SOLUTIONS CUBED

Motor Mind C
Dual or Single DC Motor Controller
Data Sheet

Revision 3

September 23rd, 2002

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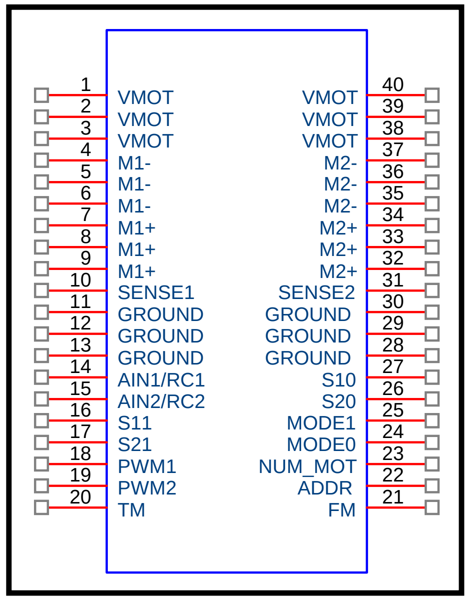
1. Revision Log – Electrical / Mechanical Specifications

Date	Rev	Description	By
02-28-02	1	Original Implementation	L. Glazner
04-29-02	2	Fixed schematic error in figure 9, changed MOT# references to NUM_MOT to match schematics.	L. Glazner
09-23-02	3	Added phone number to footer	L. Glazner

2. Introduction

Motor Mind C Module

Dual or Single Brushed DC Motor Controller



Features

- Up to 4.0A continuous current
- Up to 24VDC brushed motors
- Control 1 or 2 DC Motors
- 3 modes of operation
- Mode1: Direct serial control of 10-bit PWM
- Mode2: Bi-directional 8-bit ADC based PWM control
- Mode3: R/C 1-2ms pulse based PWM control

2.1 Description

The Motor Mind C has been designed to function as a versatile DC motor control system for controlling one or two motors. The module is ideal for use in small robotics projects for controlling two-wheel axles. The motor connections may also be tied in parallel to control a single larger motor. The Motor Mind C comes in a 40-pin DIP package with motor connections, mode settings, and control inputs all accessed through this packaging.

Three modes of operation are available in the Motor Mind C. Each mode can be used to control one or two brushed DC motors. The current rating of the Motor Mind C is 2.5A with no cooling, and 4.0.A with cooling. Motor voltages ranging from 10-24V can be used with this product.

In serial mode the user has direct control over the motor speed and direction. When configured for two motors the motor speed and direction for each motor are controlled independently. The user can also modify the PWM step limit (1-255), the PWM dead-band, and brake mode (dynamic or free spinning). Various other registers may be read and displayed including the approximate operating current of both H-bridges on the Motor Mind C.

When set for analog control mode the user has direct control over the motor speed and direction. When configured for two motors the motor speed and direction for each motor can be controlled independently with separate control voltages. Voltage inputs from 0-5V are accepted. There is a dead-band located around 2.5V, with 0V being full speed reverse, and 5V being full speed forward.

In R/C control mode the user has direct control over the motor speed and direction. When configured for two motors the motor speed and direction for each motor can be controlled independently with separate R/C pulse signals. Pulse inputs from 0.5-2.5ms are accepted. There is a dead-band located around 1.5ms, pulses down to 1ms width provide proportional reverse speed control, and those up to 2ms provide proportional forward speed control. Pulses greater than 2ms but less than 2.5ms are considered full speed forward (see section on R/C Signal Control Mode for more details). Likewise, pulses less than 1ms but greater than 0.5ms are treated as full speed reversed. Pulses outside of this range, or no pulse in a 25ms period are treated like a 1.5ms pulse and cause the motor to stop.

3. Engineering Specifications

3.1 Absolute Maximum Ratings

These are stress ratings only. Stresses above those listed below may cause permanent damage and/or affect device reliability. The operational ratings should be used to determine applicable ranges of operation.

Storage Temperature	-55°C to +150°C
Operating Temperature	-20°C to +85°C
Motor Voltage (V_{MOT})	-0.3V to 30.0V
Voltage on control pins	-0.3V to +5.5V
Voltage on V_{MOT}, Mx+, Mx-	30V
Motor Current Load	5A peak / 4A continuous

3.2 DC Electrical Characteristics

At T_A = 25°C, V_{MOTOR} = 12V, I_{LOAD} = 0.5A V_{5VDC} = 5V

Characteristic	Symbol	Min	Typ	Max	Unit	Notes
Motor Supply Voltage	V_{MOT}	10		24	V	
Motor Mind C supply current	I_{CC}		15		mA	Based on VM = 12V duty cycle = 0
ANx/RCx input voltage range	V_{AN}	0		5	V	5V is the full-scale input for the 8-bit ADC
ANx ADC resolution	ADC_{RES}	18.5	19.5	20.5	MV	Per ADC bit
PWM Resolution Serial Mode	PWM_{RES}		11		BIT	2047 steps full-reverse to full-forward
PWM Resolution Analog Mode	PWM_{RES}		8		BIT	255 steps full-reverse to full-forward
PWM Resolution R/C Mode	PWM_{RES}		8.5		BIT	Roughly 410 steps full-reverse to full-forward
Peak load current	I_{PK}			5	A	Transient <500ns
Max continuous current (cooled) both H-bridges	I_{CONT}		4.0		A	With heat sink and 6.2CFM cooling fan, tested 12V 95% duty cycle
Max continuous current (no cooling) both H-bridges	I_{CONT}		2.5		A	With no cooling, tested 12V 95% duty cycle
Over Current Fault Threshold	I_{TRIP}		2.3 (4.6)		A	2.3A for either h-bridge, 4.6A total for the device
Over Temperature Fault Threshold	T_{OVER}		165		°C	H-bridge shuts down at this temperature
Low level input logic pins	V_{IL}			0.5	V	FM pin pulled to +5V with 1.5kΩ resistor
High level input logic pins	V_{IH}	2.0			V	FM pin pulled to +5V with 1.5kΩ resistor
Low Level Output TM, PWMx pins	V_{OL}			0.6	V	
High Level Output TM, PWMx pin	V_{OH}	3.8		4.8	V	

note: "Typ" values are for design guidance only and are not guaranteed

3.3 AC Electrical Characteristics

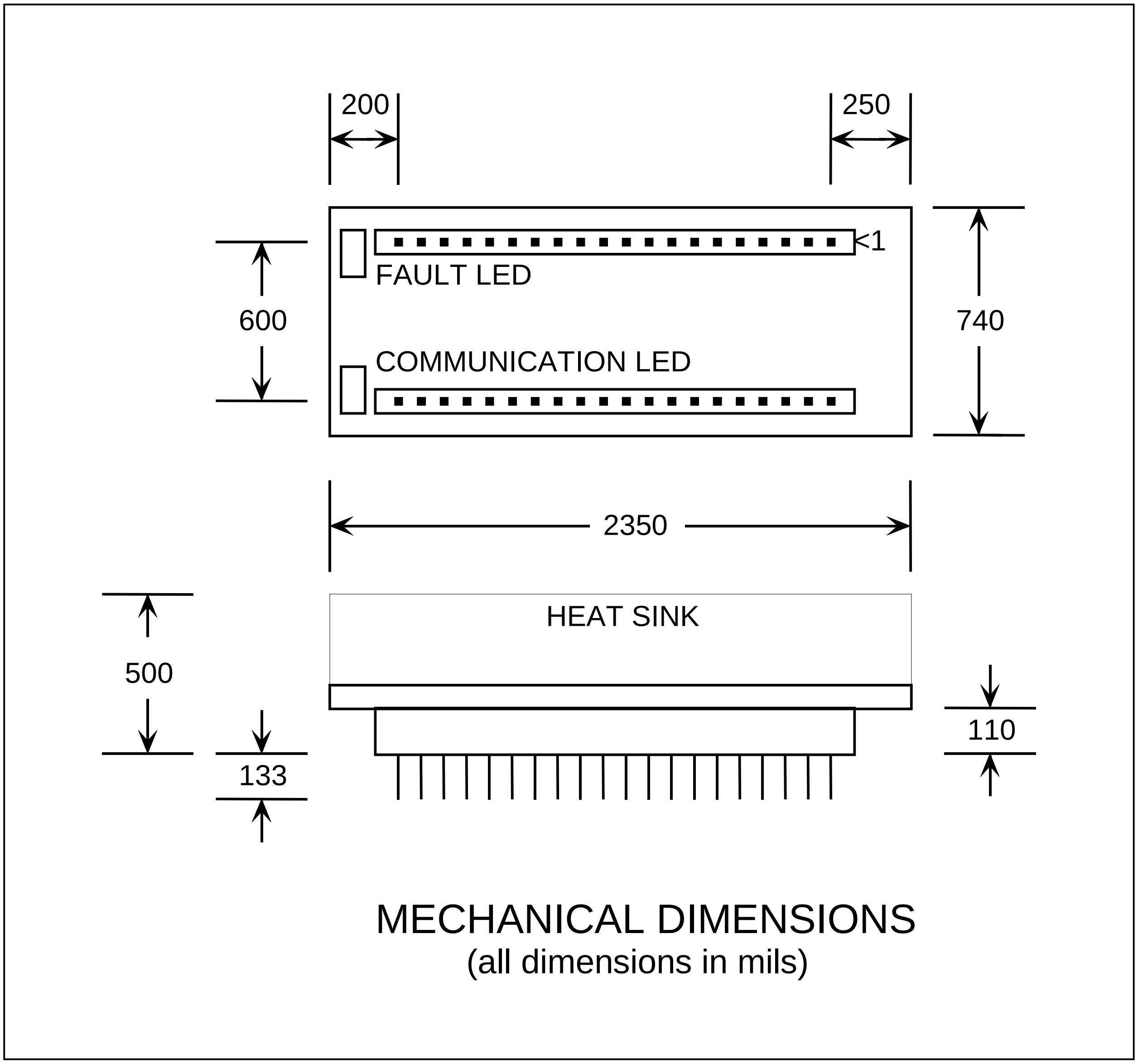
At T_A = 25°C, V_M = 12V, I_{LOAD} = 0.5A V_{5VDC} = 5V

Characteristic	Symbol	Min	Typ	Max	Unit	Notes
Communication bit period 9600BPS	T_{BIT}		104		uS	The bit period is determined by an on-board oscillator, and is temperature sensitive
Communication bit period 38400BPS	T_{BIT}		26		uS	The bit period is determined by an on-board oscillator, and is temperature sensitive
Time for a command to be responded to	T_{TURN}	2	5	7	mS	
Time after power-up before device will enable H-bridge	T_{PWRUP}		1000		mS	The onboard microcontroller allows 1000ms for the module to power up before allowing modification of PWM
V_M rise time to ensure good reset	S_{VM}	0.05			V/ ms	If this condition is not met then microcontroller may not power up correctly
PWM frequency	F_{PWM}		19.2		kHz	
PWM update rate – Serial Mode	P_{PWM}		833		uS	
PWM update rate – Analog Mode	P_{PWM}		833		uS	
PWM update rate – R/C Mode	P_{PWM}		20	25	mS	PWM is typically updated with each new pulse
PWM Step Limit	STEP		64		BIT	In serial mode the PWM Step Limit may be adjusted after power up
PWM Dead Band - Serial Mode	DB		1		BIT	In serial mode the PWM Dead Band may be adjusted after power up
PWM Dead Band - Analog Mode	DB	2.42	2.5	2.57	V	Dead band center point can be as low as 2.38V or as high as 2.64V based on on-board regulator tolerance
PWM Dead Band - R/C Mode	DB	1.44	1.5	1.56	mS	
Output impedance for ANx/RCx source	R_{IMP}	0		10K	Ω	Impedance driving the analog input ANx/RCx greater than this will cause inaccuracies

note: “Typ” values are for design guidance only and are not guaranteed

3.4 Mechanical Dimensions
The following diagram may be used to develop PCB carrying boards or enclosures for use with the Motor Mind C.

Figure 1: Mechanical Dimensions



3.5 Connectivity Overview
The Motor Mind C fits in a standard 40-pin DIP socket and has minimal connectivity requirements. The connections that may need to carry higher amounts of current (up to 5A peak) have been grouped in threes. All of these pins should be utilized to evenly distribute the load current passing through the Motor Mind C.

GND and VMx pins are electrically connected on the Motor Mind C and should be connected on any carrier board or PCB application. Therefore it is not possible to power two motors at different voltages with the Motor Mind C.

Figure 2: Motor Mind C Pin Definitions

Pin	Name	Type	Description
1	VMOT	POWER	Motor voltage input
2	VMOT	POWER	Motor voltage input
3	VMOT	POWER	Motor voltage input
4	M1-	POWER	Negative motor lead connection for motor 1
5	M1-	POWER	Negative motor lead connection for motor 1
6	M1-	POWER	Negative motor lead connection for motor 1
7	M1+	POWER	Positive motor lead connection for motor 1
8	M1+	POWER	Positive motor lead connection for motor 1
9	M1+	POWER	Positive motor lead connection for motor 1
10	RSENSE1	OUTPUT	Motor 1 low side source voltage roughly 4.5mA per mV, output is pulsed in direct relation to PWM control signal
11	GROUND	POWER	Ground return
12	GROUND	POWER	Ground return
13	GROUND	POWER	Ground return
14	AN1/RC1	INPUT	Analog input for control of motor 1 when in analog mode, R/C pulse input for control of motor 1 when in R/C mode, unconnected in serial mode, used as control input for analog and R/C modes when Motor Mind C is configured for single motor operation
15	AN2/RC2	INPUT	Used only in 2 motor configuration, analog input for control of motor 2 when in analog mode, R/C pulse input for control of motor 2 when in R/C mode, unconnected in serial mode
16	S11	OUTPUT	Left unconnected in dual motor configuration, tied to S21 (pin 17) when Motor Mind C is configured for single motor operation
17	S21	OUTPUT	Left unconnected in dual motor configuration, tied to S11 (pin 16) when Motor Mind C is configured for single motor operation
18	PWM1	OUTPUT	PWM signal driving motor 1, left unconnected in dual motor mode, tied to PWM2 (pin 19) in single motor mode
19	PWM2	OUTPUT	PWM signal driving motor 2, left unconnected in dual motor mode, tied to PWM1 (pin 18) in single motor mode
20	TX (TM)	OUTPUT	TTL level, 8N1, 38.4KBPS or 9.6KBPS serial transmission pin (data to the Master unit)
21	RX (FM)	INPUT	TTL level, 8N1, 38.4KBPS or 9.6KBPS serial reception pin (data from the Master unit)
22	ADDR	INPUT	Left unconnected for Motor Mind C to default to address 1, tied to ground to force address to 2, used only in serial mode of operation
23	NUM_MOT	INPUT	Tied to ground to force Motor Mind C to operate in single motor mode, left unconnected for dual motor mode of operation
24	MODE0	INPUT	Used in conjunction with MODE1 (pin 25) to determine mode of operation on power up
25	MODE1	INPUT	Used in conjunction with MODE0 (pin 24) to determine mode of operation on power up
26	S20	OUTPUT	Left unconnected in dual motor configuration, tied to S10 (pin 27) when Motor Mind C is configured for single motor operation
27	S10	OUTPUT	Left unconnected in dual motor configuration, tied to S20 (pin 26) when Motor Mind C is configured for single motor operation
28	GROUND	POWER	Ground return
29	GROUND	POWER	Ground return
30	GROUND	POWER	Ground return
31	RSENSE2	OUTPUT	Motor 2 low side source voltage roughly 4.5mA per mV, output is pulsed in direct relation to PWM control signal
32	M2+	POWER	Positive motor lead connection for motor 2
33	M2+	POWER	Positive motor lead connection for motor 2
34	M2+	POWER	Positive motor lead connection for motor 2
35	M2-	POWER	Negative motor lead connection for motor 2
36	M2-	POWER	Negative motor lead connection for motor 2
37	M2-	POWER	Negative motor lead connection for motor 2
38	VMOT	POWER	Motor voltage input
39	VMOT	POWER	Motor voltage input
40	VMOT	POWER	Motor voltage input

4. Operating Information

4.1 Overview

The Motor Mind C has three modes of operation with respect to control methods. These modes are serial control, analog control, and R/C pulse control. Each of these modes will be discussed in detail in this section of the datasheet. All operating mode settings must be established on power-up. The states of the various configuration pins are checked only once shortly after power is applied to the Motor Mind C. Additionally, the Motor Mind C may be configured to control dual motors or may be configured to run one larger motor. Finally, the Motor Mind C possesses some visual indicators as well as some protection from fault conditions.

In this datasheet number prefaced with 0x are defined as hexadecimal values. A number described as 0x0000 may be related to a function such as PWM, and often represents 2 bytes or 1 word of data.

4.1.1 Operating Mode Selection

The selection of the operating mode is accomplished by setting the state of the MODE0 and MODE1 pins. These pins are either grounded or left floating.

Figure 3: MODE Pin Settings

Control Mode	State of MODE0	State of MODE1	Description
Analog	Grounded	Grounded	Voltage controlled
R/C	Floating – no connection	Grounded	Pulse controlled
Serial 9.6KBPS	Grounded	Floating – no connection	Controlled by serial interface
Serial 38.4KBPS	Floating – no connection	Floating – no connection	Controlled by serial interface

4.1.2 Address Selection

Some users may wish to develop methods of connecting two Motor Mind Cs to a single serial communication bus. This can not be done without additional hardware so **tying the TX pins of two Motor Mind Cs together is not acceptable**. Regardless, if it is required the internal address of a Motor Mind C may be changed from 0x01 to 0x02 by tying the ADDR pin to ground.

Figure 4: ADDR Pin Settings

Address of Motor Mind C	State of ADDR
0x01	Floating – no connection
0x02	Grounded

4.1.3 Dual or Single Motor Operation Selection

The Motor Mind C can be configured to run one or two motors. By tying various leads of the Motor Mind C together the dual H-bridges on the device can be paralleled and used to control a single motor up to the maximum current rating of the device. Likewise, the Motor Mind C may be configured to run two motors independently with each motor rated to one-half the current rating of the device.

Figure 5: NUM_MOT Pin Settings

Number of motors	State of NUM_MOT
1	Grounded
2	Floating – no connection

When configured for single motor operation the Motor Mind C can operate in any of the control modes listed under section 4.1.1. The registers and connections normally associated with motor 1 are used to control both H-bridges on board the Motor Mind C when it is operated with a single motor. Both H-bridges load connections are tied in parallel to allow for current sharing. Serial control registers PWM1_HI and PWM1_LO are used in serial mode, and AN1/RC1 is used as the input for a control voltage or R/C pulse input when operating in the other two modes.

Figure 6: Single vs. Dual Motor Configuration Connections

Pins	Single Motor Operation	Dual Motor Operation
NUM_MOT	Grounded	Floating – no connection
M1+, M2+	Tied together and to positive motor lead	Tied to respective positive motor leads (M1+ to motor1, M2+ to motor 2)
M1-, M2-	Tied together and to negative motor lead	Tied to respective negative motor leads (M1- to motor1, M2- to motor 2)
PWM1, PWM2	Tied together	Floating – no connection
S11, S21	Tied together	Floating – no connection
S10, S20	Tied together	Floating – no connection

4.1.3 Indicator LEDs

There are both a fault indicator LED (red) and a communication indicator LED (green) on the Motor mind C. These are denoted on the device by FLT for the fault LED, and COM for the communication LED.

The FLT LED will light whenever either H-bridge on the Motor Mind C has an average current of greater than 2.3A. If this condition were to occur the internal PWM registers would be reset to 0x0000. When configured for dual motors only the H-bridge that has a fault condition will be shut down. When configured for single motor operation a fault in either H-bridge causes the both H-bridges to be shut down. This fault detection does not prevent destruction of the Motor Mind C. For more information on fault conditions see section 4.5.

The communication LED provides two visual indicators. First, on power up the COM LED will blink a certain number of times for each mode of operation. The COM LED blinks once for analog mode, twice for R/C mode, three times for serial 9.6KBPS mode, and four times for serial 38.4KBPS mode. The second visual indicator occurs only when operating in serial mode. When in serial mode the COM LED will blink briefly whenever a valid communication string is received.

4.2 Serial Control Mode

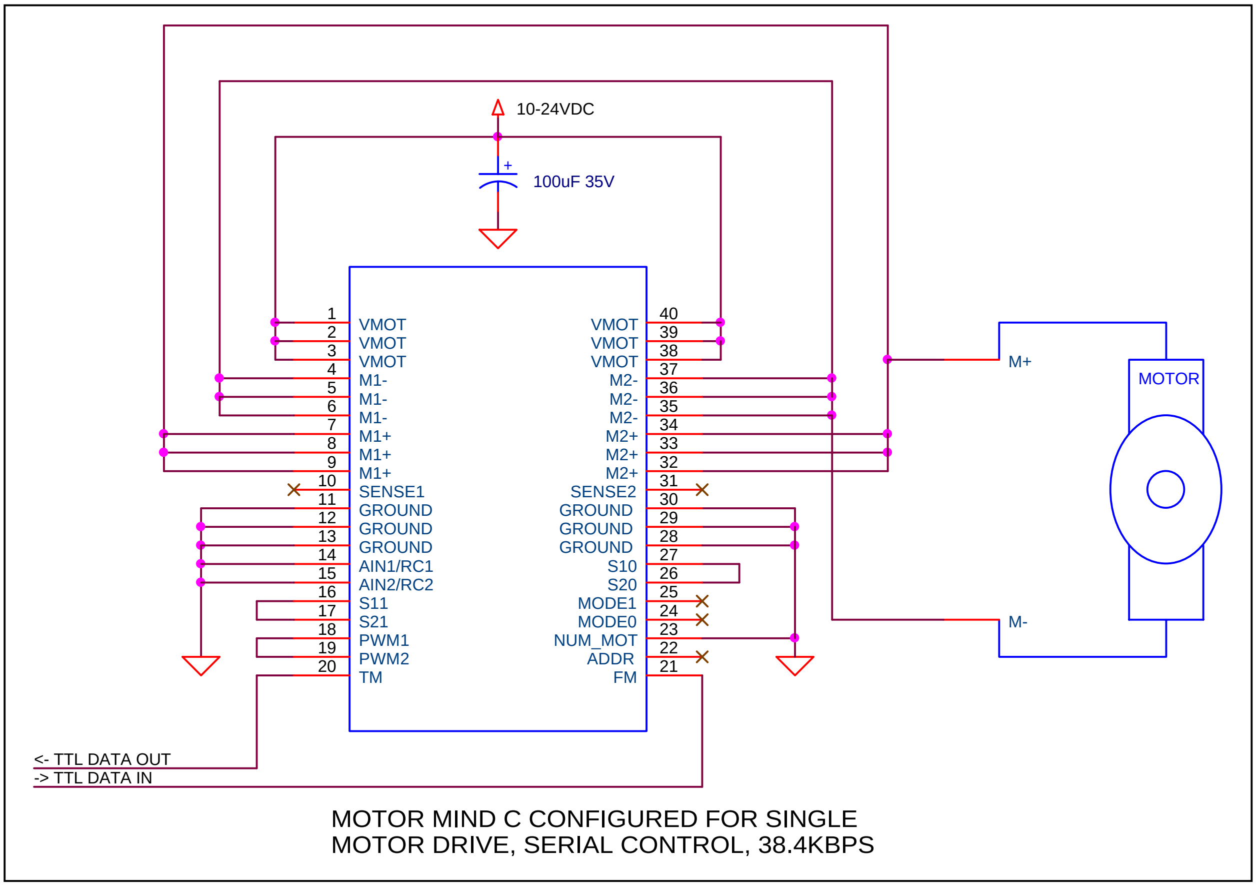
The Motor Mind C can control one or two motors with a simple serial interface. More information on the specifics of the serial interface may be found in the Motor Mind C Communication Protocol (MMCCP) included as the second portion of this data sheet.

In short, the data format is TTL level “true” data (0V signal is a logic 0, and a 5V signal is read as a logic 1). Data is sent in byte format and guided by criteria defined in the MMCCP.

The application shown in figure 8 displays a Motor Mind C configured for serial control at 38.4KBPS, configured for a single motor, and selected for an address of 0x01. Serial mode may also be set for 9.6KBPS, and may be used to control dual motors. More information on serial control is described in the MMCCP defined later in this datasheet.

Only serial mode allows PWM control to 10-bits (1024 steps) in each direction (2047 steps in all).

Figure 7: Single Motor Serial Control



4.3 Analog Control Mode

The analog control mode makes use of an on-board 8 bit analog-to-digital converter (ADC). The ADC converts voltage levels at AN1/RC1 and AN2/RC2 to digital values. The ADC is referenced to a 5V linear regulator used to power the microcontroller on the Motor Mind C. The value returned by the ADC has a full scale of 255, or 0xFF. Each step of the ADC is roughly the equivalent to 19.5mV.

Since the Motor Mind C analog control mode is used to provide forward and reverse control of motors the "stop" position is set at the midway point of the input voltage scale. Therefore, stopping a motor requires a voltage of 2.5V on the ANx/RCx pin. A dead band setting (described in more detail in the MMCCP) allows for some room for error in control voltage at the "stopped" level.

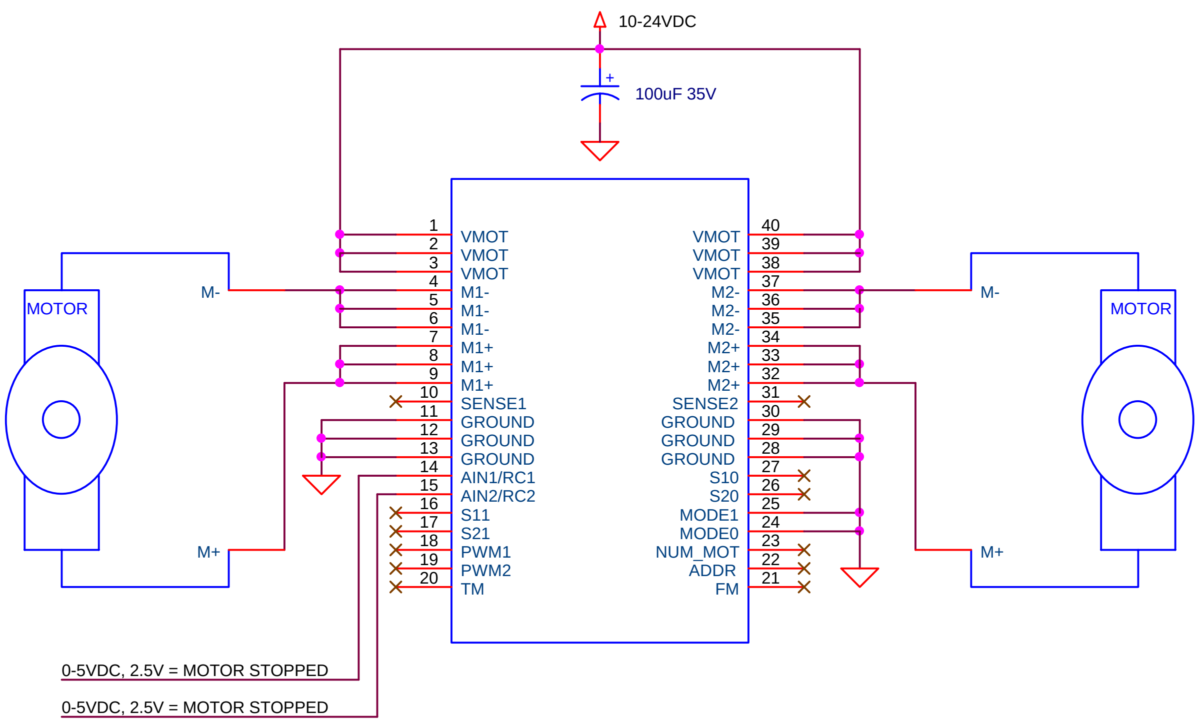
Voltages less than 2.5V cause the motor to run reversed (with 0V being full speed reverse), while voltages greater than 2.5V cause the motor to run forward (with 5V being full speed forward). Due to the resolution of the ADC some PWM output resolution is lost when the Motor Mind C is operated in analog mode. The calculation made internally by the Motor Mind C that translates the control voltage at ANx/RCx to a PWM value is…

PWM = ((Vin / 19.53mV) –128)* 8

This allows for 256 PWM steps from full reverse to full forward.

It is important to ensure that 2.5V is present on the ANx/RCx input line within 200ms of power being applied to the Motor Mind C. If the voltage input is left floating or is grounded the motor(s) may spin.

Figure 8: Dual Motor Analog Control



MOTOR MIND C CONFIGURED FOR DUAL
MOTOR DRIVE, ANALOG CONTROL

4.4 R/C Control Mode

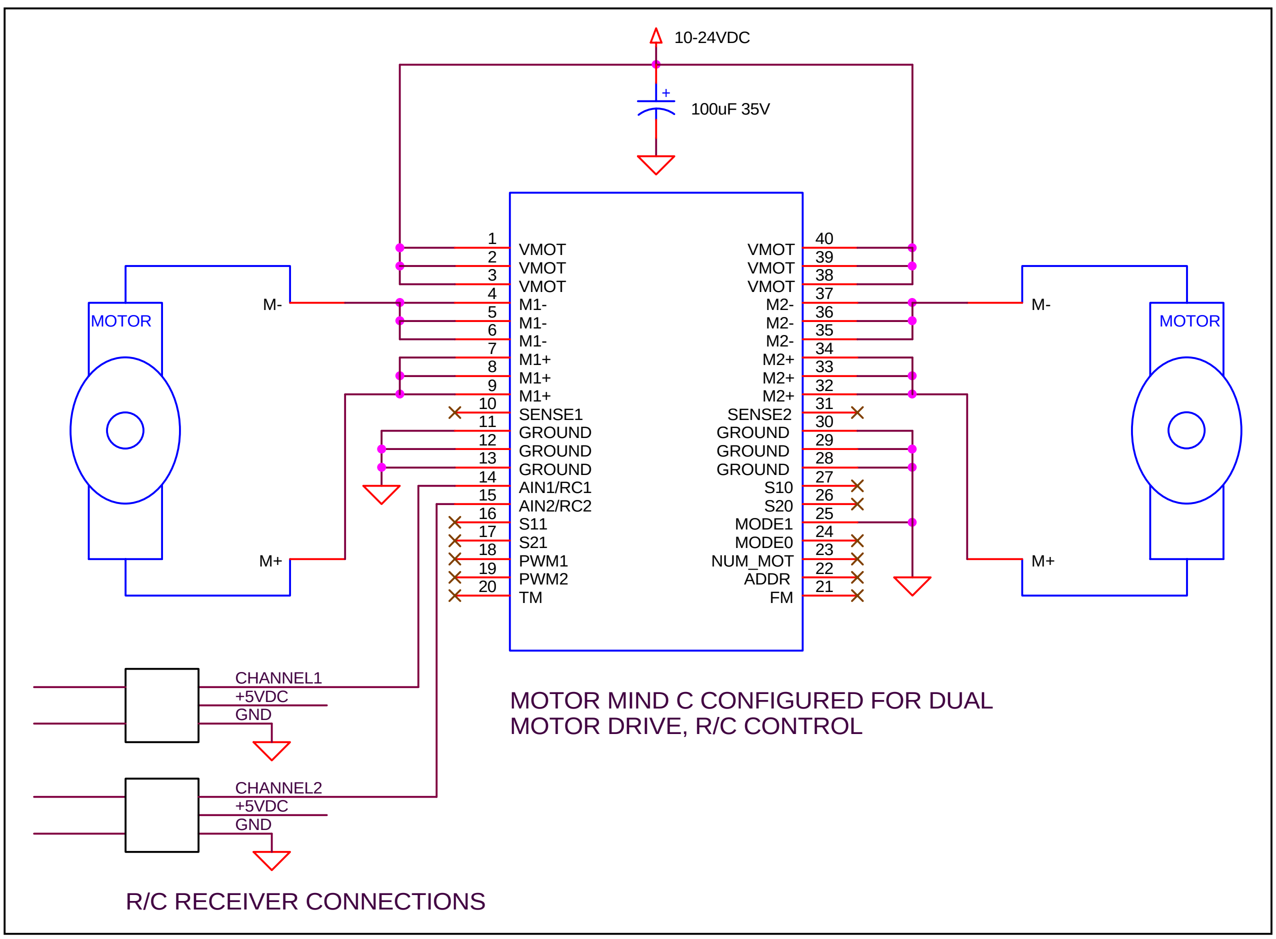
R/C control mode is designed to operate with standard R/C servo control signals. These 5V pulse signals typically range from 1ms to 2ms in duration, with 1.5ms being the neutral (or centered) position. The Motor Mind C will prevent the motor(s) from spinning if the pulse falls between 1.44-1.56ms due to the dead band function built into the device. Pulse widths between 0.5-1.08ms will generate full-reverse motor speeds, 1.91-2.5ms pulses result in full forward motor speeds. Pulse widths from 1.08-1.44ms generate proportional motor speed changes with the motor running in reverse. Likewise, pulse widths from 1.56-1.91ms generate proportional motor speed changes with the motor running forward. Pulse widths outside of the ranges described above, or a line continually low or high, are treated as if they were 1.5ms pulses.

Pulse periods must be less than 25ms for effective R/C control. And if dual motor control is used the first pulse received must be connected to AN1/RC1. In most cases the lower the channel number the earlier it is received by the R/C receiver. For example, in a two-channel system channel 1 should be connected to AN1/RC1, and channel 2 should be connected to AN2/RC2. If the earlier pulse is not received on AN1/RC1 the R/C control mode will not work correctly.

The formula used to convert pulse width to PWM output value is,

PWM = ((Tpulsewidth / 2.44us) – 615) * 6

Figure 9: Dual Motor R/C Control



4.5 Fault Conditions
There are two primary circuit conditions that can destroy the Motor Mind C. The first is the over current fault condition. The second is the over temperature fault condition. These two conditions are related two each other in a very direct way.

4.5.1 Over Current Fault
First, lets tackle over current conditions and how they are detected in the Motor Mind C. If enough current flows through the Motor Mind C the H-bridges on the device will be destroyed. The maximum current is approximately 5A for the entire device. To minimize the chance of excessive currents destroying the Motor Mind C the microcontroller on the device continuously monitors the average current passing through each of the H-bridges. If either H-bridge is averaging more than 2.3A the microcontroller will reset the appropriate PWM register to 0x0000, effectively shutting down the load. When configured for single motor operation either H-bridge exceeding 2.3A will shut down the motor (this equates to a total of 4.6A).

In serial mode it is simple enough to query the Motor Mind C regularly to see if an over current fault has occurred. In many instances the Motor Mind C can survive over current faults when operating in serial mode. The device controlling the Motor Mind C should take appropriate steps to protect the device by periodically checking the Motor1_Fault and Motor2_Fault flags in the MMC_STATUS register.

When operating in analog mode the Motor Mind C will reset the PWM registers internally to 0x0000 after an over current fault. **Once an over current fault occurs the analog control voltage must be returned within the dead band setting in order to clear the fault condition**. If the Motor Mind C is not destroyed by the excessive current it will quickly reach an over temperature fault level (165°C). When this level is reached the H-bridge IC will enter a thermal shutdown mode. The symptoms of this protective feature entail the Motor Mind C turning on and off at roughly 1-2 second intervals. After a period of time the Motor Mind C will be destroyed due to this condition.

R/C mode of operation tests for over current conditions 25 times **slower** than the analog or serial modes of operation. Therefore a short circuit or current pulses greater than 4.6A can quickly destroy the Motor Mind C when used in R/C mode. **If an over current fault occurs when operating in R/C mode, the input pulse width must be returned to a value between 1.44-1.56ms before the fault is cleared.**

4.5.2 Over Temperature Fault
The second fault condition that can occur is the over temperature fault. Over temperature fault conditions can occur when the power handling capability of the H-bridge IC is exceeded. This part is rated for 2.2W, and enters thermal shutdown at 165°C. Without cooling, the Motor Mind C can handle 2.5A in open-air (25°C) without entering thermal shutdown. With a small 6.2CFM 12V fan, like that sold in the Motor Mind C 12V Active Cooling Kit (PN: MMC_12VAC) the Motor Mind C can handle currents up to 4.0A continuous.

4.6 VM Input Capacitor Selection
Any circuit utilizing the Motor Mind C should make use of an input capacitor of at least 47uF/35V. Polarized electrolytic capacitors can work well. The capacitor should be selected so that its ripple current rating is at least ½ of the expected maximum load presented by your motor.

For example, if you expect your motors to draw 2A-peak you should provide an input capacitor rated for at least 1A of ripple current (RMS). Panasonic part number EEU-FC1V331 (330uF, 35V, 1050mA ripple current, Digi-Key PN: P10299-ND) would work for this application. Two such capacitors would work for virtually any application up to the maximum 4.0A rating of the Motor Mind C. This capacitor(s) should be located as close to the VMx pins as possible.

Table of Contents – Communication Protocol

List of Figures

1. Revision Log

Date	Rev	Description	By
02-28-02	1	Original Implementation	L. Glazner

2. Introduction

This document defines the command protocol used in conjunction with the Motor Mind C. The Motor Mind C Communication Protocol (MMCCP) must be followed in order to implement commands, or to modify functionality in the Motor Mind C.

2.1 Scope

This document provides the necessary information for implementation of MMCCP in both Master and Slave units. The Master is assumed to be a terminal controlling the Motor Mind C. The Slave device is the fore-mentioned Motor Mind C device, which has been developed by Solutions Cubed. The command structures and register / data formats are defined herein.

2.2 Definitions, Acronyms, and Abbreviations

Baud / BPS: Transmitted or received data bits per second

Byte: Eight bits of Data

Half Duplex Transmission and Reception do not take place simultaneously

Master: The computer or terminal responsible for controlling communications on the bus. The Master will initiate all communication.

Slave: Device being controlled by Master. A Device will respond only when requested to do so by the Master. In this protocol the Motor Mind C is the Slave.

TBD: To Be Determined

3. Functional Description

3.1 Overview

The MMCCP is a Master / Slave protocol implemented on a half-duplex TTL serial bus. A Slave device will *NEVER* implement communication without first being prompted by the Master.

Typically, the Master will send a command packet to a Slave to request data or perform a task. The Slave will either respond back with the requested data, respond with an acknowledge (ACK) that the task has been performed, or not respond at all, indicating that an error has taken place.

Monitoring the order of how a packet is sent performs error detection, the device address, time between received bytes, and a checksum are also used for detecting erroneous commands. The Master will be responsible for detecting errors and taking action to recover. If the Slave detects an error, no response will be sent to the Master.

3.2 Data Representation

All numeric data used by devices implementing the MMCCP will be represented by eight bit values (bytes). The relationship between these byte values and actual values such as pulse-width-modulation (PWM) duty cycle, or current measurement will be discussed later in this document.

3.3 Hardware Usage

Asynchronous communication takes place with a 9,600BPS or 38,400BPS rate, using eight data bits, no parity, and one stop bit (9600(38400), n, 8, 1). Data is sent LSB first. A single pair of TTL lines from the Master will be distributed to each Slave device.

4. Detailed Description

4.1 Binary Mode

This mode uses three types of packets. They are Command Packets, ACK Packets, and Reply Packets. No response can be thought of as a NAK Packet.

4.1.1 Command Packets

The Master always sends Command Packets to the Slave. Each Command Packet will begin with the command byte requested by that string. A Command Packet in MMCCP has *four* dependent components. The first component is an eight-bit address used to pick the Slave to receive communication. A Motor Mind C has addresses ranging from 0x01-0x02 (as determined by the state of the ADDR pin). The second component is a byte containing the length of the message. The length of the message is defined as the number of bytes of data following the Length byte and preceding the Checksum byte. The third component is the actual message, which is generally data destined for use by the Slave. The final component is a modulo 256 sum of all characters in the Command Packet.

Figure 1: Command Packet Construction

Command	Address of Destination	Length	Msg1	Msg2	…	MsgN	Checksum

4.1.2 ACK Packets

The Slave sends ACK packets to the Master when a command arrives that requires no data to be returned. The Slave will return a hex value of 0x06 if the Command Packet was received correctly and all went as planned.

Figure 2: ACK Packet Construction

0x06

4.1.3 NAK Packets

NAK Packets are not currently used in MMCCP.

4.1.4 Reply Packets

Reply Packets are used to send data from the Slave to the Master after the Master requests data. A Reply Packet is identical to a Command Packet except that it will begin with the address of the sending unit, and not a command byte.

Figure 3: Reply Packet Construction

Address Sender	Length	Msg1	Msg2	…	MsgN	Checksum

4.2 Communications Sequence

There are only two possible communication sequences in MMCCP. They are shown in figure 4.

Figure 4: Communication Sequence

		Master	Slave
Normal Message:		Command →	
			← Ack or Reply
Error in Message:		Command →	
			No Response

4.3 Error Detection / Communication Requirements

Error detection is accomplished by inspection of the received data and making sure that the data was received in a timely fashion.

Inspection of the data packets will be performed by…
1) verifying that all elements of the packet are present
2) making sure that the message is the correct length
3) verifying the checksum
4) verifying that the message is supported by the Slave
5) testing all values with limited range

Two time periods are monitored for error detection. They are…
1) inter-character time
2) response time

The inter-character time is the time between successive characters (bytes) in the same packet. The maximum time allowed is 2 milliseconds for the MMCCP.

The response time is the time from when the Master sends the last character of the Command Packet, to when the Master receives a response from the Slave. The maximum allowable response time is 7 milliseconds. Typical response time is 5ms.

The firmware in the Motor Mind C will not accept messages greater than 63 bytes in length. In practice communication strings will be much shorter than this maximum length.

4.4 Commands and Registers

4.4.1 SetDC Command (0xD0)

The SetDC command is used to set the duty cycle of the H-Bridge. The message string should consist of the Command packet byte (0xD0), the Address byte, the Length byte, and the values to be loaded into the PWMx_HI and PWMx_LO registers. All of these bytes are followed by the checksum. For example, to send a –50% duty cycle value (half-speed reversed) to motor 1, and +50% duty cycle (half speed forward) to motor 2, the data string would appear as,

D0, 01, 04, FE, 00, 02, 00, D5 (all in hexadecimal)

The SetDC command is the only command that allows direct access to the PWM registers. When operating in single motor mode the PWM2_HI and PWM2_LO registers must still be sent as part of the SetDC command. They may be sent as 0x00 or any other value, as they will be ignored.

4.4.2 Read Command (0xD1)

The Read command message string should consist of the Command packet byte (0xD1), the Address byte, the Length byte, and the register numbers that are to be read from. All of these bytes are followed by the checksum. For example, to read the MMC_STATUS register (register 0x00) from a Motor Mind C at address 0x01 the data string would appear as,

D1, 01, 01, 00, D3 (all in hexadecimal)

4.4.3 Write Command (0xD2)

The Write command message string should consist of the Command packet byte (0xD2), the Address byte, the Length byte, the register number which is to be written to, and the hexadecimal value which is to be written. All of these bytes are followed by the checksum. The Write command is used to set values within the Motor Mind C. For example, to set the Motor Mind C to disable dynamic braking mode (all H-bridge transistors are turned off when duty cycle is 0x0000 or within the dead band) the Write operation would appear as follows,

D2, 01, 02, 0A, 01, E0 (all in hexadecimal)

4.5 Motor Mind C Commands

Figure 5 shows the commands supported by the Motor Mind C.

Figure 5: Motor Mind C Commands

Command	Syntax (hex)	Reply	Description
SetDC	D0 XX 04 XX XX XX XX XX	Ack	Write to PWM1_HI, PWM1_LO, PWM2_HI and PWM2_LO registers
Read	D1 XX XX XX XX … XX	Reply	Read from one or more Motor Mind C register
Write	D2 XX XX XX XX … XX	Ack	Write to BRAKE_MODE Motor Mind C register

4.6 Motor Mind C Registers

Figure 6 shows the registers of the Motor Mind C.

Figure 6: Motor Mind C Registers

Index	Name	Size (Bytes)	Read / Write	Description
0	MMC_STATUS	1	R	Maintains flags pertinent to Motor Mind C
1	FIRMWARE	1	R	Current firmware revision running on Motor Mind C
2	PWM1_H	1	R	Pulse-width-modulation register, high byte associated with motor 1
3	PWM1_L	1	R	Pulse-width-modulation register, low byte associated with motor 1
4	PWM2_H	1	R	Pulse-width-modulation register, high byte associated with motor 2
5	PWM2_L	1	R	Pulse-width-modulation register, low byte associated with motor 2
6	AMP1	1	R	Stores current measurement from H-bridge associated with motor 1
7	AMP2	1	R	Stores current measurement from H-bridge associated with motor 2
8	DEAD_BAND	1	R/W	Sets band around mid-point settings that equates to zero (or stopped)
9	PWM_STEP	1	R/W	Maximum change in PWM allowed with each update
10	BRAKE_MODE	1	R/W	0x00 sets Motor Mind C for dynamic braking, any other value disables dynamic braking mode

4.7 Motor Mind C Status Register

The Motor Mind C status register (MMC_STATUS) maintains several status flags that could be used by a Master unit to monitor the Motor Mind C.

Figure 7: Motor Mind C Status Register (MMC_STATUS)

Name	Register	Bit	R/W	Description
MOTOR1_DIR	MMC_STATUS	0	R	Direction motor is turning, set for forward
MOTOR2_DIR	MMC_STATUS	1	R	Direction motor is turning, set for forward
MOTOR1_ERR	MMC_STATUS	2	R	Set when commanded PWM for motor 1 matches output PWM
MOTOR2_ERR	MMC_STATUS	3	R	Set when commanded PWM for motor 2 matches output PWM
MOTOR1_FAULT	MMC_STATUS	4	R	Set AMPS1 register exceeds equivalent to 2.3A
MOTOR2_FAULT	MMC_STATUS	5	R	Set AMPS2 register exceeds equivalent to 2.3A
Unused	MMC_STATUS	6	R	This bit location unused at this time
Unused	MMC_STATUS	7	R	This bit location unused at this time

4.8 Detailed Register Descriptions

Accessing the Motor Mind C registers described herein can modify various configuration settings. The registers are described by their location or "Index" value and whether they are Read only or Read / Write registers. The registers designated as Read / Write may be modified via the serial interface when the Motor Mind C is in serial mode. See figure 6 for a summary of these registers.

4.8.1 INDEX0: MM_STATUS register

The Motor Mind C status byte maintains various status flag registers useful in determining the current operating state of the module. There are six bits stored in the Motor Mind C status register. These bits designate motor direction (set for forward), whether or not the output PWM signal matches the requested PWM signal, and two bits describing whether or not either H-bridge has exceeded the predetermined current limit of 2.3A (per H-bridge). See figure 7 for the bit definitions and bit locations for this register.

4.8.2 INDEX1: FIRMWARE register

The current firmware revision loaded into the Motor Mind C is stored in this register. This value can be useful when reading errata (error-data) sheets to determine if your Motor Mind C contains a known error.

Figure 8: PWM Register Value Examples

Description	Dec	Hex	Mx+	Mx-
Forward 100%	1023	0x03FF	VM	GND
Forward 50%	512	0x0200	VM	GND
Forward 10%	102	0x066	VM	GND
Stopped BRAKE_MODE = 0	0	0x0000	GND	GND
Stopped BRAKE_MODE ≠ 0	0	0x0000	load is floating	load is floating
Reverse 10%	-102	0xFF9A	GND	VM
Reverse 50%	-512	0xFE00	GND	VM
Reverse 100%	-1023	0xFC01	GND	VM

4.8.3 INDEX2: PWM1_HI register

The Motor Mind C provides 2 channels capable of generating 10-bit pulse-width-modulation (PWM). These channels connect to the dual H-bridges located on the module. The PWM1_x registers are associated with motor speed and direction of motor 1. If operated in single motor mode the PWM1_x registers are used to generate PWM signals for both H-bridges, which are connected in parallel.

The PWM1_HI register maintains the upper two bits of the PWM duty cycle, while the PWM1_LO register maintains the lower eight bits of the duty cycle. The Master unit can only write to the PWM registers with a SetDC Command. If the Motor Mind C is operating in Analog or R/C mode then the PWM1_x registers will be generated internally based on the voltage or pulse width present at AN1/RC1 input pin.

The PWM value is based on a 2's compliment value. Negative numbers force the Motor Mind C to reverse the motor direction.

4.8.4 INDEX3: PWM1_LO register

The PWM1_L0 register maintains the lower eight bits of the PWM value associated with the motor 1 connections.

4.8.5 INDEX4: PWM2_HI register

The Motor Mind C provides 2 channels capable of generating 10-bit pulse-width-modulation (PWM). These channels connect to the dual H-bridges located on the product. The PWM2_x registers are associated with motor speed and direction of motor 2. If operated in single motor mode the PWM2_x registers are unused.

The PWM2_HI register maintains the upper two bits of the PWM duty cycle, while the PWM2_LO register maintains the lower eight bits of the duty cycle. The Master unit can only write to the PWM registers with a SetDC Command. If the Motor Mind C is operating in Analog or R/C mode then the PWM2_x registers will be generated internally based on the voltage or pulse width present at AN2/RC2 input pin.

The PWM value is based on a 2's compliment value. Negative numbers force the Motor Mind C to reverse the motor direction.

4.8.6 INDEX5: PWM2_LO register

The PWM2_L0 register maintains the lower eight bits of the PWM value associated with the motor 2 connections.

4.8.7 INDEX6: AMP1 register

The Motor Mind C has some rudimentary over current protection built into each H-bridge. The value of the measurement associated with the current monitoring for motor 1 is located in the AMP1 register. Each bit in this register is roughly equivalent to 89mA. When the register value exceeds 26 decimal or 0x1A the FLT LED will light and the internal PWM registers associated with motor 1 will be reset to 0x0000.

When operated in single motor mode both the AMP1 and AMP2 registers are used to determine if an over current condition occurs. If the current in either H-bridge exceeds 2.3A the FLT LED will light and the internal PWM registers will be reset to 0x0000.

In Analog or R/C mode, after an over current fault occurs, the PWM registers will remain at 0x0000 until the control signal returns to a value within the dead band. Once this occurs normal control of each H-bridge is allowed.

4.8.8 INDEX7: AMP2 register

The Motor Mind C has some rudimentary over current protection built into each H-bridge. The value of the measurement associated with the current monitoring for motor 2 is located in the AMP2 register. Each bit in this register is roughly equivalent to 89mA. When the register value exceeds 26 decimal or 0x1A the FLT LED will light and the internal PWM registers associated with motor 2 will be reset to 0x0000.

When operated in single motor mode both the AMP1 and AMP2 registers are used to determine if an over current condition occurs. If the current in either H-bridge exceeds 2.3A the FLT LED will light and the internal PWM registers will be reset to 0x0000.

In Analog or R/C mode, after an over current fault occurs, the PWM registers will remain at 0x0000 until the control signal returns to a value within the dead band. Once this occurs normal control of each H-bridge is allowed.

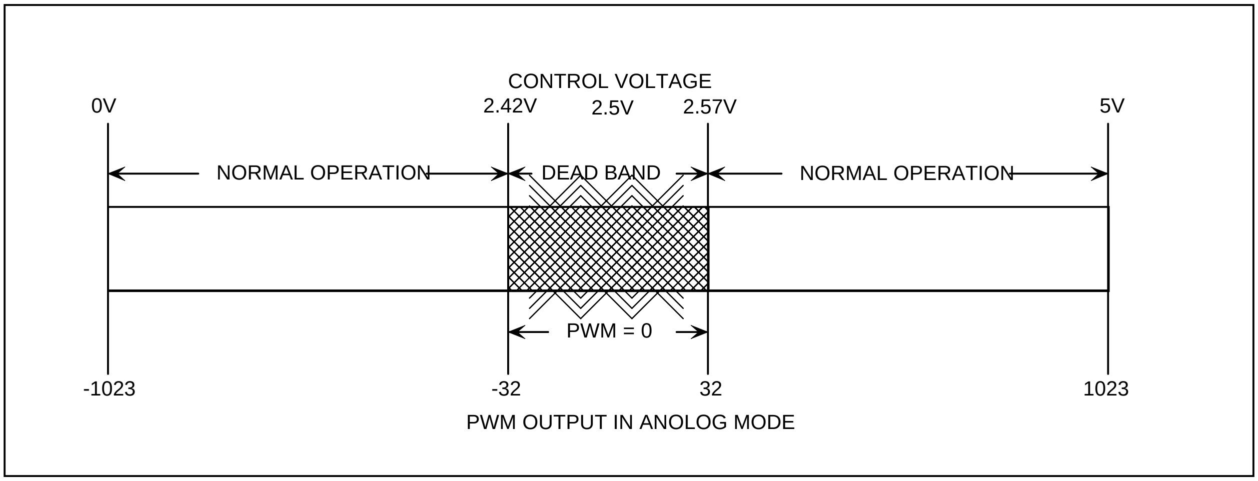
4.8.9 INDEX8: DEAD_BAND register

The dead band setting programs the Motor Mind C to shut down PWM generation whenever the analog or R/C pulse width measurement falls within the dead band value. This setting can be useful in systems where the analog input does not (or cannot) remain stable around 2.5V. It is also useful with heavily geared motors that will rotate at very low duty cycles. With these systems it may be difficult to ensure the analog control voltage remains at a value that stops the motor from turning. The dead band setting creates a wider range of analog input values that result in the PWM signals being forced to zero (or off). Figure 9 is a graphical representation of how the dead band works.

In R/C mode even with the dead band setting applied it will probably be necessary to trim the controls so that the motors do not move when the joystick is in the neutral position.

When used in serial mode the dead band defaults to 0x01. This value may be modified via the serial interface if necessary.

Figure 9: Dead Band Diagram



4.8.10 INDEX9: PWM_STEP register

The maximum change in PWM values from update to update is defined by the PWM_STEP value. If a step function were applied to the control voltage input pin the resulting change in PWM could cause significant current or voltage spikes to be seen in the system. The PWM_STEP register defines the maximum change allowed in the PWM registers from one PWM update to the next.

The PWM_STEP register defaults to 64 decimal (0x40 hexadecimal). This register may be modified to a value from 1-255 (0x01-0xFF) when used in serial mode. Setting the PWM_STEP register to lower values will increase the time it takes the Motor Mind C to reach the requested PWM signal. For instance, assume that the PWM_STEP is set to 0x01 and the motor is stopped (PWM registers are set to 0x0000), and the Master unit sends the Motor Mind C a SetDC command with a PWM value of 0x03FF (1023) for full speed forward. The Motor Mind C will begin increasing the PWM output signal by the value in the PWM_STEP register every 833us. In this example it would take 852ms to reach the desired PWM output. This is an extreme case, but it shows how the PWM_STEP setting could be used to slow motor speed transitions and therefore reduce peak currents in your motor system

4.8.11 INDEX10: BRAKE_MODE register

When loaded with 0x00 the BRAKE_MODE register enables dynamic braking when either (or both) PWM registers equal zero, or when the PWM register is within the dead band setting for the Motor Mind C's current mode of operation. Dynamic braking ties both motor leads to ground. If the BRAKE_MODE register is loaded with a value that is not 0x00 then the motor leads are left floating when the PWM value equals 0x0000. Modification of the BRAKE_MODE register can only be done when the Motor Mind C is in a serial mode of operation.

4.9 Default Values on Factory Power Up

Each Motor Mind C loads variable data into RAM on power up. These registers may be written to and modified when operating in serial mode.

Figure 10: Motor Mind C Default Settings

Index	Name	Size (Bytes)	Value (hex)	Description
8	DEAD_BAND	1	0x01 0x04 0x20	Sets band around desired analog or R/C pulse width measurement that equates to zero PWM output, numbers given are for serial, R/C, and analog modes respectively
9	PWM_STEP	1	0x40	Maximum change in PWM allowed with each update is 64 or 0x40, unused in serial mode
10	BRAKE_MODE	1	0x00	Dynamic braking is enabled

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