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Note: This datasheet pertains to the MMC Rev 4 only. The MMC Rev 4 was produced after April 2003 due to a discontinued H-bridge IC. The MMC Rev 4 is physically distinguishable from earlier revisions by the lack of a heat sink.

Motor Mind C
Dual or Single DC Motor Controller
Data Sheet

Revision 4
April 23rd, 2003

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Table of Contents – Electrical / Mechanical Specifications

1. Revision Log	2
2. Introduction	3
2.1 Description	3
3. Engineering Specifications	4
3.1 Absolute Maximum Ratings	4
3.2 DC Electrical Characteristics	4
3.3 AC Electrical Characteristics	5
3.4 Mechanical Dimensions	6
3.5 Connectivity Overview	6
4. Operating Information	8
4.1 Overview	8
4.2 Serial Control Mode	10
4.3 Analog Control Mode	11
4.4 R/C Signal Control Mode	12
4.5 Fault Conditions	13
4.6 VM Capacitor	13

List of Figures

Figure 1: Mechanical Dimensions	6
Figure 2: Motor Mind C Pin Definitions	7
Figure 3: MODE Pin Settings	8
Figure 4: ADDR Pin Settings	8
Figure 5: NUM_MOT Pin Settings	9
Figure 6: MMC_REV3 versus MMC_REV4 Differences	9
Figure 7: Single Motor Serial Control	10
Figure 8: Dual Motor Analog Control	11
Figure 9: Dual Motor R/C Control	12

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
04-23-03	4	Included physical and functional changes from MMC Rev 3 to MMC Rev 4 caused by change in H-bridge IC.	L. Glazner

2. Introduction

Motor Mind C Module Dual or Single Brushed DC Motor Controller

Features

- ◆ Up to 4.5A continuous current
- ◆ 6-24VDC 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

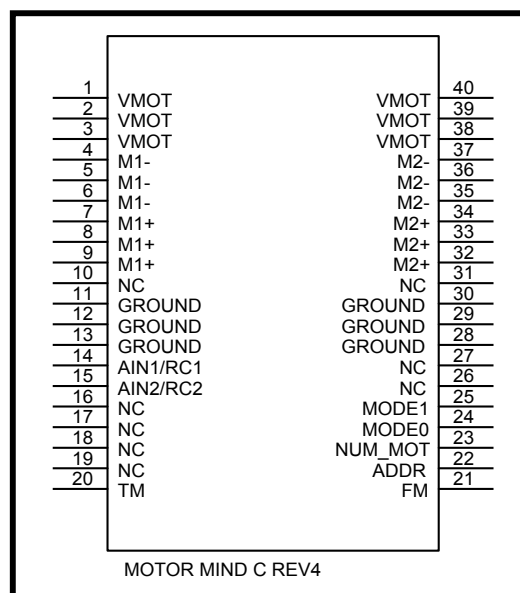
The Motor Mind C has been designed to function as a versatile DC motor control system for controlling one or two motors. The module is ideal for use in small robotics projects for controlling two-wheel axles. The Motor Mind C comes in a 40-pin DIP package with motor connections, mode settings, and control 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 3A (1.5A per motor) with no cooling, and 4.5A (2.25A per motor) with cooling. Motor voltages ranging from 6-24V 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) and the PWM dead-band. Various other registers may be read and displayed.

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 (VMOT)	-0.3V to 30.0V
Voltage on control pins	-0.3V to +5.5V
Voltage on VMOT, Mx+, Mx-	30V
Motor Current Load	6A peak / 4.5A continuous (2.25A/motor)

3.2 DC Electrical Characteristics

At $T_A = 25^\circ\text{C}$, $V_{MOTOR} = 12\text{V}$, $I_{LOAD} = 0.5\text{A}$ $V_{5VDC} = 5\text{V}$

Characteristic	Symbol	Min	Typ	Max	Unit	Notes
Motor Supply Voltage	VMOT	6		24	V	If supply is less than 6.3V the ADC full scale voltage will be less than 5V
Motor Mind C supply current	ICC		30		mA	Based on VM = 12V duty cycle = 0
ANx/RCx input voltage range	VAN	0		5	V	5V is the full-scale input for the 8-bit ADC
ANx ADC resolution	ADCRES	18.5	19.5	20.5	MV	Per ADC bit
PWM Resolution Serial Mode	PWMRES		11		BIT	2047 steps full-reverse to full-forward
PWM Resolution Analog Mode	PWMRES		8		BIT	255 steps full-reverse to full-forward
PWM Resolution R/C Mode	PWMRES		8.5		BIT	Roughly 410 steps full-reverse to full-forward
Peak load current	IPK			5	A	Transient <500ns
Max continuous current (cooled) both H-bridges	ICONT		4.5 (2.25)		A	With heat sink and 6.2CFM cooling fan, tested 12V 95% duty cycle (per motor)
Max continuous current (no cooling) both H-bridges	ICONT		3.0 (1.5)		A	With no cooling, tested 12V 95% duty cycle (per motor)
Over Current Fault	ITRIP	6	8	10	A	for either h-bridge
Over Temperature Fault Threshold	TOVER	150	175	200	°C	H-bridge shuts down at this temperature
Low level input logic pins	VIL			0.5	V	FM pin pulled to +5V with 1.5kΩ resistor
High level input logic pins	VIH	2.0			V	FM pin pulled to +5V with 1.5kΩ resistor
Low Level Output TM, PWMx pins	VOL			0.6	V	
High Level Output TM, PWMx pin	VOH	3.8		4.8	V	

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

3.3 AC Electrical CharacteristicsAt $T_A = 25^\circ\text{C}$, $V_M = 12\text{V}$, $I_{\text{LOAD}} = 0.5\text{A}$ $V_{5\text{VDC}} = 5\text{V}$

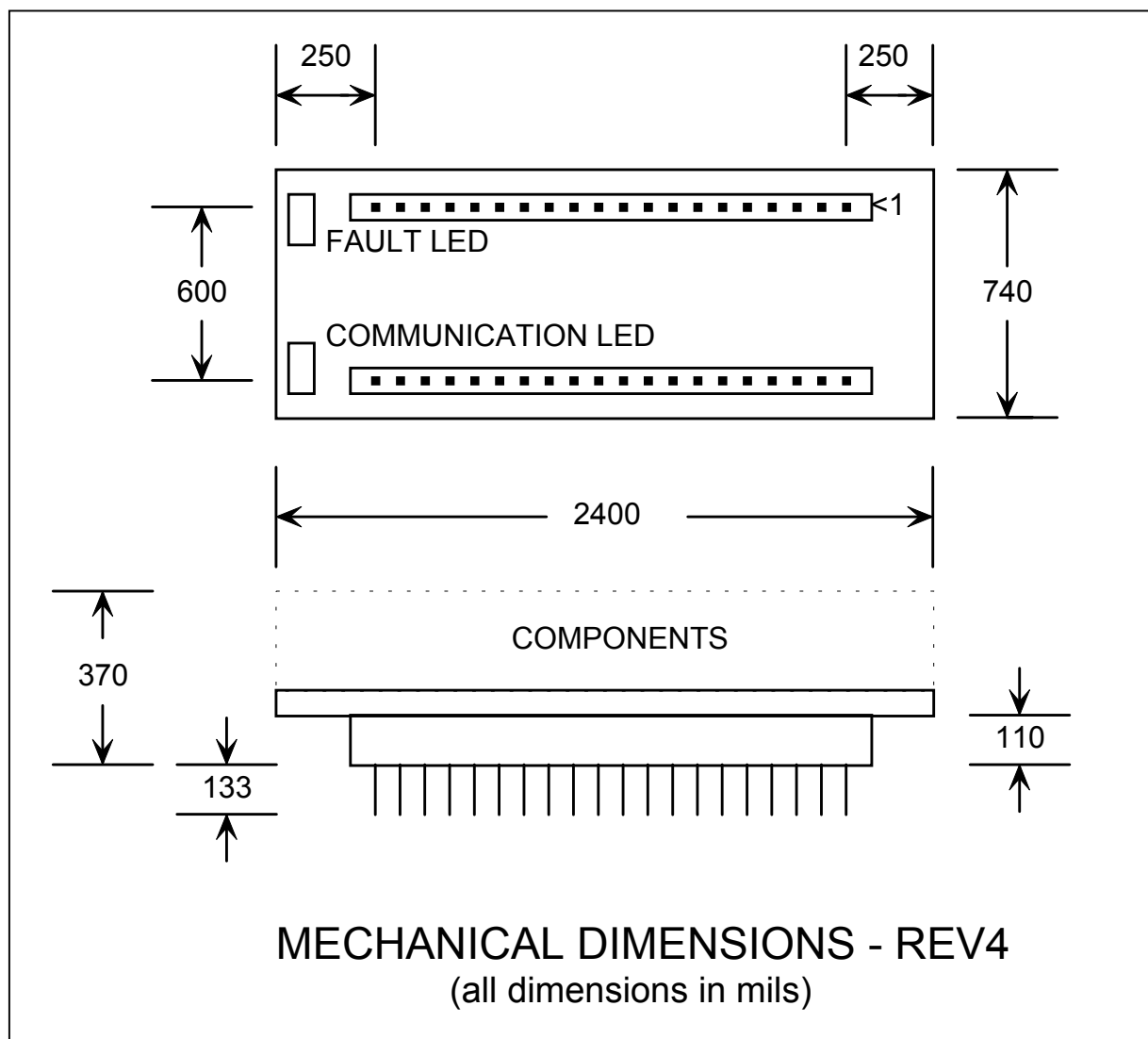
Characteristic	Symbol	Min	Typ	Max	Unit	Notes
Communication bit period 9600BPS	TBIT		104		uS	The bit period is determined by an on-board oscillator, and is temperature sensitive
Communication bit period 38400BPS	TBIT		26		uS	The bit period is determined by an on-board oscillator, and is temperature sensitive
Time for a command to be responded to	TTURN	2	5	7	mS	
Time after power-up before device will enable H-bridge	TPWRUP		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	SVM	0.05			V/ ms	If this condition is not met then microcontroller may not power up correctly
PWM frequency	FPWM		1.2		kHz	19.2kHz with Change Frequency command, but at a significant loss of duty-cycle accuracy
PWM update rate – Serial Mode	PPWM		833		uS	
PWM update rate – Analog Mode	PPWM		833		uS	
PWM update rate – R/C Mode	PPWM		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	RIMP	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 6A 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.

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	NC	No connect	No connection
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	NC	No connect	No connection
17	NC	No connect	No connection
18	NC	No connect	No connection
19	NC	No connect	No connection
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 as address only in serial mode of operation. In analog or R/C modes this pin can be tied to ground to enable dynamic braking
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	NC	No connect	No connection
27	NC	No connect	No connection
28	GROUND	POWER	Ground return
29	GROUND	POWER	Ground return
30	GROUND	POWER	Ground return
31	NC	No connect	No connection
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 motor. Finally, the Motor Mind C possesses some visual indicators as well as some protection from fault conditions.

In this datasheet numbers 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 Braking Mode

There are two methods of braking motors controlled by the MMC, they are dynamic and free spinning. In serial mode, clearing the BRAKE_MODE register enables dynamic breaking (this is the default setting for serial mode), while loading BRAKE_MODE with a non-zero value enables free spinning mode. In analog or R/C control modes the default brake mode is free spinning. In analog and R/C mode dynamic braking can be enabled by tying the ADDR pin (pin22) to ground.

Dynamic Braking ties both of the motor leads (M1+ and M1-, for example) to VM (motor supply voltage) when the PWM signal is within the error band setting. This causes the motor to stop abruptly, when used in analog or R/C modes motor speed control can be “choppy” around the edge of the dead band. In free spinning mode the PWM duty cycle is set to zero when within the dead band, but the energy built up in the motor is not shunted to the supply, as is the case with dynamic braking. Therefore the motor will slow less abruptly in free spinning mode.

4.1.4 Dual or Single Motor Operation Selection

The Motor Mind C can be configured to run one or two motors. **On the MMC REV4 the two H-bridges located on the PCB cannot be tied in parallel**, as was the case on the previous MMC REV3. This reduces the single motor current rating of the MMC, while the total current handling capability in dual motor control mode is increased. Many pins that previously had to be tied together for single motor mode can now be left unconnected.

Figure 5: NUM_MOT Pin Settings

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

4.1.5 MMC_REV3 versus MMC_REV4 Differences

Figure 6 displays the primary differences between the MMC_REV3 and MMC_REV4.

Figure 6: MMC_REV3 versus MMC_REV4 Differences

Subject of Change	MMC_REV3	MMC_REV4
Single Motor Mode	Both motors leads (M2+ tied to M1+, etc) and many other pins are tied together	Only M1+ and M1- are used to connect to the motor
Motor Supply Voltage	10-24V	6-24V
Continuous Current	4.0A (4.0A single motor)	4.5A (2.25A single motor)
Over-temperature fault	165°C	150°C
PWM Frequency	19.2KHZ	1.2KHZ (19.2KHZ with Change Frequency command and a serious loss of resolution)
PCB Size	2.35"L x 0.74"W x 0.5"H	2.4"L x 0.74"W x 0.36"H
Clearing faults in serial mode	Done by sending SetDC command	Done by sending Clear Fault command
AMPS1 / AMPS2 registers	Stores approximate motor current	No current measurements made or available to user
BRAKE_MODE register	Dynamic or free-spinning brake modes when under serial control, free spinning under analog or R/C control	Dynamic or free-spinning brake modes when under all modes of control

4.1.6 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 indicates an over-current or over-temperature fault. The fault condition may be cleared by returning the control signal to a value within the dead-band (for analog or RC control modes) or by sending the Clear Fault command while operating in serial mode.

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.

4.1 Serial Control Mode

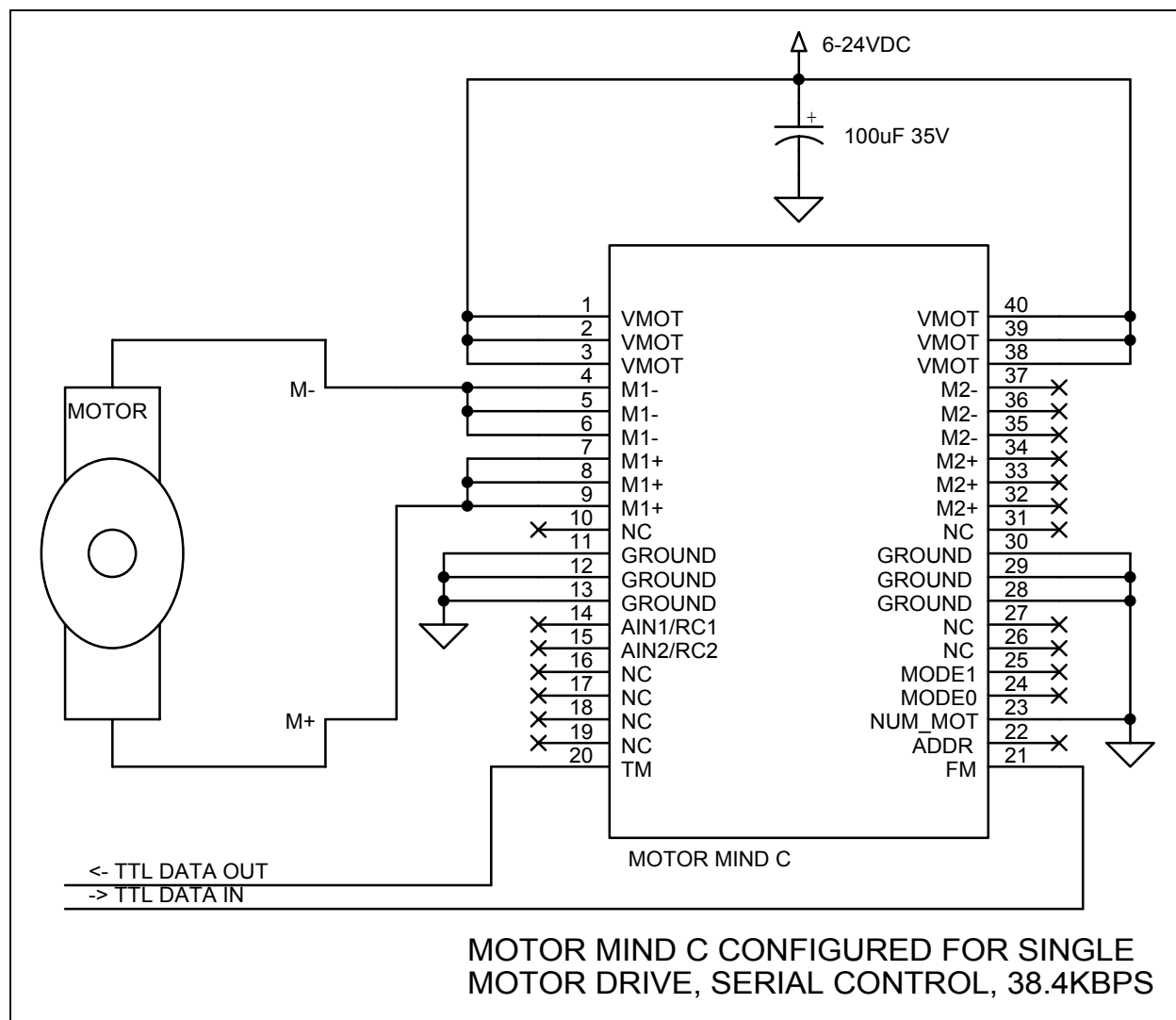
The Motor Mind C can control one or two motors with a simple serial interface. More information on the specifics of the serial interface may be found in the Motor Mind C Communication Protocol (MMCCP) included as the second portion of this data sheet.

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.

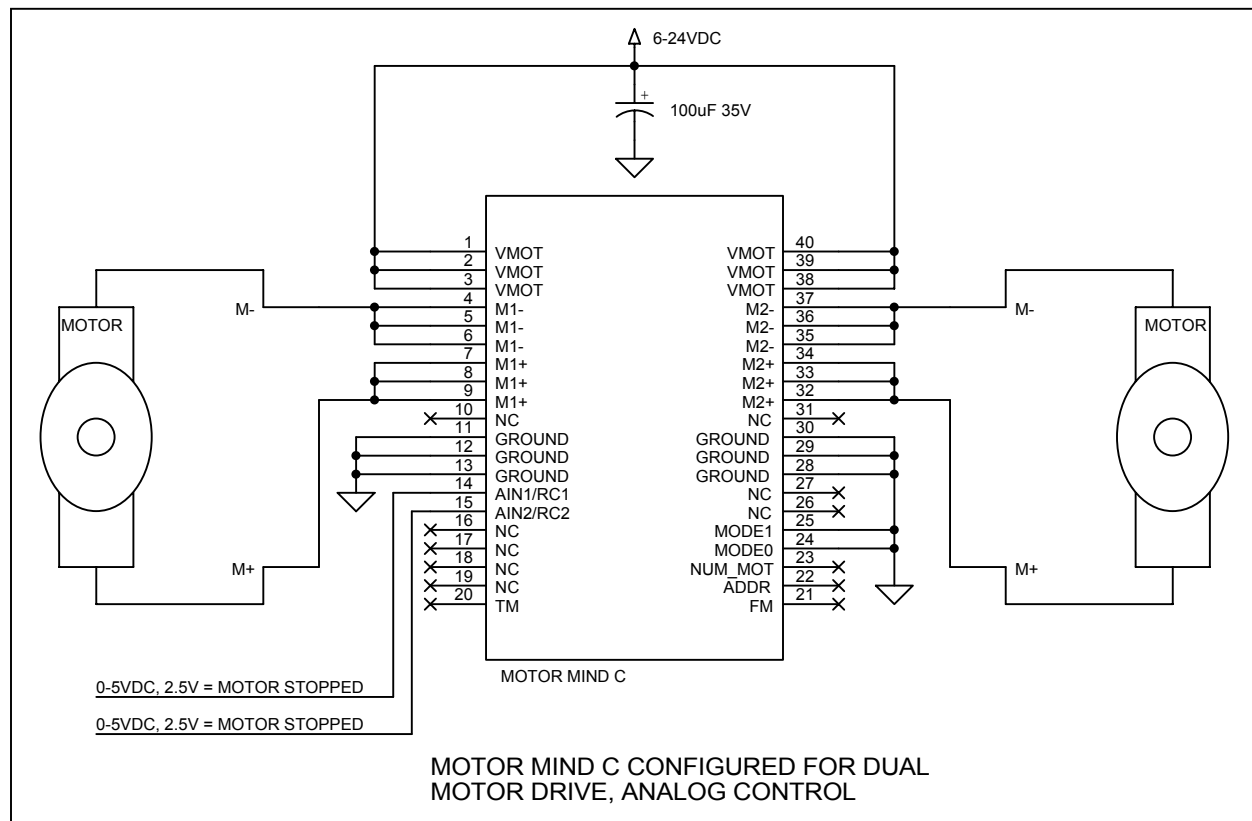
Voltages less than 2.5V cause the motor to run reversed (with 0V being full speed reverse), while voltages greater than 2.5V cause the motor to run forward (with 5V being full speed forward). Due to the resolution of the ADC some PWM output resolution is lost when the Motor Mind C is operated in analog 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



4.4 R/C Control Mode

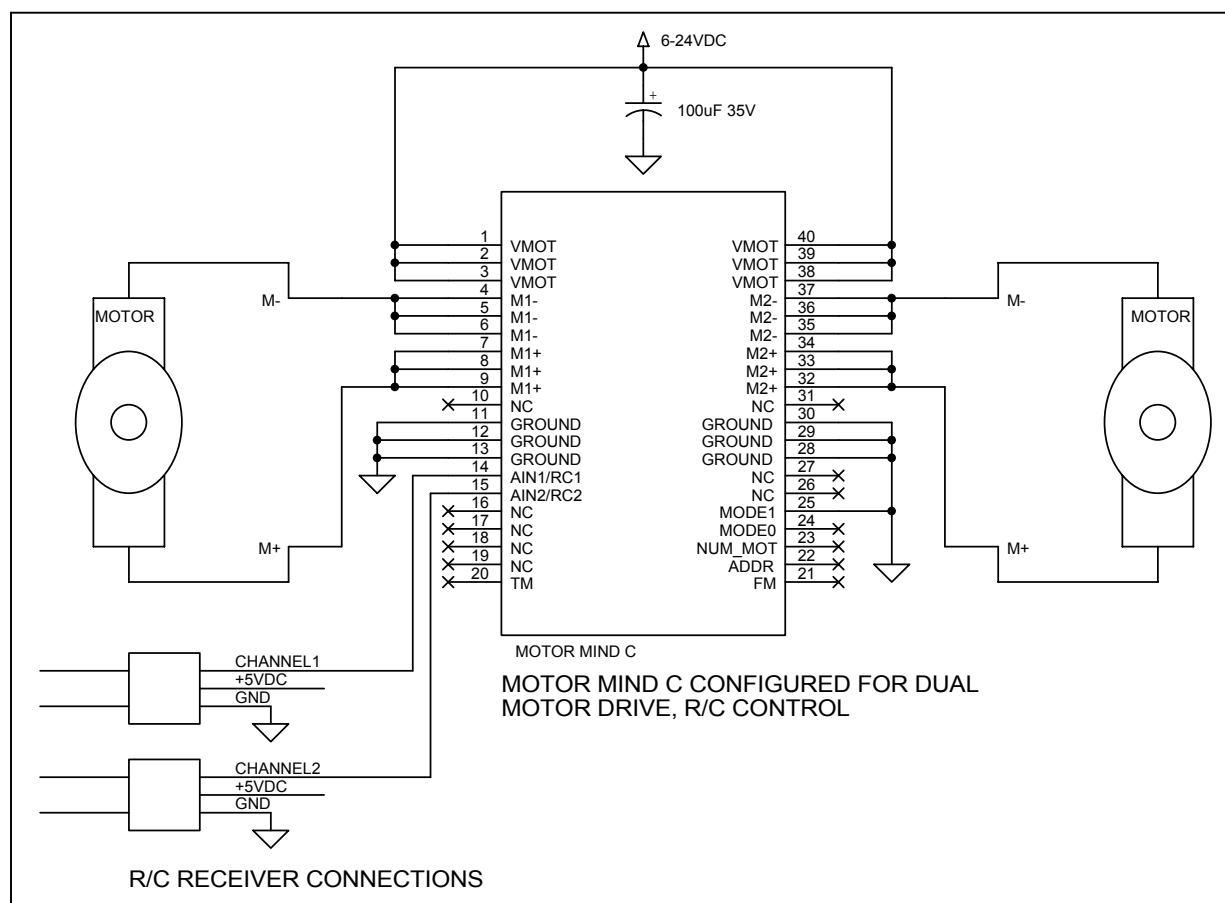
R/C control mode is designed to operate with standard R/C servo control signals. These 5V pulse signals typically range from 1ms to 2ms in duration, with 1.5ms being the neutral (or centered) position. The Motor Mind C will prevent the motor(s) from spinning if the pulse falls between 1.44-1.56ms due 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,

$$\text{PWM} = ((\text{Tpulsewidth} / 2.44\mu\text{s}) - 615) * 6$$

Figure 9: Dual Motor R/C Control



4.5 Fault Conditions

There are two primary circuit conditions that can damage the Motor Mind C. The first is the over current fault condition. The second is the over temperature fault condition. The MOTOR1_FAULT and/or MOTOR2_FAULT flags in MMC_STATUS register, if set, denote either of these fault types. These two fault conditions are related to each other in a very direct way.

In most cases the over temperature fault condition will occur after a period of time where the motors are successfully being controlled. This fault occurs when the H-bridge IC temperature exceeds roughly 175°C. Occurrence of an over temperature fault can be reduced or removed with active cooling methods (fans). Solutions Cubed sells a 12V-6.2CFM fan kit (PN: 12VACK) that is designed to mount over the Motor Mind C.

Over current faults occur when either on-board H-bridge IC detects a current in excess of 8A (at 25°C, 6A at 150°C). This will typically occur if the motor you are trying to control is too large for the Motor Mind C, or if you are abruptly starting, stopping, or reversing motor direction. Occurrence of an over current fault can be reduced or removed by implementing motor speed ramping both up and down (as opposed to slamming a motor from full speed to stop or reverse).

In serial mode it is simple enough to query the Motor Mind C regularly to see if a fault condition has occurred. The device controlling the Motor Mind C should take appropriate steps to protect the Motor Mind C by periodically checking the Motor1_Fault and Motor2_Fault flags in the MMC_STATUS register. **If a fault is detected the Clear Fault command can be sent to the Motor Mind C in an attempt to re-enable the H-bridge with the fault condition present.**

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.**

Likewise **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 where the fault is cleared automatically.**

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. This capacitor(s) should be located as close to the VMx pins as possible.

Table of Contents – Communication Protocol

1. Revision Log	15
2. Introduction	15
2.1 Scope	15
2.2 Definitions, Acronyms, Abbreviations	15
3. Functional Description	16
3.1 Overview	16
3.2 Data Representation	16
3.3 Hardware Usage	16
4. Detailed Description	16
4.1 Binary Mode	16
4.2 Communications Sequence	17
4.3 Error Detection / Communication Requirements	17
4.4 Commands and Registers	18
4.5 Motor Mind C Commands	18
4.6 Motor Mind C Registers	19
4.7 Motor Mind C Status Register	19
4.8 Detailed Register Descriptions	20
4.9 Default Values on Factory Power Up	22

List of Figures

Figure 1: Command Packet Construction	16
Figure 2: ACK Packet Construction	16
Figure 3: Reply Packet Construction	17
Figure 4: Communication Sequence	17
Figure 5: Motor Mind C Commands	18
Figure 6: Motor Mind C Registers	19
Figure 7: Motor Mind C Status Register	19
Figure 8: PWM Register Value Examples	20
Figure 9: Dead Band Diagram	21
Figure 10: Motor Mind C Default Settings	22

1. Revision Log

Date	Rev	Description	By
02-28-02	1	Original Implementation	L. Glazner
04-23-03	2	Added Clear Fault command and Change Frequency commands new to MMC REV4 and modified register descriptions to show that AMPS1, AMPS2, registers are no longer used in the MMC REV4.	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)

4.4.4 Clear Fault Command (0xD3)

The Clear Fault Command turns off the motor associated with the fault condition (sets PWM to 0x0000) and attempts to clear the fault condition.

D3, 01, 00, D4 (all in hexadecimal)

4.4.5 Change Frequency Command (0xD4)

The Change Frequency Command can be used to increase the PWM frequency from its default value of 1.2KHZ to 19.2KHZ. The higher frequency will be less likely to cause audible noise. But due to the reduced turn-on and turn-off times of the new H-bridge ICs on the MMC Rev4 there is a significant loss of duty-cycle accuracy and resolution is further lost on the upper and lower spectrums of duty-cycle settings.

D4, 01, 00, D5 (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
Clear Fault	D3 XX 00 XX	Ack	Turns off motor associated with fault condition and resets PWM to 0x0000
Change Frequency	D4 XX 00 XX	Ack	Changes PWM frequency from the default of 1.2KHZ to 19.2KHZ

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	Unused in MMC_REV4
7	AMP2	1	R	Unused in MMC_REV4
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	Loaded with 0 enables dynamic braking, a non-zero value enables free spinning braking

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 if H-bridge registers an over-current or over-temperature fault
MOTOR2_FAULT	MMC_STATUS	5	R	Set if H-bridge registers an over-current or over-temperature fault
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	0	0x0000	GND	GND
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_LO 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_LO register maintains the lower eight bits of the PWM value associated with the motor 2 connections.

4.8.7 INDEX6: AMP1 register

Unused in MMC REV4.

4.8.8 INDEX7: AMP2 register

Unused in MMC REV4.

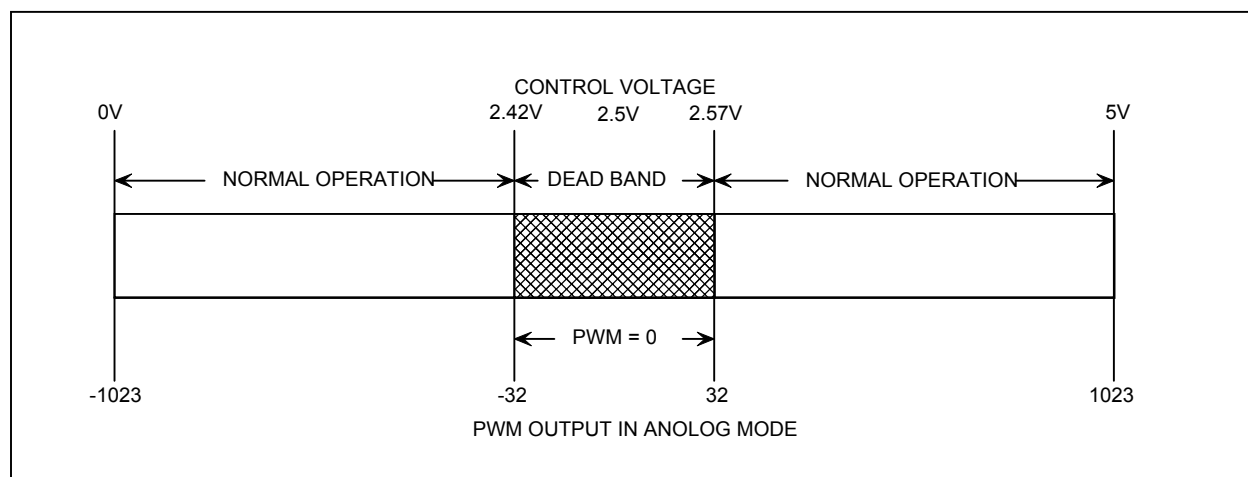
4.8.9 INDEX8: DEAD_BAND register

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 a zero value dynamic braking is enabled. This will cause greater power dissipation in the on board H-bridge IC as well as cause the motor to stop more abruptly when the motor speed is within the dead band setting. Dynamic braking ties both motor leads to VM. This allows the motor's stored energy to dissipate faster and provides electrical resistance to mechanical movement. When BRAKE_MODE is loaded with a non-zero value the motor will be allowed to spin freely (although no drive signal is present) when the commanded speed falls within the dead band setting. Free spinning mode works best with analog and R/C mode that have larger dead band settings.

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 the default setting for serial control mode. Analog and R/C control modes default to free spinning brake mode.

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