Motor Control

Questions?

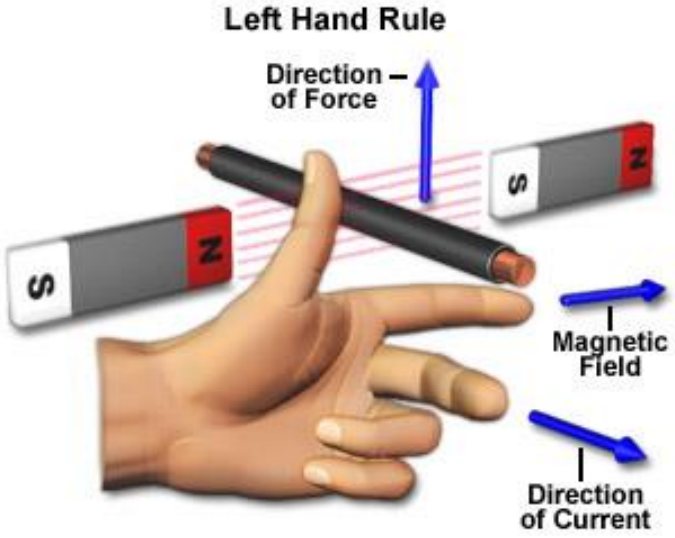
Direct Current (DC) Motors

- Rotating shaft
- Fixed pair of magnets

www.pcgadgets.com

Direct Current (DC) Motors

Wire placed within a magnetic field …

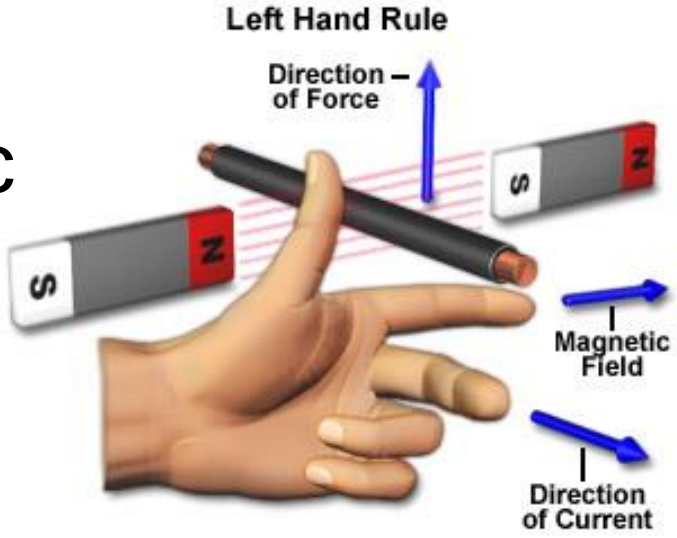


www.magnet.fsu.edu

Direct Current (DC) Motors

Wire placed within a magnetic field:

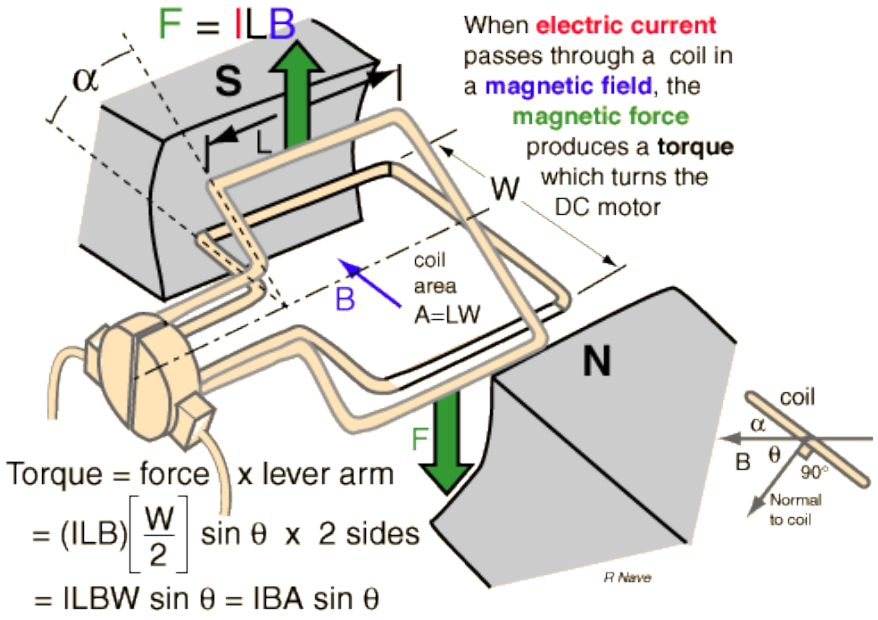
- Force on the wire is perpendicular the magnetic field and to the direction of current through the wire
- Direction of force: determined by the left-hand rule

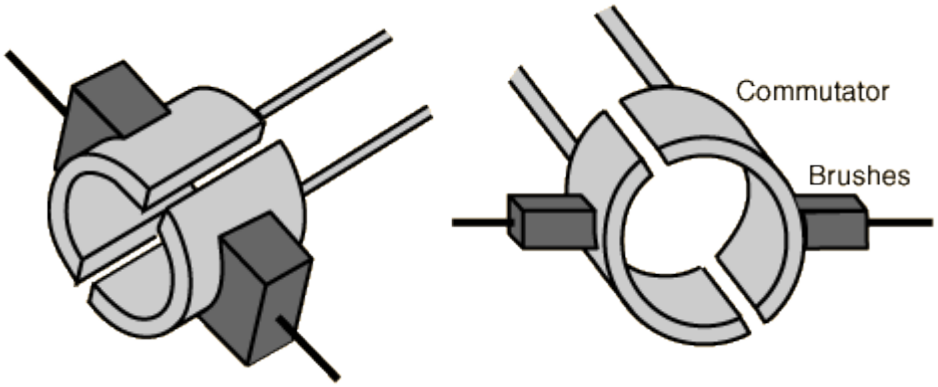


www.magnet.fsu.edu

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

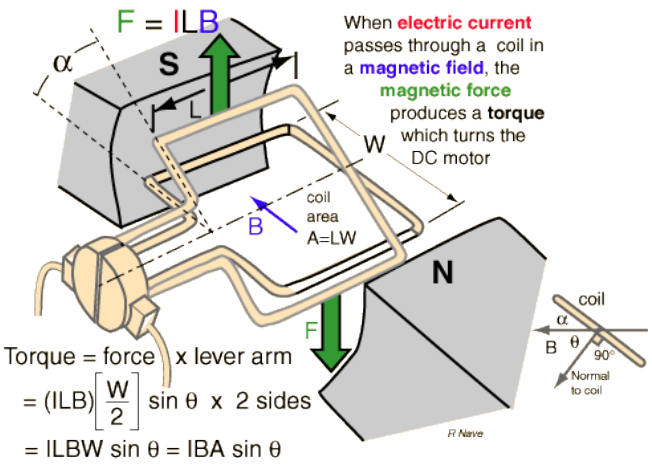




hyperphysics.phy-astr.gsu.edu

DC Motors

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



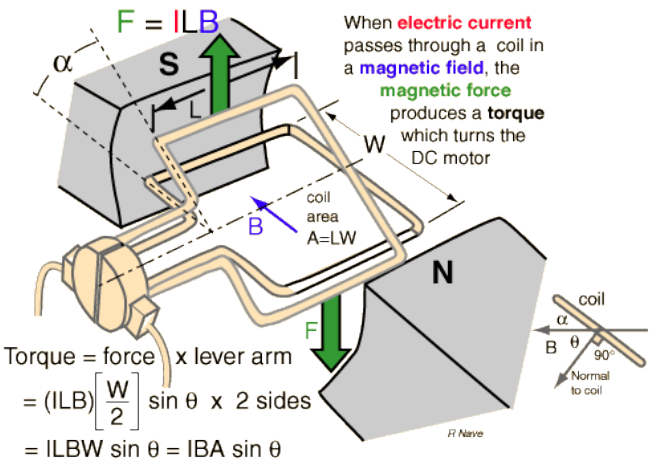
- Direction of current flow determines torque direction

How can a digital input control torque magnitude?

DC Motors

How can a digital input control torque magnitude?

- Use Pulse Width Modulation (PWM)!

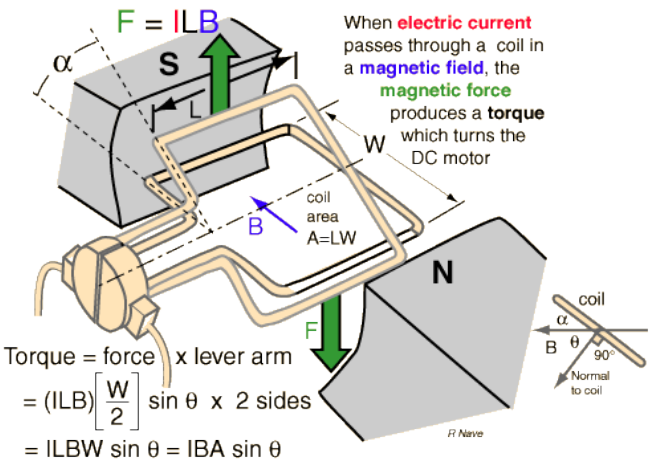


How do we handle torque direction?

DC Motors

How do we handle torque direction?

- +3.3V to north 0V to south
- 0V to north +3.3V to south



How would we implement this with our microcontroller?

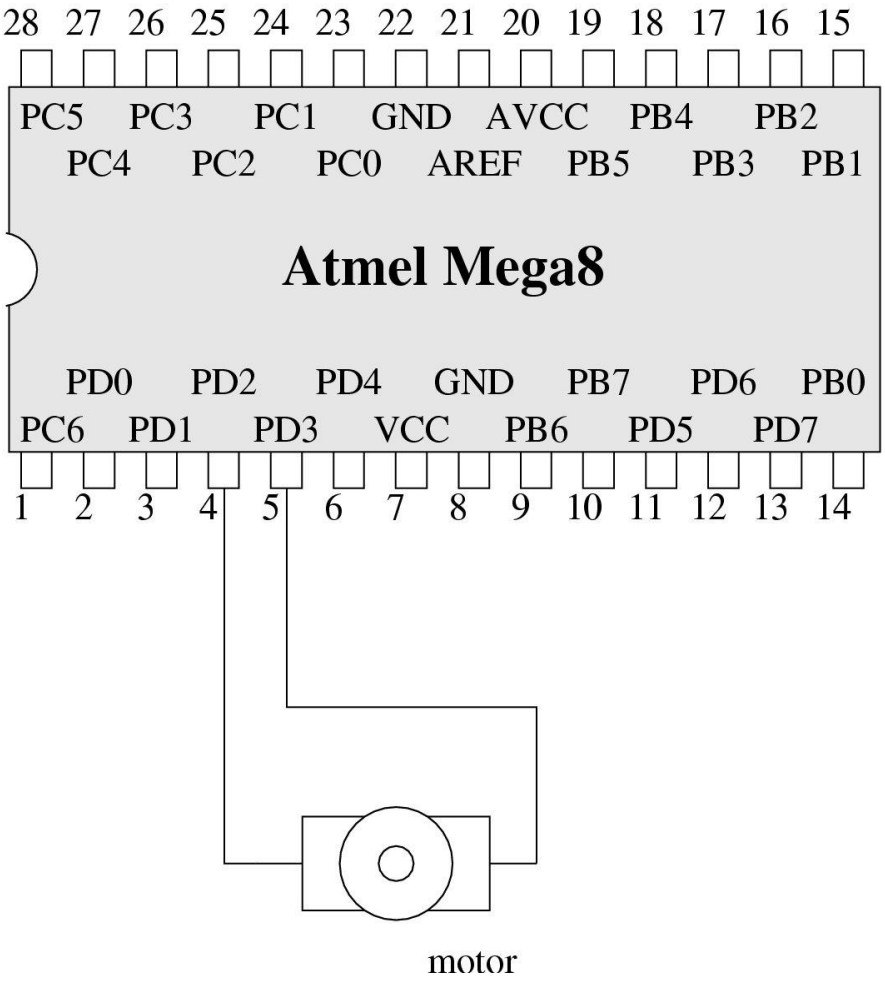
DC Motor Control

One possibility…

- Connect motor directly to the I/O pins

Two directions:

- PD2: 1; PD3: 0
- PD2: 0; PD3: 1

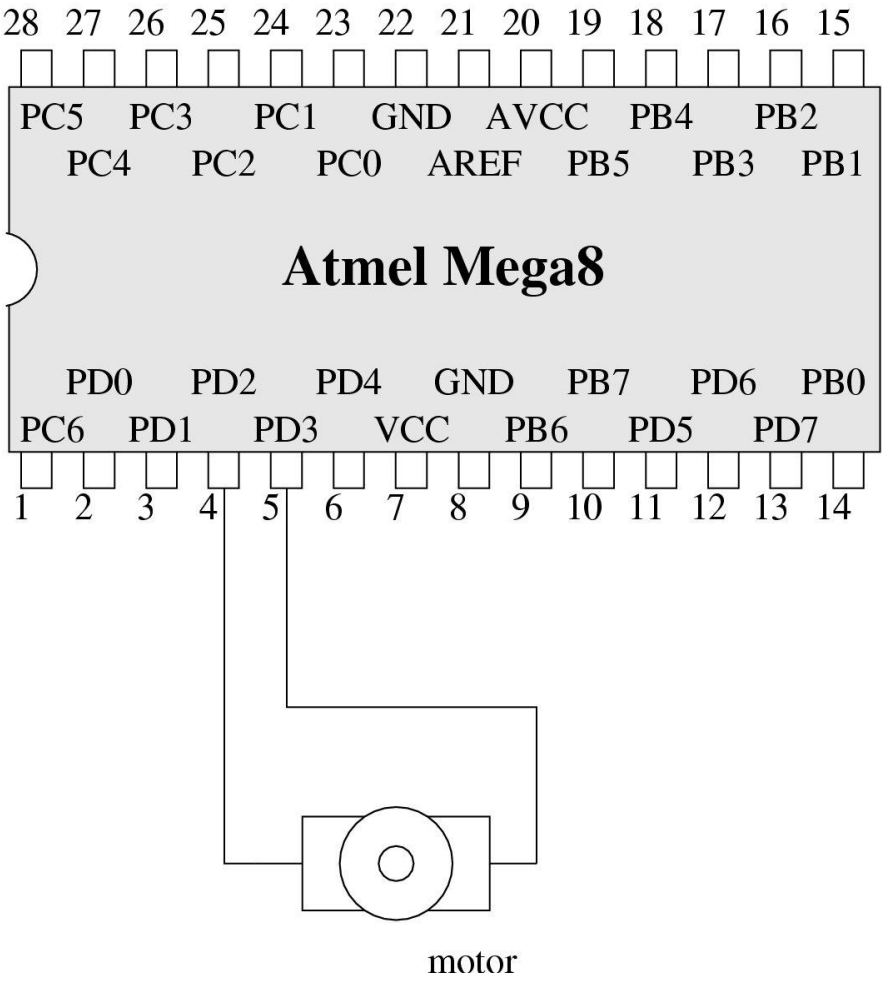


DC Motor Control

One possibility…

- Connect motor directly to the I/O pins

What is wrong with this implementation?

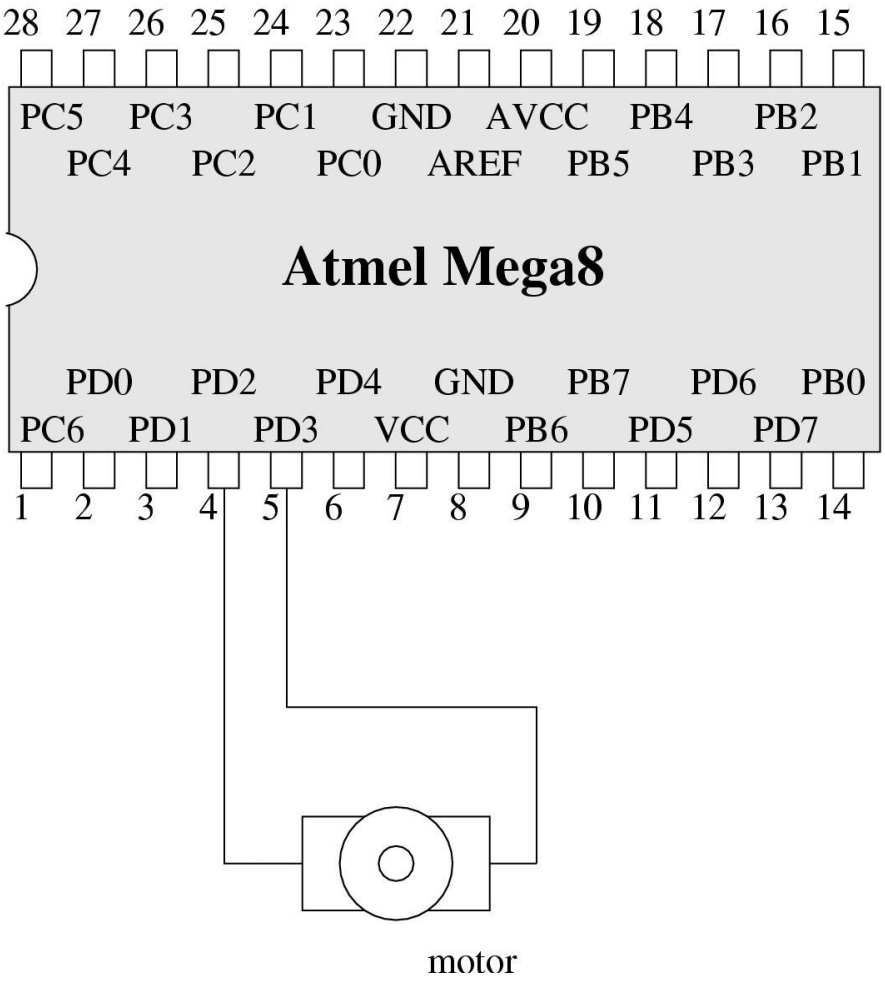


DC Motor Control

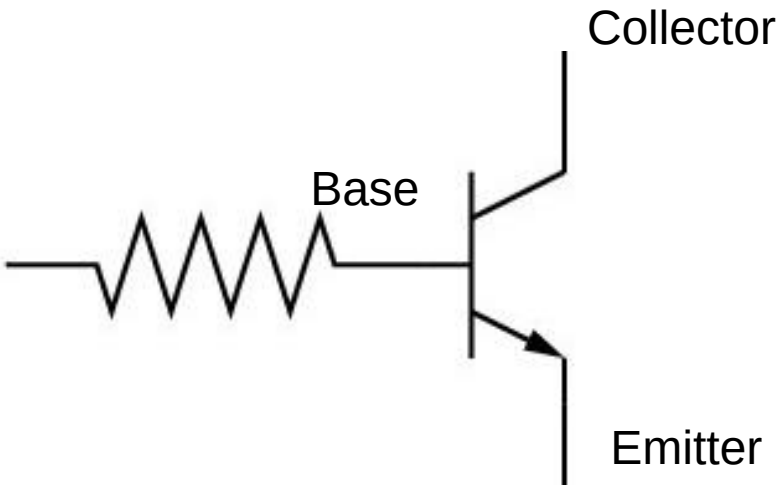
What is wrong with this implementation?

- Our I/O pins can source/sink at most 10 mA of current
- This is not very much when it comes to motors…

How do we fix this?



NPN Transistors

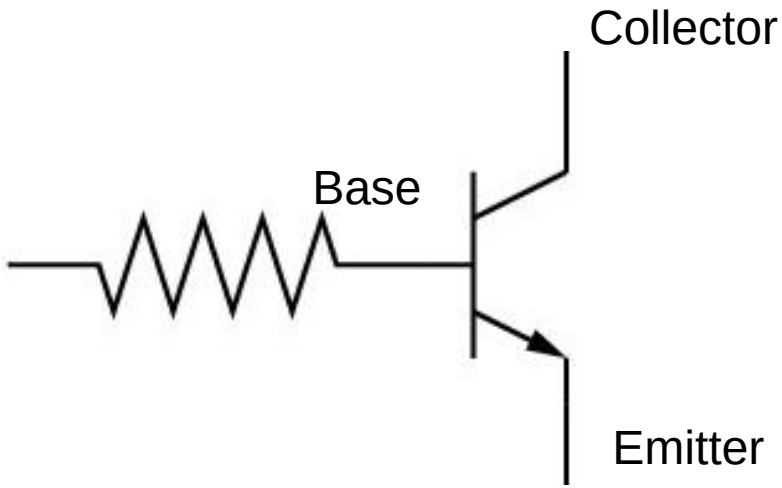


Base to emitter is a diode!

- 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)



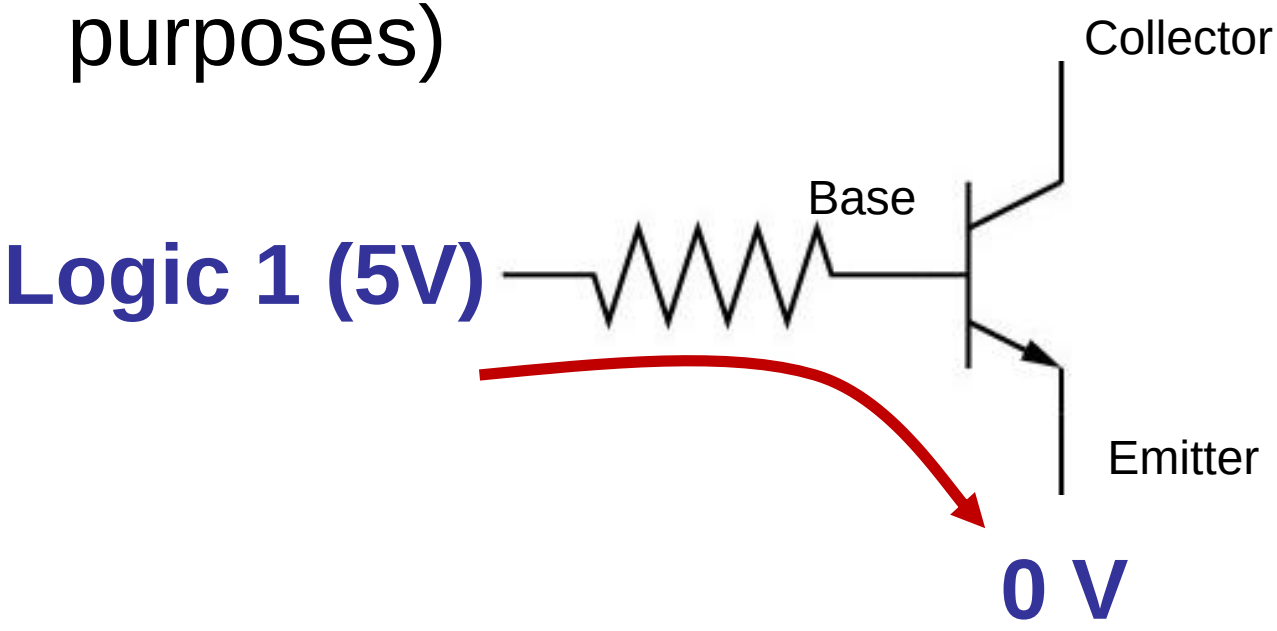
Logic 0 (0V)

0 V

0 -> no current flow

Transistors as Switches

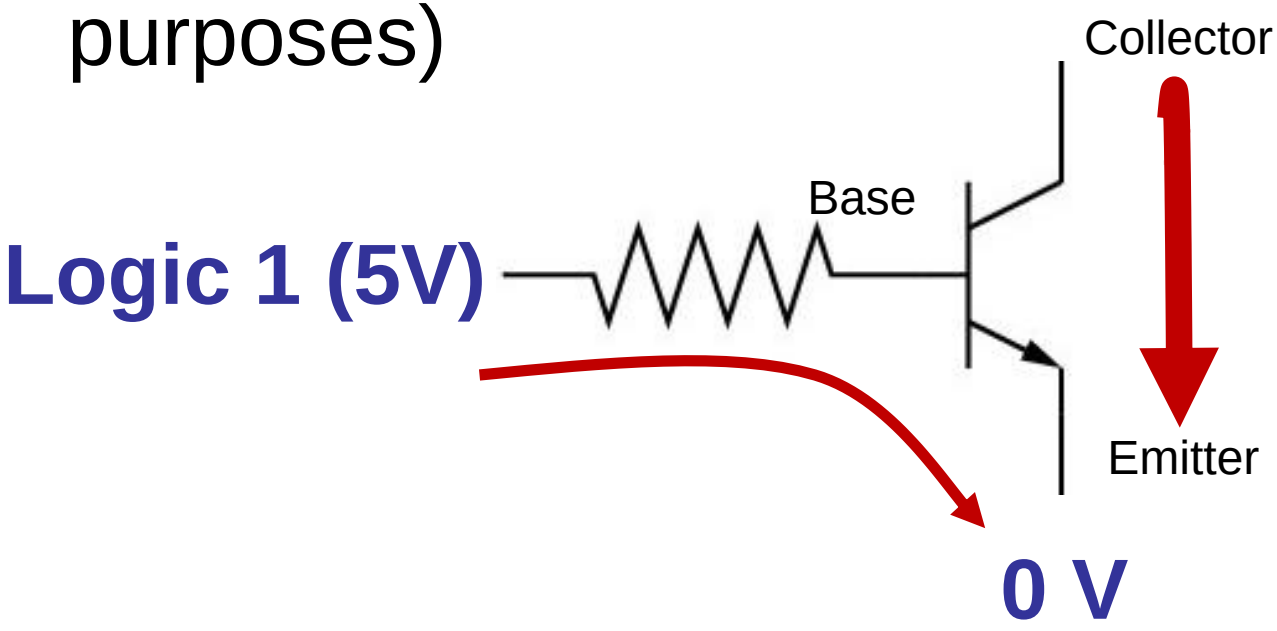
(what we need to understand for our purposes)



1 -> small amount of current flow from base to emitter

Transistors as Switches

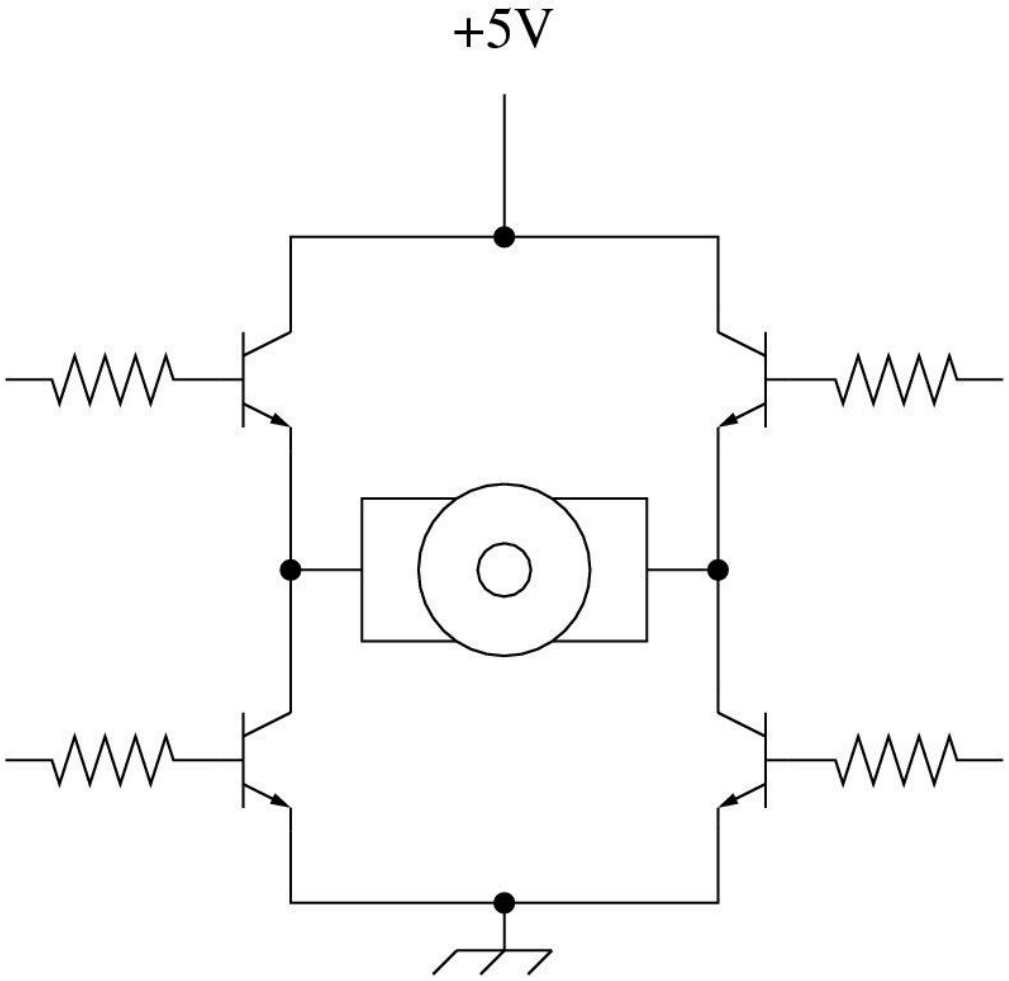
(what we need to understand for our purposes)



1 -> small amount of current flow from base to emitter

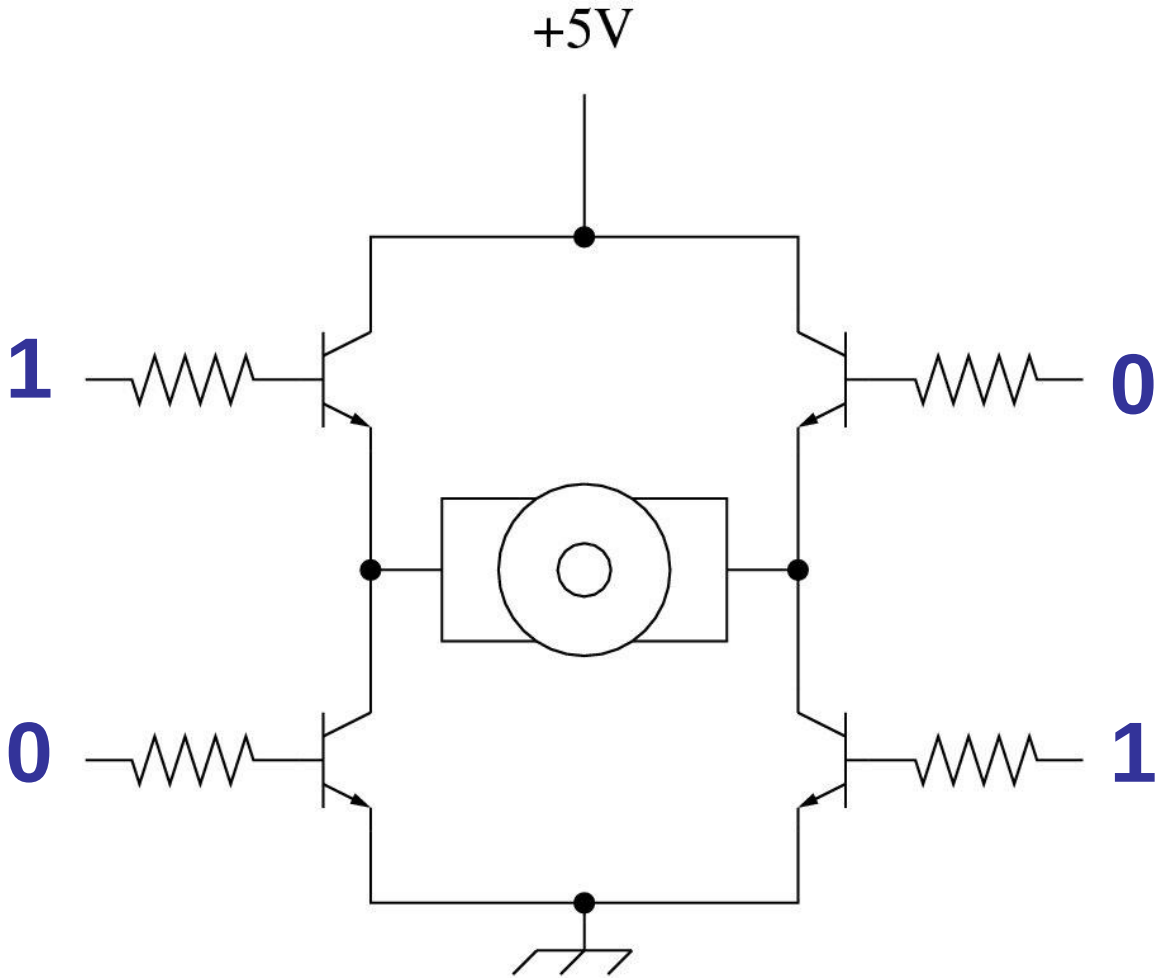
also allows (possibly large) current to flow from collector to emitter

Simple H-Bridge



Simple H-Bridge

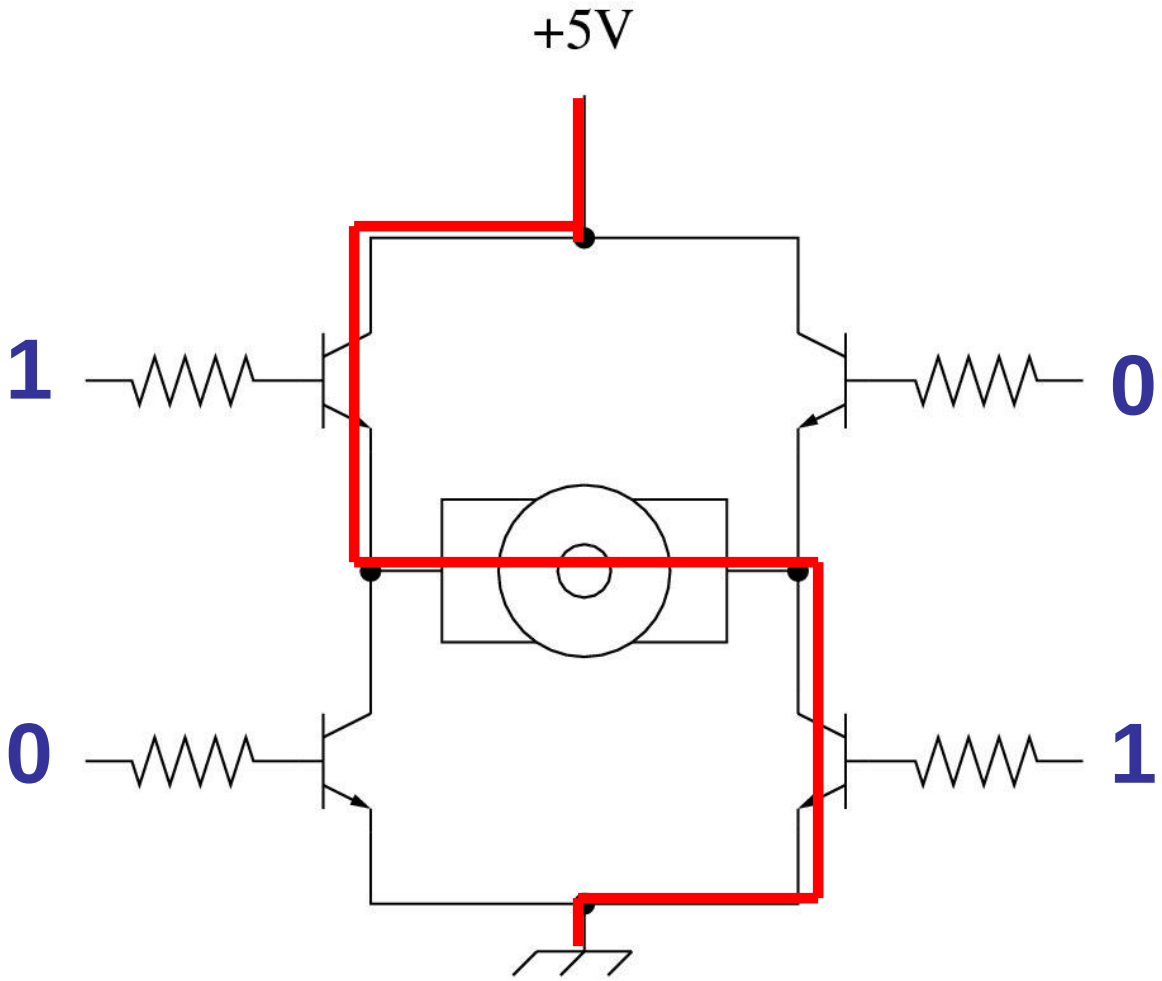
What happens with these logical inputs?



Simple H-Bridge

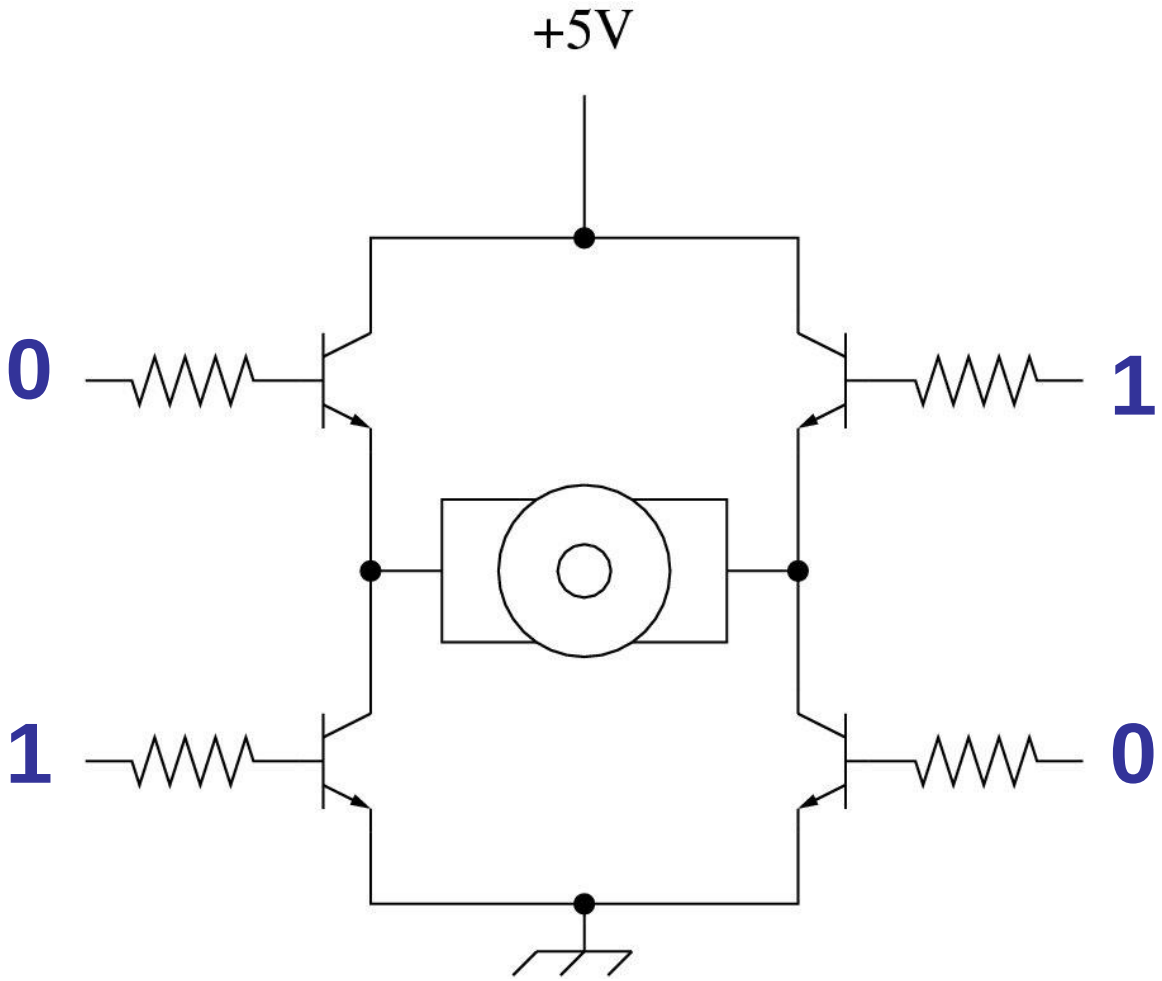
What happens with these logical inputs?

- Motor turns in one direction



Simple H-Bridge

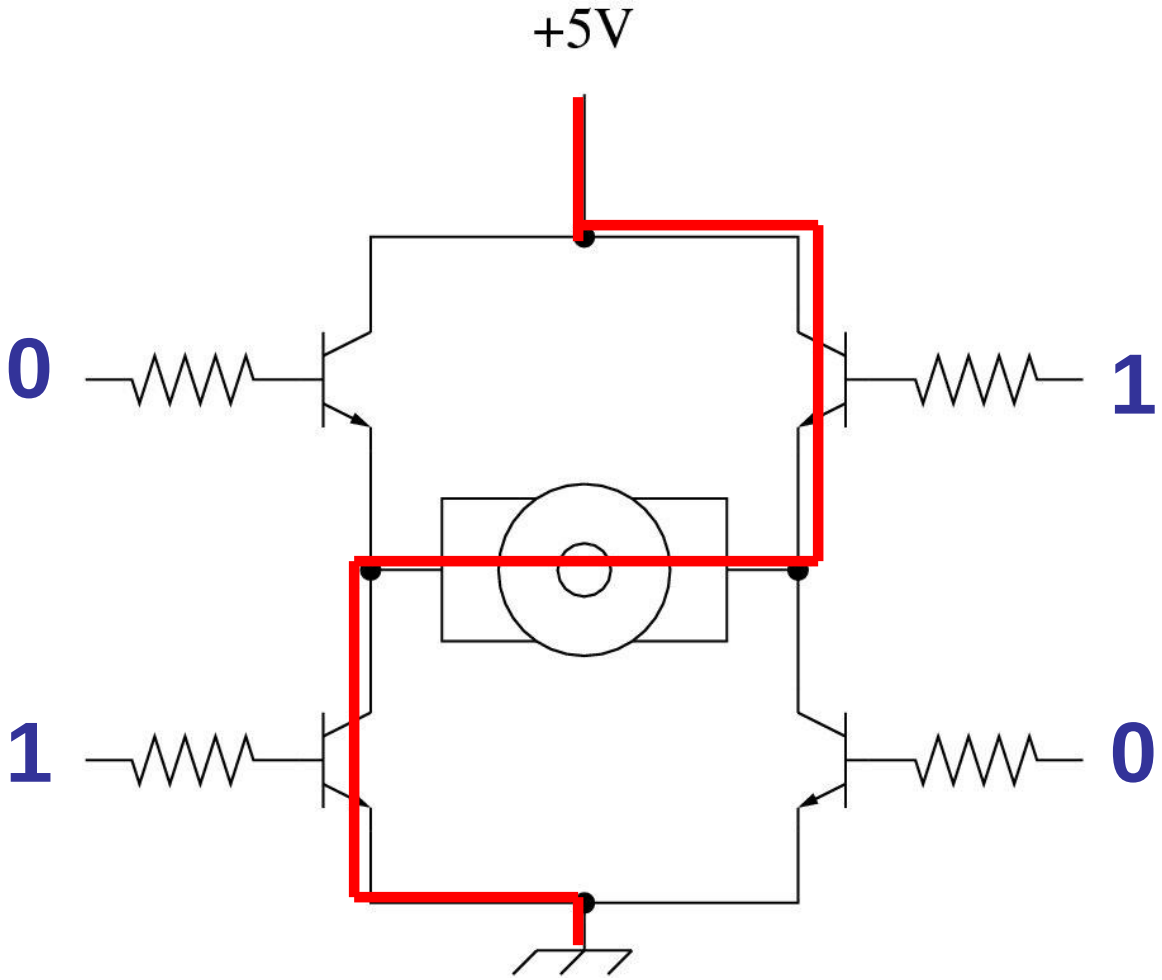
How about these inputs?



Simple H-Bridge

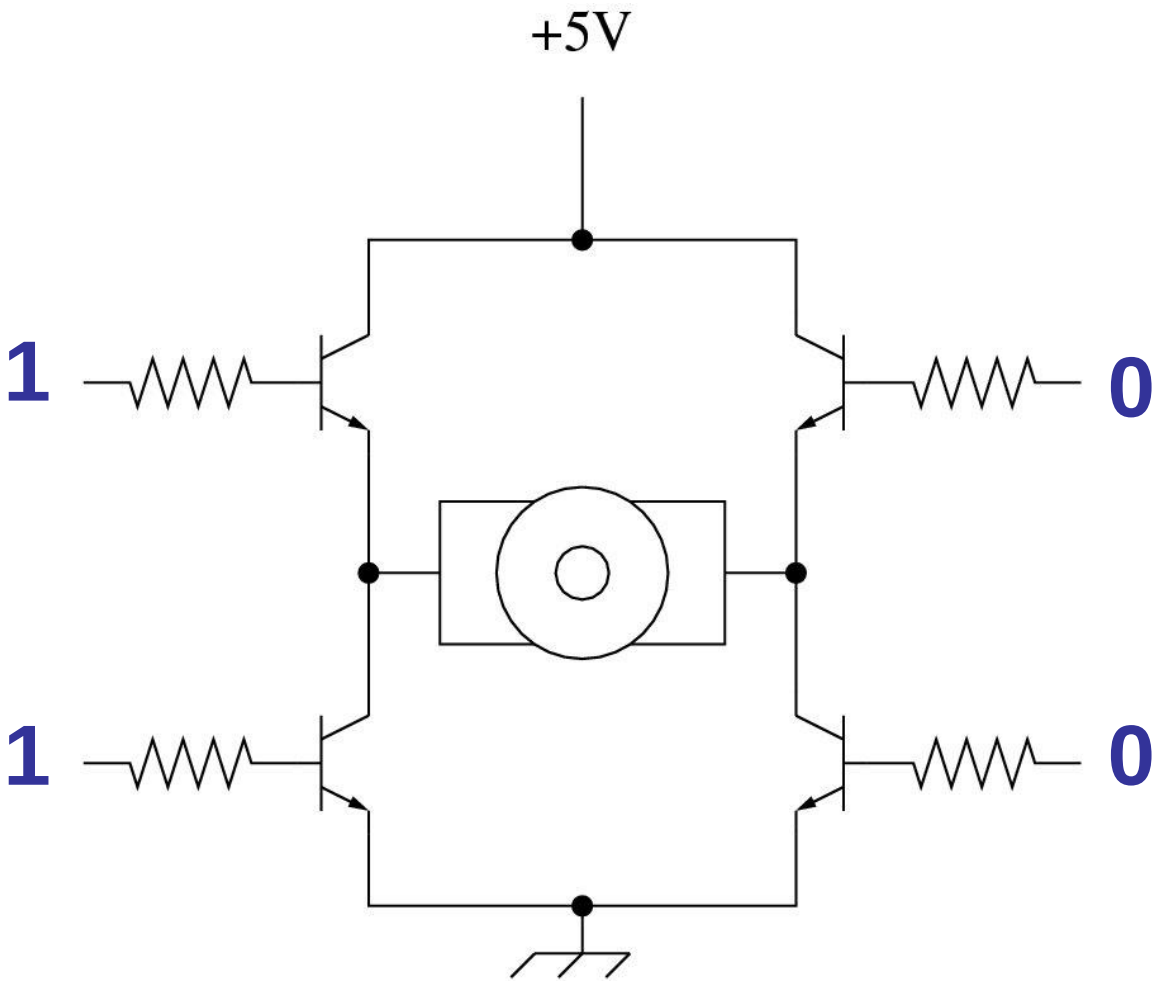
What happens with these inputs?

- Motor turns in the other direction!



Simple H-Bridge

How about these inputs?

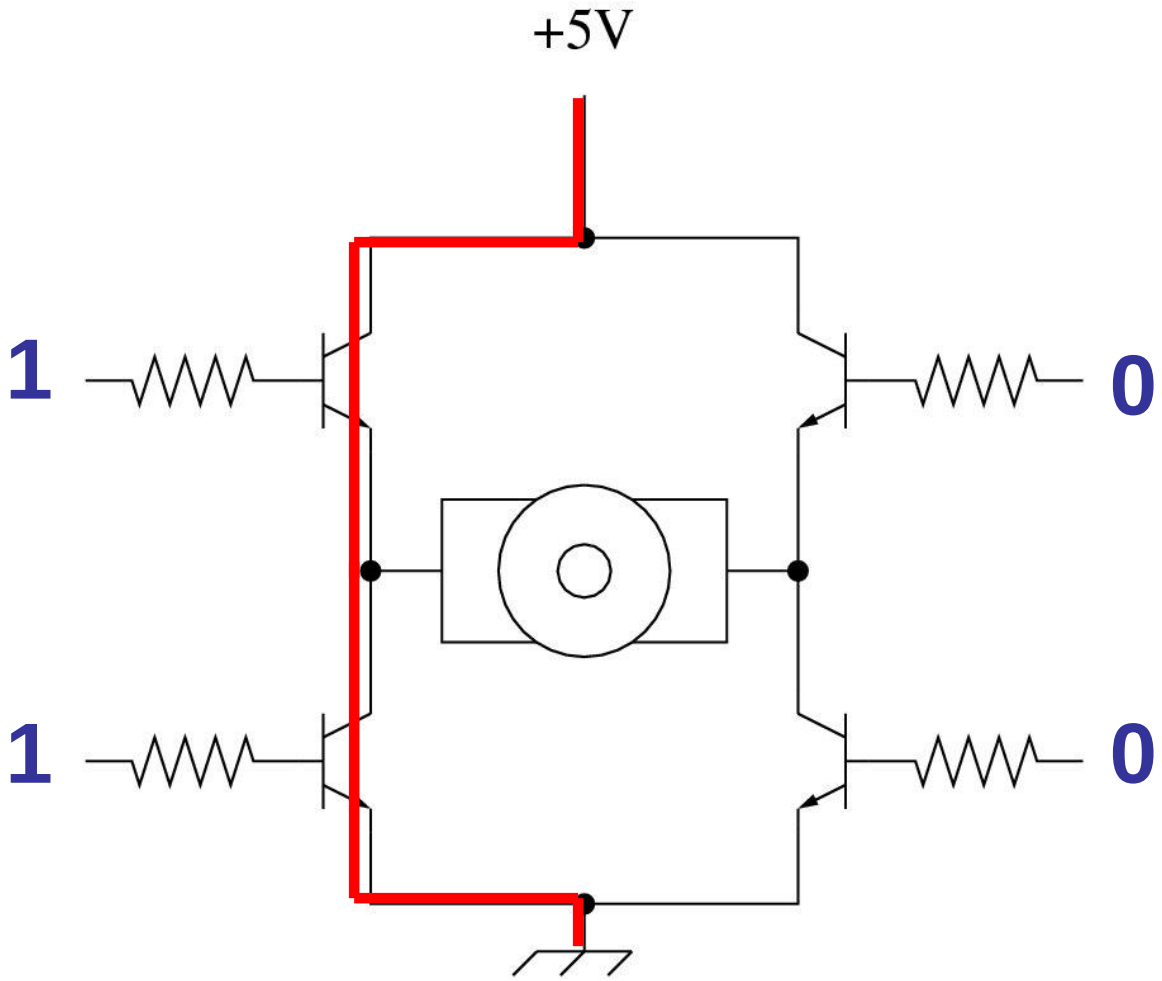


Simple H-Bridge

What happens with these inputs?

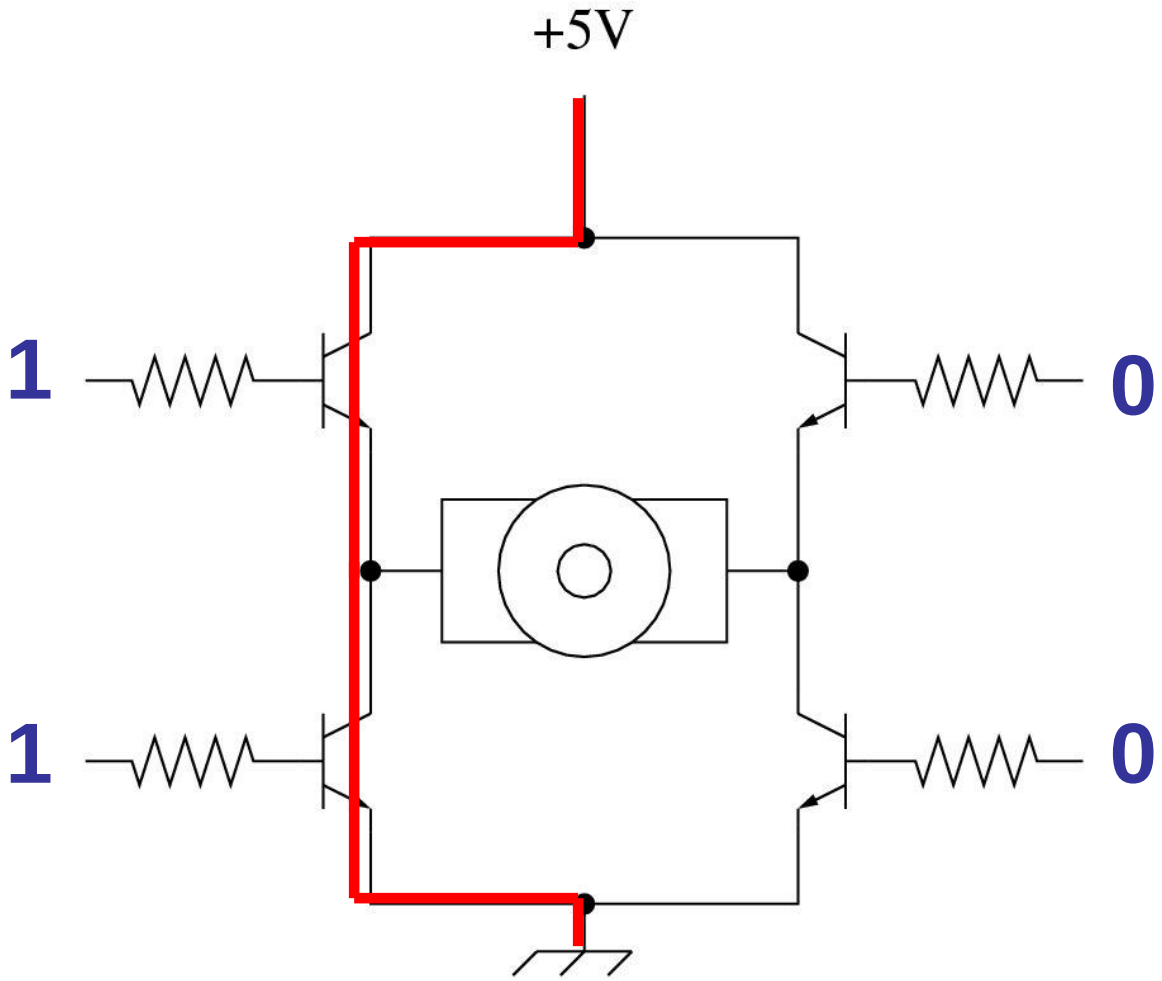
- We short power to ground

… very bad



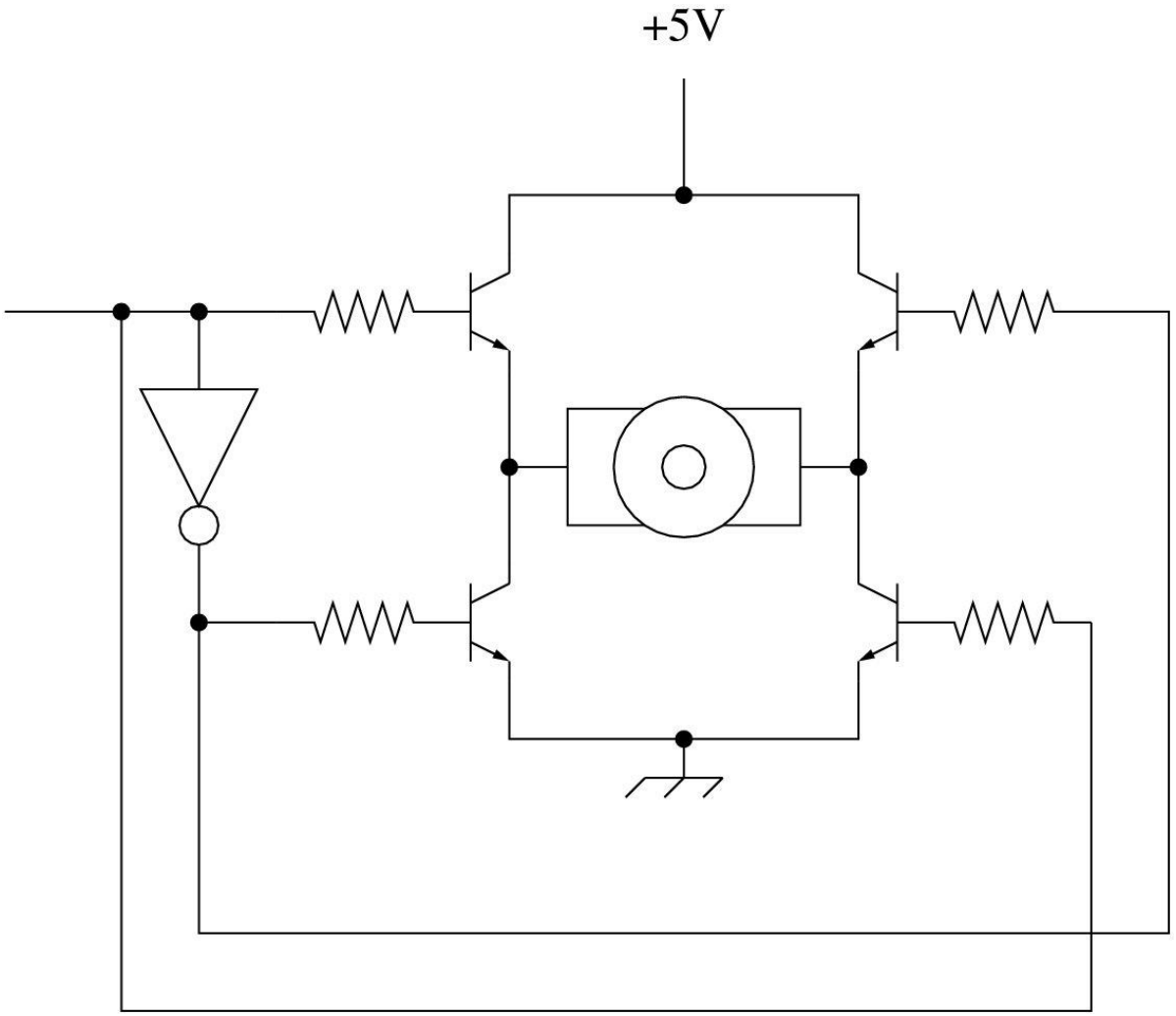
Simple H-Bridge

How can we prevent a processor from accidentally producing this case?



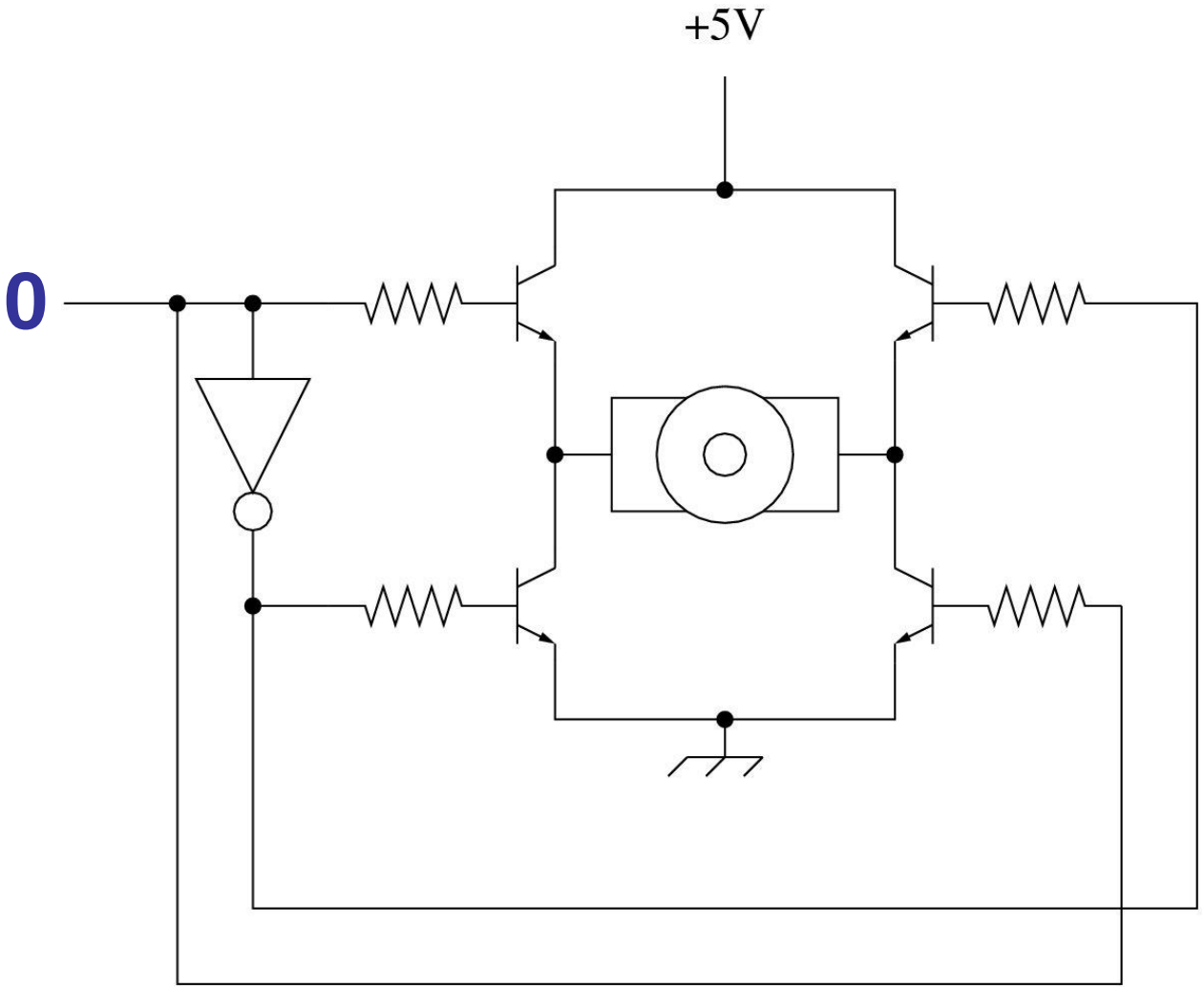
Modified H-Bridge

We introduce a little logic to ensure the short never occurs



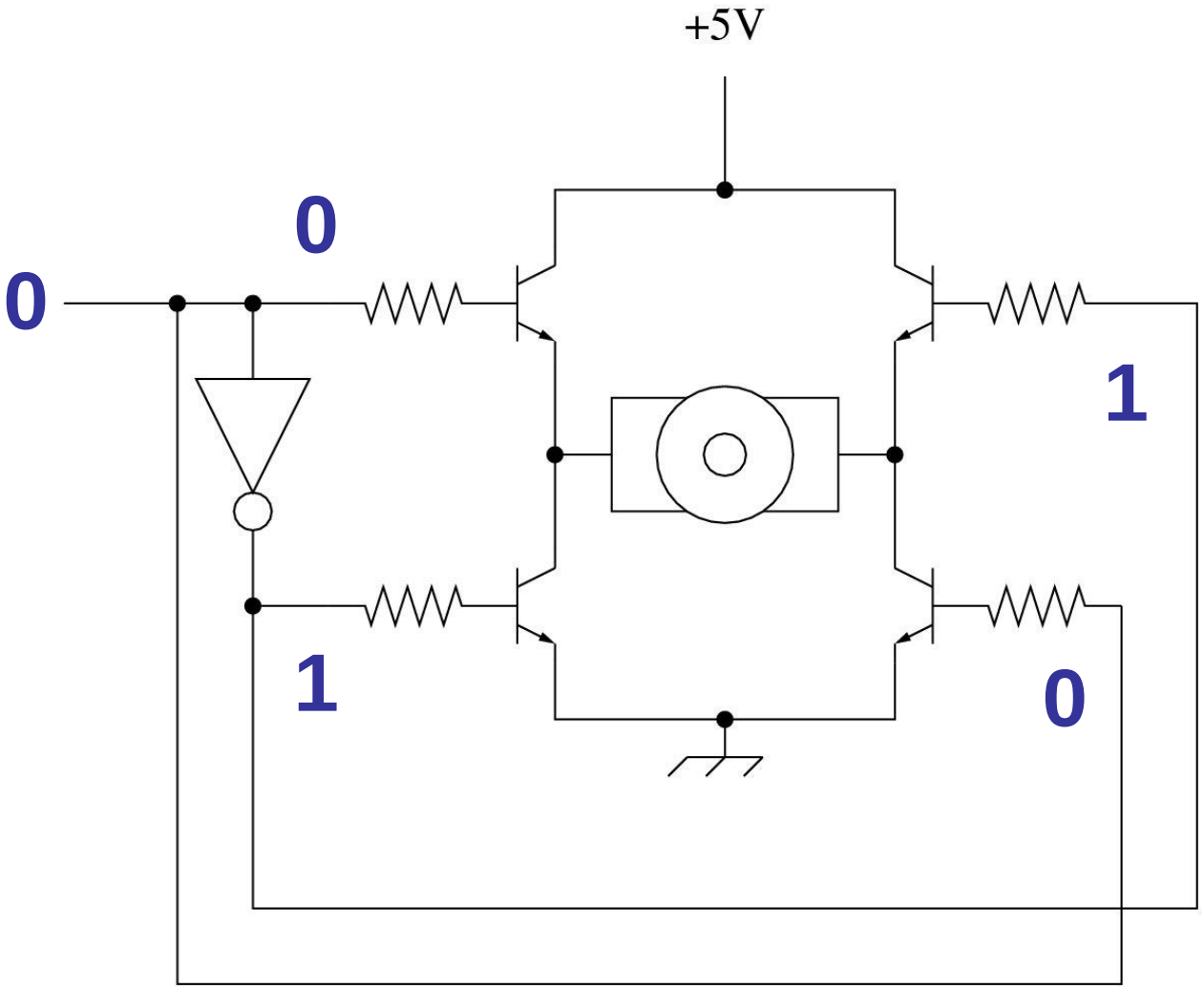
Modified H-Bridge

What happens with this input?



Modified H-Bridge

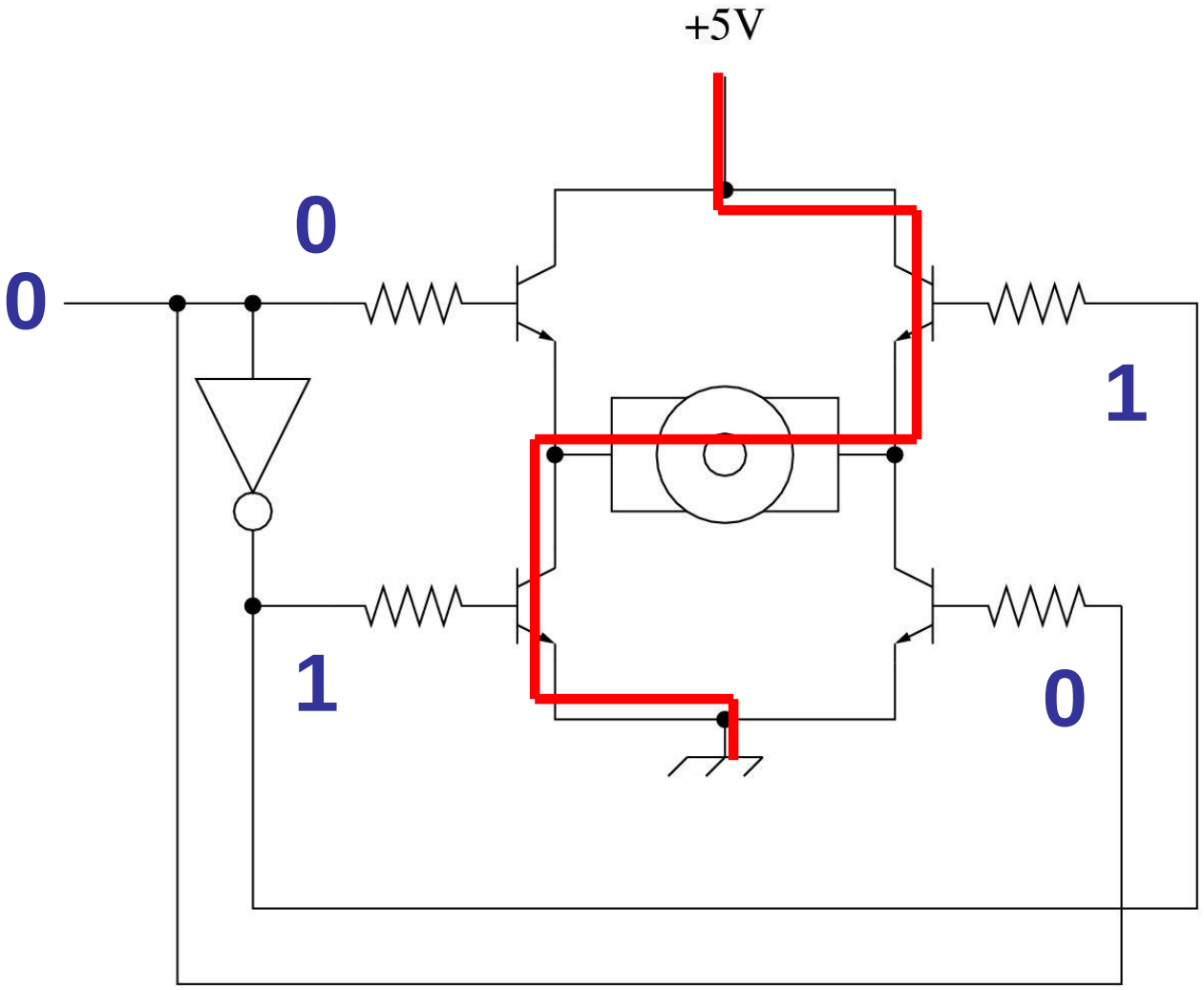
What happens with this input?



Modified H-Bridge

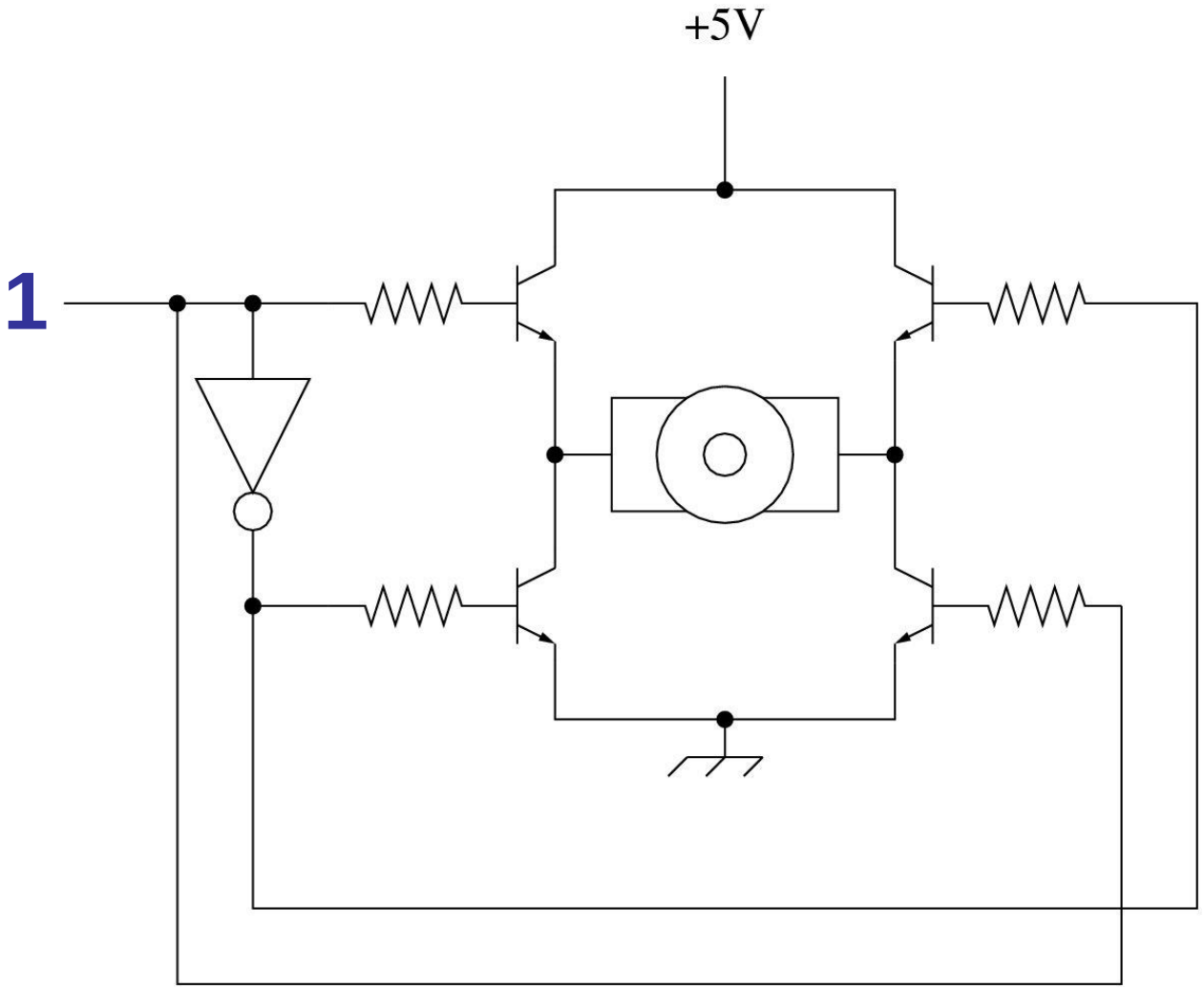
What happens with this input?

- Motor turns in one direction



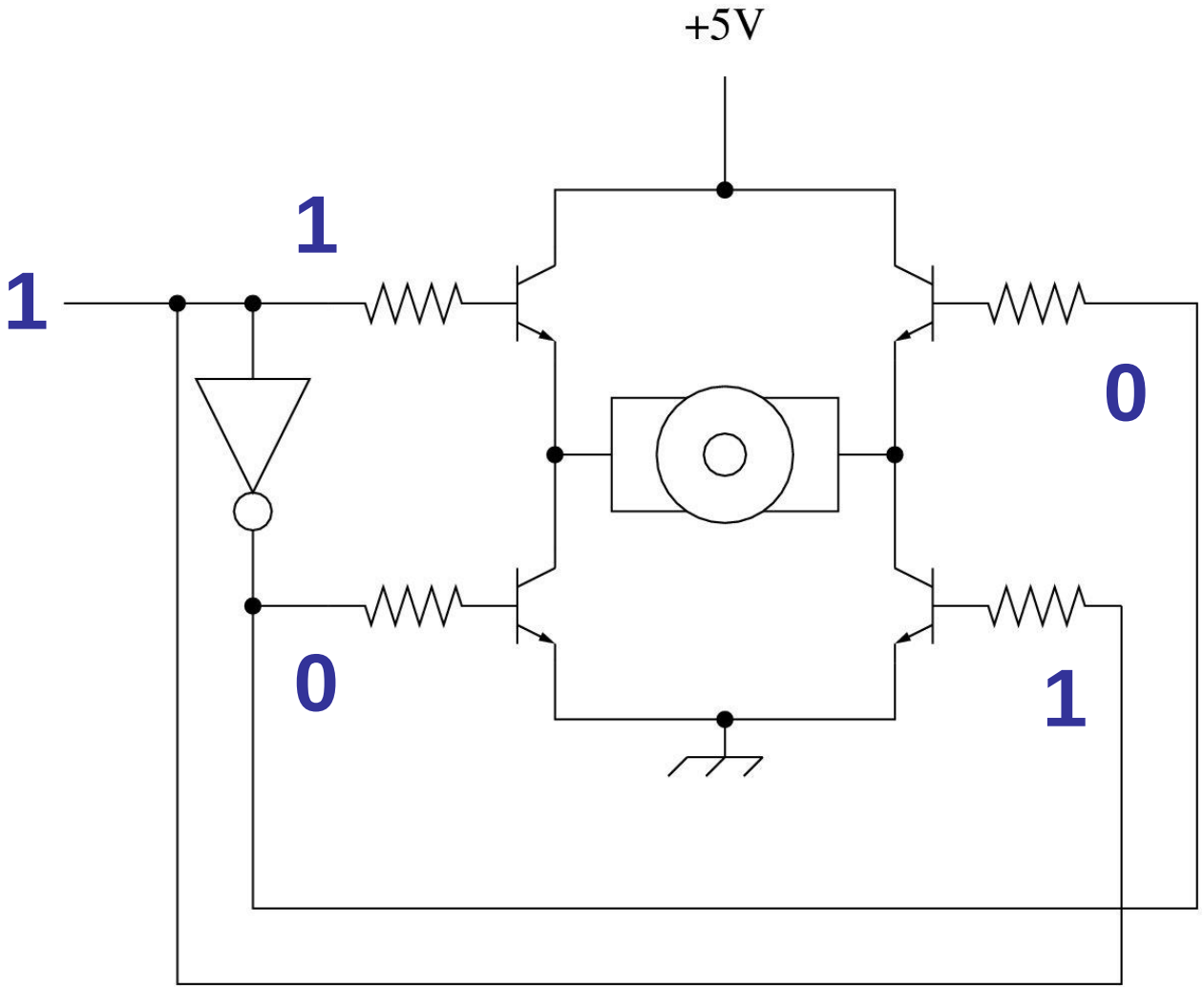
Modified H-Bridge

How about this input?



Modified H-Bridge

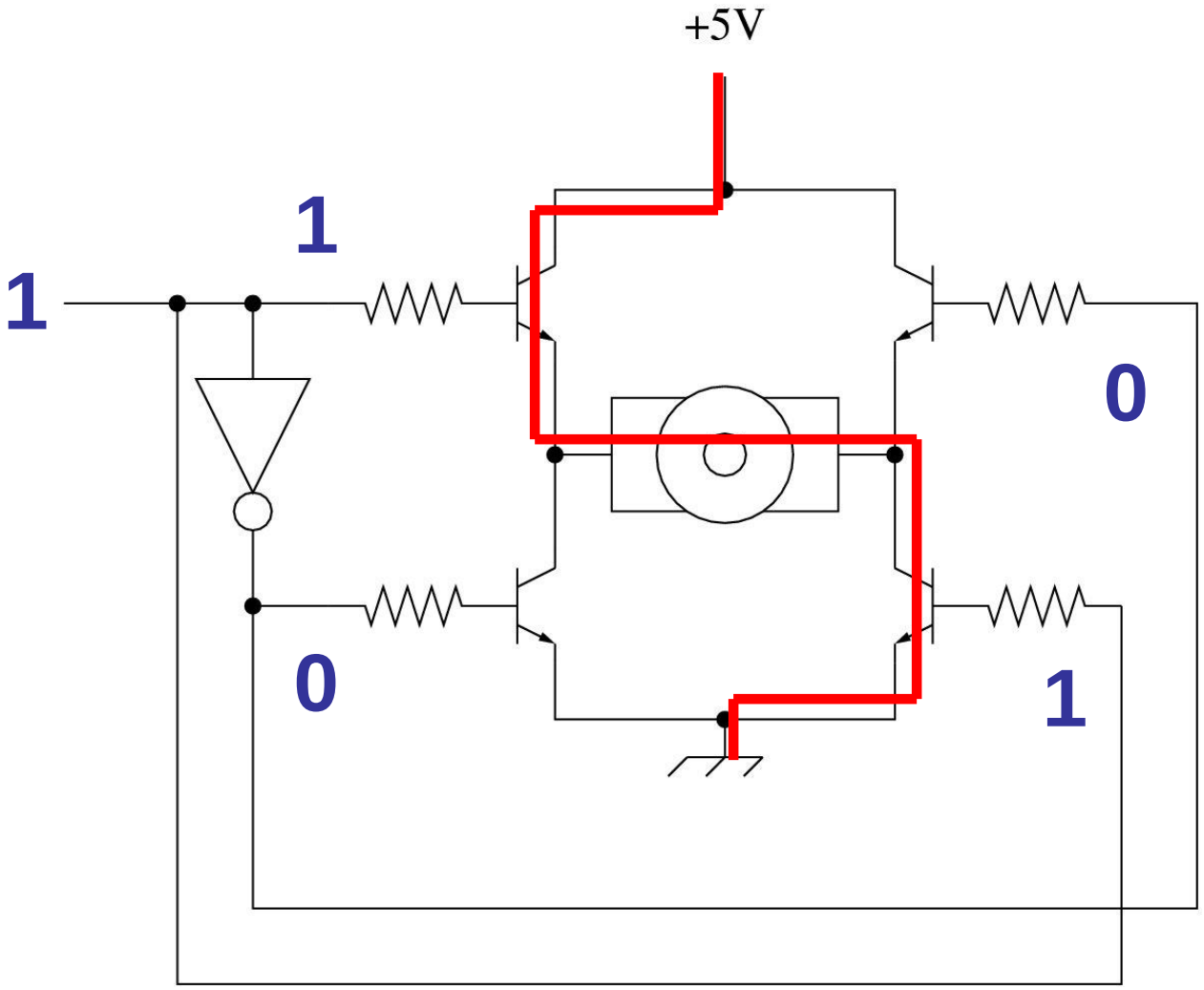
What happens with this input?



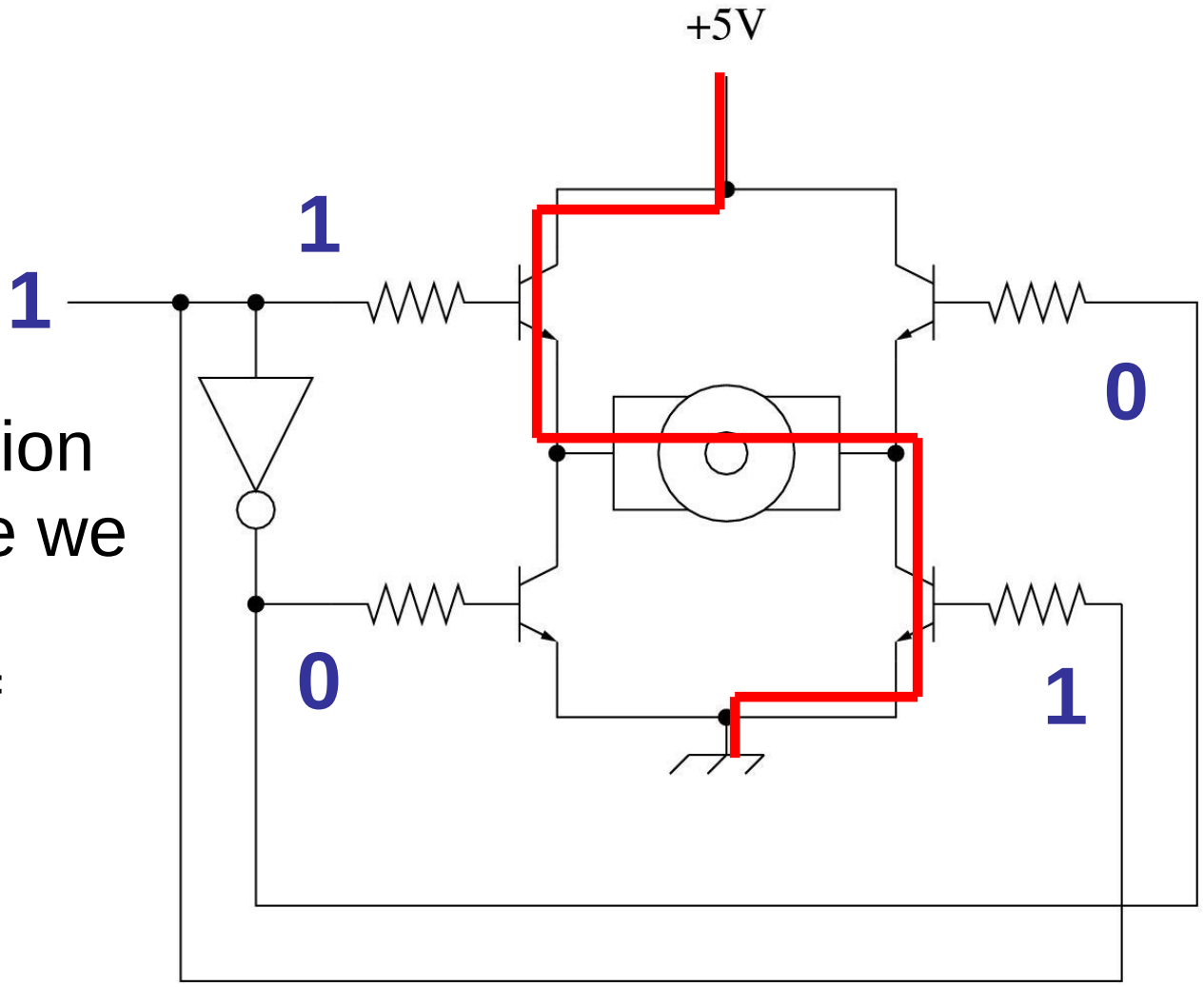
Modified H-Bridge

How about this input?

- Motor turns in the other direction



Modified H-Bridge



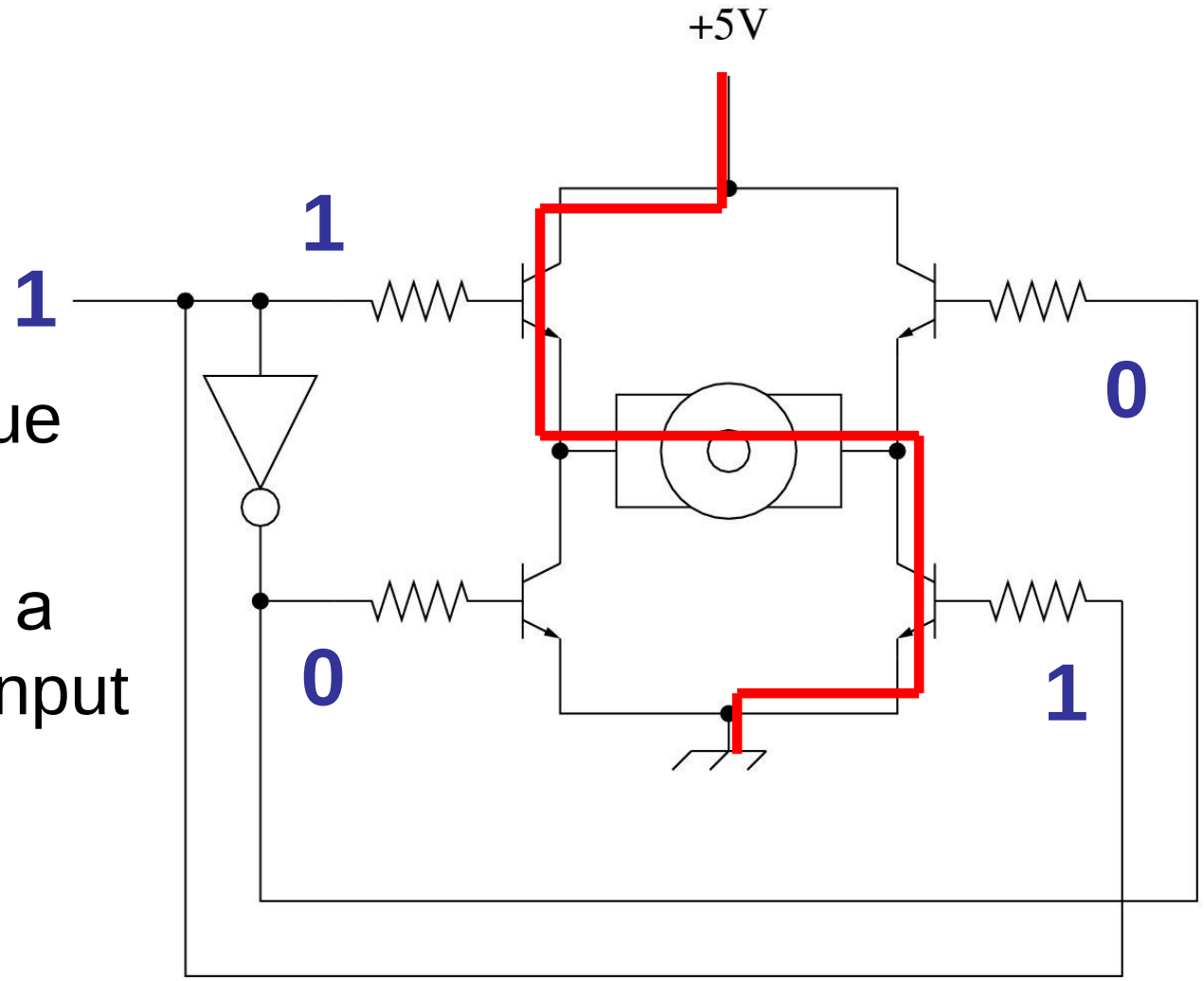
This implementation is nice because we only need one **direction** bit of control

- 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

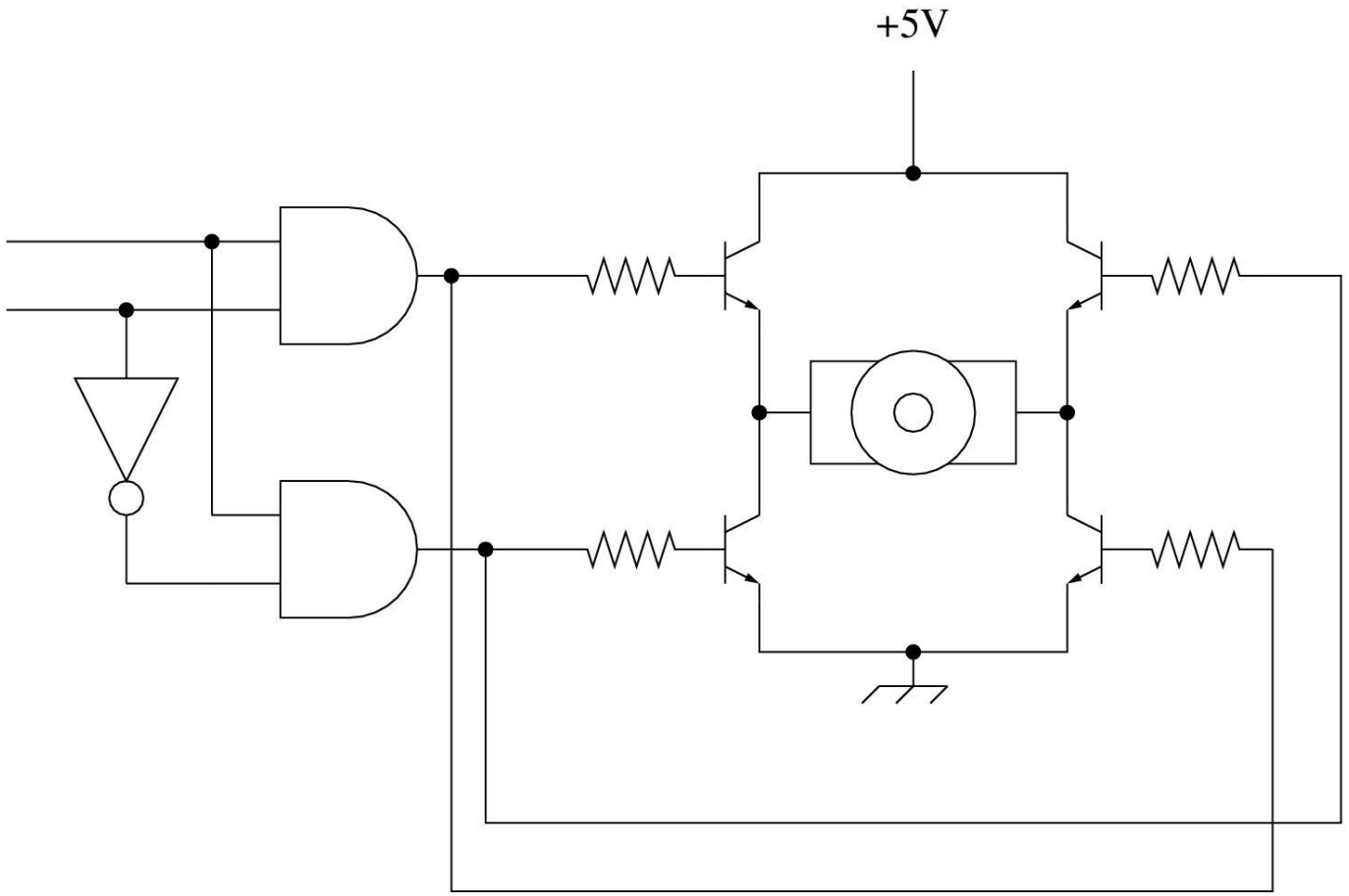


Pulse Width Modulation for Motor Control

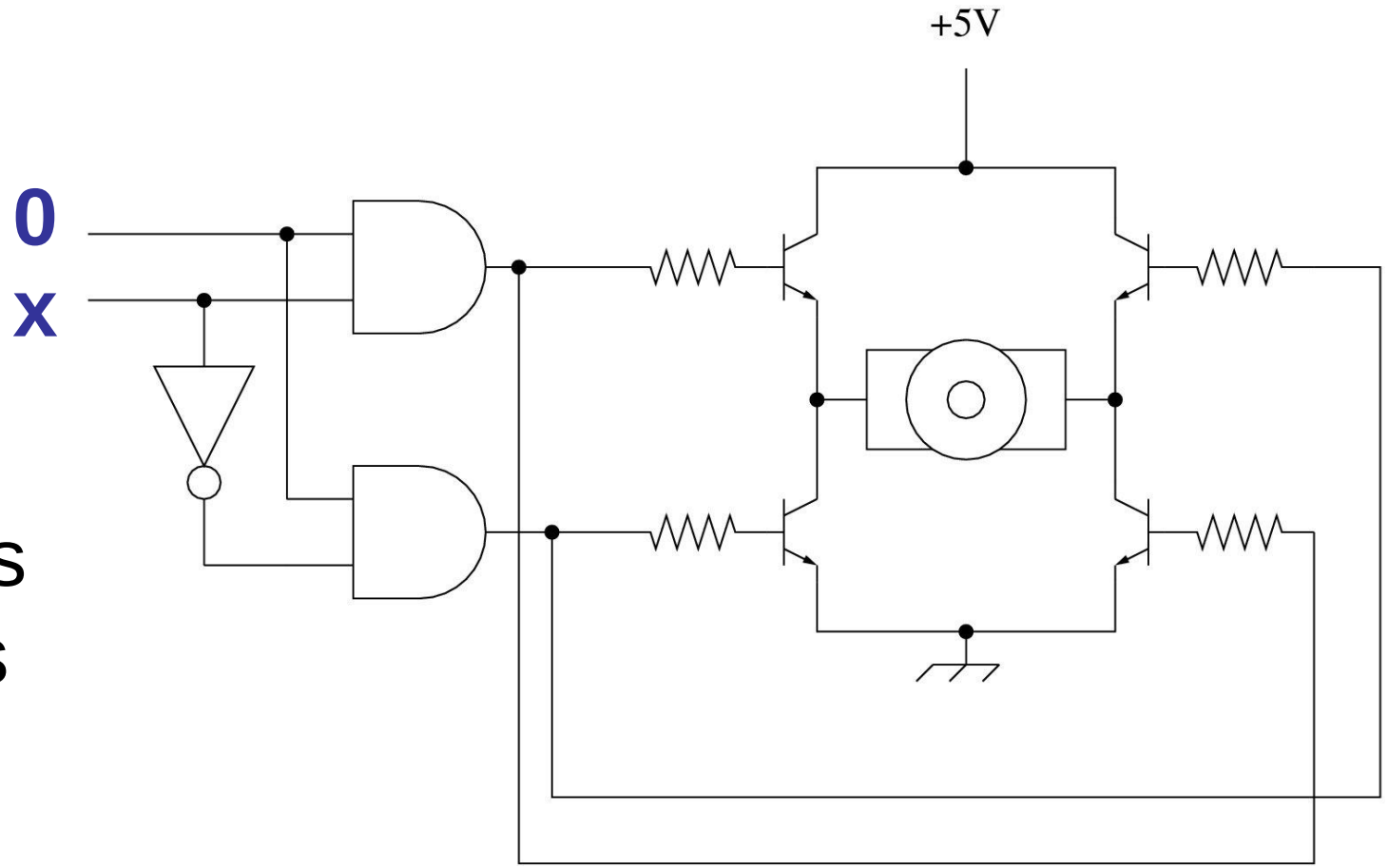
Goal: given on/off input, we want to specify the motor torque

- 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

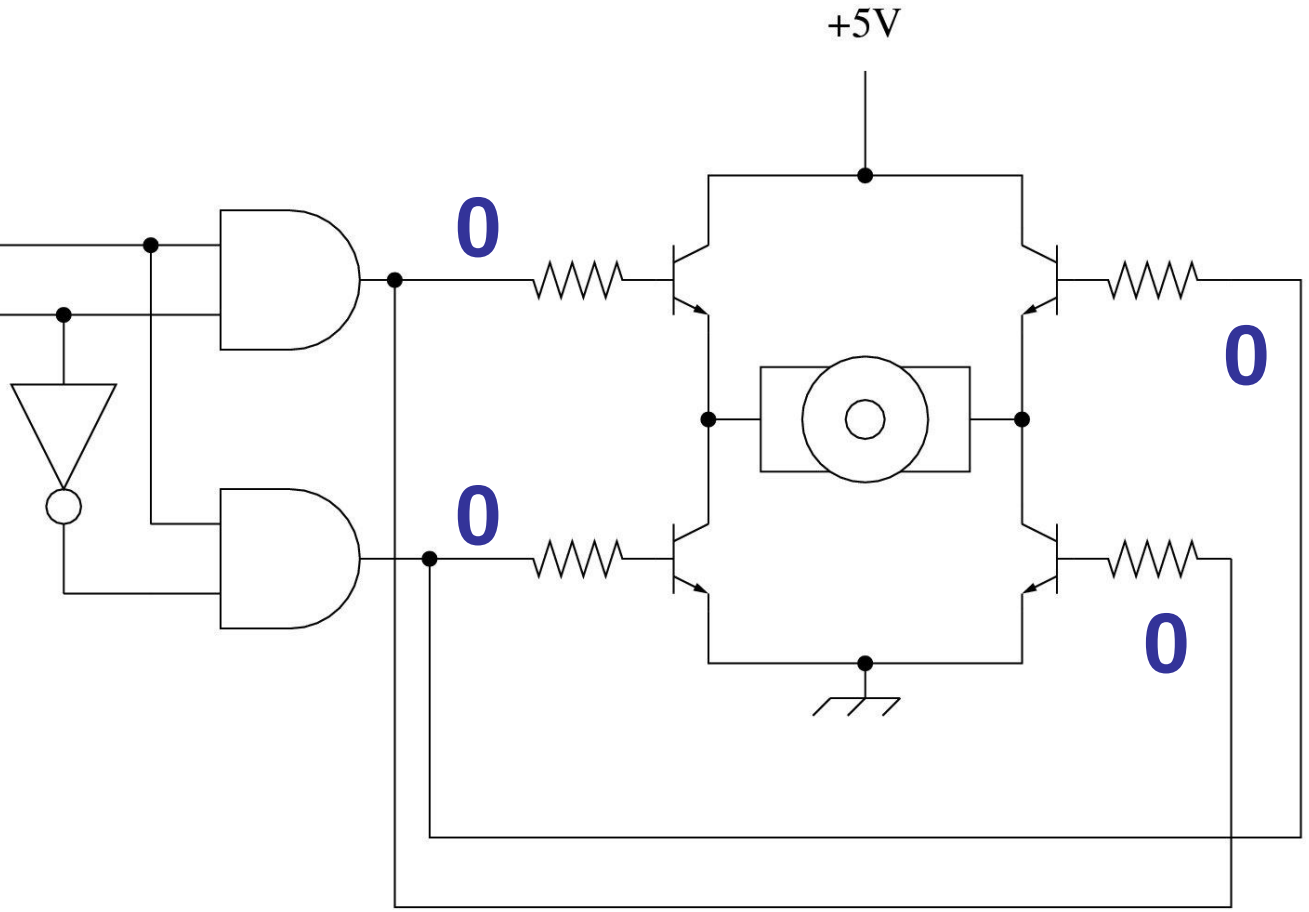


What happens with this input?

PWM and Direction Control

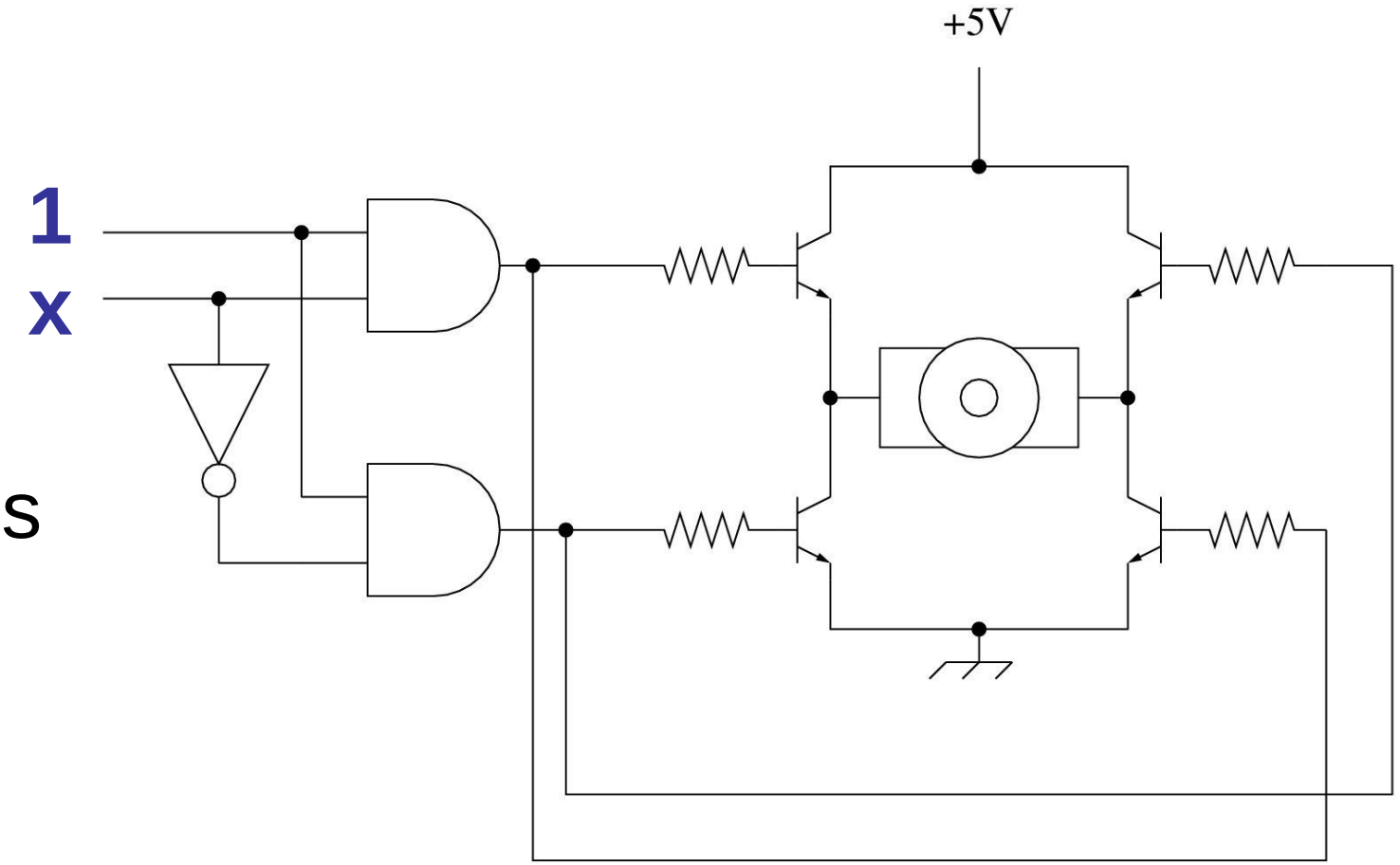
What happens?

- No current flow



PWM and Direction Control

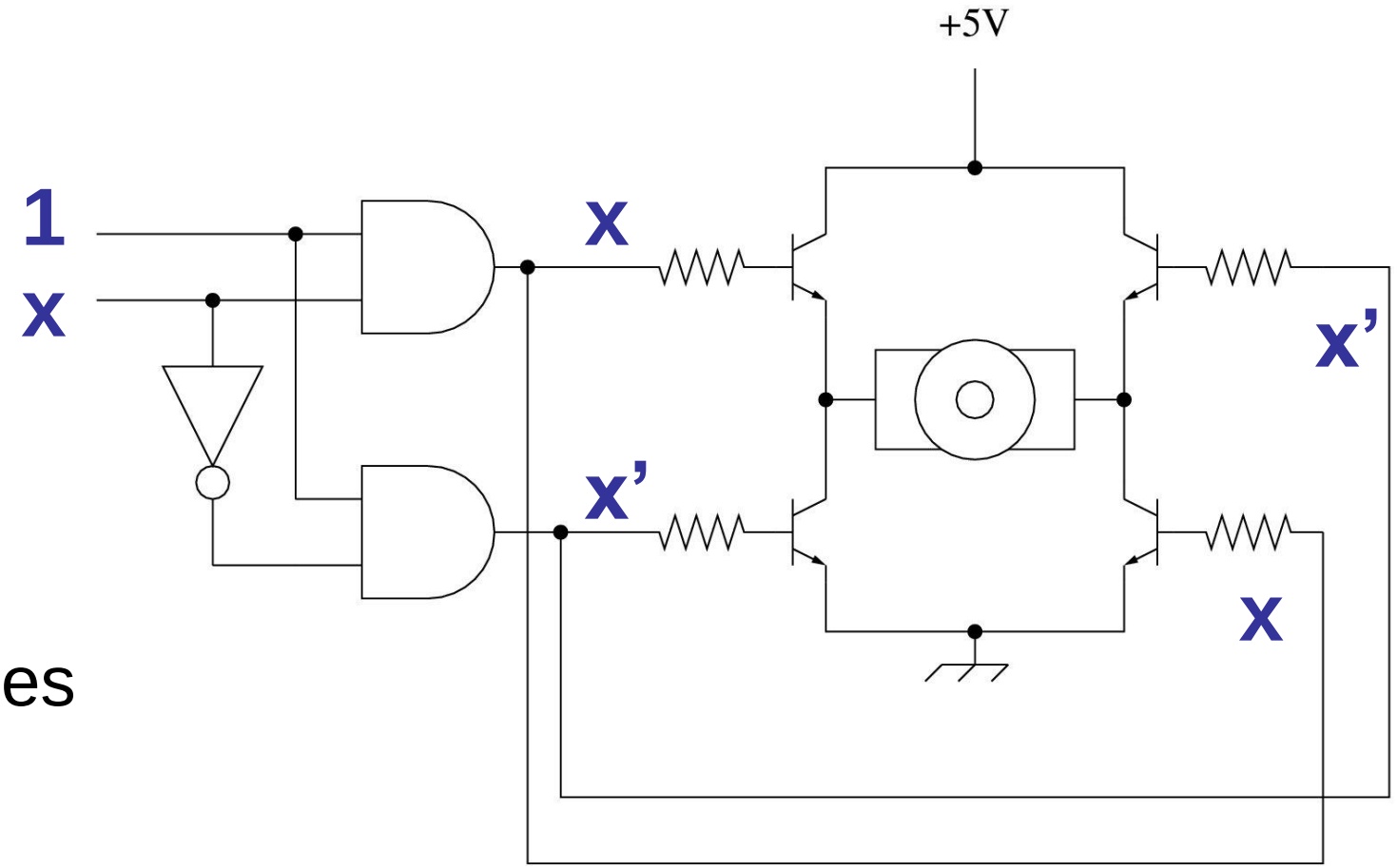
What happens now?



PWM and Direction Control

What happens now?

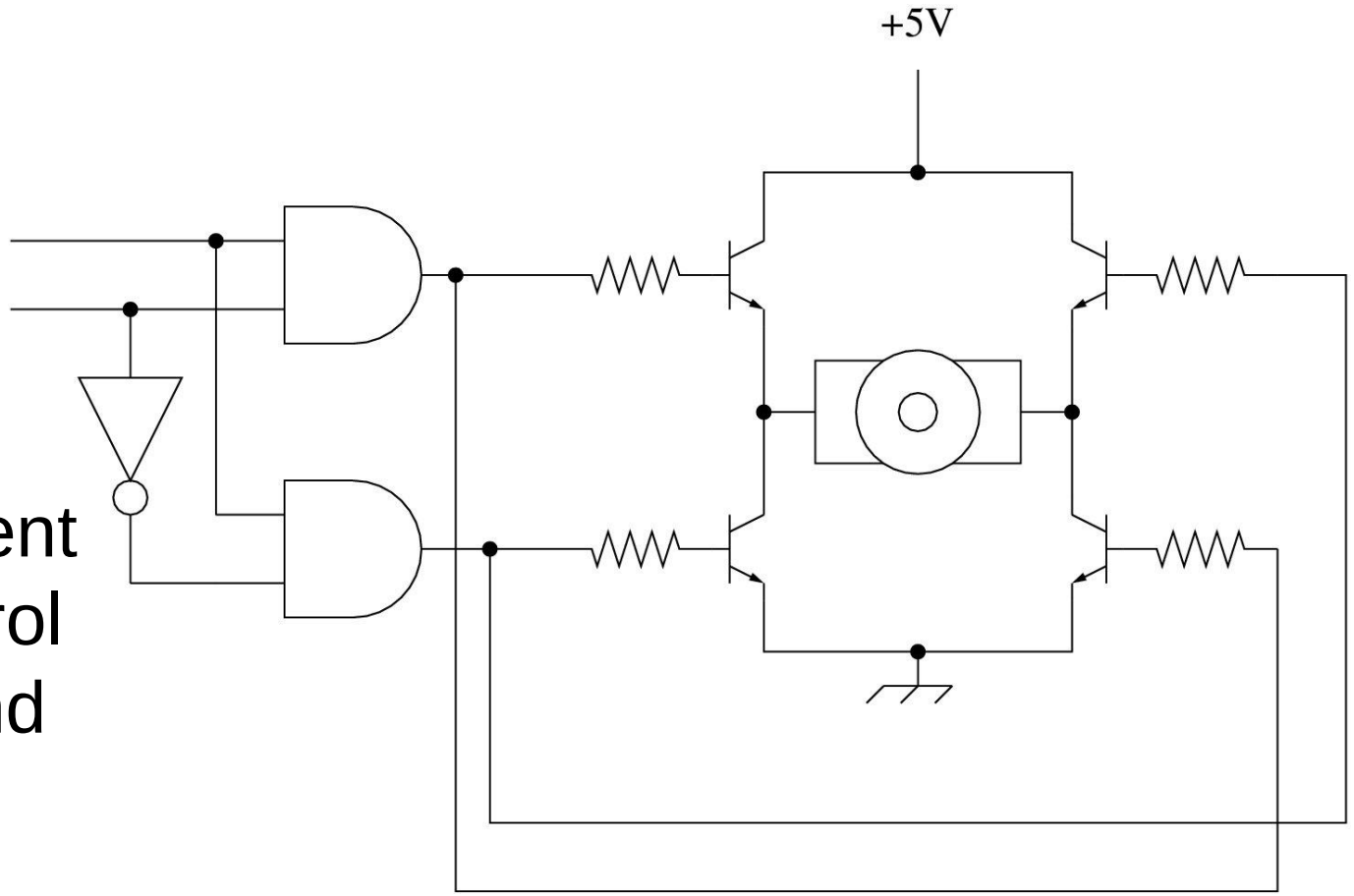
- ‘x’ determines motor direction



PWM and Direction Control

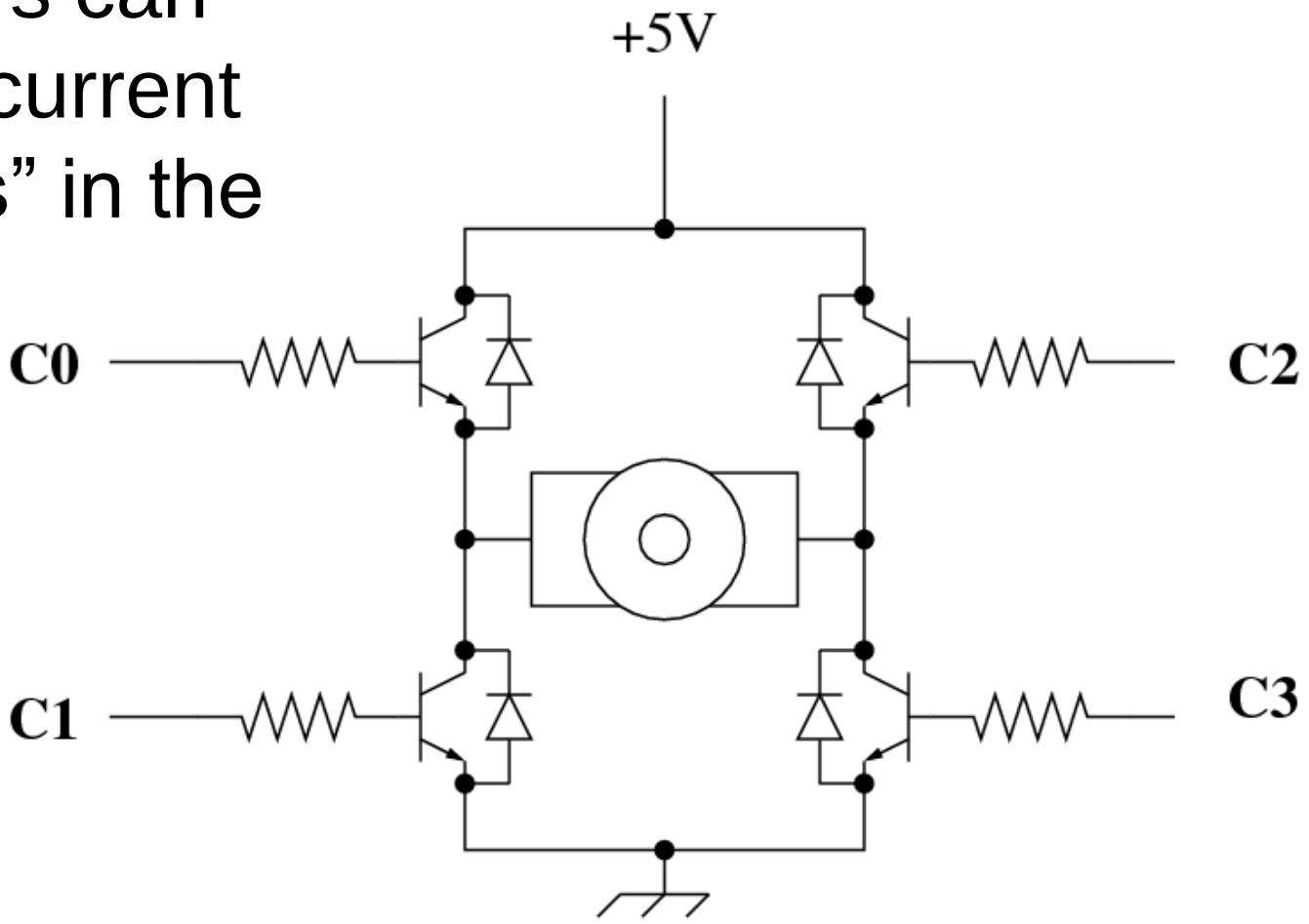
Direction

Two low-current inputs control direction and torque magnitude



H-Bridge: More Detail

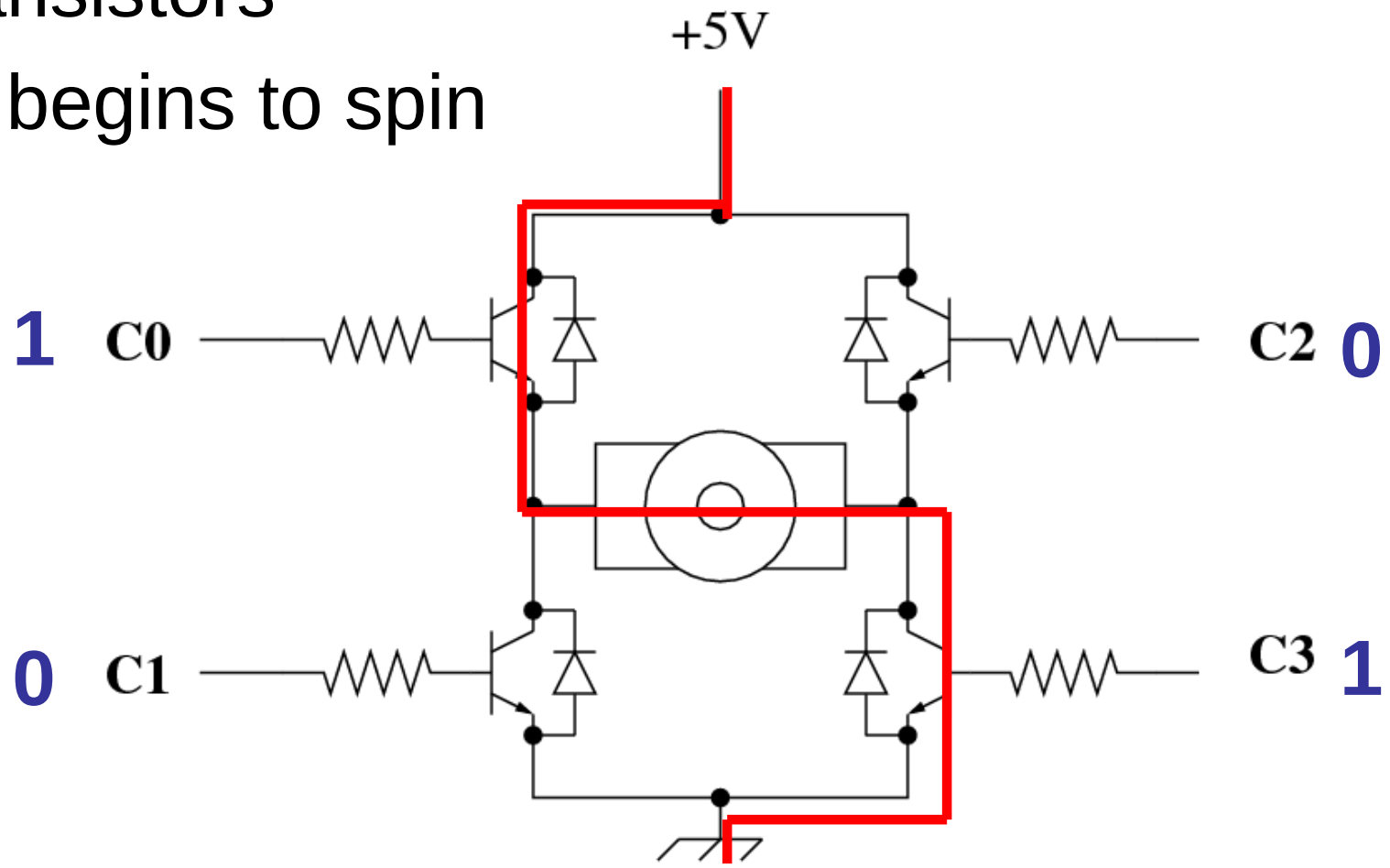
Diodes across the transistors can conduct current “upwards” in the circuit



H-Bridge: More Detail

Current flow through the transistors

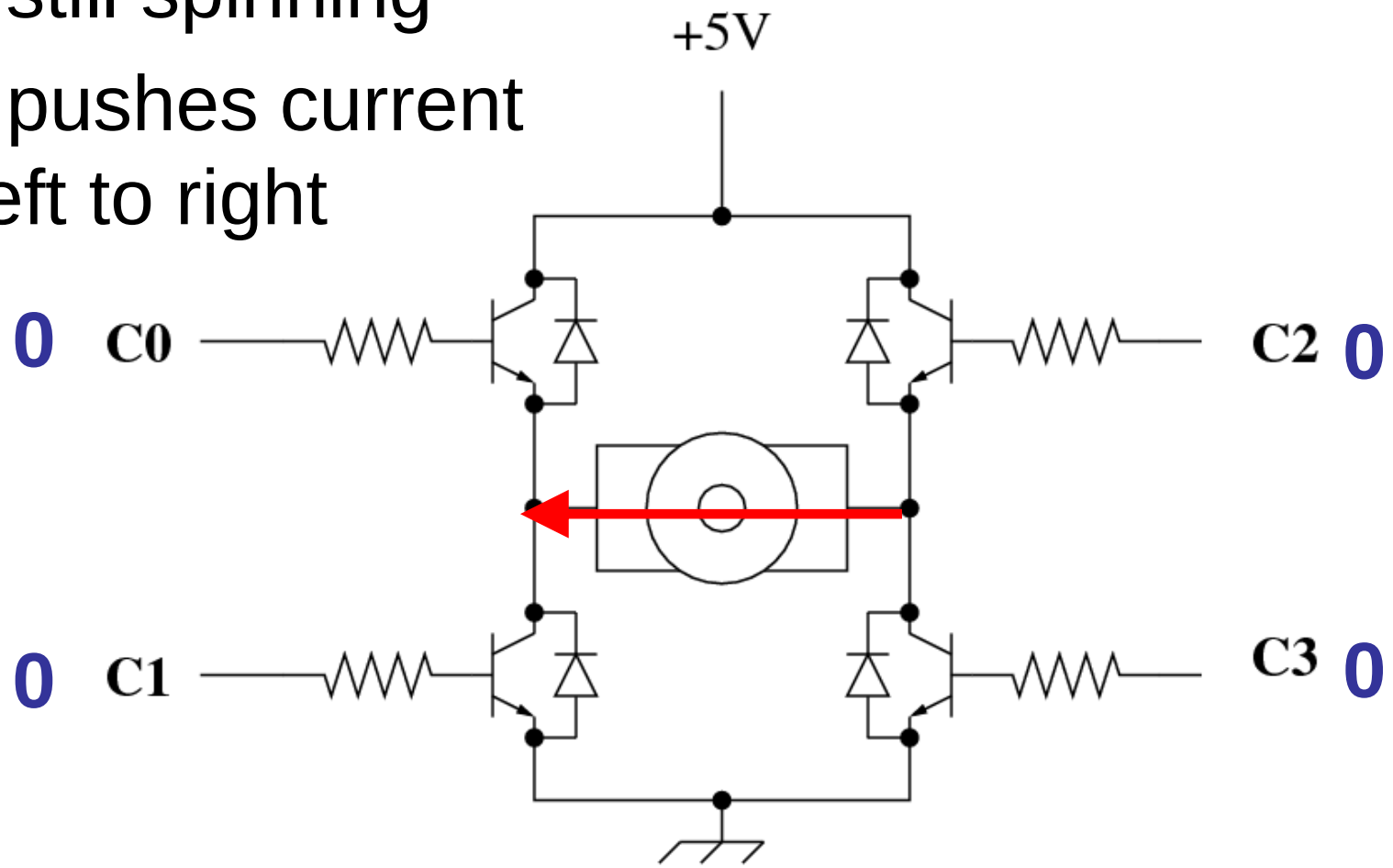
- Motor begins to spin



H-Bridge: More Detail

All transistors off, but:
motor still spinning

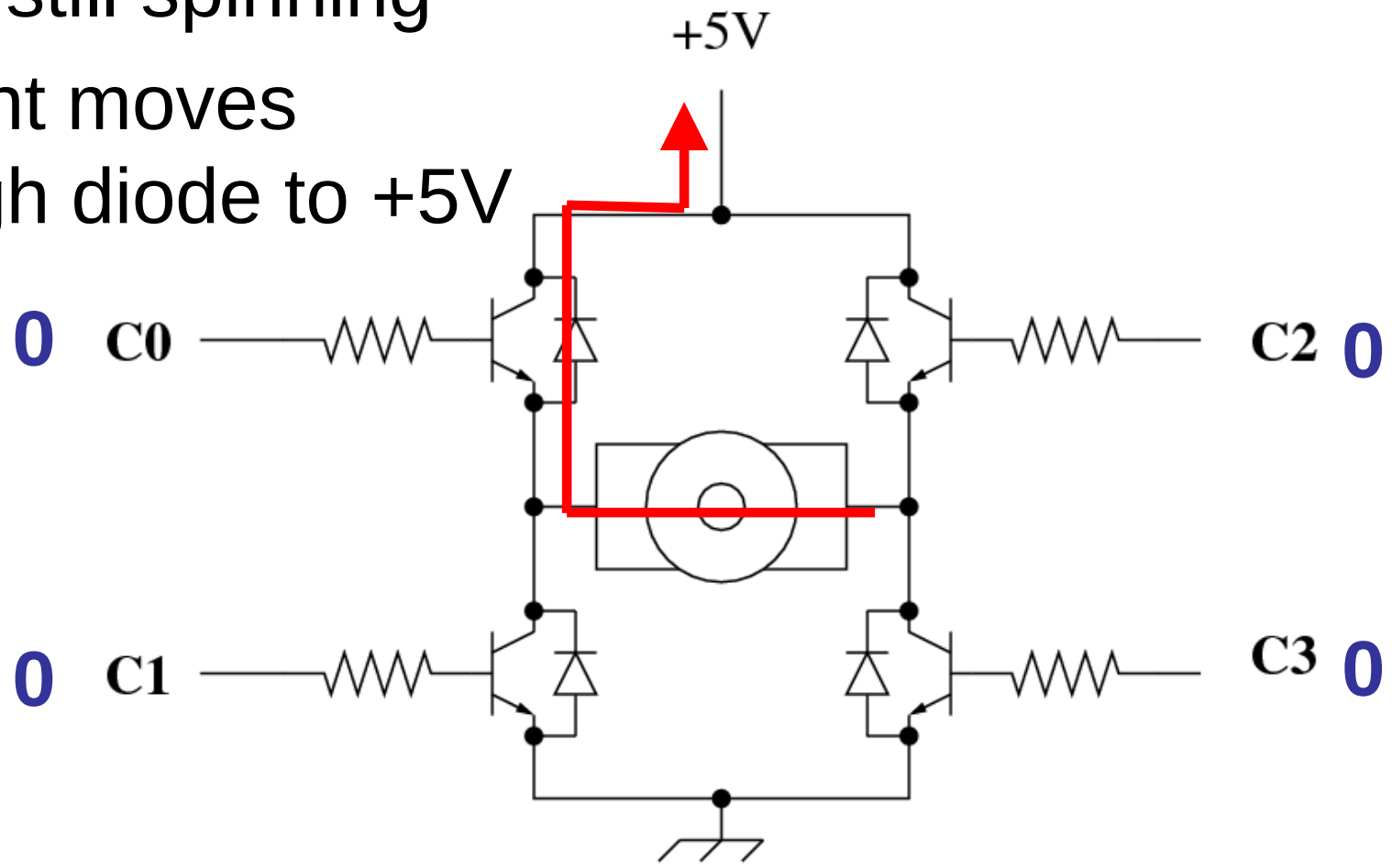
- Motor pushes current from left to right



H-Bridge: More Detail

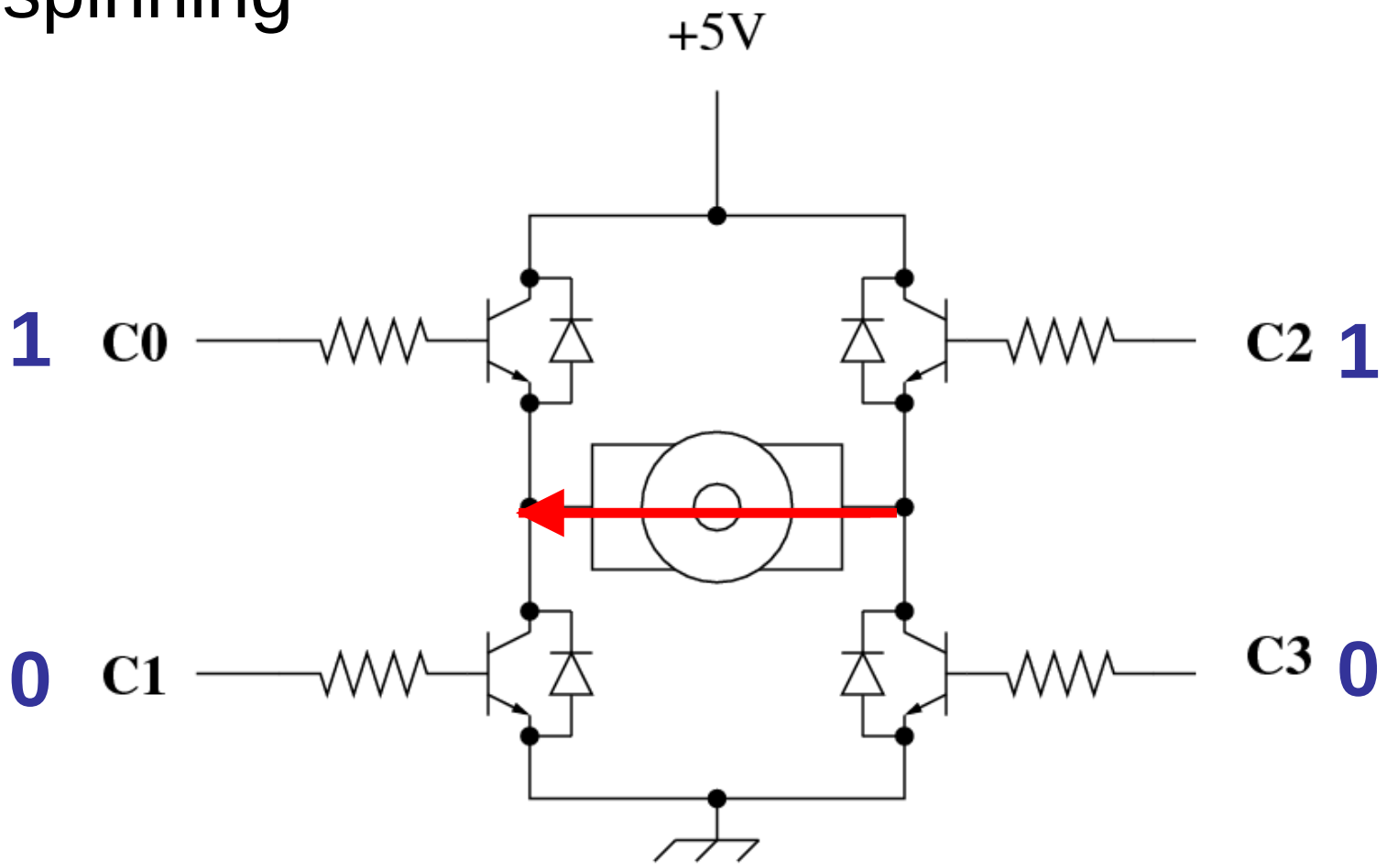
All transistors off, but:
motor still spinning

- Current moves through diode to +5V



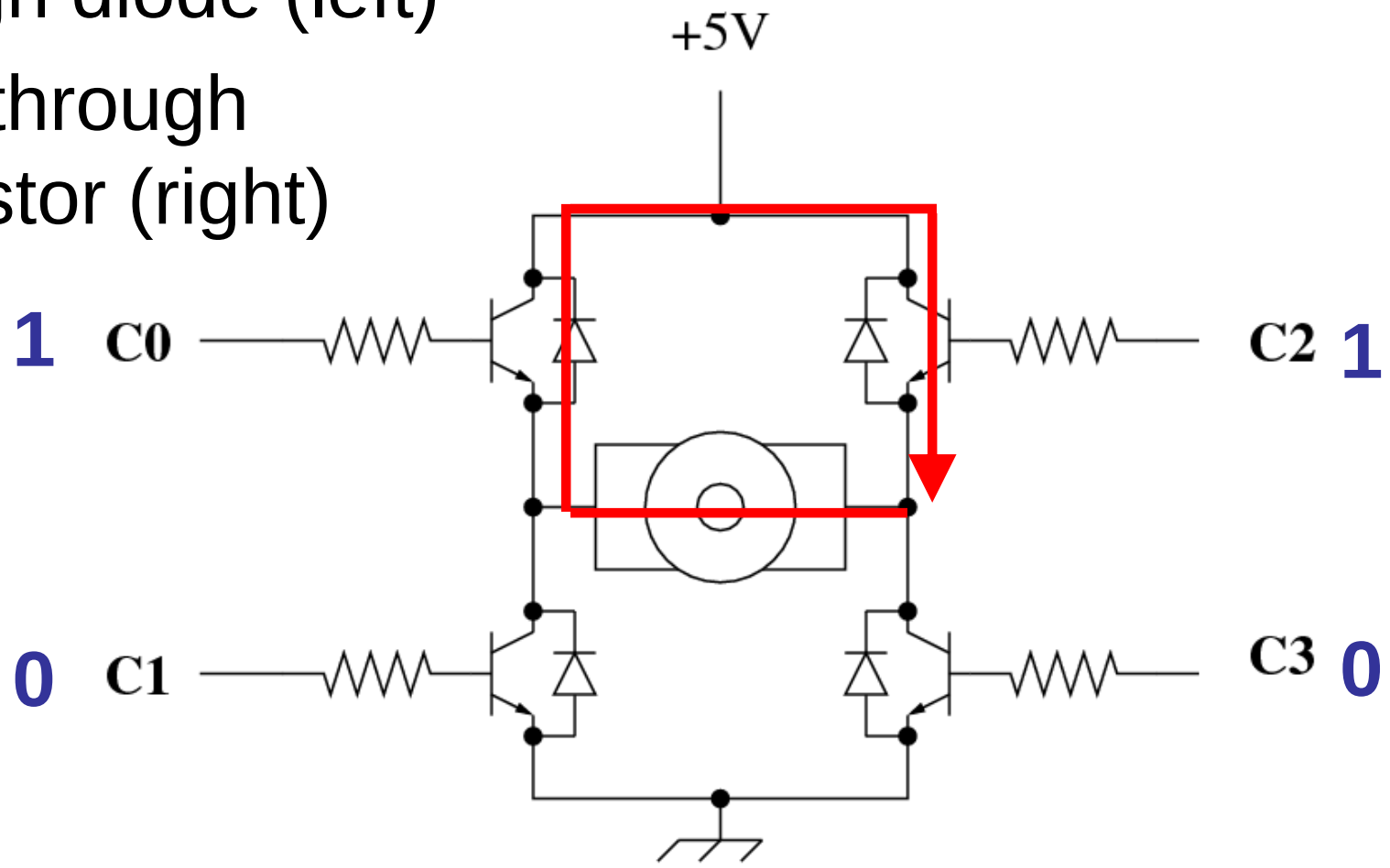
H-Bridge: Dynamic Braking

Top transistors on;
motor spinning



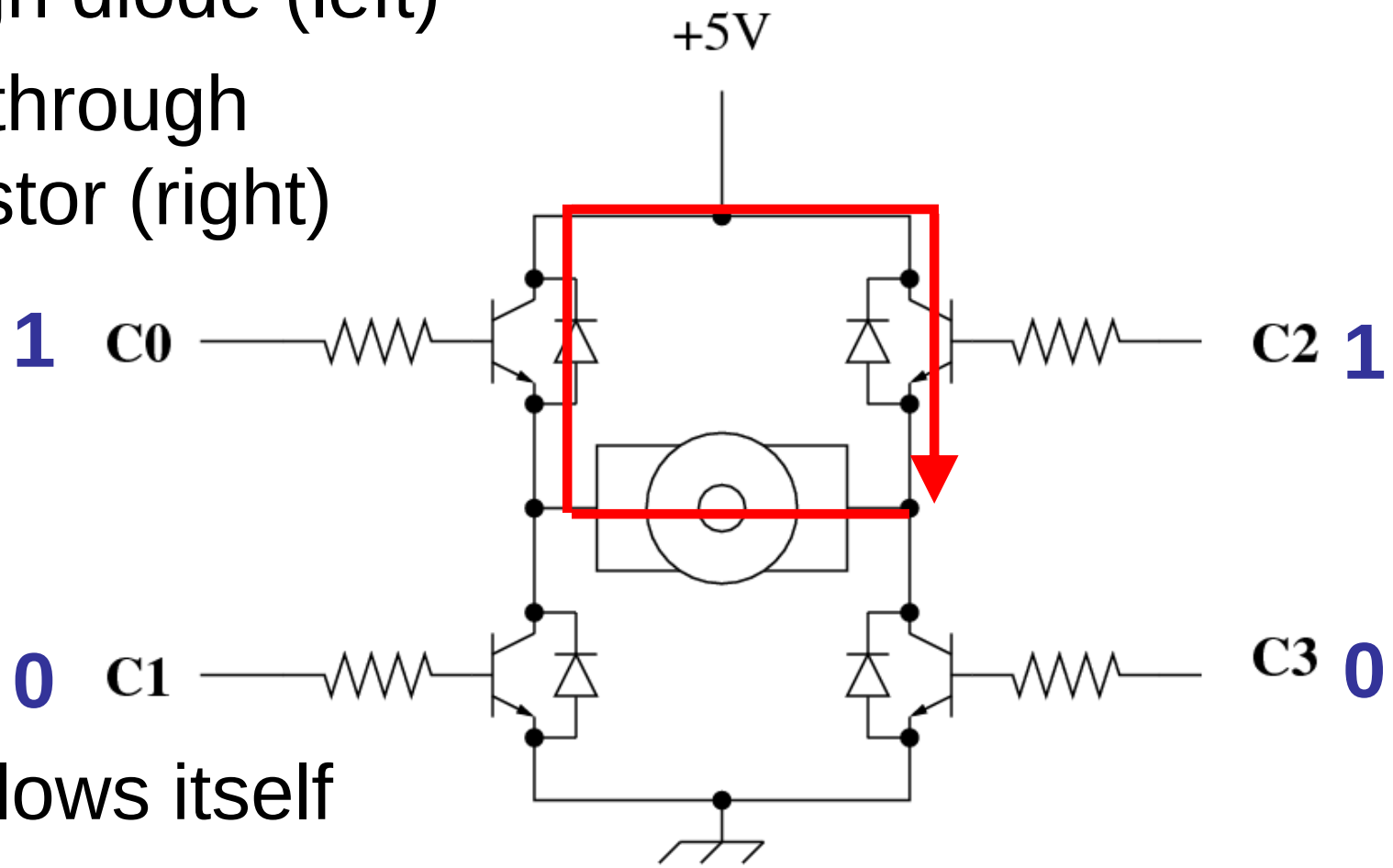
H-Bridge: Dynamic Braking

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



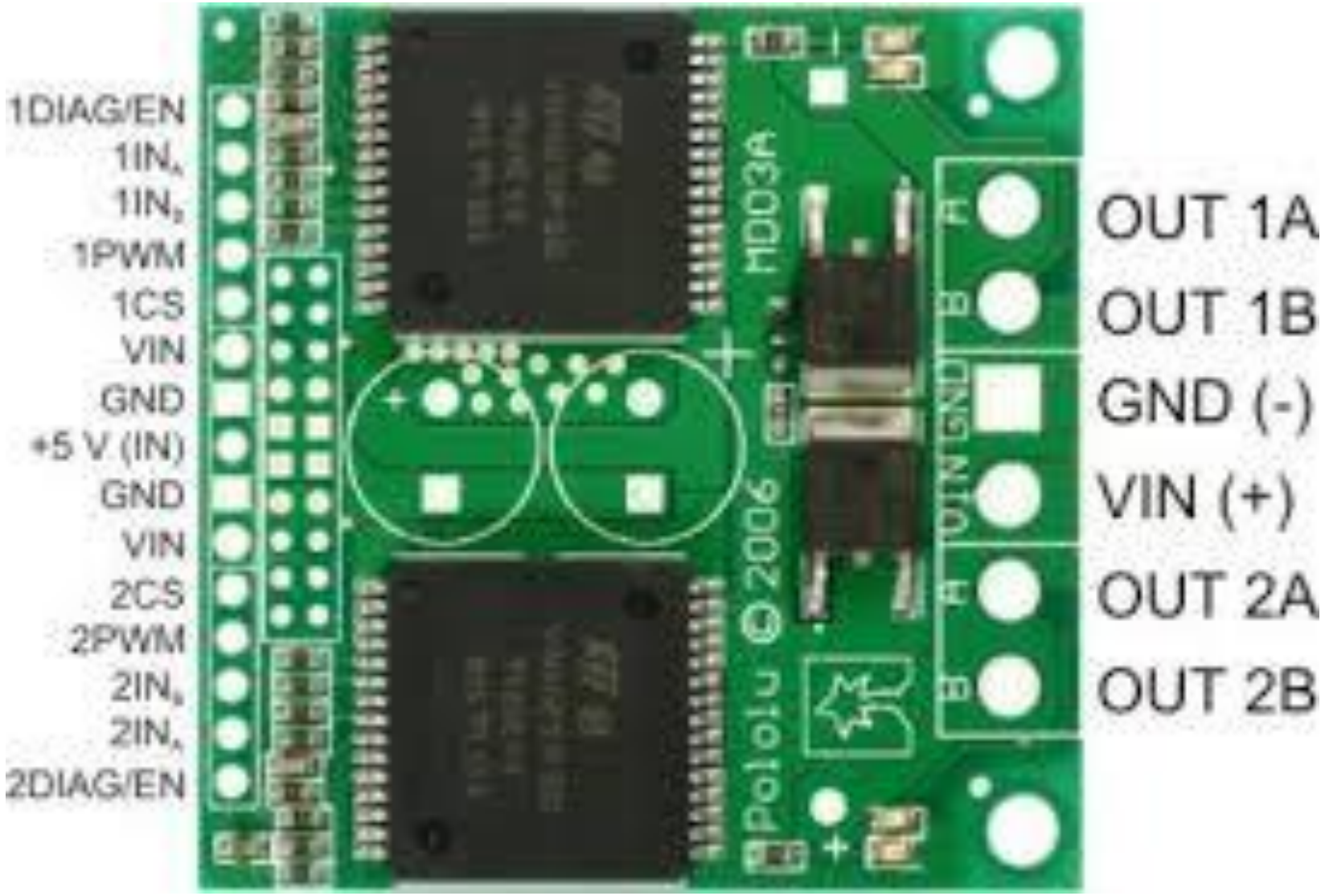
H-Bridge: Dynamic Braking

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



Motor slows itself down!

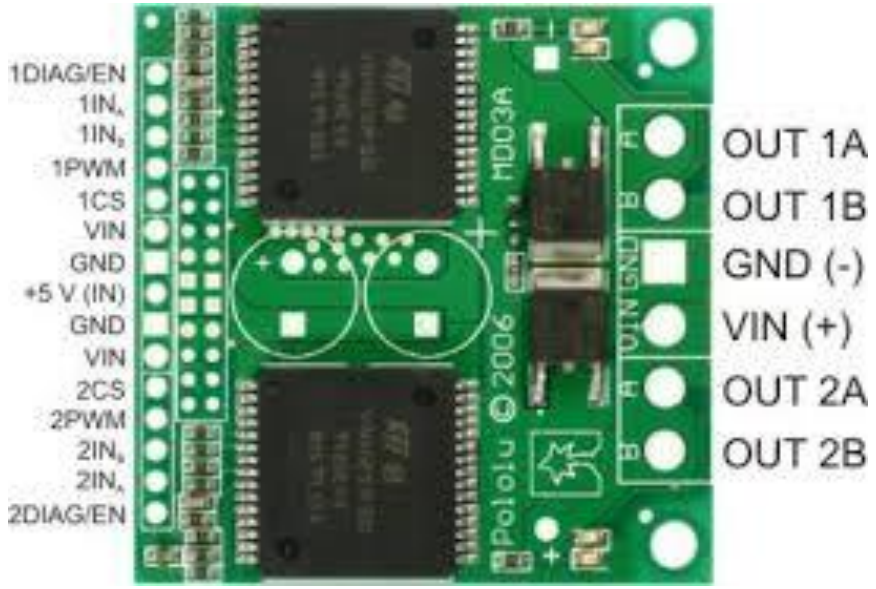
Dual H-Bridge for Project 4



Dual H-Bridge

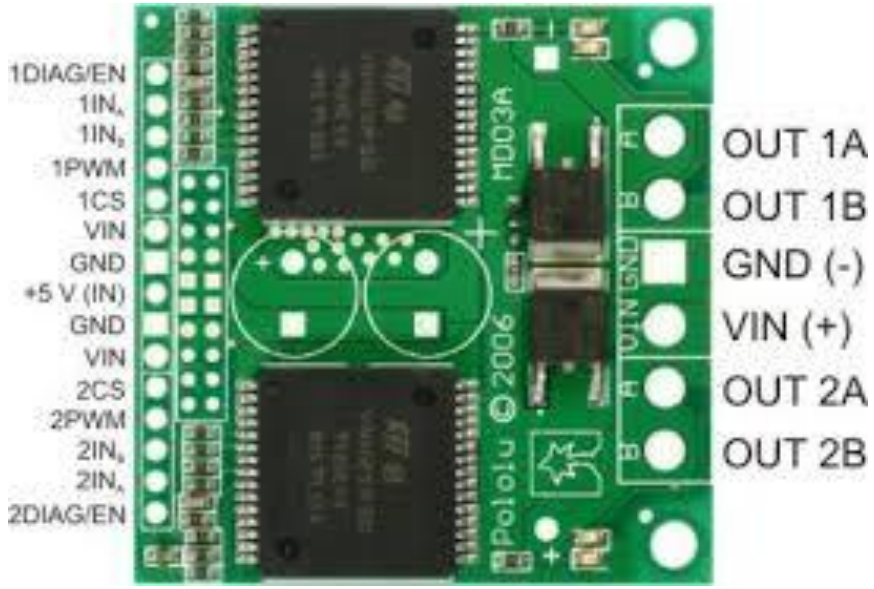
- Left side: Teensy interface
- Right side: Motor interface

Do not mix these two!



Dual H-Bridge: Motor Side

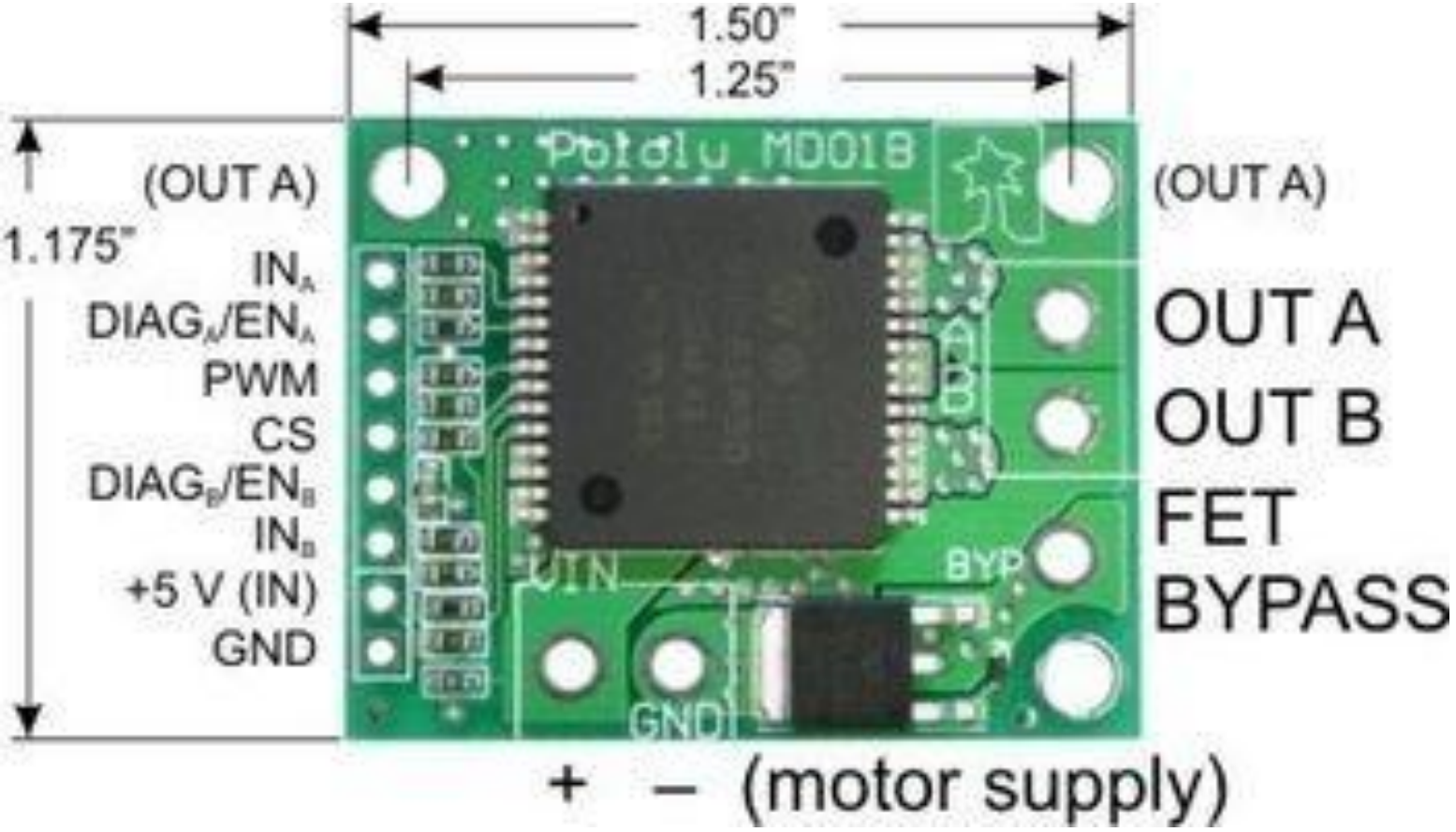
- GND: battery negative
- VIN: battery positive
  - These are the thick power cables coming up to the circuit deck
- OUT-A / OUT-B
  - Connections to motor



Dual H-Bridge: Teensy Side

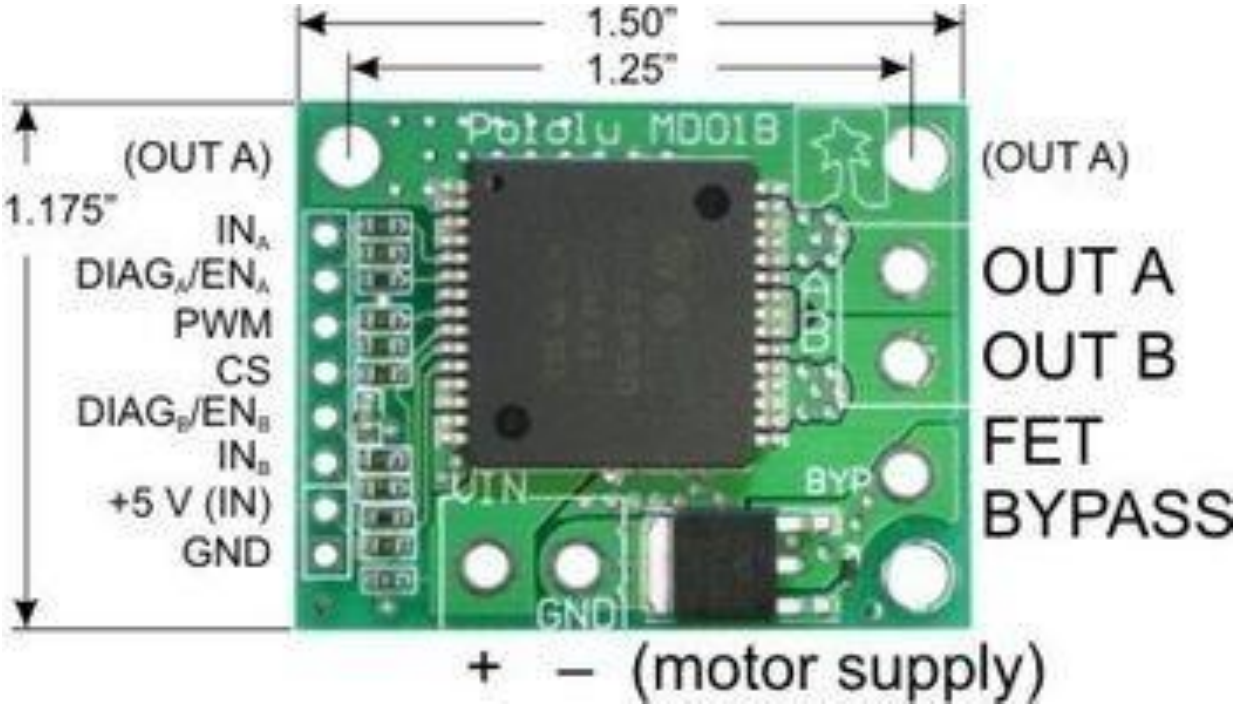
- GND: Teensy ground
- +5V: from supply (same as for cameras)
- PWM: current magnitude
- IN-A / IN-B:
  - 0/0: dynamic braking
  - 1/0: current flows in one direction
  - 0/1: current flows in other
  - 1/1: dynamic braking

Single H-Bridge

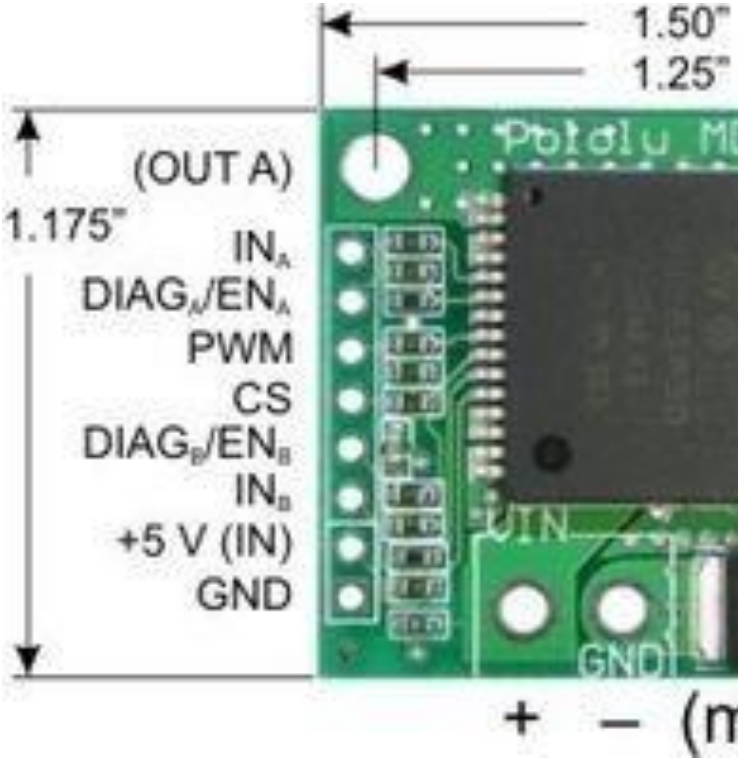


Single H-Bridge

- Left side: Teensy Interface
- Bottom side: Battery connection
- Right side: motor connection



Single H-Bridge

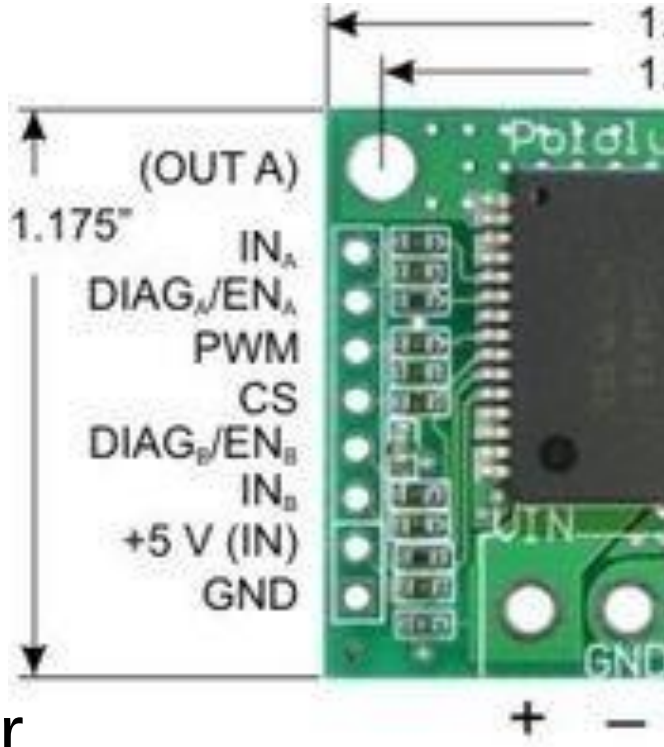


- GND: Teensy ground
- +5V: from supply
- PWM: current magnitude
- IN-A / IN-B:
  - 0/0: dynamic braking
  - 1/0: current flows in one direction
  - 0/1: current flows in other
  - 1/1: dynamic braking

Single H-Bridge

Motor supply

- Do not mix up the connections!
  - Red: +, Black: -
- Never short out red and black wires on the battery
  - Connect battery connect to motor supply before connecting battery
- Smoking battery:
  - Gets hot on its own
  - Smoke is toxic
  - Move outside and dunk in water



Single H-Bridge

- OUT A/B: connection to motor
- Attach motor cable first, then connect motor