Union College
ECE363 Fall 2017
Lecture 1 Notes

Professors Buma, Hedrick
Note: These notes are primarily from Professor Buma and do not include some of the Hedrick class notes.

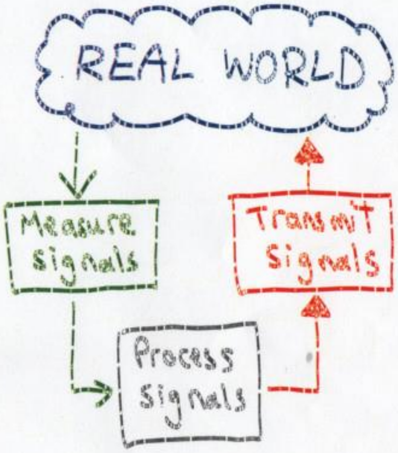
Topics: Introduction, Transistor switch, Op-Amp basics

Read in the Textbook:

1. Transistor switch: sections 6-13, 6-14, 6-8
2. Op-Amp basics: all of chapter 16 but pay particular attention to sections 16-1, 16-3, 16-4

0. Intro

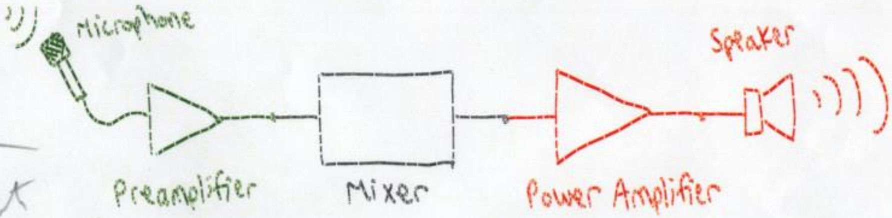
A. The Big Picture



- Interacting with the real world requires us to measure, process, and transmit signals.

  ⇒ Electronic devices play a very important role!

Example:



(2) Design

Specificat
theory
simulat
prototype

(1) Analysis
Design

B. Analysis vs. Design

- ECE 248: Analyze circuits with diodes and transistors.

☆ ECE 363: Design circuits with op amps and transistors!

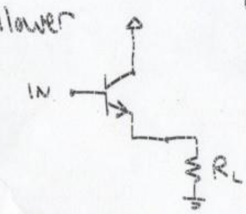
↳ "Accuracy" [e.g. Stable voltage gain]

↳ "Heavy Lifting" [e.g. Delivers load current]

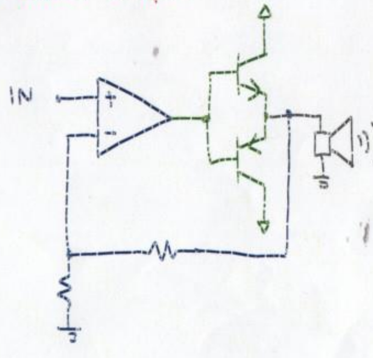
op amps typically output < 25mA

Small transistor (100 mA)
Power transistor (~5A)

Example: Emitter Follower



Example: Audio Amplifier



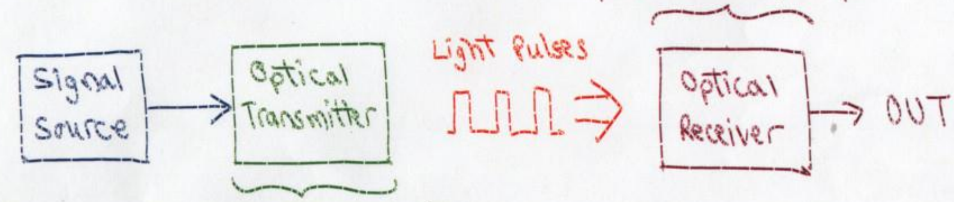
Can we design with only ICs?

1. Transistor Switch

Let's start with an application...

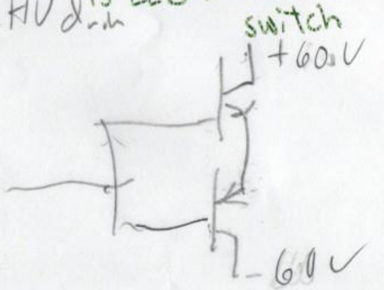
Optical communication link!

usually a photodiode + op amp

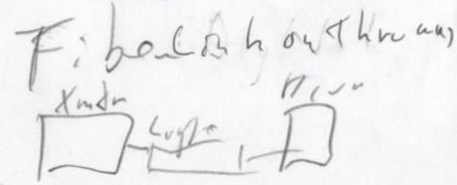


simplest approach is LED + transistor switch

example HV driver



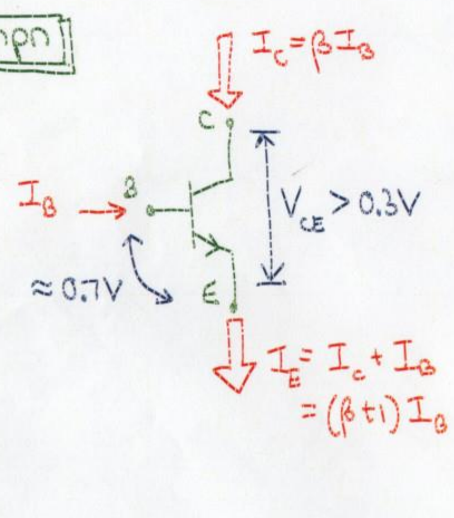
NOTE: This example is a digital comm link.



A. Quick BJT review

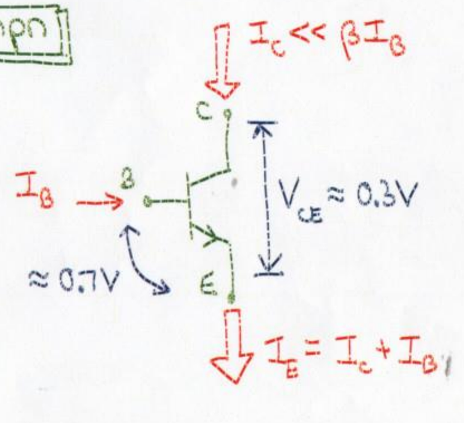
ACTIVE MODE ← Good for amplifiers

npn



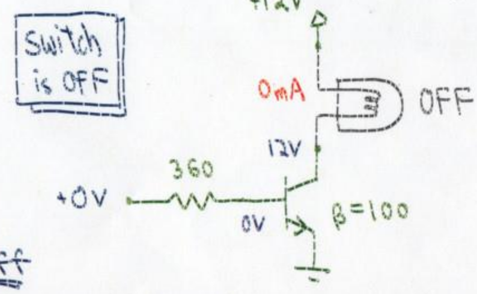
SATURATION MODE ← Good for switches

npn



1.5

B. BJT switch Analysis

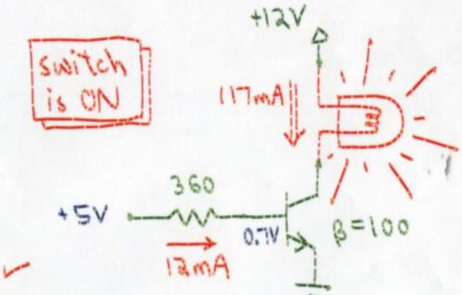


- **Example:** 12V, 0.12A lamp ($R_L = 100\Omega$)

$$V_{BE,sat} = 0.7V, \quad V_{CE,sat} = 0.3V$$

① 0V input: $V_B = 0V \rightarrow I_B = 0$

$\Rightarrow$ Transistor is cut-off



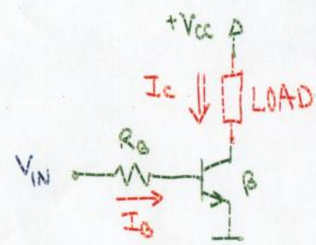
② 5V input $\rightarrow I_B = \frac{5-0.7}{360\Omega} = .012A$

- $I_C = \frac{V_{CC} - V_C}{R_L} = \frac{12-0.3}{100\Omega} = 0.117A$

- $\frac{I_C}{I_B} = 9.75 << \underbrace{100}_{\beta} \Rightarrow$ Transistor is saturated ✓

(1.6)

C. BJT switch design



Rule #1 Know your load

Rule #2 When BJT is ON, make sure it is saturated ($V_{CE} = V_{CE,sat}$)

↑ ~0.3V for small signal transistor
~1V for power transistor

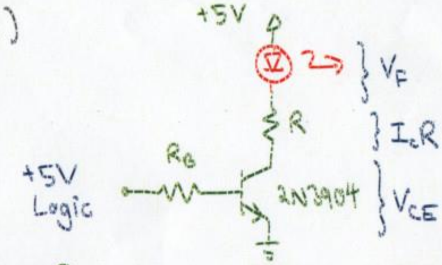
Rule #3 Use $I_C \sim 0.1 \beta I_B$

$$\Rightarrow I_B = \frac{I_C}{0.1\beta}$$

→ Called "hard saturation"

↳ Ensures that variations in β do not affect I_C.

- **Design example:** Driver for LED ($V_F = 2V$ @ 10 mA)



Rule 1 Load properties

- LED has 2V drop when $I_c = 10$ mA

Rule 2 Saturated BJT

- KVL: $5 - V_F - I_c R - V_{CE} = 0 \Rightarrow R = \frac{5-2.2}{10\text{mA}} = \underline{280\Omega}$

  V_F = 2V, I_c = 10mA, V_{CE} ↑ From datasheet, worst-case value is 0.2V

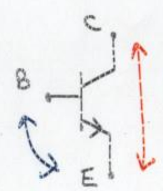
Closest 5% resistors are 270 or 300Ω

$I_c = \frac{5-2.2}{270} = 10.4\text{mA}$

$\frac{5-2.2}{300} = 9.3\text{ mA}$

Choose $R = 270\Omega$

Min $\beta = 100$



Max value = 0.85V

Max value = 0.2V

} When transistor is saturated @ $I_c = 10$mA!

From 2N3904 datasheet

ON CHARACTERISTICS*		TEST CONDITIONS	MIN	MAX	
h_{FE} ↑ Same as β	DC Current Gain	I_C = 0.1mA, V_{CE} = 1.0V	40		
		I_C = 1.0mA, V_{CE} = 1.0V	70		
		I_C = 10mA, V_{CE} = 1.0V	100	300	
		I_C = 50mA, V_{CE} = 1.0V	60		
		I_C = 100mA, V_{CE} = 1.0V	30		
$V_{CE(sat)}$	Collector-Emitter Saturation Voltage	I_C = 10mA, I_B = 1.0mA		0.2	V
		I_C = 50mA, I_B = 5.0mA		0.3	V
$V_{BE(sat)}$	Base-Emitter Saturation Voltage	I_C = 10mA, I_B = 1.0mA	0.65	0.85	V
		I_C = 50mA, I_B = 5.0mA		0.95	V

Show data sheet VDES

Rule 3 Base current drive

- $I_B = \frac{1}{0.1\beta} I_c = \frac{1}{10} I_c \Longrightarrow I_B = \frac{10.4\ mA}{10} = \underline{\underline{1.04\ mA}}$

Talk

- $R_B = \frac{V_{IN} - V_{BE}}{I_B} \Longrightarrow R_B = \frac{5 - 0.85}{1.04\ mA} = 3.99K$

Closest 5% resistors are **3.9K** and **4.3K**

$I_B = \frac{5-0.85}{3.9K} = 1.06\ mA$ (Too big is ok)

$\frac{5 - 0.85}{4.3K} = 0.97\ mA$ (Too small :( )

Choose $R_B = 3.9K$

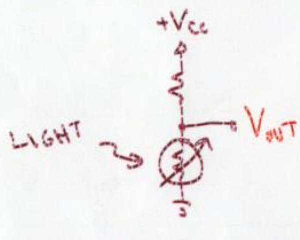
---

2. Op Amp Basics

- How to make a photoreceiver?

Choose this ↓

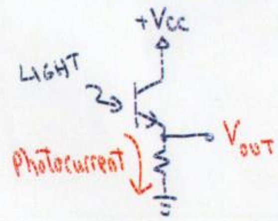
METHOD 1
Photocell



Pro: Cheap, simple

Con: Wide variation in performance
Slow

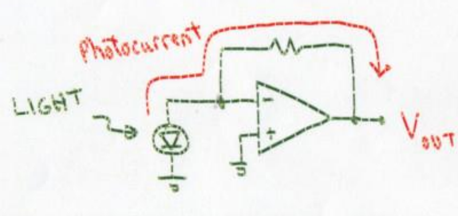
METHOD 2
Phototransistor



Pro: Large current output

Con: Somewhat noisy
Medium speed

METHOD 3
Photodiode

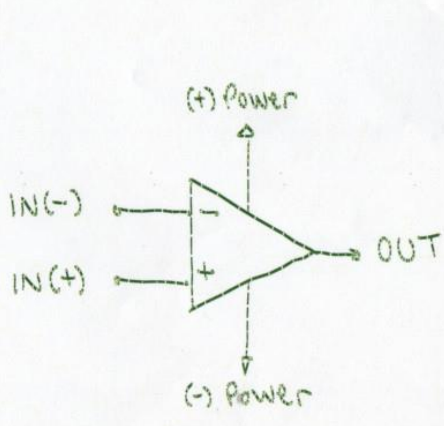


Pro: Low noise
High speed

Con: Low current output

Boost signal w/op amp!

Most op amp circuits can be understood by using 2 Golden Rules:

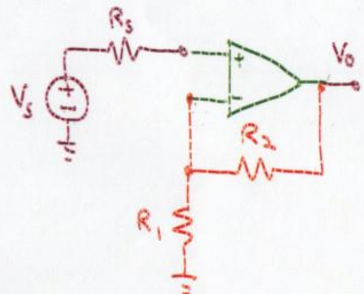


① $V_{IN(-)} = V_{IN(+)}$ ← Called a "virtual short"

② The two inputs draw no current.

NOTE: The Golden Rules assume an ideal op amp used with negative feedback!

- Non-inverting Amplifier

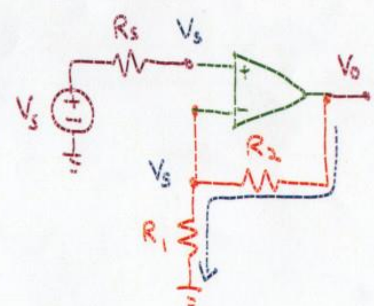


① From Rule 2, $V_+ = V_s$

② From Rule 2, $V_- = V_o \frac{R_1}{R_1+R_2}$

→ From Rule 1, $V_- = V_+$

$$V_o \frac{R_1}{R_1+R_2} = V_S \implies \boxed{\frac{V_o}{V_S} = 1 + \frac{R_2}{R_1}}$$



Ex: $R_1 = 1K$, $R_2 = 100K$ } $G = 101$

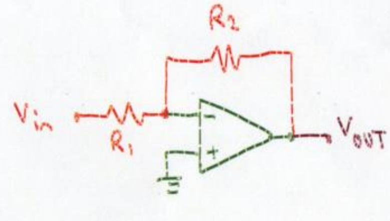
1.13

- Inverting Amplifier

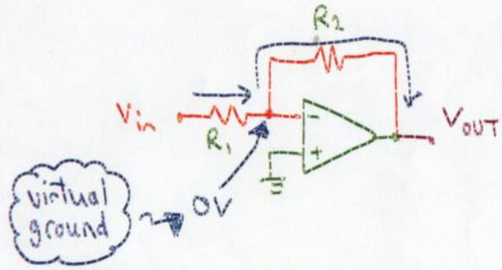
Rule 1 $V_- = V_+ = 0$

Rule 2 $\dfrac{V_{in} - 0}{R_1} = \dfrac{0 - V_{out}}{R_2}$

$$\Rightarrow \boxed{\frac{V_{out}}{V_{in}} = -\frac{R_2}{R_1}}$$



Ex: $\left.\begin{array}{l} R_1 = 1K \\ R_2 = 100K \end{array}\right\} G = \dfrac{V_{out}}{V_{in}} = -100$

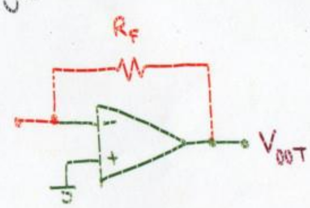


1.14

- Transimpedance Amplifier ← Also called "current-to-voltage converter"

Rule 1 Since $V_+ = 0$

$\Rightarrow V_- = 0$ (virtual ground)



Rule 2 $i_{IN} = \dfrac{0 - V_{OUT}}{R_F}$

$$\Rightarrow \boxed{V_{OUT} = -i_{IN} R_F}$$