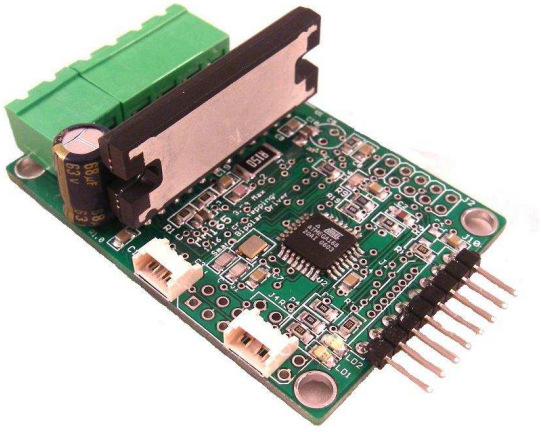
MM165 Smart Single Axis Stepper Motor Driver

1/16th Microstepping 3.5A Bipolar Driver

Technical Reference Manual

PCB Rev 1.0

Motor Control Software Version 1.00



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1935A–08/00/5M

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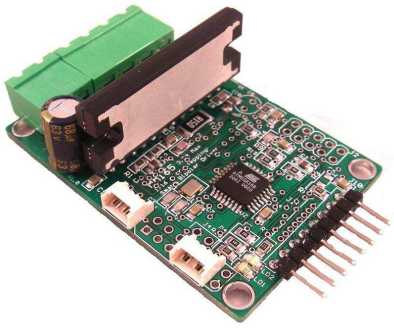
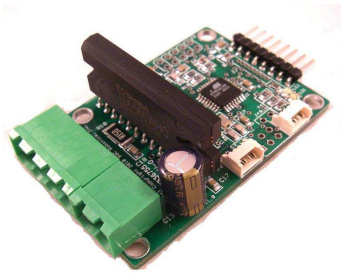
1.0 Introduction





Features:

- Bipolar 3.5A Stepper Motor Driver
- Maximum motor drive voltage 40V
- Full, half, eighth and sixteenth microstepping
- Maximum 3.5 A per phase
- Backlash compensation built-in
- On board 20MHz RISC AVR processor – ATmega168
- G Code like commands supported
- Local joystick and limit switch support
- TWI I2C Communication Protocol Built-in
- 16K Flash1, 2K SRAM, 512 EEPROM
- Software controlled step mode, decay and torque setting
- TB6560 Bipolar Driver chip
- ISP Programming Port
- GNU C Compiler, Third Party Commercial C Compiler
- Extremely small form factor (2.10x1.54 in)
- 5VDC @ 12ma Power input for logic
- Motor drive input 10-40VDC at 3.5A

Hardware

The MM165 is a 1/16th Microstepping Unipolar 3A per phase stepper motor driver that converts step and direction signals to the appropriate high voltage stepper motor drive signals. The board is designed to operate at 5VDC. Motor voltage can vary from 10-40VDC. The motor drive chip is controlled by a dedicated onboard 8 bit RISC processor (ATmega168) that provides various expansion and enhancement features. Applications can communicate with the board via an I2C interface or using encoded commands on the step and direction inputs. A Limit and eStop switch inputs can be monitored and acted on but are turned off by default. An optional joystick can be connected directly to the driver to control stepper operation.

The MM165 consumes about 12ma in active state not including motor drive current.

Motor Control Software

The MM165 is shipped with a sophisticated software application burned into the on board ATmega168 processor that controls the TB6560 bipolar driver chip, monitors step/direction inputs, limit switch state, encoded commands on the step/direction input lines and commands received on the I2C port. The MM165 can operate as a single axis G Code processing system by acting on commands sent to it via the I2C or Step/Direction input lines. See the section on software operation for a full description of the complete command structure. Free application GstepPP.exe is used to send coded commands to the MM165 on the Step/Direction lines.

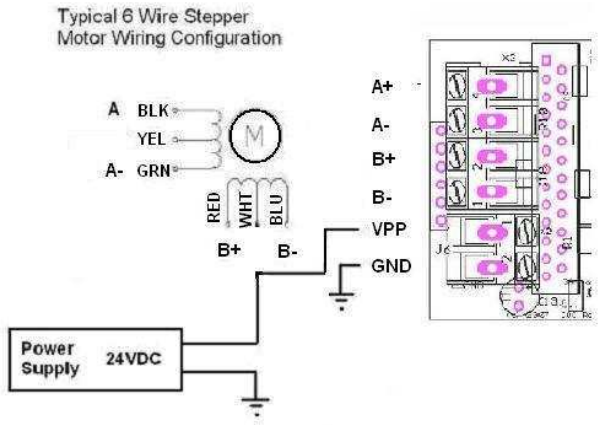
The control program in the MM165 processor can be re-Flashed using programming cable Part No. MCM-8 and the appropriate host software MK4Prog.exe.

The MM165 can be custom programmed in C using either a GNU C Compiler, AVR Studio V4.13 or higher with GNU C integrated with the IDE or a third party IDE such as ICCAVR from ImageCraft.

Stepper Motor Connection

Motor Drive voltage should be between 10-40VDC. A potentiometer sets average current and should be adjusted while the board is running. An optional heat sink is available to provide radiant cooling so forced air cooling is not required in most applications. Under extreme operating conditions forced air cooling should be used. The diagram below shows stepper motor connections for the SOC Robotics SM2006 and SM3006 stepper motors – wire color for other stepper motors may vary although most coil phase diagrams are similar. It is good practice to wire a fuse between the motor power supply and the MM165. Do not turn motor power on if the logic side of the MM165 is not turned on – damage to the TB6560 driver chip may result. If the motor will not turn then check your wiring.

MM165 Motor Connection for SM2006/SM3006



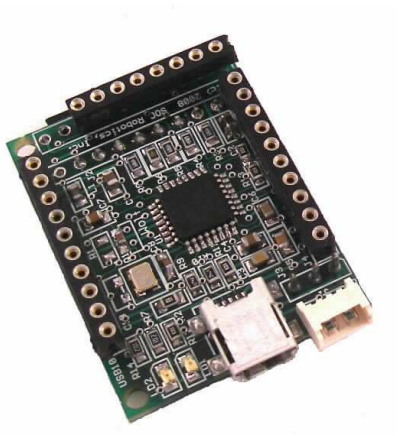
Adjusting Motor Drive Current

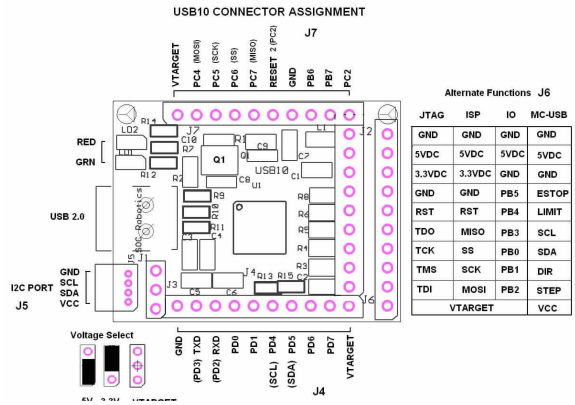
The MM165 motor drive current is set by software in four increments. Default setting is 3.5A – the maximum setting. It is possible to set the motor current in such a way that the control chip delivers too much current to the motor resulting in motor overheating. If the motor missteps at high step rates then your motor maybe undersized for your application and can not develop enough torque – in this case use a bigger motor. Increasing drive voltage will increase maximum step rate. The maximum step rate of a stepper motor is determined by drive voltage, coil inductance and step mode. Changing step mode from full step to half step can reduce effective drive torque by 40%.

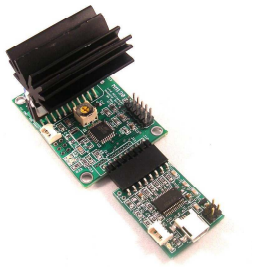
MM165 Controllers

Although the MM165 can operate standalone it usually requires a controller to send step and direction input signals to it. SOC Robotics has several controllers compatible with the MM165 - USB10M, MK1, MK4, MK14, MK54 and MK200. Each controller supports increasing levels of sophistication and control flexibility. The MK1 is a simple breakout board that allows three MM165's to be attached and controlled. The MK4 is a four axis breakout board with four auxiliary output ports, four limit switch inputs and one Estop input. The MK14 is a special version of the MK4 with a USB 2.0 interface. The MK54 is a high performance G Code processor with 10/100BaseT, CAN and USB 2.0. The MK200 is an ultra high performance G Code processor with onboard vision processing. For more information on our line of controllers and to help determine which one is best for your application go to our web site or contact the firm.

With the USB10M stepper motors can be controlled via a host PC USB port.



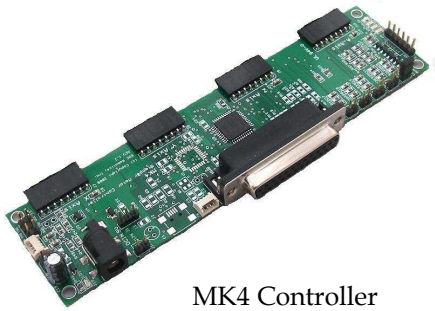




The USB10M is a USB 2.0 based controller that generates the step/direction signals to control the MM165. An I2C communications bus allows a host PC to communicate with the MM165 in real time allowing step mode changes, limit switch detection and aux IO monitoring and control.

MM165 with USB10M Controller

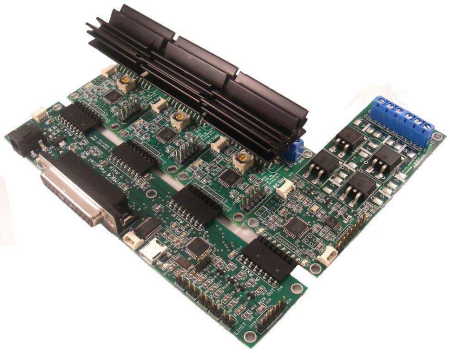
The MK4 is an optional parallel port controller with connectors for four MM165 drivers. The MK4 has four aux open collector outputs and five limit switch inputs all set/read via the parallel port. The MK4 is an excellent choice to attach up to four MM165's to a PC's parallel port and be controlled using Mach3.



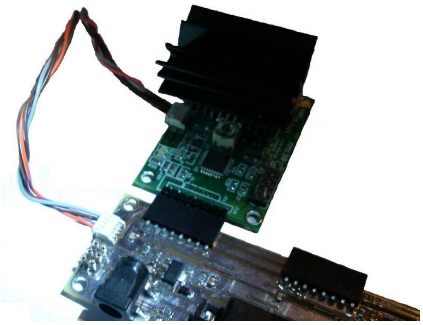
MK4 Controller

The MK14 is a USB 2.0 version of the MK4 with an onboard processor that accepts up to four MM165 drivers. The MK14 has four aux open collector outputs and five limit switch inputs all read via the parallel port. The onboard processor (AT91USB162) accepts step commands via USB and allows the host PC to communicate with the individual MM165 drivers and send high commands directly to each driver. In this case the parallel port interface can be bypassed and commands are sent directly to each MM165 processor using a standard serial communications protocol.

MK14 Controller

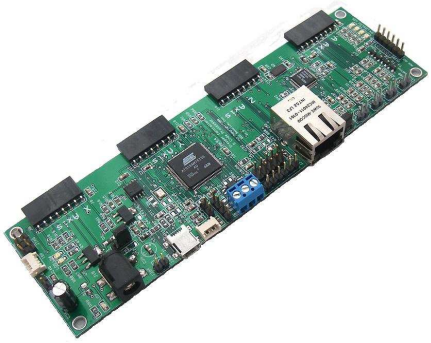


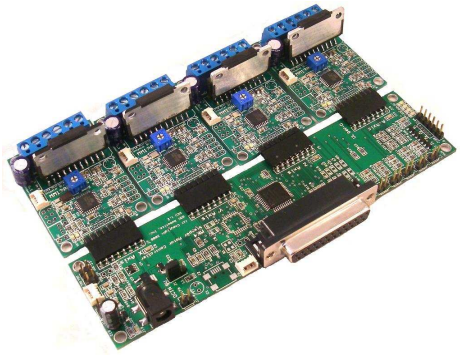
MK14 with 3 MM165's and MM133



MM165 Programming Cable

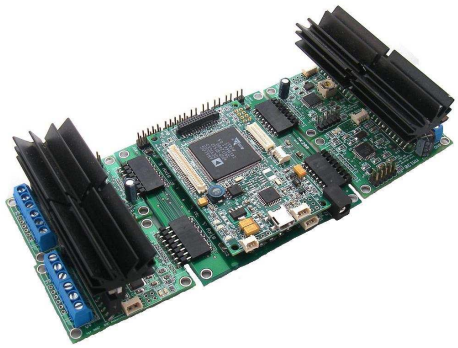
The MK54 is a high end G Code processor with onboard ARM7 processor running 48MHz. The ARM7 processor executes G Code directly eliminating the need for a PC based G Code processor. The MK54 is capable of receiving commands via a USB 2.0 interface, 10/100BaseT Ethernet or CAN.





The MK200 is a high end DSP based G Code processing platform with built-in vision processing that is capable of driving the MM165's at their maximum rate of 80,000 microsteps/second. The MK200 is

intended for high end applications that require extremely fast stepper motor operation and/or real time vision processing.



The correct controller for your application depends on many parameters. If you require help in choosing a controller or need additional information please contact the company.

2.0 MM165 Detailed Description

2.1 Introduction

The MM165 is a compact single axis bipolar stepper motor microstepping driver with a dedicated onboard processor. The processor responds to step/direction signals on the primary control input port, receives and interprets commands received on the I2C interface or encoded on the step/direction signal lines and processes sensor data received on the auxiliary IO port.

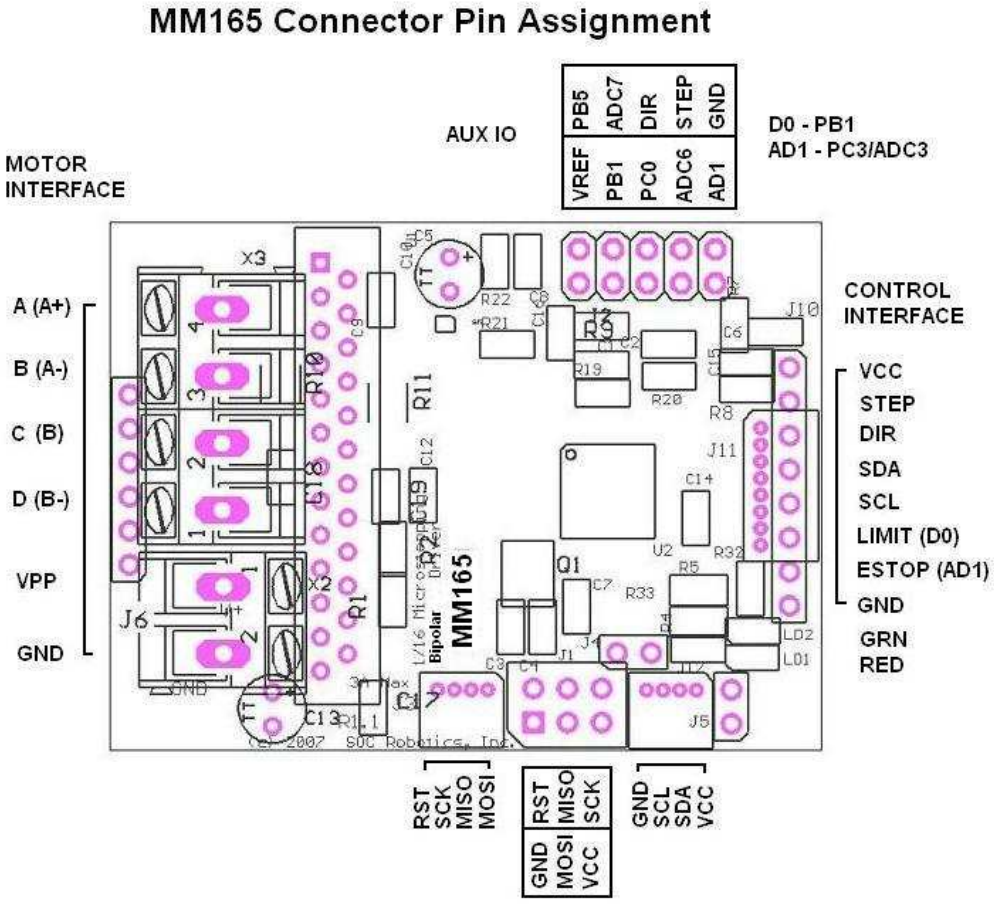


Figure 2-1. **Primary Components on top side of PCB.**

2.2 Processor

The MM165 has an 8bit RISC AVR processor (ATmega168) running at 20MHz. Note that the ATmega168 requires 5VDC to run at 20MHz. The program running in the Atmega168 monitors the step/direction input lines and drives the TB6560 microstepping driver chip. The list of commands supported by the processor firmware is described in the software operation section of this manual.

2.3 TWI Port

The MM165 has a TWI I2C port for communicating with smart peripherals or other I2C peripherals. The TWI port uses a 4 pin Molex connector with power and ground so the MM165 can power other peripherals or be powered itself via this connector. Default I2C address is 0x14. I2C address is a configuration parameter and can be changed in software. The Molex connector is not installed but can be optionally added to the board.

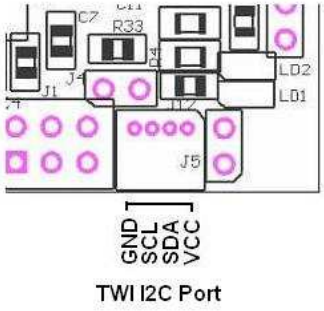


Figure 2-2. **MM165 I2C port pin assignments.**

2.4 Auxiliary IO Port

The MM165 has an auxiliary IO port. The auxiliary IO port supports three analog input lines and several digital IO lines. Version 1.0 software is capable of monitoring the position of an optional joystick attached to this port. If the center tap of a joystick is attached to pin ADC7 with one end of joystick potentiometer attached to GND and the other end to VREF the joystick can control the stepper driver directly. With the joystick at center position no movement occurs. Moving the joystick left or right causes the stepper motor to turn clockwise or counterclockwise. Speed is proportional to the degree by which the joystick off center position. By default joystick operation is disabled in software and must be enabled by the user. Maximum step rate and hysteresis (dead band) about the center point are programmable parameters.

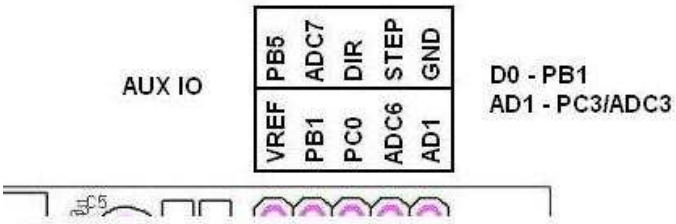


Figure 2-3. **MM165 Auxiliary IO port pin assignments.**

2.5 ISP Programming Port

The MM165 has two ISP programming ports – a 4 pin Molex connector and a 6 pin header. The MM165's Flash can be programmed by attaching a 4 line cable from the MK4 programming port to the Molex connector. The 6 pin header is not installed but can be added as an optional component. Alternatively the MM165 flash can be programmed using a separately supplied ISP10 Parallel Port Programmer and ISP610 adapter.

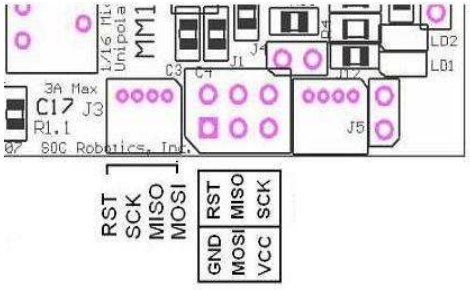


Figure 2-4. **ISP610 ISP Adapter and correct attachment to the MM165.**

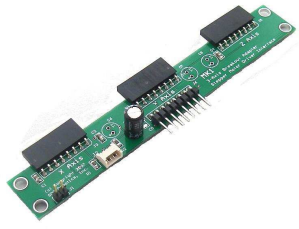
2.6 Molex Connectors

The MM165 uses two small Molex picoBlade 4 pin connectors with 1.25mm pin spacing (4 pin Molex Part No. 53048-0410 - Digikey Part No. WM1744-ND). These connectors mate with female Molex 4 housing connectors (4 pin housing Molex Part No. 51021-0400 - Digikey Part No. WM1722-ND).

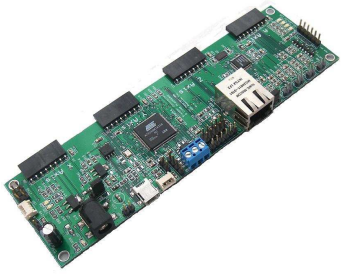
The housing connectors crimp terminal accepts 26-28AWGwire (Molex Part No. 50079-8000 - Digikey Part No. WM1722-ND – Crimp tool 63811-0300) or 28-32AWG (Molex Part No. 50058-8000 - Digikey Part No. WM1775-ND - Crimp tool 63811-0200).

2.7 Related Peripherals

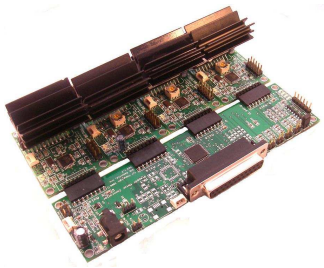
The MM165 can be controlled directly by the USB10M, MK1, MK4, MK4USB, MK54 and MK200. The MK4 attaches to a PC parallel port and provides an attachment point for up to four MM165's. The MK4 also supporst limit switch inputs and EStop. The MK4USB is a version of the MK4 that has a USB 2.0 interface to allow direct communication between each attached MM165 and a host PC for both motion control such as step/direction and configuration control such as changing step mode.



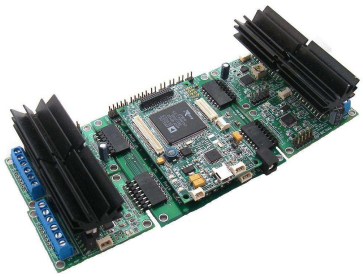
MK1



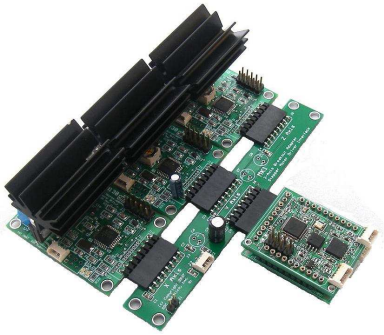
MK54



MK4 with 4 MM165's

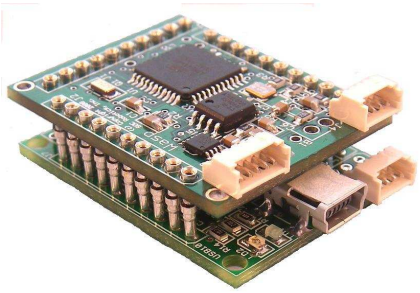


MK200 plus P0 DSP with four MM165's

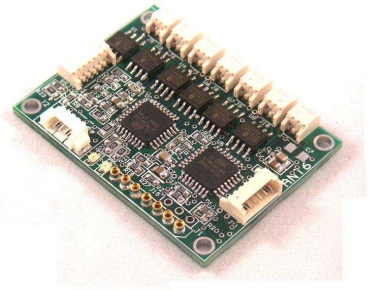


MK1 with Wasp and USB10 G Code processor

The MM165 can communicate with other SOC Robotics embedded processors such as the Wasp, WaspARM, SAM48, AmberM, SmartLCD, Ant6, Cricket and a host of other embedded processors.

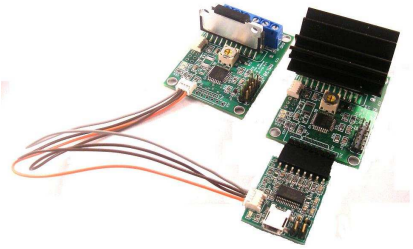


Wasp on USB10.



Ant6 6 Channel H-Bridge Controller

USB10 is a USB 2.0 device with an onboard AVR processor – the AT90USB162. The USB10 converts commands sent to it via the USB to step/direction commands that can drive the MM165.



Wasp mounted on a USB10 communications board.

Ant6 6 Channel H-Bridge Controller

2.8 Applications

The MM165 is a bipolar stepper motor driver that responds to step and direction signal inputs but is also able to communicate with other smart controllers via the I2C interface. In fact, large numbers of MM165's

can be ganged together and be controlled via a single I2C master. This enables the creation of rich motion control systems beyond simple three or four axis systems.

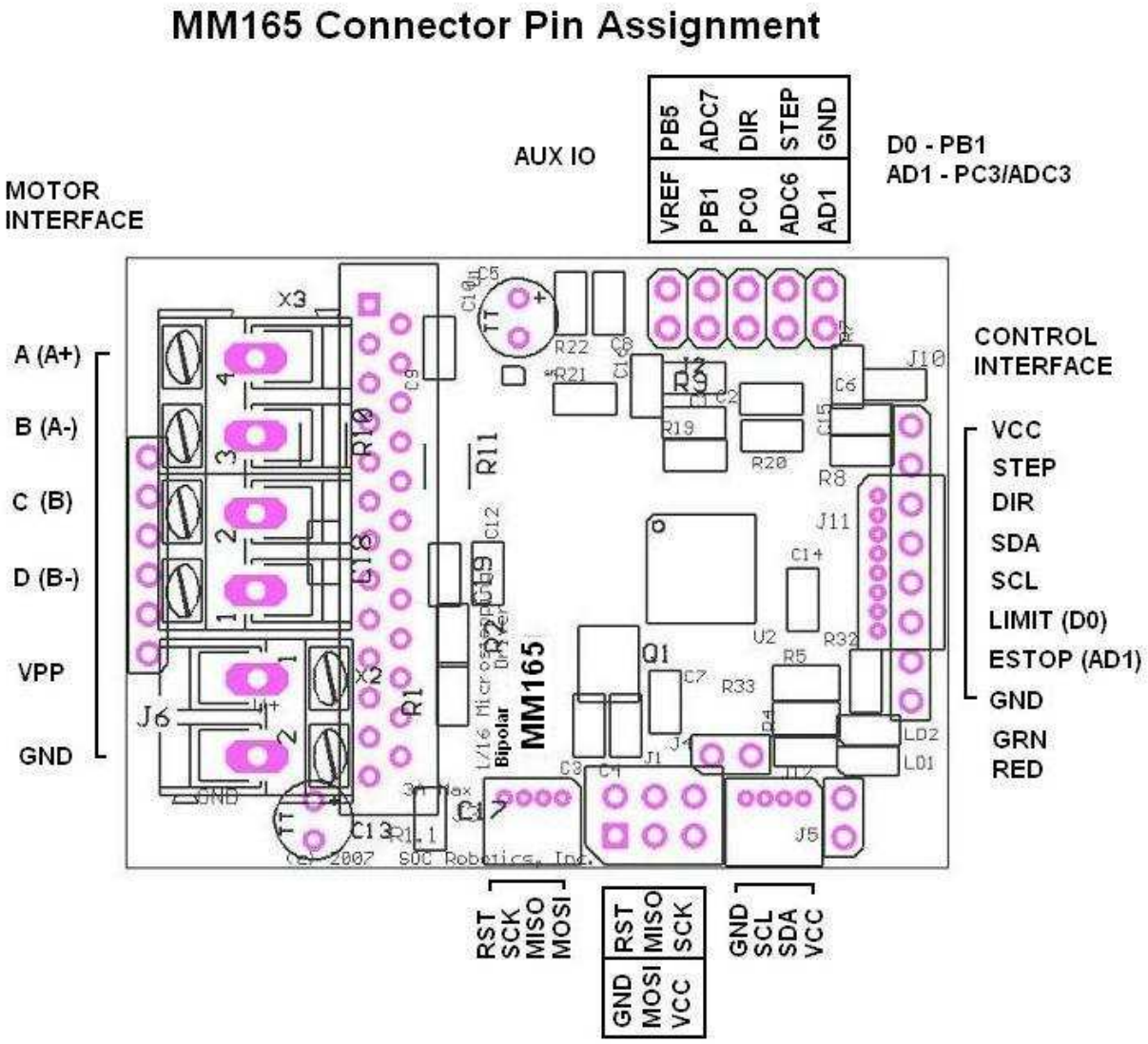
The MM165 also accepts sensor input on the Auxiliary IO and ISP programming lines providing an upgrade to a closed loop design in which sensor feedback is used to tune stepper motor operation. The example of a possible external sensor is a rotary magnetic sensor and a linear capacitive position sensor.

The MM165 can be combined with other processor technology such as the Wasp or WaspARM with onboard 3-axis accelerometers to create sophisticated embedded motion control systems.

3.0 MM165 Hardware Expansion Port Summary

3.1 Introduction

The MM165 has three I/O ports: a motor control port, programming port and an auxiliary IO port as shown in the connector layout diagram below. Two alternative configurations of the board are available: Configuration 1 replaces the 0.1" motor control port header with an 8 pin picoBlade Molex connector and configuration 2 replaces the motor 0.1" motor control port header with a 4 pin picoBlade Molex connector for the I2C port.



3.2 Motor Control Port

Motor control port is routed to connector J10. Step and direction signals are fed to the board on this port along with main power (5V DC) and ground, I2C lines and limit switch inputs. The I2C lines (SDA, SCL) allow a controller such as the MK4USB, MK54 or MK200 to communicate with the MM165 and set configuration features such as step mode, limit switch recognition, step/direction polarity, etc. The I2C lines are also routed to a dedicated 4 pin connector. Under software control the limit switch inputs can be monitored and acted on or ignored by the MM165 directly without host intervention. Configuration commands can also be encoded in the step/direction lines using a special protocol described later.

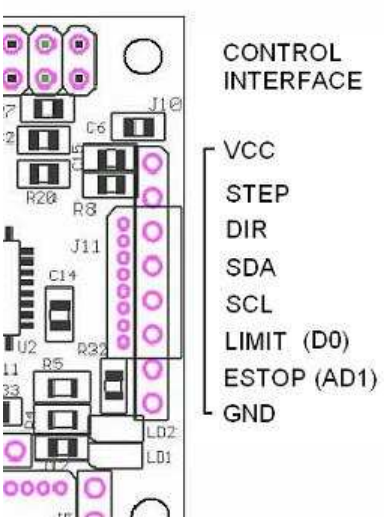


Figure 3-3. Step/Direction **Control Port Pin Assignment J10.**

3.3 Auxiliary IO Port

The auxiliary IO port accepts analog input, digital IO and step/direction inputs. The digital IO can be used to connect external sensors such as rotary and linear position sensors or to allow the MM165 to control external devices such as relays. The analog inputs allow the MM165 to measure external analog sensors. Version 1.0 software supports optional joystick control on this port.

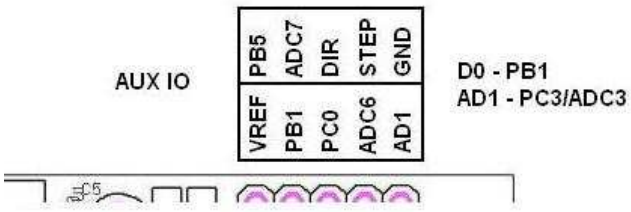


Figure 3-4. **Expansion Port Pin Assignment J2.**

If the center tap of a joystick is attached to pin ADC7 with one end of joystick potentiometer attached to GND and the other end to VREF the joystick can control the stepper driver directly. With the joystick at center position no movement occurs. Moving the joystick left or right causes the stepper motor to turn clockwise or counterclockwise. Speed is proportional to the degree by which the joystick off center position. By default joystick operation is disabled in software and must be enabled by the user. Maximum step rate and hysteresis (dead band) about the center point are programmable parameters.

3.4 I2C Expansion Port

The MM165 has an I2C communication port on connector J3. The I2C connector is not installed on the standard MM165 but is available by special order. The MM165 can be controlled via the I2C port. See the section of Drive Commands for more information. Note that the I2C signals are also on the Motor Control Port connector. The MM165 is a slaved I2C device and can be controlled by other SOC Robotics Smart Peripherals such as joysticks, LCD display controllers data acquisition modules. Default I2C address is 0x14 Hex. This address can be changed via the I2C interface using special configuration commands.

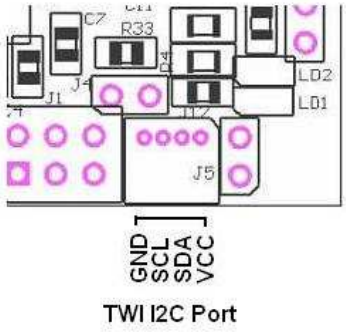


Figure 3-5. **TWI I2C Port with 4 Pin Molex picoBlade Connector.**

3.5 ISP Programming Port

The MM165 has two ISP Programming ports – a six pin header compatible with the Atmel 6 pin header ISP programming standard and a four pin picoBlade Molex connector compatible with the USB10U, MK4, MK14, MK54 and MK200 controllers. The ISP programming port allows the onboard ATmega168 processor Flash to be reprogrammed. See the Atmel ISP programming specification for detailed ATmega168 programming procedures.

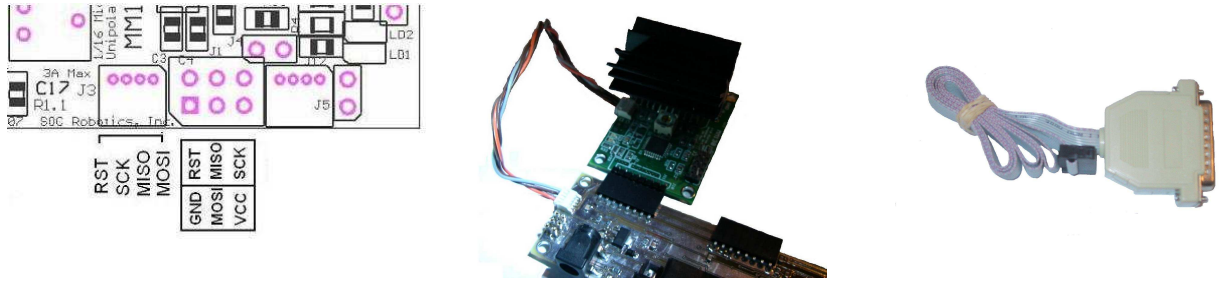


Figure 3-6. **ISP Programming Port and MCM-8 programming cable.**

4.0 Software Operation

4.1 Theory of Operation

The MM165 is driven by step and direction signals applied to connector J10. The MM165 is shipped with quarter step mode enabled. The MM165 supports full, wave, half, quarter, one eighth and one sixteenth step modes. Step mode can be changed by sending a command to the board via the I2C interface or by sending an encoded command on the step/direction signal lines. The direction signal must be set before the step pulse – the step pulse is a positive going raising edge that is held for at least 5useconds. The direction signal must not be changed during the step high level or the MM165 will enter Command Recognition mode.

The MM165 is shipped with a software application in which Command Recognition mode is enabled for the first five seconds of operation following power up after which Pass Through mode is activated. In Command Recognition mode all motion control and configuration setup commands are recognized. In Pass Through mode the step/direction signals are simply passed through the processor to the TB6560 driver. In Pass Through mode commands sent to the MM165 are no longer recognized. The MM165 defaults to Pass Through mode after 5 seconds to make sure the application software driving the MM165 works reliably. If the application driving the MM165 can meet the strict step/direction signal setup and hold times then Pass Through mode is not required and the more flexible Command Recognition mode can be used. Pass Through mode should also be used if the cables supplying the step/direction signals to the MM165 are noise prone. Pass Through mode activation can be changed to Command Recognition mode in the first 5 seconds of operation using the free application GSTepPP.exe available from our web site www.soc-robotics.com.

The motor drive chip TB6560PR is a bipolar microstepping driver with built in current sense resistors and logic to control drive current for a specific drive voltage. Motor torque is set in software – default is full torque. The TB6560 is designed to drive 2-3.5A motors but should be able to drive smaller motors without any trouble. The TB6560 has an over temperature Protection circuit that turns the driver off if die temperature exceeds a maximum value. Power must be cycled to re-enable the chip. The board power is applied through connector J10 and requires 5V regulated DC. The standard board runs at 20MHz.

4.2 Auxiliary IO

The MM165 has a number of auxiliary digital and analog inputs plus digital outputs that allow connection of rotary or linear position sensors and limit switches. The processor can be field programmed with new functions to process signals from these sensors and limit switches. An optional center tap joystick can be attached to the Auxiliary IO port.

4.3 Step Drive Connector

The MM165 controls an attached stepper motor by converting Step and Direction input signals on connector J10 to four Power Mosfets in the TB6560PR chip. By default the step signal is an active high pulse lasting at least 5 useconds in Pass Through mode and 20useconds in Command Recognition mode with optional noise reduction logic implemented in software. A high level on the Direction input causes a clockwise step. Default step mode is quarter step – step modes can be changed by sending commands encoded in the step/direction signal lines. If you are experiencing erratic operation then the application driving the MM165 is probably not meeting the minimum setup and hold times and the MM165 should be switched to Pass Through mode. In command recognition mode the direction signal can not go low before the step signal goes low – this arms the command recognition logic.

J10 also has I2C and limit/eStop switch inputs. Limit/eStop Switch inputs by default are not recognized but can be enabled by the user. Stepper motor operation can also be controlled through the I2C interface

independent of signals on J10 and by recognizing signals encoded on the step/direction lines. Operation of I2C is described in the next section.

4.4 Driver Commands

The MM165 accepts commands in two different communication formats: commands encoded on the step/direction lines (step/direction line toggling) and commands sent through the I2C interface.

Command Features

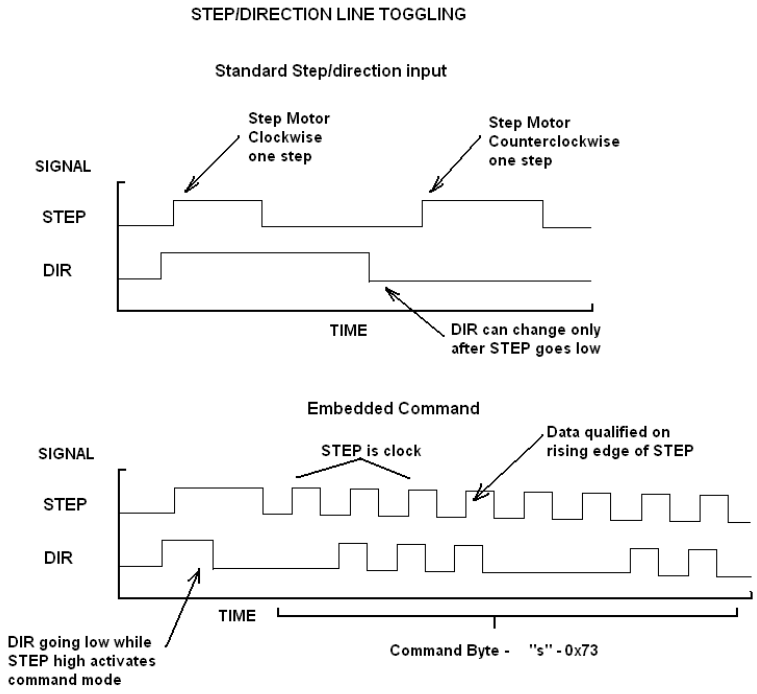
A script based parameter configuration utility allows the user to set the configuration options of each axis on an individual basis. Configuration parameters can be stored in on-chip EEPROM for automatic power up configuration control. A special built-in test/setup mode provides a simplified method for setting up the board. Configuration commands can be sent to the motor controller in real time using a special communications protocol based on the Step and Direction lines. A bi-directional communication utility provides a real time link with MM165 processor allowing dynamic change and update of system parameters on the fly. An API library is available to provide application developers access to the configuration features of the new software.

- New communication protocol for bidirectional data flow between the host and MM165 via the STEP/DIRECTION and Limit Switch lines and I2C
- The following parameters can be set by the user while the MM165 is operating:
    - Pass through mode enabled for noisy environments
    - Limit switch detection– enable, disable, smart enable, polarity settable
    - EStop switch detection– enable, disable, polarity settable
    - Step mode selection – wave, full, half, eigth, sixteenth
    - Automatic motor shut off – enable, disable and time period settable
    - Motor power - enable/disable
    - Motor decay mode and torque setting
    - Step rate, direction and number of steps to execute
    - Maximum step rate
    - Enable joystick following and set max pps and dead band at center tap
    - Distance traveled for each step in inch or metric
    - Feed Rate – ipm or cmpm
    - Linear or rotary distance commands in inch or metric
    - G1 G code commands accepted directly
    - Acceleration curve settable
    - Single Step - Clockwise or counterclockwise
    - Step Movement Direction Polarity – Clockwise or counterclockwise
    - Direction polarity settable – high – clockwise, high –counterclockwise
    - Backlash set
    - Communication mode – enable/disable
    - Save configuration settings in EEPROM

- Configuration parameters can be saved in EEPROM
- Stored configuration parameters can be read from the motor EEPROM using MK4Prog.exe and used to create a text based configuration script file

Step/Direction Line Toggling

Step/direction line toggling uses the step and direction signal lines to embed commands in step sequences. If the step and direction inputs are both high and the direction line is brought low before the step line is brought low the driver interprets this to mean a one byte command is about to be sent to the driver. The step line is then toggled as a clock input while data is encoded on the direction line. The driver does not interpret this pattern as a series of steps but as a command byte. By sending a string of bytes in this manner it is possible to send commands to the driver embedded within a stream of step signals. The exact format of the step/direction command byte is shown in the diagram below.



I2C Commands

An alternative communication protocol is to send and receive commands via the I2C interface lines. I2C is a Philips two wire (SDA and SCL) communications protocol that is widely supported by both host processors and embedded processors. See related documentation for a detailed description of I2C. The I2C interface defaults to address 0x14 but can be changed by sending a broadcast set address command. Note that each MM165 on a single I2C chain must have a unique address.

Both communication protocols support a common command set. Commands are typically ASCII character sequences. There are three classes of commands – Setup, Drive and Global. Setup commands select various configuration options, Drive commands activate stepper motor operation while Global commands configure the communications address of the board and activate a special multiple MM165's stepper motor operational state.

4.5 MM165 Command Overview

The MM165 processor responds to commands sent to it via the Step/Direction signal lines. Using a simple encoding procedure it is now possible to communicate with the Motor Controller via the Step, Direction and Limit switch lines. All commands are lower case letters and numbers. It is possible to

change Motor Controller operation and configuration on the fly while the controller is running. Configuration changes take effect immediately.

A command consists of two or more ASCII characters. Some commands require entry of integer or floating point numbers. A floating point number entered as an integer is interpreted correctly. Integer or floating point number must be terminated with a semicolon ";" character. Note that all commands are lower case characters. Commands are acted on immediately.

On power up the MM165 processor loads configuration settings from on chip EEPROM. If these settings are changed using the commands below the processor does not automatically store the new settings in EEPROM – the user must explicitly do this using the Save Settings command. If power is lost all changed settings will be lost if they have not been stored.

A desktop program called `GStepPP.exe` is used to send commands to the MM165. `GStepPP.exe` sends commands to a specific axis attached to a MK4 by entering the "c" character following by an axis identifier character (x,y,z,a) followed by one or more of the command sequences below all entered on one line. The command is sent to the driver when the enter key is pressed. Command Recognition mode must be enabled in the driver for commands to be recognized. An example of a command sequence is:

```
-cxs4
-cxcss
```

The first command instructs the x-axis driver to set the step mode to quarter step. The next command then stores this new setting in EEPROM so the next time the driver is powered up quarter step mode is activated. Some command functions can be halted by entering the character sequence `cxq`.

If the control software driving the MM165 does not need to support command mode then for increased reliability in noisy environments command recognition mode can be disabled by sending the command mode disable command `cxcci`. Once Command Recognition mode has been disable the only way to re-enable it to re-Flash the processors flash memory using a special programming utility (MK4Prog.exe) and a special cable.

NOTE: The MM165 is shipped with Command Recognition mode enabled for the first 5 seconds to allow you time to change configuration parameters such as step mode, holding torque, shut-off delay, etc without re-flashing the board using GstepPP.exe. Re-flashing the board requires a special programming utility and optional cable. Pass Through mode is the most reliable mode in noisy environments or in situations where you do not know how the host software is manipulating the step/direction lines.

The MM165 supports the following commands. A detailed description of each command follows.

Command Summary

All commands are printable ASCII characters.

s – Set Step Mode, 1-Full, 2-Half, 8-Eight, 6-Sixteenth `cxs2`

`q – Set Torque Mode, 1-100%, 2-75%, 3-50%, 4-20%`

`y – Set Decay Mode, 1-0%, 2-25%, 3-50%, 4-100%`

c – Enter Configuration Change Mode:
- s – Save settings to EEPROM (needs two 's') cxcss
- t – Pass through mode, a-active, i-inactive
- r – Reset Motor drive chip
- h – Turn motor power off
- c – Command Recognition mode, a-active, i-inactive
- n – Noise reduction mode, a-active, i-inactive
  - l – loop count for noise reduction – default 2, (int)
- f - Step/direction signals recognition enabled, y–yes, n-no
- i – I2C Mode o–on, f-off, a-address (int)
- e – EStop switch recognition, y–yes, n-no
- l – Limit switch recognition, y–yes, s–smart, n–no
- j - Joystick mode recognition, y-yes, n-no
  - h – hysteresis, default 12, (int)
  - s - scale, default 80.0, (float)
- p – Step polarity, p-positive, n-negative TBD
- d – Direction polarity, c–clockwise, w–counterclockwise
- a – Automatic motor power shut off mode, o-on, f-off
  - t – Time after which the motor power is shut off, seconds (float) cxcat25.5;
- b – Set backlash (float) cxcb24;
- x – Set acceleration parameter (float)
- m – Step resolution parameters
  - r – Resolution (float), cxcmr0.000125;
  - n – Minimum pps (float), cxcmn20.0;
  - x – Maximum pps (float), cxcmx2300;
  - m – Ramp rate (float)

d – Drive Motor Commands
- z – Zero absolute position
- g – Step continuously until told to stop
- h – Go to Home position, n-near side, f-far side, o-offset (float)
- i - Set feed rate (ipm), float cxdi10.0;
- s – Set step rate (pps), float cxds125;
- p – Pause execution (msec), int cxdp1000;
- c – Step clockwise
- w – Step counterclockwise
- l – Set slow step rate (pps), float
- f – Set fast step rate (pps), float
- m – Constant step cxdmw220000;1300;
  direction, stepmode, number of steps, step rate (pps)
- x – Ramp for n loops using default low high pps cxdx220;2000;4;
  stepmode, steps at each speed, constant step number, loops
- r – Ramp between low and high pps cxdr2300;2000;20;2000;

stepmode, slow step rate, high step rate, step increment, constant steps
d – Distance mode cxdd21.25;6.27;
stepmode, new position, feed rate (ipm)
t – Enter Test Mode
t – Toggle back and forth – all step modes, hit any key to exit
x – Ramp low to high – high to low – all step modes, hit any key to exit
v – Ramp low to high – high to low – enter step mode, hit any key to exit

l – Led Mode Command, 1-mode1, 2-mode2, 3-mode3

g – Return Data Command
b – Return controller busy status, b-busy, n-not busy
s – Return step mode
l – Return limit and estop switch enable state and value
a – Return auto motor shutoff setting and time

z - Enter Record Command Mode
b – Begin recording
h – Halt recording
e – Execute stored commands
a – Arm pin PB5 (SCK) to trigger execution of stored commands , o-on, f-off cxzao

4.6 Detailed Command Description

Step Mode Command

Set the driver step mode. The MM165 is a microstepping unipolar stepper motor driver capable of full, half, eight and one sixteenth microstepping.

s – Change Step Mode, 1-Full, 2-Half, 8-Eight, 6-Sixteenth
Set the driver step mode. Step mode is set to full, half, eight or one sixteenth microstepping. The following characters set the step mode:

1 – Full step mode
2 – Half step mode
8 - One eight step mode
6 - One sixteenth step mode

Examples: cxs1 cxs6

Note that changing step mode may not guarantee a smooth step transition. Step mode changes take effect immediately. If making these changes while to board is running you should reset the motor controller.

Configuration Change Commands

The configuration change commands set the basic default operating modes of the **MM165**. The user can turn command mode recognition on or off (if command recognition mode is turned off commands are no longer recognized), save settings to EEPROM, enable a noise reduction mode, enable step/direction recognition, set EStop and limit switch recognition, change direction polarity, automatically turn holding torque on/off and time, set backlash and step resolution, minimum and maximum pps and ramp rate.

c – Enter Configuration Change mode:
- s – Save settings to EEPROM (needs two 's') cxcss
- t – Pass through mode, a-active, i-inactive
- r – Reset Motor drive chip
- h – Turn motor power off
- c – Command Recognition mode, a-active, i-inactive
- n – Noise reduction mode, a-active, i-inactive
  - l – loop count for noise reduction – default 2, (int)
- f - Step/direction enable, y–yes, n-no
- i – I2C Mode o–on, f-off, a-address (int)
- e – EStop switch recognition, y–yes, n-no
- l – Limit switch recognition, y–yes, s–smart, n–no
- j - Joystick mode recognition, y-yes, n-no
  - h – hysteresis, default 12, (int)
  - s - scale, default 80.0, (float)
- p – Step polarity, p-positive, n-negative TBD
- d – Direction polarity, c–clockwise, w–counterclockwise
- a – Automatic motor power shut off mode, o-on, f-off
  - t – Time after which the motor power is shut off, seconds (float) cxcat25.5;
- b – Set backlash (float) cxcb24;
- x – Set acceleration parameter (float)
- m – Step resolution parameters
  - r – Resolution (float), cxcmr0.000125;
  - n – Minimum pps (float), cxcmn20.0;
  - x – Maximum pps (float), cxcmx2300;
  - m – Ramp rate (float)

c – Enter Configuration Change Mode
Top level command. Any characters entered after the "c" character are interpreted as configuration change commands.

s – Save Settings to EEPROM (needs two 's') `CXCSS`
Save all configuration parameters to EEPROM. Once saved in EEPROM the next power cycle of the board loads the new settings at power up. Note that if any configuration parameters are changed they remain in effect as long as the power is applied. Configuration changes are not automatically stored – the user must use this command to save any configuration changes. Note that two "s" characters are required.

t – Pass through mode, a-active, i-inactive
Set Pass Through Mode to active or inactive. Pass through mode is a special operating state of the MM165 that disables command recognition on both the I2C and Step/Direction lines. This mode when active ensures the step and direction signal levels are recognized under all conditions. If the setup and hold times for command recognition on the step/direction lines can not be guaranteed then the MM165 may accidently enter command mode. This can also happen if there is excessive noise on the step/direction signal lines. Once Pass through mode is activated no commands are recognized – the only way to re-enable command mode is to re-flash the processor.

r – Reset Motor Drive Chip
Sets the motor drive chip to a known start state. Note that the motor rotor may be in an intermediate start position if any microstepping modes were selected.

h – Turn motor power off

This command turns motor power off. Motor power is reapplied on the next step input.

c – Command Recognition Mode, a-active, i-inactive
Command recognition mode is enabled or disabled by this command. Once command recognition mode has been disabled the only way to re-enable is to either re-powered to the board (if this setting was not saved) or re-program the processor. In noisy environments it may be necessary to disable command recognition mode so noise spikes on the step/direction lines are not mistakenly interpreted as step signals. By default command recognition mode is active. If a desktop application that is generating setup and holds times are not within specification then if may be necessary to turn Command Recognition mode off – note this applies to Commands encoded in the Step/Direction input lines only and not recognition of commands received on the I2C lines.

n – Noise Reduction Mode, a-active, i-inactive
l – loop count for noise reduction – default 2, (int)
In noisy environments a special noise reduction mode can be enabled. Noise reduction adds delay to the step pulse recognition logic. If step pulses are shorter than 5usec noise reduction mode should not be used. The loop count parameter sets the duration of the noise reduction period. By default noise reduction is disabled.

f - Step/Direction Enable, y–yes, n-no
Recognition of step/direction signals can be enabled or disabled. Step/direction signal recognition maybe disabled if step commands are encoded on the step/direction lines or I2C lines. By default Step/direction recognition is enabled.

i – I2C Mode o–on, f-off, a-address (int)
Commands received on the I2C signal lines can be enabled or disabled. By default I2C recognition is disabled. The default I2C address can also be set. By default I2C mode is disabled.

e – EStop Switch Recognition, y–yes, n-no
EStop switch detection can be enabled, disabled. When disabled the state of the EStop switch has no effect on motor operation. If enabled the motor will stop immediately and remained stopped as long as the EStop switch is active. Motor operation will resume if the EStop switch active state is removed or EStop Switch detection is disabled. EStop switch inputs are pulled high with a 10K resistor so to activate an eStop event the switch must pull the high level to ground. By default EStop recognition is disabled.

l – Limit Switch Recognition, y–yes, s–smart, n–no
Limit switch detection can be enabled, disabled or smart enabled. When disabled the state of the limit switch has no effect on motor operation. If enabled the motor will stop immediately if the Limit Switch becomes active (a low level) and the motor must be moved manually off the stop position. Alternatively if a limit switch event has occurred then by disabling limit switch recognition it is possible to move the stepper motor. If Smart mode is enabled the motor will respond to move commands in the direction away from the switch. Limit switch inputs are pulled high with a 10K resistor so to activate a limit switch event the switch must pull the high level to ground. By default Limit switch recognition is disabled.

j - Joystick mode recognition, y-yes, n-no
A center tap joystick potentiometer can be attached to the auxiliary IO port pin ADC7 with either ends of the potentiometer attached to GND and AREF. If joystick mode recognition is enabled then movement of the joystick off center position will cause the stepper motor to move clockwise or counterclockwise at a rate set by the degree by which the joystick is off center. The potentiometer output swings from 2.5V at the center to GND or 5V. The joystick voltage output is converted to a digital value using the processors on chip A/D converter. The converted value ranges from 0 to 256. By default there is a hysteresis (dead band) at the center position to compensate for play in the potentiometer. This parameter can be set larger

or smaller using the 'h' command followed by an integer position. The default hysteresis is set to 12 representing 5% of joystick range. A second scale factor parameter converts the joystick input to pulses per second by multiplying the joystick input by the scale factor. Assuming the center point is 128 with hysteresis of 12 once the joystick input reaches 128+12=140 any increase over this will cause the stepper motor to move. A scale factor is applied to the joystick input to convert that number to a pps number. The default scale factor is 80. With a full range input of 256-128-12=116 this give a maximum pps of 116*80=9280pps. Default step mode is quarter step so this results in a maximum full step rate of 2320. Both the hysteresis and scale factor can be change to suit the characteristics of the stepper used. Scale factor changes are made using the 's' command.

Example:

cxcjy - Enable joystick following
cxcjh14 - Change joystick hysteresis to 14
cxcjs50.0; - Change scale factor to 50.0

p – Step Polarity, p-positive, n-negative TBD
Change the polarity of the step input signal. This function has not been implemented in the current version of the software. By default step polarity is an active going high pulse.

d – Direction Polarity, c–clockwise, w–counterclockwise
Change polarity of the direction input signal. Sets the direction the stepper motor turns when the direction signal is high. Note that depending on how the motor was wired clockwise and counterclockwise directions may be flipped. This command allows the user to flip the direction of rotation. By default the high level selects clockwise rotation.

a – Automatic Motor Power Shut Off Mode, o-on, f-off
t – Time after which the motor power is shut off, seconds (float)
After a step operation completes holding torque can be activated or deactived. If activated torque the time hold torque is applied can be set. The time duration is set in 0.1 second increments from a 1/10 of a second to 6000 seconds. Depending on the application if holding torque is applied for long time periods driver and motor overheating may result.

Example:

cxcao - Enable automatic power shut off
cxcaf - Disable automatic power shut off
cxcat1; - Turn motor power off after 1 second

b – Set Backlash
If the backlash of the lead screw is known this command calibrates the absolute position command when direction changes. The backlash is the number of steps required to move the thrust nut in direction change operations.

Example: `cxcb24; - Set backlash to 24 steps`

x – Set acceleration parameter (float)
The acceleration parameter controls the rate of change of stepping. Stepper motors operate within a specific pull-in pull-out torque band. A stepper motor can not instantly change speed. The acceleration parameter sets the maximum rate of change. The parameter is a floating point number between 1 and 25,000. 1 gives very slow acceleration while 25,000 is almost instantaneous.

Example: cxcx1000.0;

m – Step Resolution Parameters

r – Resolution (float), `cxcmr0.000125;`
n – Minimum pps (float), `cxcmn20.0;`
x – Maximum pps (float), `cxcmx2300;`
m – Ramp rate (float)

The distanced traveled for a single step is used to calibrate the absolute position move command. Typically this parameter depends on the tpi of the lead screw and step mode. For example a 20tpi screw moves a carriage by 0.00025 inch in full step mode. The parameter is entered as a floating point number. The minimum pulse per second (pps) setting is used by the test and drive commands to set the slow step rate. The parameter is entered as a floating point number. The maximum pps setting is used by the test and drive commands to set the high step rate. The Ramp rate is a parameter that sets the acceleration for the test, drive and absolute position commands.

Drive Motor Commands

Enter drive motor command function. The drive mode allows step commands to be executed directly by the on board processor. Relative and absolute step position functions are supported. Most of the commands can be terminated early by entering the exit command: `cxe`

d – Drive motors (enter direction and step rate), e-exit (entered at any time)
z – Zero absolute position
g – Step continuously until told to stop
h – Go to Home position, n-near side, f-far side, o-offset (float)
i - Set feed rate (ipm), float
s – Set step rate (pps), float
p – Pause execution (msec), int
c – Step clockwise
w – Step counterclockwise
l – Set slow step rate (pps), float
f – Set fast step rate (pps), float
m – Constant step `cxdmw220000;1300;`
direction, stepmode, number of steps, step rate (pps)
x – Ramp for n loops using default low high pps `cxdx220;2000;4;`
stepmode, steps at each speed, constant step number, loops
r – Ramp between low and high pps `cxdr2300;2000;20;2000;`
stepmode, slow step rate, high step rate, step increment, constant steps
d – Distance mode `cxdd21.25;6.27;`
stepmode, new position, feed rate (ipm)

z – Zero Absolute Position

Set the internal position counter to zero. This command resets the home position. The absolute position command converts a distance command to the required number of steps based on the backlash and step resolution commands.

g – Drive Motor Continuously (c-clockwise, w-counterclockwise, s-stop)

Drive the motor continuously clockwise or counterclockwise until told to stop. The motor will step at a rate set by the pps command with a direction set by the character immediately after the "g". After sending the 'g' character send a 'c' step clockwise, 'w' to setp counterclockwise and 's' to stop stepping.

Example:

`cxdgc`	Step motor continuously clockwise
`cxdgw`	Step motor continuously counterclockwise
`cxdgs`	Stop stepping motor continuously

h – Go to Home Position
Move to the home position which is closest to the stepper motor with the limit switch activated. This command should be used in combination with the Limit Switch Smart setting. There are three parameters that set which end the home position is located at and an offset from the limit switch. The offset allows the home position to be located at any position between either end of the travel.

Example:

`cxdhn`	Home position located at near side
`cxdhf`	Home position located at far side
`cxdho1.25;`	Home position is offset by 1.25 in from limit switch

i - Set Feed Rate (ipm)
Set the feed rate in inch per minute (ipm). This command sets the step rate based on the step resolution. The parameter is entered as an integer or floating point number.

Example: `cxdi12.25;` - Set feed rate to 12.25 inch per minute.

s - Set Step Rate (pps)
Set the step rate in pulses per second (ppm). This command sets the step rate based on the number of steps per second. The parameter is entered as an integer or floating point number.

Example: `cxds125;` - Set step rate to 125 steps per second.

p – Pause execution (msec)
Pause execution for a period of time. The time period is entered as an integer and is in mseconds. This command allows precisely timed delays to be added to stored programs.

Example: `cxdp1000;` Pause for 1 second.

c – Step clockwise
Step clockwise one step using the existing step mode. Note that if the desired step direction is not clockwise use the Step Direction Polarity command to change the direction.

w – Step counterclockwise
Step counterclockwise one step using the existing step mode. Note that if the desired step direction is not counterclockwise use the Step Direction Polarity command to change the direction.

s – Set slow step rate (pps)
Set the slow step rate in pulses per second (pps). This command sets the slow speed step rate that is used by several other commands such as the ramp command. The parameter is entered as an integer or floating point number.

Example: `cxds1300;` - Set slow step rate to 1300 pps.

f – Set fast step rate (pps)

Set the fast step rate in pulses per second (pps). This command sets the slow speed step rate that is used by several other commands such as the ramp command. The parameter is entered as an integer or floating point number.

Example: `cxdf1300;` - Set fast step rate to 1300 pps.

m – Constant step
Step at a constant rate (pps) given an entered direction, step mode and number of steps. This command allows a set of step parameters to be entered. Variable length parameters such as step rate may be entered as an integer or floating point number. Direction is "c" or "w". Step mode is 1, !, 2, @, 4, 8 or 6.

Entered parameters: direction, stepmode, number of steps, step rate (pps)

Example: `cxdmw220000;1300;` - Step CCW, half step, 20000 steps at 1300 pps
`cxdmc41000;400;` - Step CW, quarter step, 1000 steps at 400 pps

x – Ramp for n loops using default low high pps
Ramp from a low step rate to a high step rate, step at the maximum step rate for the entered number of steps and then step from the high step rate to the slow step rate stepping the entered number of steps at each speed and repeat for the entered number of loops. The slow and fast step rate are entered using the "s" and "f" drive commands. Note variable length command parameters are terminated with a ";" character.

Entered parameters: stepmode, steps at each speed, constant step number, loops

Example: `cxdx220;2000;4;` - Ramp using half step, 20 steps at each ramp increment, 2000 steps at max rate and loop 4 times
`cxdx410;20000;14;` - Ramp using quarter step, 10 steps at each ramp increment, 20000 steps at max rate and loop 14 times

r – Ramp Between Low and High pps
Ramp from a low step rate to a high step rate, step at the maximum step rate for the entered number of steps and then step from the high step rate to the slow step rate stepping the entered number of steps at each speed and repeat for the entered number of loops. The slow and fast step rate are entered using the "s" and "f" drive commands. Note variable length command parameters are terminated with a ";" character.

Entered parameters: stepmode, slow step rate, high step rate, step increment, constant steps

Example: `cxdr2300;2000;20;2000;` - Ramp using half step from 300 pps to 2000 pps incrementing 20 steps per speed change and step 2000 steps at the maximum rate.
`cxdr1200;700;10;1000;` - Ramp using full step from 200 pps to 700 pps incrementing 10 steps per speed change and step 1000 steps at the maximum rate.

d – Distance Mode

Move to an absolute position at the entered feed rate (ipm) given an entered step mode. The new position is entered as inches, step rate is inch per minute and step mode is 1, !, 2, @, 4, 8 or 6. At first power up the home is set to zero. Positive or negative absolute positions can be entered. Backlash compensation is applied automatically and step resolution defines the number of steps either clockwise or counterclockwise. The function automatically compensates for step mode changes so if a position command says move to absolute position 1.000 at full step and then step to 0.000 at half step the carriage will return the exact starting point.

Entered parameters: stepmode, new position, feed rate (ipm)

Example: `cxdd21.25;6.27;  - Ramp using half step from 300 pps to`

Test Mode Commands

Enter test mode. Test mode commands drive the stepper motor through a series of direction toggle and ramp motions.

t – Enter Test mode
- t – Toggle back and forth – all step modes, hit any key to exit
- x – Ramp low to high – high to low – all step modes, hit any key to exit
- v – Ramp low to high – high to low – enter step mode, hit any key to exit

t – Enter Test Mode
Enter the test mode state and interpret any subsequent characters as test mode selections.

t – Toggle Back and Forth – All step modes, hit any key to exit
This command causes the drive to step the motor in the clockwise direction for a defined number of steps and then step in a counterclockwise direction the same number of steps at a pre-defined pps rate starting with full step mode and sequencing through all the step modes. Entering cxq caused the sequence to terminate.

x – Ramp Low to High/High to Low – All step modes, hit any key to exit
This command causes the driver to step the motor through a clockwise then counterclockwise motion while ramping the speed from a minimum pps rate to a maximum pps rate sequencing through all step modes from full to sixteenth step.

v – Ramp Low to High/High to Low – Hit any key to exit
This command causes the driver to step the motor through a clockwise then counterclockwise motion while ramping the speed from a minimum pps rate to a maximum pps rate at an entered step mode and loop count.

Entered Parameters: step mode, loop count

Example: `cxtv210` - Ramp in half step mode and repeat 10 times.

LED Display Mode Command

The user can set the display mode of the LEDs to one of three different display status modes. This function has not been implemented in the current software version. Mode 1 is active.

l – Led mode, 1-mode1, 2-mode2, 3-mode3
Set the led display mode. Command character is "l". Sets mode 1, 2 or 3.

Mode 1 (Default mode in command recognition mode)
Green led displays status of stepper motor power: on - power being supplied to motor, off – no power to motor. Red led displays step rate and blinks when driver is waiting for a step signal– led blinks for each step signal sent to the motor. The slow blinking Red led indicates the driver processor is alive and waiting for a step command.

Mode 2 (Default mode if pass through mode active)
Green led displays status of stepper motor power: on - power being supplied to motor, off – no power to motor. Red led display step direction – on – clockwise, off – counterclockwise.

Mode 3
The on or off condition of the Green and Red LEDs is set using commands. The next character selects the Red or Green Led and the state (on or off).

Entered Parameters: led, state (on-o, off-f)

Examples:
cxlro - Turn the Red Led on
cxlgf - Turn Green Led off.

Return Command Status (I2C only)

The MM165 can return the status of several parameters and the busy status of the processor. The MM165 may take a while to execute certain commands. The return status command indicates the status of the processor as either busy or not busy. If commands are sent to the MM165 without regard for the time it takes to execute commands then a command overrun condition can occur. If a sequence of commands must be sent to the device then the gb command provides a method to meter the flow of commands so a command overrun condition does not occur. Note that the return data commands are implemented on the I2C interface only and do not return any data on the step/direction lines. A future version may allow this.

g – Return data command
b – Return controller busy status, b-busy, n-not busy
s – Return step mode
l – Return limit and eStop switch inputs
a – Return auto motor shutoff setting and time

b – Return controller busy status, b-busy, n-not busy
Return the driver busy status. If the MM165 is busy executing a command or function then the get busy command will return a 'b' – if the driver is not busy then 'n' is returned.

Example: gb returns 'b' or 'n'

s – Return step mode
Return the driver step mode. Step mode is set to full, half, eight or one sixteenth microstepping. The following characters are returned to indicate the current set step mode:

1 – Full step mode
2 – Half step mode

8 - One eight step mode
6 - One sixteenth step mode

A single byte is returned set to one of the characters above.

Examples: gs returns '1', '2', '8' or '6'

l – Return status of limit and estop switch enable state and level
Return the status of the limit switch and eStop switch state and current level. Four bytes are returned. The state of Limit switch checking is returned as either 'y' for enabled, 'n' for disabled and 's' for smart mode. EStop switch state checking is return as 'y' for enabled or 'n' for disabled. The level is returned a 'h' for high and 'l' for low. Four bytes are returned. The first two are the setting of the limit switch state (enabled, disabled or smart) followed by the level on the limit switch input (high or low). The next two bytes are the setting of the eStop state (enabled or disabled) followed by the level (high or low).

Examples: gl returns 'yhyh' if both limit and estop switch checking is enabled and not activated

a – Return auto motor shutoff setting and time
Return the status of the auto motor power shutoff parameter and the time associated with auto motor shutoff. Three bytes are returned. The first byte contains the auto motor shut off parameter that is either 'o' for on or 'f' for off. The turn off time is a two byte binary number in seconds.

Examples: ga returns 'o' or 'f' and a two byte binary number

Record Commands Mode

The MM165 processor has approximately 1900 bytes of EEPROM storage space that can be used to record canned command sequences. Commands to be recorded are any valid commands sent to the MM120 via the I2C or Step/Direction lines. For example, if the stepper motor needs to move a platform 1 inch left, pause for five seconds then move back 1 inch the following procedure accomplishes that. First start recording mode by sending the 'b' command. Now send the sequence of commands to execute the desired motion. At the completion of the motion send the 'h' command to halt recording. The motion sequence is not stored in the control processors EEPROM. To execute the stored motion send the 'e' command or pull the Aux IO Port pin PB5 low. Only one stored command sequence can be loaded into EEPROM and the length is limited to 1900 characters. The PB5 pin is pulled high by a 10K resistor so an additional pull up resistor is not required. A simple normally open switch is all that is necessary to pull PB5 low. Note that PB5 pin recognition must be enabled in order to have any effect.

z - Enter record command mode
b – Begin recording
h – Halt recording
e – Execute stored commands
a – Arm pin PB5 (SCK) to trigger execution of stored commands , o-on, f-off

Example:

```
cxzb
cxdd21.00;5.45;
cxdd21.25;6.57;
cxdp2000;
```

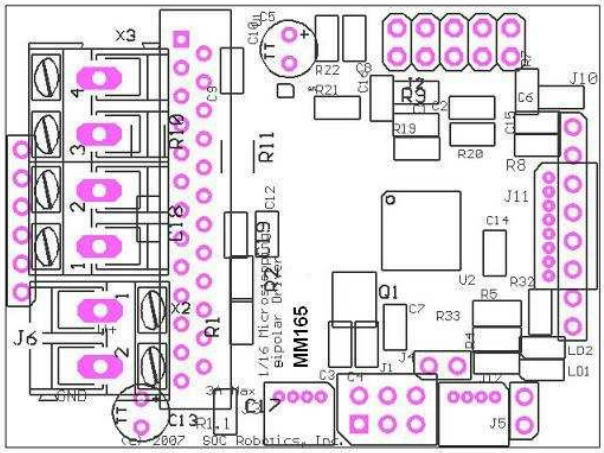
```
cxdd21.00;6.57;
cxdd20.0;5.45;
cxzh
cxze
```

In the example above the record command mode is entered followed by a movement of the carriage from position 0 to position 1.00 at 5.45 inch/minute, then the carriage is instructed to move to 1.25 at 6.57ipm followed by a pause for 2 seconds then it moves back to 1.00 at the same rate and finally returns to the starting position 0.00. Recording mode ends when the halt recording command is entered. The complete motion sequence is then executed by the start execution command or pulling PB5 (pin 2) low.

5.0 Electrical and Mechanical Description

5.1 Component Layout

Components are mounted on the top side of the board. Not all components may be mounted. See the section on optional components for more information.



5.2 Electrical Specifications

Electrical

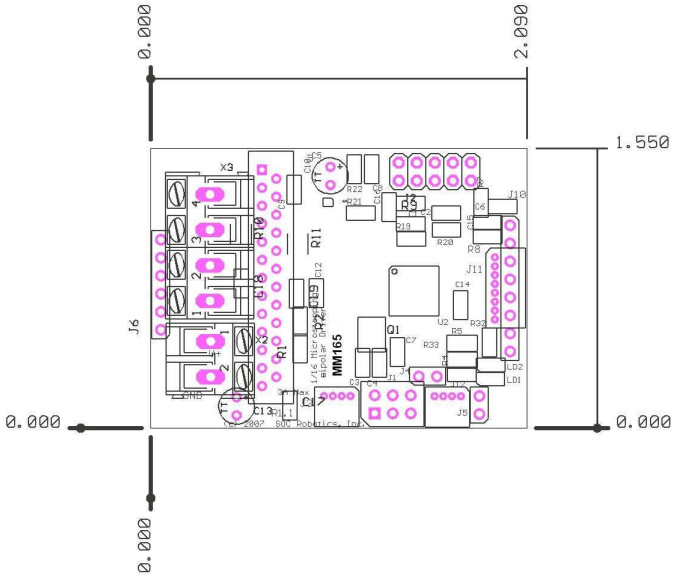
Input power: 5VDC @ 20ma

Mechanical

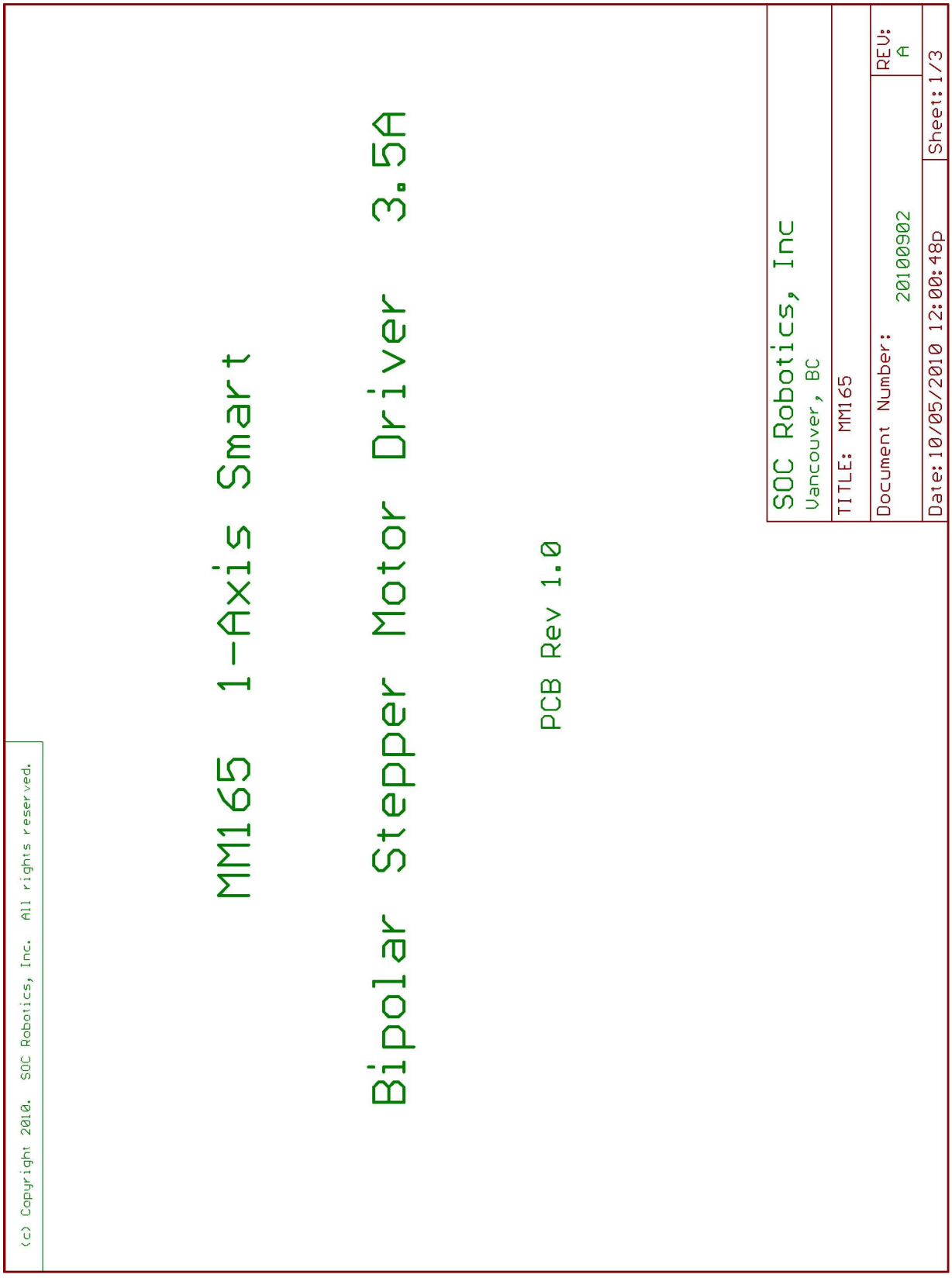
Dimensions: 2.12x1.58 in (one mounting hole)
Weight: 38 grams

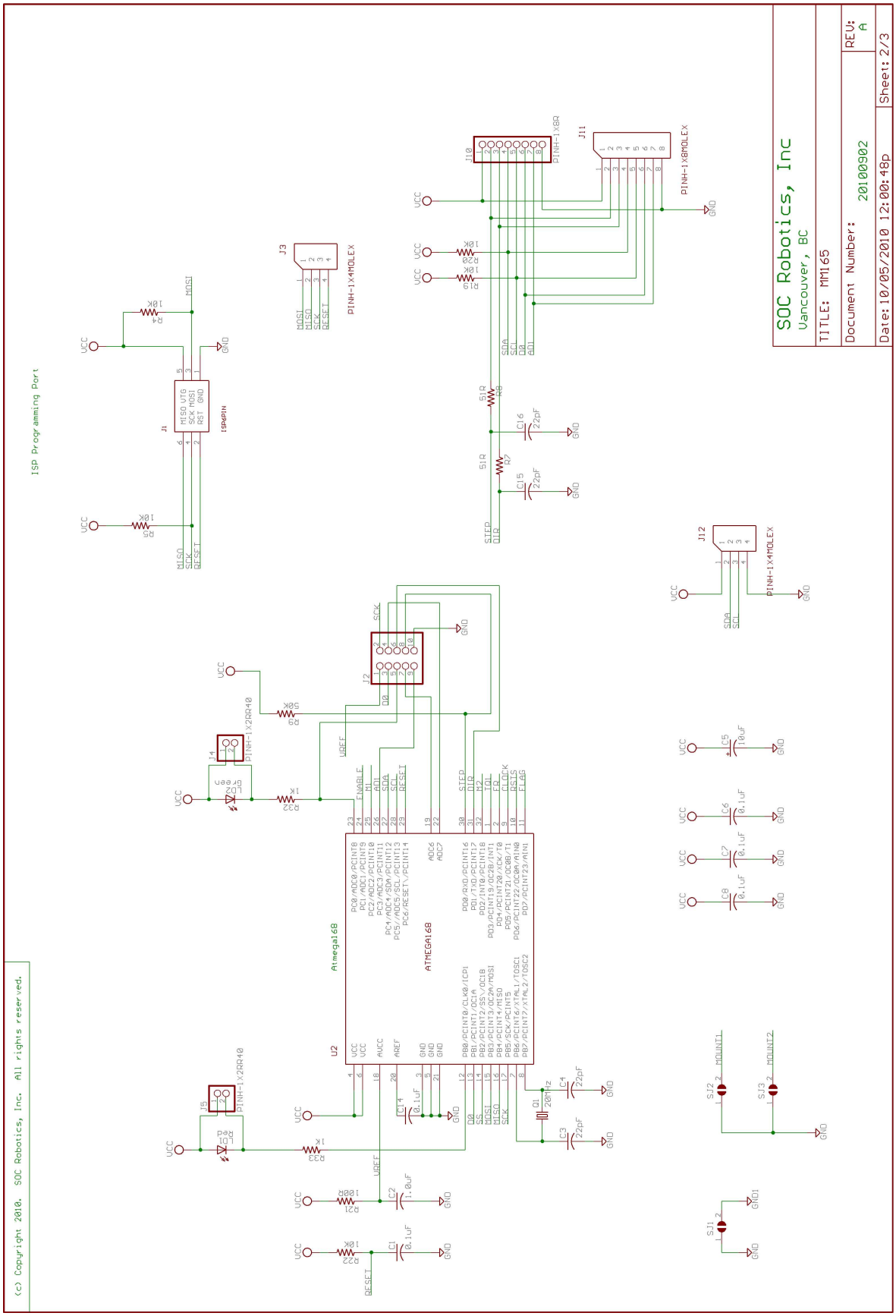
5.3 Mechanical Dimensions

Board dimensions are stated in inches.



6.0 MM165 Circuit Schematics

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Vancouver, BC
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Date: 10/05/2010 12:00:48p
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ISP Programming Port
ATMEGA168
Atmega168
PINH-1X4MOLEX
PINH-1X8MOLEX
PINH-1X2RA40
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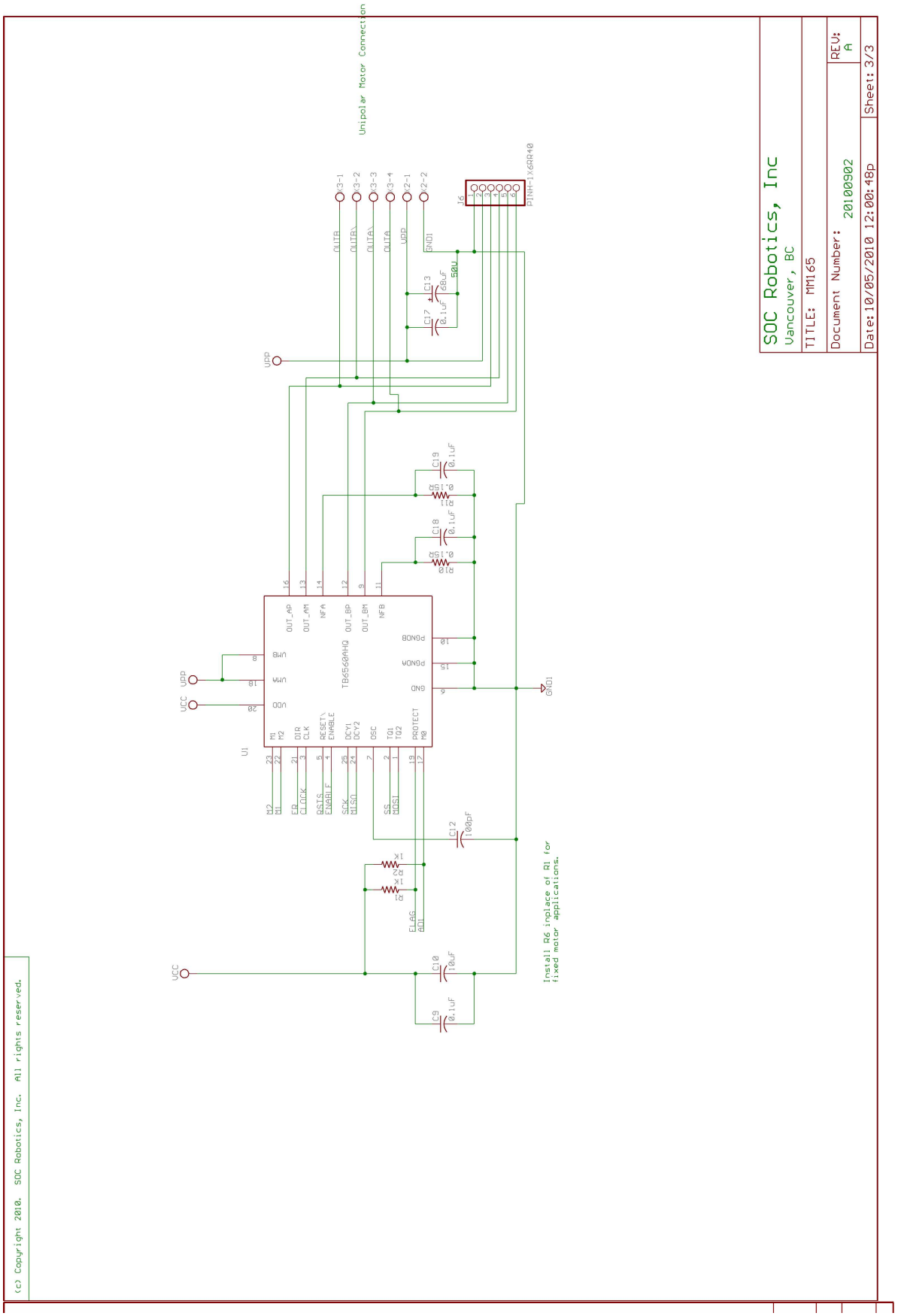
Unipolar Motor Connection
SOC Robotics, Inc
Vancouver, BC
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TB6560AHQ
Install R6 inplace of R1 for fixed motor applications.
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Notes: