Direct Current (DC) Motors

- Rotating shaft
- Fixed pair of magnets
Direct Current (DC) Motors

Wire placed within a magnetic field:

• Force on the wire is perpendicular to the magnetic field and to the direction of current through the wire.

• Direction of force: determined by the left-hand rule.
Direct Current (DC) Motors

- Force on the wire induces a torque about the motor shaft
- Commutator switches direction of current every half cycle
- Direction of torque remains the same throughout the cycle
DC Motors

• Average motor torque is proportional to current flow through the wire
  – Wire has some resistance

• Direction of current flow determines torque direction

How can a digital input control torque magnitude?
DC Motors

How can a digital input control torque magnitude?
• Use Pulse Width Modulation (PWM)!

How do we handle torque direction?
DC Motors

How do we handle torque direction?

• +5V to north 0V to south
• 0V to north +5V to south

How would we implement this with our microcontroller?
DC Motor Control

One possibility…

- Connect motor directly to the I/O pins

Two directions:

- PD2: 1; PD3: 0
- PD2: 0; PD3: 1
DC Motor Control

One possibility…

• Connect motor directly to the I/O pins

What is wrong with this implementation?
DC Motor Control

What is wrong with this implementation?

- Our I/O pins can source/sink at most 20 mA of current
- This is not very much when it comes to motors...

How do we fix this?
NPN Transistors

Base to emitter is a diode!

- Current from base to emitter is non-negative
- Small B->E current opens a “valve” that allows large C->E current
Transistors as Switches

(what we need to understand for our purposes)

Logic 0 (0V) → no current flow

0 V
Transistors as Switches

(what we need to understand for our purposes)

Logic 1 (5V)  
1 -> small amount of current flow from base to emitter
Transistors as Switches

(what we need to understand for our purposes)

Logic 1 (5V)

1 -> small amount of current flow from base to emitter
   also allows (possibly large) current to flow from collector to emitter
Simple H-Bridge

+5V
Simple H-Bridge

What happens with these inputs?
Simple H-Bridge

What happens with these inputs?

- Motor turns in one direction
Simple H-Bridge

How about these inputs?
Simple H-Bridge

What happens with these inputs?

- Motor turns in the other direction!
Simple H-Bridge

How about these inputs?
Simple H-Bridge

What happens with these inputs?

- We short power to ground

... very bad
Simple H-Bridge

How can we prevent a processor from accidentally producing this case?
Modified H-Bridge

We introduce a little logic to ensure the short never occurs
Modified H-Bridge

What happens with this input?
Modified H-Bridge

What happens with this input?
Modified H-Bridge

What happens with this input?

- Motor turns in one direction
Modified H-Bridge

How about this input?
Modified H-Bridge

What happens with this input?
Modified H-Bridge

How about this input?

• Motor turns in the other direction
Modified H-Bridge

This implementation is nice because we only need one direction bit of control

• What are we missing?
Modified H-Bridge

What are we missing?

- Control of torque magnitude
- Let’s introduce a second PWM input that turns the motor on/off
Pulse Width Modulation for Motor Control

Goal: given on/off input, we want to specify the motor torque

• With PWM, we turn the motor on/off very fast
• We can control average motor torque with duty cycle
• With a high frequency signal, the inertia of the motor smooths out the sharp on/off transitions
PWM and Direction Control
PWM and Direction Control

What happens with this input?
PWM and Direction Control

What happens?

* No current flow
PWM and Direction Control

What happens now?
PWM and Direction Control

What happens now?
- ‘x’ determines motor direction
PWM and Direction Control

Direction

Two low-current inputs control direction and torque magnitude
Note: Input1 to input5 should be connected to 5 output pins on Atmega8 and these are the control signals. Particularly, sending a PWM signal to input1 controls the rotational speed of the right fan; sending a PWM signal to input2 controls the rotational speed of the left fan; sending a PWM signal to input3 controls the rotational speed of the middle fan; input4 and input5 control the rotation direction of the middle fan. Specifically, input4=1 & input5=0, one rotation direction; input4=0 & input5=1, the other rotation direction.
H-Bridge: More Detail

Diodes across the transistors can conduct current “upwards” in the circuit.
H-Bridge: More Detail

Current flow through the transistors

• Motor begins to spin
H-Bridge: More Detail

All transistors off, but:
- Motor still spinning

- Motor pushes current from left to right
H-Bridge: More Detail

All transistors off, but:
  motor still spinning

• Current moves through diode to +5V
H-Bridge: Dynamic Braking

Top transistors on;
motor spinning

+5V

1  C0  --  1  C2

0  C1  --  0  C3
H-Bridge: Dynamic Braking

- Current moves through diode (left)
- Then through transistor (right)
H-Bridge: Dynamic Braking

• Current moves through diode (left)
• Then through transistor (right)

Motor slows itself down!