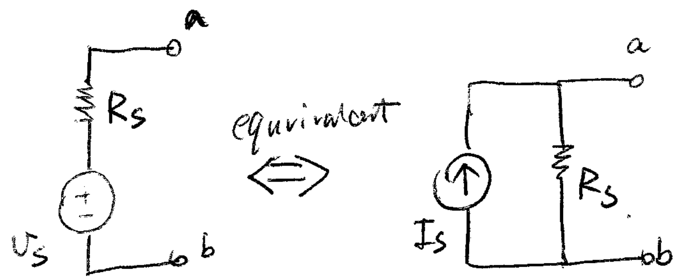
Source Transformation:

Purpose: Simplify Circuit Analysis

How? transfer between voltage & current source circuits.

1).


Voltage Source Circuit to: Current source Circuit

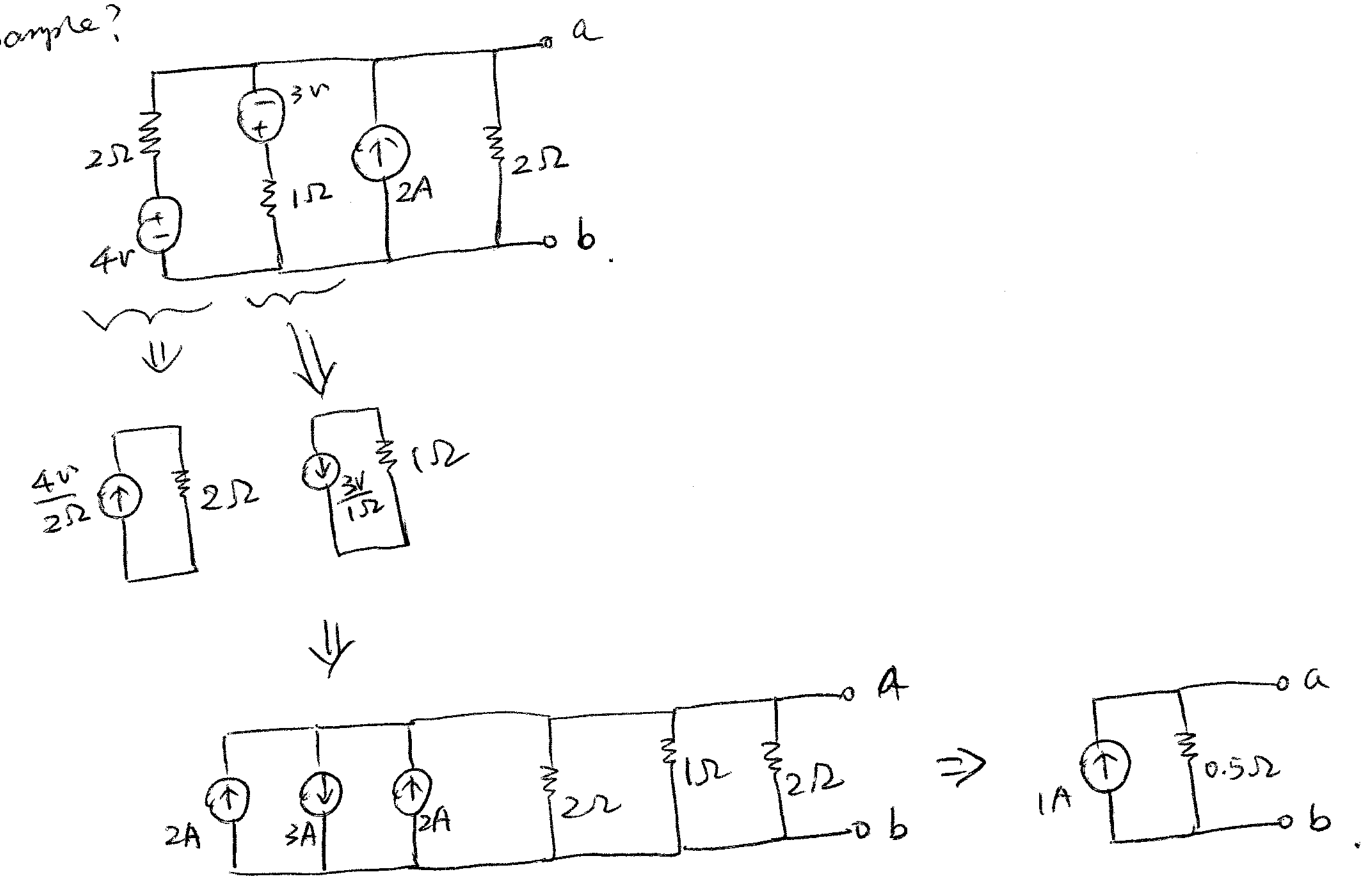
Note:

-. Direction.

-. $R_{s\_v} = R_{s\_c}$ ⇒ resistor is the same

-. $I_s = \frac{V_s}{R_s}$, or, $V_s = I_s R_s$.

Example?



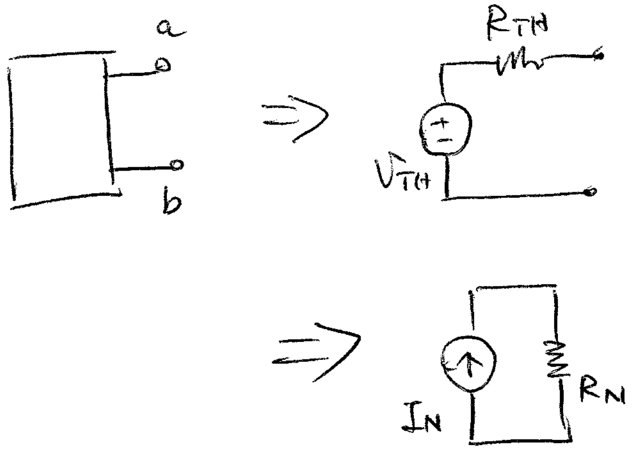
a.

Thevenin And Norton Equivalent

purpose: Transfer any Linear two terminal network/circuit to a simple circuit, So that when different load is attached to it, engineers do not need to go through the whole circuit ~~again~~ analysis again.

⇒ Simply the circit to a resistor & a voltage source
Thevenin

or a current source
Norton



From Source Transformation:

$R_{TH} = R_N$

$V_{TH} = I_N \cdot R_N$

$I_N = \dfrac{V_{TH}}{R_{TH}}$.

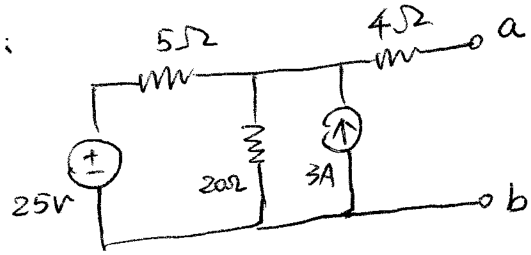
Three Methods to find V_{TH} & R_{TH}.

Method 1 (Basic)

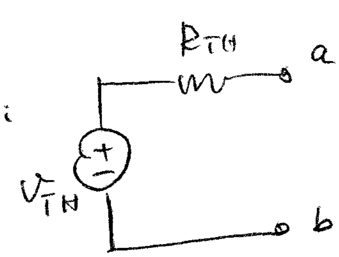
$V_{TH} = V_{open}$

$R_{TH} = \dfrac{V_{open}}{I_{short}}$.

Example:

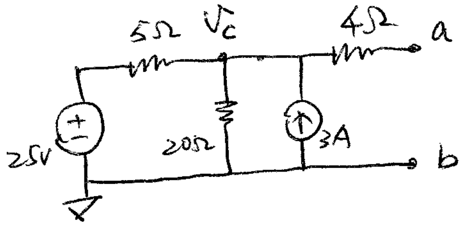


convert it to:



V_{TH} : The open circuit voltage of V_{ab}.

find V_{TH} (V_{ab}).



Node voltage method : $\frac{V_c - 25}{5} + \frac{V_c}{20} - 3 = 0$

$\Rightarrow \underline{V_c = 32V}$.

$V_a = V_c$, because no current through the 4Ω Resistor, No IR drop there.

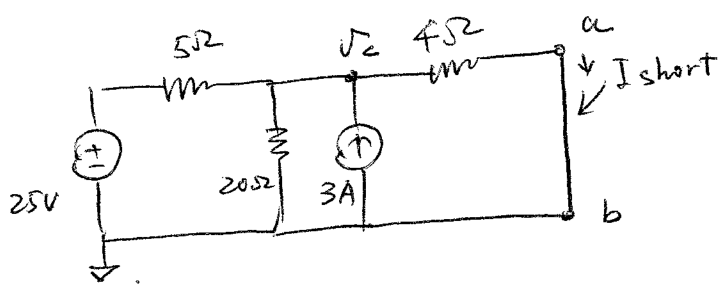
$\underline{V_{ab} = V_a - V_b = V_a = V_c = 32V.} = V_{TH}$.

find R_{TH}.

$R_{TH} = \frac{V_{open}}{I_{short}}$

found

Find it.



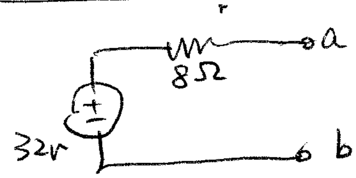
Short a & b, find the current through a & b.

Node voltage method:

$\frac{V_c - 25}{5} + \frac{V_c}{20} - 3 + \frac{V_c}{4} = 0$

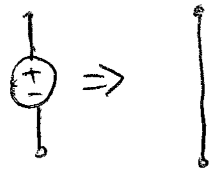
$\Rightarrow \underline{V_c = 16V}$. $\underline{I_{short} = \frac{V_c}{4\Omega} = 4A}$

$R_{TH} = \frac{V_{open}}{I_{short}} = \frac{32}{4} = 8\Omega$. $\Rightarrow$

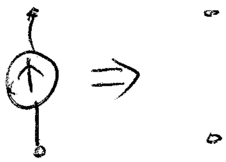


c.

Method 2: Sources deactivation (only for independent sources)



deactivate a voltage source:
⇒ short it.

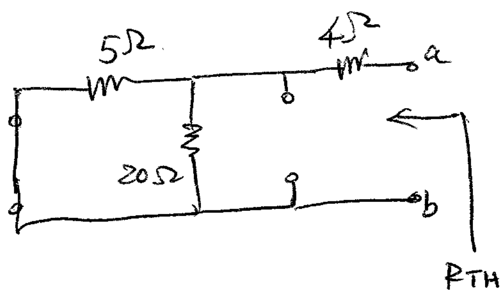


deactivate a current source:
⇒ open it.

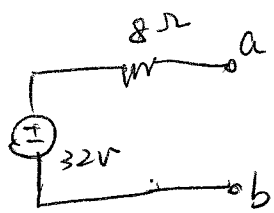
Step 1: find V_{open}, same as method 1.

Step 2: find R_{TH}.

Deactive all indepent sources,

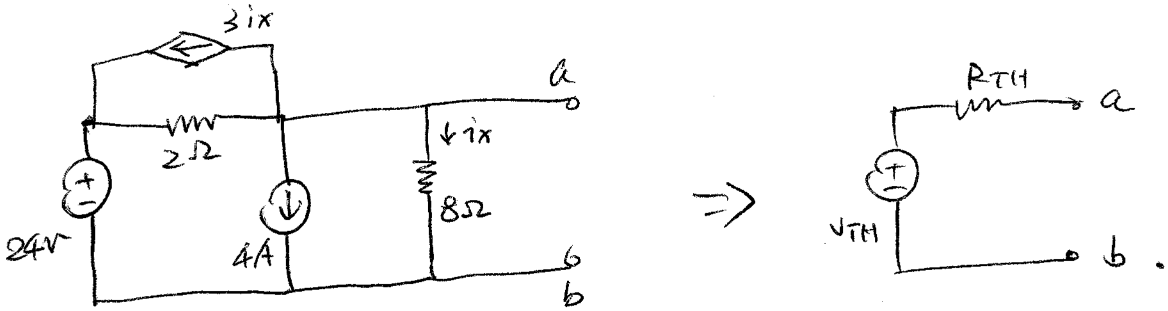


$\Rightarrow R_{TH} = 5//20 + 4 = 8\Omega$.

⇒ 

d.

Method 3: If you want to use method 2, but the circuit has dependent sources.

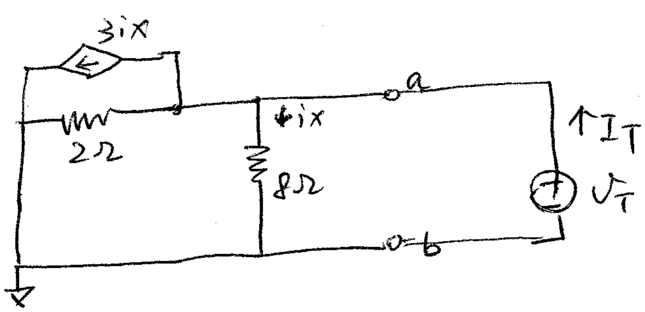


Step 1: find V_{TH} using $V_{open} = V_{TH}$.

Node-voltage-method:
$$3i_x + \frac{V_a - 24}{2} + 4 + \frac{V_a}{8} = 0$$
$$\Rightarrow 3 \times \frac{V_a}{8} + \frac{V_a - 24}{2} + 4 + \frac{V_a}{8} = 0$$
$$\Rightarrow V_a = 8V.$$
$$\Rightarrow V_{TH} = 8V.$$

Step 2: find R_{TH}.

first, deactivate all independent source:



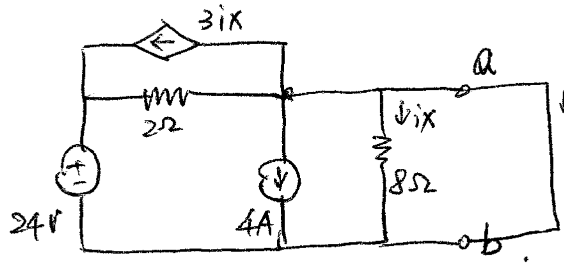
Then, add a test voltage between ab: V_T.

$$R_{TH} = \frac{V_T}{I_T}.$$

Node-Voltage-method:
$$\frac{V_T}{2} + 3i_x + \frac{V_T}{8} - I_T = 0$$
$$\frac{V_T}{2} + 3 \times \frac{V_T}{8} + \frac{V_T}{8} - I_T = 0$$
$$\Rightarrow 8V_T = 8I_T \Rightarrow \frac{V_T}{I_T} = 1\Omega = R_{TH}.$$

de

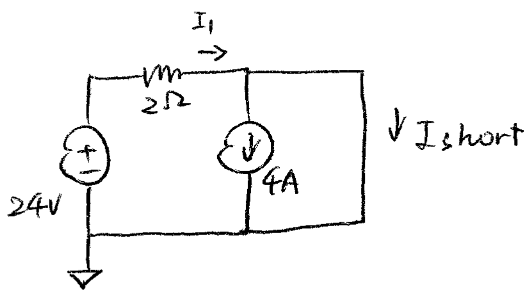
How about using method 1 to find R_{TH}? Yes, you can.



$V_{open} = 8V$, same as before (the other method)

find $R_{TH} = \dfrac{V_{open} = 8V}{I_{short} = ?}$

Since the 8Ω resistor is shorted: $i_x = 0$.



$I_1 = \dfrac{24}{2} = 12A$

$I_1 = 4A + I_{short}$

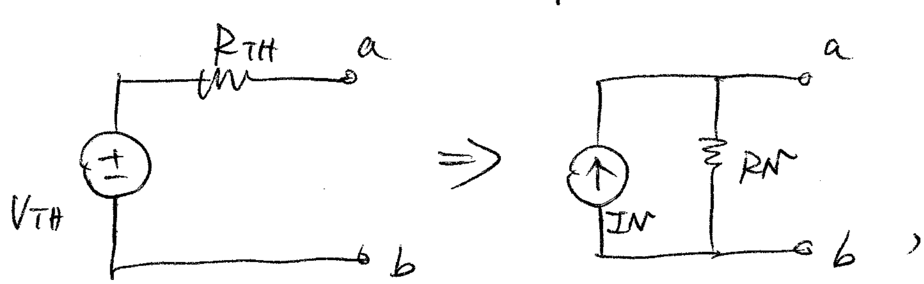
$\Rightarrow I_{short} = 12A - 4A = 8A$.

$\Rightarrow R_{TH} = \dfrac{8V}{8A} = 1\Omega$

How to find Norton Equivalent circuit?

$\Rightarrow$ 1) find Thevenin Equivalent circuit.

2). Use Source ~~Theorem~~ Trasfermation



$I_N = \dfrac{V_{TH}}{R_{TH}}$

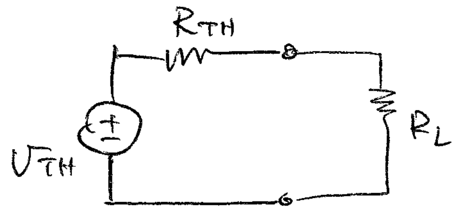
$R_N = R_{TH}$.

cf.

Maximum Power Transfer:

How to Extract the maximum power from the circuit?

$\Rightarrow$ Thevenin Equivalent circuit:



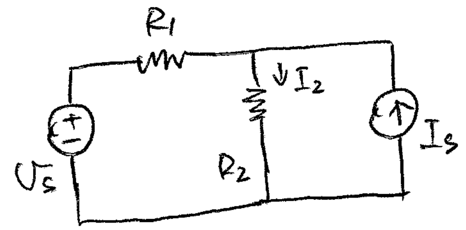
Then, when $R_L = R_{TH}$, the power extracted ~~th~~ to the load R_L is the maximum.

$$P_{max} = \left(\frac{V_{TH}}{2R_L}\right)^2 \times R_L = \frac{\left(\frac{1}{2}V_{TH}\right)^2}{R_L}$$

$$= \frac{V_{TH}^2}{4R_L}$$

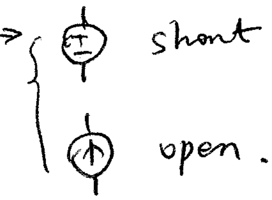
Super Position

purpose: to simplify circuit analysis, look at the impact of independent Voltage / current Source one at a time, then sum the impact up as the actual impact.

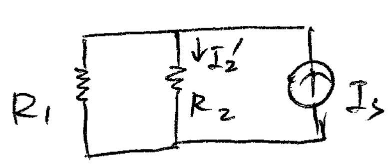


Use super position to find I_2.

Look at one source at a time (deactivate other sources)

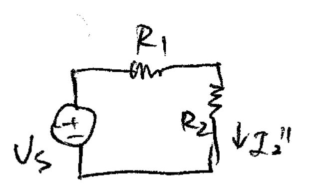


deactivate V_s :
look at I_s:



$I_2' = I_s \times \frac{R_1}{R_1+R_2}$.

deactivate I_s :
look at V_s :



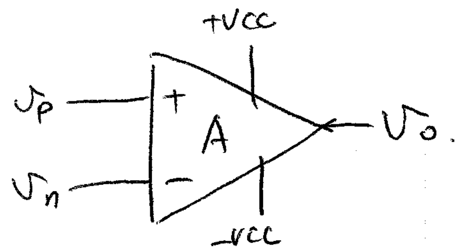
$I_2'' = \frac{V_s}{R_1+R_2}$.

$$I_2 = I_2' + I_2'' = I_s \frac{R_1}{R_1+R_2} + \frac{V_s}{R_1+R_2}$$

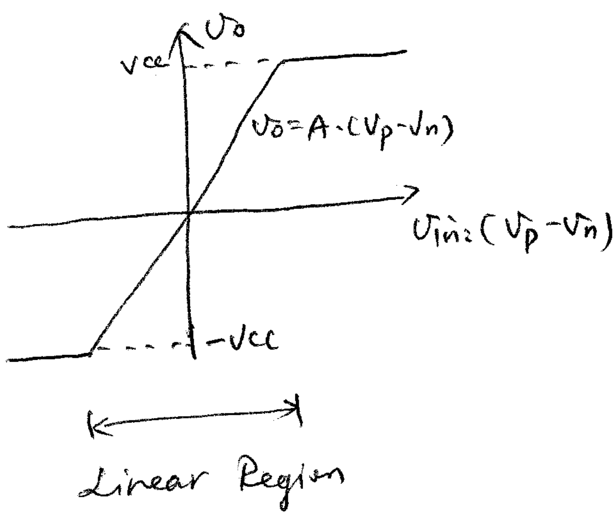
a.

Op-Amp.

Five terminal device:

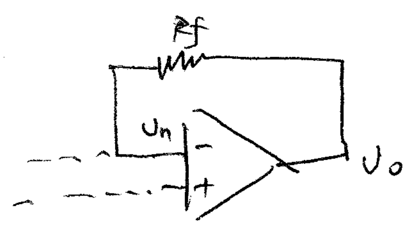


can generate/dissipate power.



A is very large: a tiny differene on v_p & v_n will saturate the op-amp.

So, an op-amp need a closed negative feed back loop to operate:



Ideal Op-amp:

1). $A \to \infty$

2) $v_n = v_p$ (only if negative loop exist)

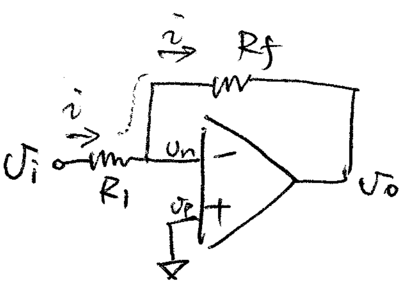
3) $i_n = 0$, $i_p = 0$.

4.) all voltages are refering to a common ground.

5) Negative feedback loop must exist for linear operation.

6). Op Output is bounded by supply.

(even negative feedback loop can not guranteed an ideal opamp ciruit is in Linear region.



How to analysis circuit with Ideal op-amp?

$\Rightarrow v_p = v_n = 0\,V$.

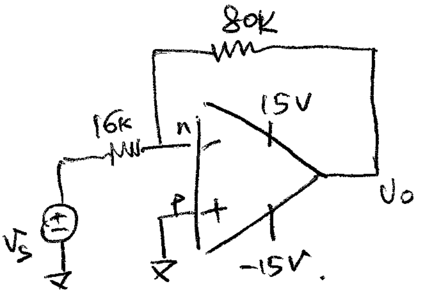
$i_n = i_p = 0\,A$.

$$\underbrace{i = \frac{v_i - v_n}{R_1} = \frac{v_n - v_o}{R_f}}$$

$\Downarrow$

$$\frac{v_i}{R_1} = \frac{-v_o}{R_f} \Rightarrow \frac{v_o}{v_i} = -\frac{R_f}{R_1} \quad \text{(inverting)}$$

c.



$v_s = 2v$.

∵ Negative feed back loop exist;

$v_n = v_p = 0$,

$i_n = i_p = 0$.

$$\frac{v_s - 0}{16K} = \frac{0 - v_o}{80K} \Rightarrow v_o = 2 \times \left(-\frac{80}{16}\right)$$

$$= -10v.$$

The supply is 15v. $|-10| < 15$. valid.

what if $v_s = 4v$?

$v_o = -4 \times 5 = -20v$. it is smaller the $-15v$ ($-v_{cc}$) not valid. v_o is clipped by the $-v_{cc}$, cannot be lower than $-v_{cc}$.

what is the input range?

$$-15 \leq v_o \leq 15$$

$$\Rightarrow -15 \leq -v_s \times 5 \leq 15$$

$\Rightarrow -3 \leq v_s \leq 3$. v_s ~~can~~ must be within this range for linear operation, otherwise, the op-amp will satnate. (v_o will reach $+/-$ v_{cc})

d.

Not only too large a v_s will satuate the op-amp, but too large the $\frac{R_f}{R_1}$ will satuate the op-amp.

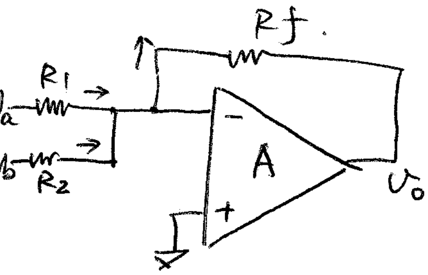
Given a fixed $v_s = 2V$. What is the largest R_f for Linear operation?

$$\underbrace{-15 \le -2 \times \frac{R_f}{16K} \le 15}_{\text{always true.}}$$

$$16K \times 15 \ge 2 \times R_f \Rightarrow R_f \le 120K.$$

if $R_f = 120K$, $v_o = -2 \times \frac{120}{16} = -15V$ (at the boundary)

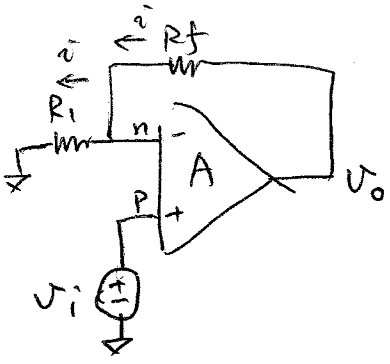
if $R_f > 120K$, v_o will be clipped,



$v_p = v_n = 0.$

$$\frac{v_a}{R_1} + \frac{v_b}{R_2} = \frac{-v_o}{R_f}$$

$$v_o = \underbrace{-\left(\frac{R_f}{R_1} \cdot v_a + \frac{R_f}{R_2} v_b\right)}_{\text{summing amp.}}$$

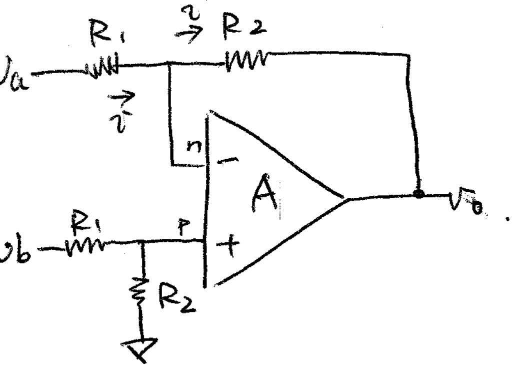


$v_n = v_p = v_i$

$$i = \frac{v_i}{R_1} = \frac{v_o - v_i}{R_f}.$$

$$\Rightarrow \frac{v_o}{v_i} = 1 + \frac{R_f}{R_1} \text{ (non-inverting)}$$

e.



$$v_p = v_b \times \frac{R_2}{R_1+R_2}$$

$$v_n = v_p = v_b \cdot \frac{R_2}{R_1+R_2}$$

$$i = \underbrace{\frac{V_a - V_n}{R_1} = \frac{V_n - V_o}{R_2}}$$

$$\Rightarrow \cancel{\frac{V_a - V_b \cdot \frac{R_2}{R_1+R_2}}{R_1} = v_b \cdot}$$

$$R_2 \cdot V_a - R_2 \cdot V_n = R_1 V_n - R_1 V_o$$

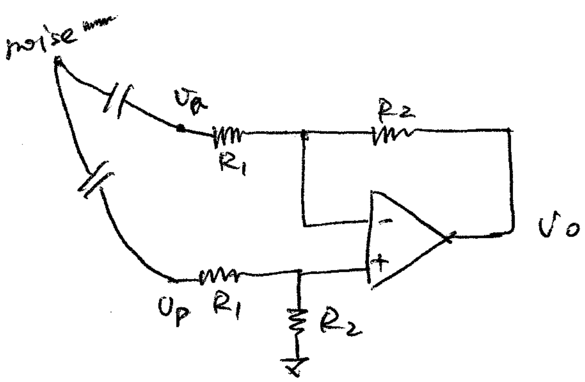
$$V_o = \frac{(R_1+R_2)V_n - R_2 V_a}{R_1}$$

$$V_o = \frac{v_b R_2 - V_a R_2}{R_1} = \frac{R_2}{R_1}(V_b - V_a)$$

$\Rightarrow$ difference amplifier.

It is good because:

only differential signal (useful) is amplified, by $\frac{R_2}{R_1}$.



Common noises will be rejected.

$$CMRR = \left| \frac{A_{dm}}{A_{cm}} \right|,$$

ideally $A_{cm} = 0$, $CMRR \to \infty$,

But in real world, $CMRR \neq \infty$ due to finite mismatches.

f.

Universal method to solve op-amp circuit:

1) $v_n = v_p$.

2) $i_n = i_p = 0$, calculate current.

3) the current cannot go in the ~~te~~ input terminals, need to find some ways out ⇒ write equations.

4). find gain, or other parameters.

5) check whether it is valid (supply)

Always works.