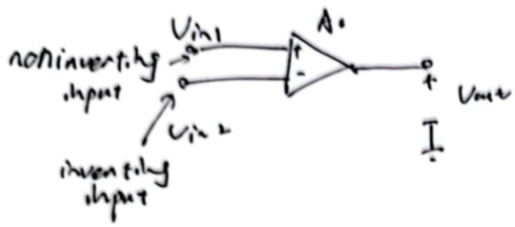
Op Amp Circuits

zrrraa

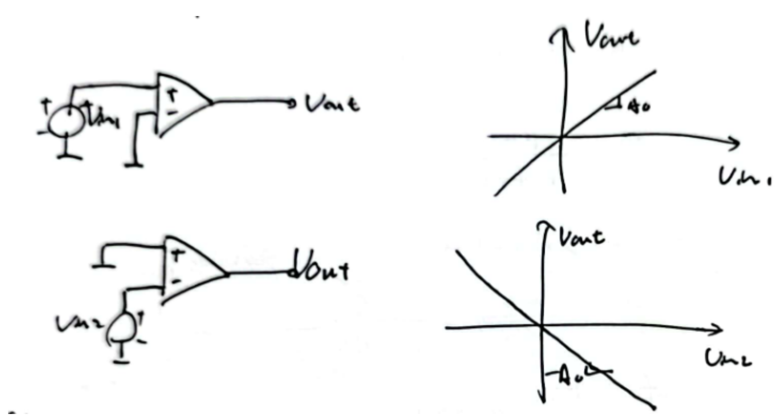
2023.12.21

Op Amp Basics



$$V_{out} = (V_{in1} - V_{in2})A_0$$

Input/Output Characteristics

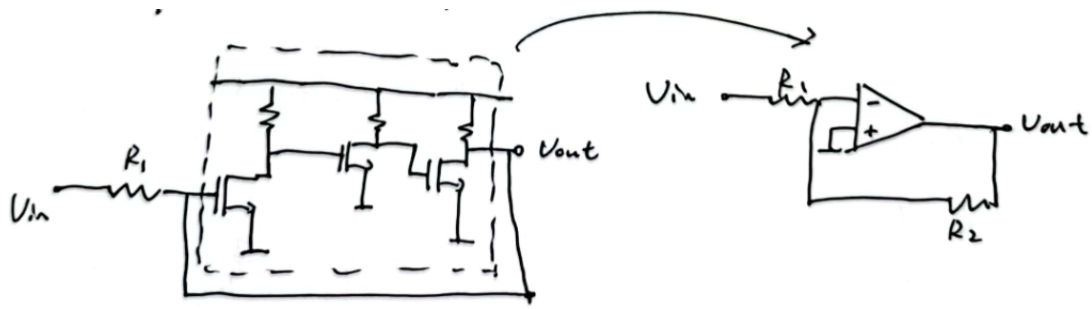


For an ideal Op Amp, Input Imp is infinite, Output Imp is zero, A_o is infinite.

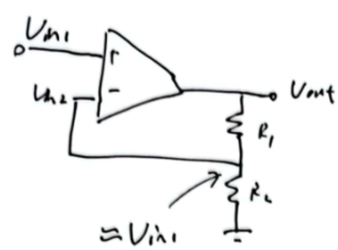
Observations

If $V_{out} \approx a\ few\ volts$ and $A_o \approx 1000 \Longrightarrow V_{in1} - V_{in2} \approx a\ few\ mV$.

If we can visualize a complex circuit as an op amp, the analysis becomes simpler.



Noninverting Amplifier



Case I: $A_o \to \infty$

$$V_{out} = (V_{in1} - V_{in2})A_0$$

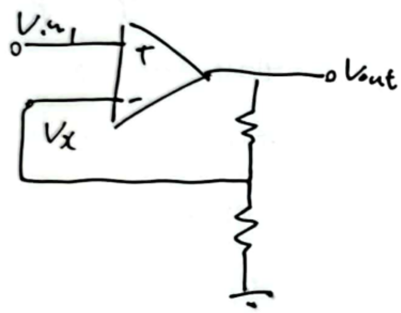
Because A_o is very large and V_{out} should be finite, $V_{in1} - V_{in2}$ should be very small.

$$V_{in1} - V_{in2} \approx 0 \Longrightarrow V_{in1} \approx V_{in2}$$

$$\Longrightarrow V_{out} = \frac{V_{in}}{R_2}(R_1 + R_2)$$

Compared with MOS amplification, using Op Amp amplification can reduce the dependence on process parameters such as transconductance, and only consider external components.

Case II: A_o is finite

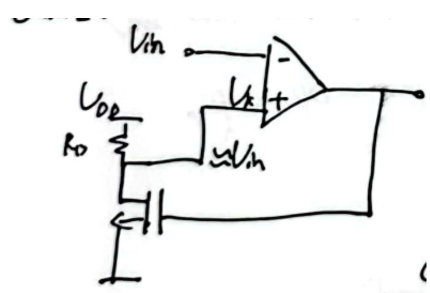


$$\begin{cases} V_x = V_{out}\frac{R_2}{R_1+R_2} \\ (V_{in} - V_x)A_o = V_{out} \end{cases}$$

$$\implies \frac{V_{out}}{V_{in}} = \frac{A_o}{1+\frac{R_2}{R_1+R_2}A_o} = \frac{1}{\frac{1}{A_o}+\frac{R_2}{R_1+R_2}}$$

We call A_o the open loop gain. The $\frac{V_{out}}{V_{in}}$ close loop gain.
If $\frac{R_2}{R_1+R_2}A_o >> 1 \implies \frac{V_{out}}{V_{in}}$ relatively independent of A_o.

0.1 Example



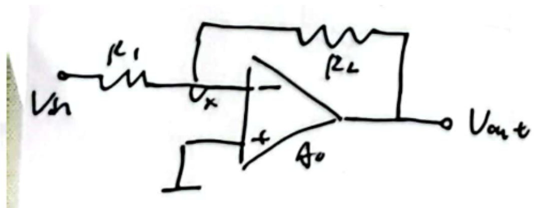
Assume $A_o \to \infty$:

$$V_x \approx V_{in}$$

Notice that it's a CS Stage Topology:

$$V_{out}(-g_m R_D) = V_{in} \implies \frac{V_{out}}{V_{in}} = -\frac{1}{g_m R_D}$$

Inverting Amplifier



Case I: $A_o \to \infty$

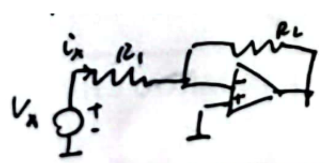
$$\frac{V_{in}}{R_1} = -\frac{V_{out}}{R_2} \Longrightarrow \frac{V_{out}}{V_{in}} = -\frac{R_2}{R_1}$$

Case II: A_o **is finite**

$$\begin{cases} V_x = \frac{V_{out}}{-A_o} \\ \frac{V_{in} - V_x}{R1} = \frac{V_x - V_{out}}{R2} \end{cases}$$

$$\Longrightarrow \frac{V_{out}}{V_{in}} = -\frac{1}{\frac{R_1}{R_2} + \frac{1}{A_o}\frac{R_1 + R_2}{R_1}}$$

Input Imp $\approx R_1$



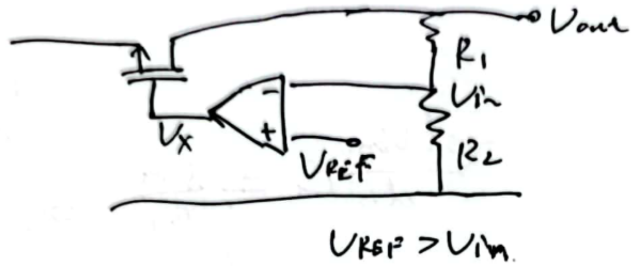
$$R = \frac{v_x}{i_x} = R_1$$

Example of Application: Voltage Regulator

We generally need a voltage regulator in an AC-DC step-down circuit to ensure that the output voltage remains constant when the input voltage fluctuates.

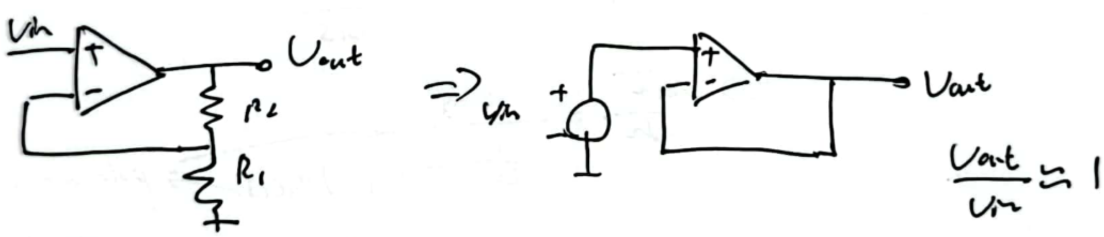
$$V_{out} \uparrow \Longrightarrow V_{in} \uparrow \Longrightarrow V_x \downarrow \Longrightarrow V_{out} \downarrow$$

Finally, V_{out} will remain at a constant value.



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

Unity-Gain Buffer



For the first topology:

$$\frac{V_{out}}{V_{in}} \approx 1 + \frac{R_2}{R_1}$$

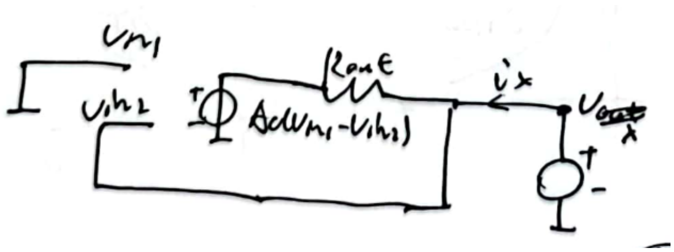
For the second topology:

$$\frac{V_{out}}{V_{in}} \approx 1$$

Calculate the input and output impedance below.

Input Imp $\approx \infty \Longrightarrow$ can sense voltage without loading the circuits.

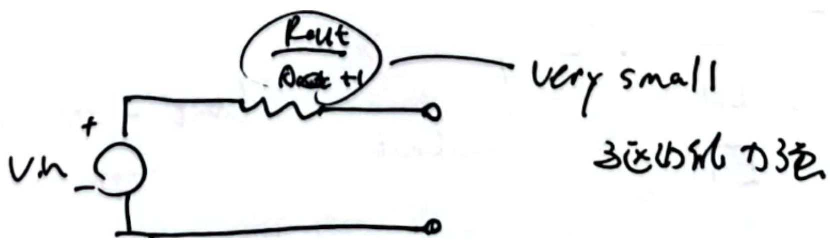
Calculate the output impedance using Thevenin's equation.



$$i_x = \frac{v_x - A_o(-v_x)}{R_{out}}$$

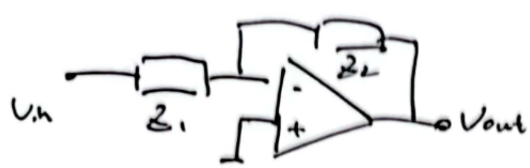
$$\frac{v_x}{i_x} = \frac{R_{out}}{A_o + 1}$$

So we can draw like this:

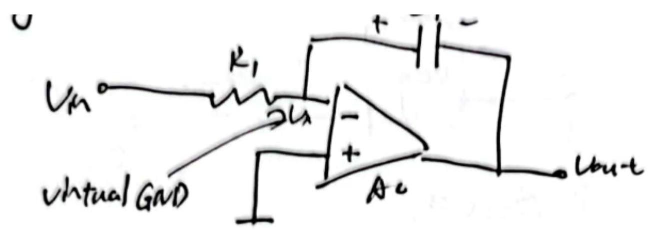


Since A_o is very large, the output impedance is very small, which means that the driving capability of the circuit is very strong.

General Inverting Amp



$$\frac{V_{out}}{V_{in}} \approx -\frac{Z_1}{Z_2}$$



Integrator

If A_o is very large:

$$\frac{V_{out}}{V_{in}} = -\frac{\frac{1}{C_1 s}}{R_1} = -\frac{1}{R_1 C_1 s}$$

Since the pole is at the origin, the circuit gain has no bounds.

$$\frac{-dV_{out}}{dt} C_1 = \frac{V_{in}}{R_1} \Longrightarrow V_{out} = -\frac{1}{R_1 C_1} \int V_{in} dt$$

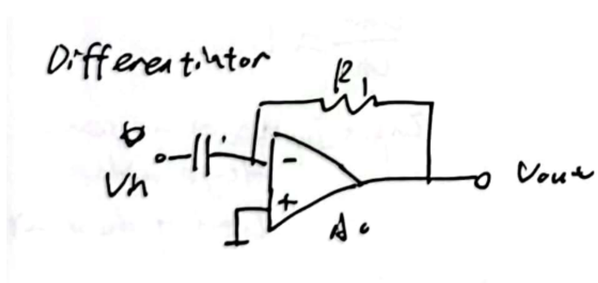
If A_o is finite:

$$V_x = -\frac{V_{out}}{A_o}$$

$$\frac{V_{in} + \frac{V_{out}}{A_o}}{R_1} = \frac{-\frac{V_{out}}{A_o} - V_{out}}{\frac{1}{C_1 s}} \Longrightarrow \frac{V_{out}}{V_{in}} = \frac{-1}{\frac{1}{A_o} + (1 + \frac{1}{A_o}) R_1 C_1 s}$$

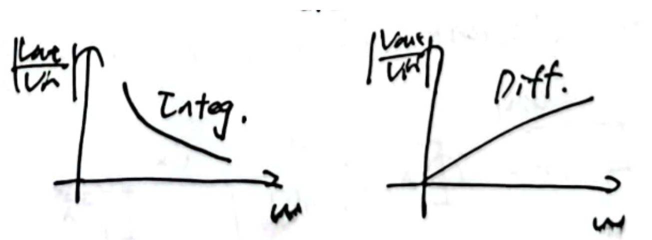
Since the pole is not the origin, the circuit gain has a bound.

Differentiator

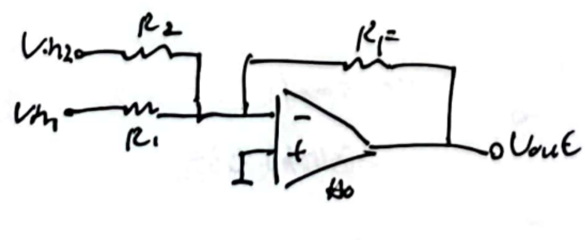


$$\frac{V_{out}}{V_{in}} = -\frac{R_1}{\frac{1}{C_1 s}} = -R_1 C_1 s$$

Plot the frequency response:



Voltage Adder (Summer)



$$V_{out} = -R_F(\frac{V_{in1}}{R_1} + \frac{V_{in2}}{R_2})$$

Link

Razavi Electronics Circuits 1: lectrue 42

Razavi Electronics Circuits 1: lectrue 43