MEMC3PBLDCLVUM/D

Motorola Embedded Motion Control

3-Phase BLDC Low-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, brushless dc (BLDC) low-voltage power stage (LV BLDC power stage) is an integral part of Motorola's embedded motion control series of development tools. It operates from a nominal 12-volt motor supply, and delivers up to 30 amps of rms motor current from a dc bus that can deliver peak currents up to 46 amps. The LV BLDC power stage is supplied in kit number ECLOVACBLDC.

In combination with one of the Embedded Motion Control series Control boards, it provides a ready made software development platform for fractional horsepower Brushless DC motors. Feedback signals are provided to facilitate control with sensorless algorithms.

An illustration of the systems architecture is shown in **Figure 1-1**. A 3D model appears in **Figure 1-2**.

The LV BLDC power stage's features are:

- dc-bus brake MOSFET and brake current limiting resistors
- 3-phase bridge inverter (6-MOSFETs)
- Individual phase and dc bus current sensing shunts with Kelvin connections
- Power stage temperature sensing diodes
- MOSFET gate drivers
- Current and temperature signal conditioning
- 3-phase back-EMF voltage sensing and zero cross detection circuitry
- Board identification processor (MC68HC705JJ7)
- Low-voltage on-board power supplies
- Cooling fans

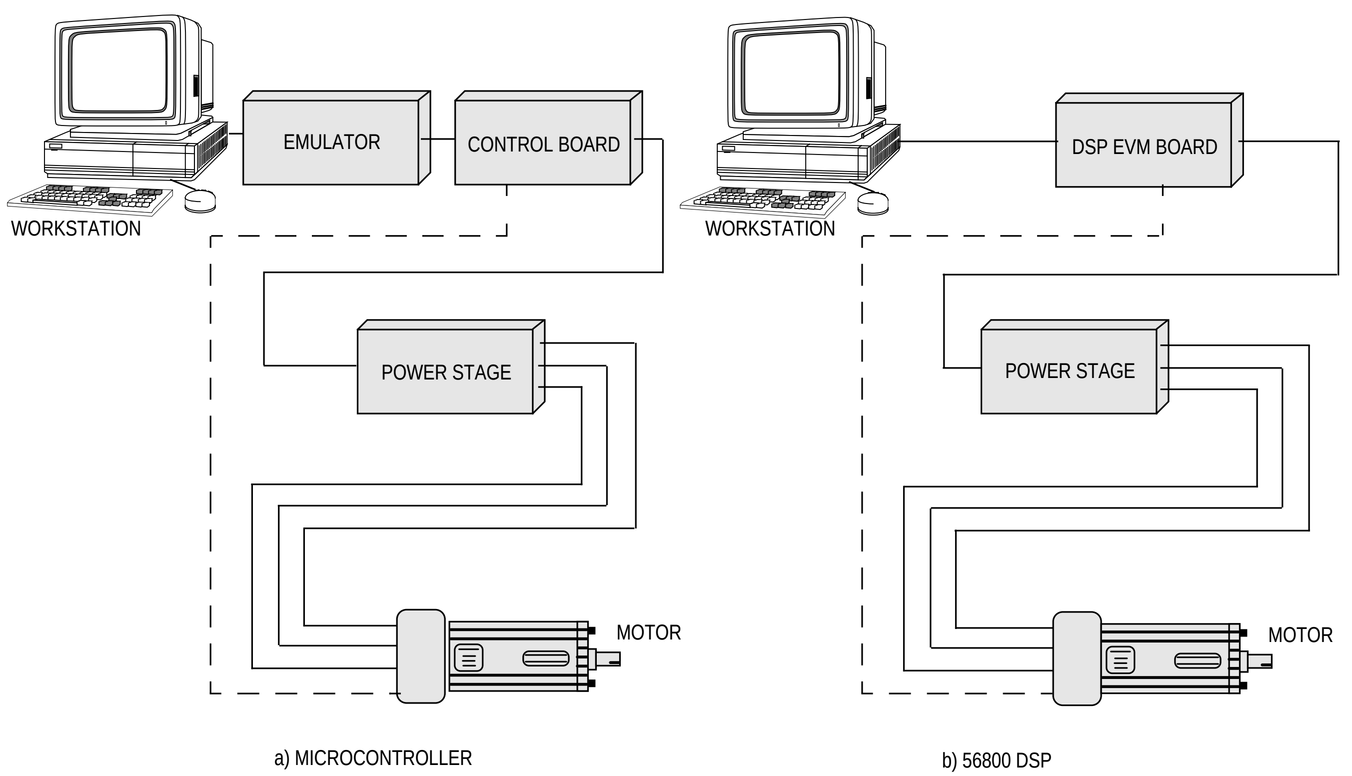

Figure 1-1. Systems' Configurations

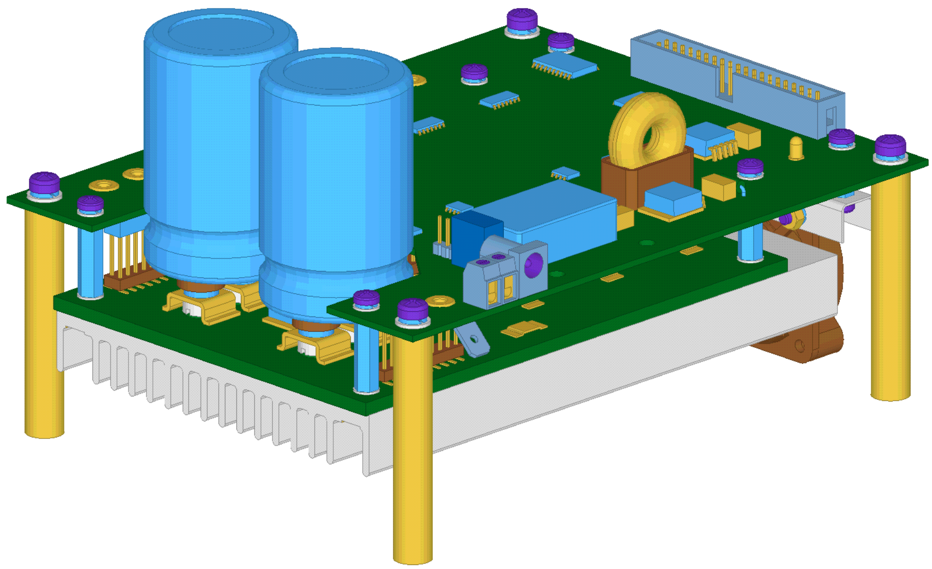

Figure 1-2. 3D Model

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 are shown in **Figure 3-1. 40-Pin Ribbon Connector J13**, and a pin-by-pin description is contained in **3.3.1 40-Pin Ribbon Connector J13**.
- 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

The LV BLDC Power Stage kit includes power components that can reach temperatures hot enough to cause burns. The motor that it operates may also reach high temperatures.

The user should be aware that:

- To facilitate safe operation, input power should come from a DC laboratory power supply that is current limited to no more than 55 Amps.
- Before moving scope probes, making connections, etc., it is generally advisable to power down the motor supply.
- Operation in lab setups that have grounded tables and/or chairs should be avoided.
- Wearing safety glasses, avoiding ties and jewelry, and using shields are also advisable.

1.5 Setup Guide

Setup and connections are very straightforward. The LV BLDC power stage connects to an embedded motion control series control board via 40-pin ribbon cable. The motor's power leads plug into output connectors, J16 – J18, and its Hall sensors plug into the control board's Hall sensor/encoder input connector. **Figure 1-3** depicts a completed setup.

1. Mount four standoffs to the LV BLDC Power Stage at the locations indicated in **Figure 1-3**. Standoffs, screws, and washers are included in the kit.

NOTE: *This step and step 3 are optional when making connections with DSP control boards such as the DSP56F805EVM. The DSP boards may be placed flat on a bench, next to the EVM motor board.*

2. Plug one end of the 40-pin ribbon cable that is supplied with the kit into input connector J13, located on the right hand side of the top board. The other end of this cable connects to the control board's 40-pin output connector.

3. Mount the control board on top of the standoffs with screws and washers from the ECLOVACBLDC kit. This step is optional with DSP control boards.
4. Plug the free end of the cable connected to input connector J13 into the control board's 40-pin output connector.
5. Connect a 12-Vdc power supply to fast-on connectors J19 and J20. Connector J19 is located on the back-left corner of the top board, and connector J20 is in the front-left corner of the top board. The positive lead goes to J19, labeled +12V. The return is connected to J20, labeled 0V. Voltage range for the power supply is 10 to 16 Vdc. The power supply's current limit should be set to less than 55 amps.

   In the as-shipped configuration, jumper JP401 is set to INT. and a bias supply at connector J21 or power jack J22 is not needed. One power supply connected to J19 and J20 is all that is required.
6. Connect motor phase A to fast-on connector J16, labeled phase A. Connector J16 is located along the back edge of the top board.
7. Connect motor phase B to fast-on connector J17, labeled phase B. Connector J17 is located along the back edge of the top board.
8. Connect motor phase C to fast-on connector J18, labeled phase C. Connector J18 is located along the back edge of the top board.
9. Apply power. The green power-on LED lights when power is present.

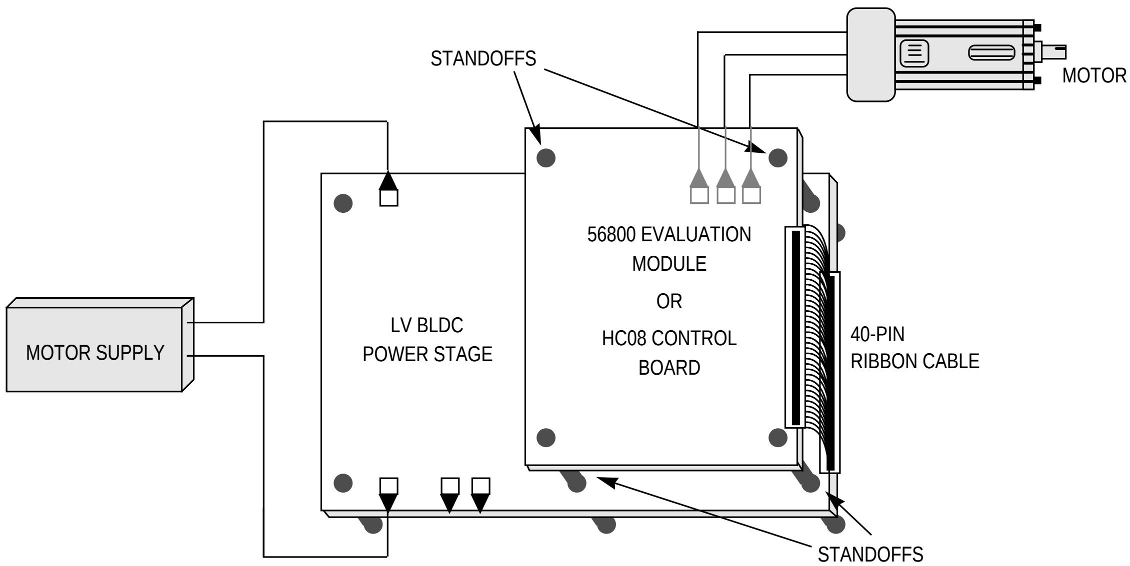

Figure 1-3. Setup

Section 2. Operational Description

2.1 Contents

2.2 Description

Motorola's embedded motion control series low-voltage (LV) brushless dc (BLDC) power stage operates from a nominal 12-volt motor supply, and delivers up to 30 amps of rms motor current from a dc bus that can deliver peak currents up to 46 amps. In combination with one of Motorola's embedded motion control series control boards, 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 BLDC motors.

Input connections are made via 40-pin ribbon cable connector J13. Pin assignments for the input connector are shown in **Figure 3-1. 40-Pin Ribbon Connector J13**. Power connections to the motor are made with fast-on connectors J16, J17, and J18. They are located along the back edge of the board, and are labeled Phase A, Phase B, and Phase C. Power requirements are met with a 12-volt power supply that has a 10- to 16-volt tolerance. Fast-on connectors J19 and J20 are used for the power supply. J19 is labeled +12V and is located on the back edge of the board. J20 is labeled 0V and is located along the front edge. Current measuring circuitry is set up for 50 amps full scale. Both bus and phase leg currents are measured. A cycle by cycle overcurrent trip point is set at 46 amps.

The LV BLDC power stage has both a printed circuit board and a power substrate. The printed circuit board contains MOSFET gate drive circuits, analog signal conditioning, low-voltage power supplies, and some of the large passive power components. This board also has a 68HC705JJ7 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 MOSFETs, brake resistors, current-sensing resistors, bus capacitors, and temperature sensing diodes. **Figure 2-1** shows a block diagram.

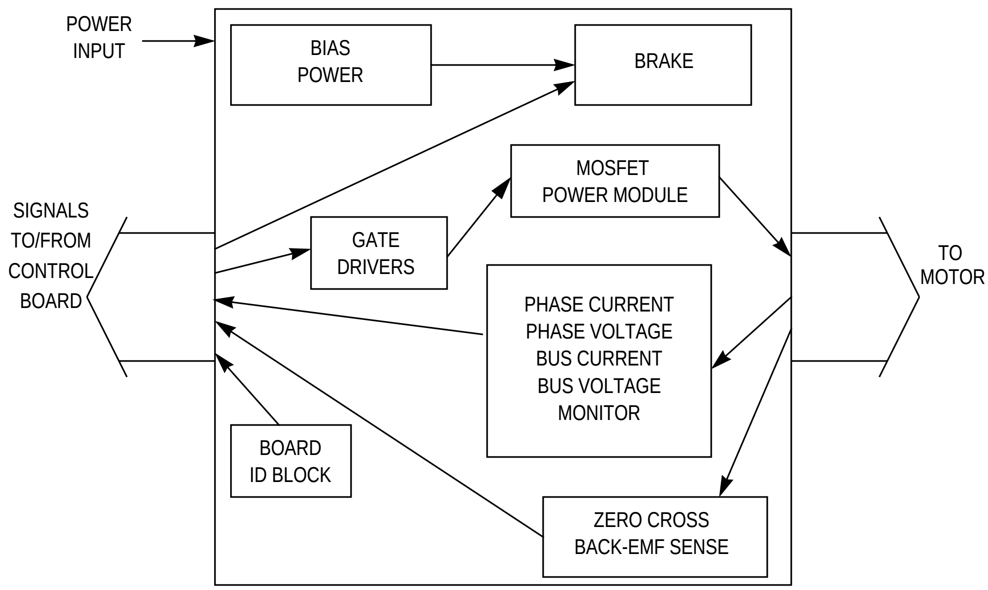

Figure 2-1. Block Diagram

2.3 Electrical Characteristics

The electrical characteristics in **Table 2-1** apply to operation at 25°C with a 12-Vdc supply voltage.

Table 2-1. Electrical Characteristics

Characteristic	Symbol	Min	Typ	Max	Units
Motor Supply Voltage	Vac	10	12	16	V
Quiescent current	I_{CC}	—	175	—	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}	—	33	—	mV/A
Bus voltage sense voltage	V_{Bus}	—	60	—	mV/V
Peak output current (300 ms)	I_{PK}	—	—	46	A
Continuous output current	I_{RMS}	—	—	30	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 42 Volts

The LV BLDC power stage can be modified for operation with a 42-volt nominal motor supply. To change input voltage range:

1. Remove power and wait until the power-on LED is off.
2. Make the resistor value changes shown in **Table 2-2**. With the values shown for 42 volts, voltage-feedback signals are scaled at 60 mV per volt.

Table 2-2. Resistor Values

Resistors	12 Volts	42 Volts
R207, R522, R523, R524	0 Ω	39 kΩ

3. 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	12 Volts	42 Volts
1-2	Open	Open
3-4	Open	Open
5-6	Open	Open
7-8	Open	**Short**

4. Set jumper JP401 to the EXT. position. JP401 is located on left side of the top board adjacent to one of the bus capacitors. The EXT. setting allows bias circuitry to be powered from a 12-volt source that is separate from the motor supply.
5. Connect a 12-Vdc power supply either to connector J21, labeled - EXT. 12V +, or power jack J22. Either one, but not both may be used. Polarity does not matter, since these inputs are connected to a full-wave bridge. Connectors J21 and J22 are located on the front left-hand corner of the top board. The 12-volt power supply should have its current limit set between 500 mA and 1 amp. The input voltage range is 10 volts to 16 volts.

Once these modifications have been made, the input voltage range for the motor supply is 10 Vdc to 55 Vdc.

Section 3. Pin Descriptions

3.1 Contents

3.2 Introduction

There are ten connectors on the top board for making input and output connections. They are listed as follows.

- J13 — 40-pin input and feedback connector
- J19 — Motor supply fast-on connector
- J20 — Motor supply fast-on connector
- J16 — Phase A fast-on connector
- J17 — Phase B fast-on connector
- J18 — Phase C fast-on connector
- J14 — Brake fast-on connector
- J15 — Brake fast-on connector
- J21 — Bias supply connector
- J22 — Bias supply power jack
- Pin assignments for input connector J13 are shown in **Figure 3-1**. Signal descriptions for each of these connectors are identified in **Table 3-1**.

3.3 Signal Descriptions

Control and feedback signals are grouped together on 40-pin ribbon connector J13. Motor outputs each have separate fast-on connectors that are designated J16 –J18. Power is supplied through fast-on connectors J19 and J20. The signals associated with each of these connectors, and the optional use of connectors J14, J15, J21, and J22 are discussed as follows.

3.3.1 40-Pin Ribbon Connector J13

40-pin ribbon cable connector J13 is located on the right side of the board. Pin assignments 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 listed in **Table 3-1**.

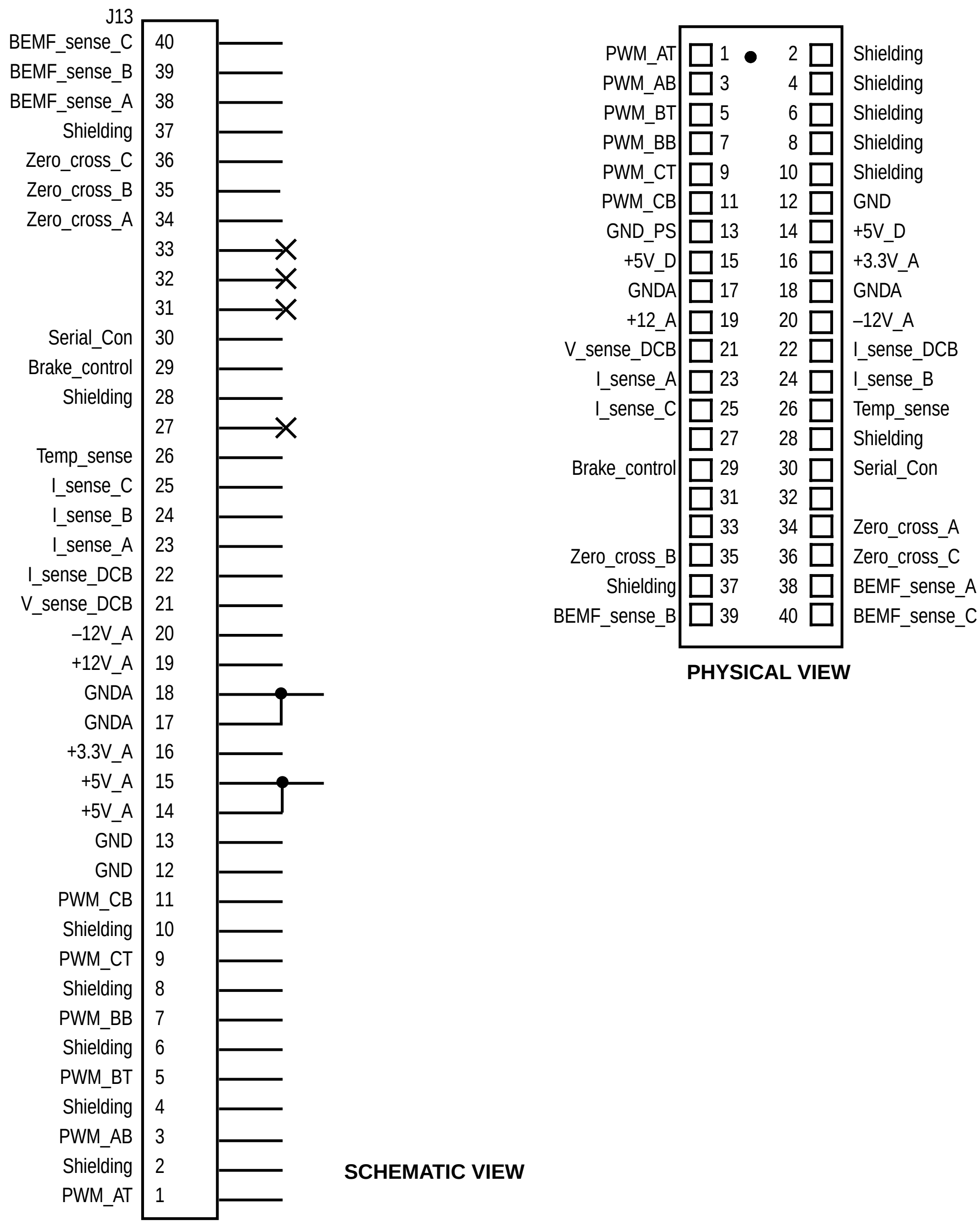

Figure 3-1. 40-Pin Ribbon Connector J13

Table 3-1. Connector J13 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 +12-volt power supply
20	–15V_A	Analog –12-volt power supply
21	V_sense_DCB	V_sense_DCB is an analog sense signal that measures dc bus voltage. It is scaled at 206 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 33 mV per amp of dc bus current.

Table 3-1. Connector J13 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 33 mV 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 33 mV 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 33 mV 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 MOSFET.
30	Serial_Con	Serial_Con is an identification signal that lets the controller know which power stage is present.
31		No connection
32		No connection
33		No connection
34	Zero_cross_A	Zero_cross_A is a digital signal used for sensing phase A back-EMF zero crossing events.
35	Zero_cross_B	Zero_cross_B is a digital signal used for sensing phase B back-EMF zero crossing events.
36	Zero_cross_C	Zero_cross_C is a 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 analog ground on the board.
38	BEMF_sense_A	BEMF_sense_A is an analog sense signal that measures phase A back EMF. It is scaled at 206 mV per volt of dc bus voltage.
39	BEMF_sense_B	BEMF_sense_B is an analog sense signal that measures phase B back EMF. It is scaled at 206 mV per volt of dc bus voltage.
40	BEMF_sense_C	BEMF_sense_C is an analog sense signal that measures phase C back EMF. It is scaled at 206 mV per volt of dc bus voltage.

3.3.2 Power Connectors J19 and J20

Motor power is supplied through fast-on connectors J19 and J20. J19 is labeled +12V, and is located on the back left-hand corner of the top board. J20 is labeled 0V, and is located on the front left-hand corner of the top board. These connectors will accept a power supply voltage from 10 volts to 16 volts as the LV BLDC power stage is shipped. When the LV BLDC power stage has been reconfigured for 42-volt nominal operation, this power supply input will accept inputs from 10 volts to 55 volts. The power supply should be current limited to less than 55 amps.

3.3.3 Motor Connectors J16, J17, and J18

Power connections to the motor are made with fast-on connectors J16, J17, and J18, located on the back edge of the top board. These connections are identified as follows.

- J16: Phase A — Connector J16, labeled Phase A, supplies power to motor phase A. This is a 30-amp RMS fast-on connection.
- J17: Phase B — Connector J17, labeled Phase B, supplies power to motor phase B. This is a 30-amp RMS fast-on connection.
- J18: Phase C — Connector J18, labeled Phase C, supplies power to motor Phase C. This is a 30 amp RMS fast-on connection.

3.3.4 External Brake Connectors J14 and J15

An optional external brake resistor can be connected to external brake fast-on connectors J14 and J15, labeled BRAKE 1 Ext. and BRAKE 2 Ext. These connectors are located on the back left-hand corner of the top board. The external resistor allows power dissipation to be increased beyond the 50 watts that brake resistors R1–R4 provide. Note that operation of the brake at 100 percent duty cycle for more than 15 seconds at 12 volts will overdissipate R1–R4. For bus voltages higher than 12 volts, maximum duty cycle is restricted to less than 100 percent. The total power dissipation limit for these four resistors combined is 50 watts continuous and 100 watts for 15 seconds.

3.3.5 Bias Power Connectors J21 and J22

Two connectors, labeled J21 and J22, are provided for an optional 12-volt bias supply. This input is only used when the LV BLDC power stage has been reconfigured for operation with a 42-volt nominal motor supply. J21 and J22 are located on the front left-hand corner of the board. Connector J22 is a 2.1-mm power jack for 12-volt plug-in type power supply connections. Connector J21 has screw terminal inputs labeled + and – for accepting wire inputs. Power is supplied to one or the other, but not both. The power supply should be current-limited to at least 500 mA, and less than 1 amp.

Section 4. Schematics and Parts List

4.1 Contents

4.2 Mechanical Characteristics

Mechanically, the LV BLDC power stage consists of an FR-4 circuit board, a 3.2-mm aluminum power substrate, two fans, a fan bracket, a heat sink, inter-board connectors, and standoffs. Construction is depicted in **Figure 1-2. 3D Model**. The aluminum circuit board, fans, and heat sink provide the thermal capability for D^2PAK MOSFETs to drive fractional horsepower motors at continuous currents up to 30 amps. The FR-4 board contains most of the circuit complexity. 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 LV BLDC Power Stage appears in **Figure 4-1** through **Figure 4-8**. An overview appears in **Figure 4-1**. H-bridge gate drive is shown in **Figure 4-2**. The 3-phase H-Bridge appears in **Figure 4-3**. Current and temperature feedback circuits are shown in **Figure 4-4**. Back EMF feedback circuitry appears in **Figure 4-5**. Brake gate drive is shown in **Figure 4-6**. The identification block is shown in **Figure 4-7**, and finally the power supply is shown in **Figure 4-8**. 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 printed circuit board and power substrate appear in **Table 4-1** and **Table 4-2**.

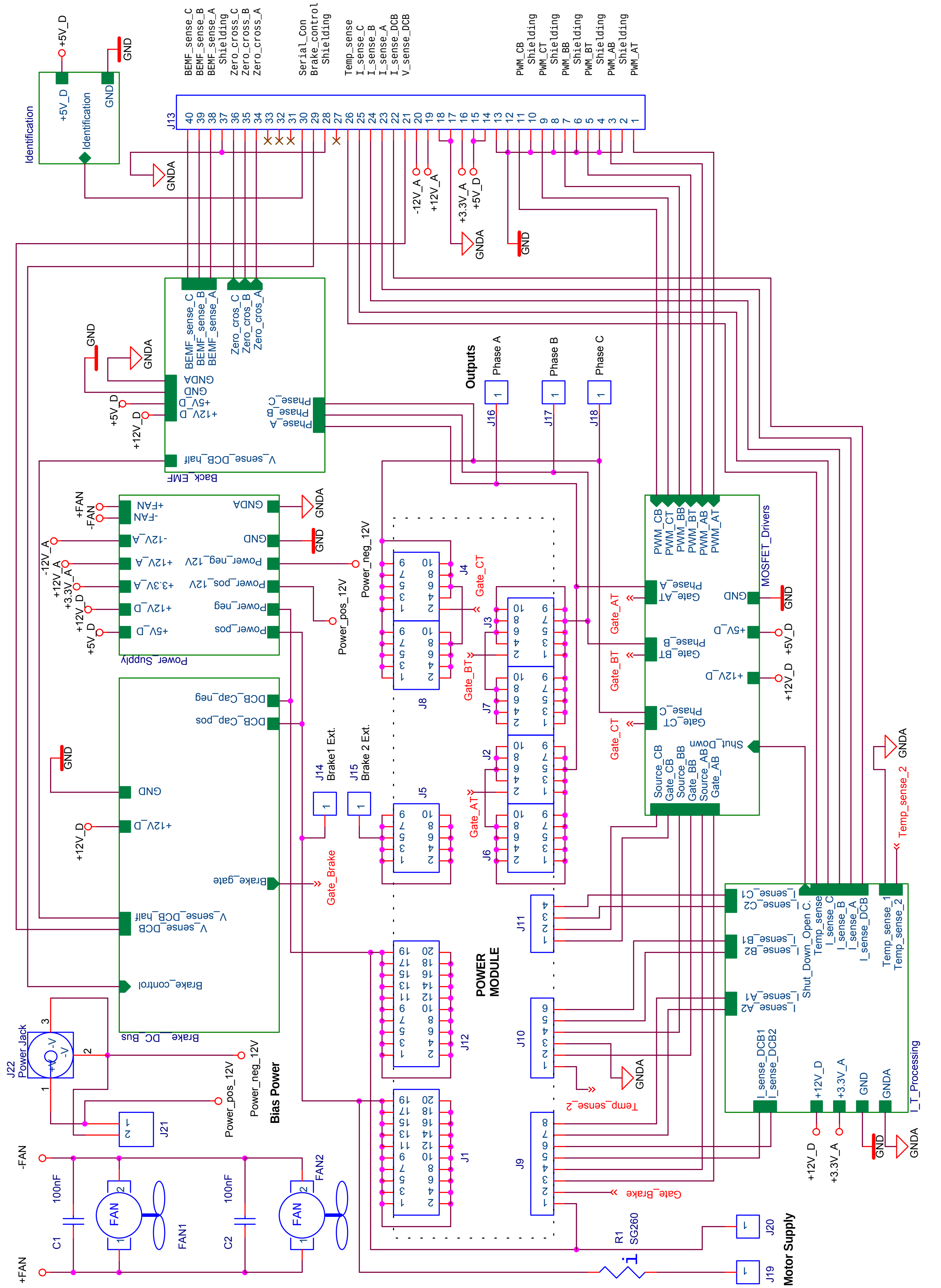

Figure 4-1. 3-Phase BLDC Low-Voltage Power Stage Overview

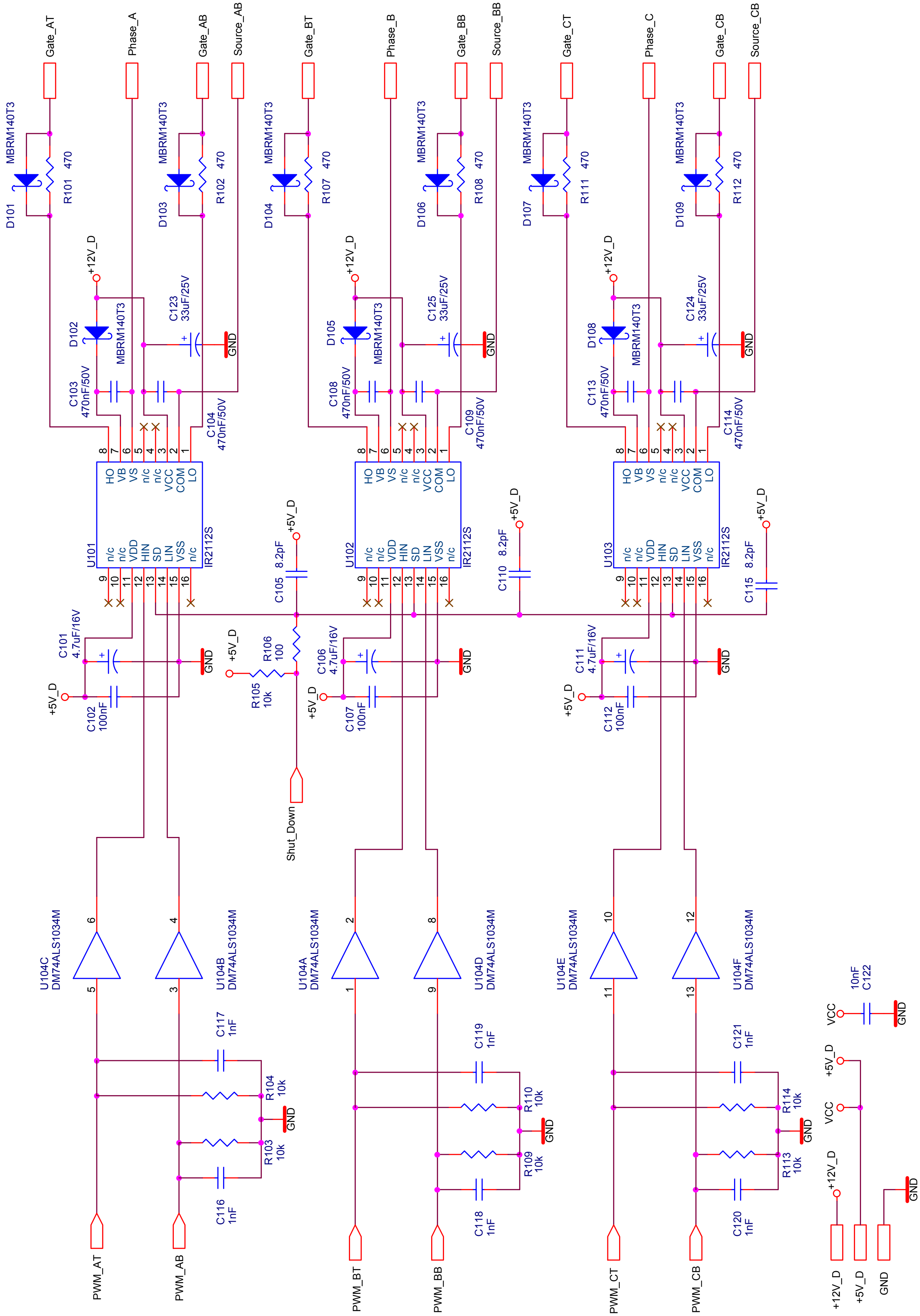

Figure 4-2. Gate Drive

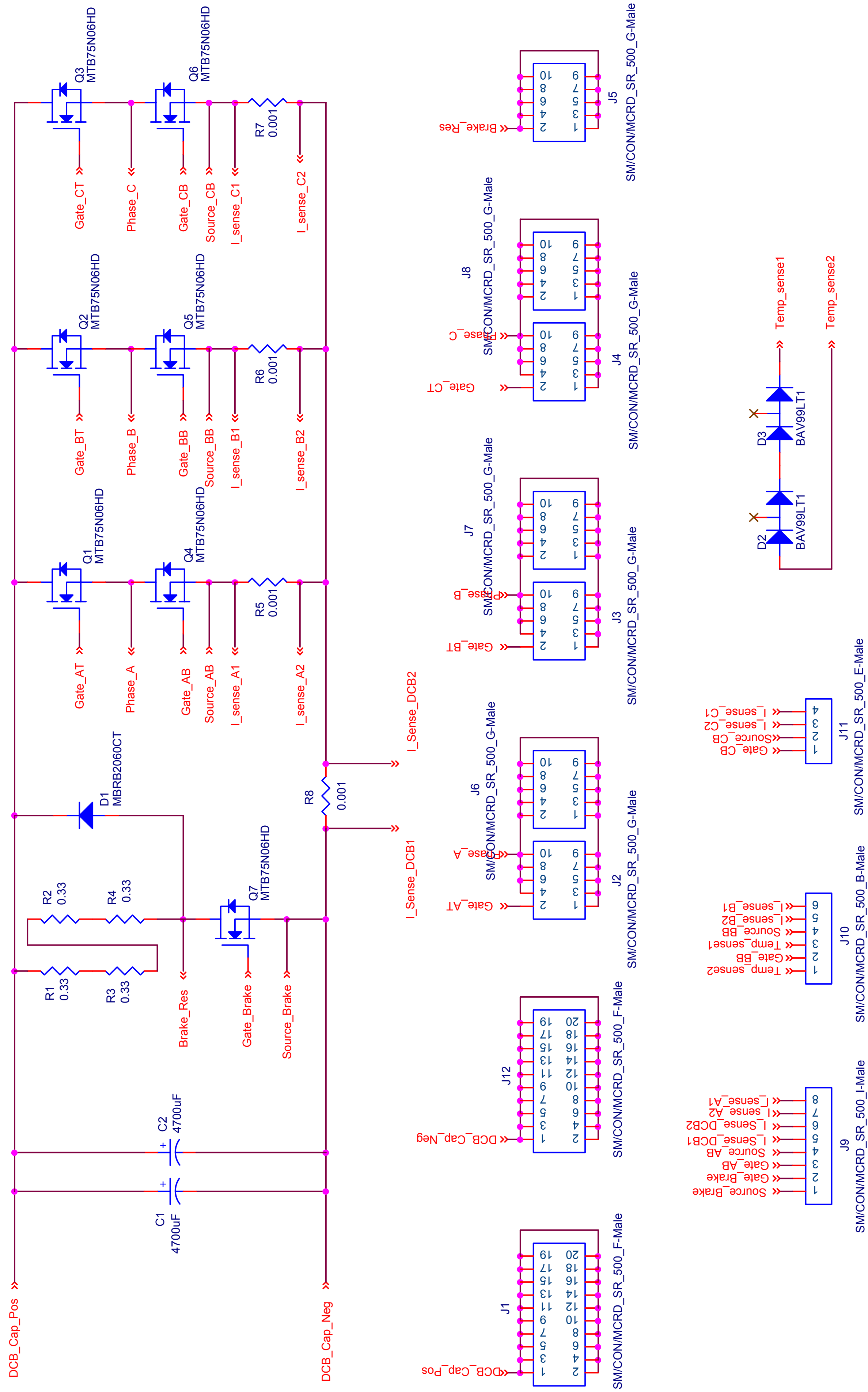

Figure 4-3. 3-Phase H-Bridge

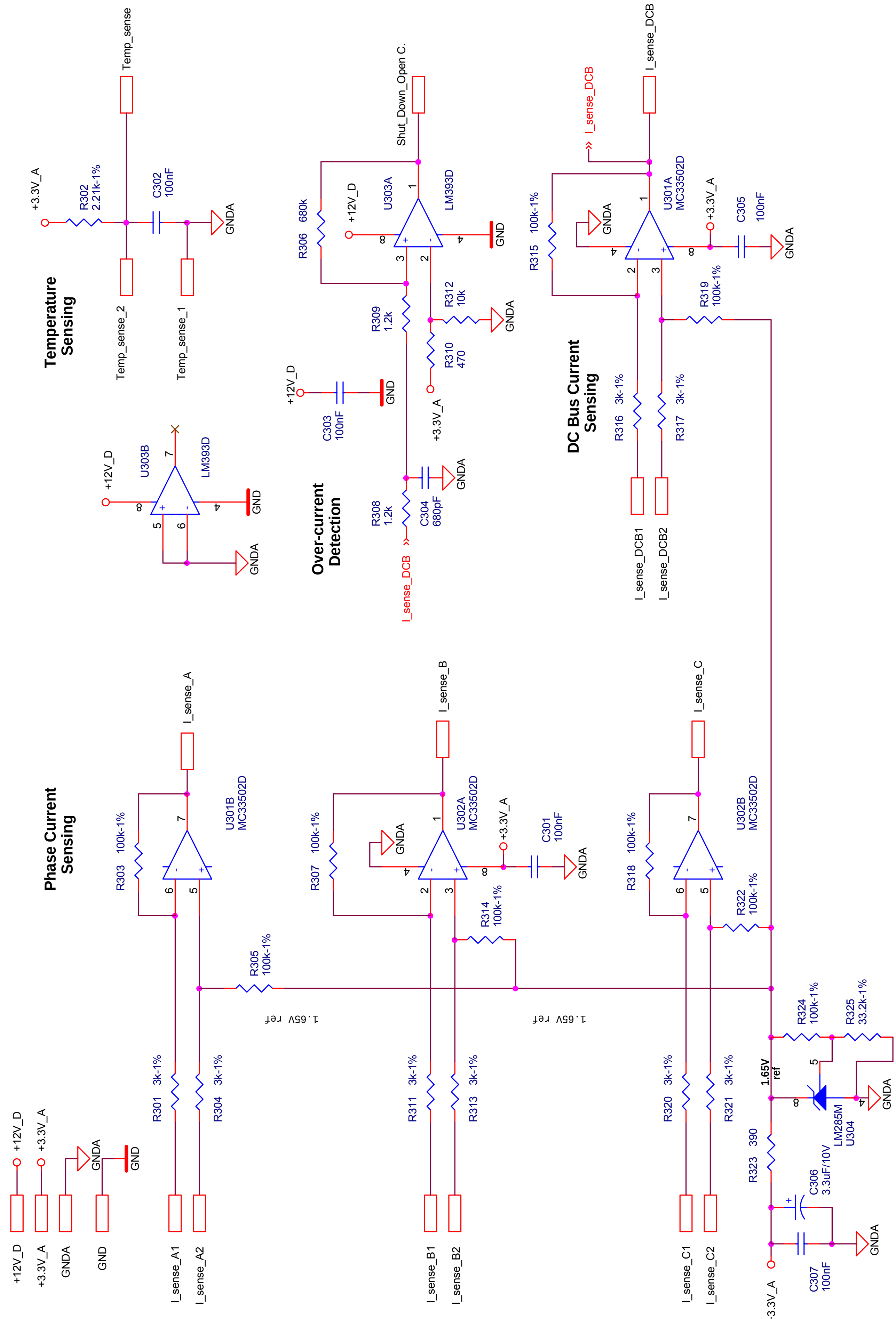

Figure 4-4. Current and Temperature Feedback

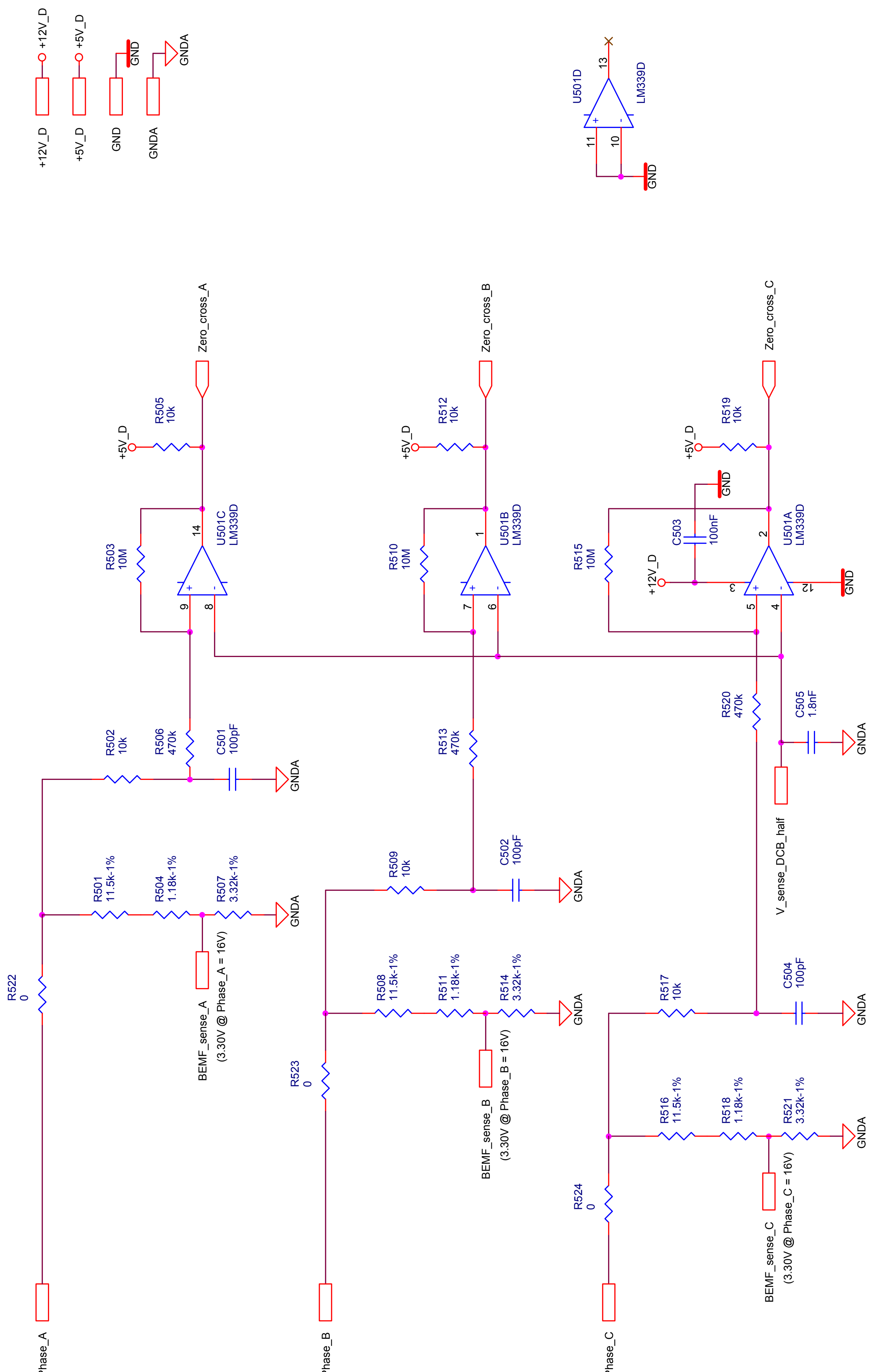

Figure 4-5. Back EMF Signals

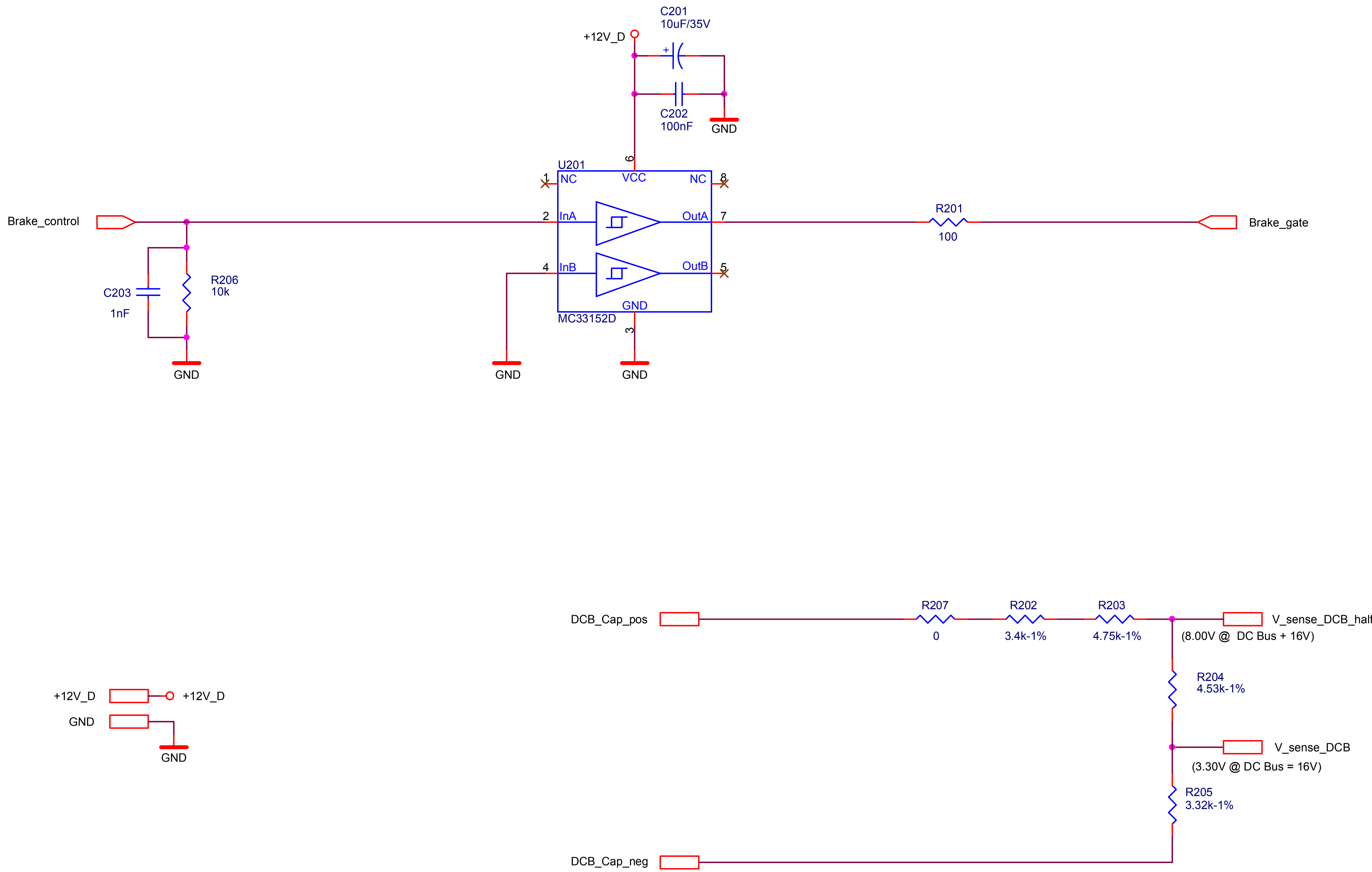

Figure 4-6. DC Bus Voltage Sense and Brake Gate Drive

Freescale Semiconductor, Inc.

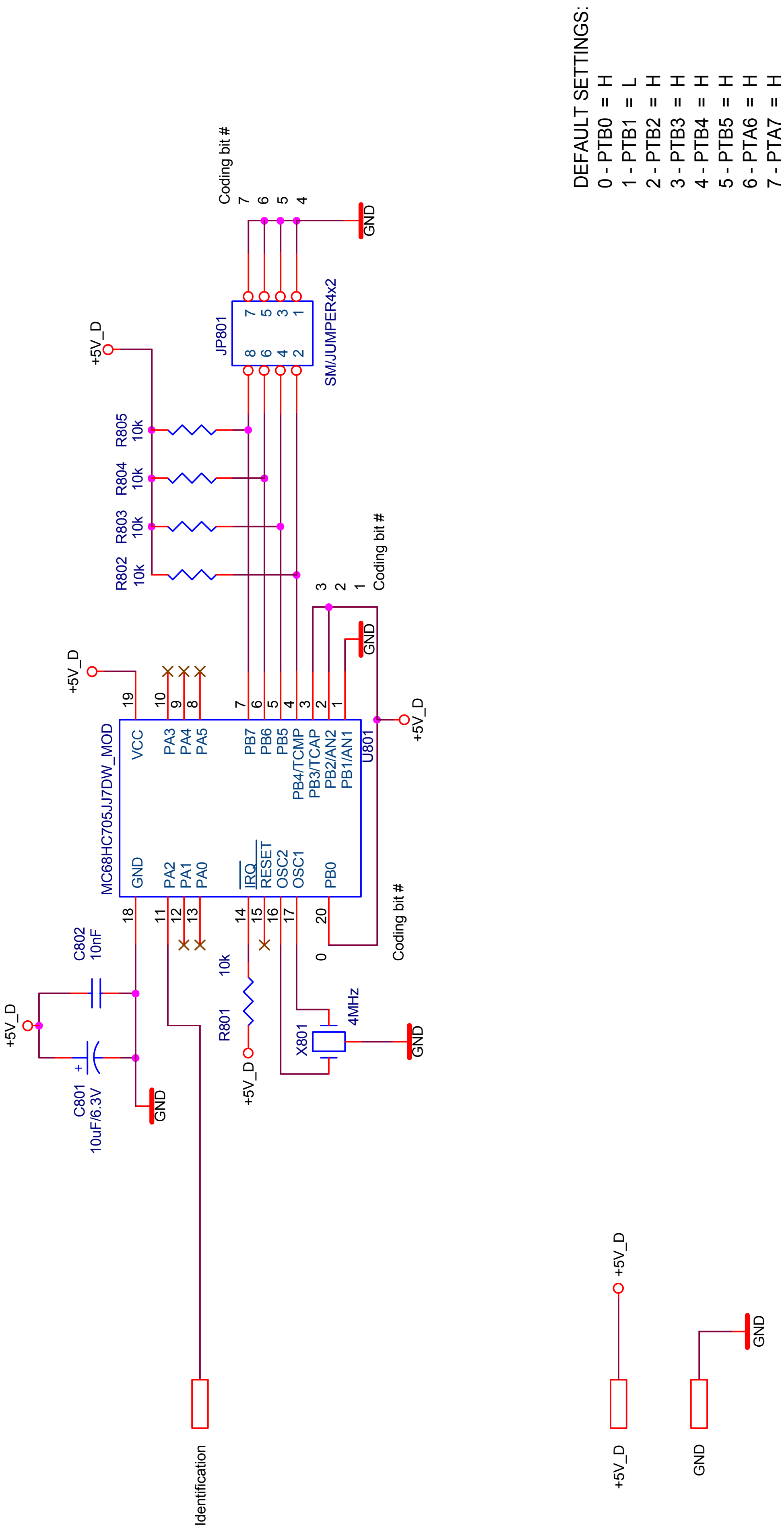

Figure 4-7. Identification Block

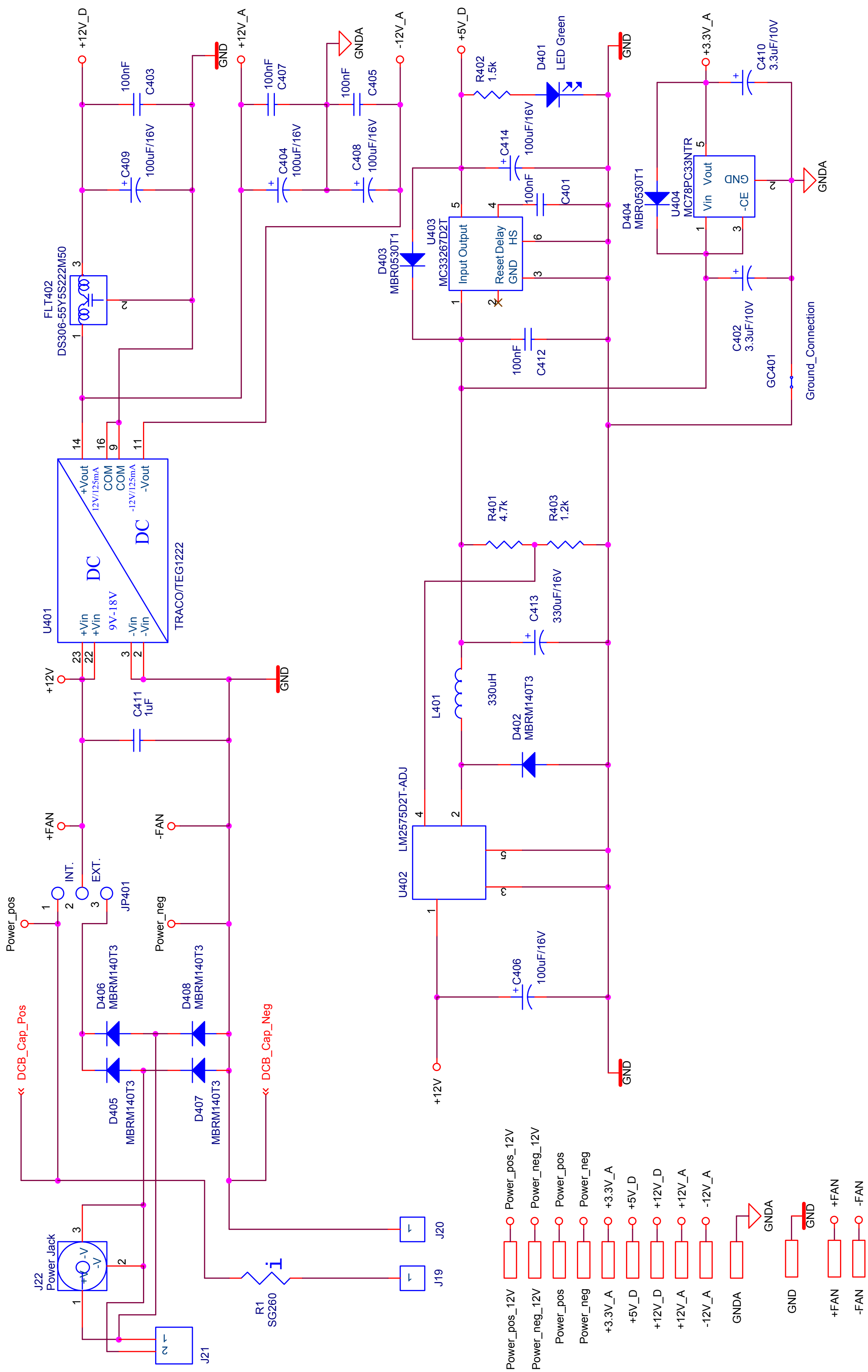

Figure 4-8. Power Supply

4.4 Parts Lists

The LV BLDC 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

Designators	Qty	Description	Manufacturer	Part Number
C1, C2	2	4700 µF		
D1	1	20 A/60 V Schottky	ON Semiconductor	MBRB2060CT
D2, D3	2	Dual diode – temp sensing	ON Semiconductor	BAV99LT1
J1, J12	2	SM/CON/MCRD_SR_500_F	Fischer Elektronik	SL 11 SMD 104 10 Z
J2, J3, J4, J5, J6, J7, J8	7	SM/CON/MCRD_SR_500_G	Fischer Elektronik	SL 11 SMD 104 5 Z
J9	1	SM/CON/MCRD_SR_500_I	Fischer Elektronik	SL 10 SMD 104 8 Z
J10	1	SM/CON/MCRD_SR_500_B	Fischer Elektronik	SL 10 SMD 104 6 Z
J11	1	SM/CON/MCRD_SR_500_E	Fischer Elektronik	SL 10 SMD 104 4 Z
Q1, Q2, Q3, Q4, Q5, Q6, Q7	7	75 A/60 V MOSFET	ON Semiconductor	MTB75N06HD
R1, R2, R3, R4	4	0.33 Ω/25 W	Caddock Electronics	MP725-0.33-5.0%
R5, R6, R7, R8	4	0.001 Ω sense resistor	Isabellenhütte Heusler	BVS-M-R001-1.0
	1	Substrate	CUBEcz	46615772

Table 4-2. Printed Circuit Board Parts List (Sheet 1 of 3)

Designators	Qty	Description	Manufacturer	Part Number
C1, C2, C102, C107, C112, C202, C301, C302, C303, C305, C307, C401, C403, C405, C407, C412, C503	17	100 nF/25 V	Vitramon	VJ0805U104MXXA_
C101, C106, C111	3	4.7 µF/16 V	Sprague	293D475X_016B2_
C103, C104, C108, C109, C113, C114	6	470 nF/50 V	Vitramon	VJ1206U474MXAA_
C105, C110, C115	3	8.2 pF	Vitramon	VJ0805A8R2DXA_
C116, C117, C118, C119, C120, C121, C203	7	1 nF/50 V	Vitramon	VJ0805A102KXAA_
C122, C802	2	10 nF/25 V	Vitramon	VJ0805U103MXXA_
C123, C124, C125	3	33 µF/25 V	AVX	TPSE336K025R0200
C201	1	10 µF/35 V	Sprague	293D106X0035D2_
C304	1	680 pF	Vitramon	VJ0805A681JXA_
C306, C402, C410	3	3.3 µF/10 V	Sprague	293D335X0010A2_
C404, C406, C408, C409, C414	5	100 µF/16 V	Sprague	293D107X0016D2_
C411	1	1 µF	Siemens	B32529-C105-K
C413	1	330 µF/16 V	Vishay Roederstein	EKA00PB333D00
C501, C502, C504	3	100 pF	Vitramon	VJ0805A101KXAA_
C505	1	1.8 nF	Vitramon	VJ0805A182KXAA_
C801	1	10 µF/6.3 V	Sprague	293D106X06R3B2_
D101, D102, D103, D104, D105, D106, D107, D108, D109, D402, D405, D406, D407, D408	14	1 A/40 V Schottky	ON Semiconductor	MBRM140T3
D401	1	LED green	Kingbright	L-934GT
D403, D404	2	0.5 A/30 V Schottky	ON Semiconductor	MBR0530T1
JP401	1	Power jumper	Fischer Elektronik	SL 1/53 3 G
FLT401	1	EMI filter	muRata	DS306-55Y5S222M50
GC401	0	Ground connection	N/A	N/A
JP401	1	Power jumper	Fischer Elektronik	CAB 4 G
JP801	0	4x2 jumper pads	N/A	N/A
J1, J12	2	20-pin female header	Fischer Elektronik	BL 2 10 Z

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

Designators	Qty	Description	Manufacturer	Part Number
J2, J3, J4, J5, J6, J7, J8	7	10-pin female header	Fischer Elektronik	BL 2 5 Z
J9	1	8-pin female header	Fischer Elektronik	BL 1 8 Z
J10	1	6-Pin female header	Fischer Elektronik	BL 1 6 Z
J11	1	4-pin female header	Fischer Elektronik	BL 1 4 Z
J13	1	40-pin connector	Fischer Elektronik	ASLG40G
J14, J15, J16, J17, J18, J19, J20	7	Fast-on	AMP	140814-2
J21	1	2-pole terminal block	WAGO	237-132
J22	1	Power jack	CUI Stack	PJ-002A
L401	1	330 µH	Pulse Engineering	53146
R1	1	30 A current limiter	Rhopoint Components	SG260
R101, R102, R107, R108, R111, R112	6	470 Ω	Dale	CRCW0805-471J
R103, R104, R105, R109, R110, R113, R114, R206, R312, R502, R505, R509, R512, R517, R519, R801, R802, R803, R804, R805	20	10 kΩ	Dale	CRCW0805-103J
R201, R106	2	100 Ω	Dale	CRCW0805-101J
R205, R507, R514, R521	4	3.32 kΩ–1%	Dale	CRCW0805-3321F
R202	1	3.4 kΩ–1%	Dale	CRCW0805-3401F
R203	1	4.75 kΩ–1%	Dale	CRCW0805-4751F
R204	1	4.53 kΩ–1%	Dale	CRCW0805-4531F
R207, R522, R523, R524	4	0	Dale	CRCW0805-000
R301, R304, R311, R313, R316, R317, R320, R321	8	3 kΩ–1%	Dale	CRCW0805-3001F
R302	1	2.21 kΩ–1%	Dale	CRCW0805-2211F
R303, R305, R307, R314, R315, R318, R319, R322, R324	9	100 kΩ–1%	Dale	CRCW0805-1003F
R306	1	68 kΩ	Dale	CRCW0805-683J
R308, R309, R403	3	1.2 kΩ	Dale	CRCW0805-122J
R310	1	470 Ω	Dale	CRCW0805-221J

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

Designators	Qty	Description	Manufacturer	Part Number
R323	1	390 Ω	Dale	CRCW0805-391J
R325	1	33.2 kΩ–1%	Dale	CRCW0805-3322F
R401	1	4.7 kΩ	Dale	CRCW0805-473J
R402	1	1.5 kΩ	Dale	CRCW0805-152J
R501, R508, R516	3	11.5 kΩ–1%	Dale	CRCW0805-1152F
R503, R510, R515	3	10 MΩ	Dale	CRCW0805-106J
R504, R511, R518	3	1.18 kΩ–1%	Dale	CRCW0805-1181F
R506, R513, R520	3	470 kΩ	Dale	CRCW0805-474J
U101, U102, U 103	3	Gate driver	International Rectifier	IR2112S
U104	1	Hex driver	Fairchild	DM74ALS1034M
U201	1	Gate driver	ON Semiconductor	MC33152D
U301, U302	2	Op amp	On Semiconductor	MC33502D
U303	1	Dual comparator	On Semiconductor	LM393D
U304	1	Voltage reference	National Semiconductor	LM285M
U401	1	DC/DC convertor	Traco Power	TEG1222
U402	1	Voltage regulator	ON Semiconductor	LM2575D2T-ADJ
U403	1	Voltage regulator	ON Semiconductor	
U404	1	Voltage regulator	ON Semiconductor	MC78PC33NTR
U501	1	Dual comparator	ON Semiconductor	LM339D
U801	1	Programmed MCU	Motorola	MC68HC705JJ7DW
X801	1	4-MHz resonator	muRata	CSTCC4.00MG
	7	Tubular rivet	INDUSTRIAL RIVET	N/A

Section 5. Design Considerations

5.1 Contents

5.2 Overview

From a systems point of view, the LV BLDC 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 are provided.

Circuit descriptions for the LV BLDC power stage appear in these subsections.

5.3 Phase Outputs

The output stage is configured as a 3 phase H-Bridge with 60-volt MOSFET output transistors. It is simplified considerably by integrated gate drivers that have a cycle by cycle current limit feature. A schematic that shows one phase is illustrated in **Figure 5-1**.

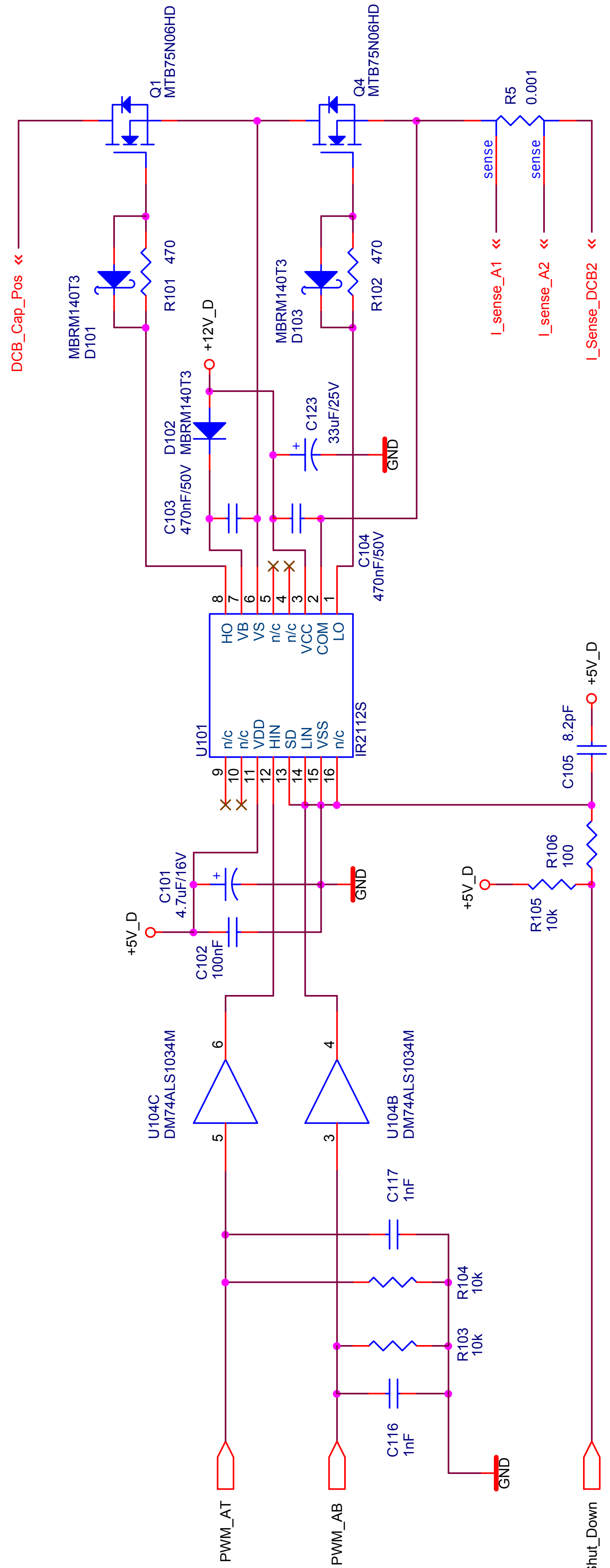

Figure 5-1. Phase A Output

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 R202–R205.

The values are chosen such that a 16-volt maximum bus voltage corresponds to 3.3 volts at output V_sense_DCB. An additional output, V_sense_DCB_half, provides a reference that is used in zero-crossing detection.

Bus current is sampled by resistor R8 in **Figure 4-3. 3-Phase H-Bridge** 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 R316 = R317 and R315 = R319, 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 ±50 mV voltage drop across the sense resistor corresponds to a measured current range of ±50 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**.

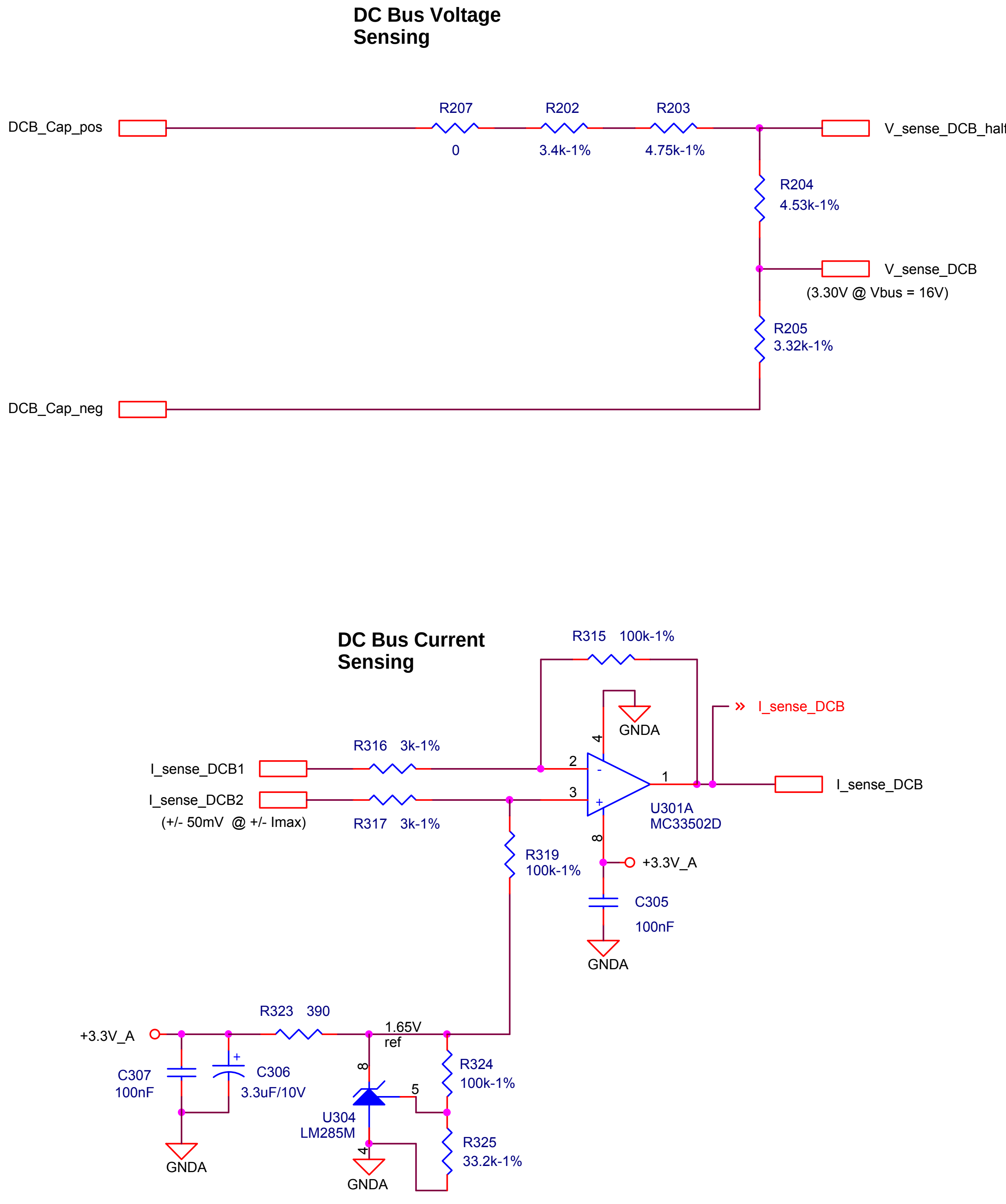

Figure 5-2. Bus Feedback

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 C304 to remove spikes, and then compared to a 3.15-volt reference in U303A. The open collector output of U303A is pulled up by R105. Additional filtering is provided by C105, C110, and C115. The resulting signal is fed into the IR2112 gate driver’s shutdown input on all three phases. Therefore, when bus current exceeds 46 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.

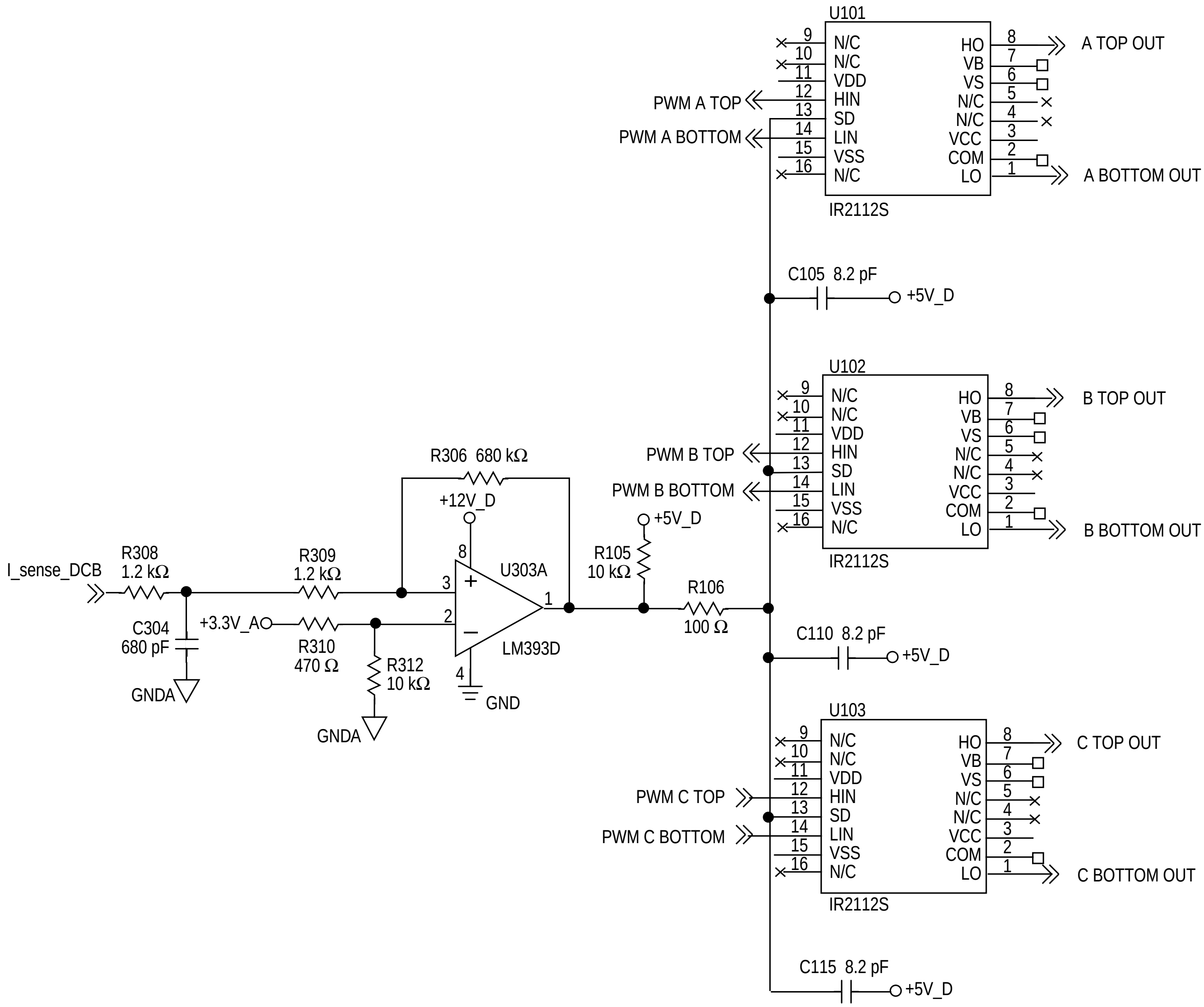

Figure 5-3. Cycle-by-Cycle Current Limiting

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 nonvolatile memory. The measured value, rather than the nominal value, is then used as a reference point for further readings.

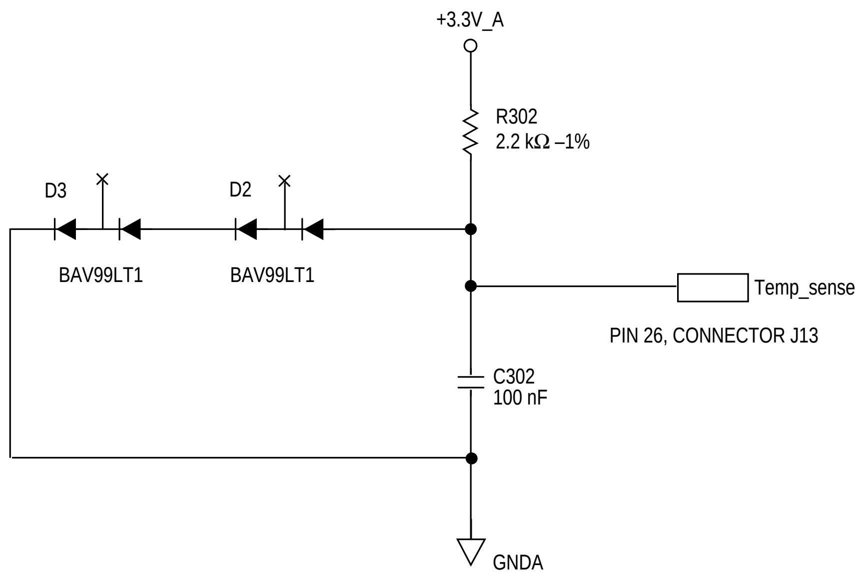

Figure 5-4. Temperature Sensing

5.7 Back EMF Signals

Back EMF and zero crossing signals are included to support sensorless algorithms. Referring to **Figure 5-5**, which shows circuitry for phase A, the raw phase voltage is scaled down by a voltage divider consisting of R501, R504, R507, and R522. One output from this divider produces back EMF sense voltage BEMF_sense_A. Resistor values are chosen such that a 16-volt maximum phase voltage corresponds to a 3.3-volt maximum A/D input. A zero crossing signal is obtained by comparing motor phase voltage with one-half the motor bus voltage. Comparator U501C performs this function, producing zero crossing signal Zero_cross_A.

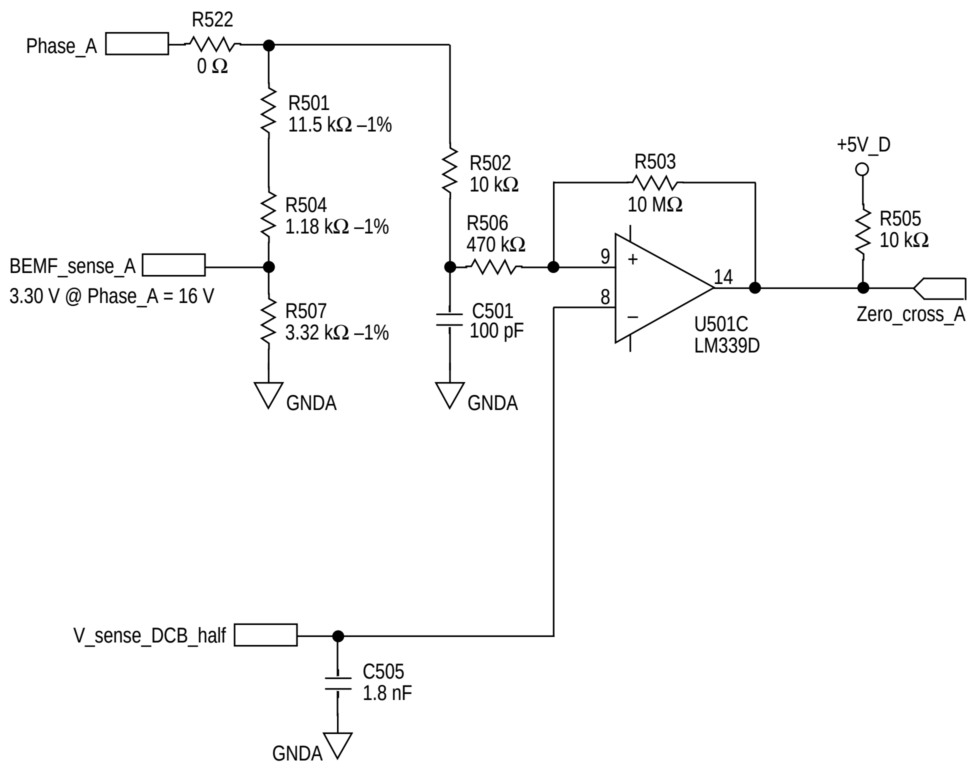

Figure 5-5. Phase A Back EMF

5.8 Phase Current Sensing

Lower half-bridge sampling resistors provide phase current information for all three phases. Since 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 a variety of motor control algorithms. The measurement circuitry for one phase is shown in **Figure 5-6**.

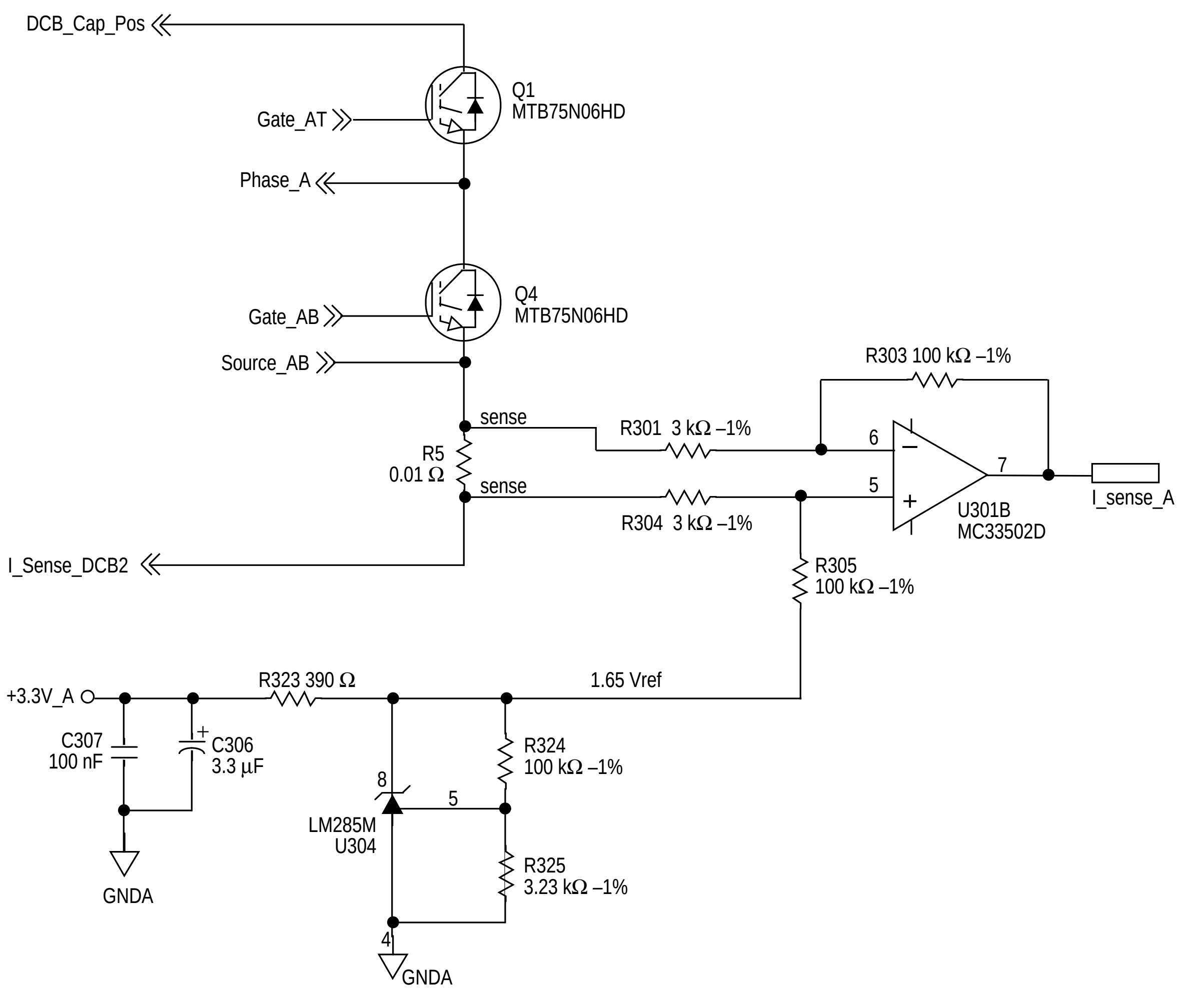

Figure 5-6. Phase A Current Sensing

Referencing the sampling resistors to the negative motor rail makes the measurement circuitry straightforward and inexpensive. Current is sampled by resistor R5, and amplified by differential amplifier U301B. This circuit provides a voltage output suitable for sampling with A/D inputs. An MC33502 is again used for the differential amplifier. The gain is given by:

$$A = \text{R303/R301}$$

The output voltage is shifted up by 1.65 V to accommodate both positive and negative current swings. A ±50-mV voltage drop across the shunt resistor corresponds to a measured current range of ±50 amps.

5.9 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 5-7** connects R1–R4 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 R1–R4 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 connectors J14 and J15.

Note that operation of the brake at 100% duty cycle for more than 15 seconds at 12 volts will over dissipate R1–R4. For bus voltages higher than 12 volts, maximum duty cycle is restricted to less than 100%.

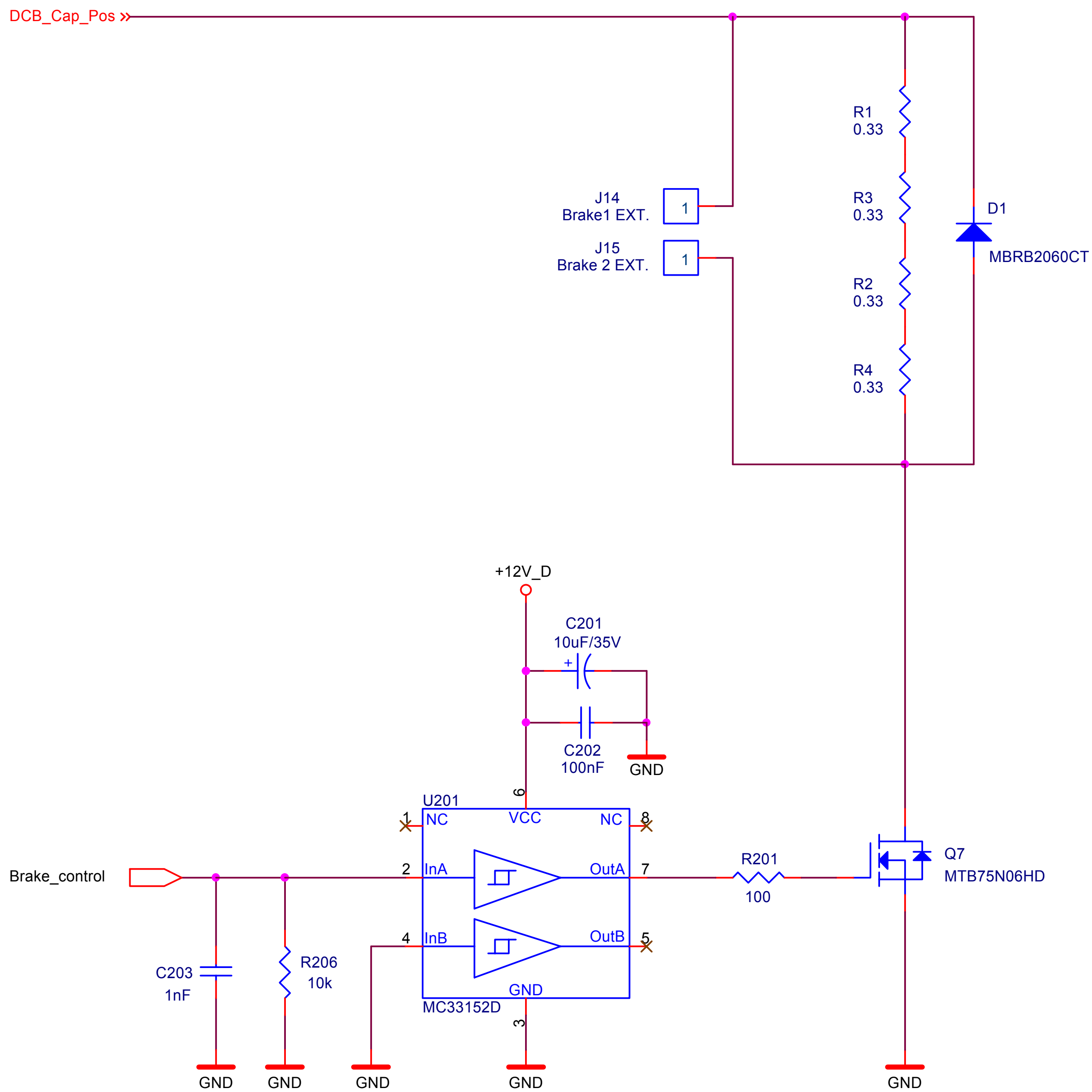

Figure 5-7. Brake

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