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HIGH VOLTAGE MEDIUM POWER BOARD FOR THREE PHASE MOTORS

By Ivan Skalka, Leos Chalupa, Radim Visinka
Industrial System Application Laboratory
Freescale, Roznov pod Radhostem, Czech Republic

1 INTRODUCTION

This application note discusses one member of the Motor Control Kit, developed by Freescale. Freescale offers a wide variety of microcontrollers, analog ICs and power devices which leads to many possible types of control and power boards suitable for different applications. The Motor Control Kit takes advantage of this portfolio by allowing the optimum combination of boards to be selected, based on customer requirements.

This application note describes and explains how to use the High Voltage (HV) Power Board with Isolated Gate Transistors such as MOS or IGBT (Isolated Gate Bipolar Transistor) of up to a maximum of 400 V DC-Bus voltage and a maximum of 5A DC-Bus current. The power board is very suitable for driving three phase AC induction motors, three phase synchronous motors, three phase Brushless DC (BLDC) motors or Switch Reluctance (SR) motors with power ratings up to 600 W

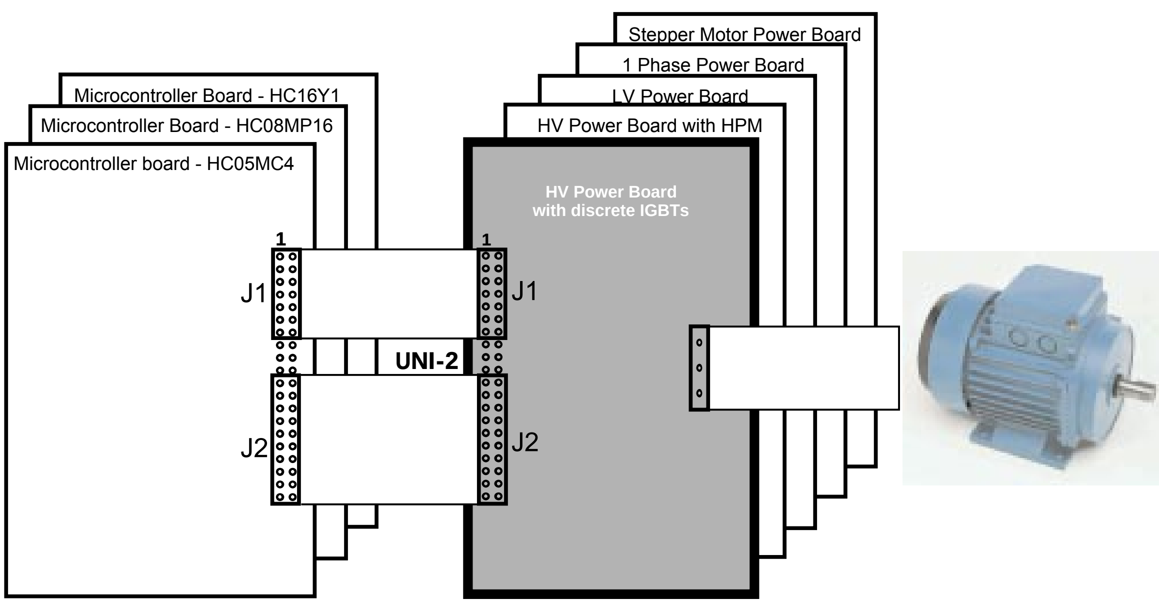

Figure 1-1. Members of the Motor Control Kit

2 FEATURES

The High Voltage Power Board with discrete IGBTs has been developed as a member of the Motor Control Kit. This means that the power board must meet some common requirements and the most important is the interface between control and power boards. The block diagram of the power board is shown in Figure 2-1.

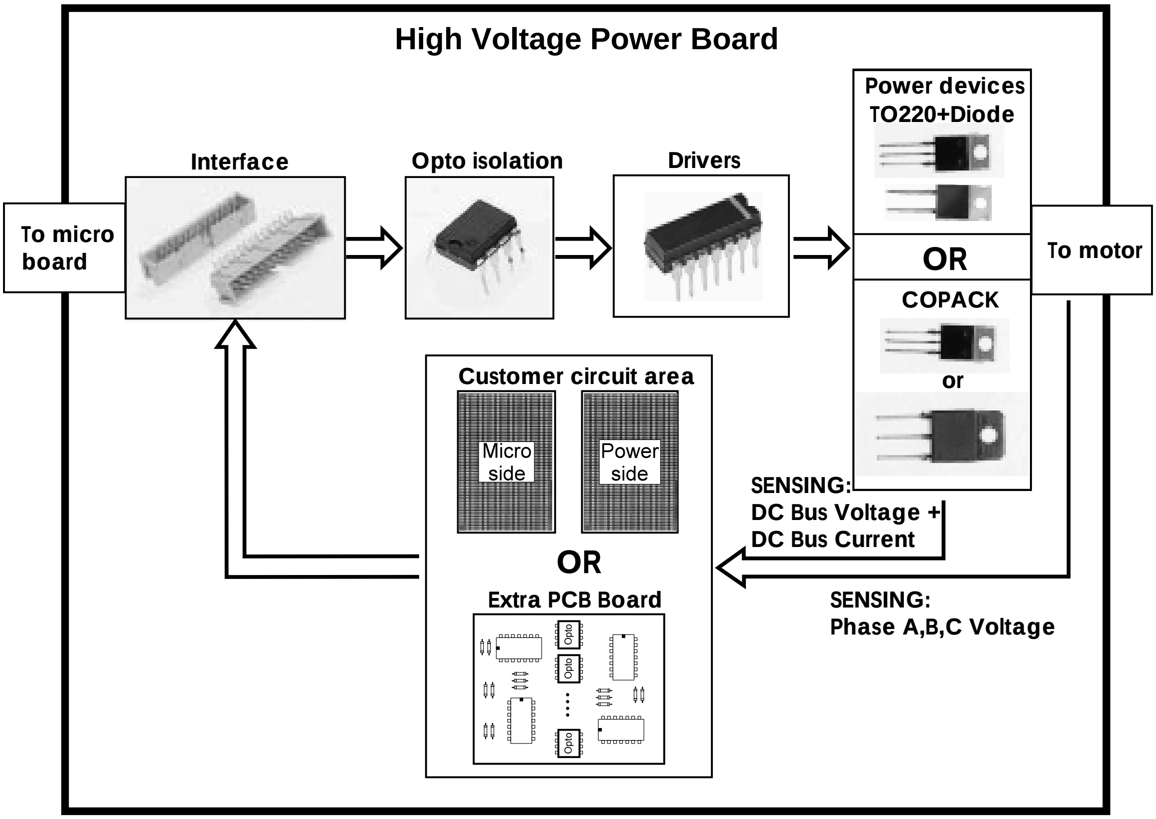

Figure 2-1. Block diagram of the High Voltage Power Board

Features included are:

- interface which meets the UNI-2 specification
- input gates (buffers or inverters) for PWM signals
- opto isolation
- support for multiple package options of power switches
- DC-Bus current sensing
- DC-Bus voltage sensing
- phase A,B, and C voltage sensing
- resistor dividers for high voltage lines sensing
- measurement points for all important signals
- variable configuration

2.1 UNI-2 Interface Connector

The connection to the all boards necessary for the whole system (microcontroller board, extra PCB boards) is provided through one common interface - **UNI-2** (connector J1). The definition of the interface covers several possibilities in order to keep compatibility with the present power boards actually available. The base is an area with 40 holes which allows placement of several different connectors. Refer to Figure 2-2. for a description of each pin and its functionality.

For more details refer to the UNI-2 specification.

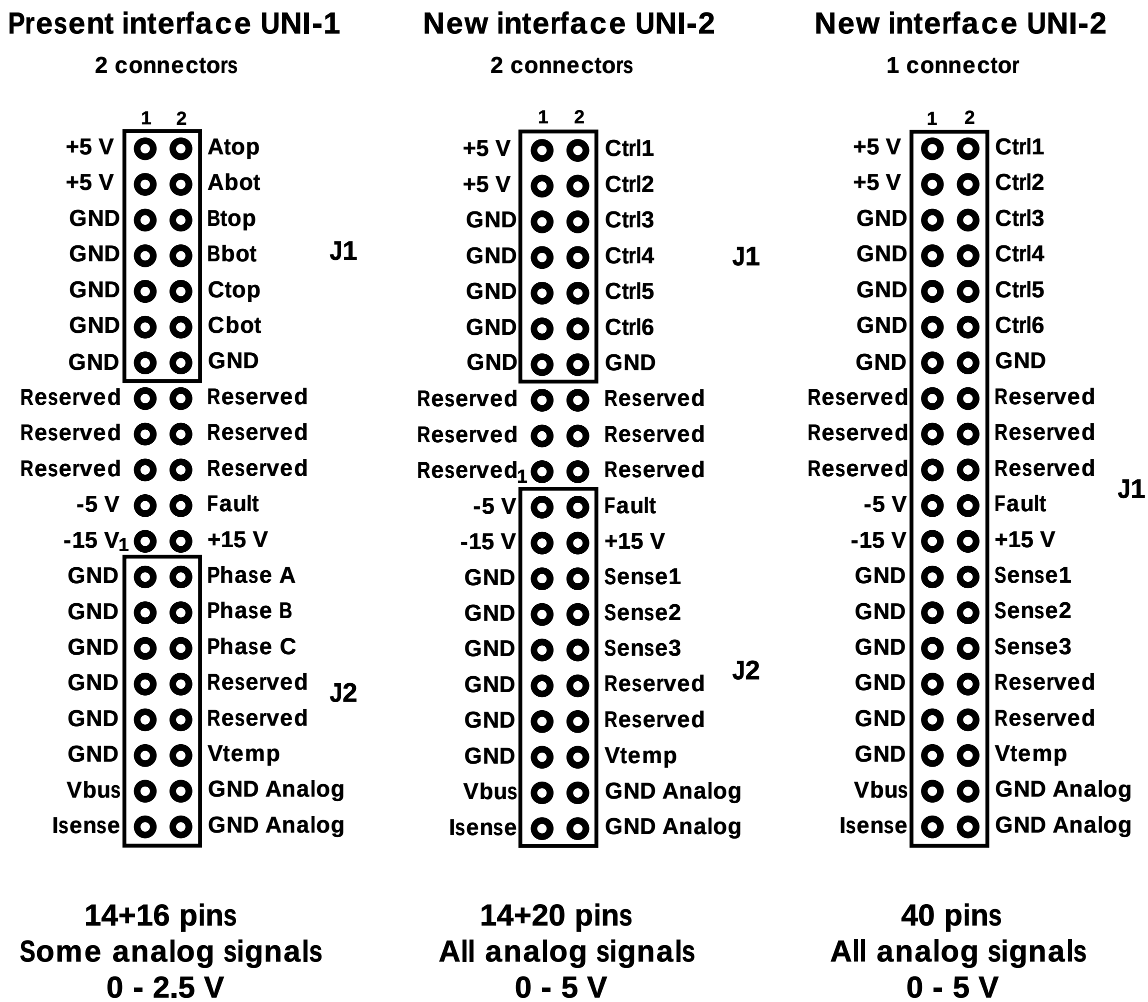

Figure 2-2. Interface connector

Signals Ctrl1 - Ctrl6 and Sense1 - Sense3 are defined for the three phase power board as follows:

Ctrl1- PWM signal for the top transistor in phase A (Atop)

Ctrl2 - PWM signal for the bottom transistor in phase A (Abot)

Ctrl3 - PWM signal for the top transistor in phase B (Btop)

Ctrl4 - PWM signal for the bottom transistor in phase B (Bbot)

Ctrl5 - PWM signal for the top transistor in phase C (Ctop)

Ctrl6 - PWM signal for the bottom transistor in phase C (Cbot)

Sense1 - It can be either an analog signal which represents voltage or current of phase A, or a digital signal. In analog form +5 V represents a maximal value of the sensed quantity.

Sense2 - It can be either an analog signal which represents voltage or current of phase B, or a digital signal. In analog form +5 V represents a maximal value of the sensed quantity.

Sense3 - It can be either an analog signal which represents voltage or current of phase C, or a digital signal. In analog form +5 V represents a maximal value of the sensed quantity.

It would be ideal to define ground signals to exclusively occupy one side of the connector and to allow an easier PCB layout, but compatibility with UNI-1 excludes this possibility. There are ground lines between all signals in the interface cable to avoid distortion of signals. The definition of the interface includes some spare pins which are available for the user. There are 2 spare pins in the two connector (14 + 20 pins) solution and 8 spare pins in the one connector (40 pins) solution.

2.2 Opto-isolation

When the power stage is supplied directly from the line, an opto isolation has to be used to fulfil the safety requirements. The high speed Motorola's opto-isolator HCPL0453 (surface mount package) is a suitable device for this application. It is ideally suited for applications requiring fast propagation delay times in industrially noisy environments and includes an internal Faraday shield on the detector, which gives the device the high level noise immunity. The layout of the HV Power Board is done strictly with through-holes. This enables easy replacement of damaged parts when a new application is developed. Because of this reason, the compatible device - HP4504 is used.

When an opto-isolator is not used it is necessary to connect together pin 3 and 6 of U2 through U7.

2.3 Driver for Isolated Gate Transistor

In order to provide a convenient and cost effective gate drive solution, one member of Motorola's MPIC family was chosen as the control IC. The system design using the MPIC2112 is simple and requires only a few external components.

The high voltage driver IC's are designed to directly drive the gates of power MOS devices. They provide the level shifting that is required to drive high side bridge circuits commonly used in motor drives and other power applications. They are capable of withstanding floating supply offset voltages up to 600 volts.

The shut-down input of the MPIC2112 can be used to switch off all IGBT's by a shut-down signal. All outputs of the MPIC2112 will turn off when the SD input goes high and the outputs will remain off, even after the SD input returns to low, until the next rising edge of the respective inputs.

This will happen when the fault signal from the microcontroller (pin 22 of J1) goes high.

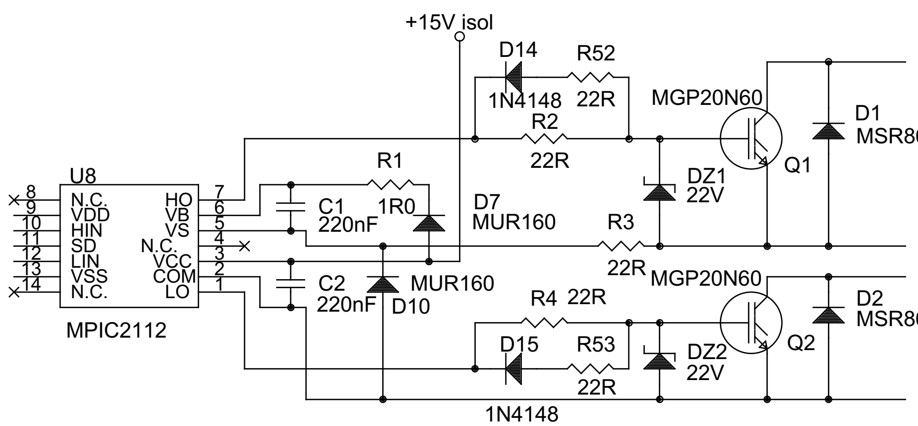

Figure 2-3. Example of Power Stage Solution

Figure 2-3. shows a solution for driving Isolated Gate Transistors.

Resistors R2,R4 (R6, R8, R10, R12) limit the switching speed and of course also the turn-off time. Increasing the value of the series gate resistors causes the amplitude of the negative spike decreases, while the turn-off time is a linear function of the series gate resistance. Experimental results show that R3 (R7, R11) suppresses the negative spikes on pin VS of the top transistor more effectively than R2. R3 (R7, R11) also has less effect on the turn-off time.

Resistors R52,R53 (R54, R55, R56, R57) and diodes D14,D15 (D16, D17, D18, D19) set different turn-off and turn-on times when such a function is required.

The diode D10 (D11, D12) is another method of suppressing the negative spike on pin VS. The most important parameter of the diode is the turn-on time. In this case resistor R3 (R7, R11) limits the current through the diode.

Freescale allows and guarantees operation of the MPIC drivers up to a maximum of -5 V on pin VS (pin 5).

2.4 Power Devices

The HV Power Board supports multiple package options for the power switches (TO220,TO247 and TO264). This also makes possible to mount discrete TMOS transistors or IGBTs with discrete fly-back diodes or a copack (IGBT with build-in diode) devices only. The following table summarises all combinations.

Device vs. package type						
Discrete power switch	TO220	No	No	No	TO247*	TO264*
Discrete diode	TO220	No	No	No	No	No
Copack IGBT	No	TO220	TO247	TO264	No	No

* only for T-MOS where its internal diode can be used instead of the discrete one

Table 2-1.

Figure 2-3. shows one possible configuration of the power stage.

Freescale MGP20N60 IGBTS and MSR860 diodes are used with the following characteristics:

MGP20N60	Collector-Emitter voltage	600 Vdc
	Collector current - continuous	20 A
MSR860	Reverse voltage	600 V
	Rectified forward current	8 A

An emitter of the high side transistor and a collector of the low side transistor are disconnected to make possible the measurement of the leg current through every Isolated Gate Transistor. Before using this board each point pair: PH1-PH2, PH3-PH4, PH5-PH6 must be connected. The PCB layout is also designed for an easy mounting of the heatsink because the power switches are all in-line.

2.5 Sensing

2.5.1 DC-Bus Voltage Sensing

The DC-Bus voltage is one of the feedback signals. An on-board resistor divider (R15-R18) and over voltage suppressor is provided (D13). The customer circuit area can be used for needed buffering, filtering and amplifying. Figure 2-4. shows an example:

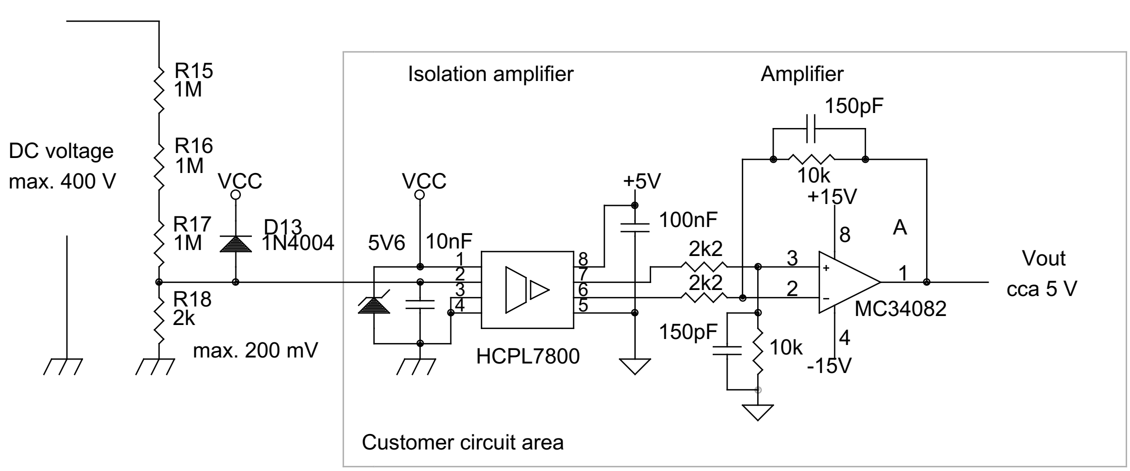

Figure 2-4. DC-Bus Voltage Sensing

2.5.2 Phase A,B,C Voltage Sensing

The resistor dividers of the phase output lines (R40-R51) give the possibility to sense the phase voltages. These can provide the feedback for the sensorless drive, the dead time compensation or other feedback techniques. The buffering, filtering and amplifying circuit can be similar as that for DC-Bus voltage sensing.

2.5.3 DC-Bus Current Sensing

The current sense resistor is placed in series with the Isolated Gate Transistor's emitters. The current sense resistor can be grounded in two different ways (See 3.3 Jumpers JP1 and JP2 - Ground Reference.). This is useful for different methods of sensing current, with or without relationship to the HV DC bus voltage sensing. Figure 2-5. shows an example:

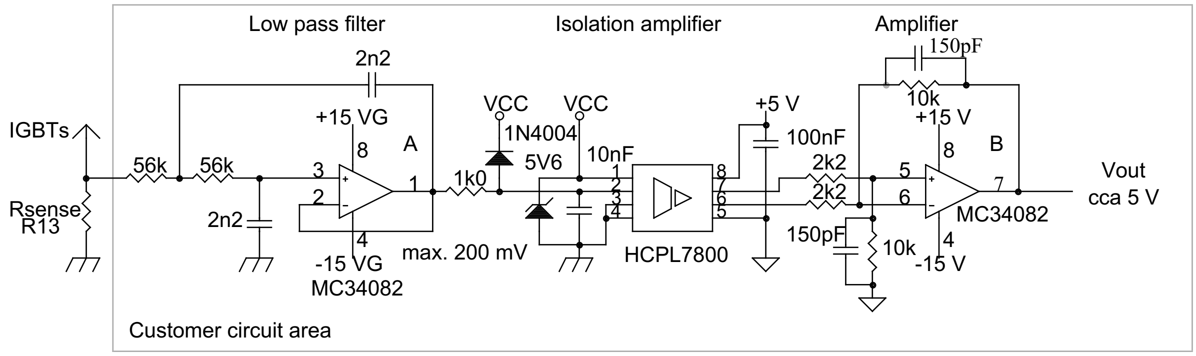

Figure 2-5. DC-Bus Current Sensing

2.6 Customer Circuit Area

The customer circuit area enables one to customise the HV Power Board functions (such as buffering, filtering, amplifying, limiting and limit detection of the sensed signals). The over(under)-voltage and the over-current detection can be designed on the board using this possibility.

All feedback signals as well as all power supply voltages are available close to the customer circuit area.

The isolation gap in the customer circuit area provides the possibility to place very easy an opto isolation device for feedback signals.

If an extra PCB board is used to handle the feedback signals (see Figure 2-1.), then it can be mounted onto the HV Power Board above the customer circuit area. See Figure A-1. Schematic.

2.7 Power Supply

Power can be connected to the power board through J1 and/or J2 and/or J3. J1 is an interface connector (refer to Figure 2-1 for specifications). All important power supply lines are included in the interface connector and this configuration allows all boards to be supplied from one board which simplifies the system. Connector J2 is dedicated for the power side and J3 for the microcontroller side when opto-isolators are used. There are also voltage regulators placed on-board: U11 (+5 V) for the power side and U12 (+5 V) for the microcontroller side.

For power supply considerations, it should be taken into account whether opto-isolators are used and how many voltages (+5 V, +15V,...) are needed on the microcontroller side and on the power side. Then the right case can be chosen and the minimal number of power supplies reached.

For example. The necessary voltages for a power board with opto-isolators and HV DC bus voltage sensing (HCPL7800 and MC34082 see Figure 2-4.) are:

Power side -
+15 V (through J2) - VCC is created on the board by U11.

Microcontroller side -
+15 V (through J3) - VCC is created on the board by U12.
-15 V (through J3)

The voltages +5 V, +15 V, -15 V are also available for the microcontroller and other board through J1.

3 CONFIGURATION

3.1 Jumper JP4 - PWM Signals

The Jumper JP4 selects between pull-up or pull-down configurations.

The logic integrated circuit (IC U1) is inserted between the microcontroller’s outputs and the opto-isolator’s inputs, because of the following reasons:

1. Creates the possibility to invert easy the drive signals (PWM) for the IGBT.
2. Creates the capability to drive the opto-couplers with logic input levels.
3. Creates the capability to drive the IGBT drivers when no opto-isolation is used.
4. Creates an easy transition from an isolated application to a non-isolated version of an application during development.

The explanation is the following. Not every microcontroller is able to sink 15 mA in a logical low level. Therefore the integrated circuit U1 has been included to provide extra current to drive the other devices. When a non-isolated application is being developed, the first step is the implementation of an isolated version with compatible functions and signals. The opto-couplers invert the signal, thus an additional IC can compensate this function and creates an easy transition from isolated to non-isolated version.

In Figure 3-1 the schematic diagram for different types of Isolated Gate Transistor’s drive signals is shown.

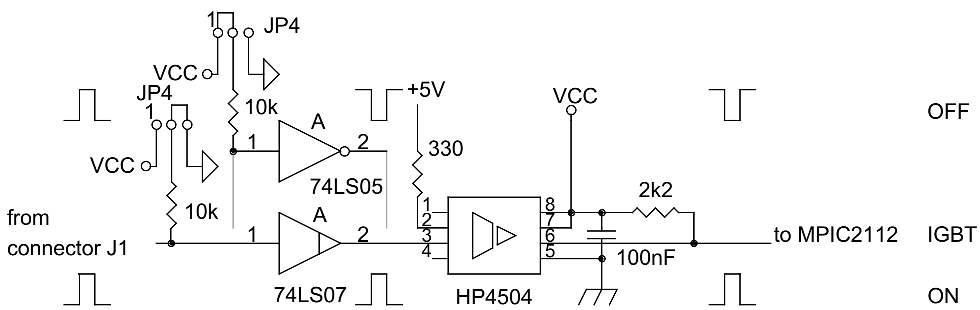

Figure 3-1. Adjusting the Signal for Isolated Gate Transistor

When the logic gates are not used, it is necessary to connect together pins 1-2, 3-4, 5-6, 8-9, 10-11, 12-13 of U1.

NOTE

Jumper JP4 and resistor network RN1 ensure the turn off level of the Isolated Gate Transistors when the connector J1 is disconnected.

WARNING

If the jumper JP4 is not set correctly, then all the power switches could be turned on during power turn on or off. If this happen when the DC-Bus capacitor is already charged, then it will cause the short circuit and may damage of the HV Power Board.

3.2 Jumpers JP3 and JP5 - Fault Signal

The shut down inputs (pin 11- SD) of the IGBT drivers (MPIC2112) can be connected either to ground or to opto-coupler's (U13) output (fault signal) using jumper JP3.

Jumper JP5 gives the possibility to ground the fault signal on the microcontroller side, if required.

WARNING

If the power supply voltage fails on the "Micro side" and an application is using the opto-couplers, then all opto-couplers' outputs are in high state. It means that all PWM signals are ON (See Figure A-1. Schematic.) and HV Power Board will be damaged.
To prevent such case, the shut-down inputs must be connected to U13 opto-coupler's output. The value of resistor R32 secures that the output of the opto-coupler U13 will be set high faster than the other opto-couplers' outputs. Thus the shut down circuit of the IGBT driver is excited before all input (PWM) signals are ON.

3.3 Jumpers JP1 and JP2 - Ground Reference

Different motor control applications require the ground potential to be referenced differently (before or after current sensing resistor R13).

The jumpers JP1 and JP2 allow to select the ground reference for the whole application accordingly (see Figure A-1. Schematic).

3.4 Soldering Bridge SB1 - Isolated or Non-isolated Configuration

When the HV Power Board is used in non-isolated (the "Micro side" is not isolated from "Power side") configuration, then the soldering bridge SB1 must be established.

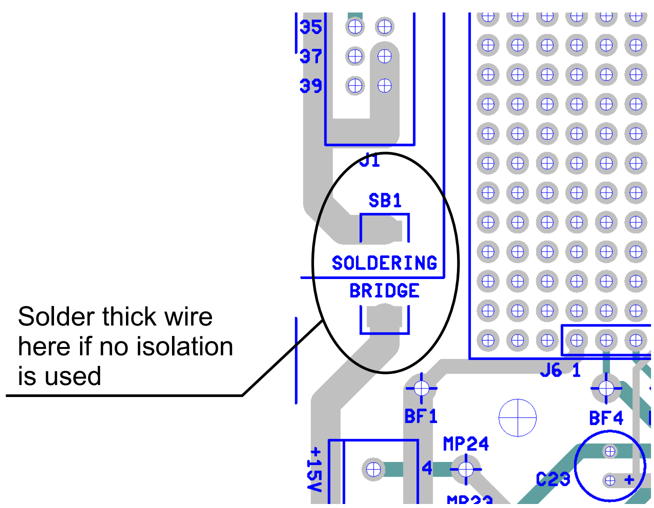

Figure 3-2. Soldering Bridge

3.5 Additional PCBs

The mechanical design of the HV Power Board offers two different connection possibilities for additional boards through the UNI-2 interface. The Figure A-3. shows the possible configuration. Some boards can be mounted on top of the customer circuit area or they can be put next the Power Board PCB. All boards can share the necessary signals via connectors of the UNI-2 interface. Thus a variable and flexible system is achieved.

4 DRIVER FOR ISOLATED GATE TRANSISTORS AND RELIABILITY CONSIDERATIONS

Since high current switching at high speed is not done without some difficulties, there are some subtle aspects which must be taken into account when designing such circuits. The PCB layout is probably more important than the schematic. Optimization of the layout requires one to minimize the stray inductances which severely affect the behaviour of the board. Stray inductances in the main current path can store a significant amount of energy and, at turn-off of the switching device, the following problems may occur:

1. High voltage spikes
2. Additional power dissipation in the switching devices due to absorbed inductive energy
3. Noise generation
4. Negative spikes on pin 5 of MPIC2112

The noise can disturb the control circuit or cause misfire of the switching devices. An excessive negative voltage spike can damage the control IC (latch-up).

A typical half-bridge circuit, that employs two Isolated Gate Transistors and an MPIC2112, is shown in Figure 4-1.. The critical stray inductances, which affect the behaviour of the circuit, are located in the high current path. Ld1 and Ls2 are due to the wiring inductance between the Isolated Gate Transistors and the decoupling capacitor. Therefore in Figure A-1. there is a decoupling electrolytic capacitor, C8 and/or C9, located very close to the Isolated Gate Transistors and the capacitor C7 is split into two parts C7a and C7b to decrease the influence of the stray inductances Ld1 and Ls2.

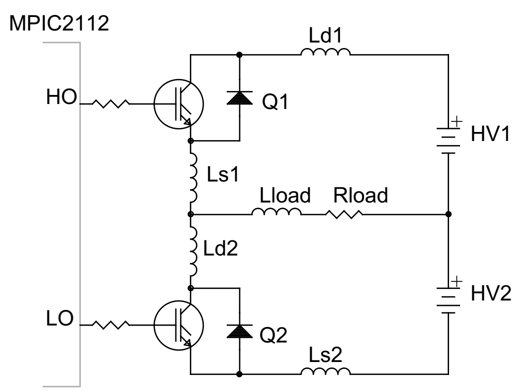

Figure 4-1. Half Bridge with Stray Inductance

5 PCB LAYOUT FOR HIGH SPEED AND HIGH CURRENT LINES

The PCB for the power board has been designed as a double-sided board. For PCB layout design it is strictly recommended not to use an common autorouter. Big problems usually occur when an autorouter is allowed to place high speed, high current lines without guidance for this kind of circuit. A few general rules are listed below, that can minimize the difficulties in PCB layouts:

1. High current switching lines as short and as wide as possible
2. Minimize the stray inductances
3. Avoid loops
4. Minimize the area of the remaining high current loops
5. Locate proper high frequency decoupling close to the Isolated Gate Transistors
6. A “three-to-one rule”: the trace width should not be less than 1/3 of its length
7. Minimize length of lines between MPIC and Isolated Gate Transistor,
8. Isolation gap (opto isolation)
9. Isolation gaps between high voltage lines
10. If Isolated Gate Transistors in case TO220 are used, then the middle pin of the transistor must be bent out of line for good isolation between soldering pads (VDE regulation on isolation distance).

6 STARTING ACTIVITIES

Before using this power board for three phase motors, perform the following steps:

1. Consider polarization of signal for opto-isolators.
2. Consider opto isolation. When the opto-isolators are omitted, then connect the solder bridge between the ground on the power side and the ground on microcontroller side (located close to the interface connector J1).
3. Consider how many power supplies are needed for the control board and the power board including HV DC bus voltages.
4. Choose the jumper JP1 or JP2 to select ground reference for the application.
5. Connect the points PH1-PH2, PH3-PH4, PH5-PH6 with wires which are only as long as necessary for leg current measurement.
6. Set the jumpers JP3, JP4, JP5 when the shutdown signal for MPIC2112 drivers is required.
7. Wire the connector J4 (only if needed) from points PH1, PH3, PH5.
8. Use the customer circuit area to create the desired circuit for feedback signals.
9. Connect the control signals via connector J1 (UNI-2 interface)
10. Turn ON all auxiliary power supplies (such as +5V, ±15V ....). The DC-Bus power supply is still turned OFF.
11. Check all signals, especially the IGBT gate signals. Check the switching sequence without motor and the DC-Bus voltage if possible.
12. Connect the DC_Bus power supply and set 0V.
13. Finally, slowly increase the DC-Bus voltage up to the required value and check the DC-Bus current continuously.
14. Connect the motor and run it (check the DC-Bus current continuously).

7 SAFETY CONSIDERATIONS

WARNING

When working with opto-isolators do not touch the board or any of its components outside the isolation barrier

When working with opto-isolators and the HV DC bus is powered directly from the line, do not connect any computer, scope or development system outside the isolation barrier. In this case is necessary to use an isolation transformer.

When working without opto-isolators, do not connect any computer, scope or development system when the HV DC bus is powered directly from the line. In this case it is necessary to use an isolation transformer.

APPENDIX A

A.1 List of Measurement's Points

The board provides a number of useful measurement points.

MP1	Gate of Q1 - Atop
MP2	Gate of Q2 - Abot
MP3	Phase A
MP4	Gate of Q3 - Btop
MP5	Gate of Q4 - Bbot
MP6	Phase B
MP7	Gate of Q5 - Ctop
MP8	Gate of Q6 - Cbot
MP9	Phase C
MP10	Shunt
MP11	DC Bus -
MP12	DC Bus +
MP13	DC Bus sensing
MP14	Fault signal (shut-down signal)
MP15	Atop from microcontroller
MP16	Abot from microcontroller
MP17	Btop from microcontroller
MP18	Bbot from microcontroller
MP19	Ctop from microcontroller
MP20	Cbot from microcontroller
MP21	GND Isol.
MP22	+5 V Isol.
MP23	-15 V Isol.
MP24	+15 V Isol.
MP25	GND
MP26	+5 V
MP27	+15 V
MP28	-15 V
MP29	Phase A voltage (divided down-to 0-15V)
MP30	Phase B voltage (divided down-to 0-15V)
MP31	Phase C voltage (divided down-to 0-15V)
MP32	Ground Reference - Isolated

A.2 HV Power Board PCB

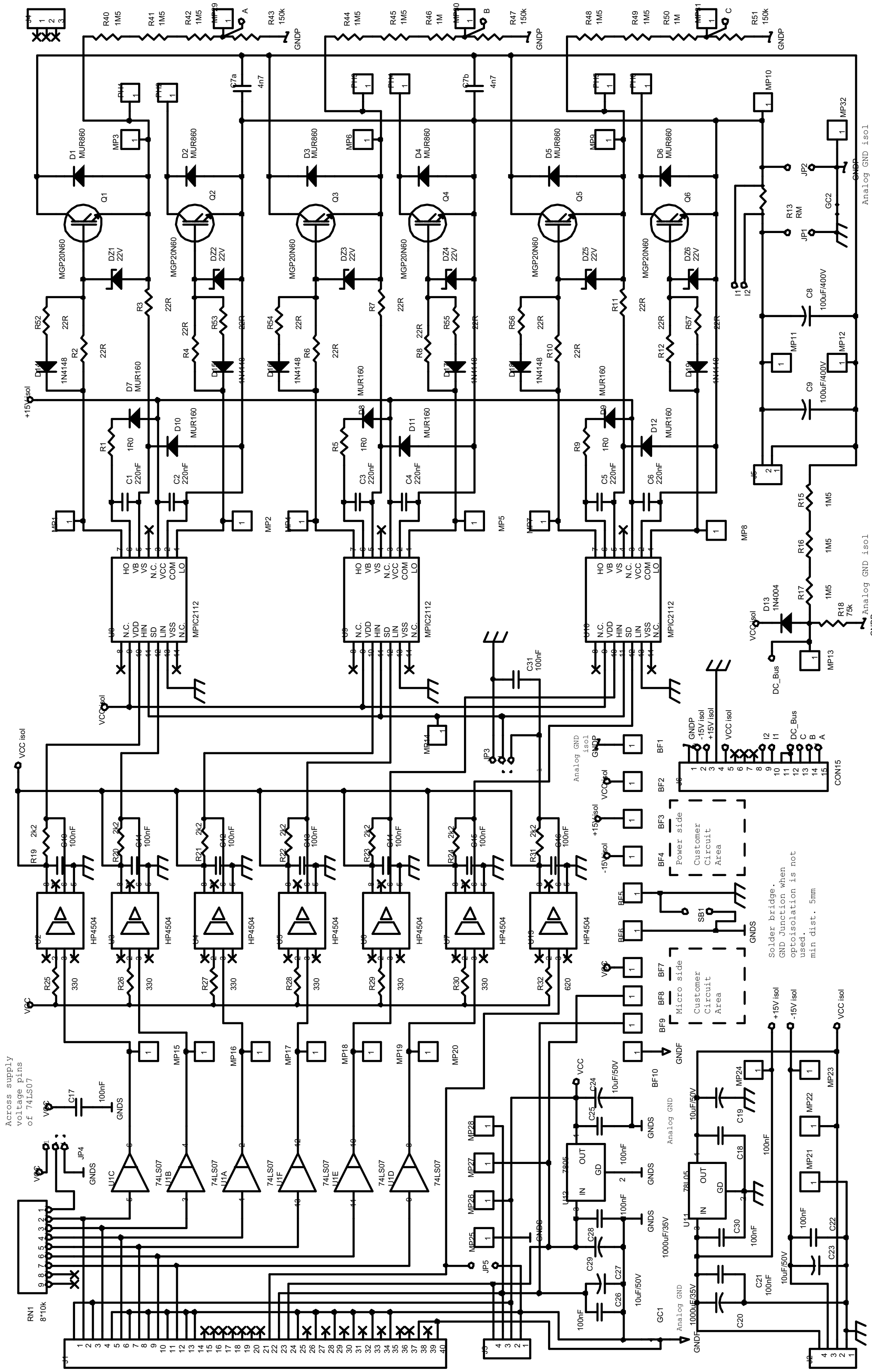

Figure A-1. Schematic

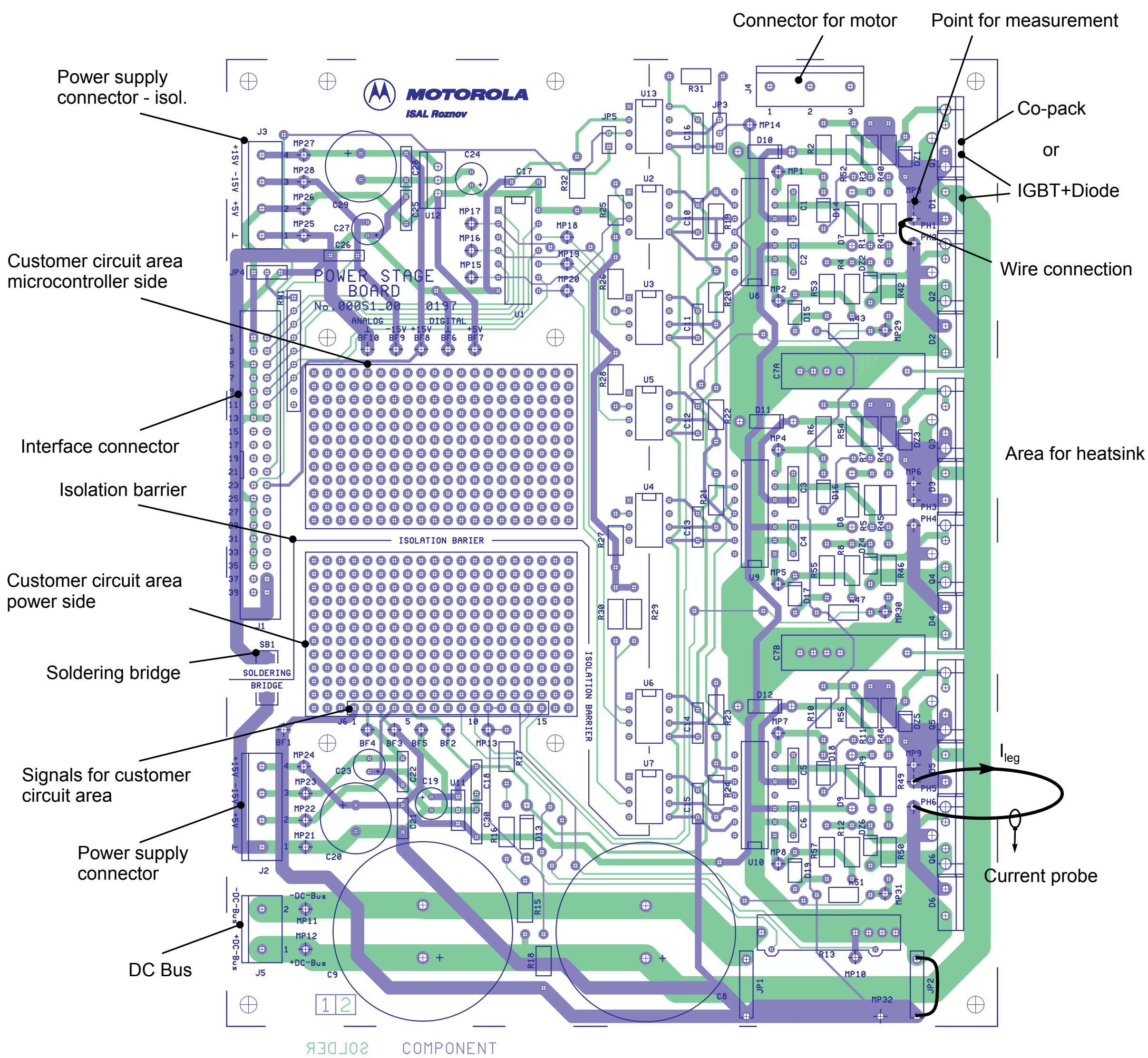

Figure A-2. PCB Layout

Table A-1. List of components

Component Reference	Component Type
U1	74LS07 *
U2,3,4,5,6,7,13	HP4504
U8,9,10	MPIC2112 or MPIC2113
U11	78L05
U12	7805
Q1,2,3,4,5,6	MGPxxN60 or MGWxxN60D *
D1,2,3,4,5,6	MSRx60 *
D7,8,9,10,11,12	MUR160
D13	1N4004
D14,15,16,17,18,19	1N4148
DZ1,2,3,4,5,6	1N4748A (22V)
R1,5,9	1R0, 0.5 W, 1%
R2,3,4,6,7,8,10,11,12,52,53,54,55,56,57	22R, 0.5 W, 1%
R13	shunt, 3-5 W, 1% *
R15-17,40-42,44-46,48-50	1M5, 0.5 W, 1% *
R18	75k, 0.5 W, 1%
R43,47,51	150k, 0.5 W, 1%
R19-24,31	2K2, 0.5 W, 1%
R25-30	330R, 0.5 W, 1%
R32	620R, 0.5 W, 1%
RN1	8x10k Resistor Network
C1-6	220nF/100 V, 10%
C7a,C7b	4n7/1000 V, 10%
C8,9	100µF/400 V, 10% electrolytic *
C10-18,21,22,25,26,28,30,31	100nF/100 V, 10%
C20,29	1000µF/35 V, 10% electrolytic
C19,23,24,27	10µF/35 V, 10% electrolytic
JP5	jumper 2 pins
JP3,4	jumper 3 pins
J1	40 pin boxed header
J2,3	4 pin screw terminals 5 mm
J4	3 pin screw terminals 7.5 mm
J5	2 pin screw terminals 7.5 mm
J6	15 pin connector (in line) *

* can be customized

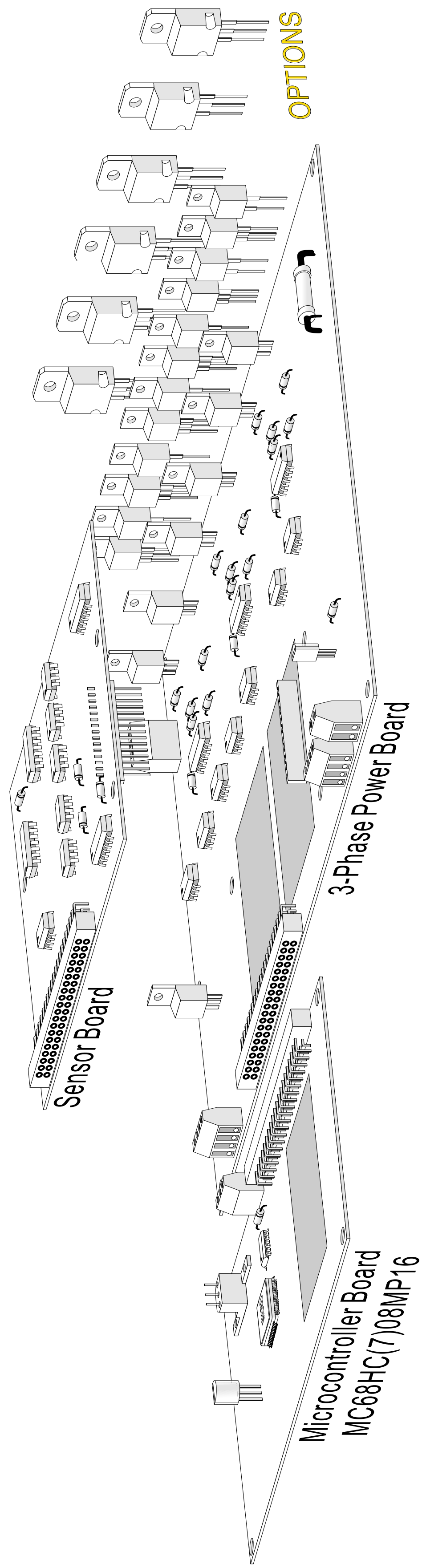

Figure A-3. Example of a Motor Control System

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support@freescale.com

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Freescale Semiconductor
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1300 N. Alma School Road
Chandler, Arizona 85224
+1-800-521-6274 or +1-480-768-2130
support@freescale.com

Europe, Middle East, and Africa:
Freescale Halbleiter Deutschland GmbH
Technical Information Center
Schatzbogen 7
81829 Muenchen, Germany
+44 1296 380 456 (English)
+46 8 52200080 (English)
+49 89 92103 559 (German)
+33 1 69 35 48 48 (French)
support@freescale.com

Japan:
Freescale Semiconductor Japan Ltd.
Headquarters
ARCO Tower 15F
1-8-1, Shimo-Meguro, Meguro-ku,
Tokyo 153-0064
Japan
0120 191014 or +81 3 5437 9125
support.japan@freescale.com

Asia/Pacific:
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