Juno Velocity & Torque Control IC MC78113 Electrical Specifications

PERFORMANCE
MOTION DEVICES

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Related Documents

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.

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, MC74113, MC75113, and MC78113.

Juno Torque Control IC User Guide

Complete description of the MC71112, MC71112N, MC73112 and MC73112N Juno torque control ICs including electrical characteristics, pin descriptions, and theory of operations.

DK73112N Developer Kit User Manual

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

Juno Step Motor Control IC User Guide

Complete description of the MC74113, MC74113N, MC75113 and MC75113N step motor control ICs including electrical characteristics, pin descriptions, and theory of operations.

DK74113N Developer Kit User Manual

How to install and configure the DK74113N developer kit. This developer kit supports the two 56-pin VQFN Juno step motor control ICs; MC74113N and MC75113N.

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1. The Juno IC Family

1

In This Chapter

- Introduction
- Family Overview
- Juno IC Developer Kit
- Guide to the Documentation

1.1 Introduction

This manual provides electrical specifications for the complete Juno family of velocity & torque control ICs from Performance Motion Devices, Inc. The Juno IC family consists of the MC71113, MC73113, and MC78113 ICs for velocity control of Brushless DC and DC Brush motors, the MC74113, MC74113N, MC75113, and MC75113N ICs for control of step motors, and the MC71112, MC71112N, MC73112, and MC73112N ICs for torque control of Brushless DC and DC Brush 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 manual PDFs
- Extensive application schematic examples

1.4 Guide to the Documentation

The Juno IC family is notable for the number of different control functions provided and motor types supported. While there are five different manuals specific to the Juno ICs, for a given application you will often need just one, or a smaller number of user guides. This is detailed in the table below:

Juno Function	Primary Reference	Companion References
Velocity Control	*Juno Velocity & Torque Control IC User Guide* is a superset description of the entire Juno IC family.	*MC78113 Electrical Specifications* *Juno Velocity & Torque Control IC Programming Reference.*
Torque Control	*Juno Torque Control IC User Guide* provides a convenient all-in-one reference for the Juno ICs that provide this dedicated control function.	*Juno Velocity & Torque Control IC User Guide* *Juno Velocity & Torque Control IC Programming Reference*
Step Motor Control	*Juno Step Motor Control IC User Guide* provides a convenient all-in-one reference for the Juno ICs that provide this dedicated control function.	*Juno Velocity & Torque Control IC User Guide* *Juno Velocity & Torque Control IC Programming Reference*

2. Functional Characteristics

2

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	Outer loop quantity, velocity, or torque command is provided via external direct analog input
	SPI	Outer loop quantity, velocity, or torque command is provided via external SPI (Serial Peripheral Interface) direct input
	Pulse & Direction	Position is provided via external pulse & direction input
	Internal profile	Outer loop quantity, position, velocity, or torque command is provided via internal profile generator function
Control feedback sources	Quadrature encoder	Position or velocity feedback is provided for the position/outer loop or velocity loop
	Hall sensors	Position or velocity feedback is provided for the position/outer loop or velocity loop
	Tachometer	Outer loop quantity or velocity feedback is provided for the outer loop or velocity loop
	SPI	Outer loop quantity feedback is provided for the position/outer loop
Host communication modes	SPI (Serial Peripheral Interface) Point to point asynchronous serial Multi-drop asynchronous serial CAN bus 2.0B	
Host SPI frequency range	1.0 MHz - 10.0 MHz	
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)	
CAN port transmission rate range	10,000 baud to 1,000,000 baud (10,000, 20,000, 50,000, 125,000, 250,000, 500,000, 1,000,000)	
Position range	-2,147,483,648 to +2,147,483,647 counts or steps	
Velocity range	-32,768 to +32,767 counts or steps per cycle with a resolution of 1/65,536 counts or steps per cycle	
Acceleration and deceleration ranges	0 to +127 counts or steps per $cycle^2$ with a resolution of 1/16,777,216 counts or steps per $cycle^2$	

Motor output modes	PWM High/Low	Individual high and low drive signals for each bridge switch
	Sign/Magnitude PWM	Separate sign and magnitude drive signal for each phase of switching bridge.
Commutation rate	19.53 kHz except MC73112 and MC73112N which is 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, Shunt, PWMHighA, PWMLowA, PWMHighB, PWMLowB, PWMHighC, PWMLowC, PWMHighD, PWMLowD*	
Serial communication signals	*SrlXmt, SrlRcv, SrlEnable*	
CANbus signals	*CANXmt, CANRcv*	
SPI signals	*SPIXmt, SPIRcv, SPIClk, SPIEnable, SPIStatus*	
Step command signals	*Pulse, Direction, AtRest*	
Encoder input signals	*QuadA, QuadB, Index*	
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	
Microsteps per full step	1 to 256	
Maximum encoder rate	40 Mcounts/sec	
Cycle time range	51.2 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.

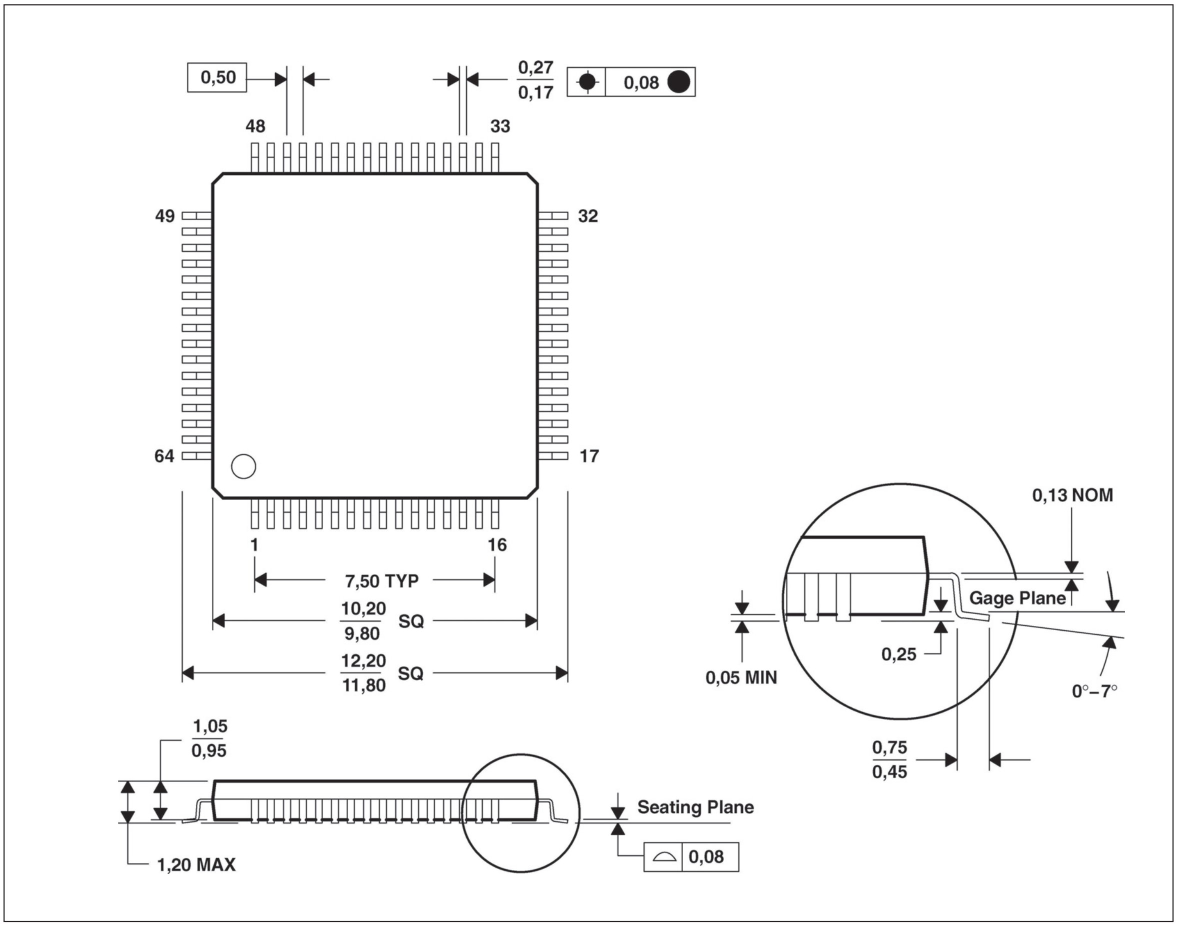


Figure 2-1: 64-Pin TQFP Physical Dimensions

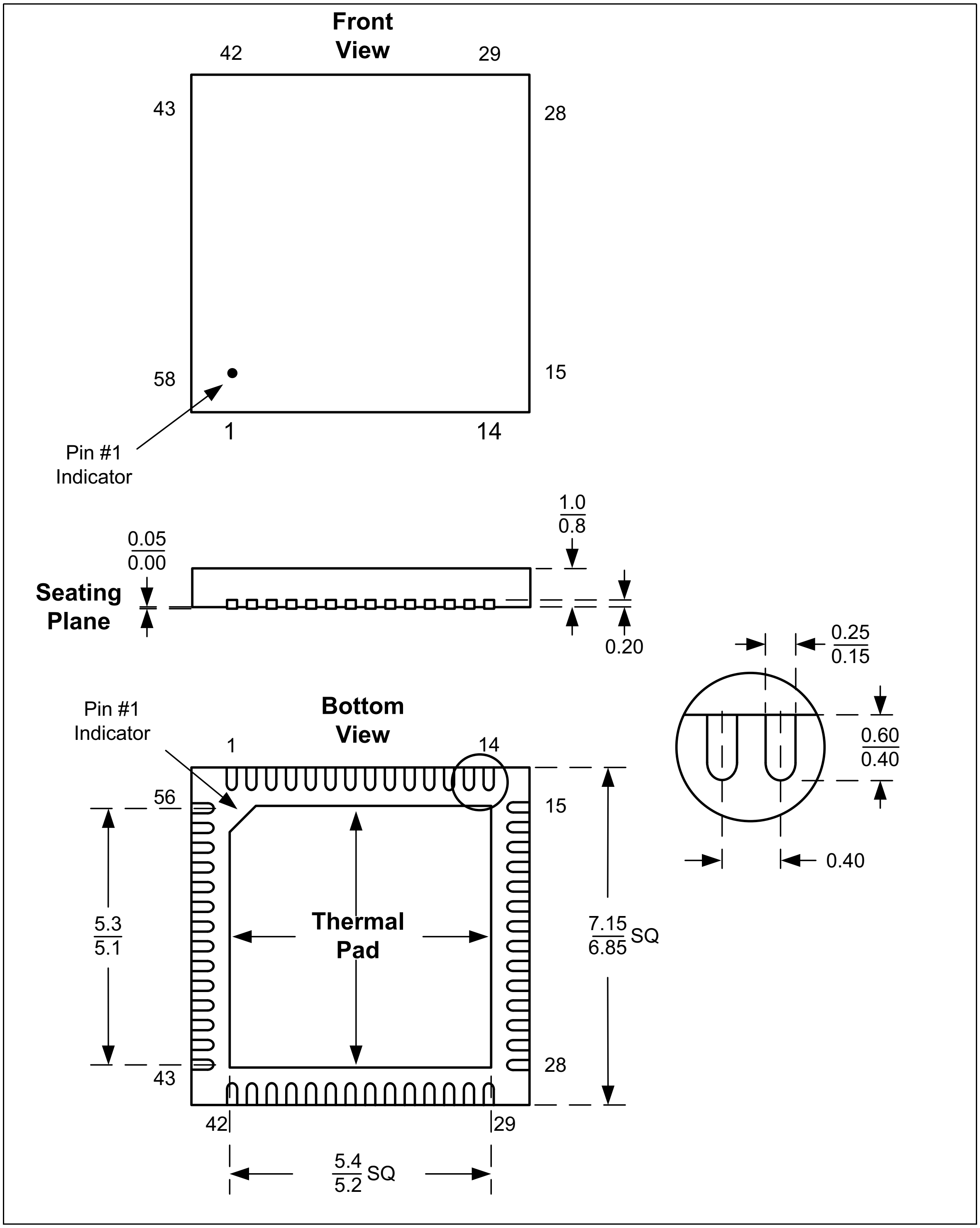
Notes:

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 for Juno ICs
- AC Characteristics

3.1 DC Characteristics for Juno ICs

(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 Clock

Timing Interval	No.	Min	Max
ClkIn frequency, typical			10 MHz
ClkIn period, typical	T1		100 nSec
ClkIn fall time	T2		6 nSec
ClkIn rise time	T3		6 nSec
ClkIn pulse duration		0.45 T1	0.55 T1

3.2.2 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.

3.2.3 Host SPI

Timing Interval	No.	Min	Max
HostSPIClock clock cycle time	T23	100 nSec	
Pulse duration, HostSPIClock high	T24	(0.5 T23-10) nSec	0.5 T23
Pulse duration, HostSPIClock low	T25	(0.5 T23-10) nSec	0.5 T23
~HostSPIEnable low to first HostSPIClock high	T26	0.5 T23	
HostSPIClock high to HostSPIXmt valid delay time	T27		21 nSec
HostSPIXmt data valid time after HostSPIClock low	T28	0	
HostSPIRcv setup time before HostSPIClock high	T29	26 nSec	
HostSPIRcv valid time after HostSPIClock low	T30	(0.5 T23-10) nSec	
Last HostSPIClock low to ~HostSPIEnable high	T31	0.5 T23	

3.2.4 Power-on Reset

Timing Interval	No.	Min	Max
Power on pulse duration driven by device (typical) (note 1)	T32		600 µSec
Device ready/ outputs initialized (typical)	T33		2 mSec
ClkIn ready to ~Reset release	T34	0	10 mSec
ClkIn high impedance before powerup	T36	0	
ClkIn high impedance after Vcc stabilizes	T37	0	

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

3.2.5 Warm Reset

Timing Interval	No.	Min	Max
~Reset low duration for warm reset	T35	32 T1	

3.2.6 Pulse & Direction

Timing Interval	No.	Min	Max
Pulse frequency			1.0 Mhz
Pulse width	T38	50 nSec	
Direction setup time before pulse low	T39	26 nSec	
Direction valid time after pulse low	T40	40 nSec	

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4. Timing Diagrams

In This Chapter

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

4.1 Clock

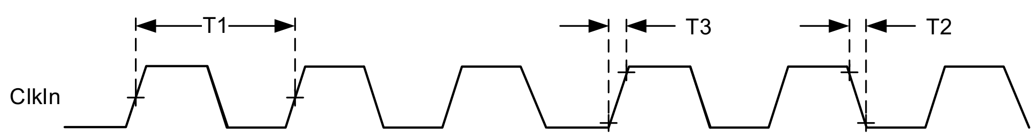


Figure 4-1: Clock Timing

4.2 Quadrature Encoder Input

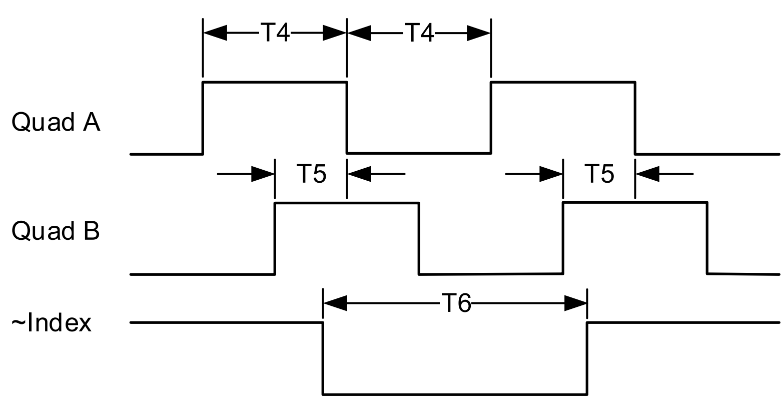
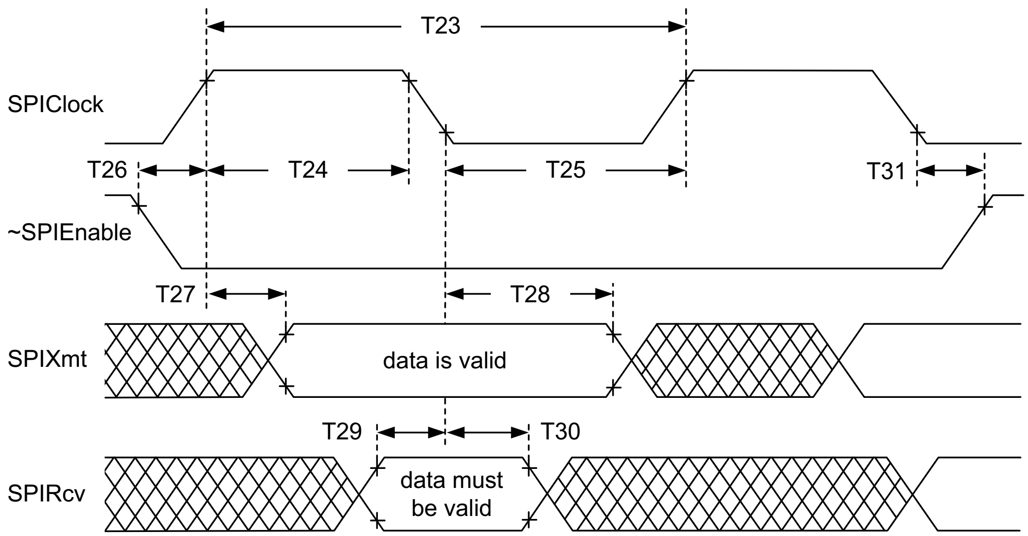


Figure 4-2: Quad Encoder Timing

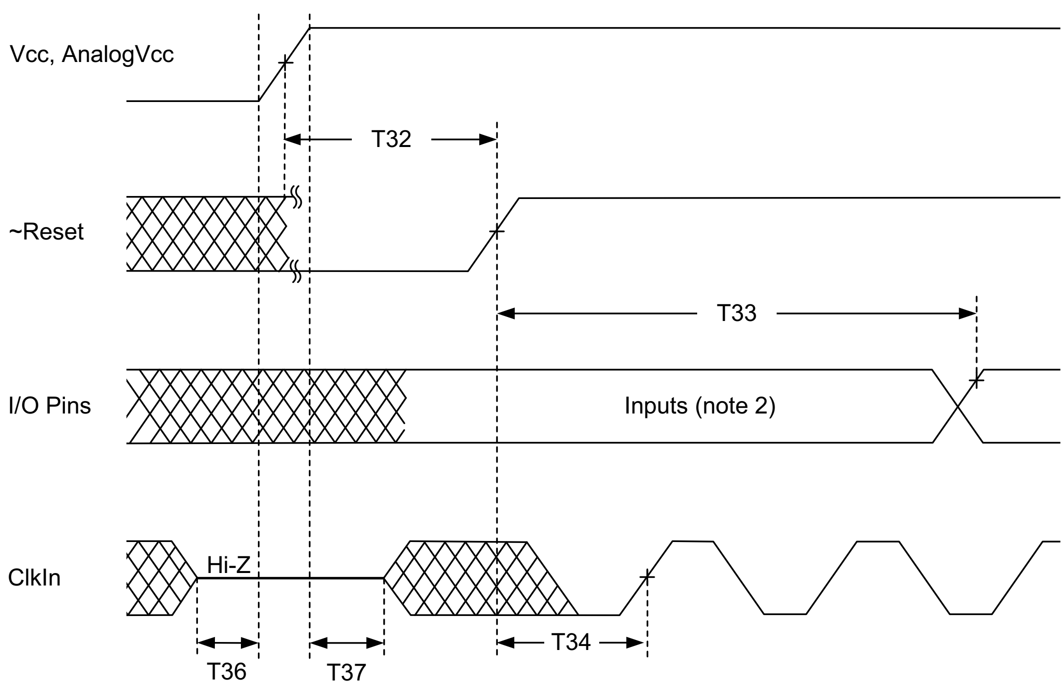
4.3 SPI Timing

Figure 4-3: SPI Timing



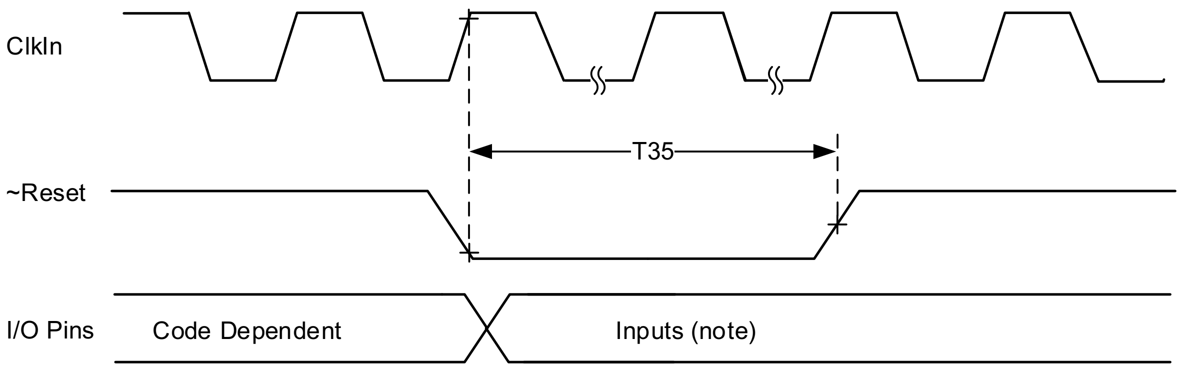
4.4 Power On Timing

Figure 4-4: Power On Timing



4.5 Warm Reset

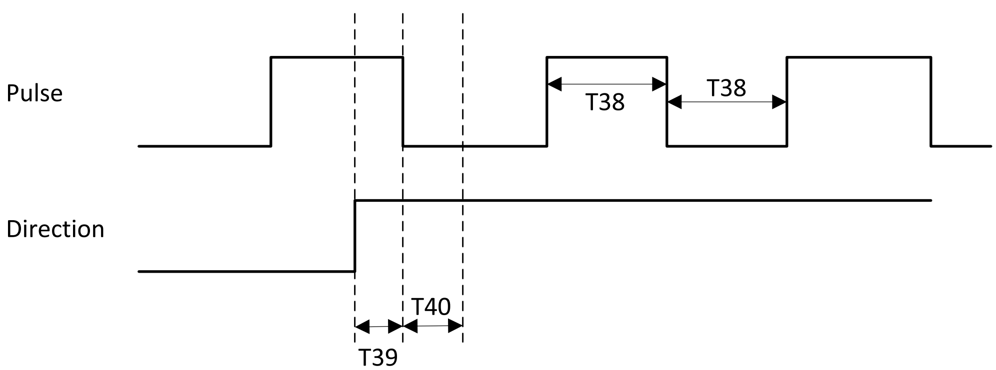
Figure 4-5: Warm Reset Timing



Please refer to Note 2 in Section 3.2.5, "Warm Reset" for more information.

4.6 Pulse & Direction

Figure 4-6: Pulse & Direction Timing



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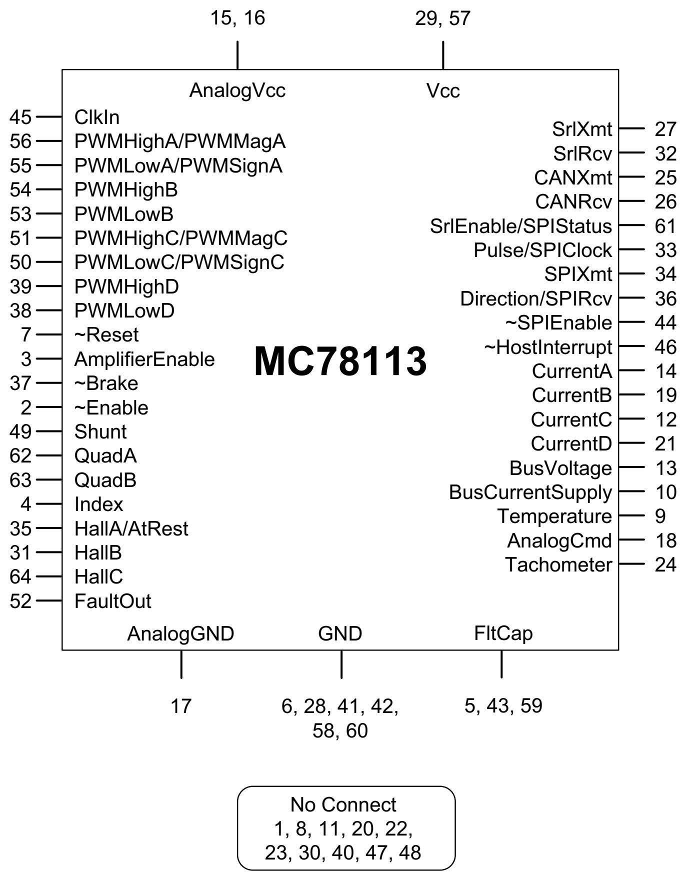
5. Pinouts and Pin Descriptions

In This Chapter

5.1 Pinouts for the MC78113

Figure 5-1: MC78113 Pinouts



5.2 Pinouts for the MC71112

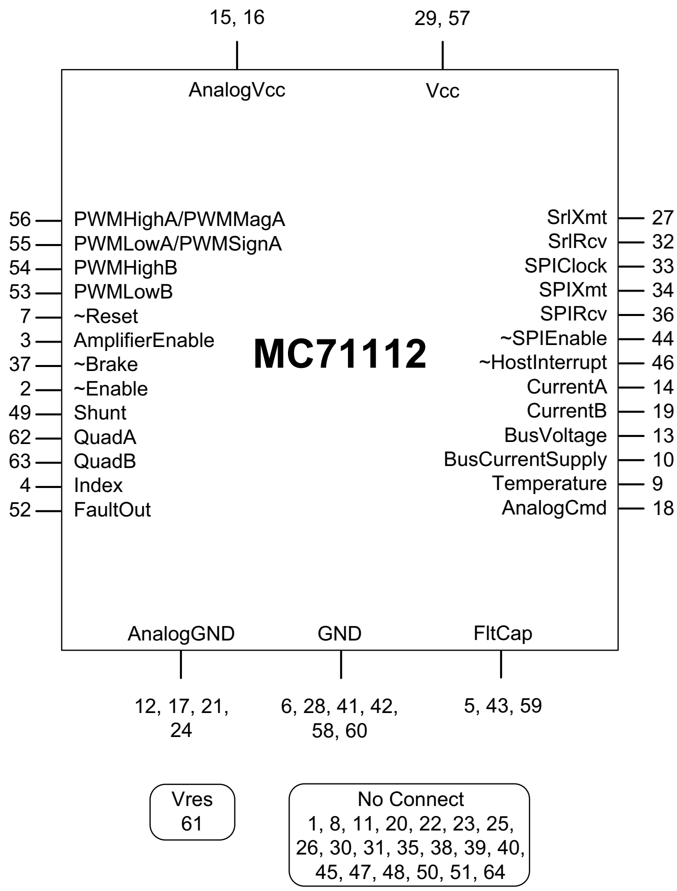
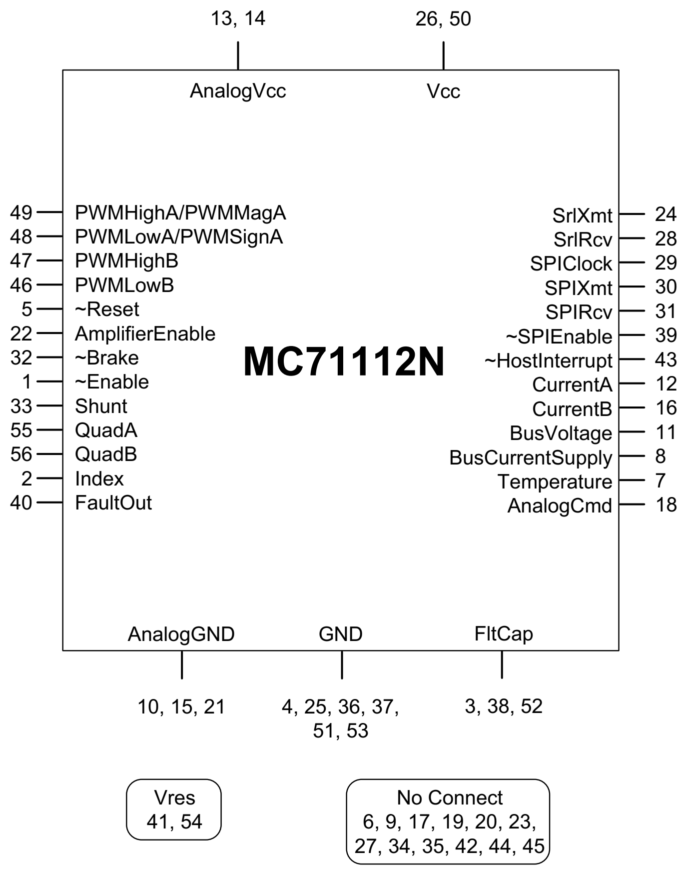


Figure 5-2: MC71112 Pinouts

5.3 Pinouts for the MC71112N

Figure 5-3: MC71112N Pinouts



5.4 Pinouts for the MC73112

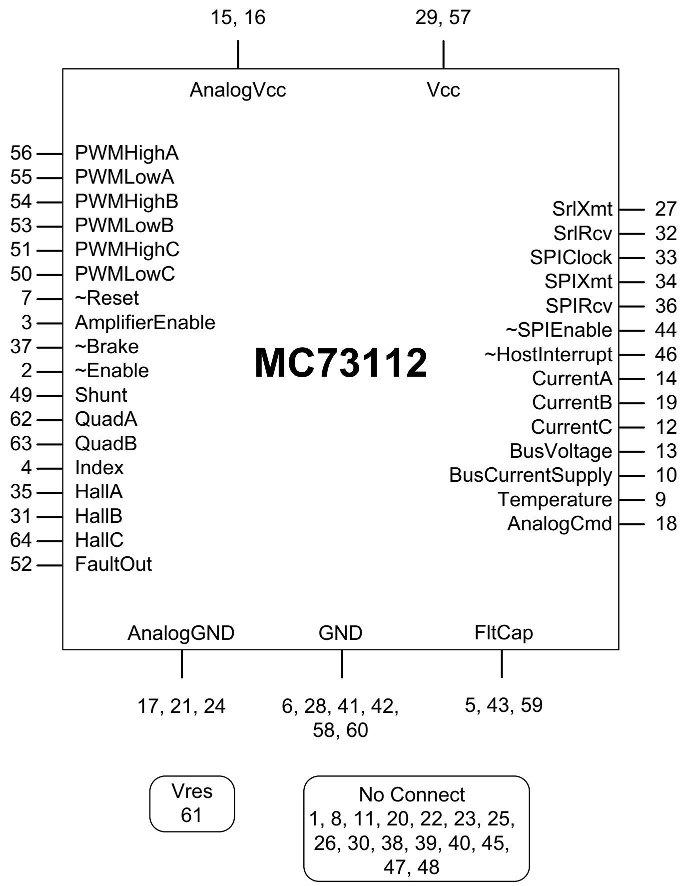
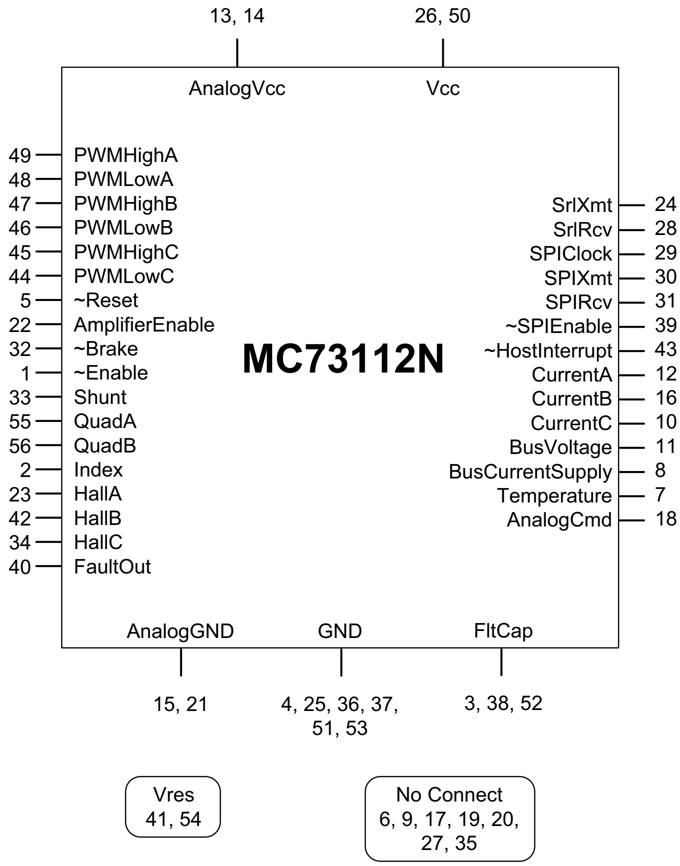


Figure 5-4: MC73112 Pinouts

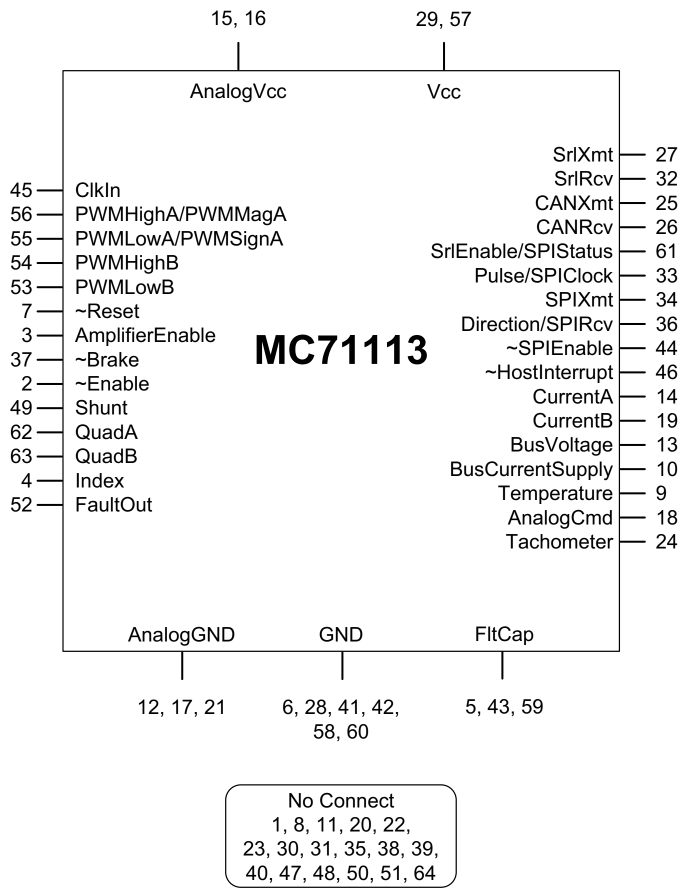
5.5 Pinouts for the MC73112N

Figure 5-5: MC73112N Pinouts



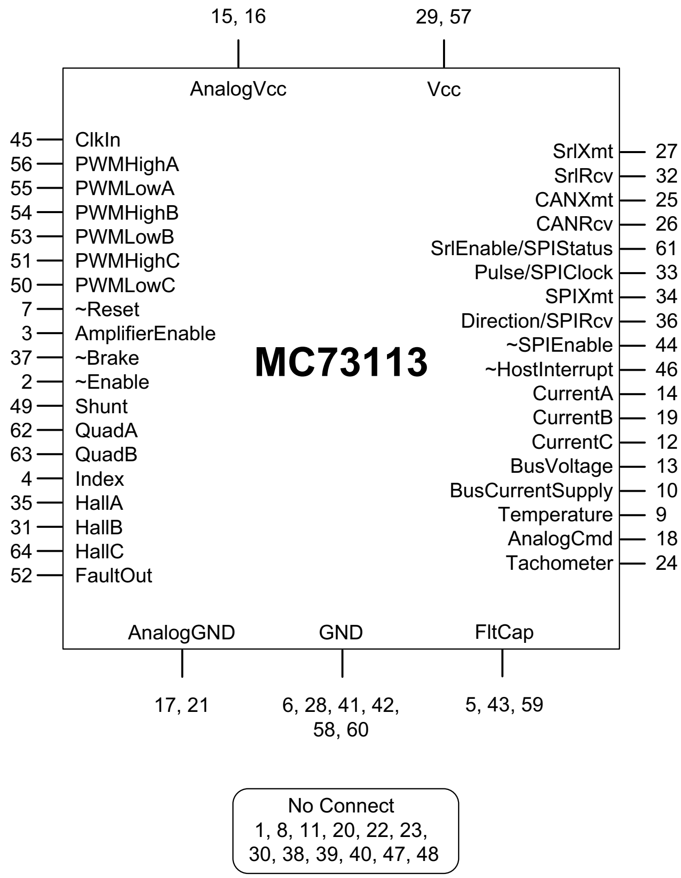
5.6 Pinouts for the MC71113

Figure 5-6: MC71113 Pinouts



5.7 Pinouts for the MC73113

Figure 5-7: MC73113 Pinouts



5.8 Pinouts for the MC74113

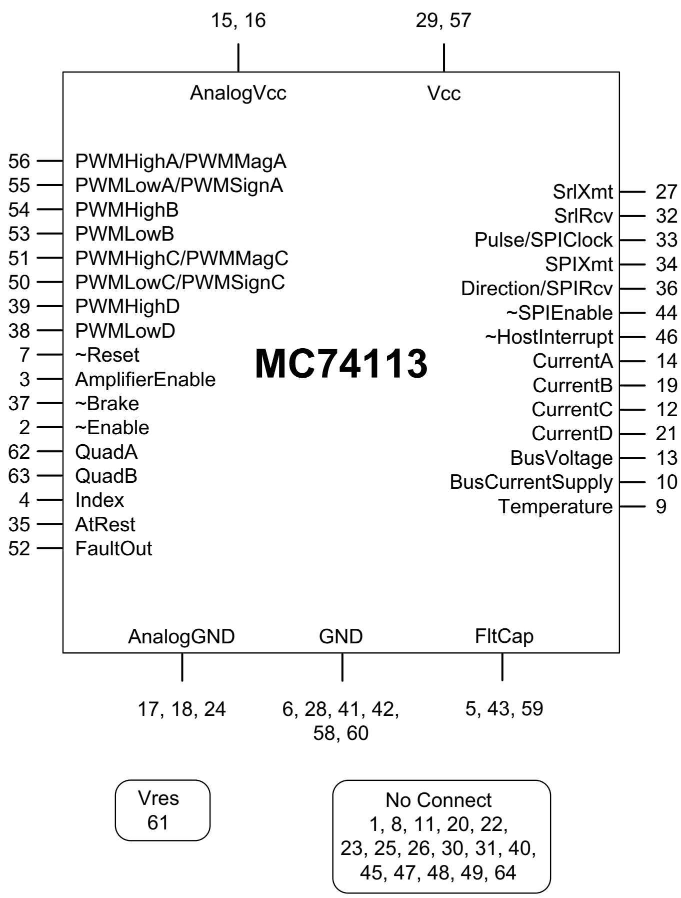
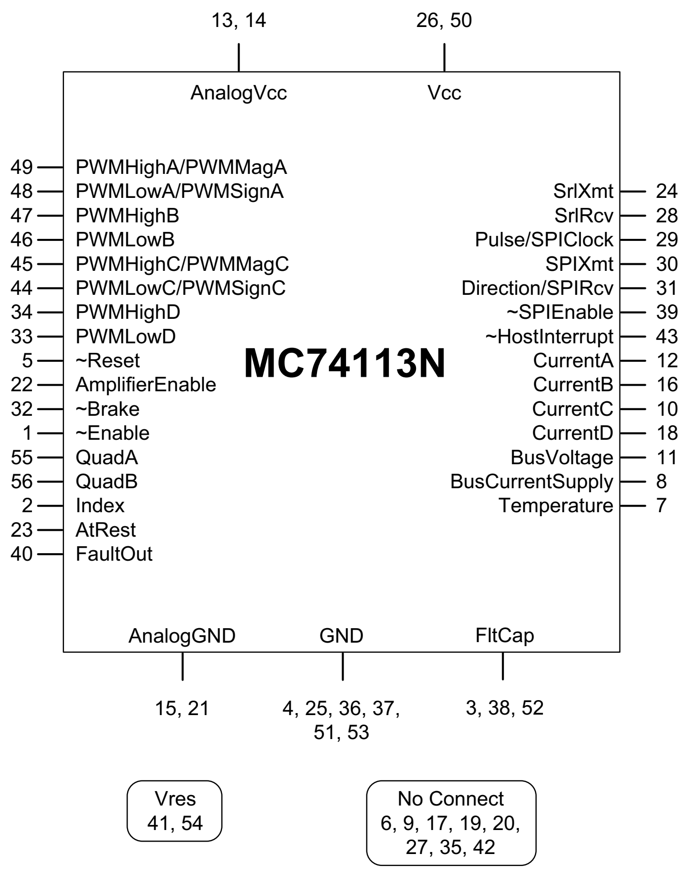


Figure 5-8: MC74113 Pinouts

5.9 Pinouts for the MC74113N

Figure 5-9: MC74113N Pinouts



5.10 Pinouts for the MC75113

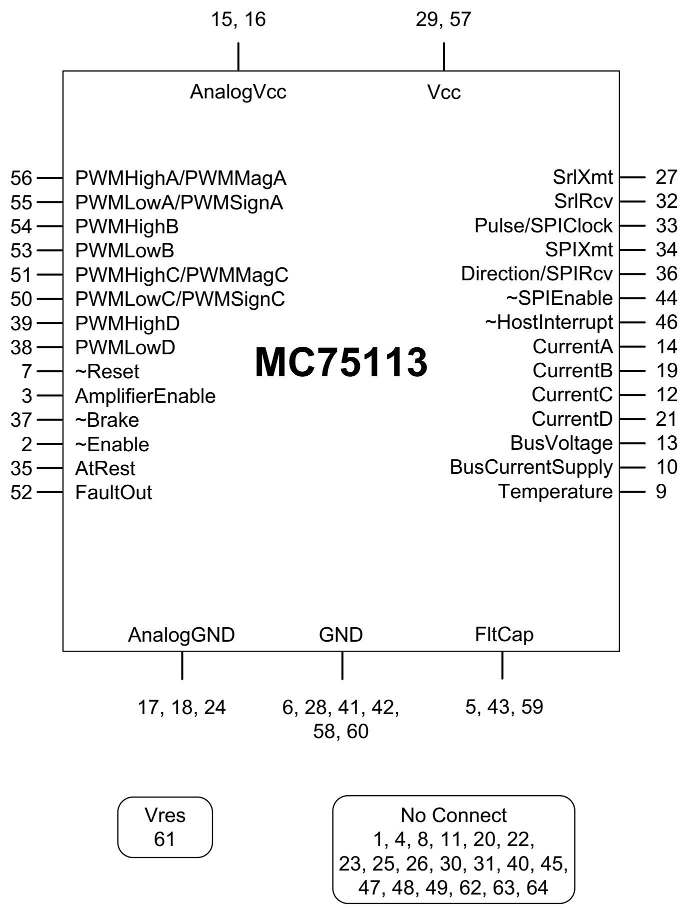
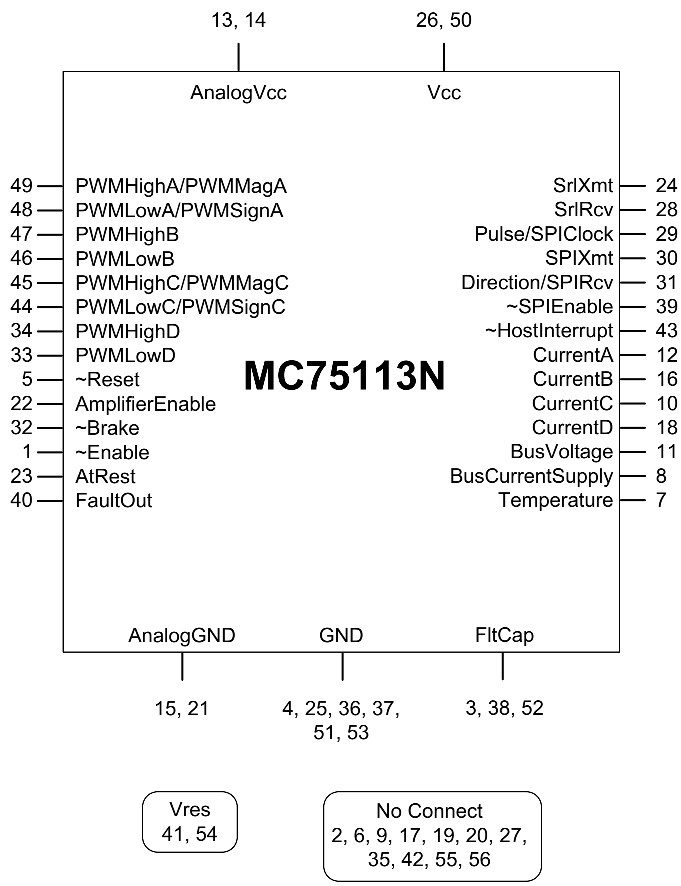


Figure 5-10: MC75113 Pinouts

5.11 Pinouts for the MC75113N

Figure 5-11: MC75113N Pinouts



5.12 Juno IC Pin Descriptions

The following table details the pinouts for the Juno ICs.

Name	64-Pin TQFP Pin #	56-Pin VQFN Pin #	Direction	Description
~Reset	7	5	in/out	This pin is the master reset input. It may be temporarily brought low to reset Juno to its initial conditions and then restored to high for normal operation. 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.
ClkIn	45	-	in	This pin is the master clock input. It is driven at a nominal 10 MHz using an external clock. For the MC71112, MC73112, MC74113 and MC75113 this pin is left unconnected, and an internal oscillator is used to generate the clock.
PWMHighA/ PWMMagA PWMLowA/ PWMSignA PWMHighB PWMLowB PWMHighC/ PWMMagC PWMLowC/ PWMSignC PWMHighD PWMLowD	56 55 54 53 51 50 39 38	49 48 47 46 45 44 34 33	out	Depending upon the selected motor type and output mode, these pins have the following functions: *PWMHighA/B/C/D* 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 changed using the SetDrivePWM command. *PWMLowA/B/C/D* 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 changed using the SetDrivePWM command. *PWMMagA/C* 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 changed using the SetDrivePWM command. *PWMSignA/C* 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 changed using the SetDrivePWM command.
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.

Name	64-Pin TQFP Pin #	56-Pin VQFN Pin #	Direction	Description
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 can be changed with the SetDrivePWM command.
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 changed via the command SetSignalSense. 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/AtRest 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 changed via the command SetSignalSense. 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. *AtRest*, which is used for stepper motor control only, indicates that the axis is at rest, and that the motor can be switched to low power or standby. By default a high level on this signal indicates the axis is at rest and a low signal indicates the axis is in motion however this signal interpretation can be changed via the command SetSignalSense. 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.
CANXmt	25	-	out	This pin transmits serial data to the CAN transceiver.
CANRcv	26	-	in	This pin inputs serial data from the CAN transceiver. If unused, this pin may be left unconnected.
SrlEnable/SPIStatus	61	-	out	When the serial port is configured for multi-drop operation, this pin sets the serial port enable line. SrlEnable is high during transmission and low otherwise. When the serial port is configured for point-to-point operation, this pin is low when there is an SPI command result waiting to be read by the host and high otherwise. In point-to-point mode, if the SPI command interface is not used then this pin will always be high. **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
Pulse/SPIClock	33	29	in	*Pulse* provides a pulse (step) signal for the pulse & direction command input function. A step occurs when this signal transitions from a high state to a low state. This default behavior can be changed using the command SetSignalSense. *SPIClock* inputs the clock signal used with synchronous serial transfer on the host communication SPI bus. If unused, this pin may be left unconnected.
SPIXmt	34	30	out	This pin transmits synchronous serial data on the host communication SPI bus to the host processor.
Direction/SPIRcv	36	31	in	*Direction* indicates the direction of motion for the pulse & direction command input function. By default a high level on this signal indicates a positive direction move and a low level indicates a negative direction move, however this signal interpretation can be changed via the command SetSignalSense. This pin inputs synchronous serial data for the host communication 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 host 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.**
CurrentA CurrentB CurrentC CurrentD	14 19 12 21	12 16 10 18	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, Brushless DC motors use the A, B, and C inputs, and two-phase step motors use the A, B, C, and D 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.

Name	64-Pin TQFP Pin #	56-Pin VQFN Pin #	Direction	Description
AnalogCmd	18	18	in	This pin is used for commanding either voltage, torque, or velocity using an analog signal. If unused, this pin should be tied to AnalogGND.
Tachometer	24	-	in	This pin is used for feedback from a tachometer or other analog device used to measure the effect of the output voltage, torque, or velocity. If unused, this pin should be tied to AnalogGND
AnalogGND	17	15 21	N/A	This pin should be connected to the analog input power supply return. Any unused analog inputs (CurrentA-D, 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 Juno 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. **Note that for the MC71113, MC73113, and MC78113 ICs pin #61 is used for the SrlEnable/SPI Status function.*
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.
No Connect	1 8 11 20 22 23 30 40 47 48	6 9 17 19 20 27 35 42	N/A	These pins must be left unconnected.
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 motor 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 a set of control parameter values tailored for that 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 host communication port.

Loading 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 one of the Juno IC's host communication ports. For more information refer to the *Juno Velocity & Torque Control IC User Guide*.

6.1 Loading the NVRAM

There are several options for loading the Juno IC's NVRAM as detailed in the following sections.

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 supports script files to program the Juno IC NVRAM. For more information on PMD Corp. script files refer to the *Juno Velocity & Torque Control IC User Guide*.

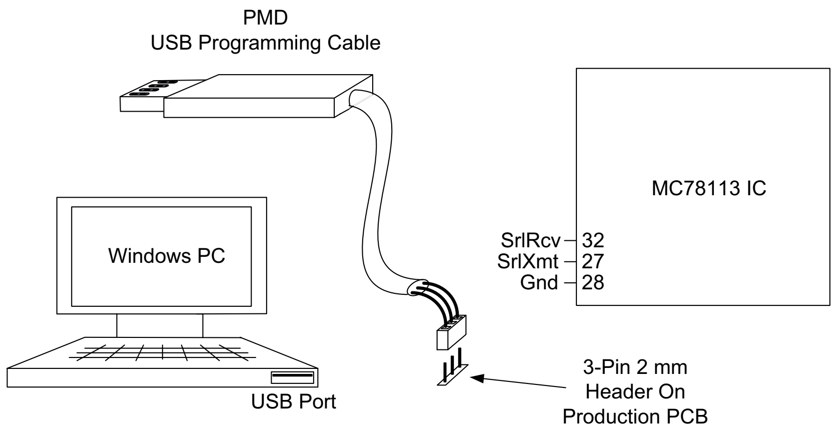
> The 56-pin VQFN Juno IC DK does not have a socket and therefore cannot be used to program the NVRAM of production 56-pin VQFN Juno ICs.

6.1.2 NVRAM Programming Via 3-pin UART Cable

An alternate NVRAM download approach is 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. Depending on the Juno IC being used the signals that can be calibrated are *AnalogCmd*, *Tachometer*, and *CurrentA-CurrentD*. For more information refer to the *Juno Velocity & Torque Control IC User Guide*.

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 the *Juno Velocity & Torque Control IC User Guide* for more information.

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7. Electrical Operational Information

7

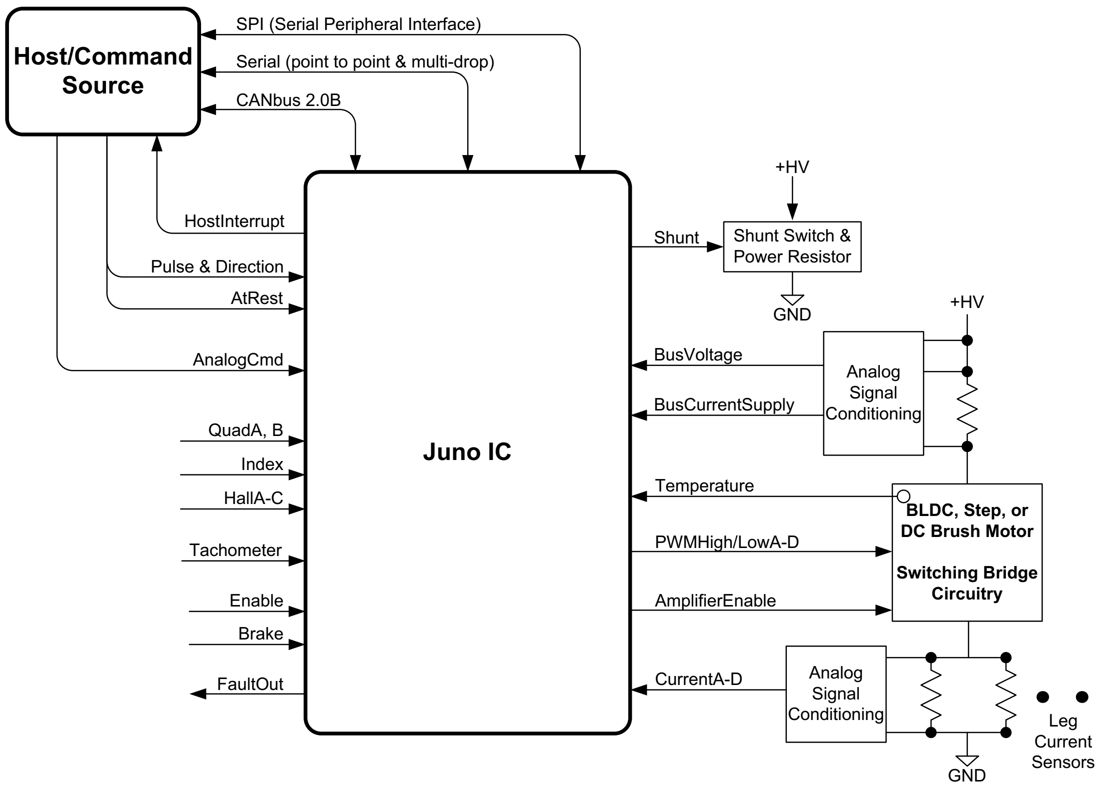
In This Chapter

7.1 Juno ICs Connection Overview

Figure 7-1 shows an overview of the connection scheme for Juno ICs.

For a general description of the Juno ICs see the *Juno Velocity & Torque Control IC User Guide*. For detailed information on commands supported by the Juno ICs see the *Juno Velocity & Torque Control IC Programming Reference*.

Figure 7-1: Juno Interconnections



7.2 Internal Block Diagram

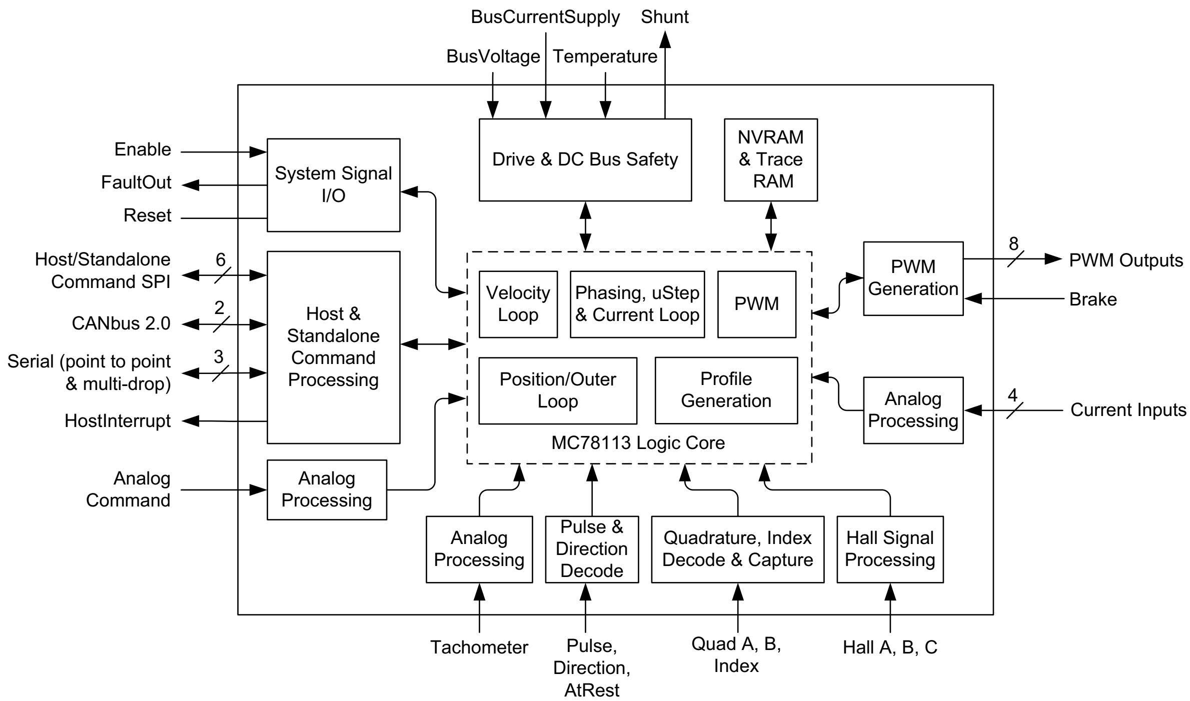


Figure 7-2: Juno ICs Internal Block Diagram

Figure 7-2 shows an internal block diagram for the Juno ICs. The functionality is divided into several major functional blocks, listed below:

- Switching amplifier control
- Current control
- Drive & DC Bus safety
- Host communications
- Input signal processing
- NVRAM & trace RAM

The subsequent sections of this chapter will provide detailed information on the electrical functions associated with these major functional blocks. For a complete theory of operations on the Juno ICs refer to to the *Juno Velocity & Torque Control IC User Guide.*

7.3 Switching Amplifier Control

Juno family ICs provide two different switch control methods. These switch control methods are known as PWM High/Low, and Sign/Magnitude PWM.

The primary switching control mode that is used when Juno's 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.

The following sections provide detailed operation, connection, and configuration information for each of these two amplifier control modes.

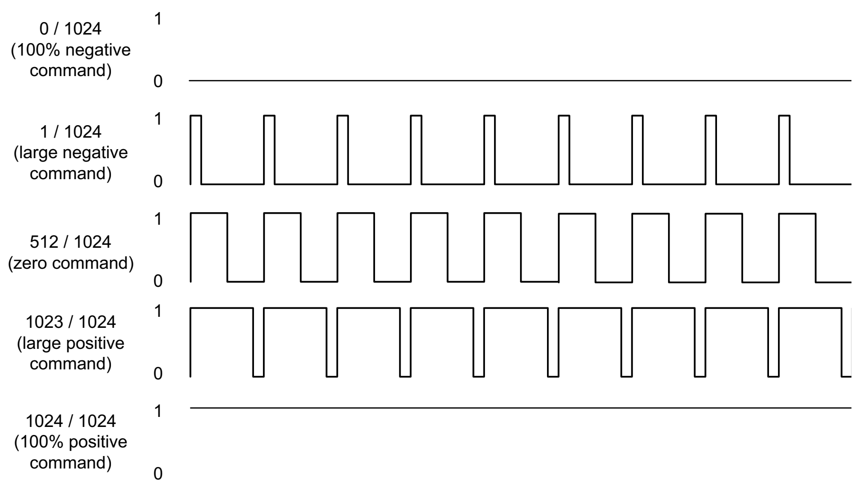
7.3.1 PWM High/Low Motor Output Mode

The Juno ICs can control high-efficiency MOSFET or IGBT power stages with individual high/low switch input control. A different configuration is used for each motor type:

- DC Brush motors are driven in an H-Bridge configuration consisting of 4 switches.
- Brushless DC motors are driven in a triple half-bridge configuration consisting of 6 switches.
- Step motors are driven in a two H-Bridge configuration consisting of 8 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 7-3.

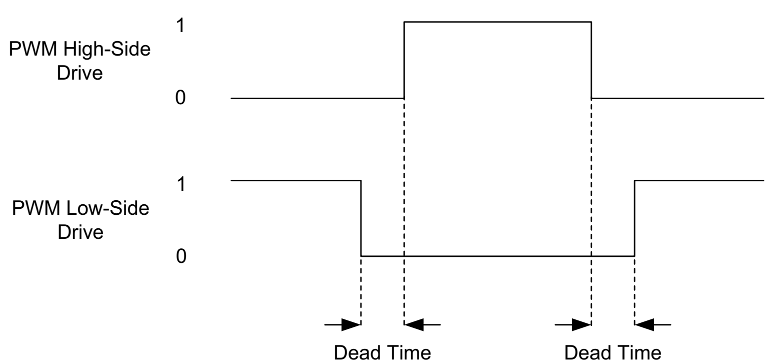
Figure 7-3: PWM High/Low Encoding



7.3.1.1 PWM High/Low Signal Generation

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 7-4 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 7-4: PWM High/Low Signal Generation



The dead time is specified in nSecs and can be programmed via the command SetDrivePWM. The correct value can generally be determined from the MOSFET or IGBT IC manufacturer's data sheet, or you can call PMD 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, set using the SetDrivePWM command, specifies this refresh time and has units of nSecs. The related parameter of refresh time period, which is the time interval between these off time refreshes, and which is also set using the SetDrivePWM command, 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. This PWM Limit parameter is set using the SetDrivePWM command.

> The Juno 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.

7.3.1.2 PWM High/Low Brushless DC Motor Drive

Figure 7-5 shows the typical amplifier stage arrangement when a MC73112, MC73112N, MC73113 IC or MC78113 IC with Brushless DC motor type selected is used in PWM High/Low mode.

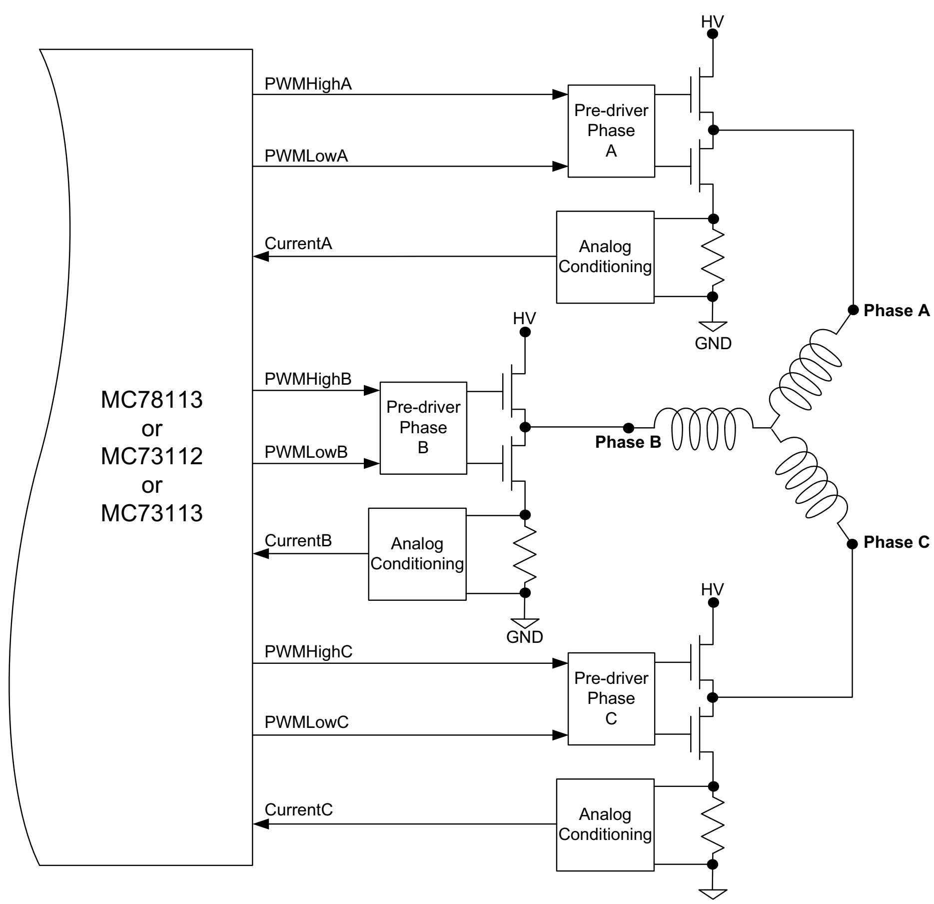


Figure 7-5: Brushless DC Motor Bridge Configuration

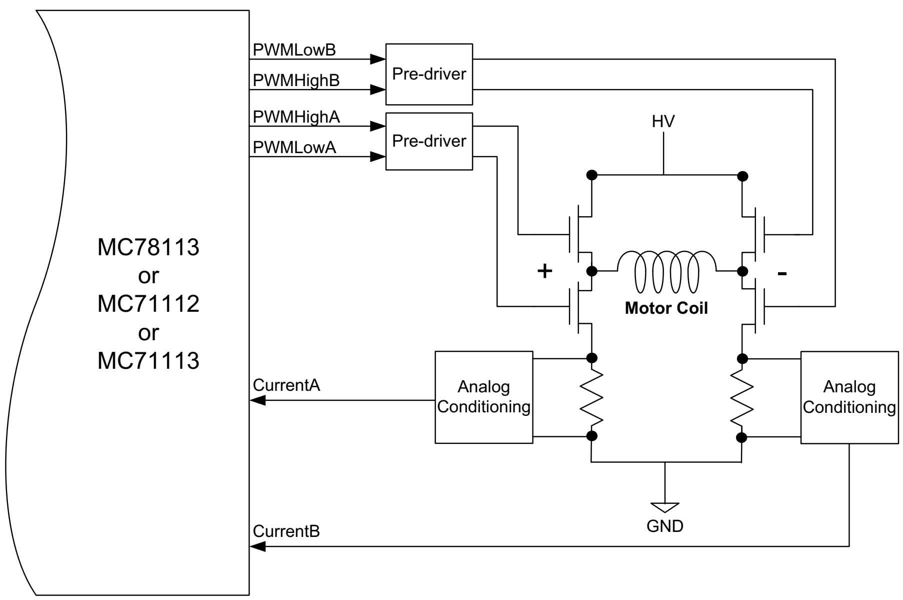
As shown in the table below six PWM output signals and, if used, three analog feedback signals for current control interface between the MC78113 IC and the switching amplifier circuitry. Note that because the 56-pin VQFN Juno ICs only support step motors, these signals are not applicable.

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.

7.3.1.3 PWM High/Low DC Brush Motor Drive

Figure 7-6 shows the typical amplifier stage arrangement when a MC71112, MC71112N, MC71113 IC, or MC78113 IC with DC Brush motor type selected is used in PWM High/Low mode.

Figure 7-6: 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

Signal	64-Pin TQFP Pin #	56-Pin VQFN Pin #	Description
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

7.3.1.4 PWM High/Low Step Motor Drive

Figure 7-7 shows the typical amplifier stage arrangement when a MC74113 IC, MC74113N IC, MC75113 IC, MC75113N IC, or MC78113 IC with step motor type selected is used in PWM High/Low mode.

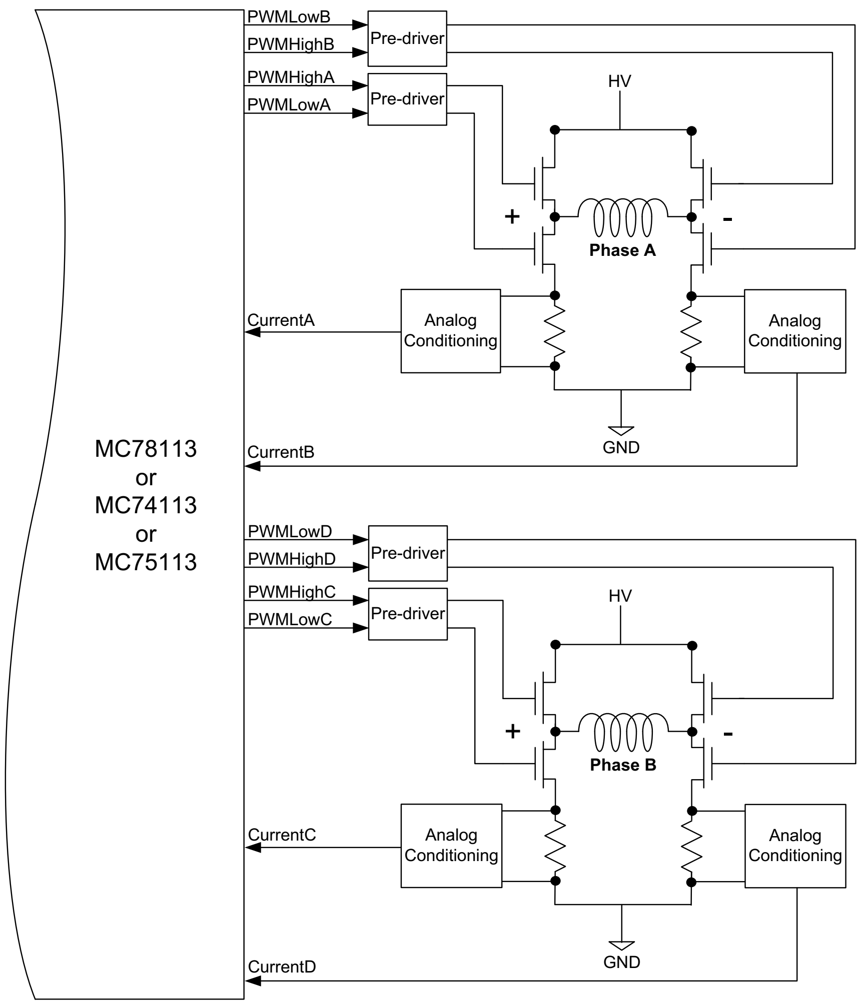


Figure 7-7: Two-phase Step Motor Bridge Configuration

As shown in the table below eight PWM output signals and, if used, four analog feedback signals for current control interface between the Juno IC and the switching amplifier circuitry. Because the Juno step motor ICs, unlike the DC Brush and Brushless DC ICs, are available both in the 64-pin TQFP and 56-pin VQFN package, both sets of pin #s are listed:

Signal	64-Pin TQFP Pin #	56-Pin VQFN Pin #	Description
PWMHighA	56	49	Digital high side drive output for motor phase A, positive coil terminal

Signal	64-Pin TQFP Pin #	56-Pin VQFN Pin #	Description
PWMLowA	55	48	Digital low side drive output for motor phase A, positive coil terminal
PWMHighB	54	47	Digital high side drive output for motor phase A, negative coil terminal
PWMLowB	53	46	Digital low side drive output for motor phase A, negative coil terminal
PWMHighC	51	45	Digital high side drive output for motor phase B, positive coil terminal
PWMLowC	50	44	Digital low side drive output for motor phase B, positive coil terminal
PWMHighD	39	34	Digital high side drive output for motor phase B, negative coil terminal
PWMLowD	38	33	Digital low side drive output for motor phase B, negative coil terminal
CurrentA	14	12	Analog input containing the current flow through the positive leg of the phase A bridge
CurrentB	19	16	Analog input containing the current flow through the negative leg of the phase A bridge
CurrentC	12	10	Analog input containing the current flow through the positive leg of the phase B bridge
CurrentD	21	18	Analog input containing the current flow through the negative leg of the phase B bridge

7.3.1.5 Using PWM High/Low Mode With Single Input Bridges

An alternate scheme for use of the PWM High/Low output mode is to utilize only the high control signals, leaving the low signals unconnected. This scheme is used to interface with amplifiers that do not provide separate high/low input but rather a single input control signal per high/low switch pair. Note that in this scheme, the *AmplifierEnable* signal, rather than being optional, must be connected to the bridge to control when the bridge should be active. For more information on the *AmplifierEnable* signal, see Section 7.3.3, "AmplifierEnable".

Since there is no separate high and low side signal to control the switches, the bridge itself, rather than the Juno IC, must handle some details of switch timing generation such as shoot through protection. Along those lines the dead time variable (see Section 7.3.1.7, "PWM High/Low Control Parameters" for details on amplifier-related Juno settings) should be set to zero when the Juno is connected in this configuration.

7.3.1.6 Low Pass PWM Signal Filtering

Some integrated amplifier ICs expect an analog command input. Using Juno 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 bridge circuitry.

7.3.1.7 PWM High/Low Control Parameters

There are a number of Juno parameters which are used to set up or control the switching amplifier circuitry shown in Figures 7-5 - 7-7 when the motor output mode is set to PWM High/Low. All of the parameters listed below are set using the SetDrivePWM command.

The following table shows these amplifier-related control parameters:

Parameter	Range & Units	Description
PWM Switching Frequency	20 KHz 40 KHz 80 KHz 120 kHz	Higher inductance motors should be set for 20 kHz. Lower inductance motors may use 40, 80, or 120 kHz to maximize current control accuracy and minimize heat generation. The default value for this parameter is 20 kHz.
PWM Dead Time	0-16,383 nSec	The correct setting of this parameter depends on the specific switching circuitry used. See the manufacturer's data sheet for more information. The default value for this parameter is 12,787 nSec.
PWM Refresh Time	0-32,767 nSec	Some high-side switch drive circuitry requires a minimum amount of off time, applied at a programmable period interval, to allow the charge pump circuitry to refresh. The default value for this parameter is 32,767 nSec.
PWM Refresh Period	1-32,767 cycles	Some high-side switch drive circuitry requires a minimum amount of off time, applied at a programmable period interval, to allow the charge pump circuitry to refresh. The default value for this parameter is 1 cycle.
PWM Limit	0-16,384 % output/163.84	This parameter allows the maximum PWM duty cycle to be set. The default value for this parameter is 16,384 which corresponds to 100% output.
PWM Signal Sense	16-bit mask	This parameter allows the signal sense of the PWM output signals to be specified. A 1 in the bit mask indicates active high, a 0 indicates active low. The default value is all signals active high.

7.3.2 Sign/Magnitude PWM Output Mode

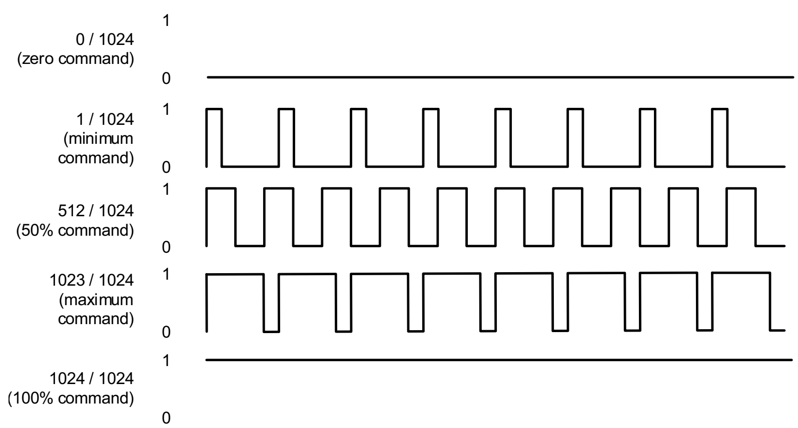


Figure 7-8: Sign/ Magnitude PWM Encoding

In Sign/Magnitude PWM mode, two pins are used to output the motor command information for each motor phase. One pin carries the PWM magnitude, which ranges from 0 to 100% as shown in Figure 7-8. 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.

> In Sign/Magnitude PWM control mode only DC Brush and step motors can be controlled. Brushless DC motors can not be controlled in this mode.

7.3.2.1 Sign/Magnitude PWM DC Brush Motor Drive

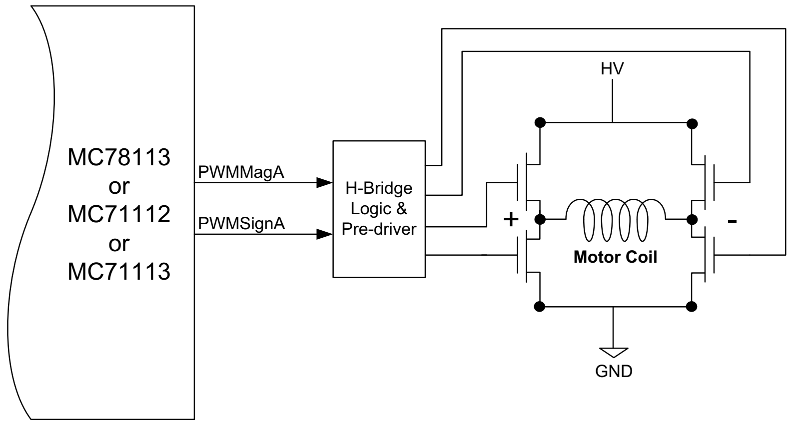


Figure 7-9: Sign/ Magnitude PWM DC Brush Motor Connections

Figure 7-9 shows a typical connection for DC Brush motors or solenoid type actuators when Sign/Magnitude PWM motor output mode is used. Note that in this mode the Juno does not provide current control, and therefore if current control is desired this capability must be provided by the amplifier bridge circuitry.

As shown in the table below a PWM magnitude and PMW sign signal are used to interface between the Juno IC and the amplifier circuitry.

MC78113 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 side drive output for the H-bridge switching amplifier

7.3.2.2 Sign/Magnitude PWM Step Motor Drive

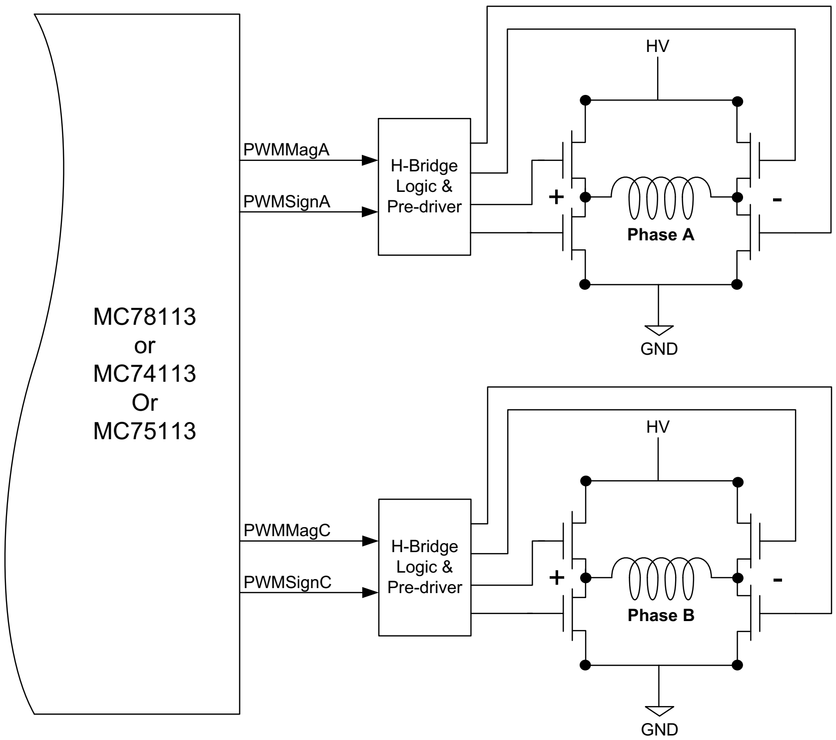


Figure 7-10: Sign/ Magnitude PWM Step Motor Connections

Figure 7-10 shows a typical connection for a two-phase step 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 bridges circuitry itself.

As shown in the table below two PWM magnitude and two PWM sign signals 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 step motor's phase A H-bridge switching amplifier
PWMSignA	55	48	Digital sign output for the step motor's phase A H-bridge switching amplifier
PWMMagC	51	45	Digital PWM magnitude output for the step motor's phase B H-bridge switching amplifier
PWMSignC	50	44	Digital sign output for the step motor's phase B H-bridge switching amplifier

7.3.2.3 Sign/Magnitude PWM Control Parameters

There are two parameters which are used to control the switching amplifier shown in Figures 7-9 - 7-10 when the motor output mode is set to Sign/Magnitude PWM.

The following table shows these amplifier-related control parameters.

Parameter	Range & Units	Description
PWM Switching Frequency	20 KHz 40 KHz 80 KHz 120 kHz	Higher inductance motors should be set for 20 kHz. Lower inductance motors may use 40, 80, or 120 kHz to maximize current control accuracy and minimize heat generation. This parameter is set using the SetDrivePWM command. The default value for this parameter is 20 kHz.
PWM Limit	0-16,384 % output/163.84	This parameter allows the maximum PWM duty cycle to be set. The default value for this parameter is 16,384 which corresponds to 100% output.
PWM Signal Sense	16-bit mask	This parameter allows the signal sense of the PWM output signals to be specified. A 1 in the bit mask indicates active high, a 0 indicates active low. The default value is all signals active high.

7.3.3 AmplifierEnable

Regardless of whether the motor output mode is set to PWM High/Low or Sign/Magnitude PWM, Juno provides an *AmplifierEnable* signal output that indicates whether the external amplifier circuitry is 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 powerup.

The output of this signal corresponds directly to the state of the motor output bit and the braking bit of the active operating mode register. If either of these bits are on, the *AmplifierEnable* signal is active. If both bits are off, this signal is inactive. For more information on Juno operating modes see the *Juno Velocity & Torque Control IC User Guide*.

7.3.4 Brake

Juno'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, for the selected motor type 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 ResetEventStatus and RestoreOperatingMode commands are used. For more information on Juno event processing see the *Juno Velocity & Torque Control IC User Guide*.

> If the braking feature is programmed it is up to the user to ensure that current flow resulting from back-EMF generation during braking does not damage the motor.

> 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.

The default setting of the *Brake* signal input is braking. To program this function the SetEventAction command is used.

7.4 Current Control

Juno provides the capability for sophisticated current control in connection with the PWM High/Low motor output mode. 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.

The following table shows the signals that are used to input the measured leg currents:

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
CurrentD	21	18	Measured Current for Leg current input D

Current sensors consist of sense resistors, as shown in Figure 7-1, or linear Hall sensors. If sense resistors are used ground-referenced operational amplifiers may be used.

Current inputs are sampled 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. MC78113s operating at 20 kHz PWM frequency in high noise environments may consider a rolloff on the lower end of the frequency range. Junos 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.

7.4.1 Typical Current Signal Processing Circuitry

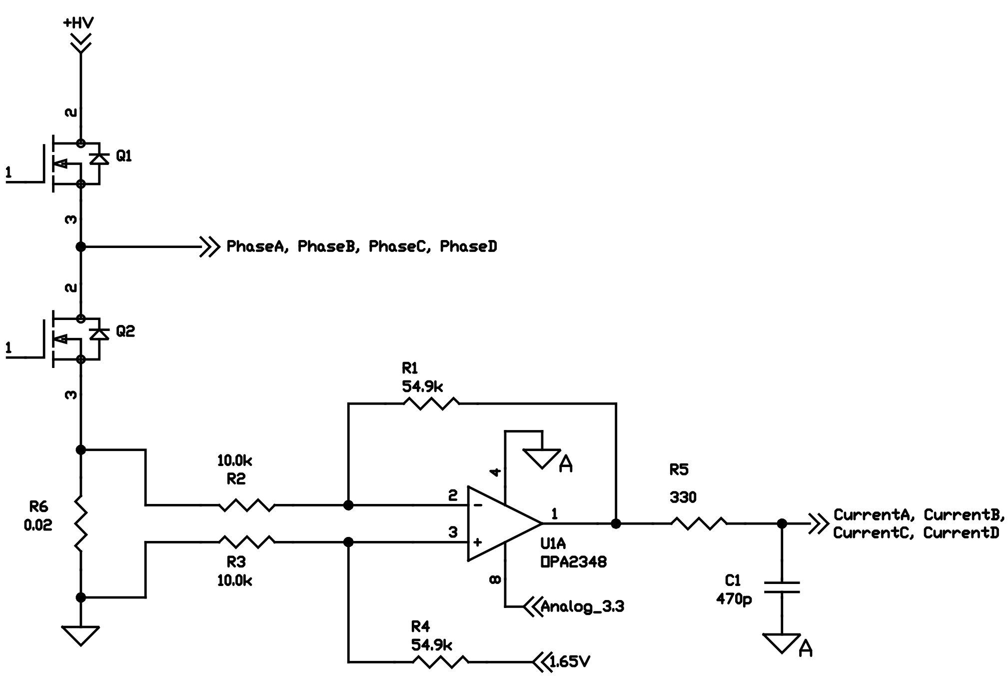


Figure 7-11: Typical Current Signal Processing Circuitry

Figure 7-11 shows a typical leg sensing processing circuit for Juno 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 8.12, "PWM High/Low Motor Drive With Leg Current Sensing/Control" for complete example schematics for various MC78113-based amplifier designs with current control.

> Juno's current control feature only functions when the PWM output mode is set to PWM High/Low.

7.4.2 Current Scaling

The value of the sense resistors and analog conditioning circuitry shown in Figures 7-5 - 7-7 determine the overall controllable current range of the switching amplifier. The overall current sense range should be 25% to 50% above the largest expected peak current. The commandable current range is 80% of the total current sense range.

Example: A brushless DC motor application will allow a peak current in each phase of 7.5 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 giving a current scaling of 10.0 amps/1.65 volts or 6.06 amps/volt.

Motor currents are read using the GetCurrentLoopValue or GetFOCValue command. The returned value is a signed twos-complement number with a full scale negative current value of -20,480, a zero current value of 0, and full scale positive value of +20,480. This same scaling is used to set as well as read quantities that represent motor currents.

Example: In the above system, the scaling of measured current to current in counts is 10.0 amps / 20,480 counts = .488 mA/count. To set an I^2t continuous current of 3.5 amps a value of 3,500 mA / .488 mA/count = 7,172 counts is used.

7.4.3 Minimum Current Read Time

When controlling Brushless DC motors with FOC (field oriented control) current control mode selected Juno's minimum current read time parameter is used to insure a valid leg current reading when two of the three phases have a saturated PWM signal. This period of time is affected by the analog processing circuitry. It can be approximated by taking the electrical time constant and multiplying by 3 to 5.

> The Juno IC 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.

7.4.4 Leg Current Analog Calibration

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

To facilitate this Juno provides the ability to zero-out analog input offsets that may exist while the motor coils are not being driven by the amplifier and the motor is not moving.

The simplest way to do this is to send a CalibrateAnalog command to Juno. This command 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 command to complete. In addition, the operating mode should be set to motor output only before this command is executed.

Alternatively, it is possible to directly read each analog input via the ReadAnalog command and then write the same values for the corresponding analog offsets using the SetAnalogCalibration command. When using this manual method it is recommended that a number of analog reads of each signal are averaged together to improve the offset accuracy.

Regardless of how the analog offsets are determined, unless explicitly stored into NVRAM they will not be retained after a reset or power cycle. For more information on NVRAM configuration storage see Section 7.9.2, "Non-Volatile RAM."

7.4.5 Current Control Parameters

There are a number of Juno IC parameters which are used to set or control current control shown in Figures 7-5 - 7-7.

The following table summarizes these amplifier-related control parameters.

Parameter	Range & Units	Description
Analog Current Offset A-D	-32,767 to 32,768 counts	The analog offset 'zero offset values' are determined when the amplifier is switching with a zero current command. The offsets are generally specific to the external circuitry of each leg current sensor, and should be separately zeroed out for best performance. These parameters are set using the SetAnalogCalibration command or via the CalibrateAnalog command. The default values for these parameters are zero.
Minimum Current Read Time	0-32,767 nSec	When using Brushless DC motors if two of three legs are driven at 100% the analog current reading of the second leg low-side switch needs to be active for a minimum amount of time for a valid current reading. This parameter, set using the SetDrivePWM command, specifies the amount of time needed for a valid analog current read when the drive is in this condition. This parameter has units of nSecs. The default value for this parameter is 32,767 nSec.

7.5 Drive & DC Bus Safety

Juno family ICs provide sophisticated DC Bus management and safety features. These features include overtemperature monitoring, over and under voltage monitoring, overcurrent monitoring, and shunt control.

The following table shows the signals that are used in connection with these 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
Shunt	49	33	Shunt Switch

The following sections provide detailed operational, connection, and configuration information for these DC Bus and safety related features.

7.5.1 Overtemperature Protection

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

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

7.5.1.1 Typical Overtemperature Processing Circuitry

Figure 7-12: Over-temperature Processing Circuitry

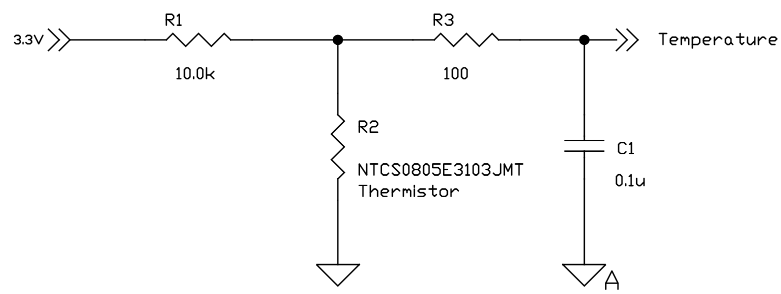


Figure 7-12 shows a typical signal processing circuit for use with the ***Temperature*** input. The thermistor is a 10k NTC temperature-voltage-decreasing type. C1 is referenced to analog ground and should be placed close to the ***Temperature*** pin of the Juno IC. R3 is optional. It can provide additional filtering to improve noise immunity if needed.

See Section 8.10, "Drive-Related Safety and Monitoring Features" for a complete example schematic of temperature input using Juno.

7.5.1.2 Overtemperature Scaling, Reading and Writing

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 measured temperature can be read using the **GetDriveValue** command. The returned value is an unsigned number with a range from 0 to 32,767. The returned temperature is direction adjusted, meaning for both voltage-increasing and voltage-decreasing thermistors a zero return value indicates the lowest possible temperature and a 32,767 represents the highest possible temperature.

The overtemperature threshold is set using the **SetDriveFaultParameter** command. 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.

In addition to the settable overtemperature Juno supports a settable temperature hysteresis. This function is used to avoid spurious re-triggering of an overtemperature event. The temperature hystersis value is set using the **SetDriveFaultParameter** command.

Example: A temperature-voltage-increasing thermistor and associated analog processing circuitry generate a voltage of 2.9V when the switching bridge circuitry is at the hottest safely operable temperature. The overtemperature limit specified using the SetDriveFaultParameter command should thus be set to 32,768 * 2.9V/3.3V = 28,796.

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

> Converting Juno-readable values to an actual temperature in units of degrees C is often complex. For this reason Juno's overtemperature protection mechanism compares directly against the unconverted temperature value in units of counts, not units of degrees C.

7.5.2 Overcurrent Monitoring

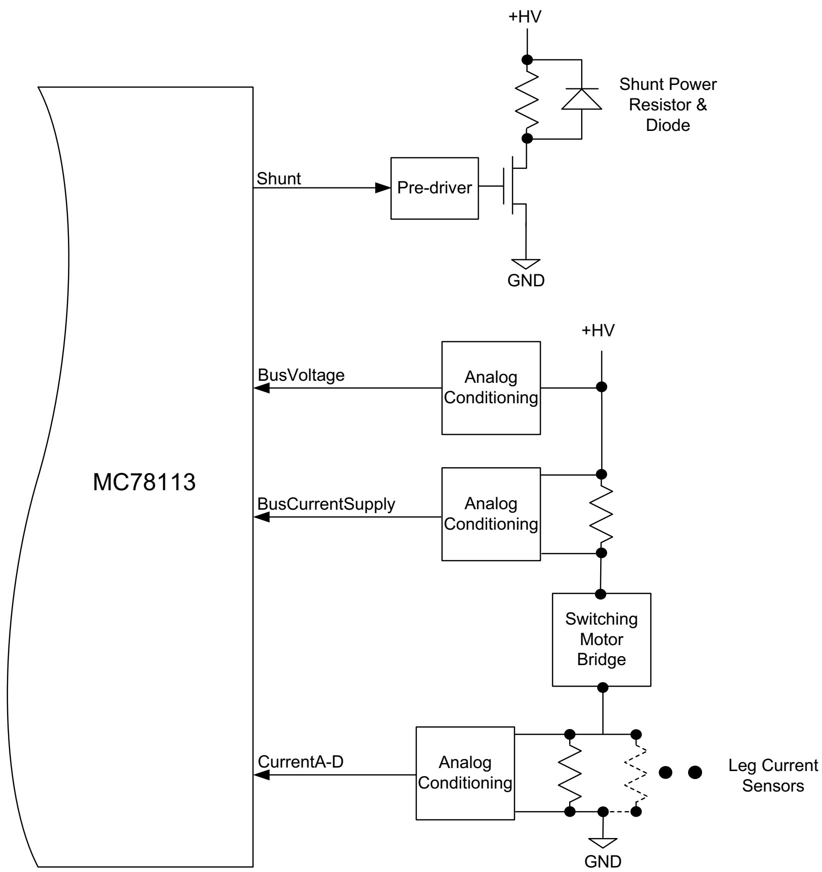


Figure 7-13: Overcurrent Monitoring Circuitry

Figure 7-13 shows the DC bus monitoring scheme used with the Juno IC. Juno monitors both the supply-side and return-side DC bus current to detect overcurrent conditions. Each can measure somewhat different overcurrent conditions. Supply side current measurement detects all excessive current flow including shorts of the motor windings to ground, shorts of the windings to each other, or a stalled rotor. Return current measurement can not measure shorts to ground, but can measure winding shorts to each other and a stalled rotor.

The *BusCurrentSupply* signal directly encodes the total current flowing through the motor amplifier bridge(s) from the +HV supply. The return-side overcurrent monitoring occurs via the leg current sensors also used during current control.

The DC bus current supply sensor typically consists of a sense resistor, as shown in Figure 7-13, 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 rolloff of 200 kHz - 500 kHz is recommended with a typical value of 350 kHz.

7.5.2.1 Typical Overcurrent-Processing Circuitry

Figure 7-14: DC Bus Monitoring Circuitry

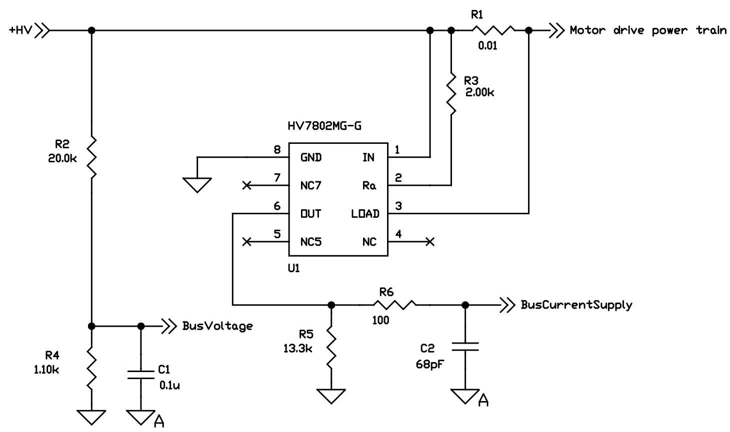


Figure 7-14 shows a typical processing circuit for DC Bus voltage and *BusCurrentSupply* over current sensing. The bus current sensing includes R1, U1, U2A and related passive parts. U1 is a high-side bus current sensing IC, and its output on R7 represents the bus current.

> Although it is possible to trace and read the value of the supply current input the resultant readings may be noisy due to the switching activity of the PWM drive. If a trace or read value for this signal is desired a peak holding circuit may be added with a hold time of 100µsec.

> 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 Juno's BusCurrentSupply analog input pin. This is generally accomplished via a diode. See Section 8.10, "Drive-Related Safety and Monitoring Features" for examples of DC bus safety-related schematics.

See Section 8.10, "Drive-Related Safety and Monitoring Features" for complete example schematics of Juno-based DC bus overcurrent protection designs.

7.5.2.2 DC Bus Supply Current Scaling, Reading and Writing

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 approximately double the maximum expected DC bus peak current flow. Note that in the case of step motors the maximum DC bus current is 150% of the peak phase current.

The measured bus supply current can be read using the GetDriveValue command. The returned value is an unsigned 16-bit number with range of 0 to 65,535. The DC bus supply overcurrent threshold is set using the SetDriveFaultParameter command. Typical threshold settings are 75-95% of the current sense range.

Example: An isolating op-amp and sense resistor generate 3.3V at a DC bus supply current flow of 15 amps. The scaling of current reads is 15.0A/65,536 = .228 mA/count. The overcurrent threshold is set at 12.0 amps, or 12,000 mA/.228 mA/count = 52,631.

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

7.5.2.3 DC Bus Return Overcurrent Measurement

Return current flow from the DC bus is measured via the leg current sensors as part of the current control mechanism. See Section 7.4.2, "Current Scaling" for more information on leg current scaling.

The bus return current can be read using the GetDriveValue command. The returned value is an unsigned 16-bit number with range of 0 to 20,480. The DC bus return overcurrent threshold is set using the SetDriveFaultParameter command.

The DC Bus return overcurrent threshold function operates continuously once programmed. To disable an overcurrent check a threshold value of 32,767 is set.

> 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 the Juno IC to measure DC bus return current. DC bus supply current measurement is not affected however and can function with or without current control active.

7.5.3 DC Bus Voltage Monitoring

Juno 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 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 by Juno at a rate of 20kHz, and therefore a low pass filter with a rolloff of 10 kHz or less is recommended.

7.5.3.1 DC Bus Voltage-Related Circuitry

Figure 7-14 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 of the Juno IC.

See Section 8.10, "Drive-Related Safety and Monitoring Features" for complete example schematics of Juno-based DC bus management designs.

7.5.3.2 DC Bus Voltage Scaling, Reading and Writing

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. The measured bus voltage current can be read using the GetDriveValue command. The returned value is an unsigned 16-bit number with range of 0 to 65,535. The over and undervoltage thresholds are set using the SetDriveFaultParameter command, and have the same units.

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.

7.5.4 Shunt Resistor

The shunt function is used with DC Brush and Brushless DC motors only. As shown in Figure 7-13 Juno controls a shunt PWM output, which in turn typically drives a MOSFET or IGBT switch which connects the voltage to the DC bus ground via a power resistor, thereby lowering the DC bus voltage.

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 32,767 should be programmed. The shunt function is not active when motor output is not enabled (the active operating mode output bit is not set).

7.5.4.1 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 7-13 for more information.

7.5.4.2 Shunt Reading and Writing

To set the shunt DC bus voltage comparison threshold the SetDriveFaultParameter is used. The scaling and units are the same as for the over and undervoltage functions. The shunt PWM duty cycle is set using the SetDriveFaultParameter command, and the provided value is an unsigned 16-bit number with range of 0 to 32,767.

Example: In the system from the example in Section 7.5.3.2, "DC Bus Voltage Scaling, Reading and Writing" 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/1.98 mV/count = 25,757 and the duty cycle value is .95 * 32,768 = 31,130.

It is possible to determine whether the shunt output is active at any given moment. To do this the command GetDriveStatus is used.

7.6 Host Communications

Juno ICs support host communications using point-to-point and multi-drop asynchronous serial, CANbus 2.0, and SPI (Serial Peripheral Interface). However not all Juno ICs support all host communications modes. This is shown in the table below:

Juno IC Type	P/Ns	Serial Point-to-point	Serial Multi-drop	CANbus	SPI*
Velocity control	MC71113, MC73113, MC78113	✓	✓	✓	✓
Torque control	MC71112, MC71112N, MC73112, MC73112N	✓			
Step motor control	MC74113, MC74113N, MC75113, MC75113N	✓			

**while Juno torque control and step motor control ICs do not support SPI for host communications, they do provide SPI input for command value input or for sensor reading input.*

Below are descriptions of each of the host communication ports supported by Juno ICs.

7.6.1 Serial

Juno series ICs provide two overall serial communication modes; point to point (used with RS232 or RS422), and multi-drop (used with RS485). All of Juno's serial-related signals are digital TTL level signals, so for typical cable-based use of these communication modes external transceiver chips are used. See Section 8.6, "Serial Communication Interface (SCI)" for example schematics for serial communications.

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 for all serial modes.
SrlXmt	27	24	Serial Transmit outputs the serial data for all serial modes.
SrlEnable	61	-	SrlEnable is held high in point-to-point mode. In multi-drop mode SrlEnable is high during transmission only. This function is not supported in the 56-pin VQFN package.

By default Juno powers up in point to point communication mode at 56 Kbaud. This configuration information can be changed via the SetSerialPortMode command.

7.6.2 CANbus

Juno ICs provide CANbus 2.0 compatible communications. All of the Juno CANbus-related signals are digital TTL level signals, so for typical cable-based use of this communication mode external transceiver chips are used. See Section 8.7, "CAN Communication Interface" for example schematics for CANbus communications.

The table below provides a summary of Juno signals used with CANbus communications. Note that CANbus communications are not supported in the 56-pin VQFN package.

Pin Name	64-Pin TQFP Pin#	56-Pin VQFN Pin#	Description
CANRcv	26	-	CANbus receive inputs the CANbus data
CANXmt	25	-	CANbus transmit output the CANbus data

Juno will coexist (but not communicate) with CANOpen nodes on that network. Juno uses CAN to receive commands, send responses, and (optionally) send asynchronous event notifications and uses different addresses for each as indicated in the table below:

Message Type	CAN Address
Command received	0x600 + nodeID
Command response	0x580 + nodeID
Event Notification	0x180 + nodeID

By default the Juno CANbus nodeID is 0, and the CAN baud rate is 20,000. This configuration information can be changed via the **SetCANMode** command.

7.6.3 SPI (Serial Peripheral Interface)

Juno ICs provide SPI communications both for host communications, and for direct input commands such as the continuous instantaneous desired velocity or torque. For more information on the formatting of SPI host communications refer to the *Juno Velocity & Torque Control IC User Guide*.

All of the SPI-related signals are digital TTL level signals. Some applications may directly connect microprocessors, FPGAs, or other on-board logic to these signals. Other applications, depending on signal lengths and noise level may benefit from external drivers to improve signal integrity of the SPI bus. See Section 8.8, "SPI Communication Interface" for example schematics for SPI communications.

> SPI is a serial hardware bus intended for communications within a PCB substrate only. It is not recommended for board to board communications. It is the responsibility of the user to insure the signal integrity of the SPI bus for the application in which it is used.

Juno's SPI interface utilizes three digital input pins *SPIEnable*, *SPSIClock* and *SPIRcv*, and two digital output pins *SPIXmt* and *SPIStatus*. These signals represent the standard SPI enable, chip select, clock, and data functions, along with a protocol packet processing status indicator. The Juno IC acts as an SPI slave, and the host processor acts as an SPI master.

The table below provides a summary of the Juno IC signals used with SPI communications or direct input commands.

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
SPIStatus	61	-	SPIStatus is used during host communications to synchronize host commands with responses. It is not used with direct input SPI commands.

For complete electrical timing information for all SPI bus operations see Section 3.2.3, "Host SPI."

7.7 Input Signal Processing

7.7.1 Quadrature Encoder Signals

Incremental encoder input along with an index pulse and associated high speed capture system is supported by all members of the Juno family except MC75113 and MC75113N. All of the Juno 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, as shown in Figure 7-15. 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.

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

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. This default value can be changed via the SetSignalSense command.

7.7.2 Typical Quadrature Encoder Processing Circuitry

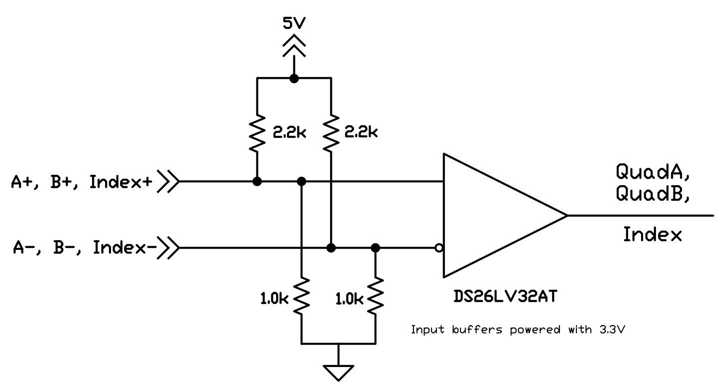


Figure 7-15: Quadrature Encoder Processing Circuitry

Figure 7-15 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.

7.7.3 Pulse & Direction

Pulse & *Direction* along with *AtRest* input is supported by all members of the Juno IC family except MC71112, MC71112N, MC73112, and MC73112N. All of these signals are digital TTL level, so for typical cable-based connection buffering circuits are recommended.

The table below provides a summary of the Juno pulse & direction related signals:

Pin Name	64-Pin TQFP Pin#	56-Pin VQFN Pin#	Description
Pulse	33	29	Pulse provides a step command signal for the pulse & direction position command input source.
Direction	36	31	Direction indicates the direction of motion for the pulse & direction position command input source.
AtRest	35	23	AtRest indicates that the axis is at rest and not actively moving. It is used to select between the 'in motion' programmable step motor torque levels and the 'at rest' level.

By default the *Pulse* signal is active low. This configuration information along with interpretation of the *Direction* and *AtRest* signals can be changed via the **SetSignalSense** command.

7.7.3.1 Typical Pulse & Direction Processing Circuitry

Figure 7-16: Pulse & Direction Processing Circuitry

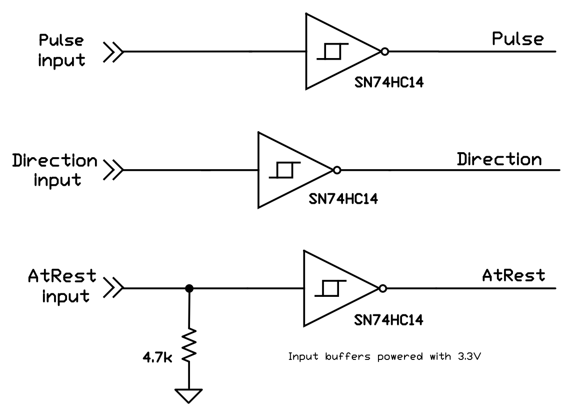


Figure 7-16 shows a typical circuit for processing the *Pulse* & *Direction*, and *AtRest* signals. The buffered signals are inverted and have a pull-down resistor at the *AtRest* input so the output of the buffer is low to ensure a deterministic state when *AtRest* is unconnected.

7.7.4 Hall Sensors

Although not required by Juno, 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.

7.7.4.1 Typical Hall Processing Circuitry

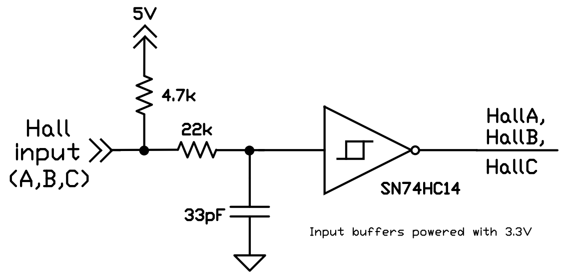


Figure 7-17: Typical Hall Processing Circuitry

Figure 7-17 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.

7.7.5 AnalogCmd & Tachometer

Juno supports input of an *AnalogCmd* direct input signal to provide a bi-polar desired velocity or torque command for the motor or actuator being controlled. In addition a *Tachometer* input signal can be used to provide velocity feedback to the Juno IC.

The table below provides a summary of the *AnalogCmd* & *Tachometer* signals.

Pin Name	64-Pin TQFP Pin#	56-Pin VQFN Pin#	Description
AnalogCmd	18	18	Analog torque or velocity command input
Tachometer	24	-	Analog velocity feedback used by velocity loop

7.7.5.1 AnalogCmd

The analog 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 Juno at a rate of 20kHz and therefore a low pass filter with a rolloff at 50kHz - 200kHz is recommended.

7.7.5.2 Tachometer

Juno supports input of a *Tachometer* signal which provide a bi-polar measured velocity for the motor or actuator being controlled. All aspects of voltage range and scaling for this signal are the same as for the *AnalogCmd* signal. The analog input range at the Juno IC is 0.0V to 3.3V and the maximum and minimum velocity feedback readings have a value of 3.3V and 0.0V respectively. See Figure 7-18 for an example schematic that inputs from an external circuit with a range of +/-10 V.

> In addition to measuring motor velocity, the *Tachometer* signal can also be used to input outer loop quantity measurements such as pressure, or temperature. See the *Juno Velocity & Torque Control IC User Guide* for more information on outer loop controller function.

7.7.5.3 Typical AnalogCmd & Tachometer Processing Circuitry

Figure 7-18: AnalogCmd and Tachometer Circuitry

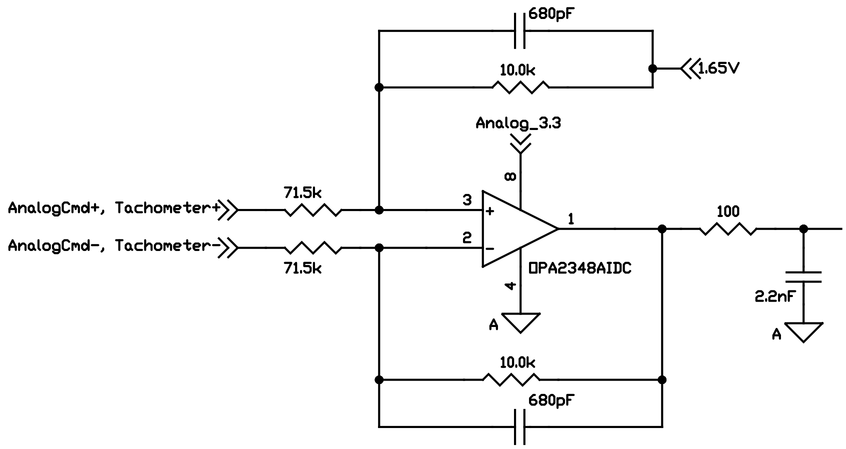


Figure 7-18 shows a typical circuit for processing +/-10V differential input command or tachometer signals. The output has an offset of 1.65V corresponding to a zero command. The bandwidth of this circuit is 23.4kHz. The 100ohm resistor and 2.2nF capacitor should be placed close to the *AnalogCmd* input pin of the Juno IC. All resistors used should be 1% or higher grade. All capacitors should be X7R or higher grade.

7.7.5.4 AnalogCmd & Tachometer Scaling and Reading

The value of the analog command and downstream analog conditioning circuitry determine the overall velocity or torque command range that can be specified. When reading the analog command via the MC78113's GetVelocityLoopValue command or via a trace the returned value is a signed number with a range from -32,768 to 32,767.

Example: Analog processing circuitry converts a +/- 10V signal to the full scale of the 0 to 3.3V input range. An incoming signal voltage of -7.0V is received, representing a request for 70% of available maximum velocity or torque in the negative direction. This incoming signal results in a voltage of 0.495V at Juno's *AnalogCmd* pin which after being read results in numerical command value of -22,937.

7.8 Reset

Juno ICs require various conditions to be present on the *Reset* and *ClkIn* pins for proper reset and powerup.

In particular, for the Juno ICs which have a *ClkIn* signal (MC71113, MC73113, and MC78113), *ClkIn* must be kept in a high impedance state during powerup until the MC78113's Vcc and AnalogVcc stabilize.

The table below provides a summary of the Juno reset related signals:

Pin Name	64-Pin TQFP Pin#	56-Pin VQFN Pin#	Description
Reset	7	5	Reset input
ClkIn	45	-	Clock input. Not used with 56-pin VQFN package.

7.8.1 Typical Reset Processing Circuitry

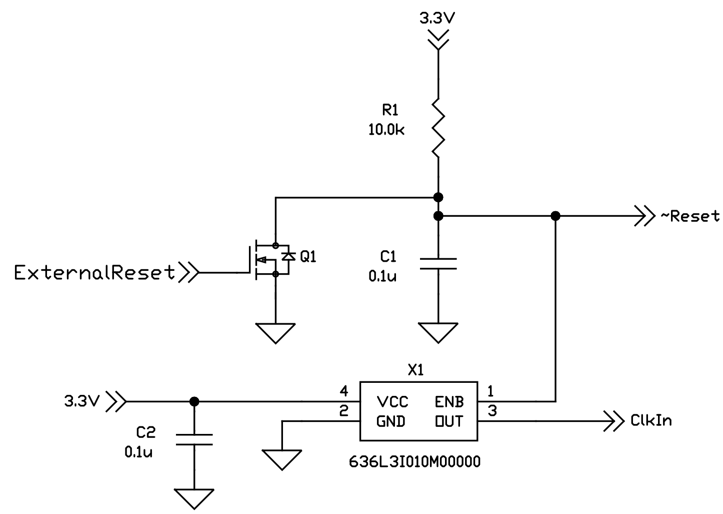


Figure 7-19: Typical Reset Processing Circuitry

Figure 7-19 shows a typical reset circuit for the Juno ICs that have a ***ClkIn*** signal. Although included in this circuit, external control of the **Reset** signal is not required since the Juno will trigger an internal reset upon power up. The ~***Reset*** pin is driven low by Juno under a power-on or reset condition. Figure 7-19 uses ~***Reset*** signal to meet the ***ClkIn*** high impedance requirement. At power on, Juno pulls down ~***Reset*** signal and puts X1 output to high impedance. If external reset is implemented an open-drain device is used. If no external reset is implemented, Q1 from the above circuit is eliminated.

For Juno ICs that do not have a ***ClkIn*** signal (MC71112, MC711112N, MC73112, MC73112N, MC74113, MC75113, MC74113N, and MC75113N) in the above circuit X1 and the connected circuitry is eliminated.

7.8.2 Power-up and Initialization

A power-up where no user-provided initialization parameters have been stored in NVRAM takes approximately 250mSec. At the end of this sequence all parameters are at their default values, and both the current loop module and the power stage module are disabled. At this point Juno is ready to receive commands and begin operation.

Juno also supports the ability to store initialization parameters that are automatically applied during the power up sequence. For this purpose, a 1,024 word memory that is non-volatile (NVRAM) is provided.

If the non-volatile initialization memory has been loaded with initialization information Juno detects this and begins executing the commands stored in the non-volatile memory. Once execution of these commands is completed, Juno initialization is done and normal operation begins. Note that processing stored commands may increase the overall initialization time depending on the command sequence stored.

See Section 7.9.2, "Non-Volatile RAM" for more information on the Juno's NVRAM.

7.9 Juno RAM and NVRAM

Juno provides two user-accessible types of memory storage, a 6,144 16-bit word RAM used primarily for trace and a 1,024 16-bit word NVRAM used primarily to store initialization configuration parameters. The RAM will be lost upon a power cycle or reset function while the NVRAM is permanent and will be retained even after a power cycle.

For more information on June IC memory buffers and trace, see the *Juno Velocity & Torque Control IC User Guide*.

7.9.1 Trace RAM

Juno's internal RAM volatile memory is most often used for performance trace, but it may also be used for general purpose storage of user-specified data. All RAM access occurs via the MC78113's buffer access commands. Buffer access commands allow memory areas to be written to and read from the memory areas using different word sizes. In addition all trace operations use buffers to specify where the trace data will be written to and read from.

The starting address of the Juno's RAM is 0. For convenience Juno's RAM memory area is pre-defined as BufferID #0

To learn more about Juno's buffer access commands and very powerful trace features for tuning and performance optimization refer to the *Juno Velocity & Torque Control IC User Guide*.

7.9.2 Non-Volatile RAM

Juno supports a memory segment that is non-volatile (NVRAM). The primary purpose of the NVRAM is to allow Juno configuration information to be stored, so that upon power up it can be loaded automatically rather than requiring an external controller to perform this configuration initialization function.

The starting address of Juno's NVRAM is 0x2000 0000. For convenience the NVRAM memory area is pre-defined as BufferID #1.

All data stored in the Juno NVRAM utilizes a data format known as PMD Structured data Storage Format (PSF). Users who rely only on PMD's Pro-Motion software package to communicate with Juno and store and retrieve initialization parameters 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. For information on loading information into the Juno NVRAM refer to Section 6.1, "Loading the NVRAM."

7.10 Output Signal Status During Powerup

The following table summarizes the Juno IC's output signal states during power up and after powerup when no initialization data is stored in the NVRAM.

Pin Name	64-Pin TQFP Pin#	56-Pin VQFN Pin#	State during powerup	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/PWMMagC	51	45	Tri-stated	Tri-stated
PWMLowC	50	44	Tri-stated	Tri-stated
PWMHighD	39	34	Tri-stated	Tri-stated
PWMLowD	38	33	Tri-stated	Tri-stated
AmplifierEnable	3	22	Pulled high	Driven low
Shunt	49	33	Tri-stated	Tri-stated (until output mode is set)
FaultOut	52	40	Tri-stated	Driven low
SrlXmt	27	24	Pulled high	Pulled high
CANXmt	25	-	Pulled high	Pulled high
SrlEnable/SPIStatus	61	-	Pulled high	Driven low

Pin Name	64-Pin TQFP Pin#	56-Pin VQFN Pin#	State during powerup	State after power up
SPIXmt	34	30	Pulled high	Driven low
~HostInterrupt	46	43	Pulled high	Driven high

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

See Section 7.9.2, "Non-Volatile RAM" for more information on NVRAM initialization storage.

7.11 Analog Signal Input

The following table summarizes the Juno's analog signals and indicates how they may be addressed during trace or for other operations such as ReadAnalog, or SetAnalogCalibration commands.

Signal	64-Pin TQFP Pin #	56-Pin VQFN Pin #	Channel
CurrentA	14	12	0
CurrentB	19	16	1
CurrentC	12	10	2
CurrentD	21	18	3
Temperature	9	7	4
BusCurrentSupply	10	8	5
BusVoltage	13	11	6
AnalogCmd	18	18	7
Tachometer	24	-	8

If used, for best performance, it is highly recommended that the *CurrentA-D*, *AnalogCmd*, and *Tachometer* signals be calibrated and offset. See Section 7.4.4, "Leg Current Analog Calibration" for information on analog input offsetting.

For the *Temperature* and *BusVoltage* signals, offsetting is allowed but generally not necessary. The *BusCurrentSupply* signal does not support an offset calibration nor is one needed for proper functioning. For information on calibrating Juno analog inputs in your production application refer to Section 6.2, "Analog Signal Calibration in the Production Application."

Regardless of how the analog offsets are determined, unless explicitly stored into NVRAM analog offsets will not be retained after a reset or power cycle.

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8. Application Notes — MC78113

8

- General Design Notes
- Design Tips
- Power Supplies
- Clock Generator, Grounding and Decoupling
- Reset Signal
- Serial Communication Interface (SCI)
- CAN Communication Interface
- SPI Communication Interface
- 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 Step Motor Amplifiers With Multi-Axis Magellan
- Two Juno BLDC Motor Amplifiers With Multi-Axis Magellan

8.1 General Design Notes

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 MC78113 is named "PWMHighA/PWMMagA" but will be referenced by the name "PW-MHighA" in the PWM High/Low motor drive example and "PWMMagA" in the DC brush motor schematics.

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

8.1.1 Interfacing to Other Logic Families

When integrating different logic families, consideration should be given to timing, logic level compatibility, and output drive capabilities. The MC78113 is 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.

8.2 Design Tips

8.2.1 Controlling PWM Output During Reset

When the MC78113 is 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.

8.2.2 Thermal Considerations

The recommended operating junction temperature range for the MC78113 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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8.3 Power Supplies

In the schematic shown in Figure 8-1 the design is powered by an external +5VCC power source. The MC78113 requires 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 MC78113 analog-to-digital converter (ADC) is 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 MC78113 device. +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 8-1 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.

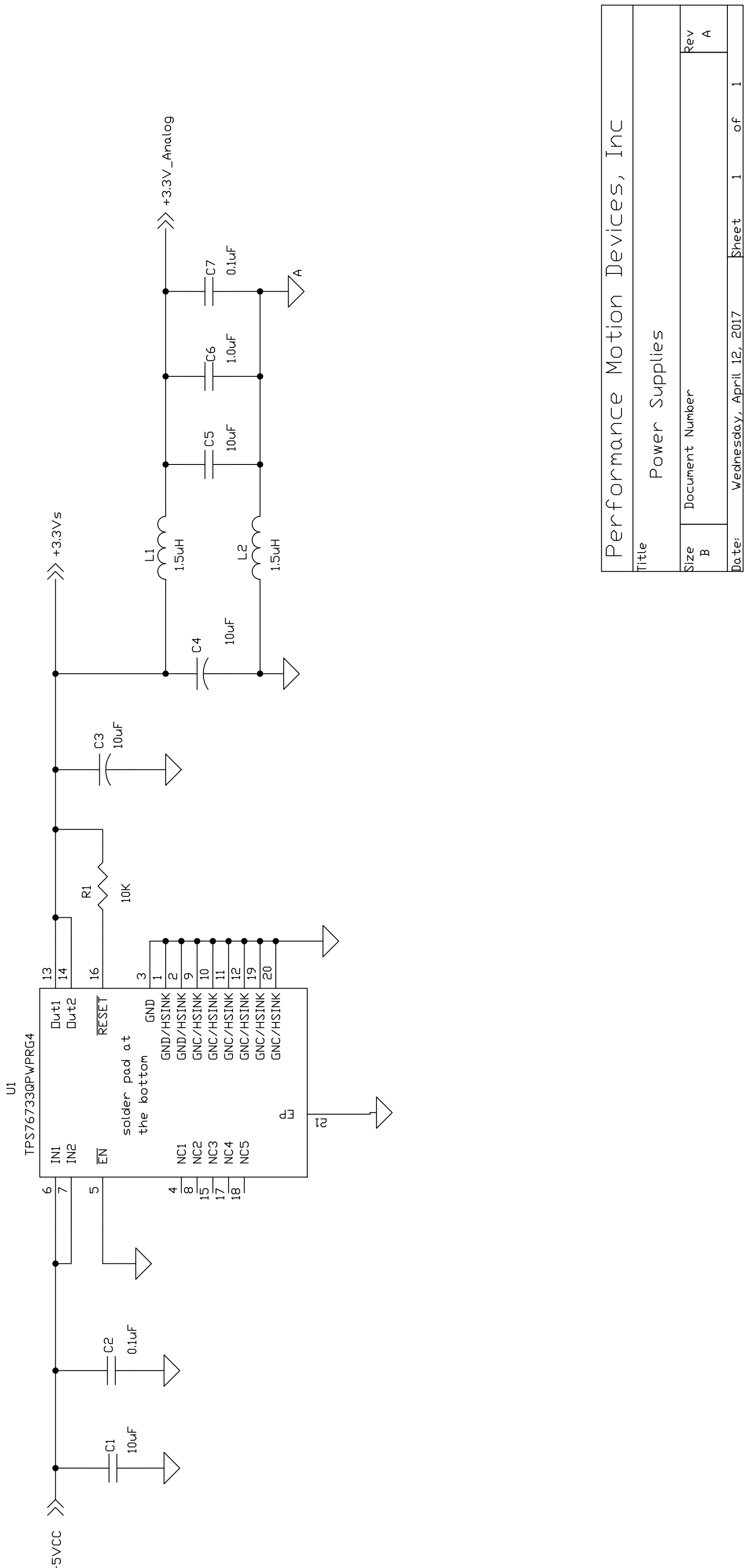


Figure 8-1: Basics, Power Supplies, MC78113

8.4 Clock Generator, Grounding and Decoupling

8.4.1 Clock Generator — MC78113

An external 3.3V 10MHz clock oscillator output should be supplied to the MC78113's ClkIn pin.

During power up, the pin ClkIn could glitch. In Figure 8-2, MC78113's ~Reset pin is connected to ENB pin of the clock oscillator. During power up, ~Reset pin holds low and keeps the output of clock oscillator at high impedance to prevent I/O conflict.

8.4.2 Grounding and Decoupling

As shown in Figure 8-2, each of the MC78113 digital supply voltage pins should be connected to the +3.3 Vcc. A minimum of 1.2uF capacitor should be used to decouple each Vcc pin. A 2.2uF 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 1.2uF filtering capacitor which in turn connects to ground. A 2.2uF 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.

8.4.3 Decoupling of the On-chip ADC

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

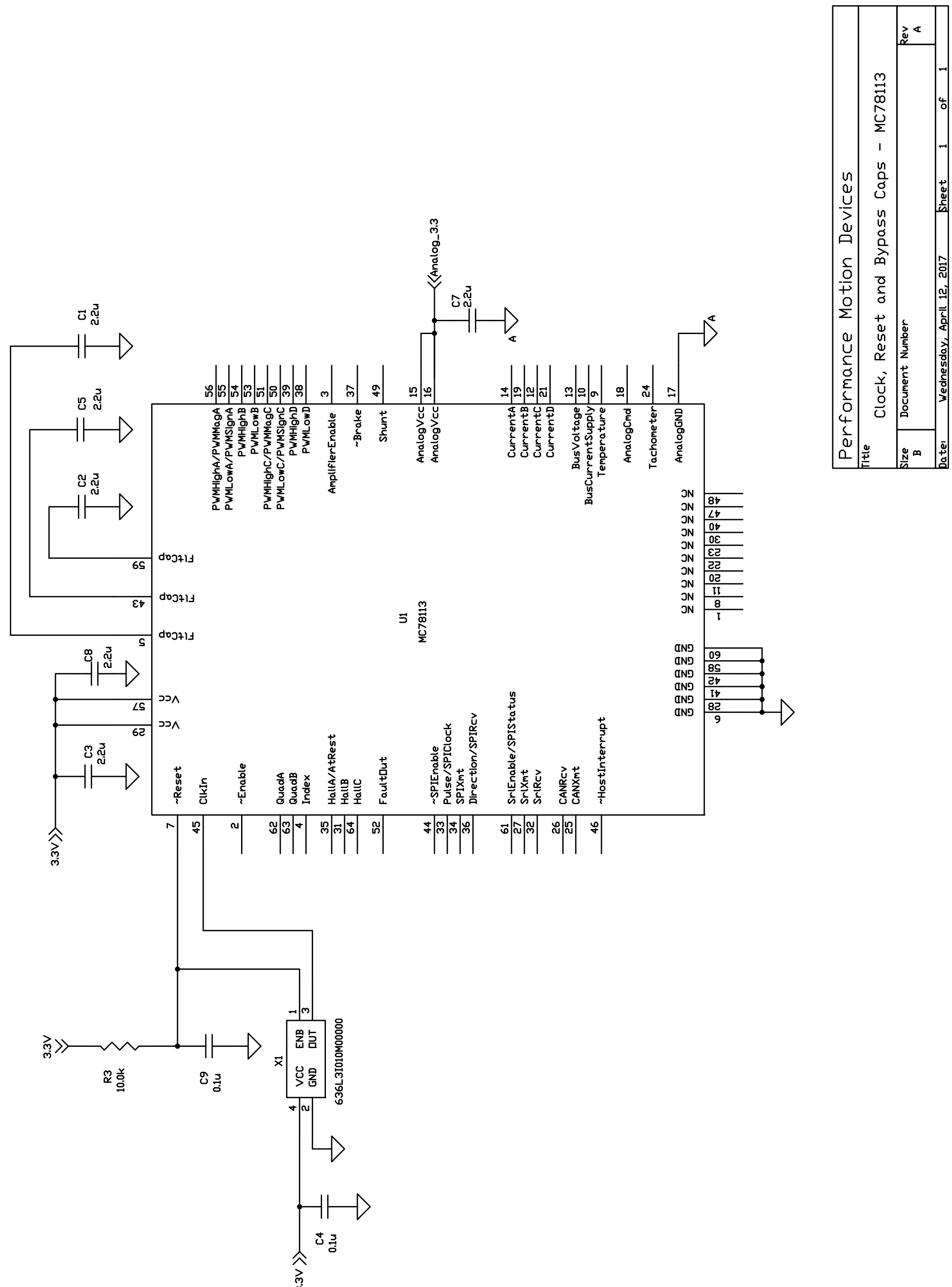


Figure 8-2: Basics, Clock and Bypass Caps, MC78113

8.5 Reset Signal

The MC78113 chip has 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 7.10, "Output Signal Status During Powerup" 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 MC78113 is configured with the default initialization parameters for motor type, serial communication and CAN communication, analog offsets, control loop gains etc. If necessary, the MC78113's on chip non-volatile storage can be used to store user-programmed initialization parameters. For more information see the *Juno Velocity & Torque Control IC User Guide*.

8.6 Serial Communication Interface (SCI)

In this section the serial communication interface to the host is described. On power-up or after a reset, unless the on board non volatile storage has been used to store alternate defaults, the MC78113 configures the SCI to its default configuration of 57,600 baud, no parity, one stop bit, point-to-point mode.

This section demonstrates the use of RS-232 and RS-485 line-drivers for interfacing to a remote host.

8.6.1 Asynchronous Serial Communications

When the host and motion control IC are located on the same physical board it is most likely that simply wiring the transmit and receive lines directly between the host and MC78113 chip is all that is required (assuming they are both 3.3V CMOS devices).

For communications between boards or modules TIA/EIA standards provide reliable communication over varying cable lengths and communication rates. The most commonly used standards are RS-232 and RS-485. These standards are separated into two categories: single-ended and differential. RS-232 is a single-ended standard allowing for moderate communication rates over relatively short cables. RS-485 is differential, offering higher data rates and longer cable runs.

Line drivers and receivers (transceivers) are commonly used in order to mediate between the cable interface and the digital circuitry signal levels. There are several design considerations that should be taken into account when deciding which of these two communication methods is the best fit for an application.

- Full-duplex vs. half-duplex

  The terms full-duplex and half-duplex are used to distinguish between a system having two separate physical communications lines from one having one common line for transmission and reception.

- Line contention

  This problem can occur in half-duplex systems. Most line-drivers supply physical protection against such conditions but there is no automatic recovery of lost data in these levels. When interfacing the MC78113 to a half-duplex communication system the designer should note that the turn-around time for command processing and response is at least 1 byte at the current baud rate. As a result the host should release the communication line before this time elapses so that contention can be avoided.

- Termination impedance

  Long cables and/or high data rates require termination resistors if the transceiver is located at the end of the transmission lines. One way to determine if termination is required is if the propagation delay across the cable is larger than ten times the signaling transition time. If this condition is satisfied, then termination is required. The RS-485 standard specifies the signaling transition time to be less than 0.3 times the signaling period, thus imposing an upper limit on the maximum cable length for a specified baud rate.

  The termination resistor should match the characteristic impedance of the cable with 20% tolerance. Resistors with a value of 80-120 are typically used. Note that for transceivers placed in the middle of the cable, no termination resistors are required. However, the stubs should be kept as short as possible to prevent reflections.

- Pin SrlEnable/HostSPIStatus at power up and reset

  MC78113's SrlEnable/SPIStatus pin must be '1' at power up and reset; only pull-up resistor is allowed. In RS-485 communication, it would enable the line driver output and affect ongoing communication so hot swap operation is not supported.

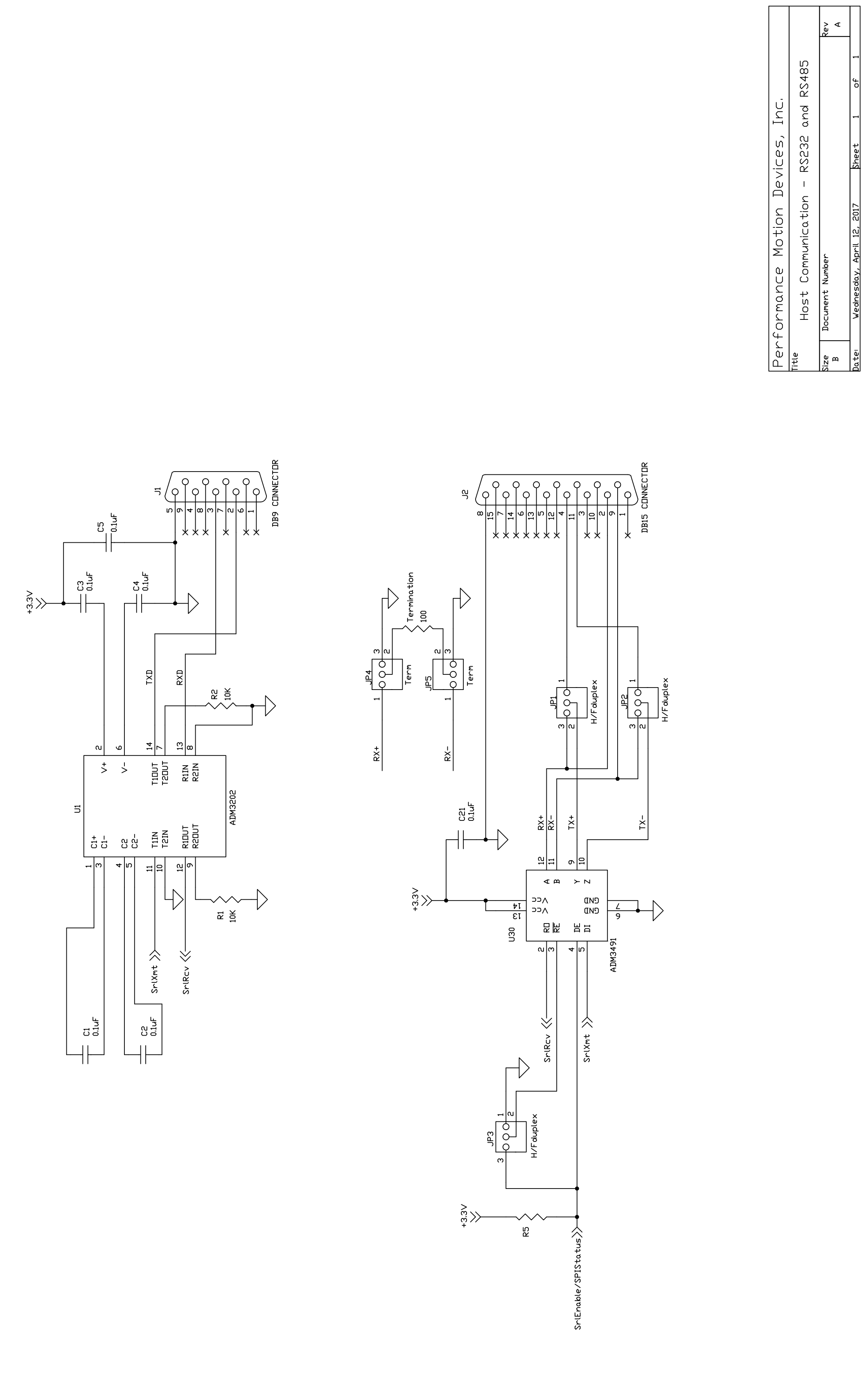
The schematic in Figure 8-3 employs the ADM3202 and ADM3491 transceivers as an example of RS-232 and RS-485 interfaces respectively. Other RS-232 transceivers may be used, such as Maxim's MAX3321E. The ADM3491 circuitry can be configured for both full-duplex and half-duplex communications, and may include termination resistors. As an alternative, transceivers from the MAX307xE family may be used.

The following table shows configuration options for the RS-422/485 circuitry of Figure 8-3:

Configuration	Jumper Position	Application
Half Duplex[1]	JP1/2/3 in 2-3	RS-422/485 in multipoint system
Full Duplex	JP1/2/3 in 1-2	RS-422/485 in point to point system
Termination on[2]	JP4/5 in 1-2	RS-422/485. For high transmission rates and/or long cable. Only when placed at the end of the cable.
Termination off	JP4/5 in 2-3	RS-422/485. For low transmission rates and short cable. Or when placed at the middle of the cable.

1. JP3 should only be placed be in the half duplex state (2-3) if multi-point communication is being used.
2. Note that the reference circuitry does not support resistance termination on the transmitting side when operated in full duplex because it is assumed that RS-422/485 will only be used in the half-duplex configuration.

Figure 8-3: Host Communication, RS-232 and RS-485



8.7 CAN Communication Interface

The following example illustrates an interface to a CAN backbone using TI's SN65HVD233 transceiver, which supports the ISO 11898 standard. This port can be operated at various communication rates from 10,000 to 1,000,000 bps (bits per second). In addition, each CANbus device is assigned three CAN identifiers (also called addresses); one for transmission of messages, one for reception of messages, and one for event messages. Generally, the CAN high-speed standard ISO 11898 provides a single line bus structure as a network topology. The bus line is terminated at both ends with a termination resistor of ~120ohms. Consult CAN ISO 11898 standard for more information on termination schemes and EMC considerations.

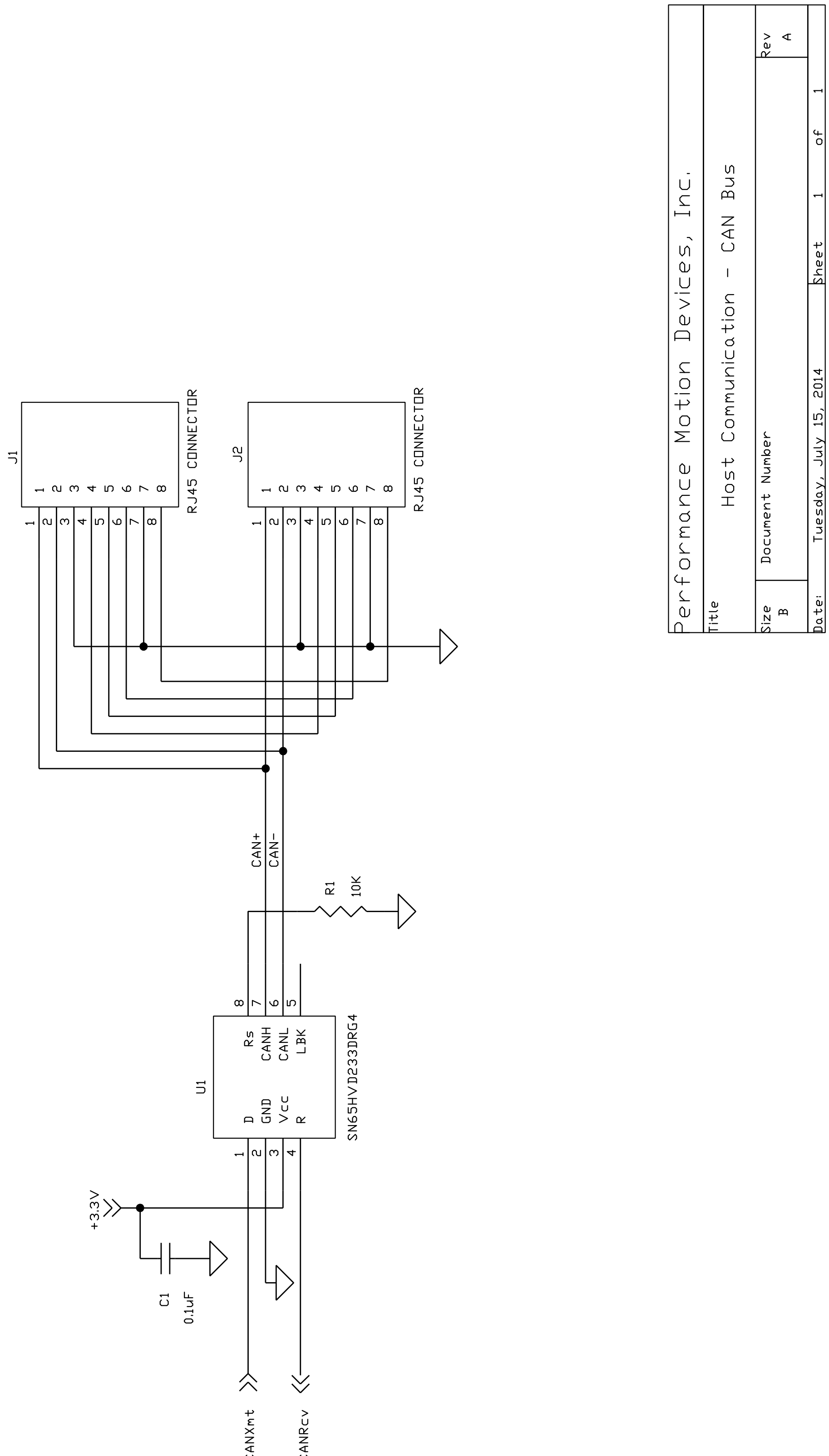
8.7.1 CAN Configuration During Power-up or Reset

On power-up or after reset, the MC78113 configures the CAN controller to its default configuration: 20 kbps with a Node ID of 0. The MC78113's on board non-volatile storage can be used to store user-programmed initialization parameters. If a non-default CAN configuration is required, please contact PMD sales representative to learn more. PMD may ship MC78113s pre-loaded with user-specified parameters.

The RS pin of the SN65HVD233 provides for three modes of operation: high-speed, slope control, or low-power standby mode. This programmable input pin may be used to adjust the rise and fall times of the transmitter. This may be important in unshielded, low-cost systems in order to reduce electromagnetic interference. This pin provides three different modes of operation: high-speed, slope control, and low-power modes. The high-speed mode of operation is selected by connecting this pin to ground, allowing the transmitter output transistors to switch on and off as fast as possible with no limitation on the rise and fall slopes. The rise and fall slopes can be adjusted by connecting a resistor to ground at this pin, since the slope is proportional to the pin's output current. This slope control is implemented with external resistor values of 10kohms, to achieve a 15-V/µs slew rate, to 100 kohms, to achieve a 2-V/µs slew rate.

If transmitter's rise/fall times do not require adjusting, the RS pin should be tied to GND or the simpler SN65HVD232 can be used.

Figure 8-4: Host Communication CANbus



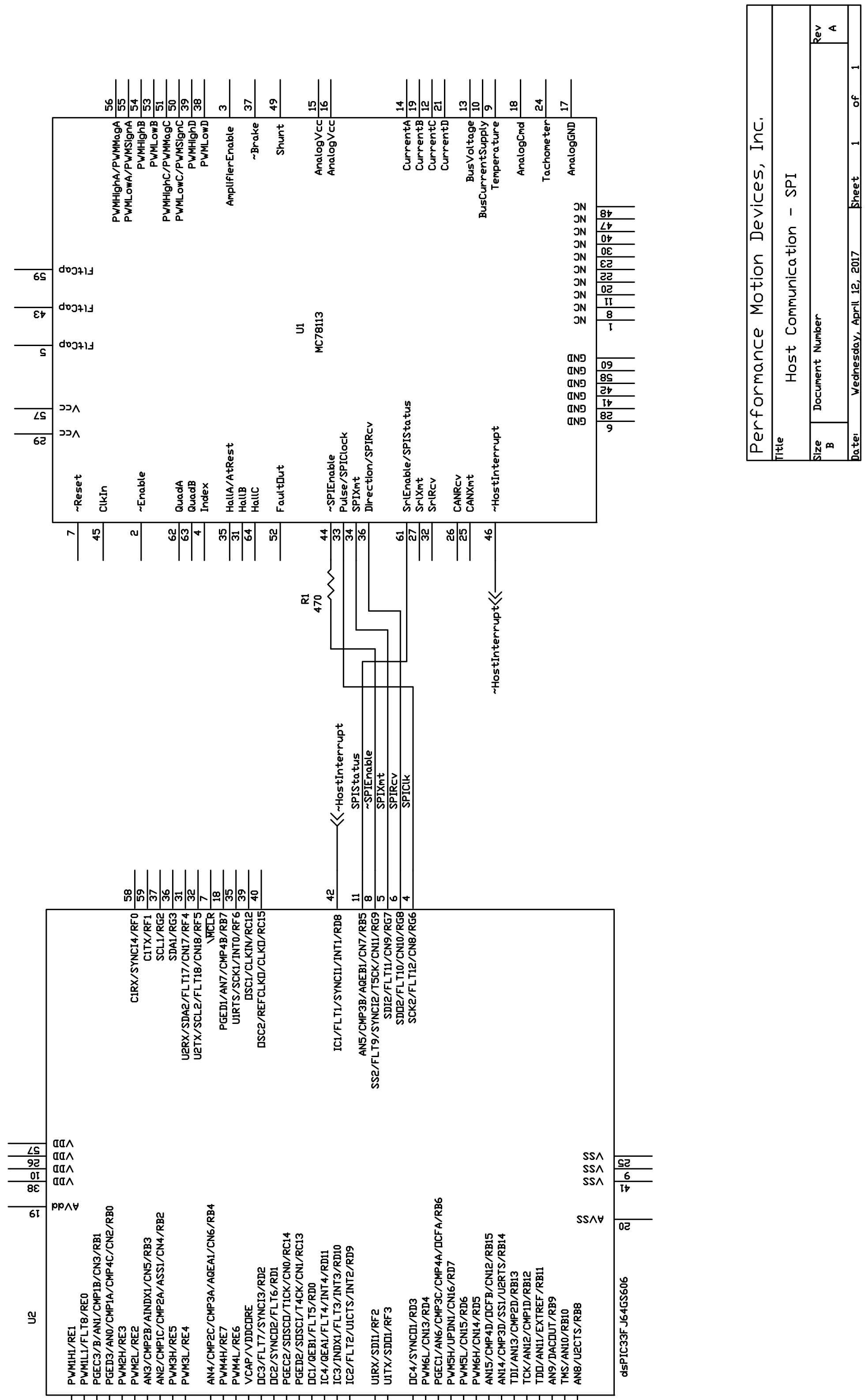
8.8 SPI Communication Interface

The MC78113 motion control IC supports SPI (Serial Peripheral Interface) for communications with a host processor such as a microcontroller. The SPI interface is an alternative to the Serial or CAN bus interfaces, and provides fast communication on a single board or over short distances.

The SPIClock pin receives the host clock signal. ***SPIXmt*** signal transmits the synchronous serial data to the host, the ***SPIRcv*** signal receives the synchronous serial data from the host processor and the active low ***~SPIEnable*** should be asserted by the host when Host SPI communication is occurring. The normally high ***SPIStatus*** signal is asserted low when the command is finished processing by the MC78113 and the data is ready to be received by the host.

The following example schematic in Figure 8-5 illustrates the Host communication via the SPI ports. The host controller is the Microchip's dsPIC33FJ64GS606. The microcontroller's SPI port is used for the host SPI communication.

Figure 8-5: Host Communication SPI



8.9 Analog Inputs

The Juno IC products support analog command signal and tachometer analog feedback signal. The following example schematic in Figure 8-6 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 uF tantalum capacitor in parallel with a 0.01-0.1 uF 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

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

Figure 8-6 shows a differential signal conditioning circuit for +/-10V analog command signal. The analog command signal is assumed to be differential, AnalogCmd+ andAnalogCmd-. 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 as1.65V, 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 kohmsand 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.

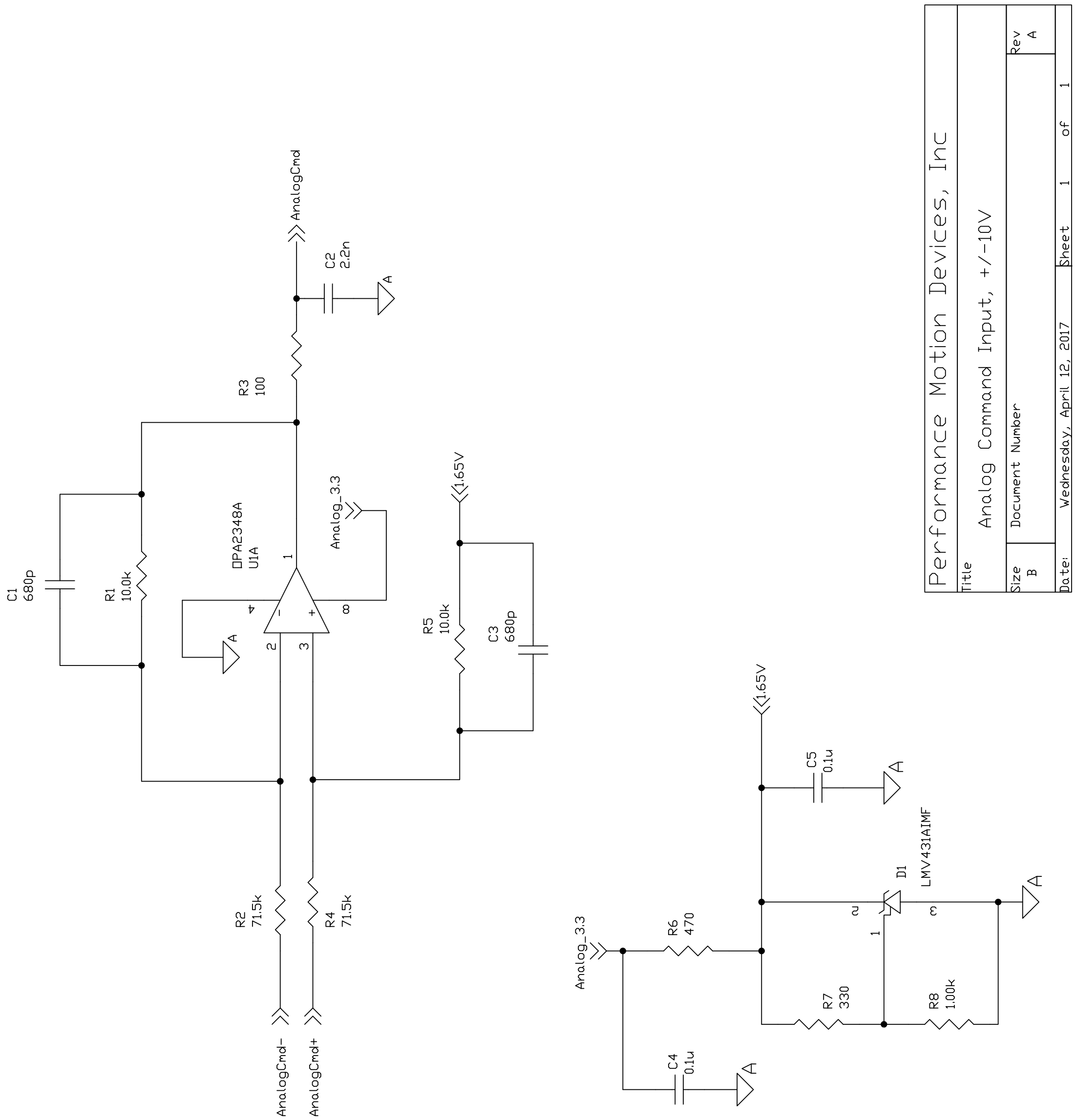


Figure 8-6: Analog Input Interface

8.10 Drive-Related Safety and Monitoring Features

This example shows the motor drive-related analog monitoring features. Please refer to Section 8.12, "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. MC78113 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 MC78113 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. *~PWMOutputDisable* 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. MC78113 will sample the analog input 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.

MC78113 support leg current sensing with current loop control, and R11 and R15 are leg current sensing resistors.

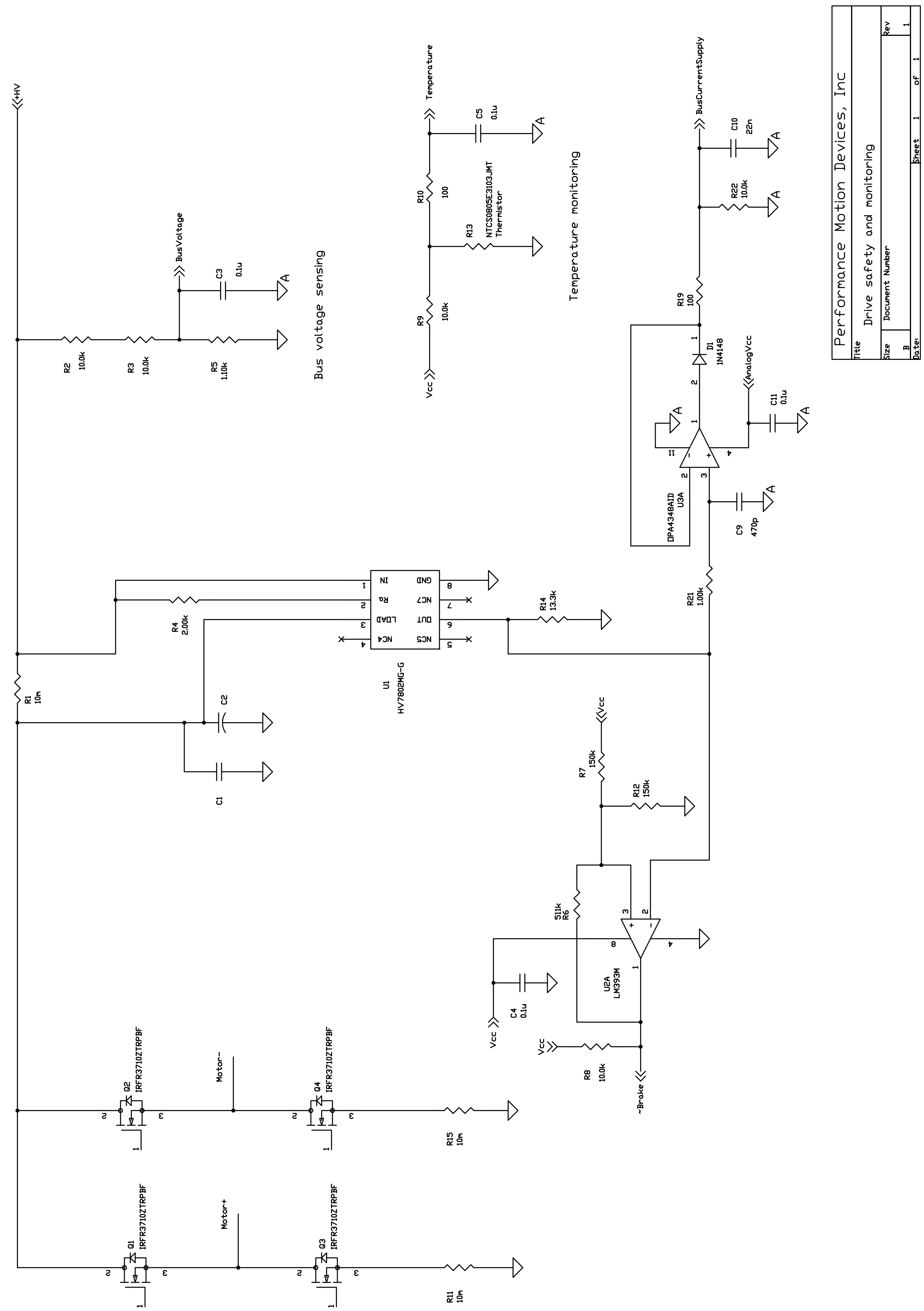


Figure 8-7: Drive Safety and Monitoring

8.11 Shunt Resistor Drive

This example shows the shunt function driving a brake resistor.

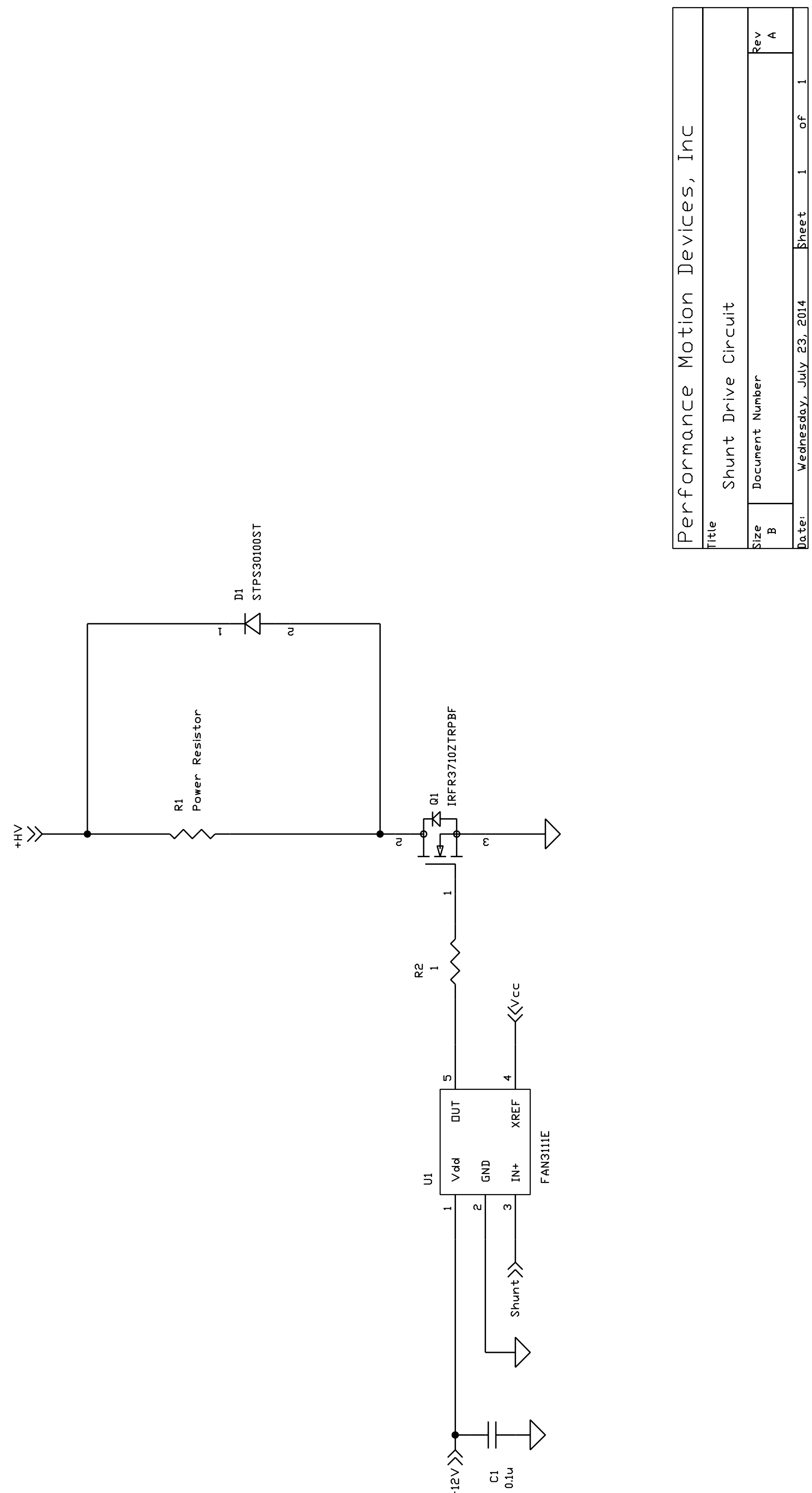
The power train driven by the MC78113 is capable of regeneration. It could harvest the mechanical energy during slow down or direction reversion and transfer the energy back to the power input. When the input power supply cannot handle the regenerative power, input voltage +HV will go up and over-voltage 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 8-8: Shunt Drive Circuit



8.12 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. Also, although specific motor type is shown in the examples, the design considerations apply to all motor types.

8.12.1 Leg Current Sensing

Figure 8-9 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. MC78113 always sample the signal 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 MC78113 ADC 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, MC78113 can sense R2 current in either direction.

By default, the MC78113 takes 1.65V reading as zero current. The MC78113 provides commands 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 MC78113 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

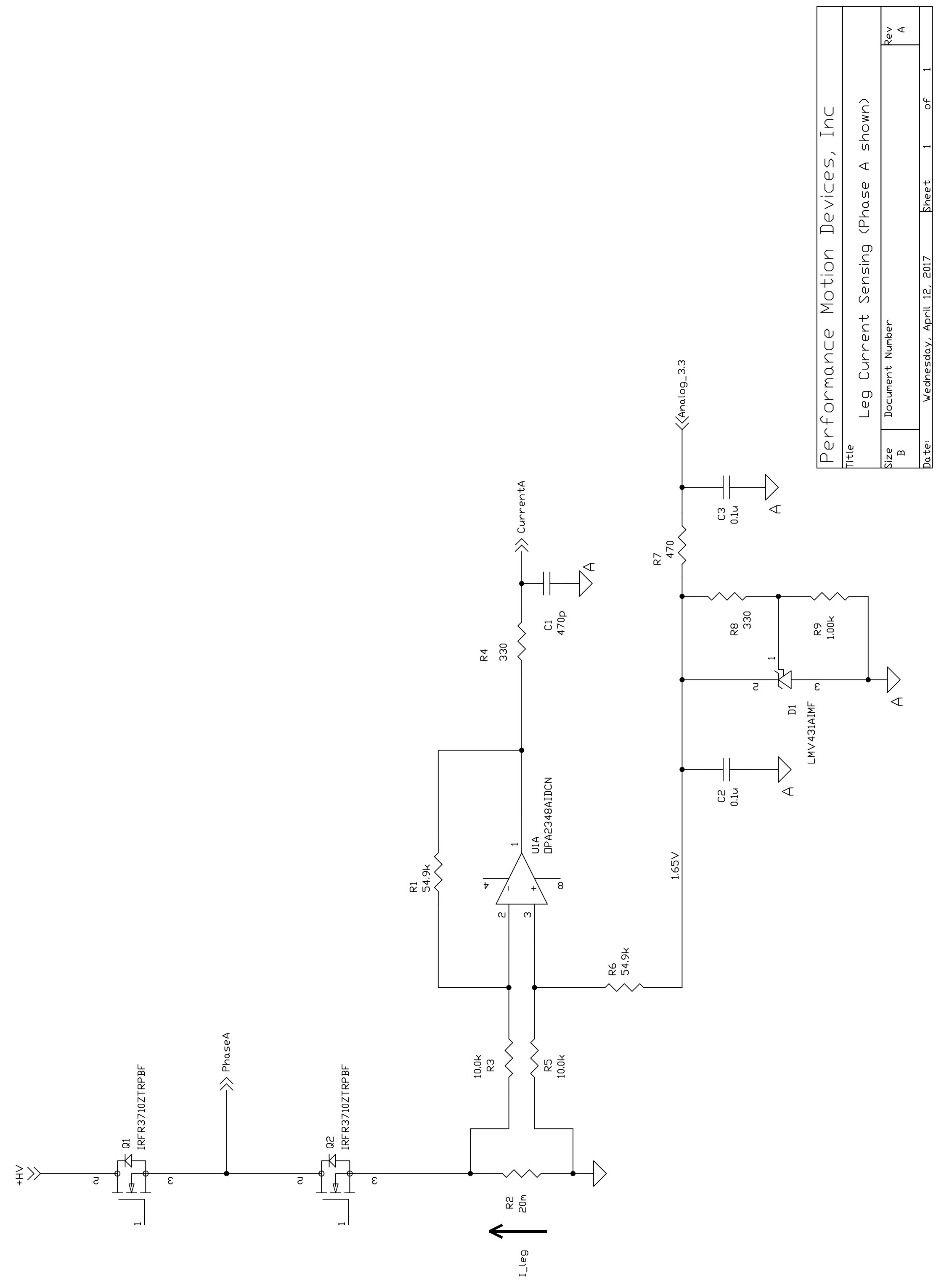
I_leg is defined as positive flowing from the ground to Q2 as shown in the schematic. It is because the current out of the half bridge and into motor winding is defined as positive.

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 8-9: Leg Current Sensing



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8.12.2 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.

The MC78113 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 8.12.1, “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.

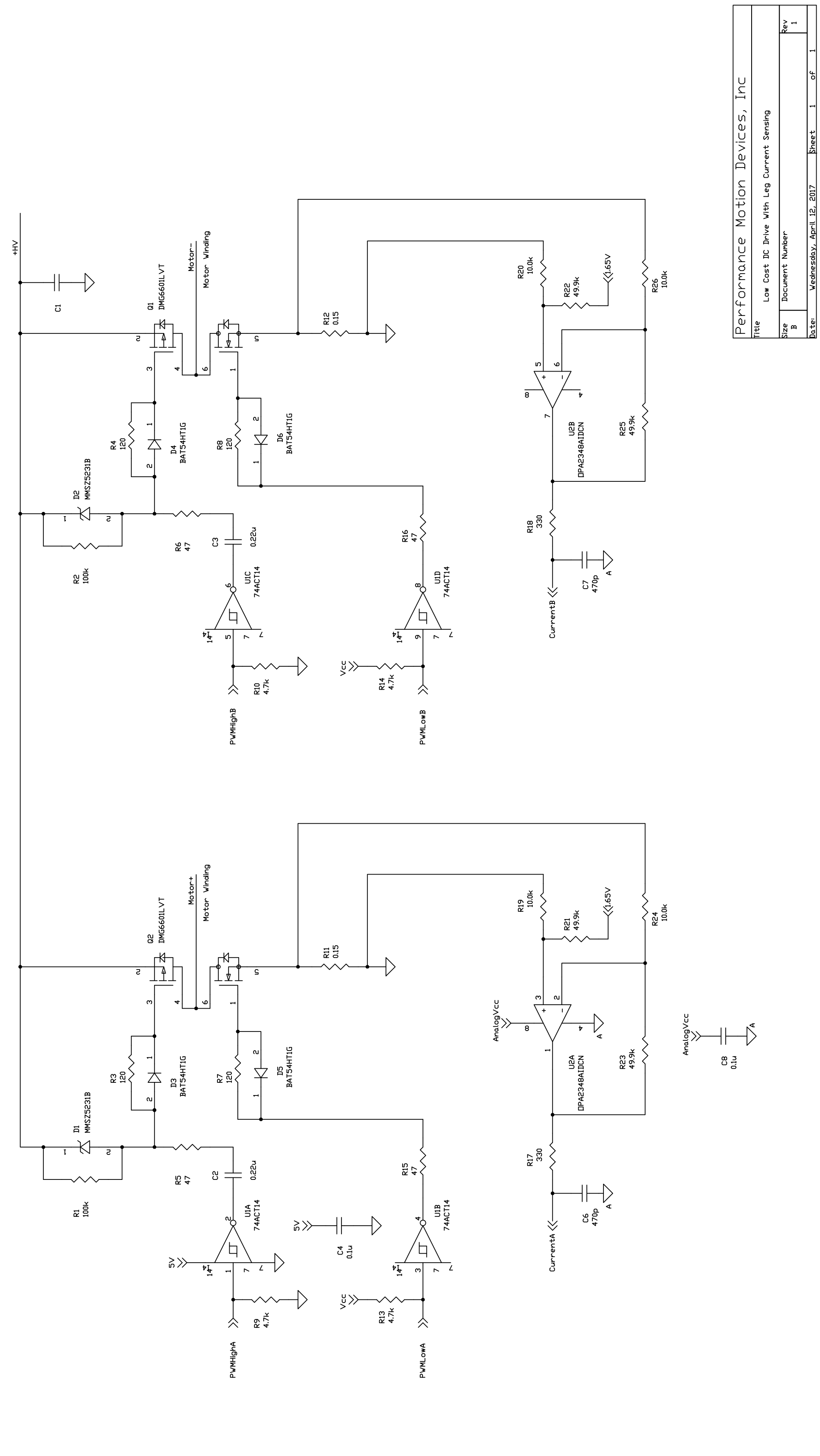


Figure 8-10: Low Cost DC Drive with Leg Current Sensing

8.12.3 Step Motor Drive

This example shows a step motor drive with leg current sensing. The power train has four half-bridges for the step motor's four winding terminals. The input voltage in this example can be up to 56V. It is capable of driving 5A continuous current with peak current of more than 10A.

The design considerations for the four half-bridges 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 switches to achieve high efficiency. The half bridge is driven by PWMHighA and PWMLowA through MOSFET driver U1, which is powered by 12V.

During normal operation, PWMHighA and PWMLowA are active high. For PWMLowA, a logic "1" turns on the MOSFET Q3. R5, R6 and D3 provide an unsymmetrical turn-on and turn-off capability.

A logic "1" PWMHighA will turn on Q1. C3 is the bootstrapping capacitor, and it is charged through D1 when Q3 is turned on. C3 provides the power to turn on Q1, and C3 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 rating should be chosen based on +HV and the +12V. R3 is optional; it can limit the charging current, especially during power up when C3 is zero voltage. R1, R4 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 R13/R14 ensure that the upper and lower switches are all off so that the half bridge output is high impedance. Also, when a hard fault is triggered, PWMHighA and PWMLowA will go into high impedance, and the pull-down resistors will turn off the MOSFETs and put the output of the half bridge into 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.

R9 is the current sensing resistor, and U3 is the differential amplifier for signal conditioning. Please see Section 8.12.1, "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 provides a balanced design reference between performance and cost for applications up to 56V and current up to 10A. With different MOSFETs, higher voltage and current capabilities can be achieved. Please refer to the low cost DC drive example if cost is critical and to BLDC drive example for high voltage and/or high current applications in noisy environments.

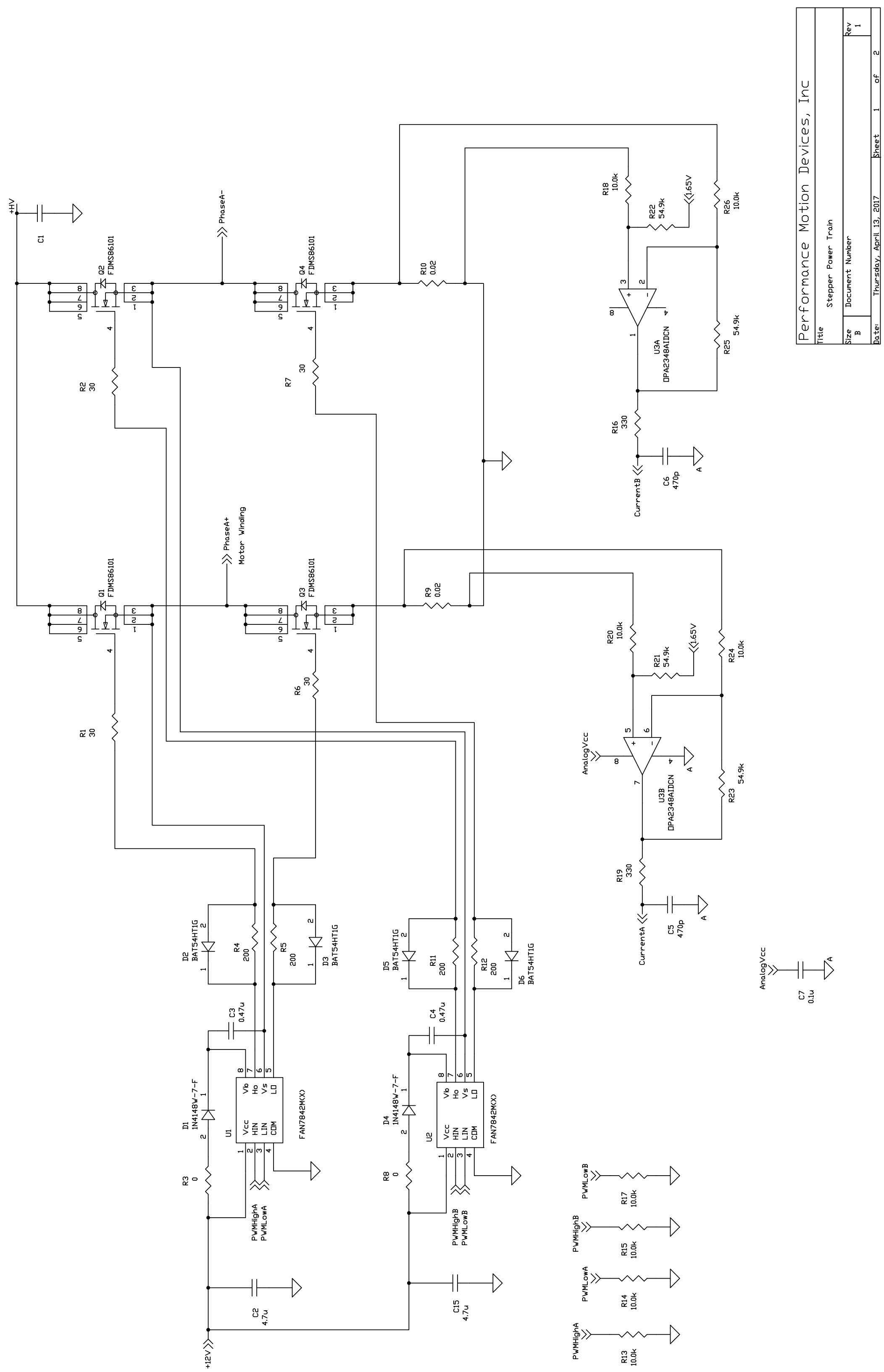


Figure 8-11: Step Motor Drive with Leg Current Sensing

8.12.4 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.

The MC78113 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 8.12.1, "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.

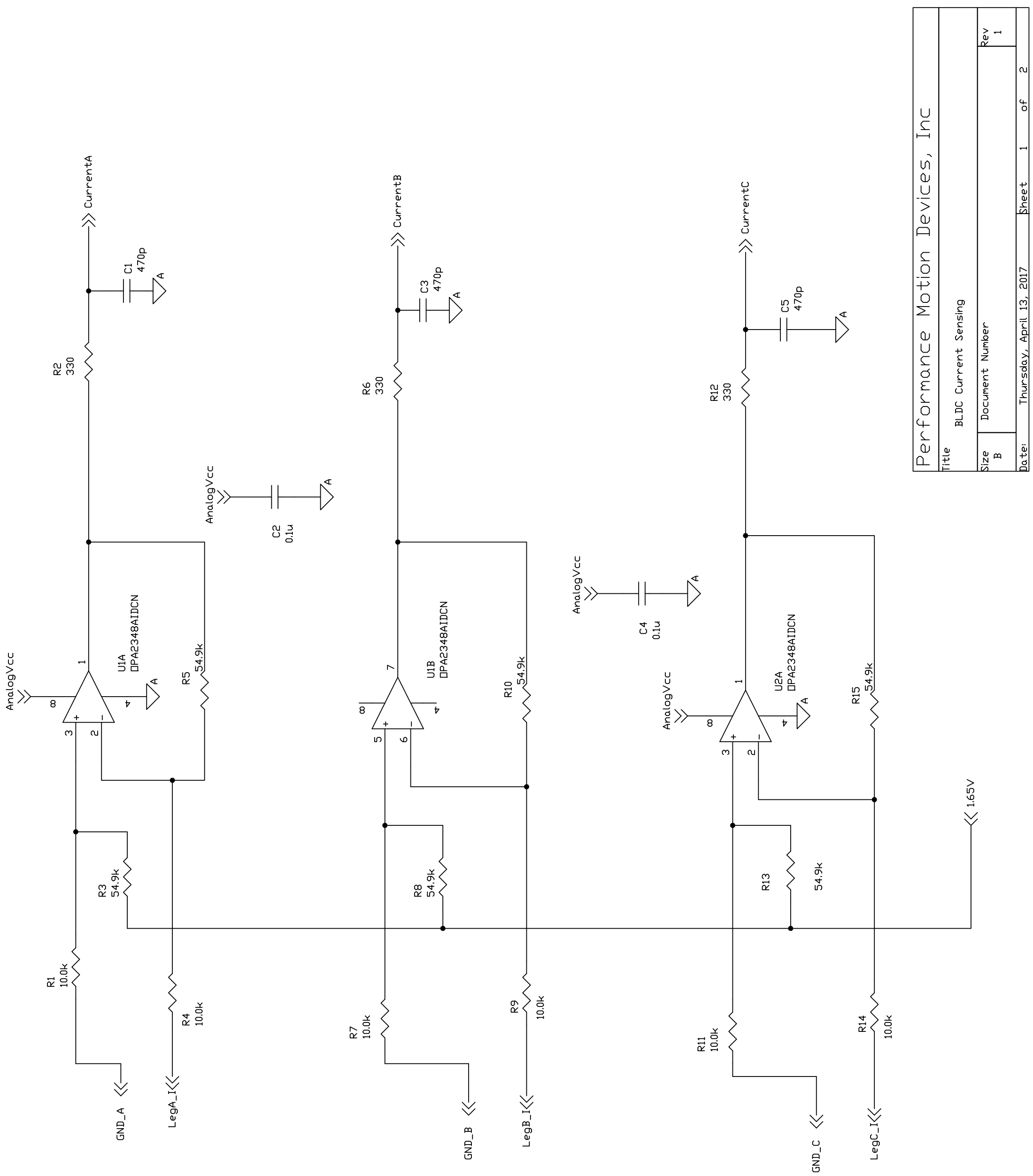
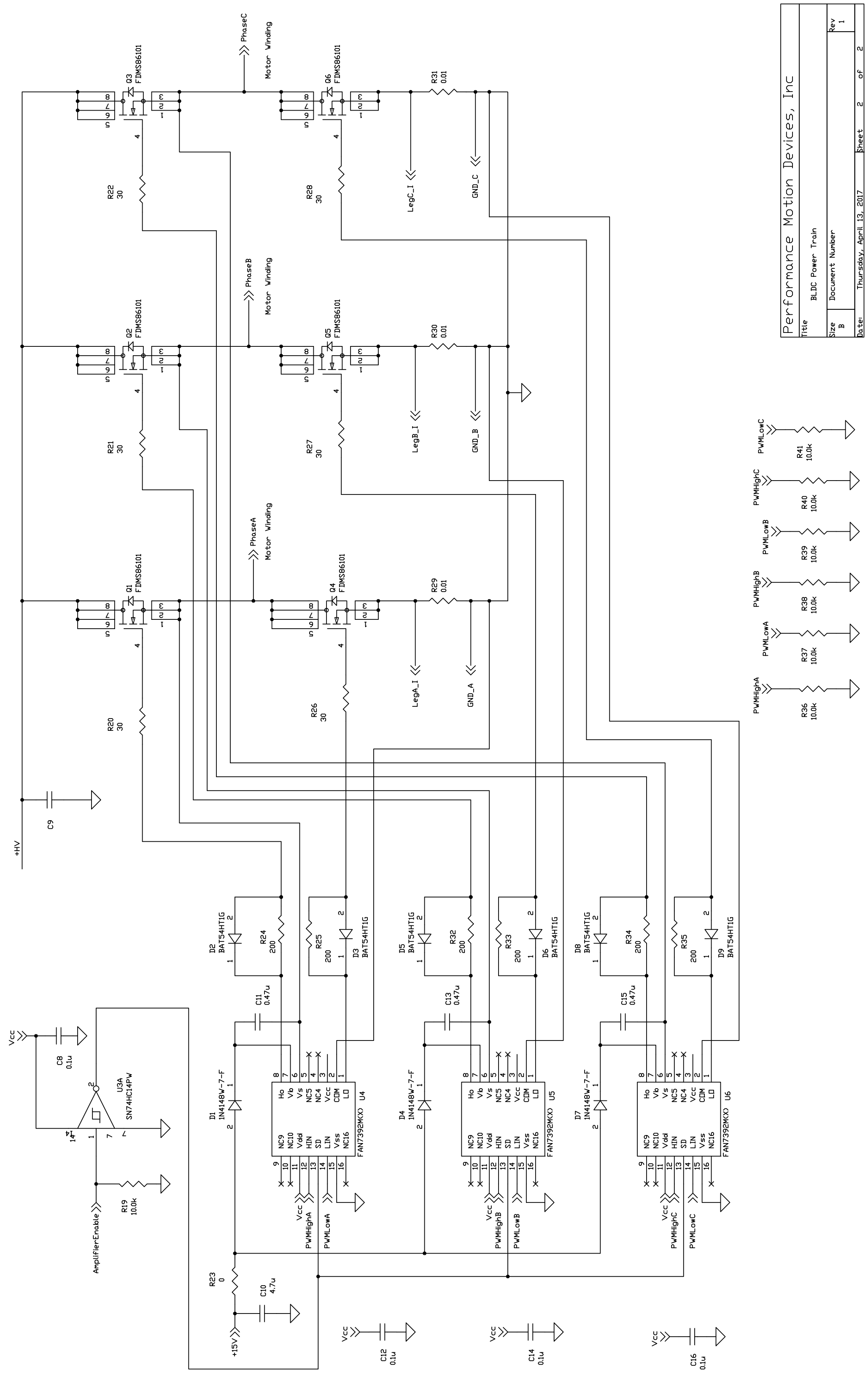


Figure 8-12: BLDC Motor Drive - Leg Current Sensing

Figure 8-13: BLDC Motor Drive - Power Train



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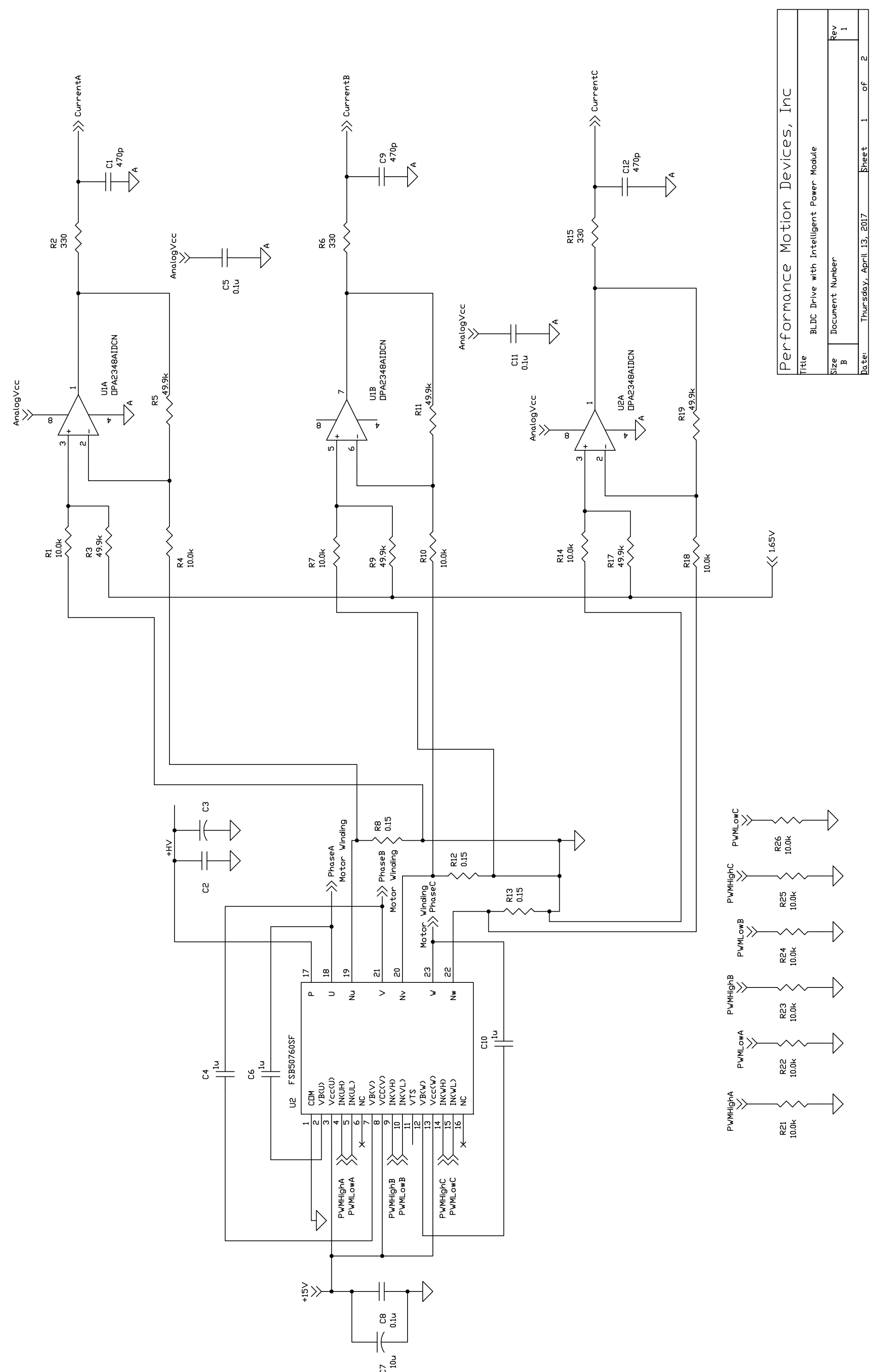
8.12.5 Brushless DC Motor Drive With Intelligent Power Module

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 8-14: BLDC Drive with Intelligent Power Module



8.13 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 the MC78113.

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

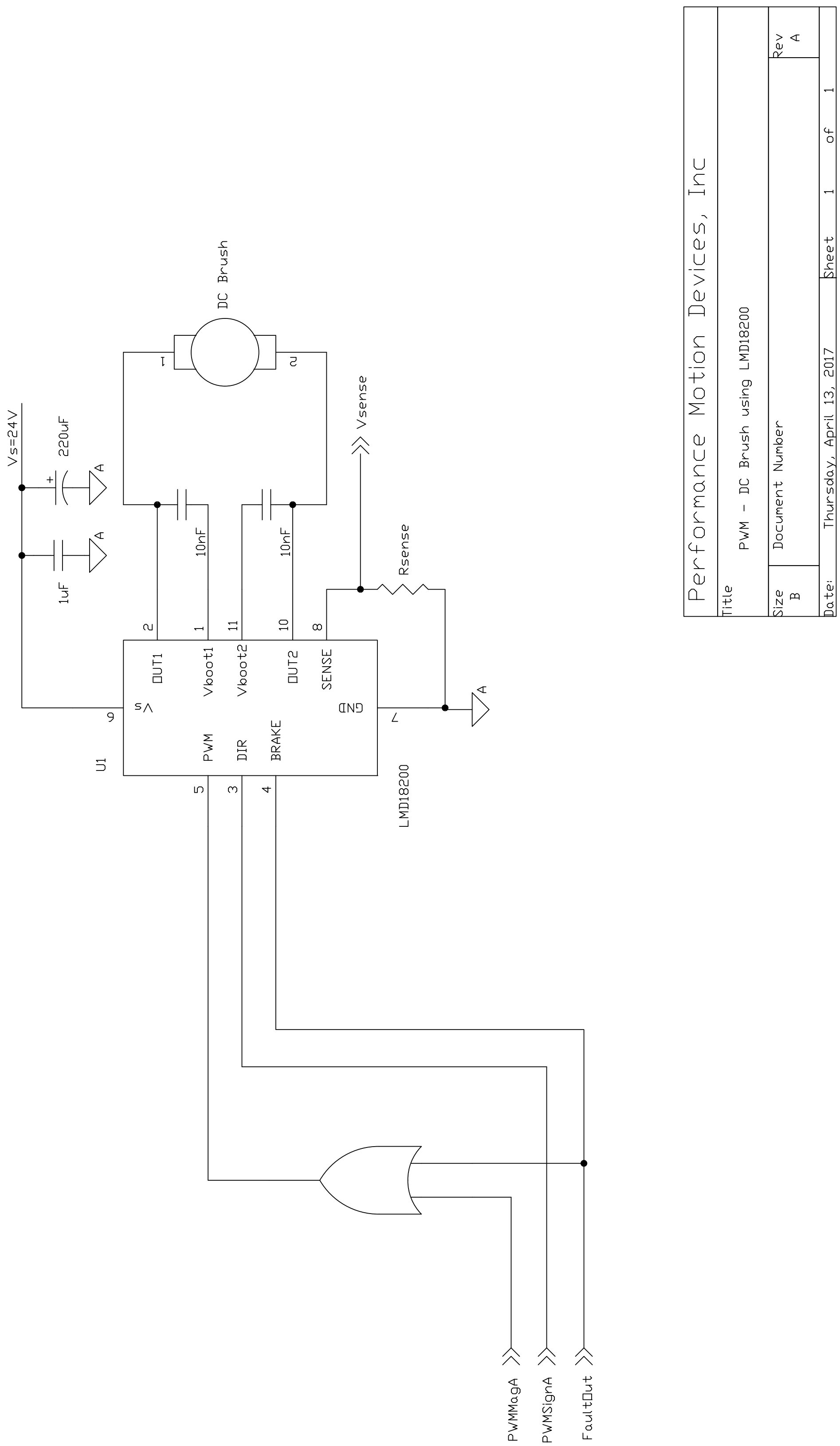
First, in the *locked anti-phase control* mode (see the LMD18200 data sheet), a 50/50 **PWM** signal is applied to the LMD18200 DIR input, while the PWM input is tied high. The current ripple in this mode is relatively high, as the circulating currents are quickly decaying.

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 8.12, "PWM High/Low Motor Drive With Leg Current Sensing/Control" for PWM-based application examples using the MC78113 IC that provide active current control.

Figure 8-15: DC Brush Amplifier Using LMD 18200



8.14 Two Juno Step Motor Amplifiers With Multi-Axis Magellan

The following schematic shows a two-axis application with two 56-pin VQFN packaged Juno Step motor ICs with a multi-axis Magellan.

In this schematic the host controller is a four-axis Magellan MC58420. Only the connections with MC75113N and MC74113N are shown. For complete Magellan wiring, please refer to the *MC58000 Electrical Specifications*.

8.14.1 MC75113N Axis 1

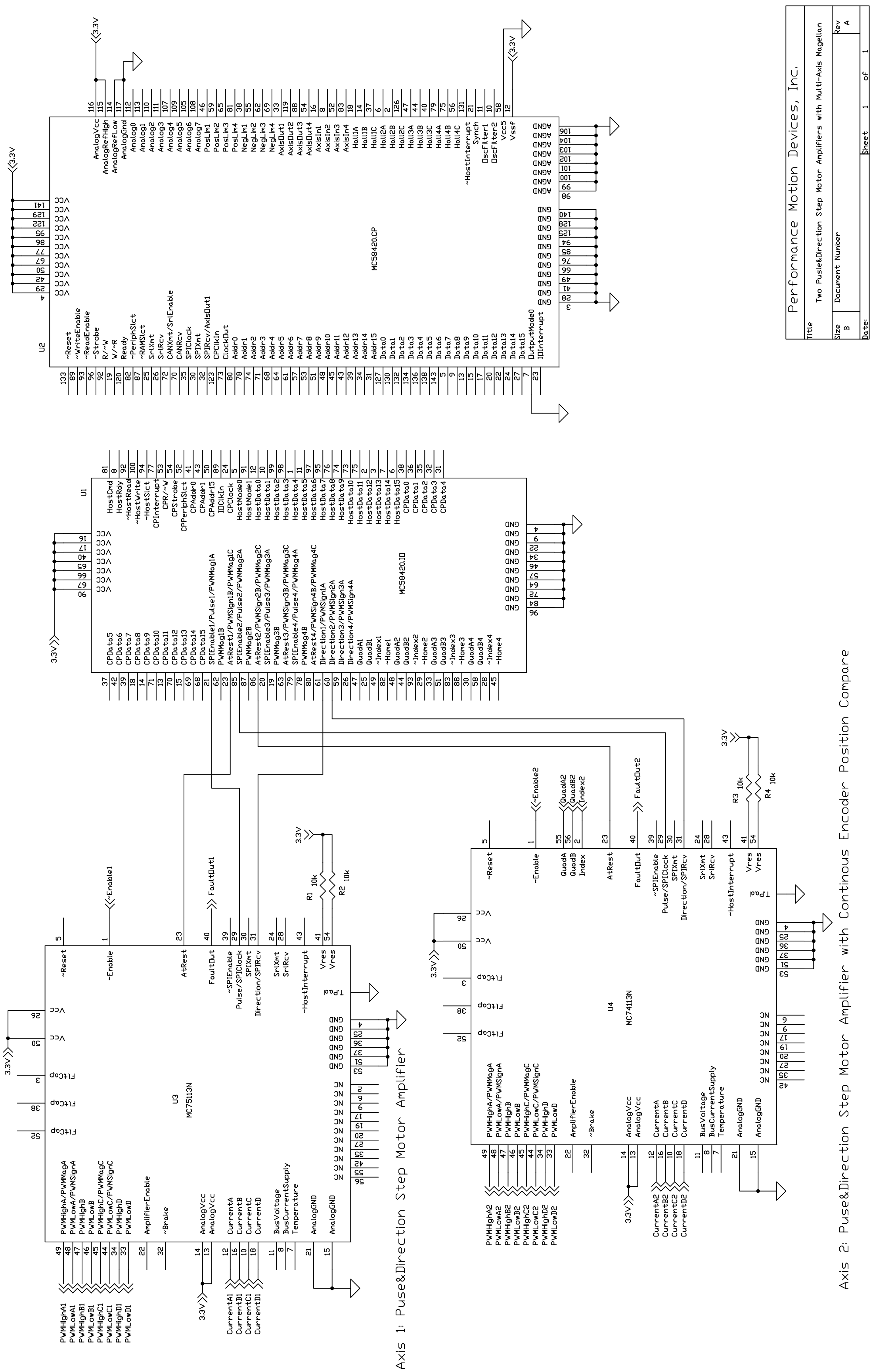
For Axis 1, the MC75113N receives ***Pulse***, ***Direction*** and ***AtRest*** from Magellan and controls the motor with PWM high/low and leg current sensing. Please refer to Section 8.12.3, "Step Motor Drive " for more details.

8.14.2 MC74113N Axis 2

For Axis 2, the MC74113N receives ***Pulse***, ***Direction*** and ***AtRest*** from Magellan and controls the motor with PWM high/low and leg current sensing. Please refer to Section 8.12.3, "Step Motor Drive " for more details.

Compared to Axis 1 with MC75113N, MC74113N receives encoder input for continuous encoder position comparison.

Figure 8-16: Two-Axis Step Motor Drive With Multi-Axis Magellan



8.15 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.

8.15.1 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.

8.15.2 MC73113 Axis 1

For Axis 1, the MC73113 is in torque mode with encoder-based commutation. It receives torque command from Magellan and controls the motor with PWM high/low and leg current sensing. Please refer to Section 8.12.4, “Brushless DC Motor Drive ” for more details

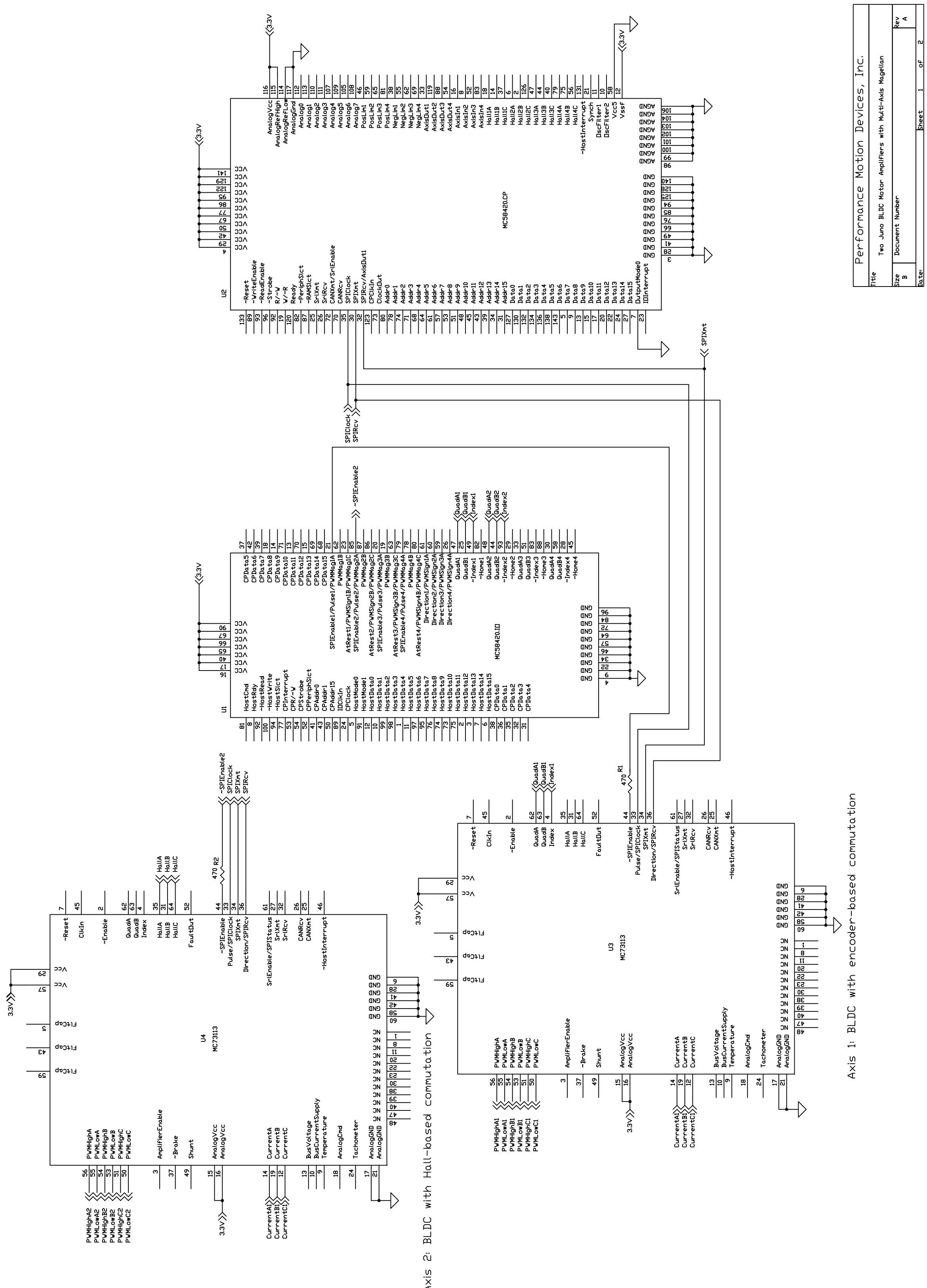
The encoder signals go to both Magellan and MC73113. Magellan uses the encoder information for position control while MC78113 for commutation.

8.15.3 MC73113 Axis 2

For Axis 2, the MC73113 is in torque mode with Hall-based commutation. It receives torque command from Magellan and controls the motor with PWM high/low and leg current sensing. Please refer to Section 8.12.4, “Brushless DC Motor Drive ” for more details.

Magellan uses the encoder information for position control, and MC73113 uses Hall signals for commutation.

Figure 8-17: Two-Axis BLDC Motor Drive With Multi-Axis Magellan



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