Freescale Semiconductor, Inc.

MEMC3PSRHVPSUM/D

Motorola Embedded Motion Control

3-Phase Switched Reluctance High-Voltage Power Stage

User's Manual

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Section 1. Introduction and Setup

1.1 Contents

1.2 Introduction

Motorola’s 3-phase, switched reluctance high-voltage power stage (HV SR power stage) is a 115/230 volt, 180 watt (1/4 horsepower), off-line power stage that is an integral part of Motorola’s embedded motion control series of development tools. The HV SR power stage is supplied in kit number ECPWRHiVSR.

In combination with one of the Embedded Motion Control series control boards and an Embedded Motion Control series optoisolation board, it provides a ready made software development platform for fractional horsepower off-line switched reluctance motors. Feedback signals are provided that allow control with a wide variety of algorithms. In addition, the HV SR power stage includes an active power factor correction (PFC) circuit that facilitates development of power factor correction algorithms.

An illustration of the systems architecture is shown in **Figure 1-1**. A line drawing appears in **Figure 1-2**.

Features of the HV SR power stage are:

- 1-phase bridge rectifier
- Power factor switch and diode
- dc-bus brake IGBT and brake resistors
- 3-phase bridge inverter (6-IGBT's)
- Individual phase and dc bus current sensing shunts with Kelvin connections
- Power stage temperature sensing diodes
- IGBT gate drivers
- Current and temperature signal conditioning
- Board identification processor (MC68HC705JJ7)
- Low voltage on-board power supplies
- Cooling fans

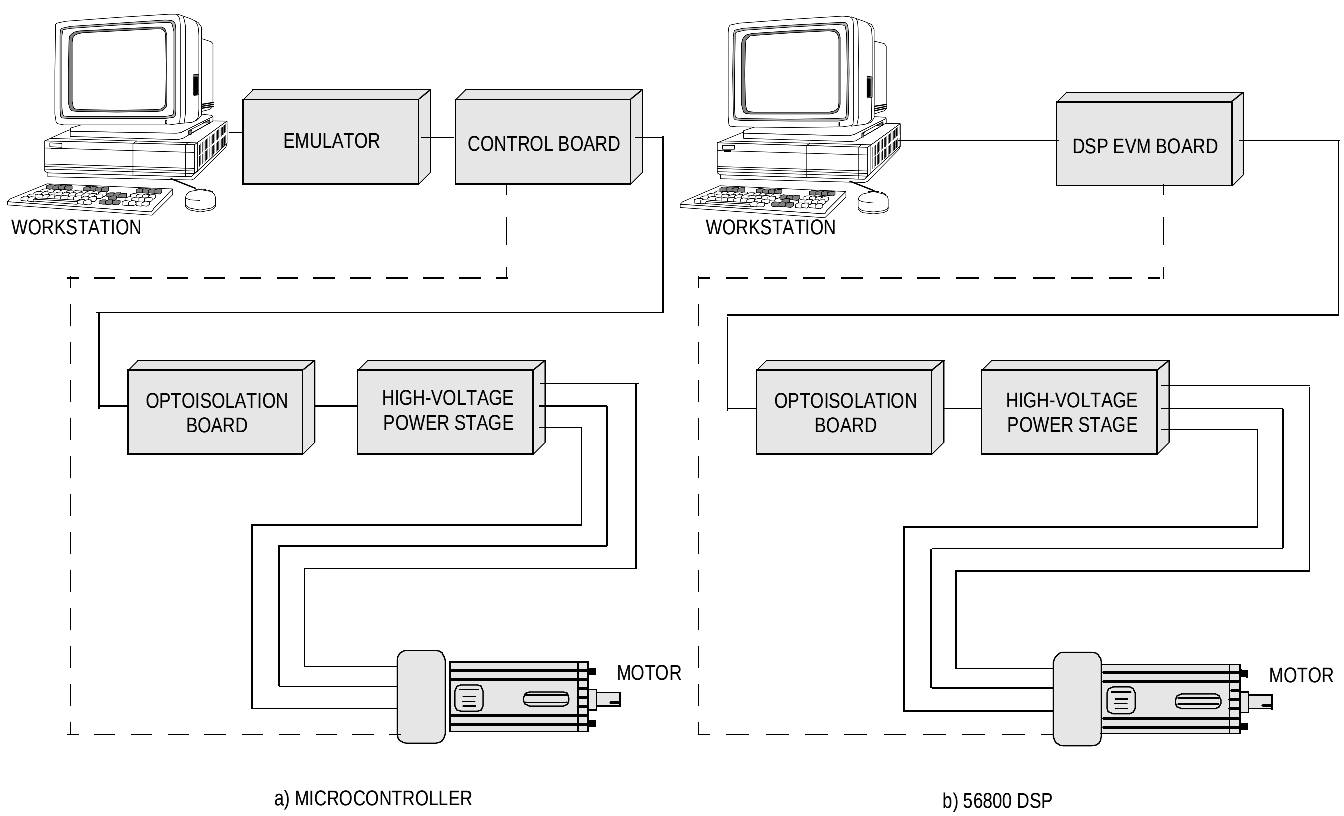


Figure 1-1. Systems' Configurations

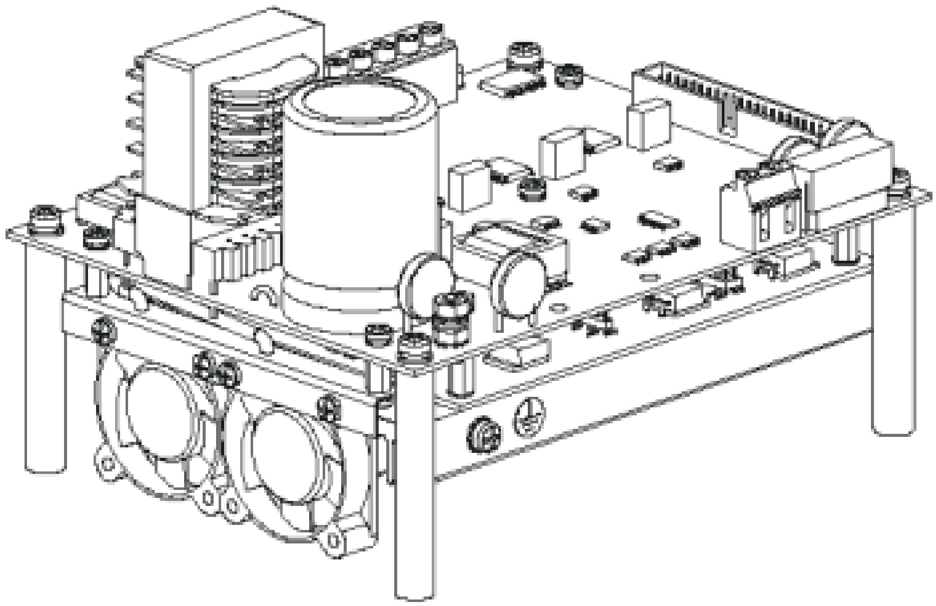


Figure 1-2. 3-Phase Switched Reluctance High-Voltage Power Stage

1.3 About this Manual

Key items can be found in the following locations in this manual:

- Setup instructions are found in **1.5 Setup Guide**.
- Schematics are found in **Section 4. Schematics and Parts List**.
- Pin assignments for 40-pin connector J14 are shown in **Figure 3-1**.
- A pin-by-pin description of input and output signals is contained in **3.3 Signal Descriptions**.
- For those interested in the reference design aspects of the board's circuitry, a description is provided in **Section 5. Design Considerations**.

1.4 Warnings

This development tool set operates in an environment that includes dangerous voltages and rotating machinery. To facilitate safe operation, input power for the HV AC power stage should come from a DC laboratory power supply, unless power factor correction is specifically being investigated.

An isolation transformer should be used when operating off an ac power line. If an isolation transformer is not used, power stage grounds and oscilloscope grounds are at different potentials, unless the oscilloscope is floating.

NOTE: *Because the probe grounds, it is subjected to dangerous voltages in the case of a floated oscilloscope.*

The user should be aware that:

- Before moving scope probes, making connections, etc., it is generally advisable to power down the motor supply.
- When high voltage is applied, using only one hand for operating the test setup minimizes the possibility of electrical shock.
- Operation in lab setups that have grounded tables and/or chairs should be avoided.
- Wearing safety glasses, avoiding ties and jewelry, using shields, and operation by personnel trained in high voltage lab techniques are advisable.
- Power transistors, the PFC coil, and motor can reach temperatures hot enough to cause burns.
- When powering down; due to storage in the bus capacitors, dangerous voltages are present until the power-on LED is off.

1.5 Setup Guide

Setup and connections are very straightforward. The HV SR power stage connects to an embedded motion control optoisolation board via a 40-pin ribbon cable and can be powered either by a 140-volt to 230-volt dc power supply or with line voltage. For both safety reasons and ease of making measurements, it is strongly recommended that a dc supply is used, unless power factor correction is specifically being investigated. The power supply should be current limited to under 4 amps. **Figure 1-3** depicts a completed setup.

A step-by-step setup procedure is described as:

1. Plug one end of the 40-pin ribbon cable that comes with the optoisolator kit into input connector J14. The other end of this cable goes to the optoisolation board’s 40-pin output connector.
2. Connect motor leads to output connector J13 located along the back edge of the top board. Phase A, phase B, and phase C are labeled Ph. A, Ph. B, and Ph. C. There are two connections for each phase, to accommodate the independent phase coil configuration that is used in switched reluctance motors.

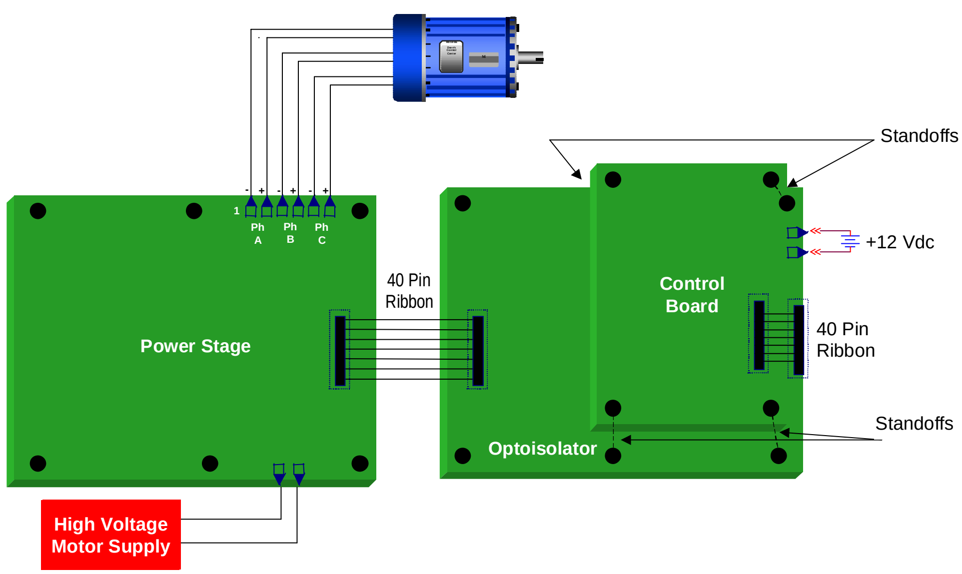


Figure 1-3. Setup

3. Connect earth ground to the earth ground terminals on the top board and on the heat sink. The top board's ground terminal is located in the front left-hand corner, and is marked with a ground symbol. The heat sink has a screw on its front edge that is also marked with a ground symbol.
4. Connect an isolated line, current limited dc power supply to connector J11 located on the front edge of the top board. The input voltage range is 140 Vdc to 230 Vdc. Current limit should be set for less than 4 amps. The dc supply's polarity does not matter.

   Either a 110-volt or 220-volt ac line that is coupled through an isolation transformer may be used in place of a dc supply to provide input power. The connection is made on connector J11. Bias voltages are developed by internal power supplies. One power input is all that is required.

CAUTION: *Operation from an ac power line is significantly more hazardous than operation from a line isolated and current limited dc power supply.*

An isolation transformer should be used when operating from an ac power line.

5. Setup the optoisolation and control boards.
6. The HV SR power stage is shipped with power factor correction (PFC) disabled. If power factor correction is desired, it is necessary to remove and re-solder power jumper JP201 from the no PFC position to the PFC position. This jumper is found on the left side of the top board, between the dc bus capacitor and PFC inductor. Circuit connections are illustrated in **Figure 1-4**. For first time setups, operation without power factor correction is recommended.
7. Apply power first to the optoisolator and then to the power stage. The green power-on LED in the upper right-hand corner lights, and both fans run when power is present.

NOTE: *The optoisolation board powers the control board. The optoisolation board is not fully powered until power is applied to the power stage.*

WARNING: ***Hazardous voltages are present. Please re-read all of the warnings in 1.4 Warnings carefully.***

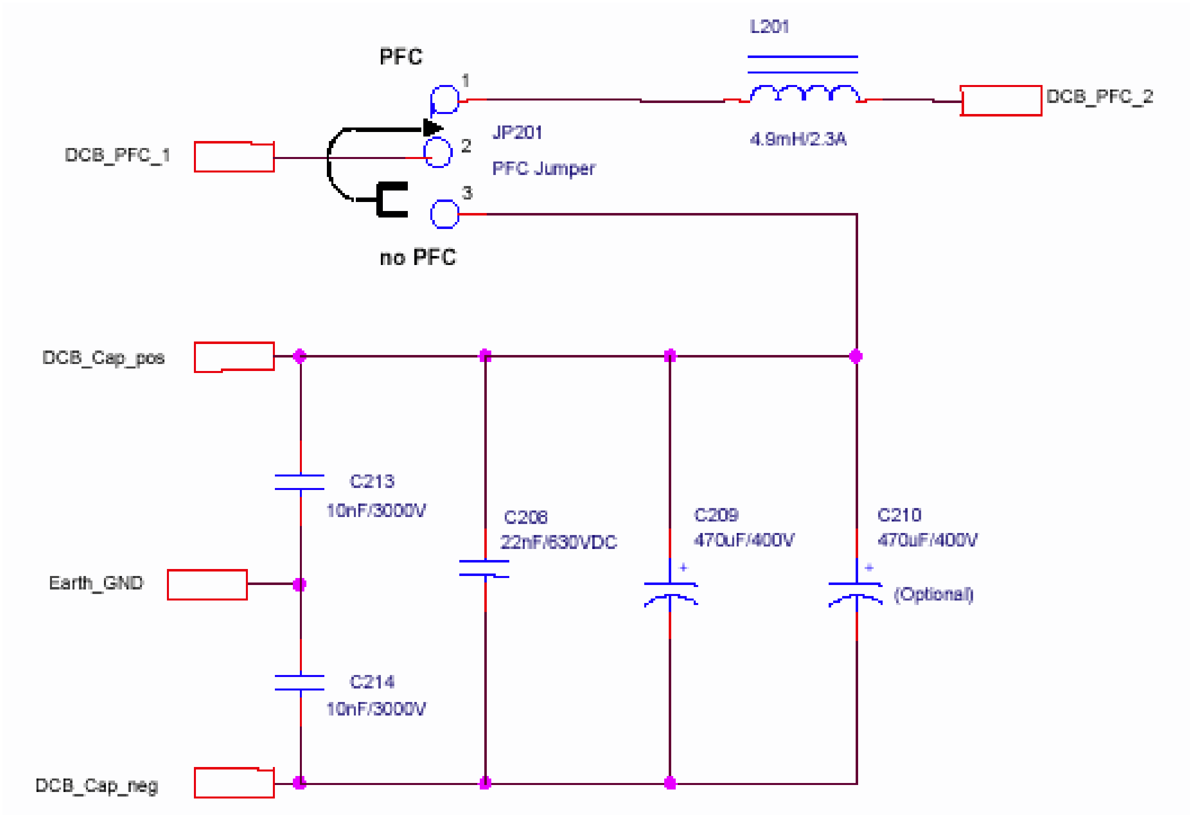


Figure 1-4. PFC Jumper

Section 2. Operational Description

2.1 Contents

2.2 Description

Motorola's embedded motion control series high-voltage (HV) switched reluctance (SR) power stage is a 180 watt (1/4 horsepower), 3-phase power stage that will operate off of dc input voltages from 140 volts to 230 volts and ac line voltages from 100 volts to 240 volts. In combination with one of Motorola's Embedded Motion Control Series control boards and an optoisolation board, it provides a software development platform that allows algorithms to be written and tested, without the need to design and build a power stage. It supports a wide variety of algorithms for controlling switched reluctance motors.

Input connections are made via 40-pin ribbon cable connector J14. Pin assignments for the input connector are shown in **Figure 3-1. 40-Pin Ribbon Connector J14**. Power connections to the motor are made on output connector J13. Phase A, phase B, and phase C are labeled Ph. A, Ph. B, Ph. C on the board. Power requirements are met with a single external 140-volt to 230-volt dc power supply or an ac line voltage. Either input is supplied through connector J11. Current measuring circuitry is set up for 2.93 amps full scale. Both bus and phase leg currents are measured. A cycle-by-cycle overcurrent trip point is set at 2.69 amps.

The HV SR power stage has both a printed circuit board and a power substrate. The printed circuit board contains IGBT gate drive circuits, analog signal conditioning, low-voltage power supplies, power factor control circuitry, and some of the large passive power components. This board also has a MC68HC705JJ7 microcontroller used for board configuration and identification. All of the power electronics that need to dissipate heat are mounted on the power substrate. This substrate includes the power IGBTs, brake resistors, current-sensing resistors, a power factor correction MOSFET, and temperature sensing diodes. **Figure 2-1** shows a block diagram.

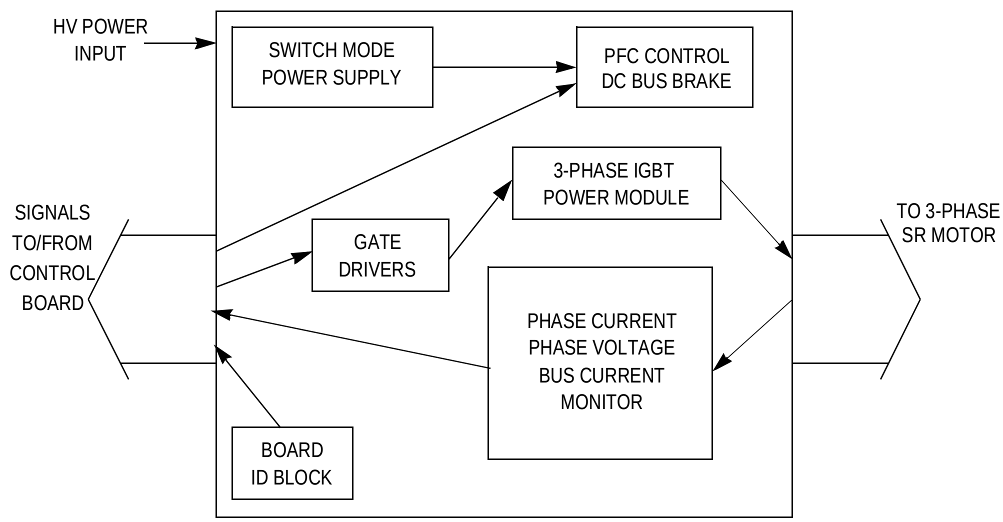


Figure 2-1. Block Diagram

2.3 Electrical Characteristics

The electrical characteristics in **Table 2-1** apply to operation at 25°C with a 160-Vdc supply voltage.

Table 2-1. Electrical Characteristics

Characteristic	Symbol	Min	Typ	Max	Units
DC input voltage	Vdc	140	160	230	V
AC input voltage	Vac	100	208	240	V
Quiescent current	I_{CC}	—	70	—	mA
Min logic 1 input voltage	V_{IH}	2.0	—	—	V
Max logic 0 input voltage	V_{IL}	—	—	0.8	V
Analog output range	V_{Out}	0	—	3.3	V
Bus current sense voltage	I_{Sense}	—	563	—	mV/A
Bus voltage sense voltage	V_{Bus}	—	8.09	—	mV/V
Peak output current	I_{PK}	—	—	2.7	A
Brake resistor dissipation (continuous)	P_{BK}	—	—	50	W
Brake resistor dissipation (15 sec pk)	$P_{BK(Pk)}$	—	—	100	W
Total power dissipation	P_{diss}	—	—	85	W

2.4 Modification for 1/2 and 3/4 Horsepower

The HV SR power stage can be modified to drive either 1/2 or 3/4 horsepower motors. To change maximum output power these steps apply:

1. Remove power and wait until the power-on LED is off.
2. If PFC jumper JP201 is in the PFC position, remove and resolder it into the no PFC position.
3. Make the resistor value changes shown in **Table 2-2**. These resistors set current amplifier gains. For 1/2 and 3/4 horsepower motors, lower gains allow for higher measured currents, and higher overcurrent trip points.

Table 2-2. Resistor Value

Resistors	1/4 HP (180 W)	1/2 HP (370 W)	3/4 HP (550 W)
R303, R305, R307, R314, R315, R318, R319, R322	75 kΩ	62 kΩ	56 kΩ
R301, R304, R311, R313, R316, R317, R320, R321	10 kΩ	15 kΩ	16 kΩ

4. Configure identification coding jumper JP801 with the settings that are indicated in **Table 2-3**. This procedure allows software to interpret the new analog values correctly.

Table 2-3. JP801 Settings

Position	1/4 HP (180 W)	1/2 HP (370 W)	3/4 HP (550 W)
1-2	Open	**Short**	Open
3-4	Open	Open	**Short**
5-6	Open	Open	Open
7-8	Open	Open	Open

5. For 3/4 horsepower motors it is also necessary to add an additional 470-µF/400-volt bus capacitor. To install the capacitor, it is first necessary to remove PFC inductor L201. Mounting holes for the additional capacitor are located within L201’s footprint. Note that it is essential to orient the capacitor such that polarity is correct. Positive and negative connections are indicated by + and – silk screened labels on the board. In addition, the pad for the capacitor’s positive lead is square, and the pad for its negative lead is round.

Once these changes have been made, configuration for either 1/2 or 3/4 horsepower is complete.

2.5 Fuse Replacement

A fast-blow fuse is located on the front right-hand corner of the top board. If this fuse has to be replaced these steps apply:

1. Remove power and wait until the power-on LED is off.
2. Remove the fuse's protective case.
3. Replace the fuse with one of the selections shown in **Table 2-4**.
4. Replace the protective case.
5. Set the controller's speed control input to 0 RPM.
6. Apply power and resume operation.

Table 2-4. Fuse Ratings

Motor Horsepower	RMS Input Current (Amps)	Fuse Current Rating (Amps)	Fuse Voltage Rating (Volts)	Fuse Type
1/4	2.3	2.5	250	Fast blow
1/2	4.8	6.3	250	Fast blow
3/4	7.1	8	250	Fast blow

Section 3. Pin Descriptions

3.1 Contents

3.2 Introduction

There are four connectors on the top board for making input and output connections. They are:

- J11 — Power input connector
- J12 — Brake connector
- J13 — Motor output connector
- J14 — 40-pin ribbon cable connector

Pin descriptions for each of these connectors are identified in this subsection. Pin assignments for the 40-pin ribbon connector, J14, are shown in **Figure 3-1**. In this figure, a schematic representation appears on the left, and a physical layout of the connector appears on the right. The physical view assumes that the board is oriented such that its title is read from left to right. Signal descriptions are provided in **Table 3-1**.

3.3 Signal Descriptions

This subsection describes the signals.

3.3.1 40-Pin Ribbon Connector J14

Signal inputs are grouped together on a 40-pin ribbon cable connector, J14, located on the right side of the board. Pin assignments are shown in **Figure 3-1**. Signal descriptions are listed in **Table 3-1**.

3.3.2 Power Connectors J11

The power input connector, labeled J11, is located on the front edge of the board. It will accept dc voltages from 140 to 230 volts, or an isolated ac line input from 100 to 240 volts. In either case, the power source should be capable of supplying at least 200 watts.

3.3.3 External Brake Connectors J12

An optional external brake resistor can be connected to external brake connector J12, labeled Ext. Brake. The external resistor allows power dissipation to be increased beyond the 50 watts that brake resistors R6–R9 provide.

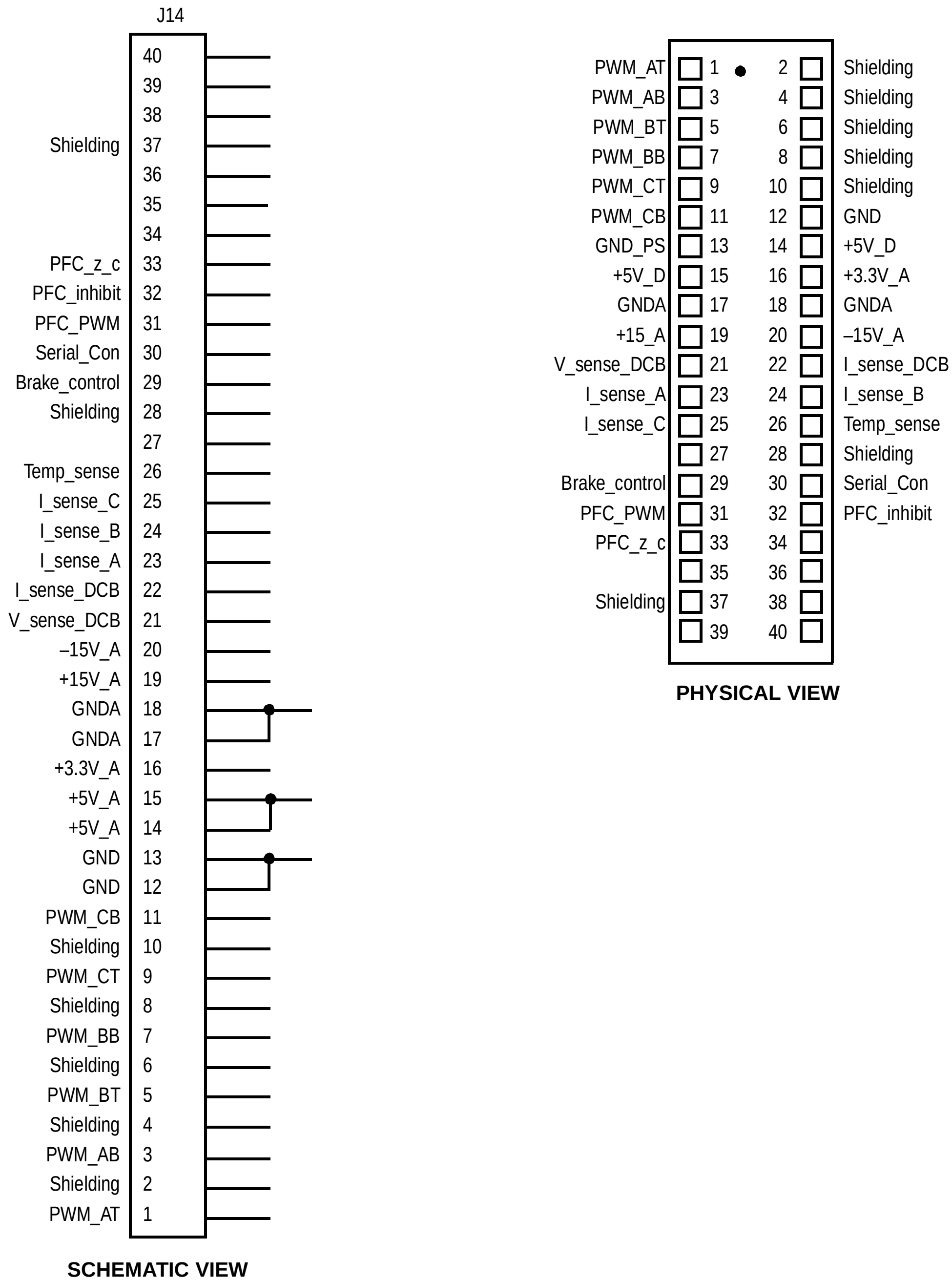


Figure 3-1. 40-Pin Ribbon Connector J14

Table 3-1. Connector J14 Signal Descriptions

Pin No.	Signal Name	Description
1	PWM_AT	PWM_AT is the gate drive signal for the top half-bridge of phase A. A logic high turns phase A's top switch on.
2	Shielding	Pin 2 is connected to a shield wire in the ribbon cable and ground on the board.
3	PWM_AB	PWM_AB is the gate drive signal for the bottom half-bridge of phase A. A logic high turns phase A's bottom switch on.
4	Shielding	Pin 4 is connected to a shield wire in the ribbon cable and ground on the board.
5	PWM_BT	PWM_BT is the gate drive signal for the top half-bridge of phase B. A logic high turns phase B's top switch on.
6	Shielding	Pin 6 is connected to a shield wire in the ribbon cable and ground on the board.
7	PWM_BB	PWM_BB is the gate drive signal for the bottom half-bridge of phase B. A logic high turns phase B's bottom switch on.
8	Shielding	Pin 8 is connected to a shield wire in the ribbon cable and ground on the board.
9	PWM_CT	PWM_CT is the gate drive signal for the top half-bridge of phase C. A logic high turns phase C's top switch on.
10	Shielding	Pin 10 is connected to a shield wire in the ribbon cable and ground on the board.
11	PWM_CB	PWM_CB is the gate drive signal for the bottom half-bridge of phase C. A logic high turns phase C's bottom switch on.
12	GND	Digital and power ground
13	GND	Digital and power ground, redundant connection
14	+5V digital	Digital +5-volt power supply
15	+5V digital	Digital +5-volt power supply, redundant connection
16	+3.3V analog	Analog +3.3-volt power supply
17	GNDA	Analog power supply ground
18	GNDA	Analog power supply ground, redundant connection
19	+15V_A	Analog +15-volt power supply
20	–15V_A	Analog –15-volt power supply
21	V_sense_DCB	V_sense_DCB is an analog sense signal that measures dc bus voltage. It is scaled at 8.09 mV per volt of dc bus voltage.
22	I_sense_DCB	I_sense_DCB is an analog sense signal that measures dc bus current. It is scaled at 0.563 V per amp of dc bus current.

Table 3-1. Connector J14 Signal Descriptions (Continued)

Pin No.	Signal Name	Description
23	I_sense_A	I_sense_A is an analog sense signal that measures current in phase A. It is scaled at 0.563 V per amp of dc bus current.
24	I_sense_B	I_sense_B is an analog sense signal that measures current in phase B. It is scaled at 0.563 V per amp of dc bus current.
25	I_sense_C	I_sense_C is an analog sense signal that measures current in phase C. It is scaled at 0.563 V per amp of dc bus current.
26	Temp_sense	Temp_sense is an analog sense signal that measures power module temperature.
27		No connection
28	Shielding	Pin 28 is connected to a shield wire in the ribbon cable and analog ground on the board.
29	Brake_control	Brake_control is the gate drive signal for the brake IGBT.
30	Serial_Con	Serial_Con is an identification signal that lets the controller know which power stage is present.
31	PFC_PWM	PFC_PWM is a digital signal that controls the power factor correction circuit’s switch.
32	PFC_inhibit	PFC_inhibit is a digital signal that is used to enable or disable the power factor correction circuit.
33	PFC_z_c	PFC_z_c is a digital signal and its edges represent power line voltage 0 crossing events.
34		No connection
35		No connection
36		No connection
37	Shielding	Pin 37 is connected to a shield wire in the ribbon cable and analog ground on the board.
38		No connection
39		No connection
40		No connection

3.3.4 Motor Output Connector J13

Power outputs to the motor are located on connector J13. Phase outputs are labeled Ph. A, Ph. B, and Ph. C. Pin assignments are:

- Pin 1: Ph. A — Pin 1 supplies power to motor Phase A. It is connected to bottom switch output signal Phase_AB. Either of the two phase A motor leads may be connected here.
- Pin 2: Ph. A — Pin 2 supplies power to motor Phase A. It is connected to top switch output signal Phase_AT. Either of the two phase A motor leads may be connected here.
- Pin 3: Ph. B — Pin 3 supplies power to motor Phase B. It is connected to bottom switch output signal Phase_BB. Either of the two phase B motor leads may be connected here.
- Pin 4: Ph. B — Pin 4 supplies power to motor Phase B. It is connected to top switch output signal Phase_BT. Either of the two phase B motor leads may be connected here.
- Pin 5: Ph. C — Pin 5 supplies power to motor Phase C. It is connected to bottom switch output signal Phase_CB. Either of the two phase C motor leads may be connected here.
- Pin 6: Ph. C — Pin 6 supplies power to motor Phase C. It is connected to top switch output signal Phase_CT. Either of the two phase C motor leads may be connected here.

Section 4. Schematics and Parts List

4.1 Contents

4.2 Mechanical Characteristics

Mechanically, the HV SR power stage consists of an FR-4 circuit board, a 3.2-mm aluminum circuit board, two fans, a fan bracket, a heat sink, inter-board connectors, and standoffs. Construction is depicted in **Figure 1-2. 3-Phase Switched Reluctance High-Voltage Power Stage**. The aluminum circuit board, fans, and heat sink provide the thermal capability surface mounted power components. The FR-4 board contains control circuitry and through-hole mounted power components. The two boards plug together via 10 vertical connectors to, in effect, form a discrete power module.

Four holes on the top board are spaced to allow mounting standoffs such that a control board can be placed on top of the power stage. This configuration allows mounting control and power functions in one compact mechanical assembly.

4.3 Schematics

A set of schematics for the HV SR power stage appears in **Figure 4-1** through **Figure 4-7**.

- An overview appears in **Figure 4-1**.
- Output transistor gate drive is shown in **Figure 4-2**.
- The 3-phase output stage appears in **Figure 4-3**.
- Current and temperature feedback circuits are shown in **Figure 4-4**.
- Power factor correction and brake gate drives are shown in **Figure 4-5**.
- The identification block is shown in **Figure 4-6**.
- The on-board power supply is shown in **Figure 4-7**.

Unless otherwise specified, resistors are 1/8 watt, have a ±5% tolerance, and have values shown in ohms. Interrupted lines coded with the same letters are electrically connected. Parts lists for the power substrate and printed circuit board appear in **Table 4-1** and **Table 4-2**.

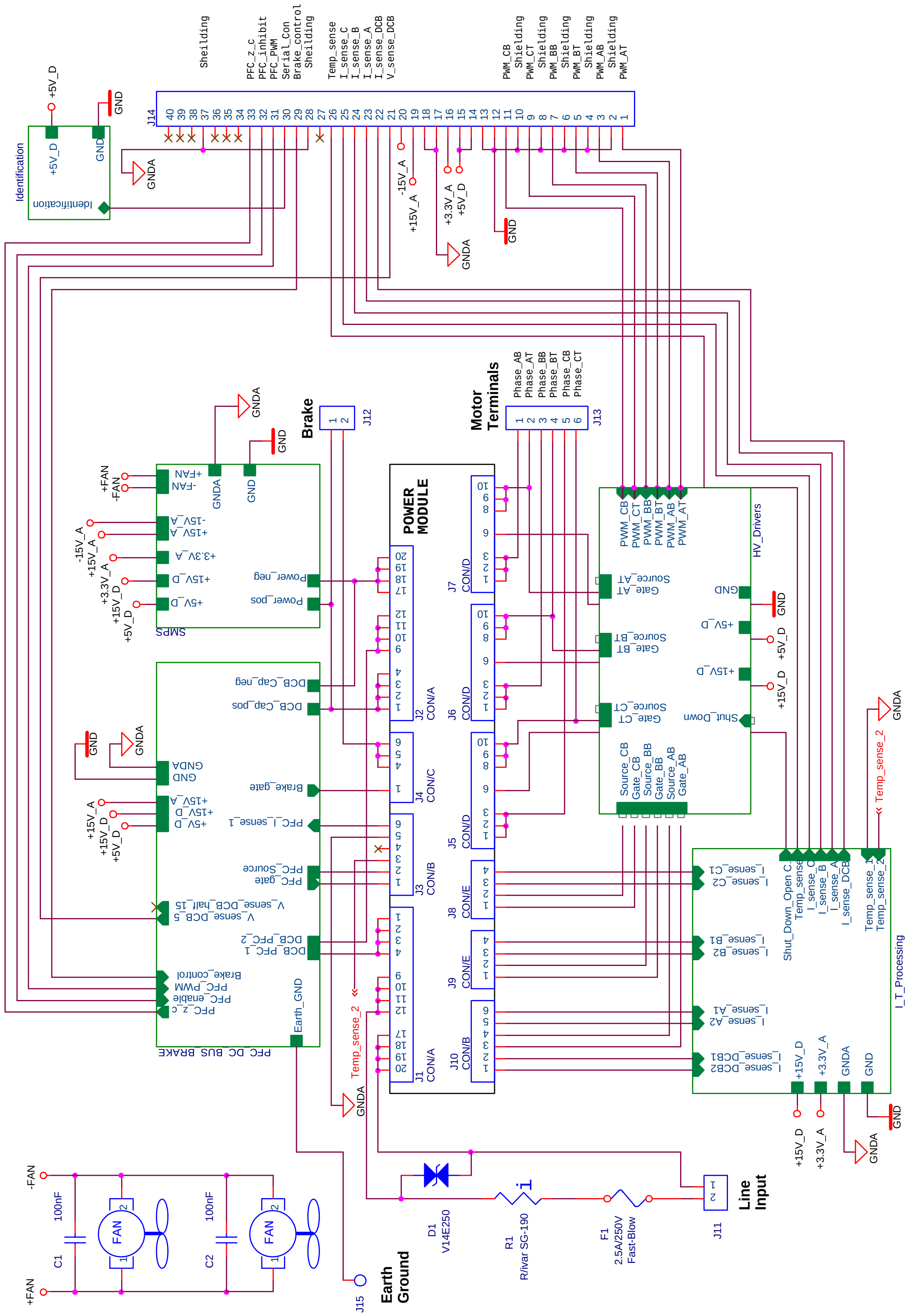


Figure 4-1. 3-Phase HR High-Voltage Power Stage Overview

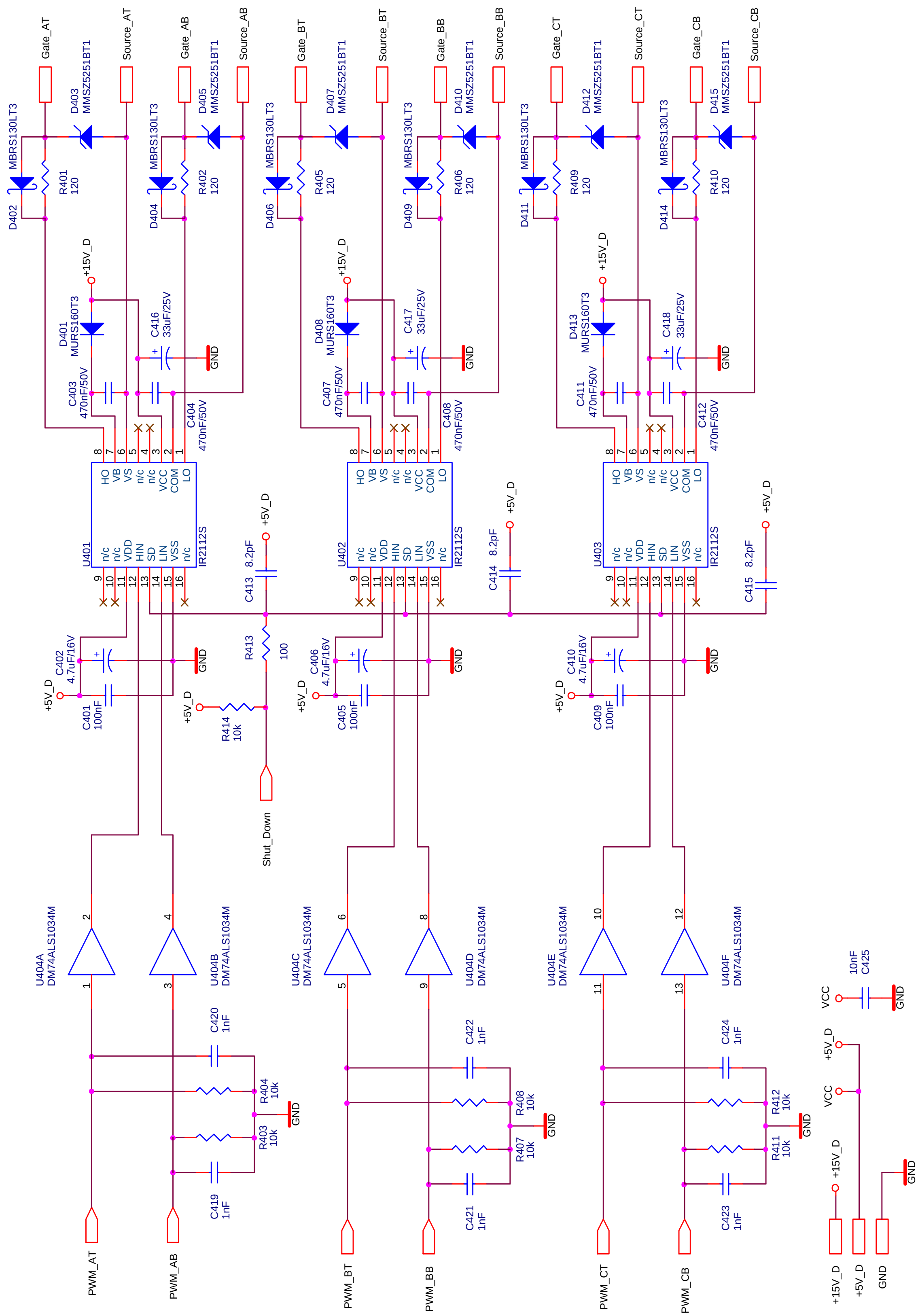


Figure 4-2. Gate Drive

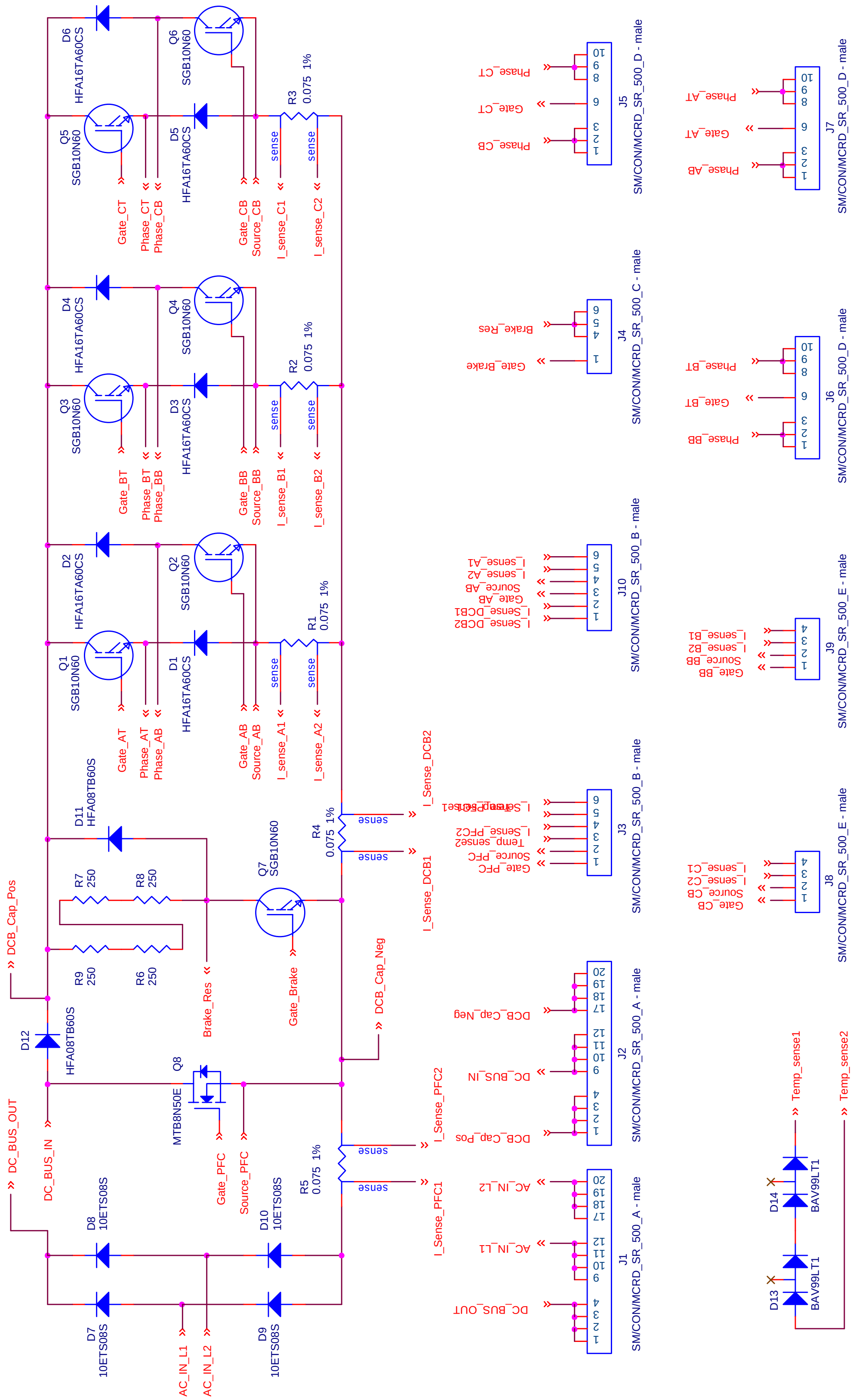


Figure 4-3. 3-Phase Output

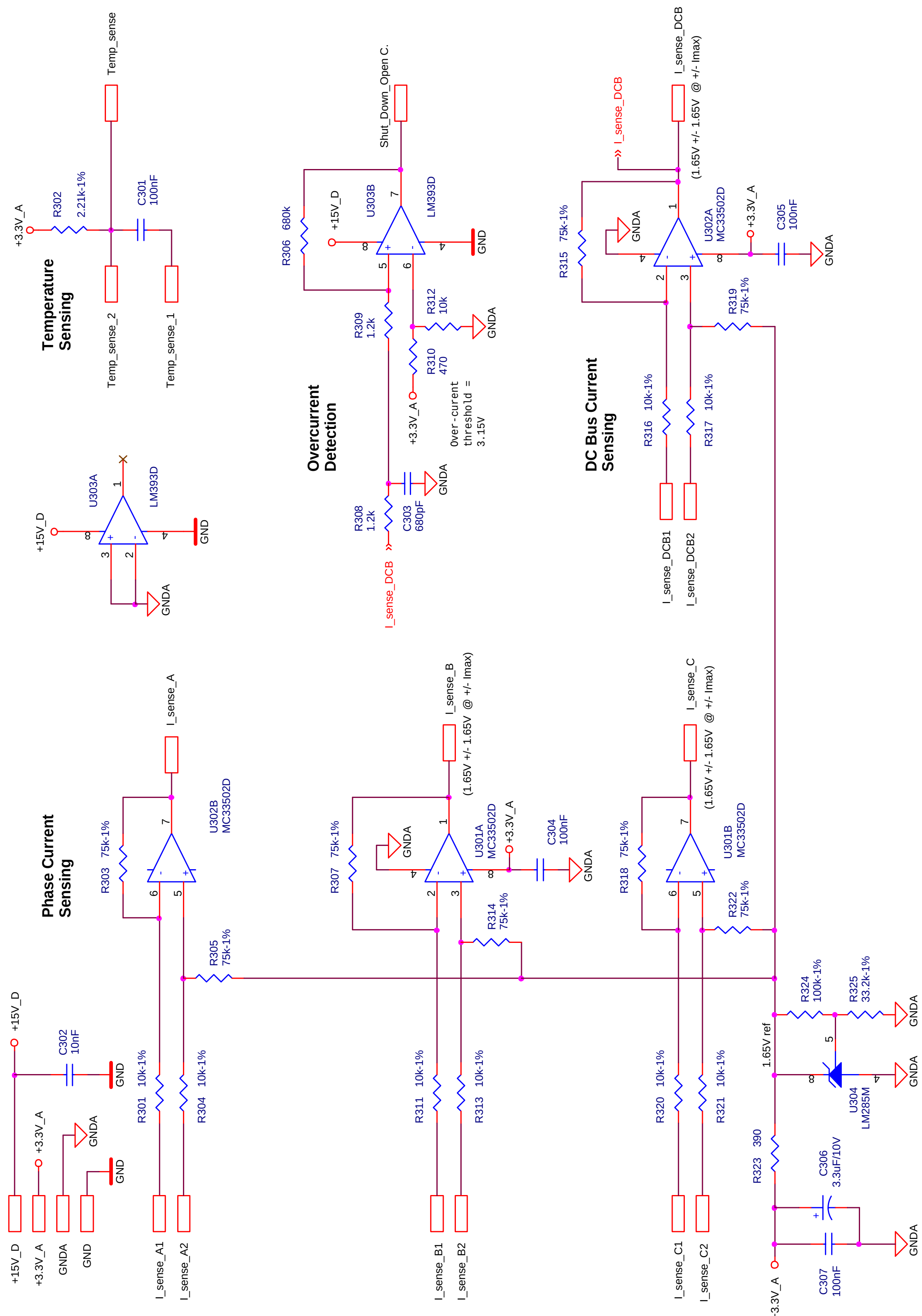


Figure 4-4. Current and Temperature Feedback

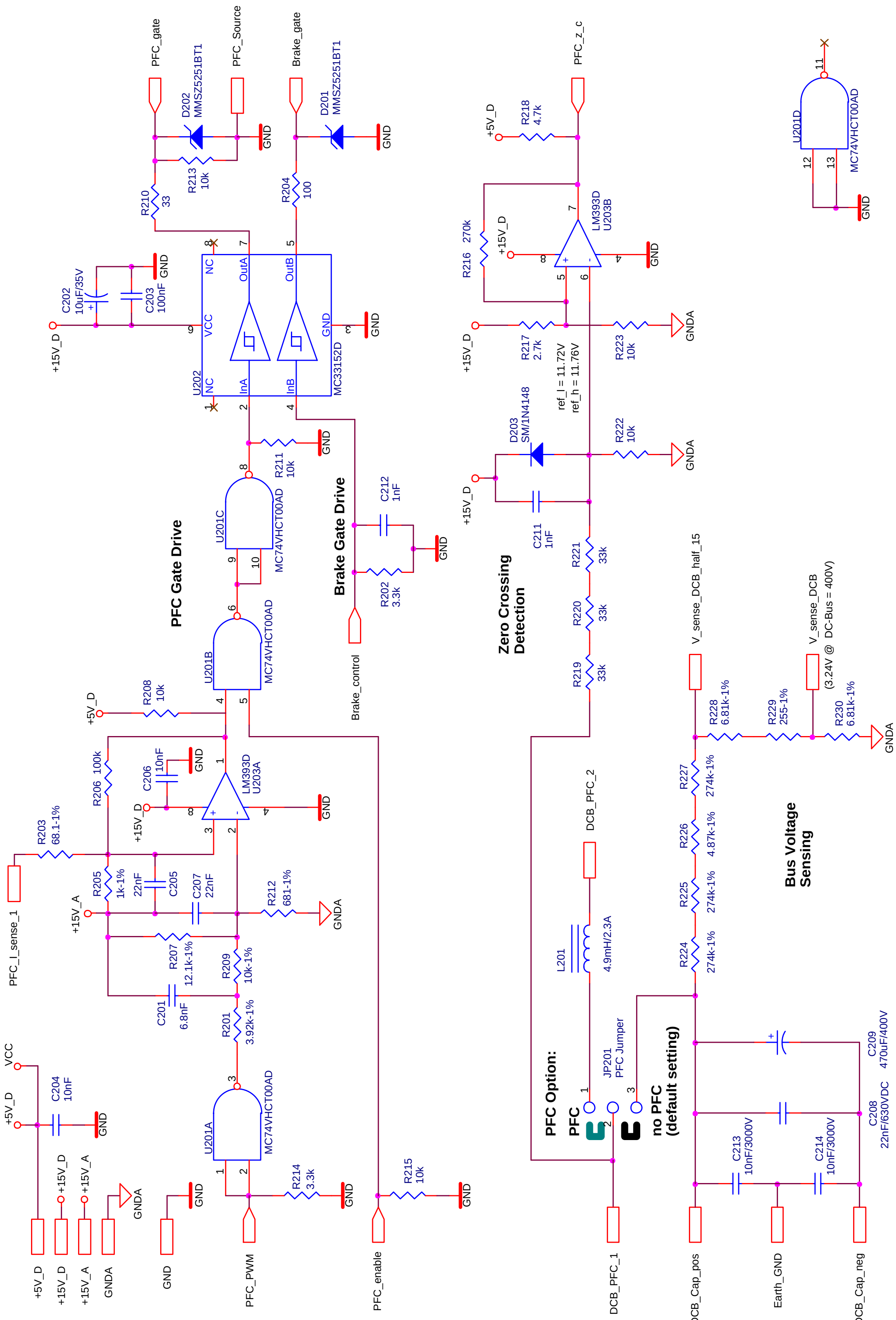


Figure 4-5. Power Factor Correction and Brake Gage Drive

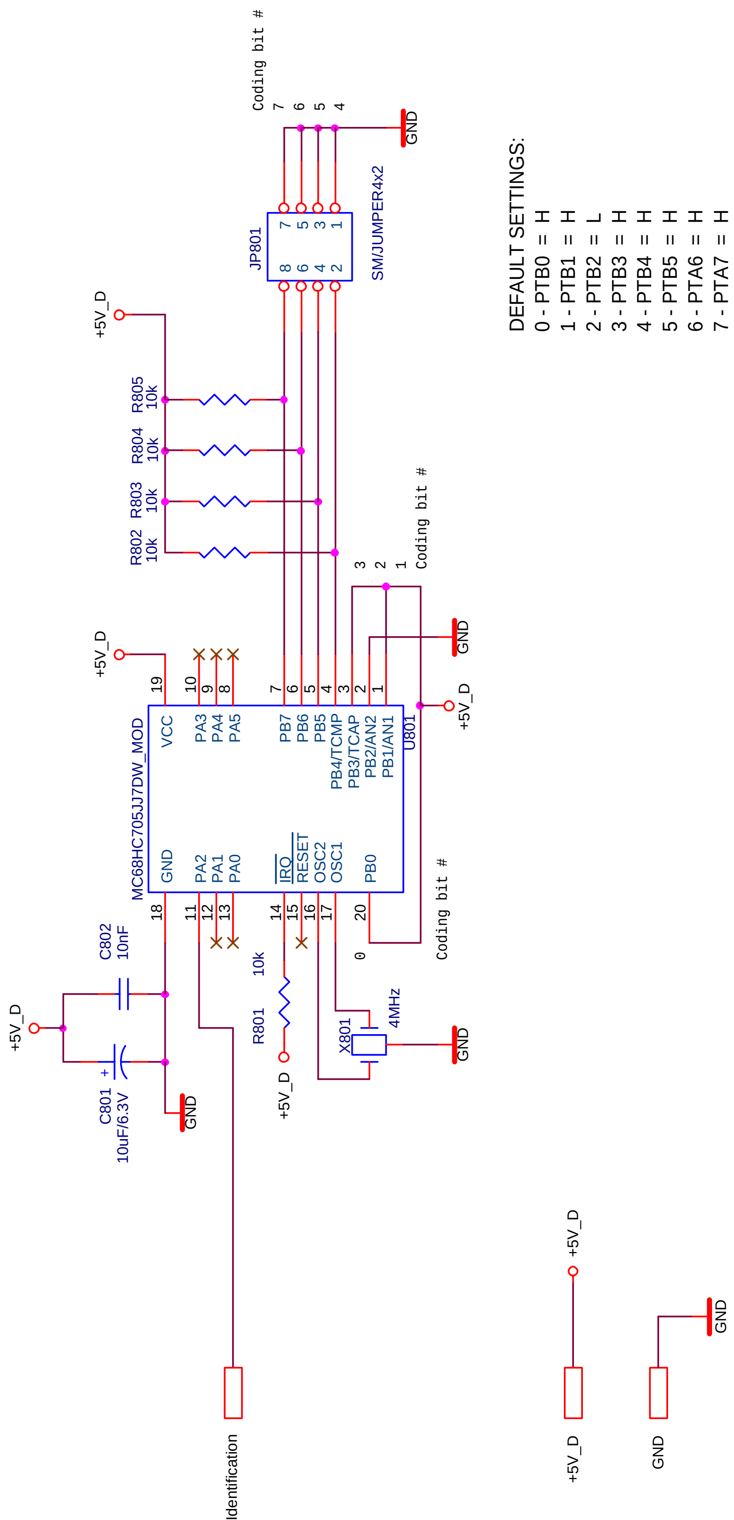


Figure 4-6. Identification Block

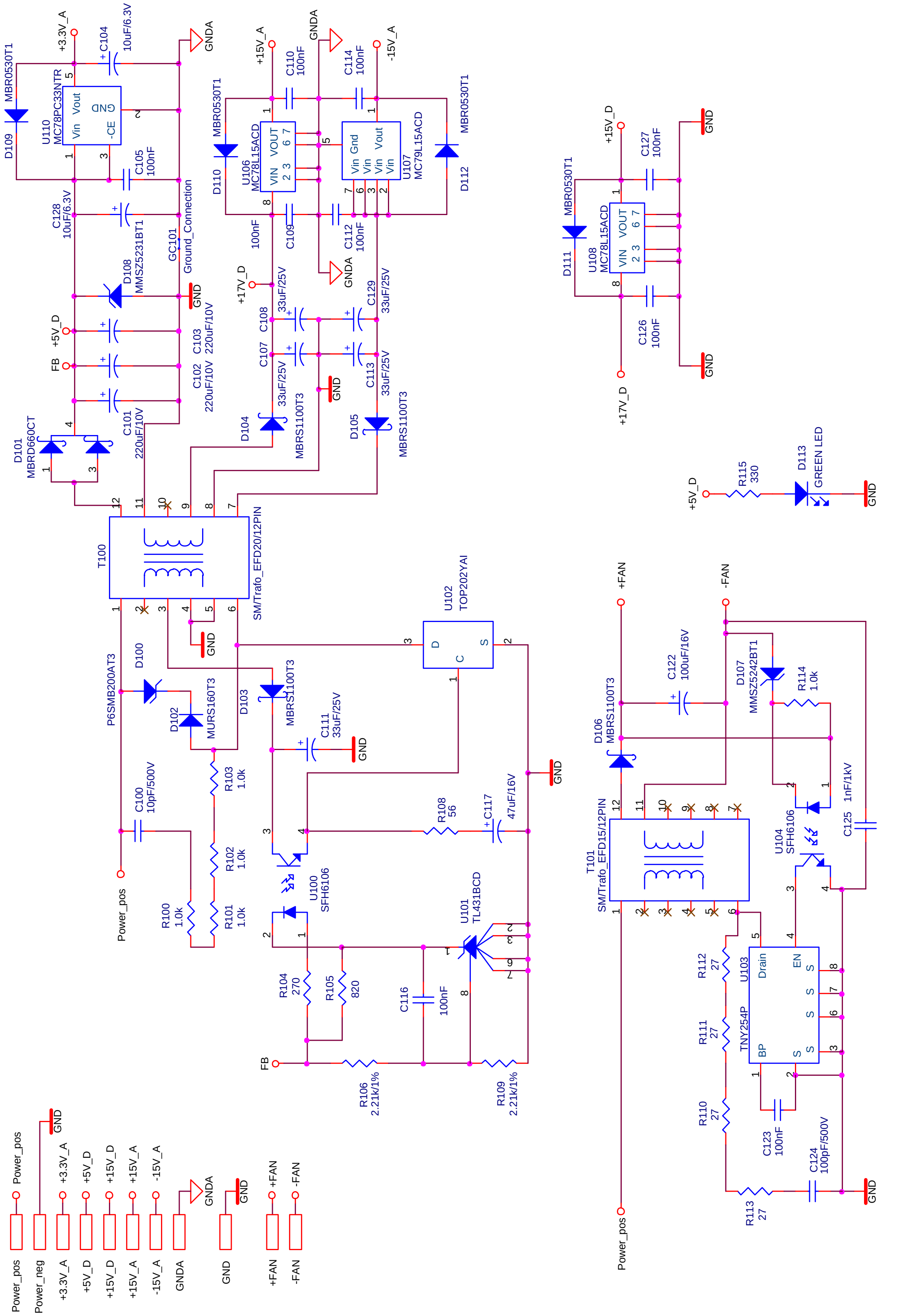


Figure 4-7. Power Supply

4.4 Parts Lists

The HV SR power stage's parts content is described in **Table 4-1** for the power substrate and in **Table 4-2** for the printed circuit board.

Table 4-1. Power Substrate Parts List

Qty	Reference	Description	Manufacturer	Part #
6	D1, D2, D3, D4, D5, D6	8A/600V Ultrafast Rectifier	International Rectifier	HFA08TB60S
4	D7, D8, D9, D10	10A/800V Rectifier	International Rectifier	10ETS08S
2	D11, D12	8A/600V Ultrafast Rectifier	International Rectifier	HFA08TB60S
2	D14, D13	Dual Diode – Temp Sensing	On Semiconductor	BAV99LT1
2	J1, J2	SM/CON/MCRD_SR_500_A — male	Fisher Elektronik	SL 11 SMD 104 20Z
2	J3, J10	SM/CON/MCRD_SR_500_B — male	Fisher Elektronik	SL 10 SMD 104 6Z
1	J4	SM/CON/MCRD_SR_500_C — male	Fisher Elektronik	SL 10 SMD 104 6Z
3	J5, J6, J7	SM/CON/MCRD_SR_500_D — male	Fisher Elektronik	SL 10 SMD 104 10Z
2	J8, J9	SM/CON/MCRD_SR_500_E — male	Fisher Elektronik	SL 10 SMD 104 4Z
7	Q1, Q2, Q3, Q4, Q5, Q6, Q7	10A/600V IGBT	Infineon	SGB10N60
1	Q8	8A/500V MOSFET	On Semiconductor	MTB8N50E

Table 4-2. Printed Circuit Board Parts List (Sheet 1 of 5)

Qty	Reference	Description	Part #	Manufacturer
19	C1, C2, C105, C109, C110, C112, C114, C116, C123, C126, C127, C203, C301, C304, C305, C307, C401, C405, C409	100nF/25V	Vitramon	VJ0805U104MXXA_
1	C100	10pF/500V	Vishay Sprague	Typ:5GAQ10, Serie: 562C
3	C101, C102, C103	220uF/10V	AVX	TPSE227K010R0100
3	C104, C128, C801	10uF/6.3V	Sprague	293D106X_6R3B2_
8	C107, C108, C111, C113, C129, C416, C417, C418	33uF/25V	AVX	TPSE336K025R0200

Table 4-2. Printed Circuit Board Parts List (Sheet 2 of 5)

Qty	Reference	Description	Part #	Manufacturer
1	C117	47uF/16V	Any available	
1	C122	100uF/16V	AVX	TPSE107K016R0100
5	C204, C206, C302, C425, C802	10nF	Vitramon	VJ0805U103MXXA_
1	C124	100pF/500V	Vishay Sprague	Typ:5GAT10, Serie: 562C
1	C125	1nF/1kV	muRata	DE0505E102Z1K
1	C201	6.8nF	Vitramon	VJ0805A682JXA_
1	C202	10uF/35V	Sprague	293D106X_035D2_
2	C207, C205	22nF	Vitramon	VJ0805A223JXA_
1	C208	22nF/630VDC	WIMA	MKP10
1	C209	470uF/400V	Philips Components	15746471
8	C211, C212, C419, C420, C421, C422, C423, C424	1nF	Vitramon	VJ0805A102JXA_
2	C213, C214	10nF/ 3000V	Thomson	5ST410MCMCA
1	C303	680pF	Vitramon	VJ0805A681JXA_
1	C306	3.3uF/10V	Sprague	293D335X_010A2_
3	C402, C406, C410	4.7uF/16V	Sprague	293D475X_016B2_
6	C403, C404, C407, C408, C411, C412	470nF/50V	Vitramon	VJ1206U474MXAA_
3	C413, C414, C415	8.2pF	Vitramon	VJ0805A8R2DXA_
1	D1	Disk Varistor	EPCOS	SOIV-S-10K250
1	D100	Transient Suppressor	On Semiconductor	P6SMB200AT3
1	D101	6A/60V Shottky	On Semiconductor	MBRD660CT
4	D102, D401, D408, D413	1A/600V Ultrafast	On Semiconductor	MURS160T3
4	D103, D104, D105, D106	1A/100V Schottky	On Semiconductor	MBRS1100T3
1	D107	12V Zener	On Semiconductor	MMSZ5242BT1
1	D108	5.1V Zener	On Semiconductor	MMSZ5231BT1
4	D109, D110, D111, D112	.0.5A/30V Schottky	On Semiconductor	MBR0530T1
1	D113	Green LED	Kingbright	L-934GT

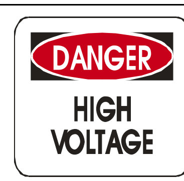
Table 4-2. Printed Circuit Board Parts List (Sheet 3 of 5)

Qty	Reference	Description	Part #	Manufacturer
8	D201, D202, D403, D405, D407, D410, D412, D415	22V Zener	On Semiconductor	MMSZ5251BT1
1	D203	SMD/1N4148	FairChild	1N4148LL-34
6	D402, D404, D406, D409, D411, D414	1A/30V Schottky	On Semiconductor	MBRS130LT3
1	F1	Fuse Holder	MULTICOMP	MCHTE15M
1	JP201	Power Jumper	—	Wire, D = 1.5mm, L = 12mm
1	JP801	4X2 Jumper Pads	—	—
2	J2, J1	20 Pin Female Header	Fisher Elektronik	BL 2 20Z
2	J3, J10	6 Pin Female Header	Fisher Elektronik	BL 1 6Z
1	J4	6 Pin Female Header	Fisher Elektronik	BL 1 6Z
3	J5, J6, J7	10 Pin Female Header	Fisher Elektronik	BL 1 10Z
2	J9, J8	4 Pin Female Header	Fisher Elektronik	BL 1 4Z
2	J11, J12	2 Pole Terminal Block	Weidmuller	LP 7.62/2/90
1	J13	3 Pole Terminal Block	Weidmuller	LP 7.62/3/90 — see note!
1	J14	40 Pin Connector — male	Fischer Elektronik	ASLG40G
1	L201	4.9mH/2.3A	Thompson Television Compon.	SMT4 ref G6982-01
1	R1	Inrush Limiter	Rhopoint Components	SG190
4	R100, R101, R102, R103	1.0k	Dale	CRCW1206-102J
1	R104	270_	Dale	CRCW0805-271J
1	R105	820_	Dale	CRCW0805-821J
2	R106, R109	2.21k–1%	Any available	—
1	R108	56_	Any available	—
4	R110, R111, R112, R113	27_	Dale	CRCW1206-270J
1	R114	1.0k	Dale	CRCW0805-102J
1	R115	330_	Dale	CRCW0805-331J
1	R201	3.92k–1%	Any available	—

Table 4-2. Printed Circuit Board Parts List (Sheet 4 of 5)

Qty	Reference	Description	Part #	Manufacturer
18	R208, R211, R213, R215, R223, R312, R403, R404, R407, R408, R411, R412, R414, R801, R802, R803, R804, R805	10k	Dale	CRCW0805-103J
2	R202, R214	3.3k	Dale	CRCW0805-332J
1	R203	68.1–1%	Any available	
2	R204, R413	100_	Dale	CRCW0805-101J
1	R206	100k	Dale	CRCW0805-104J
1	R207	12.1k–1%	Any available	
1	R210	33_	Dale	CRCW0805-330J
1	R212	681_–1%	Any available	
1	R216	270k	Dale	CRCW0805-274J
1	R217	2.7k	Dale	CRCW0805-272J
1	R218	4.7k	Dale	CRCW0805-472J
1	R219	33k	Dale	CRCW0805-333J
2	R220, R221	33k	Dale	CRCW0805-333J
1	R222	10k	Dale	CRCW0805-103J
3	R224, R225, R227	274k–1%	Any available	—
1	R226	4.87k–1%	Any available	—
2	R228, R230	6.81k–1%	Any available	—
1	R229	255_–1%	Any available	—
9	R209, R301, R304, R311, R313, R316, R317, R320, R321	10k–1%	Dale	CRCW0805-103F
1	R302	2.21k–1%	Any available	
1	R205	1k–1%	Dale	CRCW0805-102F
8	R303, R305, R307, R314, R315, R318, R319, R322	75k–1%	Dale	CRCW0805-753F
1	R306	680k	Dale	CRCW0805-684J
2	R308, R309	1.2k	Dale	CRCW0805-122J
1	R310	470_	Dale	CRCW0805-471J
1	R323	390_	Dale	CRCW0805-391J

Table 4-2. Printed Circuit Board Parts List (Sheet 5 of 5)

Qty	Reference	Description	Part #	Manufacturer
1	R324	100k–1%	Dale	CRCW0805-104F
1	R325	33.2k–1%	Any available	—
6	R401, R402, R405, R406, R409, R410	120_	Dale	CRCW0805-121J
1	T100	SMPS Transformer	Tronic Praha s.r.o	TRONIC 99 060 09
1	T101	SMPS Transformer	Tronic Praha s.r.o	TRONIC 00 003 73
2	U100, U104	Optocoupler	Infineon	SFH6106-2
1	U101	Voltage Reference	On Semiconductor	TL431BCD
1	U102	SMPS Controller	Power Integration	TOP202YAI
1	U103	SMPS Controller	Power Integration	TNY254P
2	U108, U106	15V Voltage Regulator	On Semiconductor	MC78L15ACD
1	U107	–15V Voltage Regulator	On Semiconductor	MC79L15ACD
1	U110	3.3V Voltage Regulator	On Semiconductor	MC78PC33NTR
1	U201	Quad NAND Gate	On Semiconductor	MC74VHCT00AD
1	U202	Gate Driver	On Semiconductor	MC33152D
2	U203, U303	Dual Comparator	On Semiconductor	LM393D
2	U301, U302	Rail-to-Rail Op Amp	On Semiconductor	MC33502D
1	U304	Voltage Reference	National Semiconductor	LM285M
3	U401, U402, U403	Gate Driver	International Rectifier	IR2112S
1	U404	Hex Driver	Fairchild	DM74ALS1034M
1	U801	Programmed MCU	Motorola	MC68HC708JJ7CDW
1	X801	4MHz Resonator	muRata	CSTCC4.00MG
1	—	Sticker	—	
0	R107	NOT POPULATED	—	—
0	C115, C210	NOT POPULATED	—	—

Section 5. Design Considerations

5.1 Contents

5.2 Overview

From a systems point of view, the HV SR power stage fits into an architecture that is designed for software development. In addition to the hardware that is needed to run a motor, a variety of feedback signals that facilitate control algorithm development and a PFC circuit are provided.

Circuit descriptions for the HV SR power stage appear in this subsection.

5.3 Phase Outputs

The output stage is configured as a dual output per phase, 3-phase, bridge with IGBT output transistors. It is simplified considerably by high-voltage integrated gate drivers that have a cycle-by-cycle current limit feature. A schematic that shows one phase is illustrated in **Figure 5-1**.

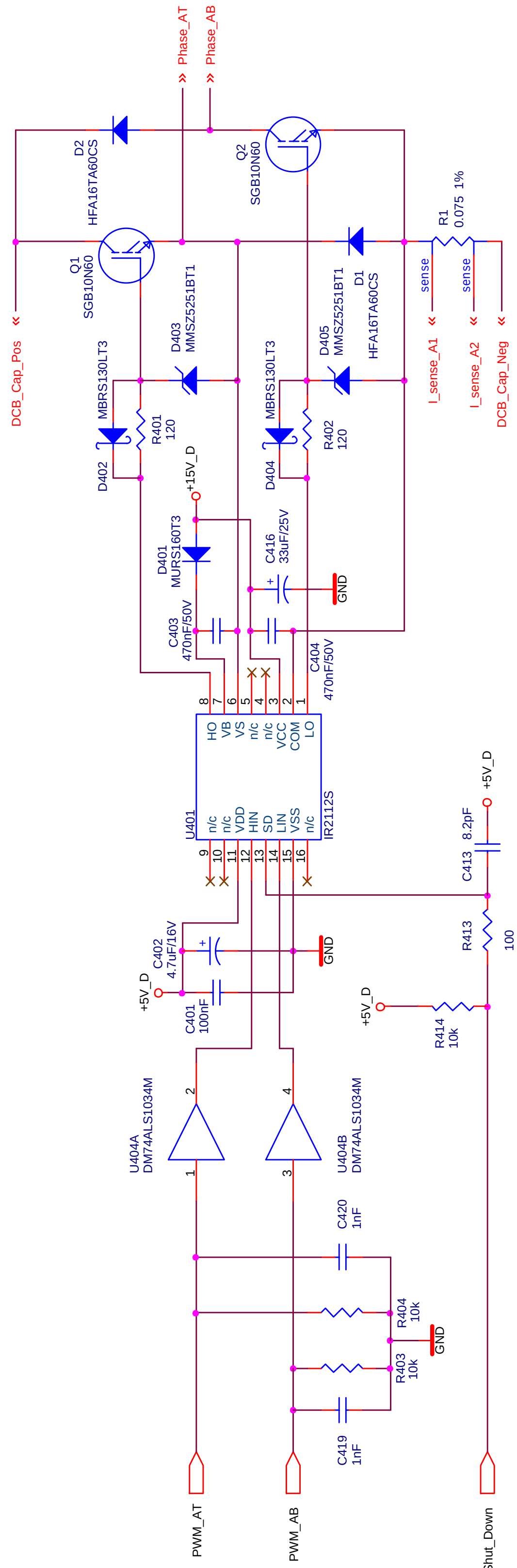


Figure 5-1. Phase A Output

At the input, pull down resistors, R403 and R404, set a logic low in the absence of a signal. Open input pull down is important, since it is desirable to keep the power transistors off in case of either a broken connection or absence of power on the control board. The drive signal is buffered by U404A and U404B. This part has a minimum logic 1 input voltage of 2.0 volts and maximum logic 0 input voltage of 0.8 volts, which allows for inputs from either 3.3-volt or 5-volt logic. Gate drive is supplied by an International Rectifier IR2112. Under-voltage lockout and cycle-by-cycle current limiting are also provided by the IR2112. Under-voltage lockout is set nominally at 8.4 volts. Current limiting is discussed further in **5.5 Cycle-by-Cycle Current Limiting**.

One of the more important design decisions in a motor drive is selection of gate drive impedance for the output transistors. In **Figure 5-1**, resistor R402, diode D404, and the IR2112's nominal 500-mA current sinking capability determine gate drive impedance for the lower half-bridge transistor. A similar network is used on the upper half-bridge. These networks set turn-on gate drive impedance at approximately 120 ohms, and turn-off gate drive to approximately 500 mA. These values produce transition times of approximately 200 ns.

Transition times of this length represent a carefully weighed compromise between power dissipation and noise generation. Generally speaking, transition times longer than 250 ns tend to get power hungry at non-audible PWM rates; and transition times under 50 ns create di/dt's so large that proper operation is difficult to achieve. The HV SR power stage is designed with switching times at the higher end of this range to minimize noise.

Anti-parallel diode softness is also a first order design consideration. If the anti-parallel diodes in an off-line motor drive are allowed to snap, the resulting di/dt's can cause noise management problems that are difficult to solve. In general, it is desirable to have peak to zero di/dt approximately equal the applied di/dt that is used to turn the anti-parallel diodes off. The HFA16TA60CS soft recovery rectifiers that are used in this design are targeted at this kind of reverse recovery characteristic.

5.4 Bus Voltage and Current Feedback

Feedback signals proportional to bus voltage and bus current are provided by the circuitry shown in **Figure 5-2**. Bus voltage is scaled down by a voltage divider consisting of R224–R230. The values are chosen such that a 400-volt maximum bus voltage corresponds to 3.24 volts at output V_sense_DCB. An additional output, V_sense_DCB_half_15 provides a reference that is used in zero crossing detection.

Bus current is sampled by resistor R4 in **Figure 4-3. 3-Phase Output** and amplified by the circuit in **Figure 5-2**. This circuit provides a voltage output suitable for sampling with A/D inputs. An MC33502 is used for the differential amplifier. With R315 = R319 and R316 = R317, the gain is given by:

$$A = R315/R316$$

The output voltage is shifted up by 1.65 V to accommodate both positive and negative current swings. A ±3000 mV voltage drop across the sense resistor corresponds to a measured current range of ±2.93 amps. In addition to providing an A/D input, this signal is also used for cycle-by-cycle current limiting. A discussion of cycle-by-cycle current limiting follows in **5.5 Cycle-by-Cycle Current Limiting**.

5.5 Cycle-by-Cycle Current Limiting

Cycle-by-cycle current limiting is provided by the circuitry illustrated in **Figure 5-3**. Bus current feedback signal I_sense_DCB is filtered with R308 and C303 to remove spikes, and then compared to a 3.15-volt reference in U303B. The open-collector output of U303B is pulled up by R414. Additional filtering is provided by C413, C414, and C415. The resulting signal is fed into the IR2112 gate driver's shutdown input on all three phases. Therefore, when bus current exceeds 2.69 amps, all six output transistors are switched off.

The IR2112's shutdown input is buffered by RS latches for both top and bottom gate drives. Once a shutdown signal is received, the latches hold the gate drive off for each output transistor, until that transistor's gate drive signal is switched low, and then is turned on again. Hence, current limiting occurs on a cycle-by-cycle basis.

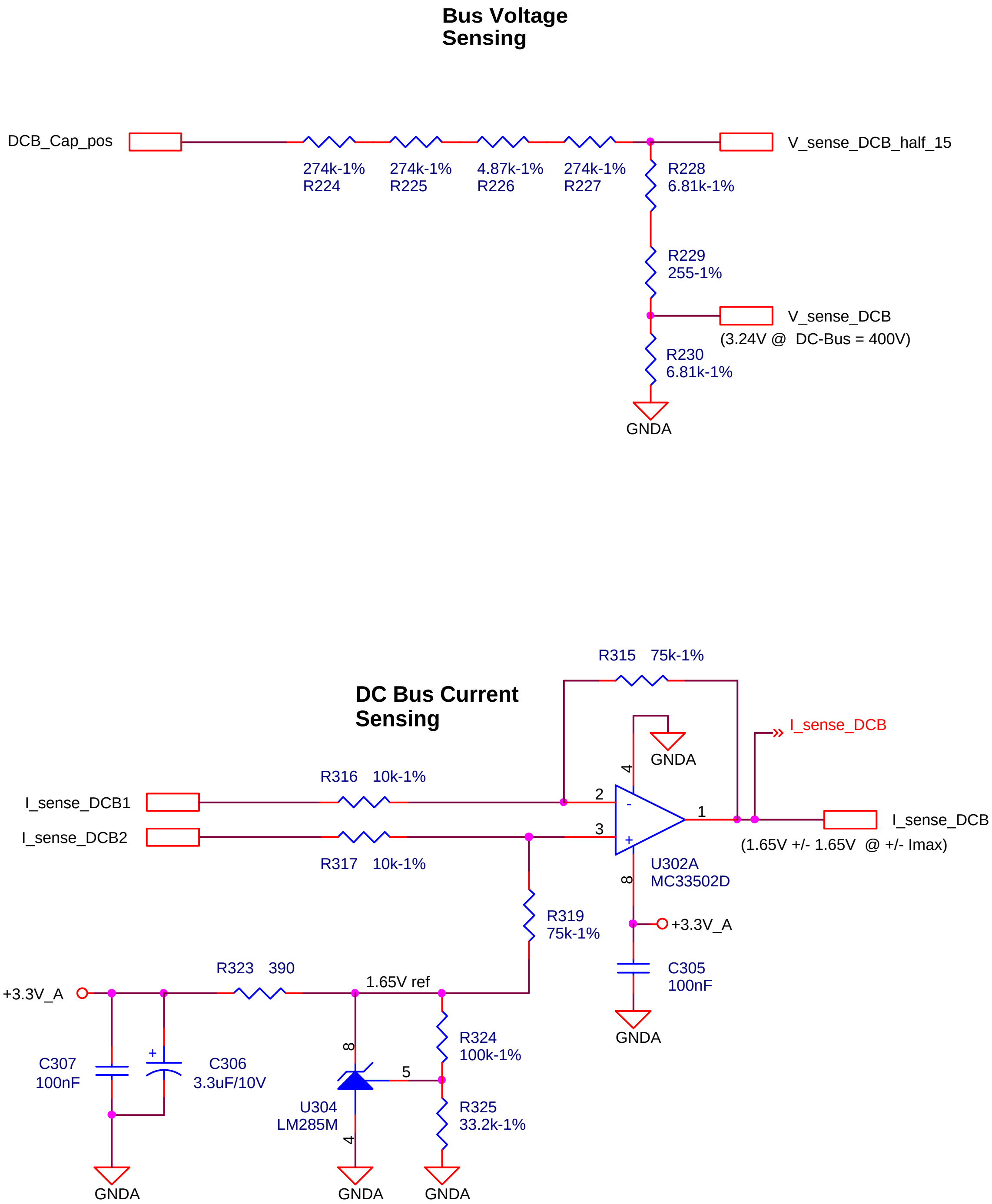


Figure 5-2. Bus Feedback

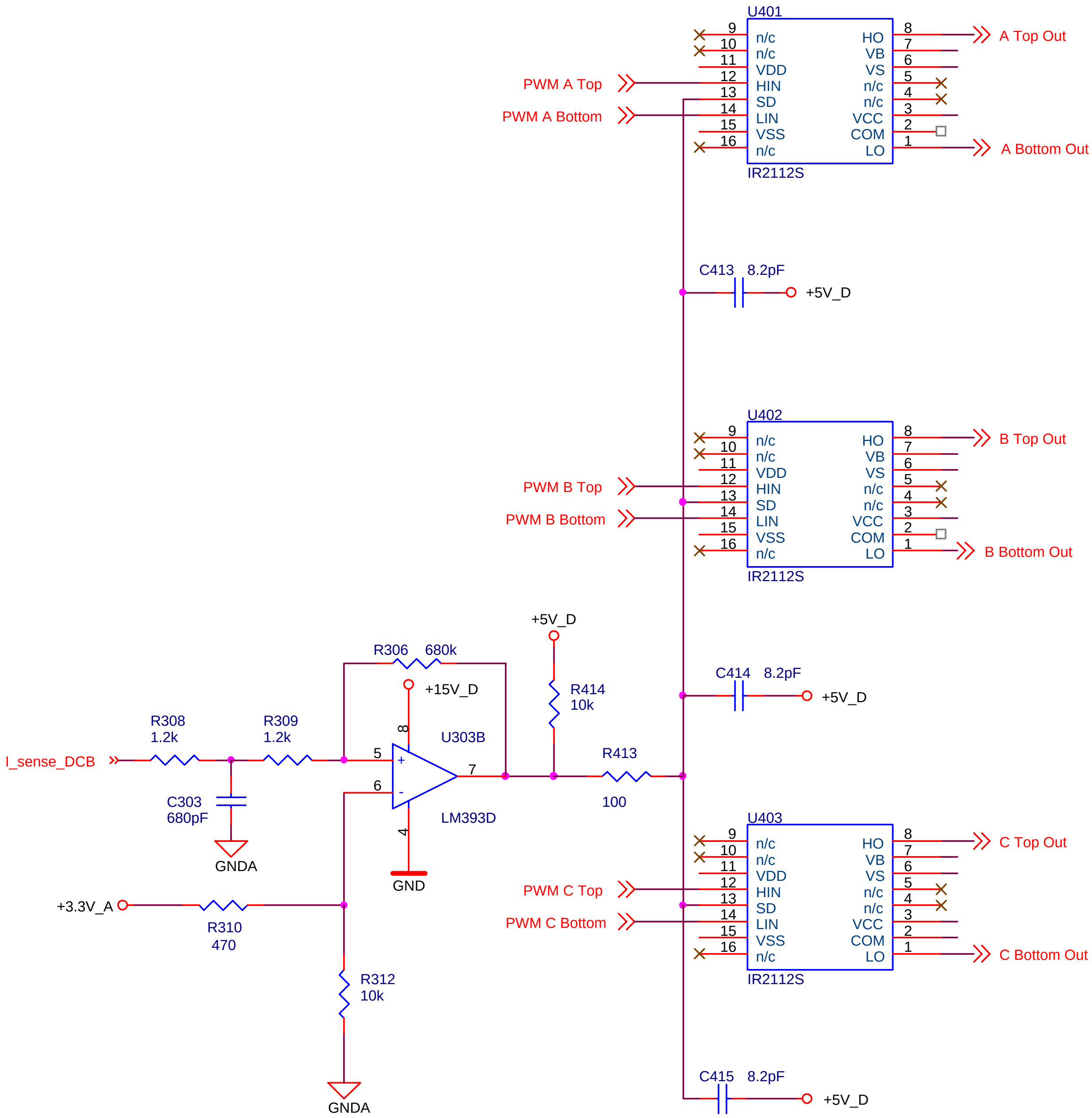


Figure 5-3. Cycle-by-Cycle Current Limiting

5.6 Temperature Sensing

Cycle-by-cycle current limiting keeps average bus current within safe limits. Current limiting by itself, however, does not necessarily ensure that a power stage is operating within safe thermal limits. For thermal protection, the circuit in **Figure 5-4** is used. It consists of four diodes connected in series, a bias resistor, and a noise suppression capacitor. The four diodes have a combined temperature coefficient of –8.8 mV/°C. The resulting signal, Temp_sense, is fed back to an A/D input where software can be used to set safe operating limits.

Due to unit-to-unit variations in diode forward voltage, it is highly desirable to calibrate this signal. To do so, a value for Temp_sense is read at a known temperature and then stored in non-volatile memory. The measured value, rather than the nominal value, is then used as a reference point for further readings.

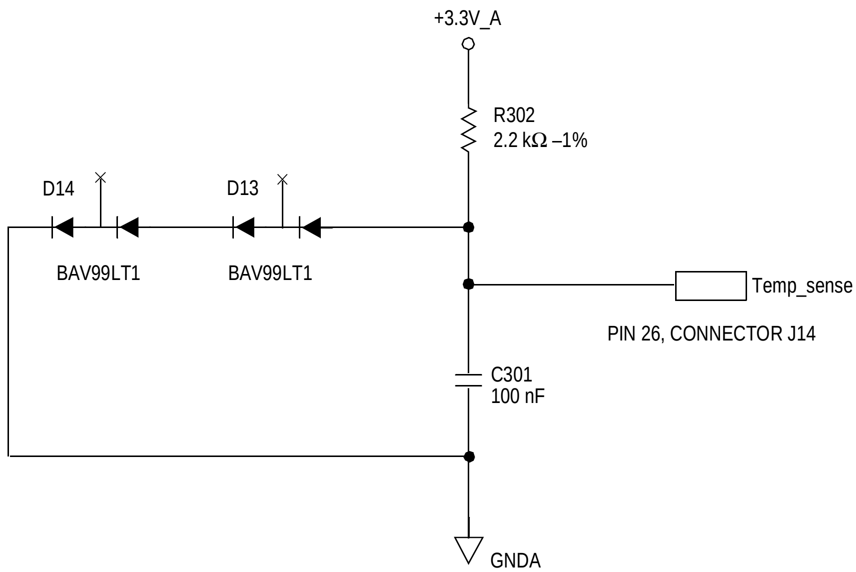


Figure 5-4. Temperature Sensing

5.7 Phase Current Sensing

Sampling resistors provide phase current information for all three phases. These resistors sample current in the lower phase legs which in a switched reluctance output directly measures phase current. The circuitry for phase A is shown in **Figure 5-5**.

Referencing the sampling resistors to the negative motor rail makes the measurement circuitry straightforward and inexpensive. Current is sampled by resistor R1, and amplified by differential amplifier U302B. This circuit provides a voltage output suitable for use with A/D inputs. An MC33502 is again used for the differential amplifier. With R301 = R304 and R303 = R305, the gain is given by:

$$A = R303/R301$$

The output voltage is shifted up by 1.65 V to accommodate both positive and negative current swings. A ±300-mV voltage drop across the shunt resistor corresponds to a measured current range of ±2.93 amps.

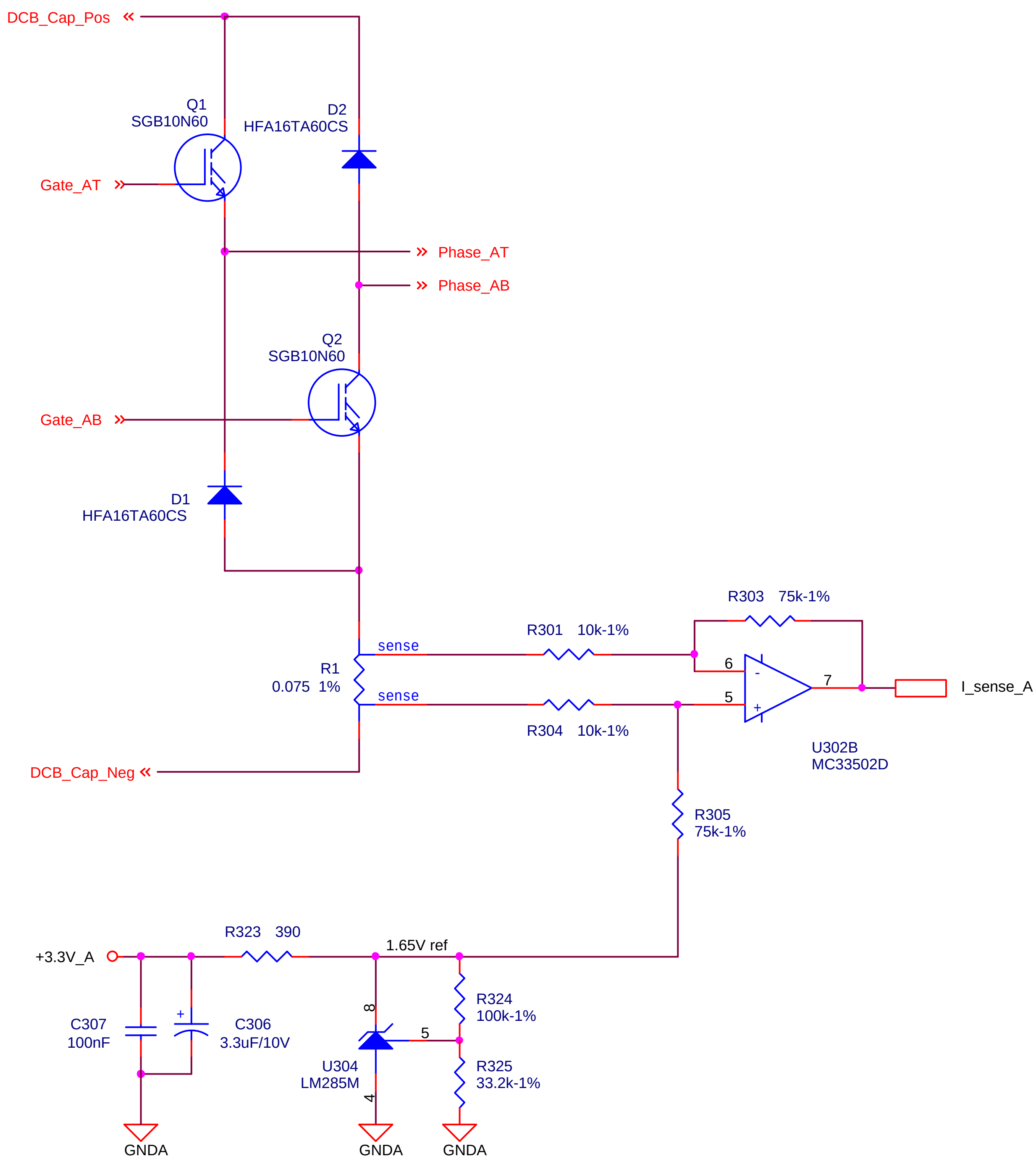


Figure 5-5. Phase A Current Sensing

5.8 Brake

A brake circuit is included to dissipate re-generative motor energy during periods of active deceleration or rapid reversal. Under these conditions, motor back EMF adds to the dc bus voltage. Without a means to dissipate excess energy, an overvoltage condition could easily occur.

The circuit shown in **Figure 5-6** connects R6–R9 across the dc bus to dissipate energy. Q7 is turned on by software when the bus voltage sensing circuit in **Figure 5-2** indicates that bus voltage could exceed safe levels. On-board power resistors R6–R9 will safely dissipate up to 50 watts continuously or up to 100 watts for 15 seconds. Additional power dissipation capability can be added externally via brake connector J12.

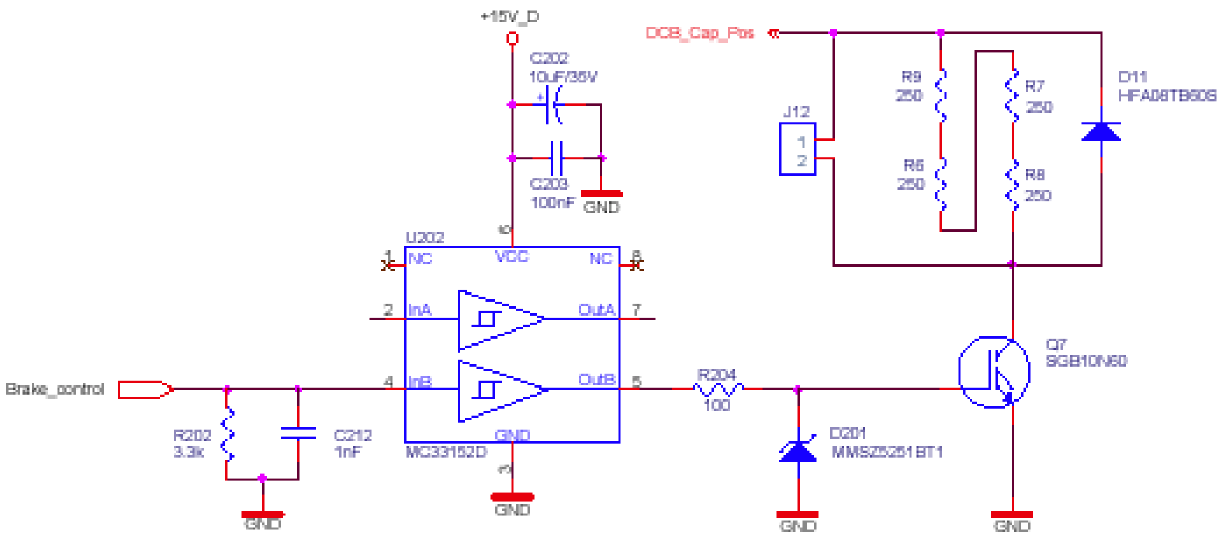


Figure 5-6. Brake

5.9 Power Factor Correction

A power factor correction (PFC) circuit is included to facilitate development of software that includes PFC control features. The objective of the PFC hardware and software are to draw sinusoidal current from the ac line in an attempt to approach as closely as possible a unity power factor. Without PFC, current is drawn from the ac line at the peak of the sine wave, when the ac line voltage exceeds the dc bus voltage. PFC circuitry is illustrated in **Figure 5-7**.

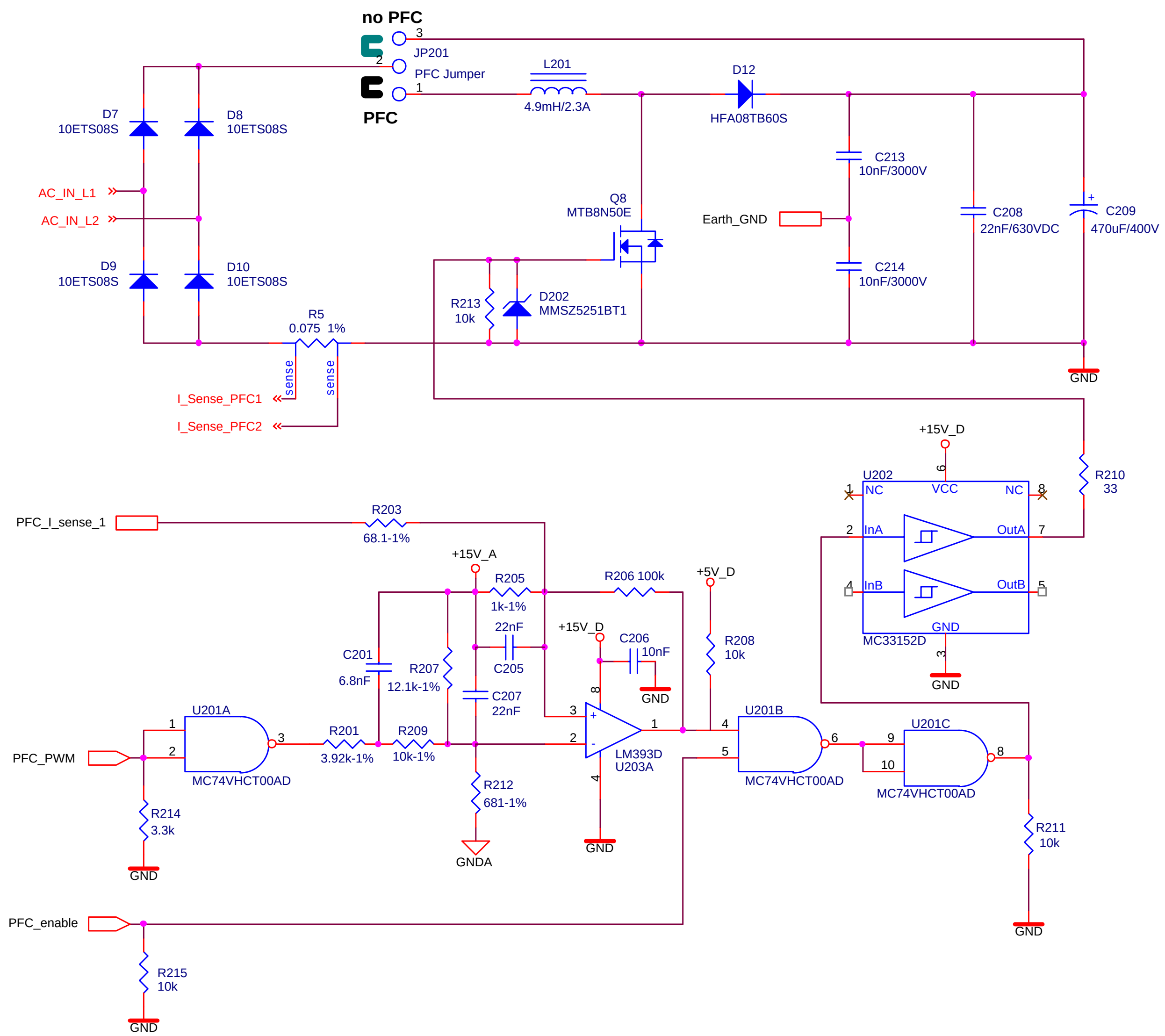


Figure 5-7. PFC Circuitry

Looking toward the top of **Figure 5-7**, Q8, L201, D12, and the bus capacitors form a boost power supply. The configuration allows current to be drawn from the ac line, when line voltage is lower than the dc bus voltage. Pulse width modulation is controlled by software, and augmented by the analog circuitry in the lower half of **Figure 5-7**. Voltage feedback is provided by the bus voltage sensing circuit in **Figure 5-2**. A zero cross feedback signal, PFC_z_c, is also used. PFC_z_c is produced by the circuit shown in **Figure 5-8**.

In this circuit, R219, R220, and R221 provide a relatively high impedance connection to the rectified line voltage, and form an 11:1 voltage divider with R222. D203 clamps the divided down voltage to approximately 15.7 volts. Comparator U203B then compares this signal to an 11.8-volt reference. Approximately 40 mV of hysteresis and a small reduction to the reference voltage are added by R216. The result is a logic high at output PFC_z_c when the comparator's input voltage falls below 11.72 volts. This output remains high until 11.76 volts is reached on the next cycle.

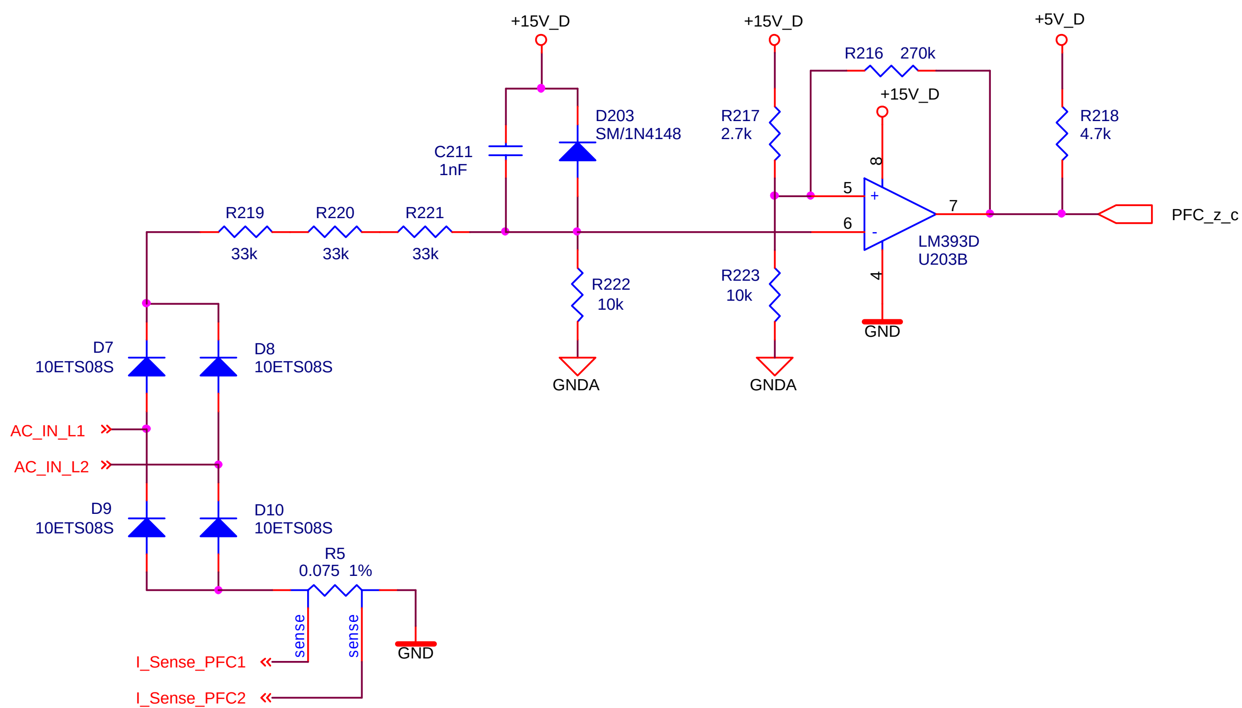


Figure 5-8. PFC Zero Crossing Feedback

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