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ME430 Mechatronics

Lab 2: Transistors, H-Bridges, and Motors

The lab team has demonstrated:

Part (A) Driving DC Motors using a PIC and Transistors

_____ **NPN BJT transistor**

_____ **N-channel MOSFET transistor**

_____ **Darlington Chip (ULN2003)**

Part (B) Using 12 Volt Power Supplies to Drive Lamps and Fans

_____ **MOSFETs**

_____ **BJTs**

_____ **Darlingtons**

Part (C) Using a Darlington to drive multiple LEDs

_____ **Dancing lights**

Part (D) Bi-directional Control of Motors with H-Bridge chips

_____ **DC Motor with bi-directional 5V drive circuit**

_____ **Stepper Motor at 5V with 2 sets of bi-directional phases**

_____ **Return the preprogrammed PIC to your instructor**

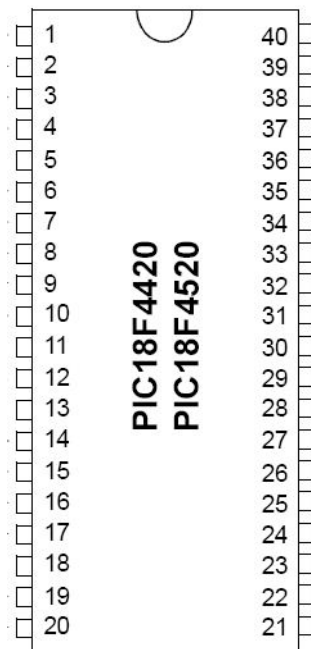## Part (A) Driving DC Motors using a PIC and Transistors

Get a brushed DC motor from the grey cabinet at the back of the room.   These are ordi-nary-looking silver-grey motors.

We are not likely to get enough power from the PIC chip to drive this motor.   So, we will use the PIC merely as input to a transistor.   The transistor will act as an electronic switch to turn the power to the motor on and off.

In this part, our goal is to use three kinds of transistors as electronic switches: an NPN BJT (Bi-polar junction transistor) transistor, an N-channel MOSFET (metal oxide semiconductor field effect transistor) transistor, and a Darlington chip (which contains many BJT transistor pairs). Note: saying MOSFET transistor is redundant since the T stands for transistor, but, much like saying PIN number, it is common practice.

(1)   NPN BJT transistor

Sketch a circuit that has a basic switch, appropriate power connections, LED/resistor combina-tion, and a PIC (just as you had at the end of Lab 1.)   Have the basic switch connected to RA0 on the PIC, and the LED/resistor connected to RB0.   Next connect RA0 and RA1.   Now use RB1 to drive an NPN BJT transistor.   You may want to refer to your notes on the "Intro to Transistors" video to complete the circuit diagram.   Use your DMM to measure the resistance of your motor to properly size the resistors in the circuit (ballpark is fine).   *ALSO, don't forget that you have a regulated and an unregulated power supply, and that the motor should have its positive power supplied from the **un**regulated rail!*

```
 _____
|  1              ⌣       40 |
|  2                      39 |
|  3                      38 |
|  4                      37 |
|  5                      36 |
|  6                      35 |
|  7                      34 |
|  8    PIC18F4420        33 |
|  9    PIC18F4520        32 |
| 10                      31 |
| 11                      30 |
| 12                      29 |
| 13                      28 |
| 14                      27 |
| 15                      26 |
| 16                      25 |
| 17                      24 |
| 18                      23 |
| 19                      22 |
| 20                      21 |
|_____|
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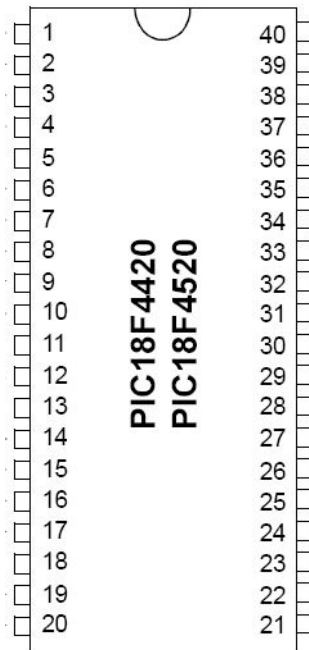
Now go ahead and build the circuit.   There are extra resistors of various sizes in the grey cabinet.   **Demonstrate that the LED and motor work when you press the button and get it checked off on the front page.**

Make sure you add snubber diodes and decoupling capacitors to all circuits.

(2)   N-channel MOSFET transistor

MOSFETs are even easier to use than BJTs, because you don't need to figure any currents or size any resistors—the MOSFETs act as voltage controlled switches.   Replace the BJT transistor/motor section of your circuit from the last part with an appropriate circuit that uses an N-channel MOSFET.   You may wish to refer to your video lecture notes again.   Sketch the circuit below, then build it.

```
      _____
   [ 1          40 ]
   [ 2          39 ]
   [ 3          38 ]
   [ 4          37 ]
   [ 5          36 ]
   [ 6          35 ]
   [ 7          34 ]
   [ 8          33 ]
   [ 9          32 ]
   [ 10         31 ]
   [ 11         30 ]
   [ 12         29 ]
   [ 13         28 ]
   [ 14         27 ]
   [ 15         26 ]
   [ 16         25 ]
   [ 17         24 ]
   [ 18         23 ]
   [ 19         22 ]
   [ 20         21 ]
      PIC18F4420
      PIC18F4520
```

Demonstrate that the LED and motor work when you press the button and get it checked off on the front page.

(3)   Darlington Chip (ULN2003)

Darlington chips are prepackaged, paired BJTs, which are intended to be used as switches. Replace the MOSFET/motor section of your circuit from the last part with an appropriate circuit that uses a Darlington.   You may wish to refer to your video lecture notes again.   Sketch the circuit below and then build it.
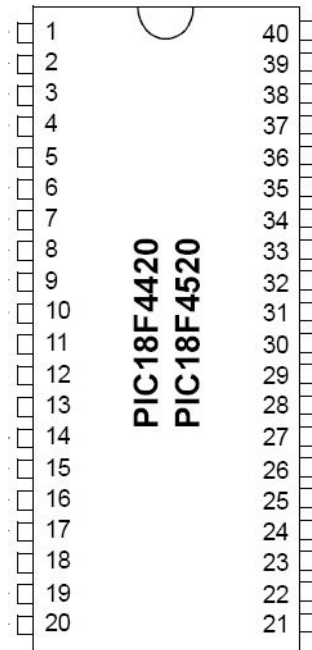

Demonstrate that the LED and motor work when you press the button and get it checked off on the front page.

Part (B) Using 12 Volt Power Supplies to Drive Lamps and Fans

In prior part, we used transistors to drive the motor because we needed more current than the PIC could provide.   Now we are going to use transistors to drive devices that need a higher *voltage*.   It is very common for motors and other actuators to require higher drive voltages. We will modify the circuits from before to control a 12 Volt power supply for the load—in this case lamps (not LEDs) and fans.

(1) <u>MOSFETs</u>

First, diagram a circuit that will let you run a lamp with a MOSFET, still using a 5 Volt power supply for everything.   This is almost identical to the MOSFET circuit you used in Part (A), but you will use a lamp instead of the motor.   (The lamps look a lot like clear LEDs, except that you can see a filament inside of them.   ***The lamps are in the grey cabinet!***   *IR emitters look like lamps, and are in your lab kit.   Don't use an IR emitter here!*)
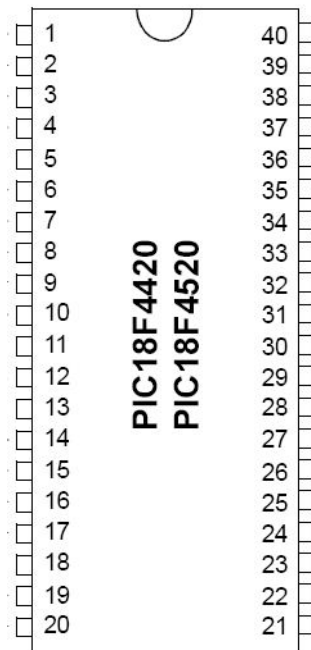
Now build this circuit and make sure that the lamp turns on.   The light will be rather dim, because you are running it from a 5V supply instead of the 12V it wants.   You can check yourself off on this part!

_____   Lamp is lit from 5V, although dim.

Next, modify the circuit you drew to light the lamp from a 12V supply.   Notice how easy the modification is!   This is why MOSFETs are wonderful.   *Note that the power to the PIC chip is still running at 5V, from the regulated power rail!*

The 12V supplies are in the grey cabinet at the back of the room.   (On the front they may say one voltage, but on the back they say 12V.)   *Keep the white power supply connected to the breadboard and running through the regulator chip.   Remember the power to the PIC chip is still 5V-- try not to burn up too many chips* ☺   *Make sure that the ground for the 12V supply is the same as the ground for the 5V supply—connect the two grounds together.*   If you don't do this, the two "ground" voltages could actually be different and your circuit might not work. *Use the positive lead from the 12V supply to run the lamp—it shouldn't be doing anything else in the circuit.*

Build this circuit and make sure that the light is brighter than it was before.   You can check yourself off on this part, too.

_____   Lamp is lit from 12V, and is pretty bright now.

For the last piece of this section, we are going to replace the lamp in the circuit with a fan. The fans are black, have a frame that is about 3"x3", and are in the grey cabinet at the back of the room.

The circuit a direct swap of the lamp and the fan, except that *running fans backwards can break them*! Make sure that the *red lead on the fan goes to the +12V line!*   Once you have this working, demonstrate it to your instructor and get this section checked off on the front page.

(2) BJTs

The MOSFETs were really easy to use, but they are much more expensive than the BJTs.   So, we will need to be able to use BJTs to do the same tasks we accomplished with the MOSFET. Remember that, for the BJTs, we need an input resistor to control the current.

The lamps we purchased were called "12 volt, 35 mA, incandescent, lamps".   They draw 35 mA when they are running.   This means that we need to choose a resistor to make the current into the base one-tenth of the load current, or 3.5 mA.

What resistor size should you choose if you could choose an arbitrary value? _____

Now go to the cabinet and pick a real resistor (note, that ballpark resistor sizes work fine). What size did you pick? _____

Build the BJT circuit to drive the lamp at 12V.   You can check this part off yourself:

_____ Got the **lamp** running at 12V with a BJT

Next, we would like to replace the lamp with a fan.   We will need to recalculate the resistor for the base.

We knew the current the lamp would draw when it was running, but we will need to measure the current drawn by the fan when it is running.   It won't work to measure the fan resistance, because the fan has a diode that confuses the measurement.   Get the fan running directly from the power supply, then put the digital multimeter (DMM) in series with the fan and measure the current it draws.

We measured a fan current of _____.

If we could choose any size resistor for the base of the BJT, we would choose_____.

However, when we went to the cabinet, we picked this resistor:_____.

Get the fan running with this resistor and the BJT.   Then have your instructor check you off on the front page.

(3) Darlingtons

Darlingtons (ULN2003 chips) are very simple to use for our switching purposes even at 12V. Build a circuit that uses a Darlington to drive the lamp, then replace the lamp with a fan.

Make sure that the power for the load (the lamp or the fan) is connected to 12V, but the power for the PIC chip is connected to 5V, regulated.   So you will need BOTH power supplies with the grounds connected together.
Make sure that the COM line on the Darlington is connected to 12V (not 5V).
Don't use the "optional" resistor on the input to the Darlington.

The COM line is connected to the internal snubber diodes on the Darlington, so that is why we need to connect it to the 12V supply.   The optional resistor on the input can actually interfere with some circuits.

You can check off the lamp yourself.

_____ Lamp running from a Darlington with 12V power to the lamp.

Demonstrate the fan running from a Darlington with 12V to the fan to your instructor, and get this section checked off on the front.

Part (C) Using a Darlington to drive multiple LEDs

If we try to drive multiple LEDs in a source configuration with a single PIC chip, we will draw too much current from the chip and the lights will be weak.   However, it is quite straightforward to use the PIC to drive a Darlington, and then let the Darlington control the LEDs.   The Darlington has 7 switches in each chip, and they have all of the snubber diodes and resistors included in the package.   Isn't it nice when they include things inside the chip for you? ☺

You can return your 12 volt power supply and go back to only your white 5 volt supply.

First, replace the lamp/fan from (B3) with a resistor/LED.   This will give you one resistor/LED directly connected to the PIC on RB0; and a second resistor/LED connected to the Darlington, which is connected to RB1.   Make sure that both LEDs are on when the button is pressed.   Sketch the circuit you used on the diagram below:
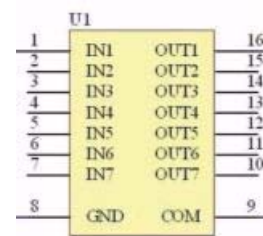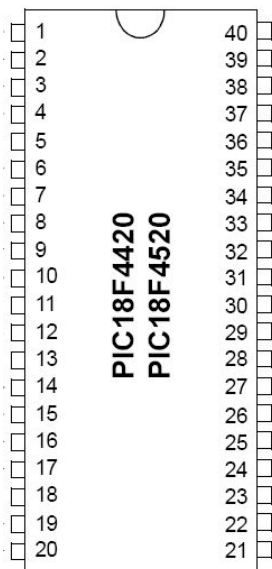
_____ We have our 2 LEDs running correctly (Self Check-Off)
              (one directly off the PIC's RB0 line, the other using RB1 + a Darlington)

Next we would like to drive 7 LEDs with this Darlington (instead of just 1).   We will make our LEDs in this part "dance"—when the button is not pressed, 4 of the LEDs will be on, and 3 will be off.   When the button is pressed, the on/off LEDs will switch.   You will want to connect resistor/LEDs to all 7 Darlington outputs.   Note that each LED needs its *own* resistor.   Then, you will want to connect inputs 1, 3, 5, and 7 of the Darlington to RB1.   Connect inputs 2, 4, and 6 from the Darlington to RA1.   RA1 and RB1 will always be opposite.   Add this circuit to the diagram, and build it.

When you press the button, the lights should "dance".   Get this checked off by your instructor on the front.

Part (D) Bi-directional Control of Motors with H-bridge chips

If we only need unidirectional control of our motors, then the transistor circuits we used in Part (A) or Part (B) are the easiest solution.   If we need to run the motor forwards and backwards, then we will need bidirectional control.   For this, an H-bridge chip is definitely the way to go.

We will have you create a bi-directional control for different motors using an H-bridge chip.

Table 2: H-Bridge motor circuits

| Motor	Type of drive
DC motor (silver-grey)	5 Volts, bi-directional
Stepper Motor (larger, silver and black)	5 Volts, 2 sets of bi-directional phases

Note, both motors are 5 volts.
So you should use the unregulated 5 volt line (which is closer to 6 volts, but that's ok).

(1) DC Motor with bi-directional 5V drive circuit

We want to use the H-bridge chip to run a motor with 2 button switches—one switch will turn the motor on or off and the other one will choose whether the motor turns clockwise or counter-clockwise.

Notice that an H-bridge is **NOT the 74LS47** chip.   The H-Bridge will be labeled either L293 or SN754410.   The SN754410 and L293 are the same chip with the same layout.

Referring to the H-bridge datasheet on the ME430 courseware page, we see that the suggested bi-directional motor circuit looks like this.
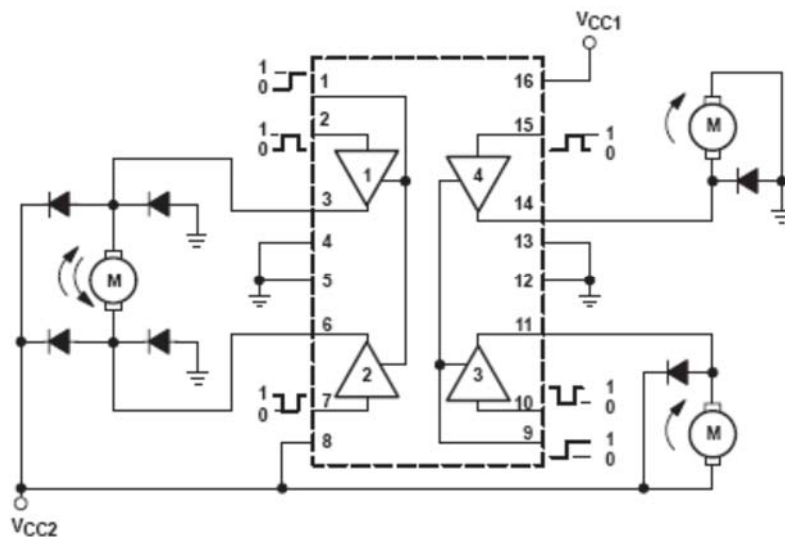
There are actually three motors here—one running bi-directionally on the left and two running uni-directionally on the right.   We will only use the connections on the left-hand side.   We've pasted a version of this circuit by itself on the next page, because we are going to want to add some switches and other connections to it.   In order to make sure that the right-hand side of the H-bridge does not interfere with the left-hand side, we also connected pin 9 to ground.

If you read through the datasheet a bit more, you find that pin 1 is the "enable" line for the left side—the signal that tells the H-bridge to turn on, pin 9 is the enable on the right side (which we want off).   On the circuit drawing on the next page, add a basic switch circuit to serve as the input to pin 1. This button switch will control whether the motor is on or off—the motor will normally be on, but if we press the button it will shut the H-bridge (and the motor) off.
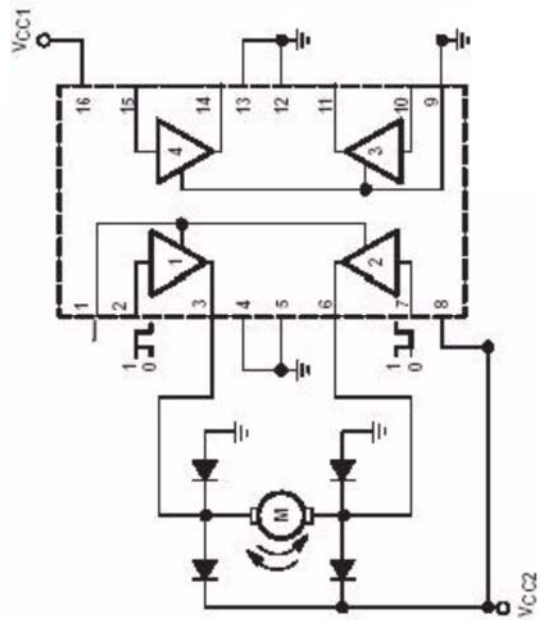
Next, we notice that pins 2 and 7 are always supposed to be opposites—when 2 is high, 7 should be low, and vice versa.   This instructs the motor to spin clockwise or counter-clockwise. We want to use just one more switch to accomplish this, so use RA1 as the input to pin 2 and RB1 as the input to pin 7.   Note again that RA1 and RB1 are always opposites.   Add this circuit to the diagram on the previous page.

Finally, we will need to connect the power to the H-bridge. V_{cc1} should be at 5 volts (regulated!) and V_{cc2} should both be at 5 volts **un**regulated. V_{cc1} is always a regulated 5 volts regardless of the motor voltage as it runs the chip logic. V_{cc2} is the motor voltage (usually 5-24 volts). In this case the motor will use the **un**regulated 5 volts (which is more like 6.3 volts, but that's ok).   Add this to your circuit diagram.

Now that you have everything planned out, go ahead and build the circuit.   When it works, demonstrate it to your instructor and get it signed off on the front page.

(2) Stepper Motor at 5V with 2 sets of bi-directional phases

Stepper motors are more complicated to drive than ordinary brushed DC motors.   Nevertheless, the H-bridge makes the task much simpler.   From the H-bridge datasheet, we have a suggested circuit for a Two-Phase Motor Driver:
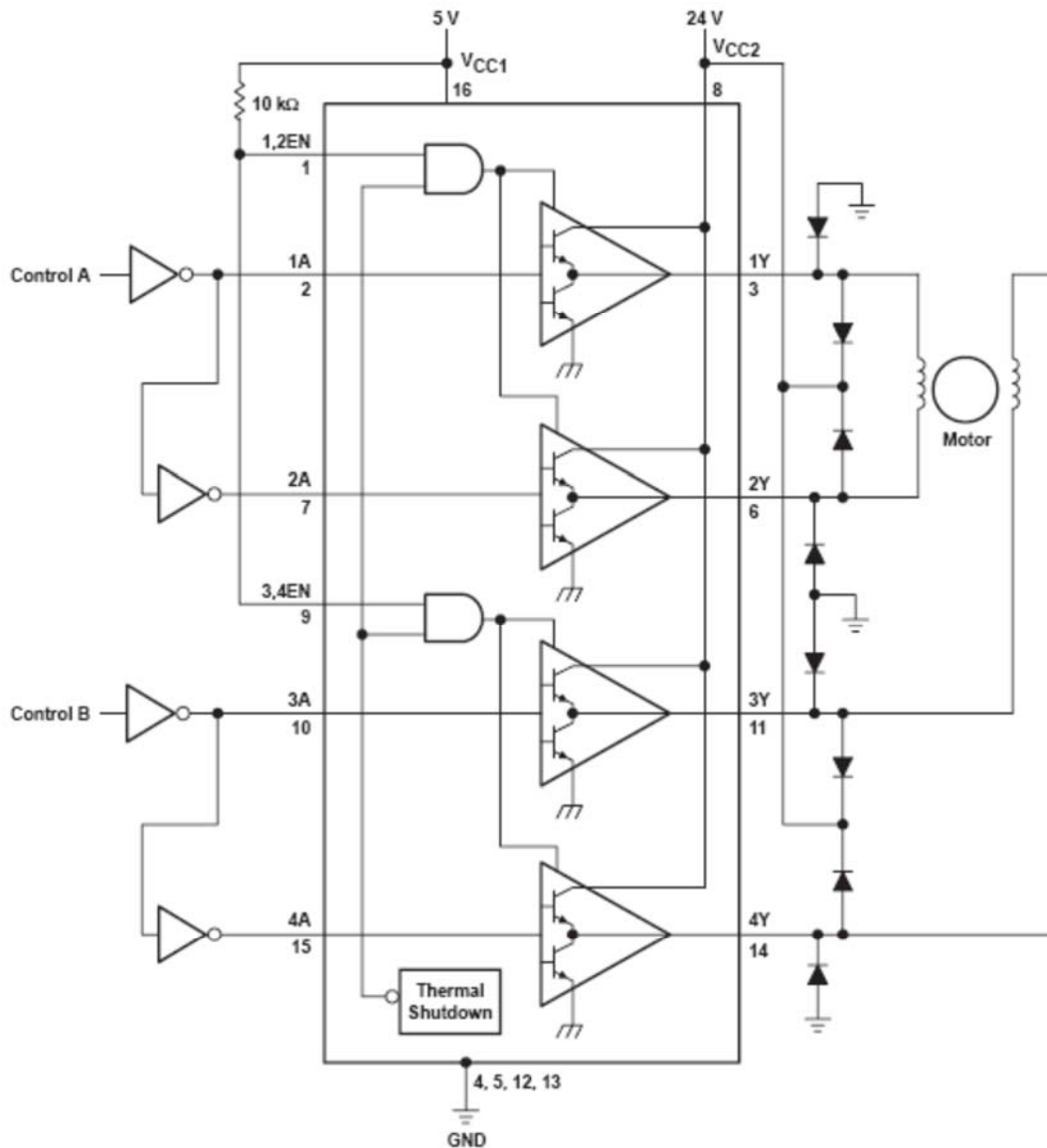
Figure 2. Two-Phase Motor Driver (L293)

In this circuit V_{cc1} should again be connected to 5 volts (regulated) and V_{cc2} should again be connected to the 5 volt unregulated supply, even though this shows V_{cc2} connected to 24V. Since this is a low power stepper motor, we could probably skip the diodes.   Notice that the layout shown above is not a literal picture of the chip—pin 14 is shown right next to pin 11! Read the pin number and figure out where they are on the real device (all this information is in the H-bridge datasheet).

We will want to set up two basic switches to control the H-bridge.   One of the switches will control one side of the H-bridge, and the other switch will control the other side of the

H-bridge.   One side is already finished using RA1 and RB1 on pins 2 and 7.   The second switch is similar, except that it will control pins 10 and 15 of the H-bridge from RA2 and RB2.

Next, we need to hook four of the six stepper motor wires up to pins 3, 6, 11, and 14.   Use your notes from the video lecture on stepper motors to understand what you need to measure in order to figure out which wires to use.

Once everything is wired correctly, we should be able to make the stepper motor go through a small "step" by pushing the buttons in the correct 4-part sequence.   The sequence is the "full-step" sequence from the video lecture.

Finally, count how many times you need to go through the 4-part sequence in order to get the motor to make one revolution.

It takes _____times through the 4-part sequence to go one revolution.

Demonstrate your working stepper motor for your instructor and get it checked off on the front page.