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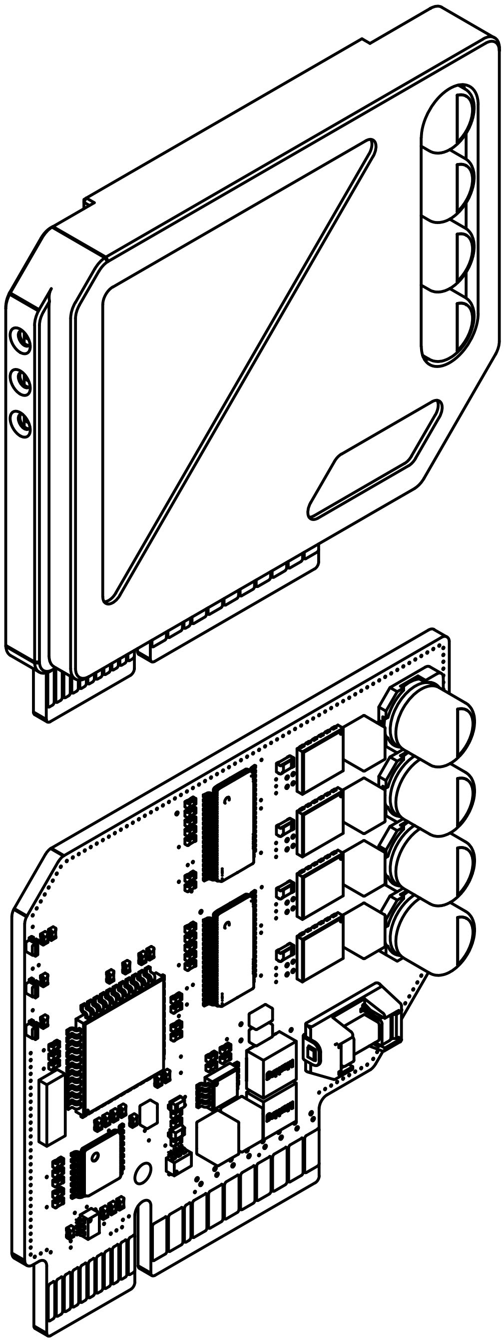
M2 User Manual



The M2 is a two-channel stepper motor driver, capable of driving small motors for laboratory automation. It offers up precision, with up to 256 microsteps per full step, power, with up to 1.3 A of maximum current per motor winding, and speed, with up to 6.2 kilosteps per second.

Contents of this document

Specifications

Parameter	Min.	Typ.	Max.
Motor channels			2
Supply voltage	12 V	24 V	30 V
Supply current[1]	20 mA	30 mA	60 mA
Microsteps per full step	1		256
Microstep rate			6200 Hz
Winding current			1.3 A
Interlock voltage		5 V	
Interlock pull-up resistance		1 kΩ	
Interlock response time			10 ms
Module height		100 mm	
Module width		35 mm	
Mass		100 g	

Theory of Operation

A stepper motor (step motor, or stepping motor), is a brushless DC electric motor that divides a full rotation into a number of equal steps. The motor's position can be commanded to move and hold at one of these steps without any position sensor for feedback via an open-loop controller. The M2 is just such a controller.

Electrical

Power Requirements

The M2 is designed for use with a 24-V input, but is tolerant to a wide range of input voltages. It requires at least 12 V to function, and can tolerate voltages up to 30 V. The supply voltage is fed directly to the motor windings; higher voltage enables higher step rates, at the cost of more power dissipation in the controller. Qontrol recommends an input power supply voltage of 24 V, able to source at least 1.5× the sum of the peak currents of each channel, for each connected M2 module. For example, if three M2 modules populate a backplane, and each channel is set to the maximum 1.3 A, the power supply should

[1] Base supply current, to be added to the sum of the maximum winding current settings of each motor.

be able to provide at least $1.5 \times (3 \times 2 \times 1.3) = 11.7$ amperes. No separate digital supply is required, as the M2 has an on-board buck converter.

Warning: The M2 is *not* hot-swappable. Always turn off power before connecting or disconnecting modules or motors. Disconnecting or unplugging motors or M2 modules while motors are running may result in shock and permanent damage to the controller and motor.

The M2 comes equipped with an on-board 3-A quick-blow fuse. This sits within the plastic enclosure and, if blown, should be replaced like-for-like with part number `Littelfuse 0453003`. For instructions on replacement, contact Qontrol at support@qontrol.co.uk.

Motor Requirements

The M2 is designed to control bipolar stepper motors, with 4 or 6 wires. It can drive motors of all sizes, but the current setting `IMAX` must be set less than the maximum current tolerated by the motor. Some motors specify a maximum voltage `V` and a winding resistance `R`: obtain the maximum current by dividing $V/R = I$. The quoted voltage does not matter, but be sure to avoid sourcing more current to the motor than it can tolerate.

Wiring and Pin Map

Note: side A is the bottom side of the circuit board, which is unpopulated.

Side	Pin Number	Function
A,B	12, 13	Motor power supply input
A,B	14, 15	Motor power supply return
B	17, 18	Motor 0, Winding A
B	19, 20	Motor 0, Winding A return
B	21, 22	Motor 0, Winding B
B	23, 24	Motor 0, Winding B return
B	25, 26	Motor 1, Winding A
B	27, 28	Motor 1, Winding A return
B	29, 30	Motor 1, Winding B
B	31, 32	Motor 1, Winding B return
A	17	Interlock 0 Connect NO switch to ground
A	25	Interlock 1 Connect NO switch to ground
A	18–24, 26–32	Ground and shield
B	10, 11	Analog inputs (not used)

Mechanical

Motor Coordinates and Microstepping

Motor position dimensions are given in human-readable floating-point numbers of full steps and binary-encoded integers of 256-microstep steps. Input and output coordinates are independent of the controller microstep setting. For example, when set to the maximum microstep resolution of 256 microsteps per full step, a target location of $+2.0$ is equivalent to $+2.0 * 256 = 512$ microsteps in the positive direction from zero. Positions may be greater than or less than zero, and are continuous across it.

Binary-encoded positions are 32 bits in length, encoding any position in the inclusive range $[-2147483648, +2147483647]$, approximately ± 8.4 million full steps. Motion beyond these limits is undefined.

Motor speeds are similarly given in position units per second. For example, a human-readable speed 200.0 is equivalent to 200 full steps per second. With a setting of 64 microsteps per full step, this gives $200.0 * 64 = 12800$ microsteps per second, the maximum step rate of the M2. This is the maximum speed of the controller at any microstep setting. Maximum full-speed settings are listed below for each microstep setting. For a typical modern stepper motor with 200 full steps per revolution, this speed translates to $200.0(step/s)/200(step/rev) = 1(rev/s)$ revolutions per second.

Microsteps per step	USTEP setting	Maximum speed
1	0	12800
2	1	6400
4	2	3200
8	3	1600
16	4	800
32	5	400
64	6	200
128	7	100
256	8	50

Acceleration and Deceleration

The M2 implements a constant-acceleration profile when changing speed. This allows higher speeds to be achieved without causing a motor stall. This profile applies to starting, stopping, and changing direction while in motion.

Four acceleration modes are possible. These are controlled by `MODE` bits 2 and 3 (see Mode Flags). The acceleration is independent of the microstep setting, but does depend linearly on the maximum speed setting: higher maximum speeds have higher acceleration.

Synchronous multi-axis moves are possible because the acceleration profile occurs over a constant time, independent of the maximum speed setting. This means that multiple axes can simultaneously accelerate, travel and constant speed, then decelerate and arrive at their respective target positions together, provided their maximum speeds are scaled to match their distances traveled. For example, for two motors, 0 and 1, producing movement in the Cartesian Y and Z directions, respectively, we can move from the origin (Y=X0=0, Z=X1=0) to a point (Y,Z)=(250, 1000) by setting VMAX0=50.0 and VMAX1=200.0 then initiating the move with the vectorised command XVEC0=250,1000.

Programming

The M2 is fully compatible with Qontrol's Python software[2], available on Github and PIP. For direct serial programming, debugging, and application-code development, details of direct programming are available here.

Command reference

The commands listed below are new for the M2.

Command	Read/Write	Units	Description
X	R/W	FS[3]	Tell motor to go to position (on write) or get motor position now (on read).
XMIN	R/W	FS	Motor negative stop location.
XMAX	R/W	FS	Motor positive stop location.
USTEP	R/W	[0,8]	Power-of-two microsteps per full step, E.g. USTEP=0 gives 1 microstep per full step (i.e. no microstepping); USTEP=8 gives 256 microsteps per full step.
MODE	R/W	[0,15]	Motor mode. See Mode Flags for more information.
STAT	R		Motor status. See Status Flags for more information.

The commands listed below are shared with other modules, but with meanings specific to the M2.

Command	Read/Write	Units	Description
V	R	FSPS[4]	Channel speed now.
VMAX	R/W	FSPS	Max speed.

[2] Available from Github (github.com/takeqontrol/api) or PyPI (pip install qontrol).
[3] Full steps (independent of microstepping).

Command	Read/Write	Units	Description
IMAX	R/W	mA	Max winding current.
VFULL	R	FSPS	Full-scale speed.
IFULL	R	mA	Full-scale winding current.
NCHAN	R	integer	Number of Channels per module.
FIRMWARE	R	–	Firmware revision.
ID	R	–	Unique device identifier.
LIFETIME	R	–	Time since module was first powered.
HELP	R	–	Basic command reference.
ECHO	R/W	{0,1}	Serial echo enable.
LED	R/W	[0,1]	Indicator brightness; 0 turns LEDs off, 1 is full brightness.
NUP	R/W	–	Number of upstream modules in daisy chain. Can be overridden. Use NUP=0 to reinitialise daisy chain. NUPALL? gives a chain manifest.
OK	R/W	{0,1}	Respond to non-read commands with OK.
NVM	R/W	–	Read module NVM[5].
LOG	R	–	Read module internal log.
QUIET	R/W	{0,1}	Suppress serial error messages.
SAFE	R/W	{0,1}	Module safety state.
RESET	A	–	Reset module.

Error Reference

The errors listed in this section are unique to the M2.

E01:NN	Requested position (X) for channel NN is out of range
E05:NN	Stall on channel NN
E20:NN	Interlock on channel NN has been tripped

[4] Full-steps per second.
[5] Non-volatile memory. Data survives when powered off.

Mode Flags

The motor mode controls several special aspects of motor behaviour, controlled by the `MODE` command. It is a 16-bit integer encoded using the bit masks below. Motor modes are preserved even when the M2 is not powered.

```
MOTOR_MODE_EN_WHEN_STOP  0b0000000000000011    1,2
MOTOR_MODE_ACCELERATION  0b0000000000001100    4,8
MOTOR_MODE_INVERT_DIR    0b0000000000010000    16
MOTOR_MODE_INVERT_INTLK  0b0000000000100000    32
```

The default mode is given below.

```
MOTOR_DEFAULT_MODE       0b0000000000000000    0
```

The mode is composed by adding together the decimal equivalent values of the desired functionalities. These functionalities are as follows:

- Bits 0 and 1 encode the fraction of full winding current to be applied when the motor is at rest. This affects the energy impact of the M2, with smaller values using less power. 3 gives 100% current; 2 gives 50% current; 1 gives 25% current; and 0 gives 0% current, completely de-energising the motor.
- Bits 2 and 3 encode the motor acceleration. 0b00 gives the shortest acceleration time and qualitatively quickest movement, and 0b11 gives the longest acceleration time and slowest movement, with 0b01 and 0b10 giving acceleration times in between.
- Bit 4 reverses the motor direction compared to the internal coordinate system. Note that in normal operation, motor direction should be controlled by passing in positive or negative position values, rather than repeatedly modifying the mode.
- Bit 5 inverts the interlock polarity. 0 should be used with normally-open (NO) interlock switches, and 1 should be used with normally-closed (NC) interlocks.

Status Flags

The `STAT` command can be used to quickly determine a motor's movement status. The return value is an ASCII numeral between 0 and 7, decoded as follows:

Bit mask	Decimal value	Set if...
`0b0001`	1	motor is in motion
`0b0010`	2	motor is accelerating
`0b0100`	4	motor interlock is triggered

The sum of these bit masks yields the status. In the table below, omitted decimal values are inaccessible.

Decimal value	Status
0	Motor is stopped
1	Motor is moving at its top speed
3	Motor is accelerating or decelerating
5	Motor is at top speed and interlock is active
7	Motor is accelerating and interlock is active

Non-volatile Memory Layout

The M2 non-volatile memory (NVM) is composed of 16-bit words, and is 256 words long. This memory survives being unpowered, and is guaranteed to 40-years retention, and at least 10*u* erase/re-write cycles. The layout of the M2 NVM is detailed in the table below.

First address	Last address	Contents
`0x40`	`0x47`	Microstep values (8 channels, 16b).
`0x48`	`0x4E`	Motor modes (8 channels, 16b).
`0x50`	`0x5F`	Motor positions (8 channels, 32b).
`0x60`	`0x67`	Negative stop positions (8 channels, 32b).
`0x68`	`0x6E`	Positive stop positions (8 channels, 32b).

Compatible Actuators

ACTL2

A high-performance linear actuator, designed to interface with stages with external `M22x0.75` threaded flanges, like the Thorlabs NanoMax™ series of multi-axis stages.

Travel	19.6 mm
Travel (full steps)	6200
Full step resolution	3.175 um
Optimal winding current	0.2 A
Maximum winding current	1.0 A
Overall length	100 mm
Overall width	35 mm

Overall height	36 mm
Mass	220 g
Positive limit switch	Yes
Negative limit switch	No
Optimal `MODE`	21

Notes and disclaimer

If you find an error in this document, or have suggestions for how we could make it better, please do get in touch with us at support@qontrol.co.uk with your ideas and feedback.

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Revision history

1.1 (this version)	2021-04-27
1.0	2021-03-12