Diodes & Transistors

ECE 401 Senior Design I

Week #3

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Introduction

In ECE 401, you can choose from a dozen different circuits to build. Regardless of which one you select, your overall design:

- Must operate at 5VDC
- Must have LEDs operating at 10mA +/- 2mA
- Must have one NPN and one PNP transistor (or more), capable of driving a 100mA load
- Must have at least one IC (PIC18F2620, MCP602 op-amp, 555 timer)

This lecture covers:

- Analysis and design of LED circuits,
- Analysis and design or NPN and PNP electronic switches,
- Analysis and design of a comparitor, and
- Analysis and design on 555 timers

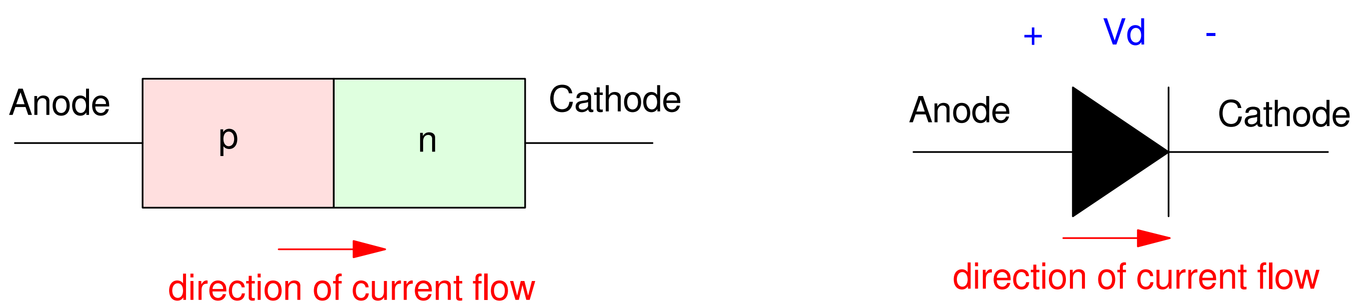
Diodes

- Covered in ECE 320 Electronics I.

Diodes act as valves:

- Current allow current to flow from the anode to the cathode,
- Current block current from flowing the other way.

Because of this, the symbol for a diode looks like an arrow: this arrow serves as a reminder for which way the current can flow.



Symbold for a diode: Diodes only allow current to flow from the anode to the cathode

Diode VI Characteristics

Diodes are nonlinear devices

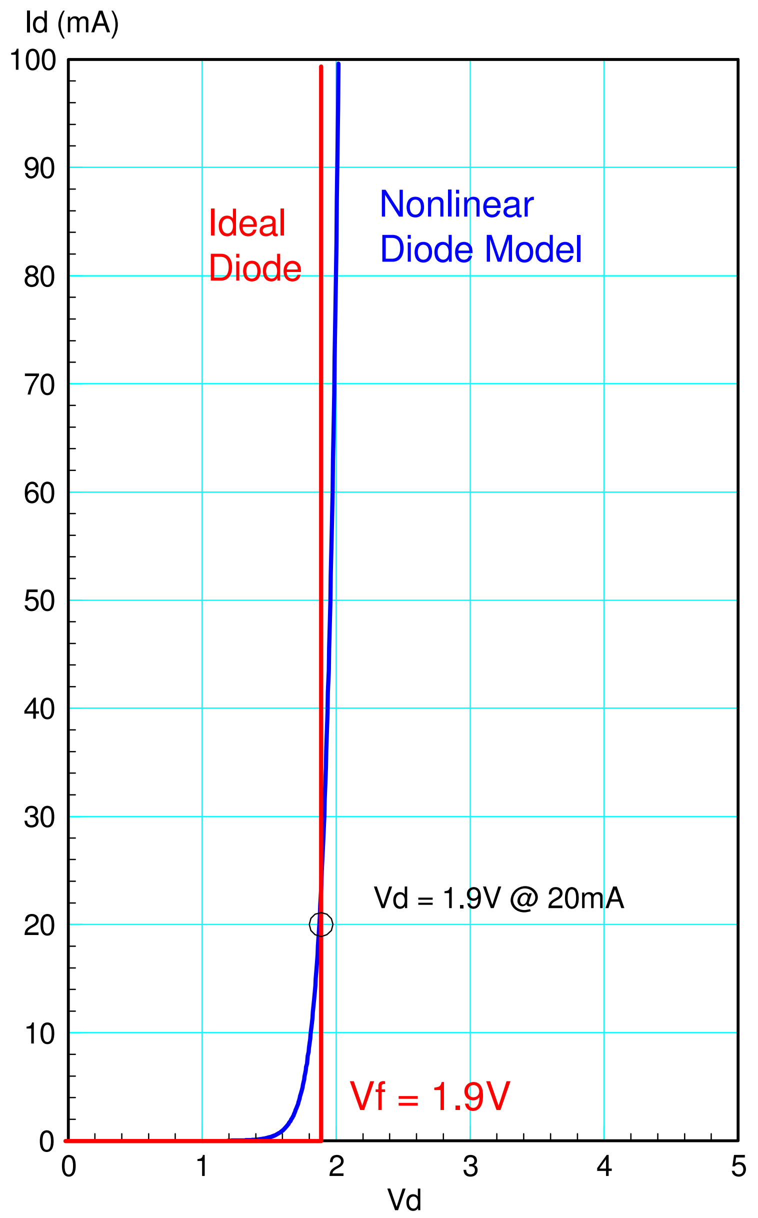
- This makes analysis of diode circuits difficult

Ideal Diode

- Simplified model of a diode
- Id = 0 when Vd < Vf
- Vd = Vf when Id > 0

Not perfect, but usually good enough

- Use CircuitLab to get better answers



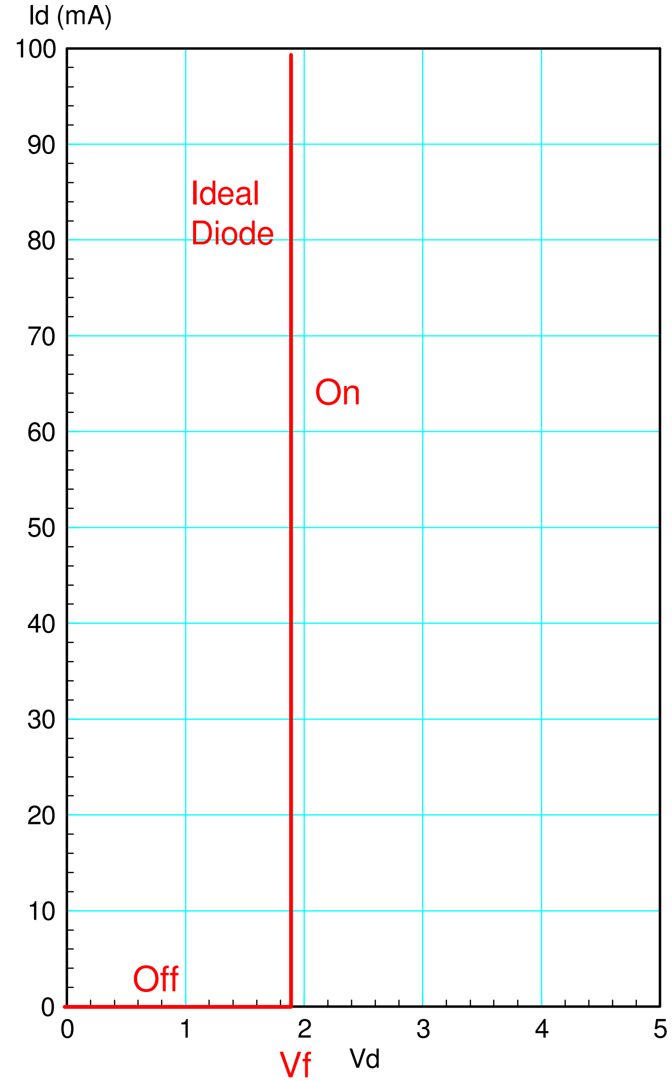
Ideal Diode Model

Vf acts like a turn-on voltage:

- Diode turns on if you apply more than Vf
- Diode turns off if you apply less than Vf

Vf depends upon the diode

- Germanium: Vf = 0.3V
- Silicon: Vf = 0.7V
- Red LED: Vf = 1.9V
- Yellow LED: Vf = 2.0V
- Green LED: Vf = 2.0V



Diode Circuit Analysis:

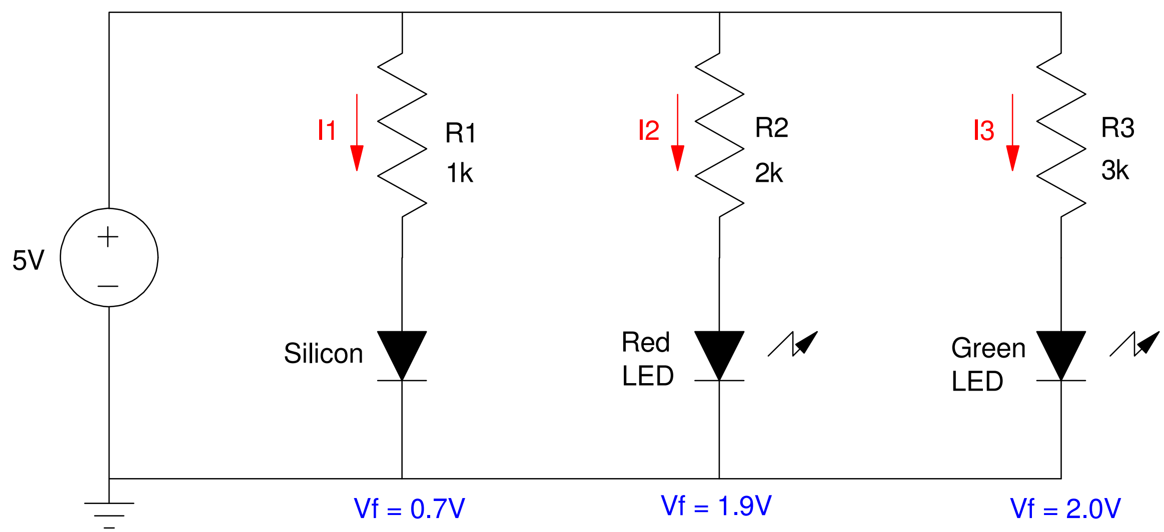
- Determine which diodes are on and off
  - Not always that easy
- Replace with the ideal diode model
- Determine voltages and currents

Calculations:

$$I_1 = \left(\frac{5V - 0.7V}{1k}\right) = 4.3mA$$

$$I_2 = \left(\frac{5V - 1.9V}{2k}\right) = 1.55mA$$

$$I_3 = \left(\frac{5V - 2.0V}{3k}\right) = 1.00mA$$



Diode Circuit Design:

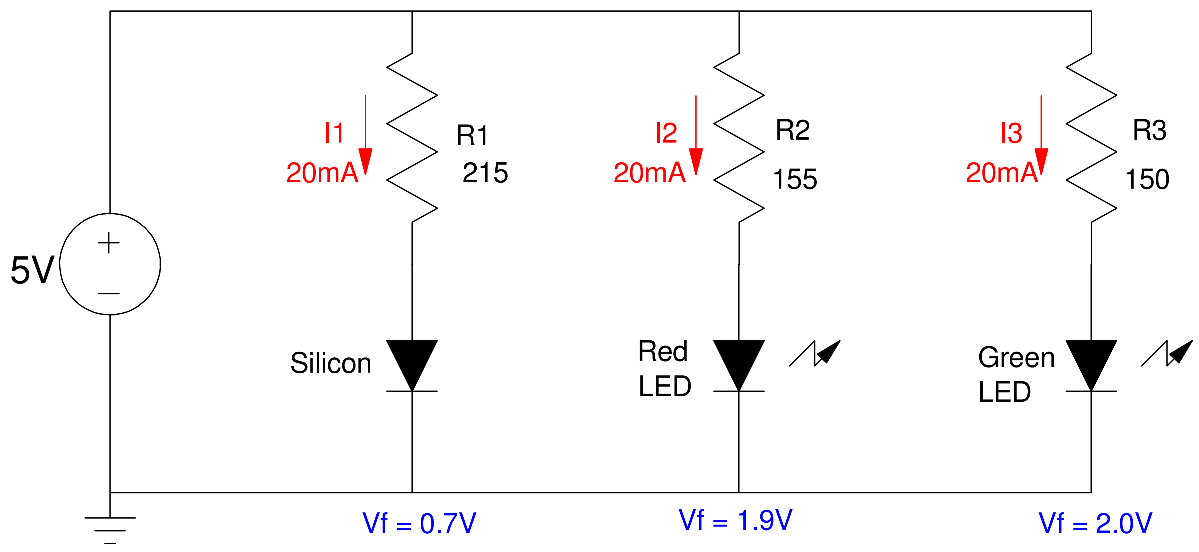
- Pick the current desired
  - Light is proportional to current
- Calculate the resistance needed

Example: Set Id = 20mA

$$R_1 = \left(\frac{5V - 0.7V}{20mA}\right) = 215\Omega$$

$$R_2 = \left(\frac{5V - 1.9V}{20mA}\right) = 155\Omega$$

$$R_3 = \left(\frac{5V - 2.0V}{20mA}\right) = 150\Omega$$



Light Emitting Diodes (LEDs)

LEDs are nothing more than diodes - except that they produce light proportional to the current flowing through them. As diodes, they can be approximated with an ideal-diode model:

- Id = 0 if Vd < Vf
- Vd = Vf if Id > 0

The on-voltage (Vf) depends upon the diode and is usually specified in the diode's data sheets:

LED	Vf	mcd	Wavelength	Cost	Digikey PN
Red	1.9V @ 20mA	30mcd @ 20mA	645nm	$0.13	732-5016-ND
Yellow	2.0V @ 20mA	450mcd @ 20mA	592nm	$0.18	732-5018-ND
Green	2.1V @ 20mA	140mcd @ 20mA	572nm	$0.21	732-5017-ND

With LEDs, brightness is proportional to current

Assuming a 9V source (the kit assume you're using a 9V battery). the current and brightness of the first diode (330 Ohms) is:

$$I = \left(\frac{9V - 2.0V}{330\Omega}\right) = 21.21mA$$

The brightness is then proportional to this current where 20mA = 450mcd:

$$\left(\frac{21.21mA}{20mA}\right) 450mcd = 477.2mcd$$

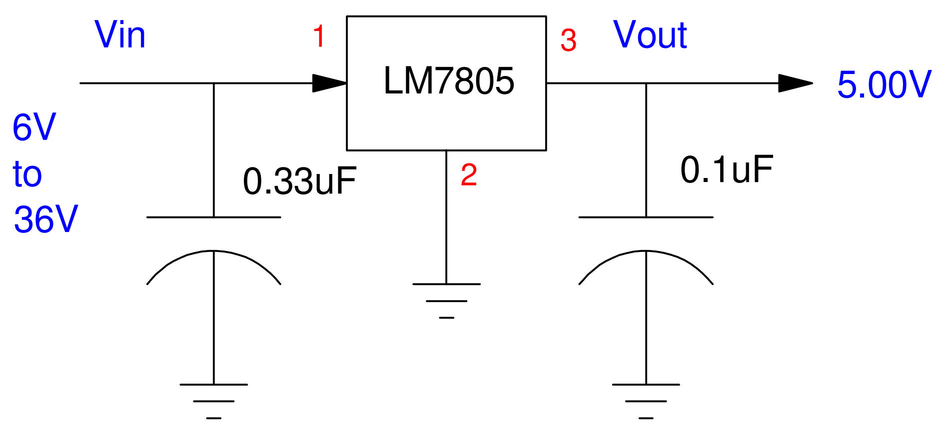
Voltage Regulation

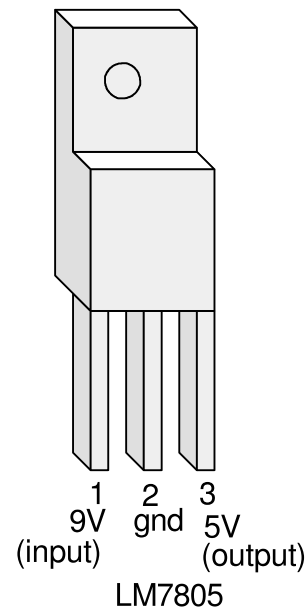
In ECE 401,

- Power to your PCB comes from a 9V battery, while
- Your components on your PCB operate off of 5VDC.

Solution: Use a LM7805 regulator

- Pro: Simple circuit
- Con: Efficiency = 55% @ 9V





Reverse Polarity Protection & Overcurrent Protection

Another requirement for your PCB in ECE 401 is to add

- Reverse polarity protection
  - connecting 9V to your PCB backwards will not fry your PCB
- Overcurrent protection
  - if your circuit draws too much current, a fuse blows.

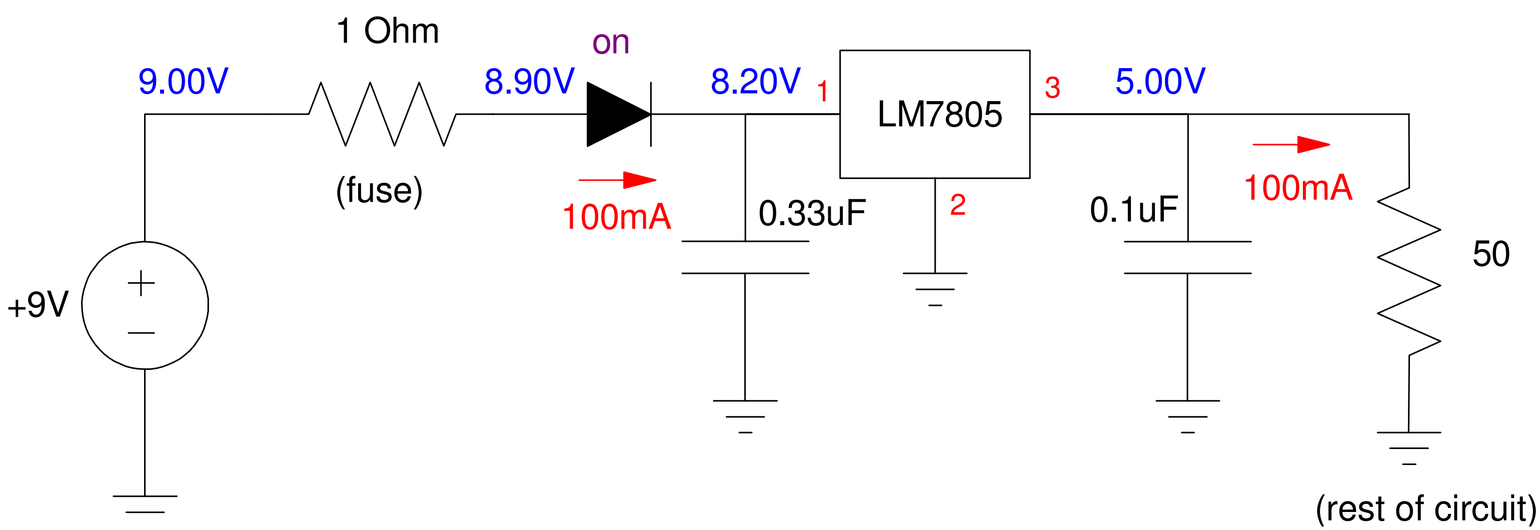
There are several ways to do this.

Method #1: Diode + Fuse.

- Diodes do not allow current to flow backwards
  - Blocks current if the 9V battery is inserted backwards
- Fuse blows if the load is too much
  - 1 Ohm resistor replaces the fuse for ECE 401 (2 cents)

Problem:

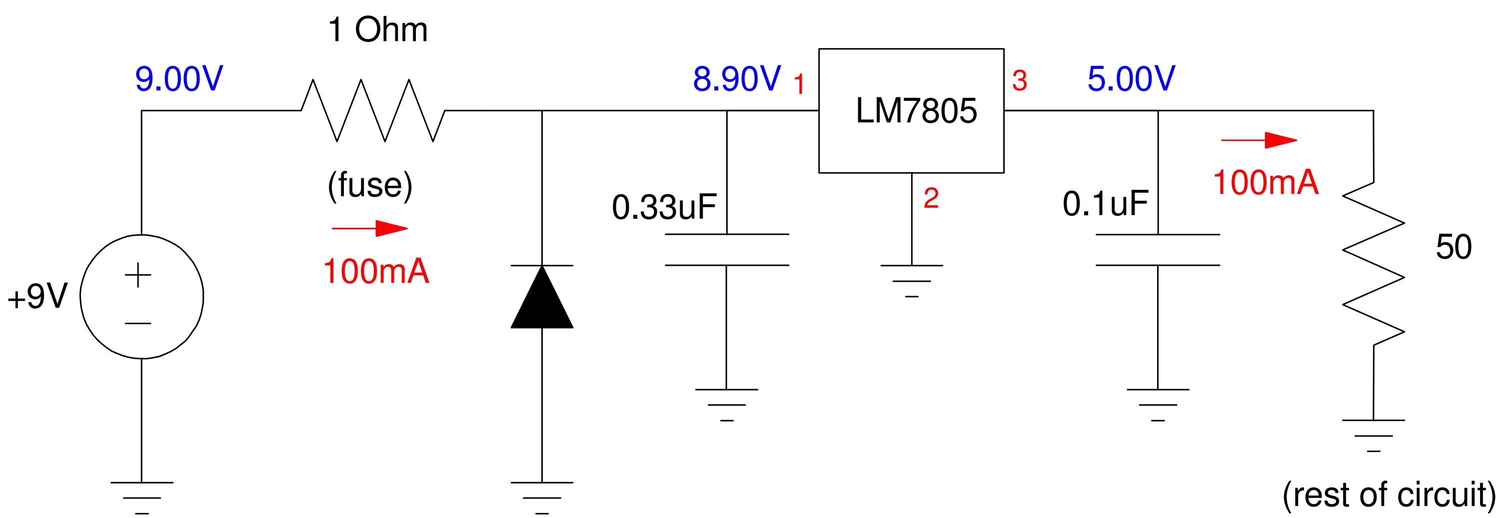
- Drops 0.7V through the diode



Method #2: Fuse + Diode.

Add a reverse biased diode to ground

- If the 9V battery is connected correctly, the diode remains off.
- If the 9V battery is reversed,
  - The diode turns on, limiting the voltage to the LM7805 to -0.7V,
  - The current through the fuse becomes large (9A), blowing the fuse.



BJT Transistors

Bipolar Junction Transistors

- Electronic switches (you can turn a device on and off using 0V & 5V),
- Which amplify current (1mA can turn on and off a device which draws 100mA)

The current amplification and the maximum current a given BJT transistor can handle depends upon which transistor you're using.

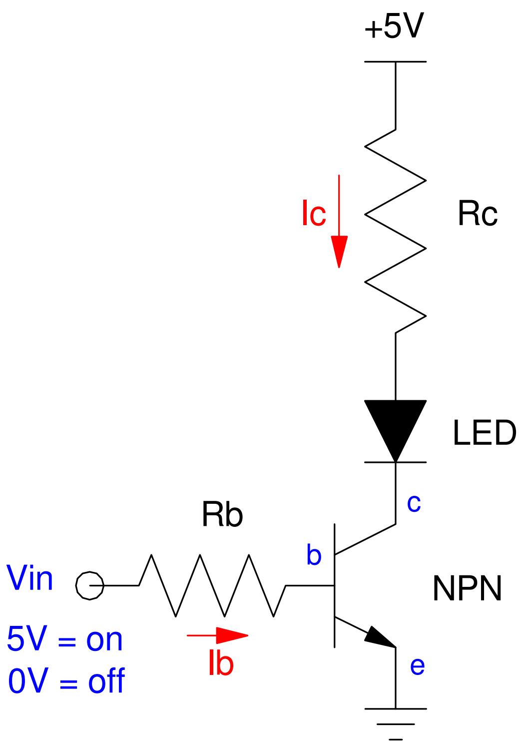
Spec	3904 NPN	3906 PNP
Current Gain (min)	100	100
Max Current	200mA	200mA
|Vbe| (on)	0.7V	0.7V
|Vce| (sat)	0.2V	0.2V
Cost (ea)	$0.11	$0.11

NPN and PNP Transistors

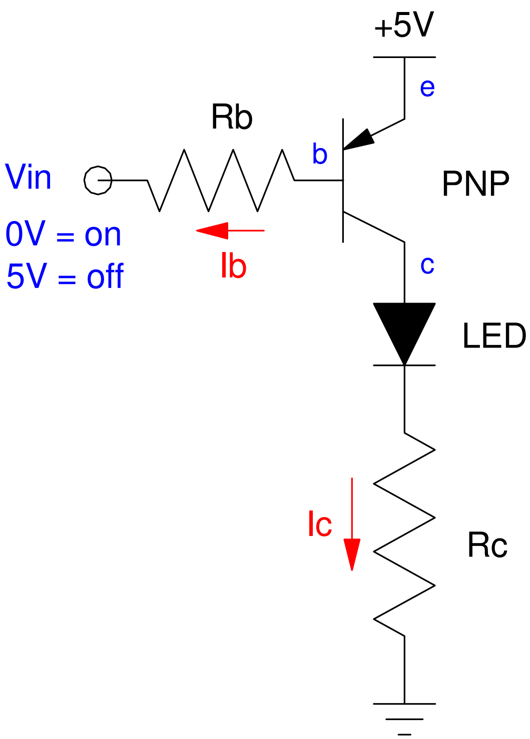
Two types of BJT transistors exist:

- PNP: an electronic switch which connects your device to +5V, or
- NPN: an electronic switch which connects your device to ground.

The basic circuit for each of these are as follows:



NPN Switch



PNP Switch

Diode from Base to Emitter

The arrow going between the base and the emitter is all important:

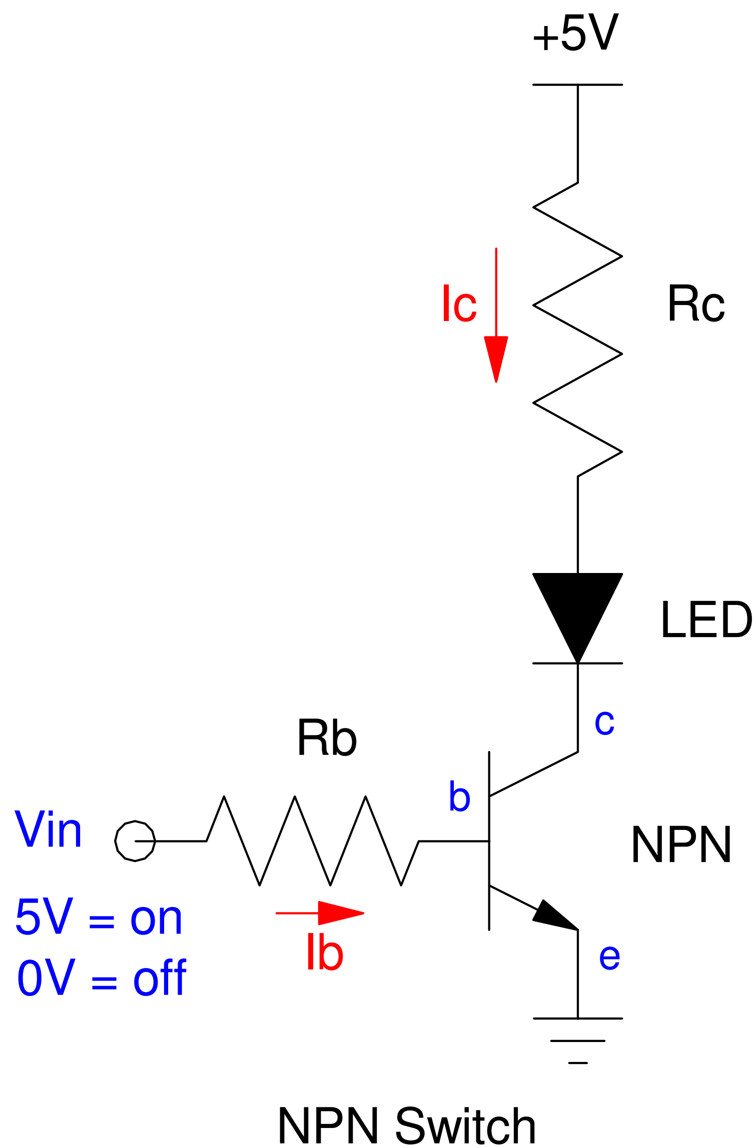
- It represents a diode (a pn junction)
- It tells you the direction current flows
- The base current controls the collector current

Ib limits the collector current

$$I_c = \beta I_b = 100 I_b$$

It does this by dumping voltage

- Whatever it takes to set Ic

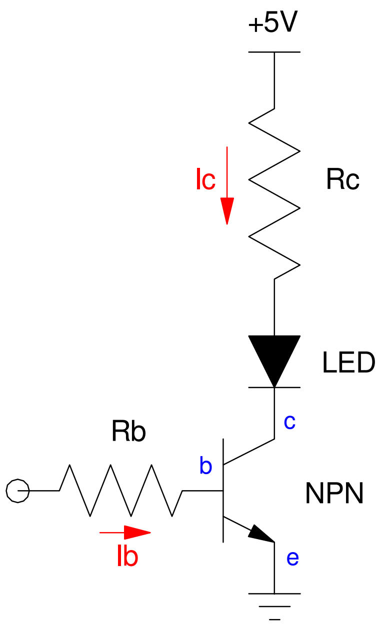


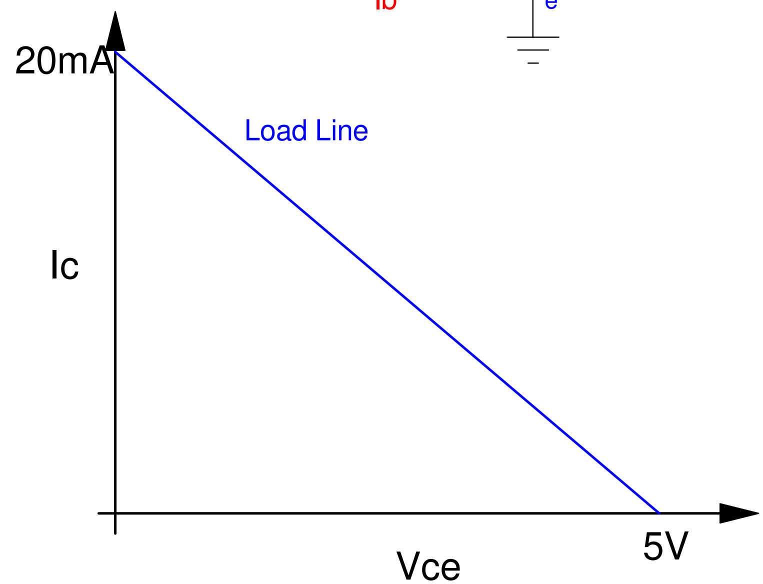
Load Lines

A good way to see how a transistor switch operates

- When Ic = 0mA, Vce = 5V
  - the x-axis intercept
- When Vce = 0V, Ic = 20mA
  - the y-axis intercept

The line connecting these two points is called *the load line.*





Any solution has to be on the load line somewhere.

Off State:

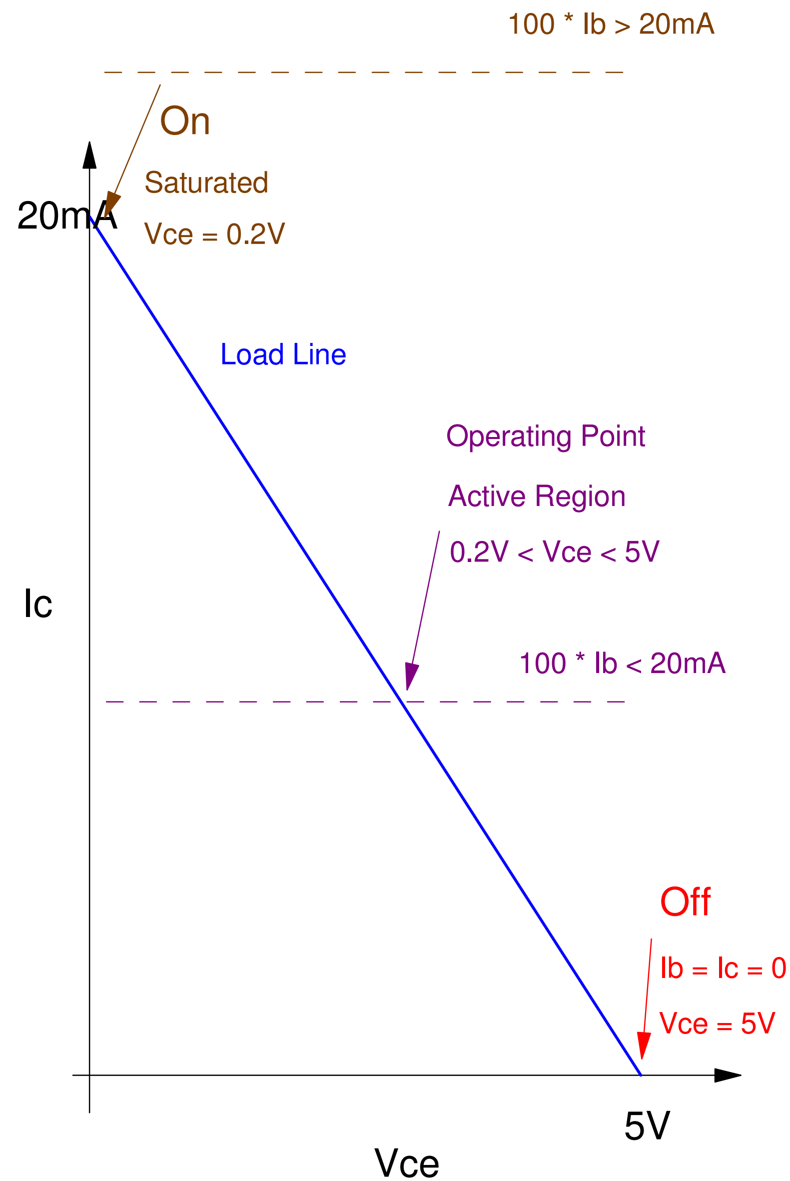
- Ib = 0
- Ic = 100*Ib = 0
- Vce = 5V

Active Region

- 0mA < Ib < 20mA
- 5V > Vce > 0.2V
- Ic = 100*Ib

On State

- Saturated Region
- 100*Ib > 20mA
- Vce = 0.2V



On & Off State

You want to operate in the ON and OFF state

Off State

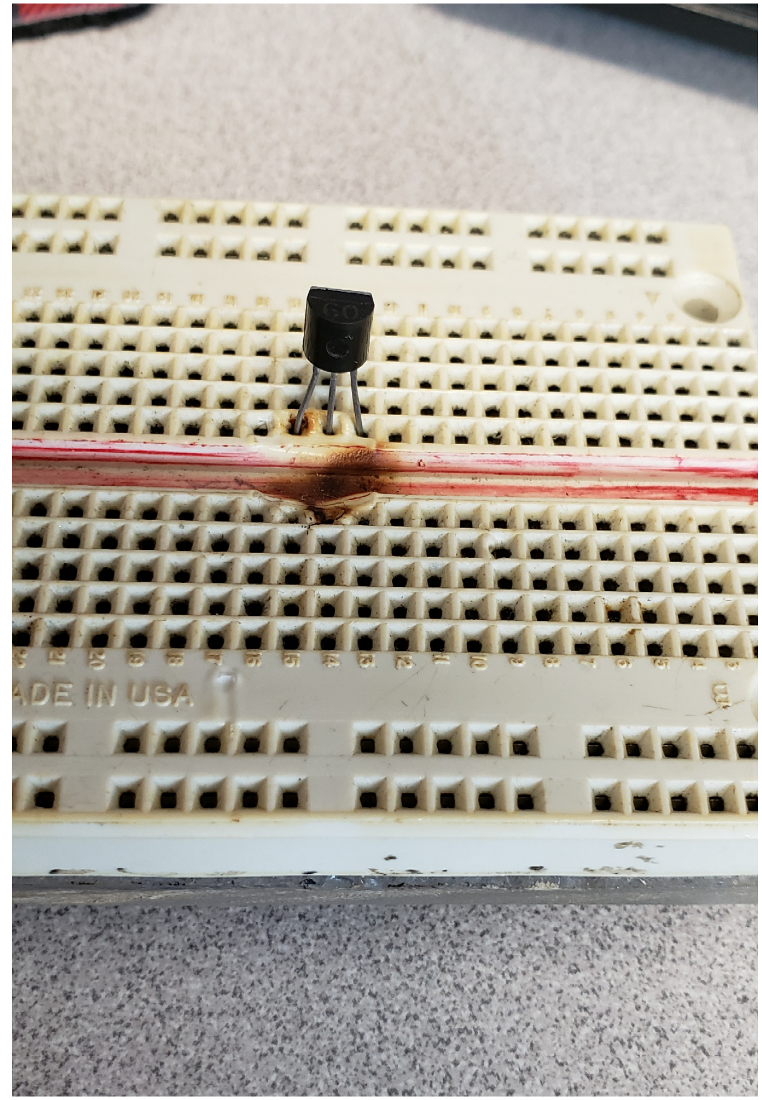
- I = 0
- P = V*I = 0

On State

- V = 0.2V (almost zero)
- I = 20mA
- P = 4mW (almost zero

Active Region

- P = V*I
- The transistor gets hot
- You start to melt your breadboard



Analysis of Transistor Switches:

- Same equations for PNP and NPN

Off State

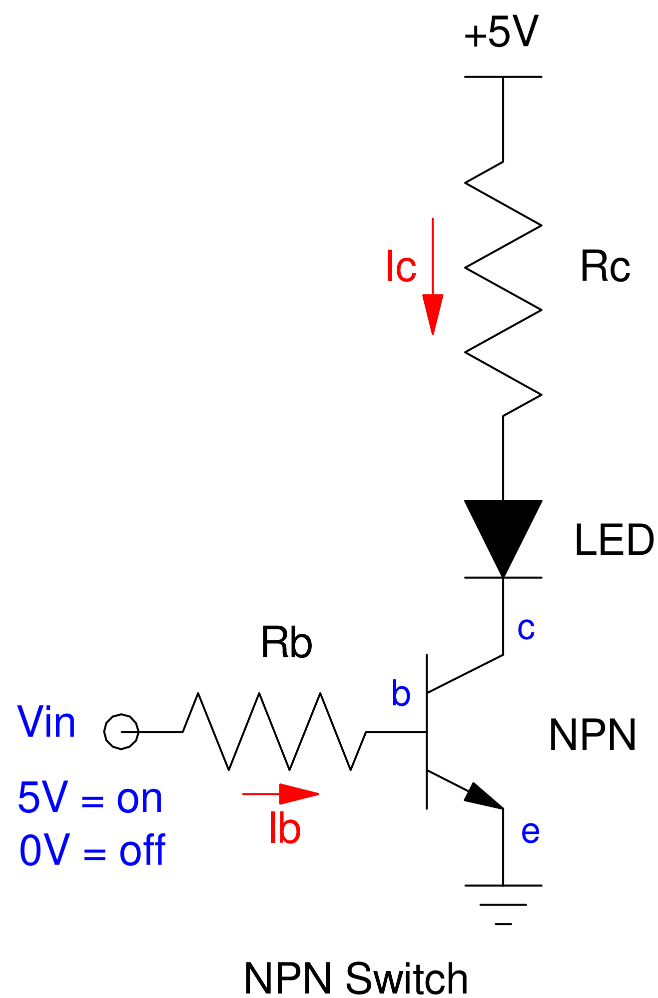
- Easy: Ib = Ic = 0

On State:

$$V_{ce} = 200mV$$

$$I_c = \left(\frac{5V - V_f - V_{ce}}{R_c}\right)$$

$$I_b = \left(\frac{5V - 0.7V}{R_b}\right)$$



Check that you're saturated:

$$\beta I_b > I_c$$

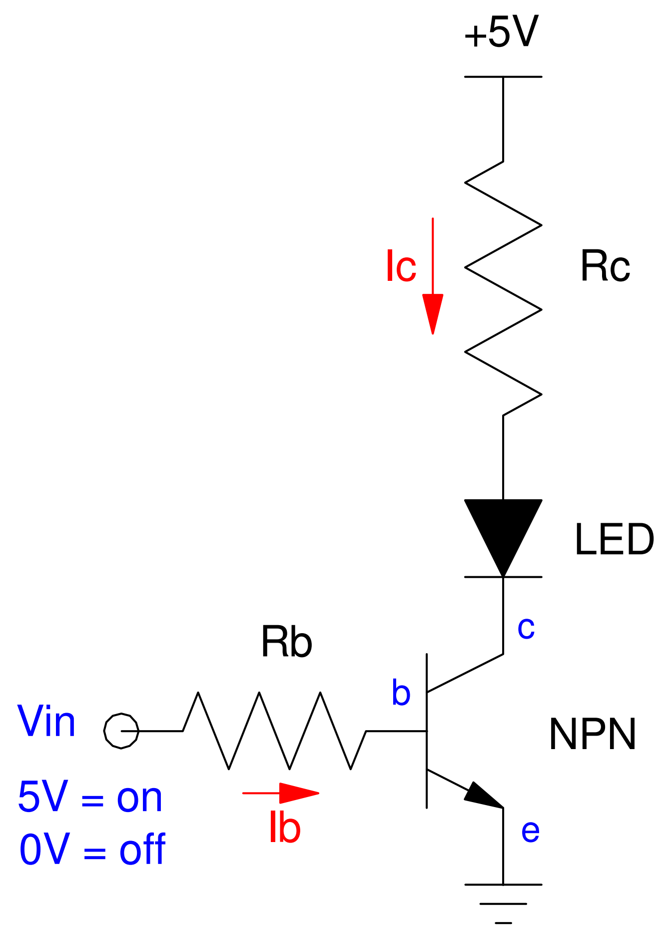
$$I_b > \left(\frac{I_c}{100}\right)$$

Design of Transistor Switches:

- Pick Rc to set the desired current
- Pick Rb to saturate the transistor
  - Ib > Ic/100

For example, design a circuit

- To turn on and off a red LED
- At 20mA when on,
- Using a 0V/5V input capable of driving at most 5mA.



NPN Switch

Solution:

First pick Rc to set the current to 20mA

$$R_c = \left(\frac{5V - 1.9V - 0.2V}{20mA}\right) = 145\Omega$$

Next, pick Ib so that the transistor is saturated

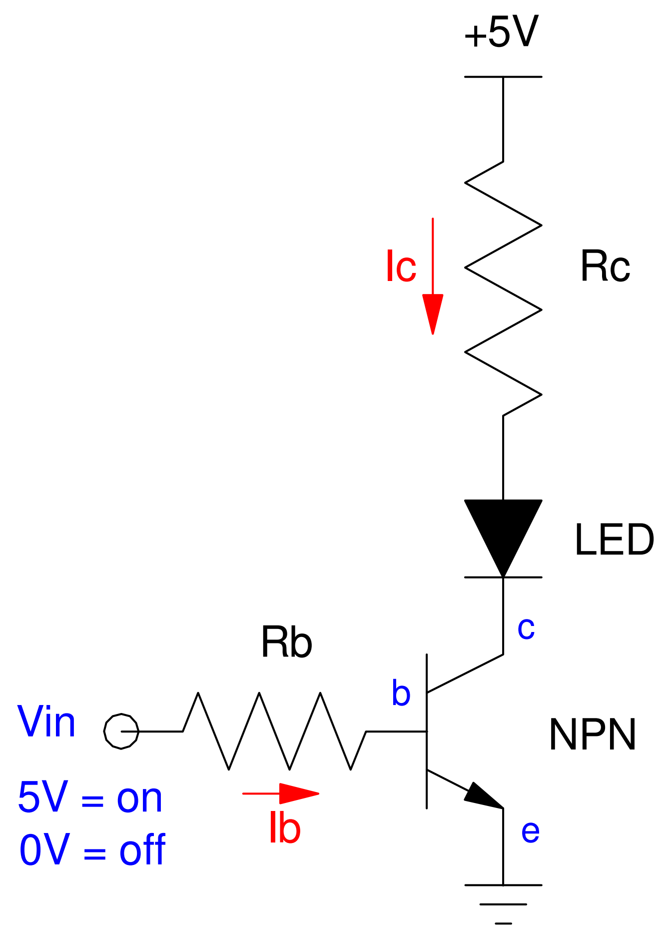
$$I_b > \left(\frac{I_c}{100}\right) = 0.2mA$$

Let Ib = 1mA

$$R_c = \left(\frac{5V - 0.7V}{1mA}\right) = 4.3k\Omega$$

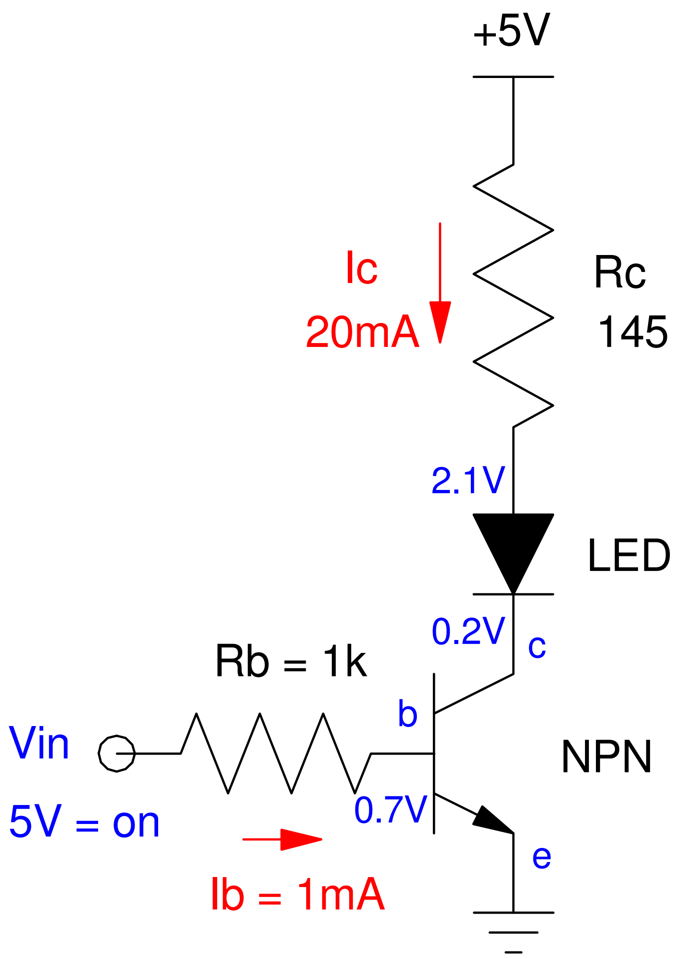
Same equations for a PNP switch

Resuting Circuit

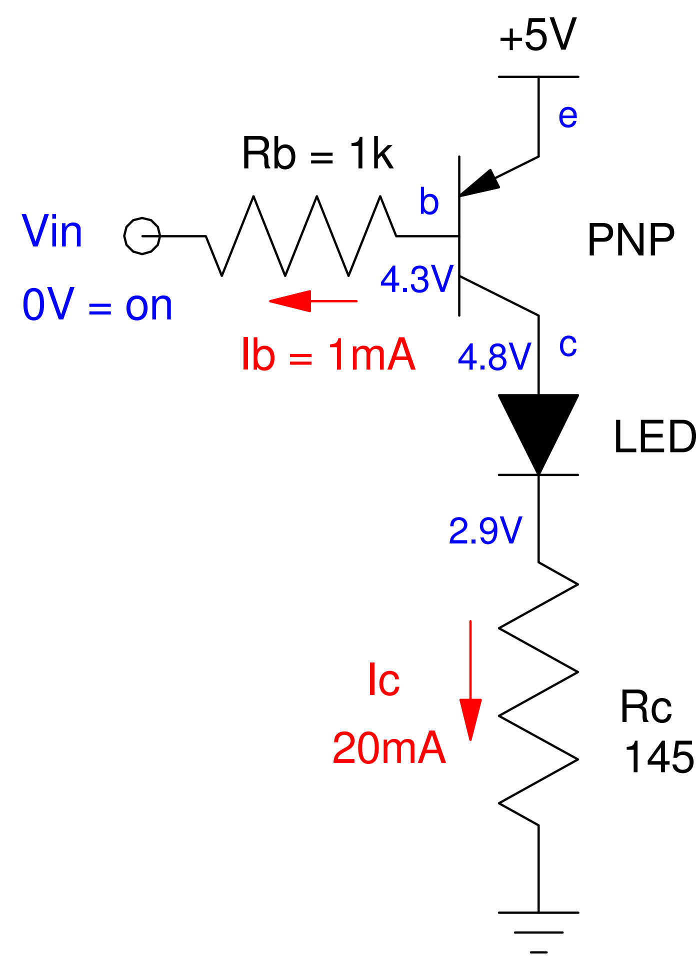


NPN Switch

NPN & PNP Switch



NPN Switch



PNP Switch

Homework #3:

Design a circuit for your ECE 401 Senior Design project.

- Must operate off of 5VDC
- Must include at least one integrated circuit
- Must include at least one LED with Id = 100mA +/- 10mA
- Must include at least one NPN and one PNP transistor

Update your OneNote document to include

- Your circuit schematics
- Calculations for R's and C's
- Calculations for voltages you exect to see.

Note: If you're using a microprocessor,

Assume the output pins are either 0V or 5V