# Juno Step Motor Control IC
# User Guide

PERFORMANCE
MOTION DEVICES

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# Related Documents

**DK78113 Developer Kit User Manual**

How to install and configure the DK78113 developer kit. This developer kit supports all 64-pin TQFP Juno ICs including MC71112, MC73112, MC71113, MC73113, MC74113, MC75113, and MC78113.

**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.

**Juno Velocity & Torque Control IC User Guide**

Complete description of all members of the Juno Velocity & Torque Control IC family including the MC71112, MC71112N, MC73112, MC73112N, MC74113, MC74113N, MC75113, MC75113N, MC71113, MC73113, and MC78113 ICs. Includes 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.

# Table of Contents

# List of Figures

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# 1. The Juno IC Family

1

***In This Chapter***

- Introduction
- Family Overview
- Juno IC Developer Kits

## 1.1 Introduction

This manual describes the MC74113, MC74113N, MC75113 and MC75113N ICs from Performance Motion Devices, Inc. These devices comprise the step motor control ICs of PMD Corp.'s Juno Velocity & Torque Control IC family. Additional members of the family are the MC71113, MC73113, and MC78113 ICs for velocity control of DC Brush and Brushless DC motors, and the MC71112, MC71112N, MC73112, and MC73112N ICs for torque control of DC Brush and Brushless DC 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 input, 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<br>MC74113N<br>MC75113<br>MC75113N<br>MC78113 | MC71112<br>MC71112N | MC71113<br>MC78113 | MC73112<br>MC73112N | MC73113<br>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 | ✓ | ✓ | ✓ | | |
| **DCBus & 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 plug and play connectors for fast setup and testing
- Pro-Motion autotuning and axis wizard setup software
- Complete Juno manuals or PDFs
- Extensive application schematic examples

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# 2. Functional Characteristics

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** | Pulse & Direction | Position is provided via external pulse & direction input |
| | SPI | Position is provided via SPI (Serial Peripheral Interface) direct input |
| | Internal profile | Position is provided via internal profile generator function |
| **Host communication modes** | Point to point asynchronous serial | |
| **Serial port baud rate range** | 1,200 baud to 460,800 baud (1,200, 2,400, 9,600, 19,200, 57,600, 115,200, 230,400, 460,800) | |
| **Position range** | -2,147,483,648 to +2,147,483,647 counts or microsteps | |
| **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. |
| **Current loop rate** | 19.53 kHz | |
| **Current measurement resolution** | 12 bits | |
| **PWM resolution & rates** | 1:1,536 @ 20 kHz<br>1:768 @ 40 kHz<br>1:384 @ 80 kHz<br>1:256 @ 120 kHz | |
| **DC Bus & safety signals** | *Brake, BusVoltage, BusCurrentSupply, Temperature* | |
| **Amplifier output signals** | *AmplifierEnable, PWMHighA, PWMLowA, PWMHighB, PWMLowB, PWMHighC, PWMLowC, PWMHighD, PWMLowD* | |
| **Serial communication signals** | *SrlXmt, SrlRcv* | |
| **SPI signals** | *SPIXmt, SPIRcv, SPIClk, SPIEnable* | |
| **SPI frequency range** | 1.0 MHz - 10.0 MHz | |
| **Step command signals** | *Pulse, Direction, AtRest* | |
| **Maximum pulse rate** | 1.0 Mpulses/sec | |
| **Encoder input signals** | *QuadA, QuadB, Index* | |
| **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 |
| **Position-capture triggers** | *Index* signal |
| **Internal RAM** | 6,144 16-bit words |
| **Maximum number of simultaneous trace variables** | 4 |
| **NVRAM** | 1,024 16-bit words |

# 2.2 Physical Dimensions, 64-PIN TQFP Package

All dimensions are in millimeters.

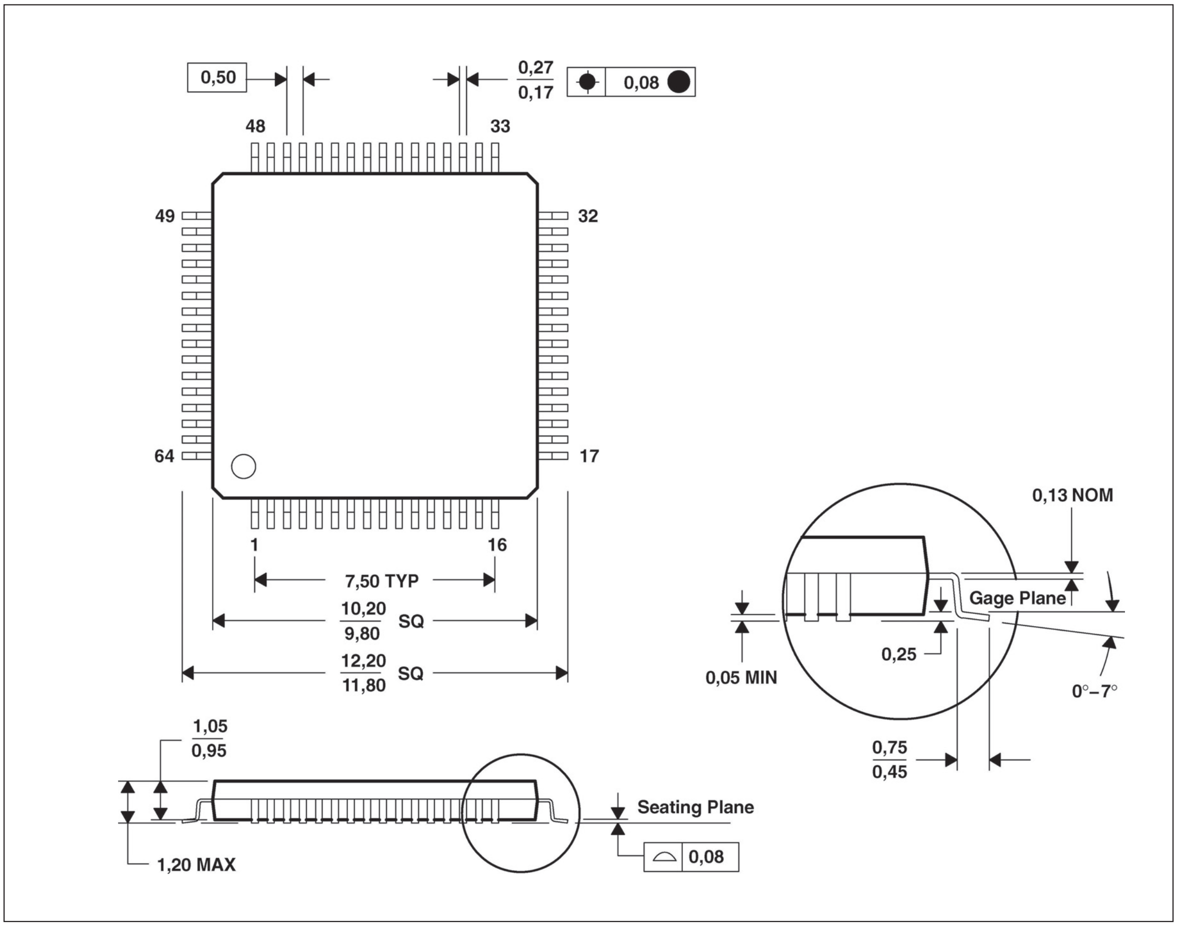



**Figure 2-1: 64-Pin TQFP Physical Dimensions**

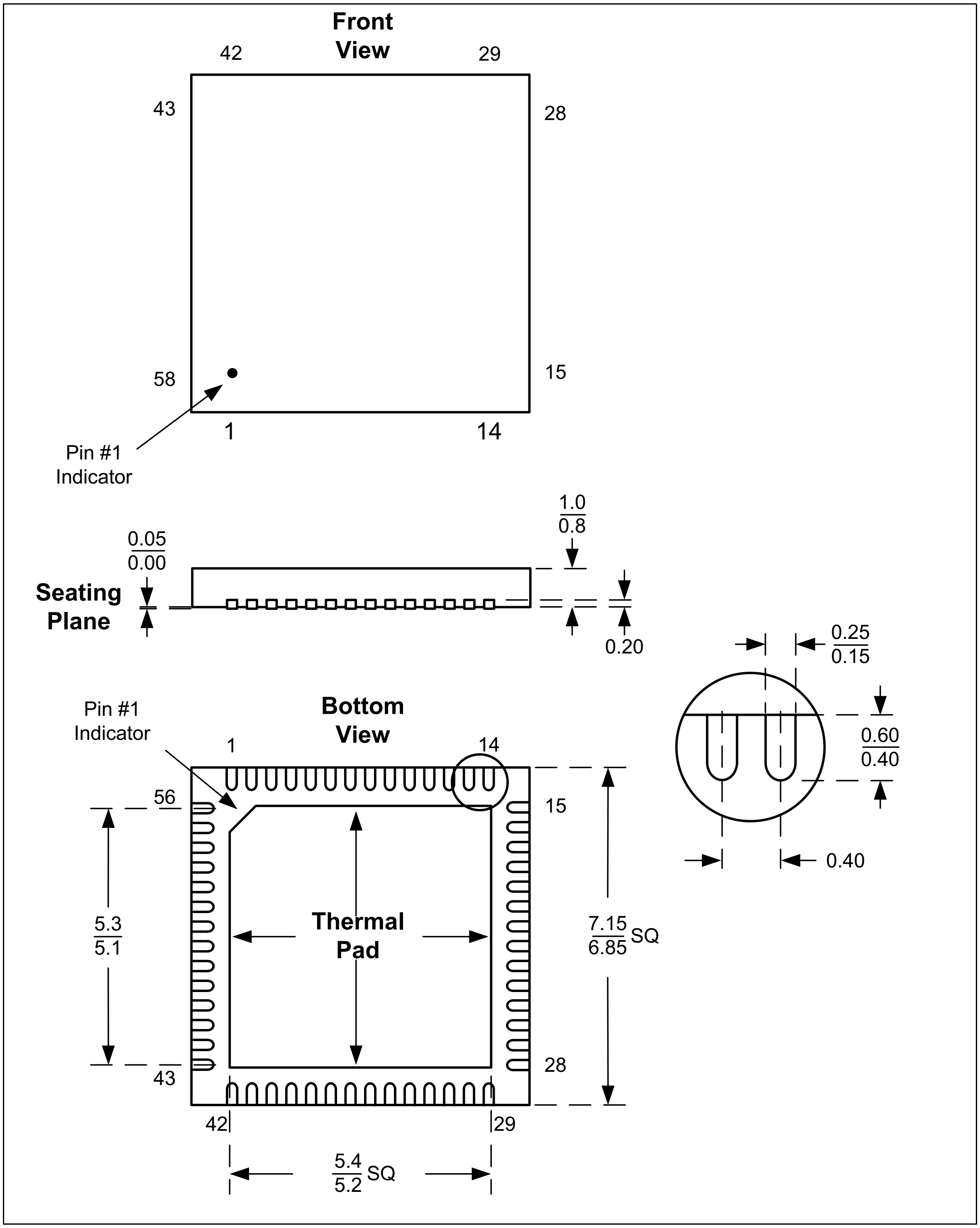
Notes:

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 ($\theta_{JA}$) | 56.5°C/W |
| Package thermal impedance, 56-pin VQFN package ($\theta_{JA}$) | 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

3

## *In This Chapter*

- DC Characteristics for MC74113, MC74113N, MC75113, MC75113N ICs
- AC Characteristics

## 3.1 DC Characteristics

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

| Symbol | Parameter | Minimum | Maximum | Conditions |
|---|---|---|---|---|
| $V_{cc}$ | Supply voltage | 2.97V | 3.63V | With respect to GND |
| $I_{dd}$ | Supply current | | 115 mA | All I/O pins are floating |
| Analog$V_{cc}$ | Analog input supply voltage | 2.97V | 3.63V | With respect to AnalogGND |
| Analog$I_{dd}$ | 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 Analog$V_{cc}$ should be within 0.3V from each other.
(2) Please refer to design tips in the Application Notes of this manual for thermal design considerations.

# 3.2 AC Characteristics

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

## 3.2.1 Quadrature Encoder Input

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

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

## 3.2.2 SPI

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

## 3.2.3 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 |

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

## 3.2.4 Warm Reset

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

## 3.2.5 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 Quadrature Encoder Input

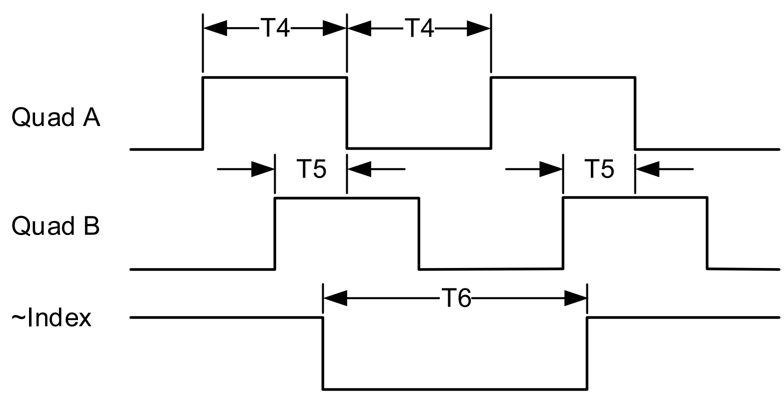
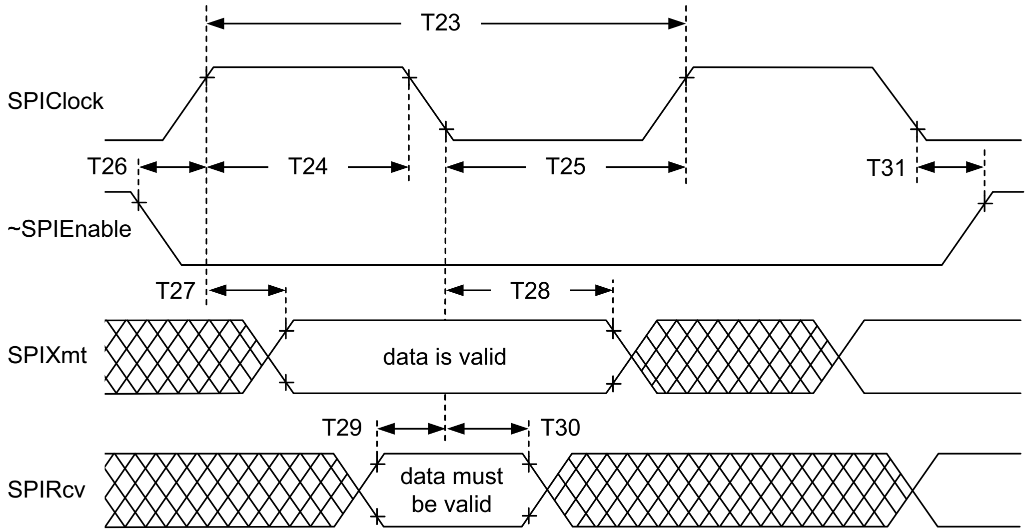



**Figure 4-1: Quad Encoder Timing**

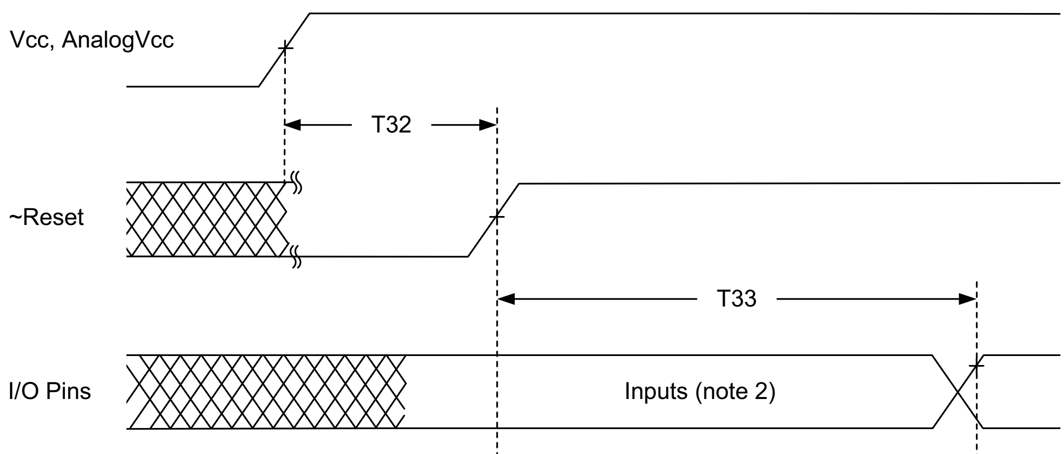
# 4.2 SPI Timing

**Figure 4-2: SPI Timing**



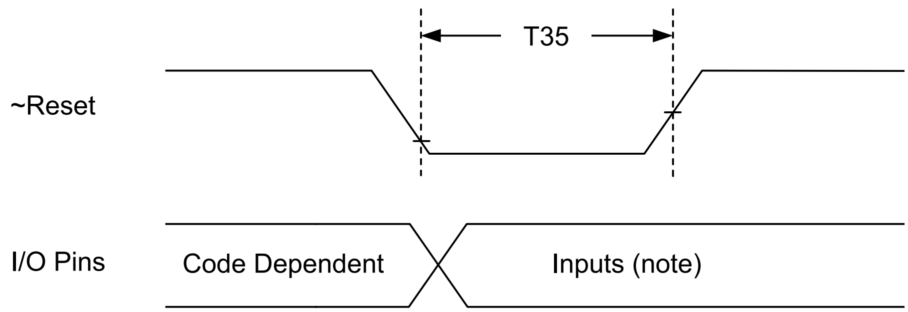

# 4.3 Power On Timing

**Figure 4-3: Power On Timing**



## 4.4 Warm Reset

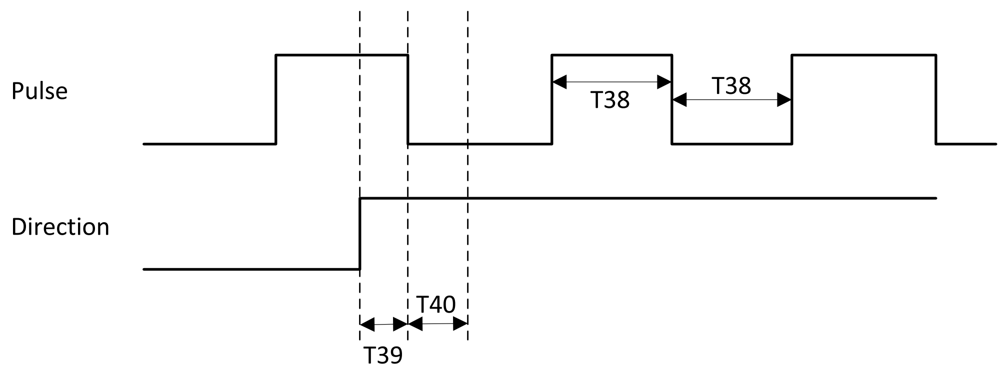
Figure 4-4: Warm Reset Timing




Please refer to Note 2 in Section 3.2.4, "Warm Reset" for more information.

## 4.5 Pulse & Direction

Figure 4-5: Pulse & Direction Timing



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# 5. Pinouts and Pin Descriptions

5

### *In This Chapter*

- Pinouts for the MC74113
- Pinouts for the MC74113N
- Pinouts for the MC75113
- Pinouts for the MC75113N
- MC74113, MC74113N, MC75113, MC75113N IC Pin Descriptions

## 5.1 Pinouts for the MC74113

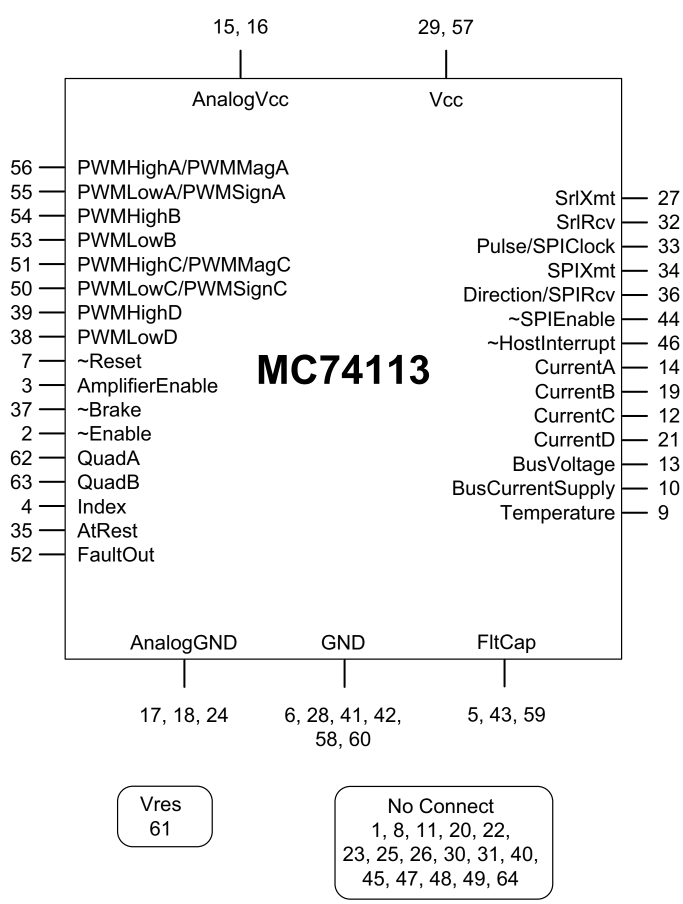
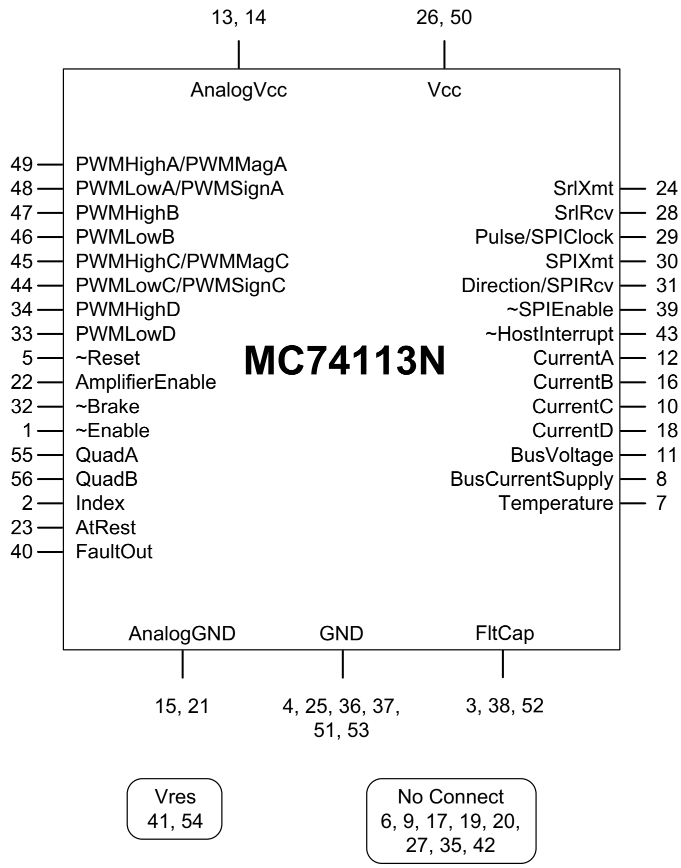



**Figure 5-1: MC74113 Pinouts**

# 5.2 Pinouts for the MC74113N

**Figure 5-2: MC74113N Pinouts**



# 5.3 Pinouts for the MC75113

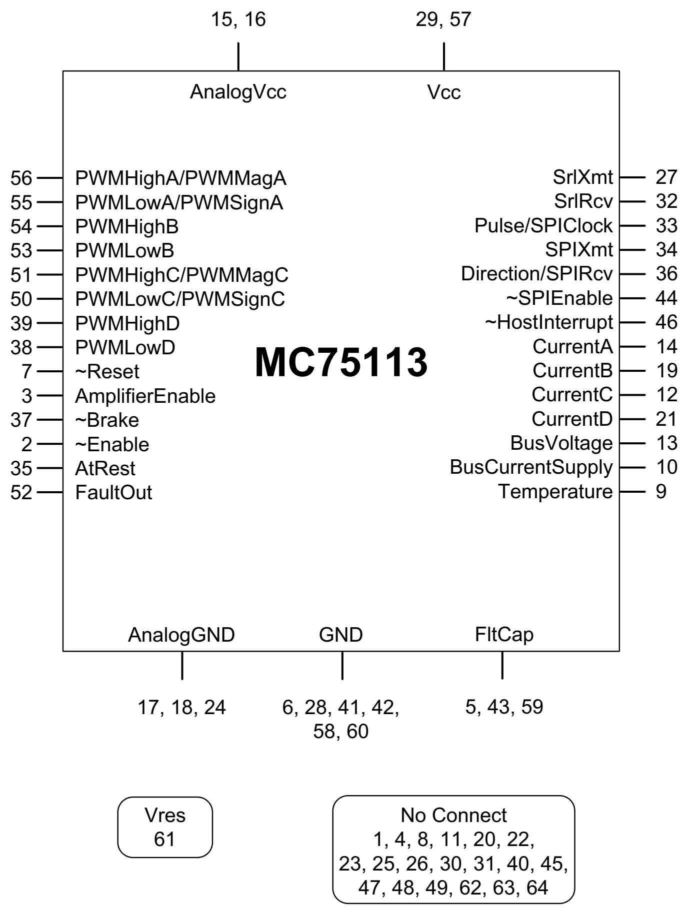
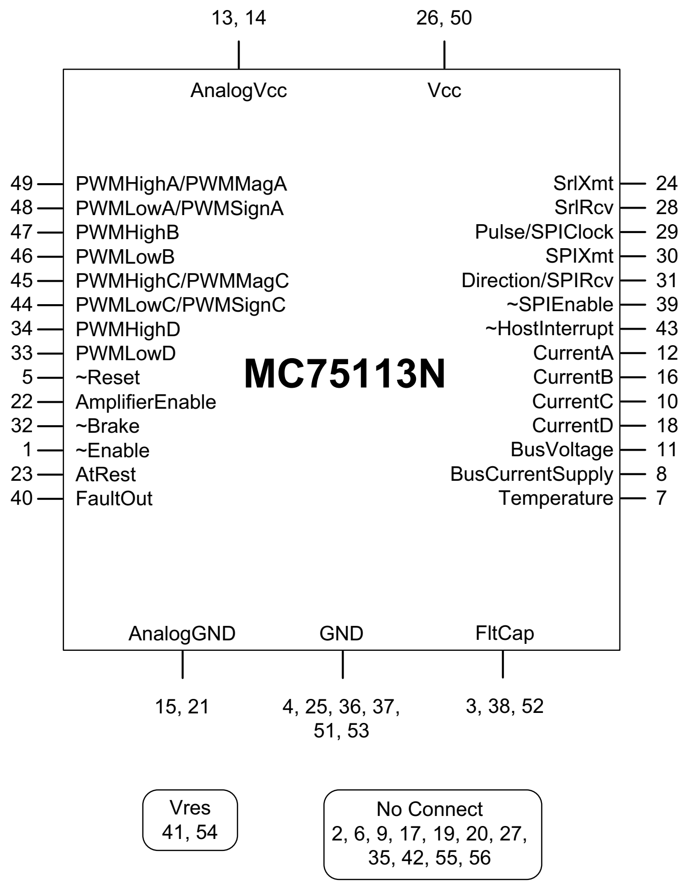



**Figure 5-3: MC75113 Pinouts**

# 5.4 Pinouts for the MC75113N

**Figure 5-4: MC75113N Pinouts**



# 5.5 MC74113, MC74113N, MC75113, MC75113N IC Pin Descriptions

The following table details the pinouts for the MC74113, MC74113N, MC75113, and MC75113N 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.<br>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.<br>During power-up it is not necessary to provide a reset. Juno generates an internal reset upon power-up. |
| PWMHighA/<br>PWMMagA<br>PWMLowA/<br>PWMSignA<br>PWMHighB<br>PWMLowB<br>PWMHighC/<br>PWMMagC<br>PWMLowC/<br>PWMSignC<br>PWMHighD<br>PWMLowD | 56<br><br>55<br><br>54<br>53<br>51<br><br>50<br><br>39<br>38 | 49<br><br>48<br><br>47<br>46<br>45<br><br>44<br><br>34<br>33 | out | Depending upon the output mode, these pins have the following functions:<br>*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.<br>*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.<br>*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.<br>*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 interpretation can be programmed. |
| 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 |
|---|---|---|---|---|
| QuadA<br>QuadB<br>Index | 62<br>63<br>4 | 55<br>56<br>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 programmed.<br>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.<br>If unused, these pins may be left unconnected. |
| AtRest | 35 | 23 | in | This pin 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 the interpretation of this signal can be programmed.<br>If unused, This pin 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.<br>If unused, this pin may be left unconnected. |
| 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 however the interpretation of this signal can be programmed.<br>*SPIClock* inputs the clock signal used with synchronous serial transfer on the host communication SPI bus.<br>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 the interpretation of this signal can be programmed.<br>This pin inputs synchronous serial data for the SPI bus.<br>If unused, this pin may be left unconnected. |
| ~SPIEnable | 44 | 39 | in | This pin inputs an enable signal for the SPI bus. This signal is active low, meaning it should be low when an SPI position command write is occurring, and high at all other times.<br>**If used, this pin must be controlled in series with a 470 ohm resistor.**<br>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.<br>**Whether this pin function is used or not this pin must be connected to a 10 Kohm pullup resistor.** |

| Name | 64-Pin TQFP Pin # | 56-Pin VQFN Pin # | Direction | Description |
|---|---|---|---|---|
| CurrentA<br>CurrentB<br>CurrentC<br>CurrentD | 14<br>19<br>12<br>21 | 12<br>16<br>10<br>18 | in | These pins input analog voltages representing leg current flow through the low sides of the switching bridges. These signals are only accessible when the PWM output mode is set to PWM High/Low.<br>These signals are used when a current loop is used, when $I^2t$ current monitoring is desired or when bus return overcurrent detection is desired. These signals are sampled by an internal A/D converter. The A/D resolution is 12 bits.<br>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.<br>The allowed signal input range is zero to 3.3V.<br>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.<br>The allowed signal input range is zero to 3.3V.<br>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.<br>The allowed signal input range is zero to 3.3V.<br>If unused, this signal should be connected to AnalogGND. |
| AnalogVcc | 16<br>15 | 13<br>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.<br>If analog inputs are not used, these pins should be tied to Vcc. |
| AnalogGND | 17 | 15<br>21 | N/A | This pin should be connected to the analog input power supply return.<br>Any unused analog inputs (CurrentA-D, BusVoltage, Bus-CurrentSupply or Temperature pins) should be tied to AnalogGND. |
| Vcc | 29<br>57 | 26<br>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<br>43<br>59 | 3<br>38<br>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<br>54 | | Each of these pins must be connected to Vcc via a 10K resistor. |
| GND | 6<br>28<br>41<br>42<br>58<br>60 | 4<br>25<br>36<br>37<br>51<br>53 | N/A | All of these pins must be connected to the digital power supply return. |

| Name | 64-Pin TQFP Pin # | 56-Pin VQFN Pin # | Direction | Description |
|---|---|---|---|---|
| No Connect | 1 | 6 | N/A | These pins must be left unconnected. |
| | 8 | 9 | | |
| | 11 | 17 | | |
| | 20 | 19 | | |
| | 22 | 20 | | |
| | 23 | 27 | | |
| | 30 | 35 | | |
| | 40 | 42 | | |
| | 47 | | | |
| | 48 | | | |
| Thermal pad | N/A | T. Pad | N/A | Thermal pad on bottom of 56-pin VQFN IC package must be connected to GND. For 64-pin TQFP package there is no thermal pad. |

# 6. Juno IC Configuration in the Production Application

6

## In This Chapter

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

Each Juno IC, before undertaking step 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 control parameter settings tailored for that user application.

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

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

## 6.1 Loading the NVRAM

### 6.1.1 NVRAM Programming via Juno DK IC Socket

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

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

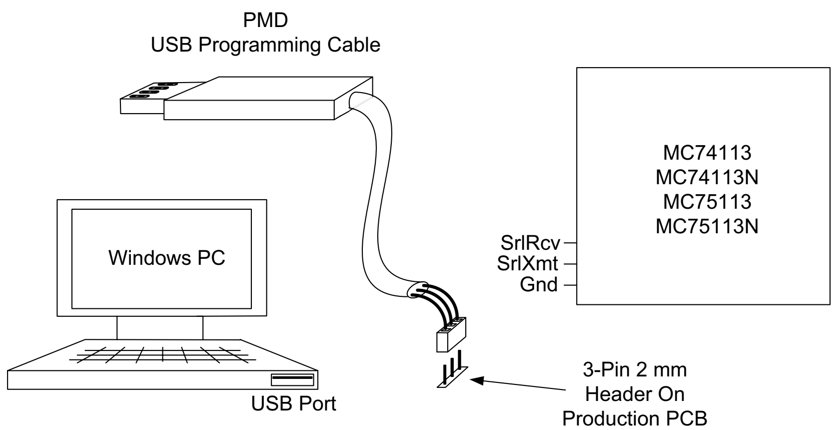
### 6.1.2 NVRAM Programming Via 3-pin UART Cable

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

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

1x3 3-pin 2 mm header component on the other. A representative PCB mounted header component is Samtec MTMM-103-04-x-S-150.

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




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

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

### 6.1.3 Purchasing Pre-Configured Parts

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

## 6.2 Analog Signal Calibration in the Production Application

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

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."

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# 7. Operational Overview

7

***In This Chapter***

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

## 7.1 Internal Block Diagram

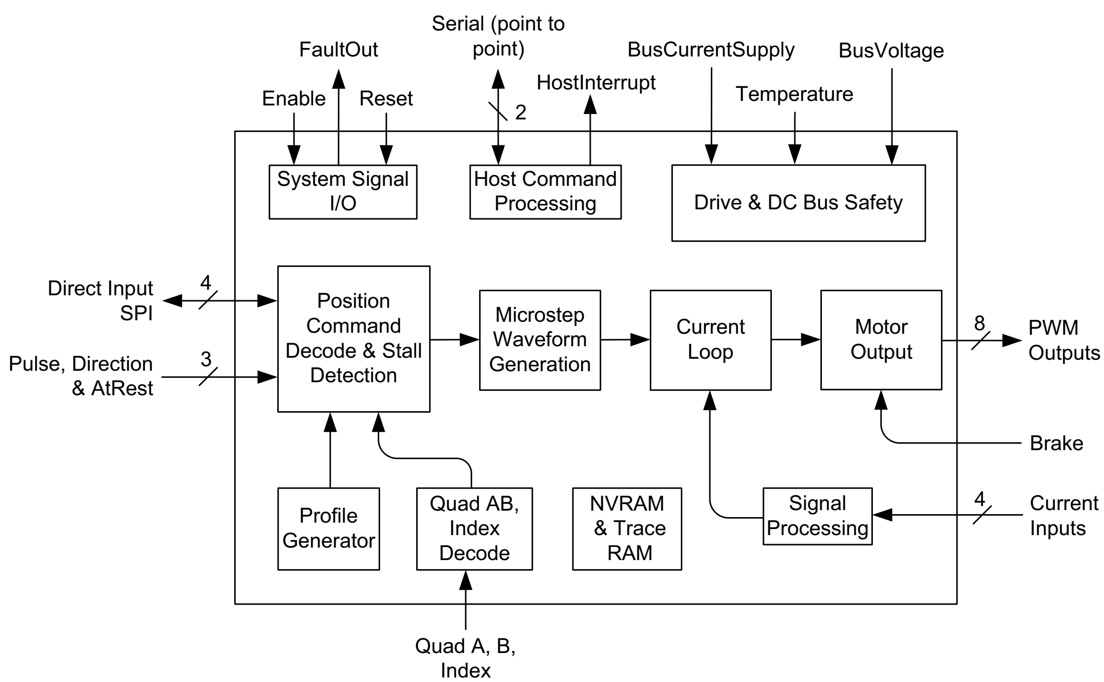



**Figure 7-1: Juno Step Motor Control ICs Internal Block Diagram**

Juno step motor control ICs are single-axis devices that provide sophisticated microstepping control of two-phase step motors.

At power-up or reset, Juno checks for the presence of stored configuration commands in its NVRAM. If detected, the stored configuration commands are loaded into the active control registers that will be used during operation. If no initial configuration is stored in NVRAM, then default values are used, and information is sent by serial from a host device such as a microprocessor or cable-connected PC to configure the Juno IC for a specific application.

Depending on how Juno has been configured an external pulse and direction or SPI (Serial Peripheral Interface) data stream may be used for the incremental position command value. Alternatively an internal profile generator commanded via the serial port may be used to generate programmable step rates.

Juno's waveform generator uses the command position, the status of the ***AtRest*** signal, and user-specified information such as the number of microsteps per full step and the desired motor current level to synthesize a waveform in each phase of the step motor.

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

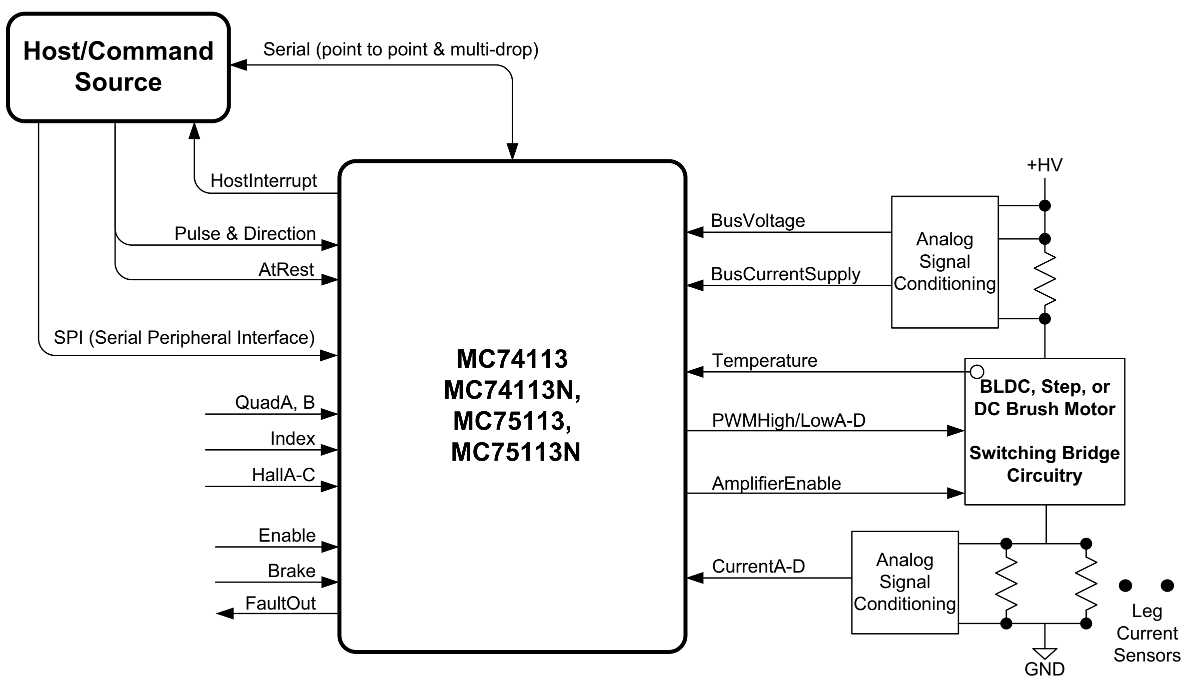
To create a complete controller Juno is connected to switching amplifiers, typically MOSFET or IGBT-based. A programmable dead time function and other timing control parameters ensure that switch synchronization and control is optimal over the entire operating range of the driven step motor.

A number of safety features are incorporated into the Juno ICs including $I^2t$ current limiting, brake signal input, DC bus overvoltage and undervoltage detect, overcurrent detect, and overtemperature detect. In addition, the MC74113 and MC74113N devices accept a quadrature encoder input which can be used for automatic stall detection.

# 7.2 Signal Connections Overview

Figure 7-2 shows an overview of the connection scheme for Juno step motor control ICs. For detailed pin description of these signals refer to Chapter 5, *Pinouts and Pin Descriptions.*

**Figure 7-2: Step Motor Juno ICs Interconnections**



# 7.3 Control Flow Overview

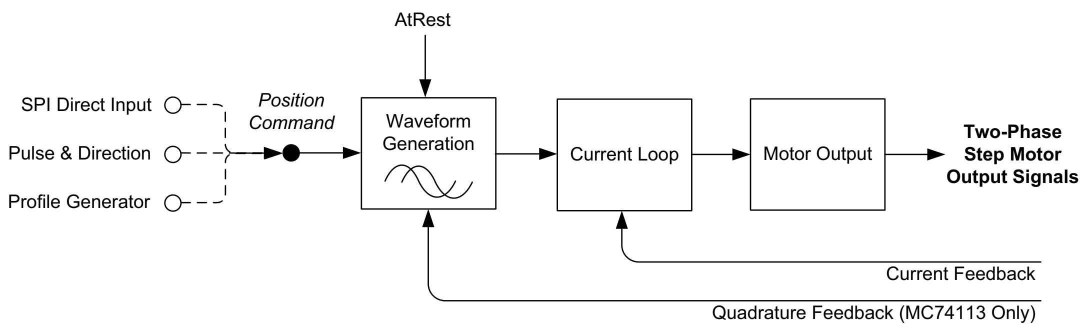



**Figure 7-3: Step Motor ICs Control Flow Overview**

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

The following table provides a brief description of the major step motor control modules:

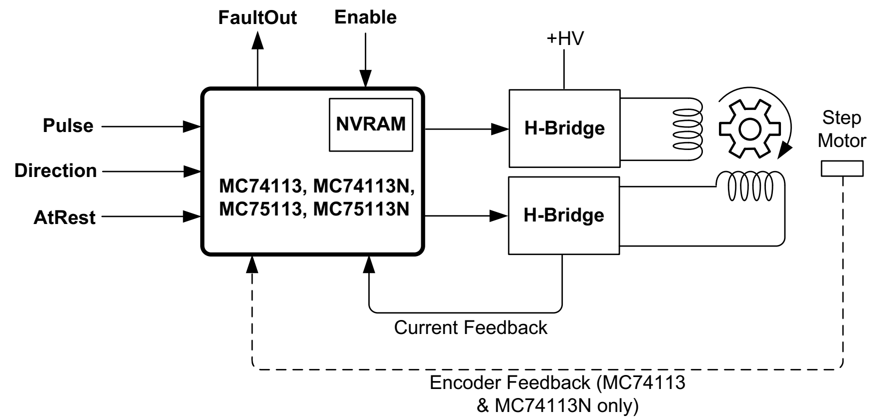
| Module Name | Function |
|---|---|
| Microstep Waveform Generator | This module inputs a command position and uses pre-programmed settings such as the desired current and the number of microsteps per full step to synthesis the two-phase step motor waveform. This module also provides stall detection via optional quadrature encoder feedback signals. |
| Current Loop | This module inputs the commanded current for each step motor phase along with the measured current for each phase and uses a sophisticated proprietary current control technique to generate motor voltage commands for each motor phase. |
| Motor Output | This module inputs the motor phase commands and generates the appropriate PWM (Pulse Width Modulation) electrical signals based on the selected output format. |

# 7.4 Control Applications

Typical Juno step motor control applications are shown in the following sections.

## 7.4.1 Pulse & Direction Control of Step Motors

**Figure 7-4: Step Motor Pulse & Direction Control Diagram**

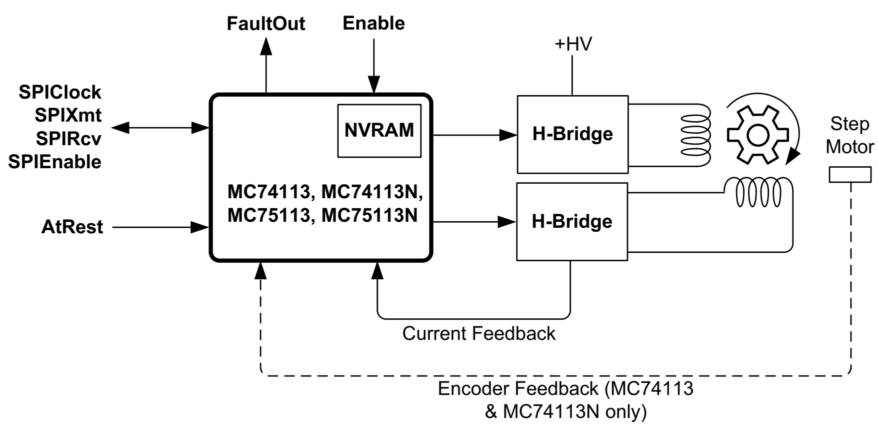



*Applications: General purpose step motor drive, laboratory automation, liquid handling, scientific instruments, printers, XY stages.*

In this configuration a microprocessor, PLC (programmable logic controller), dedicated motion control IC, or other external profile generator commands the position via a pulse, direction, and optional at rest signal. Encoder feedback signals, which can be used with the MC74113 and MC74113N ICs, can be input to provide automatic stall detection.

## 7.4.2 SPI Control of Step Motors

**Figure 7-5: Step Motor SPI Control Diagram**




*Applications: General purpose step motor drive, laboratory automation, liquid handling, scientific instruments, printers, XY stages.*

In this configuration a microprocessor or other external profile generator commands the position via an SPI bus and optional at rest signal. Encoder feedback signals, which can be used with the MC74113 and MC74113N ICs, can be input to provide automatic stall detection.

### 7.4.3 Serial Host Command Control of Step Motors

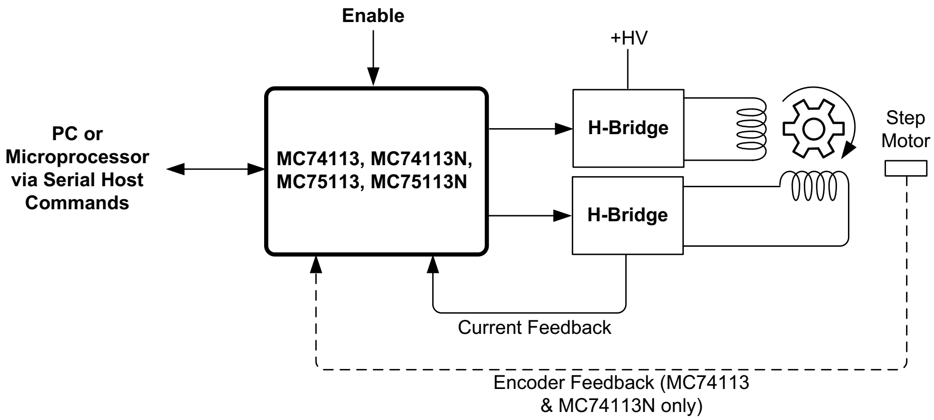



**Figure 7-6: Serial Host Command Control of Step Motors**

*Applications: Microprocessor controlled step motor drive, programming of Juno IC NVRAM, Juno IC application development.*

In this configuration a microprocessor or PC communicates via Juno's serial host command port to control the motor acceleration, deceleration, and maximum velocity.

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

Finally the serial interface may be used in conjunction with PMD Corp.'s Pro-Motion software application to monitor the Juno IC status during application tuning and optimization.

## 7.5 Host Commands

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

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

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

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

| Parameter | Host Command Mnemonic | Range & Description |
|---|---|---|
| PWM frequency | SetDrivePWM | Two parameter command, the first must be 3 and the second is a fixed code value and sets the PWM frequency to 20 kHz, 40 kHz, 80 kHz, or 120 kHz |

| Parameter | Host Command Mnemonic | Range & Description |
|---|---|---|
| Drive current | SetCurrent | Specified value has a range of 0 to 32,767 and determines the drive current, with 0 specifying a command of 0, and 32,767 specifying the highest available voltage or current command |
| Encoder to microstep ratio | SetEncoderToStepRatio | Two specified values, each have a range 1 to 32,767. The first parameter sets the number of encoder counts per motor rotation, the second specifies the number of microsteps per motor rotation |

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

## 7.5.1 Host Command Script Files

**Figure 7-7: Sample Pro-Motion Script File**

```
#ScriptVersion 1
:DESC "Motor 2 settings"
:CVER 1.3
SetDrivePWM 1 561
SetDrivePWM 2 0x80ff
SetDrivePWM 4 8
SetDrivePWM 5 2013
SetDrivePWM 6 2013
SetOutputMode 7
SetMotorCommand 0
SetSignalSense0x0001
SetPhaseParameter 0 0
SetCurrentControlMode 1
SetFOC 512 680
ETC...
```

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

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

Pro-Motion always inserts as the first entry "#ScriptVersion" indicating the script file version format that the file was stored in. This entry is not stored into the Juno IC but allows past and future versions of Pro-Motion to interpret the script file correctly. Numbers default to decimal interpretation but can be forced for hexadecimal interpretation by preceding with "0x".

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

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

## 7.5.2 Serial Port

The Juno step motor control ICs provides a point to point (used with RS232) asynchronous serial interface. All of the Juno serial-related signals are digital TTL level signals, so for typical cable-based use of the serial port external transceiver chips are used.

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. |

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

### 7.5.2.1 Settable Parameters

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

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

Juno serial communications must follow a specific format. For complete information on the **SetSerialPortMode** command as well as other commands in Juno's serial/RS232 host command protocol, refer to the *Juno Velocity & Torque Control IC Programming Reference*.

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# 8. Microstep Waveform Generation

8

## In This Chapter

- Command Position
- Microsteps Per Full Step
- Drive and Holding Current
- Encoder Feedback
- Settable Parameters
- Signal Processing

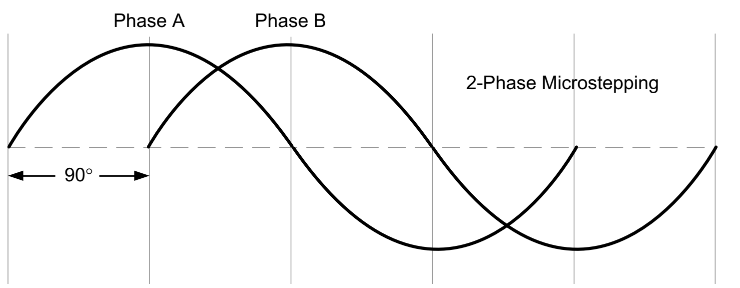


**Figure 8-1: Microstepping Waveforms**

Juno step motor control ICs generate sinusoidal waveforms consisting of phase A and phase B outputs separated by 90 degrees. This is shown in Figure 8-1. The characteristics of these waveforms are determined by the input command position along with other user-controlled settings or signals such as the number of microsteps per full step, the drive current, and the *AtRest* signal.

## 8.1 Command Position

Three position command sources are available; pulse & direction signal input, direct input SPI, and internal profile generation.

When pulse & direction is selected as the command source the incoming *Pulse* & *Direction* signals are processed by Juno and the resultant count is stored in a 32 bit position register. Pulse & direction input is a popular and easy to use method to continuously stream a commanded position to the Juno IC. For more information on signal format and timing, see Section 3.2.5, "Pulse & Direction."

Direct-input SPI is an alternate available method of position command input. When direct-input SPI is selected the user continuously streams a signed 16-bit word containing the relative position change from the previous SPI direct input command. As for pulse & direction signal input, these direct input SPI commands are continuously processed and the resultant count is maintained in a 32 bit position register.

When internal profile generation is selected the position commands come from Juno's profile generator which is in turn controlled by serial port commands specifying the profile acceleration, maximum velocity, and deceleration. For detailed information on Juno's profile generator refer to Chapter 11, *Internal Profile Generation.*

Whether via pulse & direction, SPI, or internal profile generation, to minimize the chance of spurious movement during startup, by default Juno disables position command input processing. This setting is controlled via the command source flag of the Operating Mode register and can be user programmed. See Section 8.5, Settable Parameters, for more information on how to set this flag.

> To activate position command processing the command source flag of the Operating Mode register must be enabled.

## 8.2 Microsteps Per Full Step

The overall sinusoidal waveform is broken into discrete microstep positions, with the number of microsteps per full step (a full step is one quarter of a full electrical cycle) being user settable. Each microstep represents a discrete addressable position of the step motor, and thus the greater the number of microsteps per full step the greater the number of resolvable motor positions.

The number of microsteps per full step is specified using a register known as the phase counts register. The phase counts setting represents the number of microsteps per electrical cycle (four times the desired number of microsteps per full step).

**Example**

If a 1.8° step motor (1.8° of motor rotation per full step) is set up with a resolution of 64 microsteps per full step the phase counts setting will be 64 x 4 = 256, and the number of resolvable positions per mechanical rotation will be 360° / 1.8° x 64 = 12,800 microsteps per motor rotation. Note that this represents the theoretical positioning resolution but does not necessarily mean the motor will have this precision or even this number of actual resolved mechanical positions. That depends on a number of application characteristics including system friction, drive, torque, and motor linearity.

The minimum number of microsteps per full step is one (phase counts setting of four). The maximum number of microsteps per full step is 256 (phase counts setting of 1,024).

## 8.3 Drive and Holding Current

A user-specified drive current controls the amplitude of the microstepping waveform. Depending on whether the current loop module is enabled the provided drive current value will express either a current or a voltage. With the current loop active a drive current command of, for example, 100% will command the highest possible available current to the motor. With the current loop not active (Juno operating in voltage mode) a 100% drive current command will command the highest possible available voltage.

For information on converting commanded current values to actual delivered amps at the motor refer to Section 9.2.2, "Current Signal Scaling."

Juno ICs provide an ***AtRest*** signal input which is used to indicate whether the axis is in motion. In conjunction with this signal a separate holding current command can be defined which is applied when the ***AtRest*** signal is active. A bit indicating whether the axis is currently in a holding condition is available in the Drive Status register.

# 8.4 Encoder Feedback

The Juno MC74113 and MC74113N step motor control ICs support quadrature position encoder input. To provide encoder tracking Juno continually monitors the *QuadA* and *QuadB* feedback signals and accumulates a 32-bit position value called the actual position. At power-up, the default actual position is zero. The full range of trackable positions is -2,147,483,647 to +2,147,483,647.

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

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

For more information on the Event Status register see Section 12.1.1, "Event Status Register."

## 8.4.1 Position Capture

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

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

## 8.4.2 Stall Detection

Juno step motor control ICs can actively monitor the encoder position and automatically detect when the step motor has stalled or otherwise lost steps during motion.

Automatic stall detection operates continuously once it is initiated. The current desired position (commanded position) is continuously compared with the actual position (from the encoder), and if the difference between these two values exceeds a specified limit, a stall condition, called a motion error, is recognized resulting in the corresponding flag within the Event Status register being set. For more information see Section 12.1.1, "Event Status Register."

Juno can be programmed to take various actions when a motion error occurs such as disabling motor output. The mechanism to program and process these functions is called event handling and is described in detail in Section 12.3.1, "Event Processing."

With the MC74113 and MC74113N Juno ICs the actual position units are in microsteps by default. However, if desired the actual position units can be changed to encoder counts.

**Example**

A 1.8 degree step motor has an encoder with 2,000 encoder counts per motor rotation and a microstep resolution set to 64 µSteps per full step, which is 12,800 microsteps per motor rotation. A position error limit of 128 will result in stall detection occurring if the actual step motor lags the commanded position by more than 128 µSteps or two full steps.

# 8.5 Settable Parameters

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

| Parameter | Host Command Mnemonic | Range & Description |
|---|---|---|
| Set Operating Mode register | SetOperatingMode | Specified value is a bit-oriented mask determining the state of the command source, current loop, and motor output enable/ disable flags. |
| Position command source | SetDriveCommandMode | Specified value is a fixed code and selects either pulse & direction, SPI direct input, or the profile generator as the position command source. |
| Microsteps per full step | SetCommutationParameter | Two parameter command, the first must be 0 and the second has a range of 1 to 1,024 and sets 'phase counts', which is four times the number of microsteps per full step |
| Drive current | SetCurrent | Specified value has a range of 0 to 32,767 and determines the step motor's drive current command. To convert to % of maximum output multiply by 100/32,767. |
| Holding current | SetCurrent | Specified value has a range of 0 to 32,767and determines the step motor's holding current command. To convert to % of maximum output multiply by 100/32,767. |
| Encoder to microstep ratio | SetEncoderStepRatio | Two specified values each have a range of 1 to 32,767. The first parameter specifies the number of encoder counts per motor rotation, the second parameter specifies the number of microsteps per motor rotation. |
| Position error limit | SetLoop | Two parameter command, the first must be 263 and the second has a range of 0 to 2,147,483,648 and sets the threshold of the difference, in microsteps, between the commanded position and the encoder-measured actual position. |
| Actual position units | SetActualPositionUnits | Specified value is a fixed code and selects encoder counts or microsteps as the units of the actual position register. |
| Watchdog countdown timer | SetDriveFaultParameter | Two parameter command, the first must be 3 and the second has a range of 0 to 32,767 and sets the watchdog timeout interval in units of cycles. |

For information on the SPI watchdog timer see Section 8.6.2.1, "Watchdog Timer."

# 8.6 Signal Processing

## 8.6.1 Pulse & Direction Signal Interfacing

*Pulse* & *Direction* along with *AtRest* input is supported by all members of the Juno step motor ICs. These signals are digital TTL level, so for typical cable-based connection buffering circuits are recommended.

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

| Pin Name | 64-Pin TQFP Pin# | 56-Pin VQFN Pin# | Description |
|---|---|---|---|
| Pulse | 33 | 29 | Pulse provides a step pulse) 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 however this interpretation, along with that for the *Direction* and *AtRest* signals, is user programmable.

#### 8.6.1.1 Typical Pulse & Direction Processing Circuitry

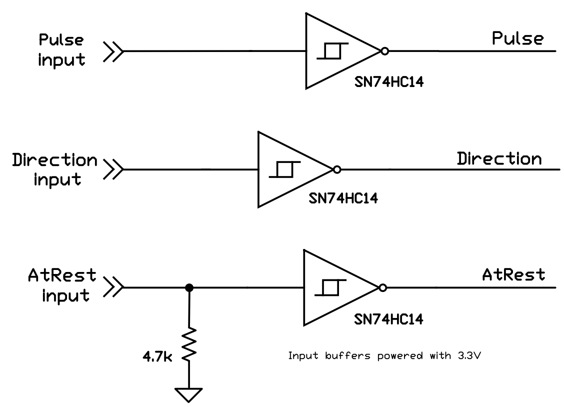


**Figure 8-2: Pulse & Direction Processing Circuitry**

Figure 8-2 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 if *AtRest* is unconnected.

### 8.6.2 SPI Signal Interfacing

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

| Pin Name | 64-Pin TQFP Pin# | 56-Pin VQFN Pin# | Description and when used |
|---|---|---|---|
| SPIRcv | 36 | 31 | SPIRcv inputs synchronous serial data for the SPI bus |
| SPIXmt | 34 | 30 | SPIXmt transmits synchronous serial data for the SPI bus |
| SPIClock | 33 | 29 | SPIClock inputs the clock signal used with synchronous serial transfer on the SPI bus |
| SPIEnable | 44 | 39 | SPIEnable inputs an enable for SPI bus communications |

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

The only SPI port operation supported by the Juno step motor ICs is a write by the external circuitry of a 16-bit position command data word. This 16-bit value represents the relative (incremental) distance that the position command has changed since the previous SPI relative position command write.

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

**Figure 8-3: Direct Input SPI Format**

| | |
|---|---|
| Direct Input Command Word | Command Data Word |
| Juno Response Word | Previous Command Data Word (may contain 0s or 1s) |
| | 15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0 |

The word returned by Juno is the previous command word received. It is recommended, but not required, that the external circuitry read this returned word and confirm that it matches the previously transmitted word. For detailed timing information on the SPI bus refer to Section 4.2, “ SPI Timing.”

**Example**

The SPI bus is used to provide position command. A series of 16-bit SPI word writes is executed to control the position. The consecutive word write values are +1, +3, +5, and +7 after which the accumulated 32-bit command position will be +16. Then word values of -3, -5, -7, and -10 are written to the SPI port after which the 32-bit command position will be -9.

> To avoid jitter in the step motor motion the SPI direct input commands should be streamed at a fixed regular interval, varying in arrival time by no more than 1% of the interval between successive updates. For best performance the update frequency should be between 1.0 kHz and 10 kHz.

#### 8.6.2.1 Watchdog Timer

Juno provides a facility for detecting when SPI commands, which normally arrive on a regular basis, unexpectedly stop. The user selects a watchdog countdown time in units of cycles. For information on Juno’s cycle time see Section 11.1, “Juno Cycle Time.” The default value for the watchdog countdown timer is 0 which indicates no watchdog function is active.

If a lack of command activity occurs for more than the watchdog countdown period a watchdog error occurs, resulting in the drive exception flag of the Event Status register being set. For more information see Section 12.1.1, “Event Status Register.”

Juno can be programmed to take various actions when a watchdog timeout occurs such as disabling the motor output. The mechanism to program and process these functions is called event handling and described in detail in Section 12.3, “Event Action Processing.”

### 8.6.3 Quadrature Encoder Signal Interfacing

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

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

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

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

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

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

### 8.6.3.1 Typical Quadrature Encoder Processing Circuitry

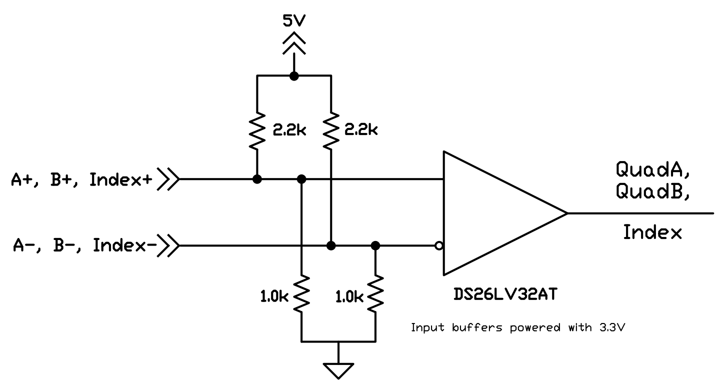


**Figure 8-4: Quadrature Encoder Processing Circuitry**

Figure 8-4 shows a typical circuit for processing differential quadrature and index signals. The pull-up and pull-down resistors provide both termination and a bias voltage. When single ended encoder signals are used connect to the positive input and leave the negative input unconnected.

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# 9. Current Loop

9

## *In This Chapter*

- Settable Parameters
- Signal Processing

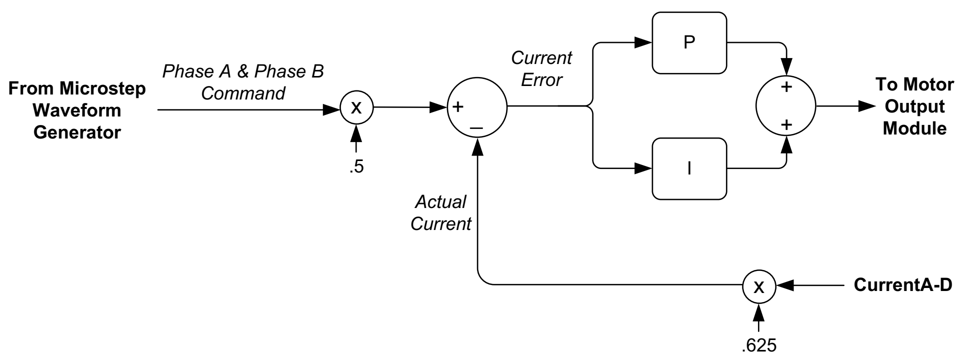



**Figure 9-1: Current Loop Control Flow Diagram**

Figure 9-1 provides a summary of the control flow of Juno's current loop control module when driving a step motor. Current control is a technique used for controlling the current (and therefore the torque) through each winding of the motor. By precisely controlling the current, response times improve, motor efficiency is higher, motion smoothness increases, and top speed increases.

The Juno digital current loop utilizes the desired current along with the measured current for each motor winding to perform a current loop function and generate an output voltage command for each motor coil. The output command for each coil is then passed to the motor output module which generates the precise PWM (pulse width modulation) timing output signals to control external switching circuitry.

To control the current loop three parameters are specified for both a "D" loop and a "Q" loop by the user; Kp, Ki, and Ilimit. Two of these are gain factors for the PI (proportional, integral) controller, one is a limit for the integral contribution. Determining correct Kp, Ki, and Ilimit parameters for the current loop controller gains can be done in a number of ways but the easiest is to utilize the auto-tuning facility provided within PMD Corp.'s Pro-Motion software package.

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

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

# 9.1 Settable Parameters

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

| Parameter | Host Command Mnemonic | Range & Description |
|---|---|---|
| Set Operating Mode register | SetOperatingMode | Specified value is a bit-oriented mask determining the state of the command source, current loop, and motor output enable/disable flags. |
| Kp | SetFOC | Three parameter command, the first specifies whether the provided gain applies to the D loop, the Q loop, or both. The second must be 0, and the third has a range of 0 to 32,767 and specifies the proportional gain value. |
| Ki | SetFOC | Three parameter command, the first specifies whether the provided gain applies to the D loop, the Q loop, or both. The second must be 1, and the third has a range of 0 to 32,767 and specifies the integral gain value. |
| Ilimit | SetFOC | Three parameter command, the first specifies whether the provided gain applies to the D loop, the Q loop, or both. The second must be 2, and the third has a range of 0 to 32,767 and specifies the integrator sum limit. |

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

# 9.2 Signal Processing

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

| Pin Name | 64-Pin TQFP Pin# | 56-Pin VQFN Pin# | Description |
|---|---|---|---|
| CurrentA | 14 | 12 | Measured Current for Leg current input A |
| CurrentB | 19 | 16 | Measured Current for Leg current input B |
| CurrentC | 12 | 10 | Measured Current for Leg current input C |
| CurrentD | 21 | 18 | Measured Current for Leg current input D |

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

Current sensors consist of sense resistors, as shown in Figure 9-2, or linear Hall sensors. If sense resistors are used ground-referenced operational amplifiers may be used.

Current inputs are sampled by Juno at a rate of 20 kHz and should be filtered to minimize noise. A low pass filter with a rolloff of 200 kHz - 1,000 kHz is recommended, with 500 kHz being a typical value for most applications. MC78113s operating at 20 kHz PWM frequency in high noise environments may consider a rolloff on the lower end of the frequency range. Juno's operating with PWM frequencies of 40 kHz, 80 kHz, or 120 kHz operating in low or normal noise environments may consider a rolloff on the higher end of this range.

## 9.2.1 Typical Current Signal Processing Circuitry

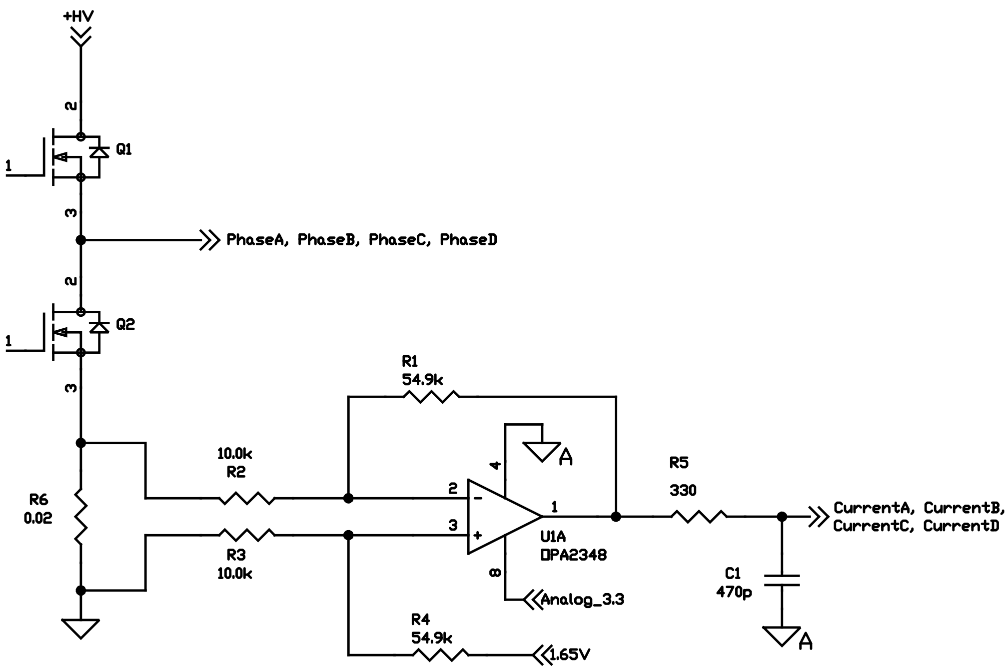



Figure 9-2: Typical Current Signal Processing Circuitry

Figure 9-2 shows a typical leg sensing processing circuit for the current signal inputs. Q1 and Q2 are the half-bridges for one motor phase, and R6 is the current sensing resistor. U1A with R1~R4 is a differential amplifier for signal conditioning; it is capable of measuring bidirectional current and has an output of 1.65V at zero current. R5 and C1 form a low pass filter, and they should be placed close to the pins on the Juno IC. R1~R4 should be 1% or higher grade. The power rating of R6 should match the winding current with 50% power margin recommended.

See Section 15.7, "PWM High/Low Motor Drive With Leg Current Sensing/Control" for complete example schematics for various Juno-based amplifier designs with current control.

Current control only functions when the PWM output mode is set to PWM High/Low. For information on motor output modes, refer to Chapter 10, *Motor Output*

## 9.2.2 Current Signal Scaling

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

**Example**

A step motor application will require 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, presenting a voltage of 0.0V for a reading of -10.0A, 1.65Vfor 0.0A, and 3.3V for +10.0A at the *CurrentA-D* pins.

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

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

Analog offsets, unless explicitly stored into NVRAM, will not be retained after a reset or power cycle. For more information on NVRAM configuration storage see Section 6.1, “Loading the NVRAM”.

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

# 10. Motor Output



### *In This Chapter*

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

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

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

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

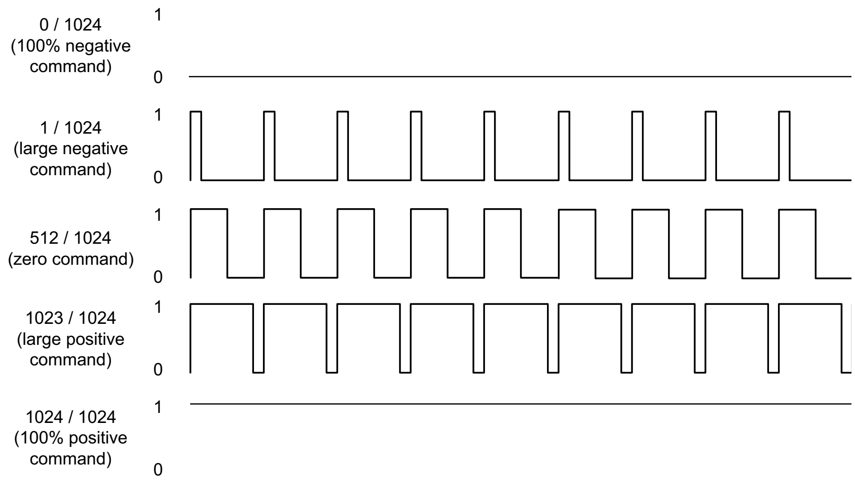
> To activate motor output the motor output flag of the Operating Mode register must be enabled.

## 10.1 PWM High/Low Motor Output Mode

The Juno step motor control ICs can control high-efficiency MOSFET or IGBT power stages with individual high/low switch input control. Step motors are driven in a two H-Bridge configuration consisting of 8 switches.

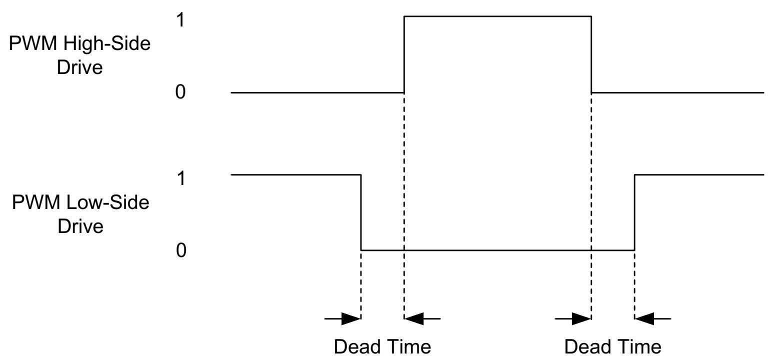
In PWM High/Low mode each signal carries a variable duty cycle PWM signal. A zero desired motor command results in the high side and low side being active for the same amount of time. Positive motor commands are encoded as a high-side duty cycle greater than 50%, and negative motor commands are encoded as a duty cycle less than 50%. This is shown in Figure 10-1.

**Figure 10-1: PWM High/Low Encoding**




In PWM High/Low mode two output pins are used per motor or per motor phase, allowing separate high-side/low-side control of each bridge switch. In this scheme, as Figure 10-2 shows, the high side output and the low side output are never active at the same time, and there is generally a period of time when neither output is active. This period of time is called the dead time, and provides a shoot through protection function for MOSFET or IGBT switches.

**Figure 10-2: PWM High/Low Signal Generation**




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

In addition to dead time, some high side switch drive circuitry requires a minimum amount of off time to allow the charge pump circuitry to refresh. This parameter 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 has units of current loop cycles.

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

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

## 10.1.1 PWM High/Low Step Motor Drive

Figure 10-3 shows the typical amplifier arrangement used with the PWM High/Low mode.

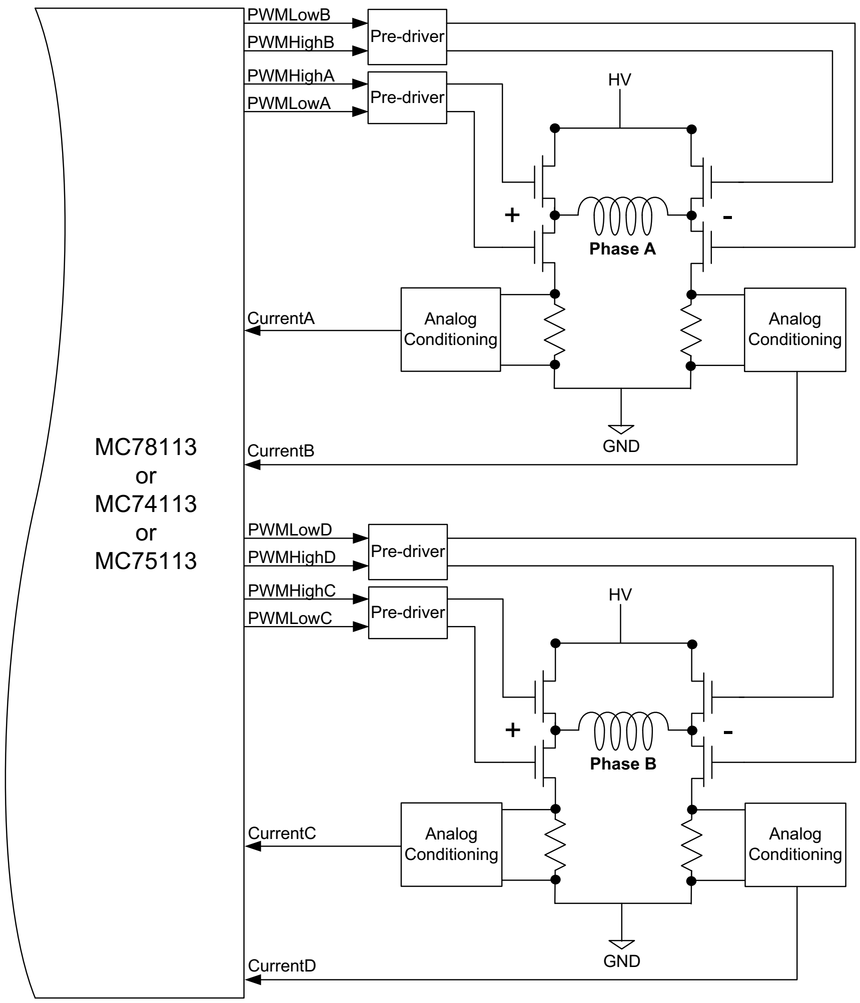



**Figure 10-3: Two-phase Step Motor Bridge Configuration**

## 10.1.2 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 10.3, "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 10.1.4, "Settable Parameters" for details on amplifier-related MC78113 settings) should be set to zero when the MC78113 is connected in this configuration.

### 10.1.3 Low Pass PWM Signal Filtering

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

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

### 10.1.4 Settable Parameters

There are a number of Juno IC parameters which are used to set up or control the switching amplifier circuitry shown in Figure 10-3 when the motor output mode is set to PWM High/Low.

The following table shows these amplifier-related control parameters:

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

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

### 10.1.5 Signal Processing

As shown in the table below eight PWM output signals are used in PWM High/Low mode to interface between the Juno IC and the switching amplifier circuitry.

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

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

There are a wide variety of switching amplifier components and designs that can be used with Juno's PWM High/Low output mode. See Chapter 15, *Application Notes — MC74113 & MC75113*, for schematic examples.

# 10.2 Sign/Magnitude PWM Output Mode

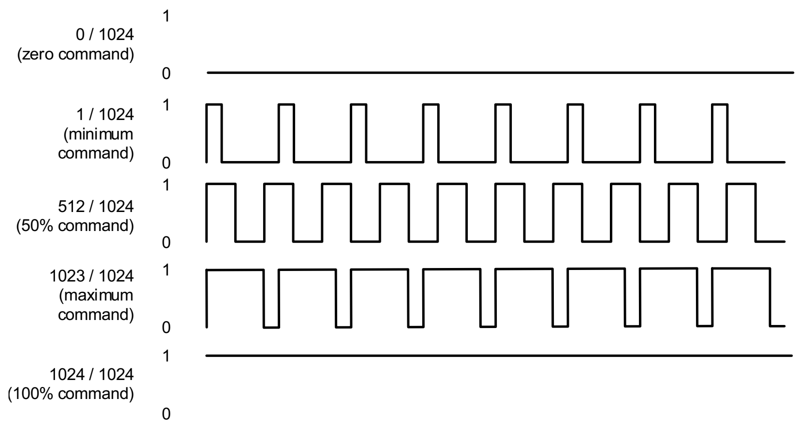



**Figure 10-4: Sign/ Magnitude PWM Encoding**

In Sign/Magnitude PWM mode two pins are used to output the motor command information for each step motor phase. One pin carries the PWM magnitude, which ranges from 0 to 100% as shown in Figure 10-4. 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.

### 10.2.1 Sign/Magnitude PWM Step Motor Drive

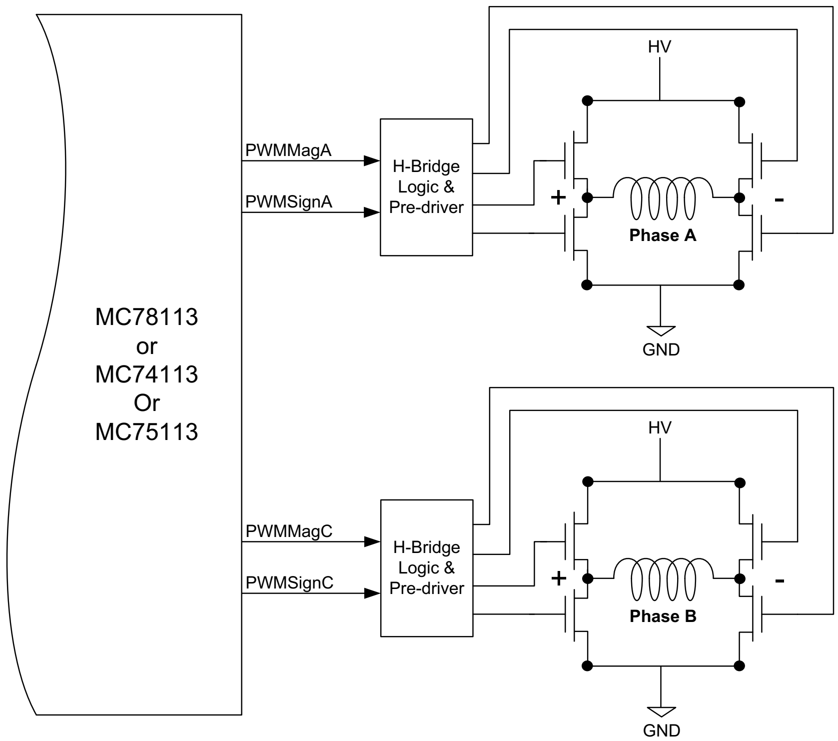



**Figure 10-5: Sign/ Magnitude PWM Step Motor Connections**

Figure 10-5 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 bridge's circuitry itself.

### 10.2.2 Settable Parameters

There are two parameters which are used when the motor output mode is set to Sign/Magnitude PWM. The following table shows these amplifier-related control parameters:

| Parameter | Host Command Mnemonic | Range & Description |
|---|---|---|
| Set Operating Mode register | SetOperatingMode | Specified value is a bit-oriented mask determining the state of the command source, current loop, and motor output enable/disable flags. |
| PWM switching frequency | SetDrivePWM | Two parameter command, the first must be 3 and the second is a fixed code value sets the PWM frequency to either 20, 40, 80, or 120 kHz. |
| PWM Limit | SetDrivePWM | Two parameter command, the first must be 0 and the second has a range of 0 to 16,384 and determine the maximum allowed PWM duty cycle in units of 16,384/163.84 percent. |

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

### 10.2.3 Signal Processing

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 |

There are a wide variety of switching amplifier components and designs that can be used with Juno's PWM High/Low output mode. See Chapter 15, *Application Notes — MC74113 & MC75113*, for schematic examples.

## 10.3 AmplifierEnable

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

The output of this signal is affected by whether the motor output module is enabled and whether the brake function is active. By default the motor output module is disabled and must be enabled by the user via serial host command or NVRAM initialization command. During operations the motor output may become disabled by safety related event processing. For more information on event processing refer to Section 12.3, "Event Action Processing".

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

## 10.4 Brake

The MC78113 *Brake* signal input provides a high speed PWM output disable that may be useful for safety protection when the motor output mode is set to PWM High/Low. When this input is active PWM output is driven to one of two user programmable states; a fully disabled state or a braking state. PWM operation is normal when this signal is inactive.

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

If a brake or disable function occurs, to re-enable normal output the event that caused the discontinuation of function must be reset. For more information on Juno event processing see Section 12.3, "Event Action Processing".

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

# 11. Internal Profile Generation

## *In This Chapter*

- Juno Cycle Time
- Profile Parameter Scaling
- Profile Stop Events
- Settable Parameters

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

To control the profile generator the user specifies a desired target acceleration, deceleration, and velocity. Using these target parameters Juno's profile generator performs calculations to determine the instantaneous position, velocity, and acceleration of the profile at any given moment. These instantaneous profile values are called the commanded values. During profile execution, some or all of the commanded values will continuously change as the profile is generated.

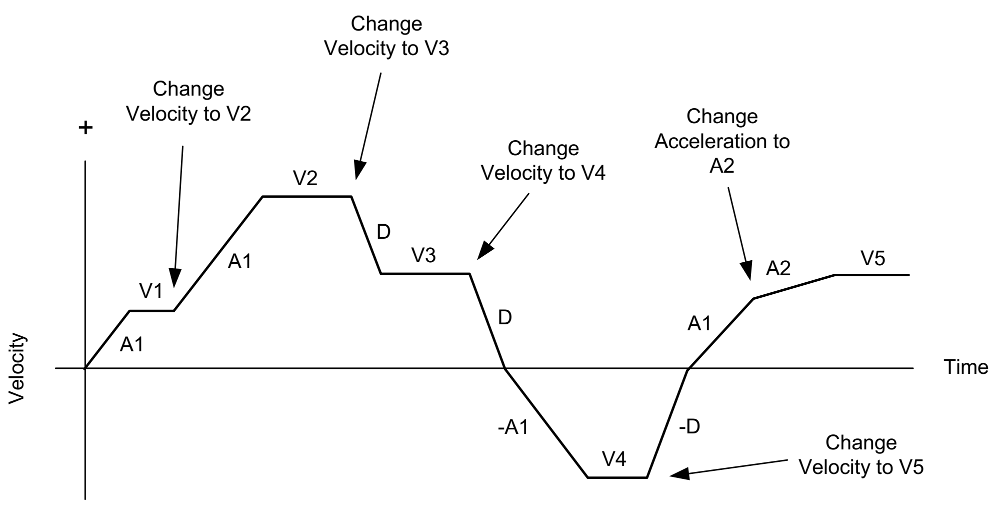



**Figure 11-1: Internally Generated Velocity Profile**

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

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

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

Figure 11-1 illustrates a complex profile in which the specified velocity and the direction of motion changes several times.

# 11.1 Juno Cycle Time

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

# 11.2 Profile Parameter Scaling

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

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

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

**Example**

A profile that achieves a velocity of 135,000 microsteps/sec is desired after an acceleration phase of 120 mSecs.

To convert microsteps/sec to microsteps/cycle we use: V (in microsteps/cycle) = V (in microsteps/sec) / (1.0 sec / .000102 cycles/sec). Plugging in, we get V = 135,000 microsteps/sec / 9,765 cycles/sec = 13.825 microsteps/cycle. To scale this command to the 16.16 format used for the Juno target velocity we multiply by $2^{16}$ giving a 32-bit target velocity command of 13.825 * 65,536 = 906,035.

The acceleration command must achieve the desired velocity in .120 sec * 9,765 cycles/sec = 1,172 cycles. Therefore the acceleration is 13.825 microsteps/cycle / 1,172 cycle = .01180 microsteps/cycle$^2$. To scale this command to the 8.24 format used for the Juno target acceleration we multiply by $2^{24}$ giving a 32-bit acceleration command value to send of .01180 * 16,777,216 = 197,971.

# 11.3 Profile Stop Events

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

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

For more information on setting up and recovering from event actions refer to Section 12.3, "Event Action Processing".

# 11.4 Settable Parameters

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

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

For information on the scaling of these profile target parameters refer to Section 11.2, “Profile Parameter Scaling”.

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# 12. Motion Monitoring & Control

### *In This Chapter*

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

## 12.1 Status Registers

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

### 12.1.1 Event Status Register

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

The Event Status register is defined in the following table:

| Bit | Name | Description |
|---|---|---|
| 0 | *Reserved* | *May contain 0 or 1.* |
| 1 | Position wraparound | Set when the encoder position exceeds 2,147,483,647h (the most positive position), and wraps to -2,147,483,647h (the most negative position), or vice versa. |
| 2 | *Reserved* | *May contain 0 or 1.* |
| 3 | Capture received | Set when the Index position capture hardware acquires a new position value. |
| 4 | Motion error | Set when the encoder position differs from the commanded position by an amount more than the specified maximum position error. |
| 5-6 | *Reserved* | *May contain 0 or 1.* |
| 7 | Instruction error | Set when an instruction error occurs. |
| 8 | Disable | Set when the user disables the Juno IC by making the enable signal inactive. |
| 9 | Overtemperature fault | Set when an overtemperature fault occurs. |
| 10 | Drive Exception | Set when one of a number of drive exceptions, such as bus overvoltage or undervoltage fault occurs. |
| 11 | *Reserved* | May contain 0 or 1. |
| 12 | Current foldback | Set when current foldback occurs. |
| 13 | Run time error | Set when a runtime error occurs. |
| 14-15 | *Reserved* | *May contain 0 or 1.* |

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

### 12.1.2 Activity Status Register

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

The Activity Status register is defined in the following table:

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

### 12.1.3 Drive Status Register

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

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

## 12.1.4 Drive Fault Status Register

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

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

## 12.1.5 Signal Status Register

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

| Bit | Name | Description |
|---|---|---|
| 0 | A encoder | A signal of quadrature encoder input. |
| 1 | B encoder | B signal of quadrature encoder input. |
| 2 | Index encoder | Index signal of quadrature encoder input. |
| 3-6 | *Reserved* | *May be 0 or 1.* |
| 7 | AtRest | AtRest signal. |
| 8-10 | *Reserved* | *May contain 0 or 1.* |
| 11 | Pulse | Pulse signal input. |
| 12 | *Reserved* | *May contain 0 or 1.* |
| 13 | /Enable | Enable signal input. |
| 14 | FaultOut | Fault signal output. |
| 15 | Direction | Direction signal input |

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

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

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

### 12.1.5.1 Signal Sense Mask

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

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

| Bit | Name | Interpretation |
|---|---|---|
| 0 | A encoder | Set 1 to invert quadrature A input signal. Clear 0 for no inversion. |
| 1 | B encoder | Set 1 to invert quadrature B input signal. Clear 0 for no inversion. |
| 2 | Index encoder | Set 1 to invert, clear 0 for no inversion. This means that for active low interpretation of index signal, set to 0; and for active high interpretation, set to 1. |
| 3-6 | *Reserved* | |
| 7 | AtRest | Set 1 to invert AtRest signal. Clear 0 for no inversion. |
| 8-10 | *Reserved* | |
| 11 | Pulse | Set 1 to define active transition as low-to-high. Clear 0 to define active transition as high-to-low. |
| 12 | Motor Direction | Set 1 to invert Motor Direction. Clear 0 for no inversion. |
| 13–14 | *Reserved* | |
| 15 | Direction | Set to 1 to invert Direction signal. Clear 0 for no inversion. |

## 12.2 FaultOut Signal

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

The bit conditions specified in this mask are logically ANDed with the Event Status register. Any resultant non-zero value will cause the *FaultOut* signal to go active. See Section 12.1.1, "Event Status Register" for information on the Event Status register.

**Example**

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

## 12.3 Event Action Processing

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

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

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

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

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

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

## 12.3.1 Event Processing

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

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

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

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

## 12.3.2 Enable-Based Event Recovery

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

Enable-based recovery, also called automatic recovery, relies on the *FaultOut* signal to indicate a fault condition. After the *FaultOut* signal goes active, external logic must delay a minimum of 150 µSec, but thereafter may request that Juno attempt to recover by deasserting, and then asserting, the ***Enable*** signal. The ***Enable*** signal must be in the deasserted state for at least 150 µSec for the request to be recognized.

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

**Example**

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

## 12.4 Host Interrupts

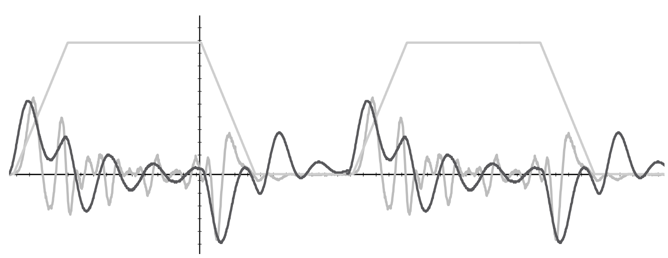
Interrupts allow a host microprocessor or other external circuitry to be automatically notified if a special Juno condition occurs. For this purpose Juno provides a ***HostInterrupt*** signal. ***HostInterrupt*** functions similarly to ***FaultOut*** but provides a separate programmable mask.

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

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

## 12.5 Trace

**Figure 12-2: Example Motion Trace Capture**



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

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

# 12.6 Settable Parameters

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

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

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# 13.Drive & DC Bus Safety



### *In This Chapter*

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

## 13.1 Drive & DC Bus Safety

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

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

### 13.1.1 Overtemperature Protection

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

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

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

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

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

**Example**

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

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

### 13.1.2 Overcurrent Monitoring

**Figure 13-3: Overcurrent Monitoring Circuitry**

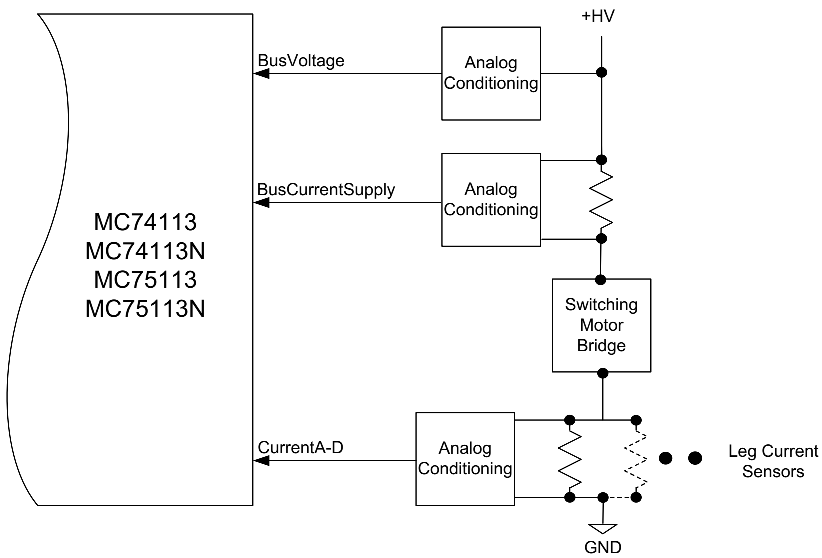



Figure 13-3 shows the DC bus monitoring scheme used with the Juno step motor control ICs. Juno monitors both the supply-side and return-side DC bus current to detect overcurrent conditions. Supply side current measurement detects shorts of the motor windings to ground and shorts of the windings to each other. Return current measurement can not measure shorts to ground, but can measure winding shorts to each other.

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

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

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

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

Return current flow from the DC bus is measured via the leg current sensors as part of the current control mechanism. See Section 9.2.2, "Current Signal Scaling" for more information on leg current scaling.

The bus return current threshold has different scaling that the supply side. It is an unsigned number with range of 0 to 20,479. A DC bus return overcurrent threshold is set to compare against the measured leg current reading.

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

**Example**

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

Using the scaling defined in the example in Section 9.2.2, "Current Signal Scaling" to set the same overcurrent threshold for the DC bus return current of 12.0A, a value of 9.50 A * 1.25 * 32,767 / 10.0 A = 31,128 is used.

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

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

### 13.1.3 Over/Under Voltage Monitoring

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

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

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

**Example**

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

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

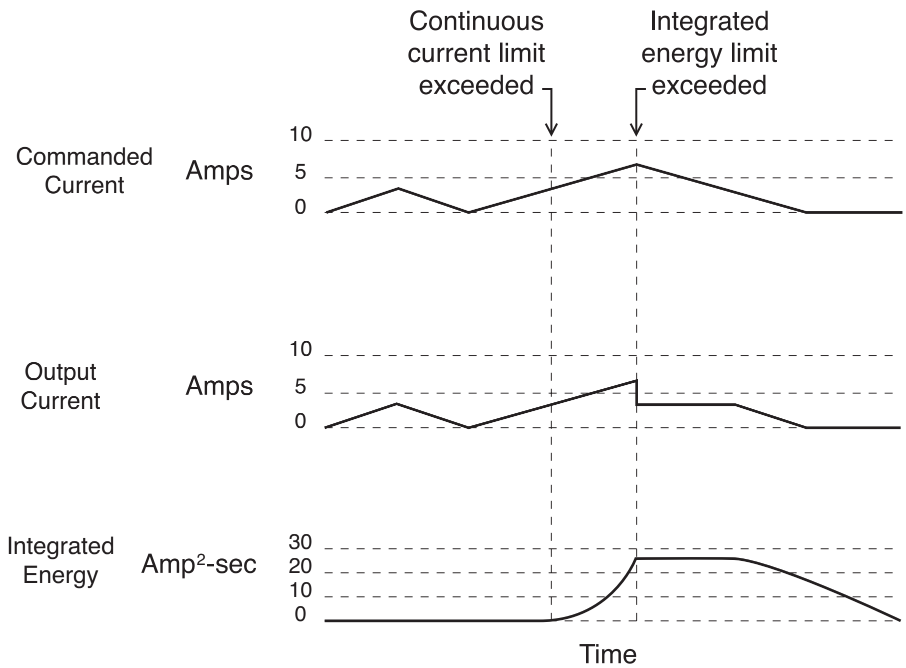
## 13.2 Current Foldback

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

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

Juno will stay in foldback until the integrator returns to zero. This is shown in Figure 13-4.

**Figure 13-4: Current Foldback Processing Example**




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

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

**Example**

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

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

Energy Limit = (peak current$^2$ - continuous current limit$^2$) * time

Energy Limit = ($5^2A^2$ - $3^2A^2$) * 2 Sec

Energy Limit = $32A^2$Sec

Following the current scaling example in Section 9.2.2, “Current Signal Scaling” the programmed continuous current limit would be 3.0 A * .625 * 32,767 / 10.0A = 6,144.

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

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

Programmed Energy Limit = 4,883

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

# 13.3 Settable Parameters

| Parameter | Host Command Mnemonic | Range & Description |
|---|---|---|
| Overtemperature threshold | SetDriveFaultParameter | Two parameter command. The first must be 4, the second has a range of -32,768 to 32,767 and specifies the thermistor sense (voltage increasing or decreasing) via the sign of the specified value and the threshold limit via the magnitude of the specified value. A value of 32,767 disables this feature. |
| Overtemperature hysteresis | SetDriveFaultParameter | Two parameter command. The first must be 5, the second has a range of 0 to 6,400 and specifies the hysteresis. |
| DC bus overcurrent supply threshold | SetDriveFaultParameter | Two parameter command. The first must be 10, the second has a range of 0 to 65,534 and specifies the DC bus supply overcurrent threshold. A value of 65,534 disables this feature. |
| DC bus overcurrent return threshold | SetDriveFaultParameter | Two parameter command. The first must be 11, the second has a range of 0 to 65,534 and specifies the DC bus return overcurrent threshold. A value of 65,534 disables this feature. |
| DC bus overvoltage threshold | SetDriveFaultParameter | Two parameter command. The first must be 0, the second has a range of 0 to 65,535 and specifies the DC bus overvoltage threshold. A value of 65,535 disables this feature. |
| DC bus undervoltage threshold | SetDriveFaultParameter | Two parameter command. The first must be 1, the second has a range of 0 to 65,535 and specifies the DC bus undervoltage threshold. A value of 0 disables this feature. |
| Current foldback continuous current limit | SetCurrentFoldback | Two parameter command. The first must be 0, the second has a range of 0 to 32,768 and specifies the foldback continuous current limit A value of 32,768 disables this feature. |
| Current foldback energy limit | SetCurrentFoldback | Two parameter command. The first must be 1, the second has a range of 0 to 32,768 and specifies the foldback energy limit A value of 32,768 disables this feature. |

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

# 13.4 Signal Processing

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

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

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

## 13.4.1 Typical Overtemperature Processing Circuitry

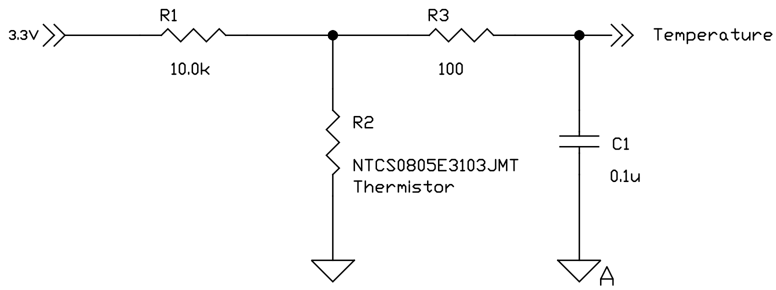



**Figure 13-5: Over-temperature Processing Circuitry**

Figure 13-5 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 MC58113. R3 is optional. It can provide additional filtering to improve noise immunity if needed.

See Section 15.6, "Drive-Related Safety and Monitoring Features" for a complete example schematic of temperature input using Juno ICs.

## 13.4.2 Typical Overcurrent Processing Circuitry

The DC bus current supply sensor typically consists of a sense resistor, as shown in Figure 13-3, or a linear Hall sensor. The analog processing circuitry required for each is somewhat different. If a dropping resistor is used an isolating operational amplifier, current mirror, or similar circuit should be used. Linear Hall sensors typically use just a ground-referenced operational amplifier.

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

### 13.4.2.1 Typical Overcurrent-Processing Circuitry

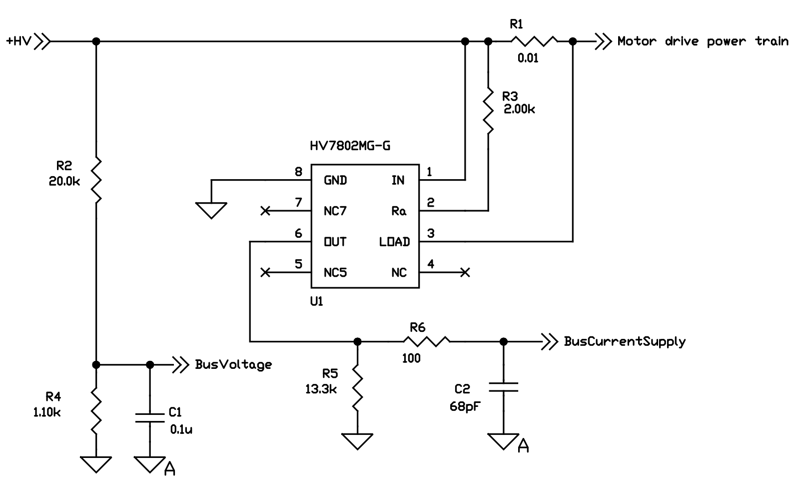



**Figure 13-6: DC Bus Monitoring Circuitry**

Figure 13-6 shows a typical processing circuit for DC Bus voltage and ***BusCurrentSupply*** over current sensing. The bus current sensing includes R1, U1, U2A and related passive parts. U1 is a high-side bus current sensing IC, and its output on R7 represents the bus current.

> During motor deceleration or other motion conditions it may be possible for the DC bus supply current flow to be negative. Care should be taken to insure that negative currents do not generate a negative voltage at the MC78113's BusCurrentSupply analog input pin. This is generally accomplished via a diode. See Section 15.6, "Drive-Related Safety and Monitoring Features" for examples of DC bus safety-related schematics.

## 13.4.3 Typical Over/Under Voltage Processing Circuitry

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

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

Figure 13-6 shows a typical processing circuit for DC Bus voltage monitoring. The bus voltage sensing consists of R2, R4 and C1. R2 and R4 scale the bus voltage, between 0 and 3.3V. C1 is referenced to analog ground and should be placed close to the ***BusVoltage*** pin.

See Section 15.6, "Drive-Related Safety and Monitoring Features" for complete example schematics of DC bus management designs.

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# 14. Power-up, Configuration Storage & NVRAM

***In This Chapter***

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

## 14.1 Power-up

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

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

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

## 14.2 NVRAM

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

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

## 14.3 Initialization Control

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

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

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

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

# 14.4 Settable Parameters

For more information on the commands and parameters associated with Juno initialization control refer to the **ExecutionControl** command description in the *Juno Velocity & Torque Control IC Programming Reference*

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

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

# 14.5 Signal Processing

## 14.5.1 Output Signal Status During Power-up

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

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

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

## 14.5.2 Reset

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

The table below shows the Juno reset signal:

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

### 14.5.2.1 Typical Reset Processing Circuitry

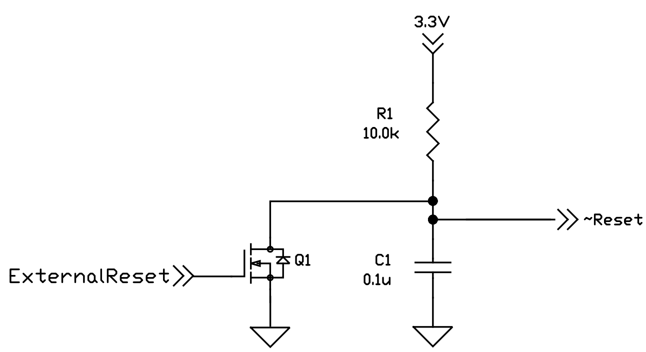


**Figure 14-1: Typical Reset Processing Circuitry**

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

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# 15. Application Notes — MC74113 & MC75113

15

### In This Chapter

- General Design Notes
- Design Tips
- Power Supplies
- Clock Generator, Grounding and Decoupling
- Reset Signal
- Drive-Related Safety and Monitoring Features
- PWM High/Low Motor Drive With Leg Current Sensing/Control
- Interfacing Juno ICs With A Multi-Axis Magellan IC

## 15.1 General Design Notes

In the subsequent sections please note that unless otherwise noted MC74113 refers to both the MC74113 and MC74113N ICs, and MC75113 refers to both the MC75113 and MC75113N ICs.

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

In the schematics, pins with multiple functions are referenced by the name corresponding to the specified functionality. For example, pin 56 on the MC74113 is named "PWMHighA/PWMMagA" but will be referenced by the name "PW-MHighA" in the PWM High/Low motor drive schematic example and "PWMMagA" in the sign/magnitude motor drive schematic example.

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

### 15.1.1 Interfacing to Other Logic Families

When integrating different logic families, consideration should be given to timing, logic level compatibility, and output drive capabilities. The MC74113 and MC75113 are 3.3V CMOS input/output compatible and cannot be directly interfaced to 5V CMOS components. In order to drive a 5V CMOS device, level shifters from the 5V CMOS AHCT (or the slower HCT) families can be used. When using a 5V CMOS component to drive the CP, a voltage divider may be used or a member from the CMOS 3.3V LVT family may serve as a level shifter.

# 15.2 Design Tips

## 15.2.1 Controlling PWM Output During Reset

When the MC74113 or MC75113 are in a reset state (when the reset line is held low), or immediately after a power on, PWM output will be in a high impedance state, which will provide design flexibility to prevent undesirable motor movement at system level. For example, when the power train is active high in PWM High/Low mode, pull-down resistors can be used to keep the power train off during reset and power up. For an active low power stage, pull-up resistors can be used.

## 15.2.2 Thermal Considerations

The recommended operating junction temperature range for the MC74113 and MC75113 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** |
| $\theta_{JA}$[°C/W] High k PCB | 56.5 | 44.7 | 42.9 | 40.3 |
| $\psi_{JT}$ [°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** |
| $\theta_{JA}$[°C/W] High k PCB | 34.8 | 23.6 | 22.3 | 20.5 |
| $\psi_{JT}$ [°C/W] | 0.24 | 0.36 | 0.43 | 0.56 |

$\theta_{JA}$ 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.

$\psi_{jT}$ (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 $\psi_{jT}$ is small, if a user chooses to, the top of package temperature might be approximated as the junctional temperature for design estimation when enough thermal design margin is included.

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# 15.3 Power Supplies

In the schematic shown in Figure 15-1 the design is powered by an external +5VCC power source. The MC74113 and MC75113 require a 3.3V supply input. +3.3Vs, the 3.3V digital supply, is generated by the TPS76733QPWPRG4, a 1.0 Amp fixed 3.3V low-dropout voltage regulator.

If the MC74113 or MC75113 analog inputs are used it should be supplied with a filtered +3.3Vs supply.

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

- +3.3Vs and +3.3V_Analog: +3.3Vs is the main digital supply for the MC74113 and MC75113 devices. +3.3V_Analog is the filtered version of the +3.3Vs supply for ADC and its related conditioning circuitry. The extra filtering is used to provide additional decoupling of the analog elements from the digital elements in the circuitry.

**Notes:**

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

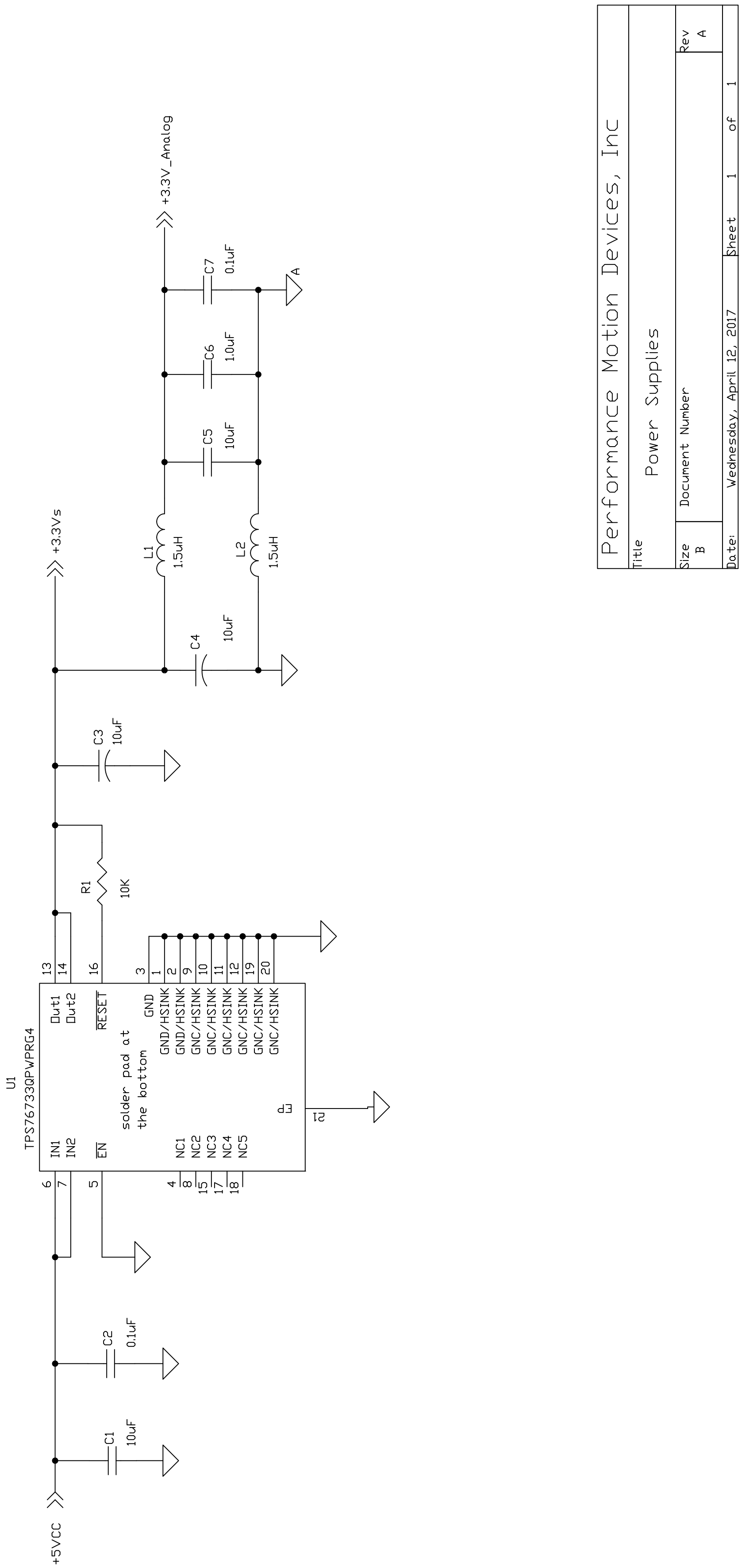



**Figure 15-1: Basics, Power Supplies, MC74113 and MC75113**

# 15.4 Clock Generator, Grounding and Decoupling

## 15.4.1 Grounding and Decoupling

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

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

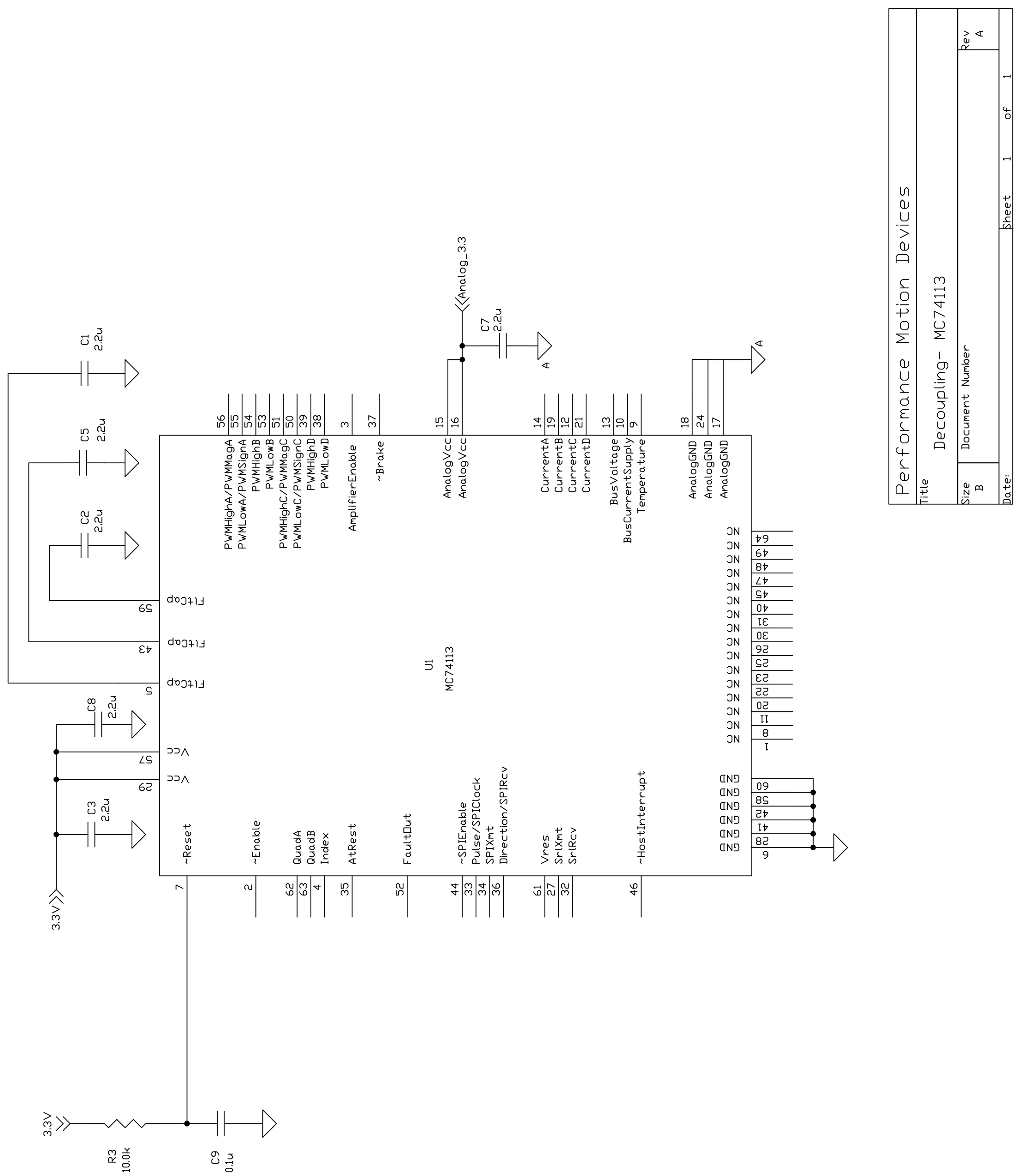
The same points should be considered when designing the ground. A good board layout practice should have a star connection at one point in the power supply.

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

## 15.4.2 Decoupling of the On-chip ADC

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

**Figure 15-2: Basics, Clock and Bypass Caps, MC74113 and MC75113**



# 15.5 Reset Signal

The MC74113 and MC75113 chips have a built-in power supervisory circuitry that generates an internal reset signal when a power-on or brown-out condition occurs. As such, no external circuitry is needed to generate a reset input pulse. An R-C circuit must be connected to this pin for noise immunity reasons.

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

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

During the initialization period, the MC74113 and MC75113 are configured with the default initialization parameters for communication, analog offsets, control loop gains etc. If necessary, the on chip non-volatile storage can be used to store user-programmed initialization parameters. For more information see Section 6.1, "Loading the NVRAM."

# 15.6 Drive-Related Safety and Monitoring Features

This example shows the motor drive-related analog monitoring features. Please refer to Section 15.7, "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. MC74113 and MC75113 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 MC74113 and MC75113 and close to the power train, which usually has the highest temperature. Accordingly, C5 is referred to the analog ground, and R13 to digital ground. R10 is optional to improve the noise immunity. If R13 is close to the analog portion, Vcc can be AnalogVcc instead and R13 be tied to the analog ground.

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

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

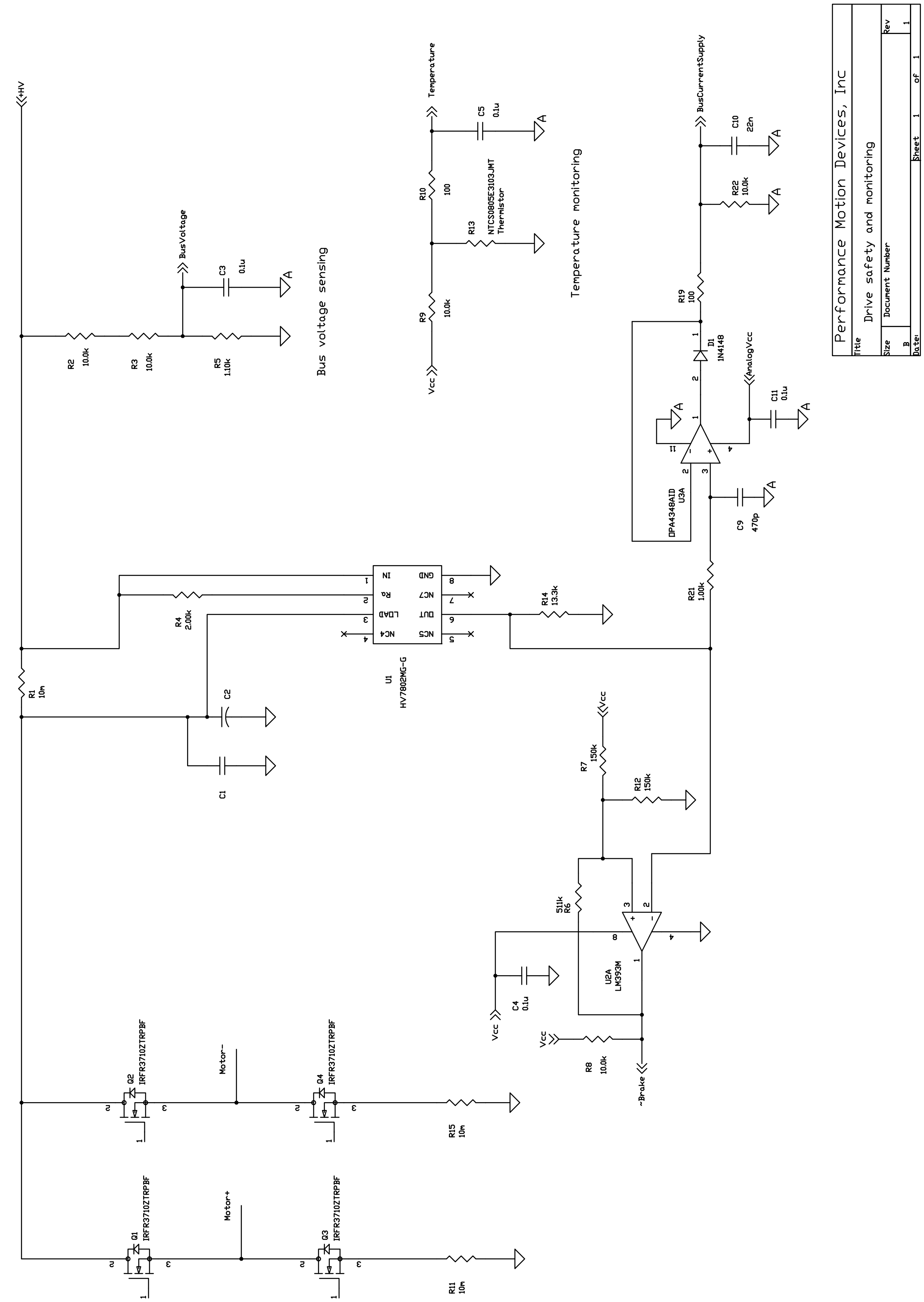
U2A is for short circuit protection. R12 and R7 set the protection trigger point, and R6 provides a hysteresis. When Vcc is 3.3V, the trigger point is 1.65V with hysteresis. Brake will go to low and trigger protection when U1 output is over 1.65V, which is (1.65/66.5mv/A)= 25A.

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

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

MC74113 and MC75113 supports leg current sensing with current loop control, and R11 and R15 are leg current sensing resistors.

**Figure 15-3: Drive Safety and Monitoring**



# 15.7 PWM High/Low Motor Drive With Leg Current Sensing/Control

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

## 15.7.1 Leg Current Sensing

Figure 15-4 shows an example for leg current sensing. Only phase A is shown here while the design for other legs are the same.

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

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

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

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

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

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

By default, the MC74113 and MC75113 take 1.65V reading as zero current. Host commands can be sent to compensate the error introduced by the offsets and tolerances of the current sensing circuit.

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

The gain of the current sensing circuit is

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

For this example, it is

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

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

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

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

$I^{2}*R_2$. 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 $I^{2}*R_2*(T_{Q2ON}/T_{PWM})$ and resistor can be sized accordingly.

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

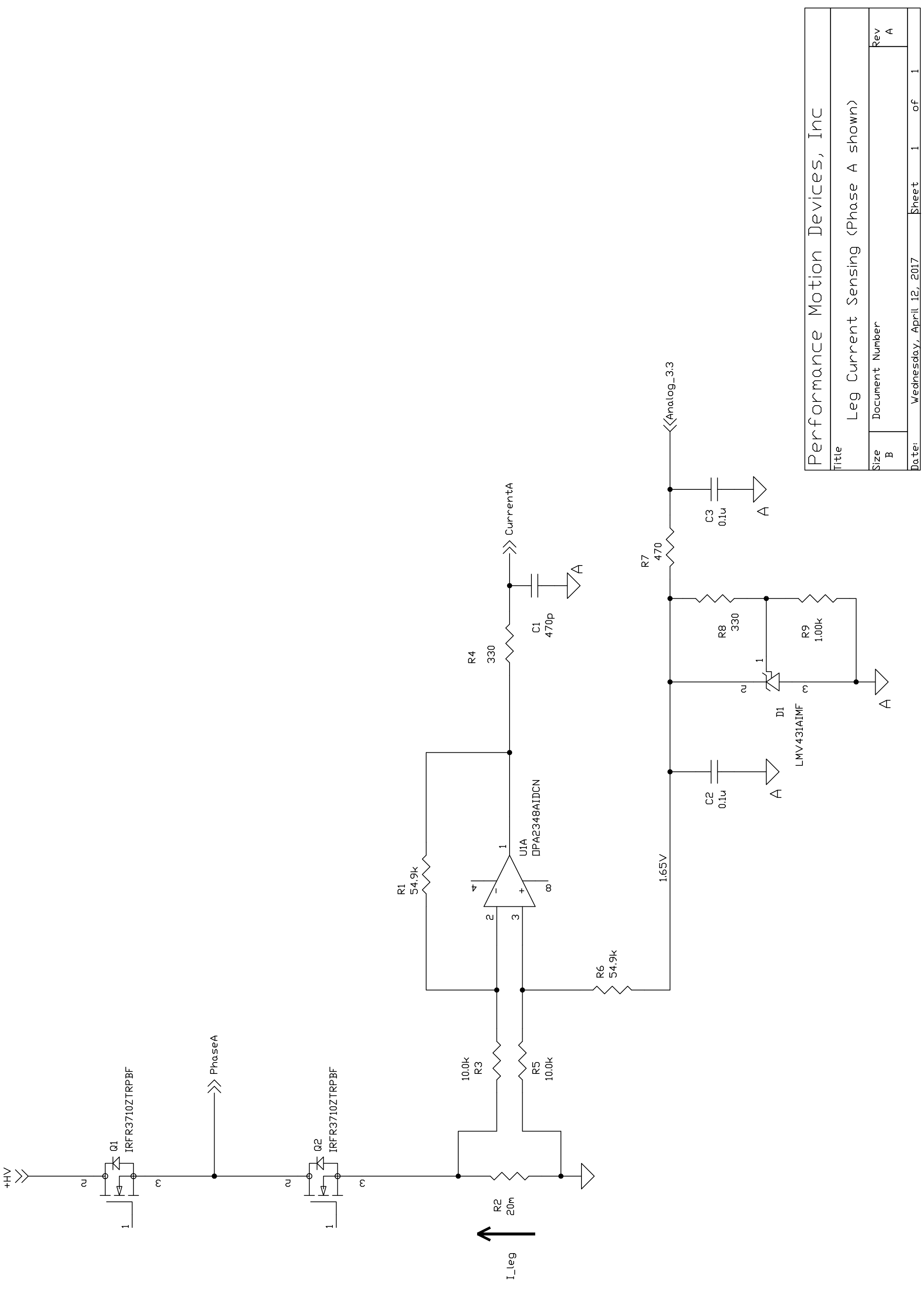



**Figure 15-4: Leg Current Sensing**

## 15.7.2 Step Motor Drive with 2A Current Rating

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 48V. It is capable of driving 2A continuous current with peak current up to 3A.

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 U3, which is powered by 15V.

During normal operation, PWMHighA is active high, and PWMLowA, active low. For PWMLowA, a logic "0" turns on the MOSFET Q1-2. R5, R6 and D3 provide an unsymmetrical turn-on and turn-off capability.

A logic "1" PWMHighA will turn on Q1-1. C6 is the bootstrapping capacitor, and it is charged through D5 when Q3 is turned on. C6 provides the power to turn on Q1-1, and C3 needs to be a low-ESR capacitor such as a ceramic capacitor. D5 should be a fast switching diode with low leakage current, and its voltage rating should be chosen based on +HV and the +15V. R21 is optional; it can limit the charging current, especially during power up when C6 is zero voltage. R1, R3 and D1 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 R24 and pull-up resistor R22 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 R22 and R24 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.

R14 is the current sensing resistor, and U1 is the differential amplifier for signal conditioning. Please see Section 15.7.1, "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. Also, Q1 is consisted of two MOSFET to reduce the board space. This example provides a balanced design reference between performance and cost for applications up to 48V and current up to 3A. With different MOSFETs, higher voltage and current capabilities can be achieved.

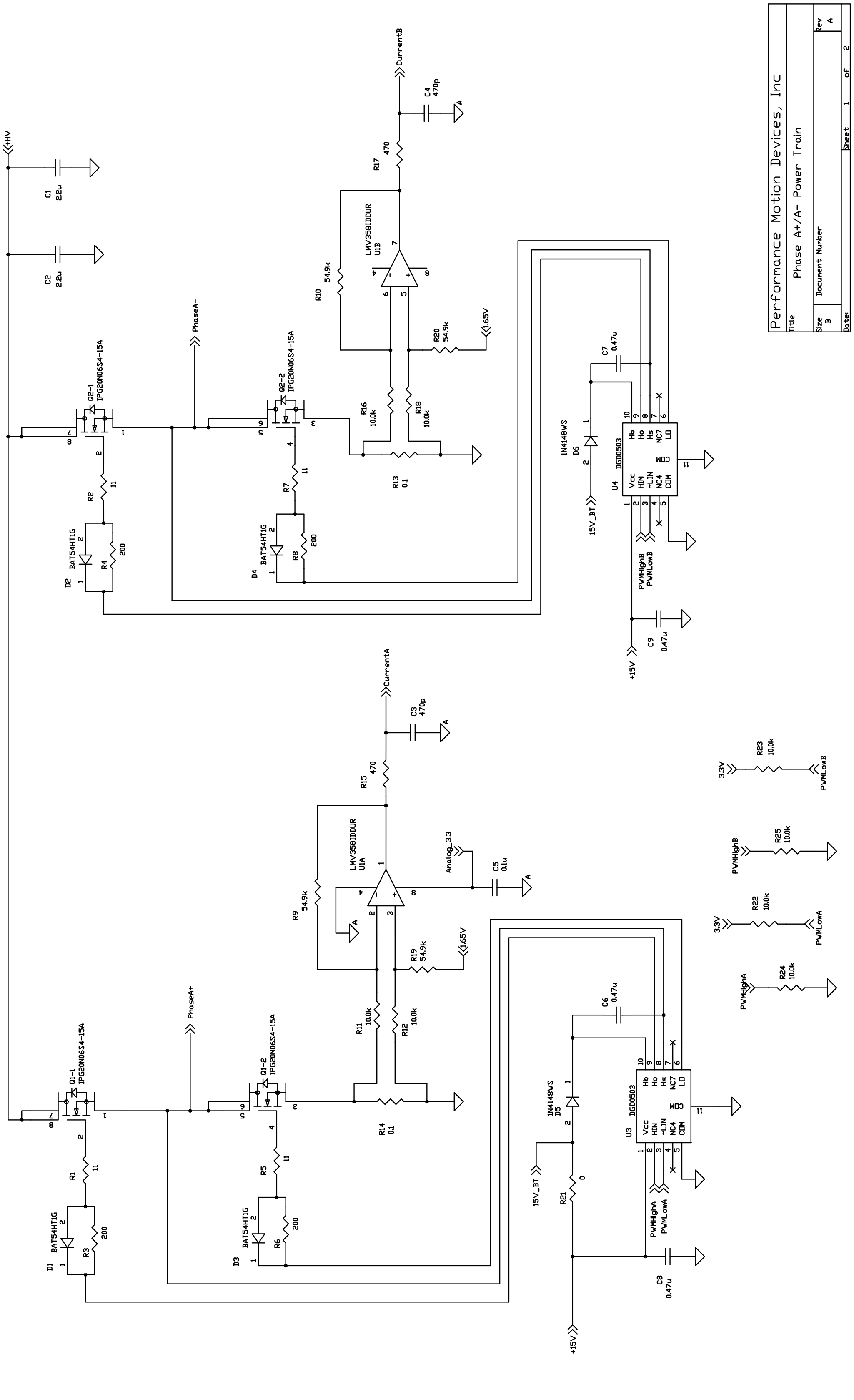



**Figure 15-5: Step Motor Drive with 2A Continuous Current Rating**

### 15.7.3 Step Motor Drive with 5A Current Rating

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 fault is triggered, PWMHighA and PWMLowA can go into high impedance if configured, 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 external resistors are necessary.

R9 is the current sensing resistor, and U3 is the differential amplifier for signal conditioning. Please see Section 15.7.1, "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.

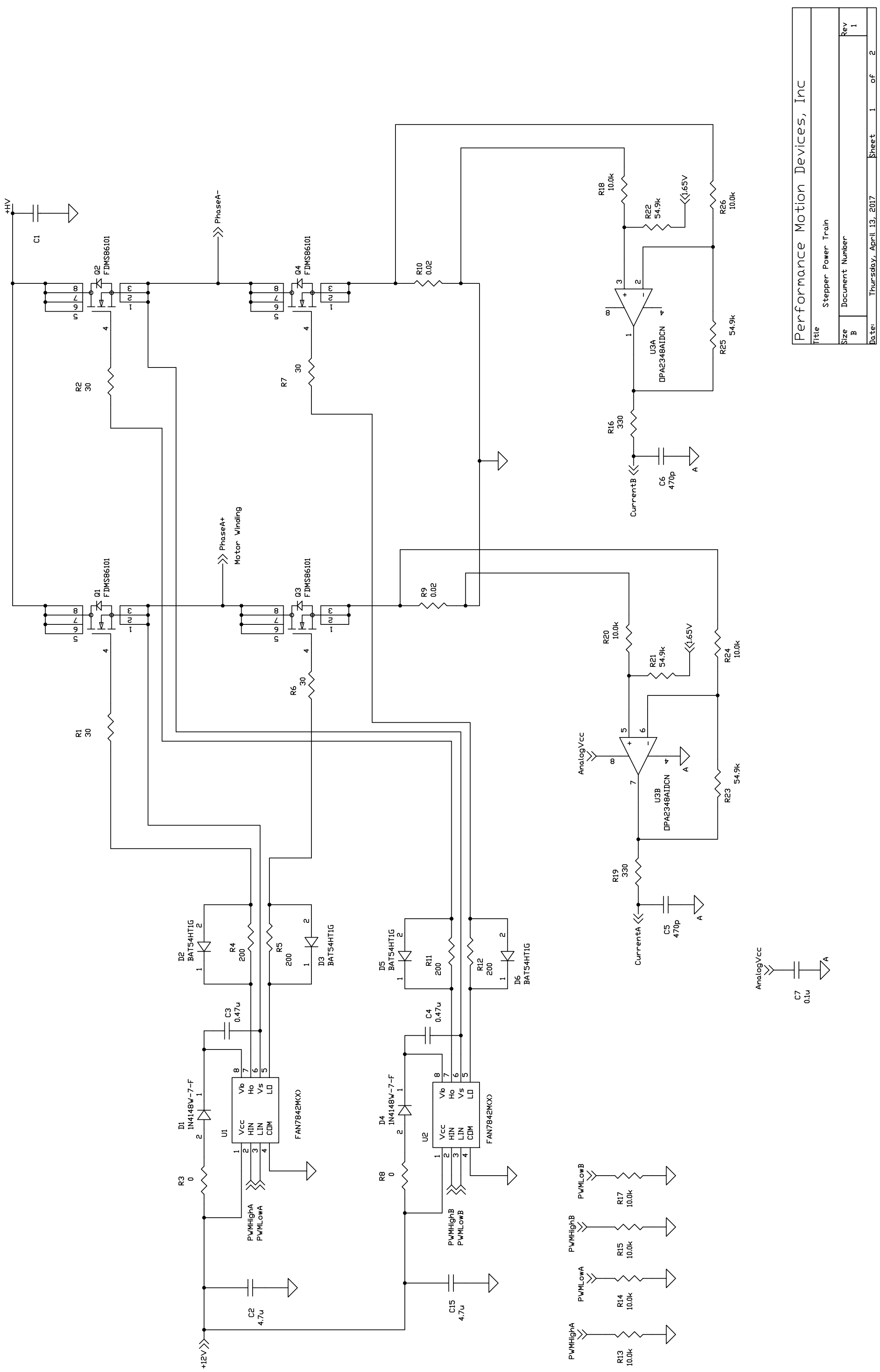



**Figure 15-6: Step Motor Drive with 5A Continuous Current Rating**

### 15.7.4 Step Motor Drive with 10A Current Rating

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 10A continuous current with peak current of more than 20A.

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 U3, which is poweredby 15V.

During normal operation, PWMHighA is active high, and PWMLowA, active low. For PWMLowA, a logic "0" 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. C6 is the bootstrapping capacitor, and it is charged through D5 when Q3 is turned on. C6 provides the power to turn on Q1, and C3 needs to be a low-ESR capacitor such as a ceramic capacitor. D5 should be a fast switching diode with low leakage current, and its voltage rating should be chosen based on +HV and the +15V. R21 is optional; it can limit the charging current, especially during power up when C6 is zero voltage. R1, R3 and D1 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 R24 and pull-up resistor R22 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 R22 and R24 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.

R14 is the current sensing resistor, and U1 is the differential amplifier for signal conditioning. Please see Section 15.7.1, "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 20A. With different MOSFETs, higher voltage and current capabilities can be achieved.

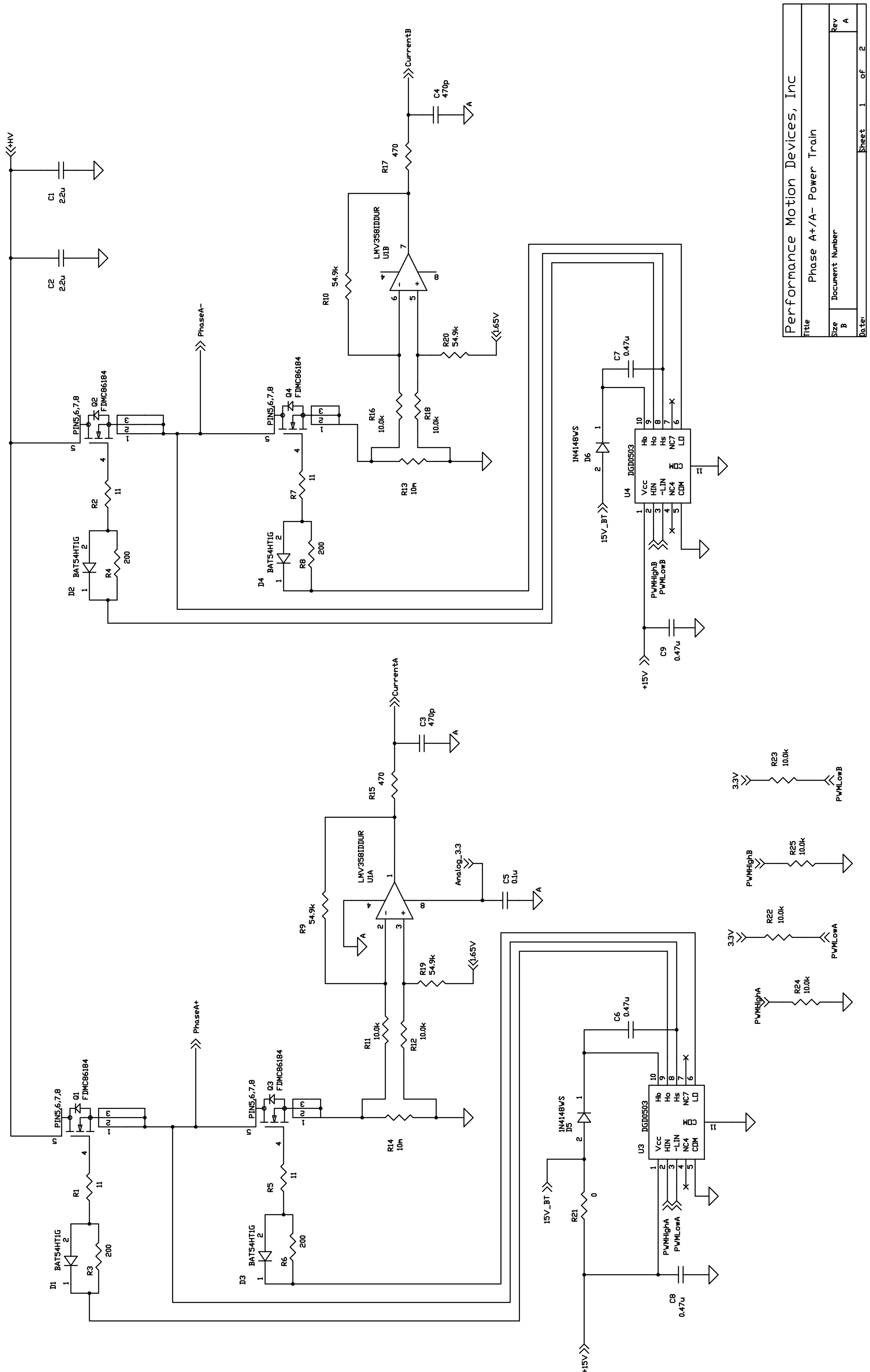



**Figure 15-7: Step Motor Drive with 10A Continuous Current Rating**

## 15.7.5 Step Motor Drive Using PWM Sign/ Magnitude Signal

In the following schematic, the sign/magnitude output is used to drive a step motor. Dual H-bridge motor driver DRV8881E is used, which is capable of 2.5A peak current up to 45V. DRV8881E can be driven directly from a 3.3V CMOS logic output and as such can be directly interfaced to the MC74113 or MC75113 ICs.

In the sign/magnitude control mode, sign signals, PWMSignA and PWMSignC, are applied to APH, BPH, respectively for winding current direction control. The filtered signals of PWMMagA and PWMMagB are applied to AVREF and BVREF, respectively, for setting instantaneous winding current.

DRV8881E regulates winding current based on reference voltage inputs AVREF and BVREF. In this example, the current sensing resistors, R1 and R2, are set at 0.45 ohm. With current scalar at 100% (TRQ1 and TRQ0 grounded), the 1A peak winding current requires reference voltage input of 2.97V. For MC74113 or MC75113 ICs with 3.3V output, it corresponds to PWM command of 90%.

PWMMagA and PWMMagC are PWM signals, and they can be set to 20kHz, 40kHz, 80kHz and 120kHz. The reference voltage input voltage inputs are filtered version of the PWM signal. In the example, a first-order RC filter is used with bandwidth of 1.42kHz with gain of -35dB at 80kHz. R3 and R4 should be 1% or better. C7 and C8 should be NP0 type with 5% or better. The bandwidth of the low-pass filter should be able to attenuate the PWM frequency component because a higher cut-off frequency results in higher ripple. However, the signal delay and attenuation should also be considered. A low cut-off frequency will introduce larger distortion at zero crossing point and delay. Higher order filter can also be used to achieve the balance of signal delay and ripple attenuation.

DRV8881E supports current control with fast decay, slow decay and mixed decay. In this example, ATE is tied to V3P3 so AutoTune operation is enabled to automatically adjust decay setting to achieve balanced current ripple and fast step response.

AmplifierEnable is used to enabled DRV8881E. During power up, AmpliferEnable is in high impedance, and DRV8881E is disabled with its internal pull-down resistors.

This drive example shows how to interface a drive circuit to the MC74113 or MC75113 ICs using PWM sign/ magnitude signals. Note that the current control accuracy of this approach compared to the PWM High/Low drive output scheme as shown in sections 15.7.2, 15.7.3, or 15.7.4 will not be as good, this approach will typically require fewer components and cost somewhat less.

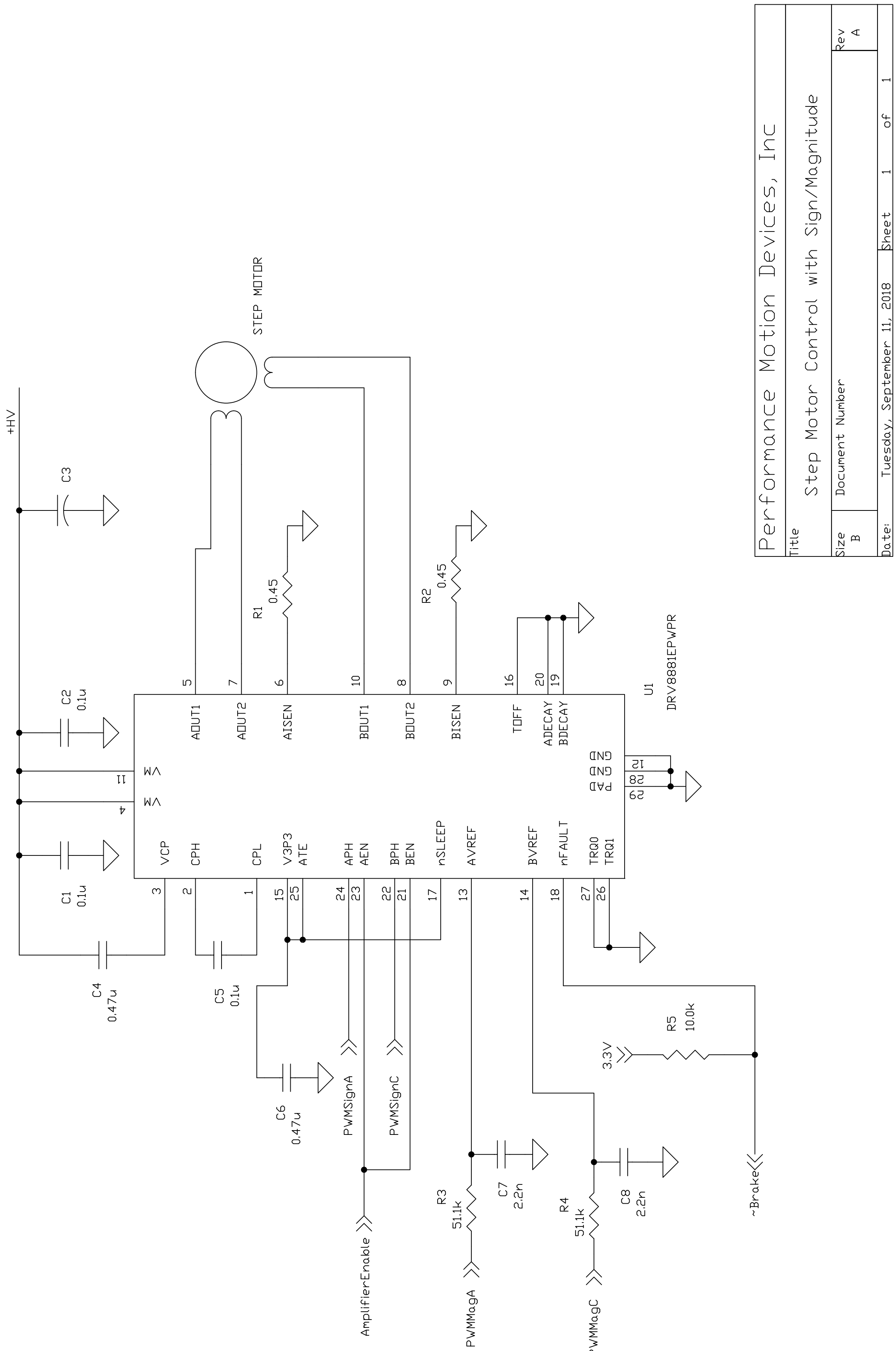



Figure 15-8: Step Motor Control with Sign/ Magnitude Signal

# 15.8 Interfacing Juno ICs With A Multi-Axis Magellan IC

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*.

## 15.8.1 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 15.7.3, "Step Motor Drive with 5A Current Rating" for more details.

## 15.8.2 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 15.7.3, "Step Motor Drive with 5A Current Rating" for more details.

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

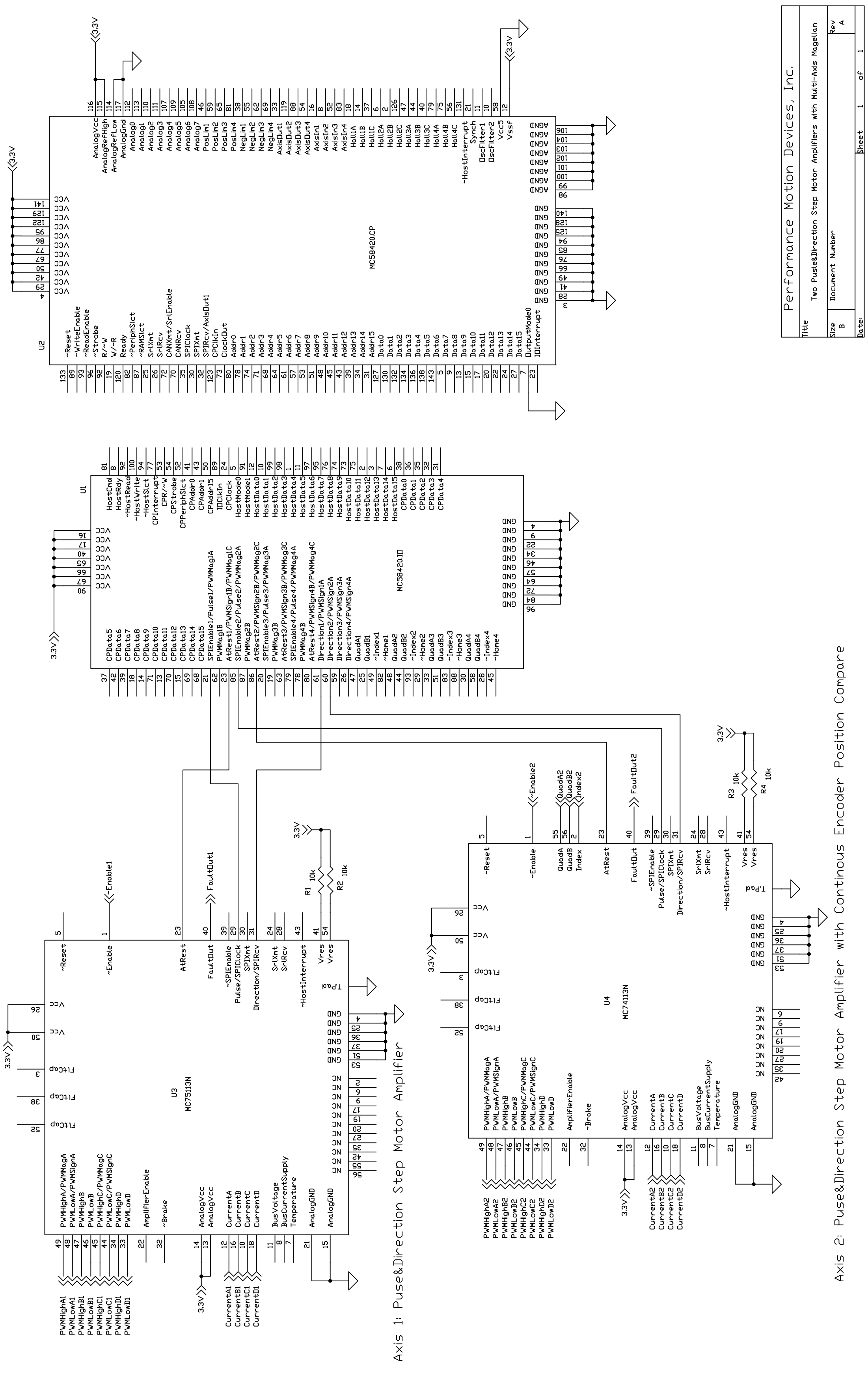



**Figure 15-9: Two-Axis Step Motor Drive With Multi-Axis Magellan**

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