Multi-Stage Amplifiers

ECE 321: Electronics II

Lecture #16

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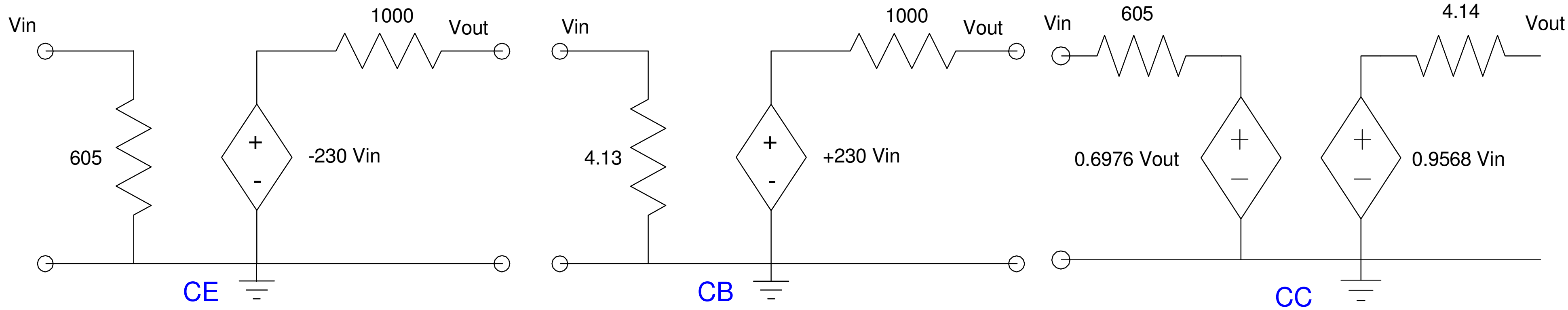
Please visit Bison Academy for corresponding lecture notes, homework sets, and solutions

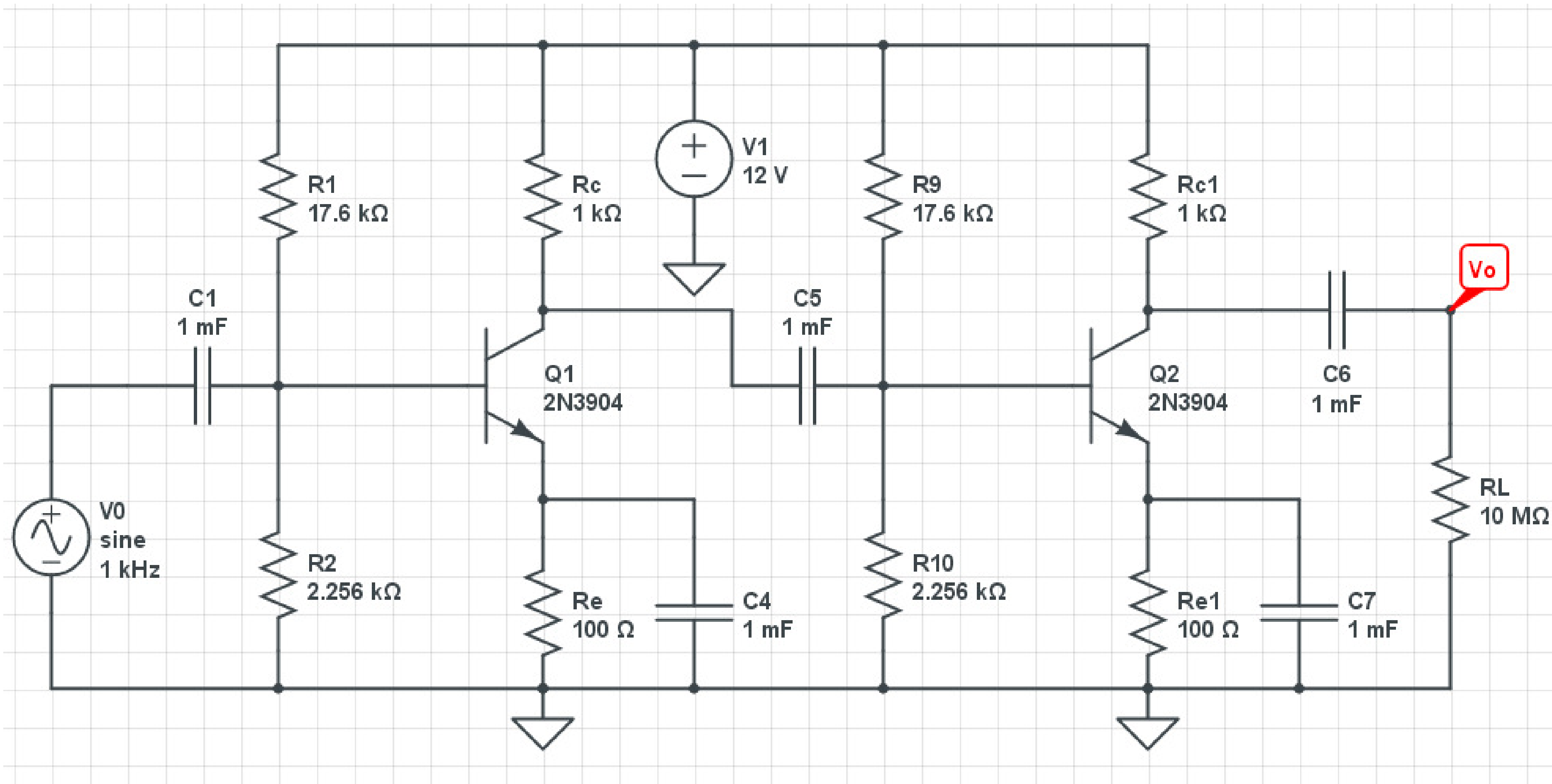
Recap:

CE, CB, CC Amplifiers

What do you get when you cancade amplifiers?

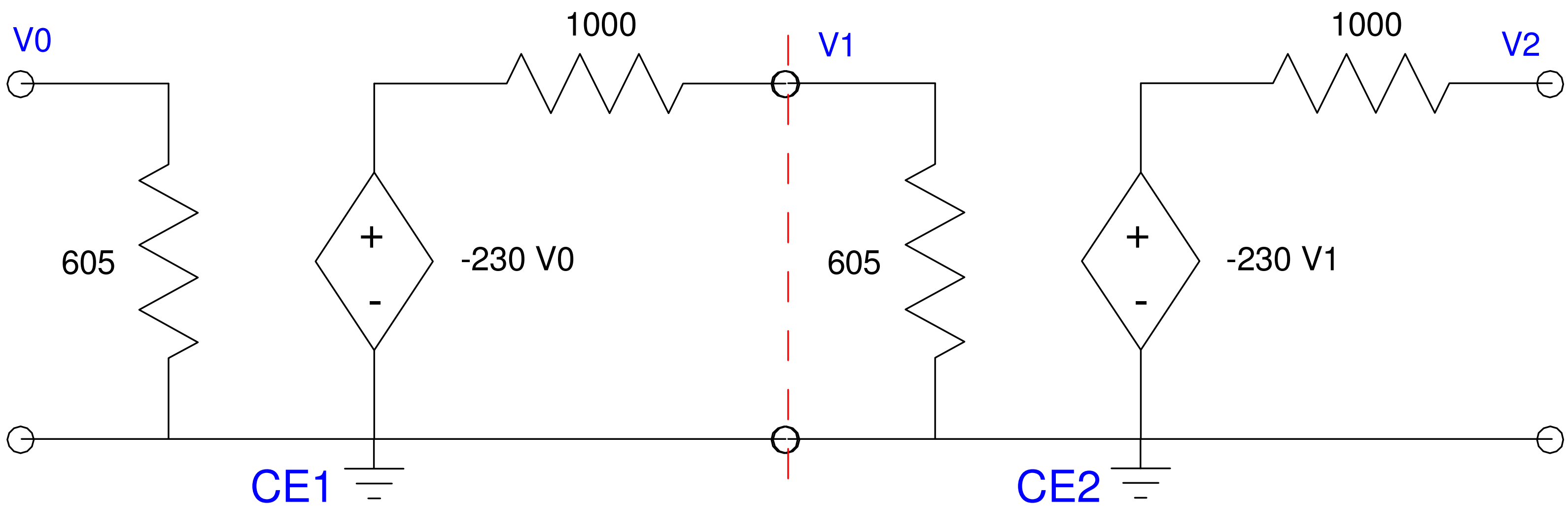


CE : CE


R1
17.6 kΩ
Rc
1 kΩ
V1
12 V
R9
17.6 kΩ
Rc1
1 kΩ
Vo
C1
1 mF
C5
1 mF
Q1
2N3904
Q2
2N3904
C6
1 mF
RL
10 MΩ
V0
sine
1 kHz
R2
2.256 kΩ
Re
100 Ω
C4
1 mF
R10
2.256 kΩ
Re1
100 Ω
C7
1 mF

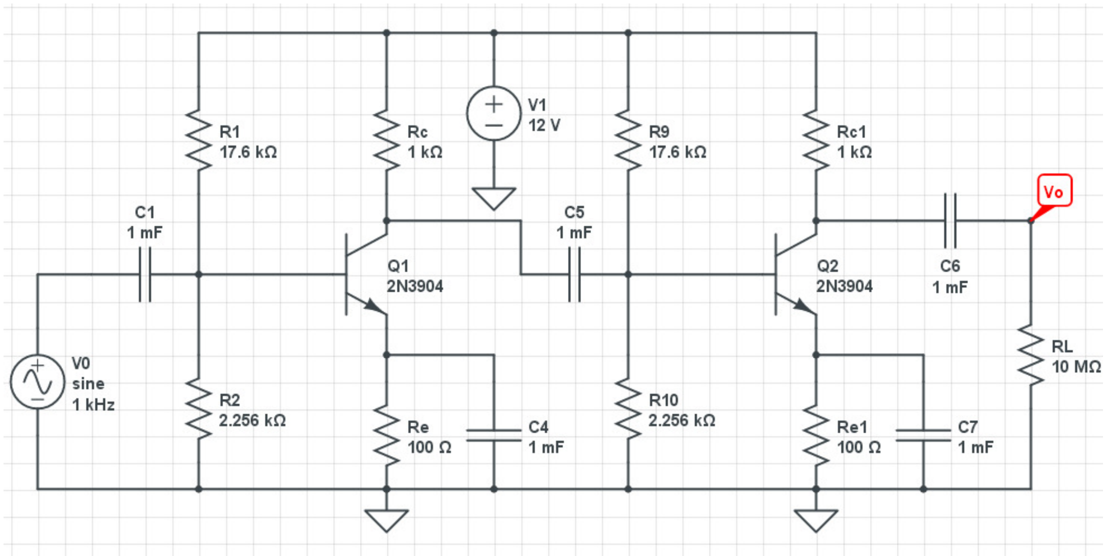
Replace with 2-Port Models

- Rin = 605
- Ai = 0
- Rout = 1000
- $A_o = (-230)\left(\frac{605}{1000+605}\right)(-230) = 19,940$



CircuitLab Results:

- Vout = 1.34V
- $A_o = \frac{1.34V}{0.1mV} = 13,400$



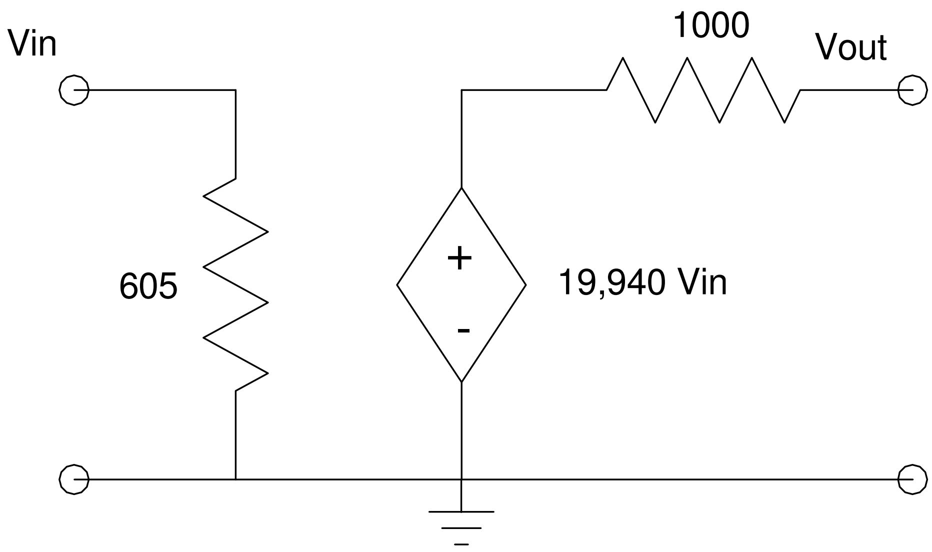
Change RL from 10M to 1k

- Vo drops to 689mV
- $R_{out} = \left(\frac{1.34V - 689mV}{689mV}\right)1000\Omega$
- $R_{out} = 944\Omega$

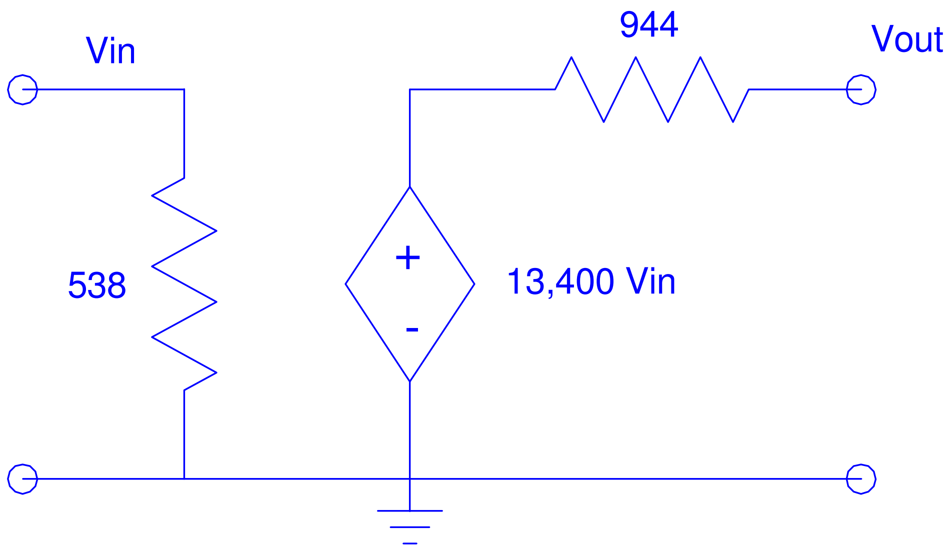
Change RL = 0 Ohms

- I(C1) = 185.8nA
- $R_{in} = \left(\frac{0.1mV}{185.8nA}\right) = 538\Omega$

CE : CE Results

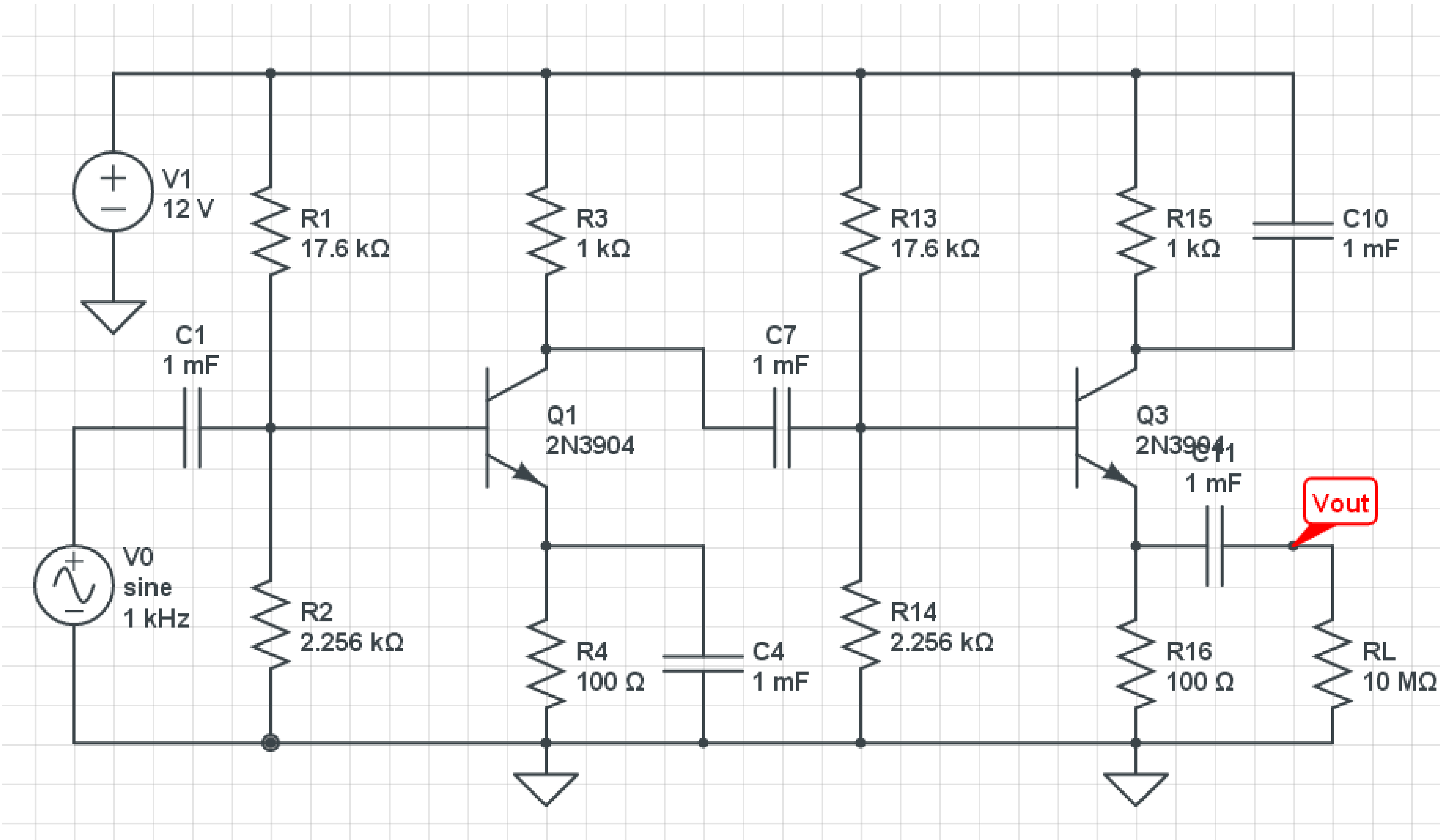


Calculated



Experimental (CircuitLab)

CE : CC

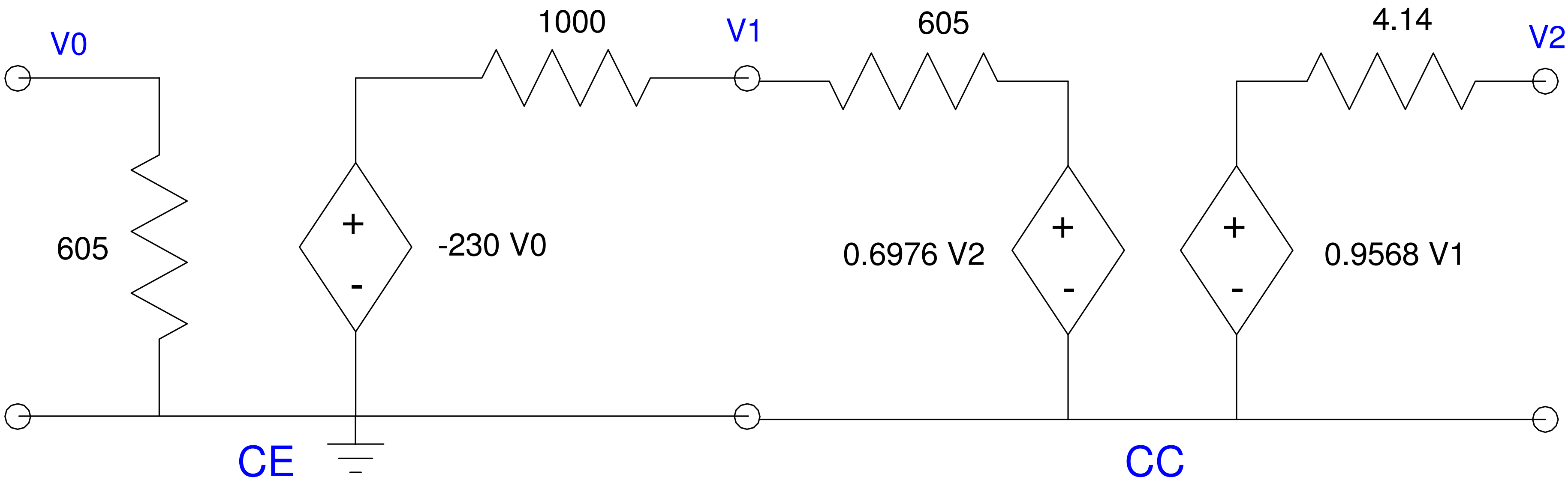


V1
12 V
R1
17.6 kΩ
R3
1 kΩ
R13
17.6 kΩ
R15
1 kΩ
C10
1 mF
C1
1 mF
C7
1 mF
Q1
2N3904
Q3
2N3904
C11
1 mF
Vout
V0
sine
1 kHz
R2
2.256 kΩ
R4
100 Ω
C4
1 mF
R14
2.256 kΩ
R16
100 Ω
RL
10 MΩ

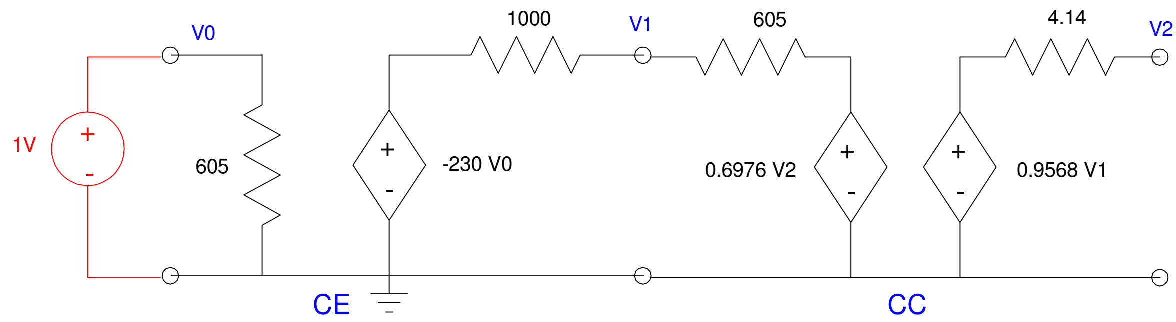
CE : CC

Step 1: Replace each stage with its 2-port model

- Rin = 605
- Ai = 0



Ao:



- Apply 1V at the input
- Compute V2
- Voltage Node equations...

$$\left(\frac{V_1-(-230)}{1000}\right)+\left(\frac{V_1-0.6976V_2}{605}\right)=0$$

$$V_2=0.9568V_1$$

substituting for V2

$$\left(\frac{V_1+230}{1000}\right)+\left(\frac{V_1-0.6976\cdot 0.9568V_1}{605}\right)=0$$

$$\left(\frac{1}{1000}+\frac{1-0.6976\cdot 0.9568}{605}\right)V_1=-\left(\frac{230}{1000}\right)$$

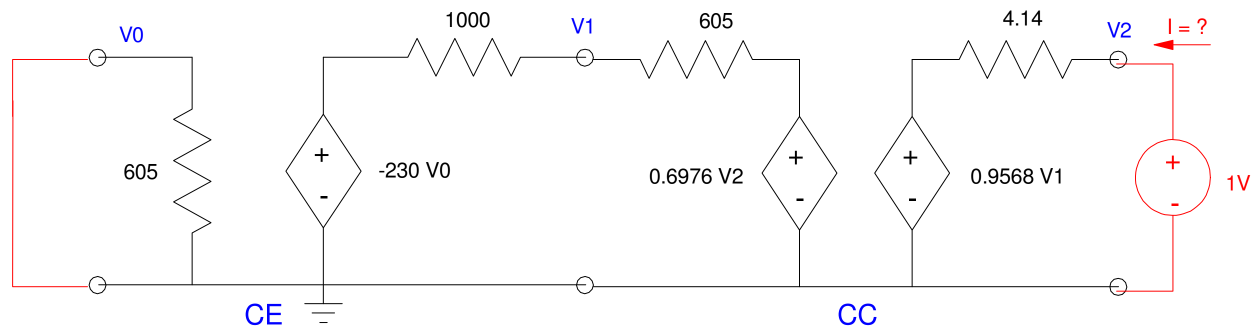
$$V_1=-148.42$$

$$V_2=0.9568V_1=-142.0$$

Ao = -142.0

Rout:

- Short Vin
- Apply 1V to Vout
- Compute the current



$$V_1 = \left(\frac{1000}{1000+605}\right)0.6876V$$

$$V_1 = 0.4346V$$

$$0.9568V_1 = 0.4159$$

$$I = \left(\frac{1V-0.4159V}{4.14\Omega}\right) = 141.1mA$$

$$R_{out} = \frac{1V}{141.1mA} = 7.087\Omega$$

Simulation Results

Ao = 130.3

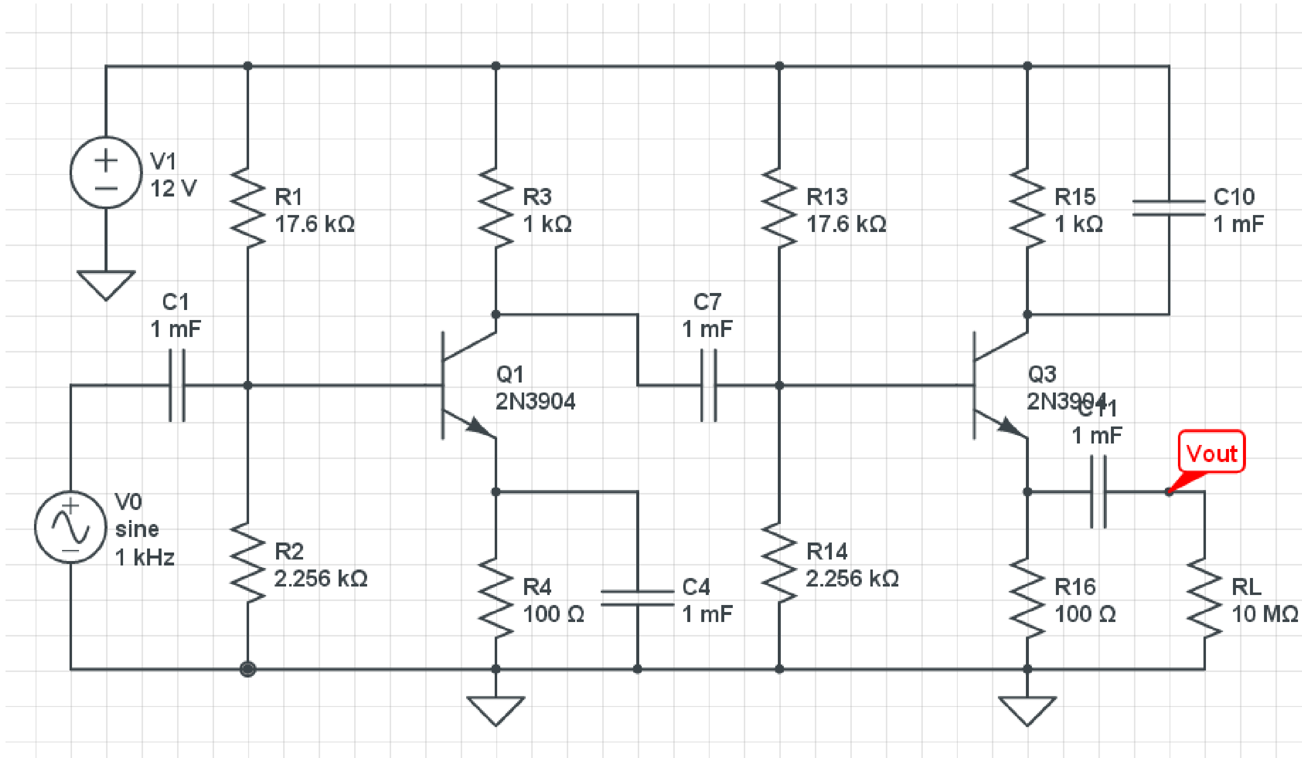
- RL = 10M
- V0 = 1mV, 1kHz
- Vout = 130.3mV

Rin = 506 Ohms

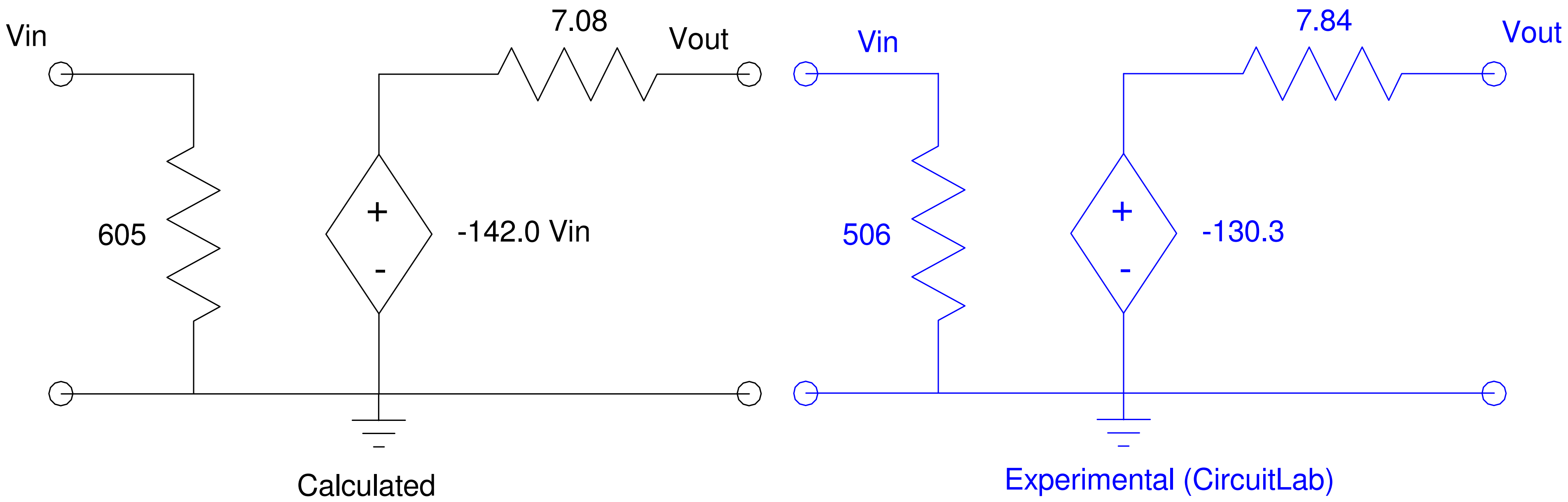
- RL = 0
- V0 = 1mV, 1kHz
- I0 = 1.974uA
- Rin = 1mV / 1.974uA

Rout = 7.84 Ohms

- RL = 8
- V0 = 1mV, 1kHz
- Vout = 67.1mV

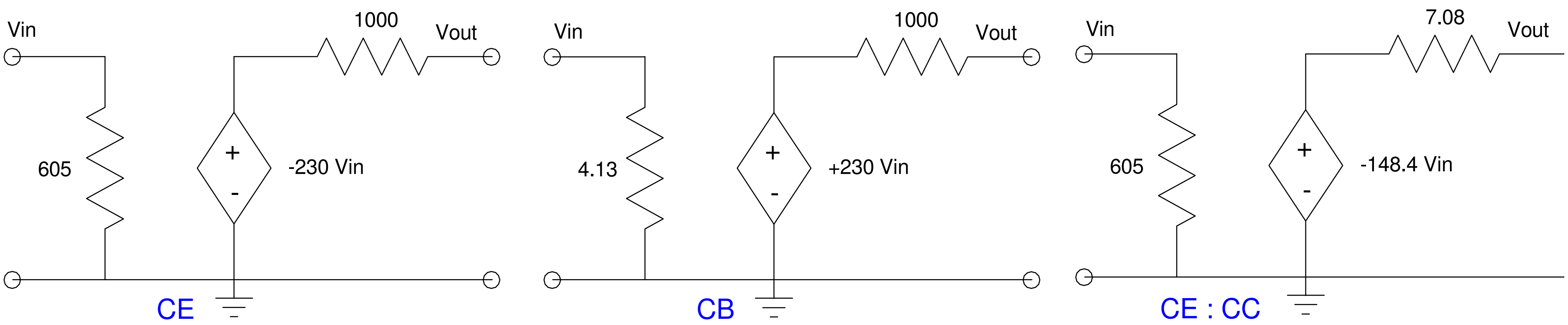


CE : CC Results



Multi-Stage Amplifiers.

The shopping list of amplifiers you have to play with are as follows:



In general:

- CE amplifiers are good for increasing the gain.
- CB amplifiers are good for te first stage if you need a low input impedance.
- CC amplifiers are good for the last stage if you are driving a low-impedance load, such as an 8-Ohm speaker.

Problem: Design an amplifier

Input: Phonograph needle: R_N = 10 Ohms

$I_{in} = 1\mu A$

Output: 8 Ohm Speaker

Relationship:

Vout > 10Vp

Design

Stage 1: CB

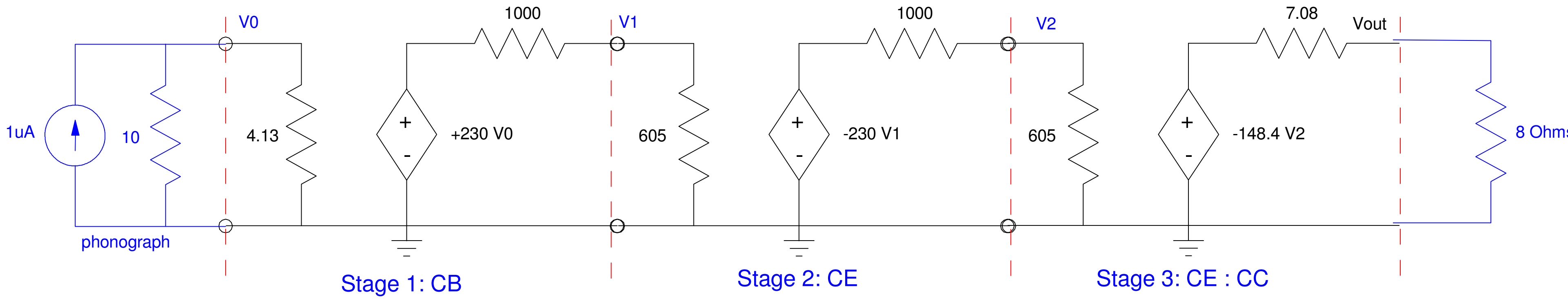
- Low input impedance (current source)

Stage N: CE : CC

- Low output impedance

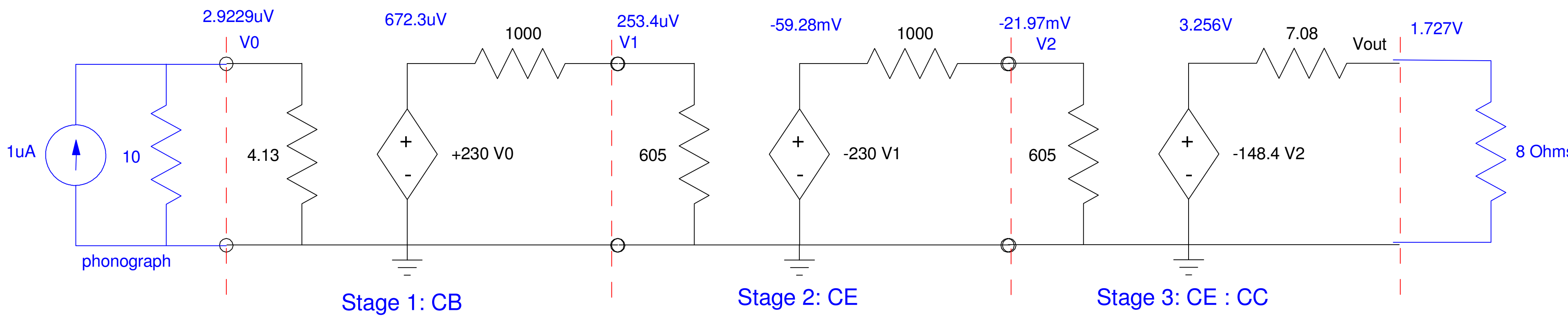
CE inbetween

- Adds gain



Voltage Analysis

- Iin = 1uA (peak)
- Vout = 1.727V (peak)



Add another CE amplifier

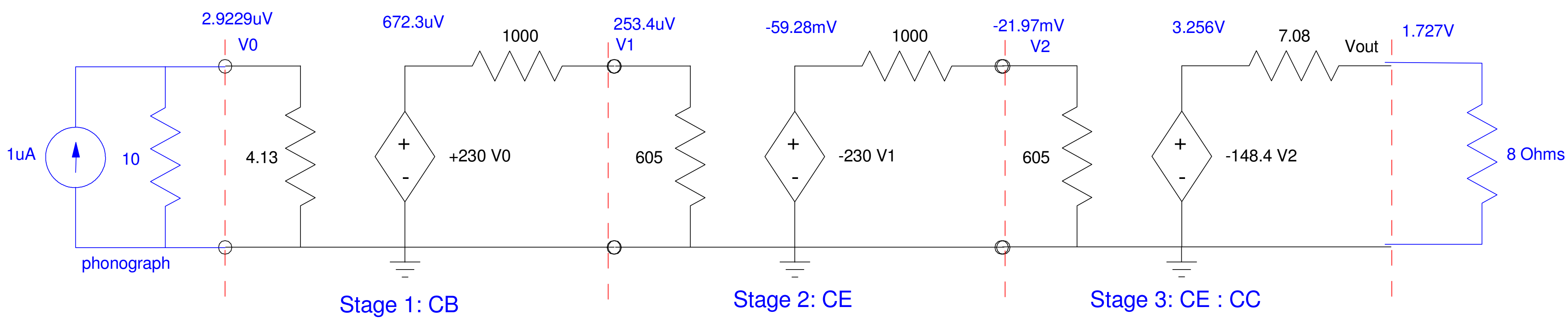
- Adds another gain of 86.7

$$-230\left(\frac{605}{1000+605}\right) = 86.7$$

- Increases Vout to 149.7V

Reduce the gain so that Vout = 10.00V

- Add a resistor in series in stage #2a or Stage #2b to reduce the gain
- Last stage wastes power (bad)
- First stage decreases the signal (hurts signal to noise ratio - also bad)



Options for Driving a Speaker

Make the last stage CE : CC

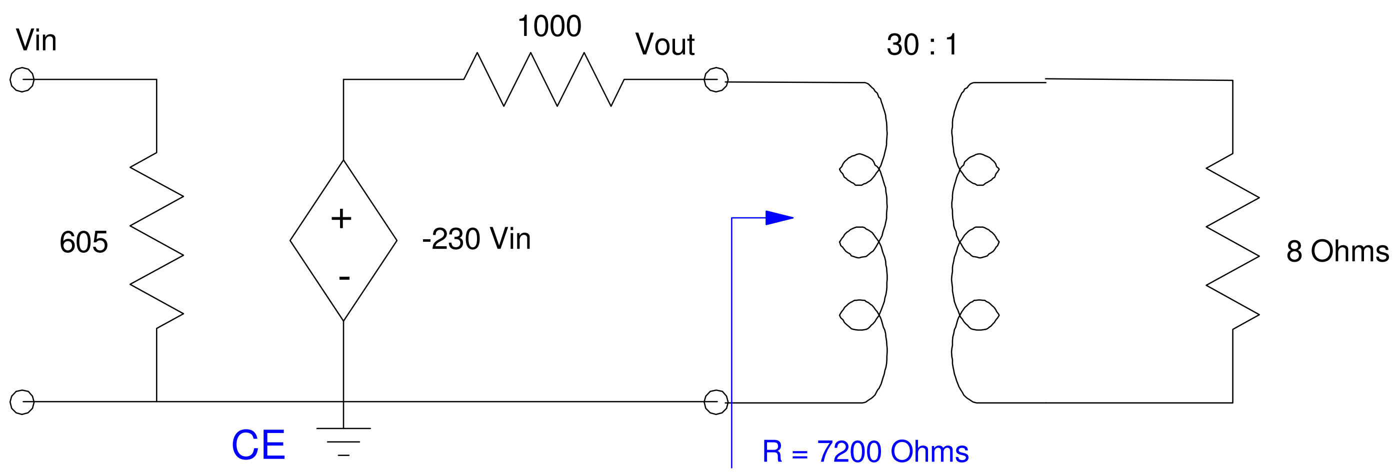
- Low output impedance

Have the last stage (CE) drive a push-pull amplifier

- Uses a transistor to amplify the current
- Input impedance is 4G Ohms (MCP602)

Add a transformer before the speaker

- Impedances go through a transformer as the turn-ratio squared



Summary

Mix and match CE, CB, CC amplifiers to create a multi-stage amplifier

First stage is either CE or CB

- CE for high input impedance, CB for low impur impedance

Middle stages are CE

- Each CE increases the gain by 86

Last stage is either CE or CC

- CE if high output impedance is OK (driving a push-pull amplifier), CC if not