# Using a Transistor as a Switch

#### **ECE 320 Electronics I**

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Please visit Bison Academy for corresponding lecture notes, homework sets, and solutions

# Using a Transistor as a Switch

Microcontrollers and function generators (555 timers) have limited outputs

• 0V / 5V up to 20mA

Many loads need more:

- 200mW LED which draws 100mA @ 1.9V
- 8-Ohm speaker which draws 625mA @ 5V.
- Motor which draws 2A at 24V

A transistor can be used as a buffer between the two



#### **Product Attributes**

ТҮРЕ	DESCRIPTION	SELECT	
Category	Integrated Circuits (ICs) (Cock/Timing - Programmable Timers and Oscillators (	) 0	
Mfr	Harris Corporation		
Series			
Package	Bulk ②		
Product Status	Active		
Туре	555 Type, Timer/Oscillator (Single)		
Count	-		
Frequency			

# **On/Off Control with a SPST Switch**

Connect your load to power and ground Add a switch,

- At the power supply, or
- At the ground side

Either solution works

#### Works for any DC load

- Motor (on/off)
- LED (on/off)
- Speaker (push/off)
- etc.



# **On/Off Control with a Transistor**

Replace the switch with a transistor

- PNP on the high side
- NPN on the low side

Either solution works

We'll be using the NPN transistor mostly in this class



#### **NPN Transistor Operation & Load Lines**

Transistors are current limiters

• 
$$I_{c(\max)} = \left(\frac{10V - 0.2V}{100}\right) = 98mA$$

•  $I_c = \min(\beta I_b, I_{c(\max)})$ 



# Goal when Using a Transistor as a Switch:

Operate Either Saturated (on) or Off (off)

- Saturated:
  - Power = 0
  - Good
- Off:
  - Power = 0
  - Good
- Active:
  - Power > 0
  - Bad

If you operate in the active region, the transistor will get hot (and may melt your breadboard)



# Strategy:

Determine how much current you need

• What is Ic when the transistor is on?

Pick a transistor which can handle the current

Set Ib so that

 $\beta I_b > I_c$ 





	2N3904 (NPN)	6144 (NPN)
lc max	200mA	13A (peak) 10A (continuous)
current gain (hfe = beta)	100 - 300	200 - 560
Vbe (on)	0.7V	0.7V
Vce (sat)	0.2V	0.18V
Cost	\$0.04 ea	\$0.62 ea

#### Example 1: Drive a 200mW LED

Input:

- 0V / 5V capable of 25mA
- Output: LED
  - Vf = 1.9V, 100mA (max)

Relationship:

- Vin = 0V: LED is off
- Vin = 5V: LED is on (100mA)



#### **NPN Solution:**

- Pick an NPN transistor that can handle the current.
  - 2N3904 works
- Pick Rc to set Ic = 100 mA
  - The diode drops 1.9V (Vf)
  - The transistor drops 0.2V: ( Vce(sat) )

$$I_c = 100mA = \left(\frac{10V - 1.9V - 0.2V}{R_c}\right)$$

 $R_c = 79\Omega$ 

• Pick Rb so that the transistor saturates

 $\beta I_b > I_c$  $I_b > 1mA$ 

Let Ib = 2mA

$$R_b = \left(\frac{5V - 0.7V}{2mA}\right) = 2150\Omega \rightarrow 2k\Omega$$



# Checking in CircuitLab

- The voltage across the LED is 2.06V (had to modify part to get it to approx 1.9V)
- Vce = 167.5mV (vs. 200mV assumed for Vce(sat))
- Vb = 800.2mV (vs. 700mV assumed for a saturated silicon diode)
- Ic = 93.18mA (vs. 100mA target)



Note that Vce = 167mV tells you that the transistor is saturated:

- Vce = 200mV is a ballpark guess
  - Close to zero but not quite zero
- If Vce > 0.2V, you are operating in the active region
  - You need more base current (Rb is too large)



# **Checking in Hardware**

Measure voltages

• Calculate currents from V = IR

Results are similar

- Calculated
- Simulated
- Measured

Vce = 0.2V (ish) meaning it's saturated

	Vbe	Vce	lb	lc
Calculated	0.7V	0.2V	2.15 mA	100mA
Simulated	0.800 V	0.167V	2.10 mA	93.15 mA
Hardware	0.867V	0.318V	2.07 mA	119.5mA



#### Example 2: Drive an 8-Ohm Speaker

Input: 0V / 5V square wave capable of 20mA

Output: 8 Ohm speaker

Relationship:

- When Vin = 0V, the speaker is off (0V and 0mA)
- When Vin = 5V, the speaker is on (4.8V, 600mA)

Step 1: Calculate the current you need:

$$I = \left(\frac{5V - 0.2v}{8\Omega}\right) = 600 mA$$

Step 2: Pick a transistor that can handle the power 6144 NPN transtor  $max(I_c) = 10A$ 



Step 3: Determine Ib ( assume Ib < 25mA )

$$\beta I_b > I_c$$
  
$$25mA > I_b > \left(\frac{600mA}{200}\right) = 3mA$$

Let Ib = 4.3mA

Step 4: Determine Rb

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

 $R_b = 1000\Omega$ 

Anything in the range of 172 .. 1433 Ohms works



# Checking in CircuitLab

- 6144 NPN transistor isn't an option, so pick one that's close
- Adjust gain to match a 6144 ( $B_F = 300$ )



# **Checking in Hardware**

Measure the voltages

- Calculate currents from V = IR
- Vce = 0.2V (ish) meaning it's saturated

	Vbe	Vce	lb	lc
Calculated	0.7V	0.2V	4.30 mA	600.0 mA
Simulated	0.977V	0.088V	4.02 mA	614.0 mA
Hardware	0.670V	0.086V	4.33 mA	614.1mA



# Note:

In Digital Electronics (ECE 320), the load connects to the collector

- This allows you to operate the transistor in the saturated (on) and off (off) regions
- The transistor acts as a switch

In Analog Electronics (ECE 321), the load connects to the emitter

- This places the transistor in the active region
- The transistor acts as an amplifier



#### **Electronic Switch with PNP Transistors**

- Place the switch on the high side
- Use a PNP transistor as an electronic switch

Note: TTL levels don't work

- Vin = 10V is off
- Vin = 0V is on



#### **PNP Switch (version 2)**

If you want to turn on and off the PNP with a 5V source, add an NPN transistor



#### **CircuitLab Simulation**



# **Pulse Width Modulation (PWM)**

You can 'fake' an analog voltage by varying the duty cycle

- Vin = 0V: off
- Vin = 5V: on
- Vin = X% X% on

Used in

- Tail-Lights
- RGB scoreboards
- Motor speed control

• etc.



#### **PWM & LED Brightness Control**

$$V3 = 5V$$
  
•  $I_b = \left(\frac{5V - 0.7V}{330\Omega}\right) = 13.03mA$   
•  $I_c = 300I_b = 3.9A$ 

This power a load up to 3.9A

#### Brightness is adjustable

- 2% with the pot all the way left
- 50% with the pot in the middle
- 100% with the pot all the way right



# **Darlington Pairs (TIP112)**

A TIP112 transistor is actually a Darlington pair

- T1 provides gain
- T2 provides high current

The net result looks like a big hogging transistor



# Example 2: Drive an 8-Ohm speaker.

Input: 0V / 5V square wave capable of 20mA

Output: 8 Ohm speaker

Relationship:

- When Vin = 0V, the speaker is off (0V and 0mA)
- When Vin = 5V, the speaker is on (5V, 625mA)

$$I_{c} = \left(\frac{5V - 0.9V}{8\Omega}\right) = 512.5mA$$
$$\beta I_{b} > I_{c}$$
$$I_{b} > 512.5\mu A$$

Let Ib = 1mA. Then

$$R_b = \left(\frac{5V - 1.4V}{1mA}\right) = 3.6k\Omega$$



#### **CircuitLab Simulation**

- Vb = 1.593V *1.4000V calculated*
- Vce = 904.4mV 900mV calculated
- Ic = 511.9 mA
- 512.5mA calculated



#### **Transistor Switch Demo**

How to annoy your friends and neighbors

# **Flyback Diodes**

Motors are inductive in nature. This causes a problem when turning them on and off

- When on, energy is stored in the magnetic field as  $E = \frac{1}{2}LI^2$
- This collapse creates large voltages  $\left(V = L \frac{dI}{dt}\right)$
- Add a flyback diode
  - Provides a path for the current
  - Clips the voltage at Vc to 12.7V



NPN Transistor Switch

# Summary

Transistors can be used as an electronic switch

- Pick a transistor that can handle the load
- Place the load on the collector side
- Connect the emitter to ground
- Pick Rb so that

 $\beta I_b > I_c$ 

