DIS 6B Indepth example of a design problem

Design? What is it → Choosing/making a circuit to accomplish a goal

goal/behavior → ckt.

Analysis : ckt → behavior (volts/currents)

1. Understand behavior/goal we want to achieve
2. Formulate this as block diagrams/math
3. Think about limitations and constraints
4. Choose circuits and modify them

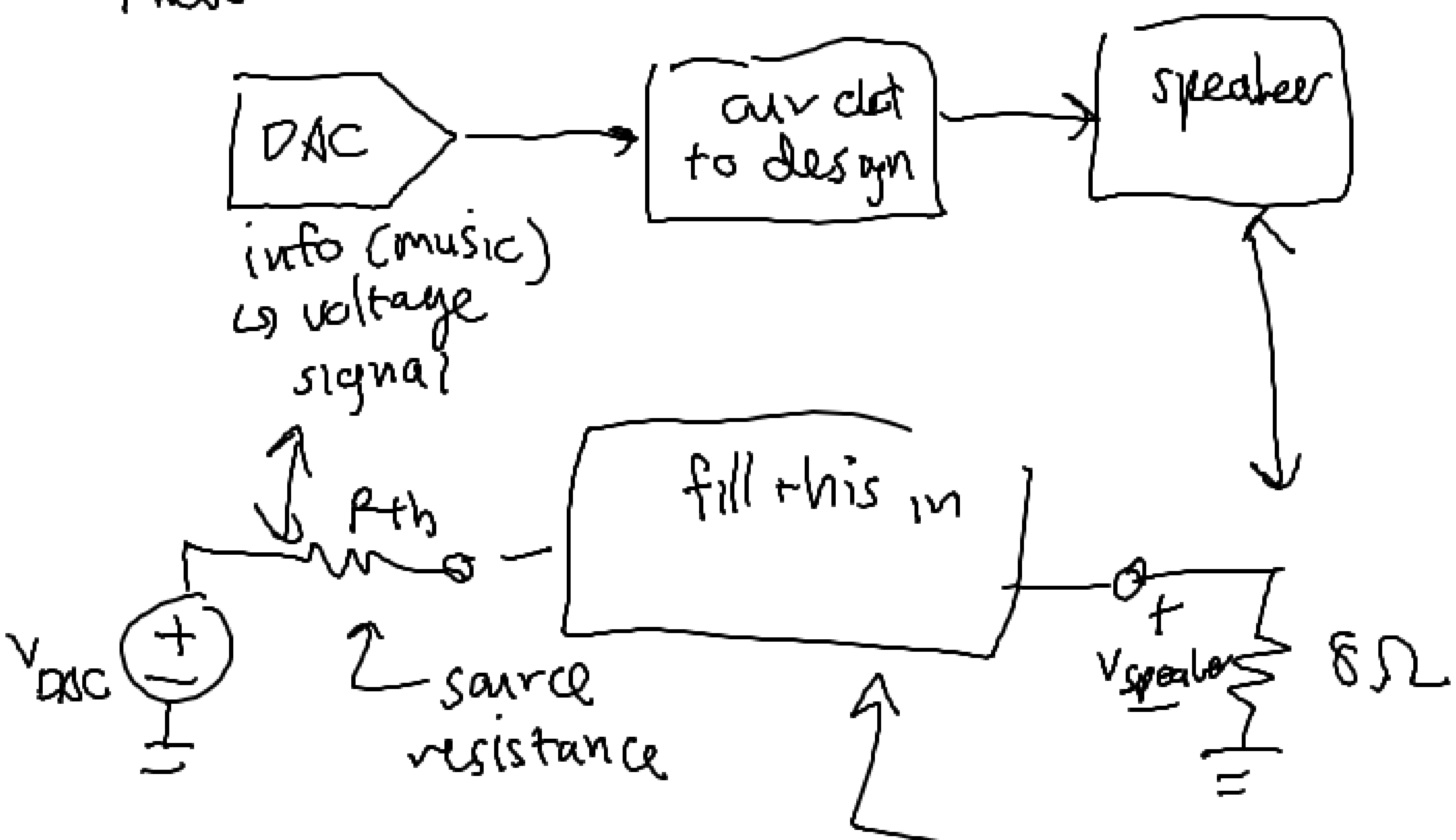
Noise cancelling headphones

1 (a) → How to get music signal to headphones

1 (b) → How to also add noise cancelling on top

Source resistance?

Thevenin model of a ckt



$0V \leq V_{DAC} \leq 1V$

Goals

$-1.5V \leq V_{speaker} \leq 1.5V$

What do we have?

- Op amps (∞)
- Voltage sources ($1.5V$, $-1.5V$)
- Resistors (∞)

$0V \le V_{DAC} \le 1V$ → centered @ $\frac{1}{2}V$

$-1.5V \le V_{speaker} \le 1.5V$ → centered @ 0V
max/min are source voltages

$-\frac{1}{2}V \le V_{DAC} - \frac{1}{2}V \le \frac{1}{2}V$

$-\frac{3}{2}V \le 3(V_{DAC} - \frac{1}{2}V) \le \frac{3}{2}V$

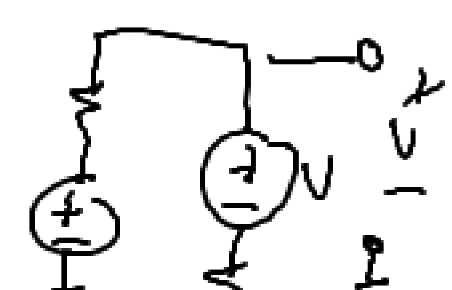
$V_{speaker} = 3(V_{DAC} - \frac{1}{2}V)$

1. "Do the math"
2. Make a block diagram
3. Ckts for each block

Candidates for $-\frac{1}{2}V$ shift

- op amp
- tran resistance X
  current + volt.
- non invert amp
  limitation
- voltage summer

$\frac{R_2}{R_1+R_2} = 1$?



can't make R_1 or $R_2 = 0$
if we want it to be useful

① $3\left(V_{DAC} - \frac{1}{2}V\right) \Longleftrightarrow$ ② $3V_{DAC} - \frac{3}{2}V$

Implement ① or ②

Design 1

- subtract $\frac{1}{2}V$
- mult. by 3

Design 2

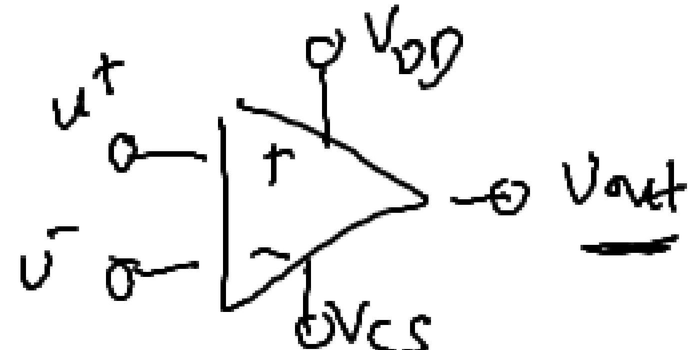
- Multiply by 3 ←
- subtract $\frac{3}{2}$

Not feasible

Why?: Can't output higher than 1.5V

$0V \leq V_{DAC} \leq 1V$

$0V \leq 3V_{DAC} \leq \underline{3V}$



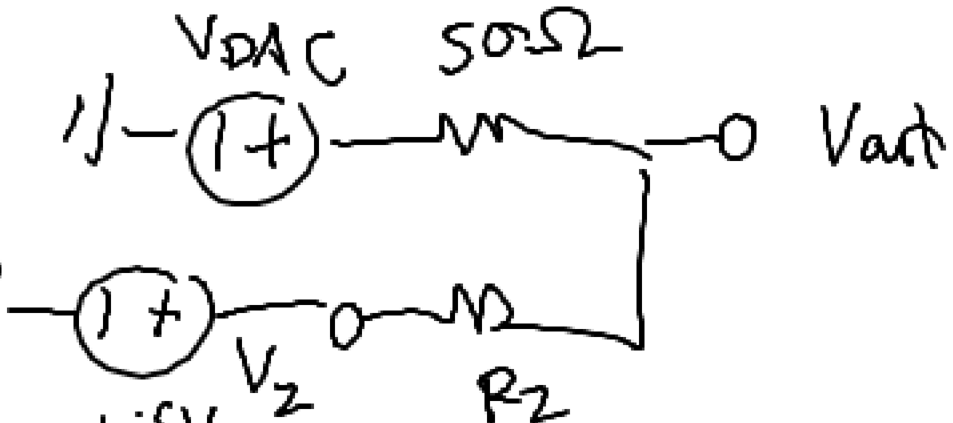
$V_{DD} = 1.5V, \quad V_{SS} = -1.5V$

$$-\frac{1}{2} \le V_{DAC} - \frac{1}{2}V \le \frac{1}{2}$$

$V_1 = V_{DAC}$ $R_{th} = 50\,\Omega$ (source resistance)

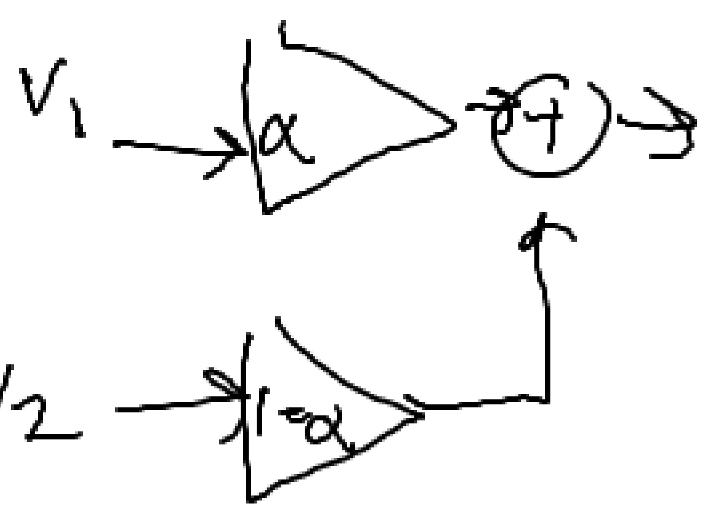
$$V_{out} = \underbrace{\left(\frac{R_2}{R_1+R_2}\right)}_{\alpha} V_1 + \underbrace{\left(\frac{R_1}{R_1+R_2}\right)}_{1-\alpha} V_2$$

$0 < \alpha < 1$



Subgoal: Find R_2 to center voltage

Make $V_2 = -1.5V$



$$V_{out} = V_{DAC}\,\alpha + \left(-\frac{3}{2}V\right)(1-\alpha)$$

Want to center @ zero to not damage speaker

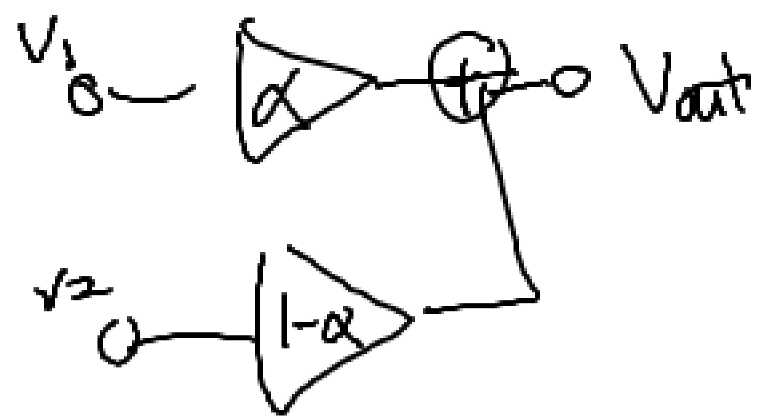
output $V_{out} = 0V$ when $V_{DAC} = \frac{1}{2}V$

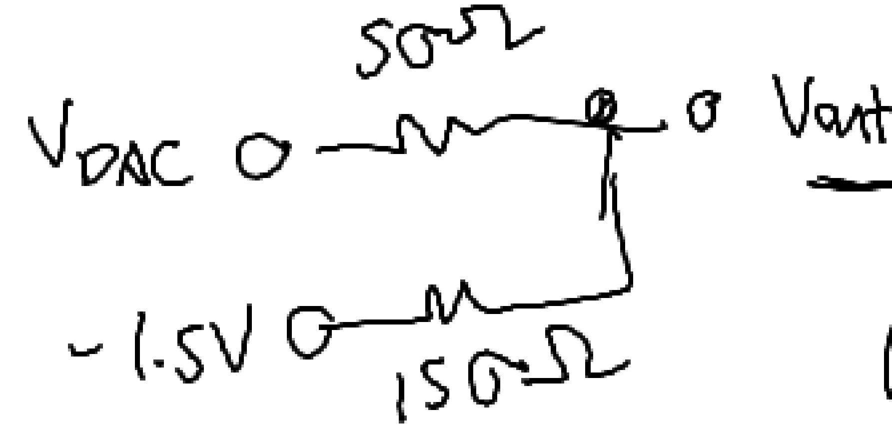
→ $\frac{1}{2}V$ is the middle of V_{DAC}'s range

$$0V = \frac{1}{2}V\alpha + \left(-\frac{3}{2}V\right)(1-\alpha) \Rightarrow \alpha = 3/4$$

$$0 = \frac{1}{2}\alpha - \frac{3}{2} + \frac{3}{2}\alpha$$

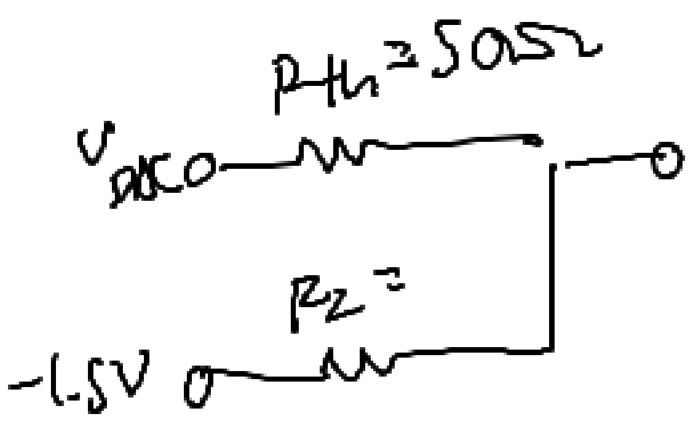
$$\frac{3}{2} = 2\alpha \Rightarrow \alpha = \frac{3}{4}$$





X $-\frac{1}{2}V \le V_{DAC} - \frac{1}{2} \le \frac{1}{2}V$

↳ $-? \le V_{out} \le ?$



$V_{DAC} = 1V$ $\quad V_{out} = \alpha V_{DAC} + (1-\alpha)(-1.5V)$

$$= \frac{1.5V}{4} = \underline{\frac{3}{8}V}$$

$\alpha = \frac{3}{4}$

$V_{DAC} = 0V$ $\quad V_{out} = \frac{3}{4} \cdot 0V + \frac{1}{4}(-1.5V)$

$$= \underline{-\frac{3}{8}V}$$

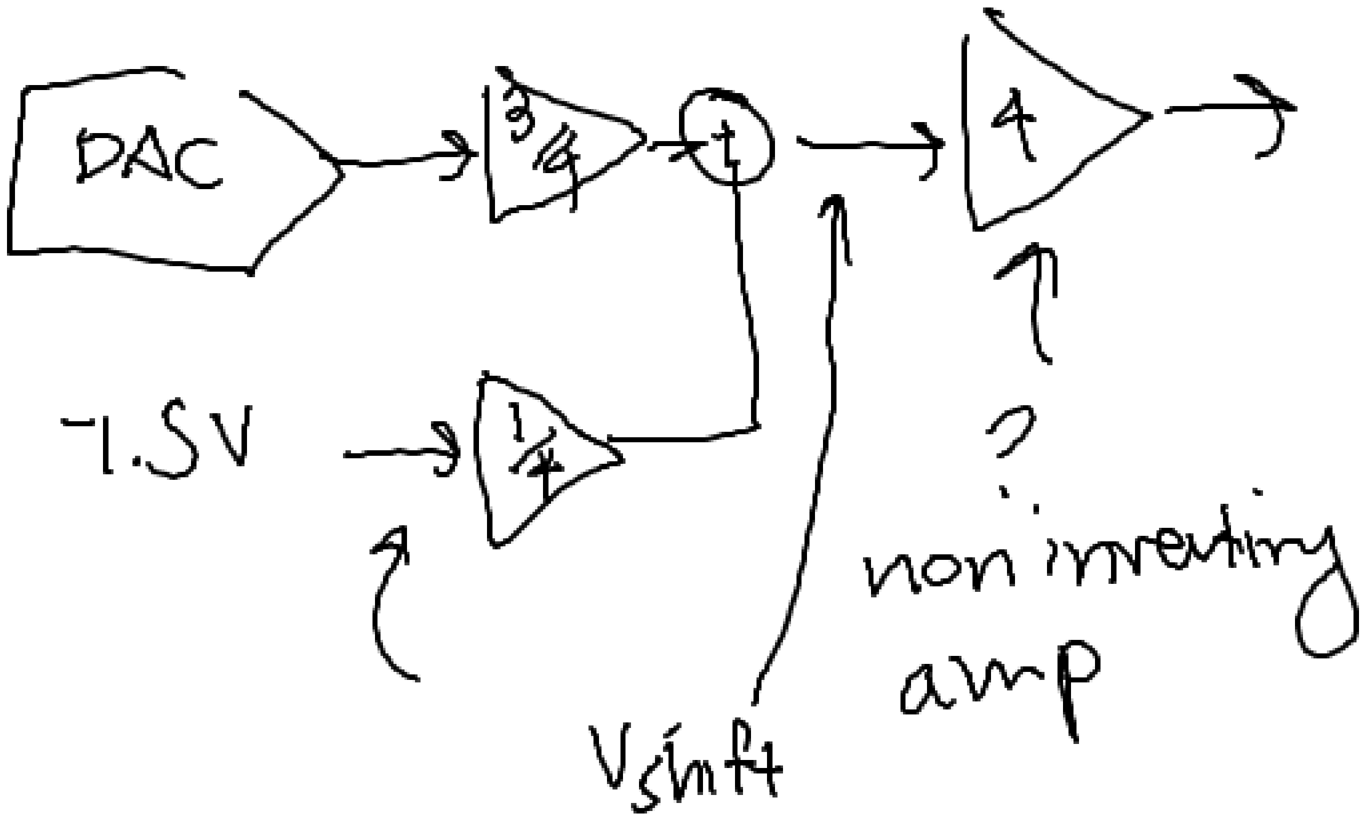
$$\frac{3}{4} = \alpha = \frac{R_2}{R_2 + R_{th}} = \frac{R_2}{R_2 + 50\Omega}$$

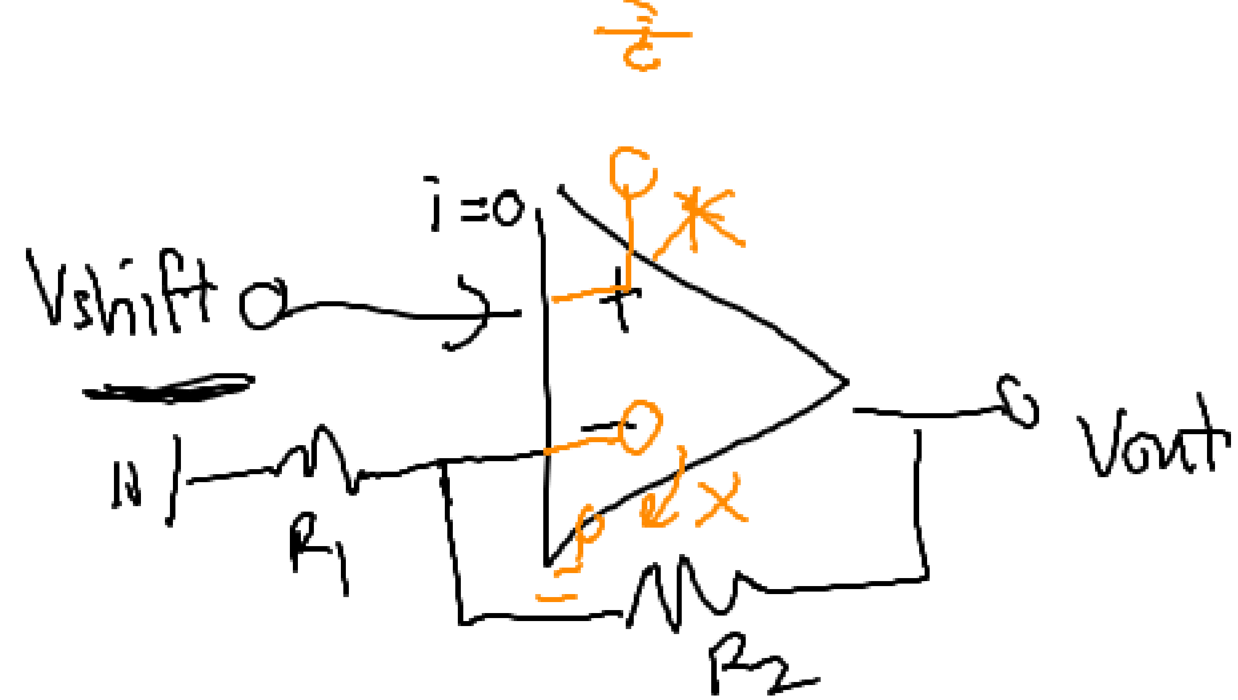
$\boxed{R_2 = 150\Omega}$ $\quad \frac{150\Omega}{200\Omega} = \frac{3}{4}V$

X Amplify by 3. $\left(\frac{1}{2} \to \frac{3}{2}\right)$

$\Rightarrow$ Amplify by 4 $\left(\frac{3}{8} \to \frac{3}{2}\right)$

Amplify by 4



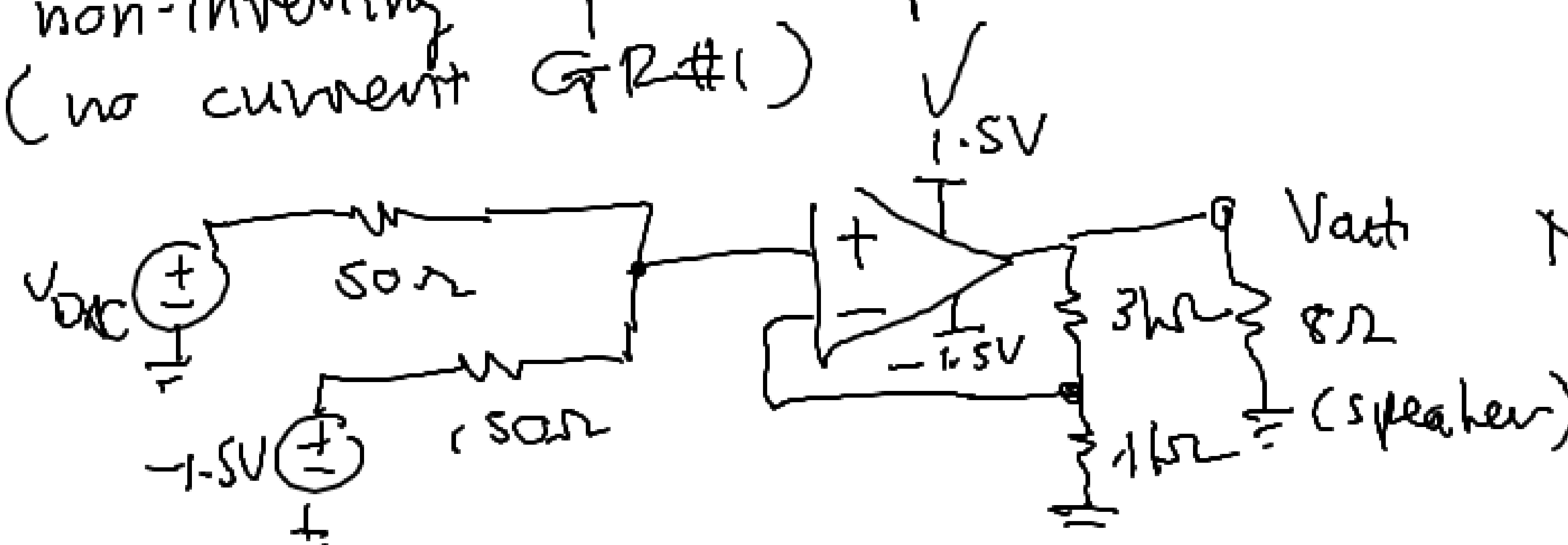


$$V_{out} = \underbrace{\left(1+\frac{R_2}{R_1}\right)}_{4} V_{shift}$$

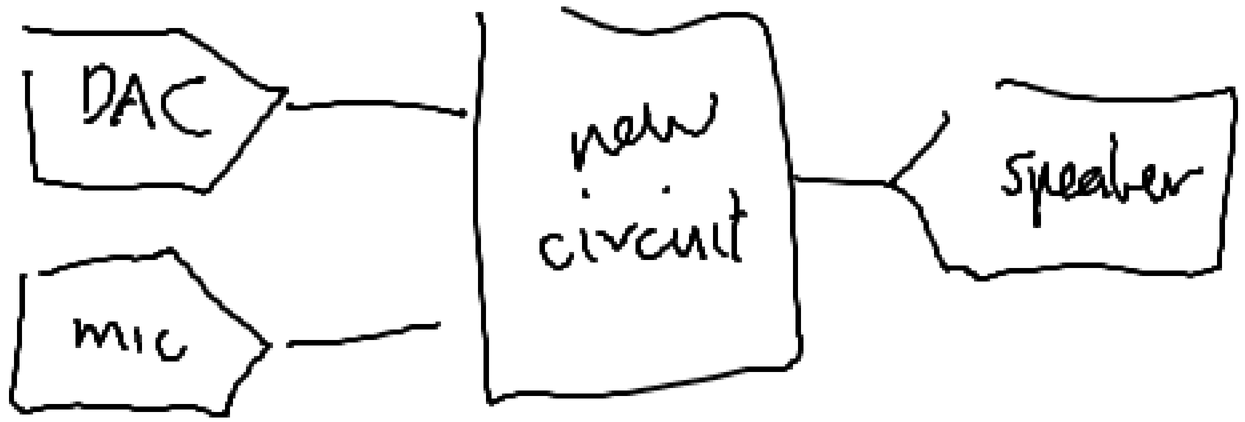
Choose $R_2 = 3R_1$

$R_1 = 1k\Omega$
$R_2 = 3k\Omega$

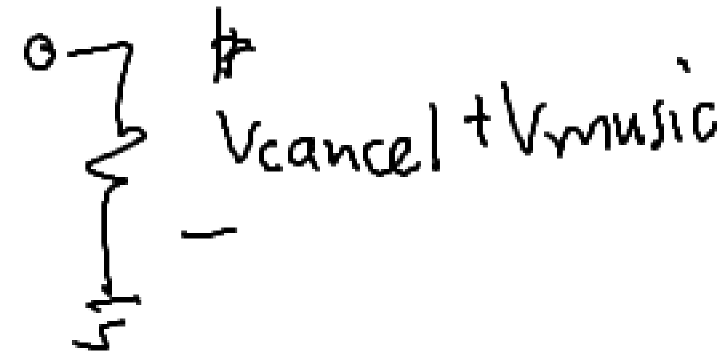
No loading: + input terminal of non-inverting amp is an open (no current GR#1)



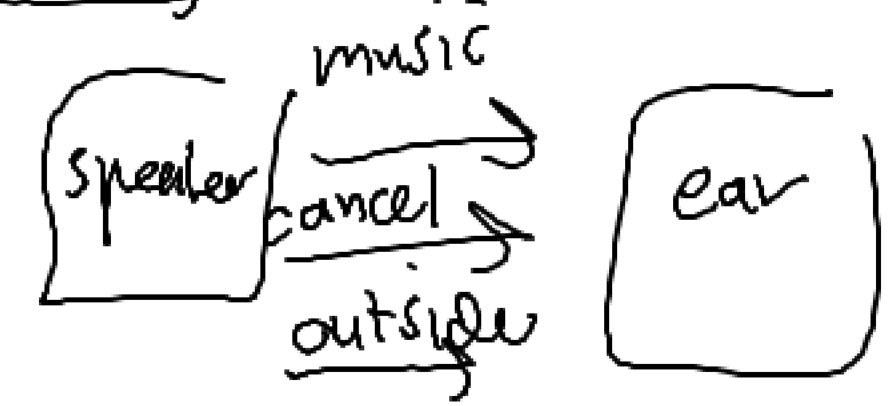
Design done
No issues from source limitations



mic – outside signal



Design goal



$$\text{heard} = \text{music} + \underbrace{\text{cancel} + \text{outside}}$$

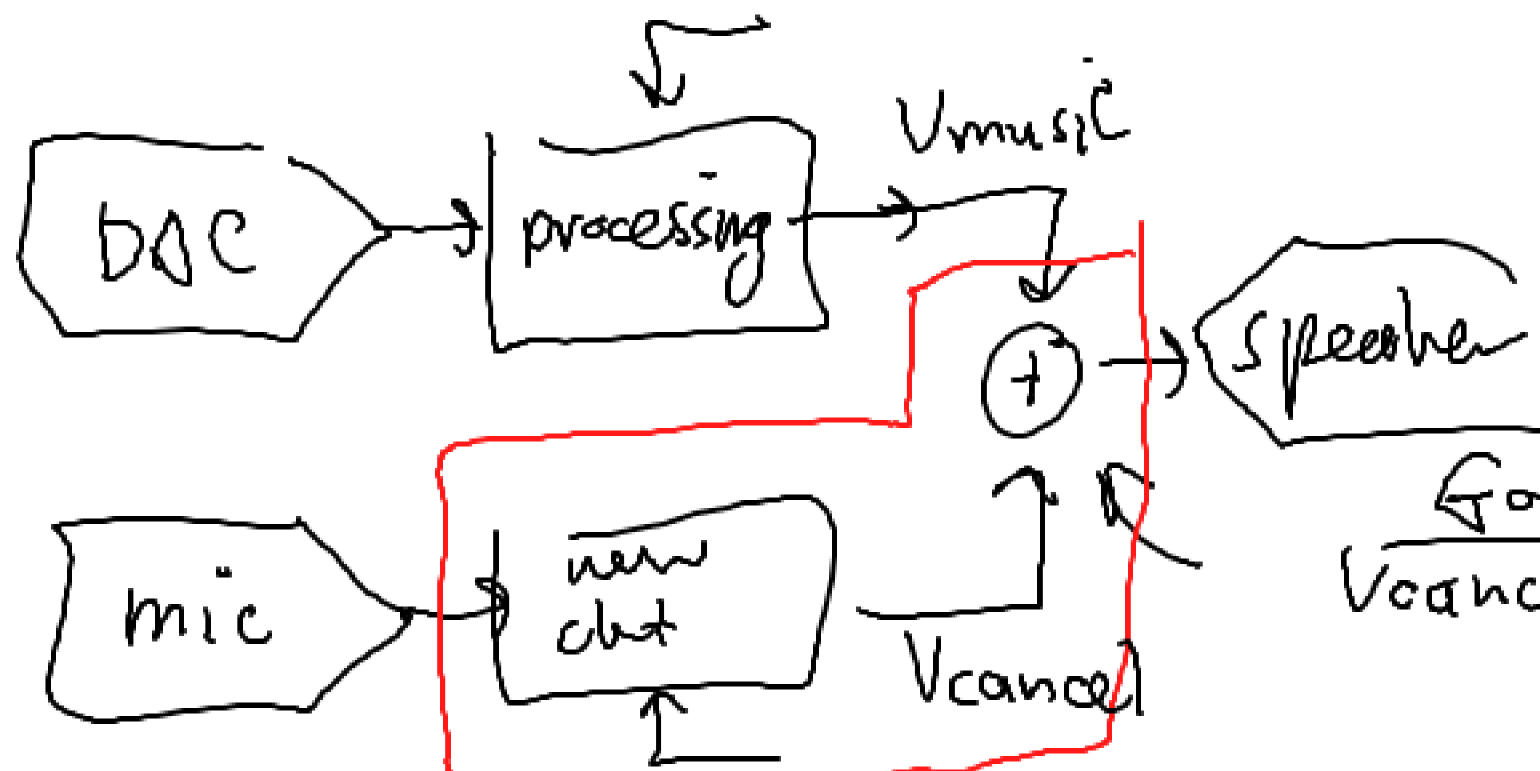
$\Rightarrow$ want: cancel = − outside

$$0 \le V_{mic} \le 1$$

$$-\frac{1}{8}V \le V_{cancel} \le \frac{1}{8}V$$

$$-\frac{1}{2} \le V_{mic} - \frac{1}{2}V \le \frac{1}{2}$$

$$-\frac{1}{8} \le \underbrace{-\frac{1}{4}\left(V_{mic} - \frac{1}{2}V\right)} \le \frac{1}{8}$$

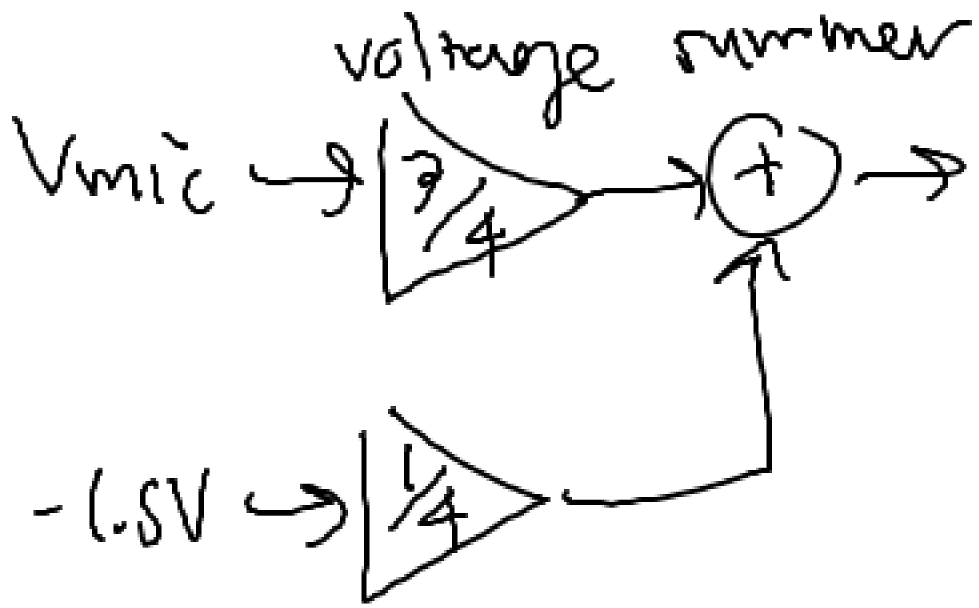


Goal

$$V_{cancel} = -\frac{1}{4}\underbrace{\left(V_{mic} - \frac{1}{2}V\right)}$$

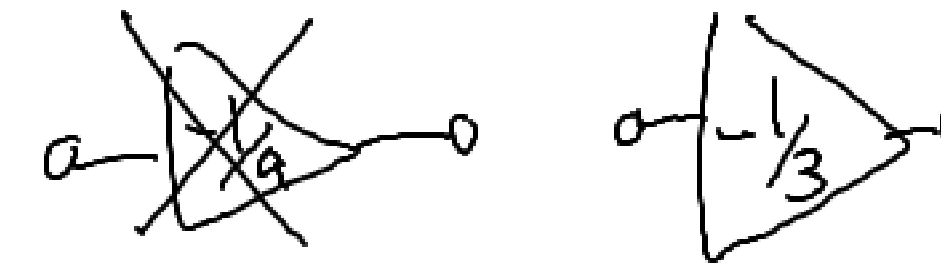
$$V_{cancel} = -\frac{1}{4}\left(V_{mic} - \frac{1}{2}V\right)$$

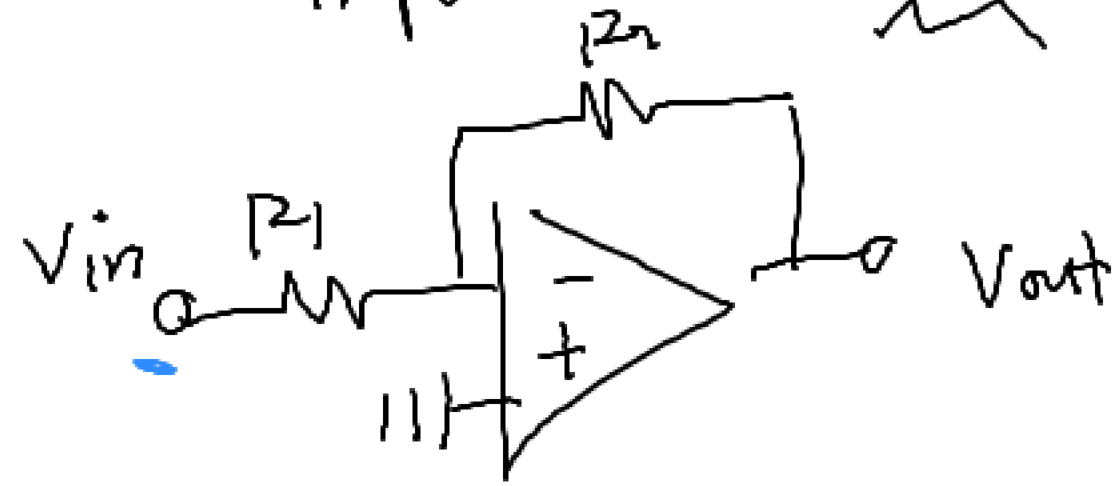
$-\frac{1}{8}V$ to $\frac{1}{8}V$



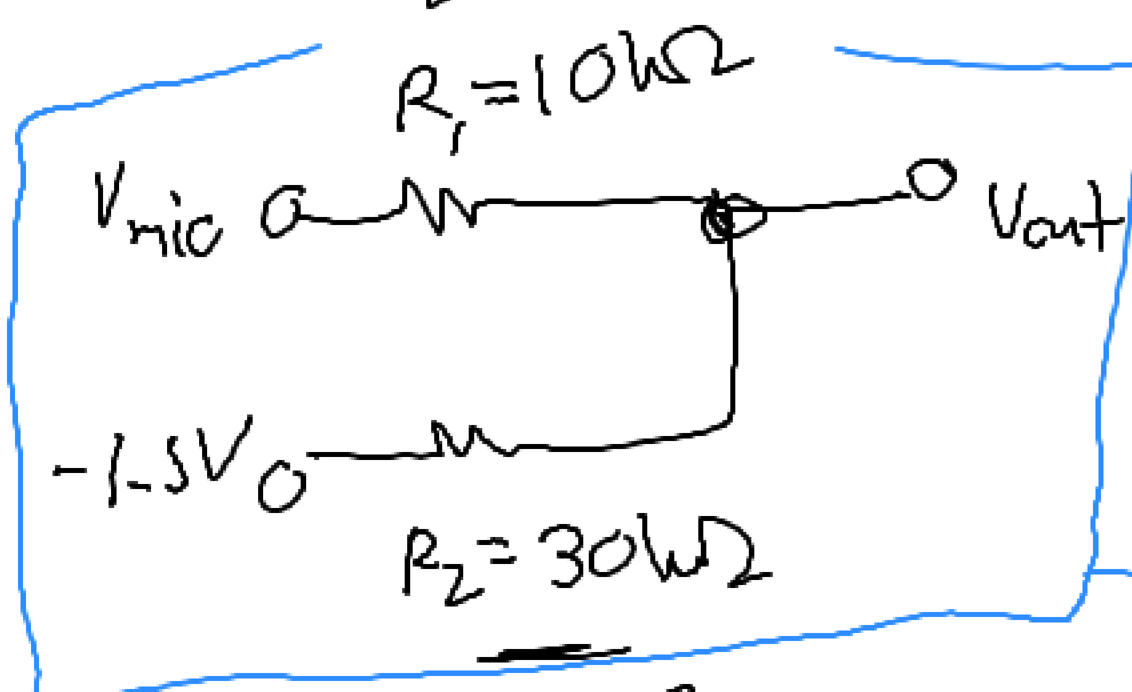
$-\frac{3}{8}V$ to $\frac{3}{8}V$

implement





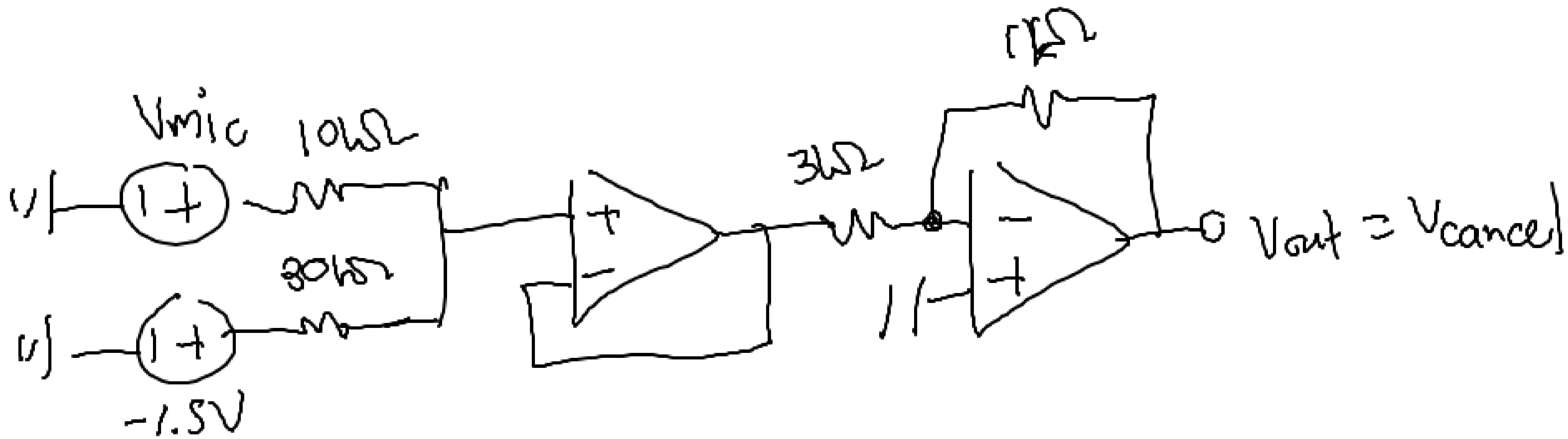
$$V_{out} = -\frac{R_2}{R_1} V_{in}$$

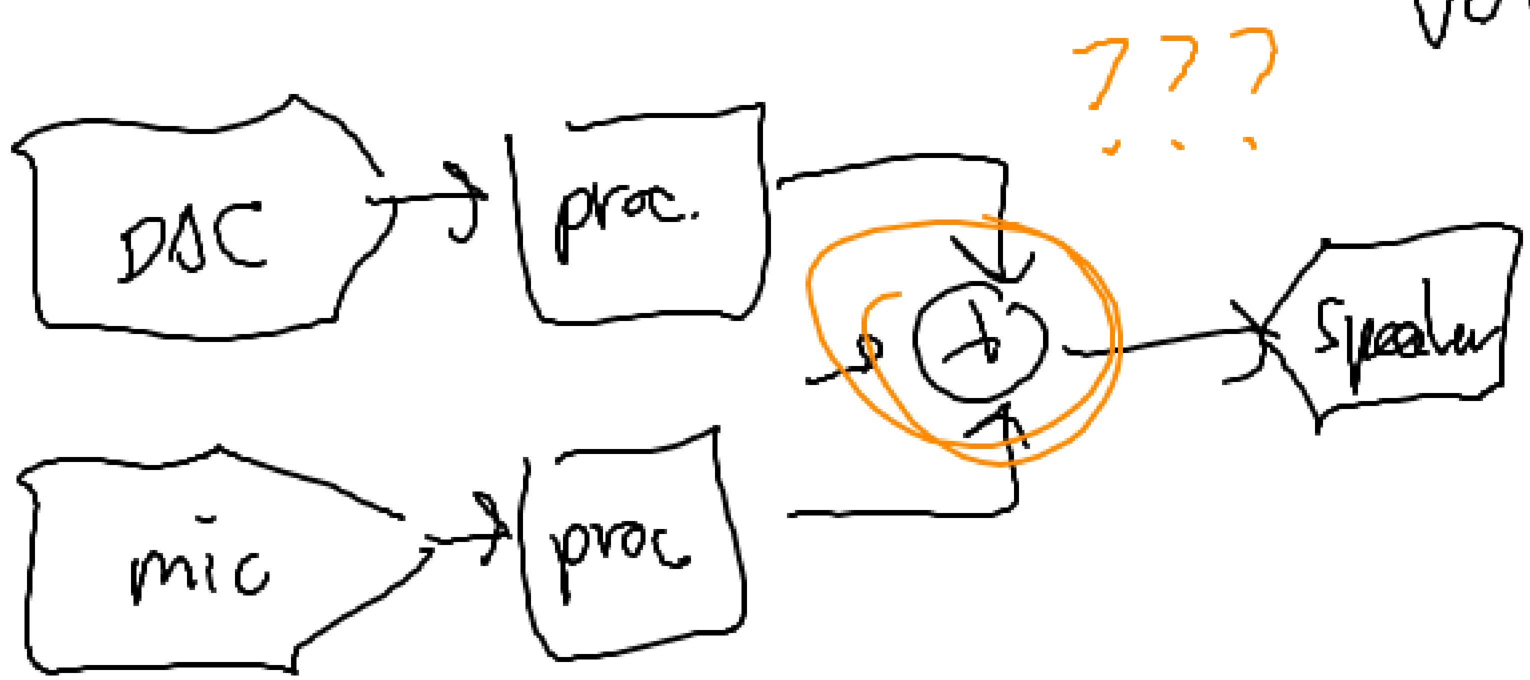


$$\alpha = \frac{R_2}{R_1+R_2} = \frac{30k}{40k} = \frac{3}{4}V$$

Can't just connect, need something

Need a buffer.





voltage summer

DISBA (yesterday)

$V_{out} = V_1 + V_2$