Basic DC Motor Circuits

Living with the Lab
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DC Motor Learning Objectives

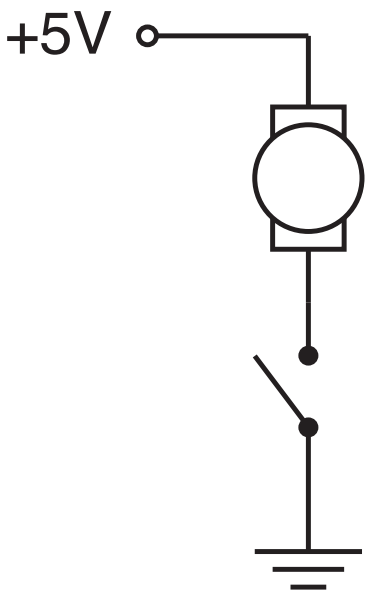
- Explain the role of a snubber diode
- Describe how PWM controls DC motor speed
- Implement a transistor circuit and Arduino program for PWM control of the DC motor
- Use a potentiometer as input to a program that controls fan speed

What is a snubber diode and why should I care?

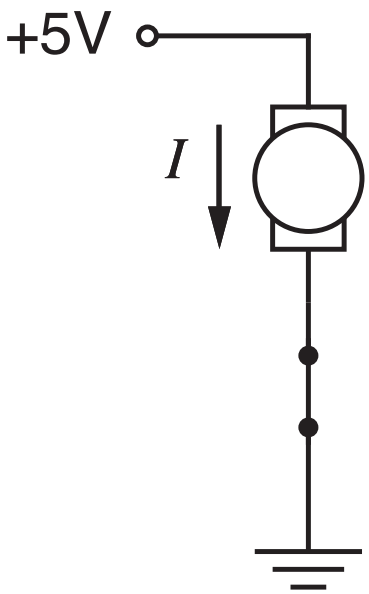
Simplest DC Motor Circuit

Connect the motor to a DC power supply

Switch open

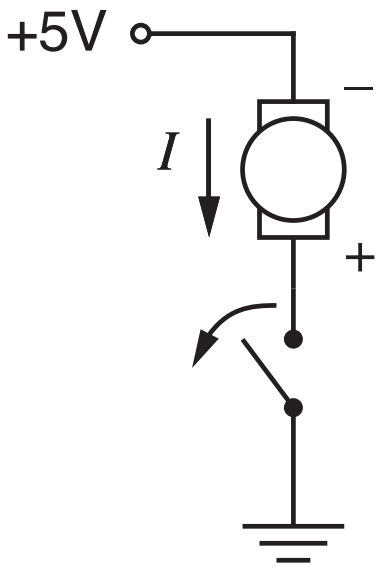


Switch closed



Current continues after switch is opened

Opening the switch does not immediately stop current in the motor windings.

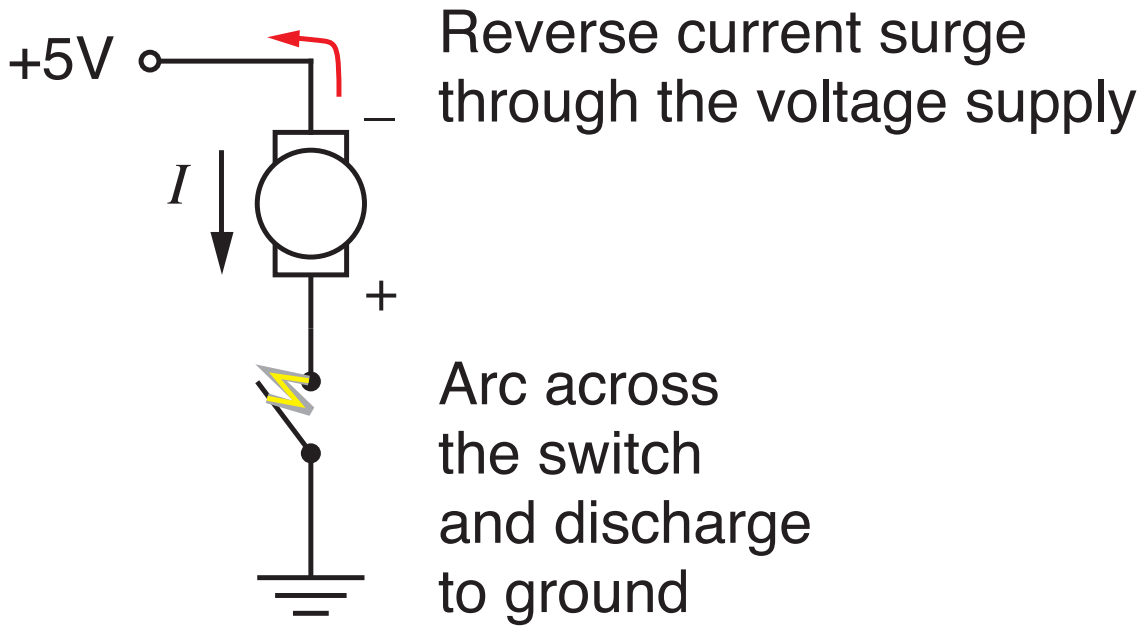


Inductive behavior of the motor causes current to continue to flow when the switch is opened suddenly.

Charge builds up on what was the negative terminal of the motor.

Reverse current

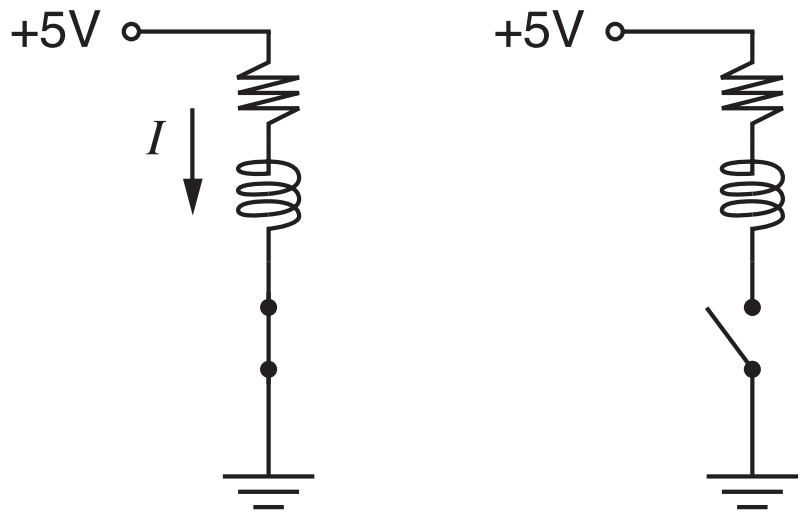
Charge build-up can cause damage



Motor Model

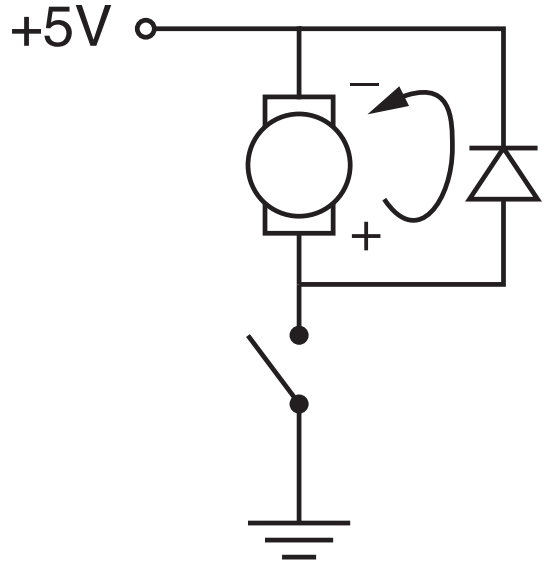
Simple model of a DC motor:

- Windings have inductance and resistance
- Inductor stores electrical energy in the windings
- We need to provide a way to safely dissipate electrical energy when the switch is opened



Flyback diode or snubber diode

Adding a diode in parallel with the motor provides a path for dissipation of stored energy when the switch is opened



The flyback diode allows charge to dissipate without arcing across the switch, or without flowing back to ground through the +5V voltage supply.

Pulse-width modulation (PWM) for DC motor speed control

Controlling DC Motor Speed

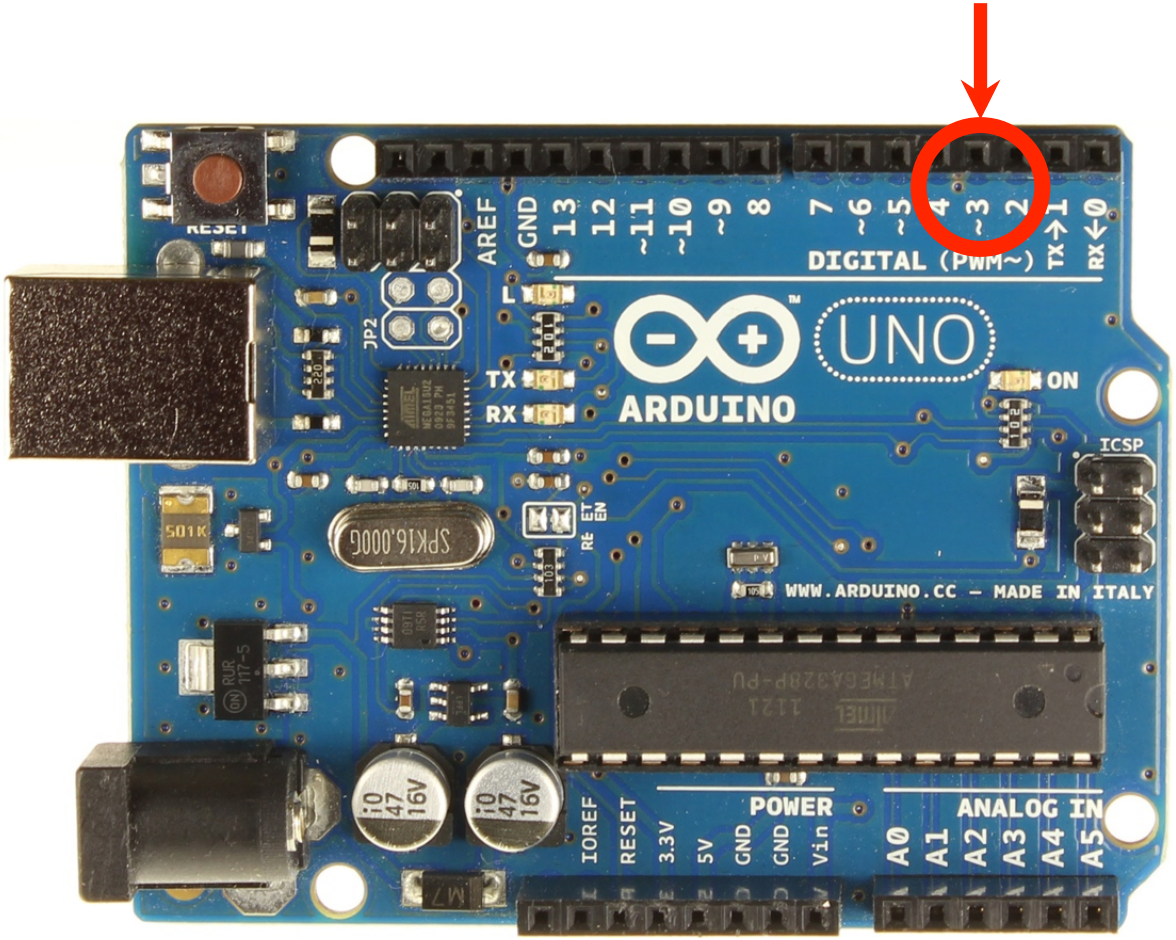
The voltage supplied to a DC motor controls its speed

Arduino cannot supply variable DC output

- Arduino lacks a true analog output
- Use Pulse-width modulation (PWM) to simulate a variable DC supply voltage
- PWM is a common technique for supplying variable power levels to "slow" electrical devices such as resistive loads, LEDs, and DC motors
- Arduino Uno has 6 PWM pins: Digital I/O pins 3, 5, 6, 9,10, and 11

Arduno Uno has 6 PWM pins

Look for the ~ prefix on the digital pin label, e.g. ~3



PWM: Pulsed with modulation

PWM simulates DC voltage control for *slow* loads

The effective voltage is $V_{\text{eff}} = V_s \frac{\tau_o}{\tau_c}$

$\frac{\tau_o}{\tau_c}$ is called the duty cycle

Arduino PWM commands

Configure the output pin:

```
PWM_pin = ... ;         //  one of 3, 5, 6, 9, 10, 11

void setup() {
  pinMode( PWM_pin, OUTPUT);
}
```

Set the duty cycle

```
void loop() {
  int duty_cycle = 150;     //  between 0 and 255

  analogWrite( PWM_pin, duty_cycle );
}
```

The duty cycle is an 8 bit value:

$0 \leq$ `duty_cycle` ≤ 255

Using a transistor to switch the load

Transistor as the switching device

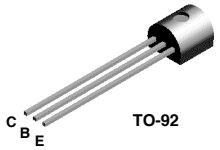
- Each Arduino output channels has a 40 mA limit
- The maximum current draw for an Arduino is 200 mA
- Use Arduino as the brain
- Let another switching element be the brawn

Use an NPN Transistor as a switch

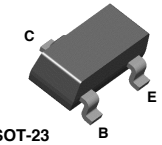
This device is designed for use as a medium power amplifier and switch requiring collector currents up to 500 mA

FAIRCHILD SEMICONDUCTOR™

2N4401 **MMBT4401**



TO-92



SOT-23
Mark: 2X

NPN General Pupose Amplifier

This device is designed for use as a medium power amplifier and switch requiring collector currents up to 500 mA.

Absolute Maximum Ratings*

TA = 25°C unless otherwise noted

Symbol	Parameter	Value	Units
V_{CEO}	Collector-Emitter Voltage	40	V
V_{CBO}	Collector-Base Voltage	60	V
V_{EBO}	Emitter-Base Voltage	6.0	V
I_C	Collector Current - Continuous	600	mA
T_J, T_{stg}	Operating and Storage Junction Temperature Range	-55 to +150	°C

*These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

NOTES:
1) These ratings are based on a maximum junction temperature of 150 degrees C.
2) These are steady state limits. The factory should be consulted on applications involving pulsed or low duty cycle operations.

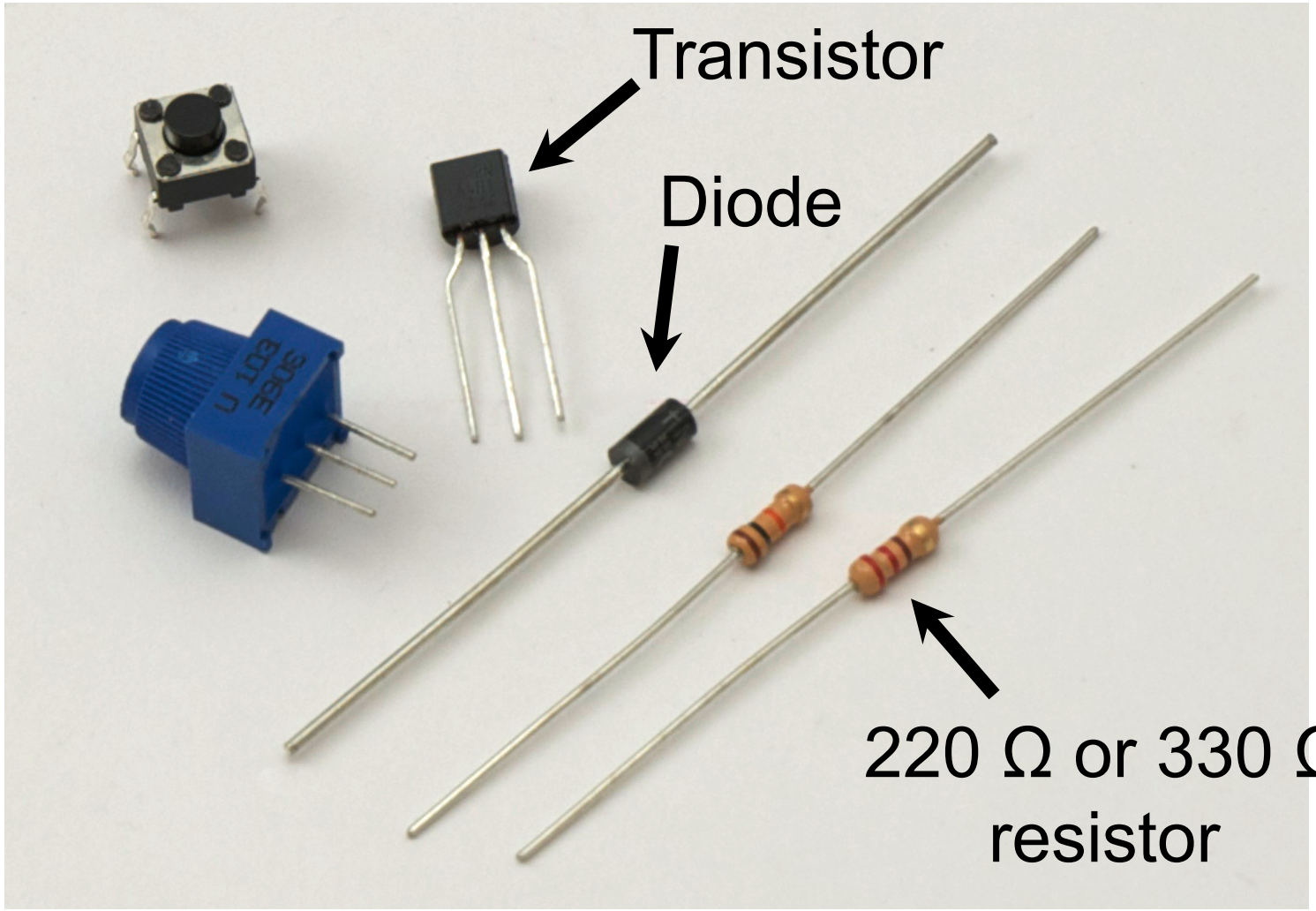
Thermal Characteristics

TA = 25°C unless otherwise noted

Symbol	Characteristic	Max		Units
		2N4401	*MMBT4401	
P_D	Total Device Dissipation Derate above 25°C	625 5.0	350 2.8	mW mW/°C
$R_{\theta JC}$	Thermal Resistance, Junction to Case	83.3		°C/W
$R_{\theta JA}$	Thermal Resistance, Junction to Ambient	200	357	°C/W

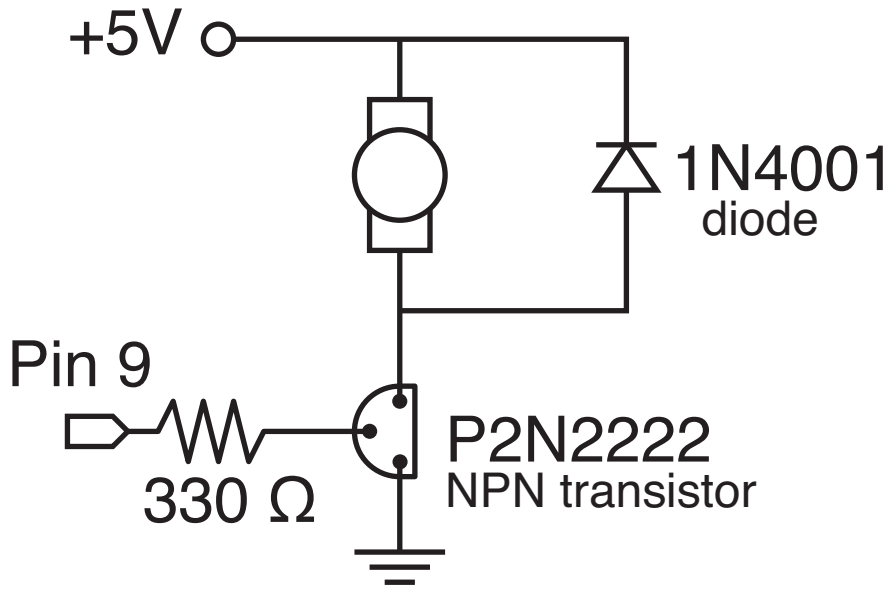
*Device mounted on FR-4 PCB 1.6" X 1.6" X 0.06."

Electronic components in the fan kit



Replace the Switch with a Transistor

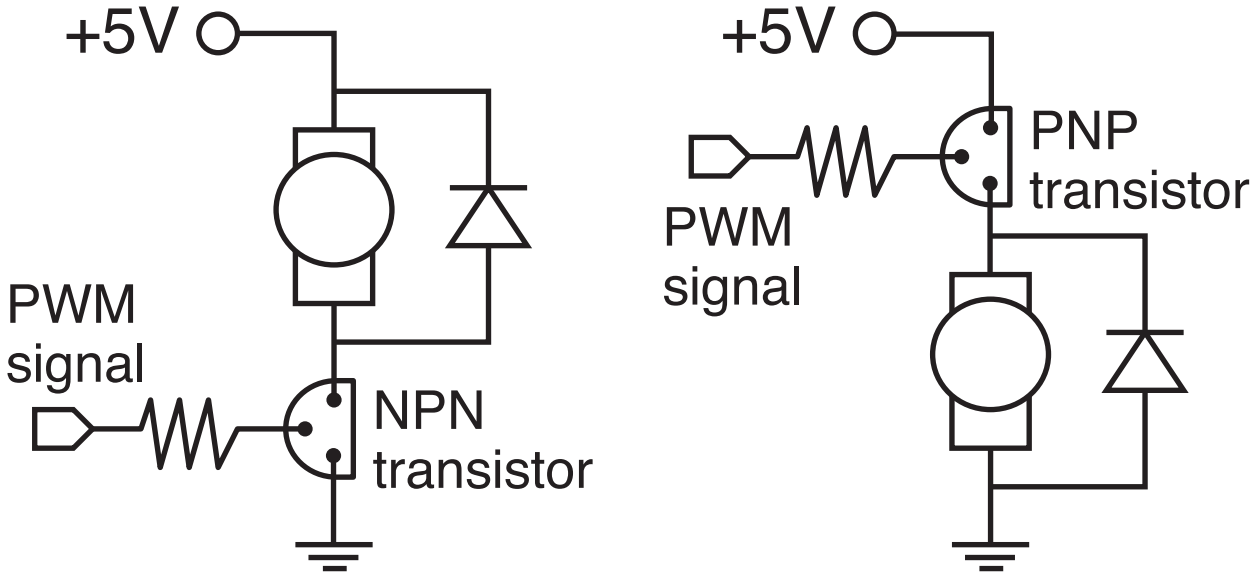
A transistor allows on/off control to be automated and it allows switching of more current than an Arduino digital pin can supply.



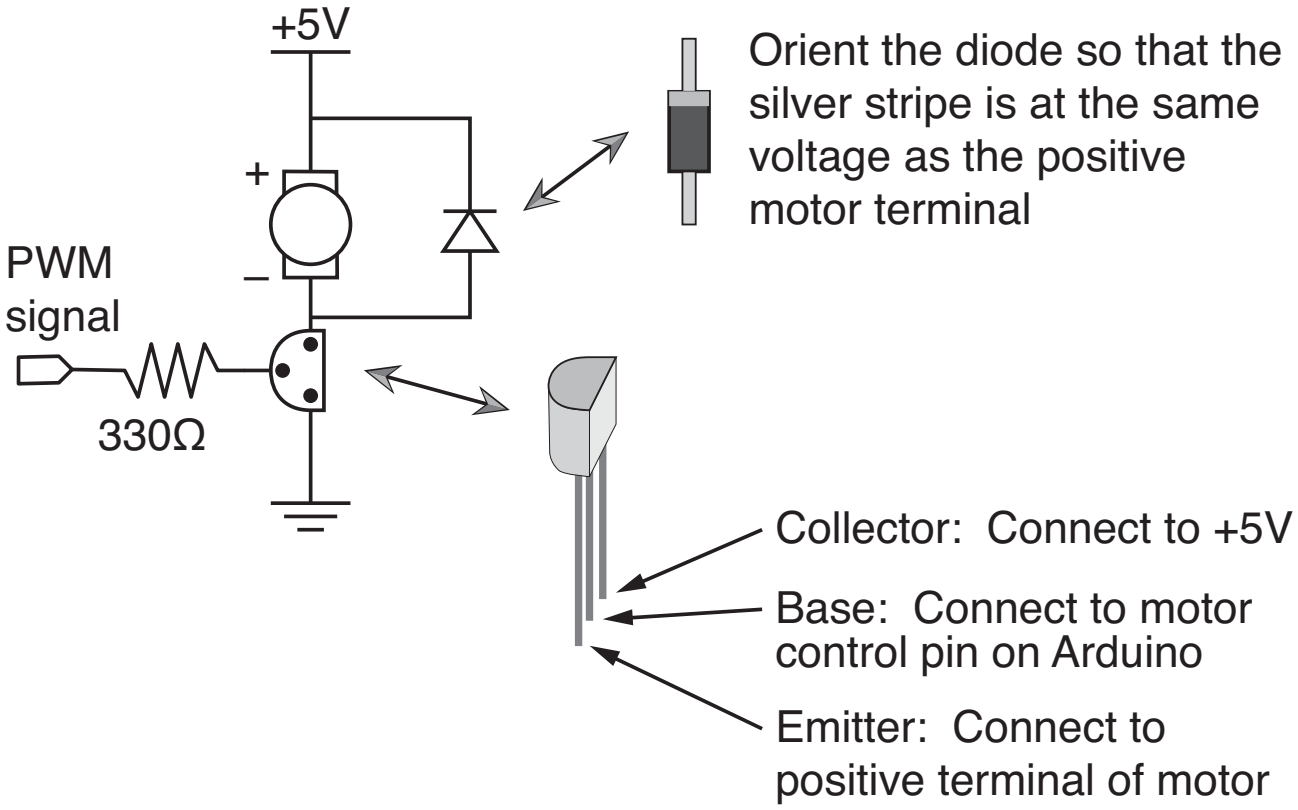
Pin 9 or another PWM pin drives the transistor base

Alternative locations for the transistor

Moving the transistor (and any switch) between the power supply and the motor adds a bit of safety by tying the motor to ground when the system is idle

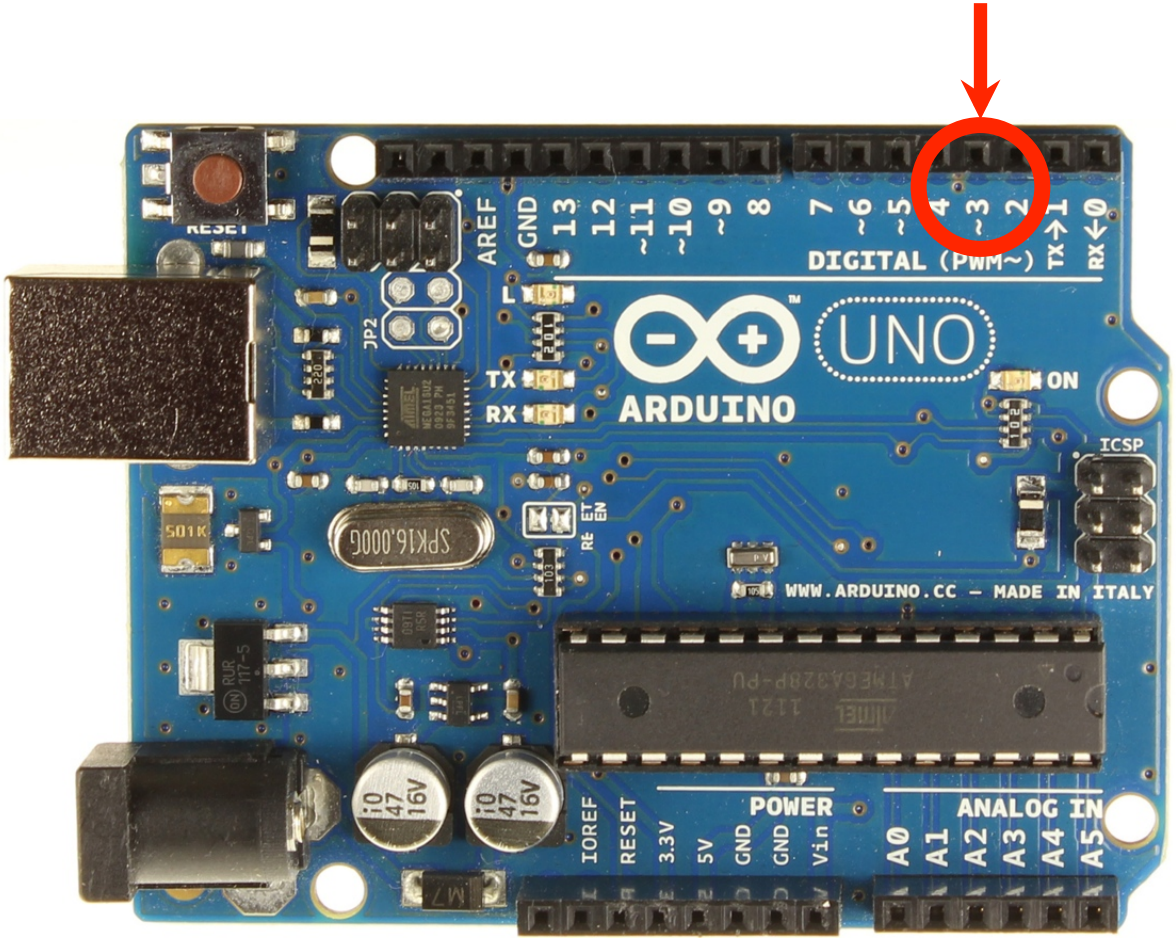


Diode and transistor orientation

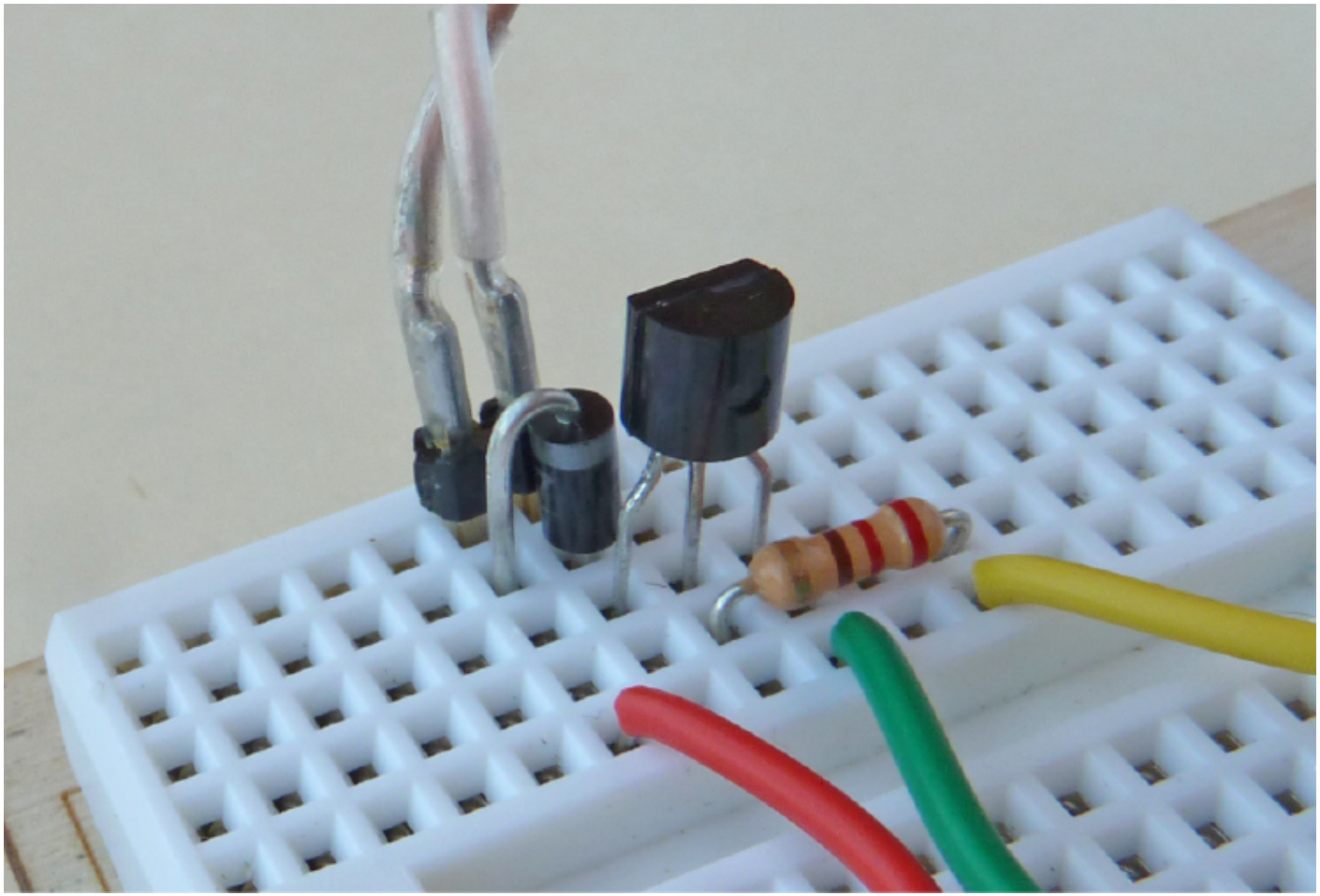


Arduno Uno has 5 PWM pins

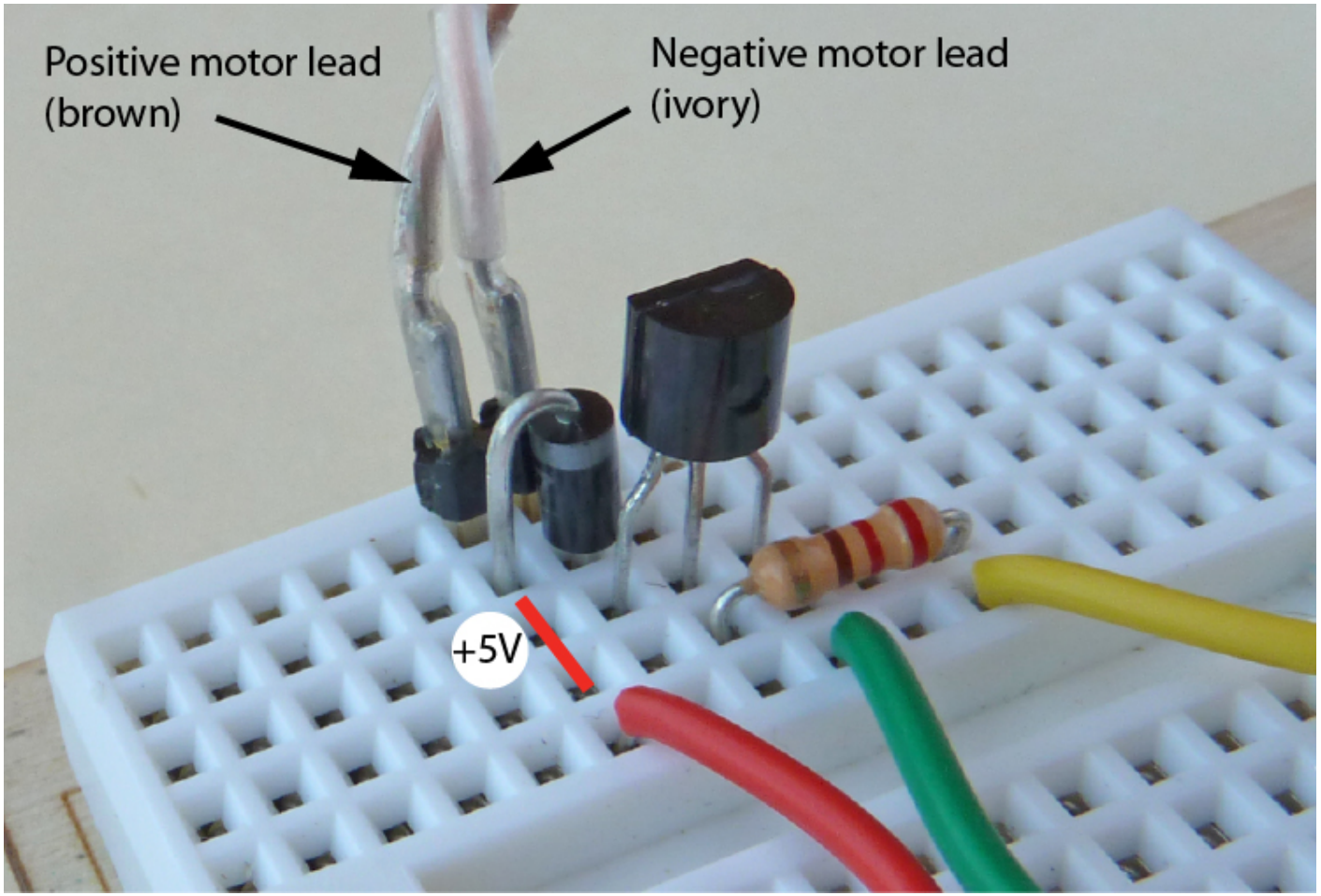
Look for the ~ prefix on the digital pin label, e.g. ~3



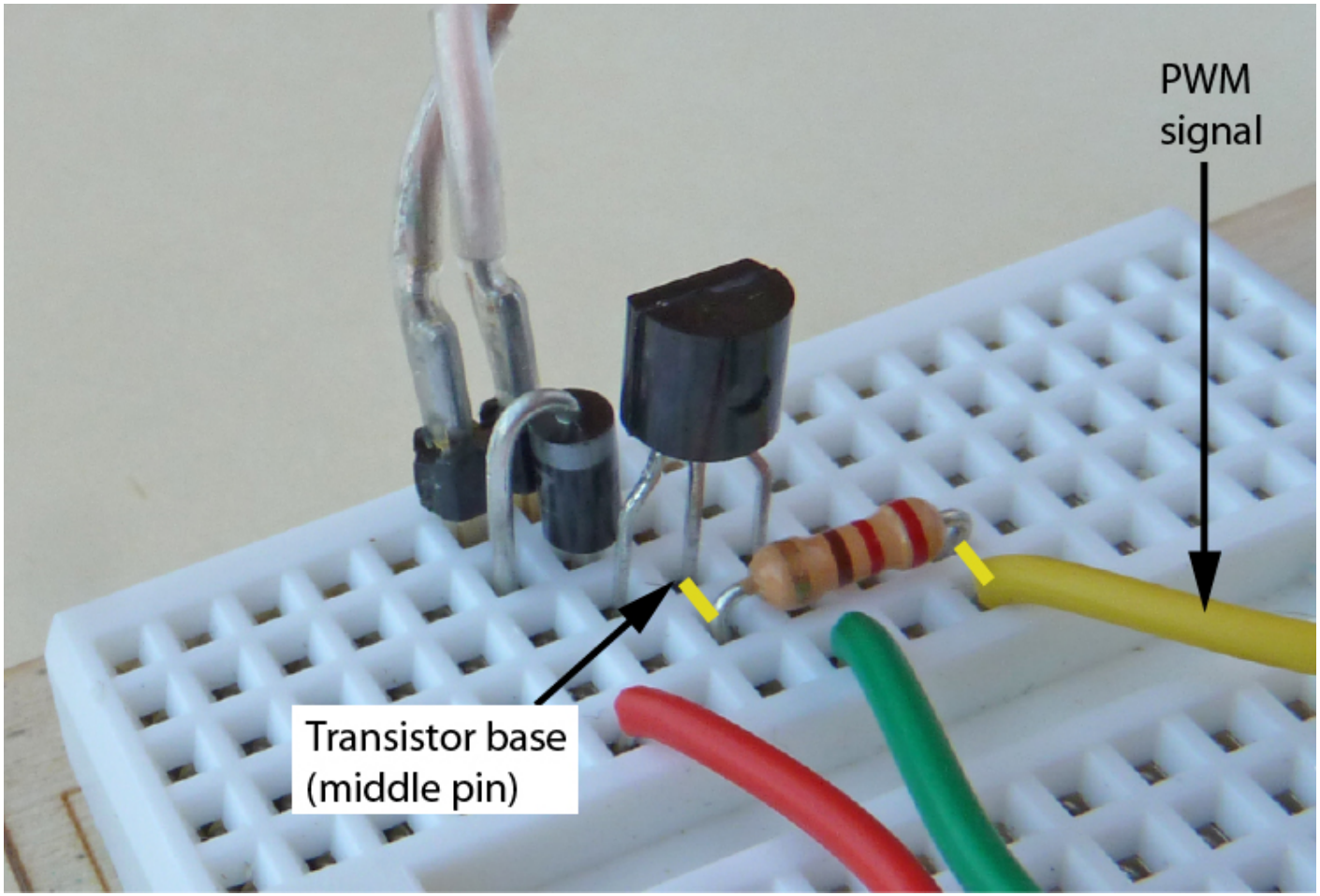
DC Motor Circuit on tiny breadboard



+5V connections



PWM signal is connected to transistor base



Arduino program to spin the DC Motor

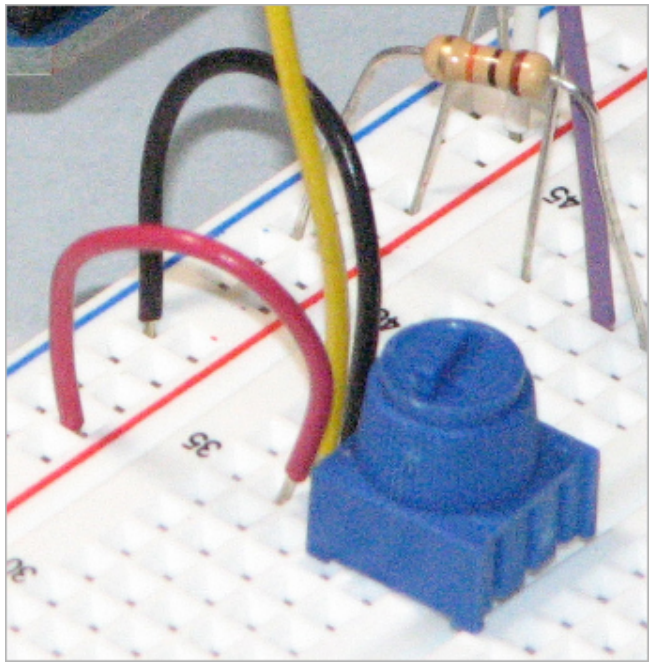
Code is in spin_DC_motor.ino

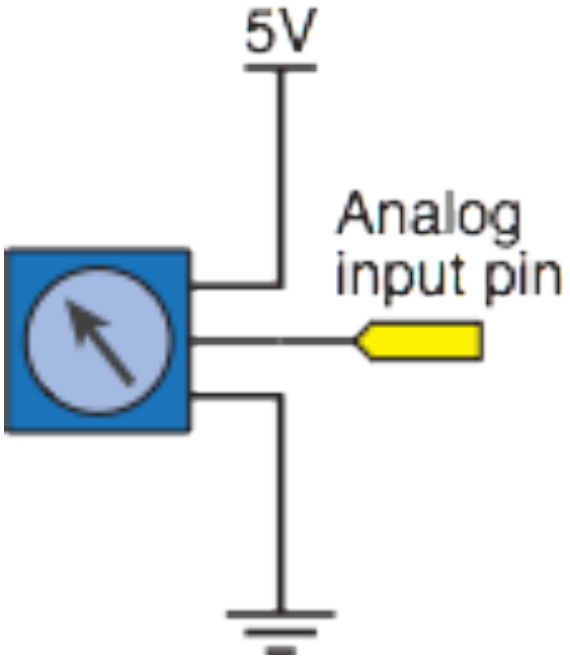
```
//  spin_DC_motor.ino   Use PWM to control DC motor speed

int motorPin = 3;   // Pin 3 has PWM, connected it to the DC motor

void setup() {
  pinMode(motorPin, OUTPUT);     // Set motor pin to output mode
}

void loop()  {
   analogWrite(motorPin, 150);   // Motor at 150/255 of full speed
   delay(1000);
   analogWrite(motorPin, 250);   // Motor at 250/255 of full speed
   delay(1000);
}
```

User input to control fan speed

Adjust fan speed with potentiometer input

Use the potentiometer circuit from the earlier analog input exercise





Adjust fan speed with potentiometer input

Code is in DC_motor_speed_control.ino

```
//  File:  DC_motor_speed_control.pde
//
//  Use potentiometer input to set the speed of a DC motor
//  Output to the motor is PWM

int motorPin = 3;   // pin connected to the DC motor
int potPin = 1;     // analog input connected to the potentiometer

void setup()
{
  pinMode(motorPin, OUTPUT);
}

void loop()
{
   int PWMoutput, potReading;

   potReading = analogRead(potPin);
   PWMoutput = map(potReading, 0, 1023, 0, 255 );
   analogWrite(motorPin, PWMoutput);
}
```

Adjust fan speed with potentiometer input

```
void loop() {

   int PWMoutput, potReading;

   potReading = analogRead(potPin);
   PWMoutput = map(potReading, 0, 1023, 0, 255 );
   analogWrite(motorPin, PWMoutput);
}
```

Each time through the loop:

- Read the voltage at the potentiometer wiper
  - Input value is a 10-bit integer: 0 ≤ `potReading` ≤ 1023
- Scale the 10-bit value (max 1023) to an 8-bit value (max 255)
  - `PWMoutput = map( potReading, 0, 1023, 0, 255 );`

  `0, 1023,` — range for potReading

  `0, 255` — range for PWMoutput
- Update the PWM signal
  - `analogWrite(motorPin, PWMoutput);`