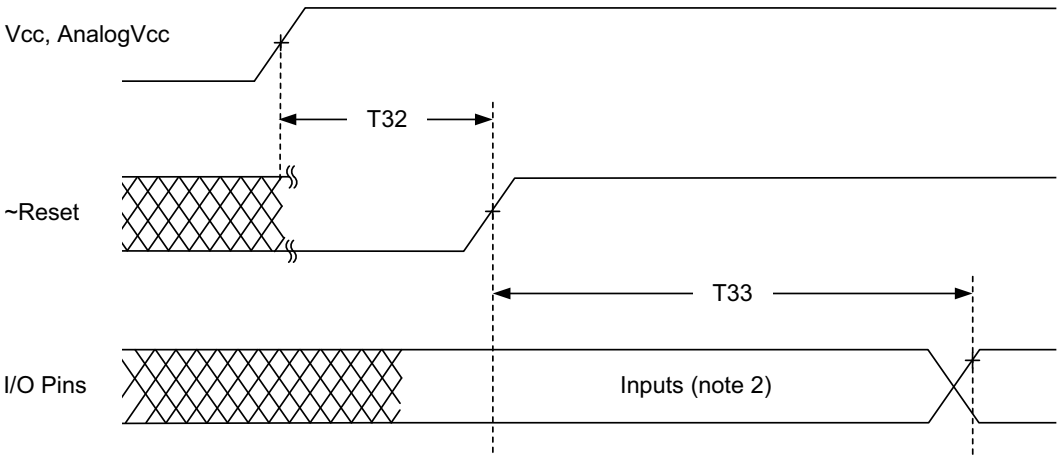
4.2 SPI Timing

Figure 4-2: SPI Timing



4.3 Power On Timing

Figure 4-3: Power On Timing



4.4 Warm Reset

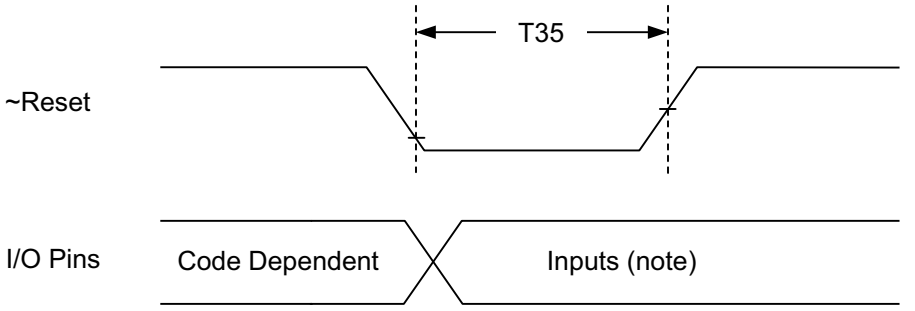


Figure 4-4: Warm Reset Timing

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5. Pinouts and Pin Descriptions

5

In This Chapter

- Pinouts for the MC71112
- Pinouts for the MC71112N
- Pinouts for the MC73112
- Pinouts for the MC73112N
- MC71112, MC71112N, MC73112, MC73112N Pin Descriptions

5.1 Pinouts for the MC71112

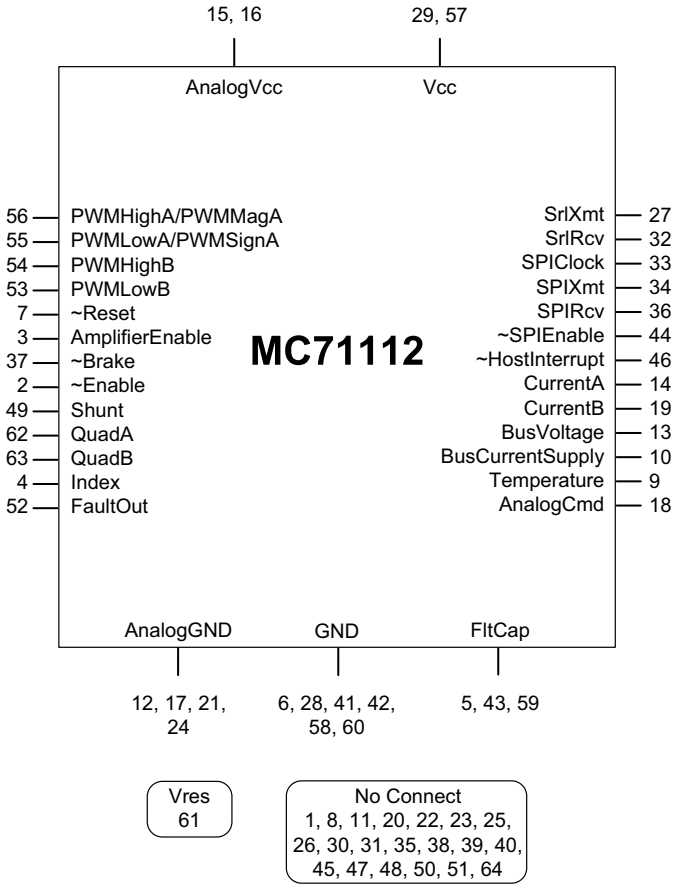
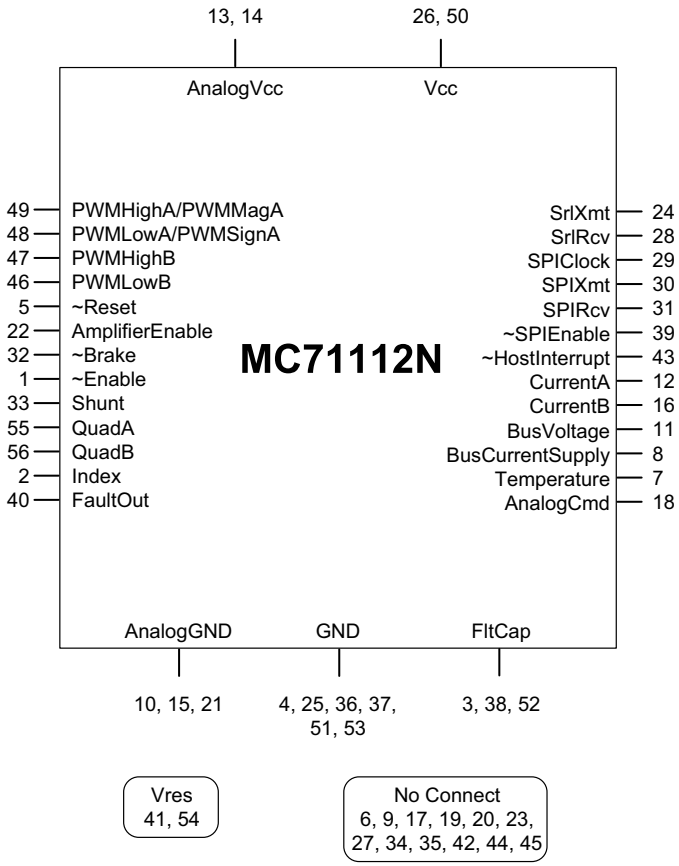


Figure 5-1: MC71112 Pinouts

5.2 Pinouts for the MC71112N

Figure 5-2: MC71112N Pinouts



5.3 Pinouts for the MC73112

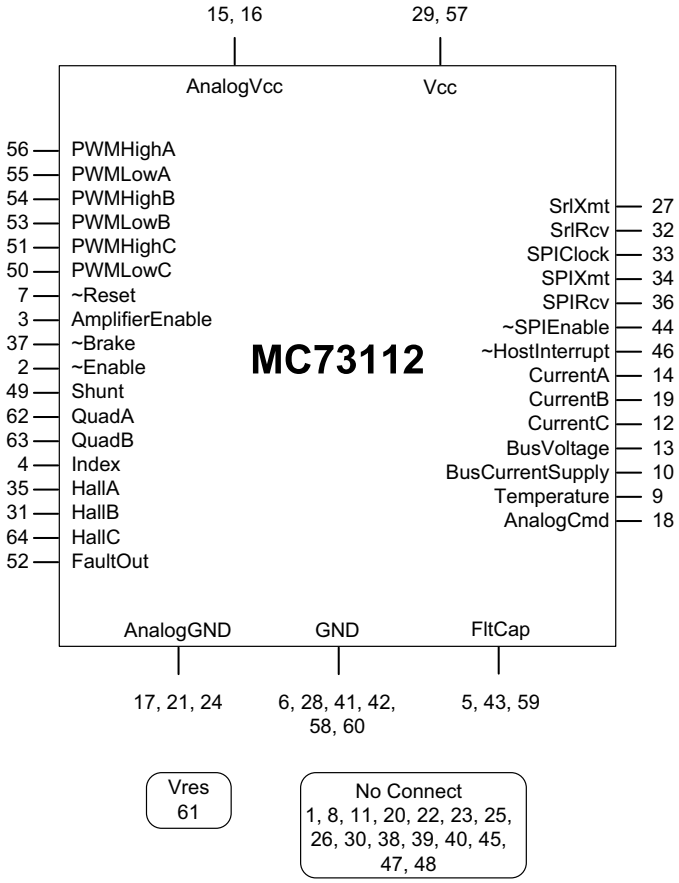
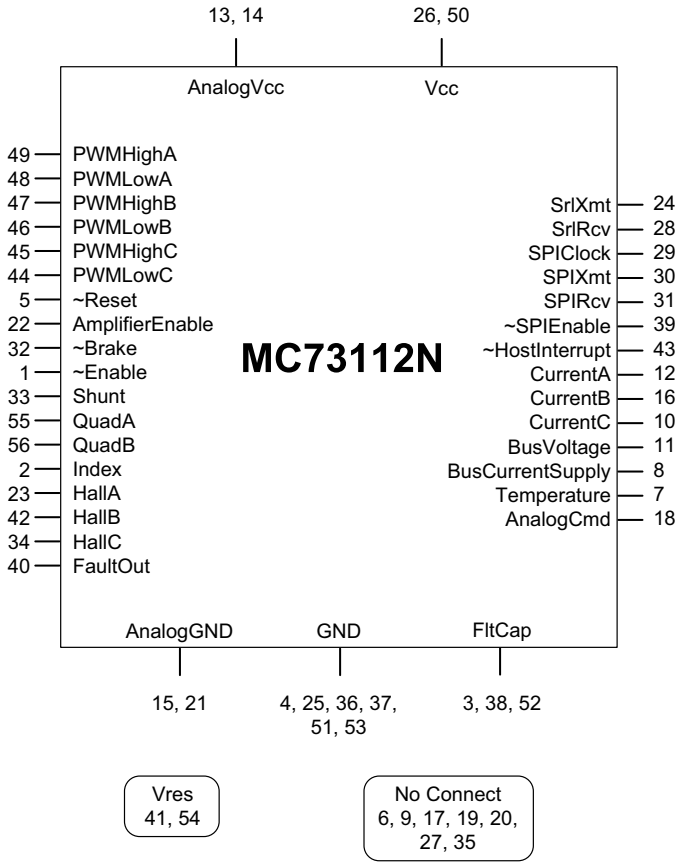


Figure 5-3: MC73112 Pinouts

5.4 Pinouts for the MC73112N

Figure 5-4: MC73112N Pinouts



5.5 MC71112, MC71112N, MC73112, MC73112N Pin Descriptions

The following table details the pinouts for the MC71112, MC71112N, MC73112, and MC73112N ICs.

Name	64-Pin TQFP Pin #	56-Pin VQFN Pin #	Direction	Description
~Reset	7	5	in/out	This pin is the master reset input. To perform a reset it may be temporarily brought low and then restored to high. During a power-on or reset condition this pin is driven low by Juno. If this pin is driven, it must be with an open drain output device. **For correct reset operation a 10k pull-up resistor should be added between Reset and Vcc. In addition, a 100nF or smaller capacitor is recommended between Reset and GND.** During powerup it is not necessary to provide a reset. Juno generates an internal reset upon powerup.
PWMHighA/ PWMMagA	56	49	out	Depending upon the selected motor type and output mode, these pins have the following functions: *PWMHighA/B/C* signals encode the high side drive for a switching bridge with separate high/low controls. The default encoding is active high, however this can be user programmed. *PWMLowA/B/C* signals encode the low side drive for a switching bridge with separate high/low controls. The default encoding is active high, however this can be user programmed. *PWMMagA* signals encode the magnitude of a pulse width modulated output for use with switching bridges with sign/ magnitude controls. The default encoding is active high, however this can be user programmed. *PWMSignA* encode the sign of the pulse width modulated output for use with switching bridges with sign/magnitude controls. The default encoding is active high, however this can be user programmed.
PWMLowA/ PWMSignA	55	48		
PWMHighB	54	47		
PWMLowB	53	46		
PWMHighC	51	45		
PWMLowC	50	44		
AmplifierEnable	3	22	out	This pin provides an amplifier enable signal that may be useful for some amplifier connection schemes. A high signal indicates that amplifier output should be enabled and a low indicates that amplifier output should be disabled.
~Brake	37	32	in	This pin inputs a high speed PWM output disable that may be useful for a braking function with some PWM amplifier schemes. When low, PWM output is overridden to execute a brake function or if so programmed, to be disabled. PWM operation is normal when this signal is high.
~Enable	2	1	in	This pin is an enable input. To allow normal operations a low signal is asserted. When a high signal is asserted a programmable response may disable motor control operations, although communications and various other operations are still available.
Shunt	49	33	out	This pin provides a PWM-based shunt signal that may be used with an external switching circuit and high wattage resistor or other energy dissipating device to regulate supply bus overvoltage conditions. The default encoding is active high however this setting can be user programmed.

Name	64-Pin TQFP Pin #	56-Pin VQFN Pin #	Direction	Description
QuadA QuadB Index	62 63 4	55 56 2	in	These pins input the A and B quadrature signals along with the *Index* signal for an incremental encoder. By default a valid index pulse is recognized when ~Index transitions low, however the interpretation of this signal can be user programmed. Note: Index capture is not conditioned by the QuadA and QuadB signals. If such conditioning is not provided by the encoder then external circuitry should be used if such conditioning is desired. If unused, these pins may be left unconnected.
HallA HallB HallC	35 31 64	23 42 34	in	These pins input Hall-encoded phasing inputs for brushless DC motors. The A, B, and C signals encode six valid states as follows: A on, A and B on, B on, B and C on, C on, C and A on. By default a sensor is defined as being on when its signal is high, however this signal interpretation can be user programmed. Note: Some Hall sensors require a pull up resistor to 3.3V on each signal to establish a proper high signal. Check your Hall sensor's electrical specification. If unused, these pins may be left unconnected.
FaultOut	52	40	out	This pin provides a general purpose fault indicator that can be programmed to indicate a number of conditions including a motion error, drive exception, or various other conditions. A high indicates that a fault condition is present.
SrlXmt	27	24	out	This pin outputs serial data from the asynchronous serial port.
SrlRcv	32	28	in	This pin inputs serial data to the asynchronous serial port. If unused, this pin may be left unconnected.
SPIClock	33	29	in	*SPIClock* inputs the clock signal used with synchronous serial transfer on the SPI bus. If unused, this pin may be left unconnected.
SPIXmt	34	30	out	This pin transmits synchronous serial data on the SPI bus to the host processor.
SPIRcv	36	31	in	This pin inputs synchronous serial data for the SPI bus. If unused, this pin may be left unconnected.
~SPIEnable	44	39	in	This pin inputs an enable signal for the host communication SPI bus. This signal is active low, meaning it should be low when an SPI communication is occurring, and high at all other times. **If used, this pin must be controlled in series with a 470 ohm resistor.** If unused, this pin may be left unconnected.
~HostInterrupt	46	43	out	This pin provides a host interrupt signal. When low, it signals an interrupt to the host processor. **Whether this pin function is used or not this pin must be connected to a 10 Kohm pullup resistor.**

Name	64-Pin TQFP Pin #	56-Pin VQFN Pin #	Direction	Description
CurrentA CurrentB CurrentC	14 19 12	12 16 10	in	These pins input analog voltages representing leg current flow through the low sides of the switching bridges. DC Brush motors use the A and B inputs, and Brushless DC motors use the A, B, and C inputs. These signals are only accessible when the PWM output mode is set to PWM High/Low. These signals are used when a current loop is used or when I2t current monitoring is desired. These signals are sampled by an internal A/D converter. The A/D resolution is 12 bits. The allowed signal input range is zero to 3.3V. If unused, these signals should be connected to AnalogGND.
BusVoltage	13	11	in	This pin inputs an analog voltage representing the DC bus voltage. The allowed signal input range is zero to 3.3V. If unused, this signal should be connected to AnalogGND.
BusCurrentSupply	10	8	in	This pin inputs an analog voltage representing the current through the supply terminal of the DC bus. The allowed signal input range is zero to 3.3V. If unused, this signal should be connected to AnalogGND.
Temperature	9	7	in	This pin inputs an analog voltage representing the temperature of the amplifier or other monitored circuitry. The allowed signal input range is zero to 3.3V. If unused, this signal should be connected to AnalogGND.
AnalogVcc	16 15	13 14	N/A	These pins are connected to the analog input supply voltage, which must be in the range of 3.0V to 3.6V. If analog inputs are not used, these pins should be tied to Vcc.
AnalogCmd	18	18	in	This pin is used for commanding either voltage or torque using an analog signal. If unused, this pin should be tied to AnalogGND.
AnalogGND	17 21 24	15 21	N/A	This pin should be connected to the analog input power supply return. Any unused analog inputs (CurrentA-C, BusVoltage, Bus-CurrentSupply, Temperature or AnalogCmd pins) should be tied to AnalogGND.
Vcc	29 57	26 50	N/A	All of these pins must be connected to the digital supply voltage, which should be in the range of 3.0V to 3.6V.
FltCap	5 43 59	3 38 52	N/A	Each of these pins must be connected to a 1.2 µF (or higher) filtering capacitor which in turn connects to GND.
Vres	61	41 54		Each of these pins must be connected to Vcc via a 10K resistor.
GND	6 28 41 42 58 60	4 25 36 37 51 53	N/A	All of these pins must be connected to the digital power supply return.

Name	64-Pin TQFP Pin #	56-Pin VQFN Pin #	Direction	Description
No Connect	1	6	N/A	These pins must be left unconnected.
	8	9		
	11	17		
	20	19		
	22	20		
	23	27		
	25	35		
	26			
	30			
	38			
	39			
	40			
	45			
	47			
	48			
Thermal pad	N/A	T. Pad	N/A	Thermal pad on bottom of 56-pin VQFN IC package must be connected to GND. For 64-pin TQFP package there is no thermal pad.

6. Juno IC Configuration in the Production Application

6

In This Chapter

- Loading the NVRAM
- Analog Signal Calibration in the Production Application

Each Juno IC, before undertaking torque control, must be programmed with control parameter settings appropriate for the application that it will be used in. These control parameters include quantities such as PWM (Pulse Width Modulation) frequency, current gains, safety thresholds, and more.

Correct values for these parameters are most easily determined by PMD Corp.'s Pro-Motion software, specifically via the Axis Wizard setup sequence. The axis wizard steps the user through a series of set up and verification pages, finally resulting in control parameter settings tailored for that user application.

Once the control parameters are determined the user has two choices for how they can be loaded into the active control registers of the Juno IC when it is in the production PCB; they can be stored permanently into the Juno IC's internal NVRAM (non-volatile memory) and auto-loaded at power-up, or they can be loaded at each power-up by an on-board microprocessor connected to the Juno IC via its serial port.

Storing the NVRAM data into the Juno IC is discussed in the next section, Section 6.1, "Loading the NVRAM." Applications that load the control registers via an on-board microprocessor use specially formatted host commands sent over the serial port. For more information refer to the *Juno Velocity & Torque Control IC User Guide*.

6.1 Loading the NVRAM

6.1.1 NVRAM Programming via Juno DK IC Socket

The 64-pin TQFP package Juno DK includes an IC socket that can be used to program the NVRAM on 64-pin Juno ICs prior to soldering into the user's production PCB. Pro-Motion as well as a more compact programming executive available from PMD Corp. supports script files to program the Juno IC NVRAM. For more information on PMD Corp. script files refer to Section 7.5.1, "Host Command Script Files."

The 56-pin VQFN Juno IC DK does not have a socket and therefore cannot be used to program the NVRAM of production 56-pin VQFN Juno ICs.

6.1.2 NVRAM Programming Via 3-pin UART Cable

An alternate NVRAM programming approach is to execute the NVRAM download by communicating to the Juno IC after it is installed in the production PCB. This approach requires that each installed Juno IC have a 3-pin connector installed on the production board. A technician plugs into this connector and performs the NVRAM download. To be programmed the Juno IC must receive power, so this generally means the PCB power is turned on during this procedure.

To facilitate this approach PMD Corp. provides a dedicated USB to 3-pin UART programming cable (PMD Corp. Part # Cable-USB-3P) with each Juno DK. This programming cable plugs into the PC's USB port on one end and into a 1x3

3-pin 2 mm header component on the other. A representative PCB mounted header component is Samtec MTMM-103-04-x-S-150.

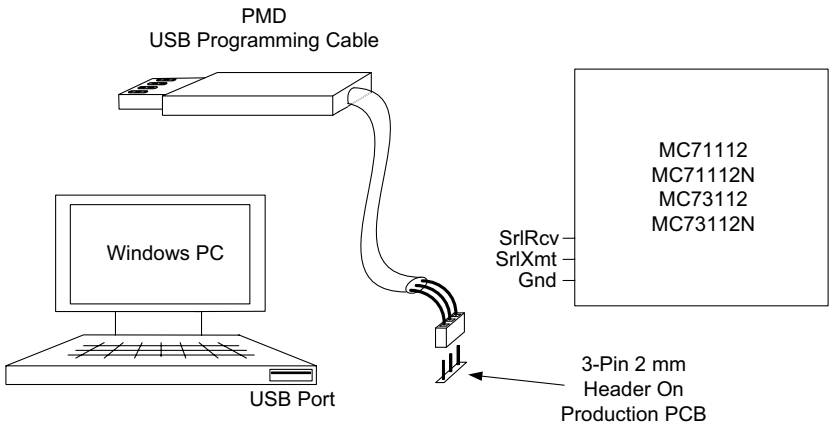


Figure 6-1: NVRAM Programming Via 3-pin UART Programming Cable

The table below shows the required wiring for the on-board connector if it is to be used with the PMD Corp. programming cable:

Connector Pin #	Pin Name	Juno Pin # (64-pin TQFP Package)	Juno Pin # (56-pin VQFN Package)
1	SrlXmt	27	24
2	SrlRcv	32	28
3	GND	28 (or other ground signal)	25

6.1.3 Purchasing Pre-Configured Parts

Some PMD Corp. distributors and sales outlets provide an NVRAM programming service for Juno ICs. Contact your PMD Corp. sales representative for availability, terms, and conditions.

6.2 Analog Signal Calibration in the Production Application

After integration into a PCB, it is recommended that the external analog signal processing circuitry that inputs to the Juno IC be calibrated. While some applications will not need these calibrations, for applications where the quietest, smoothest, and most accurate motion is desired, calibration of the analog inputs is recommended. The signals that can be calibrated for the Juno torque control ICs are *AnalogCmd* and *CurrentA-CurrentC*. For more information refer to Section 9.2.3, "Signal Processing."

When a microprocessor is on the user PCB, generally this microprocessor is used to send the serial host commands needed to calibrate the analog inputs as part of the power up sequence.

Another approach is to have the Juno IC execute the calibration procedure during its NVRAM-based initialization startup. This is done by embedding an initialization sequence that executes the calibration during the NVRAM startup at each power cycle. This approach can only be used when the startup condition of the PCB and connected motors is controllable. For example if the calibration occurs when the motors are still spinning, the calibration will not give accurate results.

A third approach that has the benefit of eliminating the need for calibration at each power cycle is to execute the calibration on the assembled PCB using a 3-pin UART programming cable. The derived calibration offsets are stored into NVRAM and recalled automatically thereafter by Juno at each power-up. PMD Corp. provides easy-to-use standalone Windows compatible executables for this function. For more information see Section 6.1.2, "NVRAM Programming Via 3-pin UART Cable."

PMD Corp.'s Pro-Motion software program provides a convenient set up facility for selecting NVRAM startup options. In addition, advanced users can directly edit Juno start up scripts using a text editor. Refer to Section 7.5.1, "Host Command Script Files" for more information.

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7. Functional Overview

7

In This Chapter

- Internal Block Diagram
- Signal Connections Overview
- Control Flow Overview
- Control Applications
- Host Commands

7.1 Internal Block Diagram

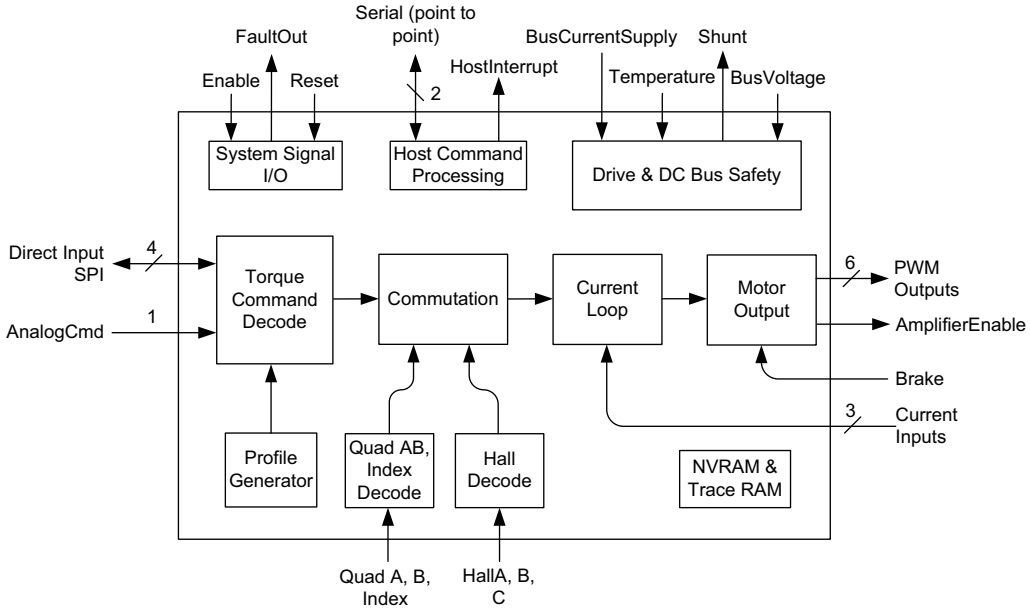

Figure 7-1: MC78113 Internal Block Diagram

Juno torque control ICs are single-axis devices for torque or voltage-mode control of three-phase brushless DC motors and DC Brush motors.

At power-up or reset, Juno checks for the presence of stored configuration commands in its NVRAM. If NVRAM is programmed, the stored configuration commands are read into the chip, providing parameter information that will be used during operation. If no initial configuration is stored in NVRAM, then default values are used and information will then be sent by serial from a host device such as a microprocessor.

Depending on how the control loop has been configured an external analog signal may serve as the torque command value, or an SPI (Serial Peripheral Interface) data stream may be used for this command value. Alternatively an internal profile generator commanded by a host microprocessor via the serial port or a direct set motor command register may be used to generate torque command values.

Current control is performed via direct input of analog signals representing the instantaneous current through the motor coils. These signals are typically derived from external dropping resistors or Hall sensors at the amplifier circuitry. This analog current information is then combined with the desired current for each phase to generate PWM signals.

To create a complete torque controller Juno is connected to switching amplifiers, typically MOSFET or IGBT-based. A programmable dead time function and other timing control parameters ensure that switch synchronization and control is optimal over the entire operating range of the driven motor.

A number of safety features are incorporated into the Juno ICs including shunt control, I^2t current limiting, brake signal input, DC bus overvoltage and undervoltage detect, overcurrent detect, and overtemperature detect.

7.2 Signal Connections Overview

Figure 7-2 shows an overview of the connections used with Juno family ICs.

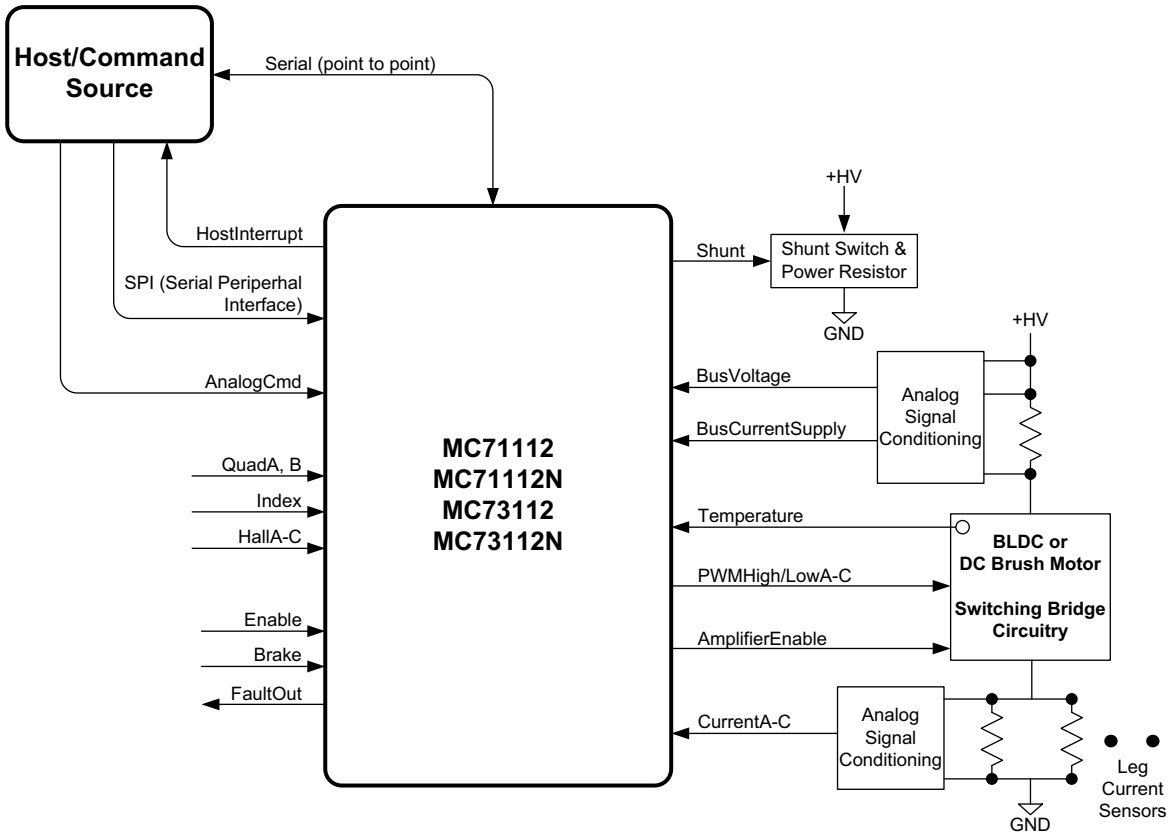

Figure 7-2: Juno Torque Control ICs

7.3 Control Flow Overview

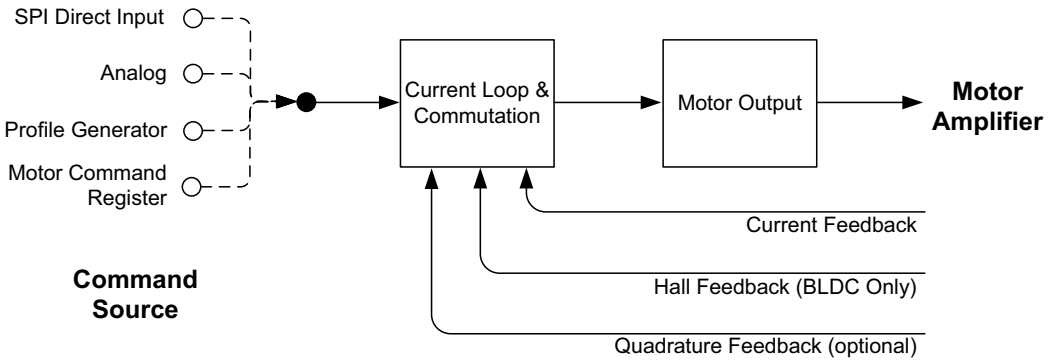

Figure 7-3: Juno Control Flow Overview

Figure 7-3 provides a control flow overview for the Juno torque control ICs. It shows how a final motor command is generated starting with the command source and ending with the motor output module that generates amplifier control signals.

The following table provides a brief description of the two control modules shown in the diagram:

Module Name	Function
Current Loop & Commutation	This module inputs the commanded current along with the actual current and uses a PI filter along with FOC (field oriented control) current control to generate motor voltage commands for each motor phase. For brushless DC motors this module also performs commutation and waveform generation.
Motor Output	This module inputs the motor phase commands and generates the appropriate electrical signals based on the selected electrical output format.

7.4 Control Applications

Typical Juno torque control applications are shown in the following sections.

7.4.1 Torque Control of Brushless DC and DC Brush Motors Using Analog Command

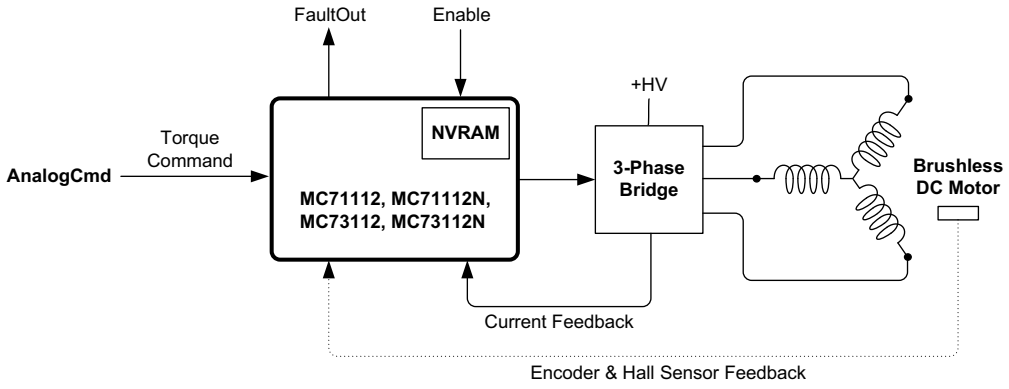

Figure 7-4: Analog Command Torque Control

Applications: General purpose amplifier, spindle control, centrifuge control, drug infusion, precision liquid pumping, turbine control.

In this configuration the Juno MC71112, MC71112N, MC73112, or MC73112N IC receives direct analog commands representing the instantaneous desired torque. For Brushless DC motors Hall sensors normally provide commutation feedback. If encoder signals are available however Halls are not required as long as the motor can move freely during startup (allowing PMD Corp.'s pulse phase initialization to be used). For DC Brush motors neither Hall sensor or encoder signals are used for torque control.

In the diagram above a Brushless DC motor is shown but similar torque control can be provided for DC Brush motors.

7.4.2 Torque Control of Brushless DC and DC Brush Motors Using SPI Command

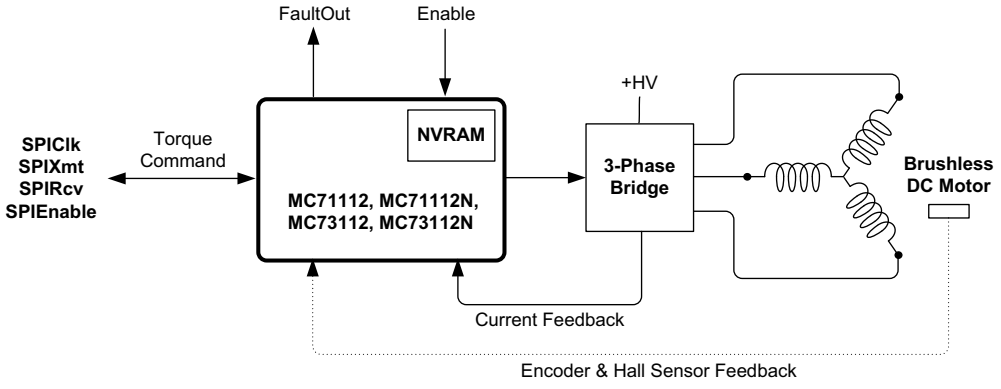

Figure 7-5: SPI Command Torque Control

Applications: General purpose amplifier, spindle control, centrifuge control, drug infusion, precision liquid pumping, turbine control.

In this configuration the Juno MC71112, MC71112N, MC73112, or MC73112N IC receives direct digital SPI (Serial Peripheral Interface) commands representing the instantaneous desired torque. For Brushless DC motors Hall sensors normally provide commutation feedback. If encoder signals are available however Halls are not required as long as the motor can move freely during startup (allowing PMD Corp.'s proprietary pulse phase initialization to be used). For DC Brush motors neither Hall signals nor encoder signals are used for torque control.

The above diagram shows a Brushless DC motor but similar torque control can be provided for DC Brush motors.

7.4.3 Torque Control of Brushless DC and DC Brush Motors Using Serial Host Command

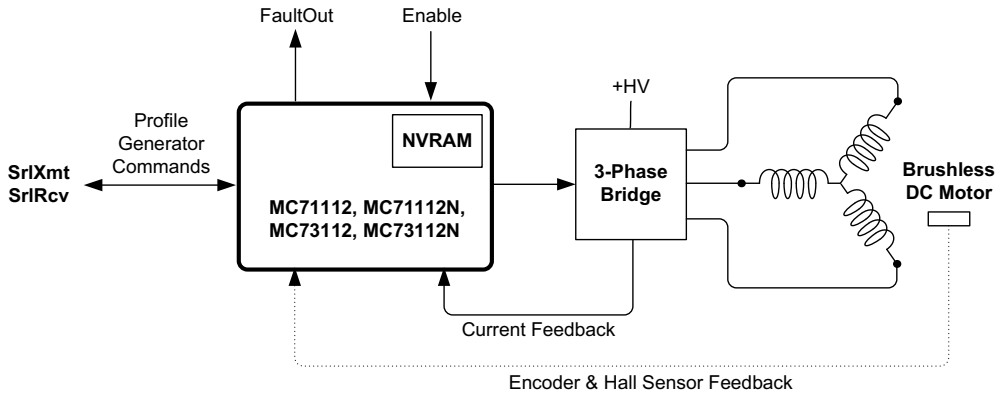

Figure 7-6: Serial Host Command Torque Control

Applications: Microprocessor controlled servo motor drive, programming of Juno IC NVRAM.

In this configuration a microprocessor or PC communicates via Juno's serial host command port to control the motor torque directly via the motor command resistor or via the profile generator. For Brushless DC motors Hall sensors normally provide commutation feedback. If encoder signals are available however Halls are not required as long as the motor can move freely during startup (allowing PMD Corp.'s proprietary pulse phase initialization to be used). For DC Brush motors neither Hall signals nor encoder signals are used for torque control.

Another use of this configuration is during set up to store the production configuration of the Juno IC into its NVRAM. For more information on NVRAM setup refer to Section 6.1, "Loading the NVRAM."

7.4.4 Torque Control Of Servo Motors with Magellan Motion Control IC

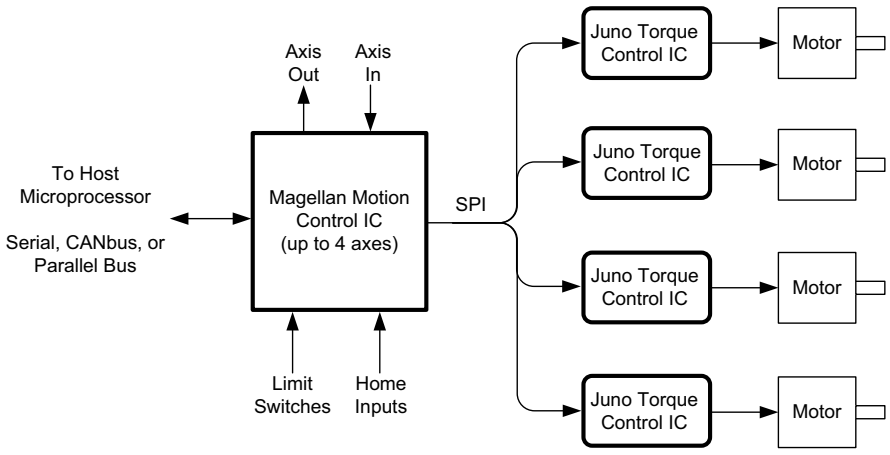

Figure 7-7: Torque Control With Magellan Motion Control IC

Applications: General purpose multi-axis motion control, laboratory automation, scientific instruments, XY stages, multi-dimensional contouring, semiconductor equipment.

PMD Corp.'s Magellan Motion Control ICs provide up to four axes of profile generation, position servo loop control, pulse & direction signal generation, and numerous other synchronization and control features. In this application one or more Juno ICs (one per motor axis) connect to the Magellan IC via SPI and provide high performance current control and motor amplifier management for Brushless DC or DC Brush motors.

7.4.5 PC-Based Torque Control Application Development

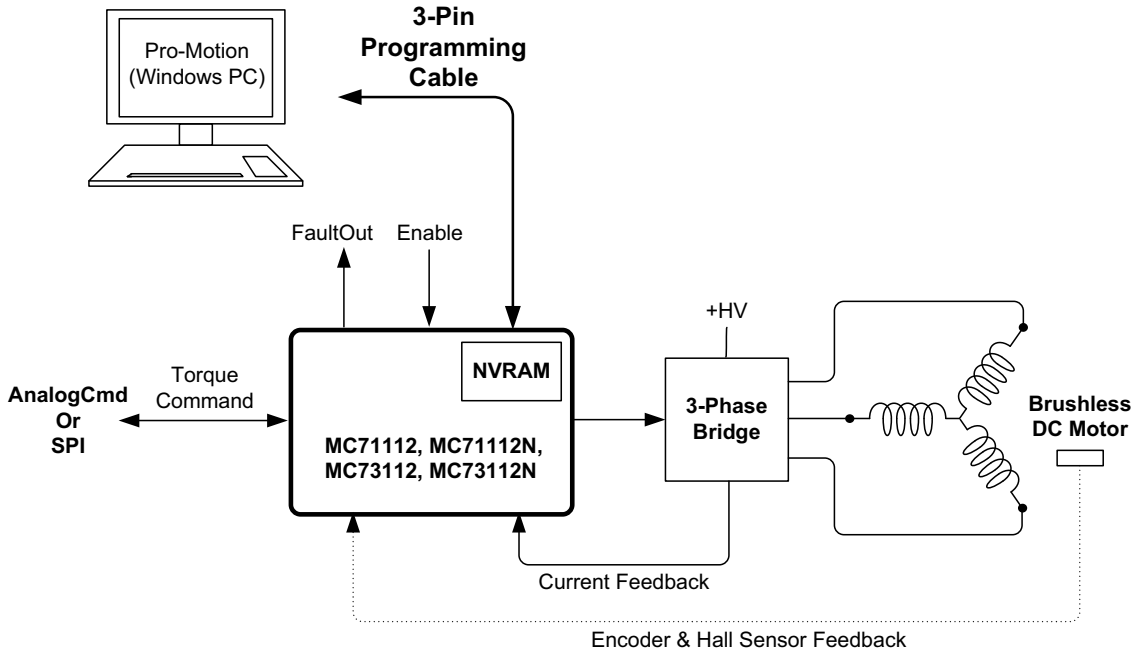

Figure 7-8: PC-Based Application Development Connections

Applications: Torque Control Application Development, programming of Juno IC NVRAM

In this configuration PMD Corp's Pro-Motion Windows-based software or a user-development application connects via a 3-pin programming cable (PMD P/N CABLE-USB-3P) to Juno's asynchronous serial port. The torque command source can be provided either by an ***AnalogCmd*** signal or SPI digital input. This configuration is also used for programming of the Juno's NVRAM.

All Juno DKs provide a serial connection for operation in this configuration. User-developed boards containing Juno ICs can utilize this configuration if they include a 3-pin connector in their PCB design. For more information refer to Section 6.1.2, "NVRAM Programming Via 3-pin UART Cable."

7.5 Host Commands

Juno ICs have more than 40 user programmable control parameters for tailoring its control to a specific application. Upon power-up these programmable settings are at their default values and are not yet tailored to a specific application.

Juno's serial port may be used to program these control parameters using what are known as host commands. Host commands are data packets that follow a particular format and protocol. Alternatively the NVRAM may be used to auto-load the control parameters upon power-up. The format of the stored NVRAM data closely resembles the serial host command packets.

Most host commands specify a single parameter but some specify two or even three. Parameters may be signed or unsigned integers, may be bit encoded, or may be a fixed code specifying one of a list of available values. Throughout this manual we will show the NVRAM script file mnemonics associated with Juno host commands in table form at the end of each chapter.

Below is an example of such a command mnemonic table showing the variable name, associated mnemonic code, and range of settable values:

Parameter	Host Command Mnemonic	Range & Description
PWM frequency	SetDrivePWM	Two parameter command, the first must be 3 and the second is a fixed code value and setting the PWM frequency to 20 kHz, 40 kHz, 80 kHz, or 120 kHz
Encoder to step ratio	SetEncoderToStepRatio	Two specified values, each have a range 1 to 32,767. The first parameter sets the number of encoder counts per motor rotation, the second specifies the number of microsteps per motor rotation

For a complete description of each command supported by Juno refer to the *Juno Velocity & Torque Control IC Programming Reference*. For general information on Juno host commands and usage, refer to the *Juno Velocity & Torque Control IC User Guide*.

7.5.1 Host Command Script Files

```
#ScriptVersion 1
:DESC "Motor 2 settings"
:CVER 1.3
SetDrivePWM 1 561
SetDrivePWM 2 0x80ff
SetDrivePWM 4 8
SetDrivePWM 5 2013
SetDrivePWM 6 2013
SetOutputMode 7
SetMotorCommand 0
SetSignalSense 0x0001
SetPhaseParameter 0 0
SetCurrentControlMode 1
SetFOC 512 680
ETC...
```

Figure 7-9: Sample Pro-Motion Script File

Juno ICs store NVRAM host commands in their native 'machine' packet format consisting of a series of hexadecimal numbers. Pro-Motion however can use a special text file format to store parameter settings. This file is known as a script file and an example is shown in Figure 7-9. Script files are convenient because they are human readable and editable.

Pro-Motion script files contain ASCII characters and terminate each line with a <CR><LF> sequence (carriage return and line feed). Each line of the script file contains a single complete command mnemonic. The apostrophe ' is used to indicate that the characters from the apostrophe to the end of the line are a comment.

Pro-Motion always inserts as the first entry "#ScriptVersion" indicating the script file version format that the file was stored in. This entry is not stored into the Juno IC but allows past and future versions of Pro-Motion to interpret the

script file correctly. Numbers default to decimal interpretation but can be forced for hexadecimal interpretation by preceding with "0x".

Script file lines that begin with a colon ":" record PSF (PMD Structured Data Format) identifiers such as the version #, user-provided content description, creation date, and other information. Users may edit these lines directly but should only do so if they are familiar with PSF.

Most users will not directly edit the script files and will instead rely on Pro-Motion to create the script file and store PSF configuration information. Pro-Motion has convenient features for exporting and importing the current Juno configuration to a script file, or loading or uploading previously stored data from the Juno IC's NVRAM.

7.5.2 Serial Port

The Juno torque control ICs provides a point to point (used with RS232) asynchronous serial interface. All of the Juno serial-related signals are digital TTL level signals.

The table below provides a summary of the signals used with serial communications:

Pin Name	64-Pin TQFP Pin#	56-Pin VQFN Pin#	Description
SrlRcv	32	28	Serial Receive inputs the serial data.
SrlXmt	27	24	Serial Transmit outputs the serial data.

By default Juno powers up at 56 Kbaud. This setting and other serial settings can be user programmed however.

7.5.2.1 Settable Parameters

Juno's serial port settings can be user programmed. This is shown in the table below:

Parameter	Host Command Mnemonic	Range & Description
Baud rate, parity, number of stop bits	SetSerialPortMode	Specified value is a single bit-encoded 16-bit word that encodes the desired baud rate, parity, and number of stop bits.

Juno serial communications must follow a specific format. For complete information on the **SetSerialPortMode** command as well as other commands in Juno's host command protocol, refer to the *Juno Velocity & Torque Control IC Programming Reference.*

8. Current Loop

In This Chapter

- Selecting the Command Source
- Current Limit
- Velocity Scalar
- Minimum Current Read Time
- Watchdog Timer
- Settable Parameters
- Signal Processing

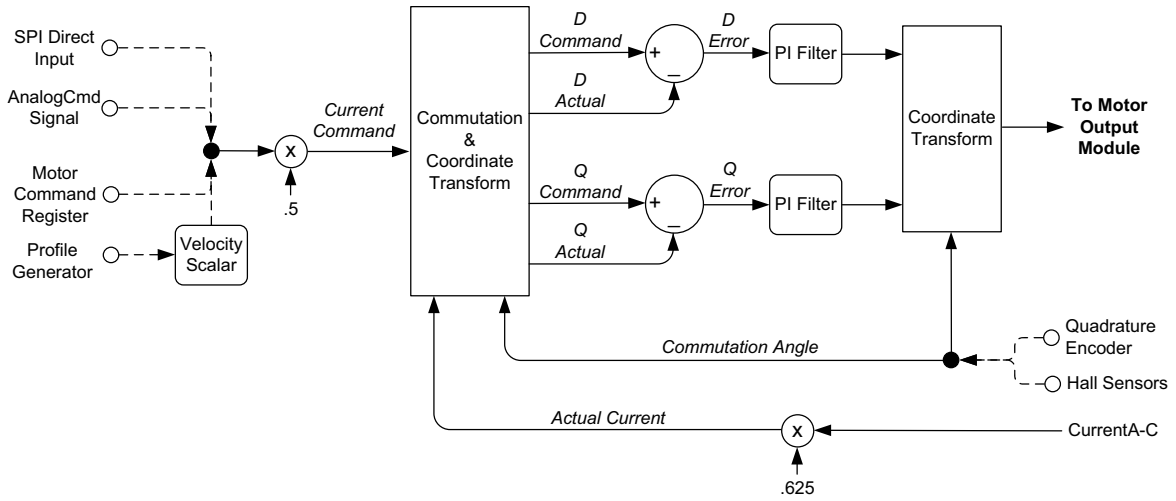

Figure 8-1: Current Loop & Commutation Control Flow

Figure 8-1 provides a summary of the control flow of Juno's current loop & commutation module. Current control is a technique used for DC Brush and Brushless DC motors for controlling the current (and therefore the torque) through each winding of the motor. By controlling the current, response times improve, motor efficiency is higher, and motion smoothness increases. Commutation is used with Brushless DC motors only, and utilizes information about the motor's rotor angle to drive the multiphase motor output.

The Juno digital current loop utilizes the desired current for each motor winding along with the actual measured current which is input by direct analog signal input into the Juno IC. For Brushless DC motors these signals are then algorithmically converted from a non-rotating coordinate frame to a rotating frame. The converted result is referred to as the D phase current and the Q phase current. The commanded and actual D and Q phase currents are then subtracted and an error generated, which in turn is passed through a PI (proportional, integral) filter.

Finally the output of the D and Q phase PI filters are converted back into the 3-phase non-rotating reference frame and output as motor commands for each phase of the motor. This commutation and current control technique is known as Field Oriented Control (FOC), and requires information about the motor rotor's phase angle to generate correctly phase output signals. The large majority of applications will use FOC for Brushless DC motor control. FOC usually provides the highest top speeds and more energy efficient operation of the motor.

A second option for Brushless DC motors is available however known as third leg floating. Third leg floating can sometimes provide a higher top speed than FOC. It uses a different method than FOC in that only two of three legs are driven at any instant with the third, non-driven leg, left floating. Third leg floating control mode may be considered with Hall-commutated Brushless DC motors.

The choice of field oriented control or third leg floating is user programmable. For more information on Brushless DC motor commutation and other settings see Chapter 12, *Brushless DC Motor Control*.

For DC Brush motors the current loop method is fixed and does not need to be set by the user. In addition, because they are single phase devices, the current loop does not require information about the motor's rotor angle.

8.1 Selecting the Command Source

The current & commutation module allows one of four command sources to be selected. The direct input SPI port or the ***AnalogCmd*** signal can be used to specify a torque command from external circuitry. Both of these externally input command values are signed 16 bit quantities representing the commanded current (torque) value.

Alternatively, the profile generator can be selected as the current loop command source. This may be useful if a ramped current command is desired. The profile generator's 32 bit velocity register contains the instantaneous torque command after being scaled by a user-specified velocity scalar value.

Finally, the current loop supports a signed 16-bit register set via host command. This choice of command source is sometimes useful for testing or calibration during system setup. To select this Motor Command register as the command source the command source enabled bit of the operating mode register must be disabled.

8.2 Current Limit

Juno provides a settable limit to the magnitude of the commanded current via the register called Currentlimit. The current limit functions by capping the magnitude of the commanded current to the specified value. For example if the specified current limit is 10,000 an incoming command of +12,345 would be set to +10,000 and an incoming command of -12,345 would be set to -10,000.

Limiting the commanded current is a useful safety feature for insuring that the physical or electrical limitations of the actual system are not exceeded.

Current limit is an unsigned 16 bit number with a range 0 - to 32,767. The default value is 32,767 meaning no limiting is applied.

The current limit only limits the commanded current. Whether or not the motor current is actually limited to this threshold is a function of whether or not the current loop is functioning properly.

8.3 Velocity Scalar

The velocity scalar register, called Kvel, is an unsigned 32 bit number with 1/65,536 scaling meaning that a scale factor of 1.0 (unity scaling) is expressed with a value of 65,536.

When used with the current loop Kvel is most commonly left at the default unity value of 65,536. However there may be special circumstances where a non-unity scale factor is desired.

8.4 Minimum Current Read Time

When controlling Brushless DC motors with FOC (field oriented control) current control mode Juno requires a minimum current read time parameter to insure a valid leg current reading when two of the three phases have a saturated PWM signal.

The minimum current read time is dependant on the external analog current signal processing circuitry. Typical values are determined by taking the electrical time constant of this external current input circuitry and multiplying by 3 to 5.

The Juno default value for minimum current read time is set to be maximally safe but is not optimum for all analog processing hardware. For proper amplifier function these values must be set with values appropriate for the current sensor circuitry being used.

8.5 Watchdog Timer

Juno provides a facility for detecting when external commands which arrive on a regular basis unexpectedly stop. The ability to detect this condition, known as a watchdog timer, is useful for safely shutting down an axis.

The watchdog feature functions with the profile generator, the SPI direct input command, and the motor command register command sources. It does not function when *AnalogCmd* is selected as the command source.

In each case the user selects a watchdog countdown time in units of cycles. The default value for the watchdog countdown timer is 0 which indicates no watchdog function is active. If a lack of command activity occurs for more than the watchdog countdown period a watchdog error occurs, resulting in the drive exception flag of the Event Status register being set. For more information see Section 11.1.1, "Event Status Register."

Juno can be programmed to take various actions when a watchdog timeout occurs such as disabling the motor output. The mechanism to program and process these functions is called event handling and described in detail in Section 11.3, "Event Action Processing."

8.6 Settable Parameters

To control the current loop in FOC mode three parameters are specified for both the D loop and the Q loop; Kp, Ki, and Ilimit. Two of these are gain factors for the PI (proportional, integral) controller, one is a limit for the integral contribution. Determining correct Kp, Ki, and Ilimit parameters for the current loop controller gains can be done in a number of ways but the easiest is to utilize the auto-tuning facility provided within PMD Corp.'s Pro-Motion software package. If a DC Brush motor is used or if the current loop is set to third leg floating then only the Q loop Kp, Ki, and Ilimit parameters are set.

By default the current loop module is disabled. To enable the current loop the user must enable the corresponding flag of the Operating Mode register.

The table below summarizes the settable parameters for the Juno current loop.

Parameter	Host Command Mnemonic	Range & Description
Current control mode	SetCurrentControlMode	Specified value is a fixed code selecting FOC or third leg floating current control mode.

Parameter	Host Command Mnemonic	Range & Description
Operating mode register	SetOperatingMode	Specified value is a bit-oriented mask determining the state of the command source, current loop, and motor output enable/disable flags.
Select command Source	SetDriveCommandMode	Specified value is a fixed code selecting either AnalogCmd, SPI, or the profile generator as the command source.
Kp	SetFOC	Three parameter command, the first specifies whether the provided gain applies to the D loop, the Q loop, or both. The second must be 0, and the third has a range of 0 to 32,767 and specifies the proportional gain value.
Ki	SetFOC	Three parameter command, the first specifies whether the provided gain applies to the D loop, the Q loop, or both. The second must be 1, and the third has a range of 0 to 32,767 and specifies the integral gain value.
Ilimit	SetFOC	Three parameter command, the first specifies whether the provided gain applies to the D loop, the Q loop, or both. The second must be 2, and the third has a range of 0 to 32,767 and specifies the integrator sum limit.
Current limit	SetCurrentLimit	Specified value has a range of 0 to 32,767 and specifies the maximum allowed incoming current magnitude.
Direct set current	SetMotorCommand	Specified value has a range of -32,767 to 32,767 and specifies a command current value.
Velocity scalar	SetLoop	Two parameter command, the first must be 64. The second has a range of 0 to 2,147,483,647 and specifies the velocity scalar.
Minimum current read time	SetDrivePWM	Two parameter command, the first must be 6. The second has a range of 0 to 32,767 and specifies the minimum current read time in units of nSecs.
Watchdog count-down time	SetDriveFaultParameter	Two parameter command, the first must be 3. The second has a range of 0 to 32,767 and has units of cycles.
Calibrate analog signals	CalibrateAnalog	Specified value is a fixed code selecting either all leg current signals or the AnalogCmd signal for calibration.
Set calibration values	SetAnalogCalibration	Two parameter command, the first is a fixed code selecting either the CurrentA, CurrentB, CurrentC, CurrentD, or AnalogCmd signal offset. The second has a range of -32,767 to 32, 767 and specifies the offset value.

For more information on Juno host commands refer to the *Juno Velocity & Torque Control IC Programming Reference.*

To activate current loop processing the current loop flag of the Operating Mode register must be enabled.

8.7 Signal Processing

The following table shows the signals that are used to input the motor coil current measurement:

Pin Name	64-Pin TQFP Pin#	56-Pin VQFN Pin#	Description
CurrentA	14	12	Measured Current for Leg current input A
CurrentB	19	16	Measured Current for Leg current input B
CurrentC	12	10	Measured Current for Leg current input C

Signals representing the instantaneously measured current of each coil leg are input in a voltage range of 0.0 to 3.3V with a voltage of 0.0 representing the largest possible negative measured current, a voltage of 1.65V representing a measured current of 0, and a voltage of 3.3V representing the largest possible positive measured current.

Current sensors consist of sense resistors, as shown in Figure 8-2, or linear Hall sensors. If sense resistors are used ground-referenced operational amplifiers may be used.

Current inputs are sampled by Juno at a rate of 20 kHz and should be filtered to minimize noise. A low pass filter with a rolloff of 200 kHz - 1,000 kHz is recommended, with 500 kHz being a typical value for most applications. Junos operating at 20 kHz PWM frequency in high noise environments may consider a rolloff on the lower end of the frequency range. Juno's operating with PWM frequencies of 40 kHz, 80 kHz, or 120 kHz operating in low or normal noise environments may consider a rolloff on the higher end of this range.

8.7.1 Typical Current Signal Processing Circuitry

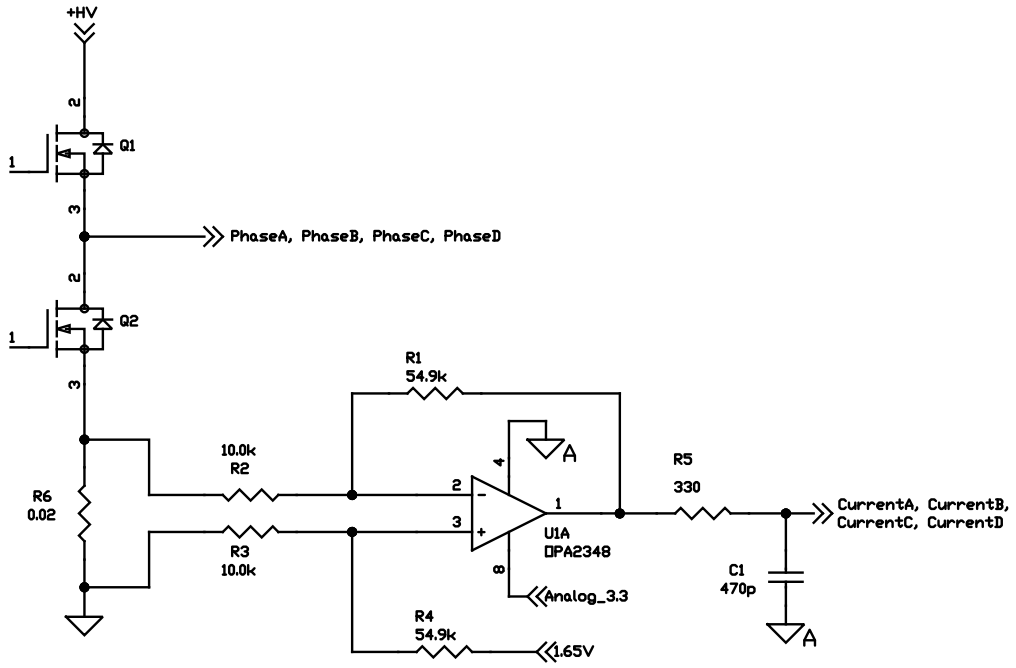

Figure 8-2: Typical Current Signal Processing Circuitry

Figure 8-2 shows a typical leg sensing processing circuit for the current signal inputs. Q1 and Q2 are the half-bridges for one motor phase, and R6 is the current sensing resistor. U1A with R1~R4 is a differential amplifier for signal conditioning; it is capable of measuring bidirectional current and has an output of 1.65V at zero current. R5 and C1 form a low pass filter, and they should be placed close to the pins on the Juno IC. R1~R4 should be 1% or higher grade. The power rating of R6 should match the winding current with 50% power margin recommended.

See Section 15.9, "PWM High/Low Motor Drive With Leg Current Sensing/Control" for complete example schematics for various Juno-based amplifier designs with current control.

Current control only functions when the PWM output mode is set to PWM High/Low. For information on motor output modes, refer to Chapter 9, *Motor Output*

8.7.2 Current Signal Scaling

The value of the user's external sense resistors and analog conditioning circuitry determine the overall controllable current range of the amplifier. The overall current sense range should be 25% to 50% above the largest expected peak current. The user commandable current range is 80% of the current sense range.

Example

A Brushless DC application will require a peak current in each phase of 7.5 amps. What is an appropriate scaling for the external current sense circuiting and what is the numerical value to command a current of 4.75 amps?

The total current sense is selected as +/- 10.0 amps, which gives a commandable range of +/- 8.0 amps (80% of the total current sense range). A sense resistor and op amp are used to generate +/- 1.65 volts for the desired current range of +/- 10 amps, presenting a voltage of 0.0V for a reading of -10.0A, 1.65Vfor 0.0A, and 3.3V for +10.0A at the *CurrentA-C* pins.

To determine the numerical value for the user specified current command we multiply by 1/ .8 reflecting the 80% scaling within Juno's current loop. So given a desired current in amps, in this example, the command numerical value is value = I * 1.25 * 32,767 / 10.0A and conversely, given a commanded numerical value the equivalent commanded current in amps is I = value * 10.0A * .80 / 32,767. Plugging in the desired command of 4.75 A, the numerical command value is 4.75 A * 1.25 * 32,767/10.0 A = 19,455.

Note that this counts to amps conversion constant can be more simply expressed as amps = .24415 mA / count or count = 4,096 / amp.

8.7.3 Current Signal Calibration

To improve efficiency and motion smoothness it is important that the leg current inputs on signals *CurrentA-C* represent the actual current value as accurately as possible.

To facilitate this Juno provides the ability to internally zero-out external analog input offsets that may exist while the motor coils are not being driven by the amplifier and the motor is not moving. This calibration sequence will automatically measure and set the offsets so that the leg current analog inputs are zeroed out. Because a number of samples are taken and averaged, 100 mSec should be allowed for this operation to complete.

Analog offsets, unless explicitly stored into NVRAM, will not be retained after a reset or power cycle. For more information on NVRAM configuration storage see Section 6.1, "Loading the NVRAM." For more information on host commands related to initiating, reading, and writing calibration offsets refer to the *Juno Velocity & Torque Control IC Programming Reference*.

Offset calibration of the analog CurrentA-C signals (if used) is recommended for best motion performance.

8.7.4 SPI Signal Interfacing

The table below provides a summary of the SPI related signals:

Pin Name	64-Pin TQFP Pin#	56-Pin VQFN Pin#	Description and when used
SPIRcv	36	31	SPIRcv inputs synchronous serial data for the SPI bus
SPIXmt	34	30	SPIXmt transmits synchronous serial data for the SPI bus

SPIClock	33	29	SPIClock inputs the clock signal used with synchronous serial transfer on the SPI bus
SPIEnable	44	39	SPIEnable inputs an enable for SPI bus communications

For electrical timing information for SPI bus operation see Section 3.2.2, "SPI."

The only SPI port operation supported by the Juno torque control ICs is a write by the external circuitry of a 16-bit torque command data word.

The write format is shown in Figure 8-3. The external circuitry serves as the SPI master generating the clock and the enable and transmitting the 16-bit data word data to Juno.

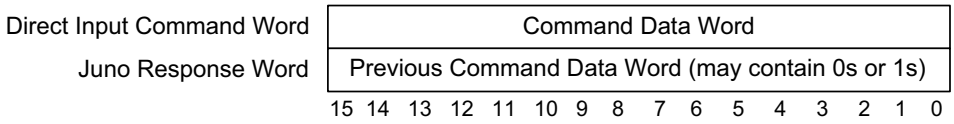

Figure 8-3: Direct Input SPI Format

The word returned by Juno is the previous command word received. It is recommended, but not required, that the external circuitry read this returned word and confirm that it matches the previously transmitted word.

8.7.5 AnalogCmd

Juno torque control ICs support input of an *AnalogCmd* direct input signal to provide a bi-polar torque command for the motor or actuator being controlled.

The table below shows the *AnalogCmd* signal.

Pin Name	64-Pin TQFP Pin#	56-Pin VQFN Pin#	Description
AnalogCmd	18	18	Analog torque command input

The *AnalogCmd* input range is 0.0V to 3.3V with the maximum positive command represented with a value of 3.3V, the maximum negative command having a value 0.0V, and a command value of 0 having a value of 1.65V.

On-board circuitry that directly outputs an analog signal in a compatible format may directly connect to the Juno input pin. External connections via cable require on-board signal conditioning to insure proper scaling and filtering.

The *AnalogCmd* input is sampled by the Juno at a rate of 20kHz and therefore a low pass filter with a rolloff at 50kHz - 200kHz is recommended.

8.7.5.1 Typical AnalogCmd Processing Circuitry

Figure 8-4: AnalogCmd Circuitry

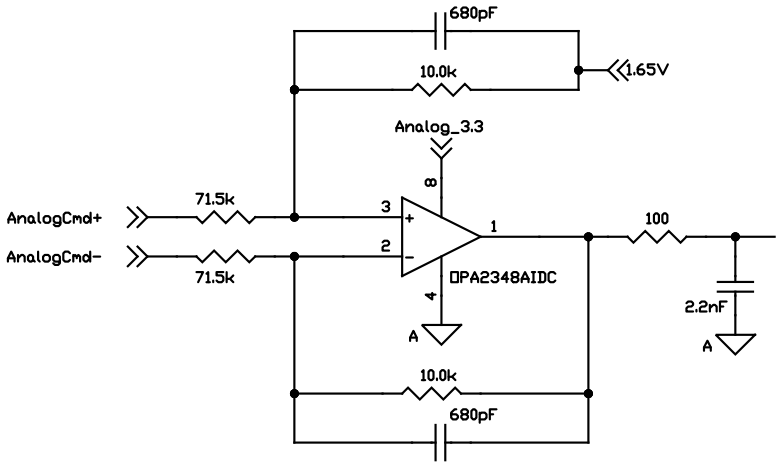

Figure 8-4 shows a typical circuit for processing a +/-10V differential input command signal. The output has an offset of 1.65V corresponding to a zero command. The bandwidth of this circuit is 23.4kHz. The 100ohm resistor and 2.2nF capacitor should be placed close to the *AnalogCmd* input pin of Juno. All resistors used should be 1% or higher grade. All capacitors should be X7R or higher grade.

8.7.5.2 AnalogCmd Scaling

The value of the analog command and downstream analog conditioning circuitry determine the overall torque command range that can be specified. Internally, Juno's torque command register is a signed number with a range from -32,768 to 32,767.

Example

A user's circuit board inputs a +/-10V analog torque command signal to drive the current controller in the example in Section 8.7.2, "Current Signal Scaling." What torque is commanded when a voltage of -7.0V is applied to the +/-10V input circuitry?

Analog processing circuitry converts a +/- 10V signal to the full scale of the 0 to 3.3V input range of the *AnalogCmd* input signal. An incoming voltage of -7.0V is received, representing a request for 70% of available maximum torque in the negative direction. Using $V_{AnalogCmd}$ = 1.65V + Vin * 3.3 / 20 and plugging in Vin = 7.0 V, this incoming signal results in a voltage of 0.495V at Juno's *AnalogCmd* pin which results in numerical command value of -22,937.

We convert this numerical value to commanded amps using the scaling determined from the example in Section 8.7.2, "Current Signal Scaling" of .24415 mA/count. This gives I = -22,937 * .24415 mA/count = -5.6A.

8.7.5.3 AnalogCmd Signal Calibration

Similar to the *CurrentA-C* analog signals, for best performance the *AnalogCmd* signal should be calibrated. See Section 8.7.3, "Current Signal Calibration" for information on calibrating analog input signals.

9. Motor Output

In This Chapter

- PWM High/Low Motor Output Mode
- Sign/Magnitude PWM Output Mode
- AmplifierEnable
- Brake

The purpose of the motor output module is to generate precisely synchronized PWM (Pulse Width Modulation) signals for use by external switching amplifier circuitry.

Juno ICs provide two different PWM motor output methods, PWM High/Low, and Sign/Magnitude PWM. The switching control mode that is used when the current control facility is utilized is PWM High/Low mode. Sign/Magnitude PWM is typically used with single-IC amplifiers or with bridges that directly input those control interfaces.

To minimize the chance of unexpected motor movement during startup, by default the motor output module is disabled. To enable motor output the user must enable the corresponding flag of the Operating Mode register.

> To activate motor output the motor output flag of the Operating Mode register must be enabled.

9.1 PWM High/Low Motor Output Mode

The Juno torque control ICs can control high-efficiency MOSFET or IGBT power stages with individual high/low switch input control. DC Brush motors are driven in an H-Bridge configuration consisting of 4 switches, while Brushless DC motors are driven in a triple half-bridge configuration consisting of 6 switches.

In PWM High/Low mode each signal carries a variable duty cycle PWM signal. A zero desired motor command results in the high side and low side being active for the same amount of time. Positive motor commands are encoded as a high-side duty cycle greater than 50%, and negative motor commands are encoded as a duty cycle less than 50%. This is shown in Figure 9-1.

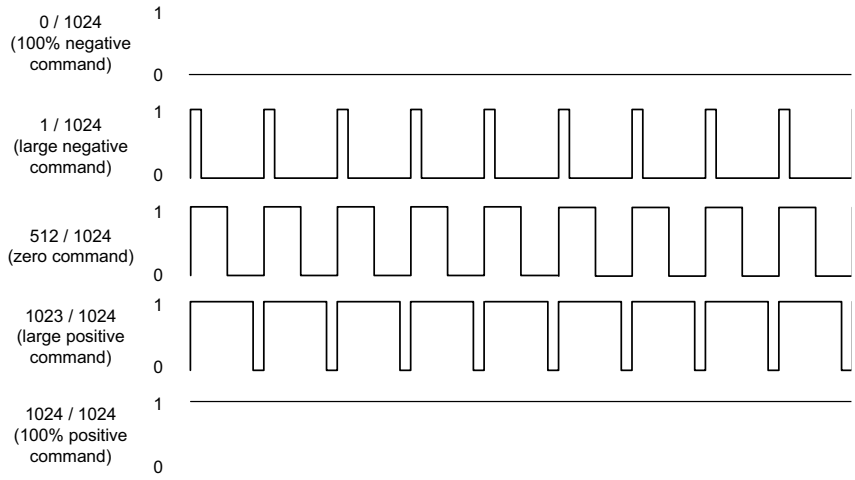

Figure 9-1: PWM High/Low Encoding

In PWM High/Low mode two output pins are used per motor or per motor phase, allowing separate high-side/low-side control of each bridge switch. In this scheme, as Figure 9-2 shows, the high side output and the low side output are never active at the same time, and there is generally a period of time when neither output is active. This period of time is called the dead time, and provides a shoot through protection function for MOSFET or IGBT switches.

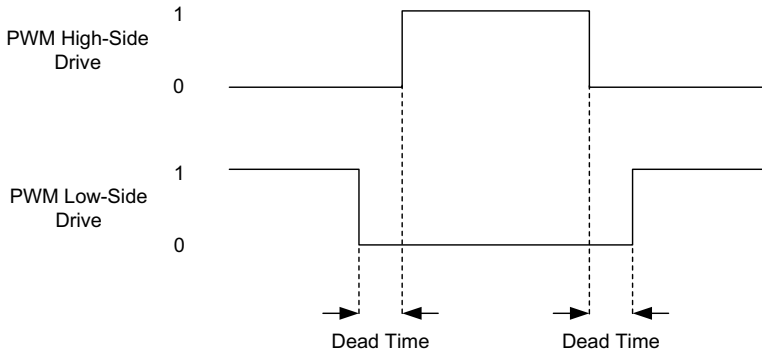

Figure 9-2: PWM High/Low Signal Generation

The dead time is specified in nSecs. The correct value can generally be determined from the MOSFET or IGBT IC manufacturer's data sheet, or you can call PMD Corp. technical support if you have questions.

In addition to dead time, some high side switch drive circuitry requires a minimum amount of off time to allow the charge pump circuitry to refresh. This parameter is known as the refresh time and has units of nSecs. The related parameter of refresh time period, which is the time interval between these off time refreshes has units of current loop cycles.

It is also possible to control the maximum allowed PWM duty cycle. This may be useful to limit the effective voltage presented to the motor windings, or to provide some other needed off-time for the switching amplifier circuitry.

The Juno torque control IC default values for dead time, refresh time, and refresh period are set to be maximally safe but are not appropriate to drive typical switching hardware. For proper amplifier function these values must be set with values appropriate for the connected switching circuitry.

9.1.1 PWM High/Low Brushless DC Motor Drive

Figure 9-3 shows the typical amplifier stage arrangement when a MC73112 IC or MC73112N IC is used in PWM High/Low mode.

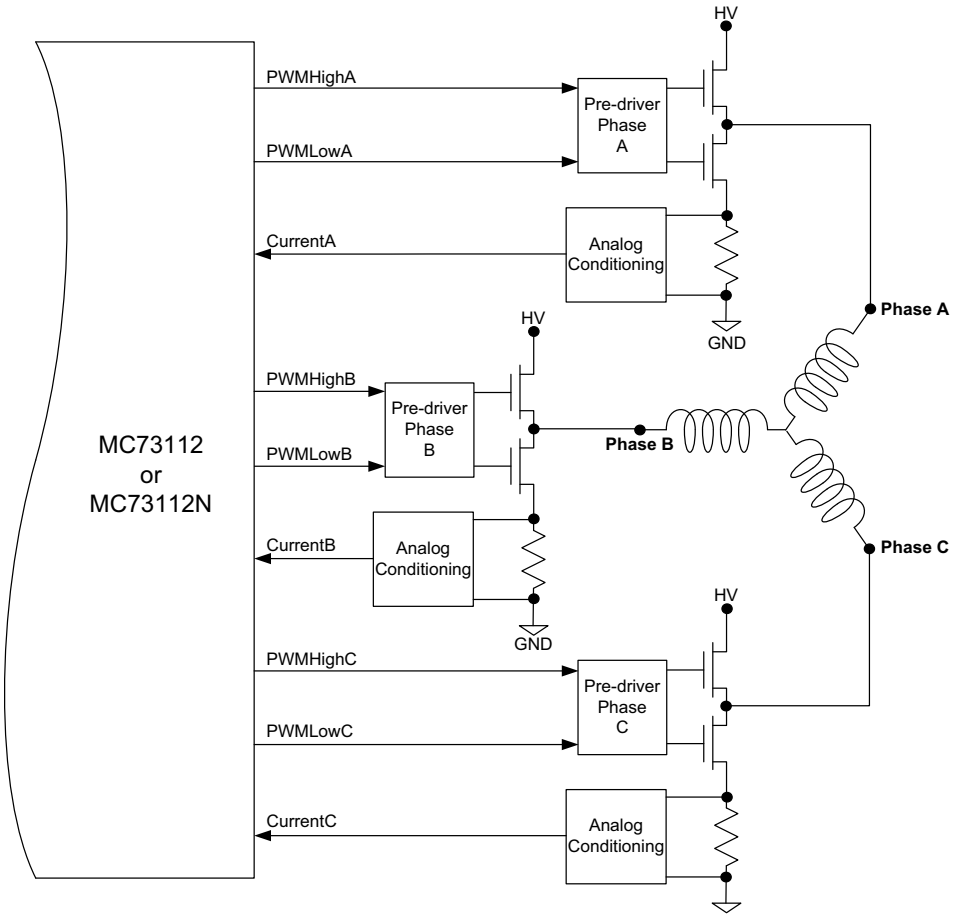

Figure 9-3: Brushless DC Motor Bridge Configuration

As shown in the table below six PWM output signals and, if used, three analog feedback signals for current control interface between the Juno IC and the switching amplifier circuitry.

Signal	64-Pin TQFP Pin #	56-Pin VQFN Pin #	Description
PWMHighA	56	49	Digital high side drive output for motor phase A
PWMLowA	55	48	Digital low side drive output for motor phase A
PWMHighB	54	47	Digital high side drive output for motor phase B
PWMLowB	53	46	Digital low side drive output for motor phase B
PWMHighC	51	45	Digital high side drive output for motor phase C
PWMLowC	50	44	Digital low side drive output for motor phase C
CurrentA	14	12	Analog input containing the current flow through the low side of the switching bridge for phase A.
CurrentB	19	16	Analog input containing the current flow through the low side of the switching bridge for phase B.
CurrentC	12	10	Analog input containing the current flow through the low side of the switching bridge for phase C.

9.1.2 PWM High/Low DC Brush Motor Drive

Figure 9-4 shows the typical amplifier stage arrangement when a MC71112 IC or MC71112N IC is used in PWM High/Low mode.

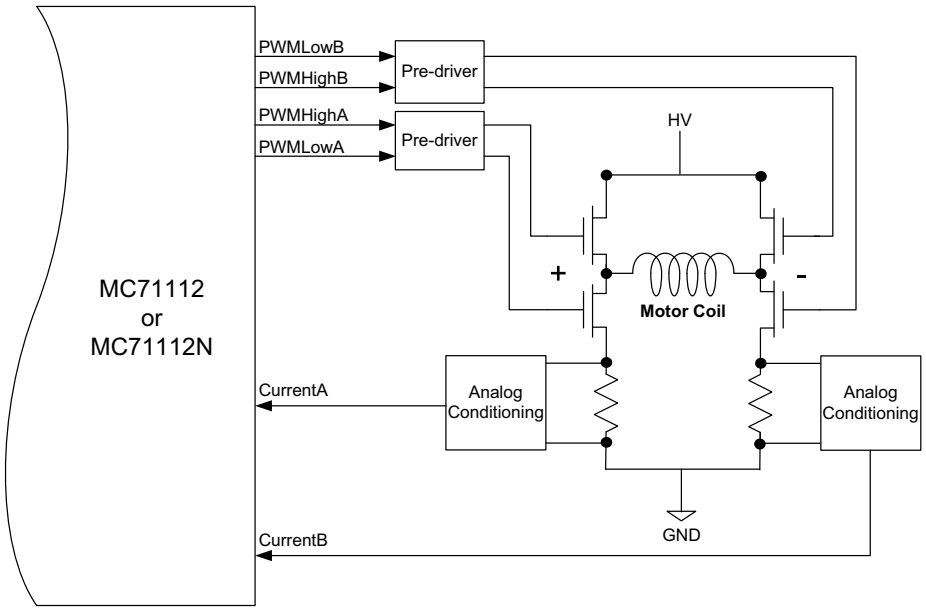

Figure 9-4: DC Brush Motor Bridge Configuration

As shown in the table four PWM output signals and, if used, two analog feedback signals for current control interface between the Juno IC and the switching amplifier circuitry.

Signal	64-Pin TQFP Pin #	56-Pin VQFN Pin #	Description
PWMHighA	56	49	Digital high side drive output for the positive coil terminal
PWMLowA	55	48	Digital low side drive output for the positive coil terminal
PWMHighB	54	47	Digital high side drive output for the negative coil terminal
PWMLowB	53	46	Digital low side drive output for the negative coil terminal
CurrentA	14	12	Analog input containing the current flow through the positive leg of the bridge
CurrentB	19	16	Analog input containing the current flow through the negative leg of the bridge

9.1.3 Low Pass PWM Signal Filtering

Some integrated amplifier ICs expect an analog command input. This can be accomplished by low pass filtering the PWM output signal thereby generating an analog signal. Depending on the input voltage required, additional analog processing circuitry may be needed. Note also that depending on the amplifier command format expected, low pass filtering of the Sign/Magnitude PWM signal may be preferred versus the PWM high/low format signal.

As was the case for interconnection to single-input bridges, when analog input integrated bridges are used, current control, if desired, must be provided by the external amplifier.

9.1.4 Settable Parameters

There are a number of Juno IC parameters which are used to set up or control the switching amplifier circuitry when the motor output mode is set to PWM High/Low.

The following table shows these amplifier-related control parameters:

Parameter	Host Command Mnemonic	Range & Description
Operating mode register	SetOperatingMode	Specified value is a bit-oriented mask determining the state of the command source, current loop, and motor output enable/disable flags
PWM switching frequency	SetDrivePWM	Two parameter command, the first must be 3 and the second is a fixed code value setting the PWM frequency to either 20, 40, 80, or 120 kHz.
PWM dead time	SetDrivePWM	Two parameter command, the first must be 1 and the second has a range of 0 to 16,383 and determines the dead time in nSecs.
PWM refresh time	SetDrivePWM	Two parameter command, the first must be 5 and the second has a range of 0 to 32,767 and determines the refresh time in nSecs.
PWM refresh period	SetDrivePWM	Two parameter command, the first must be 4 and the second has a range of 1 to 32,767 and determines the refresh period in Juno cycles.
PWM limit	SetDrivePWM	Two parameter command, the first must be 0 and the second has a range of 0 to 16,384 and determine the maximum allowed PWM duty cycle in units of 16,384/163.84 percent.

In addition to the above parameters it may be useful to change the default level sense of the PWM digital output signals. For more information refer to Section 11.1.5, "Signal Status Register."

9.2 Sign/Magnitude PWM Output Mode

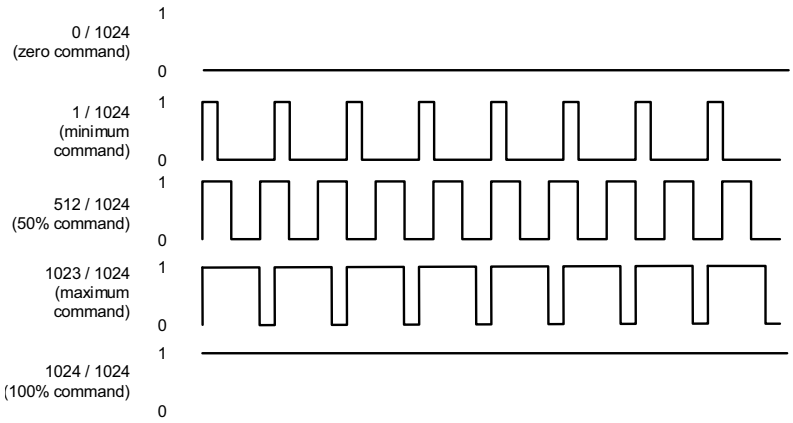

Figure 9-5: Sign/ Magnitude PWM Encoding

In Sign/Magnitude PWM mode two pins are used to output the motor command information. One pin carries the PWM magnitude, which ranges from 0 to 100% as shown in Figure 9-5. A high signal on this pin means the motor

coil should be driven with voltage. A second pin outputs the sign of the motor command by going high for positive sign, and low for negative.

PWM sign/magnitude control with Juno torque control ICs is only used with DC Brush motors. PWM sign/magnitude is not used with Brushless DC motors.

9.2.1 Sign/Magnitude PWM DC Brush

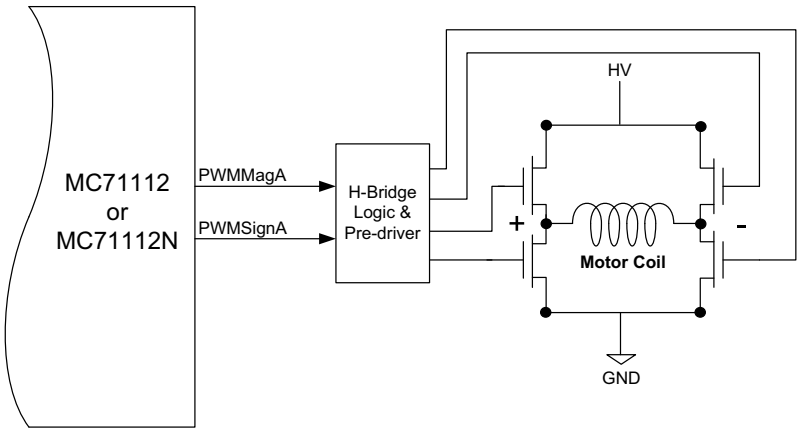

Figure 9-6: DC Brush PWM Sign/ Magnitude Bridge Configuration

Figure 9-6 shows a typical connection for a DC Brush motor when Sign/Magnitude PWM motor output mode is used. Note that in this mode the Juno IC does not provide current control, and therefore if current control is desired this capability must be provided by the amplifier bridge's circuitry.

9.2.2 Settable Parameters

The following table shows these amplifier-related control parameters when the motor output mode is PWM Sign/Magnitude:

Parameter	Host Command Mnemonic	Range & Description
Operating mode register	SetOperatingMode	Specified value is a bit-oriented mask determining the state of the command source, current loop, and motor output enable/disable flags
PWM switching frequency	SetDrivePWM	Two parameter command, the first must be 3 and the second is a fixed code value sets the PWM frequency to either 20, 40, 80, or 120 kHz.
PWM refresh period	SetDrivePWM	Two parameter command, the first must be 4 and the second has a range of 1 to 32,767 and determines the refresh period in Juno cycles. When PWM sign/magnitude mode is used the refresh period must be set to zero.
PWM limit	SetDrivePWM	Two parameter command, the first must be 0 and the second has a range of 0 to 16,384 and determine the maximum allowed PWM duty cycle in units of 16,384/163.84 percent.

In addition to the above parameters it may be useful to change the default level sense of the PWM digital output signals. For more information refer to Section 11.1.5, "Signal Status Register."

9.2.3 Signal Processing

As shown in the table below one PWM magnitude and one PWM sign signal are output to interface between the Juno IC and the amplifier circuitry:

Signal	64-Pin TQFP Pin #	56-Pin VQFN Pin #	Description
PWMMagA	56	49	Digital PWM magnitude output for the H-bridge switching amplifier
PWMSignA	55	48	Digital sign output for the H-bridge switching amplifier

For examples of PWM signal magnitude amplifiers above see Chapter 15, *Application Notes*.

9.3 AmplifierEnable

Whether the motor output mode is set to PWM High/Low or Sign/Magnitude PWM, the Juno IC provides an ***AmplifierEnable*** signal output that indicates whether the external amplifier circuitry should be active or not. While not all external amplifiers will require or provide such an input control, this signal is useful for general safety purposes, as well as to simplify the task of ensuring startup without jogging the motor after power-up.

The output of this signal is affected by whether the motor output module is enabled and whether the brake function is active. By default the motor output module is disabled and must be enabled by the user via serial host command or NVRAM initialization command. During operations the motor output may become disabled by safety related event processing. For more information on event processing refer to Section 11.3, "Event Action Processing."

If either the motor output module is enabled or if the brake function is active than the ***AmplifierEnable*** signal is active. If both the motor output module is disabled and the brake function is inactive than the ***AmplifierEnable*** signal is inactive.

9.4 Brake

The Juno IC's ***Brake*** signal input provides a high speed PWM output disable that may be useful for safety protection when the motor output mode is set to PWM High/Low. When this input is active PWM output is driven to one of two user programmable states; a fully disabled state or a braking state. PWM operation is normal when this signal is inactive.

In the fully disabled state all switches for the selected motor type are open, meaning that all high and low control signals are driven inactive and the ***AmplifierEnable*** signal is inactive. In the braking state all of the high-side switch control signals are driven inactive, all of the low-side switch signals are active, and the ***AmplifierEnable*** signal is active, thereby closing the lower side switches.

If a brake or disable function occurs, to re-enable normal output the event that caused the discontinuation of function must be reset. For more information on Juno event processing see Section 11.3, "Event Action Processing."

> The braking function is only available with the PWM control mode set to PWM High/Low. When the output mode is Sign/Magnitude PWM the ***Brake*** signal can only control a disable function.

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10. Internal Profile Generation

10

In This Chapter

- Juno Cycle Time
- Specifying Profile Parameters
- Profile Stop Events
- Settable Parameters

Juno torque control ICs include an internal profile generator that allows arbitrary contours of the current command to be generated. The profile generator is used in conjunction with serial host commands to specify move profiles.

To control the profile generator the user specifies a desired target acceleration, deceleration, and velocity. Using these target parameters Juno's profile generator performs calculations to determine the instantaneous position, velocity, and acceleration of the profile at any given moment.

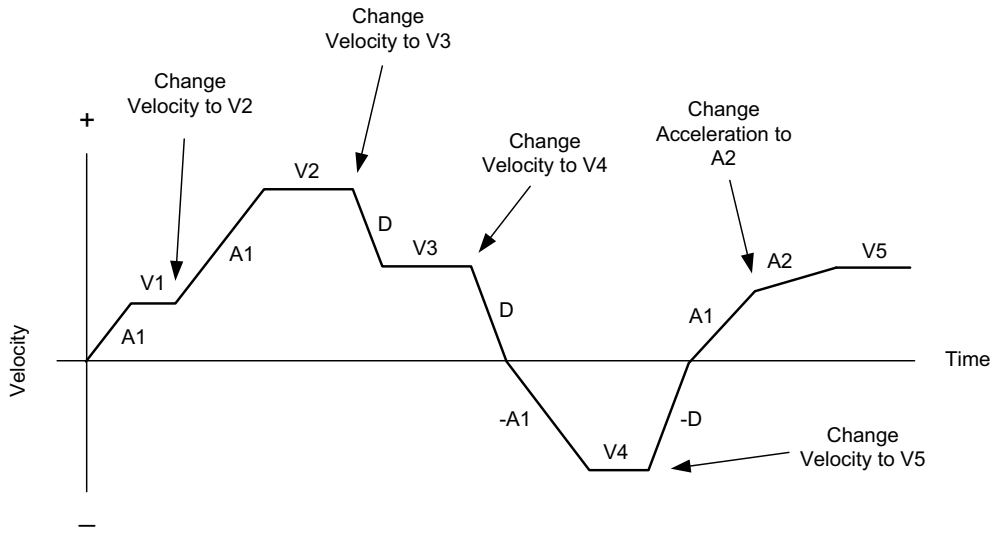

Figure 10-1: Internally Generated Velocity Profile

The profile is executed by continuously accelerating at the user-specified target acceleration rate until the user-specified target velocity is reached. The sign of the velocity parameter determines the initial direction of motion. Therefore the velocity value sent to Juno can have a positive value (for positive direction motion), or a negative value (for negative direction motion).

The axis decelerates at the user-specified target deceleration when a new velocity is specified with a smaller value (in magnitude) than the present velocity, or when a new velocity has a sign that is opposite to the present travel velocity. When a decelerating axis decelerates through a velocity of zero and reverses direction, after crossing through zero velocity the axis will apply the acceleration target rate rather than the deceleration target rate. Specified acceleration and deceleration values must always be positive.

Note that if the deceleration target value is set to zero Juno will use the specified acceleration target value for the deceleration value.

Figure 10-1 illustrates a complex profile in which the specified velocity and the direction of motion changes several times.

For Juno products that control the motor velocity or position of the motor such as the Juno velocity or step motor control ICs, these profile generation terms can be interpolated literally, meaning the command parameters for acceleration, deceleration and velocity refer directly to the motor's acceleration, deceleration, and velocity.

For the Juno torque control ICs however, the instantaneous profile generator velocity represents the torque command value, and the acceleration and deceleration parameters represent the rate of change of torque.

10.1 Juno Cycle Time

Juno ICs calculate all profile generator updates on a fixed, regular interval known as the profile cycle time. For Juno torque control ICs the nominal profile cycle time value is 102.4 µSeconds, but this may vary by as much as +/- 1/2 % over Juno's temperature operating range.

10.2 Specifying Profile Parameters

The profile parameters use an encoding denoted "X.Y" with X indicating the number of bits representing the integer portion and Y indicating the number of bits used to represent the fractional component.

Name	Format	Representation, Range & units
Velocity	16.16	signed 32 bits (-32,768 to +32,767.9998 counts/cycle/2^{16})
Acceleration	8.24	unsigned 32 bits (0 to +127.99999994 counts/cycle^2/2^{24})
Deceleration	8.24	unsigned 32 bits (0 to +127.99999994 counts/cycle^2/2^{24})

Specified target profile parameters are applied immediately. Whether or not these new parameters result in an immediate change depends on the profile being generated. For example if a new deceleration value is programmed while the axis is accelerating this new deceleration value will not be applied until the profile enters a deceleration phase.

Example

A profile is desired that ramps the commanded torque from zero to 7.5 amps in 120 mSecs. The velocity scalar and the cycle have been left at their default values of 65,536 (unity), and 102.4 µSec respectively. What are the profile parameters needed to command this ramp?

To convert the command in amps to a numerical value we use the result of the current scale factor calculation as detailed in Section 8.7.2, "Current Signal Scaling." Assuming a current scale factor of 2,500 counts per amp, the current command value is 7.5 amps * 2,500 counts/amp = 18,750.

The maximum velocity command is calculated using current command value * 2^{32}/ Velocity Scalar = 18,750 * 2^{32} / 65,536 = 1,228,800,000. With the default cycle time of 102.4 µSec, 120 mSecs is equivalent 120,000 µSecs / 102.4 µSec/cycle = 1,172 cycles. The desired acceleration is therefore 1,228,800,000 counts/cycle / 1,172 cycles = 1,048,464 counts/cycle^2. However the scaling format of the acceleration registers is 8.24 rather than 16.16, and therefore the final commanded acceleration value is 1,048,464 * 256 = 268,406,784.

10.3 Profile Stop Events

Juno provides an event action mechanism that allows automatic stopping of the motor axis under various conditions such as motion error, over temperature condition, and disable. Juno provides two types of controlled stops; a smooth stop and an abrupt stop. In a smooth stop the motor profile decelerates at the user-specified deceleration value until it reaches a velocity of zero. In an abrupt stop the velocity is instantaneously set to zero without a deceleration phase.

When the profile generator is active both a smooth stop and an abrupt stop will result in the user specified target velocity register being set to zero. This means that to restart a profile the target velocity has to be reloaded. For an abrupt stop, in addition to the target velocity being set to zero the instantaneous commanded velocity it also set to zero.

For more information on setting up and recovering from event actions refer to Section 11.3, "Event Action Processing."

In the context of profile generation of the commanded torque these abrupt or smooth stops may or may not stop the motor smoothly, abruptly, or even at all. It is the torque command profile that is being smoothly or abruptly stopped, not the motor motion itself.

10.4 Settable Parameters

The table below summarizes the settable parameters for the Juno profile generator:

Parameter	Host Command Mnemonic	Range & Description
Velocity	SetVelocity	Specified value has a range of -2,147,483,648 to +2,147,483,647 and specified the profile target velocity.
Acceleration	SetAcceleration	Specified value has a range of 0 to +2,147,483,647 and specified the profile target acceleration.
Deceleration	SetDeceleration	Specified value has a range of 0 to +2,147,483,647 and specified the profile target deceleration.

For information on the scaling of these profile target parameters refer to Section 10.2, "Specifying Profile Parameters."

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11. Motion Monitoring & Control

In This Chapter

- Status Registers
- FaultOut Signal
- Event Action Processing
- Host Interrupts
- Trace
- Settable Parameters

11.1 Status Registers

There are five bit-oriented status registers that provide a continuous report on the state of Juno and the controlled axis. These five 16-bit registers are Event Status, Activity Status, Drive Status, Drive Fault Status, and Signal Status.

11.1.1 Event Status Register

The Event Status register is designed to record events that do not continuously change in value but rather tend to occur once due to a specific event. As such, each bit in this register is set by Juno and cleared by the host.

The Event Status register is defined in the following table:

Bit	Name	Description
0	*Reserved*	*May contain 0 or 1.*
1	Position wraparound	Set when the encoder position exceeds 2,147,483,647h (the most positive position), and wraps to -2,147,483,647h (the most negative position), or vice versa.
2	*Reserved*	*May contain 0 or 1.*
3	Capture received	Set when the Index position capture hardware acquires a new position value.
4-6	*Reserved*	*May contain 0 or 1.*
7	Instruction error	Set when an instruction error occurs.
8	Disable	Set when the user disables the Juno IC by making the enable signal inactive.
9	Overtemperature fault	Set when an overtemperature fault occurs.
10	Drive exception	Set when one of a number of drive exceptions, such as bus overvoltage or undervoltage fault occurs.
11	Commutation error	Set when a commutation error occurs.
12	Current foldback	Set when current foldback occurs.
13	Run time error	Set when a runtime error occurs.
14-15	*Reserved*	*May contain 0 or 1.*

The Event Status register may be used to generate a host interrupt signal.

11.1.2 Activity Status Register

Activity Status register bits are not latched, they are continuously set and reset to indicate the status of the corresponding conditions.

The Activity Status register is defined in the following table:

Bit	Name	Description
0	Phasing initialized	Set 1 when the motor's commutation hardware has been initialized. Cleared by an **InitializePhase** command.
1	At maximum velocity	Set 1 when the commanded velocity is equal to the maximum velocity specified by the host. Cleared 0 if it is not. This bit only functions in conjunction with the profile generator and is not set if the loop command source is set to anything other than profile generator.
2-8	*Reserved*	*May contain 0 or 1.*
9	Position capture	Set 1 when a new position value is available to read from the Index capture hardware. Cleared 0 when a new value has not yet been captured. A serial host command retrieves the captured position value and clears this bit, thus allowing additional captures to occur. While this bit is set, no new values will be captured.
10	In-motion indicator	Set 1 when the profile generator commanded position is changing. Cleared 0 when the commanded position is not changing.
11-15	*Reserved*	*May contain 0 or 1.*

11.1.3 Drive Status Register

The specific status bits provided by the Drive Status register are defined in the following table. Like the Event Activity Status Register these bits are not latched.

Bit	Name	Description
0	Calibration completed	Set 1 when an analog input calibration procedure is completed. Cleared by a **CalibrateAnalog** command.
1	In foldback	Set 1 when in foldback, cleared 0 if not in foldback.
2	Overtemperature	Set 1 when the axis is currently in an overtemperature condition. Cleared 0 if the axis is currently not in an overtemperature condition.
3	Shunt active	Set 1 when shunt request is active. Cleared 0 if not.
4	*Reserved*	*May contain 0 or 1.*
5	Overvoltage	Set 1 when the axis is currently in an overvoltage condition. Cleared 0 if the axis is currently not in an overvoltage condition.
6	Undervoltage	Set 1 when the axis is currently in an undervoltage condition. Cleared 0 if the axis is currently not in an undervoltage condition.
7-11	*Reserved*	*May contain 0 or 1.*
12	Output Clipped	Set 1 when the amplifier current command can not be met because of output clipping.
13	*Reserved*	*May contain 0 or 1.*
14	Initializing	Set 1 when Juno is in the process of initializing from NVRAM commands. Set 0 when initializing is complete.
15	*Reserved*	*May contain 0 or 1.*

11.1.4 Drive Fault Status Register

The following table indicates the contents of the Drive Fault Status register. Like the Event Activity Status Register these bits are latched. They are set by Juno and cleared by the user.

Bit	Name	Description
0	Overcurrent	Set 1 to indicate a fault due to a short circuit or overload in the drive output.
1-4	*Reserved*	*May contain 0 or 1*
5	Overvoltage	Set 1 to indicate an overvoltage condition of the external bus voltage input.
6	Undervoltage	Set 1 to indicate an undervoltage condition of the external bus voltage input.
7	*Reserved*	*May contain 0 or 1*
8	Foldback	Set 1 to indicate that a current foldback event has occurred.
9, 10	*Reserved*	*May contain 0 or 1*
11	Watchdog	Set 1 to indicate that a watchdog event has occurred.
12	*Reserved*	*May contain 0 or 1*
13	Brake	Set 1 to indicate that the Brake signal input pin has gone active.
14, 15	*Reserved*	*May contain 0 or 1*

11.1.5 Signal Status Register

The Signal Status register provides real-time signal levels for various Juno IC I/O pins. The Signal Status register is defined in the following table:

Bit	Name	Description
0	A encoder	A signal of quadrature encoder input.
1	B encoder	B signal of quadrature encoder input.
2	Index encoder	Index signal of quadrature encoder input.
3-6	*Reserved*	*May contain 0 or 1.*
7	HallA	Hall affect sensor input A.
8	HallB	Hall affect sensor input B.
9	HallC	Hall affect sensor input C.
10-12	*Reserved*	*May contain 0 or 1.*
13	/Enable	Enable signal input.
14	FaultOut	Fault signal output.
15	*Reserved*	*May contain 0 or 1.*

All Signal Status register bits are inputs except bit 14 (***FaultOut***).

The input bits in the Signal Status register represent the actual hardware signal level combined with the state of the signal sense mask described in the next section. That is, if the signal level is high, and the corresponding signal mask bit is 0 (do not invert), then the bit will be 1. Conversely, if the signal mask for that bit is a 1 (invert), then a high signal on the pin will result in a read of 0.

The output bits in the Signal Status register are not affected by the signal sense mask. For these signals a 1 indicates an active condition and a 0 indicates a non active condition.

11.1.5.1 Signal Sense Mask

The bits in the Signal Status register represent the high/low state of various signal pins. It is possible to invert the incoming signal to match the signal interpretation of the user's hardware.

The default value of the signal sense mask is "not inverted" except for the *Index* signal, which has a default value of "inverted." The bits of the signal sense mask register are defined in the following table:

Bit	Name	Interpretation
0	A encoder	Set 1 to invert quadrature A input signal. Clear 0 for no inversion.
1	B encoder	Set 1 to invert quadrature B input signal. Clear 0 for no inversion.
2	Index encoder	Set 1 to invert, clear 0 for no inversion. This means that for active low interpretation of index signal, set to 0; and for active high interpretation, set to 1.
3-6	*Reserved*	
7	HallA	Set 1 to invert HallA signal. Clear 0 for no inversion.
8	HallB	Set 1 to invert HallB signal. Clear 0 for no inversion.
9	HallC	Set 1 to invert HallC signal. Clear 0 for no inversion.
10-11	*Reserved*	
12	Motor Direction	Set 1 to invert Motor Direction. Clear 0 for no inversion.
13–15	*Reserved*	

11.2 FaultOut Signal

Juno's *FaultOut* signal is used to indicate an occurrence of a fault condition. This signal is always active high and its sense cannot be changed. Any bit condition of the Event Status register may be used to trigger activation of this signal via a user-programmable mask value.

The bit conditions specified in this mask are logically ANDed with the Event Status register. Any resultant non-zero value will cause the *FaultOut* signal to go active. See Section 11.1.1, "Event Status Register" for information on the Event Status register.

Example

Programming the fault out mask with a value of 1,040 (0x410) configures the *FaultOut* signal to be driven high upon a motion error (bit #4) or a drive exception error (bit #10).

11.3 Event Action Processing

Juno ICs provide a programmable mechanism for automatically reacting to various safety or performance-related events. This mechanism is called event action processing.

Each monitored event condition may have an associated event action defined for it. The following table lists each of the event conditions that Juno monitors along with the default event actions that will occur for torque control Juno ICs if no user specified event actions are provided:

Condition Name	Default Action	Description
Current foldback	Disable Motor Output	Occurs when the amplifier current output goes into a foldback condition.
Encoder Position Capture	No Action	Occurs when the quadrature encoder Index signal has triggered a position capture
Overtemperature	Disable Motor Output	Occurs when an overtemperature condition is detected
Disabled	Disable Motor Output	Occurs when the Enable signal goes inactive. The programmed event action must be Disable Motor Output or Brake

Condition Name	Default Action	Description
Overcurrent	Disable Motor Output	Occurs when an overcurrent condition is detected. The programmed event action must be Disable Motor Output or Brake
Overvoltage	Disable Motor Output	Occurs when an overvoltage condition is detected
Undervoltage	Disable Motor Output	Occurs when an undervoltage condition is detected
Watchdog timeout	No Action	Occurs when a watchdog timeout condition is detected
Brake signal	Brake	Occurs when the Brake signal goes active. The programmed event action must be Disable Motor Output or Brake

Unless otherwise noted above the default event action may be changed by the user. The following table describes the event actions that can be programmed:

Action Name	Description
No Action	No action taken.
Smooth Stop	Causes a smooth stop of the torque profile to occur at the active deceleration rate.
Abrupt Stop	Commands an instantaneous halt of the torque profile.
Disable Current Loops	Disables profile generator and current loop.
Disable Motor Output	Disables profile generator, current loop, and motor output.
Brake	Turns the brake function on and disables the profile generator, current loop, and motor output.

11.3.1 Event Processing

Upon power-up and initialization completion Juno begins to continuously monitor the event conditions and executes the programmed event action if they occur. When the programmed action is executed, related actions may occur such as setting the appropriate bit in the Event Status register.

To recover from an event action, the cause of the event occurring should be investigated and corrected.

It is the responsibility of the user to safely and thoroughly investigate the cause of event-related events, and only restart motion operations when appropriate corrective measures have been taken.

Once programmed, an event action will be in place until reprogrammed. The occurrence of the event condition does not reset the programmed event action.

11.3.2 Enable-Based Event Recovery

Juno's serial port in conjunction with host commands can be used to recover from events such as overtemperature, current foldback, etc. However a second method that can be executed via simple external circuitry can be user-selected for recovery from events. This methods uses Juno's ***Enable*** signal.

Enable-based recovery, also called automatic recovery, relies on the ***FaultOut*** signal to indicate a fault condition. After the ***FaultOut*** signal goes active, external logic must delay a minimum of 150 µSec, but thereafter may request that Juno

attempt to recover by deasserting, and then asserting, the ***Enable*** signal. The ***Enable*** signal must be in the deasserted state for at least 150 µSec for the request to be recognized.

When an Enable-based recovery request is recognized Juno attempts to clear the Event Status register and the Drive Fault Status register, and will continue to do so until the conditions which caused the ***FaultOut*** to go active are no longer present. At this point ***FaultOut*** will be deasserted and Juno will return to normal operations.

Example

An application uses a thermistor mounted on the motor body and programs the fault out mask to generate a ***FaultOut*** signal when the motor gets too hot. Juno's default event action is left unchanged which results in motor output being disabled. External logic monitors the ***FaultOut*** signal and when it goes active, the external logic delays 200 µSec, deasserts the ***Enable*** signal for 200 µSec, and then restores ***Enable*** to an asserted condition. Once the temperature has dropped sufficiently motor operation will then proceed normally and the ***FaultOut*** signal will be deasserted.

11.4 Host Interrupts

Interrupts allow a host microprocessor or other external circuitry to be automatically notified if a special Juno condition occurs. For this purpose Juno provides a ***HostInterrupt*** signal. ***HostInterrupt*** functions similarly to ***FaultOut*** but provides a separate programmable mask.

Any or all of Event Status register bits may be programmed to cause an interrupt. If a 1 is stored in the mask, then a 1 in the corresponding bit of the Event Status register will cause an interrupt to occur. Juno continually and simultaneously scans the Event Status register and interrupt mask to determine if an interrupt has occurred. When an interrupt occurs, the ***HostInterrupt*** signal is made active.

To recover from an interrupt, Juno serial host commands may be used. Alternatively, Enable-based event recovery may be used. Once a valid recovery sequence is sent by external circuitry, Juno will attempt to clear the Event status register along with the ***HostInterrupt*** signal.

For information on processing interrupts via serial host commands refer to the *Juno Velocity & Torque Control IC User Guide*.

11.5 Trace

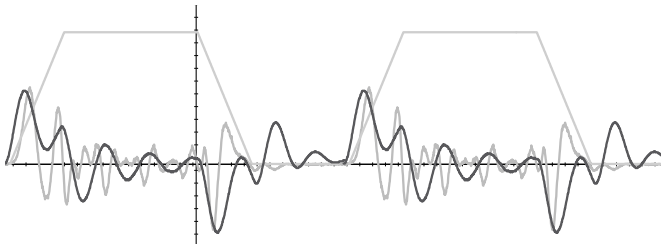

Figure 11-1: Example Motion Trace Capture

Trace is a powerful Juno IC feature that allows various parameters and registers to be continuously captured and stored to an internal RAM buffer. The captured data may later be downloaded by PMD Corp.'s Pro-Motion Windows-based software. Traces are useful for optimizing performance, capturing sensor data, or to assist with any type of monitoring where a precise time-based record of the system's behavior is required.

Trace activity with the Juno torque control ICs is undertaken using serial host commands. Most users will not concern themselves with the protocol required to achieve this and will use Pro-Motion to set up and display trace results. For users wishing to write their own trace software however, refer to the *Juno Velocity & Torque Control IC User Guide*.

11.6 Settable Parameters

Parameter	Host Command Mnemonic	Range & Description
Signal sense mask	SetSignalSense	Specified value is a 16-bit mask with each '1' bit value indicating invert, and each '0' bit value indicating don't invert
Fault out mask	SetFaultOutMask	Specified value is a 16-bit mask with each '1' bit value indicating that the corresponding bit in the Event Status register, if active, will drive the *FaultOut* signal active.
Event action processing	SetEventAction	Two parameter command. The first is a fixed value that specifies the event condition for which an action is being defined, the second is a fixed value defining the action. Juno defines 10 separate event conditions and therefore this command could be called up to 10 times, one for each condition
Event recovery method	SetDriveFaultParameter	Two parameter command. The first must be 2, the second is a fixed code value specifying either Enable-based (automatic) event recovery or commanded event recovery.
Host interrupt mask	SetInterruptMask	Specified value is a 16-bit mask with each '1' bit value indicating that the corresponding bit in the Event Status register, if active, will trigger a host interrupt and drive the *HostInterrupt* signal active.

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12. Brushless DC Motor Control

12

In This Chapter

- Hall-Based Commutation
- Encoder-Based Commutation
- Encoder Feedback
- Settable Parameters
- Signal Processing

Juno ICs provide a number of special features for support of Brushless DC motors. These include input of Hall sensors, multi-phase signal generation, and a number of other capabilities related to phasing control and commutation.

To drive a brushless DC motor the motor's rotor angle must be known as it continually changes. This is accomplished using one of two methods. The first is by using Hall sensors, and the second is by using the quadrature position encoder. In both cases these sensors must be directly connected to the motor shaft. Generally speaking, if an encoder is available it should be used for commutation as it will provide smoother motion and higher overall performance than Hall sensors.

Selection of whether the phasing of the motor will be Hall-based or encoder-based, is user programmable. Note that frequently *both* Hall sensors and encoder feedback signals are used. The Hall sensors are used during phase initialization, and the encoder is used thereafter to achieve the higher performance commutation during regular motor operation. See Section 12.2.1.1, "Hall-Based Phase Initialization" for more information.

12.1 Hall-Based Commutation

The Hall sensor signals are input directly to Juno through the signals ***HallA, HallB, and HallC***. To accommodate varying types of Hall sensors, or sensors containing inverter circuitry, the signal level/logic interpretation of the Hall sensor input signals may be user programmed via the set signal sense register.

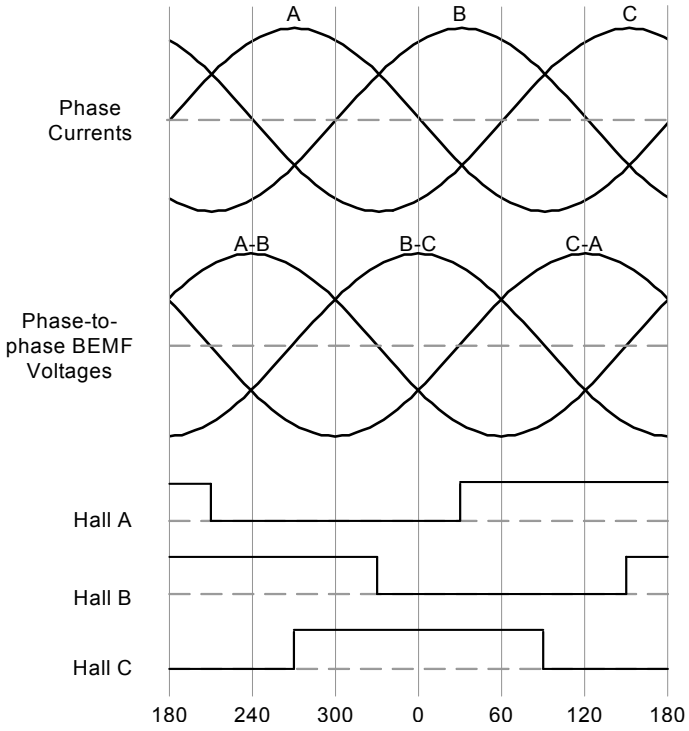
12.2 Encoder-Based Commutation

If the motor commutation will occur via an encoder the number of encoder counts per electrical cycle must be user specified. This parameter indicates to Juno the number of encoder counts required to complete a single full electrical cycle. The number of electrical cycles can usually be determined from the motor manufacturer's specification and is exactly half the number of poles.

The number of encoder counts per electrical cycle is not required to be an exact integer.

12.2.1 Phase Initialization

Figure 12-1: Hall-based Phase Initialization



When commutating via the encoder, in addition to specifying the counts per electrical cycle Juno must determine the proper initial phase angle of the motor relative to the encoder position. This information is determined using a procedure called phase initialization. Note that a phase initialization procedure is not necessary if Hall-based commutation is selected.

Juno provides three methods to perform phase initialization: Hall-based, pulse phase, and direct-set. Each are described in detail in the subsequent sections.

12.2.1.1 Hall-Based Phase Initialization

The most common and the simplest method of encoder phase initialization is Hall-based. In this mode, three Hall sensor signals are used to determine the motor phasing. Encoder-based commutation begins automatically after the motor has moved through at least one Hall state transition.

Figure 12-1 illustrates the relationship between the state of the three Hall sensor inputs, the sinusoidally commutated phase current commands, and the motor phase-to-phase back EMF waveforms during forward motion of the motor. A Hall to back EMF phasing diagram is a common way to specify the required alignment and a such a diagram is often provided by the motor supplier.

Juno expects 120-degree separation between Hall signal transitions. To commutate using Hall sensors located 60 degrees apart, swap and invert the appropriate Hall signals and motor phases to generate the expected Hall states. Note that the signal sense register can be used to accomplish hall signal inversion.

12.2.1.2 Pulse Phase Initialization

Juno provides the ability to initialize encoder-based phasing of Brushless DC motors without the need for explicit phasing signals such as Hall sensors using a proprietary technique called pulse phase initialization. Pulse phase initialization executes by applying a rapid burst of positive/negative command pulse pairs followed by a longer ramp

pulse. As long as the motor's motion is unencumbered through this sequence the resulting phase initialization should be accurate and repeatable.

The following table shows the parameters that are set in association with pulse phase initialization:

Parameter	Range & Units	Description
PositivePulseTime	0-32,767 cycles	Is the time that the positive portion of the burst pulse is applied
NegativePulseTime	0-32,767 cycles	Is the time that the negative portion of the burst pulse is applied
PulseMotorCommand	1-32,767% / 327.67	Is the motor command that will be applied during the burst mode of the initialization procedure. The specified value represents a % motor command from 0 to 100%.
RampMotorCommand	1-32,767% / 327.67	Is the motor command that is applied during the ramp portion of the initialization procedure. The specified value represents a % motor command from 0 to 100%.
RampTime	0-32,767 cycles	Is the time that the slow ramp and hold is applied.

Once these parameters are loaded an **InitializePhase** command can be sent. While varying somewhat with motor size, typical total durations of the pulse phase sequence is 500 mSec. A flag in the Activity Status register indicates whether phase initialization has completed, and a flag in the Event Status register indicates whether an error was detected during phase initialization.

Setting up appropriate pulse phase parameters for various applications can most easily be accomplished with PMD's Pro-Motion software. To perform your own determination of pulse phase parameters refer to the *Juno Velocity & Torque Control IC Programming Reference*.

Pulse phase initialization can only function properly if motor movement is free and unencumbered.

12.2.1.3 Direct-Set Phase Initialization

If, after power-up, the location of the motor phasing is known, the phase angle can be directly specified by the user. This typically occurs when sensors such as resolvers are used where the returned motor position information is absolute in nature. Note that this approach typically only applies to microprocessor controlled, rather than standalone NVRAM-based Juno operation.

12.2.2 Automatic Phase Correction

To enhance commutation reliability the Juno ICs provide the ability to automatically correct the commutation phase during encoder-based commutation. Note that if Hall-based commutation is used, this feature is not necessary. Either an index signal or Hall signals can be used for this automatic correction function.

12.2.2.1 Index-Based Phase Correction

To utilize automatic phase correction the motor encoder provides an index pulse signal to Juno once per rotation. Index phase referencing is recommended for all rotary brushless motors with quadrature encoders directly mounted on the motor shaft. For linear brushless motors, it is generally not used. However, it may be used as long as the index pulses are arranged so that each pulse occurs at the same phase angle within the commutation cycle.

With an index signal properly installed, Juno will automatically adjust the commutation angle to correct for any small losses of encoder counts that may occur. If the loss of encoder counts becomes excessive, or if the index pulse does

not arrive at the expected location within the commutation cycle, a commutation error occurs, which is indicated via bit 11 in the Event Status register. This bit is set if the required correction is greater than (PhaseCounts / 128) + 4.

To recover from a commutation error this bit should be cleared by the host. Depending on the cause of the error there may be no further errors or errors may continue to occur.

A commutation error may indicate a serious problem with the motion system, potentially resulting in unsafe motion. It is the responsibility of the host to determine and correct the cause of commutation errors.

12.2.2.2 Hall-Based Phase Correction

Hall signals may also be used for automatic commutation phase adjust when an index pulse is not available.

Hall-based phase error detection functions similarly to index-based phase correction. Bit 11 of the Event Status register signals a commutation error and recovery occurs in the same manner. The difference is that the absolute amount of error allowed before a commutation error occurs, is PhaseCount/32+4 with index-based phase correction.

12.2.3 Adjusting the Phase Angle

Juno supports the ability to change the motor's phase angle directly, both when the motor is stationary and when it is in motion. Although this is not generally required, it can be useful during testing, or during phase initialization when direct-set methods are used. Note that the phase angle can not be changed if Hall-based commutation is used. For more information on this feature refer to the *Juno Velocity & Torque Control IC User Guide.*

12.3 Encoder Feedback

The Juno torque control ICs support quadrature position encoder input for the purpose of commutation or general purpose position feedback. To provide encoder tracking Juno continually monitors the ***QuadA*** and ***QuadB*** feedback signals and accumulates a 32-bit position value called the actual position. At power-up, the default actual position is zero. The full range of trackable positions is -2,147,483,647 to +2,147,483,647.

In the event that a spinning axis exceeds either of these position limits the actual position wraps around, with the largest positive position wrapping around to become the smallest negative position, and the smallest negative position wrapping around to become the largest positive number. When such a wraparound occurs a corresponding bit in the Event Status register is set.

Position wraparound, should it occur during operation, is generally not a consequential event. A position wraparound will have no impact on the behavior of the axis, nor is there a limit to the number of such wraparound events that may occur.

For more information on the Event Status register see Section 11.1.1, "Event Status Register."

12.3.1 Position Capture

Juno ICs support a high-speed position capture function that allows the current axis location (as determined by the attached encoder) to be captured when triggered by the ***Index*** signal. When a capture is triggered, the content of the actual position register is transferred to a position capture register, and the capture-received indicator of the Event Status register is set.

The capture register can be read using serial host commands. Reading the position capture register causes the trigger to be re-armed, allowing for more captures to occur.

12.4 Settable Parameters

The table below provides a summary of the user-programmable parameters and commands described in this chapter:

Parameter	Host Command Mnemonic	Range & Description
Operating mode register	SetOperatingMode	Specified value is a bit-oriented mask determining the state of the command source, current loop, and motor output enable/disable flags.
Commutation mode	SetCommutationMode	Specified value is a fixed code selecting Hall-based or encoder-based commutation
Phase counts	SetCommutationParameter	Two parameter command, the first must be 0. The second has a range of 0 to 134,217,727 and specifies the number of encoder counts per mechanical rotation of the motor.
Phase counts denominator	SetCommutationParameter	Two parameter command, the first must be 3. The second has a range of 0 to 32,767 and specifies the number of electrical cycles per mechanical rotation of the motor.
Phase initialization mode	SetPhaseInitializeMode	Specified value is a fixed code selecting Hall-based phase initialization or pulse phase initialization.
Positive pulse time	SetPhaseParameter	Two parameter command, the first must be 1. The second has a range of 0 to 65,534 and specifies the positive pulse time in units of profile cycles.
Negative pulse time	SetPhaseParameter	Two parameter command, the first must be 2. The second has a range of 0 to 65,534 and specifies the negative pulse time in units of profile cycles.
Pulse motor command	SetPhaseParameter	Two parameter command, the first must be 3. The second has a range of 0 to 32,767 and specifies the motor command in units of % / 327.67 during burst mode of pulse phase initialization.
Ramp motor command	SetPhaseParameter	Two parameter command, the first must be 5. The second has a range of 0 to 32,767 and specifies the motor command in units of % / 327.67 during ramp mode of pulse phase initialization.
Ramp time	SetPhaseParameter	Two parameter command, the first must be 0. The second has a range of 0 to 65,534 and specifies the pulse phase initialization ramp time in units of profile cycles.
Initialize phase	InitializePhase	This host command has no parameters associated with it and initiates phase initialization using the phase initialization mode previously specified by the user.
Commutation phase correction mode	SetPhaseCorrectionMode	Specified value is a fixed code selecting either no phase correction, phase correction via index signal, or phase correction via Hall signals.

For information on the SPI watchdog timer see Section 8.5, "Watchdog Timer."

12.5 Signal Processing

12.5.1 Hall Sensors

Although not required, Hall signals are commonly used when driving Brushless DC motors. All of the Juno Hall signal inputs are digital TTL level signals, so for typical applications external signal processing circuitry is used.

The table below provides a summary of the Juno Hall-based signals.

Pin Name	64-Pin TQFP Pin#	56-Pin VQFN Pin#	Description
HallA	35	23	HallA input
HallB	31	42	HallB input
HallC	64	34	HallC input

There is some variation in how typical motors are wired, so for convenience Juno provides the ability to change the signal sense interpretation of these incoming signals.

12.5.1.1 Typical Hall Processing Circuitry

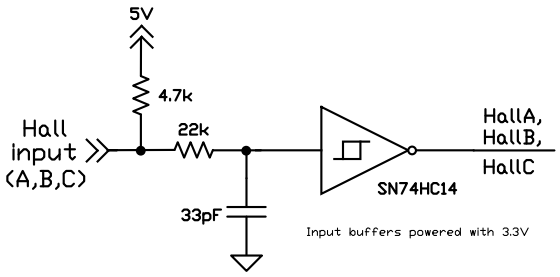


Figure 12-2: Typical Hall Processing Circuitry

Figure 12-2 shows a typical circuit for processing Hall sensor signals. The 4.7k resistor pull-up resistor is required when the Hall signals are open-collector. The 22k resistor and 33pF capacitor provide a low-pass filter with a bandwidth of 219 kHz. The selection of the low-pass filter bandwidth depends on noise and Hall signal frequency. This buffer stage has an inversion on its output.

12.5.2 Quadrature Encoder Signal Interfacing

The table below provides a summary of the encoder related signals:.

Pin Name	64-Pin TQFP Pin#	56-Pin VQFN Pin#	Description
QuadA	62	55	Quad A input
QuadB	63	56	Quad B input
Index	4	2	Index input

By default the *Index* capture signal is active low, however this interpretation is user programmable.

All of the encoder related signals are digital TTL level signals, so for typical cable-based connection to a motor encoder differential transceiver chips are used.

QuadA and *QuadB* are expected to be offset from each other by 90 degrees. When the motor moves in the position direction, *QuadA* should lead *QuadB*. When the motor moves in the negative direction *QuadB* should lead *QuadA*. Four resolved quadrature counts occur for one full phase of each A and B channel.

The *Index* signal provides a capture trigger for the instantaneous up/down quadrature position. This input signal is most often tied to the encoder's index output, but this is not required.

12.5.2.1 Typical Quadrature Encoder Processing Circuitry

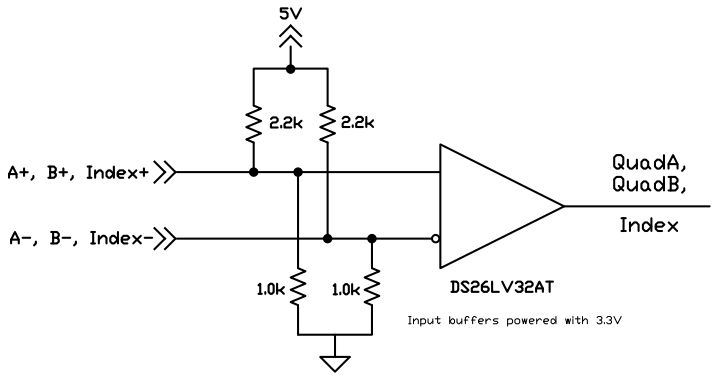


Figure 12-3: Quadrature Encoder Processing Circuitry

Figure 12-3 shows a typical circuit for processing differential quadrature and index signals. The pull-up and pull-down resistors provide both termination and a bias voltage. When single ended encoder signals are used connect to the positive input and leave the negative input unconnected.

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13.Drive & DC Bus Safety

13

In This Chapter

- Drive & DC Bus Safety
- Current Foldback
- Shunt Control
- Settable Parameters
- Signal Processing

13.1 Drive & DC Bus Safety

The Juno torque control ICs provide sophisticated drive and DC Bus safety features. These features include overtemperature monitoring, over and under voltage monitoring, overcurrent monitoring, and current foldback.

The following sections provide detailed information for these drive and DC Bus safety related features.

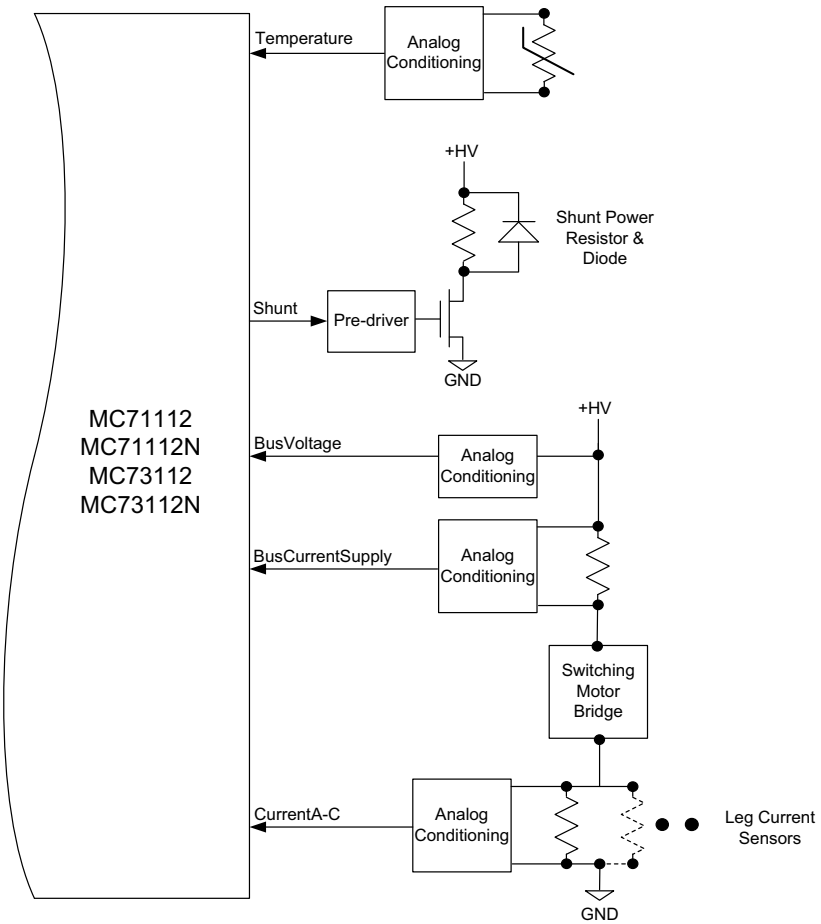


Figure 13-1: Drive & DC Bus Safety Feature Circuitry Overview

13.1.1 Overtemperature Protection

Juno supports a *Temperature* sensor input to continuously monitor the temperature of the power electronics or another part of the motion system. Although various temperature sensors may be used, the most common type of sensor is a thermistor.

The value of the temperature sensor and downstream analog conditioning circuitry determine the overall temperature range that can be measured. The overall temperature sense range should be 15% to 25% above the highest expected temperature.

The *Temperature* signal input expects a voltage in the range of 0V to 3.3V representing the sensed temperature. Both temperature-voltage-increasing (voltage increases with increasing temperature) and temperature-voltage-decreasing (voltage decreases with increasing temperature) thermistors are supported. For voltage increasing thermistors 0.0V represents the lowest possible temperature, and for voltage decreasing thermistors 3.3V represents the lowest possible temperature.

The overtemperature threshold is user programmable. The sign of the overtemperature threshold selects whether the *Temperature* input increases or decreases with rising temperature; positive thresholds indicate voltage increase while negative thresholds indicate voltage decrease. The actual limit threshold utilized by Juno for the comparison is the absolute value of the specified limit value. The magnitude of the numerical threshold value has a range of 0 to 32,767 with 0 being the lowest readable temperature and 32,767 the highest.

In addition to the settable overtemperature threshold Juno supports a settable temperature hysteresis. This function is used to avoid spurious re-triggering of an overtemperature event.

Example

A temperature-voltage-increasing thermistor and associated analog processing circuitry generate a voltage of 2.9V when the amplifier is at the hottest safely operable temperature. The overtemperature limit specified should thus be set to 32,768 * 2.9V/3.3V = 28,796. Later the design is changed so that a voltage decreasing thermistor is used. With a voltage decreasing thermistor an overtemperature limit of -28,796 would be programmed.

The overtemperature detect functions continuously once programmed. To disable the overtemperature check a threshold value of 32,767 is set.

13.1.2 Overcurrent Monitoring

Figure 13-1 shows the DC bus monitoring scheme used with the Juno torque control ICs. Juno monitors both the supply-side and return-side DC bus current to detect overcurrent conditions. Supply side current measurement detects shorts of the motor windings to ground and shorts of the windings to each other. Return current measurement can not measure shorts to ground, but can measure winding shorts to each other.

The *BusCurrentSupply* signal directly encodes the total current flowing through the motor amplifier bridge(s) from the +HV supply, with 0.0V encoding no current flow and 3.3V encoding the maximum measurable amount of current flow. The return-side overcurrent monitoring occurs via the leg current sensors, which are also used during current control.

The value of the sense resistor and downstream analog conditioning circuitry determine the overall current range that can be measured. For the DC bus supply current input this range should be at least 150% of the maximum expected DC bus peak current flow.

The measured bus supply current is an unsigned number with range of 0 to 65,535. The user-specified DC bus supply overcurrent threshold is continuously compared against the measured current.

The DC Bus supply overcurrent threshold function operates continuously once programmed. To disable an overcurrent check a threshold value of 65,535 is set.

Return current flow from the DC bus is measured via the leg current sensors as part of the current control mechanism. See Section 8.7.2, "Current Signal Scaling" for more information on leg current scaling.

The bus return current threshold has different scaling that the supply side. It is an unsigned number with range of 0 to 32,767. A DC bus return overcurrent threshold is set to compare against the measured leg current reading.

Overcurrent functions continuously once programmed. To disable an overcurrent check a threshold value of 32,767 is set.

Example

An isolating op-amp and sense resistor generate 3.3V at a DC bus supply current flow of 15 amps. The numerical scaling of the current threshold is therefore 15.0A/65,536 = .228 mA/count. The overcurrent threshold is set at 9.5 amps, or 9,500 mA/.228 mA/count = 41,667.

Using the scaling defined in the example in Section 8.7.2, "Current Signal Scaling" to set the same overcurrent threshold for the DC bus return current of 12.0A, a value of 9.50 A * 1.25 * 32,767 / 10.0 A = 31,128 is used.

Return current measurement is only available when the motor output mode is set to PWM High/Low.

If current control is not implemented then it is not possible for Juno to measure DC bus return current. DC bus supply current measurement is not affected however and can function with or without current control active.

13.1.3 Over/Under Voltage Monitoring

The Juno torque control ICs can monitor the DC bus voltage for overvoltage and undervoltage conditions utilizing the ***BusVoltage*** analog input signal. Overvoltage and undervoltage detection is accomplished by checking the measured voltage of the DC bus and comparing with user-provided thresholds.

The value of the sense resistor and downstream analog conditioning circuitry determines the overall voltage measurement range. This overall voltage range should be 15% to 50% above the maximum expected DC bus voltage.

The ***BusVoltage*** input range is 0.0V to 3.3V, with 0.0V representing a DC bus voltage of 0V, and +3.3V representing the largest measurable DC bus voltage. Both an over and undervoltage threshold are user programmable, and have a range of 0 to 65,535.

Example

In an application that will have a motor voltage of 48 volts, external circuitry has been selected to present 3.3V at the ***BusVoltage*** input when the DC bus voltage is 65 volts. The scaling is 65V/65,536 or .992 mV/count. To set an undervoltage threshold of 45V a value of 45,000 mV/.992 mV/count = 45,362 is specified. To set an overvoltage threshold of 52V a value of 52,000 mV/.992 mV/count = 52,419 is specified.

The under and overvoltage thresholds function continuously. To disable the under voltage or over voltage check, threshold values are set to 0 or 65,535 respectively.

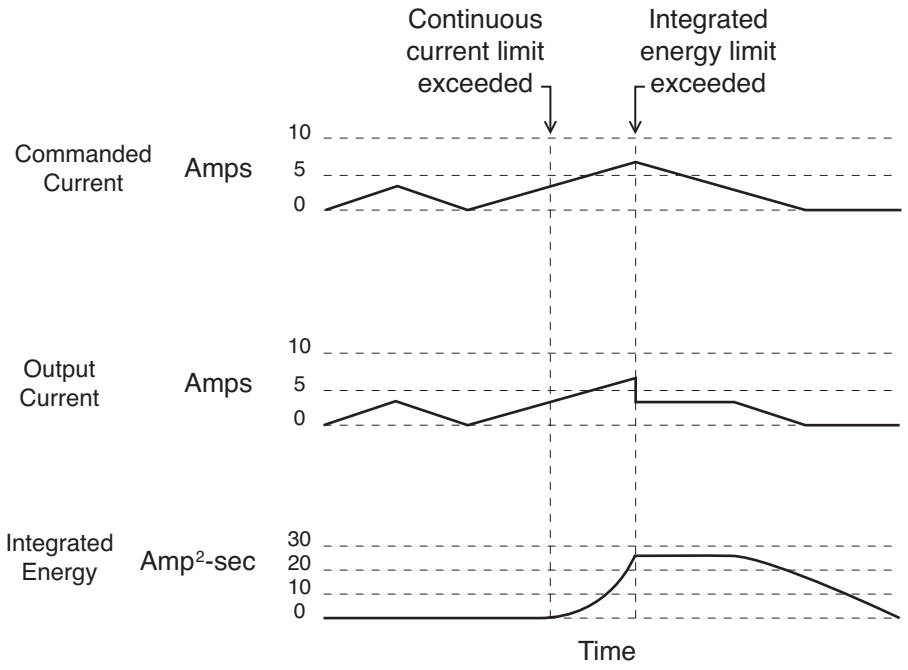
13.2 Current Foldback

Juno supports a current foldback feature, sometimes referred to as an I^2t foldback, which can be used to protect the drive output stage or motor windings from excessive current. I^2t current foldback works by integrating, over time, the difference of the square of the actual motor current and the square of the user-settable continuous current limit.

When the integrated value reaches a user-settable energy limit, Juno goes into current foldback. The default response to this event is to cause the current loop and motor output modules to be disabled. However it is also possible to program Juno to attempt to clamp the maximum current to the continuous current limit value. Note that Juno's ability to do so depends on a properly functioning current loop.

Juno will stay in foldback until the integrator returns to zero. This is shown in Figure 13-2.

Figure 13-2: Current Foldback Processing Example



Setting continuous current limit and energy limit to less than the maximum available from the amplifier circuitry is useful if the required current limit is due to the motor, rather than to the drive electronics.

The instantaneous state of current foldback (whether the foldback limit is active or not) is available in the Drive Status register. In addition, if a foldback event has occurred, this event is recorded in the Event Status register.

Example

A particular motor has an allowed continuous current rating of 3 amps. In addition, this motor can sustain a temporary current of 5 amps for 2 seconds.

In this example the *continuous current limit* would be set to 3 amps, and the energy limit would be set to:

Energy Limit = (peak current^2 - continuous current limit^2) * time
Energy Limit = (5^2A^2 - 3^2A^2) * 2 Sec
Energy Limit = $32A^2$Sec

Following the current scaling example in Section 8.7.2, "Current Signal Scaling" the programmed continuous current limit would be 3.0 A * .625 * 32,767 / 10.0A = 6,144.

The programmed energy limit value must convert seconds to Juno current loop cycles (19,531 cycles/sec) and must factor in the scaling of Juno's programmed energy limit value which is $1/2^{31}$. This gives:

Programmed Energy Limit = 32 A^2Sec * (1.25 * 32,768 / 10A)^2 * 19,531 cycles/Sec * $1/2^{31}$

Programmed Energy Limit = 4,883

Current foldback, when it occurs, may indicate a serious condition affecting motion stability, smoothness, and performance. It is the responsibility of the user to determine the appropriate response to a current foldback event.

13.3 Shunt Control

As shown in Figure 13-1 Juno can control a shunt PWM output, which in turn typically drives a MOSFET or IGBT switch which connects the HV bus voltage to the DC bus ground via a power resistor, thereby lowering the DC bus voltage. The shunt is useful for controlling excessive DC bus voltage particularly if the servo motor is decelerating rapidly resulting in back-EMF generation.

The shunt functions by continually comparing the DC bus voltage, as presented at the ***BusVoltage*** signal, to a user programmable threshold. If the DC bus voltage exceeds the comparison threshold the ***Shunt*** signal outputs a PWM waveform at a user programmable duty cycle. This PWM frequency is equal to the motor drive PWM frequency. Once active, shunt PWM output will stop when the DC bus drops to 2.5% below the threshold comparison value.

Once programmed, the shunt comparison function operates continuously. To disable it, a value of 65,535 should be programmed. The shunt function is not active when motor output is not enabled (the active operating mode output bit is not set).

The scaling and units of the shunt comparison threshold is the same as for the over and undervoltage functions—an unsigned 16-bit number having a range of 0 to 65,534. The shunt PWM duty cycle is an unsigned 16-bit numbers with a range of 0 to 32,767.

Example

In the system from the example in Section 13.1.3, "Over/Under Voltage Monitoring" the shunt will be activated when the DC bus voltage climbs to 51 volts with a duty cycle of 95%. The shunt comparison threshold is set to 51,000 mV/ .992 mV/count = 51,411 and the duty cycle value is .95 * 32,768 = 31,130.

Whether the shunt output is active at any given moment can be determined using the Drive Status register. For more information refer to Section 11.1.3, "Drive Status Register." To do this the command **GetDriveStatus** is used.

13.4 Settable Parameters

Parameter	Host Command Mnemonic	Range & Description
Overtemperature threshold	SetDriveFaultParameter	Two parameter command. The first must be 4, the second has a range of -32,768 to 32,767 and specifies the thermistor sense (voltage increasing or decreasing) via the sign of the specified value and the threshold limit via the magnitude of the specified value
Overtemperature hysteresis	SetDriveFaultParameter	Two parameter command. The first must be 5, the second has a range of 0 to 6,400 and specifies the hysteresis.
DC bus overcurrent supply threshold	SetDriveFaultParameter	Two parameter command. The first must be 10, the second has a range of 0 to 65,535 and specifies the DC bus supply overcurrent threshold.
DC bus overcurrent return threshold	SetDriveFaultParameter	Two parameter command. The first must be 11, the second has a range of 0 to 32,767 and specifies the DC bus return overcurrent threshold.
DC bus overvoltage threshold	SetDriveFaultParameter	Two parameter command. The first must be 0, the second has a range of 0 to 65,535 and specifies the DC bus overvoltage threshold.
DC bus undervoltage threshold	SetDriveFaultParameter	Two parameter command. The first must be 1, the second has a range of 0 to 65,535 and specifies the DC bus undervoltage threshold.
Current foldback continuous current limit	SetCurrentFoldback	Two parameter command. The first must be 0, the second has a range of 0 to 32,767 and specifies the foldback continuous current limit
Current foldback energy limit	SetCurrentFoldback	Two parameter command. The first must be 1, the second has a range of 0 to 32,767 and specifies the foldback energy limit
Shunt comparison threshold	SetDriveFaultParameter	Two parameter command, the first must be 8. The second has a range of 0 to 65,535 and specifies the shunt comparison threshold.
Shunt duty cycle	SetDriveFaultParameter	Two parameter command, the first must be 9. The second has a range of 0 to 32,767 and specifies the shunt PWM output duty cycle.

13.5 Signal Processing

The following table shows the signals that are used in connection with the drive and DC Bus safety features.

Pin Name	64-Pin TQFP Pin#	56-Pin VQFN Pin#	Description
Temperature	9	7	Measured Temperature
BusVoltage	13	11	Measured Bus voltage
BusCurrentSupply	10	8	Measured DC Bus Current

When using a thermistor the *Temperature* input signal should be filtered to minimize noise. The *Temperature* input is sampled at a rate of 1kHz or higher, and therefore a low pass filter with a rolloff at 500 Hz or lower is recommended.

13.5.1 Typical Overtemperature Processing Circuitry

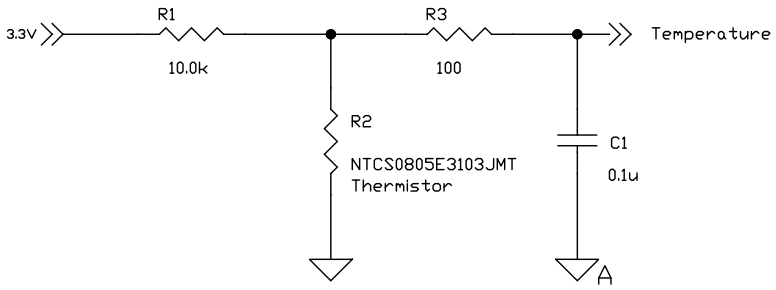


Figure 13-3: Over-temperature Processing Circuitry

Figure 13-3 shows a typical signal processing circuit for use with the *Temperature* input. The thermistor is a 10k NTC temperature-voltage-decreasing type. C1 is referenced to analog ground and should be placed close to the *Temperature* pin of the Juno IC. R3 is optional. It can provide additional filtering to improve noise immunity if needed.

See Section 15.7, "Drive-Related Safety and Monitoring Features" for a complete example schematic of temperature input using Juno ICs.

13.5.2 Typical Overcurrent Processing Circuitry

The DC bus current supply sensor typically consists of a sense resistor, as shown in Figure 13-1, or a linear Hall sensor. The analog processing circuitry required for each is somewhat different. If a dropping resistor is used an isolating operational amplifier, current mirror, or similar circuit should be used. Linear Hall sensors typically use just a ground-referenced operational amplifier.

The *BusCurrentSupply* input range is 0.0V to 3.3V with 0.0V representing no (zero) current flowing and 3.3 volts representing the maximum measurable amount of current flowing. The signal should be filtered to minimize noise, and the source impedance of the signal conditioning circuit should be less that 100 ohms. Current inputs are sampled by a dedicated high speed circuit internal to the Juno IC. To minimize false positives a low pass filter with a roll off value of 350 kHz is recommended.

13.5.2.1 Typical Overcurrent-Processing Circuitry

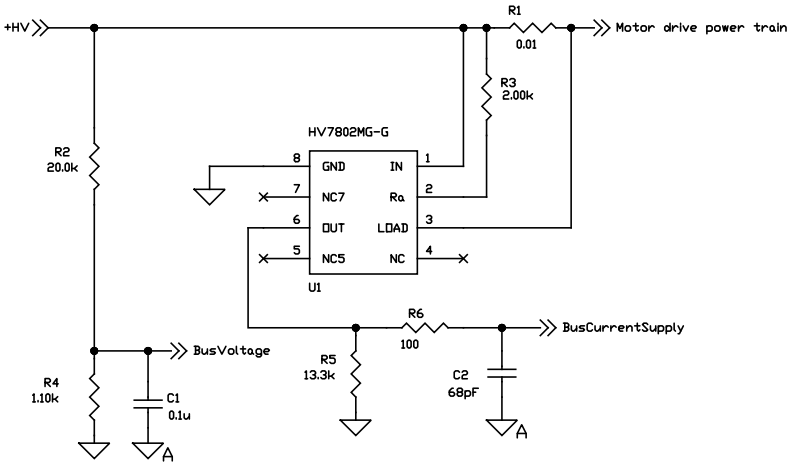


Figure 13-4: DC Bus Monitoring Circuitry

Figure 13-4 shows a typical processing circuit for DC Bus voltage and *BusCurrentSupply* over current sensing. The bus current sensing includes R1, U1, U2A and related passive parts. U1 is a high-side bus current sensing IC, and its output on R7 represents the bus current.

During motor deceleration or other motion conditions it may be possible for the DC bus supply current flow to be negative. Care should be taken to insure that negative currents do not generate a negative voltage at the Juno's BusCurrentSupply analog input pin. This is generally accomplished via a diode. See Section 15.7, "Drive-Related Safety and Monitoring Features" for examples of DC bus safety-related schematics.

13.5.3 Typical Over/Under Voltage Processing Circuitry

The DC Bus voltage sensor typically consists of a voltage divider, which may be created from an isolating operational amplifier, current mirror, or similar circuit.

The *BusVoltage* signal should be filtered to minimize noise. The DC bus voltage input is sampled at a rate of 20kHz, and therefore a low pass filter with a rolloff of 10 kHz or less is recommended.

Figure 13-4 shows a typical processing circuit for DC Bus voltage monitoring. The bus voltage sensing consists of R2, R4 and C1. R2 and R4 scale the bus voltage, between 0 and 3.3V. C1 is referenced to analog ground and should be placed close to the *BusVoltage* pin.

See Section 15.7, "Drive-Related Safety and Monitoring Features" for complete example schematics of DC bus management designs.

13.5.4 Shunt Related Circuitry

The shunt resistor connected should have a resistance such that the current flow through the shunt switch, diode and resistor do not exceed the ratings of those components at the expected DC bus voltage.

The diode, which is connected in parallel to the resistor, should have a voltage and current rating at least equal to those of the switch. See Figure 15-5 for a reference schematic.

14.Power-up, Configuration Storage & NVRAM

In This Chapter

- Power-up
- NVRAM
- Initialization Control
- Settable Parameters
- Signal Processing

14.1 Power-up

After receiving stable power at the Vcc pins Juno begins its initialization sequence. In a power-up where no user-provided configuration settings have been stored this takes approximately 250 mSec. At the end of this sequence all parameters are at their default values, and both the current loop & commutation module and the motor output module are disabled. At this point Juno is ready to receive serial host commands by microprocessor command.

Juno also supports the ability to store configuration settings that are applied during the power up sequence. For this purpose, Juno supports a 1,024 word memory that is non-volatile (NVRAM), meaning the data stored will be available even after power to the Juno IC is removed.

The power-up initialization information stored in the NVRAM takes the form of host command packets, however rather than being sent via the serial port, these packet words are stored in memory. If the non-volatile memory has been loaded with configuration information the power-up sequence detects this and begins executing these commands. Note that processing stored commands may increase the overall initialization time depending on the command sequence stored.

14.2 NVRAM

Juno torque control ICs provide a 1,024 16-bit word NVRAM. The primary purpose of the NVRAM is to allow configuration information to be stored, so that upon power up the Juno IC can be configured and initialized automatically rather than requiring serial host commands to perform this function.

All data stored in the Juno's NVRAM utilizes a data format known as PMD Structured data Storage Format (PSF). Users who rely only on PMD Corp.'s Pro-Motion software package need not concern themselves with the details of PSF. Users who want to address the NVRAM from their own software, or who want to create their own user-defined storage should refer to the *Juno Velocity & Torque Control IC Programming Reference* for detailed information on PSF.

14.3 Initialization Control

To make the initialization sequence as flexible as possible Juno provides a facility to control execution of the initialization commands stored in NVRAM. Command execution can be suspended for a specific period of time, or until various internal or external conditions are satisfied. This is useful for coordinating Juno IC startup with external processes on the user's controller board, or to execute simple motion sequences prior to normal operation.

The execution conditions that can be used to control initialization are: delay a specified amount of time, compare against the Event Status register, compare against the Activity Status register, compare against the Drive Status register, or compare against the Signal Status register

These conditions allow initialization command sequences such as "Rotate the motor after the *Index* signal goes high," and "Change the profile torque once the profile velocity has reached zero."

Pro-Motion Windows software supports a basic initialization control sequence that will be sufficient for most users. For more detailed information on the function and format of the execution control command refer to the *Juno Velocity & Torque Control IC Programming Reference.*

14.4 Settable Parameters

Parameter	Host Command Mnemonic	Range & Description
Initialization control settings	ExecutionControl	Two parameter command. The first is a bit-encoded word that specifies the execution condition as well as the scaling of the timeout delay. The second is either the timeout delay value or selection & sense masks, depending on the execution condition selected in the first parameter.

14.5 Signal Processing

14.5.1 Output Signal Status During Power-up

The following table summarizes the Juno step motor control IC output signal states during power up and after power-up when no initialization data is stored in the NVRAM.

Pin Name	64-Pin TQFP Pin#	56-Pin VQFN Pin#	State during power-up	State after power up
PWMHighA/PWMMagA	56	49	Tri-stated	Tri-stated
PWMLowA/PWMSignA	55	48	Tri-stated	Tri-stated
PWMHighB	54	47	Tri-stated	Tri-stated
PWMLowB	53	46	Tri-stated	Tri-stated
PWMHighC	51	45	Tri-stated	Tri-stated
PWMLowC	50	44	Tri-stated	Tri-stated
AmplifierEnable	3	22	Pulled high	Driven low
FaultOut	52	40	Tri-stated	Driven low
SrlXmt	27	24	Pulled high	Pulled high
SPIXmt	34	30	Pulled high	Driven low
~HostInterrupt	46	43	Pulled high	Driven high

If configuration data has been stored in the NVRAM then the final power-up condition of various outputs signals may be affected. See the detailed description of the specific commands that are stored into the NVRAM for details.

14.5.2 Reset

The Juno torque control ICs require various conditions to be present on the *Reset* pin for proper reset and power-up.

The table below shows the Juno reset signal:

Pin Name	64-Pin TQFP Pin#	56-Pin VQFN Pin#	Description
Reset	7	5	Reset input

14.5.2.1 Typical Reset Processing Circuitry

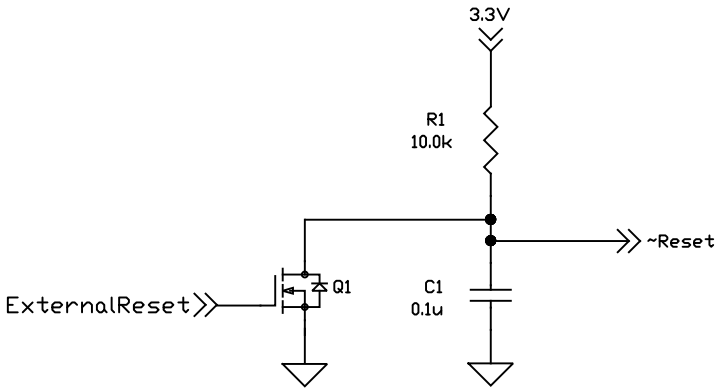


Figure 14-1: Typical Reset Processing Circuitry

Figure 14-1 shows a typical reset circuit for the torque control Juno ICs. Although included in this circuit, external control of the *Reset* signal is not required since the Juno IC will trigger an internal reset upon power up. The ~*Reset* pin is driven low by Juno under a power-on or reset condition. If external reset is implemented an open-drain device is used. If no external reset is implemented, Q1 from the above circuit is eliminated.

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15. Application Notes

In This Chapter

- General Design Notes
- Design Tips
- Power Supplies
- Clock Generator, Grounding and Decoupling
- Clock Generator, Grounding and Decoupling
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- Analog Inputs
- Drive-Related Safety and Monitoring Features
- Shunt Resistor Drive
- PWM High/Low Motor Drive With Leg Current Sensing/Control
- Using the TI LMD18200 to Drive DC Brush Motors
- Two Juno BLDC Motor Amplifiers With Multi-Axis Magellan

15.1 General Design Notes

In the subsequent sections please note that unless otherwise noted MC71112 refers to both the MC71112 and MC71112N ICs, and MC73112 refers to both the MC73112 and MC73112N ICs.

Logic functions presented in the example schematics are implemented by standard logic gates. In cases where specific parameters are of significance (propagation delay, voltage levels, etc.) a recommended part number is given.

In the schematics, pins with multiple functions are referenced by the name corresponding to the specified functionality. For example, pin 56 on the MC71112 is named "PWMHighA/PWMMagA" but will be referenced by the name "PWMHighA" in the PWM High/Low motor drive schematic example and "PWMMagA" in the sign/magnitude motor drive schematic example.

The schematic designs presented in this chapter are accurate to the best of PMD Corp.'s knowledge. They are intended for reference only and have not all been tested in hardware implementations.

15.1.1 Interfacing to Other Logic Families

When integrating different logic families, consideration should be given to timing, logic level compatibility, and output drive capabilities. The MC71112 and MC73112 are 3.3V CMOS input/output compatible and cannot be directly interfaced to 5V CMOS components. In order to drive a 5V CMOS device, level shifters from the 5V CMOS AHCT (or the slower HCT) families can be used. When using a 5V CMOS component to drive the CP, a voltage divider may be used or a member from the CMOS 3.3V LVT family may serve as a level shifter.

15.2 Design Tips

15.2.1 Controlling PWM Output During Reset

When the MC71112 or MC73112 are in a reset state (when the reset line is held low), or immediately after a power on, PWM output will be in a high impedance state, which will provide design flexibility to prevent undesirable motor movement at system level. For example, when the power train is active high in PWM High/Low mode, pull-down resistors can be used to keep the power train off during reset and power up. For an active low power stage, pull-up resistors can be used.

15.2.2 Thermal Considerations

The recommended operating junction temperature range for the MC71112 and MC73112 is between -40°C and 150°C. Proper thermal design will ensure the system reliability. Based on a simplified resistor model for heat transfer, following thermal matrices under different conditions are provided for thermal design.

AIR FLOW (64-Pin TQFP Package)				
Parameter	**0 lfm**	**150 lfm**	**250 lfm**	**500 lfm**
θ_{JA}[°C/W] High k PCB	56.5	44.7	42.9	40.3
ψ_{JT} [°C/W]	0.15	0.42	0.51	0.67

AIR FLOW (56-Pin VQFN Package)				
Parameter	**0 lfm**	**150 lfm**	**250 lfm**	**500 lfm**
θ_{JA}[°C/W] High k PCB	34.8	23.6	22.3	20.5
ψ_{JT} [°C/W]	0.24	0.36	0.43	0.56

θ_{JA} is the junction-to-ambient thermal resistance. Although it is an important design reference, this thermal metric highly depends on the board design and system configurations. Directly using it for junction temperature estimation could result in misleading results because the environmental factors are different from design to design.

ψ_{jT} (junction to top of package) is provides as an useful thermal metric for estimating the in-situ junctional temperature. The environmental factors do not affect this metric as much, and it can be easily measured. Also, because ψ_{jT} is small, if a user chooses to, the top of package temperature might be approximated as the junctional temperature for design estimation when enough thermal design margin is included.

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15.3 Power Supplies

In the schematic shown in Figure 15-1 the design is powered by an external +5VCC power source. The MC71112 and MC73112 require a 3.3V supply input. +3.3Vs, the 3.3V digital supply, is generated by the TPS76733QPWPRG4, a 1.0 Amp fixed 3.3V low-dropout voltage regulator.

If the MC71112 or MC73112 analog inputs are used it should be supplied with a filtered +3.3Vs supply.

The following is the list of supplies which are referenced in the example schematics within this application notes section of the manual:

- +3.3Vs and +3.3V_Analog: +3.3Vs is the main digital supply for the MC71112 and MC73112 devices. +3.3V_Analog is the filtered version of the +3.3Vs supply for ADC and its related conditioning circuitry. The extra filtering is used to provide additional decoupling of the analog elements from the digital elements in the circuitry.

Notes:

- The power supplies schematic provided in Figure 15-1 is for reference only, and is designed only to meet the requirements of the example schematics used in the application notes section of the manual. The actual supplies used should be designed according to the stability and precision requirements of the application.
- Power supplies for the motor drive amplifiers/switchers are not shown. Care should be taken when designing these power supplies, as they should be capable of sinking high switching currents.

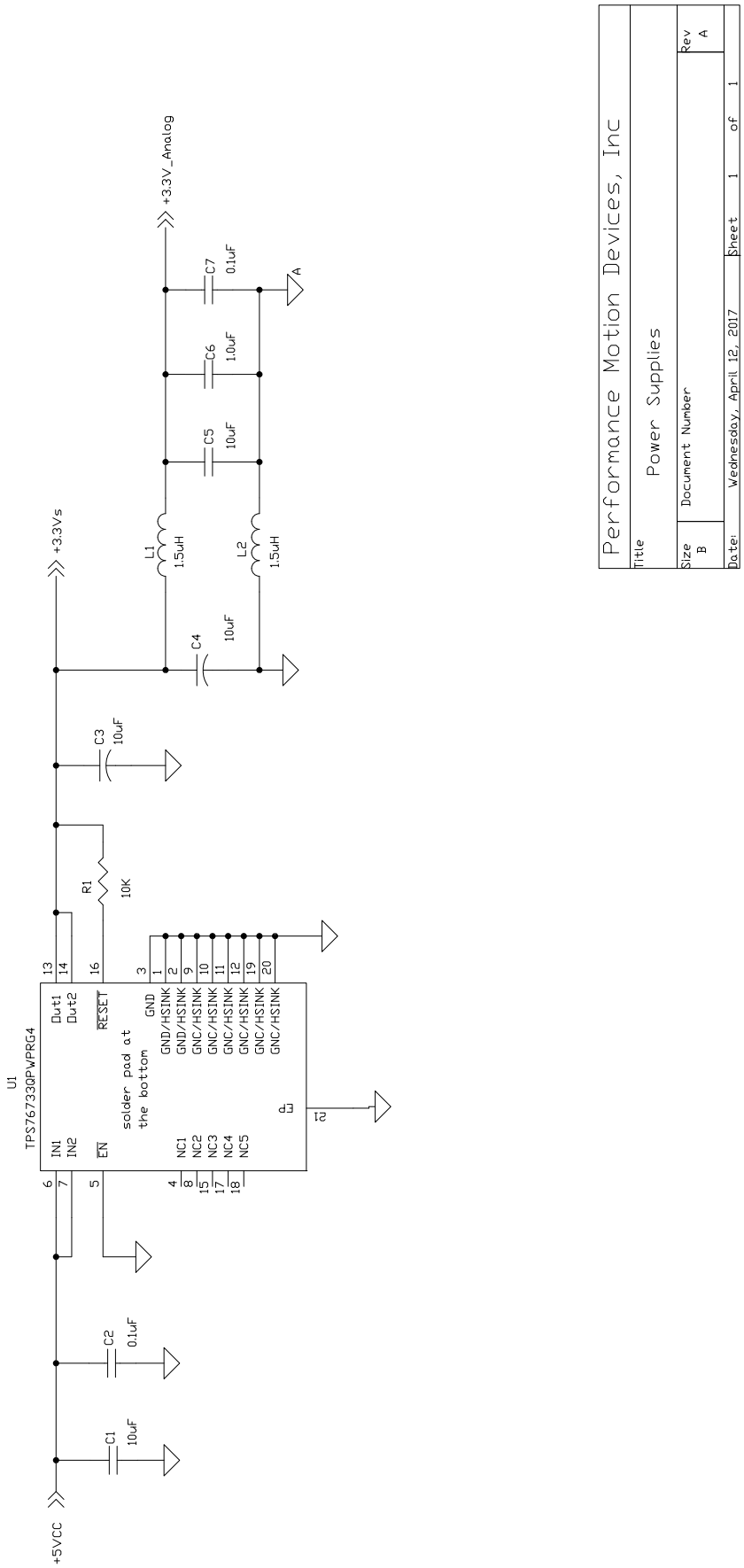


Figure 15-1: Basics, Power Supplies, MC71112 and MC73112

15.4 Clock Generator, Grounding and Decoupling

15.4.1 Grounding and Decoupling

As shown in Figure 15-2, each of the digital supply voltage pins should be connected to the +3.3 Vcc. A minimum of 1.2µF capacitor should be used to decouple each Vcc pin. A 2.2µF ceramic capacitor is recommended. If the +3.3 Vcc source is noisy, additional ferrite bead can be placed in series with the decoupling cap to form a LC filtering network on the power pin.

Each of the "FltCap" pins should be connected to a minimum of 1.2µF filtering capacitor which in turn connects to ground. A 2.2µF ceramic capacitor is used in the schematic. The filtering capacitors must be placed as close as possible to each one of the "FltCap" pins. This general rule applies to all analog and digital components, although in some of the schematics that follow these capacitors are not shown for reasons of brevity. In some cases, especially for analog processing circuitry, it may be beneficial to run a separate power line from the power supply to the component in order to prevent power supply fluctuations from impacting low-level signal components.

The same points should be considered when designing the ground. A good board layout practice should have a star connection at one point in the power supply.

Additional filtering, such as ferrite beads, may be inserted between the analog and digital grounds to suppress high frequency ground noise. Some components, such as motor drivers, require special grounding. The system designer should refer to the component data sheets of selected components in order to ensure correct usage of the grounding methods.

15.4.2 Decoupling of the On-chip ADC

The voltage supply to the ADC should be decoupled with a 2.2µF ceramic capacitor (typical) on the pin. It should be placed as close as possible to the ADC power supply input pins.

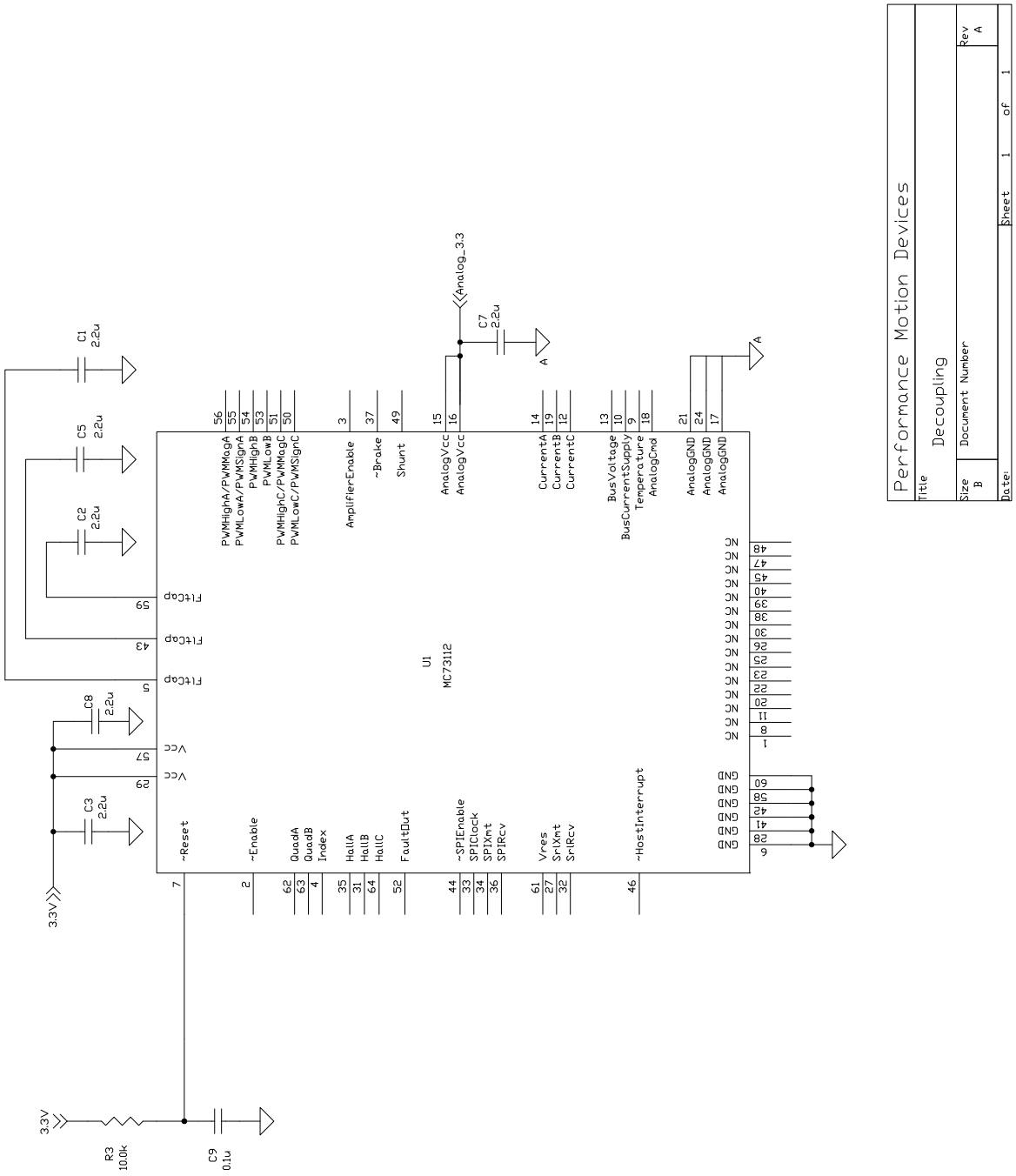


Figure 15-2: Basics, Clock and Bypass Caps, MC71112 and MC73112

15.5 Reset Signal

The MC71112 and MC73112 chips have a built-in power supervisory circuitry that generates an internal reset signal when a power-on or brown-out condition occurs. As such, no external circuitry is needed to generate a reset input pulse. An R-C circuit must be connected to this pin for noise immunity reasons.

The supervisor reset release delay time is typically 600 µsec after the power-on or brown-out condition event is removed. If need be, an external circuit may also drive this pin to assert a device reset. In this case, it is recommended that this pin be driven by an open-drain device.

All digital output signals have an internal pullup except for *FaultOut* and the *PWM* signals. See Section 14.5.1, "Output Signal Status During Power-up" for more information. If the *AmplifierEnable* and *FaultOut* signals are used they should have an external pull down resistor to prevent any glitches during reset.

During the initialization period, the MC71112 and MC73112 are configured with the default initialization parameters for communication, analog offsets, control loop gains etc. If necessary, the on chip non-volatile storage can be used to store user-programmed initialization parameters. For more information see Section 6.1, "Loading the NVRAM."

15.6 Analog Inputs

The Juno IC products support analog command signal and tachometer analog feedback signal. The following example schematic in Figure 15-3 illustrates the analog conditioning circuit.

The MC78113 is equipped with a 12-bit ADC. The ADC converts from 0 to 3.3V fixed full scale range. The ADC power supply should be decoupled with a low-ESR capacitor. For example, place a 2.2uF ceramic capacitor or a 2.2-6.8 µF tantalum capacitor in parallel with a 0.01-0.1 µF ceramic capacitor as closely as possible to the power supply and ground pins.

The digital value for analog command signal and tachometer analog feedback signal derived from the input analog voltage is determined using the following formula.

Digital value = 0 when input = Vref

Digital value = 32,768 x (input voltage- Vref)/3.3V when 0V <= input <=3.3V

where Vref is 1.65V typical, and the user can set offset value to compensate the offset in the circuit.

Figure 15-3 shows a differential signal conditioning circuit for +/-10V analog command signal. The analog command signal is assumed to be differential, AnalogCmd+ and AnalogCmd-. For single-ended input signal, connect the input signal to AnalogCmd+ and the AnalogCmd- end to ground. The same circuit can be used for tachometer analog feedback signal conditioning.

The differential amplifier stage scales the input signal to the range of 0 and 3.3V as

AnalogCmd= G(AnalgoCmd+-AnalogCmd-)+1.65V

For +/-10V input and Vref as 1.65V, the gain is G= 0.165.

When R1=R5, and R2=R4, its DC gain is

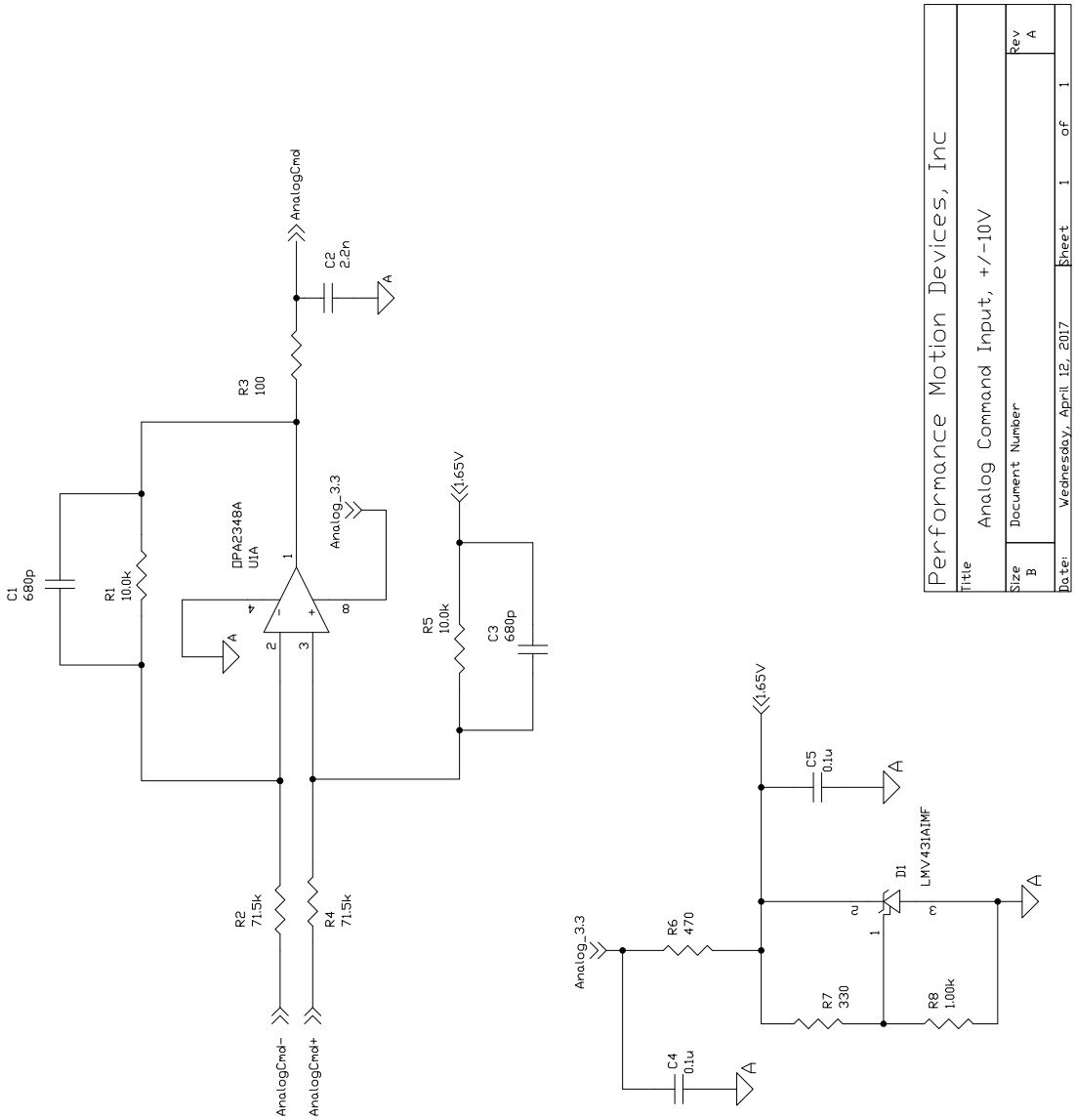
AnalogCmd= (R1/R2)(AnalogCmd+ - AnalogCmd-)+1.65V

When R1 = R5= 10.0 kohms and R2 = R4= 71.5kohms, the gain is 0.14, which is slightly lower than 0.165 to accommodate offsets and tolerances.Please use 1% or better grade resistors for better common mode performance

C1 and C3 set the bandwidth of the filter. With C1=C3, the bandwidth is 1/(2*pi*R1*C1). For R1=10.0kohms and C1=680pF, the bandwidth is 23.4kHz.

The low-pass RC filter of R3 and C2 limits the load on the opamp. C2 should be placed close to the ADC input pin, as it partially drives the sample capacitor of the ADC.

Figure 15-3: Analog Input Interface



15.7 Drive-Related Safety and Monitoring Features

This example shows the motor drive-related analog monitoring features. Please refer to Section 15.9, "PWM High/ Low Motor Drive With Leg Current Sensing/Control" for leg current sensing functions.

The block of R9, R10, R13 and C5 is for temperature sensing. R13 is a thermistor, and its resistance depends on the temperature. MC71112 and MC73112 will sense the scaled voltage and convert it into temperature reading. C5 need to be tied close to the Temperature pin to improve noise immunity.

In this example, it is assumed that the thermistor is away from the MC71112 and MC73112 and close to the power train, which usually has the highest temperature. Accordingly, C5 is referred to the analog ground, and R13 to digital ground. R10 is optional to improve the noise immunity. If R13 is close to the analog portion, Vcc can be AnalogVcc instead and R13 be tied to the analog ground.

The block of R2, R3, R5 and C3 is for input voltage sensing. This voltage divider will scale the +HV into the range between ground and 3.3V. In this example, it will scale 63V to 3.3V. C3 need to be tied close to BusVoltage pin. The voltage divider is referenced to digital ground while C3 is to analog ground. An optional resistor can be put between R5 and C3 to improve noise immunity as R10 does for temperature sensing function. This block is also a low-pass filter with bandwidth of 1.5kHz. This bandwidth should be selected to respond to real voltage fault event while attenuating bus noise.

U1 is the high side bus current sensing IC. With current sensing resistor R1 at 10mOhm, U1 has a current scaling factor of (13.3/2*0.01)=66.5mV/A.

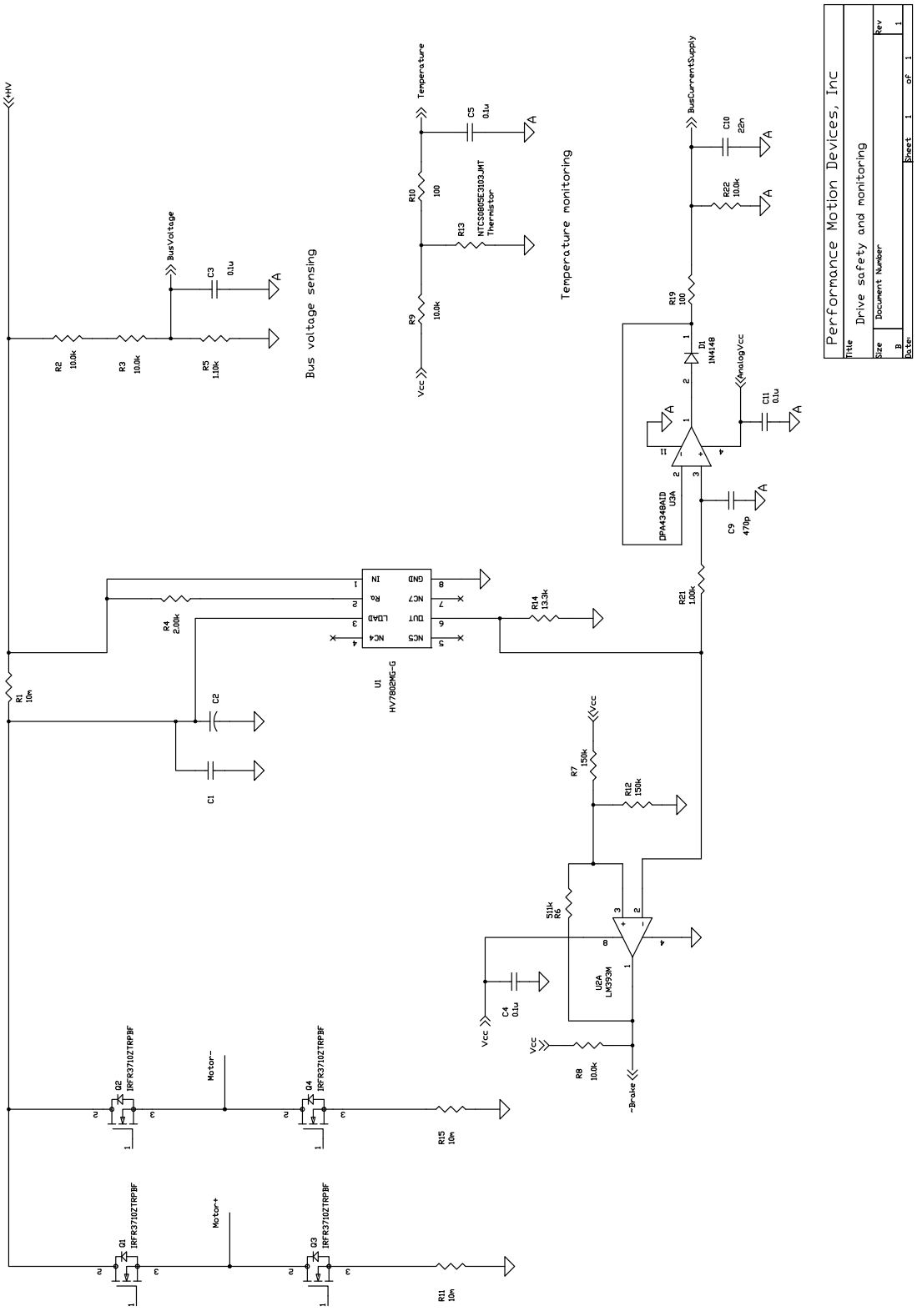
U2A is for short circuit protection. R12 and R7 set the protection trigger point, and R6 provides a hysteresis. When Vcc is 3.3V, the trigger point is 1.65V with hysteresis. Brake will go to low and trigger protection when U1 output is over 1.65V, which is (1.65/66.5mv/A)= 25A.

The output of U1 also goes to U3A, which is a peak-detection circuit. The analog input is sampled at 20kHz. The peak-detection circuit will hold the maximum peak current reading between the sampling points so MC78113 can detect the maximum current. The necessity of this peak-detection circuit depends on the power train design. For example, if C1 and C2 have big enough capacitance so that the current in R1 will be close to DC, U3A can be a buffer instead.

This peak detection circuit (U3A) is optional. If not used, the BusCurrentSupply pin has an internal comparator, and this comparator can also detect overcurrent.

MC71112 and MC73112 supports leg current sensing with current loop control, and R11 and R15 are leg current sensing resistors.

Figure 15-4: Drive Safety and Monitoring



15.8 Shunt Resistor Drive

This example shows the shunt function driving a brake resistor.

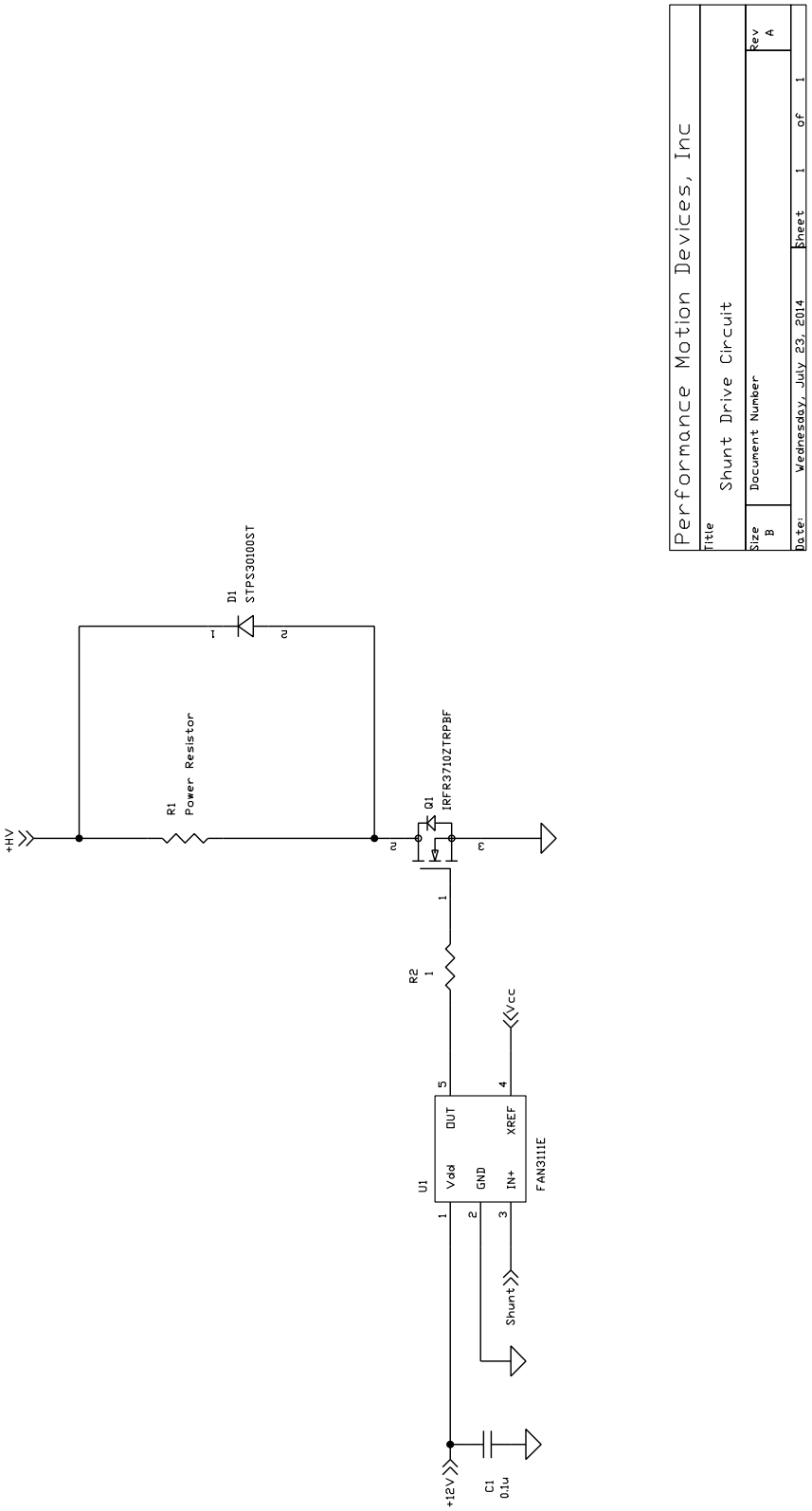
The power train driven by the MC78113 is capable of regeneration. It could harvest the mechanical energy during slow down or direction reversion and transfer the energy back to the power input. When the input power supply cannot handle the regenerative power, input voltage +HV will go up and over-voltage is possible. The Shunt pin can implement dynamic braking, which will convert the energy into heat and stabilize the +HV voltage.

The shunt signal is controlled based on the input voltage sensing, and it will become active when input voltage is too high.

Shunt is a PWM-based signal and drives MOSFET Q1 through driver U1. When Q1 is turned on, current will flow through R1 and consume energy. When Q1 is turned off, D1 will provide a free-wheeling path for the current in R1 decaying to zero. Q1 and D1 should be sized to handle the current. Also, R1, Q1 and D1 should be sized to handle both the instantaneous power and average power during braking operation.

Upon power up or during reset, the ***Shunt*** pin is high impedance. In this example, U1 has internal pull-down resistor to ensure Q1 is off. If a different driver is used a pull-down or pull-up resistor might be necessary to ensure the shunt function is off for safe power up and reset.

Figure 15-5: Shunt Drive Circuit



15.9 PWM High/Low Motor Drive With Leg Current Sensing/Control

This section presents several design examples PWM high/low motor drive with leg current sensing. The examples focus on different priorities including power rating, cost, and noise immunity.

15.9.1 Leg Current Sensing

Figure 15-6 shows an example for leg current sensing. Only phase A is shown here while the design for other legs are the same.

This example has two functional sections. The first is the current sensing sensor, and the second is the analog signal conditioning circuit.

In this example, the leg current sensor is a resistor, R2. Q1 and Q2 are the half-bridge power train for motor winding phaseA. Current sensing resistor R2 senses the leg current in Q2, which equals the motor winding current when Q2 conducts.

Q2 is switching at the PWM frequency, and the voltage drop on R2 is proportional to the motor winding current when Q2 is on. Therefore, the voltage signal is also a chopping signal. The signal is always sampled when Q2 is on to ensure an accurate reading. Also, the voltage drop can be positive, negative or zero depending on the winding current direction.

U1 and the passive parts are the analog conditioning circuit. It scales and filters the voltage signal on R2 and input to the analog input pin CurrentA.

U1A is configured as a differential amplifier with R3=R5 and R1=R6. It amplifies the voltage drop across R2, which is the differential voltage. It also attenuates the common mode noise including the noise on the power train.

D1 provide a 1.65V voltage bias source as half the 3.3V ADC range. This bias can be shared with current sensing stages of other phases. With this voltage bias, R2 current is sensed in either direction.

By default, the MC71112 and MC73112 take 1.65V reading as zero current. Host commands can be sent to compensate the error introduced by the offsets and tolerances of the current sensing circuit.

R4 and C1 is a low pass filter to reduce output noise. It also alleviates the signal glitch due to ADC sampling. R4 and C1 have to be placed close to CurrentA pin. Please note, because the signal on R2 is a chopping signal at the PWM frequency, the bandwidth of R4 and C1 should be much higher than the PWM frequency preventing signal distortion/delay.

The gain of the current sensing circuit is

$V_{CurrentA}$ = I_leg*R2*R1/R3+1.65

For this example, it is

$V_{CurrentA}$ = I_leg*0.02*54.9/10.0+3.3/2= 0.1098*I_leg+1.65

I_leg is defined as positive flowing from the ground to Q2 as shown in the schematic. It is because the current out of the half bridge and into motor winding is defined as positive.

Therefore, the current sensing range is ±15A. This current range should include the peak current during dynamic regulation. For example, during acceleration, the instantaneous current could be twice of the continuous current or even more.

With the continuous current and peak current known, the power rating of the current resistor can be determined. The conservative design rule is to assume that the current will go through R2 continuously, and the power dissipation is

$I^{\wedge 2}*R_2$. However, the current will only flow through the resistor when Q2 is on; that is, if the duty cycle is known for this leg, the power dissipation can be approximated as $I^{\wedge 2}*R_2*(T_{Q2ON}/T_{PWM})$ and resistor can be sized accordingly.

The board layout is critical for an optimal current sensing signal. The current sensing traces (to R3/R5) should be separated from the power path through R2, and these two traces should be routed in pair to improve its common-mode noise immunity. Also, a motor power train has multiple current sensing resistors, and these resistors are referred to ground. During layout, please treat those ground traces (e.g. trace to R5) as separated traces for each leg.

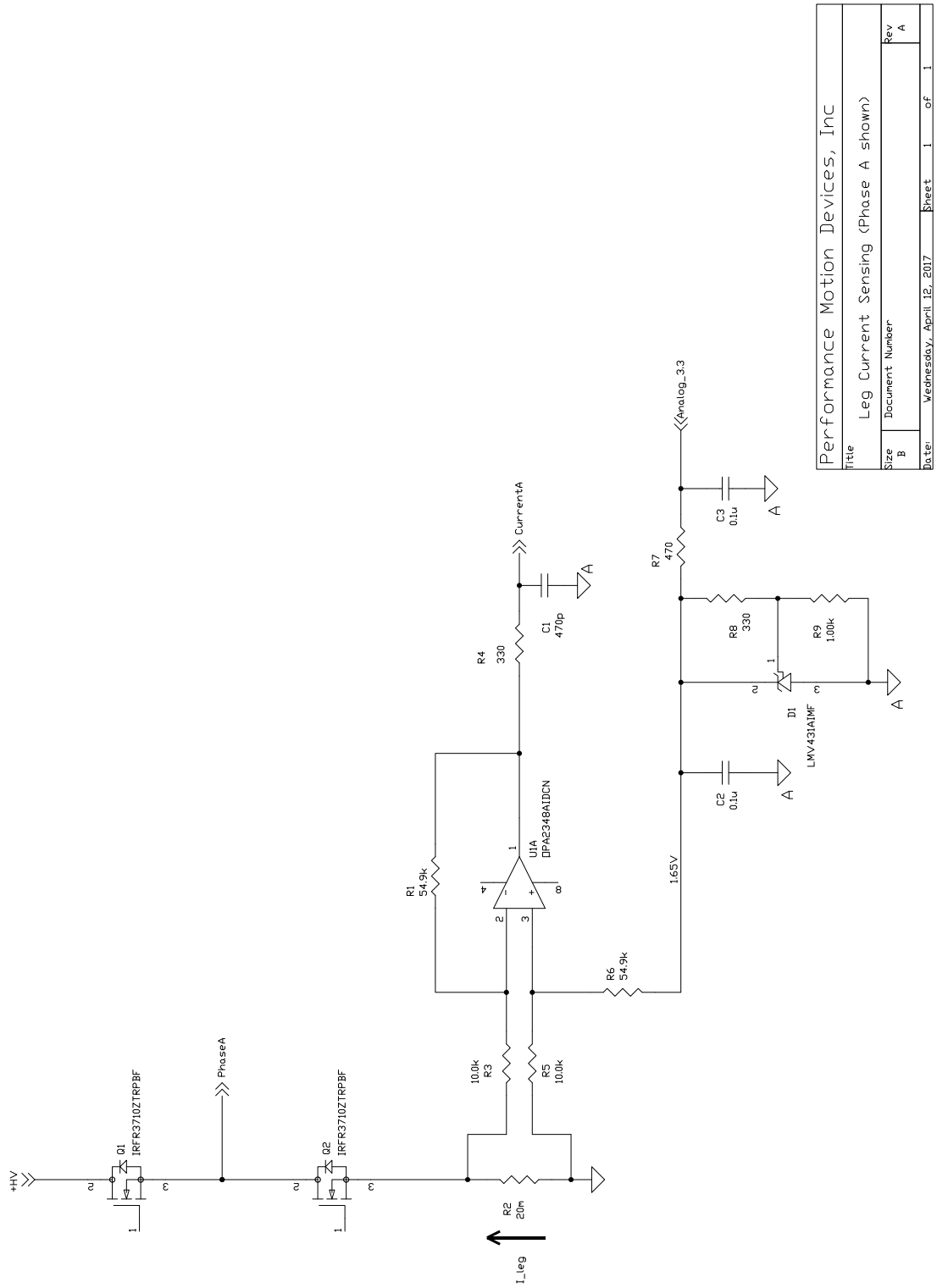


Figure 15-6: Leg Current Sensing

15.9.2 Low Cost DC Motor Drive

This example presents a low-cost, high performance DC motor drive.

The power train shown is an H-bridge (two half-bridge) for DC motor winding Motor+ and Motor-. The input voltage can be up to 24V. It is capable of driving 1A continuous current with peak current of 2A.

The design for the two half-bridges and their current sensing circuits are the same. Using Motor+ as an example, the half bridge has a P-channel MOSFET as the upper switch and an N-channel MOSFET as the lower switch, which is driven by PWMHighA and PWMLowA through buffer U1.

During normal operation, PWMLowA is active low. A logic "0" will generate 5V output at U1B, which turn on the lower N-channel MOSFET. R15, R7 and D5 provide an unsymmetrical turn-on and turn-off capability.

PWMHighA is active high. A logic "1" will generate 0V output at U1A, which will pull C2 to ground. +HV will charge C2 through D1 and R1 with voltage clamped by D1 (5.1V typical). This clamped voltage will turn on the P-channel MOSFET. When PWMHighA is "0", U1A outputs 5V, and C2 will discharge and turn off the P-channel MOSFET. R3, D3 and R5 provide an unsymmetrical turn-on and turn-off capability.

Juno allows the user to configure the active polarity of all PWMs.

Upon power up or during reset, PWMHighA and PWMLowA outputs are high impedance. Therefore, pull-up resistor R13 and pull-down resistor R9 are used to ensure that the upper and lower switches are all off. Also, when a hard fault is triggered, PWMHighA and PWMLowA will go into high impedance, and R13 and R19 will turn off the MOSFET and put the output of the half bridge into high impedance.

R11 is the current sensing resistor, and U2A is the differential amplifier for signal conditioning. Please see Section 15.9.1, "Leg Current Sensing" for more design considerations on leg current sensing.

This design has a low BOM cost and a small board footprint suitable for cost-sensitive or size-sensitive applications. However, its limits are also obvious. For example, the MOSFET driver's driving capability is limited by U1, and current capability is limited by the P-channel MOSFET. Therefore, this design is a good candidate for low voltage and low current applications. For higher voltage and higher current applications, please refer to following examples for half-bridge design.

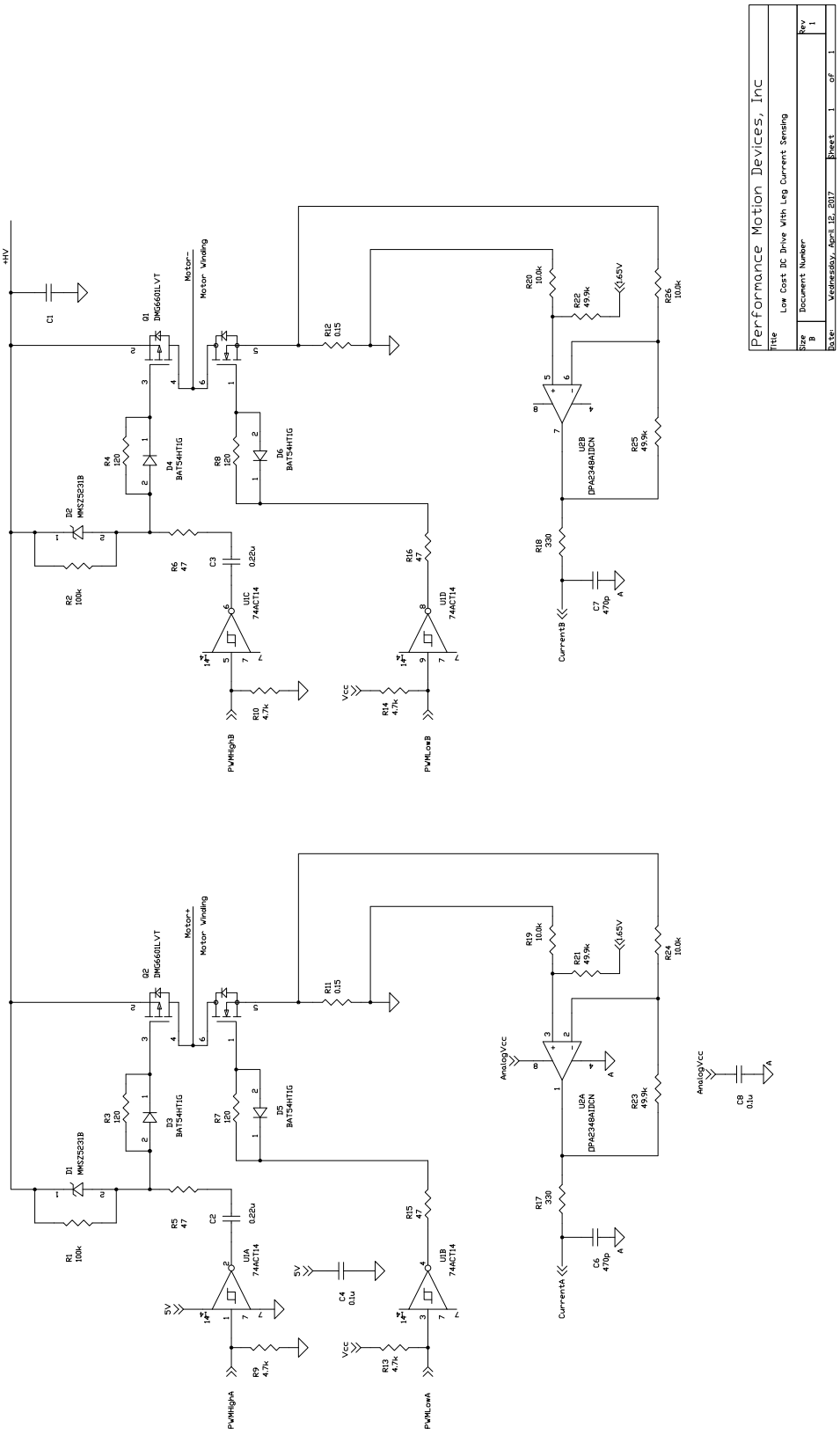


Figure 15-7: Low Cost DC Drive with Leg Current Sensing

15.9.3 Brushless DC Motor Drive

This example shows a brushless DC motor drive with leg current sensing. The power train has three half-bridge for BLDC motor's three winding terminals. The input voltage in this example can be up to 56V. It is capable of driving 15A continuous current with peak current of more than 25A.

The design considerations for each half-bridge and their current sensing circuits are the same. Using PhaseA+ as example, the half bridge uses N-channel MOSFETs for both the higher and the lower switch to achieve high efficiency. The half bridge is driven by PWMHighA and PWMLowA through MOSFET driver U4, which is powered by 15V.

During normal operation, PWMHighA and PWMLowA are active high. For PWMLowA, a logic "1" turns on the MOSFET Q3. R25, R26 and D3 provide an unsymmetrical turn-on and turn-off capability.

A logic "1" PWMHighA will turn on Q1. C11 is the bootstrapping capacitor, and it is charged through D1 when Q3 is turned on. C11 provides the power to turn on Q1, and C11 needs to be a low-ESR capacitor such as a ceramic capacitor. D1 should be a fast switching diode with low leakage current, and its voltage rate should be chosen based on +HV and the +15V. R23 is optional; it can limit the charging current, especially during power up when C11 is zero voltage. R20, R24 and D2 provide an unsymmetrical turn-on and turn-off capability.

Upon power up or during reset, PWMHighA and PWMLowA output are high impedance. Therefore, pull-down resistors R36 and R37 ensure that the upper and lower switches are all off so that the half bridge output is high impedance. Usually the MOSFET driver has internal pull-up or pull-down resistors, and the user needs to check the driver's datasheet and decide if the resistors are necessary.

Juno has an AmplifierEnable output, and it is used to shut down the MOSFET driver through the SD pin. Upon power up or during reset, AmplifierEnable is high impedance, and pull-down resistor R19 will ensure all motor output high impedance. When AmplifierEnable pin is used, the pull-down resistors R36/R37 are options.

R29 is the current sensing resistor, and U1A is the differential amplifier for signal conditioning. Please see Section 15.9.1, "Leg Current Sensing" for more design considerations on leg current sensing.

This design uses dedicated MOSFET drivers and N-channel MOSFETs to achieve high efficiency and high performance. This example is suitable for applications in high noise environments. The MOSFET driver U4 has two ground references: Vss for the digital side and COM for the power side. The MOSFET turn-on and turn-off current out of pin LO will return from dedicated traces to pin COM instead of ground plane, which makes the board layout easier for noise immunity. The COM connection scheme shown also applies for H-bridge and 3-phase MOSFET driver with dedicated COM pin. For this example with independent half-bridge MOSFET drivers, COM pins can also be connected to respective MOSFET source pins to further improve the driving performance. Please refer to the low cost DC drive example if cost is critical and to the Stepper drive example for general-purpose applications.

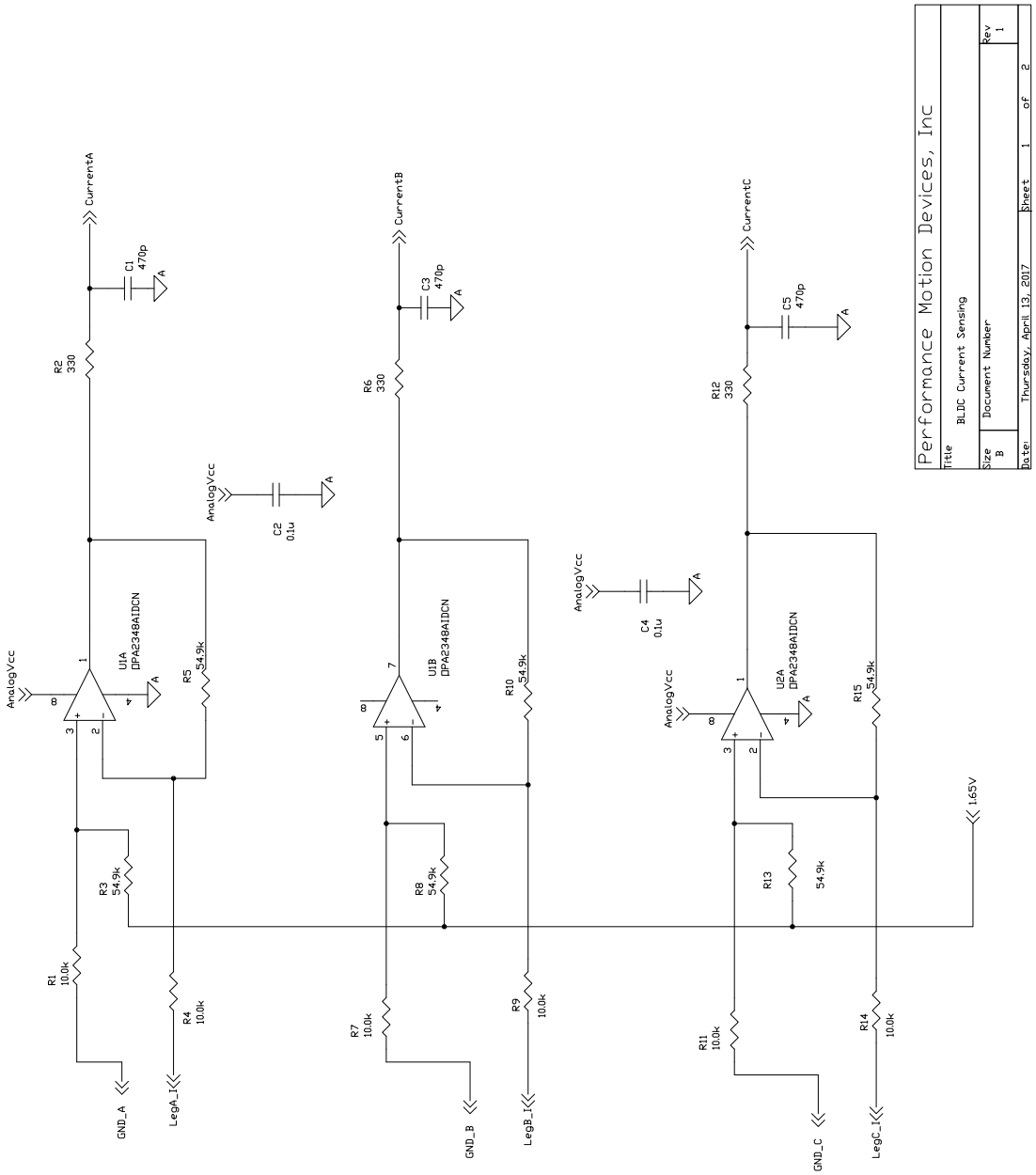
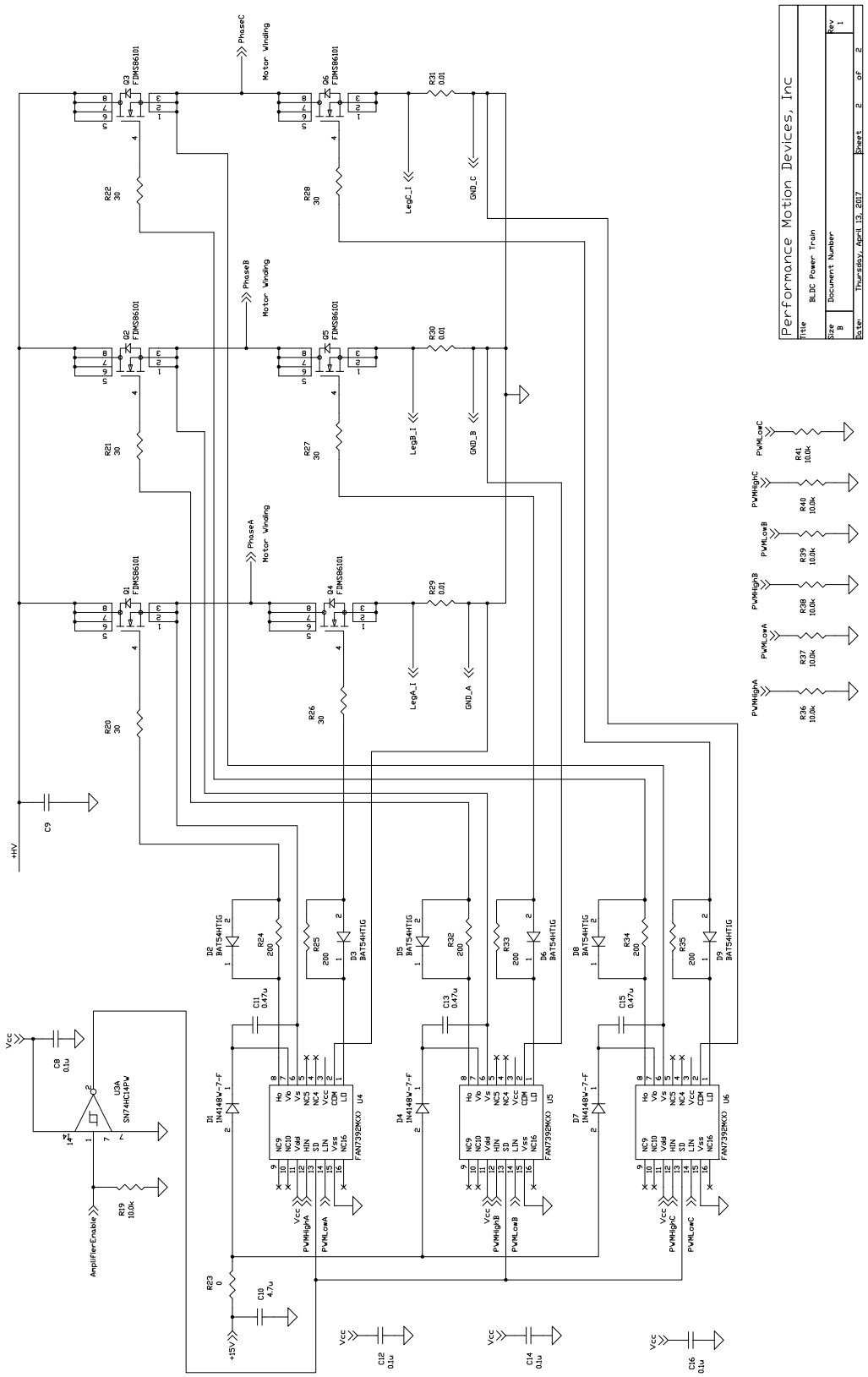


Figure 15-8: BLDC Motor Drive - Leg Current Sensing

Figure 15-9: BLDC Motor Drive - Power Train



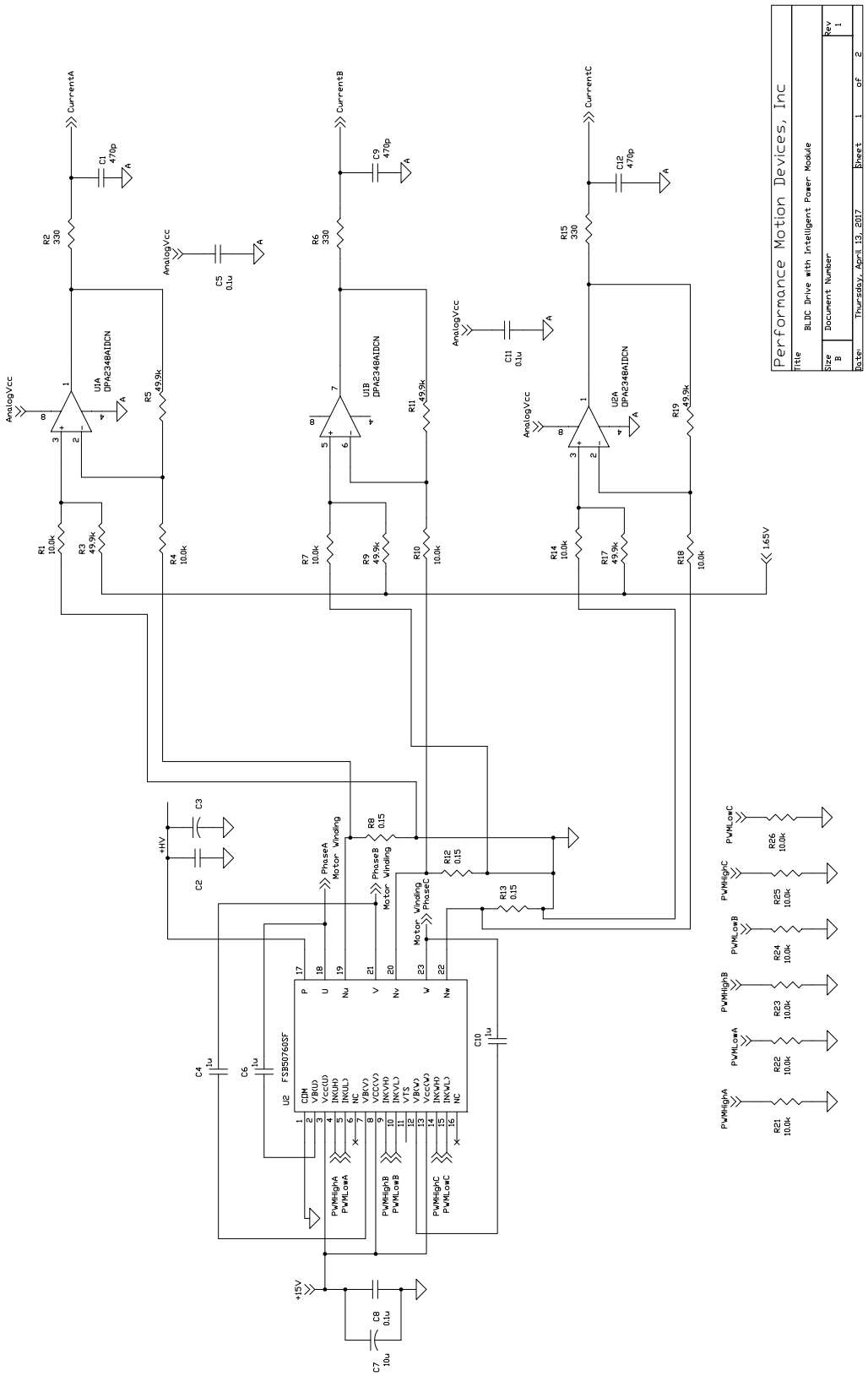
15.9.4 Brushless DC Motor Drive With Intelligent Power Module

Intelligent power modules integrate a power train, gate driver and protection circuitry into a single package. They have advantages of simply design, improved system reliability and fast time-to-market. This schematics show an example of a BLDC drive with an intelligent power module with current capability of 1A.

The module operates in the same way as the discrete solution as shown in previous sections. Please refer to the section on BLDC motor power train and step motor drive power train for details.

Because intelligent power modules have control signals and a noisy power train in one package some special filters might be required. Please refer to the specific power module's user guide for details.

Figure 15-10: BLDC Drive with Intelligent Power Module



15.10 Using the TI LMD18200 to Drive DC Brush Motors

In the following schematic, a magnitude and direction *PWM* signal is used to drive a DC brush motor with a nominal 24V, 2A drive. The H-bridge driver selected for this task is the LMD18200, which can be driven directly from a 3.3V CMOS logic output and as such can be directly interfaced to Juno ICs.

There are two methods in which the output current of the H-bridge may be controlled.

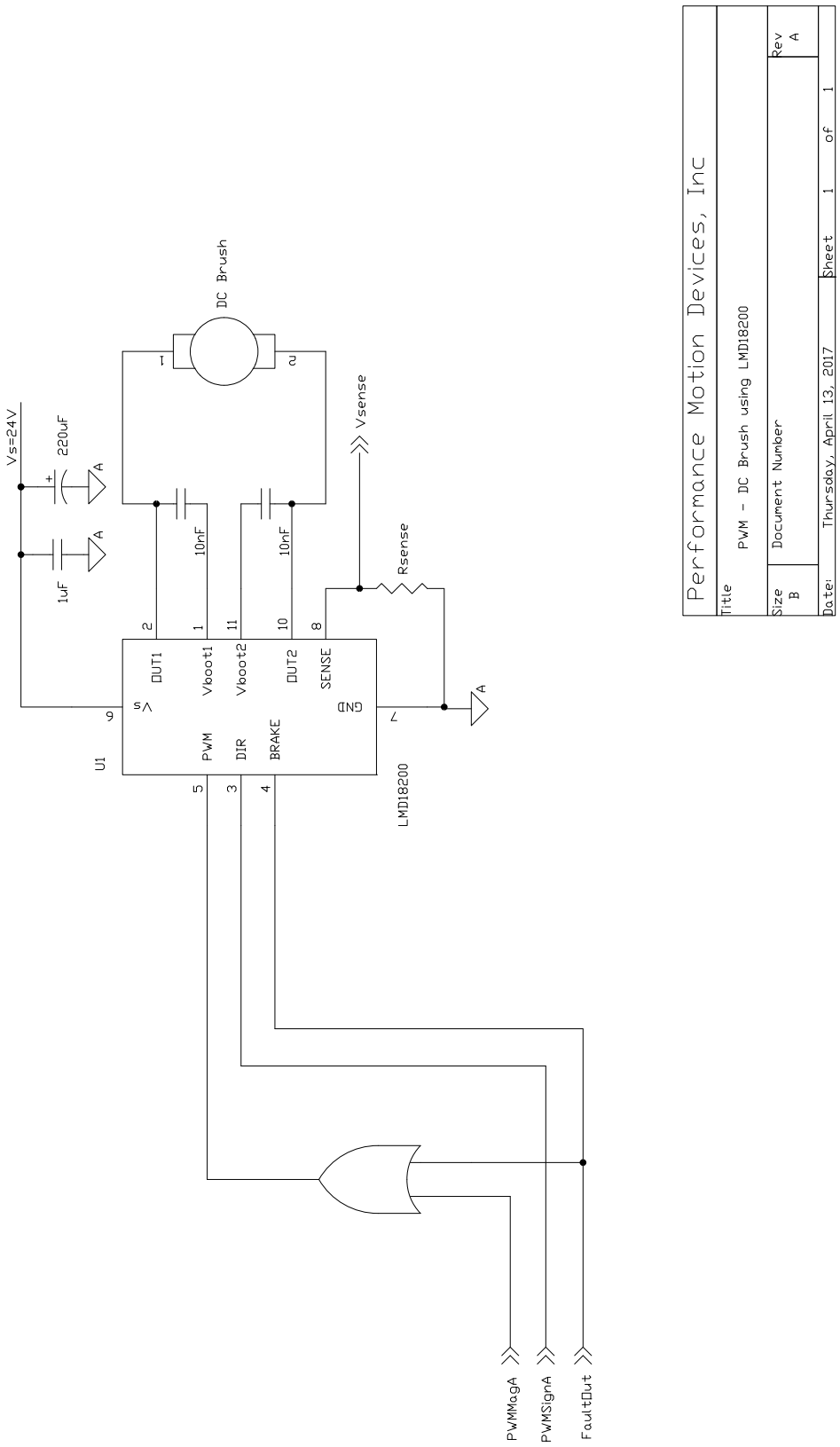
First, in the *locked anti-phase control* mode (see the LMD18200 data sheet), a 50/50 *PWM* signal is applied to the LMD18200 DIR input, while the PWM input is tied high. The current ripple in this mode is relatively high, as the circulating currents are quickly decaying.

Second, in *the sign/magnitude control* mode, sign and magnitude *PWM* signals are applied to both the PWM and DIR inputs of the LMD18200. In this mode, the resultant current ripple is reduced resulting in smoother operation of the motor. When the acceleration/deceleration requirements for the motor are not high, the sign/magnitude PWM control mode is preferred. This method is demonstrated in the example.

The LMD18200 is equipped with an internal overcurrent circuit, which is tuned to a 10A threshold. External over-current circuitry may be added for currents with a lower threshold by using the sense output. In order to detect malfunctions, the *Vsense* signal may be used to sense the amount of current flowing through the motor windings. The sense output of the LMD18200 samples only a fraction of the drive current, with a typical 377 µA sensing per 1A driving current. .

Note that the circuitry provided in this section does not provide active current control. See Section 15.9, "PWM High/Low Motor Drive With Leg Current Sensing/Control" for PWM-based application examples using the Juno IC that provide active current control.

Figure 15-11: DC Brush Amplifier Using LMD 18200



15.11 Two Juno BLDC Motor Amplifiers With Multi-Axis Magellan

The following schematic shows a two-axis application with two Juno BLDC motor amplifiers in torque mode with a multi-axis Magellan.

15.11.1 SPI Communication

MC73113 receives control commands through an SPI interface and functions as an SPI slave. The MC58420 will output a continuous stream of desired torques to each MC73113 via SPI. SPI communication is enabled when ~SPIEnable is pulled down. Only one MC73113 can be enabled at any given time.

In this schematic the SPI master is a four-axis Magellan MC58420. Only the connections with MC73113 are shown. For complete Magellan wiring, please refer to the *MC58000 Electrical Specifications*. In this example, axis 1 and axis 2 are under control. The MC58420 sends torque commands to MC73113s by pulling *SPIEnable1* and *SPIEnable2* low, respectively.

15.11.2 MC73112N Axis 1

For Axis 1, the MC73112N provides torque control with encoder-based commutation. It receives torque command from Magellan via an SPI bus and controls the motor with PWM high/low and leg current sensing. Please refer to Section 15.9.3, "Brushless DC Motor Drive " for more details

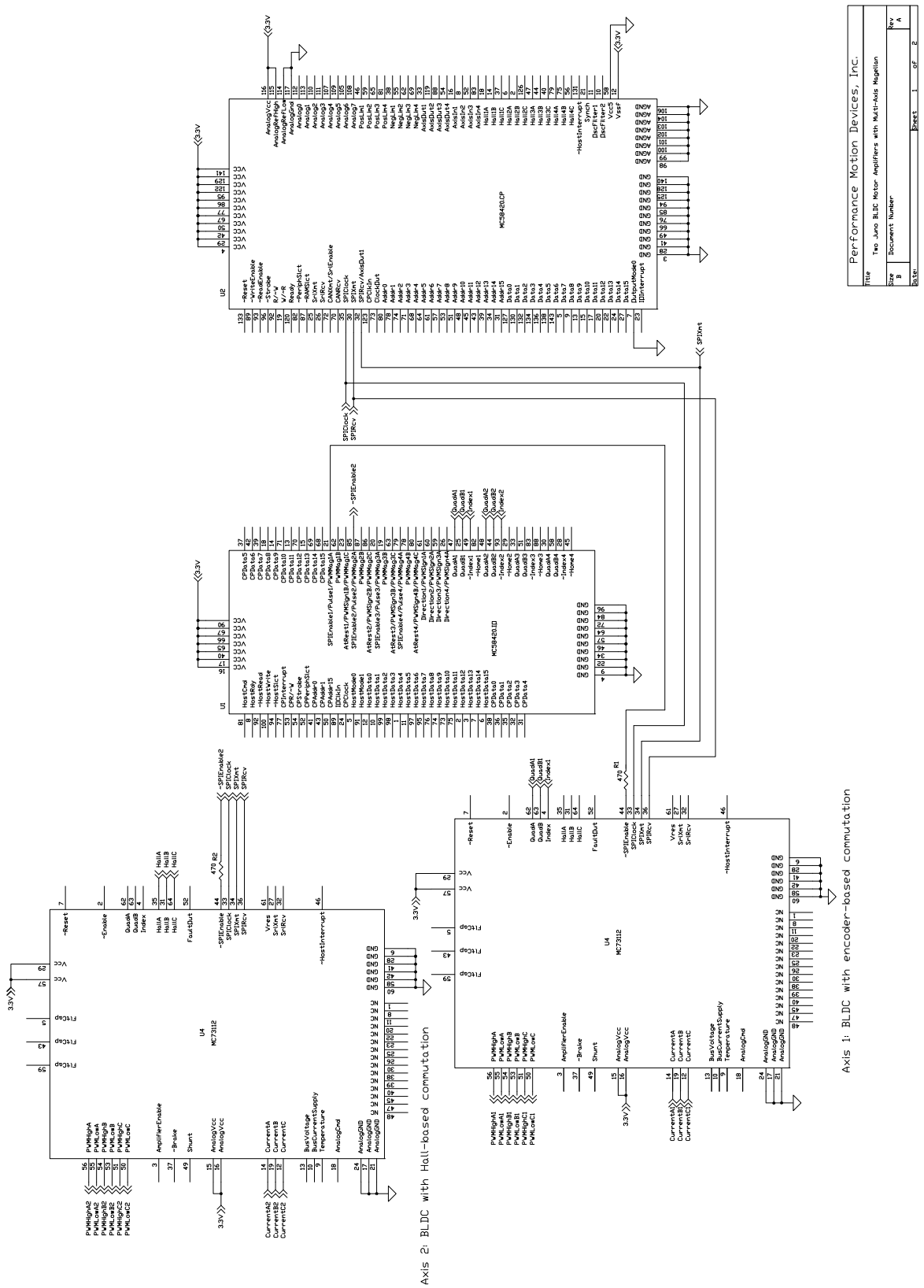
The encoder signals go to both Magellan and MC73112N. Magellan uses the encoder information for position control while MC73112N for commutation.

15.11.3 MC73112N Axis 2

For Axis 2, the MC73112N provides torque control with Hall-based commutation. It receives torque command from Magellan via an SPI bus and controls the motor with PWM high/low and leg current sensing. Please refer to Section 15.9.3, "Brushless DC Motor Drive " for more details.

Magellan uses the encoder information for position control, and MC73112N uses Hall signals for commutation.

Figure 15-12: Two-Axis BLDC Motor Drive With Multi-Axis Magellan



Juno® Torque Control IC
User Guide

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