3-Phase BLDC/PMSM Low Voltage Power Stage User Guide

Devices Supported:
MC33937A

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About This Book
This document describes the 3-Phase BLDC/PMSM Low Voltage Power Stage, targeted for rapid development of motor control applications.

To locate any published updates for this document, refer to the Freescale website at: http://www.freescale.com/

Revision History

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<tr>
<td>08/2012</td>
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</table>

Documentation

The MC33937A documentation is available at the Freescale web site, http://www.freescale.com, as follows:

- Data sheet — MC33937A modules in detail
- Product briefs — device overview
- Application notes — address specific design issues
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Chapter 1 Introduction

Freescale’s embedded motion control series 3-Phase BLDC/PMSM Low Voltage Power Stage is an 8 V–50 V, 10 Amps, surface-mounted power stage. In combination with one of the embedded motion control series controller 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 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. It is independent of the control board when you choose the internal MC33937A DC bus operational amplifier with an over-current comparator. You must therefore be careful when you drive low impedance motors. The current measuring circuitry is setup for ±10 Amps full scale. At ambient temperature (25 °C), the board remains 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 Section 2.2, “UNI3 Interface 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 8 V–50 V. The voltage should be within these limits. The board sustains a voltage of at least 8 V with a maximum of 58 V. The input power is supplied by means of the 2.1 mm jack connector J2 or clamp connector J1.

The following is summary of the information required to use the 3-Phase BLDC/PMSM Low Voltage. For design information, see Section Chapter 3, “Design Consideration.”

1.1 Features

The 3-phase low voltage power stage features are:

- MC33937A MOSFET pre-driver
- Motor control interface:
  - UNI-3
  - MC33937A pre-driver
- Braking chopper circuit
- Phase and DC-Bus voltage and current sensing circuits
- DC-Bus over current protection
- +12 Vdc, +5 Vdc DC-DC converters

1.2 Board architecture

The 3-phase low voltage power stage contains basic building blocks. See Figure 1-1.
Figure 1-1. 3-Phase BLDC/PMSM Low Voltage Power Stage controller board block diagram

The board is supplied by VBAT voltage in the range of 8 V–50 V.
Figure 1-2. 3-phase BLDC/PMSM low voltage power stage block location
Chapter 2 Interface Description

Inputs and outputs are located on eight 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 2-1 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 8 V–50 V DC.

The output for the motor is executed by the connectors J6, J7, and J8. For more details see Section 2.4, “Motor connector J6, J7, J8.”

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

2.1 Power Supply J1 and J2

The 3-Phase BLDC/PMSM Low Voltage Power Stage board can be supplied by either using the 2.1 mm DC power plug J2 or connector (J1).

The board provides 12 V, 5 V, and 3.3 V for board logic and analogue circuits, and for controllers boards connected through UNI-3 interface.

The board is designed to operate in the voltage range from 8 V–50 V. The board is protected against a reverse battery.

2.2 UNI3 Interface J3

The Unified Interface Version 3 (UNI-3) defines the interface between the 3-Phase BLDC/PMSM Low Voltage Power Stage and the dedicated controller board.

The list of UNI-3 signals is as follows:

- Control signals:
  - PWM phase A, B, C top and bottom switches control
  - Braking chopper control signal
  - Power Factor Correction (PFC)
- Monitor signals
  - DC-bus voltage
  - DC-bus current
— Phase A, B, C current
— Zero-cross signals
— Back-EMF phase A, B, C
— Temperature monitoring

- Power Supply 12 V
- Serial line — A bidirectional communication line between the Controller Board and Power Stage

Table 2-1 defines the UNI-3 pin-out.

### Table 2-1. UNI-3 signal description

<table>
<thead>
<tr>
<th>Interface Pin</th>
<th>Signal Name</th>
<th>MCU Signal</th>
<th>Description</th>
<th>Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PWM_AT</td>
<td>–</td>
<td>Phase A top switch control (H -&gt; Turn OFF)</td>
<td>Digital input</td>
</tr>
<tr>
<td>3</td>
<td>PWM_AB</td>
<td>–</td>
<td>Phase A bottom switch control (H -&gt; Turn ON)</td>
<td>Digital input</td>
</tr>
<tr>
<td>5</td>
<td>PWM_BT</td>
<td>–</td>
<td>Phase B top switch control (H -&gt; Turn OFF)</td>
<td>Digital input</td>
</tr>
<tr>
<td>7</td>
<td>PWM_BB</td>
<td>–</td>
<td>Phase B bottom switch control (H -&gt; Turn ON)</td>
<td>Digital input</td>
</tr>
<tr>
<td>9</td>
<td>PWM_CT</td>
<td>–</td>
<td>Phase C top switch control (H -&gt; Turn OFF)</td>
<td>Digital input</td>
</tr>
<tr>
<td>11</td>
<td>PWM_CB</td>
<td>–</td>
<td>Phase C bottom switch control (H -&gt; Turn ON)</td>
<td>Digital input</td>
</tr>
<tr>
<td>2, 4, 6, 8, 10</td>
<td>Shield</td>
<td>–</td>
<td>PWM signals shield (grounded on the power stage side only)</td>
<td>–</td>
</tr>
<tr>
<td>12, 13</td>
<td>GND_D</td>
<td>–</td>
<td>Digital power supply ground</td>
<td>–</td>
</tr>
<tr>
<td>14, 15</td>
<td>+5 V DC</td>
<td>–</td>
<td>+5 V digital power supply</td>
<td>–</td>
</tr>
<tr>
<td>17, 18</td>
<td>AGND</td>
<td>–</td>
<td>Analog power supply ground</td>
<td>–</td>
</tr>
<tr>
<td>19</td>
<td>+12/+15 V DC</td>
<td>–</td>
<td>Analog power supply</td>
<td>–</td>
</tr>
<tr>
<td>16, 20, 27, 28, 37</td>
<td>NC</td>
<td>–</td>
<td>Not connected</td>
<td>–</td>
</tr>
<tr>
<td>21</td>
<td>VDCBUS</td>
<td>–</td>
<td>DC-bus voltage sensing, 0 V – 3.3 V</td>
<td>Analog output</td>
</tr>
<tr>
<td>22</td>
<td>IDCBUS</td>
<td>–</td>
<td>DC-bus current sensing, 0V – 3.3V</td>
<td>Analog output</td>
</tr>
<tr>
<td>23</td>
<td>IA</td>
<td>–</td>
<td>Phase A current sensing, 0 – 3.3 V</td>
<td>Analog output</td>
</tr>
<tr>
<td>24</td>
<td>IB</td>
<td>–</td>
<td>Phase B current sensing, 0 – 3.3 V</td>
<td>Analog output</td>
</tr>
<tr>
<td>25</td>
<td>IC</td>
<td>–</td>
<td>Phase C current sensing, 0 – 3.3 V</td>
<td>Analog output</td>
</tr>
<tr>
<td>26</td>
<td>TEMP</td>
<td>–</td>
<td>Analog temperature 0 V – 3.3 V</td>
<td>Analog output</td>
</tr>
<tr>
<td>29</td>
<td>BRAKE_CONT</td>
<td>–</td>
<td>DC-bus brake control</td>
<td>Digital input</td>
</tr>
<tr>
<td>30</td>
<td>SERIAL</td>
<td>–</td>
<td>Serial interface</td>
<td>Dig. bidirectional</td>
</tr>
<tr>
<td>31</td>
<td>PFC</td>
<td>–</td>
<td>Power factor correction PWM</td>
<td>Digital input</td>
</tr>
<tr>
<td>32</td>
<td>PFCEN</td>
<td>–</td>
<td>Power factor correction enable</td>
<td>Digital input</td>
</tr>
<tr>
<td>33</td>
<td>PFCZC</td>
<td>–</td>
<td>Power factor correction Zero-cross</td>
<td>Digital output</td>
</tr>
<tr>
<td>34</td>
<td>ZCA</td>
<td>–</td>
<td>Phase A Back-EMF zero crossing</td>
<td>Digital output</td>
</tr>
<tr>
<td>35</td>
<td>ZCB</td>
<td>–</td>
<td>Phase B Back-EMF zero crossing</td>
<td>Digital output</td>
</tr>
<tr>
<td>36</td>
<td>ZCC</td>
<td>–</td>
<td>Phase C Back-EMF zero crossing</td>
<td>Digital output</td>
</tr>
</tbody>
</table>
2.3 MC33937A Interface J4

The phase top and bottom switches are controlled by the MC33937A pre-driver. The device is configured by the SPI, see Table 2-2.

<table>
<thead>
<tr>
<th>Interface Pin</th>
<th>Signal Name</th>
<th>MCU Signal</th>
<th>Description</th>
<th>Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>38</td>
<td>Back-EMF_A</td>
<td>–</td>
<td>Phase A Back-EMF voltage sensing</td>
<td>Analog output</td>
</tr>
<tr>
<td>39</td>
<td>Back-EMF_B</td>
<td>PAD2</td>
<td>Phase B Back-EMF voltage sensing</td>
<td>Analog output</td>
</tr>
<tr>
<td>40</td>
<td>Back-EMF_C</td>
<td>PAD4</td>
<td>Phase C Back-EMF voltage sensing</td>
<td>Analog output</td>
</tr>
</tbody>
</table>

2.4 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. A permanent magnet synchronous or brushless DC motor phase windings can be connected to the connectors J6, J7, and J8. Table 2-3 contains pin assignments.

<table>
<thead>
<tr>
<th>Pin</th>
<th>Signal name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>J6</td>
<td>Phase A</td>
<td>Supplies power to motor phase A</td>
</tr>
<tr>
<td>J7</td>
<td>Phase B</td>
<td>Supplies power to motor phase B</td>
</tr>
<tr>
<td>J8</td>
<td>Phase C</td>
<td>Supplies power to motor phase C</td>
</tr>
</tbody>
</table>
2.5 Braking chopper connector J5

The braking resistor can be joined to connector J5. This is located on the left top corner of the board.

Table 2-4. Brake resistor connector — signal description

<table>
<thead>
<tr>
<th>Pin</th>
<th>Signal name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>– Brake_res</td>
<td>Brake resistor negative terminal</td>
</tr>
<tr>
<td>2</td>
<td>+ Brake_res</td>
<td>Brake resistor positive terminal</td>
</tr>
</tbody>
</table>
Chapter 3 Design Consideration

The 3-phase BLDC/PMSM low voltage power stage demonstrates 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.

3.1 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 3-1 shows a schematic of the 3-phase power bridge. The pre-driver inputs are 3.3 V 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 15 us. 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.
3.2 DC Bus voltage and current feedback

Figure 3-2 shows the circuitry 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 50.05 V, 36.025 V, or 18.298 V DC bus voltage corresponds to V$_{\text{REF}}$ at output V$_{\text{DCBUS}}$. This output signal is connected to the UNI3 connector pin 21.

Figure 4-2 shows the circuitry supporting DC bus current sensing. The DC bus current is sampled by shunt resistor R33. The voltage drop for this resistor can be amplified by either 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, and R48=R50, the gain is given by:

$$A = \frac{R_{46}}{R_{48}}$$

The output voltage is shifted up by +1.65V V$_{\text{REF}}$ to accommodate positive and negative current swings. A ±150mV voltage drop across the sense resistor corresponds to a measured current range of ±10Amps.

If you use the MC33937 for current measurement, the I$_{\text{DCBUS}}$ signal is internally connected to the over current comparator, and provides an over current triggering function. A discussion about over-current limiting follows in section 3.3.

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

The output from opam I$_{\text{DCBUS}}$ is joined to the UNI3 connector pin 22. The shunt resistor is represented by a 0.015 Ω resistance (Cyntec SMD), the same type as the phase current measurement resistors.
3.3 Over-current, under-voltage, and other safety functions

The MC33937A provides over-current and under-voltage functions. The amplified DC 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. After a fault state has been detected, all six gate drivers are off, until the fault state is cleared by the SPI command or RESET pin.

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

The MC33937A 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 RESET. All these features can be configured through the SPI interface to trigger interrupts.
A detailed description is available in the driver datasheet.

Figure 3-3. MC33937A circuit

3.4 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 3-4 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 a a back EMF sense voltage BEMF_A. The resistor values are chosen so that a 50.05 V, 36.025 V or 18.298 V of phase voltage corresponds to a 3.3 V ADC input range. The BEMF_A, BEMF_B, BEMF_C signals are directly connected to the UNI3 interface pins 38, 39, 40.

Figure 3-4. Back EMF Sensing — Phase A, B, C
3.5 Phase current sensing

Phase currents are sampled by sensing resistors R30, R31, R32 in Figure 3-5, 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 are 11 with a +1.65 V offset. The output voltage is shifted up by +1.65 V \( V_{\text{REF}} \) to accommodate positive and negative current swings. A ±150 mV voltage drop across the sense resistor corresponds to a measured current range of ±10Amps.

The outputs from opamps 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 0.015 resistance (Cyntec SMD), the same shunt resistor is used for DC bus current measurement.

3.6 Power supplies and voltage reference

The 3-phase BLDC/PMSM low voltage power stage contains devices that require various voltage levels of +12 V, +5 V, and +3.3 V.

3.6.1 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 that delivers a constant output voltage of +12 V across the entire input voltage range (+8 V to +50 V). The +5 V and +3.3 V power supplies are taken from +12 V source.

3.6.2 +12 V power supply

The constant +12 V supply voltage for the wide input voltage range (6 V to 50 V) is provided by the SEPIC converter. This topology delivers 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. The output voltage regulation is based on current-mode control. It includes a start-up regulator that operates over a wide input range of 6 V 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. The switching frequency has been setup to 500 kHz.

3.6.3 +5 V power supply
The +5 V voltage level is generated by the step down DC/DC converter LM2694. This circuit delivers up to 600 mA peak output current. The switching frequency is adjusted to 500 kHz. More information is available in the converter datasheet.

3.6.4 +3.3 V power supply
An important voltage level for this board is +3.3 V. This is obtained from the MC33269D linear voltage regulator, which is able to deliver up to 800 mA. The +3.3 V level is used to supply the on-board analogue devices.

3.6.5 +1.65 V voltage reference
The +1.65 V reference is generated from the +3.3 V level by a resistors divider and an impedance isolator. This reference shifts all current sensing output signals by 1.65 V.

3.7 Brake chopper circuit
The brake chopper circuit is included to control the operation of losing the energy from the motor through regenerative braking to an external 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.
Chapter 4  Electrical Characteristics

The electrical characteristics in Table 4-1 apply to an operation at 25 °C.

Table 4-1. Electrical Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Symbol</th>
<th>Minimum</th>
<th>Type</th>
<th>Maximum</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power supply Voltage</td>
<td>$V_{DC}$</td>
<td>8</td>
<td>12, 24, 42</td>
<td>58</td>
<td>V</td>
</tr>
<tr>
<td>Quiescent Current(1)</td>
<td>$I_{CC}$</td>
<td>–</td>
<td>TBD</td>
<td>–</td>
<td>mA</td>
</tr>
<tr>
<td>Min Logic 1 Input Voltage</td>
<td>$V_{IH}$</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>mA</td>
</tr>
<tr>
<td>Max Logic 0 Input Voltage</td>
<td>$V_{IL}$</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>mA</td>
</tr>
<tr>
<td>Input Logic Resistance</td>
<td>$R_{IN}$</td>
<td>–</td>
<td>4.7</td>
<td>–</td>
<td>kΩ</td>
</tr>
<tr>
<td>Analogue Output Range</td>
<td>$V_{OUT}$</td>
<td>0</td>
<td>–</td>
<td>3.3</td>
<td>V</td>
</tr>
<tr>
<td>Bus Current Sense Voltage</td>
<td>$V_{ISNS}$</td>
<td>–</td>
<td>165</td>
<td>–</td>
<td>mV/A</td>
</tr>
<tr>
<td>Bus Voltage Sense Voltage: ......... 12 V range</td>
<td>$V_{BUS}$</td>
<td>5.3564</td>
<td>5.4445</td>
<td>5.5342</td>
<td>V/V</td>
</tr>
<tr>
<td>Continuous Output Current, $T_C = 25 ^\circ\text{C}$</td>
<td>$I_{D}$</td>
<td>–</td>
<td>35</td>
<td>–</td>
<td>A</td>
</tr>
<tr>
<td>Pulsed Output Current</td>
<td>$I_{DM}$</td>
<td>–</td>
<td>140</td>
<td>–</td>
<td>A</td>
</tr>
<tr>
<td>Total Power Dissipation (per MOSFET)(2)</td>
<td>$P_{D}$</td>
<td>–</td>
<td>TBD</td>
<td>–</td>
<td>W</td>
</tr>
<tr>
<td>Required Deadtime</td>
<td>$t_{OFF}$</td>
<td>–</td>
<td>77</td>
<td>–</td>
<td>ns</td>
</tr>
</tbody>
</table>

1—measured at 12 V power supply

2—The values are measured at 25 °C. Values may differ for other temperatures.
Figure 4.1: Schematic — Block diagram

3-Phase BLDC/PMSM Low Voltage Power Stage, Revision 4

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3-Phase BLDC/PMSM Low Voltage Power Stage, Revision

Figure 4-2. Schematic — Input circuit and power supply
Figure 4-4. Schematic — 3ph power bridge with driver circuit

3-Phase BLDC/PMSM Low Voltage Power Stage, Revision
Figure 4-5. Schematic — Analogue sensing circuits

3-Phase BLDC/PMSM Low Voltage Power Stage, Revision
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