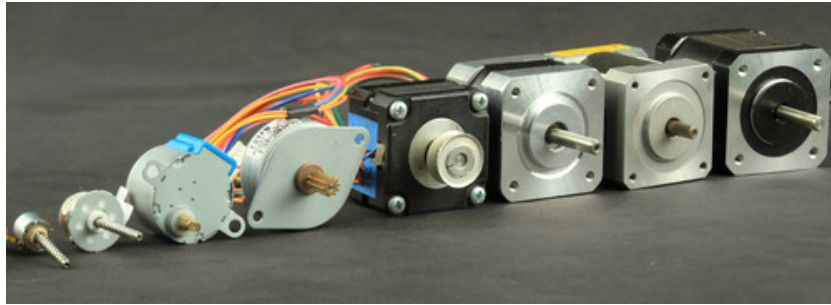




# All About Stepper Motors

Created by Bill Earl

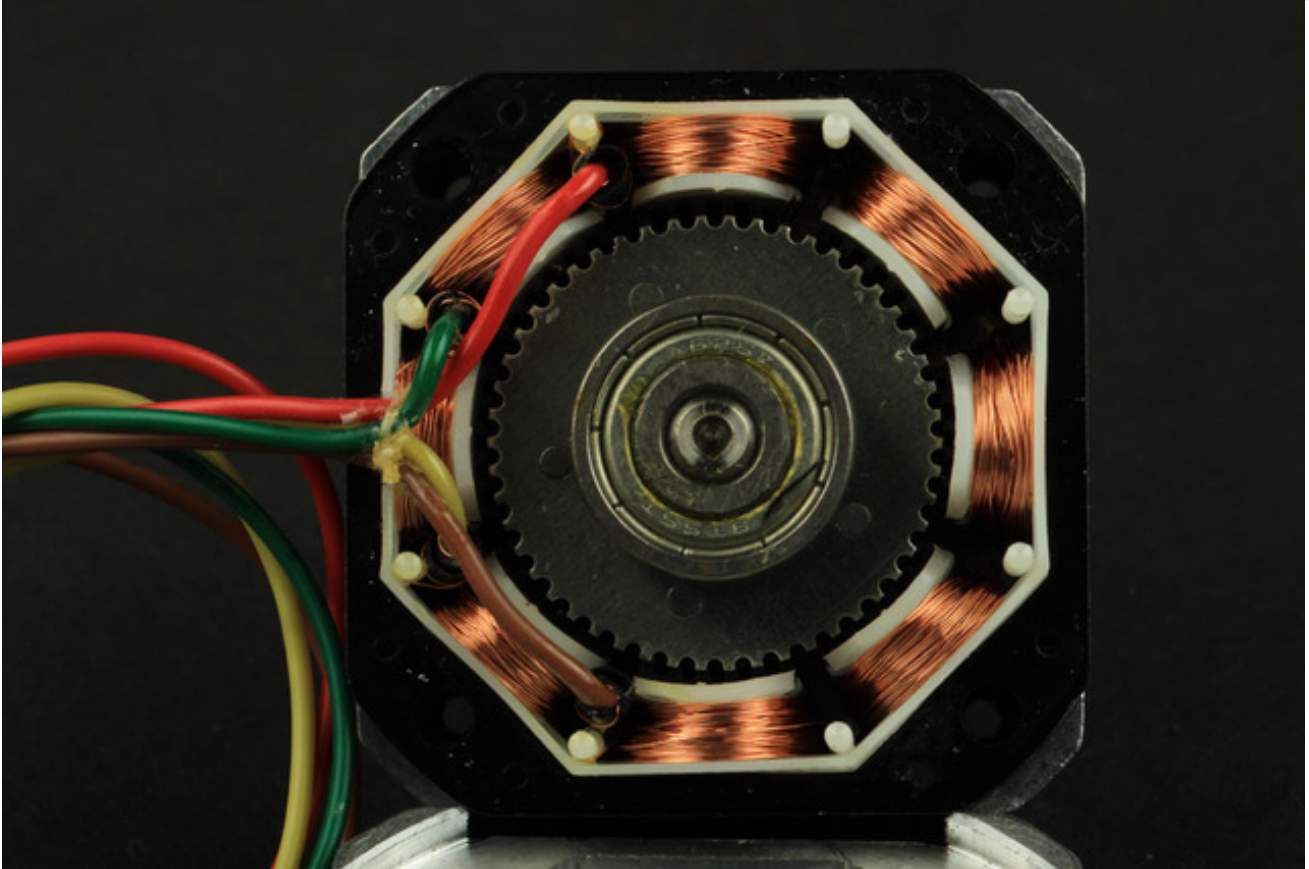


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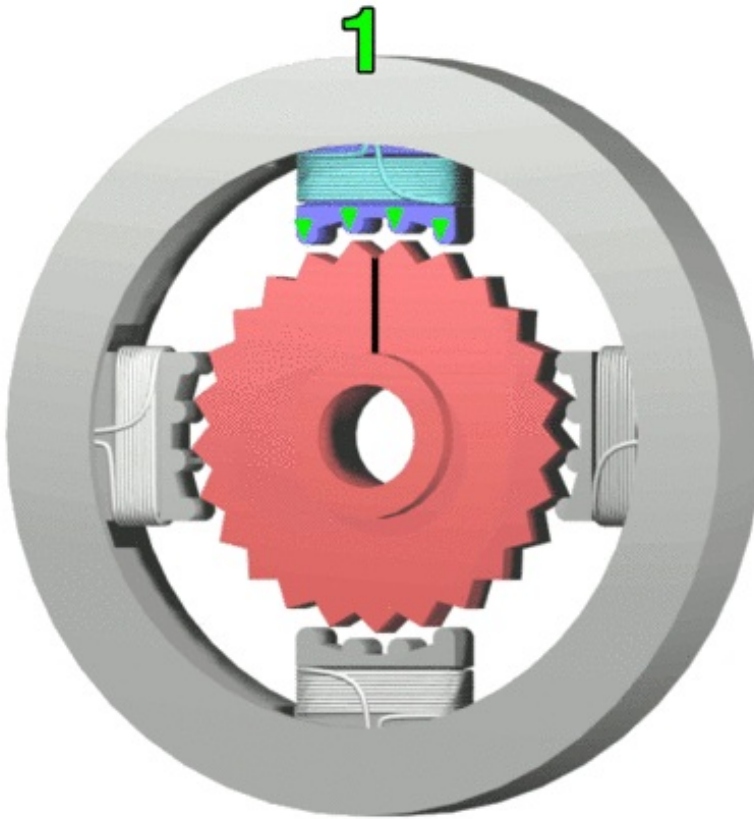
## What is a Stepper Motor?



Stepper motors are DC motors that move in discrete steps. They have multiple coils that are organized in groups called "phases". By energizing each phase in sequence, the motor will rotate, one step at a time.

With a computer controlled stepping you can achieve very precise positioning and/or speed control. For this reason, stepper motors are the motor of choice for many precision motion control applications.

Stepper motors come in many different sizes and styles and electrical characteristics. This guide details what you need to know to pick the right motor for the job.



### *A 4-phase unipolar motor.*

*Animation from Wikimedia Commons*

What are stepper motors good for?

- **Positioning** – Since steppers move in precise repeatable steps, they excel in applications requiring precise positioning such as 3D printers, CNC, Camera platforms and X,Y Plotters. Some disk drives also use stepper motors to position the read/write head.
- **Speed Control** – Precise increments of movement also allow for excellent control of rotational speed for process automation and robotics.
- **Low Speed Torque** - Normal DC motors don't have very much torque at low speeds. A Stepper motor has maximum torque at low speeds, so they are a good choice for applications requiring low speed with high precision.



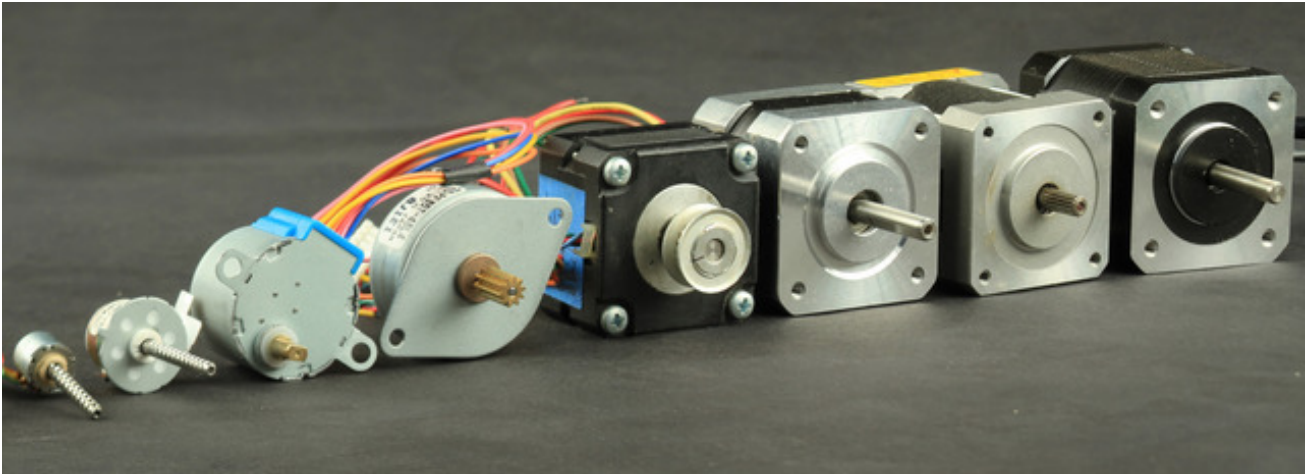
What are their limitations?

- **Low Efficiency** – Unlike DC motors, stepper motor current consumption is independent of load. They draw the most current when they are doing no work at all. Because of this, they tend to run hot.
- **Limited High Speed Torque** - In general, stepper motors have less torque at high speeds than at low speeds. Some steppers are optimized for better high-speed performance, but they need to be paired with an appropriate driver to achieve that performance.
- **No Feedback** – Unlike servo motors, most steppers do not have integral feedback for position. Although great precision can be achieved running 'open loop'. Limit switches or 'home' detectors are typically required for safety and/or to establish a reference position.

# Types of Steppers

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There are a wide variety of stepper types, some of which require very specialized drivers. For our purposes, we will focus on stepper motors that can be driven with commonly available drivers. These are: Permanent Magnet or Hybrid steppers, either 2-phase bipolar, or 4-phase unipolar.



## Motor Size

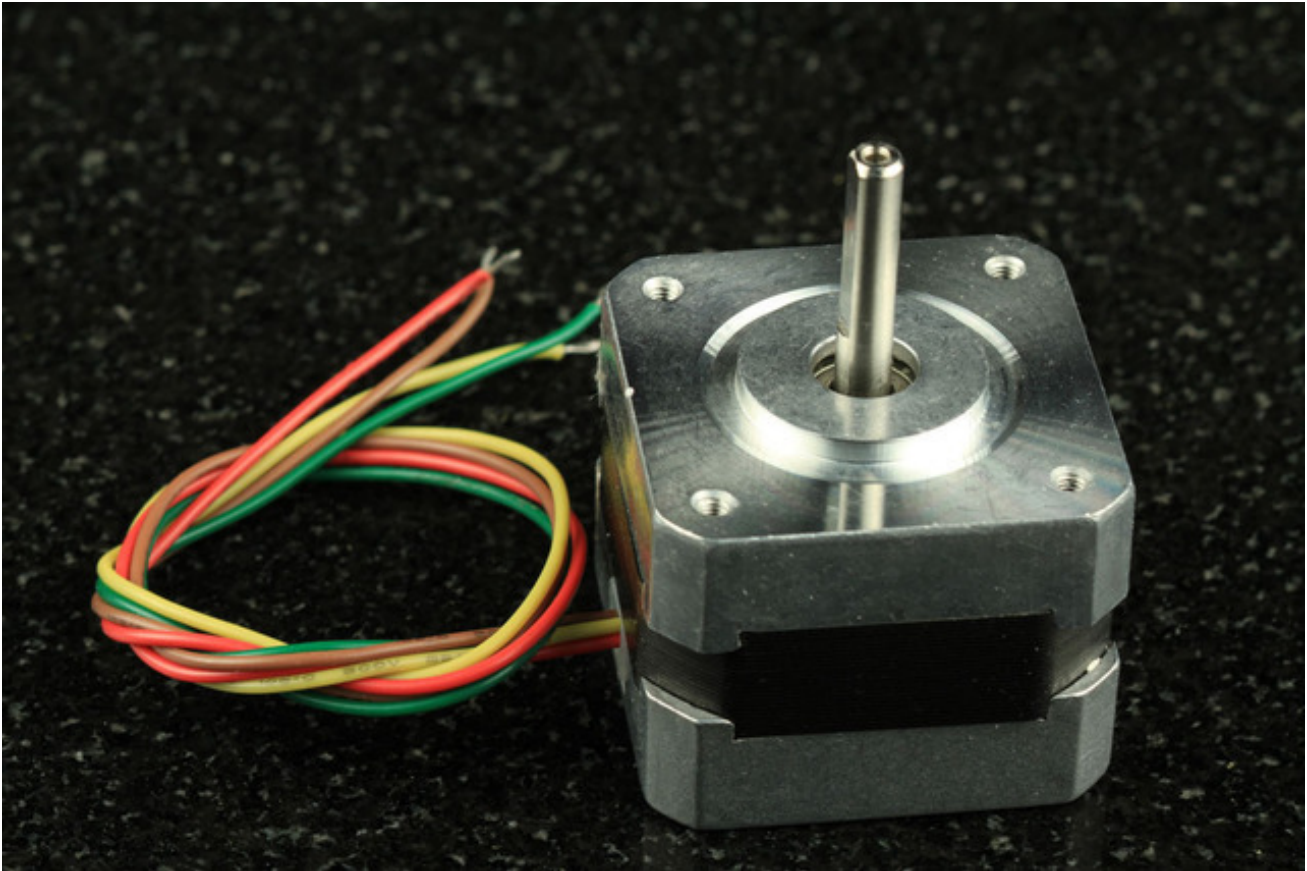
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One of the first things to consider is the work that the motor has to do. As you might expect, larger motors are capable of delivering more power. Stepper motors come in sizes ranging from smaller than a peanut to big NEMA 57 monsters.

Most motors have torque ratings. This is what you need to look at to decide if the motor has the strength to do what you want.

NEMA 17 is a common size used in 3D printers and smaller CNC mills. Smaller motors find applications in many robotic and animatronic applications. The larger NEMA frames are common in CNC machines and industrial applications.

The NEMA numbers define standard faceplate dimensions for mounting the motor. They do not define the other characteristics of a motor. Two different NEMA 17 motors may have entirely different electrical or mechanical specifications and are not necessarily interchangeable.



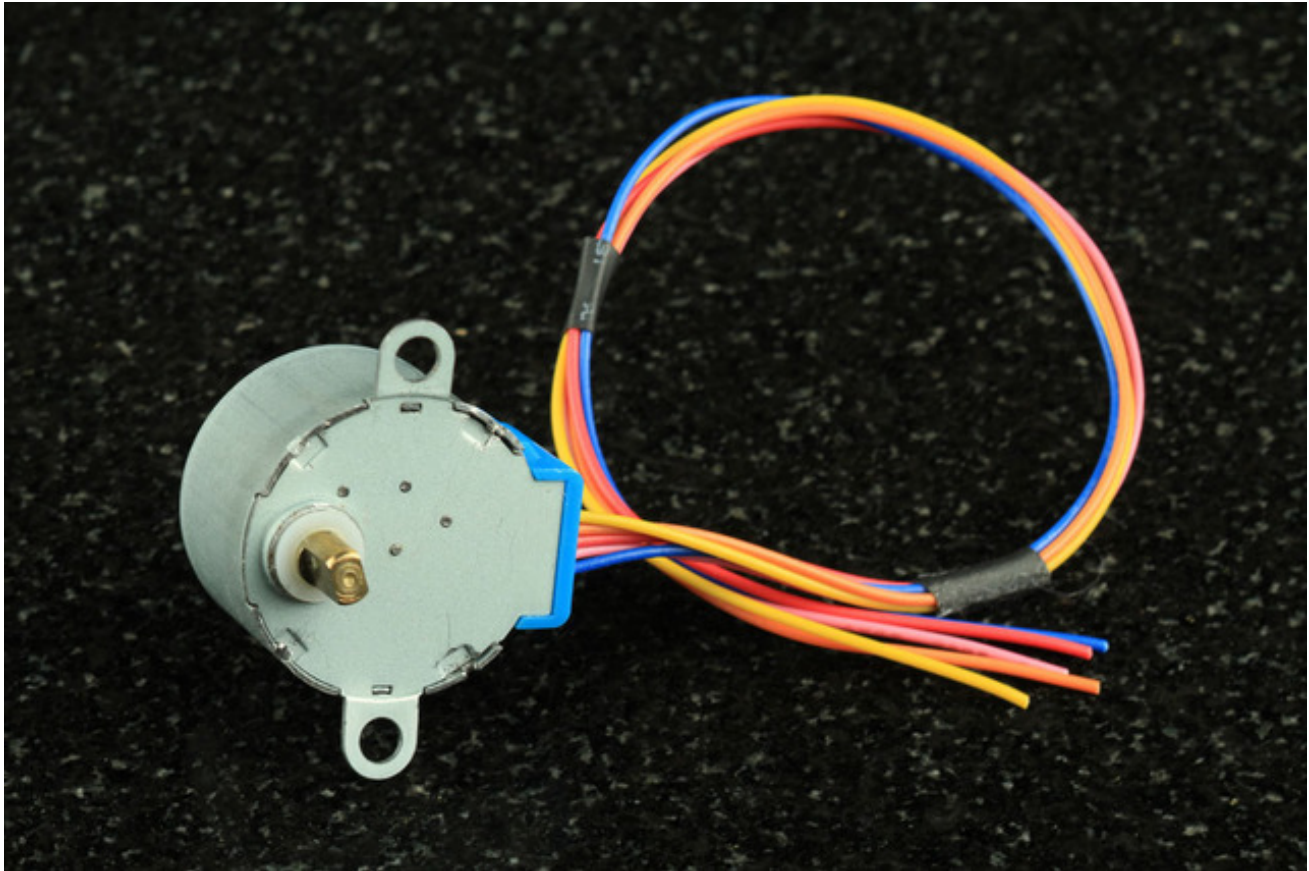
## Step Count

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The next thing to consider is the positioning resolution you require. The number of steps per revolution ranges from 4 to 400. Commonly available step counts are 24, 48 and 200.

Resolution is often expressed as degrees per step. A  $1.8^\circ$  motor is the same as a 200 step/revolution motor.

The trade-off for high resolution is speed and torque. High step count motors top-out at lower RPMs than similar size. And the higher step-rates needed to turn these motors results in lower torque than a similar size low-step-count motor at similar speeds.



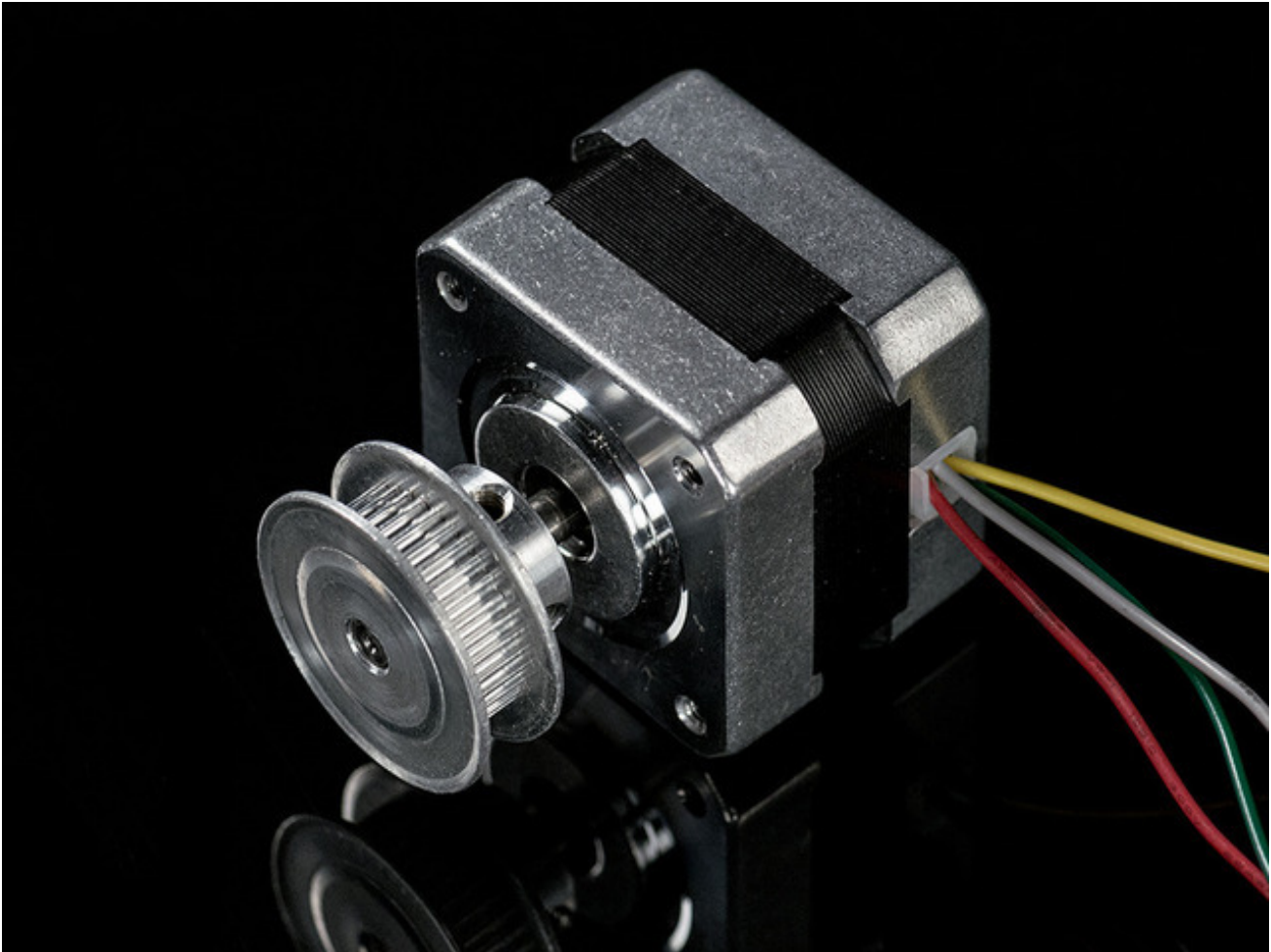
## Gearing

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Another way to achieve high positioning resolution is with gearing. A 32:1 gear-train applied to the output of an 8-steps/revolution motor will result in a 512 step motor.

A gear train will also increase the torque of the motor. Some tiny geared steppers are capable of impressive torque. But the tradeoff of course is speed. Geared stepper motors are generally limited to low RPM applications.



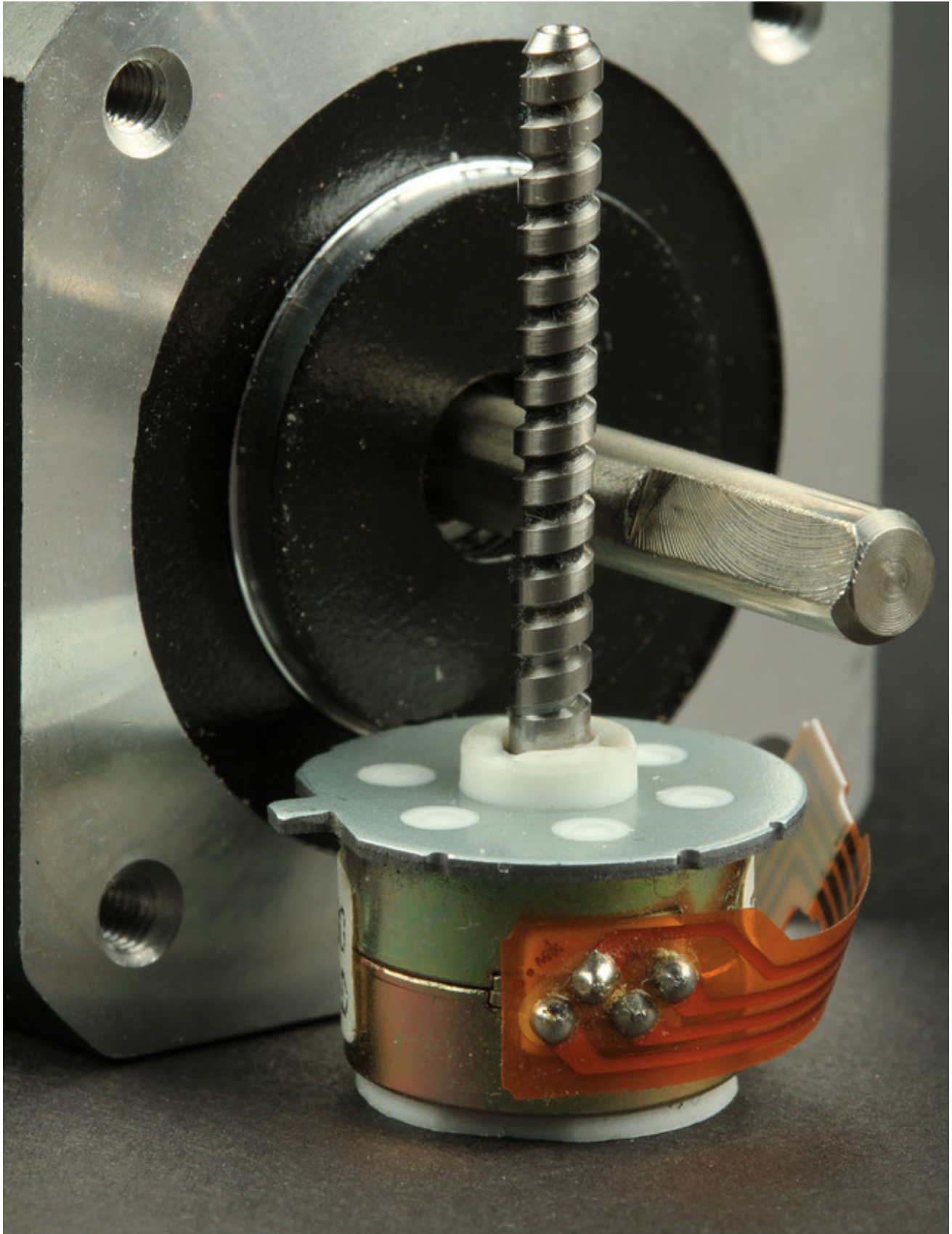


## Shaft Style

Another thing to consider is how the motor will interface with the rest of the drive system. Motors are available with a number of shaft styles:

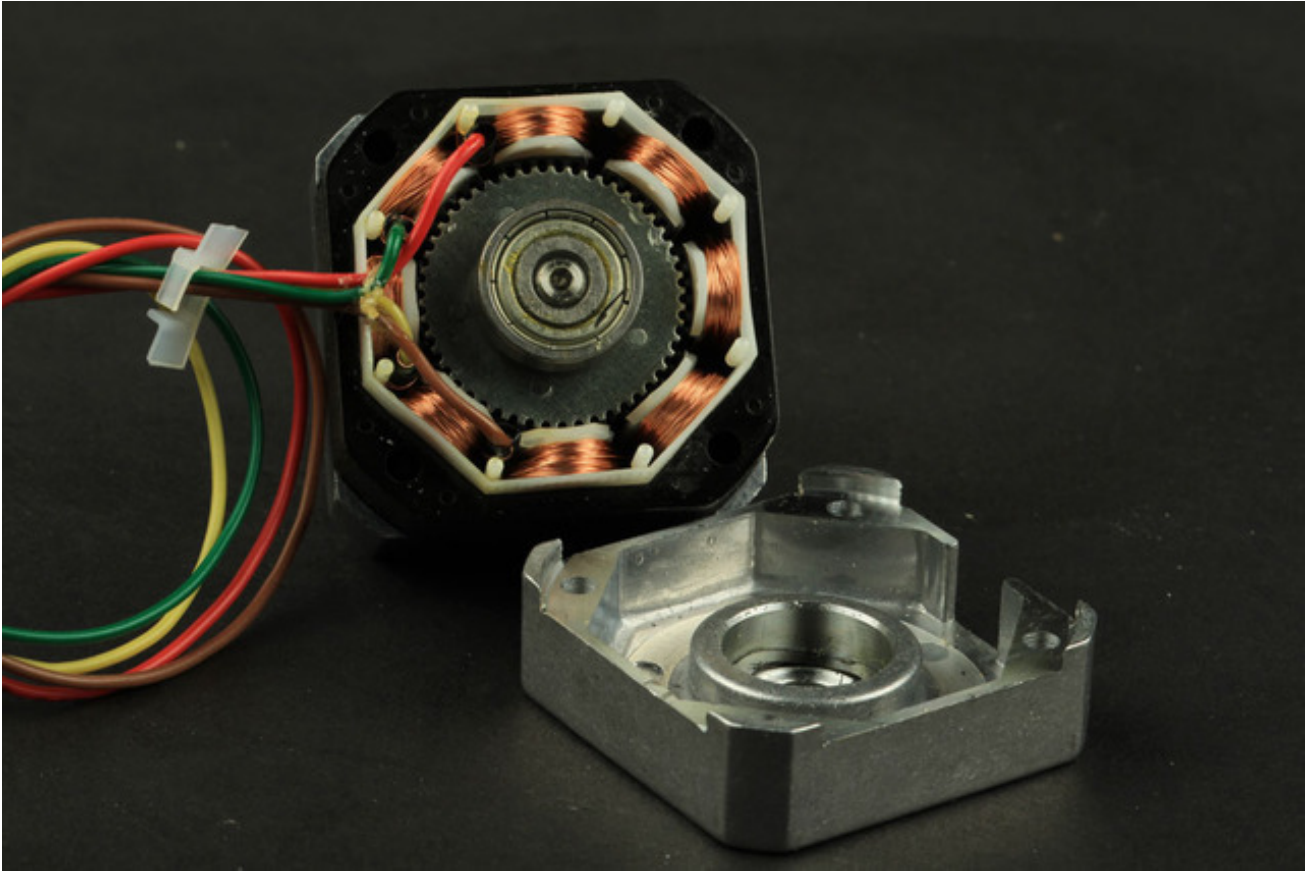
- **Round or "D" Shaft:** These are available in a variety of standard diameters and there are many pulleys, gears and shaft couplers designed to fit. "D" shafts have one flattened side to help prevent slippage. These are desirable when high torques are involved.
- **Geared shaft:** Some shafts have gear teeth milled right into them. These are typically designed to mate with modular gear trains.
- **Lead-Screw Shaft:** Motors with lead-screw shafts are used to build linear actuators. Miniature versions of these can be found as head positioners in many disk drives.





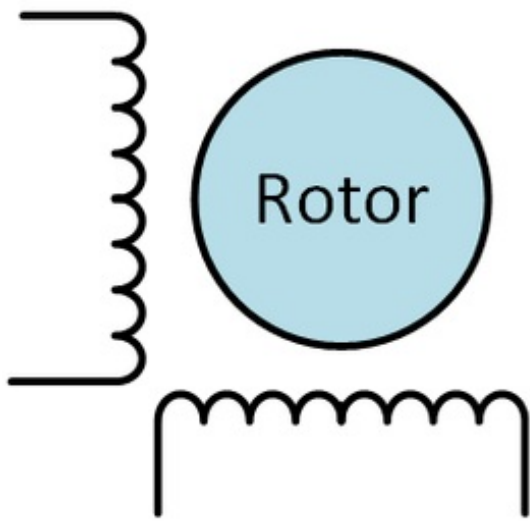
## Wiring

There are many variations in stepper motor wiring. For our purposes, we will focus on steppers that can be driven with commonly available drivers. These are Permanent Magnet or Hybrid steppers wired as 2-phase bipolar, or 4-phase unipolar.

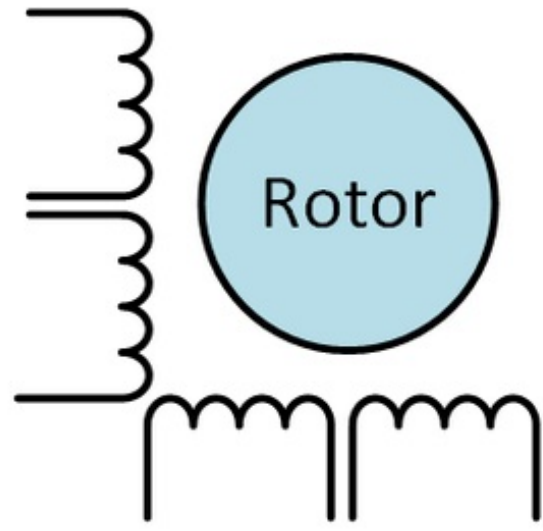


## Coils and Phases

A stepper motor may have any number of coils. But these are connected in groups called "phases". All the coils in a phase are energized together.



Bipolar



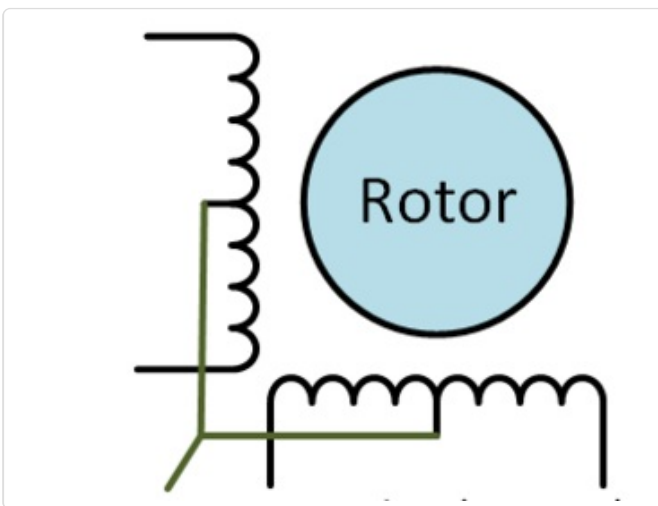
Unipolar (8 wire)

## Unipolar vs. Bipolar

**Unipolar** drivers, always energize the phases in the same way. One lead, the "common" lead, will always be negative. The other lead will always be positive. Unipolar drivers can be implemented with simple transistor circuitry. The disadvantage is that there is less available torque because only half of the coils can be energized at a time.

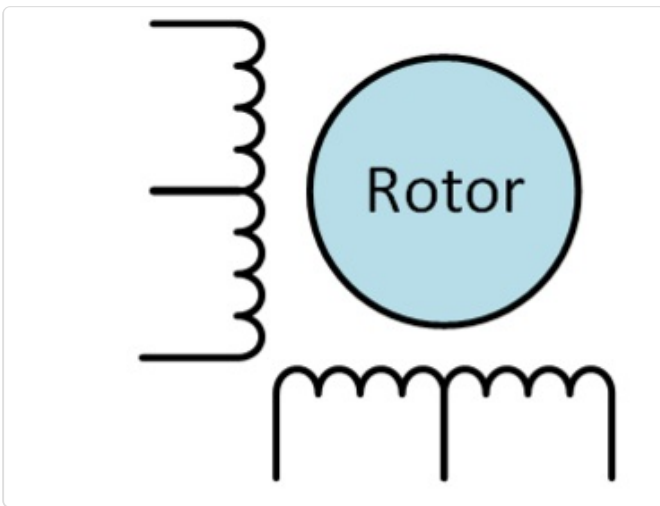
**Bipolar** drivers use H-bridge circuitry to actually reverse the current flow through the phases. By energizing the phases with alternating the polarity, all the coils can be put to work turning the motor.

A two phase bipolar motor has 2 groups of coils. A 4 phase unipolar motor has 4. A 2-phase bipolar motor will have 4 wires - 2 for each phase. Some motors come with flexible wiring that allows you to run the motor as either bipolar or unipolar.



### 5-Wire Motor

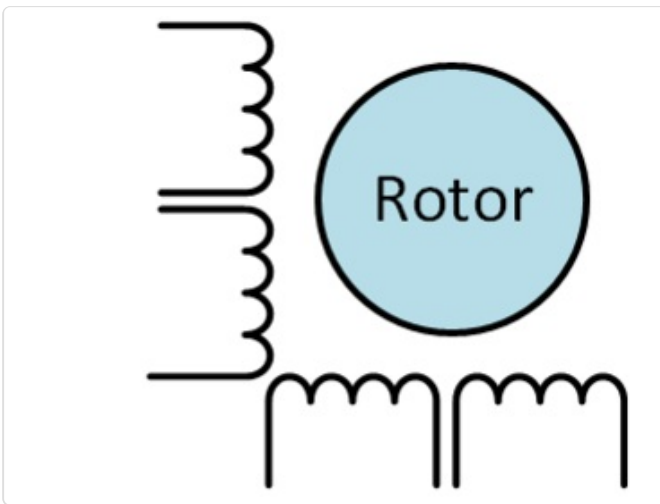
This style is common in smaller unipolar motors. All of the common coil wires are tied together internally and brought out as a 5th wire. This motor can only be driven as a unipolar motor.



### 6-Wire Motor

This motor only joins the common wires of 2 paired phases. These two wires can be joined to create a 5-wire unipolar motor.

Or you just can ignore them and treat it like a bipolar motor!



### 8-Wire Motor

The 8-wire unipolar is the most versatile motor of all. It can be driven in several ways:

- **4-phase unipolar** - All the common wires are connected together - just like a 5-wire motor.
- **2-phase series bipolar** - The phases are connected in series - just like a 6-wire motor.
- **2-phase parallel bipolar** - The phases are connected in parallel. This results in half the resistance and inductance - but requires twice the current to drive. The advantage of this wiring is higher torque and top speed.



# Driving a Stepper

*Step in time, step in time*

*Come on, mateys, step in time*

*Step in time*

*Step in time, step in time*

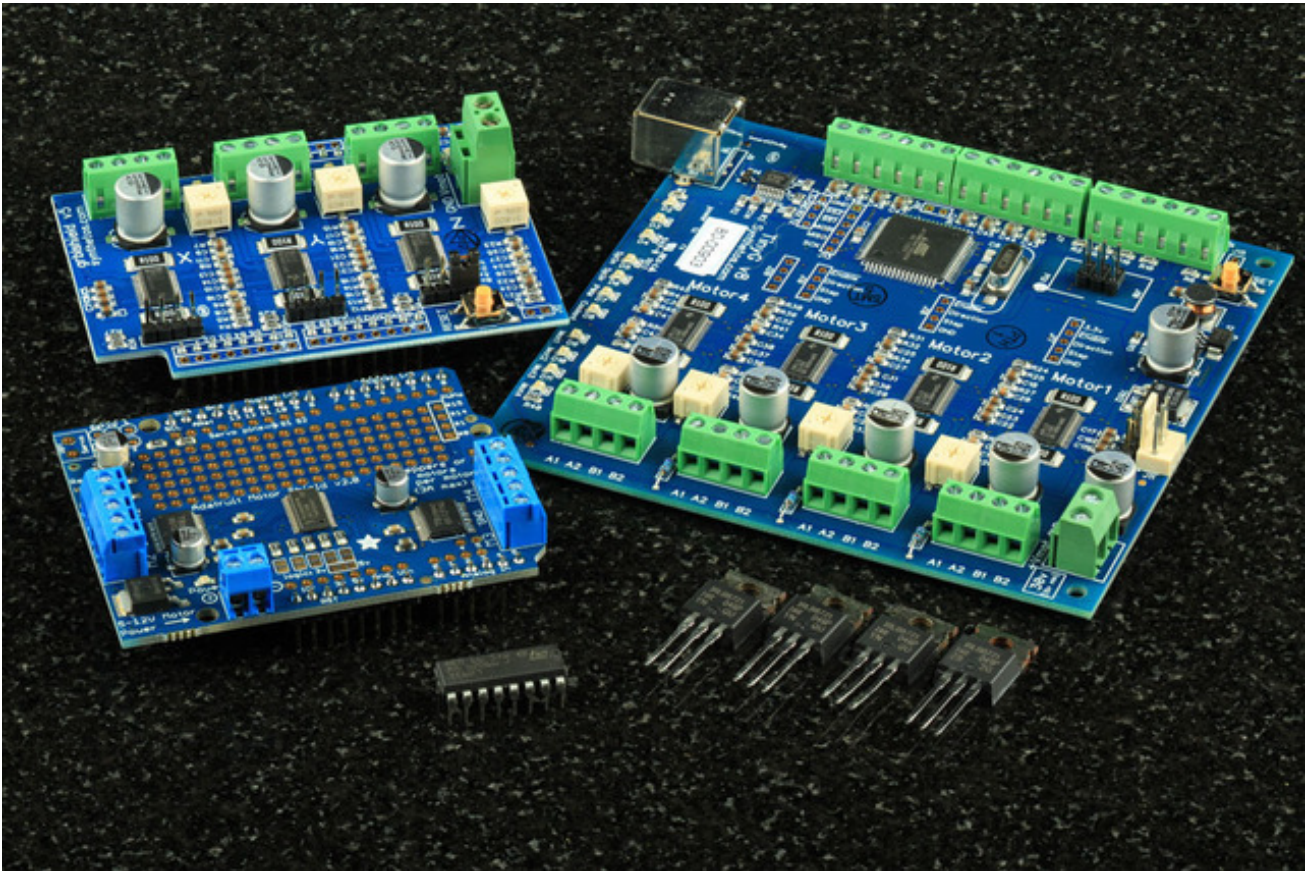
*Step in time, step in time*

*Never need a reason, never need a rhyme*

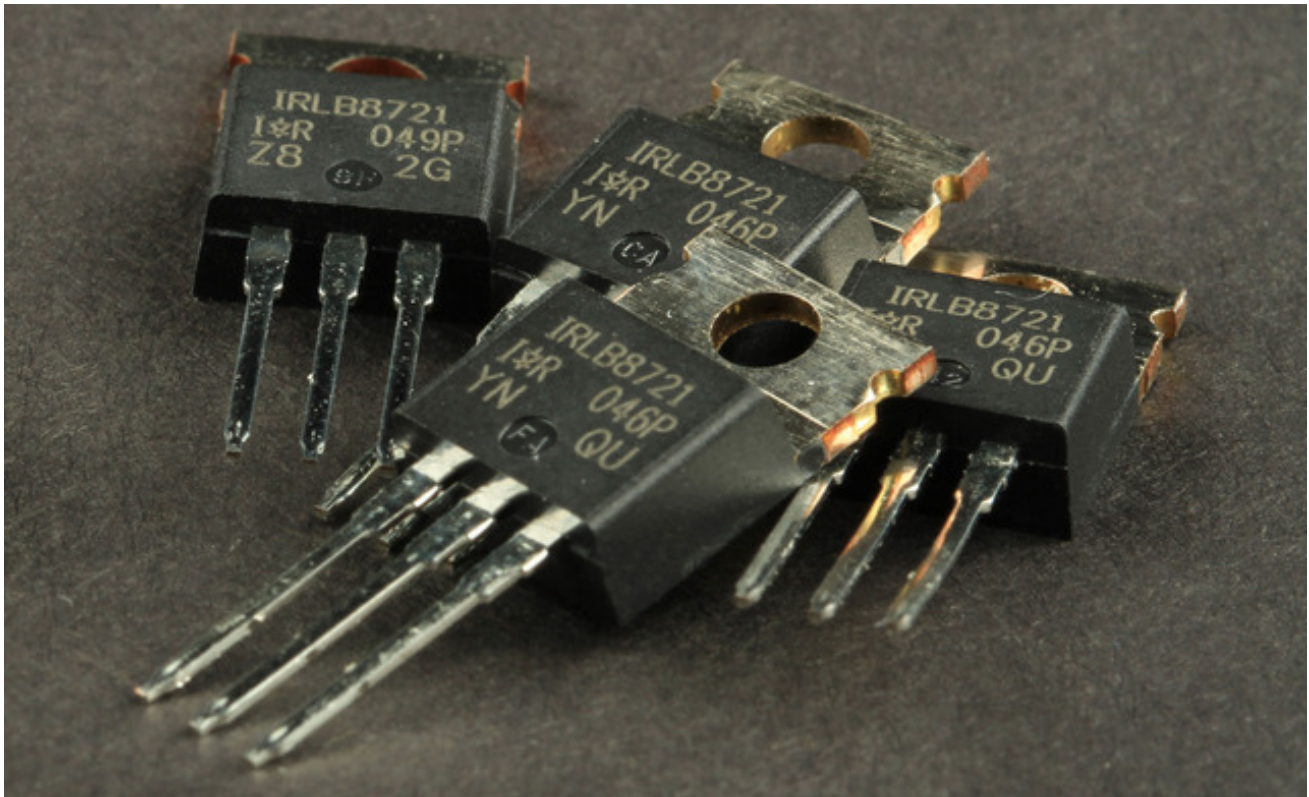
*We step in time, we step in time*

"Step In Time"

Robert B. Sherman and Richard M. Sherman



Driving a stepper motor is a bit more complicated than driving a regular brushed DC motor. Stepper motors require a stepper controller to energize the phases in a timely sequence to make the motor turn.



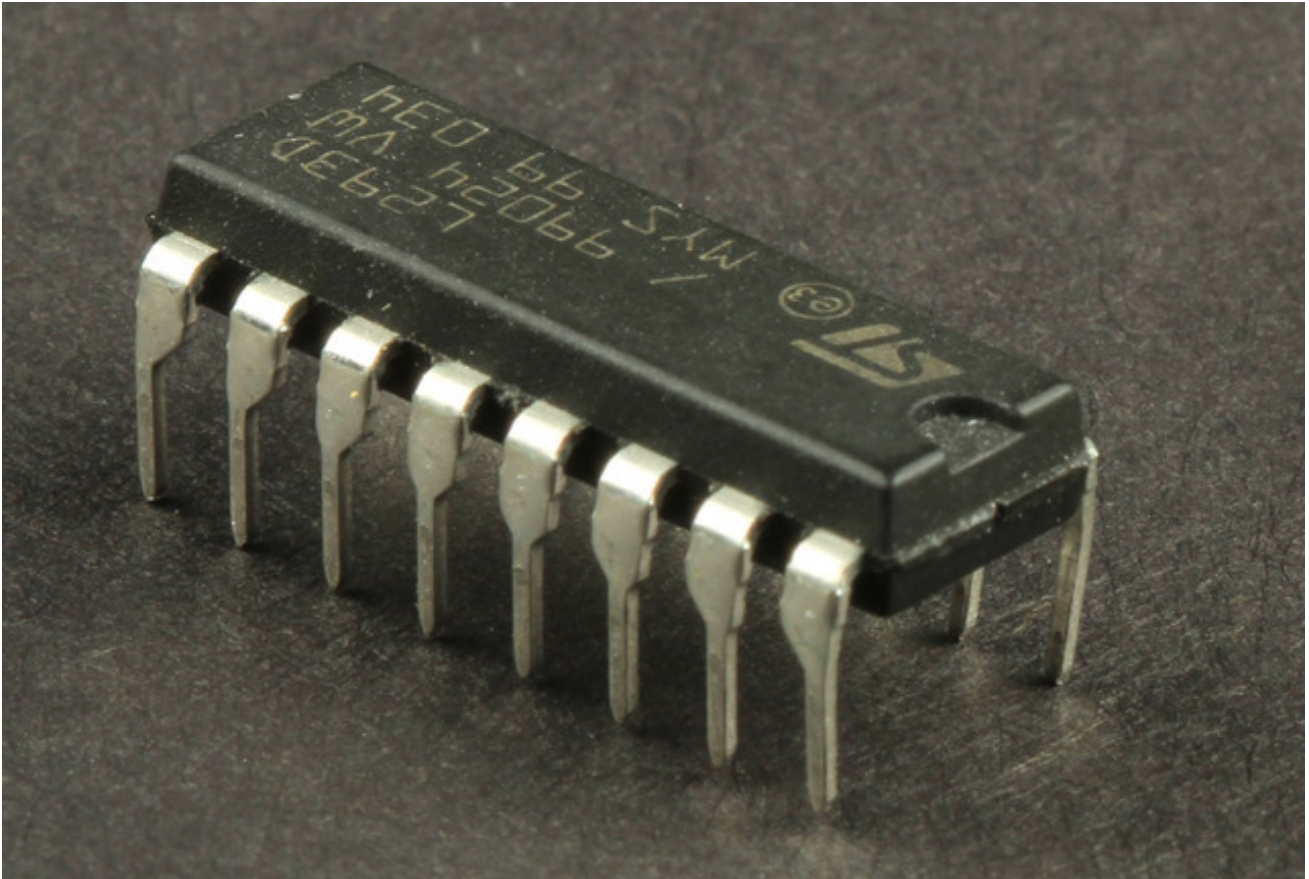
## Simple Unipolar Driver

The simplest type of driver can be built with a handful of transistors. These are simply switched on and off in sequence to energize the phases and step the motor. Unipolar drivers are relatively inexpensive to build, but only work with unipolar motors. There is an excellent tutorial on how to build one at the Arduino site.

Unipolar Stepper Drive Tutorial

<http://adafru.it/doa>





## Simple Dual H-Bridge Driver

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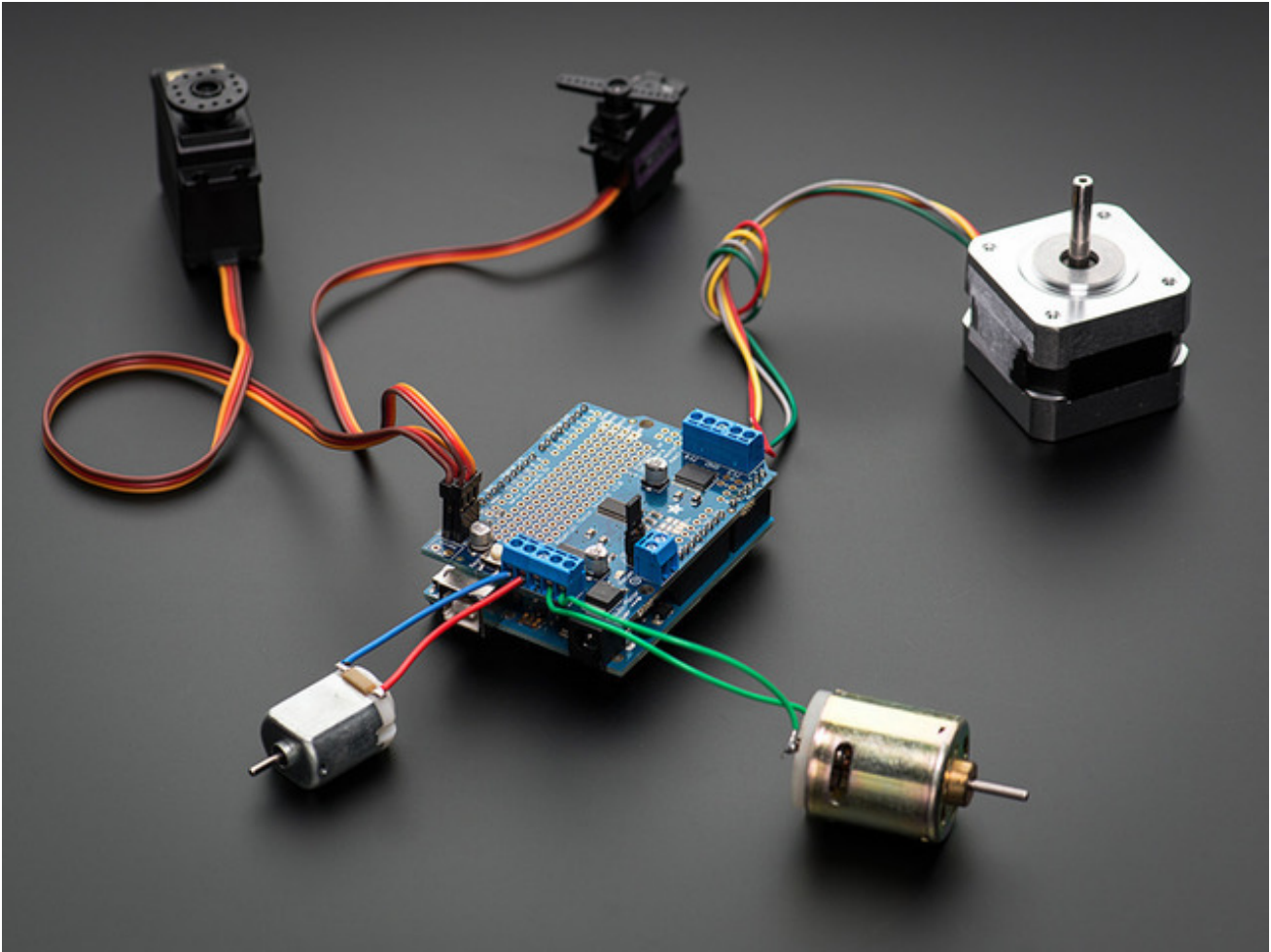
Driving a bipolar motor requires 2 full H-bridges so it can reverse the current to the phases. H-bridges can be tricky to build from scratch. But there are plenty of H-bridge chips available to simplify the task.

The L293D is one of the most popular and economical chips. These can be found at the heart of most first-generation motor shields, including the incredibly popular V1 Adafruit Motor Shield.

There is an excellent tutorial on using a bare L293D with an Arduino in the Adafruit Learning System:

Lesson 16 - Stepper Motors

<http://adafru.it/dob>



## Adafruit Motor Shield V2

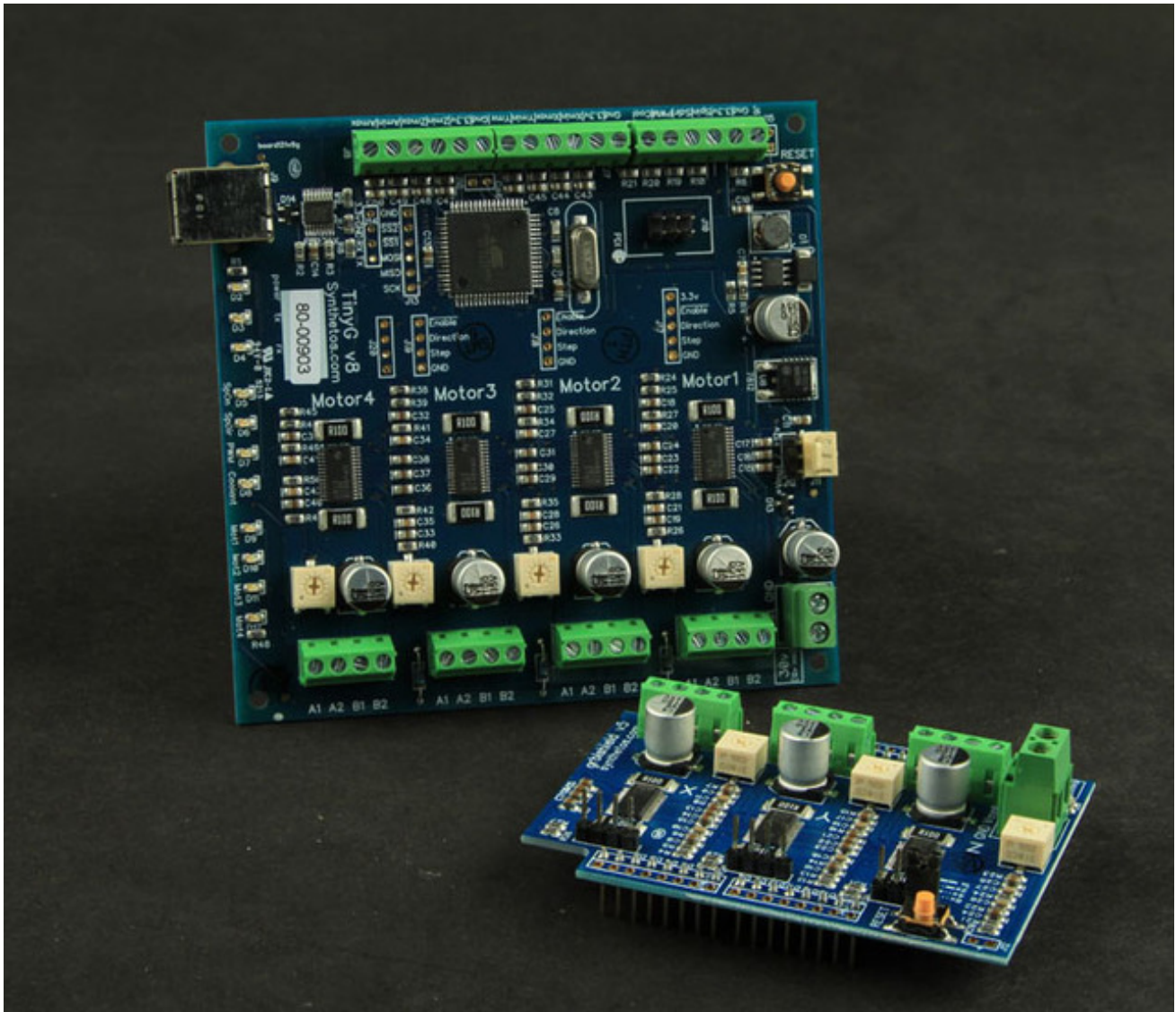
The Adafruit Motor Shield V2 is a big step up from the basic L293D based controllers. The V2 shield uses two TB6612 MOSFET drivers. Compared to the L293D, the TB6612 offers twice the current capacity and much lower voltage drops to drive your steppers more efficiently.

With 2 driver chips and 4 full H-bridges total, each shield can drive up to two stepper motors. The driver chips are interfaced via a dedicated PWM driver chip with an I2C interface. This frees up lots of GPIO pins for other uses, and makes the shield stackable too. You can stack up to 32 of them to control 64 motors with just 2 IO pins!

Complete details of this driver can be found in the Learning system.

[Adafruit Motor Shield V2 Guide](http://adafru.it/doc)

<http://adafru.it/doc>



## Advanced CNC Controllers

The gShield and TinyG CNC controller boards take you one step closer to industrial level stepper performance. These boards feature constant-current "chopper" drivers that can be tuned to deliver maximum torque and speed from your motors.

The TinyG CNC features an on-board G-code interpreter and 4 motor outputs making this a complete embedded solution for a small to medium sized 4-axis CNC machine.

As you might expect, these advanced, high-performance boards are more complex to work with and are recommended for experienced users.

Details on these boards and their operation can be found in the TinyG Wiki and the Synthetos Forums.

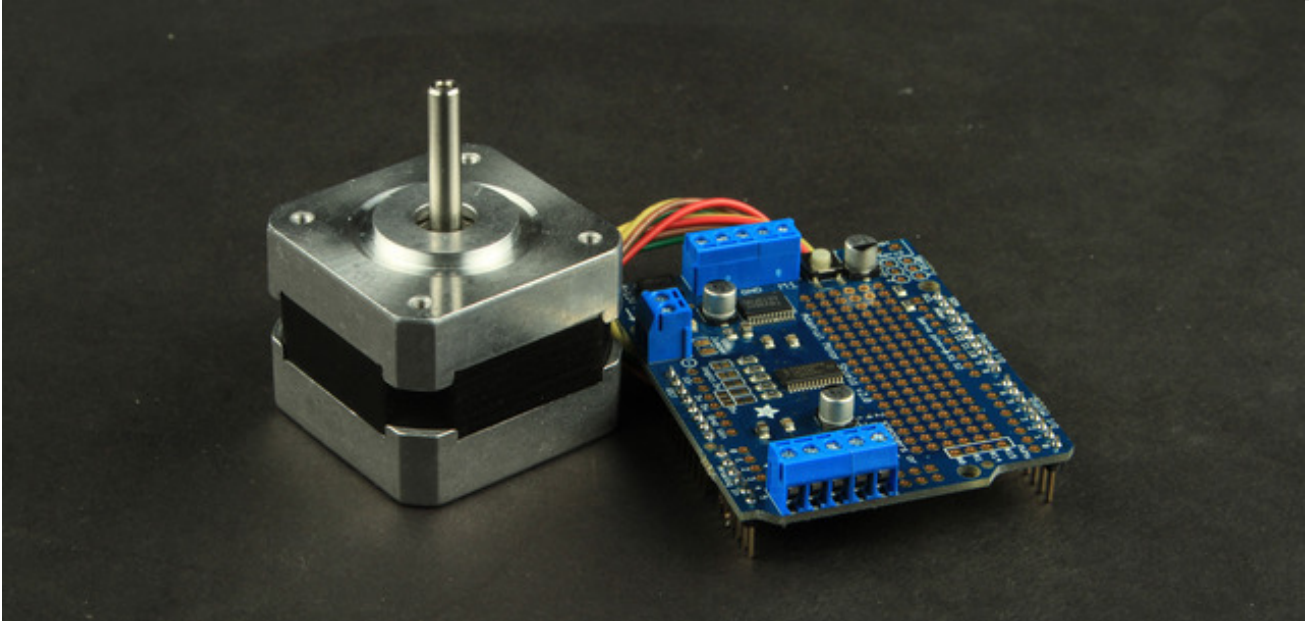
Synthetos Forums

<http://adafru.it/dod>

Tiny G Wiki

<http://adafru.it/doe>

## Matching the Driver to the Stepper



Now we come to the most important part: making sure that your motor and driver are compatible.

Mismatched motors and drivers can result in disappointing performance. Or worse: damage to the motor and/or controller.

If you choose unwisely, you might meet this guy:



## Know the Driver Specifications

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The two most important parameters in the driver specifications are:

- **Voltage** - The maximum voltage that the driver can supply to the motor.
- **Continuous Current** - The maximum current that the driver can supply to the motor.

"Peak" current ratings are not applicable to stepper motors. Always go by the "continuous" current rating.

## Know the Motor Specifications

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You will also need to know the electrical specifications for the motor. There are 2 critical parameters:

- **Amps per phase** - This is the maximum current that the motor windings can handle without overheating.
- **Resistance per phase** - This is the resistance of each phase.

A **Voltage** rating is often stated. It is usually calculated from the two above - but not always. It is

better to calculate yourself from the above parameters using **Ohm's Law**.

$$V = IR$$

## Obey the Law!

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Stepper motor phases are inductors, so they will resist rapid changes in current flow. But at the end of each step or when not moving, they behave like a purely resistive load and will behave according to **Ohm's Law** (<http://adafru.it/ikA>).

Standing still is also when a stepper motor draws the most current. So Ohm's Law allows us to use the motor specifications to calculate the current requirements of the driver.

***Voltage = Current x Resistance***

or

***Current = Voltage / Resistance***

These formulas should be strictly applied for all "constant voltage" stepper controllers. This includes both V1 and V2 Motor Shields from Adafruit, and virtually all other L293D based controllers.

But some motors have very low coil resistance. Strictly following those formulas, the drive voltage will be less than 5v and performance will not be good. This type of motor is not a good match for a constant-voltage driver. These steppers require a more specialized controller.

## Running Above the Law?

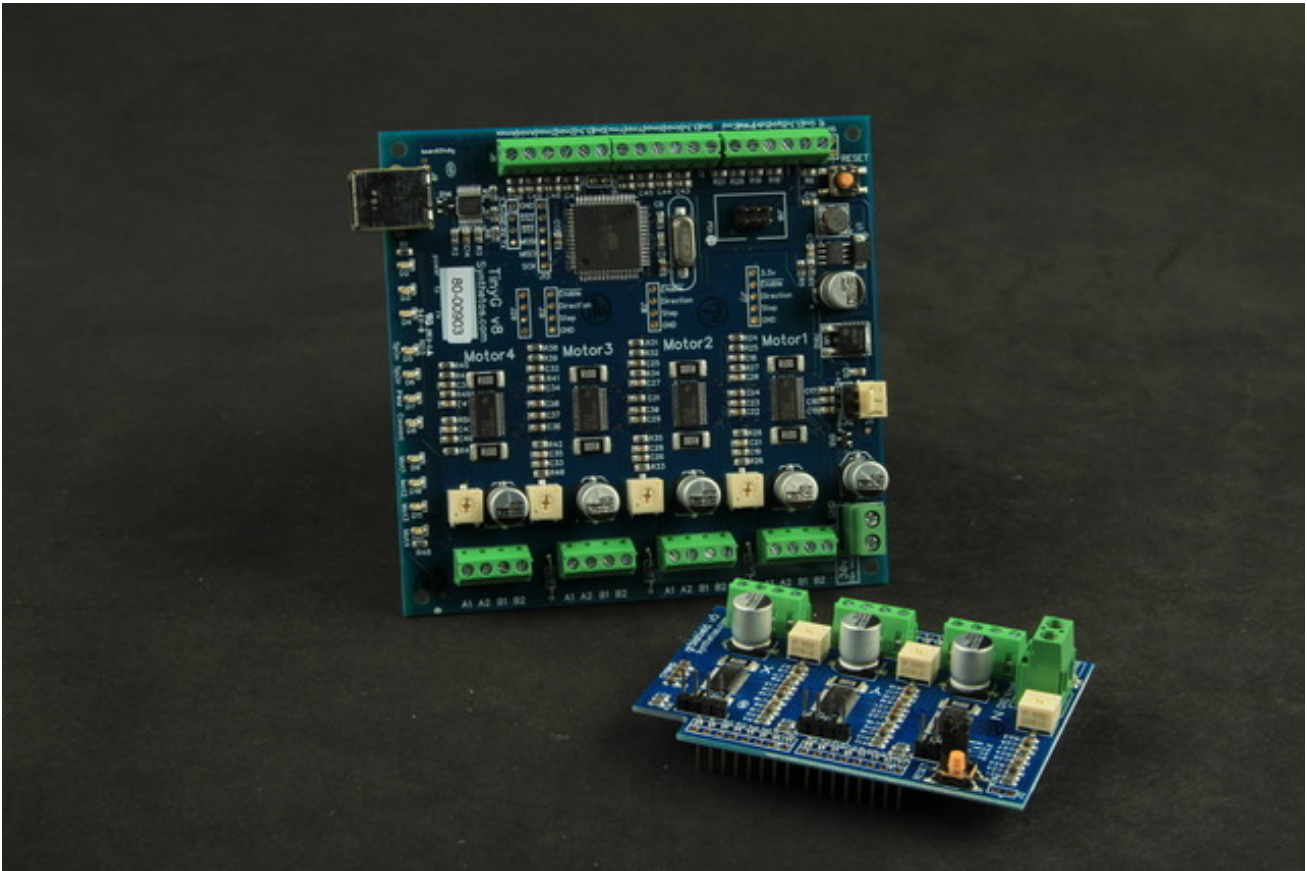
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It is not possible to cheat Ohm's Law. If you try, you will have to answer to the Blue Smoke Monster. However, there are some other laws at work here. The expertise at the law firm of Lenz, Faraday and Ohm can help you to increase the performance of your motor.

The stepper coils create a magnetic field when they are energized. According to **Faraday's Law** (<http://adafru.it/ikB>), the changing magnetic field induces a current in the coil. And according to

**Lenz's Law** (<http://adafru.it/ikC>), that current will be in the reverse direction of the current creating the field. This reverse current is known as "Back Electromotive Force" or "**Back EMF**".

This Back EMF increases the "**impedance**" or effective resistance of the coil. So **Ohm's Law** (<http://adafru.it/ikD>) still applies - but to this impedance, not to the simple phase resistance. This impedance limits the current flow through the coil at the beginning of each step.



## Chopper Drives

A **Chopper** or "**Constant Current**" drive compensates for the back EMF by driving the motor with a higher voltage. It is not unusual to drive stepper motors at several times their rated voltage using a chopper drive.

To keep things safe at these higher voltages, the chopper drive also monitors the current being delivered to the motor and "chops" it before it exceeds a pre-set level.

By starting at a higher voltage, the chopper drive is able to deliver more current to the coils at the start of the step, increasing the available torque. In addition to adding torque at slower speeds, this also allows for higher top-speeds.

Selecting a chopper driver and configuring it for a specific motor requires a good understanding of both the motor and the controller.





# FAQ

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Will this motor work with my shield?

You need to know the motor specifications as well as the controller specification. Once you have that information, check the "**Matching the Driver to the Stepper**" page to see if they are compatible.

It's a NEMA 17, so it should work, right?

NEMA frame-size standards only define the dimensions of the mounting faceplate. To figure out if it is compatible, you need to know the **electrical specifications** of the motor.

What if there are no motor specifications?

See [Jason on reverse engineering the stepper wire pinouts \(http://adafru.it/aOI\)](http://adafru.it/aOI). That will tell you the phase resistance. For phase current, you can estimate based on motors of similar design and similar phase resistance.

When in doubt, it is always better to err on the safe side and use a lower current!

What size motor do I need for my project?

Most motors have [torque \(http://adafru.it/doj\)](http://adafru.it/doj) specifications - usually in inch/ounces or newton/centimeters. One inch/ounce means that the motor can exert a force of one ounce at one inch from the center of the shaft. For example, it could hold up one ounce using a 2" diameter pulley.

When calculating the torque required for your project, be sure to allow extra torque required for [acceleration \(http://adafru.it/dok\)](http://adafru.it/dok) and to overcome friction. It takes more torque to lift a mass from a dead stop than it does to simply hold it up.

If your project requires a lot of torque and not much speed, consider a geared stepper.

How do I connect my motor to the Motor Shield?

For motors purchased from Adafruit, there are wiring instructions listed in the product descriptions.

For other motors, check the motors spec sheet if available.

If you don't have a spec sheet, check [Jason on reverse engineering the stepper wire pinouts \(http://adafru.it/aOI\)](http://adafru.it/aOI).

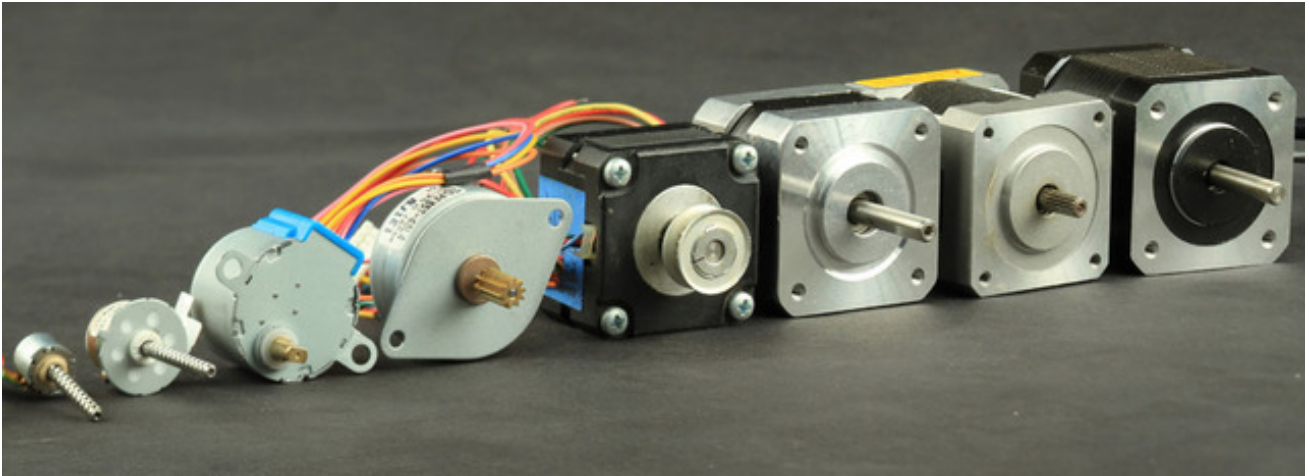
Will this power supply work with my motor?

First make sure it does not exceed the voltage rating for the motor or the controller.\* You can usually run a motor at a lower voltage, although you will get less torque.

Next, check the current rating. Most stepping modes energize two phases at a time, so the

current rating should be at least twice the current per phase for your motor.

*\* This applies to constant voltage drivers. For chopper drive controllers, check the instructions for your controller.*



# Resources

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There is a lot of excellent information on the web about stepper motors. Here are some of our favorite links:

- [Wikipedia \(http://adafru.it/aOF\)](http://adafru.it/aOF) [Stepper Motor Page \(http://adafru.it/aOF\)](http://adafru.it/aOF)
- [RepRap Stepper Motor Page \(http://adafru.it/dol\)](http://adafru.it/dol)
- [Jones on Stepper Motors \(http://adafru.it/aOH\)](http://adafru.it/aOH)
- [Jason on reverse engineering the stepper wire pinouts \(http://adafru.it/aOI\)](http://adafru.it/aOI)

