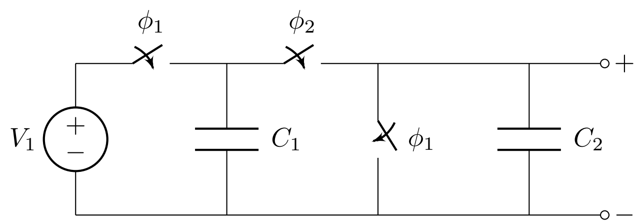
2) Charge Sharing 1:



In phase 1, $\phi_1$ is closed and $\phi_2$ is open. In phase 2, $\phi_1$ is open and $\phi_2$ is closed.

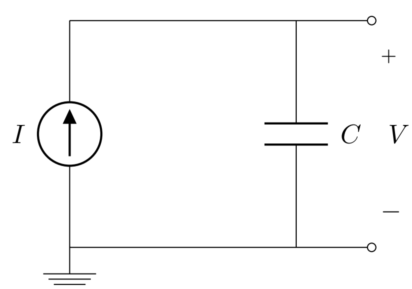
i. Draw phase 1, and find the charge on $C_1$ and $C_2$.

$$Q_1 = C_1 \cdot V_1$$
$$Q_2 = 0$$

ii. Draw phase 2, and find the voltage across $C_1$ and $C_2$.

$$Q_{tot} = C_1 V_1 = C_{eq} V_{out}$$
$$V_{out} = \frac{C_1}{C_1 + C_2} V_1$$

3) Find $V$ as a function of time.



$$I = C\frac{dV}{dt}$$

Since $I$ is constant, we know that $V$ must be a line. Therefore we can replace all differentials with a change in voltage and time.

$$I = C\frac{V_1 - V_2}{t_1 - t_2}$$
$$\frac{I(t_1 - t_2)}{C} = V_1 - V_2$$

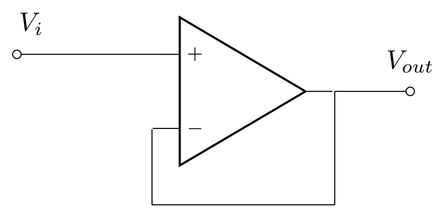
Let $V_1 = V$ and $V_2 = 0$ and $t_1 = t$ and $t_2 = 0$.

$$V = \frac{I}{C}t$$

## Design Topologies

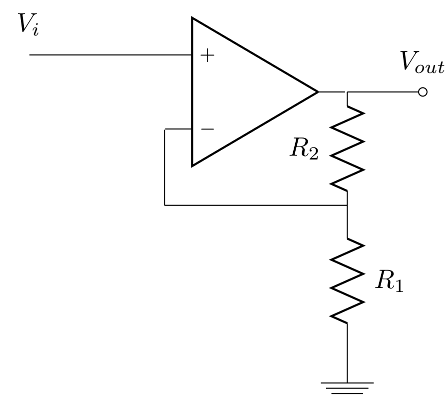
Here are very useful circuit topologies that you might want to consider using when you hear key phrases or goals in the problem. You never have to rederive the formulas for these circuits unless we explicitly ask. Just put these down on your cheatsheets and use them!!!

1. **Key Phrase**: "isolate load, zero output/source resistance"
   Use a buffer




$$V_{out} = V_i$$

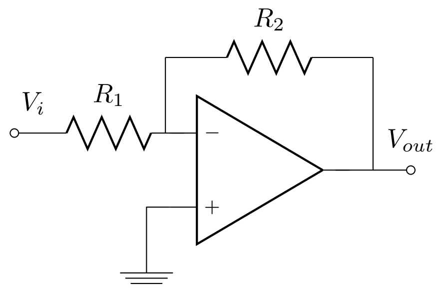
2. **Key Phrase**: "positive gain $\beta$"
   Use a noninverting amp




$$V_{out} = (1 + \frac{R_2}{R_1})V_i$$

$$\beta = (1 + \frac{R_2}{R_1})$$

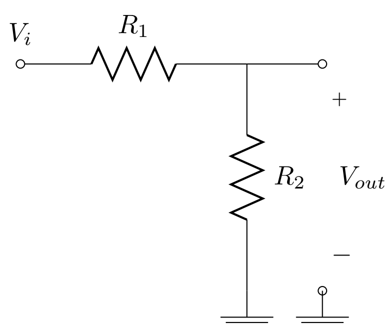
3. **Key Phrase**: "negative gain $\beta$"
   Use an inverting amp




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

$$\beta = -\frac{R_2}{R_1}$$

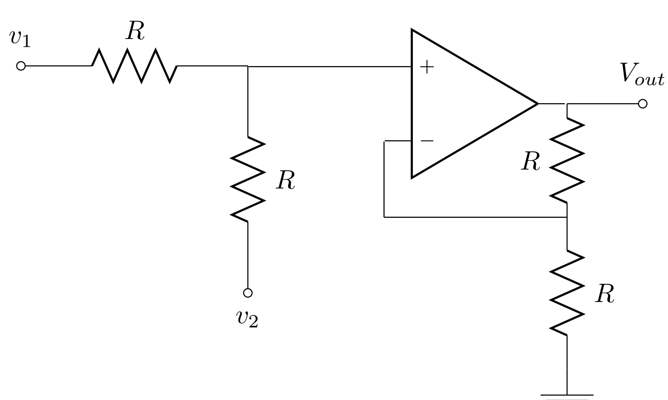
4. **Key Phrase**: "divide voltage by a factor $\beta$"
   Use a voltage divider




$$V_{out} = \frac{R_2}{R_1 + R_2}V_i$$

$$\beta = \frac{R_2}{R_1 + R_2}$$

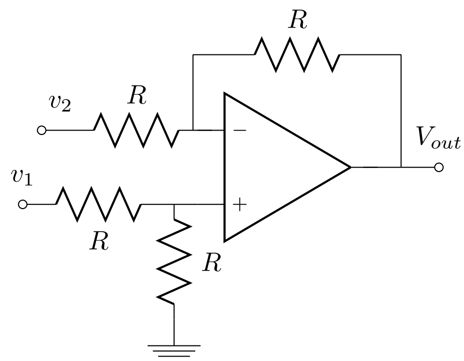
5. **Key Phrase**: "add two voltages $v_1, v_2$"
   Use a summing amp



$$V_{out} = v_1 + v_2$$

If all resistors have the same value $R$, then you get a unity sum amplifier.

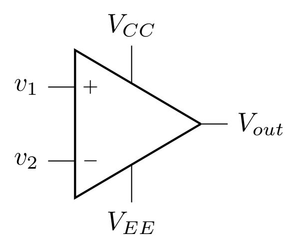
6. **Key Phrase**: "subtract two voltages $v_1, v_2$"
   Use a difference amp




$$V_{out} = v_1 - v_2$$

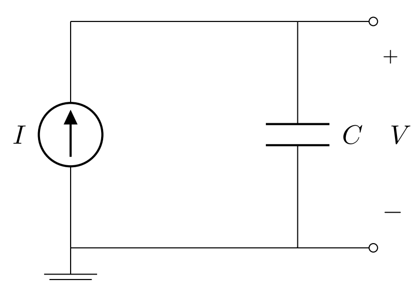
If all resistors have the same value $R$, then you get a unity difference amplifier.

7. **Key Phrase**: "compare two voltages $v_1, v_2$"
   The answer is in the phrase! Use a comparator




$$V_{out} = \begin{cases} V_{CC} & \text{if } v_1 > v_2 \\ V_{EE} & \text{if } v_1 < v_2 \end{cases}$$

8. **Key Phrase**: "create a voltage that is linear with respect to time with slope $\beta$"
   Use a current source with a capacitor



$$I = C\frac{dV}{dt}$$

Since $I$ is constant, we know that $V$ must be a line. Therefore we can replace all differentials with a change in voltage and time.

$$I = C\frac{V_1 - V_2}{t_1 - t_2}$$

$$\frac{I(t_1 - t_2)}{C} = V_1 - V_2$$

Let $V_1 = V$ and $V_2 = 0$ and $t_1 = t$ and $t_2 = 0$.

$$V = \frac{I}{C}t$$

$$\beta = \frac{I}{C}$$

## Design Challenges

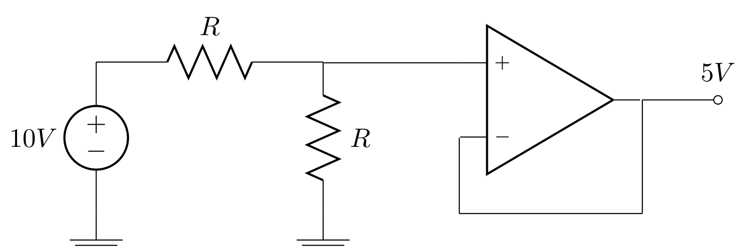
1) Make a $5V$ voltage source with zero source resistance using only a $10V$ voltage source, resistors and opamps.

   Two goals here:

   - divide the voltage by 2
   - give it 0 output resistance

   Implementation:

   - voltage divider
   - buffer

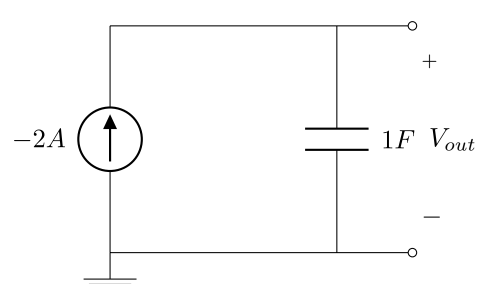



   The output voltage is $5V$ and there is no output resistance, so it isn't affected by the load of another circuit.

2) Your client wants a voltage that is linear with respect to time with slope $= -2$ using current sources and capacitors.

   One goal here: make a voltage that is linear with slope $= -2$.

   Implementation: current source and capacitor with $\frac{I}{C} = -2$.

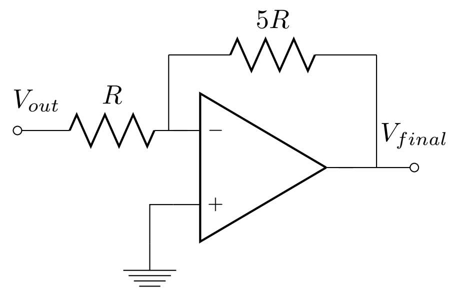


$$V_{out} = -2\frac{V}{s} \cdot t$$

Then, because your client is indecisive, they ask for a slope = 10. You ran out of current sources and capacitors, and are only left with opamps and resistsors. Implement your new circuit.

Goal: gain of $-5$

Implementation: inverting amp with gain $-5$, so $R_1 = R, R_2 = 5R$.




$$V_{final} = 10\frac{V}{s} \cdot t$$

3) You have a circuit that outputs a voltage that looks like a sine wave with amplitude $V$ and DC offset $= V_{ref}$. Call the output $V_o$.

How do you make it a square wave with peak $= V_{CC}$ and trough $= V_{EE}$ and $0V$ DC offset?

Goal: compare the waveform with it's DC offset

Implementation: use a comparator with rails $V_{CC}, V_{EE}$ and have $V_o$ at the positive input and $V_{ref}$ at the negative input.