Three-Phase Micro Power Stage Reference Manual

Devices Supported:

MCF5235
MCF5234
MCF5233
MCF5232

MEMC3PMBLDCRM
Rev. 0.1
11/2004

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Chapter 1
Introduction and Setup

Motorola's Three-phase Micro Power Stage is a 12-volt, 3-amp power stage that is an integral part of Motorola's embedded motion control series of development tools. It is supplied in a kit, along with a small brushless dc motor with Hall sensors and a 40-pin ribbon cable. In combination with one of the embedded motion control series control or evaluation boards, it provides a ready-made software development platform for small brushless dc motors among others. The enclosed motor is capable of being controlled with Hall sensors or with sensorless techniques. An illustration of the systems' configurations is shown in Figure 1-1. Figure 1-2 is an illustration of the board.

1.1 About this Manual

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

- Setup instructions are found in Section 1.4, "Setup Guide."
- Schematics are found in Section 4.1, "Schematics."
- Pin assignments are shown in Figure 3-1, and a pin-by-pin description is contained in Section 3.1, "Signal Descriptions."
- For those interested in the reference design aspects of the board's circuitry, a description is provided in Chapter 5, "Design Considerations."

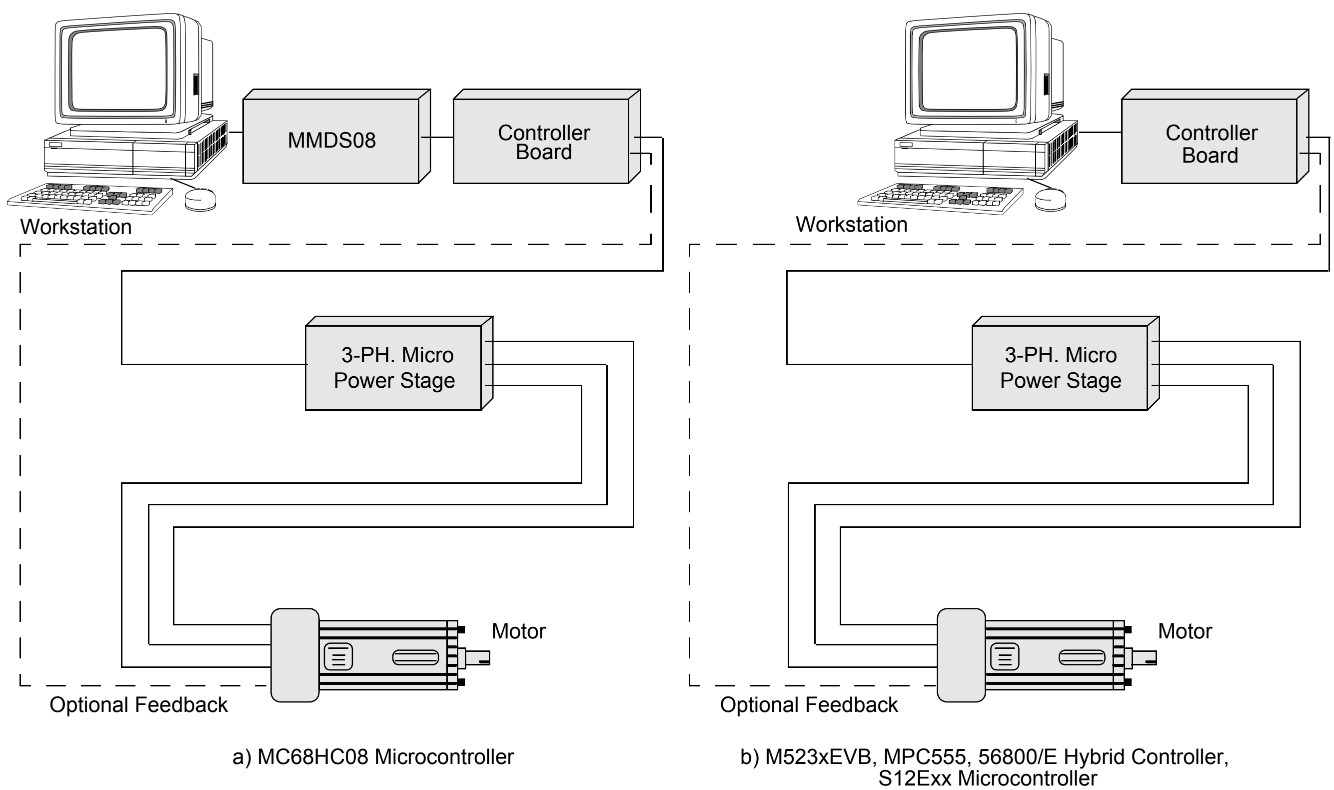

Figure 1-1. System Configurations

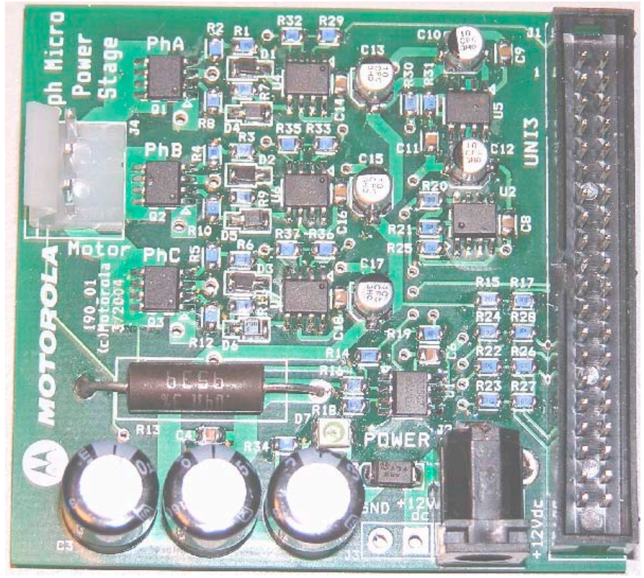

Figure 1-2. Three-Phase Micro Power Stage

1.2 Terms and Acronyms

BEMF	Back electro-motive force (EMF)
BLDC	Brushless dc
Hall sensor	Sensor whose output changes based on changes in magnetic flux. Used to measure motor position.
PWM	Pulse width modulation
UNI-3	User-to-Network Interface

1.3 Warnings

The Three-Phase Micro Power Stage includes power components that can reach temperatures hot enough to cause burns. To facilitate safe operation, 12-volt input power should come from a dc laboratory power supply that is current limited to no more than 4 amps.

The user should be aware of the following:

- Before moving scope probes, making connections, etc., it is generally advisable to power down the 12 Vdc supply.
- 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 power electronics lab techniques are also advisable.

1.4 Setup Guide

Setup and connections for the Three-Phase Micro Power Stage are straightforward. The Three-Phase Micro Power Stage connects to a Motorola embedded motion control series control board via a 40-pin ribbon cable. The motor's power leads plug into output connector J4, and its Hall sensors plug into the control board's Hall sensor/encoder input connector. Figure 1-3 depicts a completed setup.

Follow these steps to set up the board:

1. Plug one end of the 40-pin ribbon cable that is supplied with Motorola embedded motion control series control boards into input connector J1, located at the edge of the board. The other end of this cable goes to the control board's 40-pin output connector.
2. Plug the free end of the cable connected to input connector J1 into the control board's 40-pin connector.
3. Connect a 12 Vdc power supply to the power jack J2 labeled "POWER". Then either connect outgoing cable from the Three-Phase Micro Power Stage labeled "+12Vdc" to the controller board jack or use separete power supply to power the controller board. Those connectors are located in a corner of the Three-Phase Micro Power Stage.
4. If protection features are desired, set the control board's overcurrent detection comparator to 2.25 V. This value limits dc bus current to 3 amps.
5. Apply power to the Three-Phase Micro Power Stage. The green power-on LED is lit when power is present. Note that the Three-Phase Micro Power Stage doesn't power the control board, so the control board must be powered by means of this board outgoing +12 Vdc cable and/or an external 12 Vdc power supply to run a complete system.

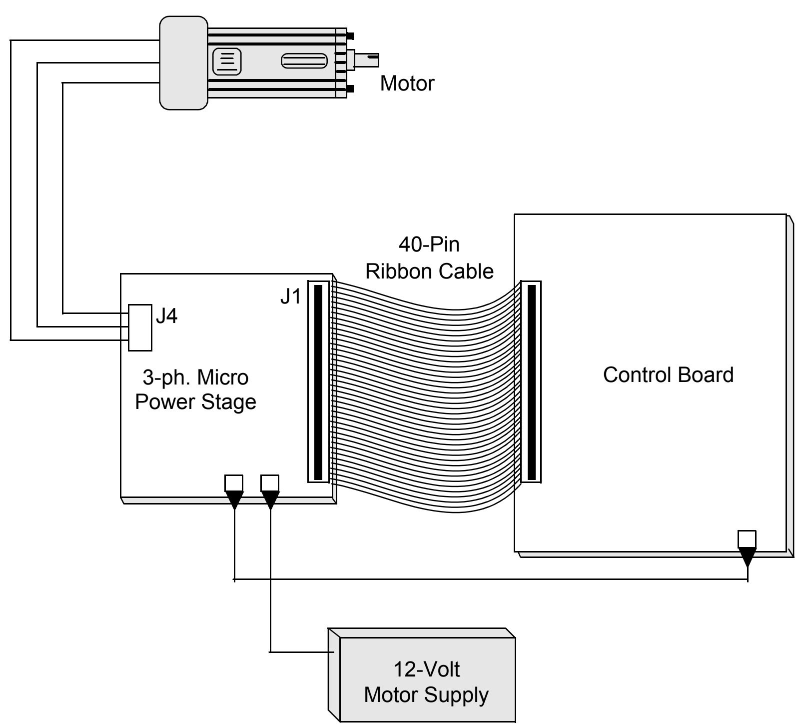

Figure 1-3. Three-Phase Micro Power Stage Setup

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Chapter 2
Operational Description

Motorola's embedded motion control series Three-Phase Micro Power Stage is a 12-volt, 3-amp, surface-mount power stage that is shipped with a Pittman (Size 23) brushless dc (BLDC) motor. In combination with one of the 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 algorithms that use Hall sensors and back EMF (electromotive force) signals for sensorless control.

The Three-Phase Micro Power Stage does not have any overcurrent protection that is independent of the control board, so some care in its setup and use is required if a lower impedance motor is used. With the motor that is supplied in the kit, the power output stage will withstand a full-stall condition without the need for overcurrent protection. Current measuring circuitry is set up for 8.25 amps full scale. In a 25^{o}C ambient operation at up to 3A continuous RMS output current is within the board's thermal limits.

Input connections are made via 40-pin ribbon cable connector J1. Pin assignments for the input connector are shown in Figure 3-1. Power connections to the motor are made on output connector J4. Phase A, B, and C are labeled on the board. Power requirements are met with a single external 12 V, 4 A power supply. Two connectors, labeled J2 and J3, are provided for the 12 Vdc power supply. While the former is used for 12 Vdc input, the latter is used for 12 Vdc output for powering the controller board. Both are located in a corner of the board.

A summary of the information needed to use the Three-Phase Micro Power Stage follows. For design information, see Chapter 4, "Schematics and Parts List."

2.1 Electrical Characteristics

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

Table 2-1. Electrical Characteristics

Characteristic	Symbol	Min	Typ	Max	Units
Power Supply Voltage	Vdc	10	12	16	V
Quiescent Current	I_{CC}	—	18	—	mA
Min Logic 1 Input Voltage	V_{IH}	2.4	—	—	V
Max Logic 0 Input Voltage	V_{IL}	—	—	0.8	V
Input Resistance	R_{In}	—	10	—	kΩ
Analog Output Range	V_{Out}	0	—	3.3	V
Bus Current Sense Voltage	I_{Sense}	—	200	—	mV/A
Bus Voltage Sense Voltage	V_{Bus}	—	202	—	mV/V
Power MOSFET On Resistance (Top Switch)	$R_{DS(On)}$	—	60	70	mΩ
Power MOSFET On Resistance (Bottom Switch)	$R_{DS(On)}$	—	170	200	mΩ
Continous Output Current	I_D	—	—	3	A
Pulsed Output Current	I_{DM}	—	—	15	A

Table 2-1. Electrical Characteristics (continued)

Characteristic	Symbol	Min	Typ	Max	Units
Total Power Dissipation	P_{diss}	—	—	2	W
Deadtime	t_{off}	400	—	—	ns

2.2 Pittman Motor Characteristics

The motor characteristics in Table 2-2 apply to operation at 25°C.

Table 2-2. Pittman (Size 23) BLDC Motor Characteristics

Characteristic	Symbol	Min	Typ	Max	Units
Reference Windind Voltage	V_t	—	—	9.6	V
Speed @ V_t		—	—	12000	RPM
Torque Constant	K_t	—	0.007	—	Nm/A
		—	1.082	—	oz-in/A
Voltage Constant	K_e	—	0.8	—	V/kRPM
Terminal Resistance	R_t	0.13	—	0.18	W
Winding Inductance	L	—	2.9	—	mH
Continuous Current	I_{cs}	—	—	9.96	A
No Load Current @ V_t	I_{ps}	—	1.20	—	A
Number of Poles	J_m	—	8	—	—
Temperature Rating		–10	—	80	°C
		14	—	176	°F

Chapter 3
Pin Descriptions

Inputs and outputs are located on four connectors:

- Four connectors that are located on the Three-Phase Micro Power Stage board (UNI-3, Motor power, Power input, Power output).
- Two connectors are associated with the motor (Power, Hall sensors).

Pin descriptions for each of these connectors and the test points are identified in the following information. Pin assignments for the UNI-3 connectors are shown in Figure 3-1. Signal descriptions are provided in Table 3-1 through Table 3-3.

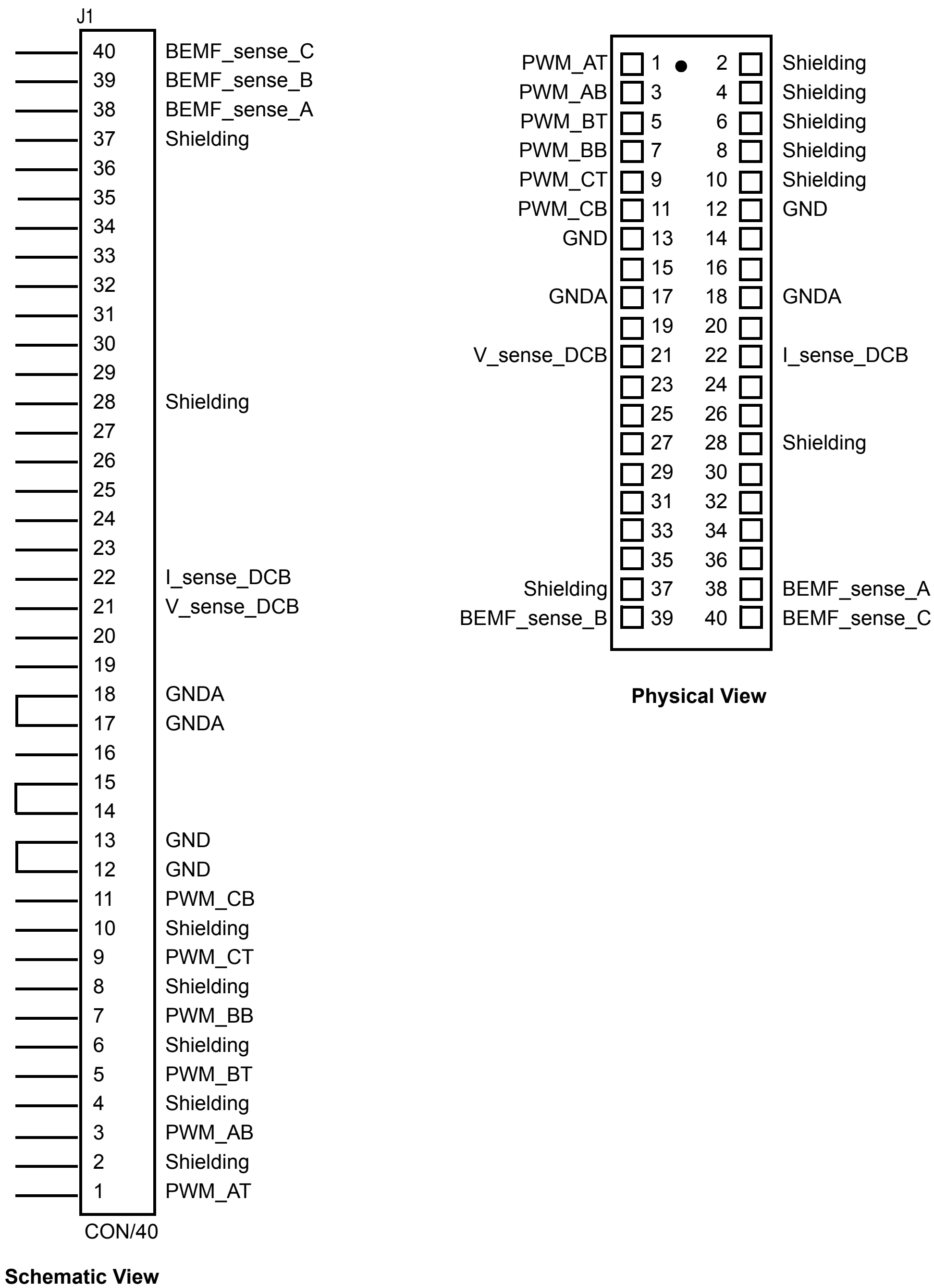

Figure 3-1. 40-Pin Input Connector J1

3.1 Signal Descriptions

Pin descriptions are identified in this subsection.

3.1.1 EVM Motor Board Power Connectors J2 and J3

Two connectors, labeled J2 and J3, are provided for the 12-volt power supply. While the former is used for power supply input, the latter is used for power supply output for the controller board powering. J2 and J3 are located in a corner of the board. The J2 connector is a 2.1-mm power jack for plug-in type 12 V power supply connections. The J3 connector is used as 12 V output which will power the controller board. Power is supplied to the J2 one. The power supply should be able to deliver at least 3 amps.

3.1.2 The Three-Phase Micro Power Stage 40-Pin Ribbon J1 Connector

Signal inputs are grouped together on a 40-pin ribbon cable connector J1, located at the edge of the board. Pin assignments are shown in Figure 3-1. Pin descriptions are listed in Table 3-1.

Table 3-1. The J1 Connector Signal Descriptions (Sheet 1 of 2)

Pin No.	Signal Name	Description
1	PWM_AT	The gate drive signal for the top half-bridge of phase A. A logic high at input connector J1 turns on the phase A top switch.
2	Shielding	Connected to a shield wire in the ribbon cable, and ground on the board.
3	PWM_AB	The gate drive signal for the bottom half-bridge of phase A. A logic high at input connector J1 turns on the phase A bottom switch.
4	Shielding	Connected to a shield wire in the ribbon cable, and ground on the board.
5	PWM_BT	The gate drive signal for the top half-bridge of phase B. A logic high at input connector J1 turns on the phase B top switch.
6	Shielding	Connected to a shield wire in the ribbon cable, and ground on the board.
7	PWM_BB	The gate drive signal for the bottom half-bridge of phase B. A logic high at input connector J1 turns on the phase B bottom switch.
8	Shielding	Connected to a shield wire in the ribbon cable, and ground on the board.
9	PWM_CT	The gate drive signal for the top half-bridge of phase C. A logic high at input connector J1 turns on the phase C top switch.
10	Shielding	Connected to a shield wire in the ribbon cable, and ground on the board.
11	PWM_CB	The gate drive signal for the bottom half-bridge of phase C. A logic high at input connector J1 turns on the phase C bottom switch.
12	GND	Digital power supply ground
13	GND	Digital power supply ground, redundant connection
14	—	No connection
15	—	No connection
16	—	No connection
17	GNDA	Analog power supply ground
18	GNDA	Analog power supply ground, redundant connection
19	—	No connection
20	—	No connection

Table 3-1. The J1 Connector Signal Descriptions (Sheet 2 of 2)

Pin No.	Signal Name	Description
21	V_sense_DCB	Analog sense signal that measures dc bus voltage. It is scaled at 0.206 V per volt of dc bus voltage.
22	I_sense_DCB	Analog sense signal that measures dc bus current. It is scaled at 0.412 V per amp of dc bus current.
23	—	No connection
24	—	No connection
25	—	No connection
26	—	No connection
27	—	No connection
28	Shielding	Connected to a shield wire in the ribbon cable, and ground on the board.
29	—	No connection
30	—	No connection
31	—	No connection
32	—	No connection
33	—	No connection
34	—	No connection
35	—	No connection
36	—	No connection
37	Shielding	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 0.206 V per volt of dc bus voltage.
39	BEMF_sense_B	Analog sense signal that measures phase B back EMF. It is scaled at 0.206 V per volt of dc bus voltage.
40	BEMF_sense_C	Analog sense signal that measures phase C back EMF. It is scaled at 0.206 V per volt of dc bus voltage.

3.1.3 The Three Phase Micro Power Stage J4 Connector

Power outputs to the motor are located on connector J4, labeled “Motor.” Pin assignments are described in Table 3-2.

Table 3-2. The J4 Connector Signal Descriptions

Pin No.	Signal Name	Description
1	Phase_A	Supplies power to motor phase A. The motor wire color is brown.
2	Phase_B	Supplies power to motor phase B. The motor wire color is red.
3	Phase_C	Supplies power to motor phase C. The motor wire color is orange.

3.1.4 Motor Power Connector

Motor power connections are grouped into a connector that plugs into the Three Phase Micro Power Stage's motor connector, J4. Pin assignments are identical to the Three Phase Micro Power Stage J4 output connector.

3.1.5 Motor Hall Sensor Connector

Hall sensor connections are made with a connector that plugs into the control board's Hall sensor/encoder connector. Pin assignments are described in Table 3-3.

Table 3-3. Motor Hall Sensor Connector

Pin No.	Signal Name	Description
1	+5V	Supplies power from the control board to the Hall sensors. The wire color is violet.
2	GND	The Hall sensor ground. The wire color is black.
3	Hall A	Open collector output from Hall sensor A. The wire color is gray.
4	Hall B	Open collector output from Hall sensor B. The wire color is blue.
5	Hall C	Open collector output from Hall sensor C. The wire color is white.

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Chapter 4
Schematics and Parts List

A set of schematics for the Three-Phase Micro Power Stage appears in Figure 4-1 through Figure 4-10. Power connectors are shown in Figure 4-1. Figure 4-2 represents 3.3 V generation for analog sensing. Figure 4-3 shows UNI-3 connector and Figure 4-4 shows three-phase motor connector. The phase pre-drivers are shown in Figure 4-5, power modules appears in Figure 4-6. Bus current feedback is shown in Figure 4-7. Back EMF signals appear in Figure 4-8. The brushless dc motor is shown in Figure 4-10.

Unless otherwise specified, resistor values are in ohms, resistors are specified as 1/8 watt ±5%, and interrupted lines coded with the same letters are electrically connected.

4.1 Schematics

The schematics for the evaluation motor board appear below and on the following pages.

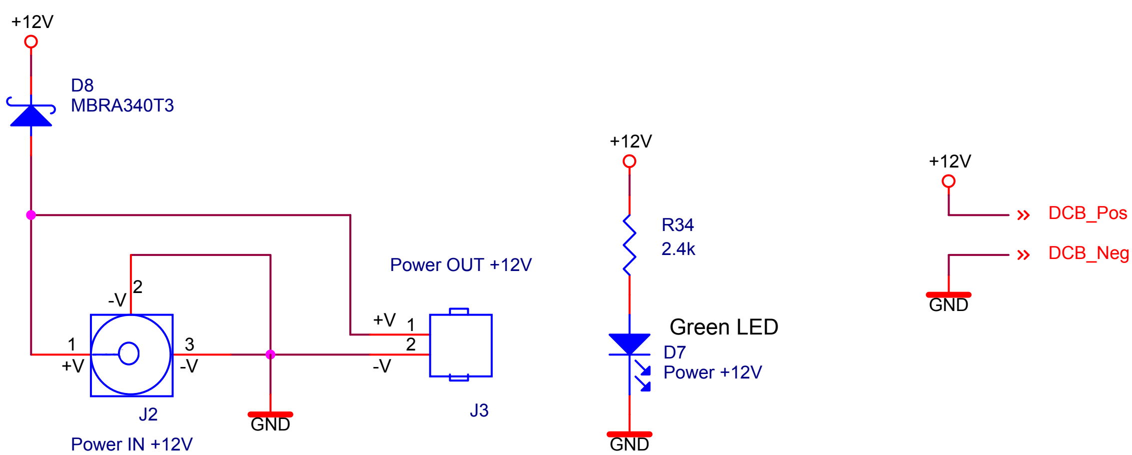

Figure 4-1. Three-Phase Micro Power Stage Power Connection

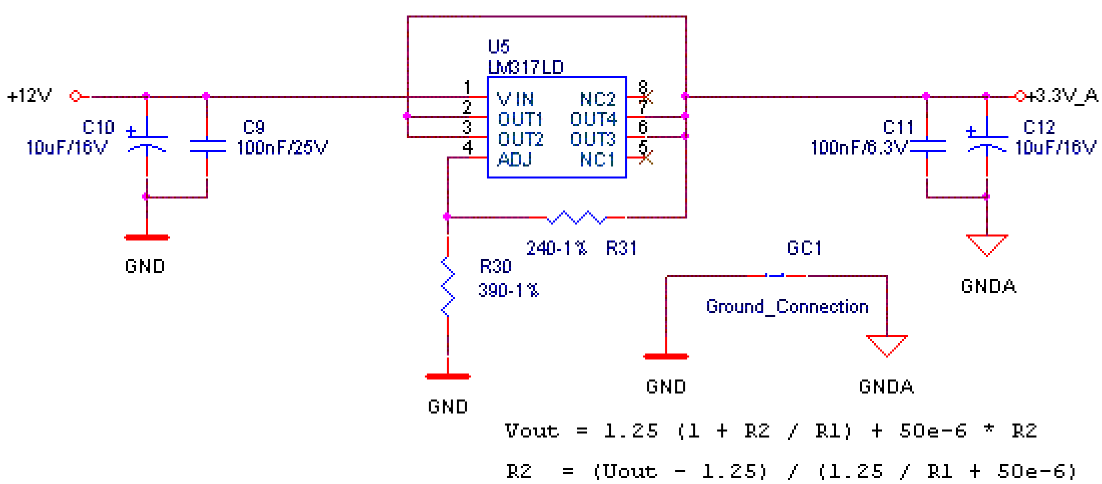

Figure 4-2. Three-Phase Micro Power Stage 3.3 V Analog Voltage Generation

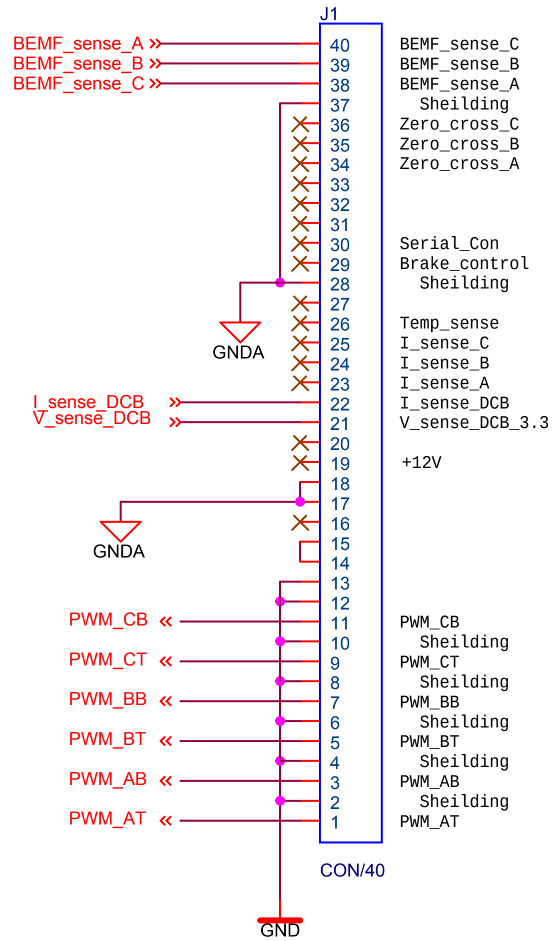

Figure 4-3. UNI-3 Connector

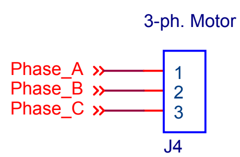

Figure 4-4. Three-Phase Motor Connector

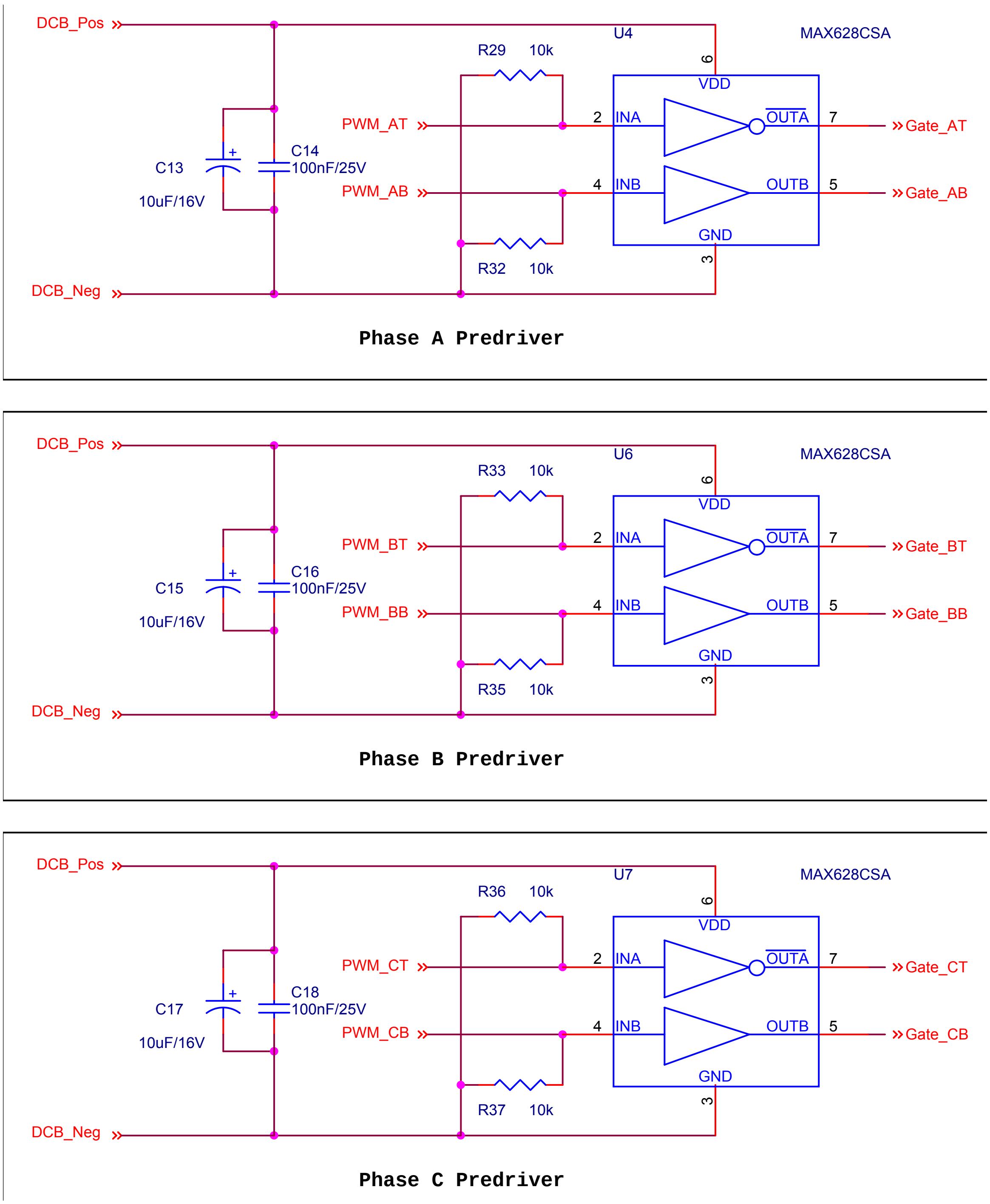

Figure 4-5. Phase Predrivers

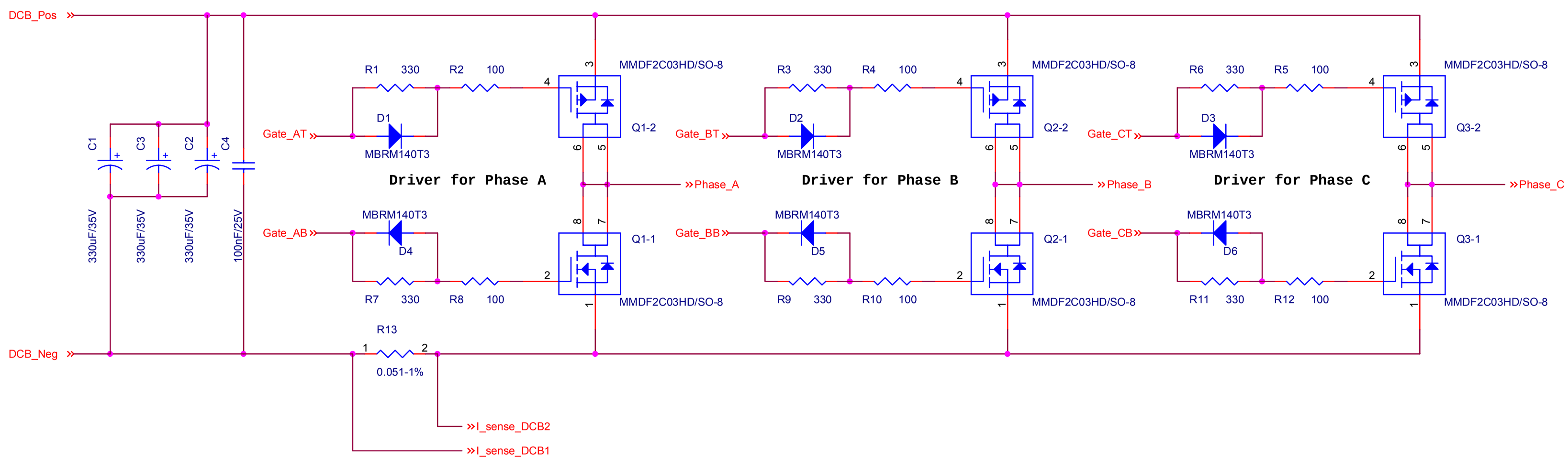

Figure 4-6. Power Modules

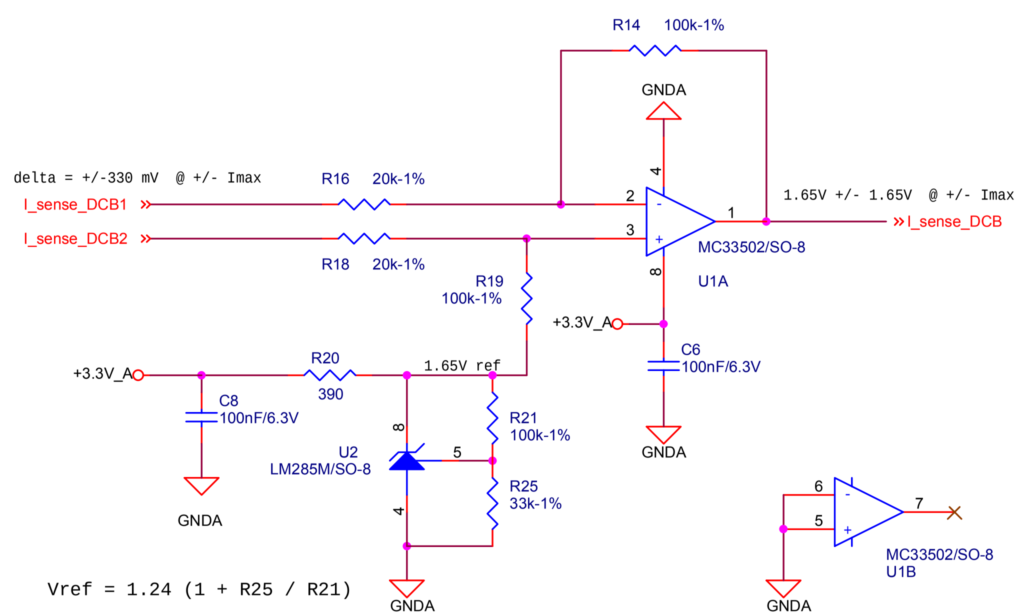

Figure 4-7. Bus Current Feedback

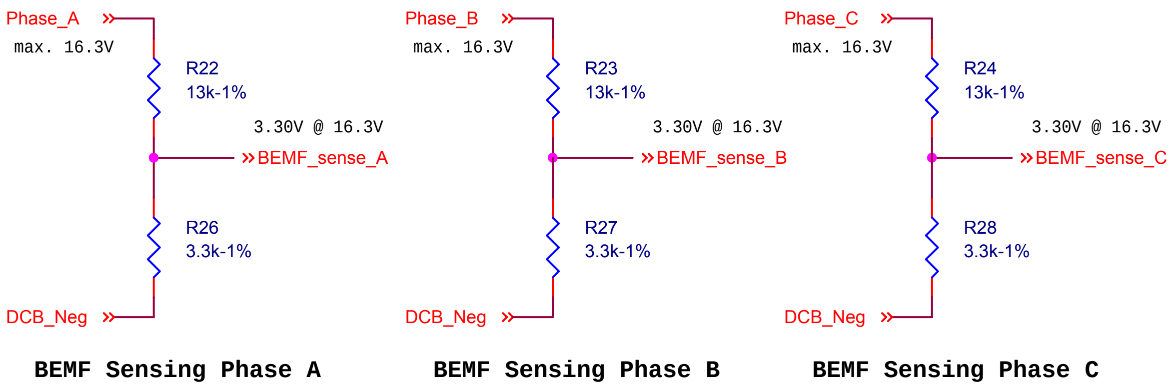

Figure 4-8. Back EMF Signals

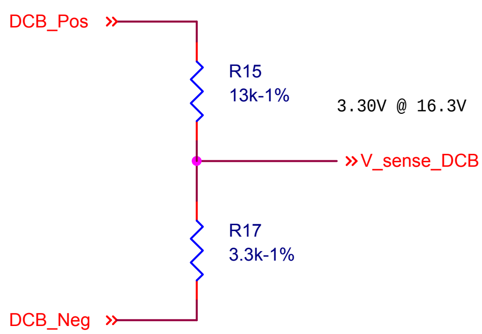

Figure 4-9. Dc Bus Voltage Sensing

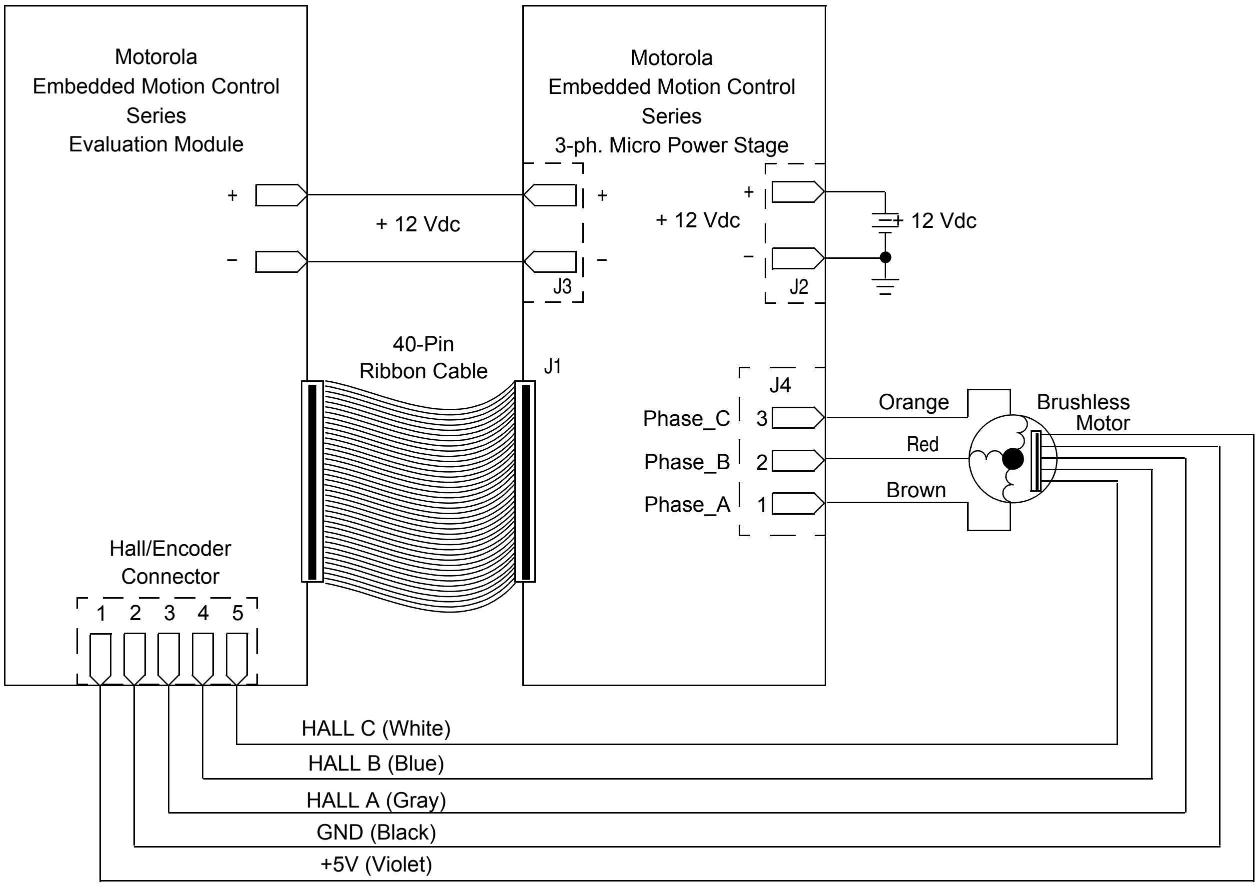

Figure 4-10. Brushless dc Motor Connections — Schematic View

4.2 Parts List

The Three-Phase Micro Power Stage's parts content is described in the following parts list.

Table 4-1. Parts List

Qty.	Reference	Part Value	Description	Mfg.	Mfg. Part No.
3	C1, C2, C3	330 μF/35 V	Electrolytic Capacitor 10mm, 330 μF/35 V	Multicomp	921-373
5	C4, C9, C14, C16, C18	100 nF/25 V	Ceramic capacitor, 0805, 100 nF	AVX	08055G104ZAT1A
3	C6, C8, C11	100 nF/6.3 V	Ceramic capacitor, 0805, 100 nF	AVX	08055G104ZAT1A
5	C10, C12, C13, C15, C17	10 μF/16 V	SMD Aluminiun Electrolytic Capacitor, 4 mm, 10 μF/16 V	Panasonic	EEVFC1C100R
6	D1, D2, D3, D4, D5, D6	MBRM140T3	Shottky Rectifiers 40 V, 1A	ON Semiconductor	MBRM140T3
1	D7	LED Green	LED_QT_PLCC2_CA	EZK	KA3528LSGT

Table 4-1. Parts List (continued)

Qty.	Reference	Part Value	Description	Mfg.	Mfg. Part No.
1	D8	MBRA340T3	Voltage Antireverse Avoid	ON Semiconductor	MBRA340T3
1	J1	CON/40	Header 40 pins breakaway connector	Fischer Elektronik	ASLG40G
1	J2	Power Jack	Power Jack type connector 2.5 mm	CUI Stack	PJ-002A
1	J3	Header with Lock	2 Way Header with Lock	Molex	22-29-2021
1	J4	Header with Lock	3 Way Header with Lock	Molex	39-26-3030 (mating with Molex 26-11-2033)
3	Q1, Q2, Q3	MMDF2C03HD	P+N MOSFET transistor, 30 V, 6 A	ON Semiconductor	MMDF2C03HD
6	R1, R3, R6, R7, R9, R11	330	Resistor 330 Ω, 5%, 0805	Multicomp	MC 0.1W 0805 5% 330R
6	R2, R4, R5, R8, R10, R12	100	Resistor 100 Ω, 5%, 0805	Multicomp	MC 0.1W 0805 5% 100R
1	R13	0.040-1%	Shunt Resistor	Vishay	LVR-3 0.040 1%
3	R14, R19, R21	100k-1%	Resistor 100 kΩ, 1%, 0805	Multicomp	MC 0.1W 0805 1% 100K
4	R15, R22, R23, R24	13k-1%	Resistor 13 kΩ, 1%, 0805	Multicomp	MC 0.1W 0805 1% 13K
2	R16, R18	20k-1%	Resistor 20 kΩ, 1%, 0805	Multicomp	MC 0.1W 0805 1% 20K
4	R17, R26, R27, R28	3.3k-1%	Resistor 3.3 kΩ, 1%, 0805	Multicomp	MC 0.1W 0805 1% 3K3
1	R20	390	Resistor 390 Ω, 5%, 0805	Multicomp	MC 0.1W 0805 5% 390R
1	R25	33k-1%	Resistor 33 kΩ, 1%, 0805	Multicomp	MC 0.1W 0805 1% 33K
6	R29, R32, R33, R35, R36, R37	10k	Resistor 10 kΩ, 5%, 0805	Multicomp	MC 0.1W 0805 5% 10K
1	R30	390-1%	Resistor 10 kΩ, 1%, 0805	Multicomp	MC 0.1W 0805 1% 390R
1	R31	240-1%	Resistor 240 Ω, 1%, 0805	Multicomp	MC 0.1W 0805 1% 240R
1	R34	2.4k-1%	Resistor 2.4 kΩ, 1%, 0805	Multicomp	MC 0.1W 0805 5% 2K4
1	U1	MC33502/SO-8	Operational Amplifier	ON Semiconductor	MC33502/SO-8
1	U2	LM285M/SO-8	Adujstable Voltage Reference	National Semiconductor	LM285M
3	U4, U6, U7	MAX628CSA	MOSFET pre-driver	Maxim	MAX4428CSA
1	U5	LM317LD	Linear Voltage Regulator	ON Semiconductor	LM317LD

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Chapter 5
Design Considerations

From a systems point of view, the Three-Phase Micro Power Stage kit fits into an architecture that is designed for code 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.

The Three-Phase Micro Power Stage's power output stage is a complementary MOS field effect transistor (MOSFET) 3-phase bridge that is capable of supplying and sensing 4 amps of continuous current. Feedback signals include bus voltage, bus current, and back EMF (electromotive force). Descriptions of each of these blocks are contained in Section 5.1, "3-Phase Driver," Section 5.2, "Bus Voltage and Current Feedback," and Section 5.3, "Back EMF Signals."

5.1 3-Phase Driver

The output stage is configured as a 3-phase driver with complementary MOSFET output transistors. It is simplified considerably by dual integrated gate drivers that each have one inverting and one non-inverting driver. A simplified schematic that shows one phase is illustrated in Figure 5-1.

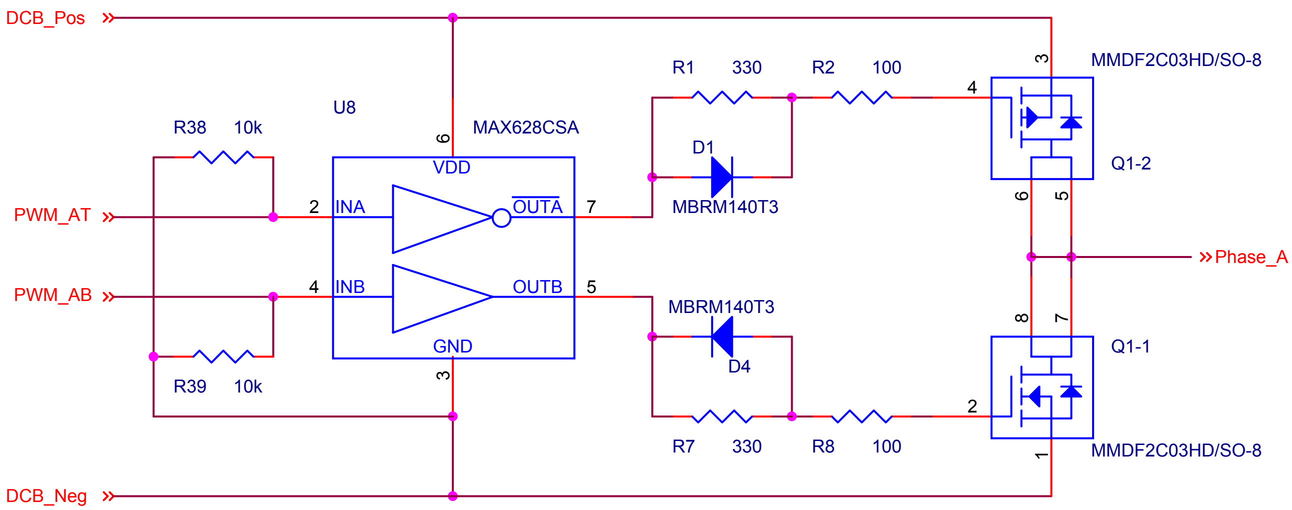

Figure 5-1. Phase A Output

At the input, weak pulldown resistors, R38 and R39, set a logic low in the absence of a signal. Open input pulldown 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. Gate drive is supplied by a Maxim MAX628CSA, which has a minimum logic 1 input voltage of 2.4 volts and maximum logic 0 input voltage of 0.8 volts. The Three-Phase Micro Power Stage will, therefore, accept inputs for either 3.3 or 5 volt logic. Under-voltage lockout is not included in the gate drive. If this feature is desired, the control board's under-voltage detection comparator can be set for 1.24 volts.

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, resistors R1, R2, and diode D1 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 430 Ω and turn-off gate drive impedance at approximately 100 Ω. These values produce transition times of approximately 60 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 Three-Phase Micro Power Stage is designed with switching times at the lower end of this range to minimize power dissipation.

5.2 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 R15 and R17. The values are chosen such that a 16-volt maximum bus voltage corresponds to a 3.3 volt maximum analog-to-digital (A/D) input. Bus current is sampled by resistor R13 in Figure 4-6 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. The gain is given by:

$$A = R14 / R16$$

The output voltage is shifted up by 1.65 V, to accommodate both positive and negative current swings. A ±209 mV voltage drop across the shunt resistor corresponds to a measured current range of ±8.25 amps.

Note that the Three-Phase Micro Power Stage measures, but does not limit, current. Current limiting is performed on the control board, where a 2.25 volt setting for the overcurrent detection comparator produces a 3.0 amp current limit.

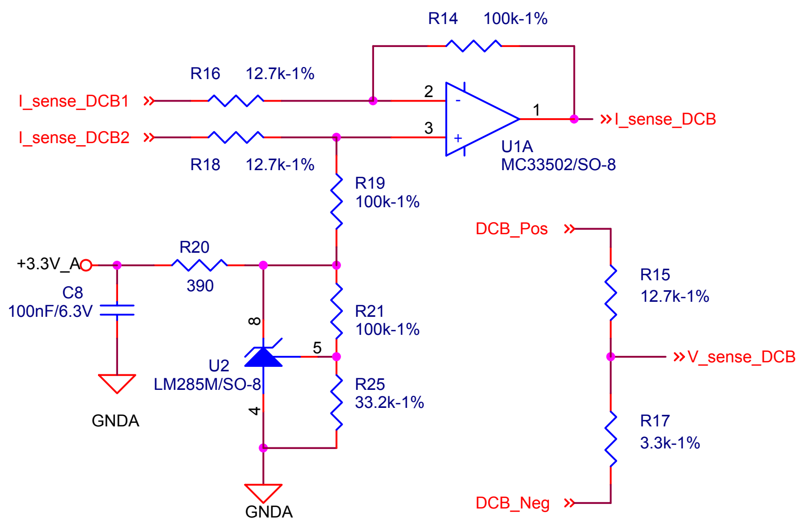

Figure 5-2. Bus Feedback

5.3 Back EMF Signals

Back EMF and zero crossing signals are included to support sensorless algorithms for brushless DC motors. Referring to Figure 5-3, which shows circuitry for phase C, the raw phase voltage is scaled down by a voltage divider consisting of R24 and R28. One output from this divider produces back EMF sense voltage BEMF_sense_C. Resistor values are chosen such that a 16 volt maximum phase voltage corresponds to a 3.3 volt maximum A/D input.

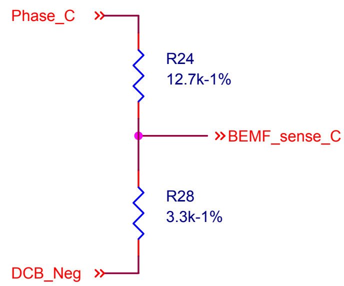

Figure 5-3. Phase C Back EMF Feedback

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