NEC

User's Manual

Low-Voltage Power Module For Motor Control

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CAUTION

This is a Test- and Measurement equipment with possibility to be significantly altered by user through hardware enhancements/modifications and/or test or application software. Thus, with respect to Council Directive 89/336/EEC (Directive on compliance with the EMC protection requirements), this equipment has no autonomous function. Consequently this equipment is not marked by the CE-symbol.

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NOTES FOR CMOS DEVICES

① **VOLTAGE APPLICATION WAVEFORM AT INPUT PIN**

Waveform distortion due to input noise or a reflected wave may cause malfunction. If the input of the CMOS device stays in the area between V_{IL} (MAX) and V_{IH} (MIN) due to noise, etc., the device may malfunction. Take care to prevent chattering noise from entering the device when the input level is fixed, and also in the transition period when the input level passes through the area between V_{IL} (MAX) and V_{IH} (MIN).

② **HANDLING OF UNUSED INPUT PINS**

Unconnected CMOS device inputs can be cause of malfunction. If an input pin is unconnected, it is possible that an internal input level may be generated due to noise, etc., causing malfunction. CMOS devices behave differently than Bipolar or NMOS devices. Input levels of CMOS devices must be fixed high or low by using pull-up or pull-down circuitry. Each unused pin should be connected to V_{DD} or GND via a resistor if there is a possibility that it will be an output pin. All handling related to unused pins must be judged separately for each device and according to related specifications governing the device.

③ **PRECAUTION AGAINST ESD**

A strong electric field, when exposed to a MOS device, can cause destruction of the gate oxide and ultimately degrade the device operation. Steps must be taken to stop generation of static electricity as much as possible, and quickly dissipate it when it has occurred. Environmental control must be adequate. When it is dry, a humidifier should be used. It is recommended to avoid using insulators that easily build up static electricity. Semiconductor devices must be stored and transported in an anti-static container, static shielding bag or conductive material. All test and measurement tools including work benches and floors should be grounded. The operator should be grounded using a wrist strap. Semiconductor devices must not be touched with bare hands. Similar precautions need to be taken for PW boards with mounted semiconductor devices.

④ **STATUS BEFORE INITIALIZATION**

Power-on does not necessarily define the initial status of a MOS device. Immediately after the power source is turned ON, devices with reset functions have not yet been initialized. Hence, power-on does not guarantee output pin levels, I/O settings or contents of registers. A device is not initialized until the reset signal is received. A reset operation must be executed immediately after power-on for devices with reset functions.

⑤ **POWER ON/OFF SEQUENCE**

In the case of a device that uses different power supplies for the internal operation and external interface, as a rule, switch on the external power supply after switching on the internal power supply. When switching the power supply off, as a rule, switch off the external power supply and then the internal power supply. Use of the reverse power on/off sequences may result in the application of an overvoltage to the internal elements of the device, causing malfunction and degradation of internal elements due to the passage of an abnormal current.

The correct power on/off sequence must be judged separately for each device and according to related specifications governing the device.

⑥ **INPUT OF SIGNAL DURING POWER OFF STATE**

Do not input signals or an I/O pull-up power supply while the device is not powered. The current injection that results from input of such a signal or I/O pull-up power supply may cause malfunction and the abnormal current that passes in the device at this time may cause degradation of internal elements.

Input of signals during the power off state must be judged separately for each device and according to related specifications governing the device.

For further information, please contact:

NEC Electronics Corporation
1753, Shimonumabe, Nakahara-ku,
Kawasaki, Kanagawa 211-8668,
Japan
Tel: 044-435-5111
http://www.necel.com/

[America]

NEC Electronics America, Inc.
2880 Scott Blvd.
Santa Clara, CA 95050-2554, U.S.A.
Tel: 408-588-6000
800-366-9782
http://www.am.necel.com/

[Europe]

NEC Electronics (Europe) GmbH
Arcadiastrasse 10
40472 Düsseldorf, Germany
Tel: 0211-65030
http://www.eu.necel.com/

Hanover Office
Podbielskistrasse 166 B
30177 Hannover
Tel: 0 511 33 40 2-0

Munich Office
Werner-Eckert-Strasse 9
81829 München
Tel: 0 89 92 10 03-0

Stuttgart Office
Industriestrasse 3
70565 Stuttgart
Tel: 0 711 99 01 0-0

United Kingdom Branch
Cygnus House, Sunrise Parkway
Linford Wood, Milton Keynes
MK14 6NP, U.K.
Tel: 01908-691-133

Succursale Française
9, rue Paul Dautier, B.P. 52180
78142 Velizy-Villacoublay Cédex
France
Tel: 01-3067-5800

Sucursal en España
Juan Esplandiu, 15
28007 Madrid, Spain
Tel: 091-504-2787

Tyskland Filial
Täby Centrum
Entrance S (7th floor)
18322 Täby, Sweden
Tel: 08 638 72 00

Filiale Italiana
Via Fabio Filzi, 25/A
20124 Milano, Italy
Tel: 02-667541

Branch The Netherlands
Steijgerweg 6
5616 HS Eindhoven
The Netherlands
Tel: 040 265 40 10

[Asia & Oceania]

NEC Electronics (China) Co., Ltd
7th Floor, Quantum Plaza, No. 27 ZhiChunLu Haidian
District, Beijing 100083, P.R.China
Tel: 010-8235-1155
http://www.cn.necel.com/

NEC Electronics Shanghai Ltd.
Room 2509-2510, Bank of China Tower,
200 Yincheng Road Central,
Pudong New Area, Shanghai P.R. China P.C:200120
Tel: 021-5888-5400
http://www.cn.necel.com/

NEC Electronics Hong Kong Ltd.
12/F., Cityplaza 4,
12 Taikoo Wan Road, Hong Kong
Tel: 2886-9318
http://www.hk.necel.com/

Seoul Branch
11F., Samik Lavied'or Bldg., 720-2,
Yeoksam-Dong, Kangnam-Ku,
Seoul, 135-080, Korea
Tel: 02-558-3737

NEC Electronics Taiwan Ltd.
7F, No. 363 Fu Shing North Road
Taipei, Taiwan, R. O. C.
Tel: 02-8175-9600
http://www.tw.necel.com/

NEC Electronics Singapore Pte. Ltd.
238A Thomson Road,
#12-08 Novena Square,
Singapore 307684
Tel: 6253-8311
http://www.sg.necel.com/

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[MEMO]

Preface

Readers

This manual is intented for users who want to understand the functions of the low voltage power module for motor control.

Purpose

This manual presents the hardware manual of the low voltage power module for motor control.

Organization

This system specification describes the following sections:

- Inverter module
- IGBT module
- Opto isolation
- Power supplies
- User connections

Legend

Symbols and notation are used as follows:

Weight in data notation	:	Left is high-order column, right is low order column
Active low notation	:	$\overline{xxx}$ (pin or signal name is over-scored) or /xxx (slash before signal name)
Memory map address:	:	High order at high stage and low order at low stage
Note	:	Explanation of (Note) in the text
Caution	:	Item deserving extra attention
Remark	:	Supplementary explanation to the text
Numeric notation	:	Binary... XXXX or XXXB Decimal... XXXX Hexadecimal... XXXXH or 0x XXXX

Prefixes representing powers of 2 (address space, memory capacity)

K (kilo): $2^{10} = 1024$

M (mega): $2^{20} = 1024^2 = 1,048,576$

G (giga): $2^{30} = 1024^3 = 1,073,741,824$

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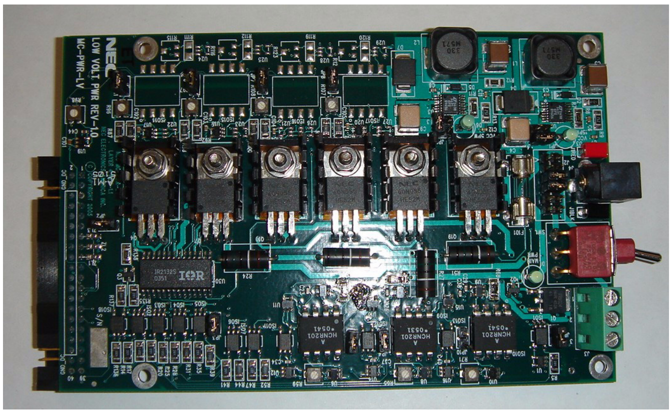
Chapter 1 Introduction

The low-voltage motor control power module from NEC Electronics is designed to drive low-voltage, three-phase, permanent-magnet asynchronous-current (PMAC) motors such as brushless DC (BLDC) and permanent-magnet sinusoidal motors (PMSM). The module contains a six-transistor power MOSFET H-bridge, driver circuits, optical isolation and feedback signal conditioning circuits.

Figure 1-1: Low-Voltage Motor Control Power Module



To evaluate a complete PMAC motor drive system, you need three parts that are all available from NEC Electronics:

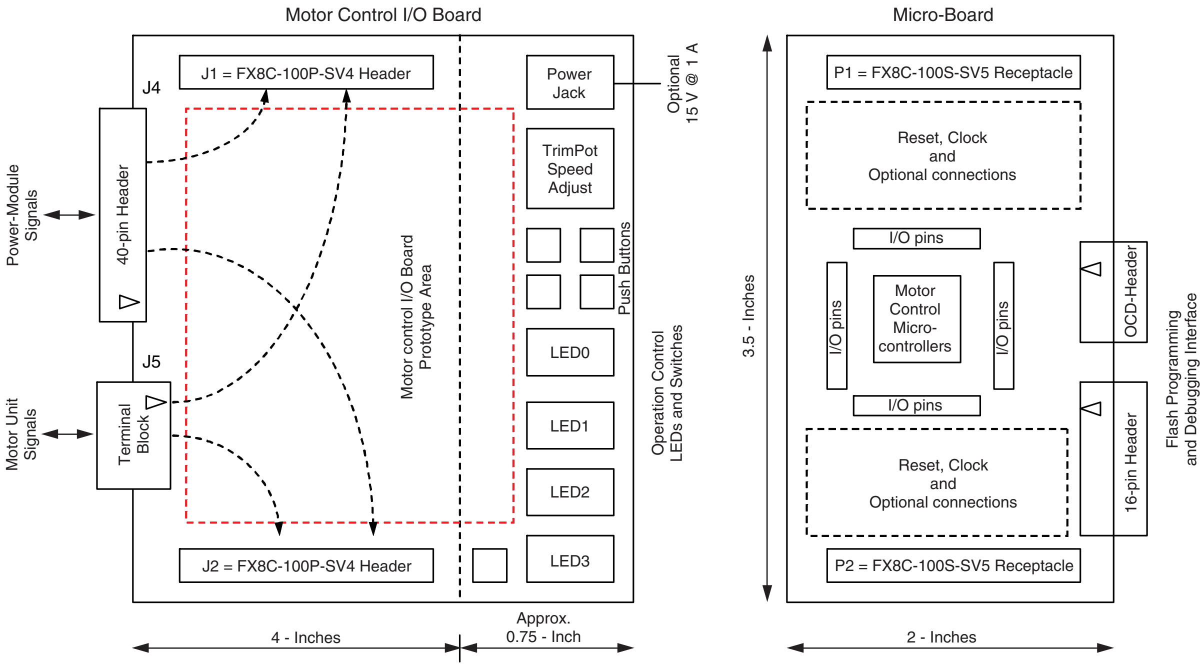
- A micro-board containing a motor-control microcontroller
- A motor control I/O board (MC-I/O-GENERAL board) that interfaces between the micro-board and the power module
- The low-voltage power module containing the power MOSFETs

By adding a low-voltage PMAC motor and software packages that support various driving methods and control algorithms, you can quickly explore the principals of three-phase PMAC motor control as well as jump start your application development with minimum effort.

1.1 Micro-Board Connection to Motor Control I/O Board

The micro-board contains an NEC Electronics microcontroller that supports three-phase motor-control functions. NEC Electronics offers a series of dedicated motor control microcontrollers ranging from 8-bit CISC-type devices to high-performance 32-bit RISC products. Please contact your NEC Electronics America sales representative to obtain a list of available choices.

Figure 1-2: Development Boards for Motor Control

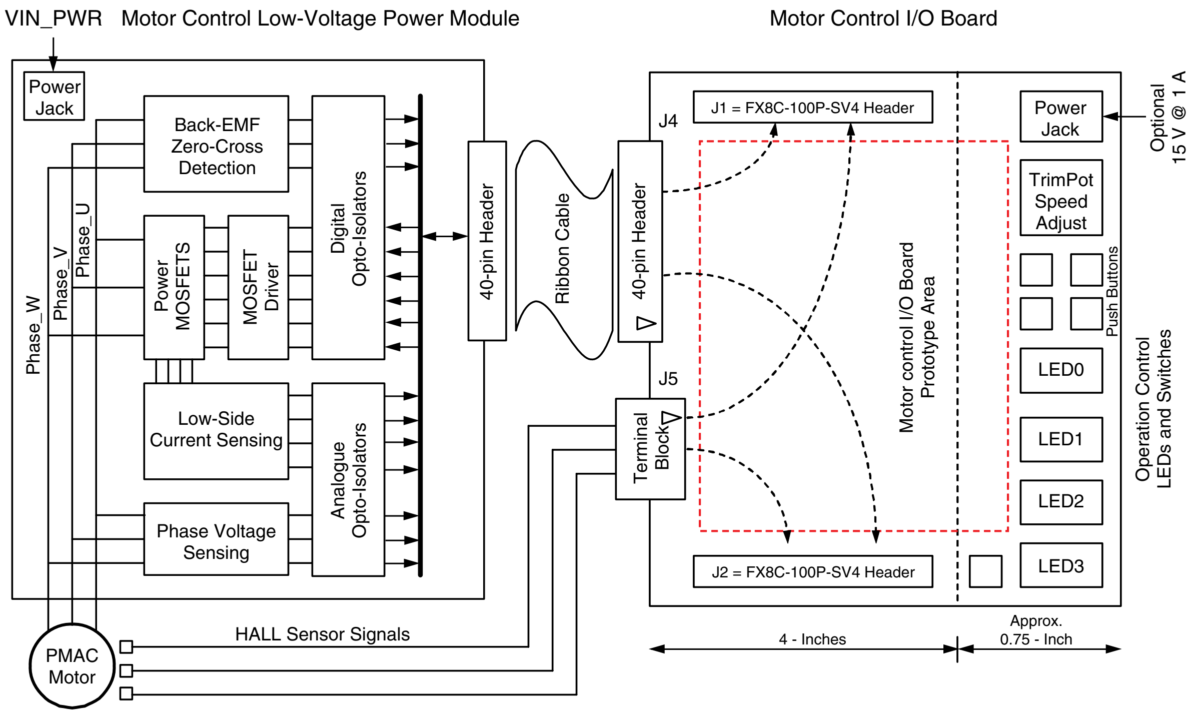


The micro-board connects to the motor-control I/O board via two 100-pin connectors. All MCU signals connect to the I/O board hardware or prototype area.

The I/O board interfaces between the motor-control power module and the microboard containing the microcontroller.

1.2 Low-Voltage Power Module Connection to Motor Control I/O Board

Figure 1-3: Development Board Connections



The low-voltage motor control power module connects to the I/O board through a 40-pin ribbon cable. This cable carries pulse-width modulation (PWM) signals from the MCU, as well as motor-control and sensing signals to the MCU; all of these signals pass through the I/O board. When Hall sensors are used, connect their signal lines directly to the terminal block J5 on the I/O board.

The low-voltage motor control power module has its own power terminals. It is best to use these terminals, although you can supply the module with up to 15V/2A power through the I/O board. Use only one of these methods of supplying power as described in sections 3.3.1 and 3.3.2 of this manual.

1.3 Signal Definitions

Table 1-1: 40-Pin Header Signals

Category	Signal Name	Signal Description
System power	VCC_15V	Power input to MC I//O board
	VCC_5V	Regulated 5V power
PWM signals	HI_U, HI_V, HI_W: high-side FET drive LO_U, LO_V, LO_W: low-side FET drive	PWM signals from CPU
Back-EMF comparator	CMPU, CMPV, CMPW	Back-EMF comparator signals from power mod-ule connected to interrupt inputs of CPU
Current sense signals	ANI0_IU, ANI1_IV, ANI2_IW ISHUNT	Motor phase current: low-side current detection Motor shunt current: low-side current detection Connected to A/D converter inputs of CPU
Safety control signals	PX_ITRIP	Over-current detection signal from power module Connected to Port_X of CPU for further action
	TRIP	CPU-generated signal Turn-off power for power MOSFETs
Phase-voltage detection	V-U, V-V, V-W	Motor phase voltage-detection signal Connected to A/D converter inputs of CPU
Power module temperature	ANI7_TMP	Power-module temperature-sense signal Connected to A/D converter input of CPU

Chapter 2 Specifications

The motor-control low-voltage power module has on-board hardware for controlling and operating PMAC motors.

Low-voltage power module specification:

- System power
  - Power jack: up to 24 VDC at 4A
  - External power terminal: up to 24 VDC at 4A
  - VCC_15V from MC I/O board
  - ON/OFF power switch
  - 4A fast-acting fuse
  - Power-select jumper
- 40-pin ribbon cable that carries signals to/from motor control I/O board
- 3-pin terminal block: Phase_U, Phase_V and Phase_W signal connections to PMAC motor terminals
- Opto-coupler isolation that physically separates high- and low-voltage plane
  - Digital opto-isolators that isolate and couple digital signals
  - Analog opto-isolators signals isolate and couple analog signals
  - Ground-shorting jumpers: high- and low-voltage GND-plane shorting jumpers
  - Connect two power planes when motor power is supplied from the MC-I/O board VCC_15V
  - Remove GND-shorting jumpers when motor power is supplied from either the external power jack or the external power terminal
- Board size of 3.5 × 5.5 inches (W × L)

2.1 Physical Placement of Components

Figure 2-1: Power Module Layout

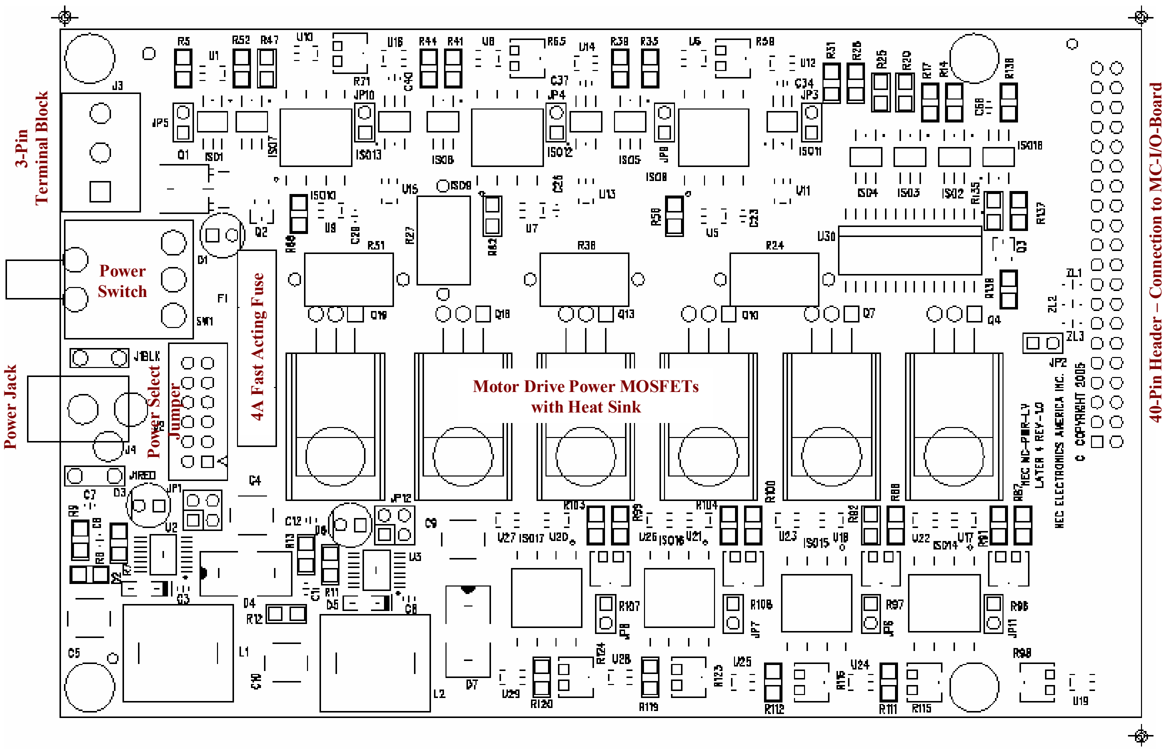


Table 2-1: Default Jumper Settings

Jumper	Jumper Setting	Functions	Descriptions
JP1	2–4	Selects 15 volts	Selects power module VCC_15PW from I/O module VCC_15V
JP2–JP11	Short	GND-shorting jumpers	Connects high-voltage GND plane to low-voltage GND plane
JP12	2–4	Selects 5 volts	Select power module VCC_5PW from I/O module VCC_5V

2.2 Operating Modes

2.2.1 Normal operation

The low-voltage power module operates as part of a BLDC or PMAC motor control system when connected to a motor-control I/O board that has a micro-board attached.

2.2.2 Debugging configuration

The methods used to debug the motor controller depend on the micro-board you use. Consult your micro-board user's manual for details.

2.3 On-Board Components

Table 2-2: Power Inputs

Power Terminal	Function	Description
J4	Main power jack	24 VDC at 4A from user-supplied wall-mount power supplies
J1RED/J1Black	External power input	User-supplied power-input terminal; two single-jacks (red and black)

Table 2-3: Power Terminal Connections

Power Terminal	Function	Connections	Description
J2	Power source select	1–2 and 3–4	Power from user-supplied external power J1RED/ J1BLK
		5–6 and 7–8	VCC_15V coming from I/O board
		9–10 and 11–12	Power from main power jack J4

When selecting power from the motor control I/O board, you must set JP1 and JP12 as shown in the table.

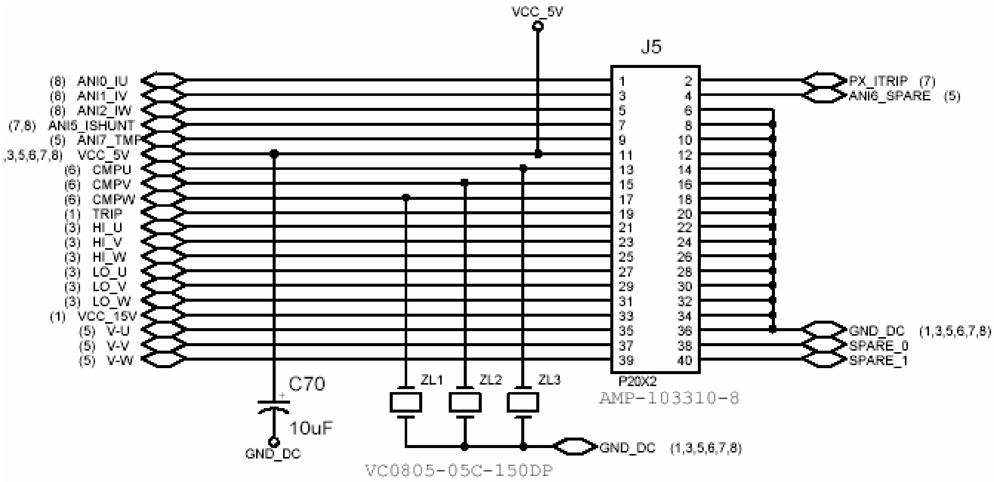
Table 2-4: Power Selection Jumpers

Jumper	Function	Jumper Setting	Description
JP1	15VDC power source select	1–2	From power module to VCC_15V MC-I/O board
		3–4	From power module to VCC_15PW for power module
		2–4	From MC-I/O board to power module
JP12	5VDC power source select	1–2	From power module to VCC_5V MC-I/O board
		3–4	From power module to VCC_5PW for power module
		2–4	From MC-I/O board to power module

2.3.1 40-pin ribbon cable header

The 40-pin ribbon cable connects motor-control and motor feedback signals between the power module and the I/O board. The signals on the cable header connect to the MCU after passing through isolation and signal conditioning circuits.

Figure 2-2: 40-Pin Header Signals



2.3.2 3-pin terminal block

A 3-pin terminal block connects Phase_U, Phase_V and Phase_W signals to the PMAC motor. However, other signals from the motor such as those from the Hall sensor or shaft encoder can be connected directly to the MC-I/O board (J5) and from there to the CPU.

Figure 2-3: 3-Pin Terminal Signals

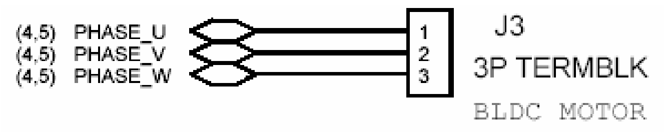


Table 2-5: Solder Blob Connections

Solder Blob	Function	SB Connection	Description
SB16 and SB18	IU_PW to ANI0_IU (current sense at Phase_U)	Connect SB16	Use optional analog opto-isolator to connect IU_PW to ANI0_IU
		Connect SB18	IU_PW connects directly to ANI0_IU
SB17 and SB19	IV_PW to ANI1_IV (current sense at Phase_V)	Connect SB17	Use optional analog opto-isolator to connect IV_PW to ANI1_IV
		Connect SB19	IV_PW connects directly to ANI1_IV
SB20 and SB22	IW_PW to ANI2_IW (current sense at Phase_W)	Connect SB20	Use optional analog opto-isolator to connect IW_PW to ANI2_IW
		Connect SB21	IW_PW connects directly to ANI2_IW
SB21 and SB23	ISHUNT_PW to ANI5_ISHUNT	Connect SB21	Use optional analog opto-isolator to connect ISHUNT_PW to ANI5_ISHUNT
		Connect SB23	Bypass analog opto-isolator
SB13	Phase_U voltage sense	Connect SB13	Analog opto-isolator output to ANI6_SPARE
		Open SB13	Analog opto-isolator output to V-U only
SB14	Phase_V voltage sense	Connect SB14	Analog opto-isolator output to ANI7_TMP
		Open SB14	Analog opto-isolator output to V-V only
SB15	Phase_W voltage sense	Connect SB15	Analog opto-isolator output to ANI3_TEMP
		Open SB15	Analog opto-isolator output to V-W only
SB24 and SB25	Current sense by IR2132S (low-side current sense)	Connect SB24	Disable motor over-current sense by IR2123S
		Connect SB25	Use IR2132S motor over-current sense feature
SB26 and SB27	PX_TRIP signal to MCU	Connect SB26	Use ANI5_ISHUNT to PX_TRIP
		Connect SB27	Use FAULT_B generated by IR2132S to PX_ITRIP

2.3.3 Current sense output connections

The IU_PW, IV_PW and IW_PW current-sense outputs connect to A/D converter inputs through optional analog opto-isolators or are bypassed.

2.3.4 Phase-voltage sense

The phase-voltage sense outputs connect to V-U, V-V and V-W. Select these signals on the MC-I/O board and connect them to the MCU A/D converter inputs if supported. SB13, SB14 and SB15 provide optional connections to MCU A/D converter inputs.

Note: ANI3_TEMP signal through SB15 is not connected to the 40-pin MC-I/O-Board connector J5. To connect the Phase_W voltage-sense output V-W to ANI3_TEMP on the MC-I/O board, use the single-post J_ANI3 terminal on the power module. Connect J_ANI3 with a jumper wire to J5-8 on the MC-I/O board. Make sure that no other signals are connected to J5-8.

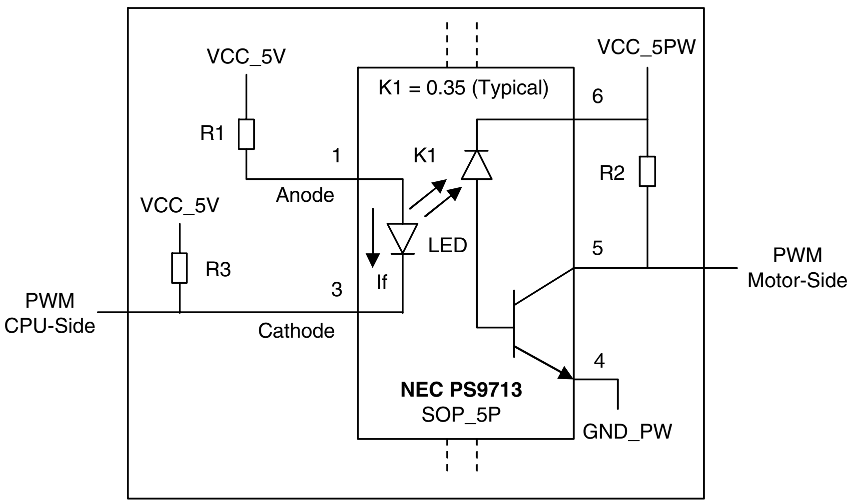
Chapter 3 Appendix

This section describes the power module's signals and functions as well as its circuit implementation.

3.1 Digital-Signal Isolation

A PMAC motor requires the power-MOSFET H-bridge to switch bus voltages as high as 24 V_{DC}. To turn on the high-side MOSFETs, their gate voltage has to be 10 to 15V higher than their source potential floating at half the DC bus voltage. To prevent these high voltages from affecting the CPU and controller, a digital-signal isolation circuit on the power module physically isolates the motor-side signals from the signals on the CPU side.

Figure 3-1: Digital Isolation Circuit



Opto-couplers provide the physical separation between input and output. This galvanic isolation barrier provides isolation voltage protection up to approximately 2500V, yet the output closely tracks the input signal. The power module uses digital isolation for the following signals:

- PWM signals from the MCU to the power module
- Back-EMF zero-cross comparator outputs to the MCU

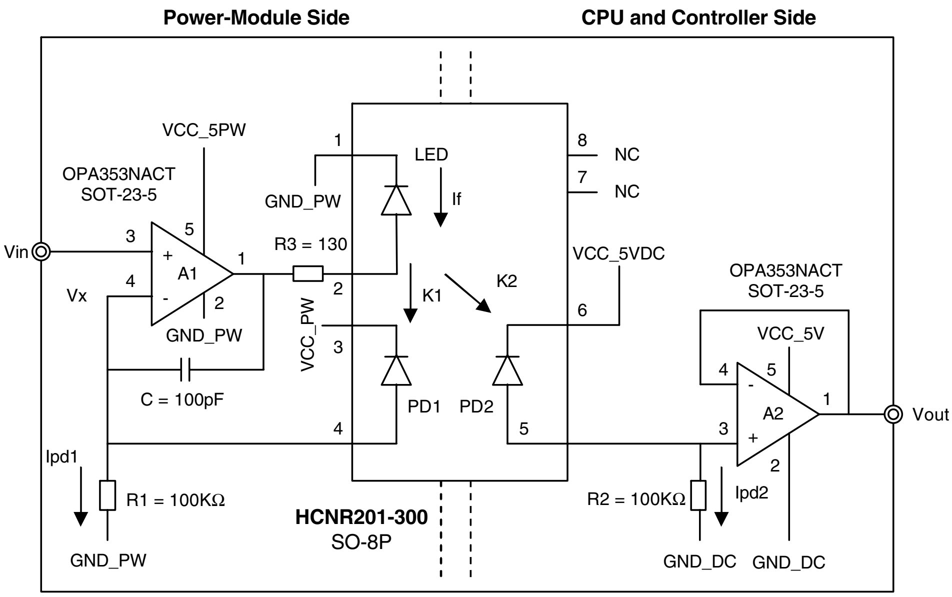
3.2 Analog-Signal Isolation

For analog signal isolation, the power module provides a circuit that uses input photo detectors in a servo feedback loop. The figure below shows this circuit with an Agilent HCNR201-300 device. In this circuit, op amps control the current to LEDs, which provide a proportional amount of light to internal photodiodes. The input feedback loop adjusts the LED current to reflect any changes in the input. The output photodiode converts the LED light output into current, which a voltage-follower output amplifier then converts back into a suitable voltage.

The relationship between the input voltage (VIN) and output voltage (VOUT) is:

- VOUT = (R2/R1) * VIN
- If R1 = R2, then the output voltage closely follows the input voltage.

Figure 3-2: Analog Isolation Circuit

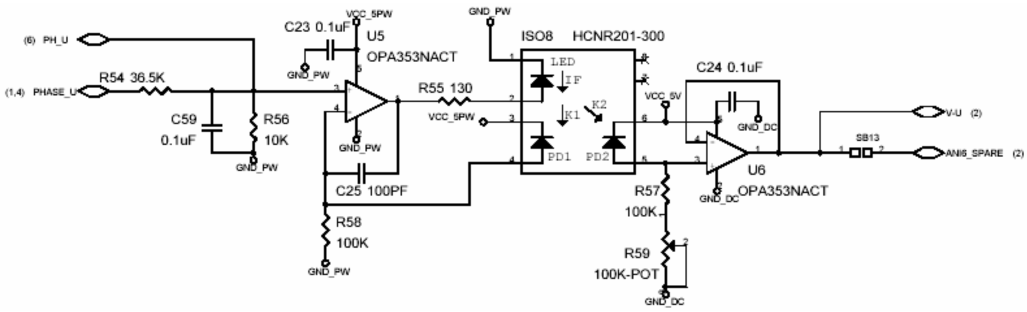


VOUT = VIN (R2/R1)

An adjustable gain is achieved by using a potentiometer in series with R2.

The power module combines the resistor at the output side (R2) with a potentiometer so that you can adjust the (R2/R1) gain. Combined R2 value allows a gain adjustment of R2/R1. Consider, for example, the phase-voltage detect circuit diagram shown below.

Figure 3-3: Adjustable Analog Isolation Circuit



Potentiometer R59, on the output side, allows you to adjust the amplifier gain. This adjustability is particularly convenient for small input voltages. The power module implements a number of other gain-adjustment potentiometers:

- Phase-voltage detect circuit

- Phase_U generating V-U signal	R59
- Phase_V generating V-V signal	R65
- Phase_W generating V-W signal	R71

- Current-sense outputs to MCU A/D inputs through analog isolation

- Phase_U current sense	IU_PW	R115
- Phase_V current sense	IV_PW	R116
- Phase_W current sense	IW_PW	R123
- SHUNT current sense	ISHUNT_PW	R124

3.3 Note on Analog Signal Isolation

By default, analog signal isolators for low-side current sensing ISO14–ISO17 are optional, and the low-voltage power module does not include them. The module does provide locations for these analog isolators; you can populate these locations with suitable components if your application requires total signal isolation. Most applications do not require such isolation because normal current levels are low, and failures that would result in high currents are quite unlikely.

To see why, consider that the power module provides two separate ground planes, one for the 5VDC CPU side (GND_DC) and one for the higher-voltage motor-side circuits (GND_PWR). By default, these ground planes are connected together with jumper blocks J2 through J11 (JP2–JP11) and analog isolators ISO14-ISO17 are bypassed by solder blobs SB18–SB23. Low-side current sensing by voltage-drop measurements on two 0.05-ohm resistors is referenced to GND_PWR. A fast-acting 4A fuse limits both the motor current and the current through the low-side resistors. In normal operating conditions (when the motor draws less than 4A), the voltage drop on the current-sensing resistors is less than 400 mV, and analog isolation is not necessary.

The maximum supply voltage for the power module is 24DC, and this voltage can be present on the sensing resistor terminals if both upper and lower MOSFET transistors conduct at the same time or both fail. Simultaneous conduction is prevented by the dedicated cross-conduction prevention circuits inside the IR2132S driver IC, and it is very unlikely that both high-side and low-side transistors will fail simultaneously.

If you do want to install analog signal isolators, however, populate module locations ISO14–ISO17, and remove solder blobs SB18–SB23 and jumpers JP2–JP11.

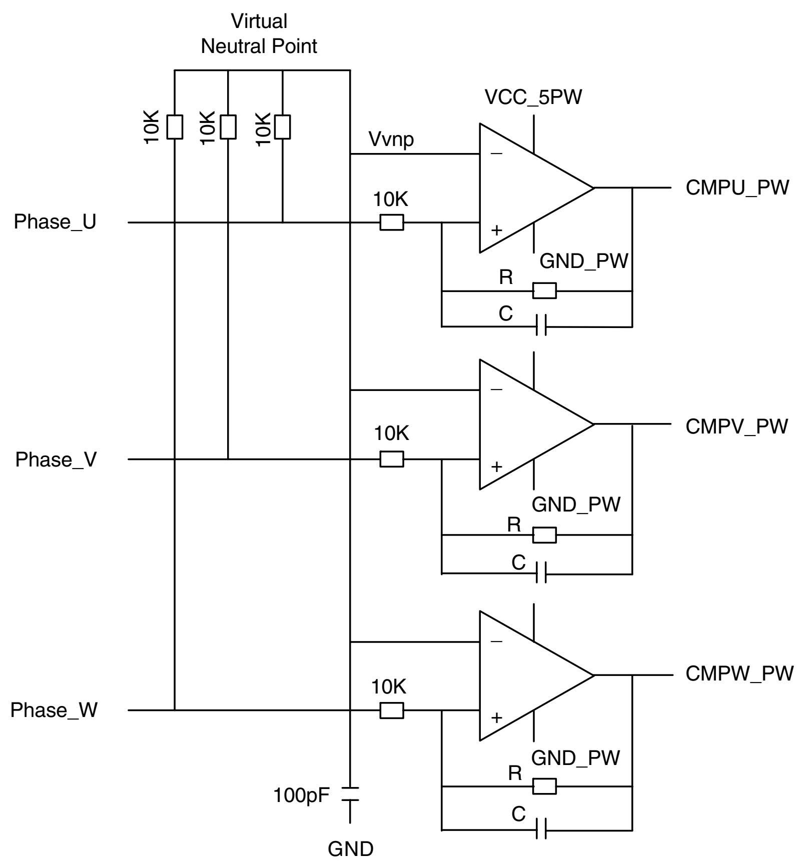
3.4 Back-EMF Zero-Cross-Detection Comparator

The low-voltage power module provides back-EMF comparators for sensorless motor control. Back-EMF is a voltage induced in a motor's stator windings by the permanent-magnet rotor. During each of the six commutation periods in trapezoidal drives, only two stator windings are energized at a time, leaving the third one floating. The back-EMF induced in this floating winding can be detected and used to determine the rotor position.

More precisely, the zero-crossing point of the back-EMF signal is detected. The low-voltage power module includes three comparators for this task, configured as shown below. The back-EMF signal from each motor phase passes through a resistor divider and is then compared with a virtual neutral point created by connecting three resistors together (see the figure). With this configuration, the virtual neutral-point potential is at half the DC bus voltage—the threshold level at which the comparator output changes from Low to High and vice versa.

The back-EMF signal is close to a sinusoidal wave with zero value at half the DC bus voltage. The comparator circuit compares the signal amplitude with the virtual neutral point, and at zero-crossing, the comparator output changes state.

Figure 3-4: Back-EMF Comparator Circuit

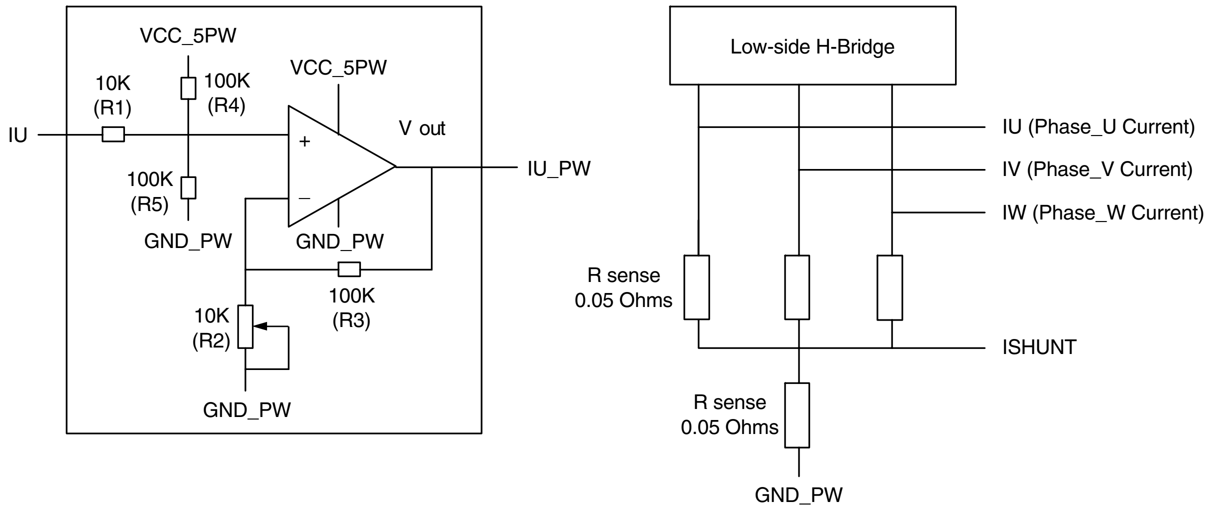


After the CMPU_PW, CMPV_PW and CMPW_PW signals pass through the digital opto-isolation circuits, they become CMPU, CMPV and CMPW, respectively, and connect to the MCU's interrupt inputs.

3.5 Current Sense and MCU Interface

Current measurement, current limiting and over-current sensing are often critical to the operation of motor-control systems. Control feedback loops use measured current values to regulate a motor's mechanical output torque. Current limitation prevents the current in the motor windings from exceeding the set limits, while over-current sensing triggers a fast disabling of the MCU PWM driving pins as well as a total shut-down of the power stage. The low-voltage power module employs low-side current-sense circuits to implement all of these capabilities.

Figure 3-5: Current-Sense Circuit



The diagram shown above is for Phase_U current sensing. The same circuit is used for sensing Phase_V, Phase_W and ISHUNT currents. The potentiometer allows you to adjust the gain of the amplifier. Phase voltages IU, IV and IW are very small signals, typically 10 to 100 mV. Resistors R4 and R5 center the amplifier's output to the midpoint of the supply voltage.

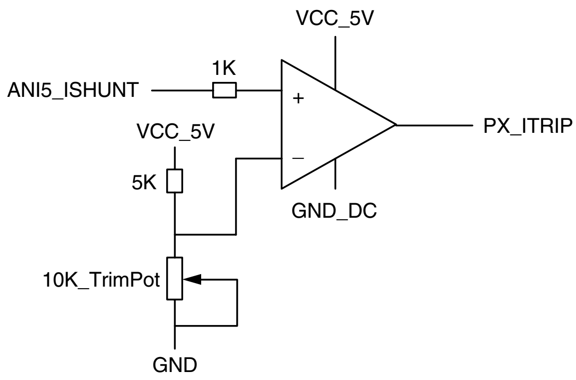
3.6 Over-Current Protection

The power module's ISHUNT current-detect circuit detects the voltage level at the low side of a motor's windings. The ISHUNT voltage is a function of the current passing through a sense resistor.

The ISHUNT current-detect signal becomes ANI5_ISHUNT after it is amplified by Op amp U20 and connects to an MCU A/D converter input through the 40-pin connector on the MC-I/O-Board. The MCU software can monitor the A/D converter input and take appropriate current-limiting or soft-shut-down action if the current exceeds a set limit.

For a fast hardware-based shutdown, use the on-board comparator U19 as shown below. If ANI5_ISHUNT exceeds the threshold value preset by the 10K TrimPot, the comparator output sets the PX_ITRIP signal, which is input to the MCU hardware shutdown pin. Upon receiving this input signal, the MCU immediately switches all six PWM outputs to a high-impedance state, disabling the motor drive.

Figure 3-6: Trip Circuit for Hardware Shutdown

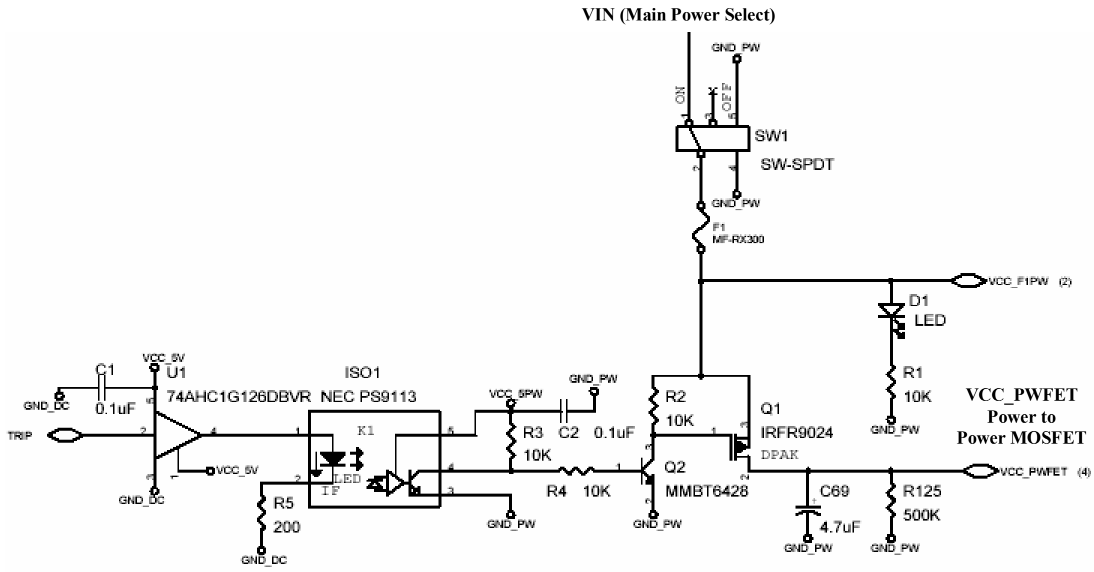


As an extra protection against motor over-current (due to a locked rotor, for example), the current-sensing signal ISHUNT also connects to the over-current-sensing circuit of the IR2132S driver IC. With R127=20K and R128=10K, the driver will shut down the outputs to the power MOSFETs if the current exceeds 3.3A.

3.7 Safety Shut-Down

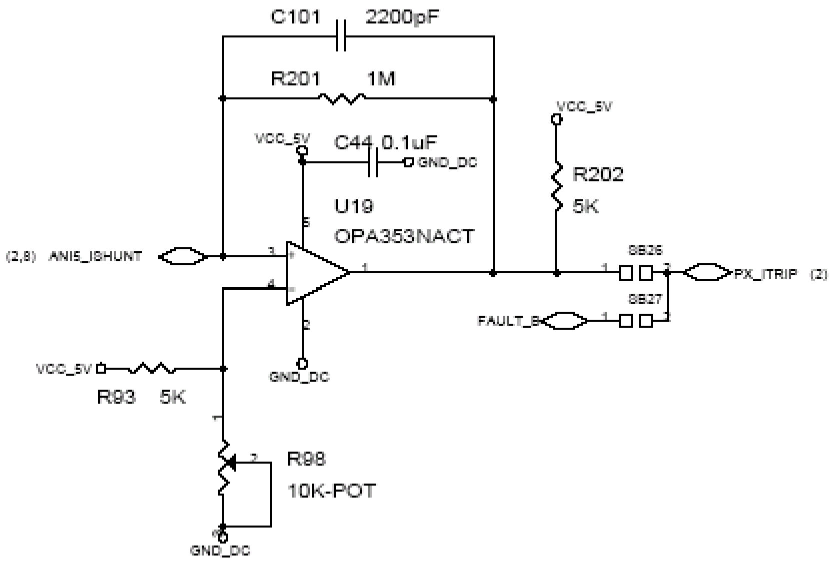
Whether based on detection of an over-current limit ISHUNT voltage or other safety criteria, the MCU may shut-down the power stage by issuing the TRIP signal as shown below. When the TRIP signal goes High, Q2 turns off, turning off Q1 and thus turning off power to the power MOSFETs.

Figure 3-7: Safety Shutdown Circuit



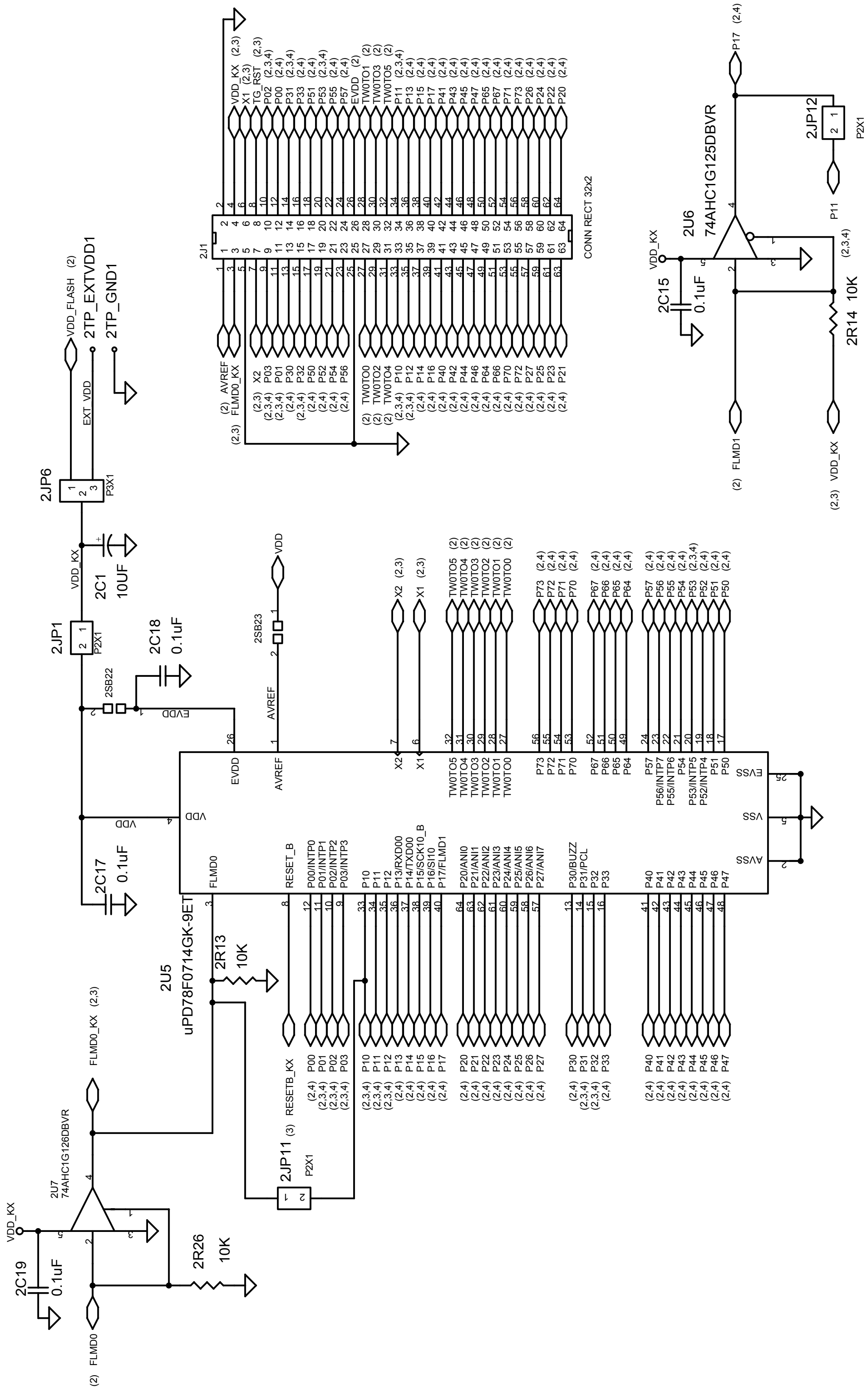
As described above, the power module includes an IR2132S 3-phase bridge driver for the power MOSFETs drive, and this component's over-current detection circuit can also monitor the motor over-current through the ISHUNT signal if SB24 is connected and SB25 is open. When ISHUNT exceeds the preset level, the bridge driver shuts down its outputs and sets a flag on its FAULT_B output pin. You can select the FAULT_B signal to connect to PX_ITRIP as an option by connecting solder blob SB27 and opening SB26 at the output of U19.

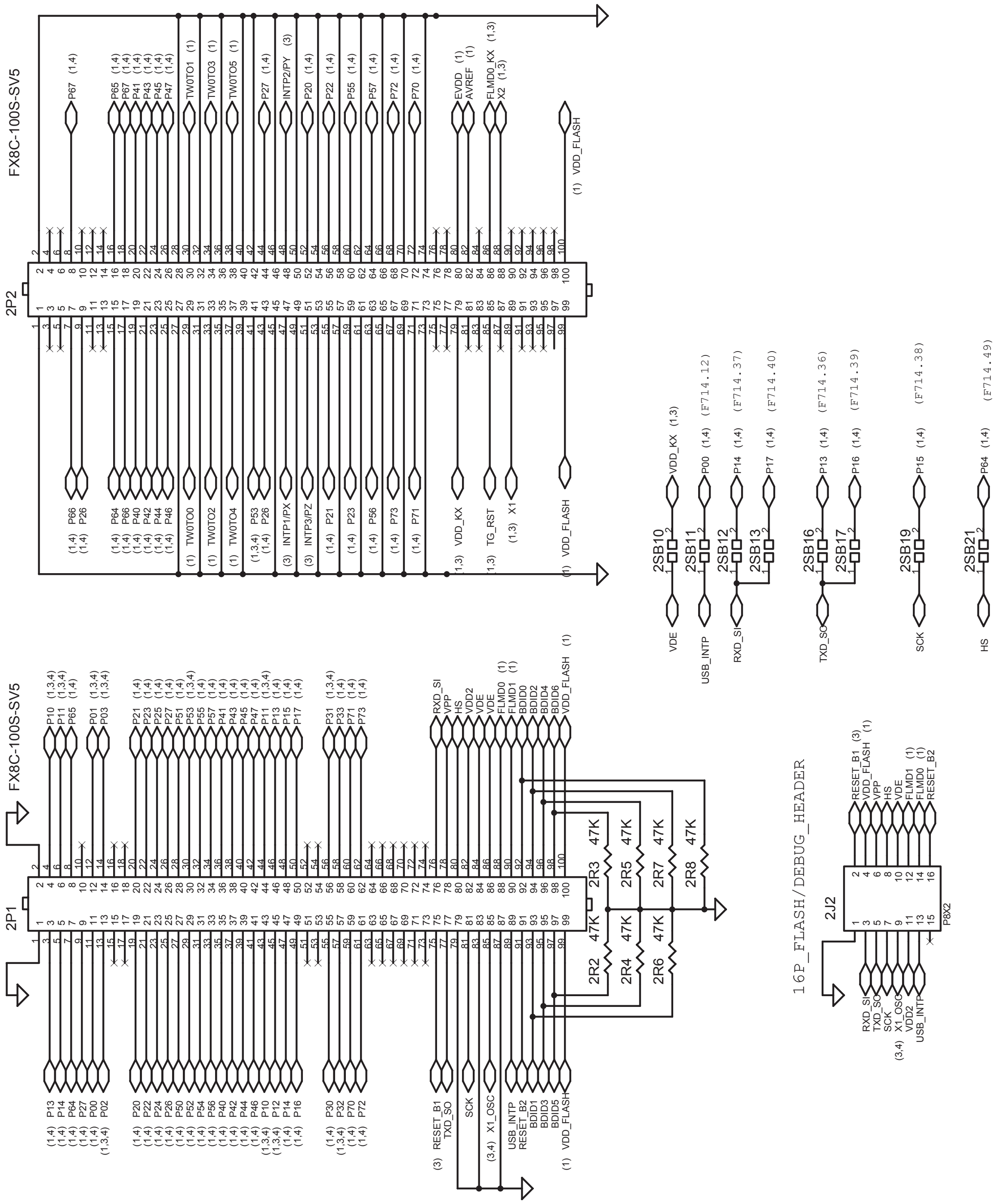
Figure 3-8: Safety Shutdown Selection Circuit

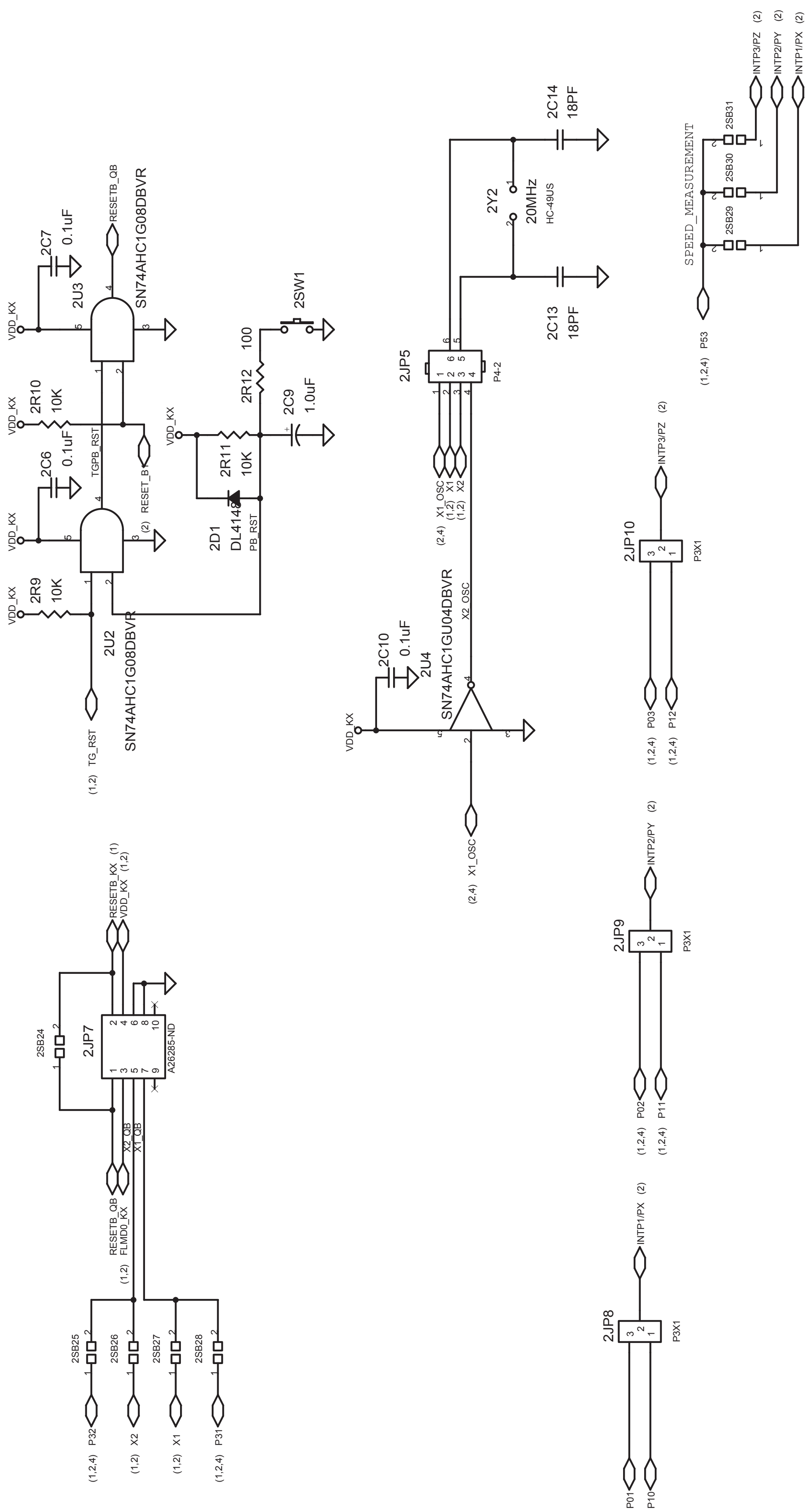


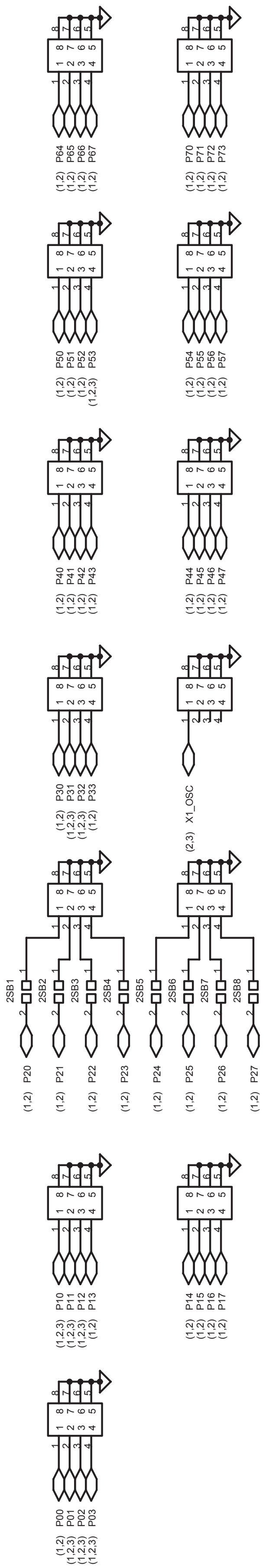
[MEMO]

Chapter 4 Schematics




FX8C-100S-SV5
2P1
FX8C-100S-SV5
2P2
16P_FLASH/DEBUG_HEADER
2J2
P8X2
2R2 47K
2R3 47K
2R4 47K
2R5 47K
2R6 47K
2R7 47K
2R8 47K
2SB10
2SB11 (F714.12)
2SB12 (F714.37)
2SB13 (F714.40)
2SB16 (F714.36)
2SB17 (F714.39)
2SB19 (F714.38)
2SB21 (F714.49)


2U2
SN74AHC1G08DBVR
2U3
SN74AHC1G08DBVR
2U4
SN74AHC1GU04DBVR
2R9
10K
2R10
10K
2R11
10K
2R12
100
2C6
0.1uF
2C7
0.1uF
2C9
1.0uF
2C10
0.1uF
2C13
18PF
2C14
18PF
2Y2
20MHz
HC-49US
2D1
DL4148
2SW1
2JP5
P4-2
2JP7
A26285-ND
2JP8
2JP9
2JP10
P3X1
SPEED_MEASUREMENT
VDD_KX
RESETB_QB
RESET_B
TGPB_RST
PB_RST
TG_RST
X1_OSC
X2_OSC
RESETB_KX
FLMD0_KX
X1_QB
X2_QB
INTP1/PX
INTP2/PY
INTP3/PZ
P01
P02
P03
P10
P11
P12
P31
P32
P53
X1
X2
2SB24
2SB25
2SB26
2SB27
2SB28
2SB29
2SB30
2SB31


(1,2) P64
(1,2) P65
(1,2) P66
(1,2) P67
(1,2) P70
(1,2) P71
(1,2) P72
(1,2) P73
(1,2) P50
(1,2) P51
(1,2) P52
(1,2,3) P53
(1,2) P54
(1,2) P55
(1,2) P56
(1,2) P57
(1,2) P40
(1,2) P41
(1,2) P42
(1,2) P43
(1,2) P44
(1,2) P45
(1,2) P46
(1,2) P47
(1,2) P30
(1,2,3) P31
(1,2,3) P32
(1,2) P33
(2,3) X1_OSC
2SB1
2SB2
2SB3
2SB4
2SB5
2SB6
2SB7
2SB8
(1,2) P20
(1,2) P21
(1,2) P22
(1,2) P23
(1,2) P24
(1,2) P25
(1,2) P26
(1,2) P27
(1,2,3) P10
(1,2,3) P11
(1,2,3) P12
(1,2) P13
(1,2) P14
(1,2) P15
(1,2) P16
(1,2) P17
(1,2) P00
(1,2,3) P01
(1,2,3) P02
(1,2,3) P03