Lecture 12: Differential Amplifier (Part 1)

0. Review
1. Intro
2. Long-Tail Pair
3. Input Impedance
4. Output Impedance

Textbook reading:

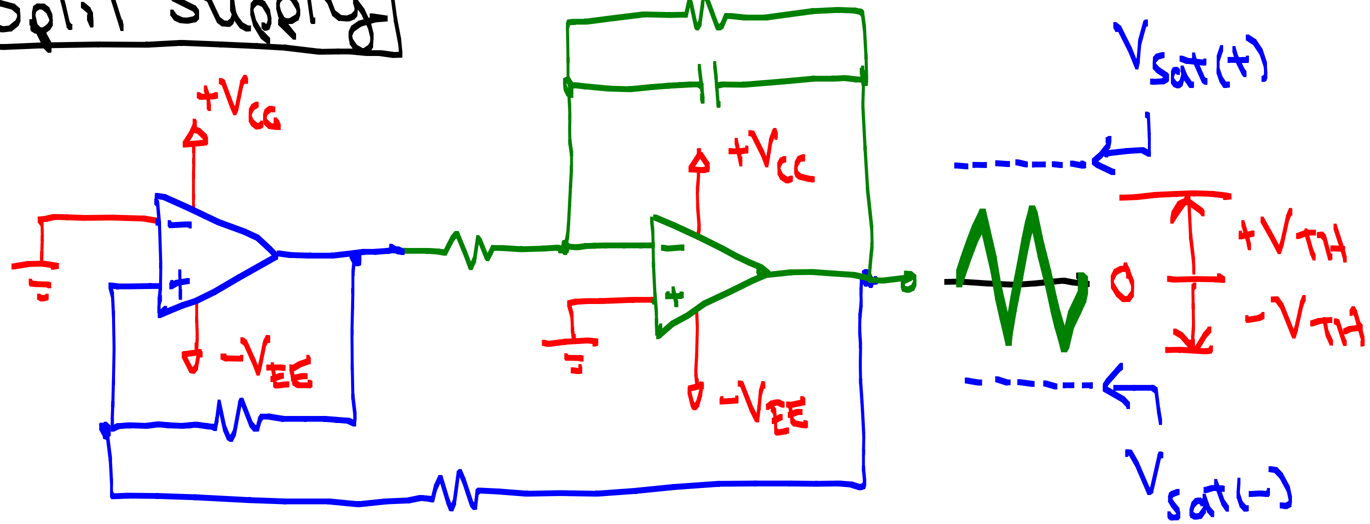
15-1 The differential amplifier
15-2 DC analysis
15-3 AC analysis

- HW 5 due Fri (Nov 01)
- PreLab 5 due today
  - → Team Project (2-3 people)
  - → Choose from 3 topics
  - → Determine responsibilities (who does what circuit)
  - → Formulate design requirements (e.g. servo pulse freq)
  - "Rough" circuit schematics (no component values)
- Lab 3 report due Nov 4 (Mon)
- Exam #2 (Nov 12) !

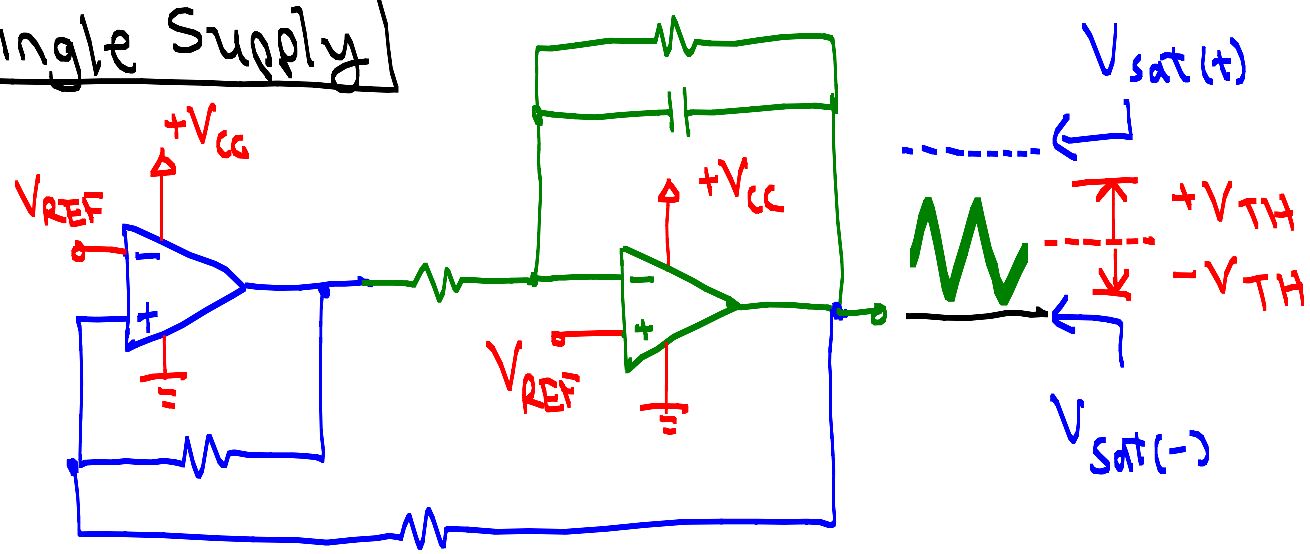
0. Review

- Triangle Wave Generator using op amps

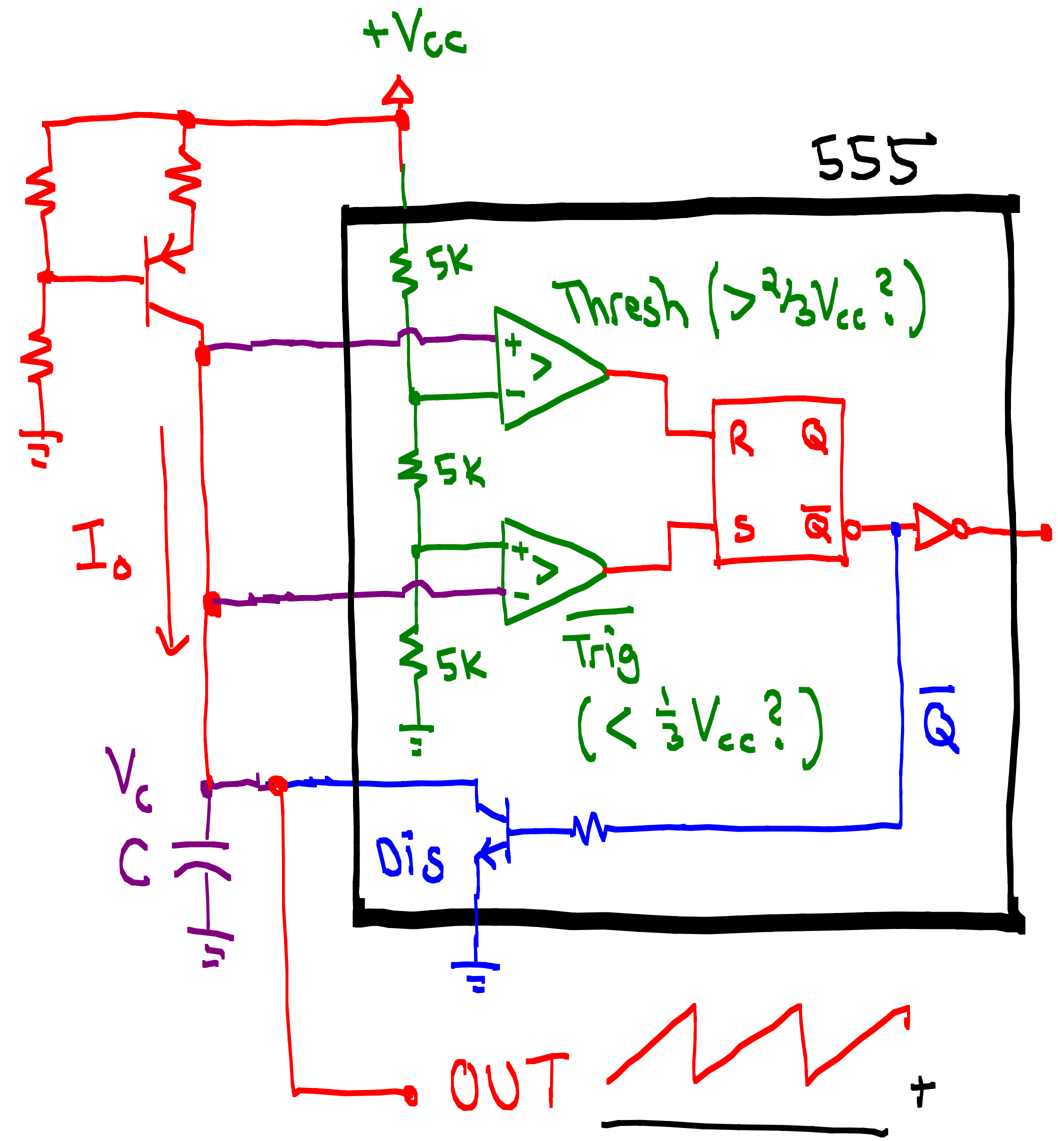
Split Supply



Single Supply



- Sawtooth Generator using 555 timer:



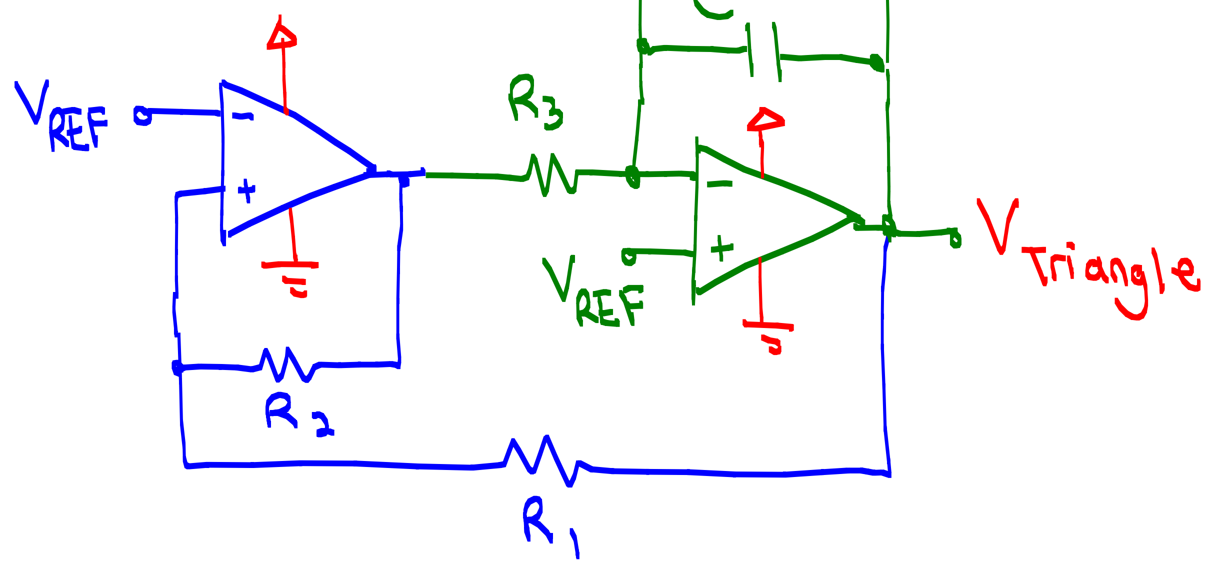
Design example — 12.0a

Triangle wave w/ single-supply op amps

$f = 1\ \text{kHz}$, $6\ V_{pp}$

$V_{cc} = 9V$	$+V_{sat} = V_{cc} - 1$
$-V_{EE} = 0V$	$-V_{sat} = 0$

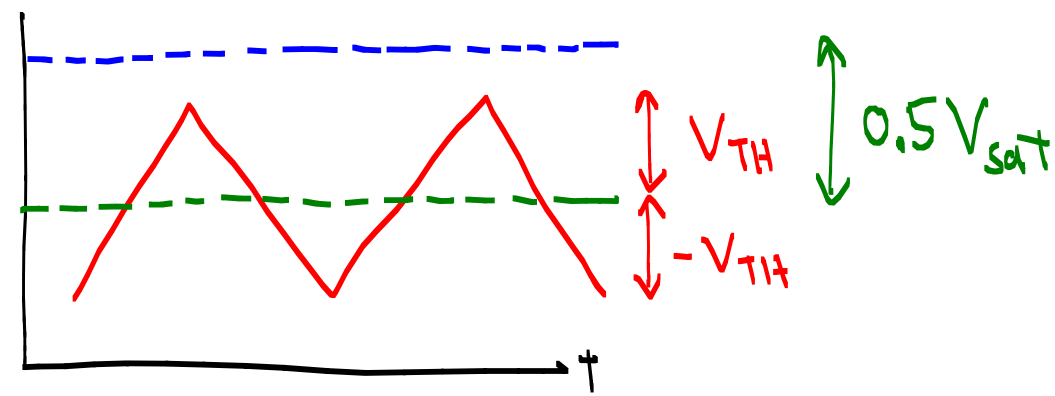
single supply op amp (e.g. LM358)



① $V_{TH} = \frac{R_1}{R_2} \times 0.5\,V_{sat} = 3V$

$\frac{9-1}{2} = 4V$

$V_{REF} = 0.5\,V_{sat}$



$\rightarrow \frac{R_1}{R_2} = 0.75$

Typically, $R_2 \sim 100k$ range

Choose $R_1 = 75K$, $R_2 = 100K$

② $f = \frac{R_2}{4R_1R_3C} = \frac{100K}{4 \times 75K \times R_3C} = 1000\,Hz \Rightarrow R_3C = 3.333 \times 10^{-4}\,s$

Typically $C < 0.1\mu F$ and $R_3 \sim 100K$:

R_3	C	$C_{5\%}$	ΔC
100K	3333 pF	3300 pF	33 pF
110K	3030	3000	30 ←
120K	2778	2700	78
130K	2564	2400	164

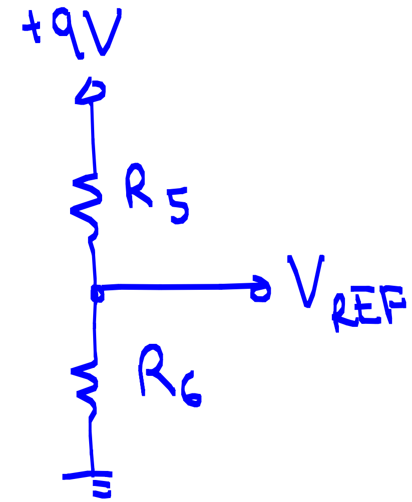
$\frac{100K}{4 \times 75K \times (110K)(3000pF)} = 1010.1\,Hz$ (within 1%)

③ Choose $R_4 > 10R_3$ (or higher)

→ $R_4 = 1.5M$ (limit to few $M\Omega$ or less)

④ $V_{REF} = 0.5\,(V_{sat(+)} - V_{sat(-)})$

$= 0.5\,(8 - 0) = \underline{\underline{4V}}$



$\rightarrow 9 \cdot \dfrac{R_6}{R_5 + R_6} = 4V$

$\frac{9}{4} R_6 = R_5 + R_6$

$\frac{5}{4} R_6 = 1.25 R_6 = R_5$

Typically, $R_6 \sim 100K$:

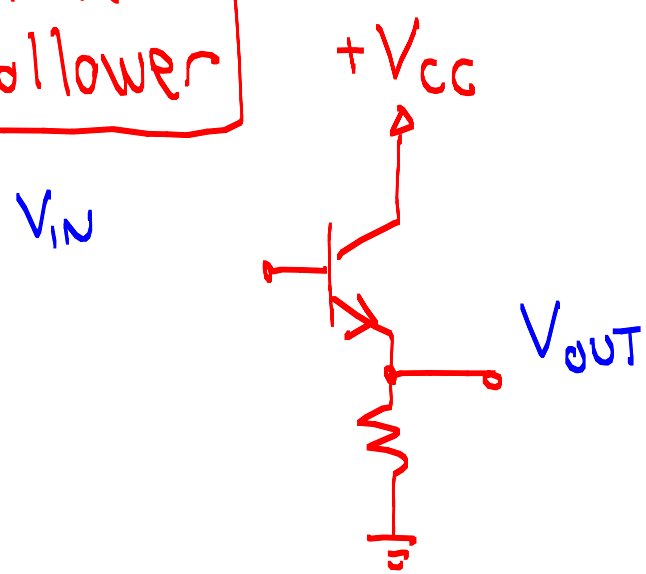
R_6	R_5
100K	125K
110K	137.5K
120K	150K

☺

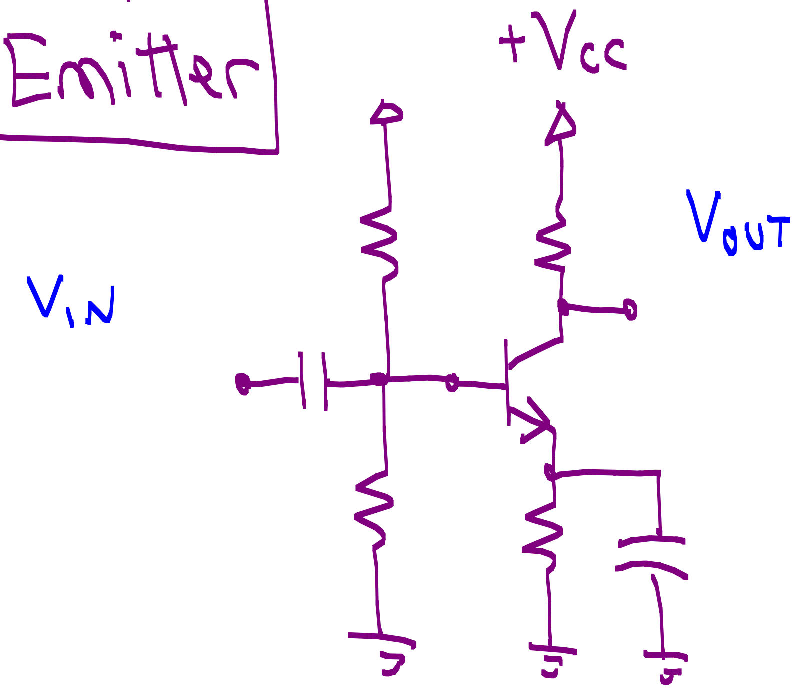
1. Intro

- Many amplifiers have a single input V_{IN}

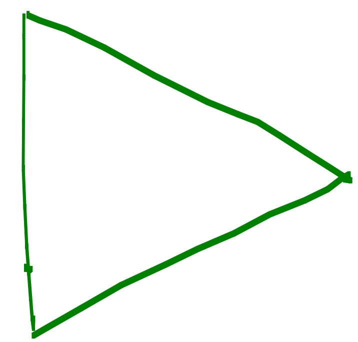
Emitter Follower



Common Emitter

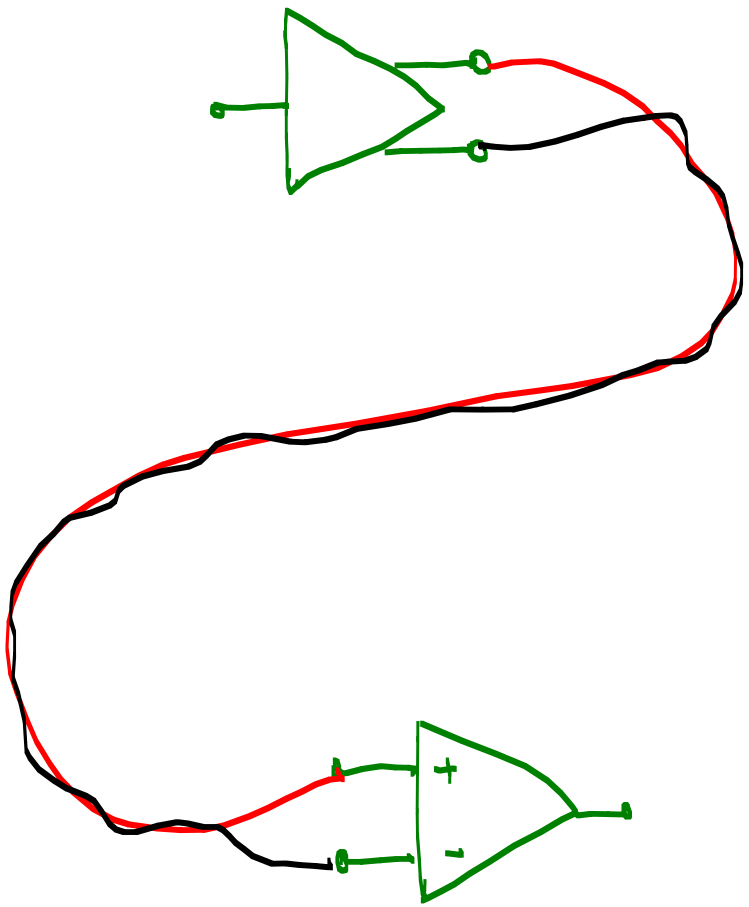


- A differential amplifier has ________



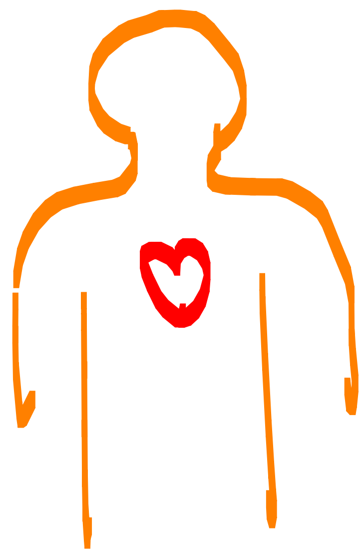
Application #1

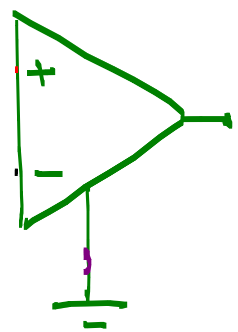
* Signal transmission over long cables



Application #2

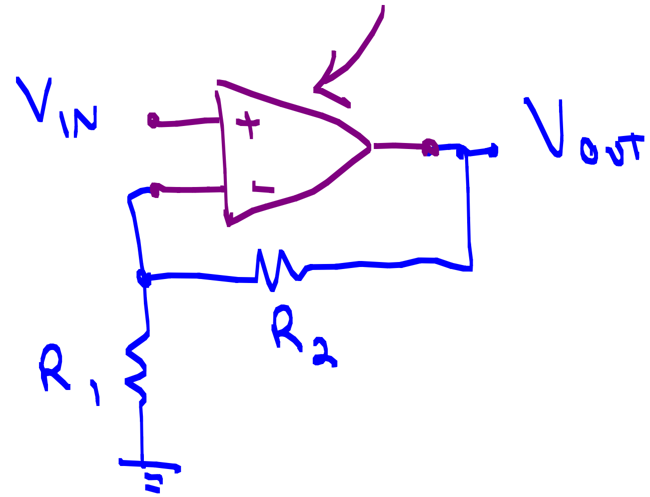
Electrocardiogram (ECG) signals





Application #3

Input stage for an op amp



2. BJT Long Tail Pair

- Classic configuration for differential amplifier

① Two inputs

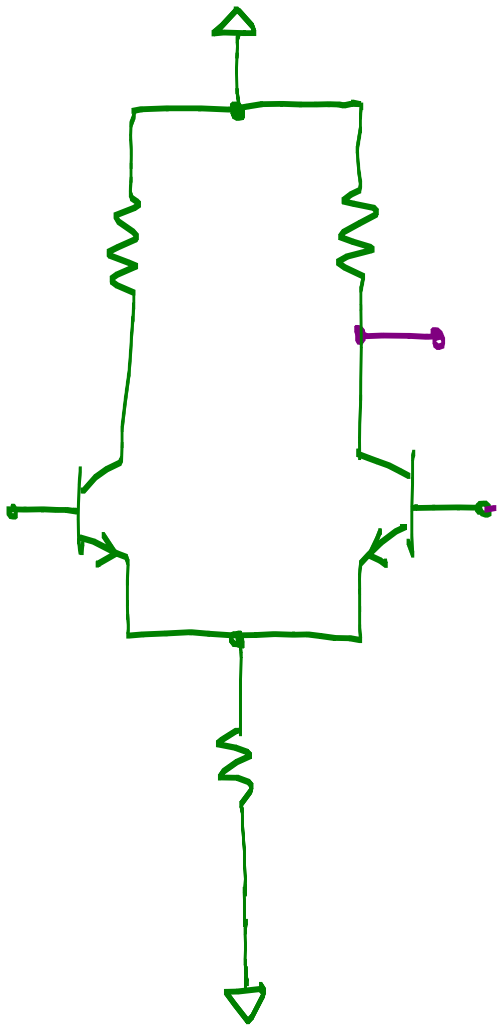
② Note the symmetry

③ Output

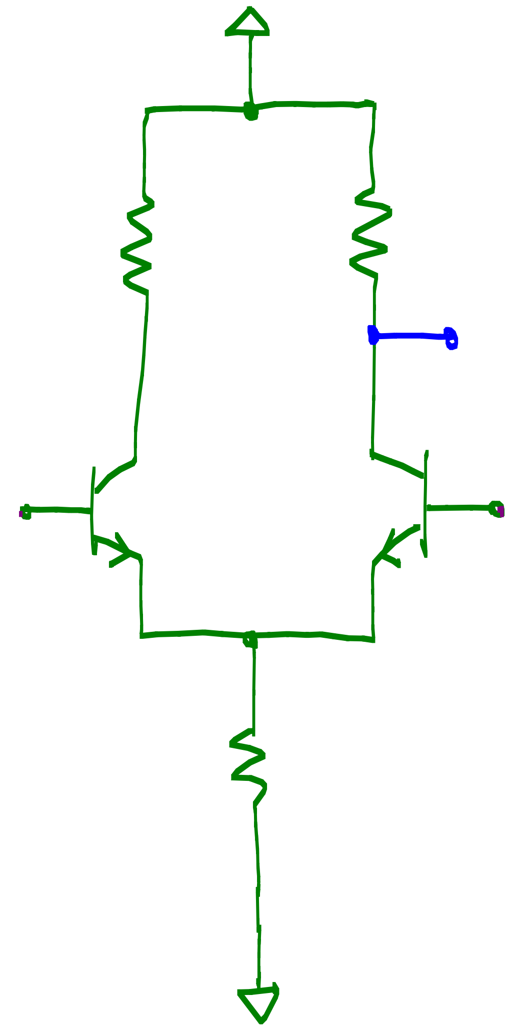
④ R_E

- How does this work?

Quiescent



Differential Input



Quiescent ($V_{IN1} = V_{IN2} = 0$)

- Assuming Q_1 + Q_2 are ON
- Tail current is therefore
- Due to symmetry, both Q_1 and Q_2 have
- Quiescent output voltage is

Differential Input

$\left(V_{IN1} = +\frac{\Delta V_{in}}{2},\ V_{IN2} = -\Delta V_{in}/2\right)$

- Q_1 and Q_2 act like a "see saw"

$V_{BE1} =$

$V_{BE2} =$

$i_{E1} =$

$i_{E2} =$

$i_{C1} =$

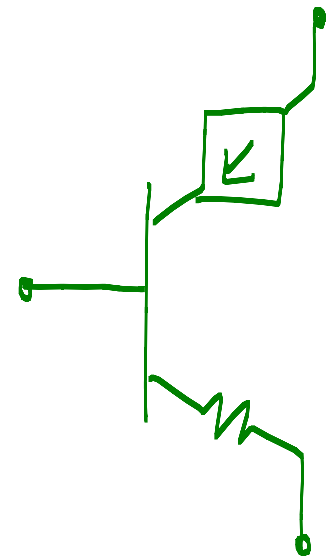
$i_{C2} =$

- Output voltage is therefore:

$V_{OUT} =$

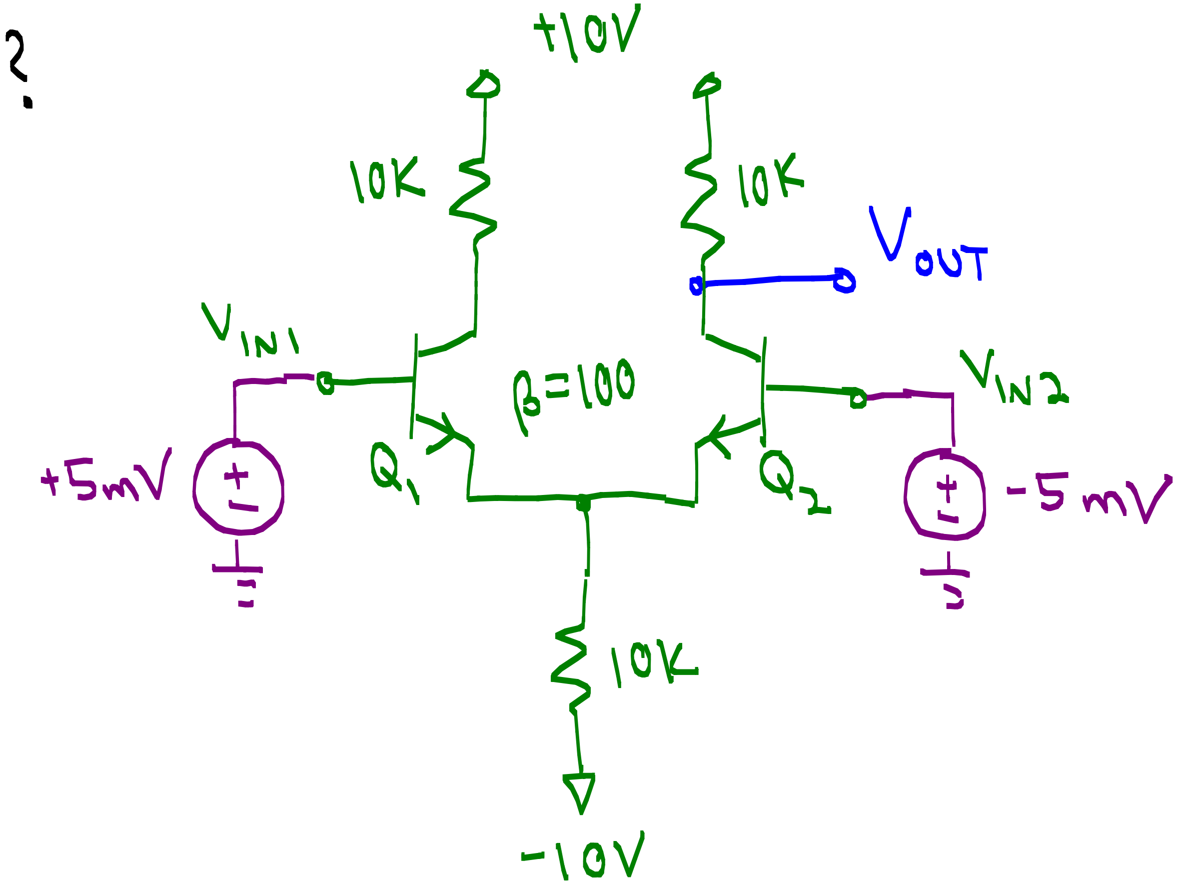
- What is i_e?

Recall the T-Model for BJT small signal behavior



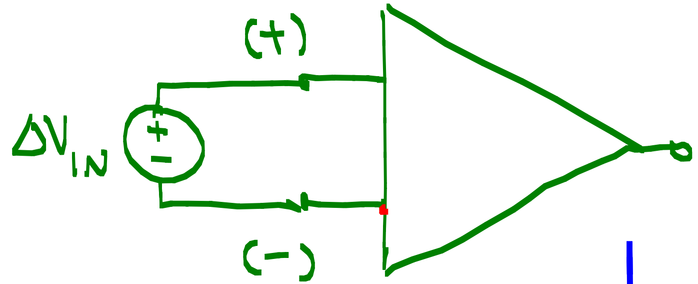
- Therefore, $A_d =$

D. Analysis Example: What is V_{OUT}?



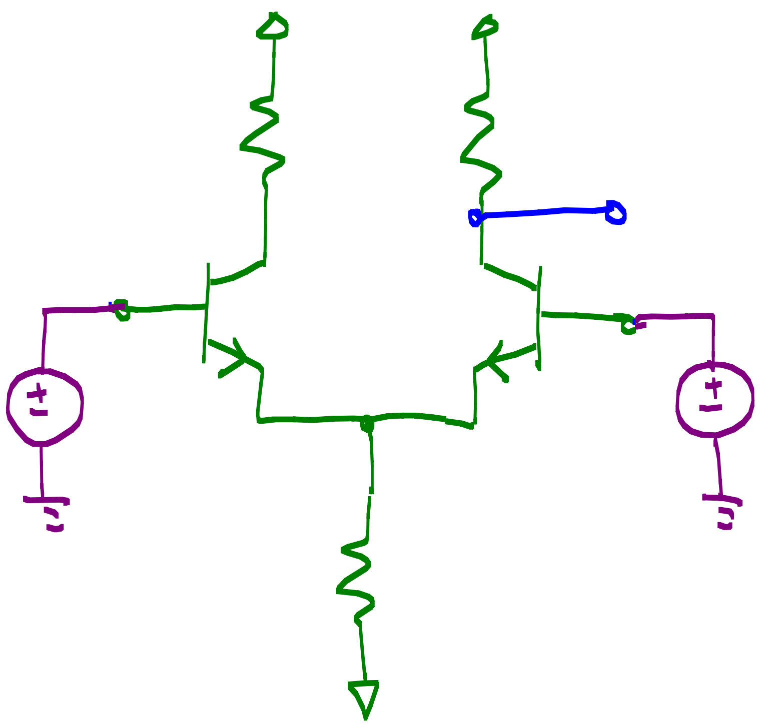
$V_{OUT} =$

3. Input Impedance

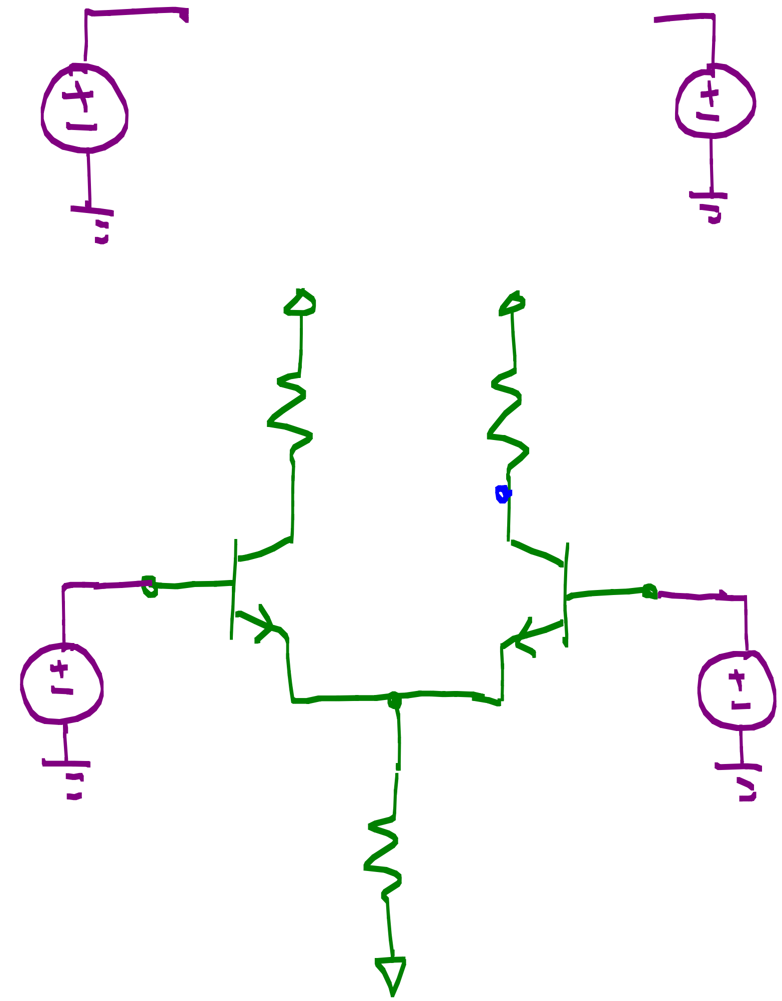


Derivation 1

$R_{in} =$

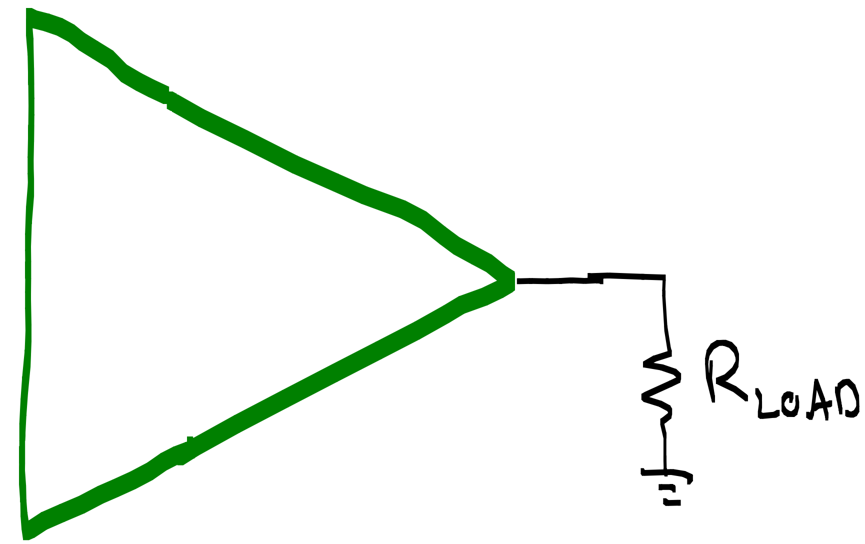


Derivation 2



4. Output Impedance

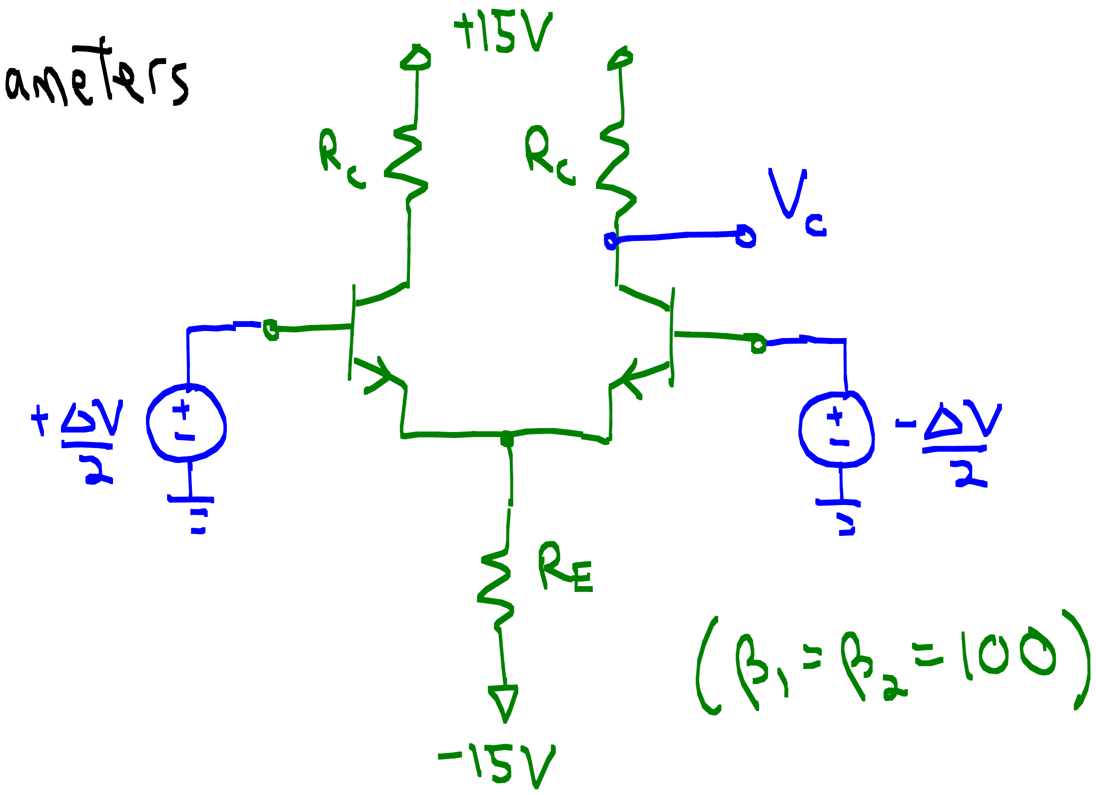
- A voltage amplifier ideally has $R_{OUT} \approx$



3. Design Example ← use "default" parameters

Gain ≥ 50, $R_{IN} \geq 10\,k\Omega$, $V_{CC} = V_{EE} = 15V$

Where to start?



12.12

②

③

④