3-Phase AC/BLDC High Voltage Power Stage Board

Users Guide

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3-Phase AC/BLDC High-Voltage, Power-Stage Board

Users Guide

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The following revision history table summarises changes contained in this document. For your convenience, the page number designators have been linked to the appropriate location.

Revision History

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Chapter 1
Introduction

1.1 Contents

1.2 3-Phase AC/BLDC High Voltage Power Stage Outline

Freescale's 3-Phase AC high-voltage brushless dc (BLDC) power stage (HV AC power stage) is a 115/230 volt AC, 750 voltamps (one horsepower), off-line power stage that is an integral part of Freescale's embedded motion control series of development tools.

With one embedded-motion-control-series control board, it provides a ready-made, software-development platform for one horsepower off-line motors. Feedback signals are provided that allow a variety of algorithms to control 3-phase AC induction and BLDC motors. The HV AC power stage also allows the connection of an external active power factor correction (PFC) board that facilitates development of PFC algorithms.

Figure 1-1 shows an illustration of the system architecture. Figure 1-2 is an illustration of the board.

The HV AC power stage features:

- 1-phase bridge rectifier
- dc-bus brake IGBT and brake antiparallel diode
- power and signal connectors for external PFC board
- 3-phase bridge inverter (6-IGBT's)
- Individual phase and dc bus-current-sensing shunts with Kelvin connections
- Power stage temperature sensing
- IGBT gate drivers
- Current and temperature signal conditioning
- 3-phase back-EMF voltage sensing and zero cross detection circuitry
- Low-voltage on-board power supplies
- Cooling fan

1.3 About this Manual

Key items are in the following locations in this manual:

- Setup instructions — 1.5 Setup Guide.
- Schematics — Appendix A. 3-Phase AC/BLDC High Voltage Power Stage Board Schematics.
- Pin assignments — Chapter 3 Pin Description
- Pin-by-pin description — 3.3 Signal Descriptions.
- Description of reference design aspects of the board's circuitry — Chapter 4 Design Consideration.

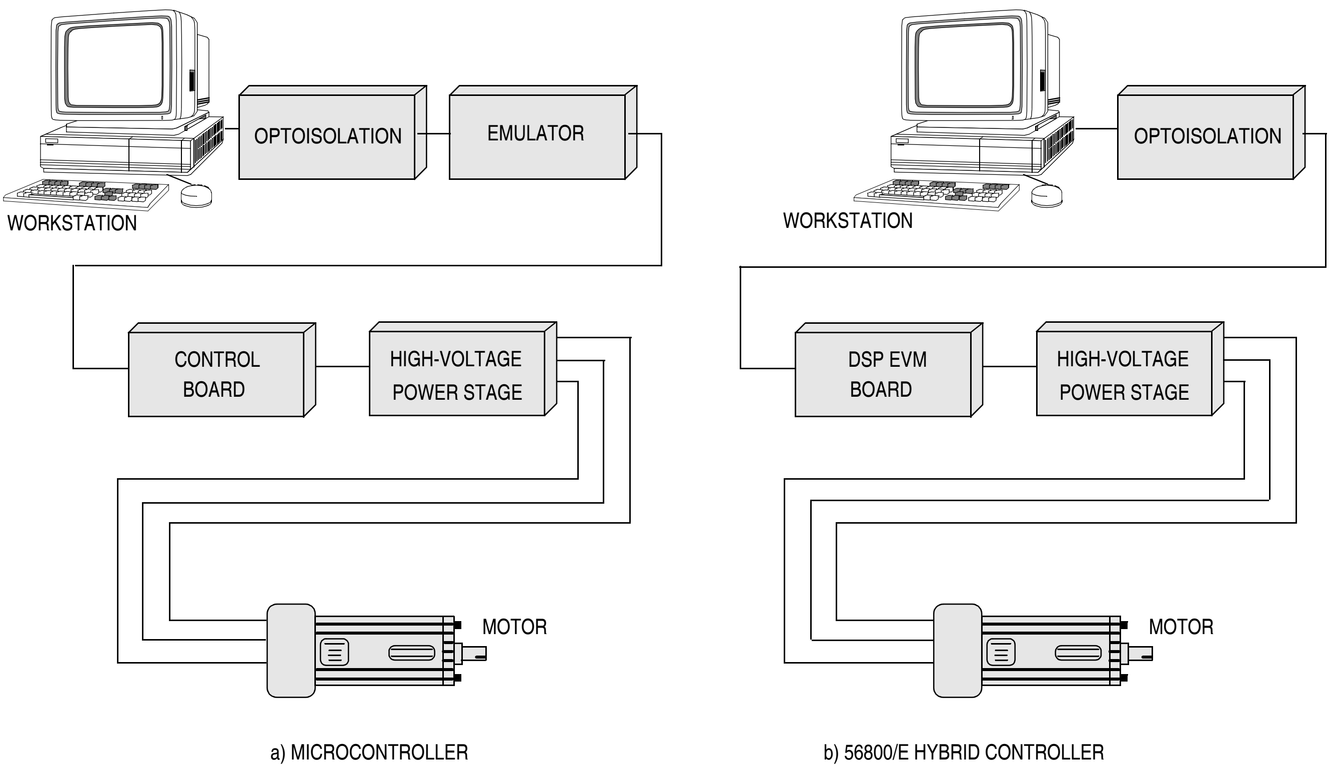

Figure 1-1 System Configurations

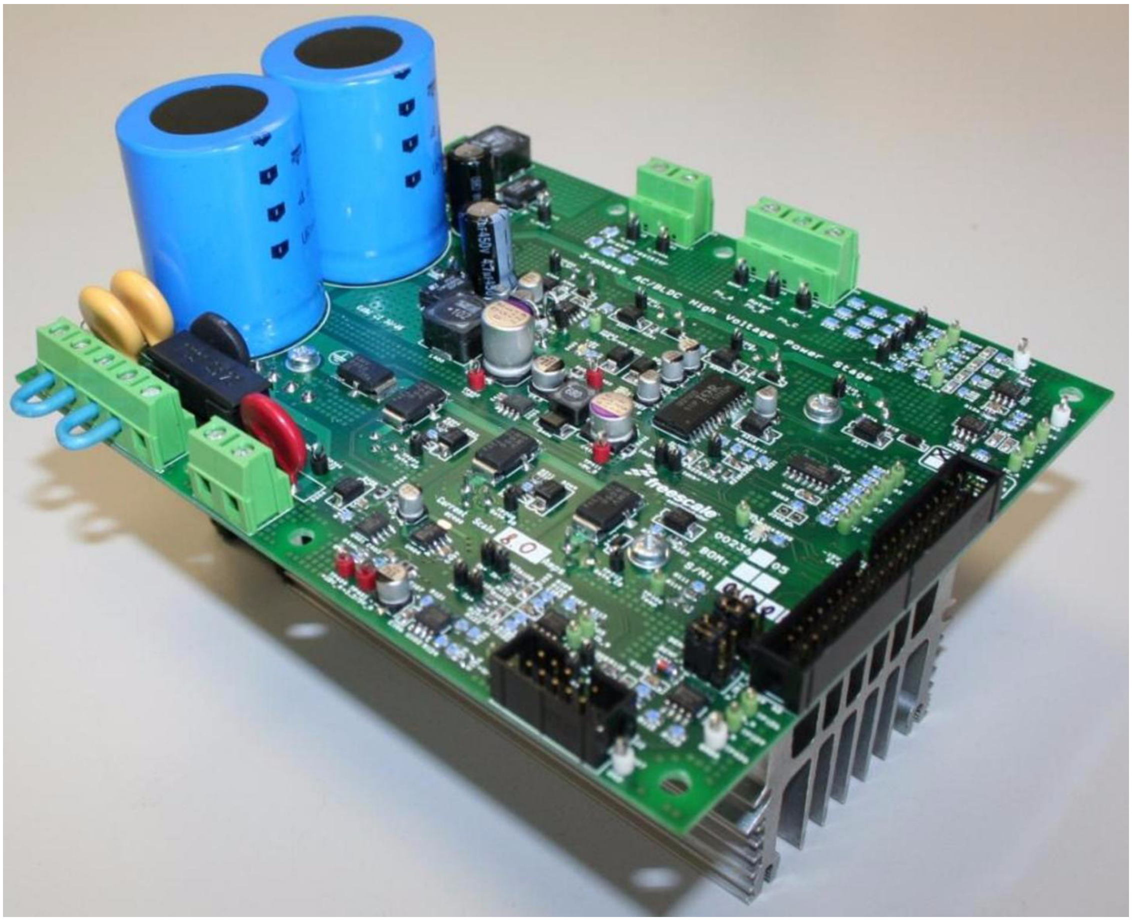

Figure 1-2 3-Phase AC/BLDC High-Voltage Power Stage

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 current-limited dc laboratory power supply, unless power-factor correction is specifically being investigated.

An isolation transformer must be used when operating off an AC power line.

If an isolation transformer is not used, the power stage grounds and oscilloscope grounds are at different potentials, unless the oscilloscope is floating.

Probe grounds. Therefore, the case of a floated oscilloscope is subjected to dangerous voltages.

Be aware:

- Before moving scope probes, making connections, etc., power down the high-voltage supply.
- When high voltage is applied, using only one hand for operating the test setup minimizes the possibility of electrical shock.
- Do not operate in lab setups that have grounded tables and/or chairs.
- Wear safety glasses, avoid ties and jewelry, use shields. Only personnel trained in high-voltage lab techniques should operate.
- Power devices and the motor can reach temperatures hot enough to cause burns.

When powering down, due to storage in the bus capacitors, dangerous voltages are present until all three power-on LEDs are off.

1.5 Setup Guide

Setup and connections for the HV AC power stage are straightforward. The power stage connects to an embedded motion-control-series control board via a 40-pin ribbon cable and can be powered by a 140 to 325-volt dc power supply or with line voltage. For safety reasons and ease of making measurements, use a dc supply, unless power-factor correction is specifically being investigated. Limit power supply to under eight amps. Figure 1-3 depicts a completed setup. The step-by-step setup procedure:

1. Plug one end of the 40-pin ribbon cable (that comes with the power stage kit) into the input connector J8. The other end of this cable goes to the embedded motion control board's 40-pin output connector (UNI-3 connector).
2. Connect motor leads to output connector J6, located along the back edge of the board. Phase A, phase B, and phase C are labelled Ph_A, Ph_B, and Ph_C.

   For an AC induction motor, it does not matter which lead goes to which phase. For BLDC motors, it is important to get the wire color coded for phase A into the connector terminal labelled Ph_A, and so on for phase B and phase C.
3. Connect earth ground to the connector J5 pin 3. It is labelled “Ground connections”.
4. Connect a line-isolated, current-limited dc power supply to connector J9, located on the front edge of the board. The input voltage range is 140 to 325 Vdc. Current limit should be set for less than 8 amps. The dc supply’s polarity does not matter.

   A 115-volt or 230-volt AC line coupled through an isolation transformer may be used instead of a dc-supply to provide input power. The connection is made on connector J9. Internal power supplies develop bias voltages. Only one power input is required.

   WARNING

   Operation off 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 off an AC power line.
5. Optional PFC — The power stage allows connection of an external PFC board. Connect a power terminal on the PFC board to the PFC POWER connectors J5 and J11. The control signals are connected via a 10-pin ribbon cable to the PFC SIGNAL connector J2. To run the power stage without a PFC, interconnect the pins J5.1 (PFC_Neg2) and J5.2

(PFC_Neg1), J11.1 (PFC_Pos2) and J11.2 (PFC_Pos1) by a power-jumper wires (manufacturer setting).

6. Optional braking resistor — If braking mode is investigated during motor operation, an external resistor must be connected to the connector J4, Brake resistor.
7. Set up the control board. For safety reasons and avoiding damaging the computer, insert any galvanic isolation, as an opto box, between the control board and computer.
8. Apply power to the power stage. All green power-on LEDs (+18V and +5V_D in the center, +12V in the upper left-hand corner) light, and the fan runs when power is present. If the fan does not run, check if the jumper J1 is installed (default setting). The power stage powers the control board.

WARNING

Hazardous voltages are present. Re-read all of 1.2 Warnings carefully.

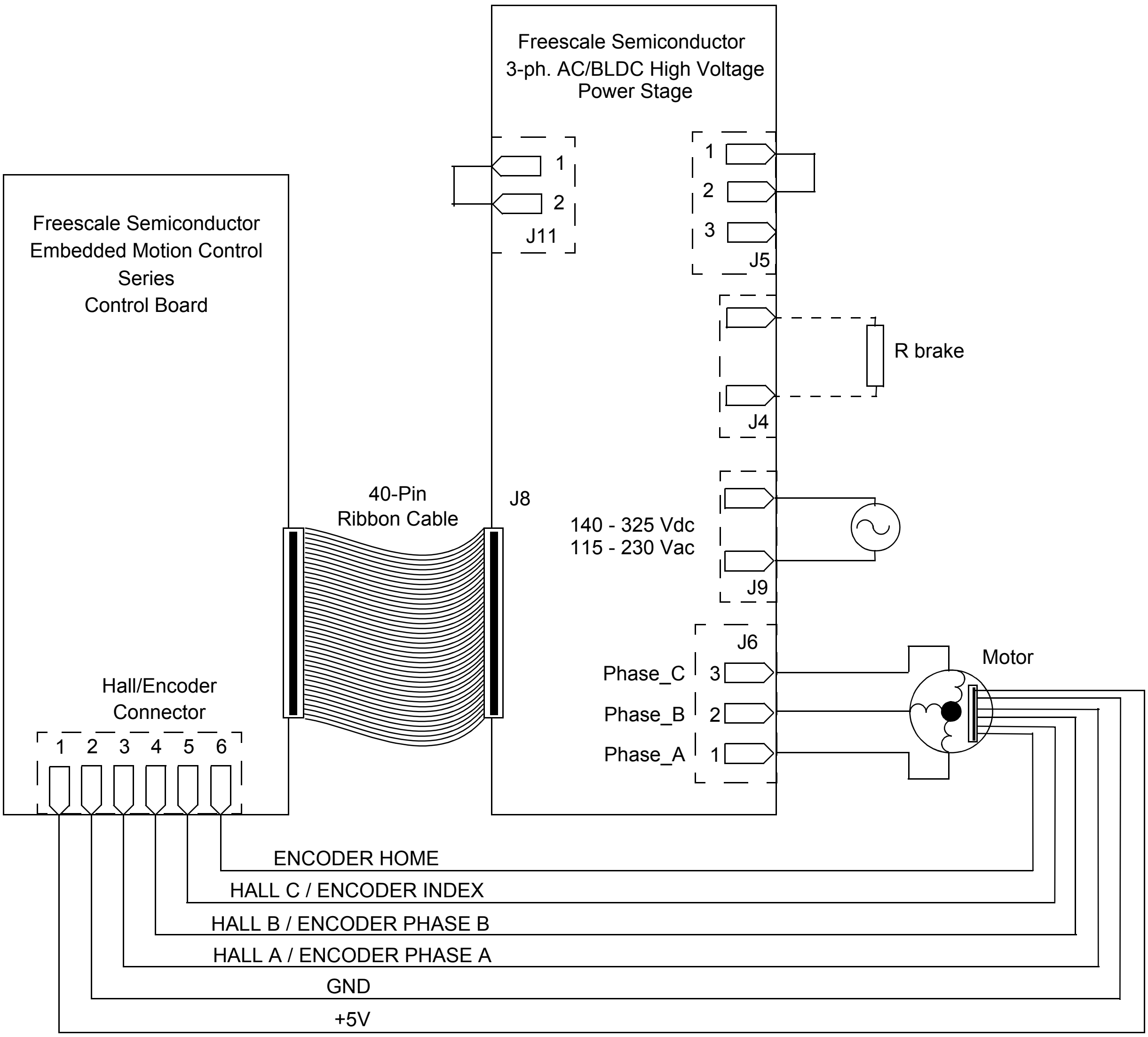

Figure 1-3 3-Phase AC/BLDC High-Voltage Power Stage Setup Without External PFC

Chapter 2
Operational Description

2.1 Contents

2.2 Introduction

Freescale's embedded motion-control series high-voltage (HV) ACAC power stage is a 750-voltamps (one horsepower), 3-phase power stage that will operate off dc input voltages from 140 V to 325 V, and AC line voltages from 100 V to 240 V. With an embedded motion-control-series control boards, it provides a software-development platform that allows algorithms to be written and tested without designing and building a power stage. It supports a variety of algorithms for AC induction and brushless dc (BLDC) motors.

The high-voltage AC-power stage has a printed circuit board. The printed circuit board contains an input rectifier, brake IGBT and diode, bridge IGBTs, IGBT-gate-drive circuits, analog-signal conditioning, low-voltage power supplies, and some large, passive, power components. All power devices that need to dissipate heat and a temperature sensor are mounted on a heatsink situated below the printed circuit board (Figure 1-2).

Figure 2-1 shows a block diagram. Input connections are made via 40-pin ribbon-cable connector J8. Figure 3-1 shows pin assignments for the input connector. Power connections to the motor are made on output connector J6. Phase A, phase B, and phase C are labelled Ph_A, Ph_B, and Ph_C on the board. Power requirements are met by a single external 140V to 325V dc-power supply or an AC-line voltage. Either input is supplied through connector J9. An external brake resistor can be connected via connector J4. The power stage can be extended by an external PFC board. PFC board connection is made via power connectors J5, J11 and signal connector J2.

Current measuring circuitry is set up for 8 amps full scale. Both bus and phase leg currents are measured. An overcurrent trip point is set at 10 amps.

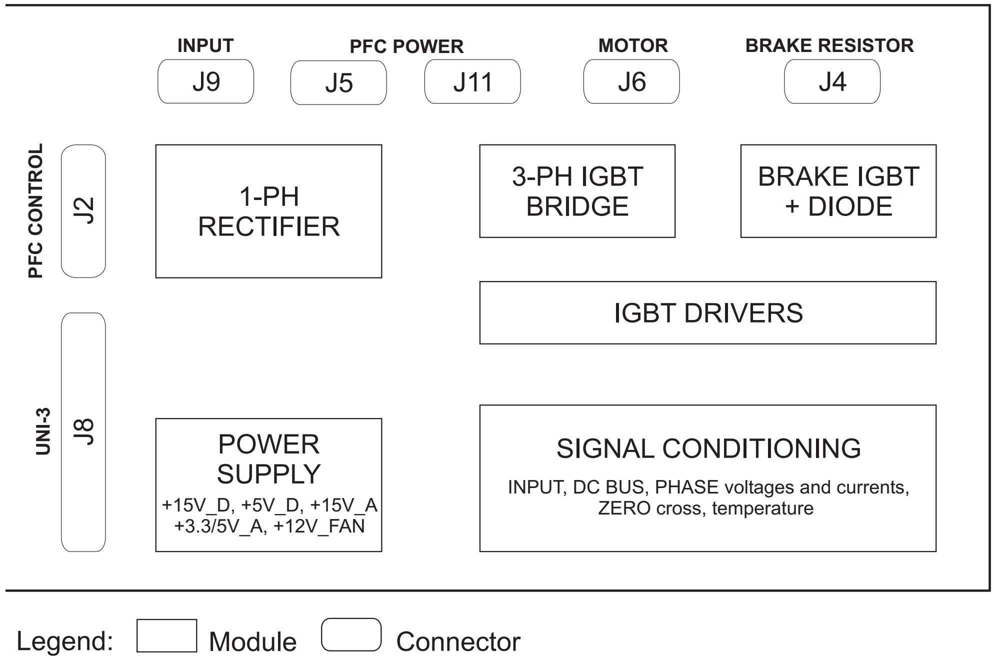

Figure 2-1 Block Diagram

2.3 Electrical Characteristics

The electrical characteristics in Table 2-1 apply to operations at 25°C with a 325-Vdc power-supply voltage.

Table 2-1 Electrical Characteristics

Characteristic	Symbol	Min	Typ	Max	Units
dc input voltage	V_{dc}	140	—	325	V
AC input voltage	V_{ac}	100	—	240	V
Quiescent Current*	I_{CC}	—	TBD	—	mA
Logic 1 Input Voltage	V_{IH}	1.5	—	1.7	V
Logic 0 Input Voltage	V_{IL}	0.9	—	1	V
Input Resistance	R_{In}	—	10	—	kΩ
Analog Output Range**	V_{Out}	0	—	3.3	V
Bus Current Sense Voltage	I_{Sense}	—	206.25	—	mV/A
Bus Current Sense Offset	I_{offset}		$+V_{REF}$		V
Bus Voltage Sense Voltage	V_{Bus}	—	8.09	—	mV/V
Bus Voltage Sense Offset	V_{offset}		0		V
Continuos Output Current ***)	I_C	—	—	10	A
Total Power Dissipation (per MOSFET) ***	P_D	—	—	TBD	W
Deadtime (build in IR2133)	t_{off}	—	250	—	ns

* Measured with an input power of 24V.
** Range set according +3.3V_A/+5V_A Power Supply
*** The values are measured at 25°C, for other temperatures the values may be different

2.4 Fuse replacement

A fast blow fuse is located on the front left side behind the PFC power connector J5. If this fuse needs replaced, follow these steps:

1. Remove power and wait until all power-on LEDs are off.
2. Remove the fuse’s protective case.
3. Replace the fuse with a new one — F 250V/6A.
4. Replace the protective case.
5. Set the controller’s speed control input to zero RPM.
6. Apply power and resume operation.

Chapter 3
Pin Description

3.1 Contents

3.2 Introduction

Inputs, outputs, and jumper terminals are located on twelve connectors available on the board:

- Fan
- PFC signals
- Jumper J3 and J7
- Brake resistor
- PFC power
- 3-pin motor
- 40-pin UNI-3
- Line input
- Earth ground connection
- External -15V_A jumper

Pin descriptions for each connector and the test points are identified in the following information. Figure 3-1 shows the pin assignments for the UNI-3 connectors. Table 3-7 shows the signal descriptions.

The 3-phase AC/BLDC High-Voltage Power Stage contains several connectors that serve for a connection of a power supply, for motor phases connection, and other functions.

The input power supply attached to the J9 line AC input must not be less than 100V or higher than 230V, or a DC power supply between 140V and 325V.

The output for the motor is done by a 3-way connector J6. See 3.3.5 Motor Connector J6 for more details.

3.3 Signal Descriptions

Pin descriptions are identified in this subsection.

3.3.1 Fan Terminal J1

Cooling efficiency can be increased by using a fan mechanically mounted on a heat-sink. To use a fan, set the jumper plug on Fan Terminal J1.

3.3.2 PFC Signals Connector J2 and PFC POWER Connectors J5 and J11

These connectors allow connecting an external PFC board that facilitates development of PFC algorithms. On the PFC signals connector, control and sensing signals are available for an external PFC board. Table 3-1 shows the pin connections and descriptions. Signals V-IN and I_IN from the PFC signals connector can be shared with BEMF sense signals, or with phase-current sense signals on the UNI-3 connector, to further evaluate these signals in the controller board, according to the PFC algorithms.

Table 3-1 Connector J2 Signal Descriptions

Pin No.	Signal Name	Description
1	PWM_PFC	Signal for PFC transistor control connected only to PFC_PWM pin 31 of UNI-3 connector
2	GND	Digital and power supply ground
3	V_IN	V_IN is an sense signal from an external PFC board. Connection is determined by the settings of the J3 and J7 jumper terminals.
4	I_IN	I_IN is an sense signal from an external PFC board. Connection is determined by the settings of the J3 and J7 jumper terminals.
5	+3.3_A/+5V_A	+3.3-volt or +5-volt power supply depends on board configuration
6	GNDA	power supply ground
7	+Vref	Reference signal Vref for current sensing offset
8	+5V_D	Digital +5-volt power supply
9	+18V_D	Digital +18-volt power supply
10	GND	Digital and power supply ground

Table 3-2 and Table 3-3 shows pin descriptions of the PFC POWER Connectors J5 and J11. To supply the board through the J9 line input connector, a power wire jumpers should be plugged. Connect a power wire jumpers between pins DCB_Pfc_Pos1 and DCB_Pfc_Pos2, DCB_Pfc_Neg1 and DCB_Pfc_Neg2 to select line input as the source for the power stage board (see Figure 1-3). Pin 3 of J5 connector is used as ground connection. It is marked with a ground symbol. You can also supply the power stage from an external PFC board. Then do not plug jumpers, or remove them if plugged, and connect the external PFC board according to Table 3-2 and Table 3-3. The external PFC can then be controlled by signals available on the PFC signals connector J2.

Table 3-2 PFC POWER Connector J5 Descriptions

Pin Number	Signal Name	Description
1	DCB_Pfc_Neg2	Negative bus input and external PFC board negative bus input.
2	DCB_Pfc_Neg1	Negative output from input bridge rectifier and external PFC board negative output from input bridge rectifier.
3	Earth_GND	Ground connection for the line input and external PFC board ground.

Table 3-3 PFC POWER Connector J11 Descriptions

Pin Number	Signal Name	Description
1	DCB_Pfc_Pos2	Positive bus input and external PFC board positive bus input.
2	DCB_Pfc_Pos1	Positive output from input bridge rectifier and external PFC board positive output from input bridge rectifier.

3.3.3 Jumper Terminals J3 and J7

Table 3-4 and Table 3-5 show jumper terminal settings for selected configurations. Each table row means one option of configuration and determines the pins shorted by a jumper plug.

Table 3-4 Jumper J3 Setting Descriptions

Shorted pins	Description
1-3	BEMF_sense_C signal from UNI-3 connector J8 is connected to BEMF_sense_C signal on power stage board
5-3	BEMF_sense_C signal from UNI-3 connector J8 is connected to V_IN signal on PFC signals connector J2
2-4	BEMF_sense_B signal from UNI-3 connector J8 is connected to BEMF_sense_B signal on power stage board
6-4	BEMF_sense_B signal from UNI-3 connector J8 is connected to V_IN signal on PFC signals connector J2

Table 3-5 Jumper J7 Setting Descriptions

Shorted pins	Description
1-3	I_sense_C signal from UNI-3 connector J8 is connected to I_sense_C signal on power stage board
5-3	I_sense_C signal from UNI-3 connector J8 is connected to V_IN signal on PFC signals connector J2
2-4	I_sense_B signal from UNI-3 connector J8 is connected to I_sense_B signal on power stage board
6-4	I_sense_B signal from UNI-3 connector J8 is connected to I_IN signal on PFC signals connector J2

3.3.4 Brake Resistor Connector J4

A brake resistor can be connected to brake-resistor connector J4. The brake resistor allows power dissipation and can be controlled through the brake control situated on pin 29 of the UNI-3 connector J8.

3.3.5 Motor Connector J6

Power outputs to the motor are located on connector J6. Phase outputs are labelled Ph_A, Ph_B, and Ph_C. Table 3-6 contains pin assignments. Section 1.5 Setup Guide shows how to connect the motor. On an induction motor, any one of three phase windings can be connected here. For brushless dc motors, you must connect the wire color coded for phase A into the connector terminal labelled Ph_A, and so on for phase B and phase C.

Table 3-6 Connector J6 Signal Descriptions

Pin Number	Signal Name	Description
1	Ph_A	Phase_A supplies power to motor phase A.
2	Ph_B	Phase_B supplies power to motor phase B.
3	Ph_C	Phase_C supplies power to motor phase C.

3.3.6 UNI-3 Connector J8

Signal inputs and outputs are grouped together on the 40-pin ribbon cable connector J8, located on the board's right-side edge. Figure 3-1 shows pin assignments. 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. Table 3-7 lists signal descriptions.

The UNI-3 connector serves for interconnection with a control or EVM board.

3.3.6.1 Changes to Standard UNI-3 Connection

The 3-Phase AC/BLDC High Voltage Power Stage Board board does not use full UNI-3 interface and brings a few UNI-3 signals changes. First, a change exists in the supply voltage, -15V_A on pin 20. -15V_A can be gained only from external power supply source - see 3.3.9 External -15V_A jumper J12.

The serial communication pin 30 is unconnected, as are PFC_enable pin 32 and PFC_z_c pin 33.

See Figure 3-1 for more details.

Table 3-7 Connector J8 Signal Descriptions

Pin Number	Signal Name	Description
1	PWM_AT	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	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	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	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	Gate-drive signal for the top half-bridge of phase C. A logic high turns on phase C's top switch.
10	Shielding	Pin 10 is connected to a shield wire in the ribbon cable and ground on the board.
11	PWM_CB	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	+3.3/5V_A	Analog +3.3-volt or +5-volt power supply
17	GNDA	Analog-power supply ground
18	GNDA	Analog-power supply ground, redundant connection

Table 3-7 Connector J8 Signal Descriptions (Continued)

Pin Number	Signal Name	Description
19	+15V_A	Analog +15-volt power supply
20	-15V_A	Analog -15-volt power supply
21	V_sense_DCB	Analog-sense signal that measures bus voltage. It is scaled at 8.09V per volt of dc bus voltage.
22	I_sense_DCB	Analog-sense signal that measures bus current. It is scaled at 8.09V per amp of dc bus current.
23	I_sense_A	Analog-sense signal that measures current in phase A. It is scaled at 50V per amp of dc bus current.
24	I_sense_B	Analog-sense that measures current in phase B. It is scaled at 0.563V per amp of dc bus current.
25	I_sense_C	Analog-sense signal that measures current in phase C. It is scaled at 0.563 volts per amp of dc bus current.
26	Temp_sense	Analogu-sense signal that measures temperature on the heatsink.
27	NC	No connection
28	Shielding	Pin 28 is connected to a shield wire in the ribbon cable and ground on the board.
29	Brake_control	Gate-drive signal for the brake IGBT.
30	Serial_Con	No connection
31	PFC_PWM	Digital signal that controls the power factor correction circuit's switch.
32	PFC_enable	No connection
33	PFC_z_c	No connection
34	Zero_cross_A	Digital signal used for sensing phase A back-EMF zero-crossing events.
35	Zero_cross_B	Digital signal used for sensing phase B back-EMF zero-crossing events.
36	Zero_cross_C	Digital signal used for sensing phase C back-EMF zero-crossing events.
37	Shielding	Pin 37 is connected to a shield wire in the ribbon cable and ground on the board.
38	BEMF_sense_A	Analog-sense signal that measures phase A back EMF. It is scaled at 8.09mV per volt of dc bus voltage.
39	BEMF_sense_B	Analog-sense signal that measures phase B back EMF. It is scaled at 8.09mV per volt of dc bus voltage.
40	BEMF_sense_C	Analog-sense signal that measures phase C back EMF. It is scaled at 8.09mV per volt of dc bus voltage.

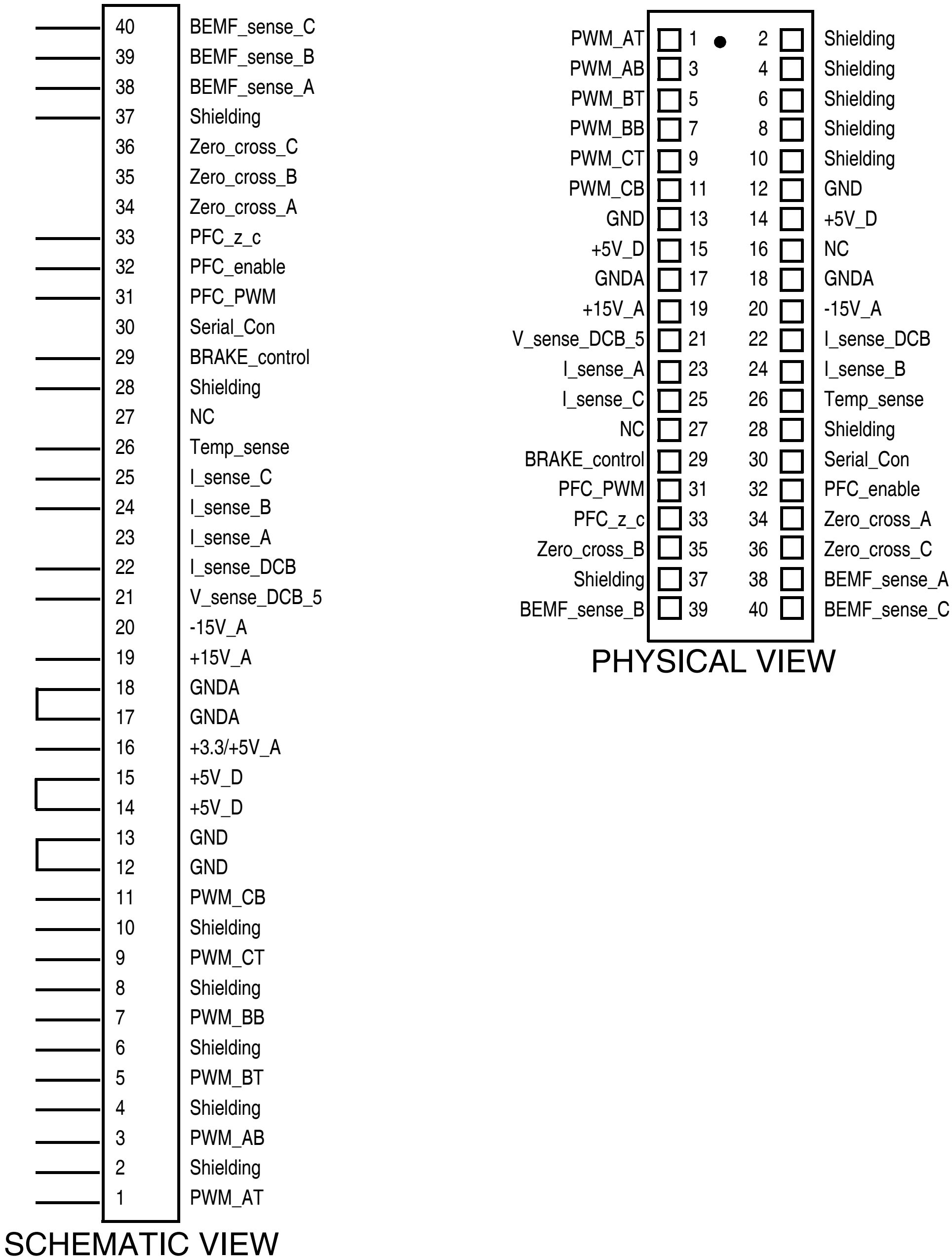

Figure 3-1 40-Pin Connector J8

3.3.7 Line Input Connector J9

The line input connector, labelled J9, is located on the front edge of the board. It accepts dc voltages from 140V to 315V or an isolated AC line input from 100V to 230V. In either case, the power source should be capable of supplying at least 750 watts.

3.3.8 Earth Ground Terminal J10

One hole is used as earth ground connection J10. The J10 hole is used for mounting and ground connection of the heatsink.

Connect an earth ground to the earth ground terminal on the heat sink. The heat sink has a screw on its front edge that is marked with a ground symbol.

As mentioned in previous chapters, the 3-phase AC/BLDC High-Voltage Power Stage board contains more grounds. These grounds are connected into one point. If necessary, the user can remove ground connection GC400 to disconnect the grounds and perform measurements.

3.3.9 External -15V_A jumper J12

An external -15V power supply source can be connected to the power stage board through jumper J12 to supply boards connected through UNI-3 connector J8 by -15V_A (pin 20).

Chapter 4
Design Consideration

4.1 Contents

4.2 Overview

From a systems point of view, the HV AC power stage fits into an architecture designed for software development. In addition to the hardware needed to run a motor, a variety of feedback signals that facilitate control algorithm development are provided. A set of schematics for the 3-phase AC/BLDC High-Voltage Power-Stage appears in the following section.

Circuit descriptions for the HV AC power stage appear in 4.3 3-Phase Bridge through 4.12 Power Supplies and Voltage Reference. One phase leg of the 3-phase bridge is examined in 4.3 3-Phase Bridge. Bus voltage and bus current feedback are discussed in 4.4 Bus Voltage and Current Feedback. Safety functions are highlighted in 4.5 Over-current and Undervoltage Functions. Temperature sensing is discussed in 4.6 Temperature Sensing. Back-EMF signals appear in 4.7 Back EMF Signals. Phase current sensing is discussed in 4.8 Phase Current Sensing. The brake is highlighted in 4.9 Brake. Power-factor correction is discussed in 4.10 External Power Factor Correction. Test Points description and LED description are made in 4.11 Test Points and LED Indication, and finally, all power supplies and Voltage reference are described in 4.12 Power Supplies and Voltage Reference.

4.3 3-Phase Bridge

The output stage is configured as a 3-phase bridge with IGBT-output transistors. It is simplified considerably by a high-voltage, integrated-gate driver that has an over-current and undervoltage limit feature. Figure 4-1 shows a schematic of one phase. At the input, pull-down resistors R207 and R208 set a logic low in the absence of a signal. Open input pull-down is important because the power transistors must stay off in case of a broken connection or an absence of power on the control board. The drive signal is buffered and inverted by U200A and U200B. This part has a minimum logic 1 input voltage of 1.2V and a maximum logic 0 input voltage of 0.5V, which allows for inputs from 3.3V or 5V logic. An international rectifier, IR2133, supplies gate drive. IR2133 also provides undervoltage lockout and over-current. Undervoltage lockout is 8.2V/8.6V volts, depending on the current threshold. IR2133 has an implemented 250 ns deadtime insertion. Current limiting and undervoltage lockout are discussed further in 4.5 Over-current and Undervoltage Functions. One important design decisions in a motor drive is the selection of gate-drive impedance for the output transistors. In Figure 4-1, resistor R206, diode D203, and the IR2133 nominal 420-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 75 Ω and turn-off gate drive to approximately 420 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, transition times longer than 250 ns tend to get power hungry at non-audible PWM rates; transition times under 50 ns create di/dts so large that proper operation is difficult to achieve. The HV AC power stage is designed with switching times at the higher end of this range to minimize noise.

Anti-parallel diode softness is also a primary design consideration. If the anti-parallel diodes in an off-line motor drive are allowed to snap, the resulting di/dts can cause noise management problems difficult to solve. In general, the peak to zero di/dt should be approximately equal to the di/dt applied to turn off the anti-parallel diodes. The SKP10N60 IGBT’s used in this design are targeted at this kind of reverse recovery.

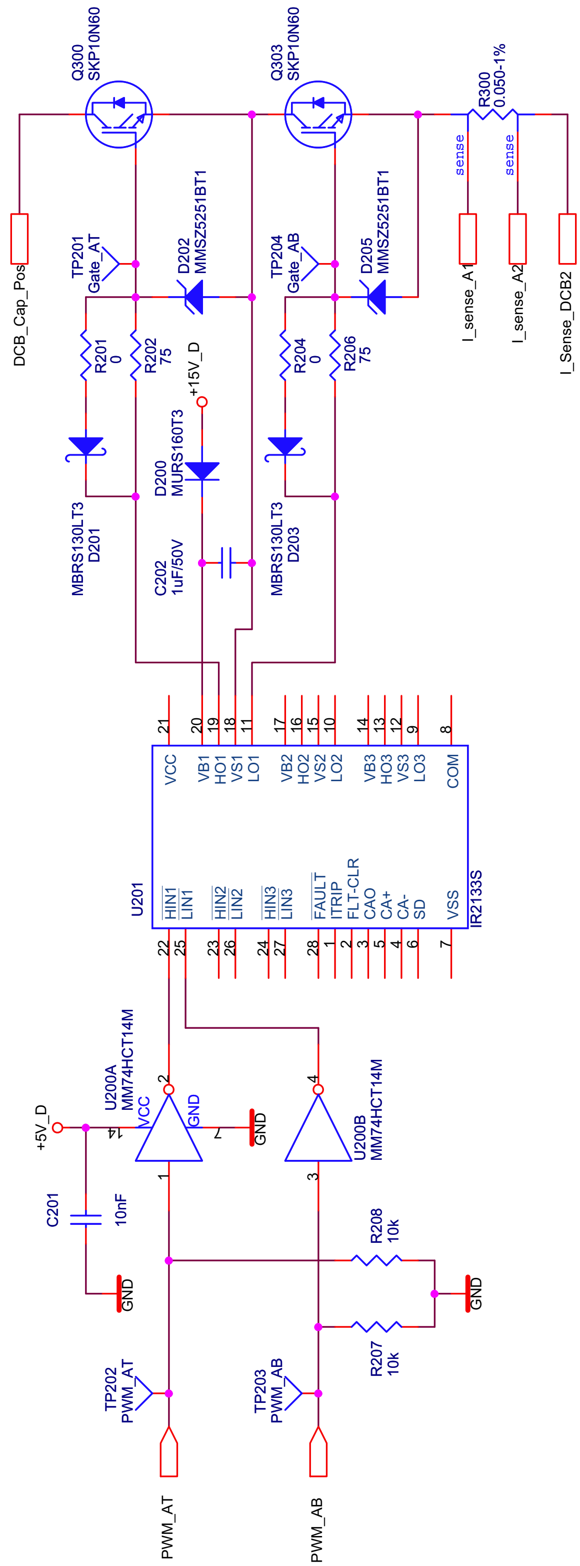

Figure 4-1 Phase Output

4.4 Bus Voltage and Current Feedback

Figure 4-2 shows the circuitry that provides feedback signals proportional to bus voltage and bus current. Bus voltage is scaled down by a voltage divider consisting of R135, R138, R142, R144, R147, R150, and R152. The values are chosen such that a 400-volt bus voltage corresponds to 3.235V at output V_sense_DCB. An additional output, V_sense_DCB_half_15, provides a reference used in zero-crossing detection. Bus current is sampled by resistor R303 in Figure A-5 and amplified in IR2133's operational amplifier (Figure 4-2). This circuit provides a voltage output suitable for sampling with A/D (analog-to-digital) inputs. IR2133's operational amplifier is used as a differential amplifier for bus-current sensing. With R200 = R217, R218 = R226, and R221 = R227, the gain is given by:

A = R227/(R200+R226)

The output voltage is shifted up by +Vref to accommodate positive and negative current swings. A ±400-mV voltage drop across the sense resistor corresponds to a measured current range of ±8 amps. The default current range 8 amps is marked on the actual PCB board (see Figure 4-3). In addition, a -I signal is connected to the ITRIP input of IR2133 and provides an over-current triggering function. A discussion of over-current limiting follows in 4.5 Over-current and Undervoltage Functions.

The output is connected to the UNI-3 pin 22 I_sense_DCB. V_dcb is scaled at 8.09mV per volt of the DC bus voltage and connected to the UNI-3 pin 21 V_sense_DCB_5.

The shunt resistor is represented by a 0.050-ohm resistance Isabellenhutte SMV SMD precision resistor, the same as the phase current measurement resistors.

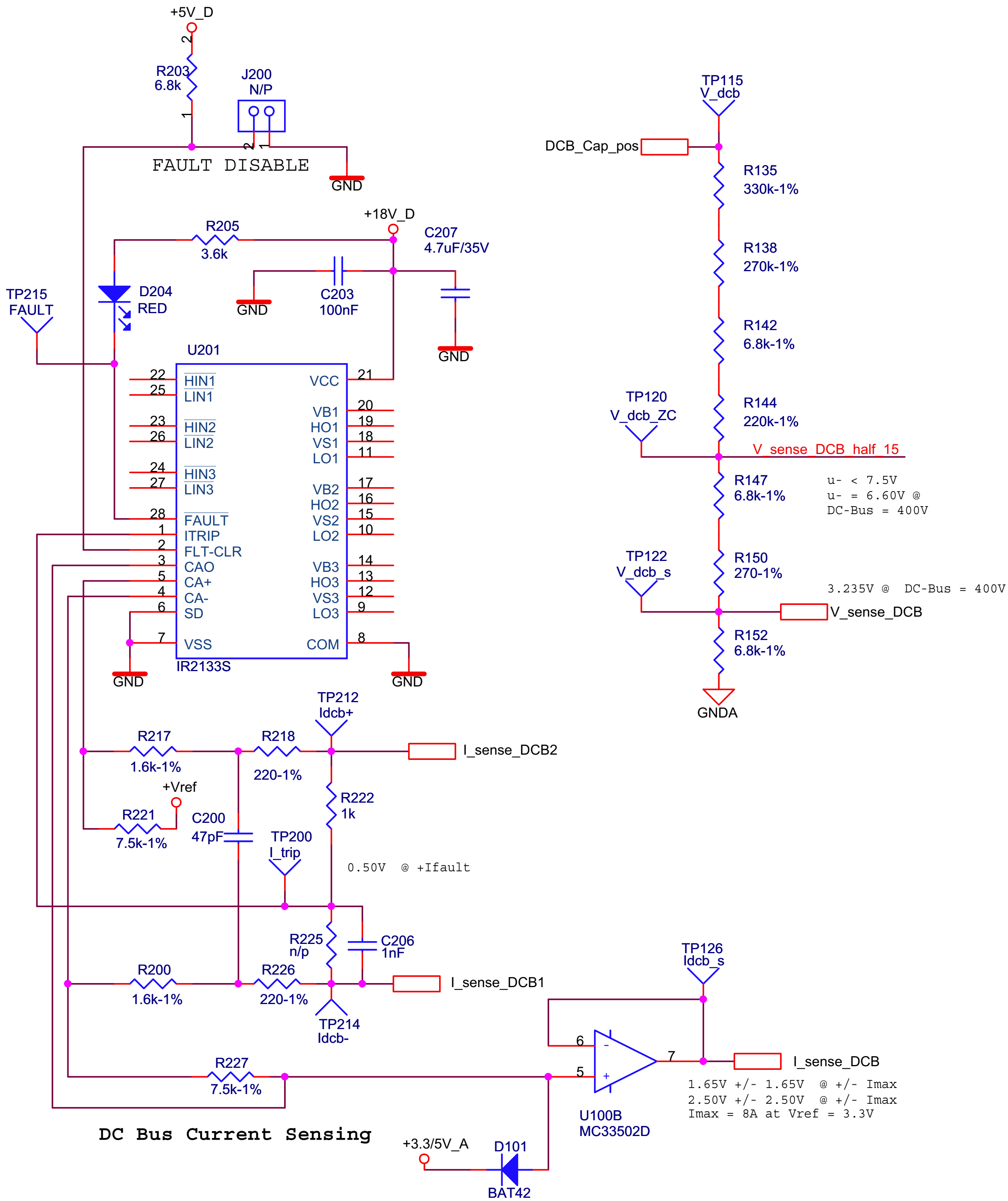

Figure 4-2 Bus Feedback

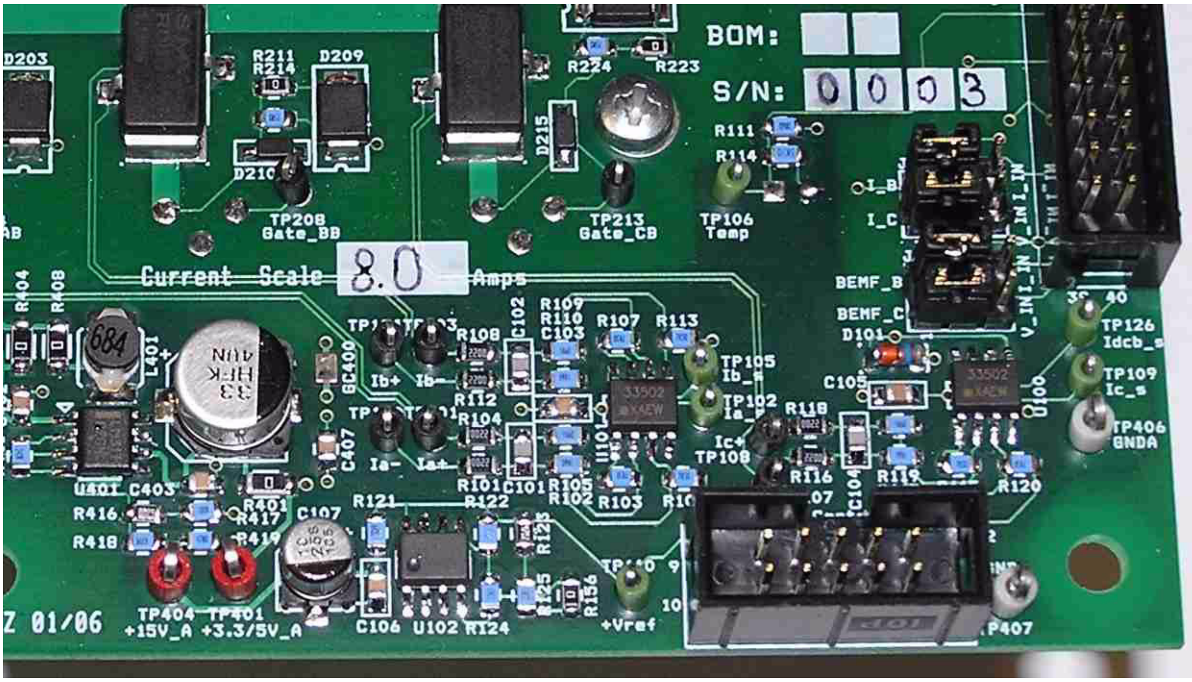

Figure 4-3 Current Range - Board Detail

4.5 Over-current and Undervoltage Functions

IR2133 provides over-current and undervoltage functions (Figure 4-2). Bus current feedback signal, I_sense_DCB1, is filtered with R222 and C206 to remove spikes, and this signal is fed into the IR2133 current comparator input ITRIP. Therefore, when bus current exceeds 10 amps, all six output transistors are switched off. After a fault state is detected, all six gate drivers are off until the fault state is cleared by the low level on pin $\overline{\text{FLT-CLR}}$. To clear a fault state, switch the power stage off and leave it off until all LEDs are off. Then you can switch the power stage on.

WARNING

Fault functions can be disabled, but then the power stage board is not protected against shortouts. This is not recommended because if an over-current appears, the power stage board can be damaged.

The undervoltage function is implemented internally. The IR2133's supply voltage is sensed internally. If this voltage is lower than 8.2V/8.6V, depending on the current threshold, the fault state is evaluated.

4.6 Temperature Sensing

The IR2133 safety functions keep the bus current and voltage 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 4-4 is used. It consists of a voltage divider from an NTC thermistor, resistor R111 and R114 for linearisation. The temp_sense signal is fed back to an A/D input where software can be used to set safe operating limits.

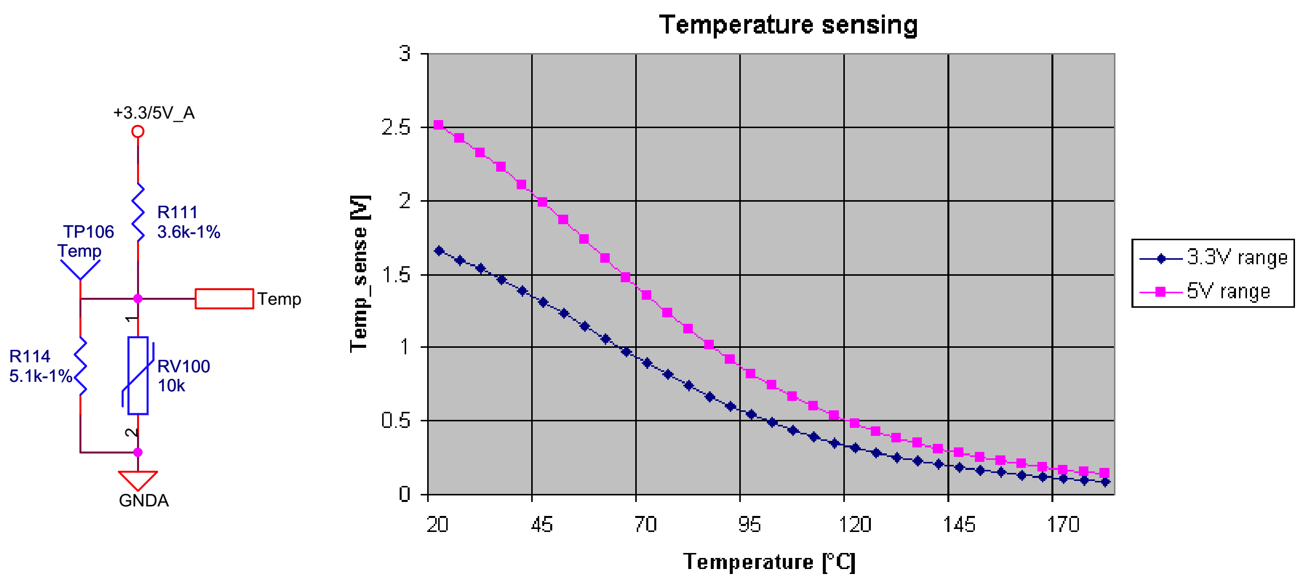

Figure 4-4 Temperature Sensing Circuit and Linearisation Chart

4.7 Back EMF Signals

Back EMF and zero-crossing signals are included to support sensorless algorithms for brushless dc motors and dead time distortion correction for AC induction motors. Referring to Figure 4-5, which shows circuitry for phase A, the raw phase voltage is scaled down by a voltage divider consisting of R126, R127, R128, R132, and R133. One output from this divider produces back EMF sense voltage BEMF_sense_A. Resistor values are chosen such that a 400-volt maximum phase voltage corresponds to a 3.235-volt maximum A/D input. BEMF_sense_A is led directly to the UNI-3 pin 38 without any offset correction (see Figure A-1). A zero-crossing signal is obtained by comparing the scaled motor phase voltage BEMF_A_ZC to the scaled bus voltage. Comparator U103B performs this function, producing zero-crossing signal Zero_cros_A.

The V_sense_DCB_half_15 is provided by the R5135, R138, R142, R144, R147, R150, and R152 resistor divider from the bus voltage (see Figure 4-2).

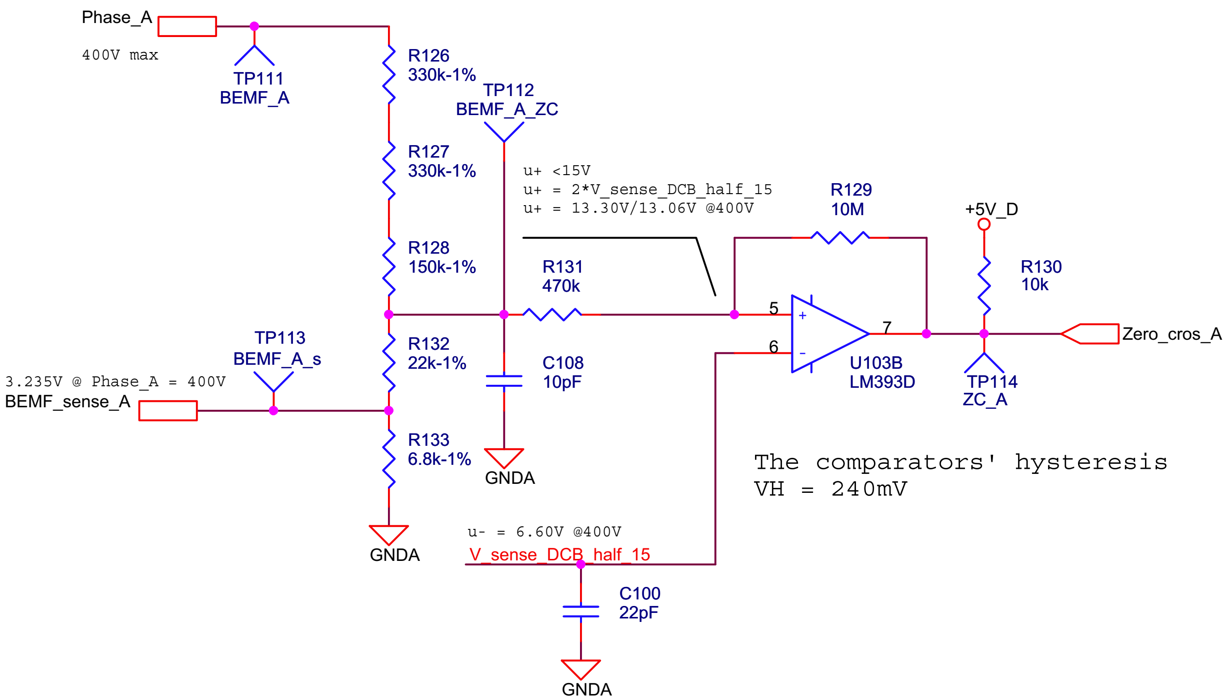

Figure 4-5 Back EMF sensing

4.8 Phase Current Sensing

Sampling resistors provide phase current information for all three phases. Because these resistors sample current in the lower phase legs, they do not directly measure phase current. However, given phase voltages for all three phases, phase current can be constructed mathematically from the lower phase leg values. This information can be used in vector-control algorithms for AC induction motors. The measurement circuitry for one phase is shown in Figure 4-6. Referencing the sampling resistors to the negative motor rail makes the measurement circuitry straightforward and inexpensive. Current is sampled by resistor R300 and amplified by the differential amplifier U100A. This circuit provides a voltage output suitable for sampling with A/D inputs. An MC33502D is used as a differential amplifier. With R115 = R120 and R116 = R118

R117 = R119, the gain is given by:

A = R115/(R116+R117)

The input voltage is shifted up by $+V_{ref}$ to accommodate both positive and negative current swings. A ±400-mV voltage drop across the shunt resistor corresponds to a measured current range of ±8 amps. As a source for $+V_{ref}$ we use the voltage reference described in 4.12.7 +1.65V/2.5V Reference.

The gain of this op. amplifier is 4.12 with the $+V_{ref}$ offset, i.e. the output ±1.65V corresponds to ±8A. The output is connected to the UNI-3 pin 22.

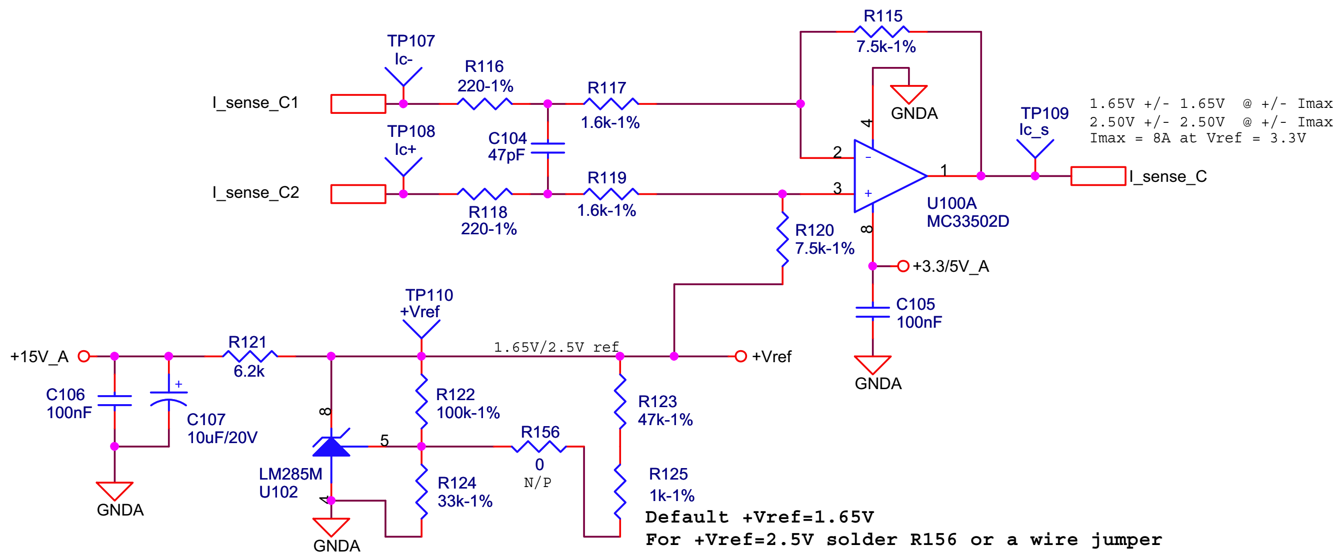

Figure 4-6 Phase Current Sensing

4.9 Brake

An external brake resistor can be connected to dissipate re-generative motor energy during periods of active deceleration or rapid reversal. Under these conditions, motorback 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 4-7, with an external dissipative resistor connected to J4, serves to dissipate energy across the dc bus. Q306 is turned on by software when the bus voltage sensing circuit in Figure 4-2 indicates that bus voltage could exceed safe limits.

Power dissipation capability depends, of course, on the capability of the externally connected dissipative resistor.

The MC33152 is a dual MOSFET predriver of up to 18V. This board uses its A channel to drive the braking resistance MOSFET.

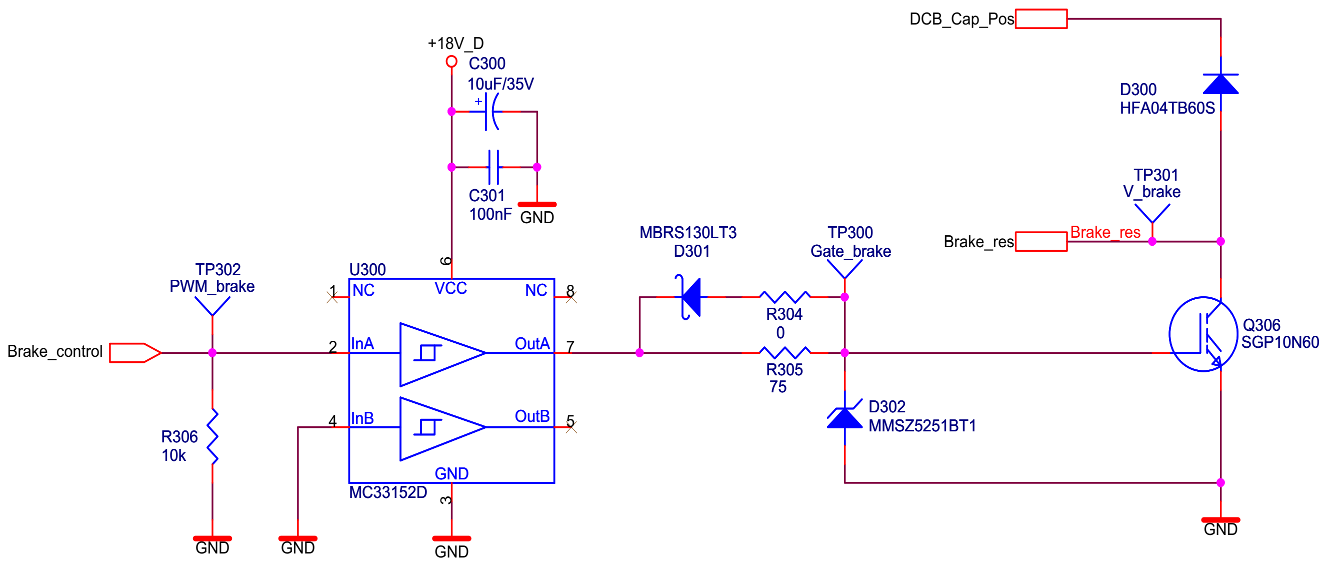

Figure 4-7 Brake

4.10 External Power Factor Correction

An external active Power Factor Correction circuit can be connected to the power stage board through connectors J5 and J11. See 3.3.2 PFC Signals Connector J2 and PFC POWER Connectors J5 and J11 for a connection description. Supplying the power stage board from the line-input requires connecting a power jumpers. The external PFC board is a controlled from a controller or an EVM board. Pin connections are in sections 3.3.2 PFC Signals Connector J2 and PFC POWER Connectors J5 and J11 and 3.3.6 UNI-3 Connector J8.

4.11 Test Points and LED Indication

Some voltages and currents of the 3-Phase AC/BLDC High Voltage Power Stage Board can be sensed, whilst some are connected to the UNI-3 pins. Those are: back-EMF voltage, phase current, bus-power voltage, bus current, zero-crossing signals, brake-control signal, PWM signal for all 6 swiches of the 3-phase power bridge, and the heatsink temperature.

Test points have different colors for better signal recognition. Black refers to raw signals. Green is for a signal scaled to the MCU range or for control signals. White indicates all grounds. Red is for positive voltage power supplies.

The 3-phase AC/BLDC High-Voltage Power-Stage contains 61 test points to allow the user to easily check the voltage of all important points:

- TP100 Ia– — Phase A current sense resistor test point for node I_sense_A1.
- TP101 Ia+ — Phase A current sense resistor test point for node I_sense_A2.

- TP102 Ia_s — Phase A current output test point for node I_sense_A, scaled at 0.275V/0.417V per amp of phase current A and shifted by 1.65V/2.5V.
- TP103 Ib– — Phase B current sense resistor test point for node I_sense_B1.
- TP104 Ib+ — Phase B current sense resistor test point for node I_sense_B2.
- TP105 Ib_s — Phase B current output test point of node I_sense_B, scaled at 0.275/0.417 volts per amp of phase current B and shifted by 1.65V/2.5V.
- TP106 Temp — Temperature sensing testing point.
- TP107 Ic– — Phase C current sense resistor test point for node I_sense_C1.
- TP108 Ic+ — Phase C current sense resistor test point for node I_sense_C2.
- TP109 Ic_s — Phase C current output test point of node I_sense_C, scaled at 0.275/0.417 volts per amp of phase current C and shifted by 1.65V/2.5V.
- TP106 Temp — Temperature sensing test point.
- TP110 +Vref — Reference voltage test point.
- TP111 BEMF_A — Back EMF phase A test point.
- TP112 BEMF_A_ZC — Phase A zero-crossing test point, scaled at 33.25V per volt of phase voltage A.
- TP113 BEMF_A_s — Back EMF phase A test point, scaled at 8.09V per volt of phase voltage A.
- TP114 ZC_A — Phase A zero-crossing test point.
- TP115 V_dcb — Bus voltage test point.
- TP116 BEMF_B — Back EMF phase B test point.
- TP117 BEMF_B_ZC — Phase B zero-crossing test point, scaled at 33.25V per volt of phase voltage B.
- TP118 BEMF_B_s — Back EMF phase B test point, scaled at 8.09V per volt of phase voltage B.
- TP119 ZC_B — Phase B zero-crossing test point.
- TP120 V_dcb_ZC — Half of bus voltage test point used for zero-crossing comparison.
- TP121 BEMF_C — Back EMF phase C test point.
- TP122 V_dcb_s — Bus voltage test point, scaled at 8.09V per volt.
- TP123 BEMF_C_ZC — Phase C zero-crossing test point, scaled at 33.25V per volt of phase voltage C.
- TP124 ZC_C — Phase C zero-crossing test point.
- TP125 BEMF_C_s — Back EMF phase C test point, scaled at 8.09V per volt of phase voltage C.
- TP126 Idcb_s — Bus current scaled and shifted +1.65V/+2.5V.

- TP200 I_trip — Over-current and under-voltage shut-down test point of 3-phase bridge driver U201.
- TP201 Gate_AT TP200 I_trip —Top transistor gate of phase A test point.
- TP202 PWM_AT — PWM control signal for top transistor gate of phase A, test point on connector J8 pin.
- TP203 PWM_AB — PWM control signal for bottom transistor gate of phase A, test point on connector J8 pin.
- TP204 Gate_AB — Bottom transistor gate of phase A test point.
- TP205 Gate_BT — Top transistor gate of phase B test point.
- TP206 PWM_BT — PWM control signal for top transistor gate of phase B, test point on connector J8 pin.
- TP207 PWM_BB — PWM control signal for bottom transistor gate of phase B, test point on connector J8 pin.
- TP208 Gate_BB — Bottom transistor gate of phase B test point.
- TP209 PWM_CT — PWM control signal for top transistor gate of phase C, test point on connector J8 pin.
- TP210 Gate_CT — Top transistor gate of phase C test point.
- TP211 PWM_CB — PWM control signal for bottom transistor gate of phase C, test point on connector J8 pin.
- TP212 Idcb+ — Bus current sense resistor test point for node I_sense_DCB2.
- TP213 Gate_CB — Bottom transistor gate of phase C test point.
- TP214 Idcb– — Bus current sense resistor test point for node I_sense_DCB1.
- TP215 FAULT — Over-current or undervoltage of the 3-phase bridge driver IR2133 test point.
- TP300 Gate_brake — Brake transistor gate test point.
- TP301 V_brake — Brake resistor voltage test point.
- TP302 PWM_brake — PWM control signal for brake transistor gate, test point on connector J8 pin 29 Brake Control.
- TP303 AC1 — Main input voltage test point on connector J9 pin 1.
- TP304 AC2 — Main input voltage test point on connector J9 pin 2.
- TP400 GNDA — Analog ground test point.
- TP401 +3.3V/5V_A — This point is the output of the U401 linear voltage regulator. It serves as the power supply for the on-board op. amplifiers and for supplying the temperature measuring circuit. It is connected to the PFC signals connector J2.
- TP402 +18V — This point is an output of the U402 switching step-up/down inverter. It serves as the power supply for U401, U404 and +18V_D digital supplies.

- TP403 +18V_D — This point is an output of the U402 switching step-up/down inverter. It serves as the power supply for the comparators, for the MOSFET driver and the 3-phase bridge driver, and as the source for U403 in generating +5V_D. It is connected to the PFC signals connector J2.
- TP404 +15V_A — This point is an output of the U404 linear voltage regulator. It serves as the power supply for the voltage reference source. It is connected to the UNI-3 connector J8 pin 19.
- TP405 +12VFAN — This point is the output of the U400 step-up/down inverter. It serves as a power supply for the fans only.
- TP406 GNDA — Analog ground test point.
- TP407 GND — Ground test point.
- TP408 GND — Ground test point.
- TP409 GND — Ground test point.
- TP410 GND — Ground test point.
- TP411 +5V_D — This point is the output of the U403 switching step-down inverter. It serves as the power supply for the on-board logic IC's. It is connected to the UNI-3 connector J8 pins 14 and 15 and to the PFC signals connector J2.
- TP412 V_dcb_1 — Bus voltage test point.
- TP413 V_dcb_2 — Bus voltage test point.

This board also contains four LEDs as indicators:

- D204 — Indicates over-current or undervoltage of the 3-phase bridge driver IR2133 (see Figure 4-2).
- D400 — Indicates that the +12V_Fans level is properly generated.
- D403 — Indicates that the +18V level is properly generated.
- D407 — Indicates that the +5V_D level is properly generated.

For more details see Figure 4-8.

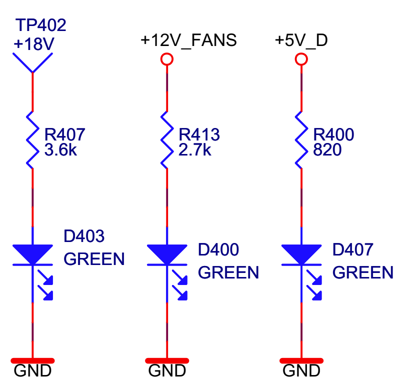

Figure 4-8 LED Indication

4.12 Power Supplies and Voltage Reference

The 3-phase AC/BLDC High-Voltage Power-Stage contains devices that require various voltage levels of +18V, +15V, +12V and +5V or +3.3V.

4.12.1 Input Power Supply

All power supplies are served from bus voltage. Bus can be supplied from two sources, from the line input across the power bridge or from the external PFC board. The power source should be able to deliver at least 8 amps.

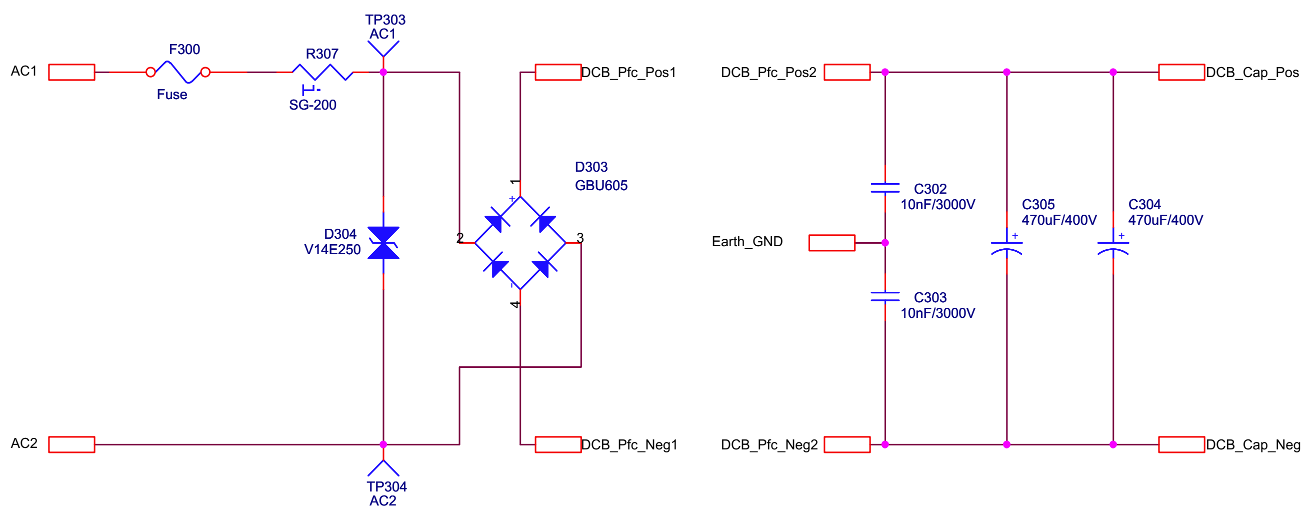

Figure 4-9 DC Bus Power Supply

4.12.2 +18V Power Supply

The +18V level is generated by means of the LNK306P switching step-up/down inverter (see Figure 4-10) that generates this level from bus voltage. This inverter can supply up to 300 mA. This voltage level serves the LM317LD and MC78L15ACD linear regulators, comparators, 3-phase bridge driver and brake gate driver. +18V_D is directly supplied from LNK306P. If the LNK306P inverter operates properly, the D403 green LED is lit.

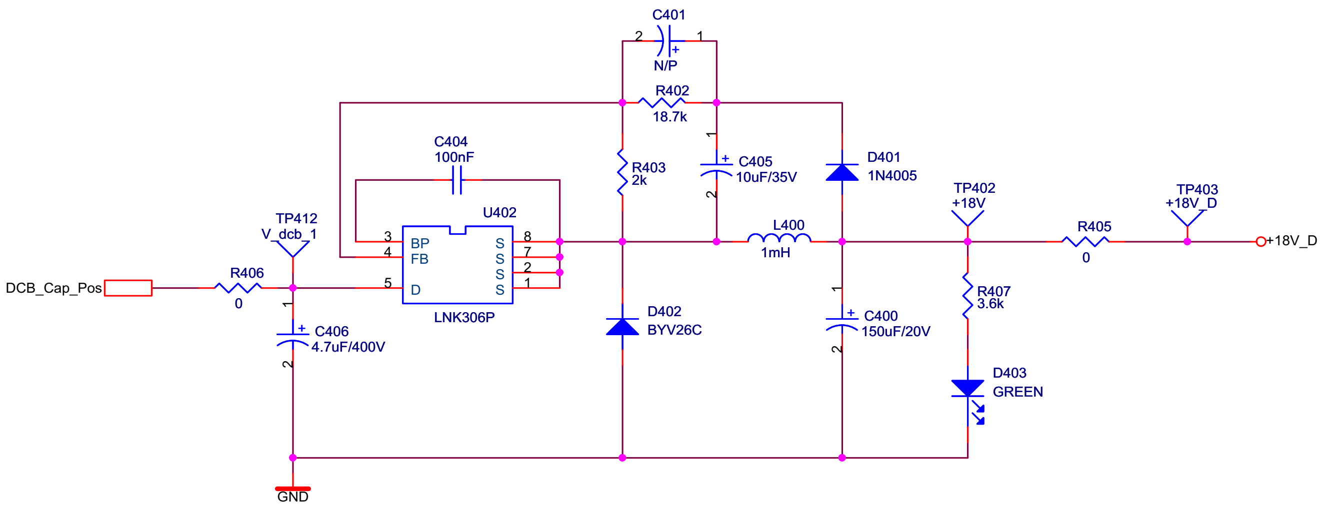

Figure 4-10 +18V Power Supply

4.12.3 +15V_A Power Supply

The +15V_A power supply is generated from the +18V level by means of the MC78L15ACD linear voltage regulator (see Figure 4-11). It can supply up to 100 mA. The +15V_A level is used to supply the linear voltage reference LM285M. It is connected to the UNI-3 connector J8 pin 19.

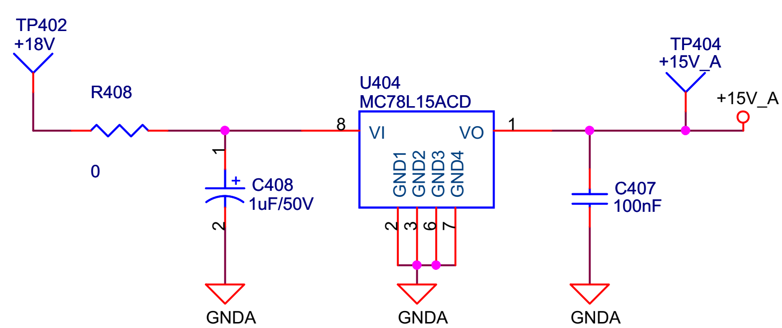

Figure 4-11 +15V_A Power Supply

4.12.4 +5V_D Power Supply

An important voltage level for this board is +5V_D. This voltage level is obtained by the LM2674M switching step-down inverter and can supply up to 500 mA (Figure 4-12). The +5V_D level is used to supply the on-board logic IC's. It is connected to the PFC signals connector J2 and to the UNI-3 connector J8 pins 14 and 15.

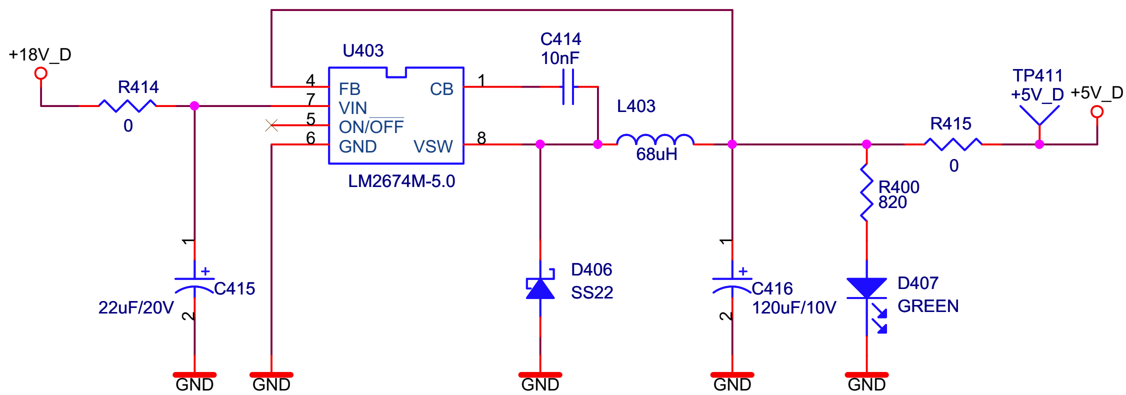

Figure 4-12 +5V_D Power Supply

4.12.5 +3.3V_A/+5V_A Power Supply

The +3.3V/+5V power supply is generated from the +18V level by means of the LM317LD linear voltage regulator (see Figure 4-13). It's capable of sinking up to 100 mA. This voltage level serves the on-board operational amplifiers and for supplying the temperature-measuring circuit. It is also connected to the PFC signals connector J2 and to the UNI-3 connector J8 pin 16. Output voltage level can be set to 3.3V or 5V according to the analog-voltage range used on the controller board (see Figure 4-14). Default output voltage is set at 3.3V_A. To select +5V_A, remove resistor R419. This description is also available on the actual PCB board (see PCB board picture and Figure 4-13).

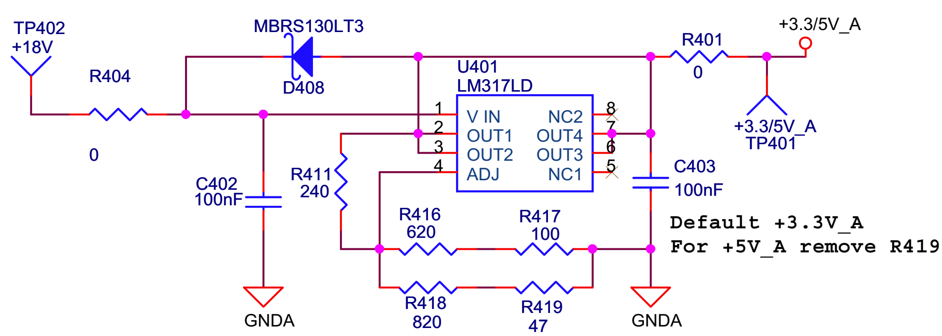

Figure 4-13 +3.3V/+5V_A Power Supply

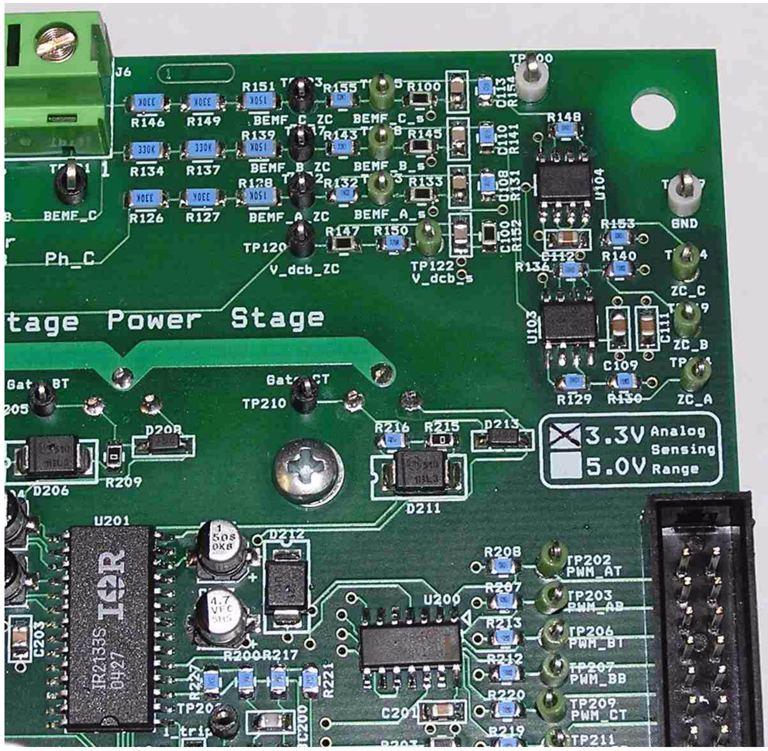

Figure 4-14 Analogue Sensing Range - Board Detail

WARNING

Set +3.3V_A/+5V_A Power Supply output voltage level according to the analog-voltage range used on the controller board. When you change the +3.3V_A/+5V_A power supply output voltage level, also change the voltage-reference level.

4.12.6 +12V_Fan Power Supply

Bus voltage generates +12V_Fan Power Supply by means of the LNK306P step-down/up inverter (see Figure 4-15). This power supply is used only for supplying fans with +12V up to 200 mA.

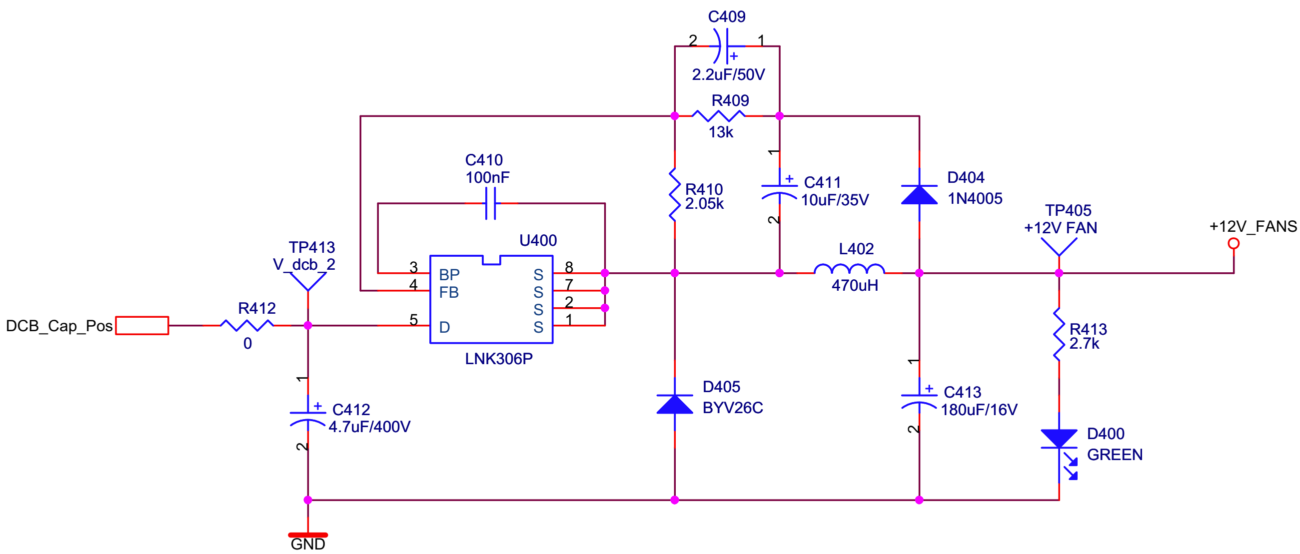

Figure 4-15 +12V_Fan Power Supply

4.12.7 +1.65V/2.5V Reference

The +1.65V/2.5V reference is generated from the +15V_A level by means of the LM285M linear voltage reference (see Figure 4-16). This reference serves to shift the phase-current-sensing values. It can sink up to 20 mA. The default voltage reference level value is +1.65V.

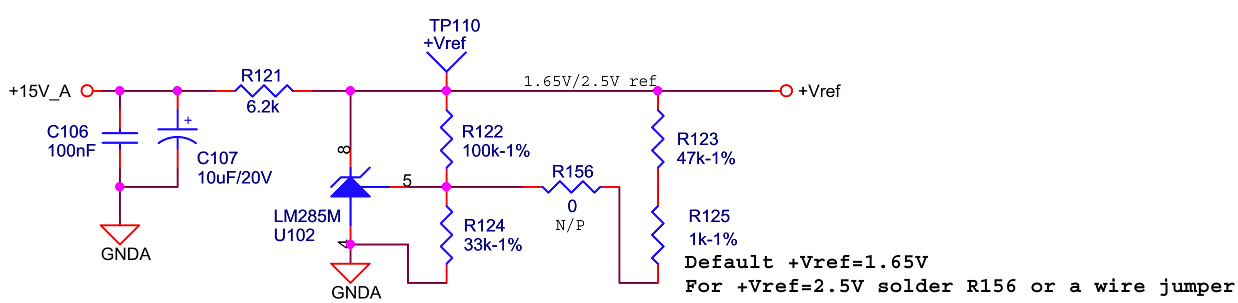

Figure 4-16 Voltage Reference

WARNING

Set the voltage reference level according to the analog voltage range used on the controller board. When you change the voltage reference level, also change the +3.3V_A/+5V_A Power Supply output voltage level.

Appendix A.
3-Phase AC/BLDC High Voltage Power Stage Board Schematics

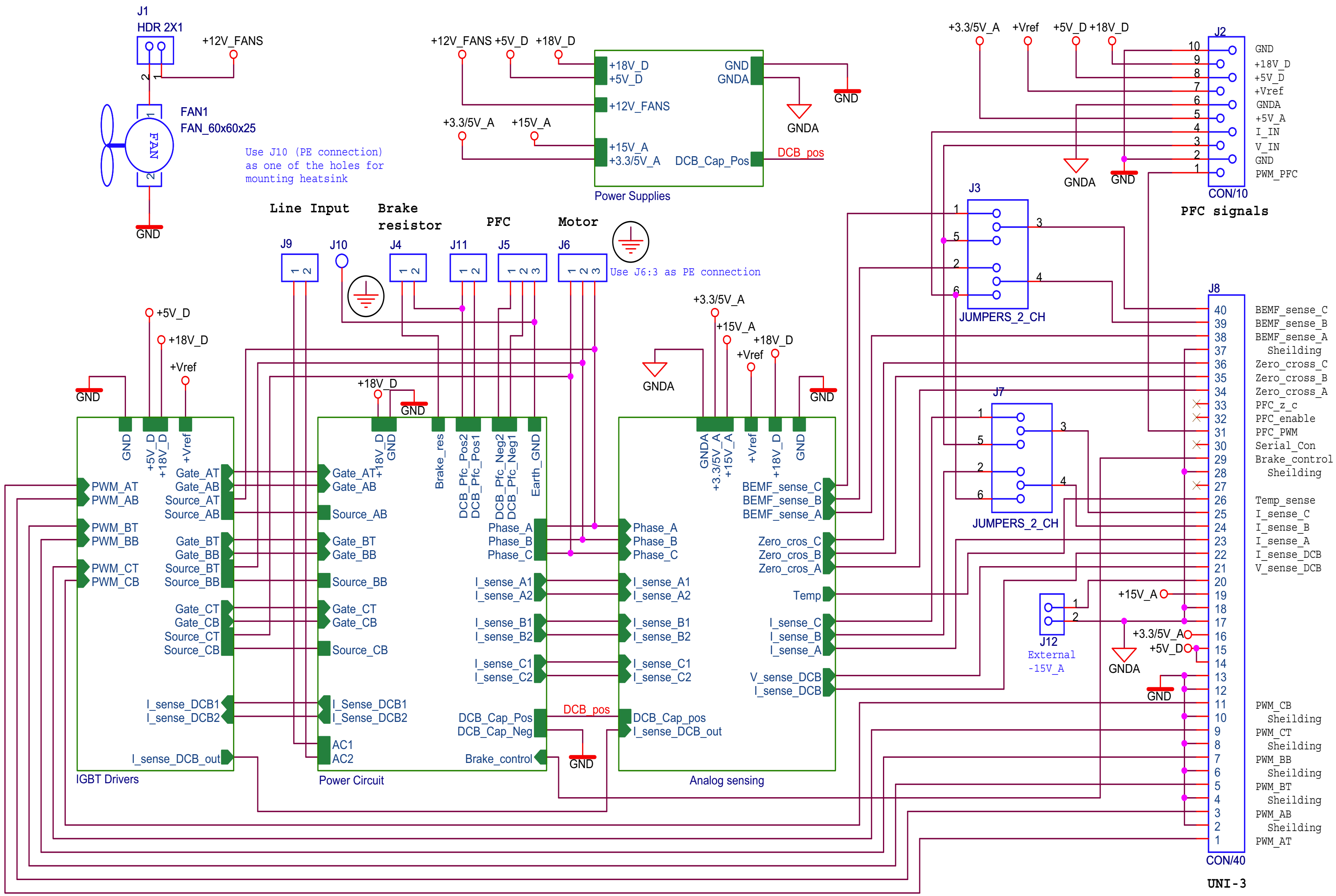

Figure A-1 Power Stage Overview

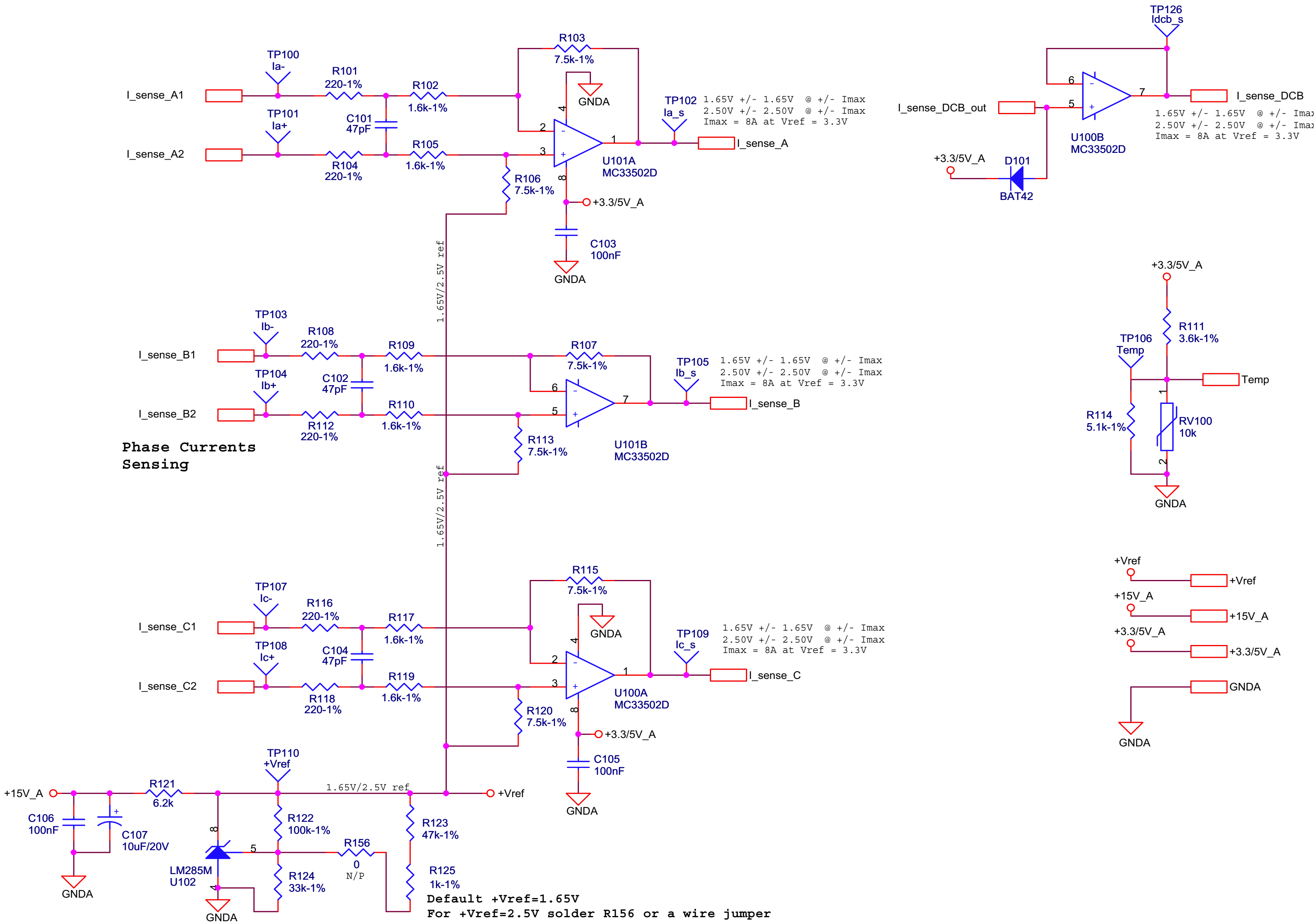

Figure A-2 Phase Current Sensing

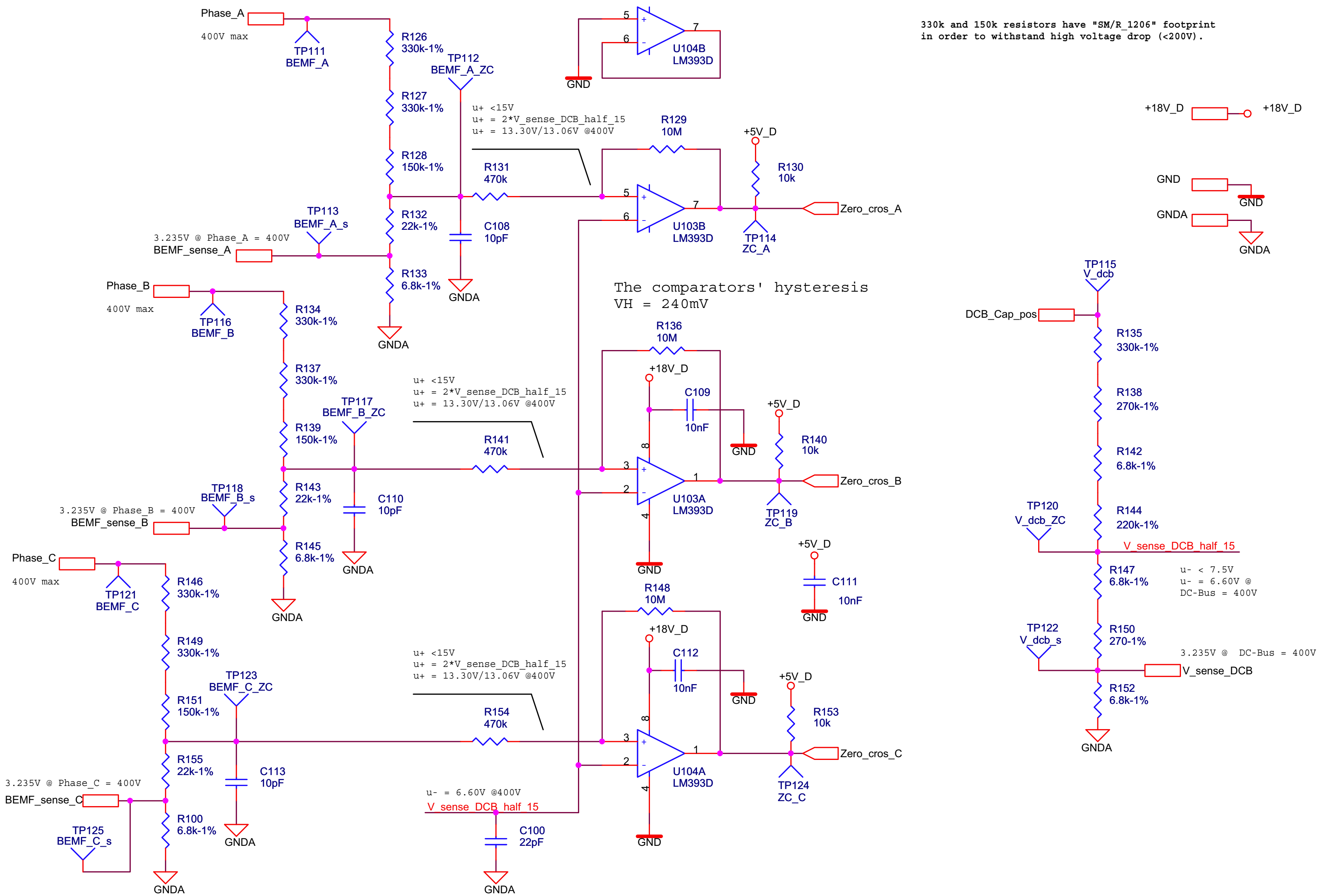

Figure A-3 Back EMF Sensing

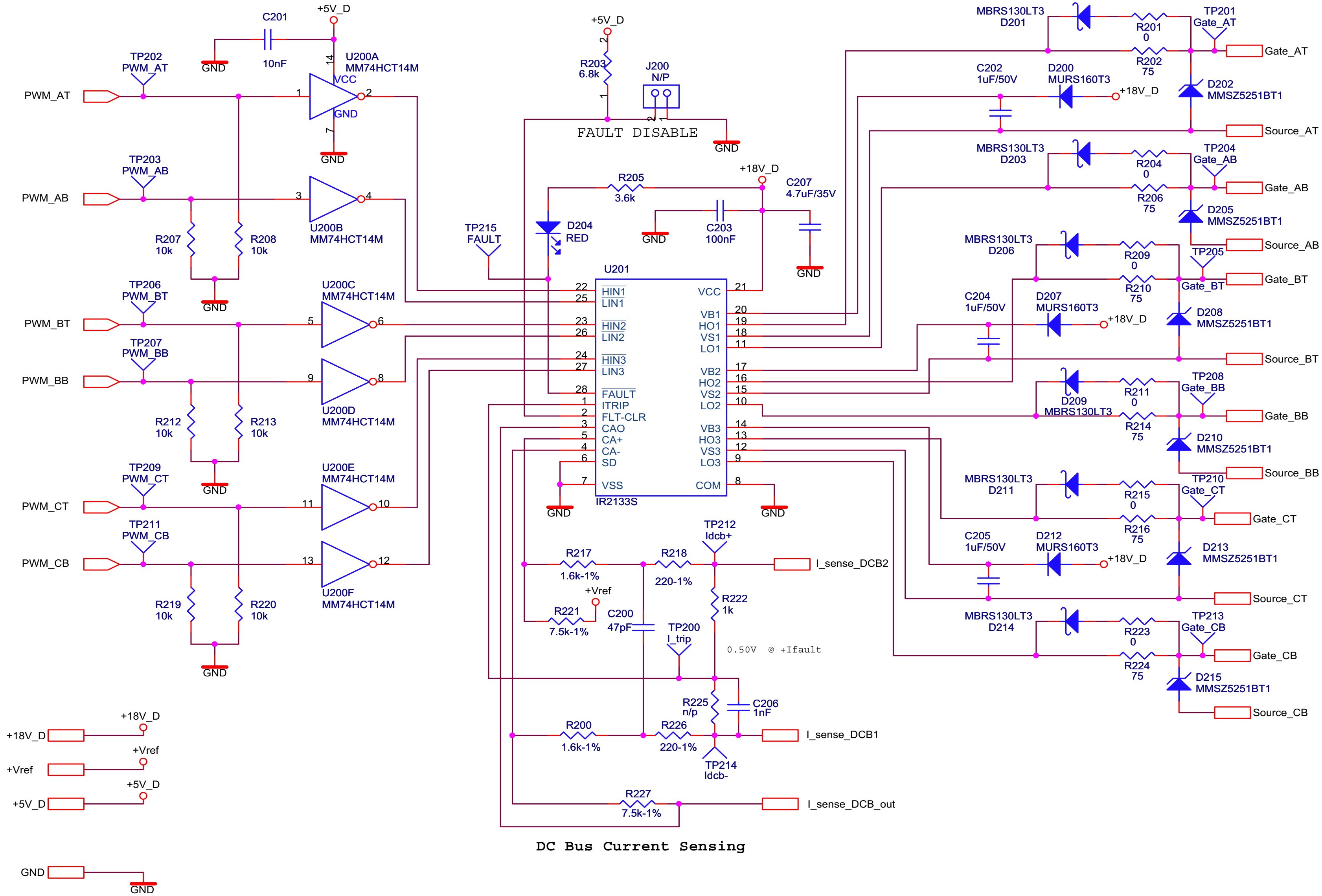

Figure A-4 IGBT Drivers

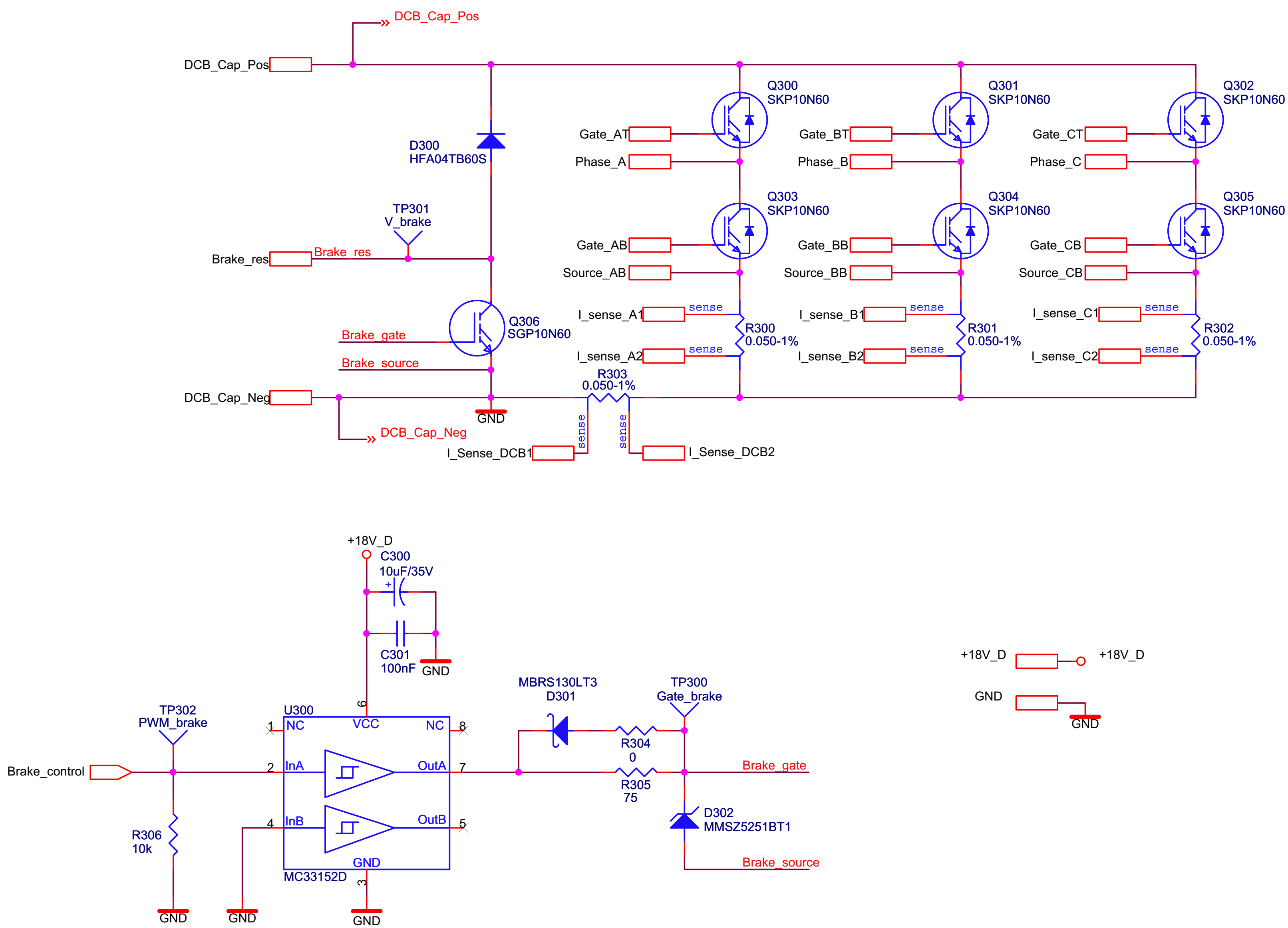

Figure A-5 3-Phase Power Bridge

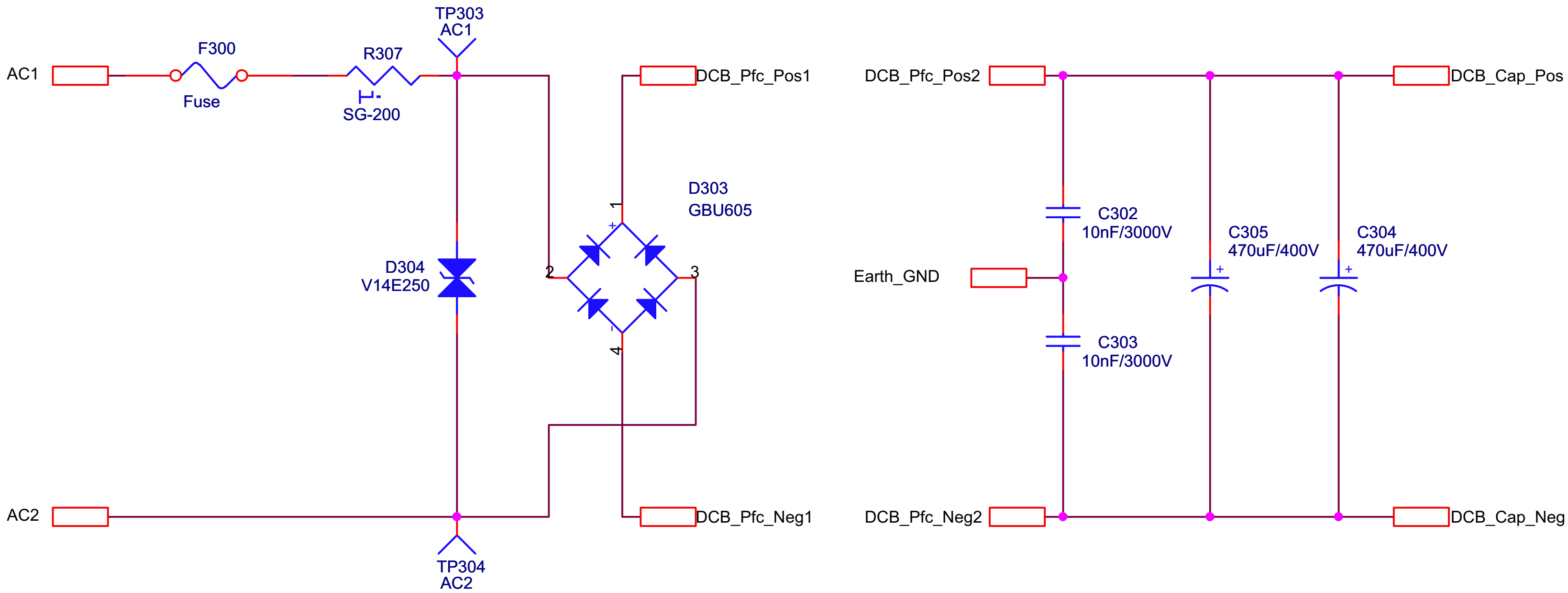

Figure A-6 DC bus Power Supply

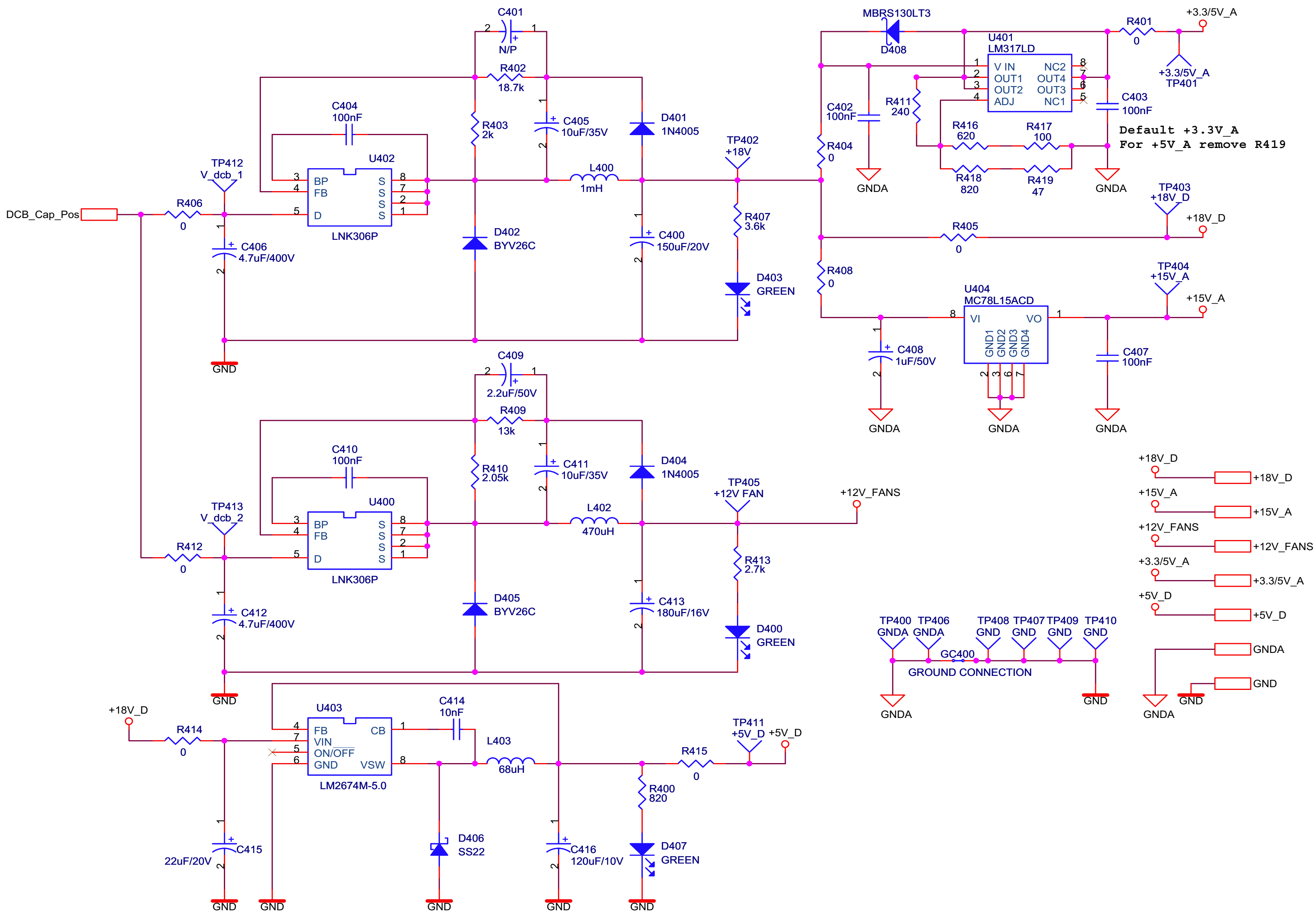

Figure A-7 Power Supplies

Appendix B. Bill of Materials

Table B-1 Parts List

DESIGNATORS	QUANTITY	DESCRIPTION	MANUFACTURER	PART NUMBER
C100	1	22pF size 0805	ANY ACCEPTABLE	-
C101, C102, C104, C200	4	47pF size 0805	ANY ACCEPTABLE	-
C206		1nF size 0805	ANY ACCEPTABLE	
C103, C105, C106, C301, C402, C403, C404, C407, C410, C203	10	100nF size 0805	ANY ACCEPTABLE	-
C107	1	10µF/ 20V size C	ANY ACCEPTABLE	-
C108, C110, C113	3	10pF size 0805	ANY ACCEPTABLE	-
C109, C111, C112, C201, C414	5	10nF size 0805	ANY ACCEPTABLE	-
C409	1	2.2µF/ 50V size B	ANY ACCEPTABLE	-
C401	1	N/P	ANY ACCEPTABLE	-
C207	1	4.7µF/ 35V size B	ANY ACCEPTABLE	-
C202, C204, C205, C408	4	1µF/ 50V size B	ANY ACCEPTABLE	-
C300, C405, C411	3	10µF/ 35V size C	ANY ACCEPTABLE	-
C302, C303	2	10nF/ 3000V	PANASONIC	ECKATS103MF
C304, C305	2	470µF/ 400V	ANY ACCEPTABLE	-
C400	1	150µF/ 20V	SANYO	20SVP150M
C406, C412	2	4.7µF/ 400V	ANY ACCEPTABLE	-
C413	1	180µF/ 16V	SANYO	16SVP180MX
C415	1	22µF/ 20V size D	ANY ACCEPTABLE	-
C416	1	120µF/ 10V	SANYO	20SVP100M
D200, D207, D212	3	1A/600V Ultrafast Rectifier size SMA	ON SEMICONDUCTOR	MURS160T3
D201, D203, D206, D209, D211, D214, D301, D408	8	1A/30V Schottky Rectifier size SMB	ON SEMICONDUCTOR	MBRS130LT3
D101	1	BAT42 size MINIMELF	ANY ACCEPTABLE	-
D202, D205, D208, D210, D213, D215, D302	7	20V Zener Diode SOD-123	ON SEMICONDUCTOR	MMSZ5250BT1
D204	1	Red Display LED size 0805	ANY ACCEPTABLE	-
D300	1	4A/600V Ultrafast Rectifier D2-Pak	INTERNATIONAL RECTIFIER	HFA04TB60S
D303	1	6A/500V Bridge Rectifier	DIODES INCORPORATED	GBU605
D304	1	Varistor V14E250	LITTELFUSE	V14E250
D400, D403, D407	3	Green Display LED size 0805	ANY ACCEPTABLE	-
D401, D404	2	1A/600V Recovery Rectifier DO-41	ON SEMICONDUCTOR	1N4005

Table B-1 Parts List

DESIGNATORS	QUANTITY	DESCRIPTION	MANUFACTURER	PART NUMBER
D402, D405	2	1A/600V Fast Recovery Rectifier SOD-57	VISHAY	BYV26C
D406	1	2A/20V Schottky Rectifier/ DO-214AA	VISHAY	SL22
FAN1	1	FAN 60x60x25	ANY ACCEPTABLE	-
F300	1	Fuse 6A	ANY ACCEPTABLE	-
GC400	1	ground connection		-
J12, J200	2	N/P	ANY ACCEPTABLE	-
J1	1	HDR 2x1	ANY ACCEPTABLE	-
J2	1	CON/10	ANY ACCEPTABLE	MLW10G
J3, J7	2	JUMPERS_2_CH	ANY ACCEPTABLE	-
J4, J9, J11	2	CON/TOP 1.5 GS 2/90	CAMDEN ELECTRONICS	CTB0110/2
J5, J6	2	CON/TOP 1.5 GS 3/90	CAMDEN ELECTRONICS	CTB0110/3
J8	1	CON/40	ANY ACCEPTABLE	MLW40G
J10	1	ground connection		-
L400	1	1.2mH	COILCRAFT	RFB1010-122
L402	1	470mH	COILCRAFT	RFB1010-471
L403	1	68mH	COILCRAFT	DO3308P-683ML_
Q300, Q301, Q302, Q303, Q304, Q305	6	10A/600V Fast IGBT TO-220AB	INFINEON TECHNOLOGIES	SKP10N60
Q306	1	10A/600V Fast IGBT TO-220AB	INFINEON TECHNOLOGIES	SGP10N60
RV100	1	10 kΩ Thermistor	EPCOS	B57703M103G
R225	1	N/P	ANY ACCEPTABLE	-
R130, R140, R153, R207, R208, R212, R213, R219, R220, R306	10	10 kΩ Resistor 1/10W size 0805	ANY ACCEPTABLE	-
R100, R133, R142, R145, R147, R152	6	6.8 kΩ Resistor 1/10W 1% size 0805	ANY ACCEPTABLE	-
R101, R104, R108, R112, R116, R118, R218, R226	8	220 Ω Resistor 1/10W 1% size 0805	ANY ACCEPTABLE	-
R102, R105, R109, R110, R117, R119, R200, R217	8	1.6 kΩ Resistor 1/10W 1% size 0805	ANY ACCEPTABLE	-
R103, R106, R107, R113, R115, R120, R221, R227	8	7.5 kΩ Resistor 1/10W 1% size 0805	ANY ACCEPTABLE	-
R111	1	3.6 kΩ Resistor 1/10W 1% size 0805	ANY ACCEPTABLE	-
R114	1	5.1 kΩ Resistor 1/10W 1% size 0805	ANY ACCEPTABLE	-
R121	1	6.2 kΩ Resistor 1/10W size 0805	ANY ACCEPTABLE	-
R122	1	100 kΩ Resistor 1/10W 1% size 0805	ANY ACCEPTABLE	-
R123	1	47 kΩ Resistor 1/10W 1% size 0805	ANY ACCEPTABLE	-

Table B-1 Parts List

DESIGNATORS	QUANTITY	DESCRIPTION	MANUFACTURER	PART NUMBER
R124	1	33 kΩ Resistor 1/10W 1% size 0805	ANY ACCEPTABLE	-
R125	1	1 kΩ Resistor 1/10W 1% size 0805	ANY ACCEPTABLE	-
R126, R127, R134, R135, R137, R146, R149	7	330 kΩ Resistor 1/4W 1% size 1206	ANY ACCEPTABLE	-
R128, R139, R151	3	150 kΩ Resistor 1/4W 1% size 1206	ANY ACCEPTABLE	-
R129, R136, R148	3	10 MΩ Resistor 1/10W size 0805	ANY ACCEPTABLE	-
R131, R141, R154	3	470 kΩ Resistor 1/10W size 0805	ANY ACCEPTABLE	-
R132, R143, R155	3	22 kΩ Resistor 1/10W 1% size 0805	ANY ACCEPTABLE	-
R138	1	270 kΩ Resistor 1/4W 1% size 1206	ANY ACCEPTABLE	-
R144	1	220 kΩ Resistor 1/4W 1% size 1206	ANY ACCEPTABLE	-
R150	1	270 Ω Resistor 1/10W 1% size 0805	ANY ACCEPTABLE	-
R201, R204, R209, R211, R215, R223, R304, R156	7	0 Ω Resistor 1/10W size 0805	ANY ACCEPTABLE	-
R202, R206, R210, R214, R216, R224, R305	7	75 Ω Resistor 1/10W size 0805	ANY ACCEPTABLE	-
R203	1	6.8 kΩ Resistor 1/4W size 1206	ANY ACCEPTABLE	-
R205, R407	2	3.6 kΩ Resistor 1/10W size 0805	ANY ACCEPTABLE	-
R222	1	1 kΩ Resistor 1/10W 1% size 0805	ANY ACCEPTABLE	-
R401, R404, R405, R406, R408, R412, R414, R415	8	0 Ω Resistor 1/4W size 1206	ANY ACCEPTABLE	-
R300, R301, R302, R303	4	50 mΩ Resistor 1% size 4723	ISABELLENHüTTE	SMV-R050-1.0
R307	1	7A Inrush Current Limiter	RHOPOINT COMPONENTS	SG200
R400	1	820 Ω Resistor 1/10W size 0805	ANY ACCEPTABLE	-
R402	1	15 kΩ Resistor 1/10W size 0805	ANY ACCEPTABLE	-
R403	1	2 kΩ Resistor 1/10W size 0805	ANY ACCEPTABLE	-
R409	1	13 kΩ Resistor 1/10W size 0805	ANY ACCEPTABLE	-
R410	1	2.05 kΩ Resistor 1/10W size 0805	ANY ACCEPTABLE	-
R411	1	240 Ω Resistor 1/10W size 0805	ANY ACCEPTABLE	-
R416	1	620 Ω Resistor 1/10W size 0805	ANY ACCEPTABLE	-
R417	1	100 Ω Resistor 1/10W size 0805	ANY ACCEPTABLE	-
R418	1	820 Ω Resistor 1/10W size 0805	ANY ACCEPTABLE	-
R419	1	47 Ω Resistor 1/10W size 0805	ANY ACCEPTABLE	-
R413	1	2.7 kΩ Resistor 1/10W size 0805	ANY ACCEPTABLE	-

Table B-1 Parts List

DESIGNATORS	QUANTITY	DESCRIPTION	MANUFACTURER	PART NUMBER
TP100, TP101, TP103, TP104, TP107, TP108, TP111, TP112, TP115, TP116, TP117, TP120, TP121, TP123, TP200, TP201, TP204, TP205, TP208, TP210, TP212, TP213, TP214, TP300, TP301, TP303, TP304, TP412, TP413	29	Test Point Black 1mm	ANY ACCEPTABLE	-
TP102, TP105, TP106, TP109, TP110, TP113, TP114, TP118, TP119, TP122, TP124, TP125, TP202, TP203, TP206, TP207, TP209, TP211, TP215, TP126, TP302	21	Test Point Green 1mm	ANY ACCEPTABLE	-
TP400, TP406, TP407, TP408, TP409, TP410	6	Test Point White 1mm	ANY ACCEPTABLE	-
TP401, TP402, TP403, TP404, TP405, TP411	6	Test Point Red 1mm	ANY ACCEPTABLE	-
U100, U101	2	Operational Amplifier/ SOIC-8	ON SEMICONDUCTOR	MC33502D
U102	1	Voltage Reference/SOIC-8	NATIONAL SEMICONDUCTOR	LM285M
U103, U104	2	Comparators/ SOIC-8	FREESCALE	LM393D
U200	1	Schmitt Inverter/ SOIC-14	FAIRCHILD SEMICONDUCTOR	MM74HCT14M
U201	1	3-Phase Bridge Driver/SOIC-28	INTERNATIONAL RECTIFIER	IR2133S
U300	1	MOSFET Driver/ SOIC-8	FREESCALE	MC33152D
U400, U402	2	Step-Up/Down Inverter/SOIC-8	POWER INTEGRATIONS	LNK306P
U401	1	Voltage Regulator/SOIC-8	FREESCALE	LM317LD
U403	1	Step-Down Inverter/SOIC-8	NATIONAL SEMICONDUCTOR	LM2674M-5.0
U404	1	MC78L15ACD/SOIC-8	FREESCALE	MC78L15ACD

Appendix C.
3-Phase AC/BLDC High Voltage Power Stage Board Layouts

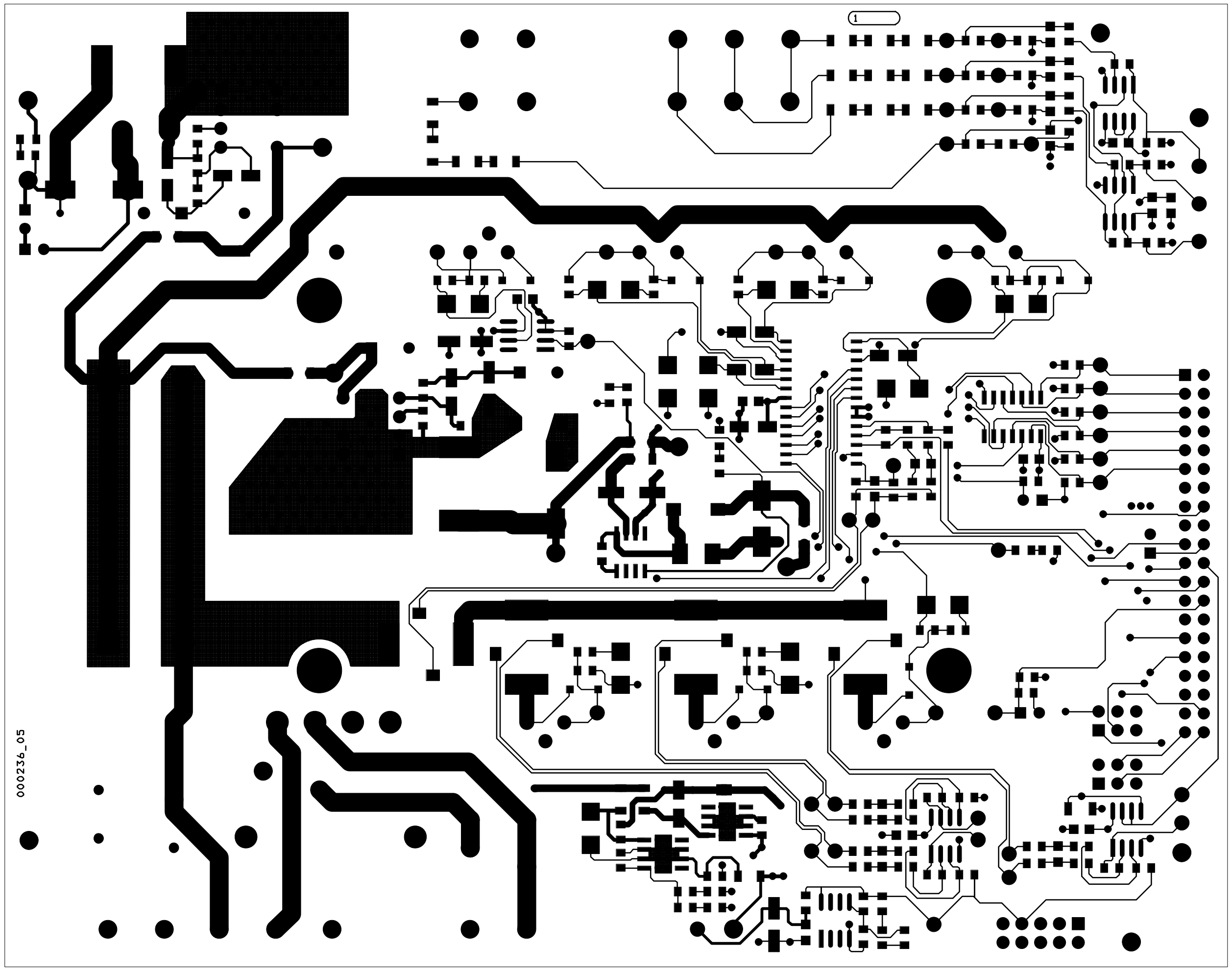

Figure C-1 Power Stage Board Top Layer

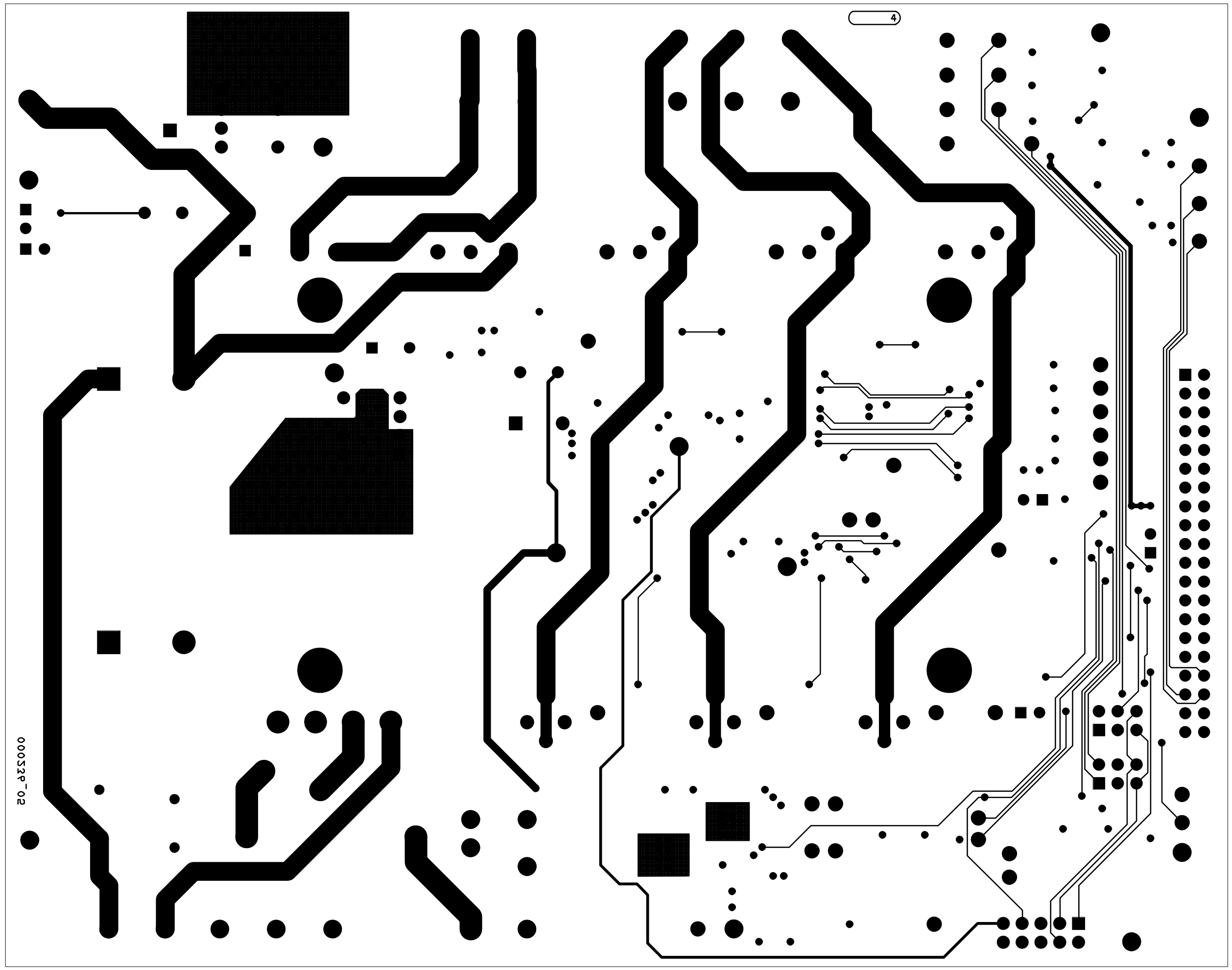

Figure C-2 Power Stage Board Bottom Layer

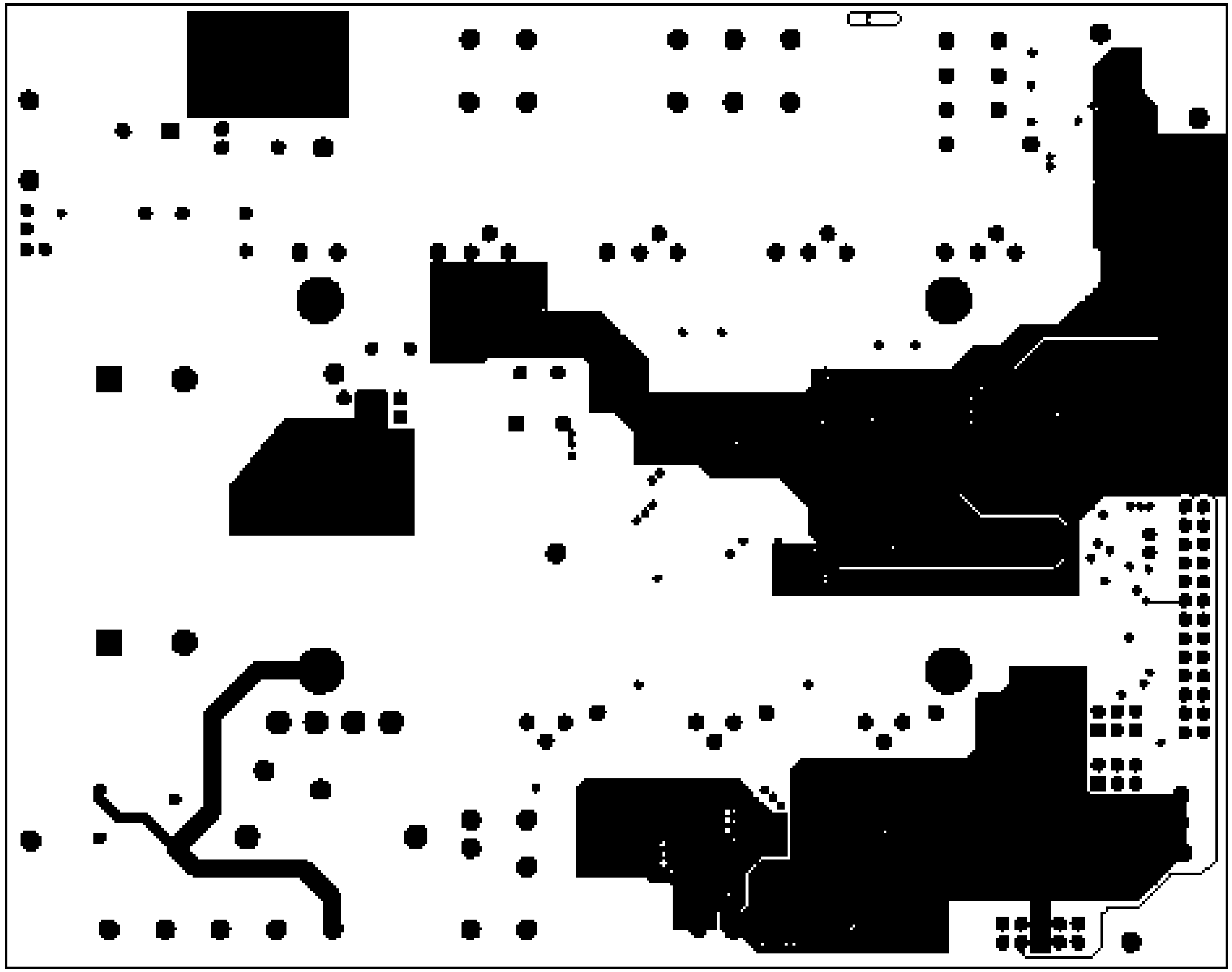

Figure C-3 Power Stage Board Inner 1 Layer

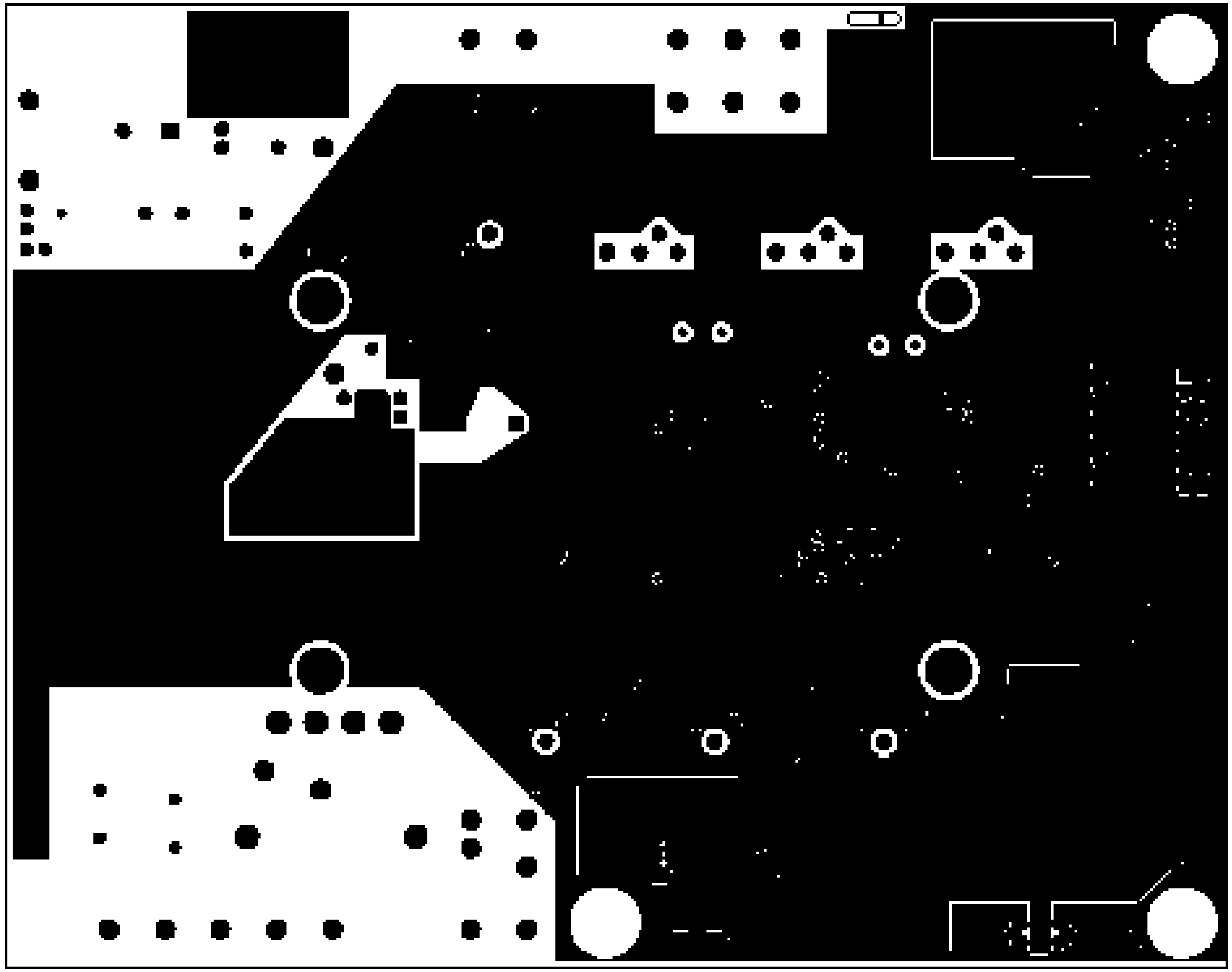

Figure C-4 Power Stage Board Inner 2 Layer

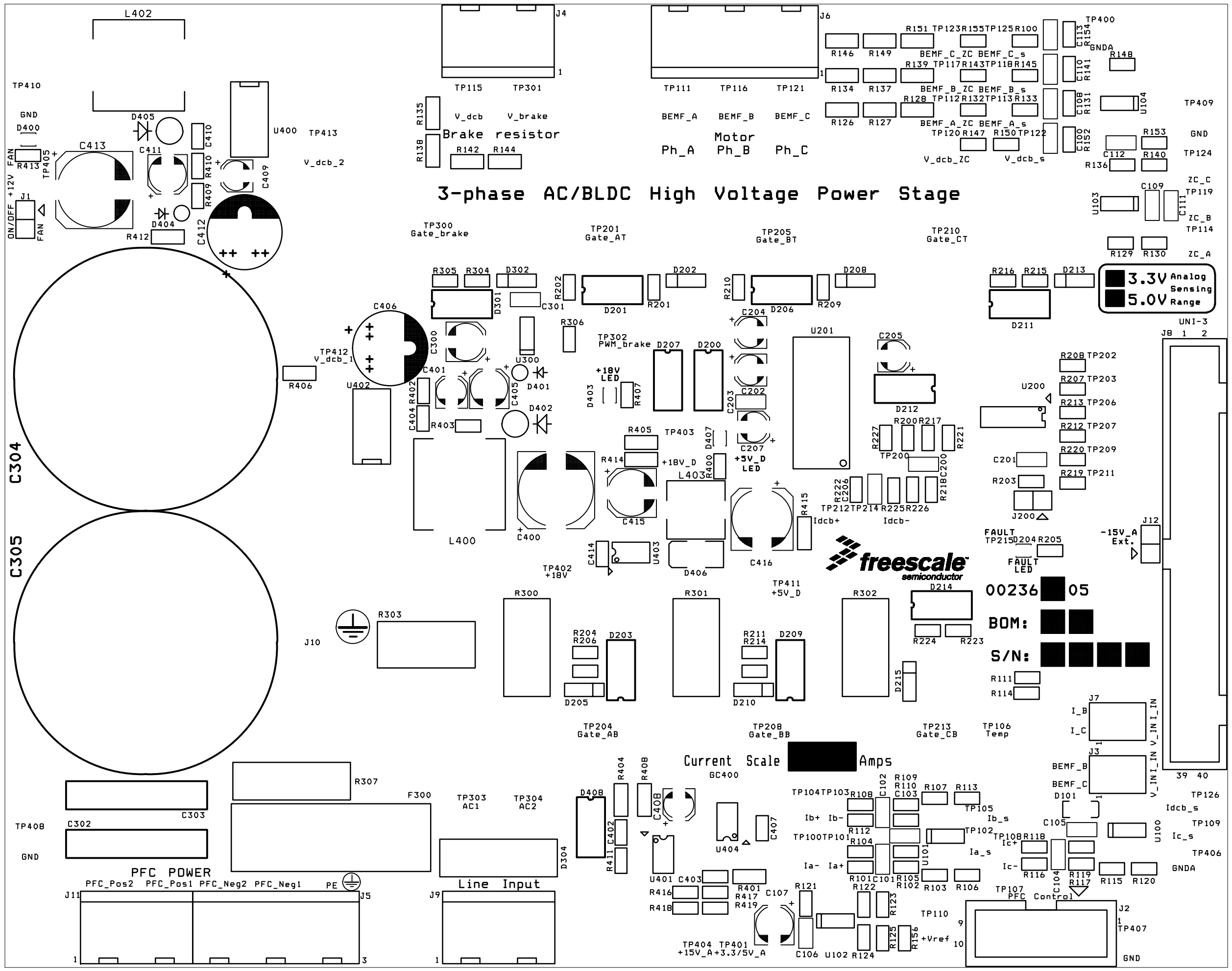

Figure C-5 Power Stage Board Silkscreen Top Layer

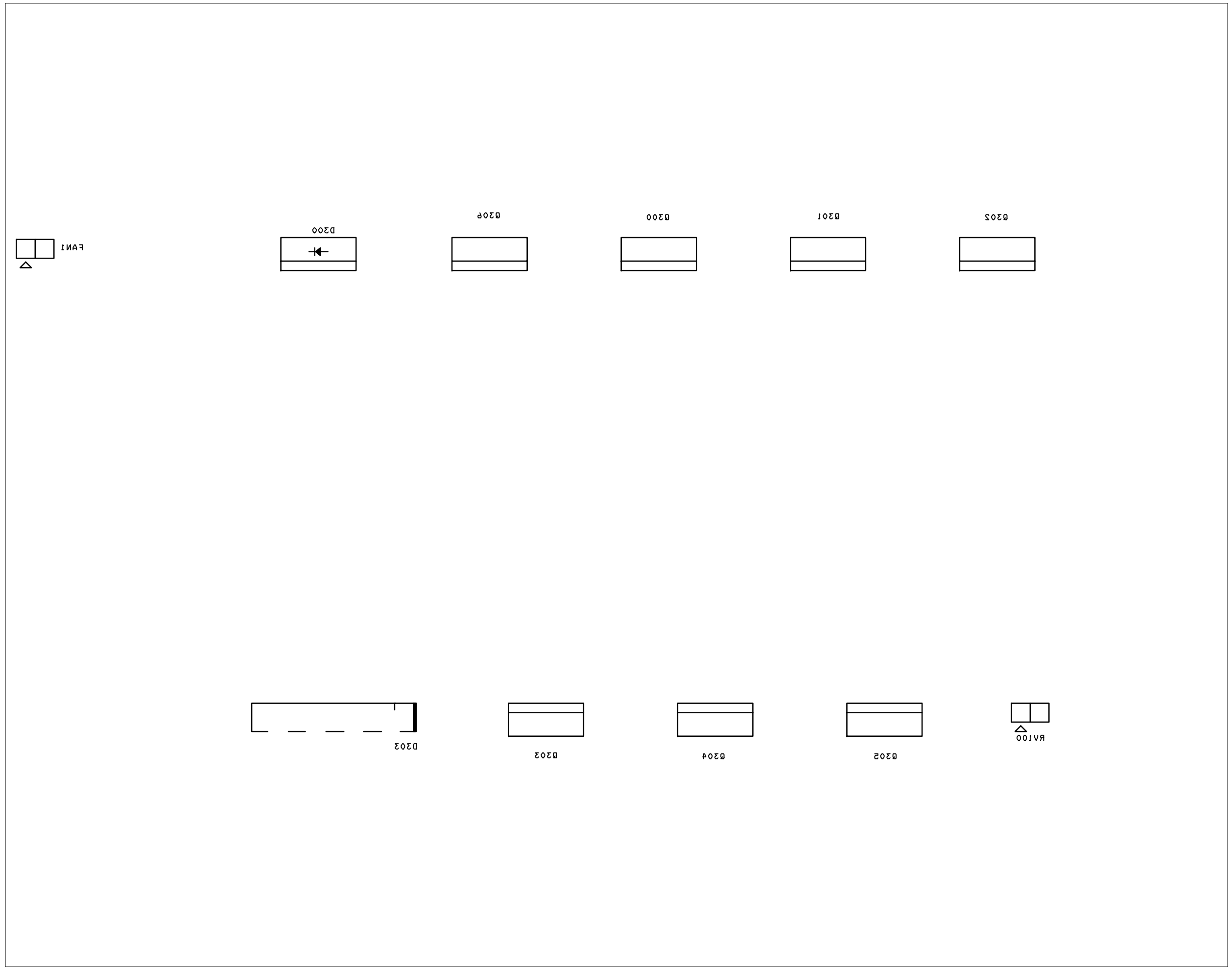

Figure C-6 Power Stage Board Silkscreen Bottom Layer

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