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3-Phase BLDC/PMSM Low Voltage Power Stage

User's Manual

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3-phase BLDC/PMSM Low Voltage Power Stage

User Manual

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Freescale Semiconductor

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The following revision history table summarizes the 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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Section 1. Introduction

1.1 Contents

1.2 Introduction

Freescale Semiconductor's 3-Phase PMSM/BLDC Power Stage is based on popular SMARTMOS^{TM} MC33937 pre-driver integrated circuits. It operates on a wide range of input voltages from 8V up to 50V, being capable of driving currents of up to 10A. The 3-Phase Power Stage is an integral part of Freescale Semiconductor's embedded motion control series of development tools and can be used to drive 3-Phase BLDC, PMSM and ACIM motors operating at voltages ranging up to 50V. It is supplied with a 40-pin ribbon cable, interconnecting with, amongst others, one of the embedded motion control or evaluation boards, providing a ready-made software development platform for small permanent magnet synchronous or brushless DC motors. A new feature, differing from the usual 3-Phase BLDC/PMSM Low Voltage Power Stage, consists of DC/DC SEPIC and step-down converters. These converters are capable of delivering a constant supply voltage for the MOSFET pre-driver and controller board through the entire input voltage range of 6V to 50V.

1.3 About this Manual

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

- Setup instructions are found in 1.4 Setup Guide.
- Pin assignments and a pin-by-pin description are shown in Section 3. Pin Description.
- Schematics and the board circuitry description are found in Section 4. Design Consideration.

1.4 Setup Guide

Setup and connections for the 3-Phase BLDC/PMSM Low Voltage Power Stage are straightforward. It connects to a Freescale Semiconductor embedded motion control series control board via a 40-pin and 10-pin ribbon cables. The motor power leads plug into output connectors J6, J7, J8 of the 3-Phase Power Stage and its Hall, encoder or resolver sensors plug directly into the respective Hall, encoder or resolver connectors of the controller board. Figure 1-1 depicts a complete setup.

Follow these steps to set up the board:

1. Plug one end of the 40-pin ribbon cable (supplied with the Freescale Semiconductor embedded motion control series control boards) into connector J3, located at the edge of the 3-Phase BLDC/PMSM Low Voltage Power Stage. The other end of this cable goes into the controller board's 40-pin connector.
2. Plug one end of the 10-pin ribbon cable into connector J4, located at the edge of the 3-Phase BLDC/PMSM Low Voltage Power Stage below connector J3. The free end of the cable plugs into the controller board's 10-pin connector.
3. Connect an 8V - 50V DC power supply to the power jack J2 or connector J1. These connectors are located in a corner of the 3-Phase BLDC/PMSM Low Voltage Power Stage. The input power supply should be rated for at least 10Amps and should have its current limit set to 15Amps depending on needs.
4. If protection features are desired, set the controller board's over current and over voltage detection comparators according to your needs. These values limit the DC bus current and voltage. The DC bus current limit, 1.65V corresponds to 0Amps, and 3.3V corresponds to 15Amps. The voltage limit can be set in several input ranges, 3.3V corresponds to 50.05V.
5. Apply power to the 3-Phase BLDC/PMSM Low Voltage Power Stage.

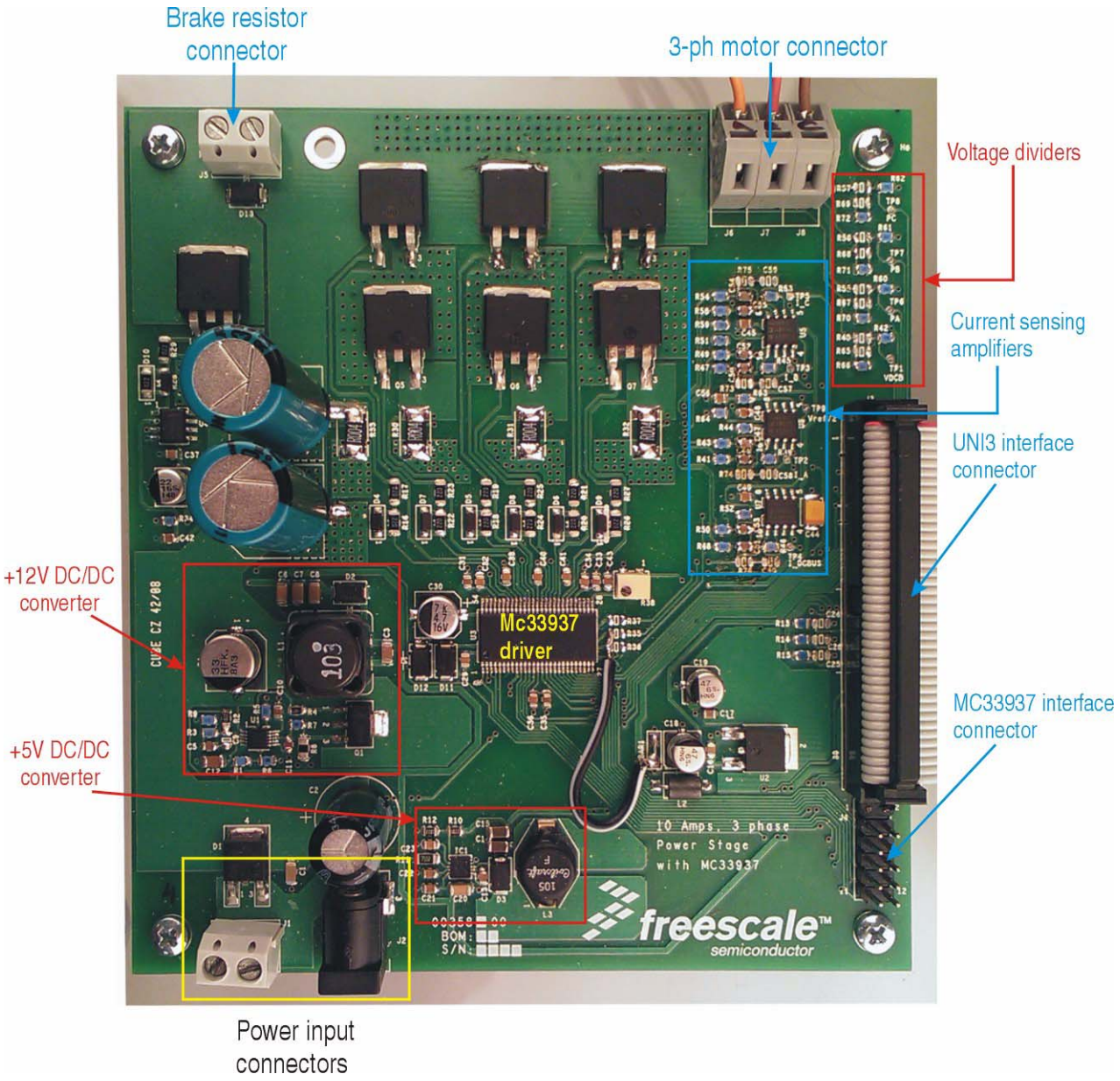


Figure 1-1 3-Phase BLDC/PMSM Low Voltage Power Stage

Section 2. Operational Description

2.1 Contents

2.2 Introduction

Freescale Semiconductor's embedded motion control series 3-Phase BLDC/PMSM Low Voltage Power Stage is an 8V - 50V, 10Amps, surface-mounted power stage. In combination with one of the embedded motion control series controller boards, it provides a software development platform allowing algorithms to be written and tested without the need to design and build a power stage. It supports speed and position sensing based on Hall sensors, resolver sensors, encoder sensors and back electromotive force (BackEMF) signals for sensorless control.

The 3-Phase BLDC/PMSM Low Voltage Power Stage has an over-current protection independent of the control board, when you choose the internal MC33937 DC bus operational amplifier with an over-current comparator. Otherwise, you must be careful when you drive low impedance motors. The current measuring circuitry is setup for 15Amps full scale. At ambient temperature (25°C), the board will remain within thermal limits when operating with output currents of up to 10 Amps continuous RMS.

Input connections are made via the 40-pin and 10-pin ribbon cable connectors J3 and J4. Pin assignments for the input connector are illustrated in 3.3.4 UNI 3 connector J3. Power connections to the motor are made on the 3-way connectors J6 (Phase A), J7 (Phase B), and J8 (Phase C). The input voltage requirements are met by a power supply of 8V - 50V. The voltage should be within these limits. The board sustains a voltage of at least 8V with a maximum of 58V. The input power is supplied by means of the 2.1mm jack connector J2 or clamp connector J1.

A summary of the information required to use the 3-Phase BLDC/PMSM Low Voltage Power Stage follows. For design information, see Section 4. Design Consideration.

2.3 Electrical Characteristics

The electrical characteristics in Table 2-1 apply to operations at 25°C.

Table 2-1 Electrical Characteristics

Characteristic	Symbol	Min	Typ	Max	Units
Power supply Voltage	V_{DC}	8	12, 24, 42	58	V
Quiescent Current(1)	I_{CC}		TBD		mA
Min Logic 1 Input Voltage	V_{IH}				mA

Table 2-1 Electrical Characteristics

Characteristic	Symbol	Min	Typ	Max	Units
Max Logic 0 Input Voltage	V_{IL}				mA
Input Logic Resistance	R_{IN}	-	4.7	-	kΩ
Analogue Output Range	V_{OUT}	0	-	3.3	V
Bus Current Sense Voltage	V_{ISNS}	-	110	-	mV/A
Bus Current Sense Offset	$V_{ISNSOFF}$	-	1.65	-	V
Bus Voltage Sense Voltage: ..... 12V range 24V range 48V range	V_{BUS}	5.3564 10.7203 14.8861	5.4445 10.9167 15.1667	5.5342 11.117 15.4529	V/V
Phase A, B, C Current Sense Voltage	V_{IASNS}	-	110	-	mV/A
Phase A, B, C Current Sense Offset	$V_{IASNSOFF}$	-	1.65	-	V
Power MOSFET On Resistance	$R_{DS(ON)}$	-	22.5	28.5	mΩ
Continuous Output Current, T_C =25°C	I_D		35		A
Pulsed Output Current	I_{DM}		140		A
Total Power Dissipation (per MOSFET)(2)	P_D		TBD		W
Required Deadtime	t_{OFF}		77	-	ns

1. Measured with an input power of 12V.
2. The values are measured at 25°C. Values may differ for other temperatures.

Section 3. Pin Description

3.1 Contents

3.2 Introduction

Inputs and outputs are located on six connectors and headers available on the board:

- Two power supply connectors J1 and J2
- Three-pin motor connector (J6, J7, J8)
- Two-pin brake connector J5
- 40-pin UNI3 connector J3
- 10-pin MC33937 interface connector J4

Pin descriptions for each connector and header are identified in the following information. Table 3-3 shows the pin assignments and signal descriptions for the UNI3 interface connector J3.

The 3-Phase BLDC/PMSM Low Voltage Power Stage contains several connectors and headers that serve for connecting the power supply, for motor phases connections and other functions.

The input power supply, attached to inputs J1 and J2, must be in the range 8V - 50V DC.

The output for the motor is done by the connectors J6, J7 and J8. See 3.3.2 Motor Connector J6, J7, J8 for more details.

Each connector and header is labelled from the top side of the board.

3.3 Signal Description

Pin descriptions are identified in this subsection.

3.3.1 Power supply Input connectors J1 and J2

The power supply input connectors, labelled J1 and J2, are located in the left bottom corner of the board. They accept DC voltages from 8V to 50V / 10A maximum. The J1 connector is a two-wire connector, the J2 connector is a 2.1 mm power jack for plug-in type DC power supply connections. The power supply polarity for connector J1 is shown in Figure 1-1 3-Phase BLDC/PMSM Low Voltage Power Stage. The board has reverse polarity protection.

3.3.2 Motor Connector J6, J7, J8

Power outputs to the motor are located on connectors J6, J7, and J8. Phase outputs are labelled A, B, and C. Table 3-1 contains pin assignments. Section 1.4 Setup Guide shows how to connect the motor. On a permanent magnet synchronous motor, any of the 3-phase windings can be connected here. For a brushless DC motor, you must connect the wire colour coded for phase A into the connector J6, and so on, for phase B and phase C..

Table 3-1 Motor Connector - signal description

Pin	Signal name	Description
J6	Phase A	Supplies power to motor phase A
J7	Phase B	Supplies power to motor phase B
J8	Phase C	Supplies power to motor phase C

3.3.3 Brake resistor connector J5

The brake resistor can be joined to connector J5. This is located in the left top corner of the board.l

Table 3-2 Brake resistor connector - signal description

Pin	Signal name	Description
1	- Brake_res	Brake resistor negative termination
2	+ Brake_res	Brake resistor positive termination

3.3.4 UNI 3 connector J3

The UNI3 interface (connector J5) joins the controller board to the power stage. UNI3 is a defined standard interface for Freescale motor control boards and applications. It is located on the right side of the board. A detailed description is identified in this section.

Table 3-3 UNI3 connector - signal description

Pin	Signal name	Description
1	PWM_AT	Gate signal for phase A top transistor
3	PWM_AB	Gate signal for phase A bottom transistor
5	PWM_BT	Gate signal for phase B top transistor
7	PWM_BB	Gate signal for phase B bottom transistor
9	PWM_CT	Gate signal for phase C top transistor
11	PWM_CB	Gate signal for phase C bottom transistor

Table 3-3 UNI3 connector - signal description

Pin	Signal name	Description
2, 4, 6, 8, 10, 12	Digital shielding	Digital shielding. Must be grounded on the power stage side only
13	GND	Digital power supply ground
14, 15	+5Vdc	+5V digital power supply
16	+5VAdc	+5V analogue power supply
17, 18, 28, 37	AGND	Analogue power supply ground
19	+12Vdc	Analogue power supply
20, 26, 27, 30, 31, 32, 33	NC	not connected
21	V_{DCBUS}	DC-BUS voltage sensing, 0 - 3.3V
22	I_{DCBUS}	DC-BUS current sensing, 0 - 3.3V
23	I_A	Phase A current sensing, 0 - 3.3V
24	I_B	Phase B current sensing, 0 - 3.3V
25	I_C	Phase C current sensing, 0 - 3.3V
29	BRAKE_CONT	Digital output, DC-BUS brake control
34	ZCA	Phase A Back-EMF zero crossing
35	ZCB	Phase B Back-EMF zero crossing
36	ZCC	Phase C Back-EMF zero crossing
38	BEMF_A	Phase A Back-EMF voltage sensing
39	BEMF_B	Phase B Back-EMF voltage sensing
40	BEMF_C	Phase C Back-EMF voltage sensing

3.3.5 MC33937 interface header J4

The control and diagnostic signals for the MC33937 MOSFET pre-driver are joined to connector J4. This is located on the right side of the board bellow the UNI3 connector. Table 3-4 shows the pre-driver interface pin description.

Table 3-4 MC33937 header - signal description

Pin	Signal name	Description
1	NC	Not connected

Table 3-4 MC33937 header - signal description

Pin	Signal name	Description
2	NC	Not connected
3	33937_EN	Device enable
4	33937_OC	Over current. Totem pole digital output of overcurrent comparator
5	33937_/RST	Reset input
6	33937_INT	Interrupt pin output
7	33937_SOUT	Output data for SPI port. Tri-state until $\overline{CS}$ becomes low
8	33937_SCK	Clock for the SPI port
9	33937_CS	Chip select input. It frames the SPI command and enables the SPI port
10	33937_SIN	Input data for the SPI port. Clocked on the falling edge of SCLK, MSB first

Section 4. Design Consideration

4.1 Content

4.2 Overview

The 3-Phase BLDC/PMSM Low Voltage Power Stage is designed for demonstrating the ability of Freescale microcontrollers and DSCs to control various electrical motors and for easy SW 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 drive is explained in the following section.

4.3 3-Phase Power Bridge

The power stage is configured as a 3-Phase Power Bridge with MOSFET output transistors. It is simplified considerably by an integrated gate driver that has several safety features. Figure 4-1 shows a schematic of the 3-Phase Power Bridge. The pre-driver inputs are 3.3V compatible. A Freescale MC33937 pre-driver provides a supply voltage for the low and high side MOSFET gates. The MC33937 also provides the MOSFETs and application protection. It integrates an under voltage hold-off, desaturation, phase comparators, and over-current protection circuits. The dead time insertion can be configured using SPI. The default dead time value is typically 15us. The low and high side drivers are capable of providing a typical current of 1 Amp. This gate drive current may be limited by an external resistor to achieve a good trade-off between the efficiency and EMC compliance of the application. In order to achieve a 100% duty cycle operation of the high side externals FETs, a fully integrated trickle charge pump provides the charge necessary to maintain the external FET gates at a fully enhanced level.

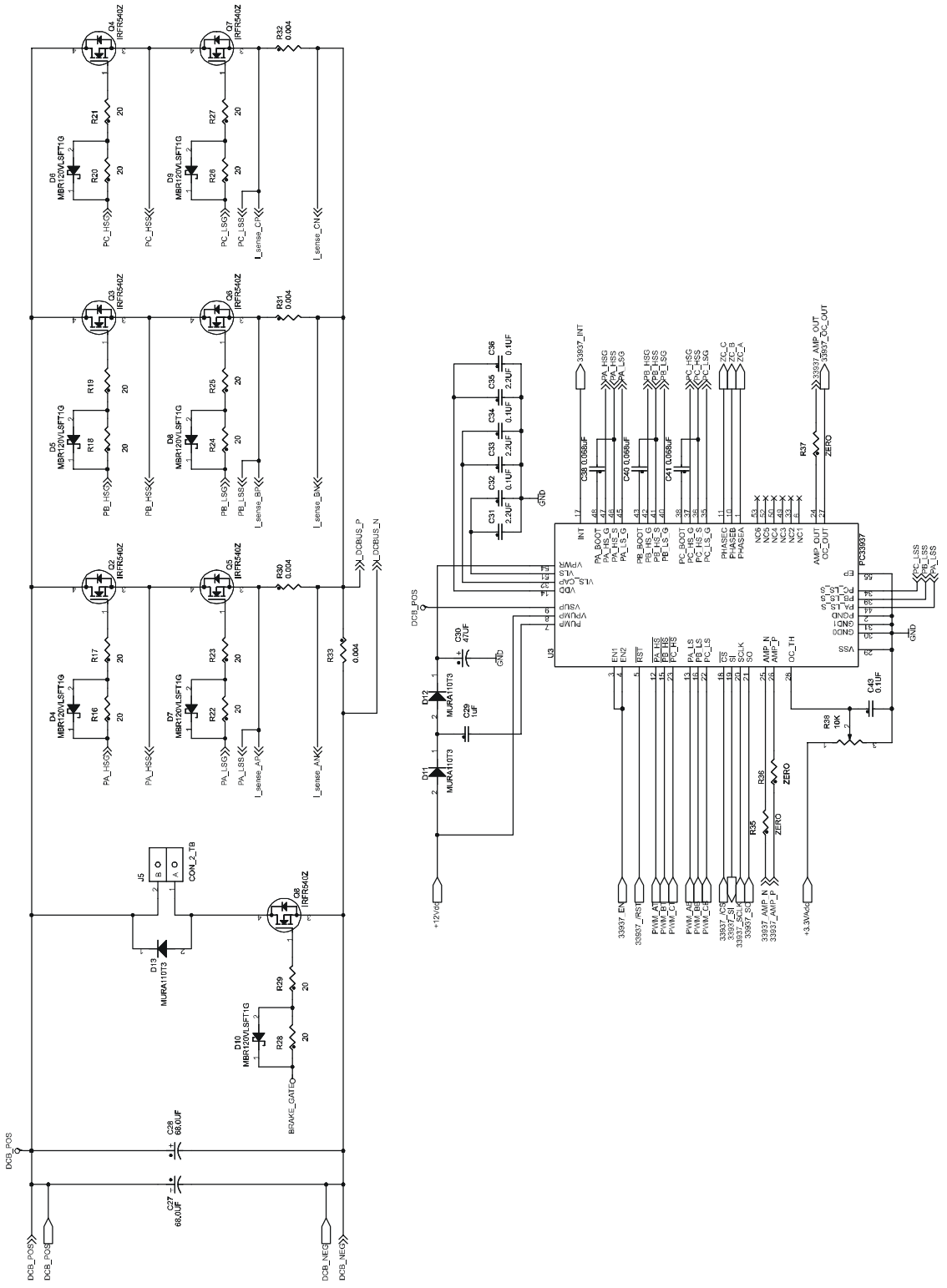


Figure 4-1 3-Phase Power Bridge

4.4 DC Bus voltage and current feedback

Figure 4-2 shows the circuity that provides feedback signals proportional to DC bus voltage and current. Bus voltage is scaled down by a voltage divider consisting of R40, R42. The populated resistor values are chosen in such way that a 50.05V, 36.025V or 18.298V DC bus voltage corresponds to V_{REF} at output V_DCBUS. This output signal is connected to the UNI3 connector pin 21.

Figure 4-2 shows circuitry supporting DC bus current sensing. DC bus current is sampled by shunt resistor R33. The voltage drop of this resistor can be amplified either by the MC33937 internal amplifier or an AD8656 operational amplifier (if populated). Both amplifiers are used as a differential amplifier for DC bus current sensing. With R46=R52, R48=R50, the gain is given by:

$$A = \frac{R46}{R48}$$

The output voltage is shifted up by +1.65V V_{REF} to accommodate positive and negative current swings. A ±60mV voltage drop across the sense resistor corresponds to a measured current range of ±15Amps.

If you use MC33937 for current measurement, the I_DCBUS signal is internally connected to the overcurrent comparator, and provides an over current triggering function. A discussion about over-current limiting follows in section 4.5.

DC bus current may be measured by an AD8656. In order to use this option, the zero resistors R35, R36 and R37 cannot be populated and inputs of the MC33937 operational amplifier must be grounded to avoid incorrect behaviour of the OC output.

The output from opam I_DCBUS is joined to the UNI3 connector pin 22. The shunt resistor is represented by a 0.004 Ω resistance (Cyntec SMD), the same type as the phase current measurement resistors.

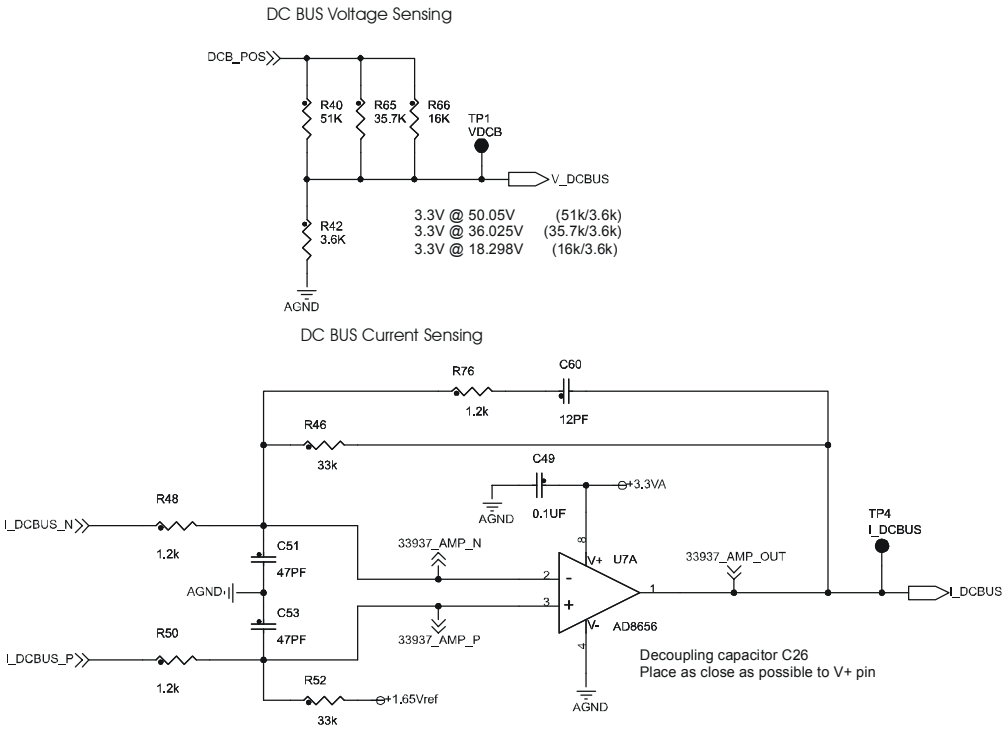


Figure 4-2 DC Bus current and voltage sensing

4.5 Over-current, Under-voltage, and other safety functions

The MC33937 provides over-current and under-voltage functions. The amplified Bus current signal is filtered to remove spikes, and then it is internally fed into the MC33937 over-current comparator input. The OC comparator threshold level is adjusted by external trimmer R38 and filtered by C43. This signal is connected to the MC33937 pin 28 OC_TH. Therefore, when DC bus current exceeds the adjusted threshold level, all six bridge transistors are switched off. Once a fault state has been detected, all six gate drivers are off, until the fault state is cleared by the SPI command or $\overline{\text{RESET}}$ pin.

The under voltage function is implemented internally. The IC guarantees that the output FETs are turned off in the absence of V_{DD} or V_{PWR} by means of the Hold-off circuit. When V_{DD} is less than about 3.0V or V_{PWR} is lower than the typically 8.0V, a small current source pulls all output gate drive pins low and an interrupt is generated if set.

The MC33937 safety functions keep the driver operating properly and within safety limits. It has a thermal warning feature. If the IC temperature rises above 170°C on one of three individual thermal warning circuits, then an interrupt is generated if set. The IC has other safety functions, such as desaturation detection, phase error, framing error, write error after a lock, and exiting $\overline{\text{RESET}}$. All these features can be configured through the SPI interface to trigger interrupts.

A detailed description is available in the driver datasheet.

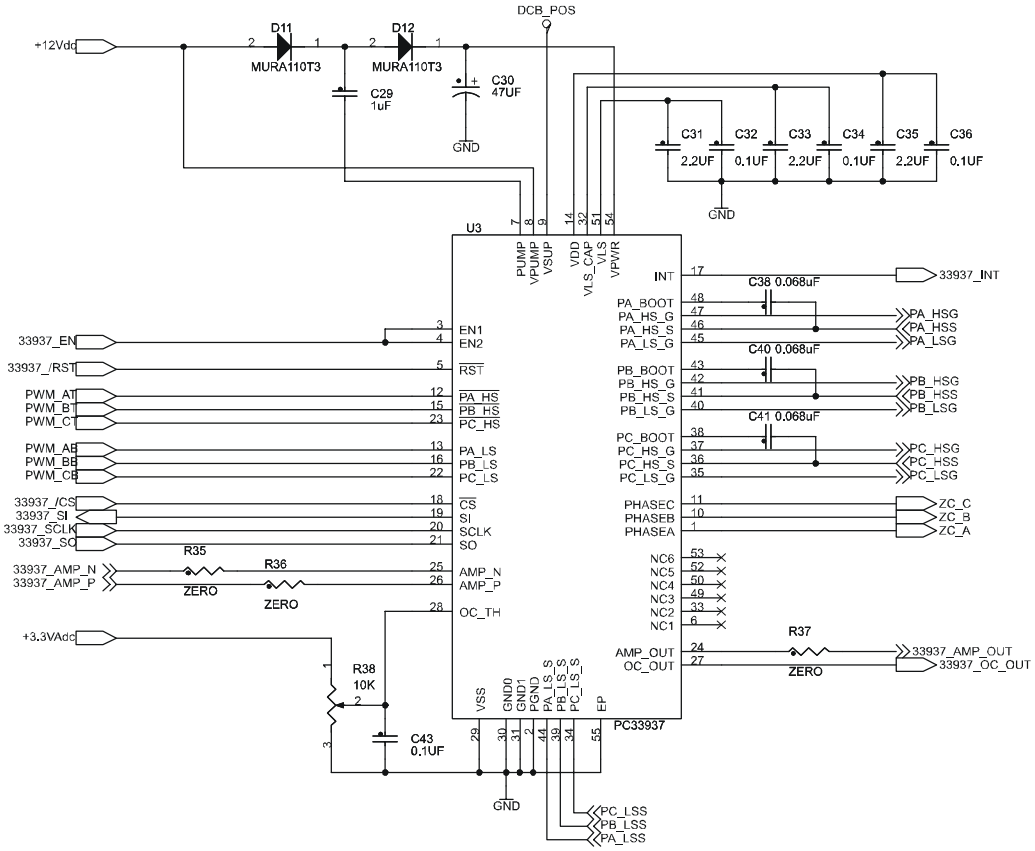


Figure 4-3 MC33937 circuit

4.6 Back EMF Signals

Back EMF signals are included to support sensorless algorithms for BLDC motors, and dead time distortion correction for a sinusoidal motor. Figure 4-4 shows circuitry for phase A; the raw phase voltage is scaled down by a voltage divider consisting of R55 (R67 or R70) and R60. Output from this divider produces back EMF sense voltage BEMF_A. The resistor values are chosen so that a 50.05V, 36.025V or 18.298V of phase voltage corresponds to a 3.3V ADC input range respectively. The BEMF_A, BEMF_B, BEMF_C signals are directly connected to the UNI3 interface pins 38, 39, 40.

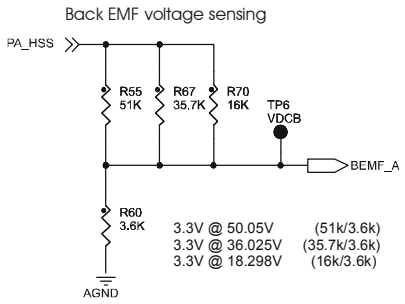


Figure 4-4 Back EMF Sensing - Phase A

4.7 Phase Current Sensing

Phase currents are sampled by sensing resistors R30, R31, R32 in Figure 4-5, and amplified in the U5, U6 (AD8656) operational amplifiers. All amplifiers are used as a differential for phase current sensing. With R41=R43, R39=R44, the gain is given by:

$$A = \frac{R39}{R41}$$

The gain of these operational amplifiers is 27.5 with a +1.65V offset. The output voltage is shifted up by +1.65V V_{REF} to accommodate positive and negative current swings. A ±60mV voltage drop across the sense resistor corresponds to a measured current range of ±15Amps.

The outputs from opams I_A, I_B, I_C are connected to the UNI3 connector pins 23, 24, 25 through RC filters R13, C24. The shunt resistor is represented by a 0.004 resistance (Cyntec SMD), the same shunt resistor is utilized for DC bus current measurement.

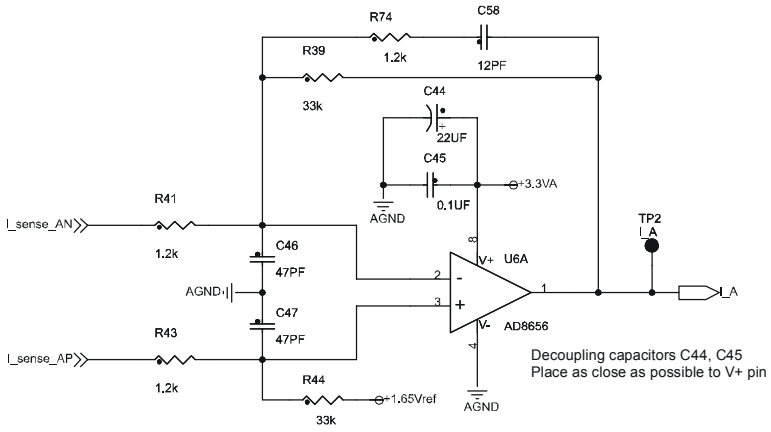


Figure 4-5 Phase current sensing circuit

4.8 Power Supplies and Voltage Reference

The 3-phase BLDC/PMSM Low Voltage Power Stage contains devices that require various voltage levels of +12V, +5V and +3.3V.

4.8.1 Input Power Supply

The DC bus can be supplied from two input connectors, J1 and J2. The DC bus has reverse polarity protection. The MC33937 driver is supplied from a SEPIC DC/DC converter which delivers a constant output voltage of +12V accros the entire input voltage range (+8V to +50V). The +5V and +3.3V power supplies are served from +12V.

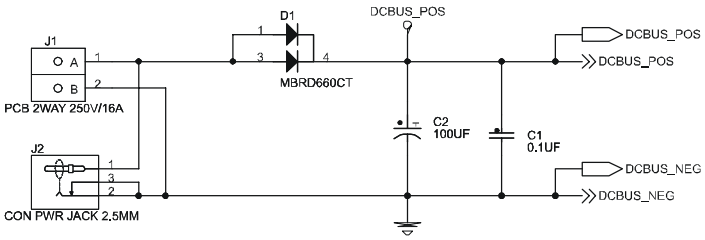


Figure 4-6 Input power supply

4.8.2 +12V Power Supply

The constant +12V supply voltage for the wide input voltage range (6V to 50V) is provided by the SEPIC converter (see Figure 4-7). This topology is able to deliver a constant output voltage when the input

voltage is below or above the nominal output voltage. It is suitable for this input voltage range. The LM5022 is a high voltage low side N-channel MOSFET controller. Output voltage regulation is based on current-mode control. It includes a start-up regulator that operates over a wide input range of 6V to 60V, an error amplifier, precision reference, line under-voltage lockout, cycle-by-cycle current limit, slope compensation, soft-start, external synchronization capability and thermal shutdown. Switching frequency has been setup to 500kHz.

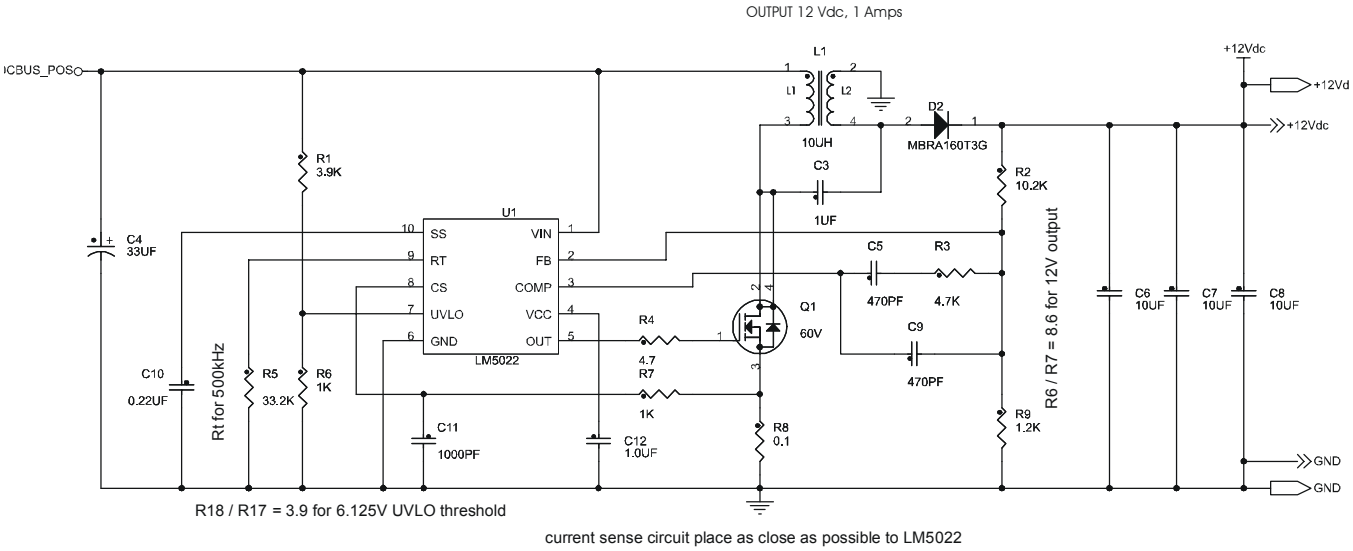


Figure 4-7 +12V SEPIC converter

4.8.3 +5V Power Supply

The +5V voltage level is generated by the step down DC/DC converter LM2694. This circuit delivers up to 600mA peak output current (see Figure 4-8). The switching frequency is adjusted to 500kHz. More information is available on the converter datasheet.

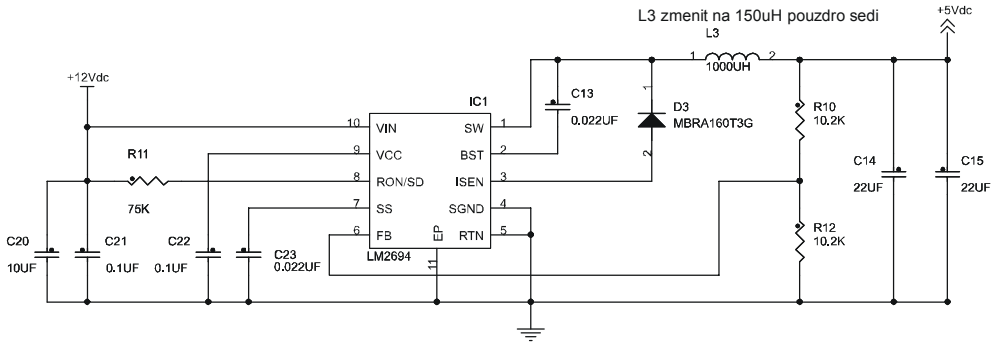


Figure 4-8 +5V Step Down Converter

4.8.4 +3.3V Power Supply

An important voltage level for this board is +3.3V. This is obtained from the MC33269D linear voltage regulator, which is able to deliver up to 800 mA. The +3.3V level is used to supply the on-board analogue devices.

4.8.5 +1.65V Voltage Reference

The +1.65V reference is generated from the +3.3V level by a resistors divider and an impedance isolator (see Figure 4-9). This reference shifts all current sensing output signals by 1.65V.

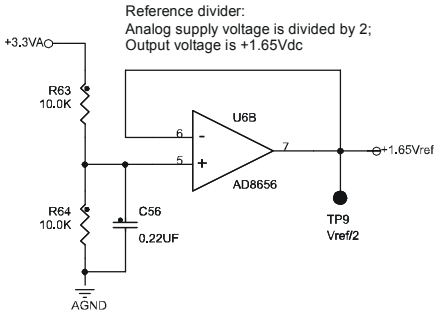


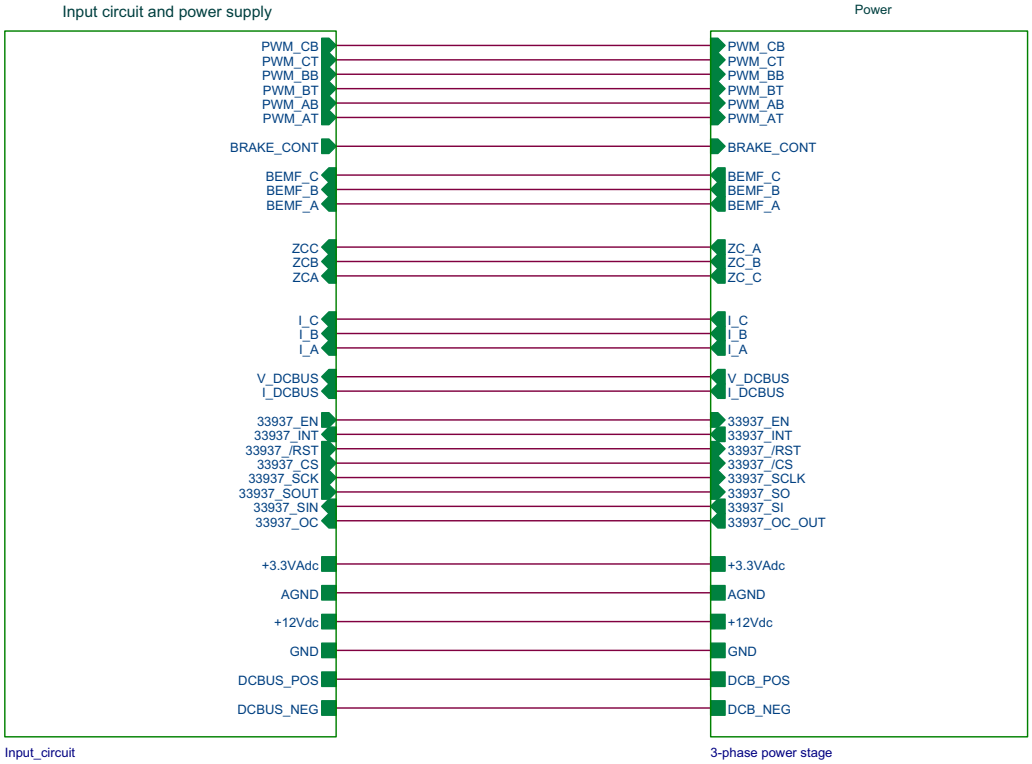
Figure 4-9 +1.65V Voltage Reference

4.9 Brake Switch Circuit

The brake switch circuit is included to control the operation of losing the energy from the motor through regenerative braking, to anexternal brake resistor.

There is only a power switch, with a pre-driver and a freewheeling diode populated on the board. An external brake resistor must connected through the two pin connector J5.

Appendix A. 3-Phase BLDC/PMSM Low Voltage Power Stage Schematics



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Designer: Petr Konvicny	Drawing Title: **10A LV 3-ph PS with MC33937**
Drawn by: Petr Konvicny	Page Title: **Block diagram**
Approved: <Approver>	Size A4 / Document Number SCH-00358_01 PDF: SPF-00358_01 / Rev 01
	Date: Tuesday, February 24, 2009 / Sheet 1 of 5

Figure A-1 Board overview

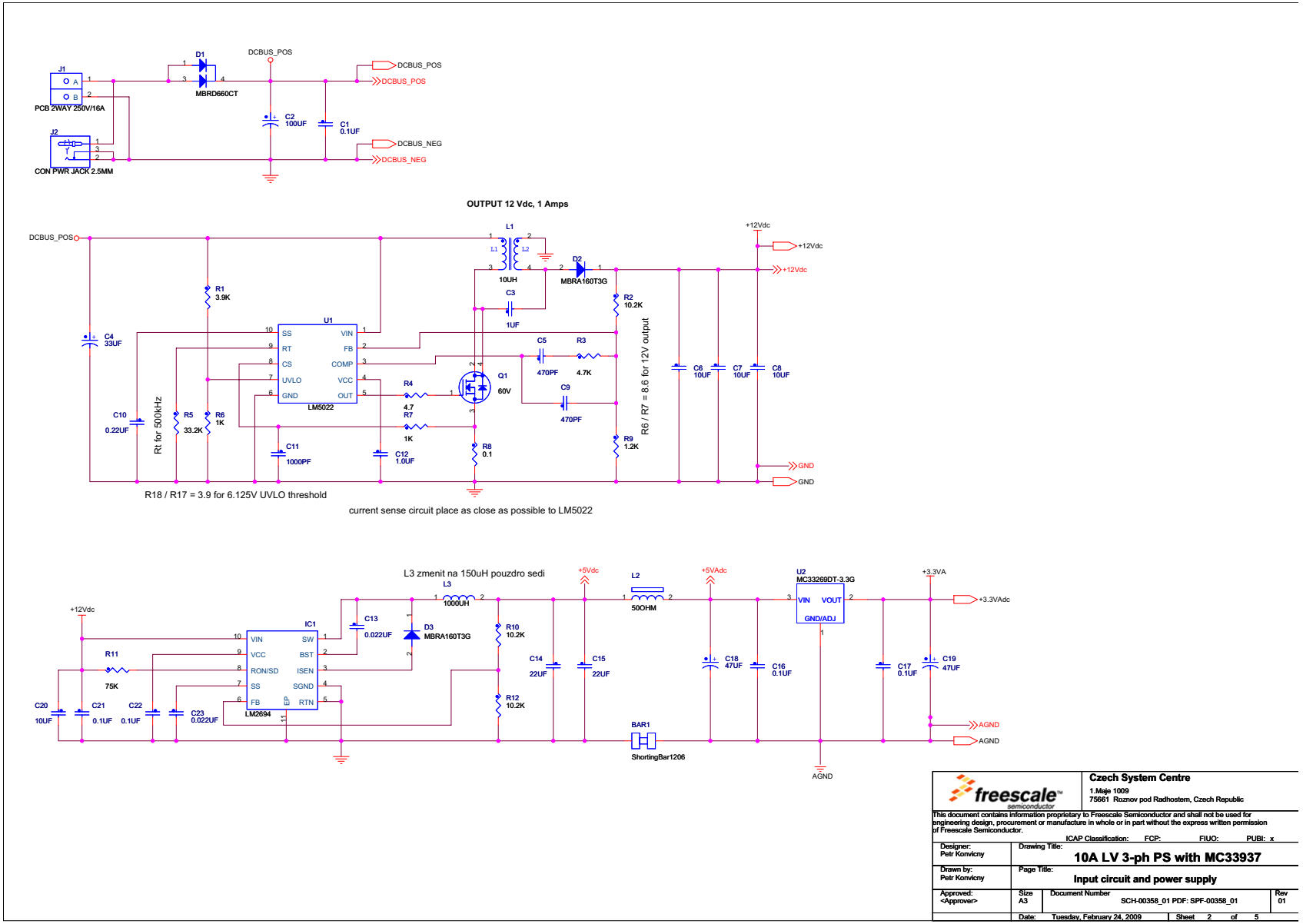
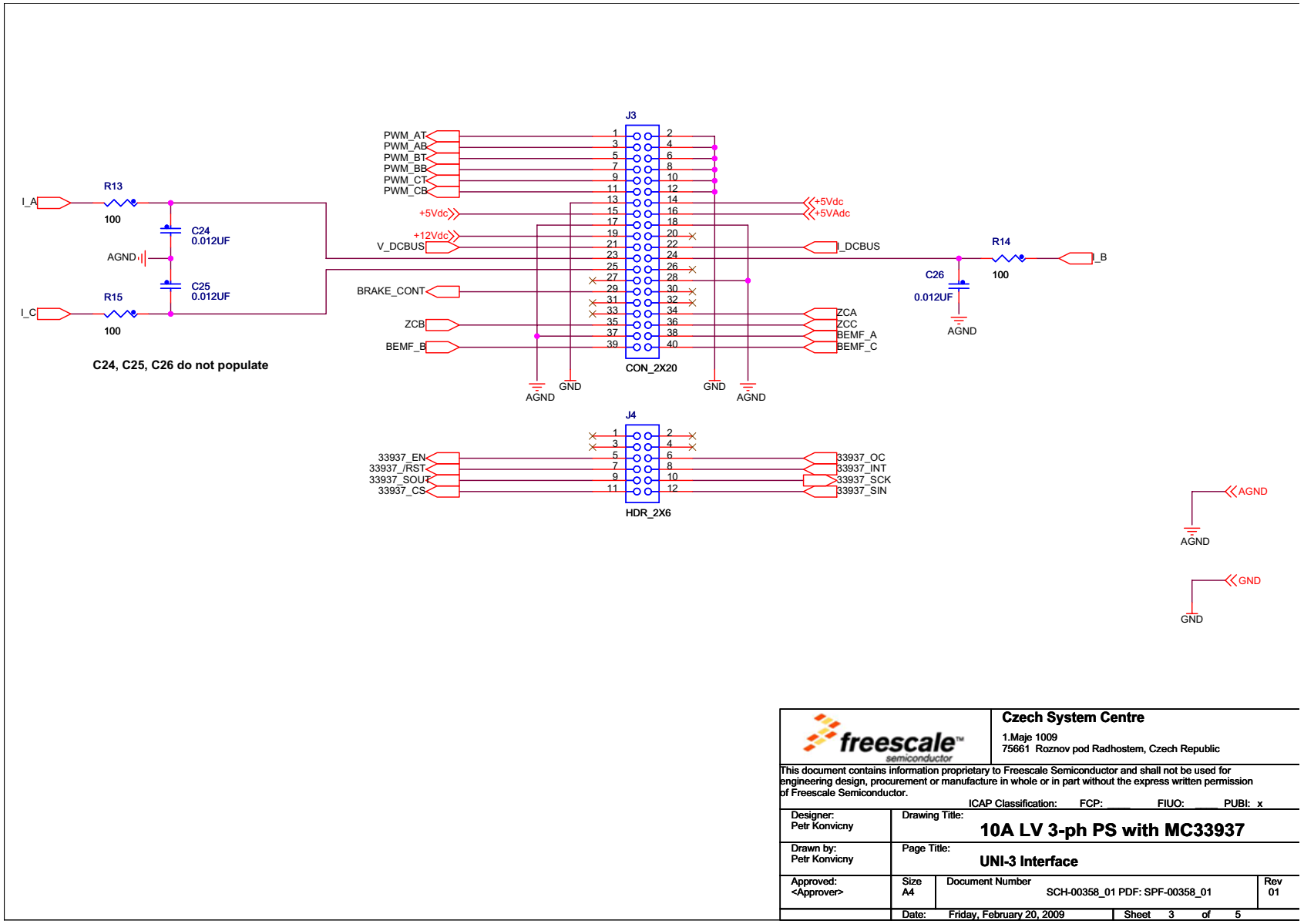


Figure A-2 Board Power Supply



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Designer: Petr Konvicny	Drawing Title: 10A LV 3-ph PS with MC33937	
Drawn by: Petr Konvicny	Page Title: UNI-3 Interface	
Approved: <Approver>	Size A4 / Document Number SCH-00358_01 PDF: SPF-00358_01	Rev 01
	Date: Friday, February 20, 2009	Sheet 3 of 5

Figure A-3 UNI3 Interface

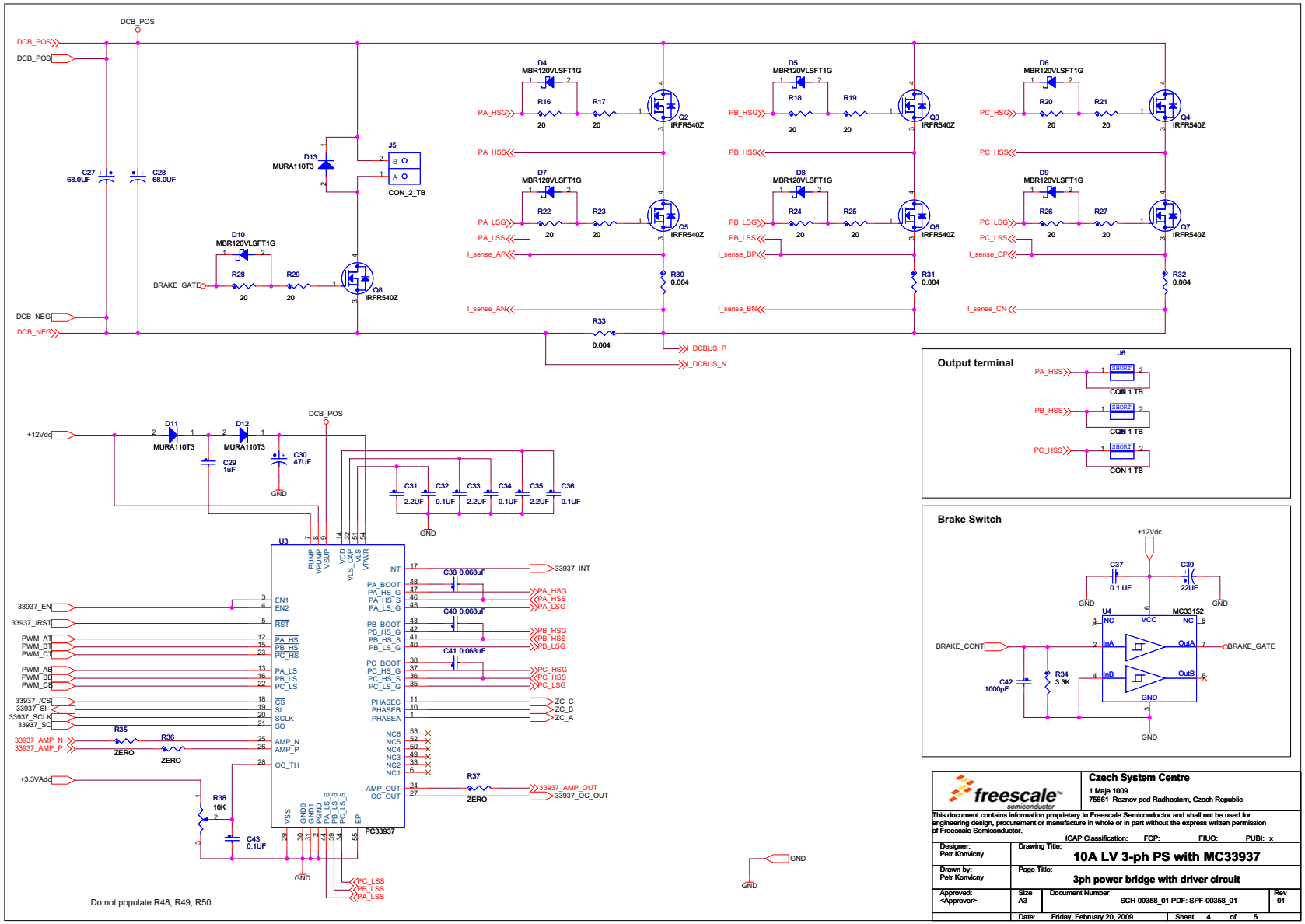

Figure A-4 3-Phase Bridge and pre-driver

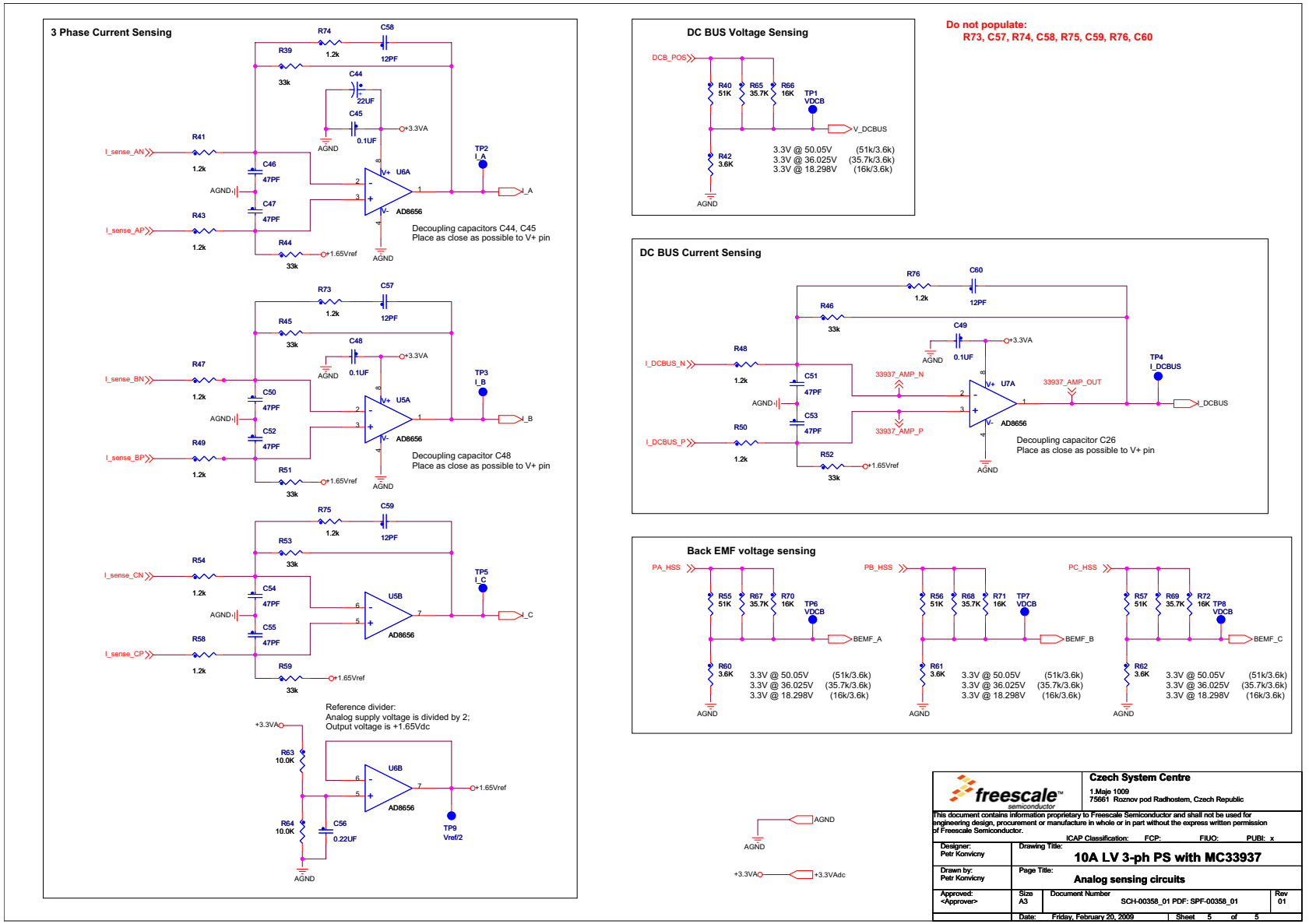

Figure A-5 Analogue signal sensing

Appendix B. Bill of Materials

Table B-1 Parts List

Designators	Quantity	DESCRIPTION	MANUFACTURER	PART NUMBER
C1	1	100nF, size 1206, X7R	ANY ACCEPTABLE	---
C2	1	100uF, size 12.5x20, elyt	ANY ACCEPTABLE	---
C3, C12	2	1uF, size 1206, X7R	ANY ACCEPTABLE	---
C4	1	33uF		
C5, C16, C17, C21, C22, C32, C34, C36, C37, C43, C45, C48, C49	13	100nF, size 0805, X7R	ANY ACCEPTABLE	---
C6-C8,C20	4	10uF, size 1206, Y5D	AVX	1206YD106KAT2A
C9	1	220pF, size 0805, X7R	ANY ACCEPTABLE	---
C10, C56	2	220nF, size 0805, X7R	ANY ACCEPTABLE	---
C11, C42	2	1nF, size 0805, X7R	ANY ACCEPTABLE	---
C13, C23	2	22nF, size 0805, X7R	ANY ACCEPTABLE	---
C14	1	22uF, size 1210	ANY ACCEPTABLE	---
C18, C19	2	47uF/6.3V, size D	ANY ACCEPTABLE	---
C27, C28	2	68uF/100V, size H13	PANASONIC	EEVFK2A680Q
C30	1	47uF/16V, case 0605	ANY ACCEPTABLE	---
C31,C33,C35	3	2.2uF, size 0805	ANY ACCEPTABLE	---
C38, C40, C41	3	150nF, size 0805, X7R	ANY ACCEPTABLE	---
C39	1	22uF	PANASONIC	EEE1CA220SR
C44	1	22uF	AVX	TPSB226K010R0400
C46,C47,C50-C55	8	47pF, size 0805, X7R	ANY ACCEPTABLE	---
C57-C60	4	12pF, size 0805, X7R	ANY ACCEPTABLE	---
D1	1	MBRD620CT	ON SEMICONDUCTOR	MBRD640CTT4G

Table B-1 Parts List

Designators	Quantity	DESCRIPTION	MANUFACTURER	PART NUMBER
D2, D3	2	MBRA160T3G	ON SEMICONDUCTOR	MBRA160T3G
D4-D9	6	MMSD914T1	ON SEMICONDUCTOR	MMSD914T1G
D10	1	MBR120VLSFT1G	ON SEMICONDUCTOR	MBR120VLSFT1G
D13	1	MURA110	ON SEMICONDUCTOR	MURA110T3G
IC1	1	LM2694	National Semiconductor	LM2694SD/NOPB
J1, J5	1	2 way connector	CAMDEN ELECTRONICS LTD	CTB5000/2
J2	1	Power Jack, 2.1mm	ANY ACCEPTABLE	---
J3	1	Header 2x20	ANY ACCEPTABLE	---
J4	1	Header 2x5	ANY ACCEPTABLE	---
J6-J8	3	WAGO connector, RM5/5.08mm	WAGO	236-401
L1	1	10uH, coupled inductors MSD1278 series	COILCRAFT	MSD1278-103MLD
L2	1	EXCELSA35T	ANY ACCEPTABLE	---
L3	1	150uH, inductor DO3316 series	COILCRAFT	DO3316P-154KL_
Q1	1	NDT3055L N-channel MOSFET	FAIRCHILD	NDT3055L
Q2-Q8	7	IRFR3710Z, Power MOSFET	INTERNATIONAL RECTIFIER	IRFR3710Z
R1	1	3.9k, size 0805	ANY ACCEPTABLE	---
R2,R10,R12	3	10.2k, size 0805	ANY ACCEPTABLE	---
R3	1	4.7k, size 0805	ANY ACCEPTABLE	---
R4	1	4.7R, size 0805	ANY ACCEPTABLE	---
R5	1	33.2k. size 0805	ANY ACCEPTABLE	---
R6, R7	2	1k, size 0805	ANY ACCEPTABLE	---
R8	1	0.1R	PANASONIC	ERJ-8BWFR100V
R9	1	1.2k, size 0805, 1%	ANY ACCEPTABLE	---
R11	1	75k, size 1206	ANY ACCEPTABLE	---

Table B-1 Parts List

Designators	Quantity	DESCRIPTION	MANUFACTURER	PART NUMBER
R15	1	2.2R, size 0805	ANY ACCEPTABLE	---
R16-R29	14	47R, size 1206	ANY ACCEPTABLE	---
R30-R33	4	0.004R, sensing resistor	CYNTEC	RL-3264-6-R004-JN
R34	1	3.3k, size 0805	ANY ACCEPTABLE	---
R35-R37,R77,R78	5	0R, size 0805	ANY ACCEPTABLE	---
R38	1	10k, trimer	BOURNS	3224W-1-103E
R40,R55-R57	4	51k, size 0805, 1%	ANY ACCEPTABLE	---
R41, R43, R47-R50, R54, R58, R73-R76	12	1.2k, size 0805, 1%	ANY ACCEPTABLE	---
R42,R60-R62	4	3.6k, size 0805, 1%	ANY ACCEPTABLE	---
R63,R64	2	10k, size 0805, 1%	ANY ACCEPTABLE	---
R65,R67-R69	4	35.7k, size 0805, 1%	ANY ACCEPTABLE	---
R66,R70-R72	4	16k, size 0805, 1%	ANY ACCEPTABLE	---
U1	1	LM5022	National Semiconductor	LM5022MME/NOPB
U2	1	MC33269DT-3.3G	ON SEMICONDUCTOR	MC33269DT-3.3G
U3	1	PC33937	FREESCALE SEMICONDUCTOR	PC33937EK/R2
U4	1	MC33152	ON SEMICONDUCTOR	MC33152DG
U5-U7	3	AD8656	ANALOG DEVICES	AD8656ARZ

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