

# dsPICDEM™ MC1L 3-Phase Low Voltage Power Module User's Guide

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## dsPICDEM<sup>™</sup> MC1L 3-PHASE LOW VOLTAGE POWER MODULE

## **Safety Notice**

The safety notices and operating instructions provided should be adhered to, to avoid a safety hazard. If in any doubt, consult your supplier.



WARNING – This system must be earthed (grounded) at all times.

CAUTION – The system should not be installed, operated, serviced or modified except by qualified personnel who understand the danger of electric shock and energy discharge hazards and have read and understood the user instructions. Any service or modification performed by the user is done at the user's own risk and voids all warranties.

CAUTION – Although the system has DC voltages of comparatively low value present, current and energy storage levels are such that a hazard to the user still exists if contact with live terminals or circuitry should occur.

WARNING – The output terminals are NOT isolated from the incoming supply. These terminals are live during operation AND for 5 minutes after disconnection from the supply. Do not attempt to access the terminals or remove the cover during this time. Note that this same hazard applies to any external brake resistor connected.

WARNING – The unit may obtain power through the output terminals if these are connected to a rotating motor acting as a generator. If this is the case, then the previous warning also applies (i.e., the output terminals are live when connected to the generator and for 5 minutes after the generator has been stopped). Note that this case can arise even when the unit has been disconnected from the incoming DC supply.

CAUTION – If a motor is connected to the output of this unit, the frame should be connected to the output protective ground terminal provided. Particular care should be taken to mechanically guard such a motor, bearing in mind that unexpected behavior is likely to result from the process of code development.

CAUTION – For continued protection against the risk of fire, replace the fuse with one of the same type only (15A high breaking capacity with an appropriate DC voltage rating). Suitable parts are Wickmann 314 Series or Bussmann ABC series both of which can break 10 kA at 125V DC.

- The system is intended for evaluation and development purposes and should only be operated in a normal laboratory environment as defined by IEC 61010-1:2001.
- Clean with a dry cloth only.
- Operate flat on a bench, do not move during operation and do not block the ventilation holes.
- The system should not be operated without all the supplied covers fully secured in place.
- Screws should not protrude into the unit by more than 5mm (0.2"), type M3 ISO metric.
- The system should not be connected or operated if there is any apparent damage to the unit.
- The unit has no switch for interrupting the incoming DC supply. If connected to a DC power supply, output switch is the disconnection means and it should therefore be easily accessible to the user. If a battery is used, an external DC contactor of an appropriate rating should be used and the control of the contactor forms the disconnection means.



## dsPICDEM<sup>™</sup> MC1L 3-PHASE LOW VOLTAGE POWER MODULE

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## dsPICDEM™ MC1L 3-PHASE LOW VOLTAGE POWER MODULE

## Preface

This chapter contains general information about this manual and contacting customer support.

## HIGHLIGHTS

Topics covered in this chapter:

- · About this Guide
- Warranty Registration
- Recommended Reading
- The Microchip Web Site
- Development Systems Customer Notification Service
- Customer Support

## **ABOUT THIS GUIDE**

## **Document Layout**

This document describes how to use the Microchip dsPICDEM<sup>™</sup> MC1L Low Voltage 3-Phase Power Module. The manual layout is as follows:

- Chapter 1: Set Up and Operation Describes what the product is, what makes it
  a desirable development tool, how to install it and the basic features of the
  interface.
- Worldwide Sales and Service Lists Microchip sales and service locations and telephone numbers worldwide.

## **Documentation Updates**

All documentation becomes dated and this user's guide is no exception. Since MPLAB<sup>®</sup> IDE, MPLAB C1X and other Microchip tools are constantly evolving to meet customer needs, some actual dialogs and/or tool descriptions may differ from those in this document. Please refer to our web site to obtain the latest documentation available.

## **Documentation Numbering Conventions**

Documents are numbered with a "DS" number. The number is located on the bottom of each page, in front of the page number. The numbering convention for the DS Number is: DSXXXXXA,

where:

XXXXX = The document number. A = The revision level of the document.

## WARRANTY REGISTRATION

Please complete the enclosed Warranty Registration Card and mail it promptly. Sending in your Warranty Registration Card entitles you to receive new product updates. Interim software releases are available at the Microchip web site.

## **RECOMMENDED READING**

This user's guide describes how to use the dsPICDEM MC1L 3-Phase High Voltage Power Module. The data sheets contain current information on programming the specific microcontroller devices.

## THE MICROCHIP WEB SITE

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The Microchip web site is available by using your favorite Internet browser to attach to:

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The web site provides a variety of services. Users may download files for the latest development tools, data sheets, application notes, user's guides, articles and sample programs. A variety of information specific to the business of Microchip is also available, including listings of Microchip sales offices, distributors and factory representatives.

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- Microchip Consultant Program Member Listing
- · Links to other useful web sites related to Microchip products

## **Engineer's Toolbox**

- Design Tips
- Device Errata

## Other available information

- Latest Microchip Press Releases
- · Listing of seminars and events
- Job Postings

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The Development Systems product group categories are:

- Compilers
- Emulators
- In-Circuit Debuggers
- MPLAB<sup>®</sup> Development Systems
- Programmers

Here is a description of these categories:

**Compilers** – The latest information on Microchip C compilers and other language tools. These include the MPLAB C17, MPLAB C18 and MPLAB C30 C compilers; MPASM<sup>™</sup> and MPLAB ASM30 assemblers; MPLINK<sup>™</sup> and MPLAB LINK30 object linkers; MPLIB<sup>™</sup> and MPLAB LIB30 object librarians.

**Emulators** – The latest information on Microchip in-circuit emulators. This includes the MPLAB<sup>®</sup> ICE 2000 and MPLAB<sup>®</sup> ICE 4000.

**In-Circuit Debuggers** – The latest information on Microchip in-circuit debuggers. These include the MPLAB  $^{\mbox{\scriptsize RD}}$  ICD and MPLAB ICD 2.

**MPLAB Development Systems** – The latest information on Microchip MPLAB<sup>®</sup> IDE, the Windows<sup>®</sup> Integrated Development Environment for development systems tools. This list is focused on the MPLAB<sup>®</sup> IDE, MPLAB SIM and MPLAB SIM30 simulators, MPLAB IDE Project Manager and general editing and debugging features.

**Programmers** – The latest information on Microchip device programmers. These include the PRO MATE<sup>®</sup> II device programmer and PICSTART<sup>®</sup> Plus development programmer.

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- Distributor or Representative
- Local Sales Office
- Field Application Engineer (FAE)
- Corporate Applications Engineer (CAE)
- Hotline

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Corporate Applications Engineers (CAEs) may be contacted at (480) 792-7627.

In addition, there is a Systems Information and Upgrade Line. This line provides system users a list of the latest versions of all of Microchip's development systems software products. Plus, this line provides information on how customers can receive any currently available upgrade kits.

The Hotline Numbers are:

1-800-755-2345 for U.S. and most of Canada.

1-480-792-7302 for the rest of the world.



## dsPICDEM™ MC1L 3-PHASE LOW VOLTAGE POWER MODULE

## **Chapter 1. Set Up and Operation**

## 1.1 INTRODUCTION

The dsPICDEM MC1L 3-Phase Low Voltage Power Module is intended to aid the user in the rapid evaluation and development of a wide variety of low voltage DC motor control applications using the dsPIC<sup>®</sup> microcontroller. The design of the system includes several Microchip analog components, as well as a PIC<sup>®</sup> microcontroller used to provide isolated voltage feedback. The main components of the system are shown in Figure 1-1.

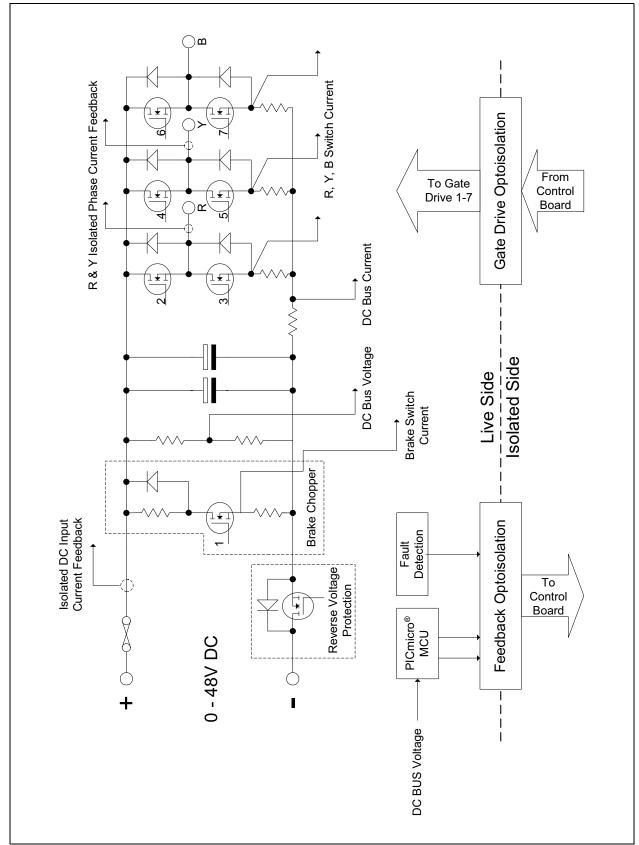
The unit is capable of operating from any voltage up to a maximum of 48V (average) and 58V (peak). It is therefore suitable for use on a very wide range of applications. These include conventional commercial and industrial applications running off up to 48V DC supplies, as well as automotive applications including the new 42V bus standard. Protection is provided for accidental reverse connection of the DC input, as well as for motor and wiring short circuits.

The continuous rated input current is 15A (RMS). The continuous rated output current from the inverter is also 15A (RMS). This results in the maximum output power being linearly related to the input voltage. Approximately 400VA/300W output may be achieved when running from a 24 DC input voltage up to a 30°C (85F) ambient. Thus, the system is ideally suited to running quite large 3-phase brushless DC motors or specialist induction machines wound for operation at low voltage. The power module is capable of driving other types of motors and electrical loads that do not exceed the maximum power limit and are predominantly inductive. Furthermore, single-phase loads can be driven using 1 or 2 of the inverter outputs.

The user should read Section 1.2 "Using The Motor Control 3-Phase Low Power Module" and Section 1.4 "Current and Power Limitations" carefully before using the system.

FIGURE 1-1: POWER MODULE WITH ATTACHED DEVELOPMENT BOARD (SOLD SEPARATELY)







## 1.2 USING THE MOTOR CONTROL 3-PHASE LOW POWER MODULE

## 1.2.1 Introduction

The user should be aware of the operating procedures outlined below and ensure that they are followed. Failure to do so may result in damage to the system.

#### 1.2.2 Making Power Connections

It is recommended that cables be terminated with insulated crimp terminals.

If crimp terminals are not used, care should be taken to ensure that stray strands of wire do not short to adjacent terminals or the enclosure. If possible, all wires should be stripped and tinned with solder before connecting to the power module terminals.

The recommended input and output cable size is 2.5 mm<sup>2</sup> (14 AWG).

Access to the terminal screws is provided via holes in the lid of the enclosure. A flat blade screwdriver should be used.

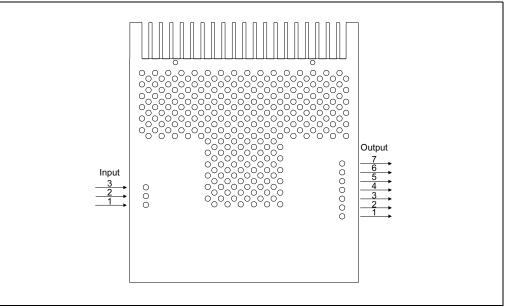
**Note:** The user should only access the power terminals when the system is fully discharged.

The power connections are shown in Table 1-1 and Figure 1-3:

#### TABLE 1-1: POWER CONNECTIONS

Connection Number	Input	Output
1	Ground	Ground
2	-DC	Red Phase
3	+DC (Fused)	Yellow Phase
4	-	Blue Phase
5	-	-DC
6	-	External Brake Resistor
7	_	+DC

#### FIGURE 1-3: POWER CONNECTIONS



Using output connections 6 and 7, the user may connect an external braking resistor. The user should consider the maximum and average power to be dissipated at the required DC bus voltage when considering the resistor value. They should also consider the peak allowable resistor current of 20A. For example, if regulating at 24V then a  $1.2\Omega$  minimum value should be used which would allow 480W (at most) to be dissipated.

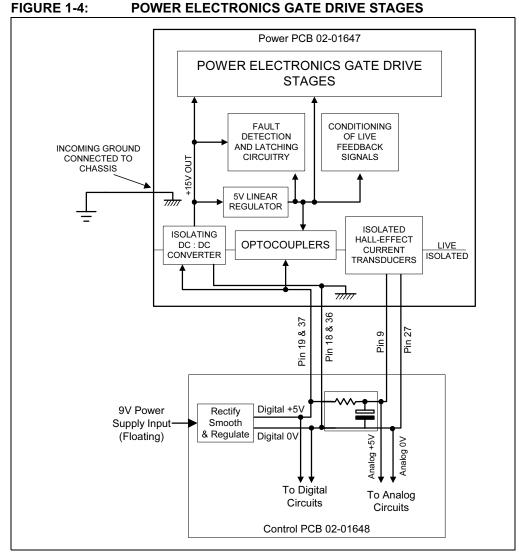
The user may feed in a DC supply using output connections 5 and 7. Using these terminals, the input current rating increases to 20A (RMS) continuous, but the inverter output current rating is unaffected. Thus more output power may be used. Note that if using the auxiliary DC input, the internal fuse, soft-start, reverse voltage and over-current protection is bypassed. It is up to the user to ensure adequate external protection circuitry is used and incoming DC voltage is regulated.

## 1.2.3 Connecting To The Control Board

The system has been designed so that the Microchip dsPICDEM MC1 Motor Control Development Board (02-01648) plugs directly into the 37-pin, D-Type connector. **Section 1.8 "User Signal Connector Pinout (37-Pin, D-Type)"** contains details of the pin allocation.

Correct operation with the use of an extension cable can not be guaranteed as it may introduce additional noise. If an extension is used, it should be as short as possible and shielded cable should be used.

The power module derives its low voltage power supplies from the control PCB. The supplies on the isolated supply are taken directly from the control PCB via the 37-pin connector. The supplies on the live side of the isolation barrier are derived using an isolating DC-DC converter that is connected to the digital +5V supply input on the 37-pin connector. In this way, the power module may be used at any input voltage up to the maximum. This arrangement is shown in Figure 1-4.



Note that the incoming digital 0V from the control card is grounded internally within the power module (as shown in the Figure 1-4) to ensure user safety. When a PC or any other device is connected to the control card there is therefore the possibility of a "ground loop" occurring. If this is suspected, the user should first try to eliminate the stray magnetic field causing the problem by relocating the offending transformer or by using shielding. If this is not possible, then the equipment connected to the control card should be isolated from the digital 0V.

Position and speed feedback transducers are connected to the control board directly and not via the power module. No electrical isolation is provided on the control board for these signals and so the transducers must be isolated.

Consult the dsPICDEM<sup>™</sup> MC1 Motor Control Development Board (DS70098) documentation for details of signal interfacing and how to connect in-circuit emulators and debugging equipment.

## 1.2.4 Power-Up/Power-Down Sequence

The user should ensure that the following sequence, are followed.

#### 1.2.4.1 POWER-UP SEQUENCE

- With the control card plugged in, turn on the power supply feeding the control PCB (if not already on).
- · One or more of the fault lights may illuminate. This is normal.
- Turn on the DC supply to the power module.
- Reset the system by activating the active high ISO\_RESET line. The ISO\_RESET line is on pin 33 of the 37-pin, D-type (see Section 1.8 "User Signal Connector Pinout (37-Pin, D-Type)"). On the dsPICDEM MC1 Motor Control Development Board, this signal is routed to pin 14 of the 30F6010 dsPIC device, which is on Port RE9. The minimum pulse width for the reset is 2 µs. The RESET should be done in coordination with the SPI<sup>™</sup> handling routine of the dsPIC device to ensure correct synchronization of the serial interface providing the isolated voltage feedback (see Section 1.5.7.2 "Isolated Voltage Feedback"). The system is now ready to use.

#### 1.2.4.2 POWER-DOWN SEQUENCE

- Stop firing all power devices.
- Turn off the incoming DC supply.
- Wait until the red DC bus LED indicator visible through the ventilation holes in the top of the unit has gone out. (This will take 5 minutes or less.)
- Turn off the power supply feeding the control card (if required).

## 1.2.5 Modulating The Power Devices

The Brake chopper switch has been designed so that it may be modulated up to a maximum frequency of 16 kHz. This frequency limit is chosen for power dissipation and low voltage power supply consumption reasons. In most braking applications, a lower modulation frequency will be used, as there is little benefit (apart from acoustic noise) from modulating at such a high frequency.

The six inverter switches have been designed so that they may be modulated up to a maximum frequency of 20 kHz. This frequency limit is chosen for power dissipation and low voltage power supply consumption reasons. Unless extremely low output current harmonics or very high bandwidth control is required, it is suggested that a 16 kHz modulation frequency be used. This offers lower loss while still being inaudible. It also has the advantage that the "dead time" will cause less distortion of the output voltage.

Given the high side and low side switches of the inverter are connected in series across the DC bus (see Figure 1-2), both switches should never be turned on at the same time. Turning both switches on effectively places a short circuit across the DC bus and is called "shoot-through". Shoot-through should be avoided at all costs. In order to avoid shoot-through, an appropriate time delay must be inserted between the turn off command to one device and the turn on command to the other device of the same inverter leg. This time is called the "dead time". The required dead time depends on the switching speeds of the power devices and the timing delays due to the optocouplers and the gate drive circuits. No hardware dead time is included in the design as it is included as a feature of the Motor Control PWM module of the dsPIC device. A minimum dead time of 2  $\mu$ s should be used. This applies to both turn on and turn off of both devices. Writing to the appropriate registers in the dsPIC (DTCON1 and DTCON2) sets the dead time. Refer to the *dsPIC30F Family Reference Manual* (DS70046) for details.

Although not necessary for correct operation of the system, it is common practice to eliminate very narrow firing commands. This is because they will have negligible effect on the output waveform but incur additional switching loss. It is suggested that a duty cycle that gives transistor on or off times of less than 100 ns be eliminated by rounding the duty cycle up or down as appropriate. Note that pulses, which are narrower than the dead time set in the Motor Control PWM module, are automatically eliminated.

**Note:** The user should verify that all modulation frequencies and dead time settings are correct using an oscilloscope before connecting the control PCB to the power module.

In order to provide an economic design, so-called bootstrap power supplies are used for the high side inverter switches (see **Section Section 1.5.3.3 "Gate Drive"** for details). As the charging path for these is only made when the corresponding low side switch or diode conducts, this places some minor restrictions on modulation. These are as follows:

- When the power module is first energized after a period of time where no modulation has taken place, all low side switches should be turned on for 2-3 μs. This ensures the bootstrap supplies are "primed". This can be done simply by using the output override facility in the dsPIC Motor Control PWM module by setting the correct bits in the OVDCON register. Care should be taken to ensure a shoot-through does not accidentally occur. The possibility of a shoot-through fault will be minimized if the dsPIC Motor Control PWM module is operated in the complementary Output mode (module default).
- 2. If the user is continuously modulating all the low side switches as part of their PWM strategy, the "priming" step is not strictly necessary, as it will happen automatically. There will however, be a delay of variable duration before the high side switches actually fire. The delay will depend on the particular operating circumstances and whether it is acceptable or not will depend on the particular application.
- 3. In extreme circumstances, it is possible that the high side bootstrap supply will discharge while the system is running. This will not happen for typical sinusoidal modulation schemes provided an inductive load (e.g., a motor) is connected. If a bootstrap supply collapses, an under-voltage lockout will automatically occur to protect the high side switch entering the linear region of operation. The high side switch is turned off whatever the command. The lockout is automatically cleared when the bootstrap supply is restored and the next turn-on edge occurs. If necessary, the user should periodically apply a refresh pulse to the low side switch in a similar manner to that described for "priming".

## 1.2.6 Power Module Feedback Signals

## 1.2.6.1 INTRODUCTION

The power module may be operated in two distinct ways with respect to signal isolation. This effects which of the feedback signals are available. All feedback signals are preconditioned and scaled within the power module. Which particular set of feedback signals the user requires will change depending on the application. Typically industrial applications tend to use isolated signals for both safety, noise and performance reasons. More cost-sensitive applications, and especially those that have little or no user input, tend to run the control electronics live and use non-isolated feedback signals. High current applications may use isolated Hall effect current transducers, due to issues of power dissipation in shunt resistors.

## 1.2.6.2 ISOLATED FEEDBACK

Table 1-2 gives the scaling of the isolated feedback signals as the system is delivered.

#### TABLE 1-2: ISOLATED SCALING

Feedback Signal	Scaling
Inverter Output (R and Y) Hall Current Sensor	12 A / V with 2.5V = 0A
DC Input Hall Current Sensor	12 A / V with 2.5V = 0A
DC Bus Voltage via SPI™ Channel	230 = 58.7V (1LSB = 0.255V)

#### 1.2.6.3 NON-ISOLATED FEEDBACK

As the system is delivered, access is not given to the non-isolated feedback signals to ensure user safety. If an experienced user wishes to access these signals, they should read Section 1.5 "Detailed Description of Operation" along with Section 1.6.3.4 "Accessing The Additional (non-isolated) Feedback Signals". Note that once the isolation barrier is bridged, all signals can no longer be considered to be isolated from the power circuit. When operating in the non-isolated configuration, the Hall current sensors and SPI voltage feedback signals are also available.

The scaling for the signals as the system is delivered is given below. For details of changing the scaling, see **Section 1.6.3** "**Changing Current Feedback and Trip Scaling**".

#### TABLE 1-3: NON-ISOLATED SCALING

Feedback Signal	Scaling
R, Y, B Inverter Leg Shunts	12.0 A/V with 2.5V = 0A*
DC Bus Shunt	11.9 A/V with 2.5V = 0A*
Brake Chopper Shunt	5.45 A/V
DC Bus Voltage	13.05 V/V
R. Y, B Inverter Output Voltages	13.05 V/V

\* If a large rate of change of current occurs due to the use of a load with low inductance, the voltage across the self-inductance of the shunts will cause an additional shunt voltage that will add to the shunt feedback signals.

## 1.2.7 FAULT Protection

The following FAULT protection is provided which automatically disables all firing independent of firing commands.

## TABLE 1-4:FAULT PROTECTION

Fault Source	Nominal Trip Level	LED Indicator	
R, Y, B Bottom Switch Current	±24.0A*	Shunt Overeurrent	
DC Bus Current	±23.9A*	Shunt Overcurrent	
DC Bus Voltage	58.7V	Over Voltage	
Brake Switch Current	+24.5A	Brake Overcurrent	
Heat sink Over Temperature	65°C (150F)	Over Temperature	
Isolated DC Input Current Feedback	+22.2A	Hall Overcurrent	
R, Y Isolated Phase Current Feedback	±22.2A		

\* If a large rate of change of current occurs due to the use of a load with low inductance, then the voltage across the self-inductance of the shunts will cause trips to occur at a lower level than that stated.

Reset of a FAULT is done by asserting the ISO\_RESET line of the 37-pin connector. This should be done for a minimum time of 2  $\mu$ s. The RESET must be carried out in coordination with the SPI handling routine of the dsPIC device to ensure correct synchronization of the serial interface providing the isolated voltage feedback (see **Section 1.5.7.2 "Isolated Voltage Feedback"**).

Note:	If SHUNT OVERCURRENT trips are occurring, but not HALL
	OVERCURRENT trips, this may indicate that an inverter shoot-through is
	occurring. The user should immediately remove AC power from the system
	and check that the correct 2 $\mu$ s dead time exists on the inverter firing signals
	using an oscilloscope.

Note that the fault levels are set to represent abnormal operation. Operation of the system just beneath the trip levels may be beyond the thermal capability of the system. See **Section 1.4 "Current and Power Limitations"** for details.

## 1.2.8 Operation at Low Output Frequencies and Stall

As far as the inverter power devices are concerned, it is the instantaneous temperatures of their junctions that matter for correct operation and reliability. As the current that flows through a particular power device changes through an electrical cycle, so does the loss. At high fundamental output frequencies (e.g., 60 Hz), the devices have sufficient thermal "mass" to smooth out much of the effect of the variation in loss, so that the peak device junction is due to the (much lower) average dissipation. As the output frequency reduces, the peak device junction temperature reaches the worst case loss.

It is common practice to include a stall detection algorithm in software. This is designed to not only protect the power components, but also the motor from thermal overload. As it is impractical to include stall detection in hardware that maintains flexibility for development but still provides 100% protection, it is assumed that the software in the dsPIC device provides this feature. The algorithm should monitor rotor speed and cause a system trip if the rotor speed is at or near zero for greater than an appropriate length of time while the inverter is energized. A stall trip time of 2 seconds is suggested.

## 1.2.9 Field Weakening

If the user is operating a brushless permanent magnet motor using field weakening by employing phase advance, great care should be taken. If a FAULT trip occurs, firing will stop, and the full back EMF magnitude, due to the motor's speed, will be present on the output terminals. Should the peak of the back EMF be above the DC bus, sudden uncontrolled motor braking will occur. The DC bus will rise in an uncontrolled manner possibly causing damage to the power devices, DC bus capacitors and the DC input supply. A speed greater than that which would produce a peak back EMF of greater than 63V, with no field weakening, should not be used. This will protect the power module, but the user should check the rating of their DC supply.

The same care should be taken with separately excited brushed DC motors if employing field weakening at high speed. If the field current were to be increased in error, a similar braking phenomenon will occur if the back EMF rises above the DC bus. The effect is likely to be less severe as a DC over-voltage will occur tripping out both the armature and field supply (assuming the field is not supplied separately). For this reason, if using a separately excited DC motor, it is recommended that both the field and the armature are supplied from the unit.

## 1.3 DC POWER SUPPLY REQUIREMENTS

The user's DC power supply must be electrically isolated from the AC supply. The -DC bus is connected to ground internally within the power module. This ensures that the DC supply has a fixed potential with respect to ground rather than floating.

Typical DC power supplies are configured to only source current. If using such a power supply when generating/braking, the brake chopper should be used to dissipate the returned energy. The regulation voltage for the brake chopper will be slightly above the DC power supply. This ensures that when braking occurs there is a seamless transition between power being drawn from the supply and power being dissipated by the brake chopper. The user should check that damage will not occur to the DC power supply when this higher voltage is present on its output. If this is of concern, then the user should fit a series diode of suitable current and voltage rating between the DC supply and the DC input to the system. Clearly, if a battery supply is used, energy can be returned to it by recharging. However, the user should ensure that maximum recharge rates are not exceeded and that suitable ventilation is used.

## 1.4 CURRENT AND POWER LIMITATIONS

## 1.4.1 Introduction

The maximum power and current capability of the system is dictated by the allowable temperature rise of the different components. Establishing maximum limits is not simple given the host of different ways the user may use the system. The voltage and the nature of the electrical load used both affects the dissipation that occurs. In determining the allowable limits for the power semiconductors, the following assumptions have been made:

- Heat sink is at 70°C (worst case over temperature trip point)
- Thermal resistance of the insulating thermal pad is 4°C/W

Note that the maximum output power of the system will always be the lower value due to the DC input stage or the inverter output stage.

## 1.4.2 Inverter Output Current Limits

The inverter is capable of providing the full rated output of 15A (RMS) within the entire operating range (voltage, temperature and at up to 20 kHz modulation frequency) of the system. This includes being continuously stalled at such an electrical angle that one of the motor phases is at the peak of the rated output (21A) at just less than 100% duty cycle. This is a condition that causes high thermal loading because one of the inverter switches has the peak worst case conduction and switching loss continuously. Note that as far as the power devices are concerned, operation at output frequencies of less than approximately 10 Hz are equivalent to stall as far as peak device temperature is concerned because of low thermal capacitance.

In a practical application, this condition of low output frequency/stall and high duty cycle is unlikely to happen. With a motor correctly matched to the DC bus voltage, the switch duty cycle at stall will be approximately 50% thus significantly reducing the conduction loss in a particular switch. The complementary diode of the inverter phase will also conduct for approximately 50% thus spreading the conduction loss between two different power device packages. This in turn leads to a substantial reduction in device temperature.

As the maximum output current is fixed, the maximum possible output power is linearly related to the DC input voltage.

## 1.4.3 DC Input Current Limits

The continuous rated input current is limited to 15A RMS by the allowable temperature rise of the tracking on the PCB. Short term (10s duration with a low duty cycle) overloads to 20A RMS are permitted. The overload is limited by the reverse voltage protection MOSFET dissipation and the PCB tracking.

## 1.4.4 Brake Chopper Output Current Limits

The brake chopper switch and diode are capable of providing the full rated output of 20A (peak) within the entire operating range (voltage, temperature and at up to 16 kHz modulation frequency) of the system provided the load is predominantly resistive. If the brake chopper is being used to control a load that is predominantly inductive, the rated output must be reduced to 10A (peak) in order to protect the diode from thermal overload. This is because the current may be continuous with an inductive load, which will significantly increase the proportion of the current that flows through the diode.

The user should note that the over current trip levels are set above the peak of the rated output. This is to prevent nuisance trips. The user should avoid operating the system beyond the peak outputs of 20A (resistive load) or 10A (inductive load) continuously. Operation of the system just beneath the over-current trip of 24.5A may affect long term reliability of the brake chopper switch and diode and should be avoided. The value of the brake chopper resistor should be chosen to ensure no more than 20A can flow, even at the peak DC bus voltage.

## 1.5 DETAILED DESCRIPTION OF OPERATION

## 1.5.1 Input Stage (Appendix A Sheet 1)

The input stage of the board consists of the following components:

- F1 1.25" x 0.25" 125 VDC 15A High Rupture Current Fuse Note: only replace with part of the same rating.
- C9, C10 Film capacitors to aid in the suppression of supply borne transients and to also provide a low impedance return path for any currents that flows from the power device tabs to the heat-sink and enclosure due to capacitive coupling.
- V1 A metal oxide varistor located across the incoming supply lines to suppress high energy transients.

## 1.5.2 Input Power Stage (Appendix A Sheet 1)

## 1.5.2.1 SOFT-START PROTECTION

As is normal for a low voltage system, soft-start protection is not provided within the unit. The NTC (NTC1) on the PCB is replaced by a wire link. When using a current-limiting DC power supply, this will cause no problem as the inrush of current on application of DC power, due to the DC bus capacitors, will be controlled. If using a substantial battery supply, the user may need to provide some form of soft-start to prevent the fuse blowing on power-up. If fitting a device to NTC1 on the PCB, the user should carefully monitor the temperature of the PCB around it.

## 1.5.2.2 REVERSE VOLTAGE PROTECTION

In order to protect the unit from accidental reversal of the input voltage, a circuit has been included which blocks the reverse voltage. Although a series diode could have been used, this would have incurred a very significant amount of loss during normal running. The circuit used is described below:

- Q9 A 75V 13 mΩ (cold) MOSFET of the same type used for the inverter. During normal operation (correct polarity of input voltage), the MOSFET is turned on with current flowing from source to drain. The voltage drop will be due to the resistance of the MOSFET, rather than that of a diode. When reverse polarity is applied, Q9 is turned off and blocks the reverse voltage.
- D32, R6 and R58 The gate drive components for Q9. During normal operation, Q9 is turned on via R6 with D32 limiting the gate source voltage to 15V. On application of reverse voltage, Q9 turns off with R59 being a gate source pull-down.

## 1.5.3 Phase Inverter (Appendix A Sheet 2)

## 1.5.3.1 INTRODUCTION

The 3-phase inverter has three identical circuits, shown as R (RED), Y (YELLOW) and B (BLUE). These are often referred to as inverter "legs". They invert the DC bus to a variable AC output waveform by appropriate modulation of the switches. When a star or delta connected three-phase motor is used, the electrical symmetry can be exploited to provide bi-directional current and voltage with just three such legs. In this way, both motoring and generating/braking operation can be used in either direction of rotation, commonly called "4 Quadrant" control.

There is no reason why the user can not use two of the legs in an "H-bridge" configuration for control of DC motors or other single-phase applications requiring bi-directional current and voltage. Even a single leg could be used with just the low side switch controlled for a simple unidirectional current application (e.g., field control of a separately excited DC motor).

The detailed description of one "leg" (RED phase) is given below. The other legs are identical in function.

- 1.5.3.2 POWER DEVICES
- Q3, Q4 75V N-Channel MOSFET transistors packaged in the industry standard TO220. As the tabs of the devices are not isolated, a thermally conductive insulator is used. Note that the internal parasitic body diodes of the MOSFETs are used as the inverter freewheeling diodes.
- The tracking between the devices and to the DC bus is designed to minimize the inductance that causes transient over/undershoots.
- R4 A 3W 5 mW shunt resistor through which the low side switch and diode returns to the -DC bus. The shunt is used for FAULT protection and (optionally) for an alternative feedback signal - see Section 1.2.7 "FAULT Protection" and Section 1.5.6 "Shunt Feedback (Appendix A Sheet 3)".

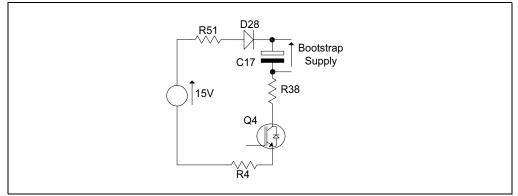
## 1.5.3.3 GATE DRIVE

U22 – An integrated high voltage IC (IR 2112) which provides gate control of a low side and a high side power transistor. As the source of the high side device (Q3) can be at any potential between -DC and +DC, and even beyond transiently, internal circuitry must provide for the necessary level shifting to ensure correct operation. The IR2112 does this without providing isolation. The 2112 also monitors the low and high side power supplies and shuts down if an under voltage is detected. The under-voltage lockout is automatically reset by a rising edge of a firing command once a valid voltage is present. See www.irf.com for a full data sheet.

The function of groups of the discrete gate drive components is explained below:

 R51, D28, C14, C17 – These components form a floating power supply for the high side gate driving stage of U22. Whenever the low side MOSFET (Q4) or it's anti-parallel diode is conducting, a charging path for C14 and C17 is formed. This is because the 15V supply is referenced to the -DC bus and D28 conducts. When the high side switch is on, and the low side switch is therefore off, D28 blocks reverse current flow that would result from the bus voltage present on the inverter output. This kind of floating supply is usually referred to as a "bootstrap". This circuit is commonly used because it is both efficient and economical. It is assumed that any bootstrap initial priming or any necessary refresh is carried out in software by the dsPIC device. This is discussed in Section 1.2.5 "Modulating The Power Devices".

## FIGURE 1-5: BOOTSTRAP SUPPLY



- R33, D21, R39 and R38 These components aid in the correct control of the gate of the high side power device. The same circuit is repeated for the low side switch using R54, D27, R57 and R58. Generally speaking, the larger value of gate resistance used, the slower the device switches. Slower switching reduces over/undershoots and consequently EMI, but increases switching loss and hence device junction temperature. Turning the device on uses R39 and R38. Turning the device off uses D21+R33 in parallel with R39 and R38. In this way, different turn on and turn off resistance can be used to optimize switching performance.
- D31 This is a high voltage clamping diode located directly adjacent to the IC. It is necessary to ensure correct operation of the IC during extreme transients that can occur during a FAULT. In combination with R38 and R53, it ensures Pin 6 of U22 never goes more than 5V negative with respect to Pin 2.
- R27 and R26 These resistors form a passive Gate Source pull-down to ensure the MOSFETs stay off if the low voltage power supplies are not present.

## 1.5.4 Brake Chopper (Appendix A Sheet 1)

Clearly, if the motor is used as a brake or generator, any average power that flows back from the inverter must have somewhere to go. As most DC supplies, with the exception of batteries, will not sink current, a circuit for dissipating excess returned power is provided. The most common form of brake chopper has been implemented and is described below:

- Q10 A 75V N-Channel MOSFET transistor of the same type as used for the inverter. Apart from acoustic noise reasons, there is no reason to modulate the device at high frequency. As the tab of the device is not isolated, a thermally conductive insulator is used.
- D3 A 8A 200V diode required to freewheel the current around the resistor due to it's inductance. As the tab of the device is not isolated, a thermally conductive insulator is used.
- R9 A 3W 5 mW shunt resistor through which the low side switch and diode returns to the -DC bus. The shunt is used for FAULT protection and (optionally) for an alternative feedback signal - see Section 1.2.7 "FAULT Protection" and Section 1.5.6 "Shunt Feedback (Appendix A Sheet 3)".
- U23 Microchip TC1412N gate drive IC. This contains a low resistance complementary push-pull MOSFET pair and input circuitry suitable for interfacing to a wide range of input voltages. It has a small footprint allowing it to be located physically close to the transistor, allowing a low inductance gate circuit layout. Note that the full current drive capability of the TC1412N is not necessarily required, as high frequency modulation is not essential for a brake chopper. A less expensive TC1410N or TC1411N could be used.

- R60, R62, R67, Q12, C24, C28 These components act to provide a dynamic level shifting circuit to U23 while Q10 switches. Inductance of the power tracking between the source of Q10 due to the physical board layout means there is a substantial transient voltage (up to 2V in this case) between the +15V supply star point reference and the source of Q10. This simple low cost circuit allows the power supply of U23 to move transiently. Q12 provides a level shift to ensure correct assertion of the firing command. In applications with fewer constraints on physical layout and/or lower switching speed requirements, these components may not be needed.
- Brake Resistor A 50W metal clad 75W resistor mounted to the heat sink is connected to pads J7 and J8. The value of the resistor has been chosen to allow a maximum dissipation of 45W. If the user wishes to be able to dissipate more power, then an external resistor can be connected to pins 6 and 7 of the 7-pin output connector. This will operate in parallel with the internal resistor. If the user wishes to change the value of the internal resistor or disconnect it, they should read Section 1.6.3.2 "Modifying or Removing the Internal Braking Resistor".

## 1.5.5 Isolated Current Feedback (Appendix A Sheets 1 and 2)

In order to provide isolated current feedback, Hall effect closed loop DC current transducers (LEM LTS 15-NP) devices have been installed. These devices have the following characteristics:

- Single 5V supply with 2.5V (nominal) representing 0A
- Bipolar current sensing with ±48A given by 4.5V and 0.5V respectively with a single turn through the transducer.
- >200 kHz bandwidth
- 3 kV AC isolation

A detailed device data sheet can be obtained from www.lem.com.

Two such devices (U3 and U4) are installed in series with the output connections of phases R and Y. These are configured to have 2 turns through the device with LK 14 and 17 installed. This gives a maximum sensed current of  $\pm$ 24A and a gain of 12A/V. Note that a third device is not required, as the sum of the output line currents must always be zero due to symmetry. The one exception to this is during a FAULT condition that is detected elsewhere.

The third device (U2) is on the positive DC input of wire of the input power stage (see Figure 1-1). This device is configured to have 2 turns through it as delivered with LK2 installed. This gives a maximum sensed current of 24A and a gain of 12A/V. U2 is used to provide input over current protection, as well as feedback of the DC input current.

## 1.5.6 Shunt Feedback (Appendix A Sheet 3)

#### 1.5.6.1 INTRODUCTION

In many applications, the cost of isolated current transducers is prohibitive or the isolation is not required. In these instances, it is common practice to use resistive shunts. The shunts can be placed in series with the output connections, but this inevitably requires the use of level-shifting and the creation of floating power supplies. Therefore, it is more usual to have shunts referenced to the same potential as the low voltage power supplies which is invariably the -DC bus. The disadvantage of using shunts referenced to the low side is that the feedback information is clearly only available during certain portions of the PWM cycle. In order to extract the required information, the shunts must be sampled at precise intervals. This feature has been allowed for in the dsPIC device by the inclusion of sample and hold amplifiers in the ADC module that can be triggered from the PWM module (see the *dsPIC30F Family Reference Manual* for details).

On high voltage low power systems, it may be possible to use shunts of high enough value to have sufficient voltage for direct input to an ADC. More commonly, the dissipation in the shunt dictates the use of low resistance values and appropriate amplification. If too high, the voltage drop across the shunt can also cause problems for driving the power transistors. For low gains, it may be possible to use single ended amplification. Differential amplification is required as the gains increase in order to provide a signal of sufficient quality and accuracy.

The Microchip MCP6022 (dual) and MCP6024 (quad) parts have been used in the design for providing the differential amplification. They are an ideal choice for the following reasons:

- Low power consumption (1 mA typical / amp) this is especially important where the power supplies are derived from the DC bus with a resistor/zener network.
- Low offset voltage (0.5 mV max.).
- · Rail-rail inputs and outputs.
- No gain inversion with negative inputs this is important as it is common for the amplifier to have negative spikes on it's inputs that occur during switching events due to the shunt's inductance. Gain inversion can lead to current control instability and false tripping of protection circuits.
- High gain bandwidth product (10 MHz typical) this is often a more important factor in determining the speed of response than slew rate in this application, due to the requirements to amplify rapidly changing signals of low amplitude.

Note that in applications requiring less gain and/or slower speed of response, the MCP602/604 family offers a good alternative with even lower power supply consumption.

#### 1.5.6.2 INVERTER LEG SHUNT RESISTOR FEEDBACK

A shunt is located between the source of the low side switches (e.g., Q4) and the -DC bus in every leg of the inverter. A simple differential amplifier circuit is used as shown in Appendix A Sheet 3. The operation of the circuit used for the RED phase leg is described below:

- U24-A One quarter of the MC6024 op amp.
- R94, R99 and C34 These provide a small amount of passive differential filtering. This helps to reduce input stage overloading of the op amp that would occur due to spikes of voltage produced by the shunt's self-inductance. Clearly, this has a beneficial effect on the output signal.

- R84, R85, R88 and R89 The resistors form the differential configuration of the amplifier.
- LK5 and LK6 These allow two different gain settings to be used by shorting out R85 and R89. Note that both links must be used together for correct operation.
- LK4 Provision is made for either bipolar or unipolar sensing by changing this link. It changes the non-inverting input reference point between 2.5V and 0V.
   Bipolar sensing is required for applications using sinusoidal modulation, whereas unipolar sensing is sufficient for other applications.

#### Other points to note:

- No common mode filtering has been used, as the amplifier's inherent common mode rejection is sufficient and it requires tight tolerance components to be effective.
- Note that the output of the op amp is not glitch-free during switching transitions, but tracks the current rapidly. It is assumed that suitable synchronization of the sampling of the output is used to reject the glitches.
- The self-inductance of the shunts (approx. 10nH) causes an additional voltage to be produced proportional to the rate of change of current. For typical motors, this additional voltage is negligible, as the inductance is high enough to ensure a low rate of change of current. If a low inductance load is used, the effect of the additional voltage will have to be compensated for in the user's software.

#### 1.5.6.3 DC BUS SHUNT RESISTOR FEEDBACK

In addition to the three inverter leg shunts, provision has been made to monitor the current in the -DC bus. In many applications, the information contained in this signal alone is sufficient to provide the required closed loop control. The operating range and the quality of control will dictate whether a bus shunt alone can be used. Clearly, it is the cheapest of all schemes to implement.

The current that the shunt has flowing in it at any given time depends on the state of all three inverter legs. It should be recalled that having both switches in the same leg on at the same time is not allowed. The top switch being off (Top Fire = 0) assumes a bottom switch is on. It does not matter whether the current actually flows in the switch or the anti-parallel diode. The result depends only on the magnitude and direction of the output currents.

Fire R Top	Phase Y Top	Phase B Top	DC Bus Shunt
0	0	0	0
0	0	1	+IB
0	1	0	+IY
0	1	1	-IR
1	0	0	+IR
1	0	1	-IY
1	1	0	-IB
1	1	1	0

TABLE 1-5: DC BUS SHUNT RESISTOR FEEDBACK

From Table 1-5 it is clear that bipolar sensing requires with the same scaling as that used for the inverter leg shunts. It can be seen that for the 000 and 111 conditions (which corresponds to zero output phase voltage), no information is available. This can cause considerable problems if operation at low output voltages is required when using sinusoidal modulation.

Instead of actually physically implementing the bus shunt, in this instance, the signal has been derived as the sum of the three inverter leg shunts. In this way, power circuit layout was not compromised. In a commercial application, it is normal to implement all three leg shunts or the bus shunt rather than both schemes. The summing amplifier circuit used can be seen on Sheet 3 in Appendix A.

## 1.5.6.4 BRAKE SHUNT RESISTOR FEEDBACK

Knowledge of the brake resistor current magnitude is not required for control of the DC bus voltage with a brake chopper. Only feedback of the DC bus magnitude is required. Knowledge of the brake resistor value and the applied PWM can be used to determine peak and average current flowing for thermal protection of both the resistor and the power devices. However, knowledge of the brake chopper current is useful for protection of the switch should a wiring fault occur or the resistor fail. Although a fuse could be used, it is often difficult to design and expensive, requiring very fast acting types. In this instance, instead of a fuse, the switch current is monitored by a shunt between the source and the -DC bus in exactly the same way as used for the inverter. This is used for an over-current trip and is also made available as an optional feedback signal. Thus, the brake chopper can also be used as either an open or closed loop, low-side chopper for single quadrant applications. The differential amplifier circuit is shown on Sheet 3 of Appendix A. See **Section 1.5.6.1** "Introduction" for a more detailed explanation.

## 1.5.7 Voltage Feedback (Appendix A Sheets 1, 6 and 7)

## 1.5.7.1 INTRODUCTION

Provision has been made for three different types of voltage feedback:

- DC bus voltage feedback This is required for regulation via the brake chopper. It
  is also used to compensate for variations in the inverter output voltages that occur
  due to any ripple on the DC bus and as a FAULT trip.
- Inverter output voltage feedback As well as providing the feedback signal, a comparator circuit is included for sensorless operation.

The first of these signals is available as an isolated signal whereas the inverter output voltages are only available when the system is used in the non-isolated manner (see Section 1.2.6.3 "Non-isolated Feedback" and Section 1.6.3.4 "Accessing The Additional (non-isolated) Feedback Signals").

## 1.5.7.2 ISOLATED VOLTAGE FEEDBACK

There are many different ways that the isolated voltage feedback signals could be provided. Clearly, the DC level must be correctly maintained while still giving sufficient bandwidth. There was also an additional requirement for a second higher bandwidth isolated feedback signal. This is due to the high voltage version of the unit that uses the same PCB. All the above requirements can be met by the use of an inexpensive PIC<sup>®</sup> microcontroller, along with two additional low current optocouplers.

In this case, an 8-pin PIC12C671 PIC microcontroller was chosen, as it had the necessary ADC on-board and was low cost. Full advantage could be taken of the on-board 4 MHz RC clock. Three different methods for representing the magnitude of the two signals (only one required for this version of the system) were considered. In all cases, only two optocouplers were required.

- A serial communication interface A simplified two-wire SPI (Clock and Data Out). It would operate as a master with the dsPIC device as the slave. Given the PIC12C671 does not have a hardware SPI module, the interface would be reproduced in software. The code latency was to be used for ADC acquisition and conversion timing. This was the method chosen and the code is given in Appendix B along with a diagram showing the transmission data cycle. Note that the code is the same as that used for the high voltage version of the power module and so transmits a second feedback signal that will read '0'.
- Pulse width modulation at constant frequency This was rejected partly due to concerns over distortion of the pulse width by economic optocouplers. Also, it was thought that it would not be possible to provide the required bandwidth, while maintaining the 8-bit resolution of the captured data, given the lack of a hardware PWM module.
- Frequency modulation This was considered given pulse distortion by the optocouplers ceased to be an issue. However, concerns about how the bandwidth of the feedback could be maintained over the 8-bit data range led to its rejection.

The actual hardware is described below:

- <u>U34</u> The PIC12C671. Note that the PIC microcontroller is reset whenever the RESET line is asserted, as this pin has been configured as the MCLR. This allows correct synchronization of the SPI with the dsPIC device to be established. The RESET line must be asserted for a minimum pulse width of 2 μs.
- R122 The bottom resistor in the |VAC| pot down chain used on the high voltage version of the power module. This is left in to ensure the ADC input is not floating.
- C43 The filtering capacitor for the |VAC| pot down chain, which is left in, although not required.
- R10, R13, R14, R140, R141 These form a potential divider so that the maximum expected voltage on BUS\_SENSE is 4.5V. Note that HALF\_BUS\_SENSE is used by the sensorless position detection comparators (see Section 1.5.7.3 "Inverter Output Voltage Feedback and Sensorless Detection").
- C57 this acts to filter out any noise spikes on the DC bus voltage sensing.
- D40, D42 clamping diodes to protect the PIC microcontroller inputs.
- U16, U17 low current (1.6 mA), medium speed (1 MHz) optocouplers to provide the isolation for the clock and data lines.
- R149, R150 series resistors that help to set the current through the optocoupler emitters. They are sized to allow a minimum of 1.8 mA to flow.
- C64, C70 speed up capacitors to help reduce the effect of the optocoupler's emitter capacitance at high data rates.
- R170, R171 pull-up resistors for the open collector outputs of U16 and U17.

## 1.5.7.3 INVERTER OUTPUT VOLTAGE FEEDBACK AND SENSORLESS DETECTION

Knowledge of the actual inverter output voltage is useful for two different uses. The first is for accurately compensating for output voltage errors due to dead time and power device voltage drops. This can be especially important for high current low voltage systems with high PWM frequencies and high performance requirements. The second use is for back EMF sensing for sensorless position detection schemes for Brushless Permanent Magnet (BPM) and other types of motors.

The hardware for providing this is now discussed with reference to the RED phase. The other two phases have identical circuits.

- R20, R21 and R144 A resistor divider chain with scaling, the same as the DC voltage feedback. The same scaling is required in order that the "back EMF crossing" detection works correctly. The scaling is such that the maximum expected output voltage will give 4.5V.
- C61 This provides filtering of the inverter output voltage in combination with R20, R21 and R144.
- D41 This provides a clamp to ensure R\_VPH\_SENSE is protected.
- U31-B A comparator used to provide a simple sensorless position detection scheme for BPM motors. Whenever R\_PH crosses half the DC bus voltage, an output transition will occur. The R\_CROSSING signal is only valid during regions of the electrical cycle, where the RED phase output current is zero, so that the back EMF of the motor determines the voltage of R\_VPH. Thus the scheme is only suitable for use on BPM motors where 120 degree conduction scheme is used. Careful decoding of all three crossing signals and appropriate angle interpolation is required for correct commutation. An alternative method for commutation feedback must be used near zero speed where the back EMF is insufficient for the scheme to work.
- R143, R147 these provide a small amount of hysteresis to prevent oscillation of R\_CROSSING.
- R142 the pull-up resistor for the open-collector output of the comparator.

## 1.5.8 Firing Signal Isolation and Low Voltage Power Supplies

## 1.5.8.1 INTRODUCTION

The choice of isolation strategy and how the low voltage power supplies are to be derived are two of the major decisions that determine the architecture of a motor drive controller. For this design, the requirement was for flexibility while maintaining user safety. It was essential that the system could work off a wide range of input voltages. Although the system only operates off comparatively low voltages, fault currents can be very high. Furthermore, given the common PCB with the high voltage version of the system, a similar isolation strategy was used.

## 1.5.8.2 FIRING SIGNAL ISOLATION (APPENDIX A SHEET 5)

Either optical or transformer-based isolation strategies can be used for transmitting gate firing commands. For this design, it was decided to use optocouplers as it was possible that a particular firing command may be used for commutation as opposed to high frequency modulation. This could lead to transformer saturation at low speeds. The hardware implemented is described below:

- U6-U13 6N136 optocouplers. These parts were chosen to provide good noise immunity, while requiring low current consumption on the output side. Speed was also a consideration, so that too much delay or pulse distortion was not introduced.
- R153-R160 pull-up resistors for the open collector outputs of the optocouplers.
- R162-169 series resistors to ensure at least 18 mA flows through the emitter stage of the optocouplers. Note that the ground return is via a transistor (Q15) that allows shutdown during detection of an over-current from one of the isolated Hall effect current transducers.
- U32 and U33 Schmitt-triggered inverters which clean up the edges from the outputs of the optocouplers.

## 1.5.8.3 LOW VOLTAGE POWER SUPPLIES (APPENDIX A SHEET 5 AND 8)

The requirement for operation over a wide range of input voltages resulted in using the +5V supply coming from the control board as the power source for all the low voltage power supplies. This was true for both the isolated and live sides of the system. The power supply circuitry on the live side is described below:

- U18 An isolating 1W unregulated DC-DC converter with 5V input and 15V (nominal) output. The +15V supply is used for the gate drive of the power devices and the comparators on the live side of the isolation barrier.
- L4 and C83 A filter to reduce the reflected ripple on the +5V supply from the control board caused by the DC-DC converter.
- L3 and C77 A filter to reduce the magnitude of the ripple on the live +15V supply.
- U5 A 5V linear regulator for the live control circuit supplies.
- D4 A 1A diode to protect U5 against reverse bias during power-down.
- R61 A 0R resistor linking the low voltage power supply star point to the -DC bus.

## 1.5.9 FAULT Protection (Appendix A Sheets 4, 5 and 6)

#### 1.5.9.1 INTRODUCTION

Given the development nature of the system, robust independent FAULT protection is provided on the power board rather than relying on software intervention. Five different fault categories are used to indicate a FAULT to the user. Four of the fault categories are detected on the live side. All FAULTs are latched and automatically disable all firing commands. In a commercial application using the dsPIC device, much of the hardware described below may be eliminated. In particular, the latches are not required as the Output Compare and Motor Control PWM modules both have dedicated fault inputs that can be configured to shutdown PWM outputs to their inactive state.

The operation of the fault action is described below:

- D35-D38 and R114 These form an active high wire OR of all four (live) FAULT signals. R114 provides a passive pull-down during normal operation. The resulting FAULT signal is used to directly shutdown the inverter gate drive ICs via their shutdown logic input.
- R113, Q13, R110, D34, and Q14 These components act to shutdown the brake chopper during a FAULT. Q14 must be on for the detector stage of their optocouplers to be powered. Under normal conditions, D34 and R110 provide the base current for Q14. If the FAULT line is asserted, causing Q13 to turn on, or if the +15V supply drops below approximately 10V, then Q14 turns off.
- U15 and R151 If FAULT is asserted, current flows via R151 to cause the (open-collector) output of U15 to turn on. This indicates back to the isolated side that a FAULT has occurred on the live side.
- R176 and Q15 If a Hall over-current is detected on the isolated side, the base current for Q15 that normally flows via R176 is removed. As all the firing command optocoupler emitters return via Q15, when Q15 is off, no firing can take place.
- D43, D44 and R172 These form an active low wire OR of the isolated and live fault indications for feedback to the dsPIC device.

#### 1.5.9.2 INVERTER SHUNT OVER-CURRENT

The feedback signals from the inverter leg shunts and the bus current signal derived from them (see Section 1.5.6.2 "Inverter Leg Shunt Resistor Feedback" and Section 1.5.6.3 "DC Bus Shunt Resistor Feedback"), are used to detect over current trips. Note that the shunts will see "shoot-through" events which bypass the Hall current sensors. The circuitry used to implement this is described below:

- U25 A quad package comparator used for the over current threshold comparisons. Each comparator has a small amount of hysteresis (formed by R119 and R120 for example) to ensure no output chattering occurs. Note that the inverter leg shunts are compared for positive current, which is when the current is flowing in a switch. The bus shunt is compared for a negative value to protect against faults during braking/generating. R109 forms the pull-up for the open collector outputs of U25. A small amount of filtering is used (e.g., R118, C45) to prevent spikes on the shunt signals causing false trips.
- U27-B A remaining op amp package used to generate the HIGH\_REF (+4.5V) from the Microchip MCP1525 2v5 reference.
- U26 (A and B) Two, two-input NAND gates configured as a SET dominant SR flip-flop. The SET dominance is important to ensure correct fault action even if the RESET input is active.
- D5, R202 An LED and its associated current limiting resistor for the visual indication of the FAULT.

#### 1.5.9.3 DC BUS OVER-VOLTAGE

The feedback signal derived for the DC bus voltage (see Section 1.5.7 "Voltage Feedback (Appendix A Sheets 1, 6 and 7)" is used to detect an over-voltage condition. The threshold is set at approximately 59V in order to protect the power devices and the DC bus capacitors. A similar circuit as described in Section 1.5.9.2 "Inverter Shunt Over-current" is used.

#### 1.5.9.4 BRAKE OVER-CURRENT

The feedback signal derived from the brake chopper shunt is used to detect an over-current. The threshold is set at 24.5 A. The circuitry used to implement the trip is similar to that described in **Section 1.5.9.2** "**Inverter Shunt Over-current**".

#### 1.5.9.5 HEAT SINK OVER-TEMPERATURE

To protect the power devices from thermal overload, a heat sink temperature trip is included. The trip temperature is set at nominal value of 65°C (150F). The circuitry used to implement this is described below:

- U1 A Microchip TC622EAT temperature trip IC. This IC only requires an external resistor (R34) to set the nominal trip temperature. As the version chosen is packaged in a TO220, this is easily mounted along with the other power devices to the heat sink. This ensures excellent thermal coupling. As the tab of the device is not isolated, a thermally conductive insulator is used.
- R116 and C42 These filter the output of U1 to prevent false tripping due to noise.
- Latching and indication is identical to that described in **Section 1.5.9.2 "Inverter Shunt Over-current"**.

#### 1.5.9.6 HALL OVER-CURRENT

The signals from the three Hall effect current transducers are used to provide protection against overload, wiring and earth (ground) faults. The two inverter output Halls (U3 and U4) are checked for both positive and negative current. The DC input Hall (U2) is only checked for positive current. The circuitry to implement the trip is shown on Sheet 6 of Appendix A. Being similar to that described in **Section 1.5.9.2 "Inverter Shunt Over-current"**, it requires little further explanation. The one difference is that the input signals to the comparator are divided down in order to stay within the input voltage limitations of the comparators when running from +5V.

## 1.6 MODIFYING THE BOARD

## 1.6.1 Introduction

Certain modifications have been allowed for in the design of the system, as described below. Clearly, any additional modifications that the user chooses to make can not be guaranteed to be functional or safe. It is assumed that relevant qualified personnel only will use the system.

## 1.6.2 Accessing The System

Before removing the lid of the system, the following procedure should be rigidly followed:

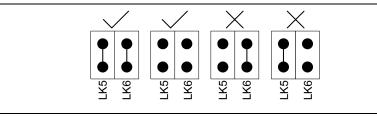
- Turn off all power to the system.
- Wait a minimum of 5 minutes so that the internal discharge circuit has reduced the DC bus voltage to a safe level. The red LED bus voltage indicator visible through the top ventilation holes should be out.
- Verify with a voltmeter that discharge has taken place by checking the potential between the + and - DC terminals of the 7-pin output connector before proceeding. The voltage should be less than 5V.
- The system is now safe to work on.
- · Remove all cables from the system.
- Remove the screws fixing the lid to the chassis and heat sink on the top and bottom.
- Slide the lid forwards while holding the unit by the heat sink.

## 1.6.3 Changing Current Feedback and Trip Scaling

- Provision has been made to change the current feedback scaling of both the isolated Hall transducers and the inverter leg and bus shunts. As the trip levels are set at a fixed voltage, changing the feedback scaling also changes the trip levels. Changing the scaling is accomplished in the following way:
- Follow the procedure given in **Section 1.6.2** "Accessing The System" for accessing the unit.
- Changing the inverter leg shunt sensing between unipolar and bipolar is accomplished with LK4. LK4 is located directly under the "Danger High Voltage" label on the PCB. Table 1-6 shows the settings:

TABLE 1-6:         SHUNT FEEDBACK POLARITY SELECTION		
L	K 4 Setting	Feedback Range
	1-2	Bipolar
	2-3	Unipolar

## • Two different gain settings for the inverter leg shunt and DC bus shunt feedback are implemented via LK5-12. These are located directly under the "Danger High Voltage" label on the PCB. The user should consult Sheet 3 of the Schematics in Appendix A to establish which links correspond to which signal. Note that links must be changed in pairs (e.g., LK5 and LK6 together or LK7 and LK8 together, etc.) for correct operation (see below).



• The Scaling and trip levels for the inverter leg shunt signals are shown in Table 1-7:

	Links Open Bipolar Unipolar		Links	Shorted
			Bipolar	Unipolar
Scaling (A/V)	5.45	5.45	12.0	12.0
Trip Level (A)	±10.9	24.5	±24.0	54.0

**Note:** The shaded setting should not be used, as it will not adequately protect the power devices from thermal overload.

• The scaling and the trip levels for the bus shunt signal is given in Table 1-8:

#### TABLE 1-8: BUS SHUNT SCALING SELECTION

	Links Open	Links Closed
Scaling (A/V)	5.39	11.9
Trip Level (A)	±10.8	±23.9

Changing the Hall Sensors scaling is accomplished via solderable links (e.g., LK1, LK2 and LK3 for U1). These are located adjacent to the transducers. The links change the number of turns that pass through the transducer over a 3:1 range. Tinned copper wire of a suitable current rating should be used. Only one link at a time should be used or unpredictable current scaling will occur. The user should ensure that the maximum length of lead protruding below the PCB is 4 mm for voltage clearance reasons. The scaling and corresponding trip levels are shown in Table 1-9 where the links referred to are for U2.

	LK1/LK15/LK18 Closed	LK2/LK14/LK17 Closed	LK3/LK13/LK16 Closed
Scaling (A / V)	8	12	24
Trip Level (A)	±14.8	±22.2	±44.4

TABLE 1-9:HALL EFFECT CURRENT TRANSDUCER SCALING SELECTION

**Note:** Important: For the system, as delivered, the highest current range (LK3, LK13 and LK16) should not be used. This is because of thermal limitations of the power devices. If the user requires less current, then using the lowest current range (LK1) will give improved current feedback range and resolution.

Once the modification is complete, install the lid ensuring all the screws are replaced.

#### 1.6.3.1 CHANGING VOLTAGE FEEDBACK AND TRIP SCALING

The voltage feedback scaling is configured for the maximum range of input voltages. If the user requires full ADC resolution at lower voltages, then this can easily be accomplished by changing the high voltage resistors mounted on the top of the PCB.

- Follow the procedure given in **Section 1.6.2** "Accessing The System" for accessing the unit.
- To change DC bus voltage scaling, modify R10, R13, R14. Note, if using the back EMF crossing detection circuitry (see Section 1.5.7.3 "Inverter Output Voltage Feedback and Sensorless Detection"), the user should also change the phase voltage feedback resistors to ensure consistent scaling.
- To change phase voltage scaling modify R16 R20.
- In all cases, it is suggested that the changes are made from the top of the board. If new component legs are inserted, these should be cropped to ensure that the maximum length of lead protruding below the PCB is 4 mm.
- Once the modification is complete, install the lid ensuring all the screws are replaced.

## 1.6.3.2 MODIFYING OR REMOVING THE INTERNAL BRAKING RESISTOR

The type of braking resistor installed on the heat sink allows a maximum continuous dissipation of 50W, but can tolerate many times this power level for short periods. The value installed as standard only allows a maximum dissipation of 45W owing to its high resistance. If the user wishes to change the resistor to a lower value or remove the resistor completely as they are using an external resistor, then they should follow the procedure given below.

- Follow the procedure given in **Section 1.6.2** "Accessing The System" for accessing the unit.
- De-solder or cut the wires to J7 and J8. This can be done from the top of the PCB.
- Undo the screws attaching the resistor to the heat sink and remove the resistor and its wiring.
- If not fitting a new resistor proceed to the last step.
- Make up a wiring assembly for the new resistor with similar lead lengths and the terminals protected with heat shrink sleeving. Ensure the wire has sufficient current and voltage rating.
- Apply a thin, even coating of thermally conductive heat sink compound (e.g., Dow-Corning 340) to the back of the resistor.

- Fit the resistor to the heat sink and solder the wires into J7 and J8. Ensure the leads are cropped so that the maximum length of lead protruding below the PCB is 4 mm.
- Once the modification is complete, install the lid ensuring all the screws are replaced.

Note that if the user fits a lower value of internal resistor to allow higher transient dissipation, then the user's software must ensure adequate thermal protection for the resistor. Failure to do so can cause the resistor to rupture. Consult the manufacturers data sheet carefully.

#### 1.6.3.3 BYPASSING THE REVERSE VOLTAGE PROTECTION

The reverse voltage protection MOSFET dissipates an appreciable amount of power. If the user is satisfied that this is not required, they can easily remove it by using the following procedure. Alternatively, the user can use the auxiliary DC input on the 7-pin output connector but this also bypasses the DC input current transducer and its associated trip protection.

- Follow the procedure given in Section 1.6.2 "Accessing The System" for accessing the unit.
- To remove the reverse voltage protection MOSFET Q9, undo the clip mounting the device and de-solder it from the top of the PCB. Solder a wire link between pads 2 and 3 of a suitable rating having cropped the leads, ensuring that the maximum length of lead protruding below the PCB is 4 mm.
- Once the modification is complete, install the lid ensuring all the screws are replaced.

#### 1.6.3.4 ACCESSING THE ADDITIONAL (NON-ISOLATED) FEEDBACK SIGNALS

All the non-isolated feedback signals are brought to a series of links that run along the edge of the isolation barrier. In order to access these signals, the user should rigidly carry out the procedure given below. Failure to do so could represent a safety hazard to the user.

- Follow the procedure given in **Section 1.6.2** "Accessing The System" for accessing the unit.
- Disconnect the input wiring from the DC supply outlet.
- · Ensure that the earth (ground) continuity is maintained to the unit.
- In order to make the links for the non-isolated signals, it is recommended that two 0.3" pitch, 14-pin DIL resistor packages are used. These should be of the "straight-through" type with 7 independent resistors. The suggested value is 330Ω, as this will provide some ESD protection without too high a source impedance being introduced. Note that LK28 has no circuit connections and is provided to allow the second DIL resistor package to be installed. If the user decides to fit links or individual resistors, these should be installed so that not more than 4 mm of lead protrudes beneath the PCB.
- Note that all signals to and from the system are now referenced to the -DC bus that is at earth (ground) potential. The Digital 0V of the control card is permanently connected to the enclosure chassis and is therefore also referenced to ground.
- Once the modification is complete, install the lid ensuring all the screws are replaced.

#### 1.6.3.5 OTHER MODIFICATIONS

Clearly, there are many other modifications that an experienced engineer could make to the system. These could include:

- Changing the inverter power devices for lower voltage devices if operation at low input voltages only is required.
- Changing the DC bus capacitors for higher capacitance lower voltage components.
- A simple boost circuit is included in the design of the unit, but is only populated for the high voltage version of the system. This can be seen on Sheet 1 of Appendix A. If the user has an application requiring operation of a higher voltage motor from a low voltage power supply, this could be explored. Clearly, all voltage ratings of all the power components will need to be very carefully considered.

No guarantee or liability can be accepted for any modifications that the user makes to the system. If the user removes the PCB from the enclosure chassis, they should ensure that the power device clamping force and the insulation is unaltered when the PCB is re-installed.

### 1.7 TEST POINTS

The following test points are all located on the topside of the PCB. See Appendix A for references to the net names on the schematics.

Test Point	Signal Function	Net Name
TP 1	LIVE PFC Switch Firing Command (Active Low)	PFC_FIRE
TP 2	LIVE Red Top Switch Firing Command	FIRE_R_TOP
TP 3	LIVE Red Bottom Switch Firing Command	FIRE_R_BOT
TP 4	LIVE Yellow Top Switch Firing Command	FIRE_Y_TOP
TP 5	LIVE Yellow Bottom Switch Firing Command	FIRE_Y_BOT
TP 6	LIVE Blue Top Switch Firing Command	FIRE_B_TOP
TP 7	LIVE Blue Bottom Switch Firing Command	FIRE_B_BOT
TP 8	LIVE Fault Indication	FAULT
TP 9	LIVE Brake Chopper Firing Command (Active Low)	BRAKE_FIRE
TP 10	LIVE Serial Data from PIC12C671 for voltage feedback	LIVE_DATA
TP 11	LIVE Serial Clock from PIC12C671 for voltage feedback	LIVE_SCLK
TP 12	LIVE Divided down voltage of half DC bus	HALF_BUS_SENSE
TP 13	LIVE High reference used for FAULT trips	HIGH_REF
TP 14	LIVE Low reference used for FAULT trips	LOW_REF
TP 15	LIVE Fault Reset (and PIC12C671 MCLR) line (Active Low)	RESET
TP 16	LIVE +15V power supply	+15V
TP 17	Live +5V power supply	+5V
TP 18	ISOLATED High reference used for FAULT trips	ISO_HIGH_REF
TP 19	ISOLATED Low reference used for FAULT trips	ISO_LOW_REF
TP 20	LIVE Star Reference Point for Low Voltage PSUs	—

## 1.8 USER SIGNAL CONNECTOR PINOUT (37-PIN, D-TYPE)

Pin	Function	Net Name	Input/Output	Isolated
1	Not Used			
2	Yellow Phase Shunt Current Feedback	Y SHUNT	Output	No if LK20 Fitted
3	DC Bus Shunt Current Feedback	BUS SHUNT	Output	No If LK22 Fitted
4	Not Used			_
5	Yellow Phase Voltage Feedback	Y VPH SENSE	Output	No If LK25 Fitted
6	Blue Phase Back EMF crossing	B_CROSSING	Output	No if LK27 Fitted
7	Red Phase Back EMF crossing	R_CROSSING	Output	No if LK29 Fitted
8	Rectifier Output Voltage ( VAC ) Feedback	VAC _SENSE	Output	No if LK31 Fitted
9	Analog +5V from control PCB (±2%)	ISO_A+5V	Input	Yes
10	PFC Switch Firing Command	CMD_PFC	Input	Yes
11	Blue Phase Top Switch Firing Command	CMD_B_TOP	Input	Yes
12	Yellow Phase Top Switch Firing Command	CMD_Y_TOP	Input	Yes
13	Red Phase Top Switch Firing Command	CMD_R_TOP	Input	Yes
14	Active Low Serial Clock	ISO_SCLK	Output	Yes
15	Active Low Fault	FAULT_ISO	Output	Yes
16	Yellow Phase Hall Current Sensor Feedback	Y_HALL	Output	Yes
17	PFC Hall Current Sensor Feedback	PFC_HALL	Output	Yes
18	Digital GND from control PCB	ISO_GND	Input	Yes
19	Digital +5V from control PCB (±2%)	ISO_+5V	Input	Yes
20	Blue Phase Shunt Current Feedback	B_SHUNT	Output	No if LK19 Fitted
21	Red Phase Shunt Current Feedback	R_SHUNT	Output	No if LK21 Fitted
22	Brake Chopper Switch Shunt Current Feedback	BRAKE_SHUNT	Output	No if LK23 Fitted
23	Blue Phase Voltage Feedback	B_VPH_SENSE	Output	No if LK24 Fitted
24	Red Phase Voltage Feedback	R_VPH_SENSE	Output	No If LK26 Fitted
25	Yellow Phase Back EMF crossing	Y_CROSSING	Output	No if LK28 Fitted
26	DC Bus Voltage Feedback	BUS_SENSE	Output	No if LK30 Fitted
27	Analog GND from control PCB	ISO_AGND	Input	Yes
28	Brake Chopper Switch Firing Command	CMD_BRAKE	Input	Yes
29	Blue Phase Bottom Switch Firing Command	CMD_B_BOT	Input	Yes
30	Yellow Phase Bottom Switch Firing Command	CMD_Y_BOT	Input	Yes
31	Red Phase Bottom Switch Firing Command	CMD_R_BOT	Input	Yes
32	Active Low Serial Data	ISO_DATA	Output	Yes
33	Fault Reset Command	ISO_RESET	Input	Yes
34	Not Used		—	—
35	Red Phase Hall Current Sensor Feedback	R_HALL	Output	Yes
36	Digital GND from control PCB	ISO_GND	Input	Yes
37	Digital +5V from control PCB (±2%)	ISO_+5V	Input	Yes

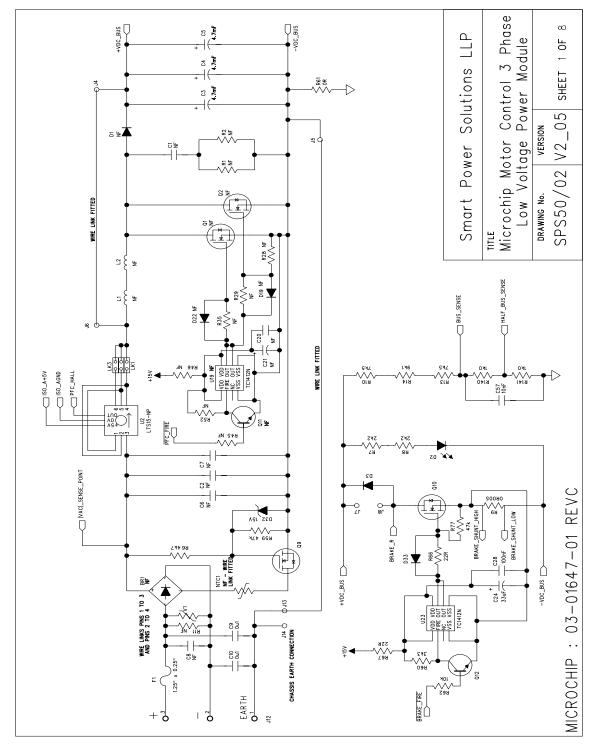
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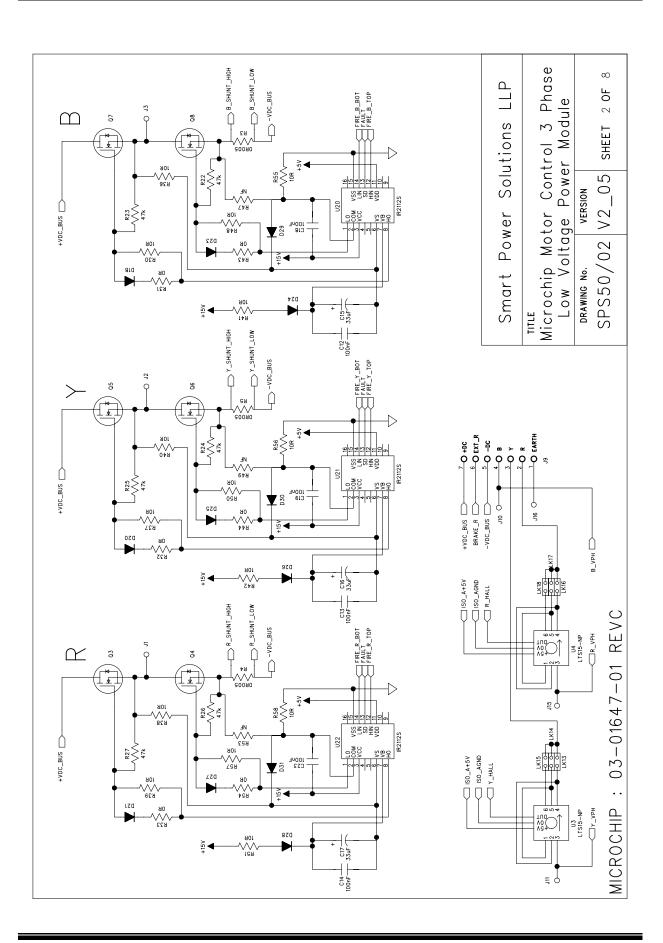


## dsPICDEM<sup>™</sup> MC1L 3-PHASE LOW VOLTAGE POWER MODULE

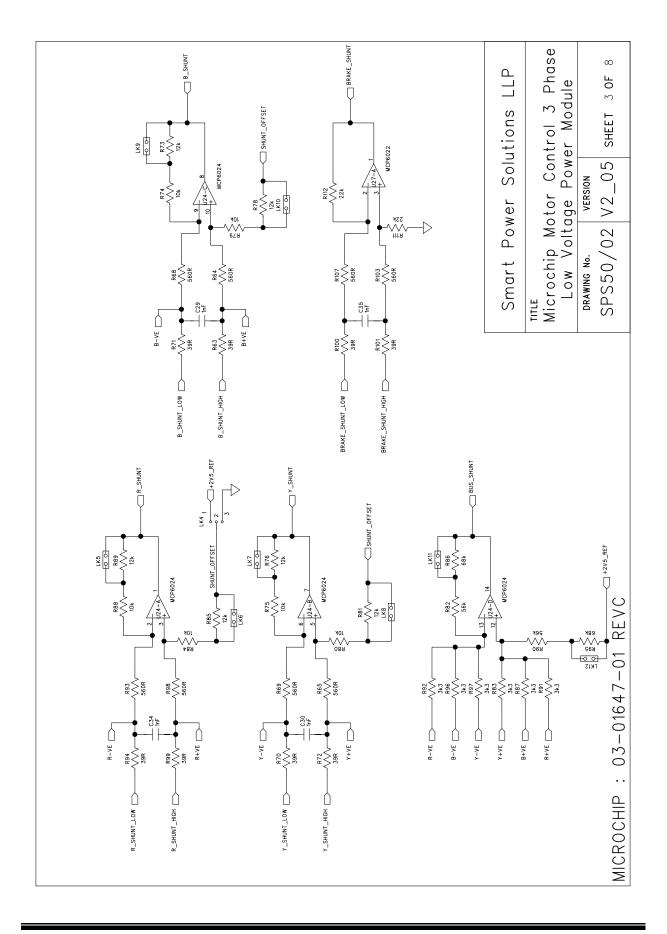
## **Appendix A. Circuit Diagrams**

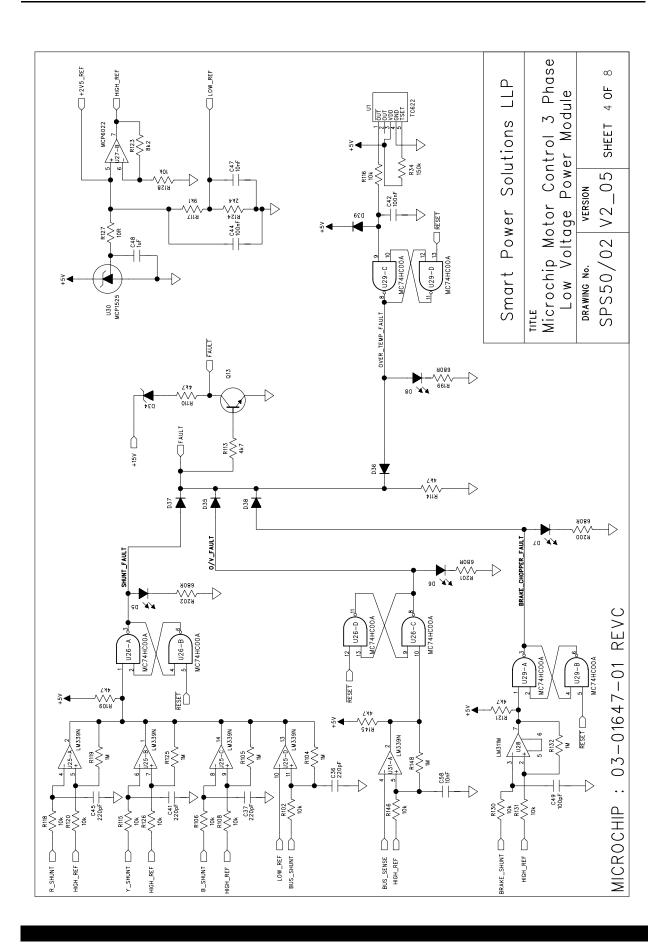
### A.1 CIRCUIT DIAGRAMS

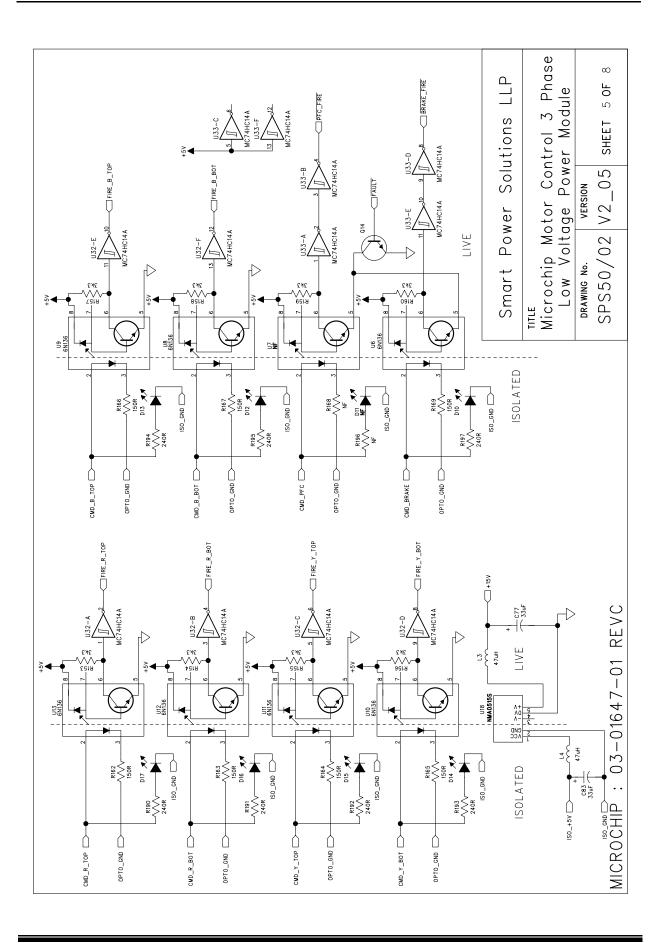




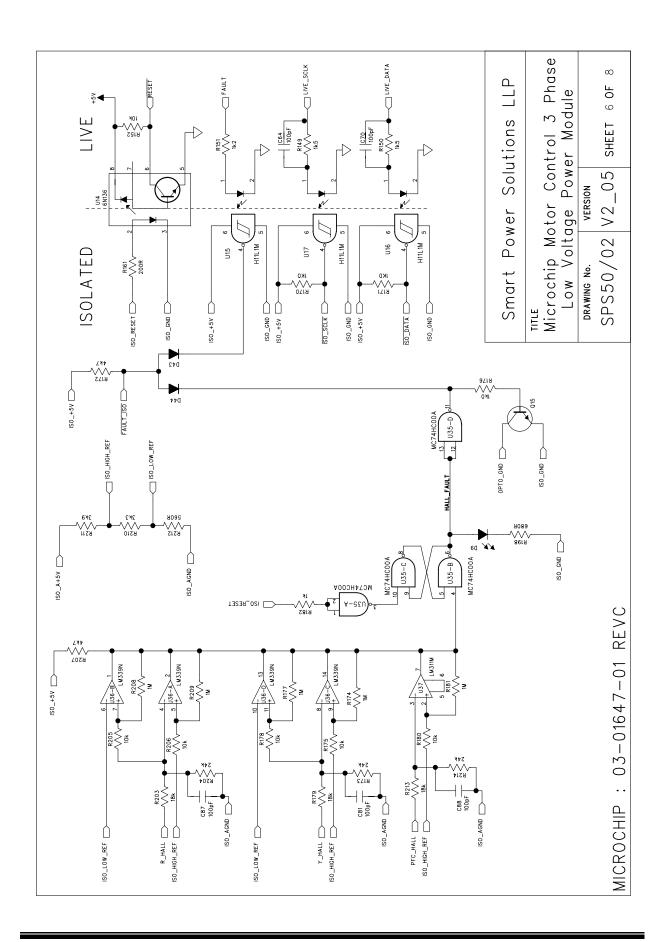
# Appendix



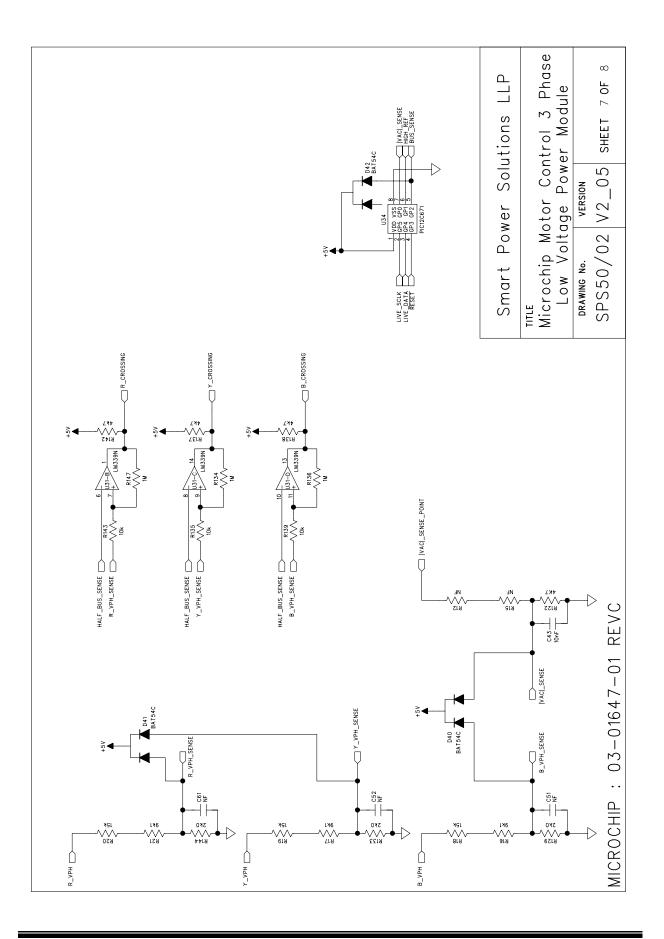


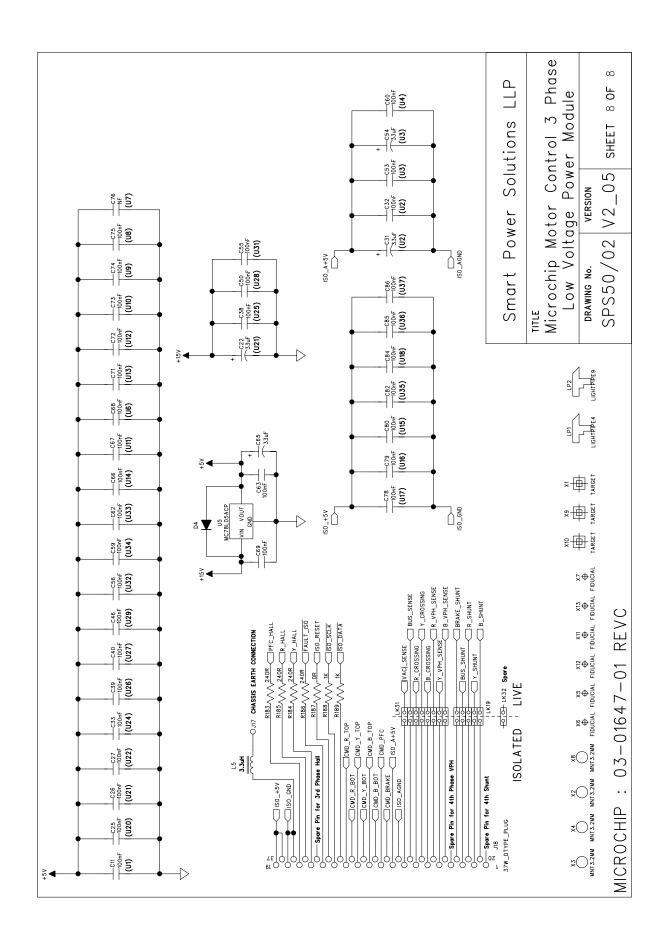


# Appendix



# Appendix

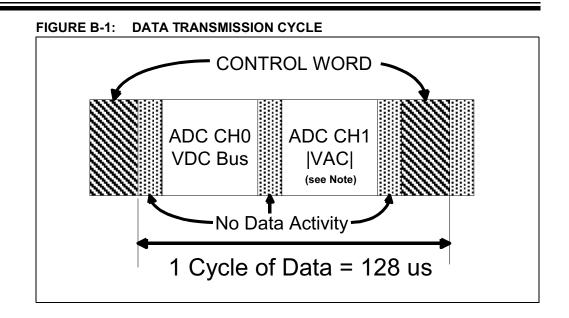






## dsPICDEM<sup>™</sup> MC1L 3-PHASE LOW VOLTAGE POWER MODULE

## **Appendix B. Source Code**



**Note:** The data transmitted via the SPI interface is inverted by the opto-isolators. The user software should invert the received data.

Note: The VAC signal referenced in Figure B-1 will be the same as the VDC bus signal for the default configuration of the power module. (Refer to Sheet 1 of the schematics). This signal is provided for the support of active power factor applications where the incoming power source is AC and a voltage boost circuit is used to control the incoming current. The power module PCB supports the components for an active power factor correction circuit. These components are not installed on the low voltage version of the power module.

## B.1 PIC<sup>®</sup> MCU CODE AND DATA CYCLE DIAGRAM FOR SERIAL INTERFACE

```
; *
   50_10_v3.ASM
; *
   Smart Power Solutions LLP
   13th April 2003
;*
; *
   Assembled with MPLAB v6.13
;*
   This program continuously converts two ADC channels, ANO
; *
   & AN2 and writes the results out via SPI followed by a
;*
   control word 0xF9.
;*
   The software latency of the SPI transmission
;*
   is used to fulfill the aquire, conversion & wait time of
;*
   the ADC module for maximum data transmission rate.
;*
   If transmission is corrupted, MCLR is asserted to re-sync
;*
   transmission, therefore no watchdog is required.
;*
   SPI clock, SCK, is GP5 pin 2 idle low and data is valid on
;*
  the falling edge. SPI data out line, SDO, is PGP4 pin 3.
;*
   Use config word 0xE4 when programming
list p=12c671
     ; Include file, change directory if needed
     include "p12c671.inc"
BYTE_TO_SEND
             EQU
                   0x20
STARTUP TIMER
            EOU
                   0x21
                   0 \times 05
SCK
             EQU
SDO
             EOU
                   0x04
     ; Start at the reset vector
          0 \times 000
     orq
Start
                     ; begin in bank0 initially
     clrf GPIO
                     ;Clear GPIO
     bsf
          STATUS, 5
                     ;select bank1
     movlw 0x0f
     movwf TRISIO
                     ;GP5, GP4 outputs
                     ;also in bank 1
     movlw 0X02
                     ;AD0,AD1 and AD2 are analog channels
     movwf ADCON1
                     ;with VDD and VSS references
     call 0x03ff
                     ; factory programmed data to trim
                     ; internal oscillator
     movwf OSCCAL
     clrf STATUS
                    ;select bank0 FOR REST OF CODE
```

Initial\_Capture ; before starting SPI transmission, ;aquire &convert ADC ch0, BUS\_SENSE movlw 0x41 ;set:Fosc/8, A/D enable, ch0 select ;begin sampling ch0 movwf ADCON0 movlw 0x04 ;wait for approx 20us aquisition time movwf STARTUP\_TIMER delav decf STARTUP\_TIMER,F btfss STATUS,Z goto delay ;Start A/D conversion Channel 0 bsf ADCON0,GO finish\_1st\_conversion btfsc ADCON0,GO ;wait for end of conversion flag goto finish\_1st\_conversion movf ADRES,W movwf BYTE\_TO\_SEND ;extra wait before starting new aquisinop tion ; \* \* \* \* \* \* \* \* \* \* \* \* \* \* \* \* Main movlw 0x51 ;Fosc/8, A/D enabled, ch 2 selected movwf ADCON0 ; begin sampling channel 2 |VAC| SENSE ; begin to transmit value from channel 0 bcf GPIO,SDO ;send bit 7 bsf GPIO,SCK btfsc BYTE TO SEND,7 bsf GPIO,SDO bcf GPIO,SCK bcf GPIO,SDO ;send bit 6 bsf GPIO,SCK btfsc BYTE\_TO\_SEND,6 bsf GPIO,SDO bcf GPIO,SCK bcf GPIO,SDO ;send bit 5 bsf GPIO,SCK btfsc BYTE\_TO\_SEND,5 bsf GPIO,SDO bcf GPIO,SCK bcf GPIO,SDO ;send bit 4 bsf GPIO,SCK btfsc BYTE\_TO\_SEND,4 bsf GPIO,SDO

bcf

GPIO,SCK

;start ADC convertion on ch2, which has now finished aquiring bsf ADCON0,GO bcf GPIO,SDO ;send bit 3 bsf GPIO,SCK btfsc BYTE\_TO\_SEND,3 bsf GPIO,SDO bcf GPIO,SCK bcf GPIO,SDO ;send bit 2 bsf GPIO,SCK btfsc BYTE TO SEND,2 bsf GPIO,SDO bcf GPIO,SCK bcf GPIO,SDO ;send bit 1 bsf GPIO,SCK btfsc BYTE\_TO\_SEND,1 GPIO,SDO bsf GPIO,SCK bcf bcf GPIO,SDO ;send bit 0 bsf GPIO,SCK btfsc BYTE\_TO\_SEND,0 bsf GPIO,SDO bcf GPIO,SCK finish conversion btfsc ADCON0,GO goto finish\_conversion movf ADRES,W movwf BYTE TO SEND ;need a min 4us delay before starting next acquire ; begin to transmit value from channel 2 |VAC|\_SENSE GPIO,SDO ;send bit 7 bcf bsf GPIO,SCK btfsc BYTE\_TO\_SEND,7 GPIO,SDO bsf GPIO,SCK bcf ;set up ADC to begin sampling channel 0 movlw 0x41 ;Fosc/8, A/D enabled channel 0 selected movwf ADCON0 ; begin sampling ch0 BUS SENSE bcf GPIO,SDO ;send bit 6 bsf GPIO,SCK btfsc BYTE TO SEND,6 bsf GPIO,SDO bcf GPIO,SCK

bcf GPIO,SDO ;send bit 5 bsf GPIO,SCK btfsc BYTE\_TO\_SEND,5 bsf GPIO,SDO bcf GPIO,SCK bcf GPIO,SDO ;send bit 4 bsf GPIO,SCK btfsc BYTE\_TO\_SEND,4 bsf GPIO,SDO bcf GPIO,SCK bcf GPIO,SDO ;send bit 3 bsf GPIO,SCK btfsc BYTE\_TO\_SEND,3 bsf GPIO,SDO bcf GPIO,SCK bcf GPIO,SDO ;send bit 2 bsf GPIO,SCK btfsc BYTE\_TO\_SEND,2 bsf GPIO,SDO bcf GPIO,SCK bsf ADCON0,GO ;Start A/D conversion Channel 0 bcf GPIO,SDO ;send bit 1 bsf GPIO,SCK btfsc BYTE\_TO\_SEND,1 bsf GPIO,SDO bcf GPIO,SCK bcf GPIO,SDO ;send bit 0 GPIO,SCK bsf btfsc BYTE TO SEND,0 bsf GPIO,SDO bcf GPIO,SCK nop nop nop nop ;while ADC is still converting Channel 0, send control word 0xF9 bsf GPIO,SCK ;send bit7 bsf GPIO,SDO bcf GPIO,SCK nop bsf GPIO,SCK ;send bit6 bcf GPIO,SCK nop bsf GPIO,SCK ;send bit5 bcf GPIO,SCK nop

# dsPICDEM<sup>™</sup> MC1L 3-Phase Low Voltage Power Module

bsf bcf	GPIO,SCK GPIO,SCK	;send bit4				
nop bsf bcf	GPIO,SCK GPIO,SCK	;send bit3				
nop bsf		;send bit2				
bsi bcf	GPIO,SCK GPIO,SDO	, send bitz				
nop bcf	GPIO,SCK					
nop bsf	GPIO,SCK	;send bit1				
bcf nop	GPIO,SCK					
bsf bsf	GPIO,SCK GPIO,SDO	;send bit0				
bcf	GPIO,SCK					
movf	of channel ( ADRES,W BYTE_TO_SENI	) now complete				
goto	Main	;Do it again				

end

NOTES:



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05/30/03