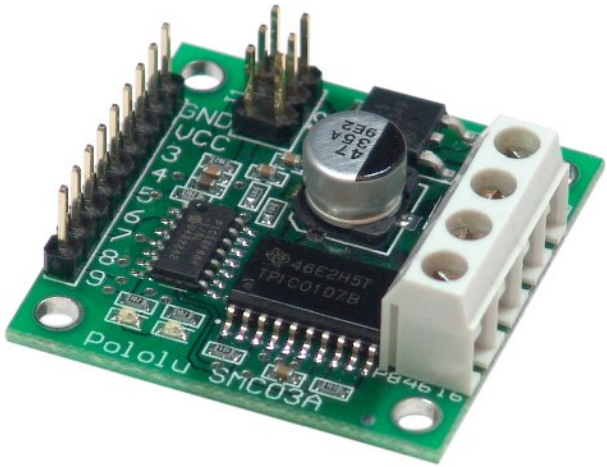
3-Amp Motor Controller with Feedback

User's Guide (preliminary)



Contents:

- Safety Warning
- Contacting Pololu
- Motor Controller Layout and Pinouts
- Connecting the Motor Controller
- PID Control and the Motor Feedback Modes
- Basics of the Serial Interface
- Using the Motor Controller
- Example BASIC Stamp II Program
- Troubleshooting Tips
- Configuring the Motor Controller
- Description and Specifications

© 2005
http://www.pololu.com/

Important Safety Warning

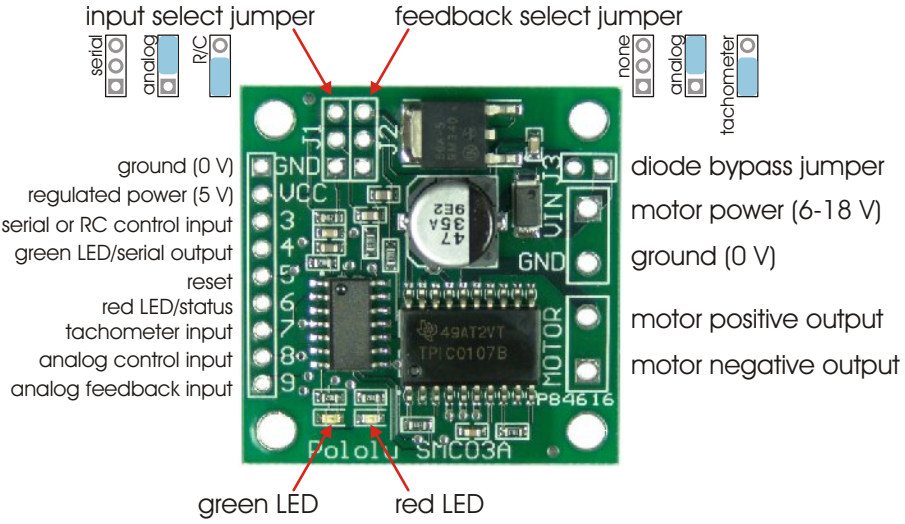
The motor controller module is not intended for young children! Younger users should use this module only under adult supervision. **By using this product, you agree not to hold Pololu liable for any injury or damage related to the use or to the performance of this product. This product is not designed for, and should not be used in, applications where the malfunction of the product could cause injury or damage.**

Contacting Pololu

You can check the Pololu web site at **http://www.pololu.com/** for the latest information about the motor controller, including color pictures, application examples, and troubleshooting tips.

We would be delighted to hear from you about your project and about your experience with our motor controller. You can contact us through our online feedback form or by email at support@pololu.com. Tell us what we did well, what we could improve, what you would like to see in the future, or anything else you would like to say!

Motor Controller Layout and Pinouts



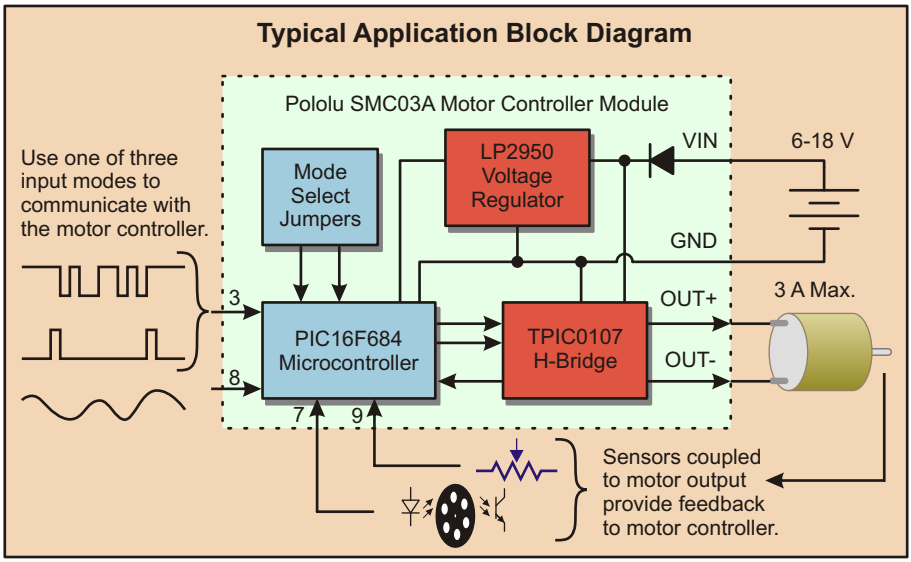
Connecting the Motor Controller

The connections to the motor controller are shown on the facing page, and the block diagram below shows how the motor controller would typically be integrated into a motion control system. There are three main connections to make: the motor itself, the motor power, and motor control inputs. For the control inputs, you can use one of three motor control interfaces (serial, hobby radio control, or analog voltage) and one of two optional feedback options (tachometer for speed feedback or analog voltage for position feedback).

Connecting Power. The main power connections for the motor controller are on the upper-right corner of the board. Your power source should be between 6 V and 18 V, and it must be able to supply the current that the motor will draw.

A reversed-battery protection diode is incorporated into the motor controller. This diode has a low voltage drop but still results in a few tenths of a volt being lost between the battery voltage and the motor output (in addition to the losses of the motor driver H-Bridge). This diode can be bypassed by installing a shunt in location "J3".

Connecting the Motor. The motor output ports are on the lower-right corner of the board. The polarity of the motor connection does not matter too much, but the "motor positive output" will be positive when the motor is set to go "forward" with the motor direction reverse option turned off. Of course, "forward" is a relative term, and if the motor goes in the opposite direction from what you desire, you can switch the two motor lead connections or enable the motor direction reverse setting.



Connecting the Motor Controller (continued)

Control Inputs. The control inputs are the connection points for the main controlling unit (such as a robot controller or radio control receiver) and any feedback signals. The control inputs are along the left side of the board, and their functions depend on the modes selected by the input select and feedback select jumpers. The "Vcc" connection provides regulated 5 V that can be used as a power source for the feedback sensors or for the main control unit. The current drain from this pin should not exceed 90 mA.

Reset (pin 5). The reset input is internally kept high (at 5 V) through a 1 kOhm resistor. Bringing this line low for at least 2 microseconds will reset the motor controller, bringing it to the same state as if it had just been turned on. This input can generally be left disconnected.

Status outputs (pins 4 and 6). Pins 4 and 6 are connected to the red and green LEDs and indicate various statuses depending on the modes selected by the input select and feedback select jumpers. These outputs can generally be left disconnected.

Motor Control Interfaces

The motor controller supports either an analog voltage interface, a hobby RC (radio control) interface, or a serial interface. Each interface allows you to control either the direction and speed or the position of the motor, depending on the feedback mode you choose: no feedback, analog voltage (motor position) feedback, or tachometer (motor speed) feedback.

Analog Voltage Interface
The analog voltage interface allows you to control the motor using a device that outputs an analog voltage, such as a potentiometer. To select the analog voltage interface, place a shorting block across the upper two pins in the "input select jumper" (J1) as illustrated on page 2.

The neutral, or stopped value for the analog input is 2.5 V. Lowering the voltage will increase the speed in reverse; raising the voltage will increase the speed forward.

Hobby RC (Radio Control) Interface
The Hobby RC interface allows you to control the motor with a standard hobby RC transmitter and receiver pair; you can also use any device that outputs the standard servo control signal (50 Hz train of 1-2 ms pulses), such as a serial servo controller. To select the hobby RC interface, place a shorting block across the lower two pins in the "input select jumper" (J1) as illustrated in page 2. Connect a ground line off of the receiver to the motor controller GND pin and the RC control signal to pin 3.

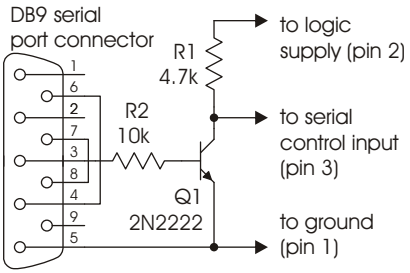
A 1.5-ms pulse is neutral or stopped, with longer pulses raising the speed forward and shorter pulses increasing the speed in reverse.

Serial Interface

The serial interface allows motor control with a series of commands over an asynchronous serial link. This interface would typically be used with a computer or robot controller. The serial link must be non-inverted, with a baud rate of approximately 2,000-40,000. The motor controller will automatically detect the baud rate that you are using. The serial input is pin 3.

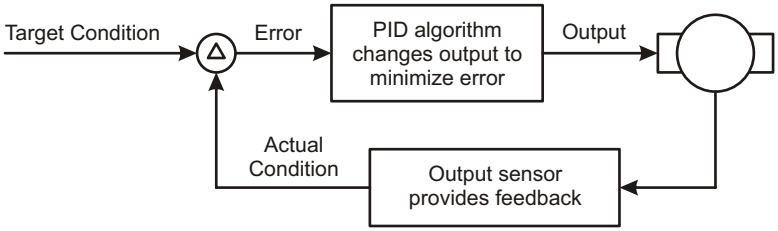
The details of the serial interface are covered in "Basics of the Serial Interface" below.

Important note: unlike RS-232 serial lines (the standard for serial ports used to connect devices to personal computers), the motor controller uses logic voltages between 0 and the supply voltage (5 V). The higher voltages used on RS-232 lines will damage the motor controller. If you need to convert RS-232 levels to TTL levels, you will need to use a level converter such as the MAX220 (made by Maxim). You could also use the simple circuit shown to the right. (The handshaking lines, pins 4, 6, 7, and 8 on a DB9 connector might be necessary depending on the serial port and software accessing it.) **When building circuits that connect to a PC, be especially careful because you could potentially destroy the PC's serial port. Before attempting to connect your own electronics to a computer, make sure you know what you are doing!**



PID Control and the Motor Feedback Modes

The primary feature of this motor controller is the ability to use feedback from sensors to continually update the motor operation. If one of the two feedback modes is enabled, the motor controller uses a proportional-integral-derivative (PID) algorithm to continually minimize the feedback error. This error is the difference between the desired condition, set by the user through one of the input modes, and the actual condition, reported back by a sensor that somehow monitors the motor output. Two separate types of sensors are supported: an analog voltage sensor and a frequency sensor. The general concept of feedback-based control is illustrated below:



Analog Voltage Motor Feedback (Position)

In position feedback mode, an analog voltage representing a measurement of the output is connected to pin 9. The voltage range must be 0-5 V, and this voltage is converted into an 8-bit representation. A potentiometer is the most typical sensor for this mode, but any other device that provides an analog voltage output, such as the Sharp GP2Y0A21YK optical distance sensors, can be used.

Frequency Motor Feedback (Speed)

In frequency feedback mode, an oscillating signal is connected to pin 7. The frequency of the oscillation is measured with 7 bits of resolution. A typical application for this mode of operation is a tachometer that uses an infrared emitter and detector pair and a slotted wheel to measure rotational speed.

The PID Calculation

The motor controller minimizes the error between the desired state and the measured state using three terms: one that is proportional to the error, one that is proportional to the integral of the error (limited to 255), and one that is proportional to the derivative of the error. The full equation for the calculation is

$$\text{output} = c_E E + c_I \Sigma E + c_D \frac{\Delta E}{T_{PID}}$$

where E is the error, c_E, c_I, and c_D are the user-specified coefficients, and T_{PID} is the PID loop period, which is also user configurable.

Each of the three coefficients are specified through two parts: a multiplicative coefficient and an exponent that divides the result. For example, setting the parameters ERRORMULT to 29 and ERRORDIV to 3 will result in the error term being multiplied by $29/2^3 = 29/8 = 3.625$.

The PID loop period is a multiple of the PWM (pulse width modulation) period of 510 microseconds, based on the PIDRATE parameter, of which bits 6-3 specify a coefficient and bits 2-0 specify a base-2 exponent:

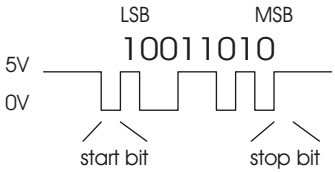
$$T_{PID} = 510\ \text{us} \times [(\text{PIDRATE6:3}) + 1] \times 2^{\text{PIDRATE2:0}}$$

All of the parameters can be set through the serial interface, and the optimal coefficients must be determined experimentally. In general, begin by setting the proportional term and leaving the integral term and derivative term 0. Depending on the application, a proportional term alone could cause oscillations or inability to correct for small errors. Increasing the integral term improves correction for small errors but can contribute to oscillation if the integral term is too large. The derivative term functions as a brake when the error is rapidly being reduced, which limits oscillation.

Basics of the Serial Interface

The motor controller uses a serial interface to communicate with a main controller, which could be a small microprocessor or a desktop computer. To use the motor controller, you must program your main controller to send data with the correct format to the motor controller's asynchronous serial input, pin 3.

The motor controller expects eight bits at a time (with no parity bit) at a constant baud rate ranging from 2000 to 40000 (the motor controller will automatically detect the baud rate). The serial bits must be at logic levels and *non-inverted*, meaning that a zero is sent as a low voltage, and a one is sent as a high voltage, as shown in the diagram to the right. (An inverting circuit must be used with a PC serial port since it outputs inverted serial data.) *Commands sent to the serial input **must** conform to the above format or else the motor controller and other devices connected to the serial line may behave unexpectedly.*



Once you can send individual bytes correctly, you must send the correct sequence of bytes to get the motor controller to run your motors. This motor controller *interface protocol* is compatible with other Pololu serial devices such as our servo controller, so you can control multiple Pololu serial devices on a single line. The protocol requires one start byte, a one-byte device identifier, and then any number of bytes, as required by the device specified in the second byte:

start byte = 0x80	device type	data byte 1	data byte 2

The start byte is identified by its most significant bit being set; all subsequent bytes must have bit 7 clear, giving them possible values of 0 to 0x7F (0 to 127 decimal). Whenever a byte is transmitted on the serial line, all devices on that line check to see if the byte is the start byte; if it is, then all devices check the next byte to see if the data is meant for them. All subsequent bytes, the data bytes in the diagram above, are only interpreted by the appropriate devices, while all other devices wait for a new start byte.

If you did not understand all of the details above and you just want to use your motor controller, don't worry. You just need to use the right serial settings and send the correct sequences of bytes, as described on the following pages.

Summary: Use non-inverted, logic-level serial transmission at baud rates between 2000 and 40000, 8 bits at a time with no parity and one stop bit.

© 2005

Using the Motor Controller

To set the speed and direction of a motor, send a four-byte command with the following structure to the motor controller:

start byte = 0x80	device type = 0x00	motor # and direction	motor speed

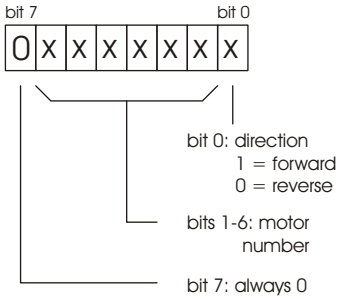
The Four-Byte Motor Controller Command

Byte 1: Start Byte. This byte should *always* be 0x80 (128 in decimal) to signify the beginning of a command. The start byte is the only byte with the highest bit (bit 7) set, and it alerts all devices on the serial line that a new command is being issued. All succeeding bytes sent down the serial line must have their highest bit cleared to zero.

Byte 2: Device Type. This byte identifies the device type for which the command is intended, and it should be 0x00 for commands sent to this motor controller. All devices that are not motor controllers ignore all subsequent bytes until another start byte is sent.

Byte 3: Motor Number and Direction. This byte has three parts, as shown in the diagram to the right:

- Bit 0 specifies the direction of the motor. Set this bit to 1 to make the motor go forward; clear the bit to make it go backward.
- Bits 1-6 specify the motor number. All motor controllers respond to motor number 0
- Bit 7 must be cleared since this is not a start byte.



To obtain the complete byte 3 value from a motor number and a direction, multiply the motor number by 2 and add 1 if the direction is forward. For example, to make motor 5 go forward, byte three should be 5 x 2 + 1 = 11. To make motor 1 go backward, byte 3 should be 1 x 2 = 2. (Two efficient ways to multiply by 2 in a microcontroller program are shifting left by one digit or adding the motor number to itself.)

Byte 4: Motor Speed. The most significant bit must be zero since this is not a start byte. The remaining seven bits specify the motor speed. The possible range of values for byte 4 is thus 0x00 to 0x7F (0 to 127 decimal). 0x00 turns the motor off, and 0x7F turns the motor fully on; intermediate values correspond to intermediate speeds. Setting a speed of 0 in reverse will cause the motor controller to hold position 0 using the PID loop; setting a speed of 0 forward will cause the PID loop to be turned off.

Examples: (Using PBASIC "SEROUT" command with serial line on pin 5)

```
' "84" parameter sets up 9600 baud serial communication
SEROUT 5, 84,[$80,0,5,127]  'motor 2 full on, forward
SEROUT 5, 84,[$80,0,5,0]    'motor 2 off, forward (coasting)
SEROUT 5, 84,[$80,0,4,0]    'motor 2 holding position 0
```


© 2005

Controlling Multiple Motor Controllers with One Serial Line
To control a particular motor, you must specify its motor number in command byte 3. Regardless of configuration, every motor controller responds to commands for motor number 0. To control more than one motor with a single serial line, you need to use motor numbers 1 through 63. Configure each motor controller to respond to different motor numbers, then connect them to the same serial line; each motor controller will respond only to the motor number to which it is configured. After you configure a motor controller, you can write its motor number on a label to keep track of your motor numbers.

Example BASIC Stamp II Program

The program on the next page, which can run on a BASIC Stamp II controller, makes motor 1 gradually speed up, then slow down, then speed up in the other direction, and then slow down again. For the code to work, pin 15 must be connected to the reset input (pin 5), and pin 14 must be connected to the serial input (pin 3). The interface code should look similar in other programming languages; the description below should help you in understanding the code and, if necessary, in translating it to other languages.

On line 1, the 8-bit variable `speed` is declared for later use. The serial line is then taken high, to its idle state, before the motor controller is reset by a low-going pulse on pin 15 (lines 3 and 4). A 100-ms pause on line 5 ensures that the motor controller is up and running before any serial data is sent to it.

The first *for loop* on lines 6-9 causes motor 1 to gradually speed up. The serial output is created by the `serout` statement on line 7. The first parameter, 14, specifies the pin number through which to send the serial signal. The next parameter, `84`, sets up the serial characteristics to be 8 bits with no parity, non-inverted, at a baud rate of 9600. The four numbers in square brackets are the data to be sent, and they correspond to the four control bytes for the motor controller. The first two bytes should always be `$80` and `0`. The second `0` makes motor 1 go backward. The speed variable, which increases every time through the loop, is the only part of the command that changes, and that is what makes the motor gradually speed up. The `pause` statement on line 8 causes the program to wait for 20 ms (0.02 seconds) before sending the next command.

When the first loop ends, the motor is set to its full speed of 127. The second loop on lines 10-13 slows the motor back down by sending speeds from 127 down to 0. The next two loops on lines14-21 then repeat the process, except for the parameter value of `1` in byte three, which causes motor 1 to spin forward.

```
1       speed   var   byte
2       high 14       'take serial line high
3       low 15        'reset motor controller
4       high 15
5       pause 100     'motor controller startup time
6       for speed = 0 to 127
7          serout 14,84,[$80, 0, 0,speed]
8          pause 20
9       next
10      for speed = 127 to 0
11         serout 14,84,[$80, 0, 0,speed]
12         pause 20
13      next
14      for speed = 0 to 127
15         serout 14,84,[$80, 0, 1,speed]
16         pause 20
17      next
18      for speed = 127 to 0
19         serout 14,84,[$80, 0, 1,speed]
20         pause 20
21      next
```

Troubleshooting Tips

All motor controllers are fully tested prior to shipment; if your motor controller does not work at first, it can be difficult to determine the cause. Nevertheless, patience and meticulous attention to detail, along with these few tips, should usually help you through.

- Double check all of your connections. Are your logic and motor supply grounds connected?
- Double check your code. Are your baud rate settings correct? If you cannot get your design working with the top baud rate of 40000, try lowering it to 9600, where slight timing mismatches are less likely to frustrate your efforts.
- Are you using the correct motor number? If nothing seems to be working, start by using motor number 0, which should work regardless of the configuration.
- If your motors unexpectedly run for a second then stop for a second and repeat, your motor controller is probably overheating, and the thermal protection feature is being activated. You can help the situation by putting a heat sink on the motor driver chip, lowering your motor supply voltage, and putting short stops between changes in motor direction.
- Setting the PID coefficients to certain values can cause unexpected results. If you are in a feedback mode, check what you are setting the PID loop to do.

Configuring the Motor Controller

To change any of the settings of the motor cotnroller, send a four-byte command with the following structure to the motor controller:

start byte = 0x80	config type = 0x02	parameter address	value

The configuration command is very similar to the usual speed setting command, but byte 2 has a device type of '2' instead of '0'. The next two bytes specify the parameter that is to be set and the value for that parameter. The parameters and their functions are listed below:

address	name	description
0	MOTORID	motor number to which this motor controller responds valid range is 0-63; default value is 1
1	ERRORMULT	error (proportional) term multiplier valid range is 0-127; default value is 21
2	ERRORDIV	error (proportional) term divider valid range is 0-7; default value is 1
3	INTEGMULT	integral term multiplier valid range is 0-127; default value is 3
4	INTEGDIV	integral term divider valid range is 0-7; default value is 4
5	DERIVMULT	derivative term multiplier valid range is 0-127; default value is 16
6	DERIVDIV	integral term divider valid range is 0-7; default value is 1
7	PIDRATE	sets the PID update rate valid range is 0-127; default value is 72 (195 Hz)
8	MISCPARAMS	direction inversion bits and frequency feedback divider bits 4-3 set the frequency feedback divider bit 2 inverts the analog feedback if set bit 1 inverts the analog control input if set bit 0 inverts the motor direction if set valid range is 0-31, default value is 0

The Pololu 3-Amp Motor Controller with Feedback

The Pololu 3-Amp motor controller with feedback simplifies servo control of commonly available DC motors. The module features three independent interfaces: a serial protocol for microcontroller-based applications, a pulse-width interface for connection to hobby radio control equipment or serial servo controllers, and an analog voltage interface for simple tests and demonstrations. Two feedback alternatives allow for closed-loop control of position or speed.

The 3-A motor controller offers a complete feedback-based solution for applications requiring bi-directional, closed-loop control of motor speed or motor position. You can select either an analog voltage feedback or a digital encoder feedback (quadrature encoding is not supported). Various simple devices such as potentiometers can be used as sensors to achieve position or speed control.

In a typical application, a user first sets up the motor controller's parameters to suit the mechanical system that is being driven. A feedback potentiometer is coupled to the mechanism output, and the user can then send position commands to the motor controller, which automatically drives the motor to reach the position. Alternatively, the mechanism and sensor can be arranged to provide speed feedback, in which case the motor controller maintains given speeds despite fluctuations in friction or supply voltage.

The motor controller measures 1.4" x 1.4" and has an operating voltage of 6-18 volts, making the device well-suited for small robots and other projects using toy motors and rechargeable 7.2 V or 9.6 V battery packs. The motor controller serial protocol is compatible with other Pololu motion control devices, allowing multiple units to be connected to a single serial line to control a mixture of motors sizes and hobby RC servos.

Specifications

PCB size	1.4" x 1.4"
Motor ports	1
Motor speeds	127 forward and backward, off
Motor Positions	256 (analog modes)
Maximum current	3 A
Motor supply voltage	6-18 V
PWM frequency	2 kHz
Serial baud rate	2000-40000 (automatically detected)