Stepper Motor
&
PM DC Motor

Testing Unit

Operations Manual

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Stepper & PM DC Motor Testing Unit Functional Overview

This unit is designed to test up to 4 individual Bi-polar or Uni-polar stepper motors or 8 PM (permanent magnet) DC motors. The unit is intended to be programmed by an AVR MKII programming running AVR Studio version 4.12 or higher.

Power

DC power can be applied to any or all of the 3 DC input jacks. There is a standard wall adapter jack, a screw type power jack and a large diameter battery jack that allows the user to connect a battery for higher current. The power traces on the board are rated for 10A but a load on no greater than 6A is recommended. The Max current load for each output is dependant upon the voltage regulator chosen but the L298 is limited to 4A per channel. There are two user adjustable onboard Voltage regulators to allow testing of motors with input voltages from 1.2V to Vin -1.4V. Vin is determined by voltage regulators chosen with a Max Vin of 37VDC. It is important to check the datasheet of your voltage regulator before applying a voltage to Vin greater than 15VDC.

Clock Generator

The unit is also equipped with an onboard clock generator capable of frequencies in excess of 10Mhz. The circuit is comprised of a 555 timer and the output frequency can be calculated by the equation: **F =** $\frac{1.44}{C(2Rb + Ra)}$, where Ra is R4 , Rb is P3 and C= C7. Capacitor C6 acts as a decoupling capacitor to eliminate feedback on the Control Voltage pin of the 555 timer. The output of the 555 is tied in parallel to the external clock jumper block. Here the user can select which of the AVR's will received this signal on the PB6 pin. The jumpers can be removed and an external signal can be applied to the female headers directly below the jumper block as well.

Inputs and Outputs

The unit allows the user access to most of the ports on the AVR micro controller through several methods. Each AVR has 4 active Low tactile switches numbered 1-4 connected to the AVR PA3-PA0 respectively. These ports are also available along with ports PB3, PB4, and PB5 in a female header block adjacent to the switches. The outputs to the H-bridges are on ports PA4-PA7 with no user access to these pins. Programming of the AVR's is achieved through the ISP (In System Programming) ports at the foot of each AVR. The pins used for programming are also available at the Expansion Port located at the bottom right of the unit.

Operational Configurations

Each different type of motor will require a unique driving program to be loaded on to the AVR. Following is a few parameters for testing the different types of motors. A more detailed explanation of each type of motor can be found in the Motor Theory of Operation Section starting on page 12. If you are unsure of what type of motor you nee for your application this may also aid in your selection. As a general rule, bi-polar motor achieve a greater torque and higher speed output over uni-polar motors. Uni-polar motors operate much more smoothly, quietly, and consume less power than bi-polar motors.

Bi-Polar Stepper Motor

Bi-polar motors use two independent phases (inductors) that must be energized in a certain order for the motor to operator correctly. For testing bi-polar motors you will want implement one of the following sequences depending on your application:

Wave Drive			
A1	**A0**	**B1**	**B0**
0	1	0	0
0	0	1	0
1	0	0	0
0	0	0	1

Hi-Torque			
A1	**A0**	**B1**	**B0**
0	1	0	1
0	1	1	0
1	0	1	0
1	0	0	1

Half Step			
A1	**A0**	**B1**	**B0**
0	1	0	0
0	1	0	1
0	0	1	0
0	1	1	0
1	0	0	0
1	0	1	0
0	0	0	1
1	0	0	1

The speed at which you write these to the motors determines how fast the motor will spin. If you run the sequence in reverse the motor will spin the opposite direction. There are other methods of stepping the motors but this is the most commonly used. Wave drive is smooth, power efficient and ideal for higher rpm applications, Hi-Torque consumes higher current but has much higher torque, and half step doubles the resolution of the motor but causes and uneven torque curve. These driving methods are discussed further starting on page 12.

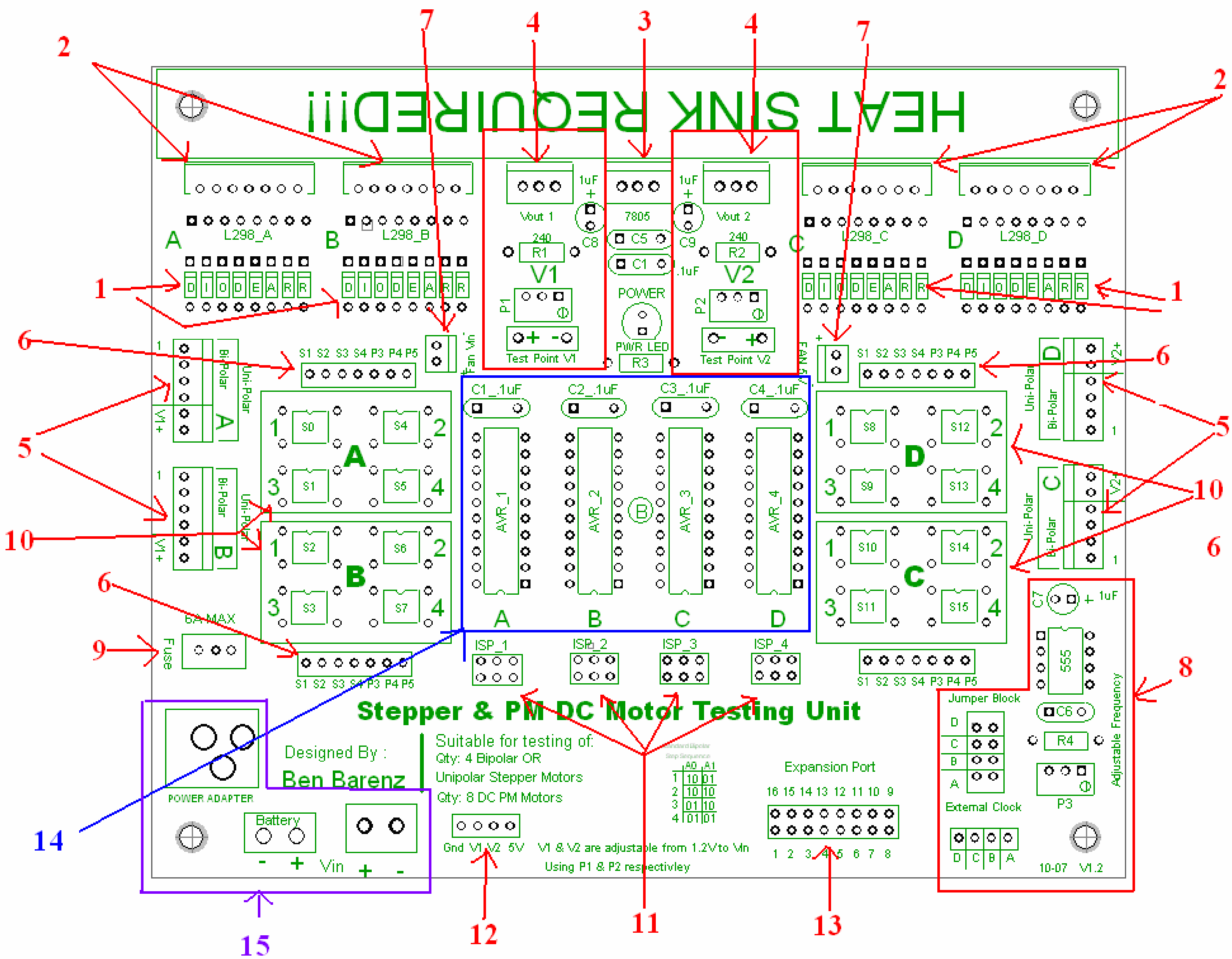
Uni-Polar Stepper Motor

Uni-polar motors are essentially a bi-polar motor with a center tap on each inductor. (This allows you use a uni-polar as a bi-polar if you wish). If you use a uni-polar as a bi-polar take note that the rated voltage will be doubled in a bi-polar configuration. For a uni-polar motor, you connect each of the center taps to V+ and switch the negative potential to each of the 4 ends of the coil. This allows the final control circuit to be less complex than for a uni-polar motor. Uni-polar motors use the same step sequence as bi-polar motors they just have there center terminals tied to V+.

DC-Motors

Each output of the L298 can be used to control 1 DC motor allowing the capability to control 2 DC motor from 1 motor port. The sequence to make a motor go forward on PA7, PA6 would be 10, reverse 01, free spin 00 or 11. The speed of the DC motor cannot be controlled by a clock input so PWM (Pulse Width Modulation) must be used instead. More on PWM can be found in the Motor Theory of Operation Section. It is possible to control more than 2 DC Motors from one port if the motors are not needed to be run simultaneously by jumping across the two outputs of the L298.

Component Identification



1. Diode Suppression Array
2. L298 Dual H-Bridges
3. 7805 +5V Regulator
4. **Adjustable Voltage Sources V1 & V2 ****
5. Motor Outputs
6. **Ancillary Inputs ****
7. +5V & Vin Fan Power Plugs
8. **Onboard Clock Generator ****
9. .3" Socket type fuse
10. Input Switches (Active Low)
11. Atmel AVR ISP Programming Ports
12. Power Port
13. **Expansion Port ****
14. Attiny261 µC & Decouple Cap.
15. DC Inputs

Bold ** greater detail on next page

Adjustable Voltage Sources V1 & V2

As previously stated, the voltage applied to the motors can be adjusted from 1.2 to Vin-1.4V on V1 and V2. Voltage V1 supplies test blocks A & B, and V2 supplies C & D. Capacitors C1,C5,C8,C9 are used to bias the regular and help with stability. C1,C5 are tied from the inputs to ground and C8,C9 are tied from the outputs to ground. Typical values for these are .1uF and 1uF respectively. These regulators are supposed be tough as nails but it is possible to damage them very quickly if they are not bias properly. Please consult your data sheet for proper values of these capacitors and the maximum ratings of your regulators.

Ancillary Inputs

These inputs are tied in directly to the ports on the AVR and are in parallel with their corresponding switch. For example S1 is tied directly to PA3 and in parallel with switch S1. These switches must be active low because there are no external pull up/ pull down resistors and the AVR only allows for internal pull up resistors. Special care must be taken when programming the AVR's not to disable these pull up resistors. The other pins are tied directly to ports PB3,PB4, PB5 and are not connected anywhere else in the circuit.

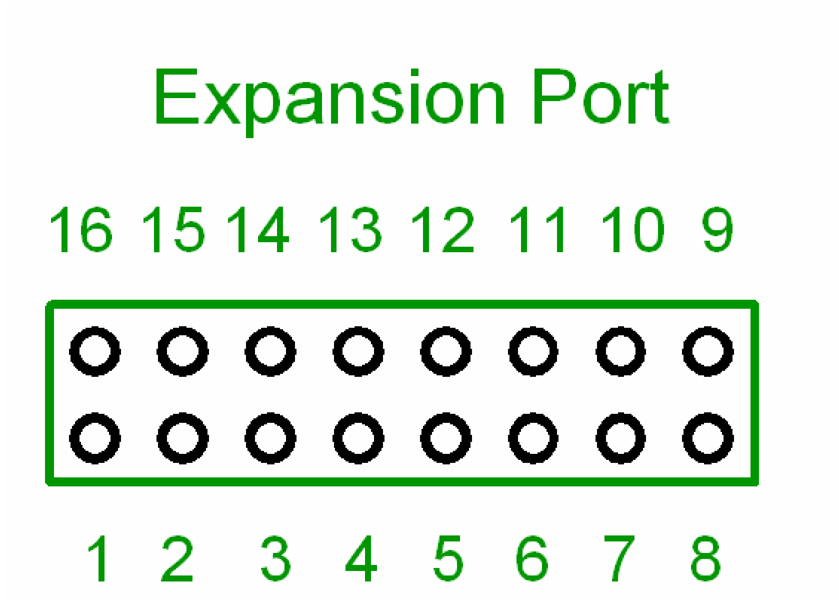
Onboard Clock Generator
As previously stated, this is the 555 timer that generates the clock signal.

Expansion Port
The expansion port allows access to the power pins: +5V, V1,V2, Gnd and the MISO, MISO, and SCK pins of each of the AVR's. A ribbon cable or female header may be soldered here for further access to the onboard ports.
***NOTE* These Pins must be disconnected when programming the AVR**

Component ID & Ordering Information

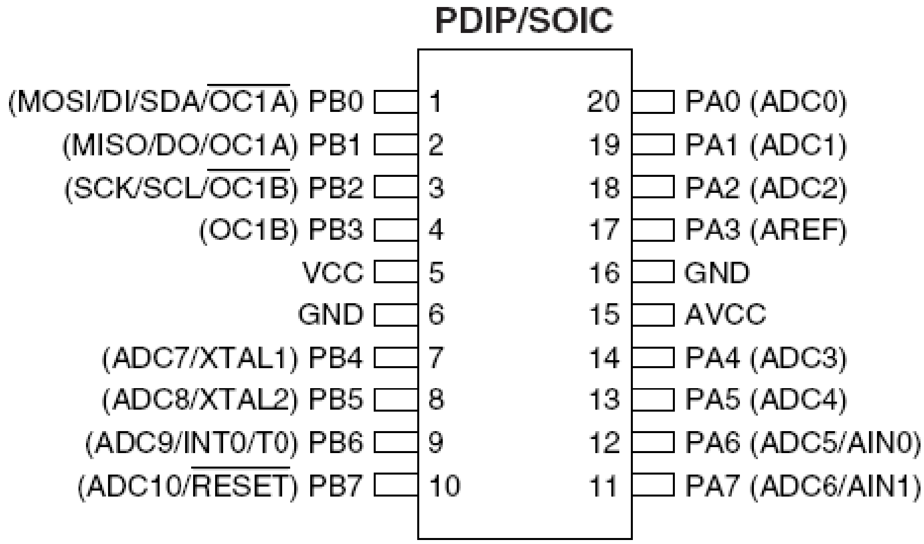
Motor Testing Board Component ID			
Ref. ID	Value	Supplier	Part #
R1	240Ω	Mouser	291-240RC
R2	240Ω	Mouser	291-240RC
R3	330-1kΩ	Mouser	291- **Val** RC
R4	1kΩ	Mouser	291-1kRC
C1	.1uF	Digi-Key	rP4525-ND
C2	.1uF	Digi-Key	rP4525-ND
C3	.1uF	Digi-Key	rP4525-ND
C4	.1uF	Digi-Key	rP4525-ND
C5	.1uF	Digi-Key	rP4525-ND
C6	.1uF	Digi-Key	rP4525-ND
C7	1uF	Mouser	581-BQ074D0105K
C8	1-10uF	Various	Various
C9	1-10uF	Various	Various
P1	5kΩ	Mouser	72-T93YA-5K
P2	5kΩ	Mouser	72-T93YA-5K
P3	50kΩ	Mouser	72-T93YB-50K
S0-S15	Tactile	Digi-Key	EG4346-ND
6-Pin M	N/A	Mouser	538-22-23-2061
6-Pin F	N/A	Mouser	538-10-11-2063
2-Pin M	N/A	Mouser	538-22-23-2021
2-Pin F	N/A	Mouser	538-10-11-2023
Crimp Terminals	N/A	Mouser	538-08-50-0114
L298 A-D	N/A	Mouser	511-L298
Diodes	1n4148	Digi-Key	1N4148FS-ND
555 Timer	N/A	Mouser	511-NE555N
8-DIP Socket	N/A	Mouser	571-1-390261-2
AVR 1-4	N/A	Digi-Key	ATTINY261-20PU-ND
20-DIP Socket	N/A	Mouser	571-3902616
LED	Various	Various	Various
AME1084ACBT	N/A	Mouser	827-AME1084ACBT
7805 Voltage Reg.	5V Reg	Mouser	511-L7805ACV
Fuse	6A-Max	Digi-Key	507-1176-ND
Header M	N/A	Mouser	571-41032390
Header F	N/A	Mouser	517-974-01-36
Insulator (2)	N/A	Mouser	532-56-77-11
Insulator Washer (2)	N/A	Mouser	532-7721-3PPS
6-32 Screw (5)	N/A	Various	Various
4-40 Screw (2)	N/A	Various	Various
Alligator Clip (20)	N/A	Mouser	548-30-BL
Clip Insulator (20)	N/A	Mouser	548-32-**0**
2 Pos Screw Terminal	N/A	Mouser	571-2828362
Power Adapter	N/A	Digi-Key	erCP-002A-ND
2-Pin Jumper		Various	Various
Heat Sink	N/A	B.E	MTB-HS1

Expansion Port Pin-Outs



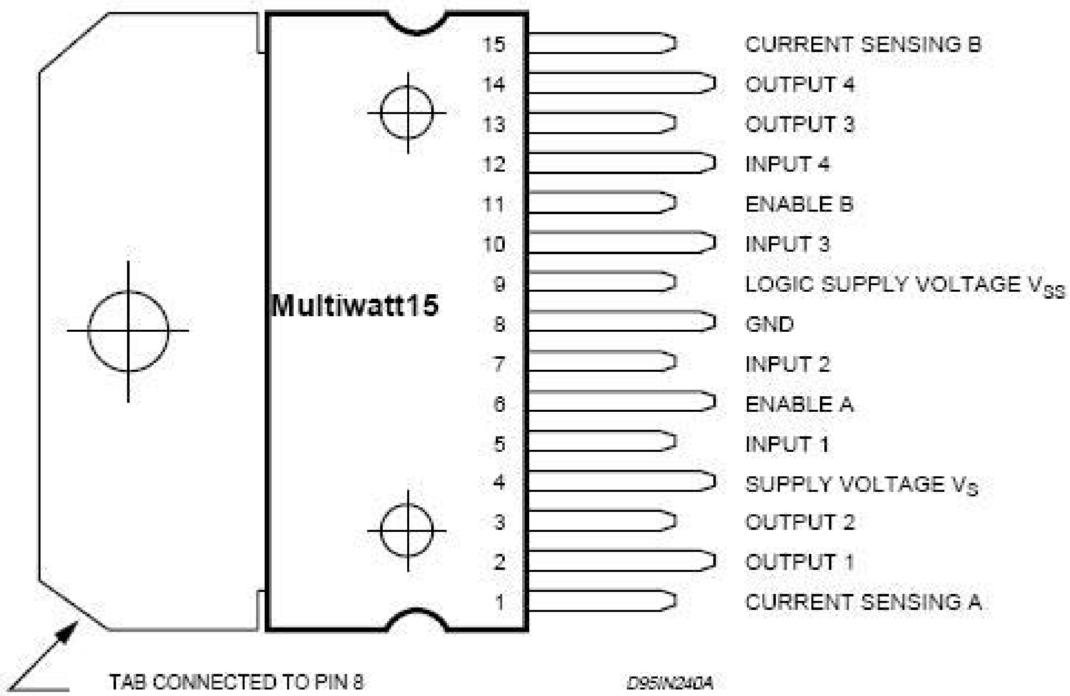
1. **+ 5V**
2. **V2**
3. **V3**
4. **Gnd**
5. **AVR_4 (D) PB1 MISO**
6. **AVR_4 (D) PB2 SCK**
7. **AVR_4 (D) PB0 MOSI**
8. **AVR_3 (C) PB1 MISO**
9. **AVR_3 (C) PB2 SCK**
10. **AVR_3 (C) PB0 MOSI**
11. **AVR_2 (B) PB1 MISO**
12. **AVR_2 (B) PB2 SCK**
13. **AVR_2 (B) PB0 MOSI**
14. **AVR_1 (A) PB1 MISO**
15. **AVR_1 (A) PB2 SCK**
16. **AVR_1 (A) PB0 MOSI**

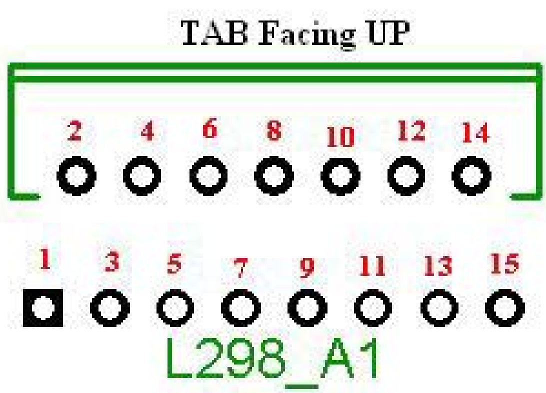
AVR PIN CONNECTIONS



1. **PB0** Reserved for SPI interface **MOSI**
2. **PB1** Reserved for SPI interface **MISO**
3. **PB2** Reserved for SPI interface **SCK**
4. **PB3** Ancillary Ports
5. **+5V**
6. **Gnd**
7. **PB4** Ancillary Ports
8. **PB5** Ancillary Ports
9. **PB6** External Clock Input
10. **PB7** Reserved for SPI interface **RESET (Internal Pull up must be ON!)**
11. **PA7** **Phase B0**
12. **PA6** **Phase B1**
13. **PA5** **Phase A0**
14. **PA4** **Phase A1**
15. **+5V**
16. **Gnd**
17. **PA3** **S1 (Active Low)**
18. **PA2** **S2 (Active Low)**
19. **PA1** **S3 (Active Low)**
20. **PA0** **S4 (Active Low)**

L298 Board Orientation





Motor Theory of Operation

This section contains information about Stepper and DC motors. The information was collected from internet sources. The work and the websites will be sited.

Stepper Motors and Control

Part I - Unipolar Stepper Motor and Control

http://www.stepperworld.com/Tutorials/pgUnipolarTutorial.htm

Introduction

Stepper Motors have several features which distinguish them from AC Motors, and DC Servo Motors.

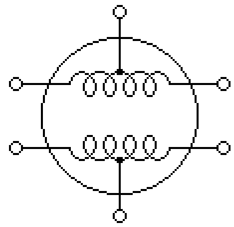
- **Brushless** - Steppers are brushless. Motors with contact brushes create sparks, undesirable in certain environments. (Space missions, for example.)
- **Holding Torque** - Steppers have very good low speed and holding torque. Steppers are usually rated in terms of their holding force (oz/in) and can even hold a position (to a lesser degree) without power applied, using magnetic 'detent' torque.
- **Open loop positioning** - Perhaps the most valuable and interesting feature of a stepper is the ability to position the shaft in fine predictable increments, without need to query the motor as to its position. Steppers can run 'open-loop' without the need for any kind of encoder to determine the shaft position. Closed loop systems- systems that feed back position information, are known as *servo* systems. Compared to servos, steppers are very easy to control, the position of the shaft is guaranteed as long as the torque of the motor is sufficient for the load, under all its operating conditions.
- **Load Independent** - The rotation speed of a stepper is independent of load, provided it has sufficient torque to overcome slipping. The higher rpm a stepper motor is driven, the more torque it needs, so all steppers eventually poop out at some rpm and start slipping. Slipping is usually a disaster for steppers, because the position of the shaft becomes unknown. For this reason, software usually keeps the stepping rate within a maximum top rate. In applications where a known RPM is needed under a varying load, steppers can be very handy.

Types of steppers

Stepper Motors come in a variety of sizes, and strengths, from tiny floppy disk motors, to huge machinery steppers rated over 1000 oz in. There are two basic types of steppers--

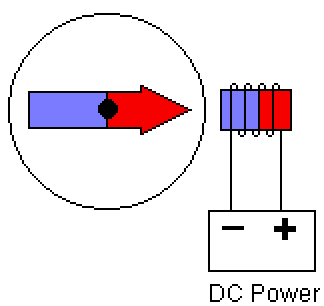
bipolar and unipolar. The bipolar stepper has 4 wires. Unipolar steppers have 5,6 or 8 wires. This document will discuss control of Unipolar Steppers.

Motor Basics

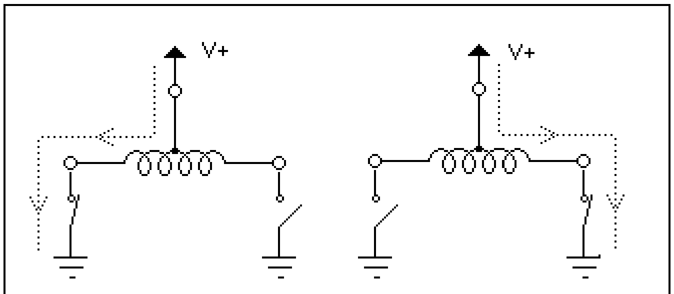


The Unipolar Stepper motor has 2 coils, simple lengths of wound wire. The coils are identical and are not electrically connected. Each coil has a center tap - a wire coming out from the coil that is midway in length between its two terminals. You can identify the separate coils by touching the terminal wires together-- If the terminals of a coil are connected, the shaft becomes harder to turn. Because of the long length of the wound wire, it has a significant resistance (and inductance). You can identify the center tap by measuring resistance with a suitable ohm-meter (capable of measuring low resistance <10 ohm) The resistance from a terminal to the center tap is half the resistance from the two terminals of a coil. Coil resistance of half a coil is usually stamped on the motor; For example, '*5 ohms/phase'* indicates the resistance from center tap to either terminal of a coil. The resistance from terminal to terminal should be 10 ohms.

Motor Control Circuitry



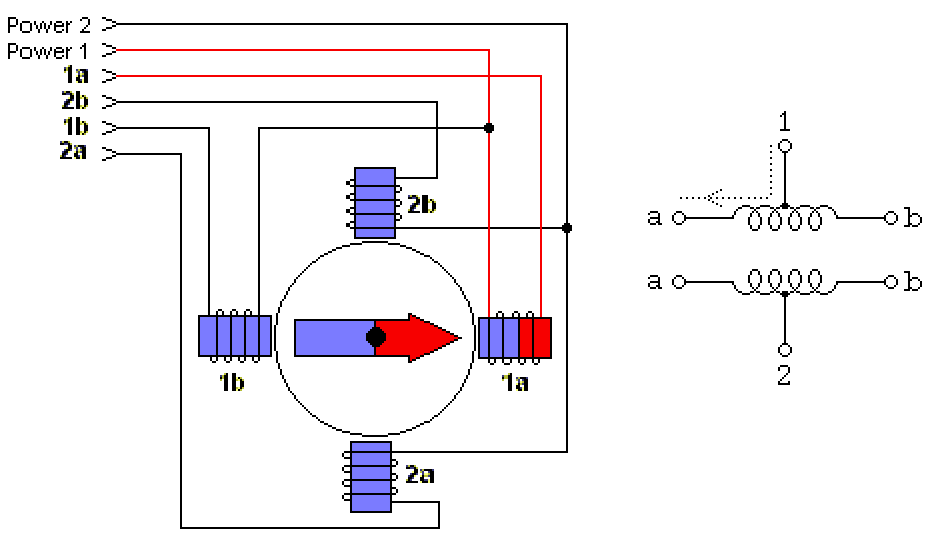
Current flowing through a coil produces a magnet field which attracts a permanent magnet rotor which is connected to the shaft of the motor. The basic principle of stepper control is to reverse the direction of current through the 2 coils of a stepper motor, in sequence, in order to influence the rotor. Since there are 2 coils and 2 directions, that gives us a possible 4-phase sequence. All we need to do is get the sequencing right and the motor will turn continuously. You may wonder how the stepper can achieve such fine stepping increments with only a 4-phase sequence. The internal arrangement of the motor is quite complex- the winding and core repeating around the perimeter of the motor many times. The rotor is advanced only a small angle, either forward or reverse, and the 4-phase sequence is repeated many times before a complete revolution occurs.



Reversal of current in one coil of a Unipolar Stepper

Let us return to the 4-phase sequence of reversing the current though the 2 coils. A Bipolar stepper controller achieves the current reversal by reversing the polarity at the two terminals of a coil. The Unipolar controller takes advantage of the center tap to achieve the current reversal with a clever trick -- The Center tap is tied to the positive supply, and one of the 2 terminals is grounded to get the current flowing one direction. The other terminal is grounded to reverse the current. Current can thus flow in both directions, but only half coils are energized at a time. Both terminals are never grounded at the same time, which would energize both coils, achieving nothing but a waste of power.

Conceptual Model of Unipolar Stepper Motor



Conceptual Model of Unipolar Stepper Motor

With center taps of the windings wired to the positive supply, the terminals of each winding are grounded, in sequence, to attract the rotor, which is indicated by the arrow in the picture. (Remember that a current through a coil produces a magnetic field.) This conceptual diagram depicts a 90 degree step per phase.

In a basic "Wave Drive" clockwise sequence, winding 1a is de-activated and winding 2a activated to advance to the next phase. The rotor is guided in this manner from one winding to the next, producing a continuous cycle. Note that if two adjacent windings are activated, the rotor is attracted mid-way between the two windings.

The following table describes 3 useful stepping sequences and their relative merits. The sequence pattern is represented with 4 bits, a '1' indicates an energized winding. After the last step in each sequence the sequence repeats. Stepping backwards through the sequence reverses the direction of the motor.

Table of Stepping Sequences

Sequence	Name	Description
0001 0010 0100 1000	Wave Drive, One-Phase	Consumes the least power. Only one phase is energized at a time. Assures positional accuracy regardless of any winding imbalance in the motor.
0011 0110 1100 1001	Hi-Torque, Two-Phase	Hi Torque - This sequence energizes two adjacent phases, which offers an improved torque-speed product and greater holding torque.
0001 0011 0010 0110 0100 1100 1000 1001	Half-Step	Half Step - Effectively doubles the stepping resolution of the motor, but the torque is not uniform for each step. (Since we are effectively switching between Wave Drive and Hi-Torque with each step, torque alternates each step.) This sequence reduces motor resonance which can sometimes cause a motor to stall at a particular resonant frequency. Note that this sequence is 8 steps.

Stepper Motors and Control

Part II - Bipolar Stepper Motor and Control

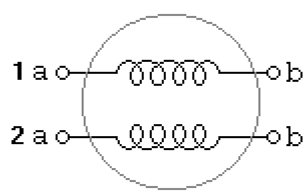
http://www.stepperworld.com/Tutorials/pgBipolarTutorial.htm

Introduction

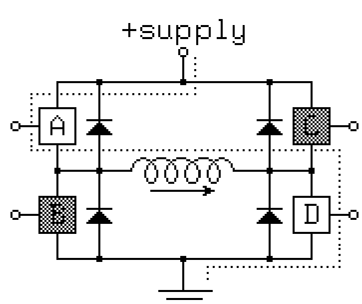
The Bipolar Stepper motor is very similar to the Unipolar Stepper discussed in part I of this Tutorial, except that the motor coils lack center taps. Because of this, the Bipolar motor requires a different type of controller, one that reverses the current flow through the coils by alternating polarity of the terminals, giving us the name - Bipolar. A Bipolar motor is capable of higher torque since entire coil(s) may be energized, not just half-coils. Where 4-wire steppers are strictly 'Bipolar', 5 and 6 wire motors with center-taps can be used with the Bipolar controller.

Bipolar Basics

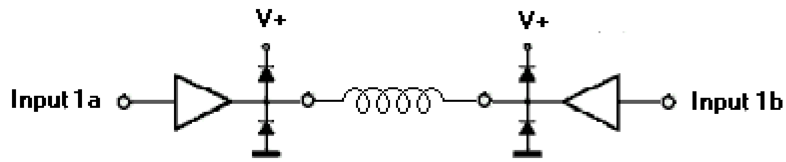
The Bipolar Stepper motor has 2 coils. The coils are identical and are not electrically connected. You can identify the separate coils by touching the terminal wires together-- If the terminals of a coil are connected, the shaft becomes harder to turn.



The Bipolar Controller must be able to reverse the polarity of the voltage across either coil, so current can flow in both directions. And, it must be able to energize these coils in sequence. Let us look at the mechanism for reversing the voltage across one of the coils...



This circuit is called an H-Bridge, because it resemble a letter "H". The current can be reversed through the coil by closing the appropriate switches - AD to flow one direction then BC to flow the opposite.

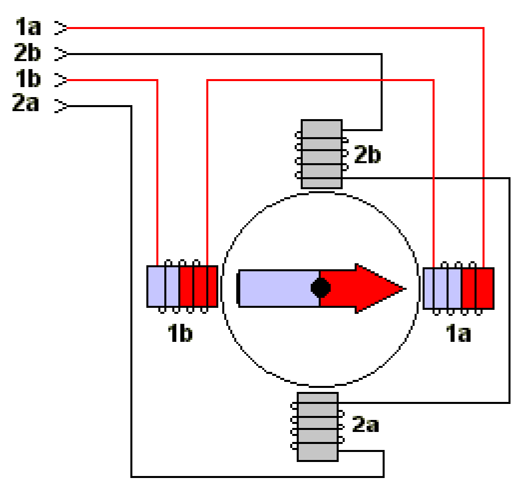


Another way of depicting the H-Bridge... Since each half of the bridge can both sink and source current, it qualifies as a push-pull type amplifier, and can be drawn with the symbol for the amplifier.

H-bridges are applicable not only to the control of stepping motors, but also to the control of DC motors, solenoids and many other applications, where polarity reversal is needed. Diodes protect the switches from the kickback of inductive type loads, such as the coils of a stepper.

Two such circuits are needed to drive both coils of the Bipolar stepper, and is commonly called a "Dual H-Bridge."

Conceptual Model of Bipolar Stepper Motor



Conceptual Model of Bipolar Stepper Motor

The coils are activated, in sequence, to attract the rotor, which is indicated by the arrow in the picture. (Remember that a current through a coil produces a magnetic field.) This conceptual diagram depicts a 90 degree step per phase. Assuming Terminal 1a is positive and 1b is negative, the rotor points to the East in this diagram. If these two terminals were reversed in polarity the rotor would point to the West. Coil 2 is entirely de-activated in the diagram.

In a basic "Wave Drive" clockwise sequence, winding 1 is de-activated and winding 2 activated to advance to the next phase. The rotor is guided in this manner from one winding to the next, producing a continuous cycle. Note that if two adjacent windings are activated, the rotor is attracted mid-way between the two windings.

The following table describes 3 useful stepping sequences and their relative merits. The polarity of terminals is indicated with +/-. After the last step in each sequence the sequence repeats. Stepping backwards through the sequence reverses the direction of the motor. Note that these sequences are identical to those for a Unipolar Stepper Motor.

Table of Stepping Sequences

Sequence	Polarity	Name	Description
0001 0010 0100 1000	---+ --+- -+-- +---	Wave Drive, One-Phase	Consumes the least power. Only one phase is energized at a time. Assures positional accuracy regardless of any winding imbalance in the motor.
0011 0110 1100 1001	--++ -++- ++-- +--+	Hi-Torque, Two-Phase	Hi Torque - This sequence energizes two adjacent phases, which offers an improved torque-speed product and greater holding torque.
0001 0011 0010	---+ --++ --+-	Half-Step	Half Step - Effectively doubles the stepping resolution of the motor, but the torque is not uniform for each step.

0110 0100 1100 1000 1001	-++- -+-- ++-- +--- +--+		(Since we are effectively switching between Wave Drive and Hi-Torque with each step, torque alternates each step.) This sequence reduces motor resonance which can sometimes cause a motor to stall at a particular resonant frequency. Note that this sequence is 8 steps.

One of the benefits of the Bipolar drive circuitry is that it allows us to use both "Bipolar" and "Unipolar" motors. Bipolar motors are simply Unipolar without the center taps, which simplifies construction of the motor. So we can drive 4,6, and 8 wire steppers. Furthermore, ***Unipolar motors may be used in 2 different configurations***-- One, simply ignore the center taps. Two, use half the coil only by using the center tap and one of the terminals. This will produce less hold torque but allows higher top speeds because of the lower inductance.