Amplifiers Summary

By:Mohammed Abuhashieh

POWERUNIT

Electronics II

Summary

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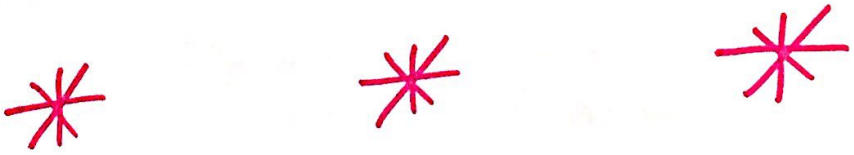


First Material

* Mode of Operations for BJT:

① Forward-active mode → BE forward, BC reverse. ⇒ (Amplifier).

② Saturation mode → BE → Forward, BC → Forward. ⇒ (switch).

③ Inverse-active mode → BE reverse, Bc forward.

④ Cutoff mode → BE → Reverse, Bc → Reverse.

* How To Find The Mode of Operation:

1 Assume forward-active mode:

↳ use $V_{BE(ON)} = 0.7$ & $I_C = \beta I_B$

I/p: To find I_B then I_C

o/p: To find V_{CE}

CHECK: $V_{CE} \overset{?}{>} V_{CE(sat)}$ → if yes (F.W.), if No (wrong assumption).

2 Assume Saturation mode:

⛔ warning: DO NOT USE $I_C = \beta I_B$

↳ use $V_{CE(sat)} = 0.2$ or 0.3 , $V_{BE(ON)} = 0.7$

I/p: To find I_B.

o/p: To find I_C

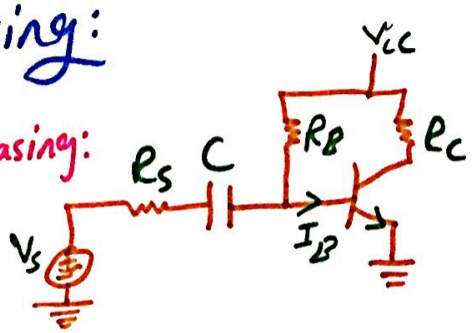
CHECK: $I_C \overset{?}{<} \beta I_B$ → if yes (sat. mode), if No (cut off mode). ⇒ $I_C = I_B = I_E = \phi$

* DC-load line: Take output loop to find the relation between V_I & V_{CE}

* V_o & V_I : check the effect on transistor (V_o & V_I) in the three modes (FW/sat/cutoff) Then draw the graph.

* Types of Biasing:

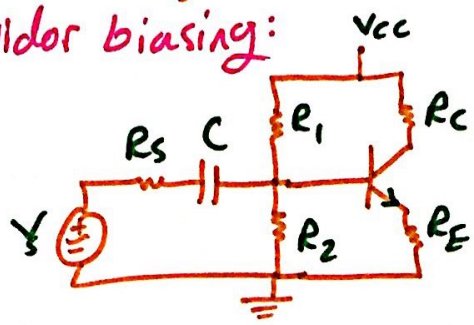
① single base-resistor biasing:



Disadvantages:

① R_B high value (MΩ)
② Non-stable Q-point.

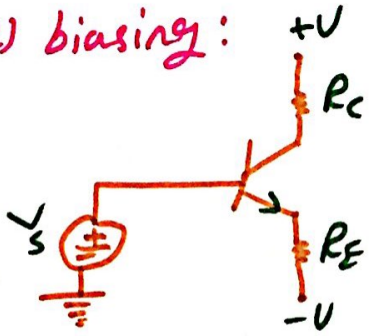
② Voltage divider biasing:



Advantages:

① stable Q-point.
② Low values of resistors.

③ (+ve) & (-ve) biasing:



Advantages:

① stable Q-point.
② No need for coupling capacitor.

* Amplifier Circuit:

* To design Amplifier circuit:
① the transistor should be FW.
② AC signals should be small to get linear amplifier.

* What does mean Linear amp.?

$V_o = (\text{constant}) V_I$, constant > 1

* How to get Linear amp? All components in the amp. ckt. must be Linear.

* What is the way to make transistor linear to get amp ckt?
if the AC signals in the amp ckt are small.

→ see the proves
→ graphically
→ Mathematically

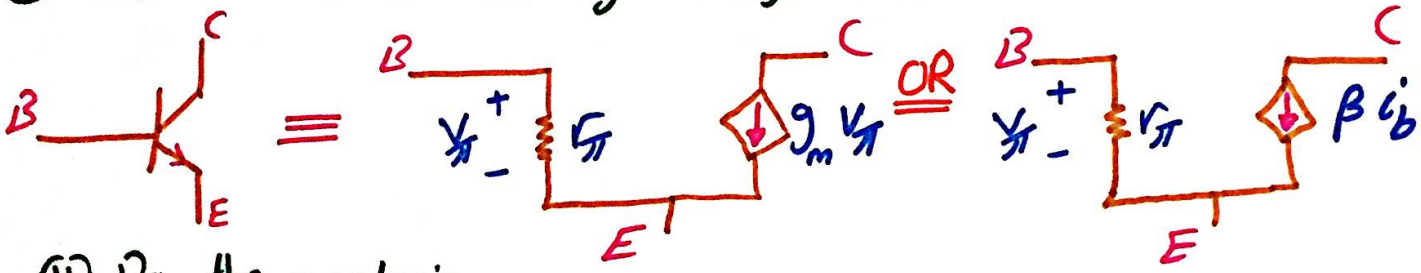
* Analysis of Amplifier Circuit:

* step 1: DC analysis:

① Replace all capacitors by Open Circuit.
② Replace all (AC voltage sources) by Short Circuit.
③ find I_{CQ}, I_{BQ}, V_{CEQ}.

* step 2: AC analysis:

① Replace all capacitors by short circuit.
② Replace all (DC voltage sources) by short circuit.
③ Replace the transistor by its Hybrid-π model



④ Do the analysis.

$$r_\pi = \frac{V_T}{I_{BQ}} \rightarrow 0.026 \text{ volt}$$

$$g_m = \frac{I_{CQ}}{V_T}$$

$$\beta = g_m r_\pi$$

voltage gain:

$$A_V = \frac{V_o}{V_s}$$ → take loops to find V_o & V_s as functions of (V_π).

current gain:

$$A_i = \frac{i_o}{i_i}$$

To find R_i & R_o:

use Thevenin equevelant ckt.
↳ Kill the independent sources & put a voltage test source V_x with I_x.

* Notes:

i_B , i_c , v_{CE} , v_o $\Rightarrow$ (AC + DC value)

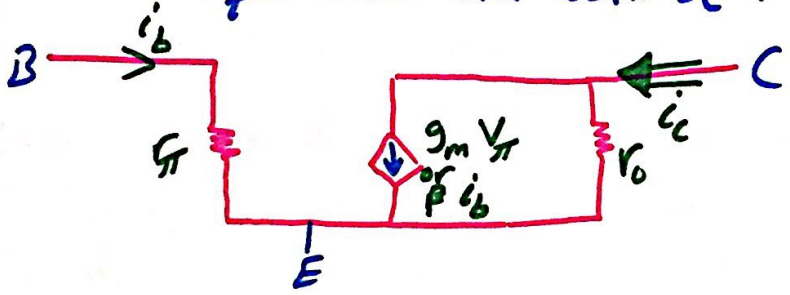
$i_B = i_b + I_{BQ}$, $i_C = i_c + I_{CQ}$, $v_{CE} = v_{ce} + V_{CE}$, $v_O = v_o + V_O$

* Hybrid-π with the early effect:

→ without early effect: I_c is independent on V_{CE}.

→ with early effect: $I_C \propto V_{CE}$ & the junction C-E has resistance called r_o

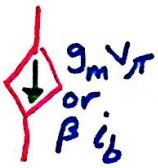
$\Rightarrow$ the equivelent cKt will be :



$r_o = \frac{V_A}{I_{CQ}}$ (high value)

→ will be given.

* So, Now if he say the cKt with early effect
$\Rightarrow$ You must add the part (r_o) to the Hybrid-π cKt.

* Note: 

$\Rightarrow$ The best use for $g_m V_\pi$ when R_E is Not existing.
The best use for βi_b when R_E is exist.

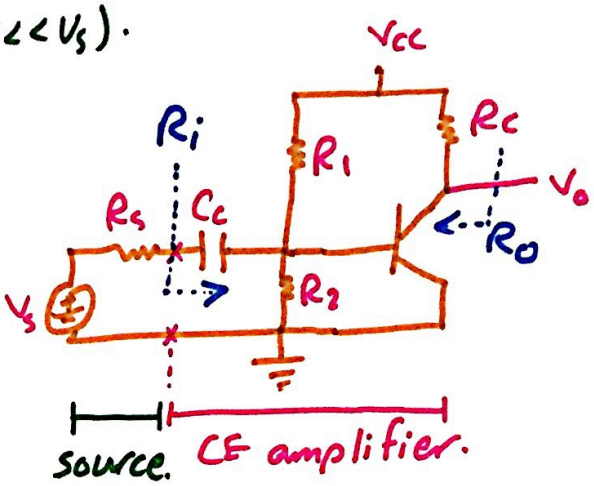
* Basic BJT Amp. Configurations:

- Common Collector Amplifier (CC).
- Common Base Amplifier (CB).
- Common Emitter Amplifier (CE).
  - Basic CE Amp.
  - CE with R_E.
  - CE with R_E & bypass capacitor.
  - Advanced CE Amp.

※ Common Emitter Amplifier:

① Basic CE Amplifier:

* **Advantages:** High gain.
* **Disadvantages:**
  1. High loading effect due to small R_i ($V_i << V_s$).
  2. Highly sensitive to $V_{BE(ON)}$



R_S: internal resistance of the source.

C_c: coupling capacitor.

↳ it is used before & after the amplifier ckt. (why)?

To Block any DC component from the user that may change the position of the Q-point (change the mode of operation).

* After finding R_i & R_o we can draw Two-port equivalent ckt.

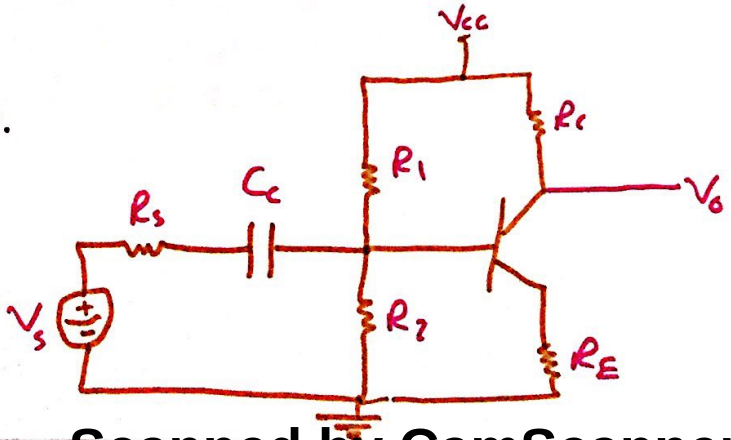
$$V_i = V_s \left(\frac{R_i}{R_i + R_s} \right)$$ ← This value represents: "Loading effect"

* To reduce loading effect: need high R_i & small R_o
* To have a good voltage Amp. ckt: ① High R_i ② small R_o ③ High A_V

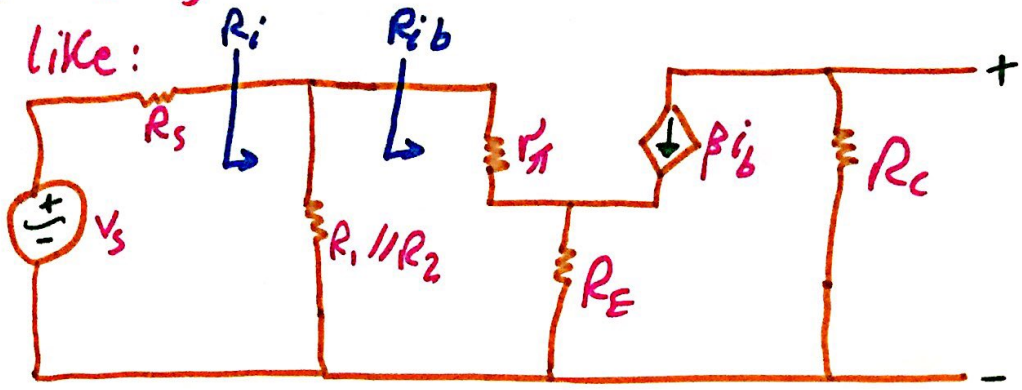
② CE with R_E:

* **Advantages:**
  1. small loading effect.
  2. stable Q-point (less sensitive to β).
* **Disadvantages:**

small gain.



⇒ Notice that: The hybrid-π for CE with R_E would be like:



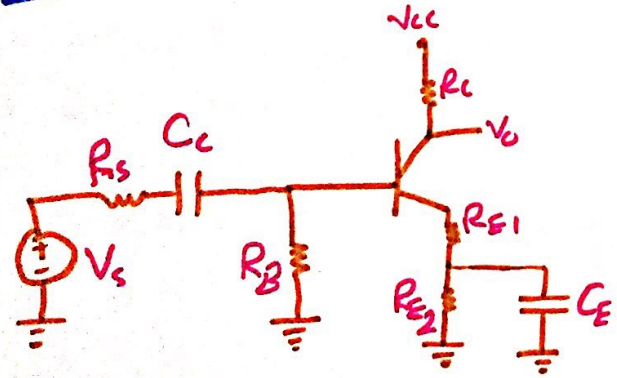
⇒ Also for this type of circuits for finding the voltage gain you can simply use the following relation:

$$A_V = \frac{-R_C}{R_E} \quad ***$$

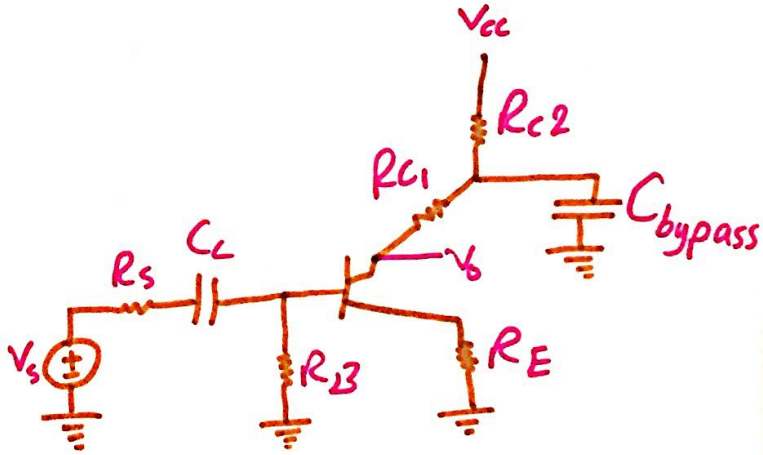
*Note: Finding R_ib then find R_i will be the easiest way to solve.

* stability rule: $R_{th} = 0.1(1+\beta)R_E$ ***

3 CE with R_E & bypass capacitor:



OR



C_E: Bypass Capacitor.

↳ What is the advantage of C_E?

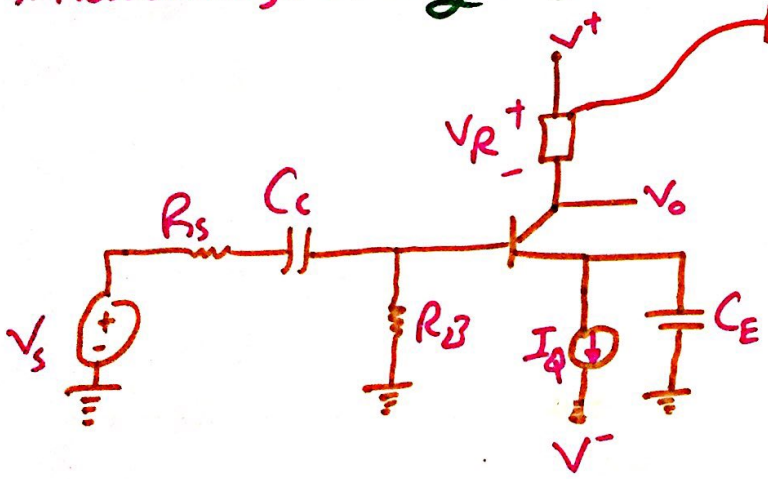
AC requirement, need R_E small
DC " , need R_E high
} ⇒ so, bypass capacitor simplifies the design process (satisfies AC & DC requirements)

* AC req.: (i.e) A_V, R_i ...
* DC req.: (i.e) I_{CQ}, V_{CEQ} ...

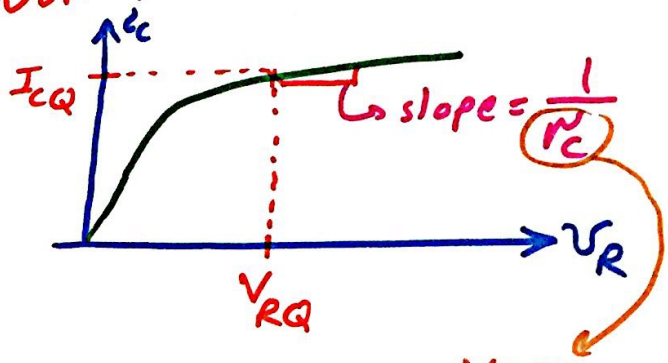
*Note: if we solve in an example on ordinary CE with R_E, and we had a Confliction between AC & DC Neq. ⇒ Bypass Capacitor will solve this. (so, solve CE with R_E & bypass capacitor.

4 Advanced CE Amplifier:

* Advantage: very high A_v.



Non-linear Resistor.



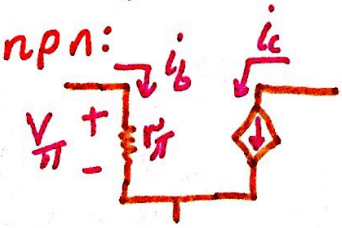
* DC Load line & AC Load line:

draw DC equivalent cKt then from output loop find relation between $(I_C \propto V_{CE})$

Draw AC equivalent cKt then find a relation between $(i_c \propto v_{ce})$

*Note: in AC equivalent cKt:

if npn:



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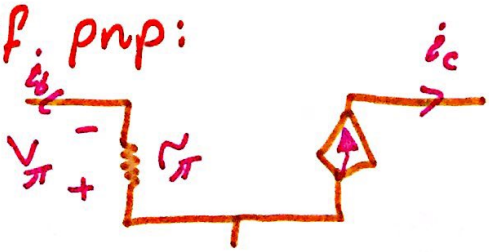
But if pnp:



※ Common Collector Amplifier:

**** Features:**

① High input impedance. → small loading effect in the input side.
② Low output impedance. → small loading effect in the output side.
→ so, CC Amp. is called buffer or impedance transformer
↳ it is equivalent to ideal voltage source.

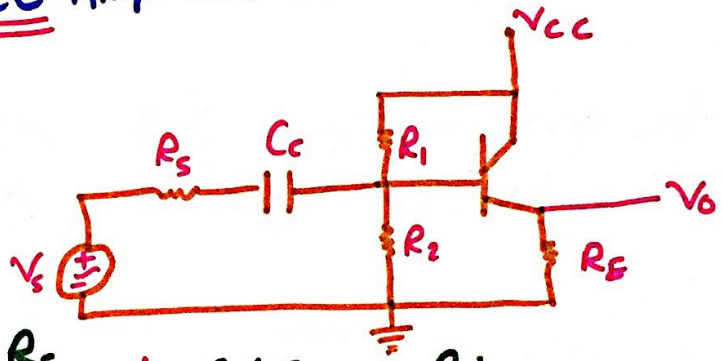
③ $A_V \simeq 1$ → $(V_o \simeq V_s)$ so, it is called emitter follower.

④ used as the final stage in multi-stage Amplifier.

⑤ R_1 & R_2 should be high value ⇒ To exploit the advantage of high R_{ib}

⑥ $A_i \simeq 1+\beta \simeq \beta$

* if you have a standard CC Amp like that shown in the figure:



you can directly use the features $A_V \simeq 1$, $A_i \simeq 1+\beta \simeq \beta$

↳ under conditions:

R_1 & R_2 High and $R_i >> R_s$ and $R_1 // R_2 >> R_{ib}$

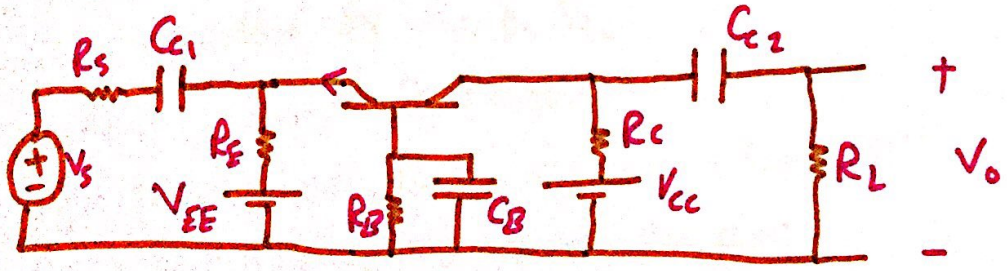
⚠ Be carful: if the conditions weren't true you have to calculate A_V or A_i by circuit analysis methods.

※ Common Base Amplifier:

**** features:**

① small R_i
② High R_o
③ $A_i \simeq 1$
④ $A_V > 1$

*** Standard form:**



↳ you can use the features $(A_i \simeq 1)$ under conditions: – standard form.
– must be said that $R_L \to 0$
$R_E \to \infty$

* Here some techniques could be usful in calculations:

① To find R_i, separate R_i by finding R_{i_b} at first if it is CE or CC, R_{i_e} if it is CB.

② $v_i = v_s \frac{R_i}{R_s + R_i}$ could be usful sometimes in relations.

③ Always put in mind voltage division / current division / Nodal analysis; to connect the variables with eachother.

* Multi-stage Amplifier:

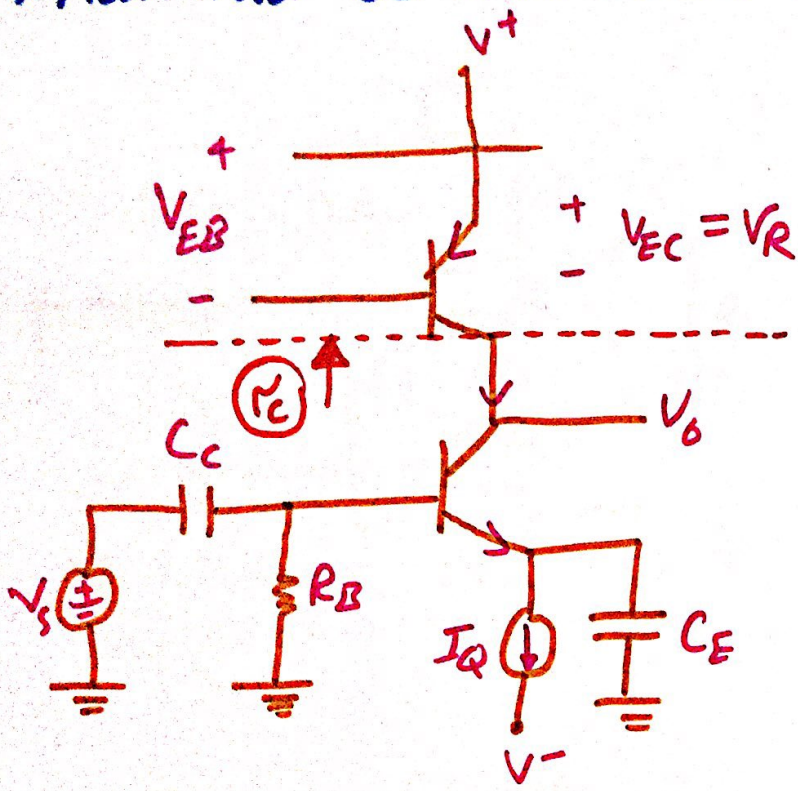
↳ Why we Need it? To satisfy certin requirements that can not be satisfied by single stage amplifier.

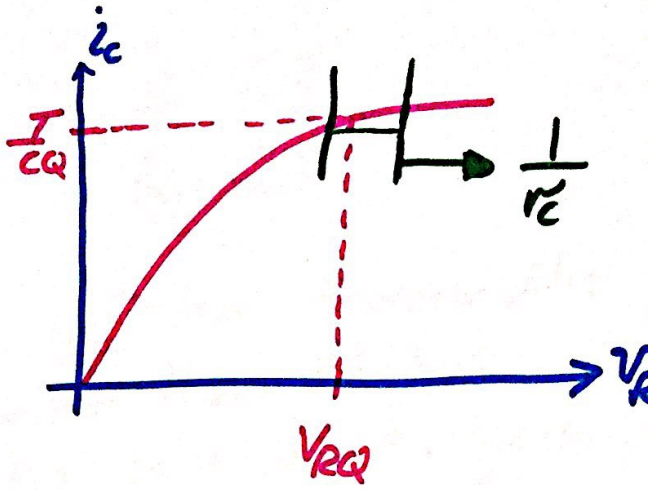
* Could ask to find overal voltage gain:
Here you need to do the analysis for each stage alone to find A_{v_1} & R_{o_1} then R_{o_1} will be R_s for the next stage with voltage source $V_s A_{v_1}$ and so on, Then find $A_{v_{total}}$ from the last stage.

* Also if he asked about R_o (total):
Do the same, then $R_{o\,total}$ found from the last stage since itis included by R_{o_1} & R_{o_2}.

* Also if he asked about R_i (total):
some of the teqniques that find R_i for stage(3) the make it load for stage(2) and so on until you find R_i (total).

*Advanced CE with active load:





*Advantages:

① r_o : high value ⇒ very high A_V

② small size so it is used in ICs.

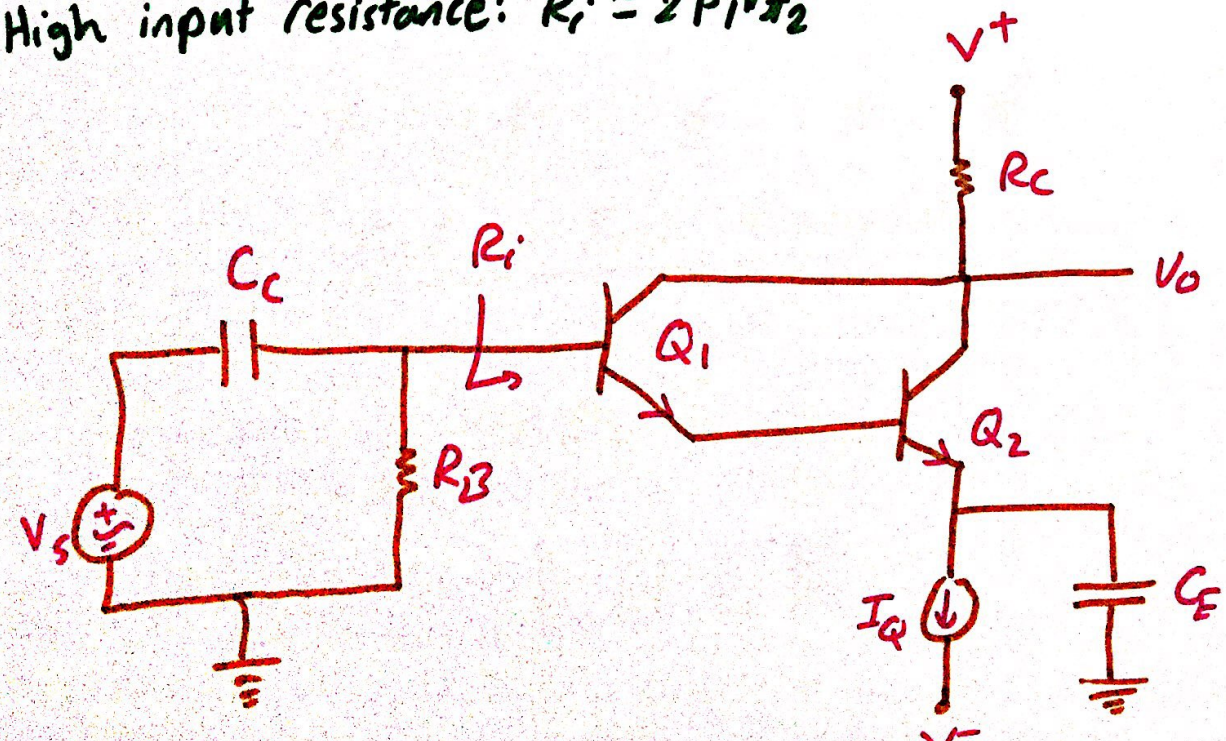
③ No need for bypass capacitor.

* Darlington Pair Circuit:

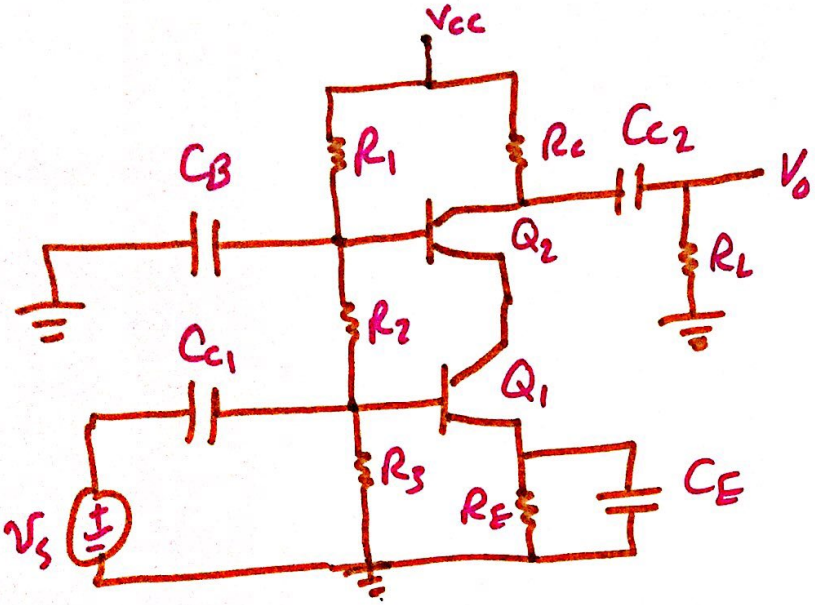
features:

① High current gain : $A_i = \beta_1 \beta_2$

② High input resistance: $R_i \simeq 2\beta_1 r_{\pi 2}$



*Cascade Configuration:



Q_1: CE.
Q_2: CB.

CB: has bandwidth wider than CE but CB has low input impedance so, caseade config. will have wide bandwidth & high input impedance.

⇒ These special ckts.
Darlington Pair & Cascade config.
↳ he could ask you: about the type of configuration for the transistors that useed in the ckt or ask about the features for the ckt.

* * * * *

End of First Material.

GOOD LUCK

Second Material

* Field Effect Transistor Amplifier:

⇒ we will focus on the type MOSFET in enhancement mode

⇒ MOSFET → n-channel
→ p-channel.

* Advantages of using MOSFET instead BJT:

① Small size. ② low power consumption. ③ High input impedance

* Disadvantage:

g_m of MOSFET << g_m of BJT so, $A_{v\,(MOSFET)} << A_{v\,(BJT)}$

* Always in MOSFET:

$I_G = 0$, $I_D = I_S$

* Note: FET to work as amplifier should be in saturation mode ⇒ $V_{DSQ} > V_{DS\,(sat)}$

* Analysis of FET-Amplifiers:

* step1: DC analysis:

① Draw DC eq. ckt.
② find V_{GSQ}, I_{DQ}, V_{DSQ} → I/p loop. → o/p loop.

* Note:
$V_{TN} > 0$
$V_{TP} < 0$

* n-channel:

$$I_{DQ} = K_n (V_{GS} - V_{TN})^2 \quad , \quad V_{DS\,(sat)} = V_{GS} - V_{TN}$$

* p-channel:

$$I_{DQ} = K_p (V_{GS} + V_{TP})^2 \quad , \quad V_{SD\,(sat)} = V_{SQ} + V_{TP}$$

※ Step 2: AC analysis:

① Draw AC eq. ckt.

② find g_m, r_o.

$$r_o = [\lambda I_{DQ}]^{-1}$$

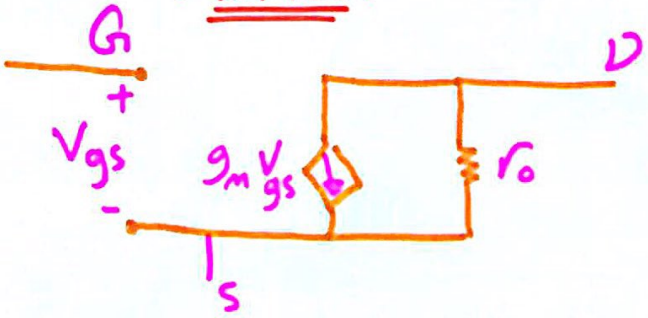
n-channel:

$$g_m = 2K_n(V_{GSQ} - V_{TN})$$

p-channel:

$$g_m = 2K_p(V_{SGQ} + V_{TP})$$

* NMOS:



* PMOS:

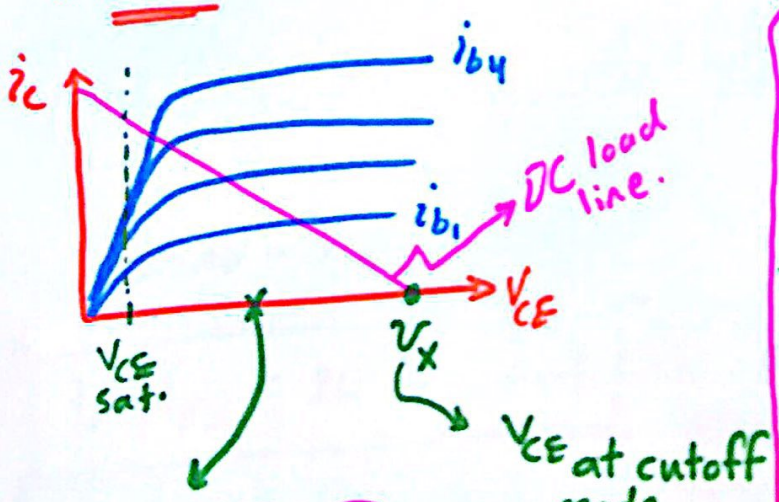
※ Basic FET-Amplifier Configurations:

- Common Source.
- Common Drain.
- Common Gate.

* DC load line: $I_D \propto V_{DS}$ * AC load line: $i_d \propto V_{ds}$

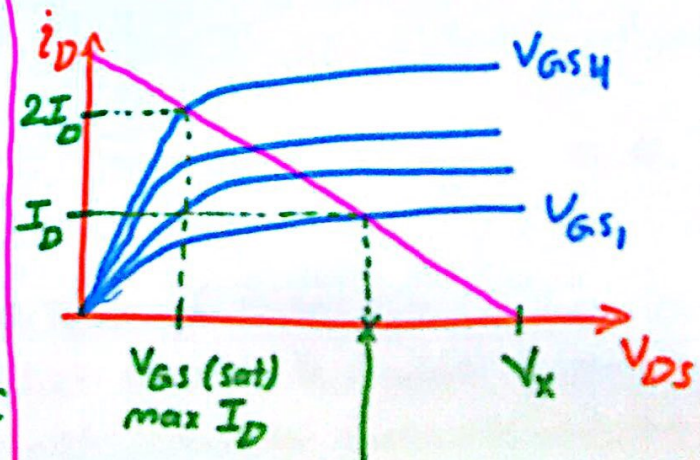
※ How to select the best value of V_{CEQ} & V_{DSQ}:

* BJT:



$$V_{CE} = \frac{V_x + V_{CE(sat)}}{2}$$

* FET:

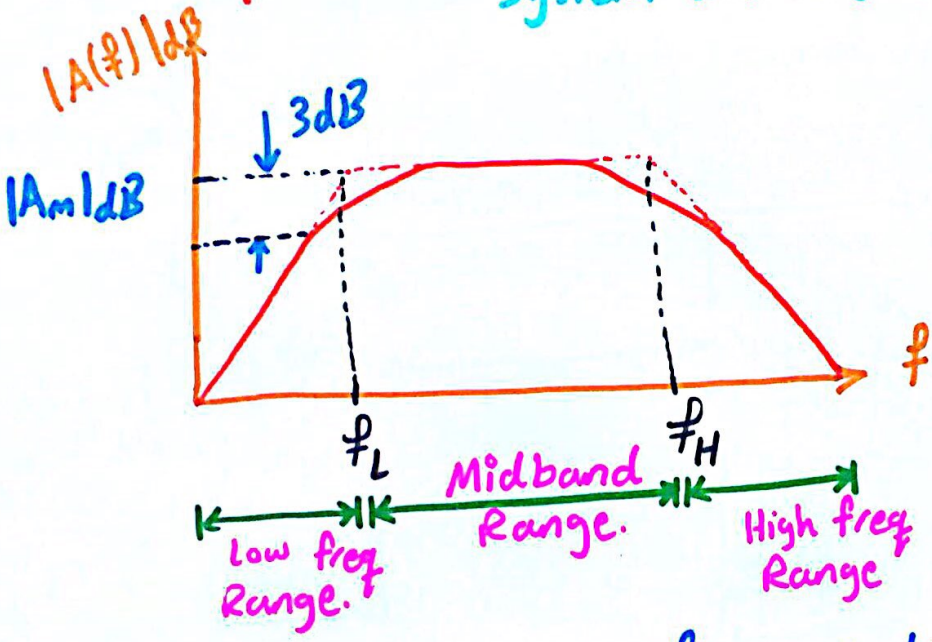


$$V_{DSQ} = \frac{V_x + V_{GS(sat)\ \text{max}\ I_D}}{2}$$

Note: You have to solve examples from the book on Common source, Common drain, common gate and they are similer to BJT examples.

※ Frequancy Response:

what is freq. response? it is the steady state output of linear system due to a sinusoidal input.



at $\begin{cases} f=0 \text{ (DC analysis).} \\ f>0 \text{ (AC analysis).} \end{cases}$

f_L: Lower freq. or corner freq. or break point or 3dB freq.

f_H: Higher freq. or " " . or " " or " " .

$f_L = \frac{1}{2\pi \tau_L}$, $f_H = \frac{1}{2\pi \tau_H}$

where: τ: Time Constant.

* Bandwidth of Amplifier: $BW = f_H - f_L$ **

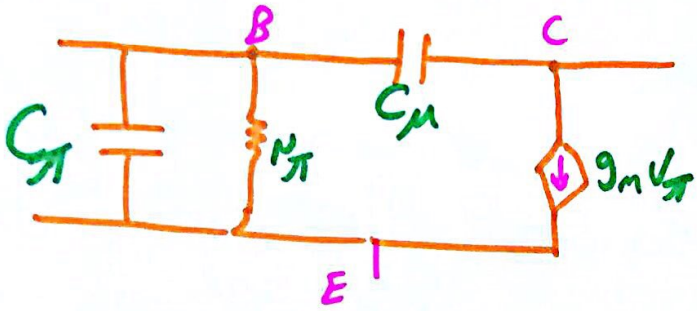
$$|A_v|_{dB} = 20 \log_{10} |A_v|$$

* Types of capacitors in Amp. CKt:

① group1: coupling & bypass capacitors.

② group2: Transistor Capacitors (C_π & C_μ) and load capacitor.

* C_π & C_μ in the transistor:

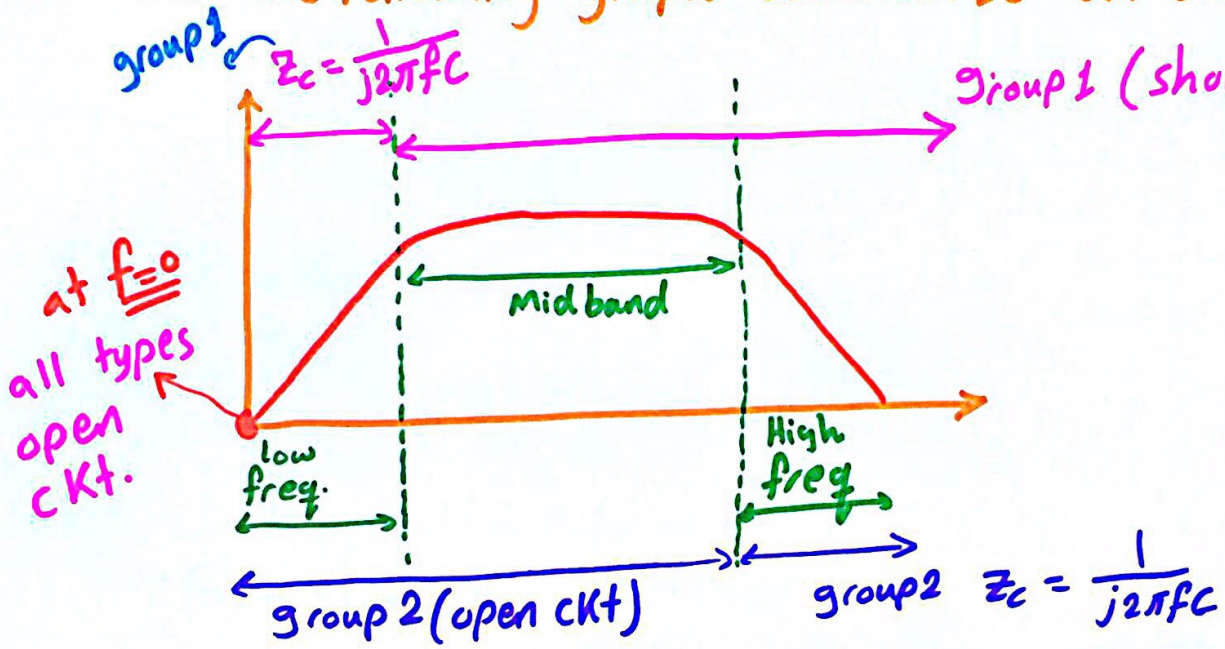


*Note:

values of group1 > values of group2

* The capacitors could be open ckt or short ckt or have impedance:

⇒ The following graph summarize all statuses:



* Transfer function of a system ≡ $\frac{\text{output}}{\text{input}}$.

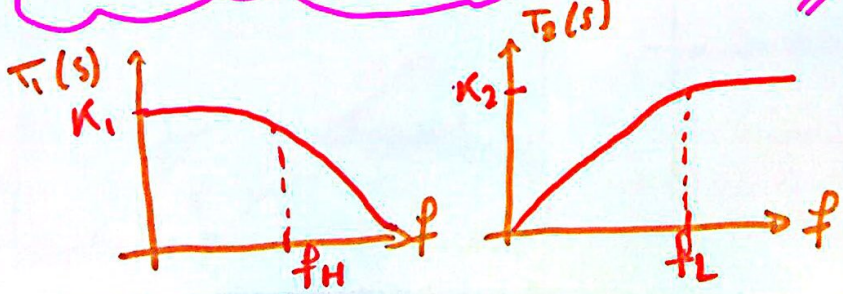
* Complex freq. of a system ≡ $S = j\omega$.

$Z_c = \frac{1}{SC}$

$$T_1(s) = K_1 \frac{1}{1+s\tau_1}$$

$$T_2(s) = K_2 \frac{s\tau_2}{1+s\tau_2}$$

⇒ see the prove in Notebook.



⇒ from them we can know the corner freq.

* What is "Bode Plot" ?

a simplified technique for obtaining approximate plots of the magnitude & phase of a transfer function given the poles & zeros or equivalent time constant.

* To draw the Bode Plot:

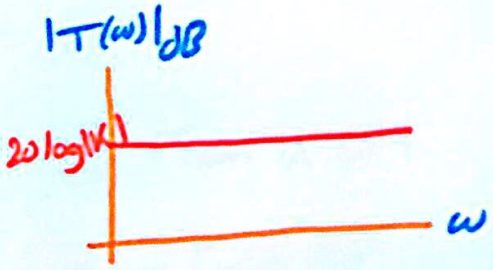
1. write the function in log form.
2. You will have multi-part; draw each one alone.
3. To draw the main function find the sum of slopes on the left & the right of the point when $|T(f)|_{dB} = 0$

↳ it will be the sum of the points on the vertical line at that point $|T(f)|_{dB} = 0$

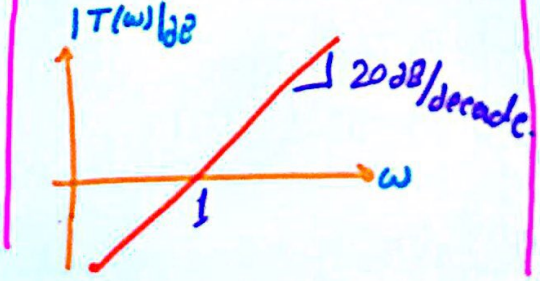
※ Short method to draw Bode Plot:

By writing the function similar to one or more of the following five types:

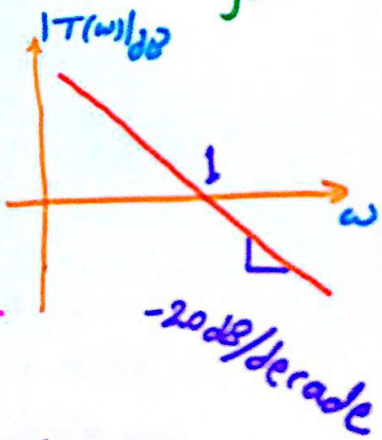
① $T(\omega) = K_{constant}$.



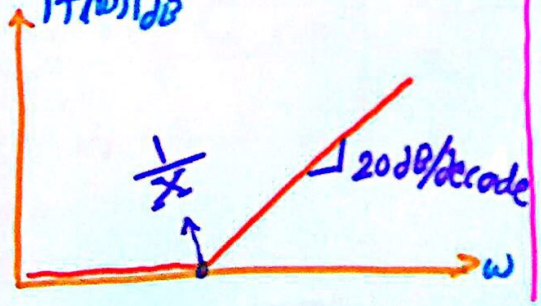
② $T(\omega) = j\omega$



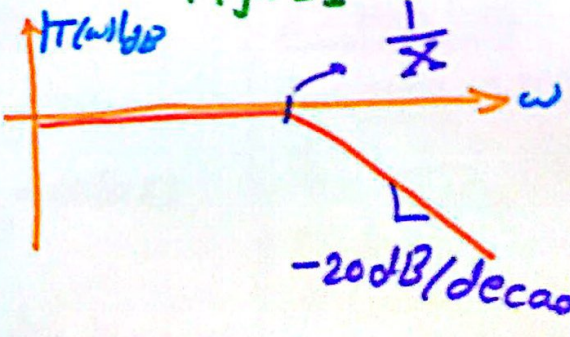
③ $T(\omega) = \frac{1}{j\omega}$



④ $T(\omega) = 1 + j\omega X$



⑤ $T(\omega) = \frac{1}{1 + j\omega X}$



※ How to find the time Constant:

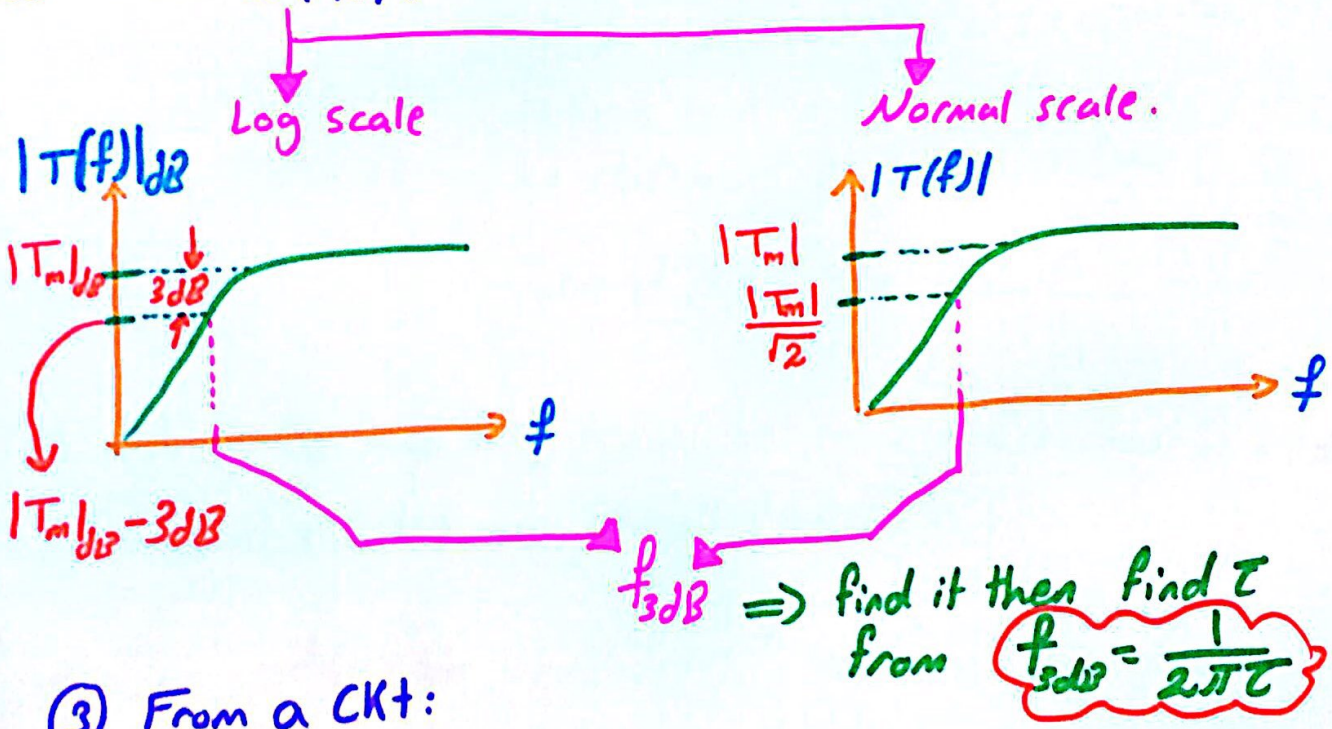
- from a transfer function.
- from a Plot.
- from a circuit.

① From a Transfer Function:

⇒ write the given function on the form of

$T_1(s) = K\frac{1}{1+s\tau}$ or $T_2(s) = K\frac{s\tau}{1+s\tau}$ ⇒ then find τ.

② From a Plot:



f_{3dB} ⇒ find it then find τ from $f_{3dB} = \frac{1}{2\pi\tau}$

③ From a CKt:

※ One Capacitor:

* Draw the ckt in AC form then:

$\tau = R_{eq} C$

it is R_{th} that seen from the one capacitor.

※ Two Capacitors: [$C_1 > C_2$]

* it will be two time constant ⟨ at low freq. / at high freq.

At low freq:

$Z_{C_1} = \frac{1}{j2\pi f C_1} \equiv$ Value

$Z_{C_2} = \frac{1}{j2\pi f C_2} = \infty$ (o.c)

$\tau = R_{eq} C_1$

it is called O.C time Const.

At High freq:

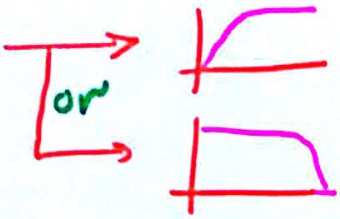
$Z_{C_1} = \frac{1}{j2\pi f C_1} = 0$ (s.c)

$Z_{C_2} = \frac{1}{j2\pi f C_2} \equiv$ Value.

$\tau = R_{eq} C_2$

it is called S.C time constant.

* Drawing the transfer func. to a given ckt:

① if one capacitor →  ⇒ find f_L.

or

 ⇒ find f_H.

or

if two capacitors  ⇒ Need f_L & f_H.

② Find the max value then draw.

- if just f_L: find max when $f=\infty$ (capacitor s.c)
- if just f_H: find max when $f=0$ (capacitor o.c)
- if f_L & f_H: take a point in the middle and see the statement of the capacitors [are they open ckt or short ckt] depending on the value of capacitors then find max.

* Why in the high freq transistor small devices must be used?
since it must have small capacitors.

* f_T: "unity gain bandwidth" or "Cutoff freq".

* f_{3dB} or f_β: "Beta Cutoff freq" or "the Bandwidth of the transistor"

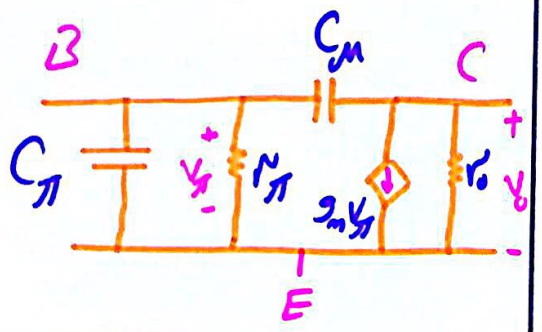
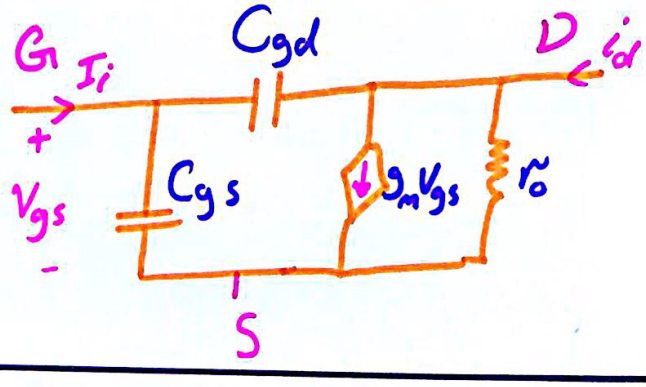
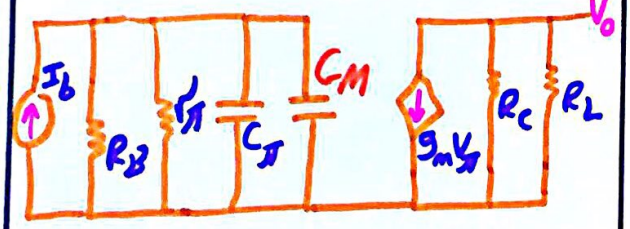
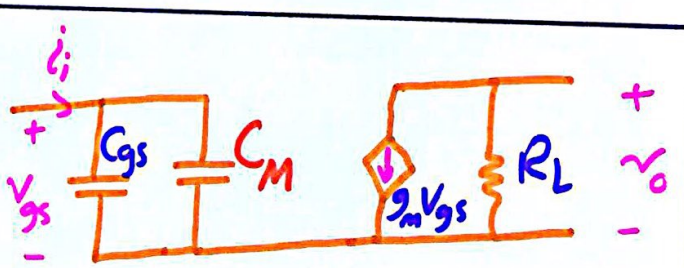
$$f_\beta = \frac{1}{2\pi r_\pi (C_\pi + C_\mu)}$$

* Why in BJT C_μ or C_{gd} in FET can't be ignored at High freq?

⇒ Due to Miller Effect.

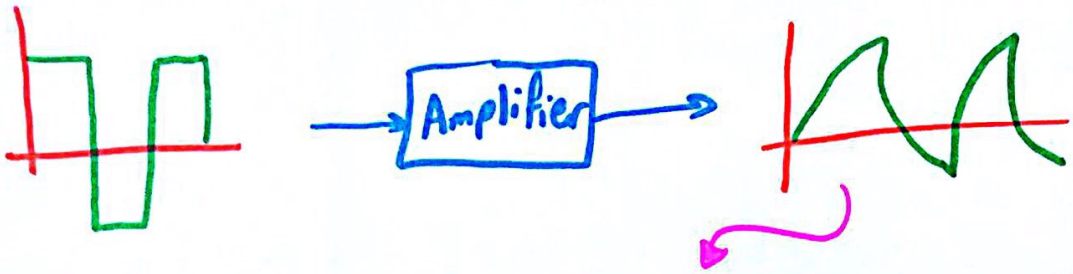
$$f_T = \beta f_\beta$$

※ Frequancy Response for BJT & FET Amplifiers At High Frequancy:

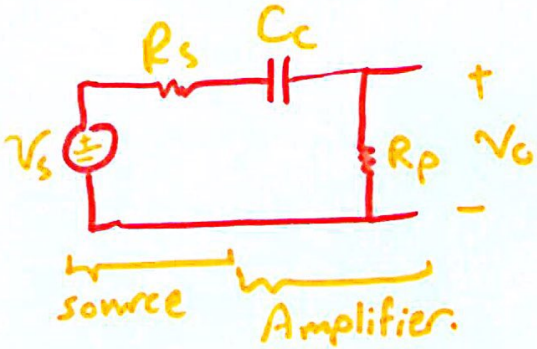
	BJT	FET.
AC CKt.		
f_T	$f_T = \frac{\beta}{2\pi r_\pi (C_\pi + C_\mu)}$	$f_T = \frac{g_m}{2\pi (C_{gd} + C_{gs})}$
AC CKt with Miller Effect		
C_M	$C_M = C_\mu * [1 + g_m (R_c \| R_L)]$	$C_M = C_{gd} * [1 + g_m R_L]$

※ Time Response:

* Why we study it? since sometime we need to amplify non-sinusoidal signal such as square wave signal. (Digital Signal).



due to charging & discharging of capacitors.
(C_c & C_L).



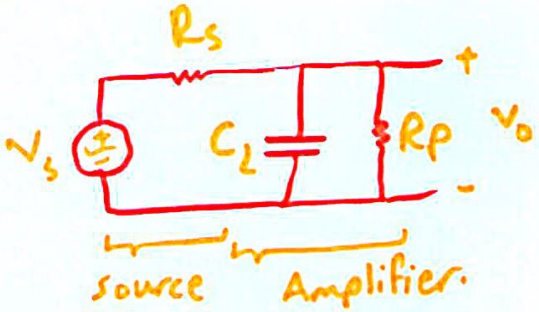
$\Rightarrow$ for this ckt: need $\tau \geq 10T$

where $T = \frac{1}{2} T_s$

$\tau = C_c (R_p + R_s)$

$\Rightarrow$ we need High C_c:

Rule: $C_c \geq \frac{5\,T_s}{R_p + R_s}$



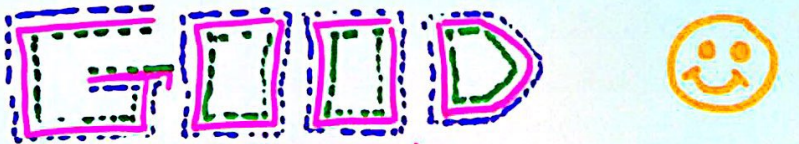
$\Rightarrow$ for this ckt: need $\tau \leq \frac{T}{10}$

where $T = \frac{1}{2} T_s$, $\tau = C_L (R_p // R_s)$

$\Rightarrow$ we need C_L such that:

Rule: $C_L \leq \frac{T_s}{20(R_p + R_s)}$

End of Second Material.



Final Material

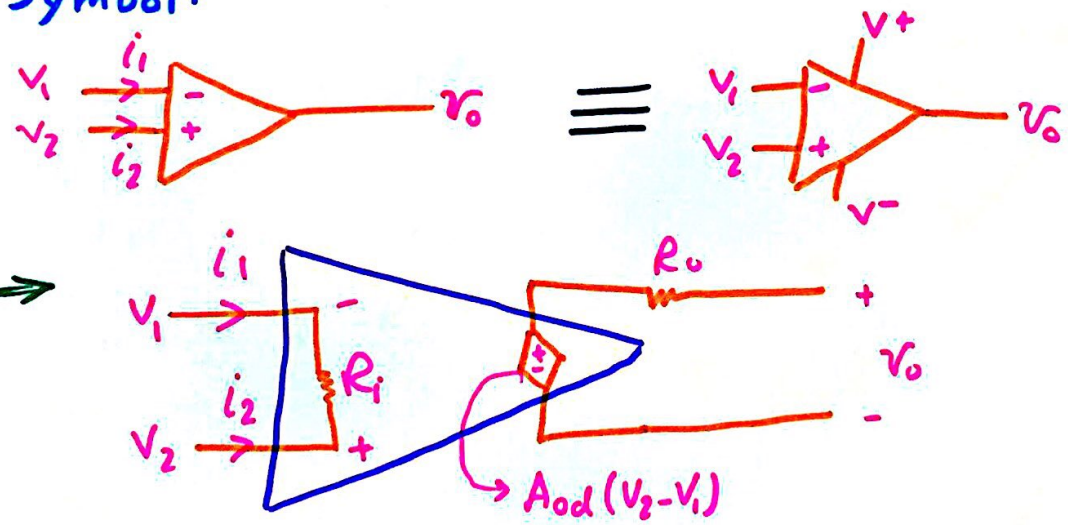
* Operational Amplifier [Op-Amp]:

↳ What is Op-Amp? it is an integrated ckt that amplifies the difference between two input signals & produces one output signal (This is the basic function).

Why we use it? it was used in analog computers to perform mathematical operations to solve differential & integral equ.

What is the number of transistors that op-Amp cosists?
it is consists of 20-30 transistors.

* Symbol:



V_1 is called: inverting terminal
V_2 is called: Non-inverting terminal.

A_{od}: open-loop differential voltage gain.

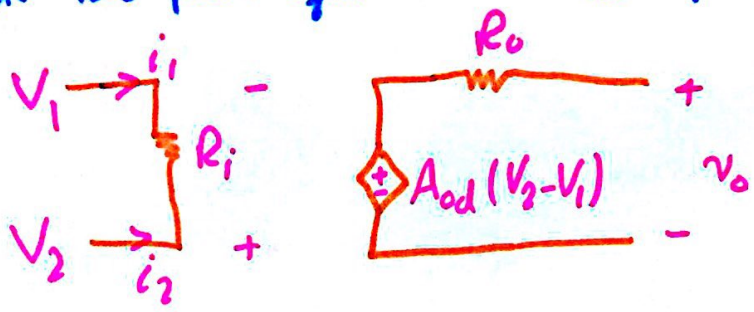
* Ideal Op-Amp:

① $R_i = \infty$
$\Rightarrow$ $\boxed{i_1 = i_2 = 0}$

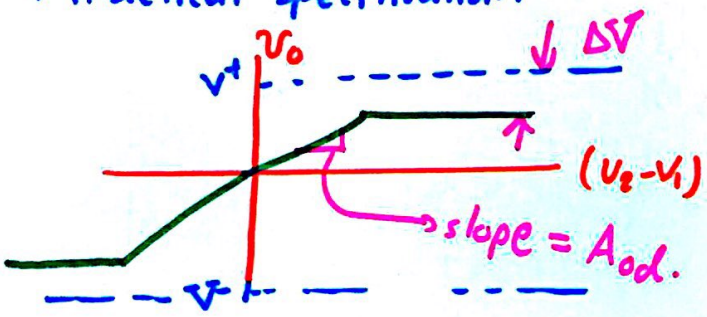
② $R_o = 0 \Rightarrow V_o = V_{od}(V_2 - V_1)$
$V_{od} = \infty$
$\Rightarrow$ $\boxed{V_1 = V_2}$

③ V_1 & V_2 could be DC or AC or both.

* Two-port equivalent ckt for Op-Amp:

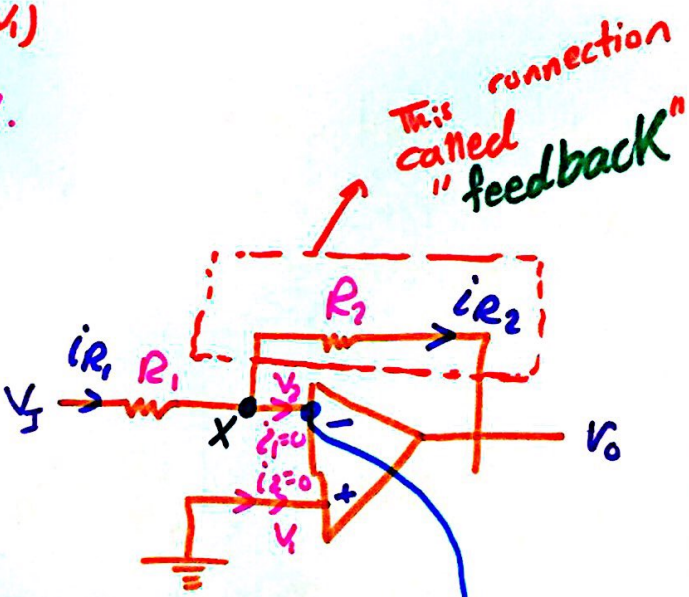


* Practical specification:



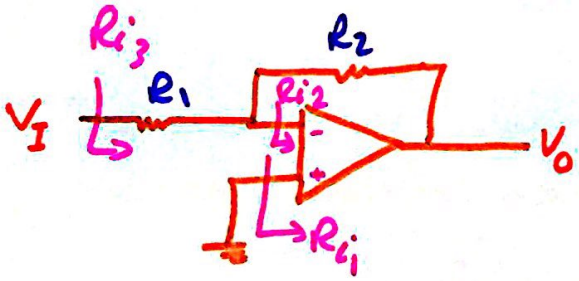
※ Op-Amp Applications:

① Inverting Amplifier:



if it is an ideal op-amp.

$$A_v = \frac{V_o}{V_I} = \frac{-R_2}{R_1}$$ ⇒ do KCL at X.



$R_{i_1} = \infty$
$R_{i_2} = \infty$
$R_{i_3} = R_1$

it is called virtual ground.

(why?)

the voltage at this point = 0 (as actual ground)

but the current in this point = 0 (so virtual ground).

② Amplifier with T-network:

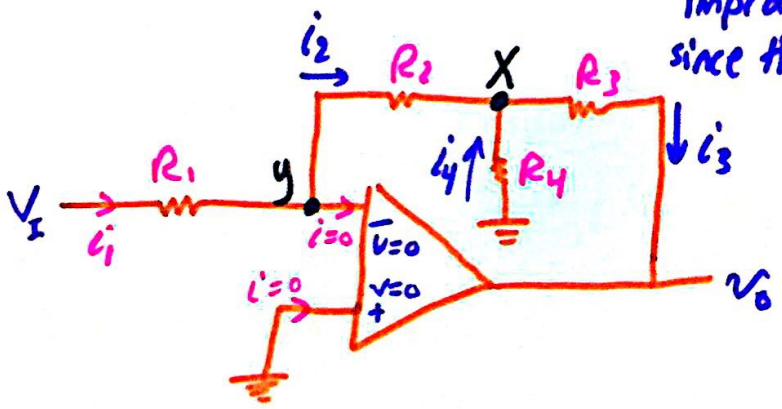
*Why we used it?

since sometime in first application if we have

$R_i = 50K\Omega$ & $A_V = -100$

$R_i = R_1 = 50K$ $\Rightarrow$ $A_V = \frac{-R_2}{R_1}$ $\Rightarrow$ $R_2 = 5M\Omega$

this impractical value since that we use it.



*You have to Know how to use Nodal analysis at x and y.

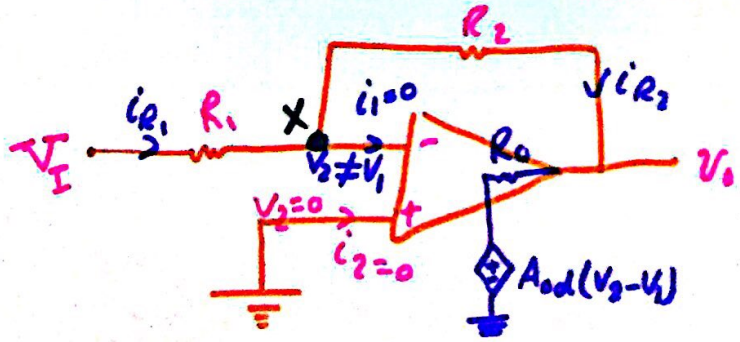
you can reach that:

$$A_V = \frac{V_o}{V_I} = \frac{-R_2}{R_1}\left(1 + \frac{R_3}{R_4} + \frac{R_3}{R_2}\right)$$

حفظ.

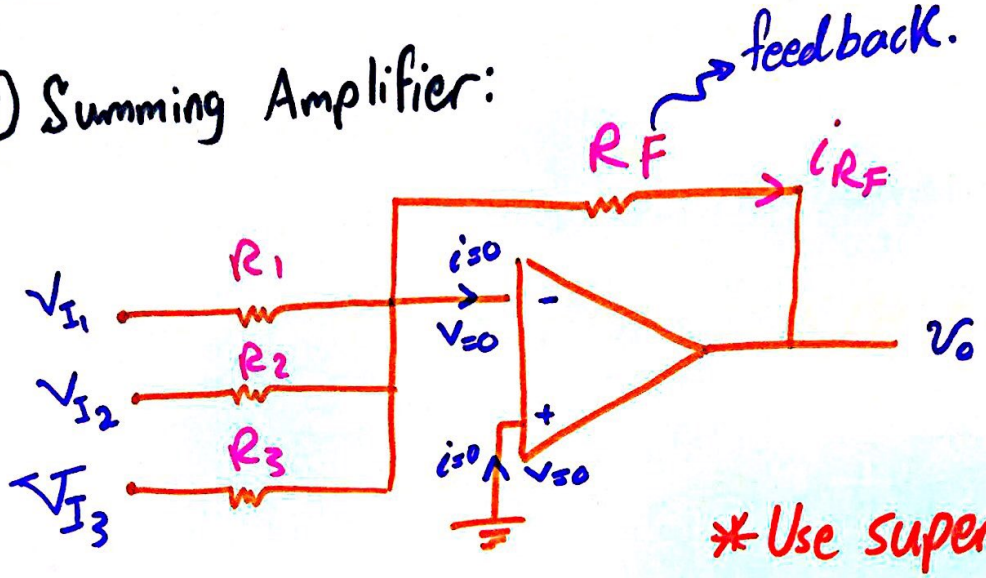
لكنه يجب أن تعرف مواقع المقاومات الأربعة بالزبط.
كما مبينة بالشكل العلوي.

*The previous ckts was Ideal op-amp, now if an inverting amplifier wasn't ideal:



Do KCL at (X) and find $A_V = \frac{V_o}{V_I}$.

③ Summing Amplifier:

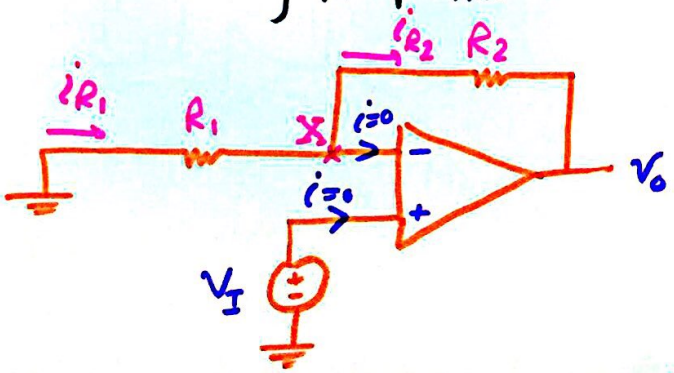


* Use super position To solve.

⇒ You can reach: if $R_1 = R_2 = R_3 = R$

$$* \quad v_o = -\frac{R_F}{R}\left[V_{I_1} + V_{I_2} + V_{I_3}\right] \quad *$$

④ Noninverting Amplifier:



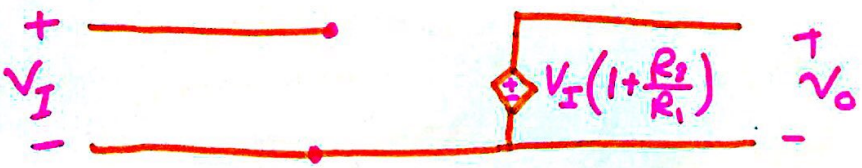
* KCL @ X:

where: $v_2 = V_I = V_1$

$$\Rightarrow * \quad A_V = 1 + \frac{R_2}{R_1} \quad *$$

* Note that $A_V > 1$ in this Application.

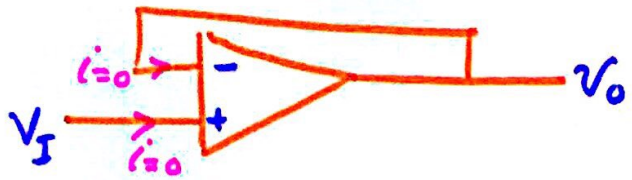
⇓ The two-port equivalent network:



⑤ Voltage Follower:

↳ similar to common collector amplifier.

* other names: Buffer, Impedance Transformer.



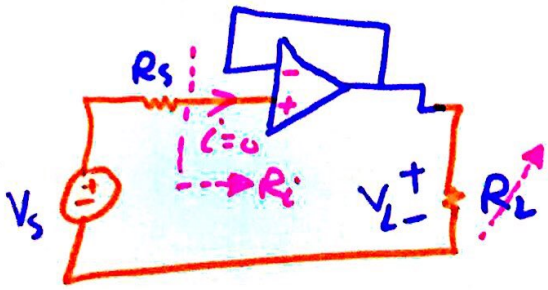
$\Rightarrow$ * $V_I = V_o$ *

* $A_V = 1$ *

* Where we use it ?

$\Rightarrow$ we use it with ckt that has High-loading effect

$\Rightarrow$ it will make the ckt has No loading effect.

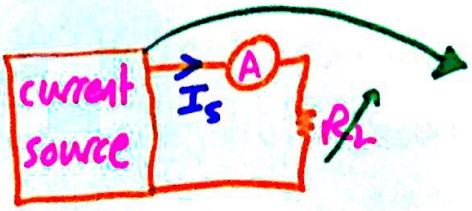


$\Rightarrow$ $R_i = \infty$

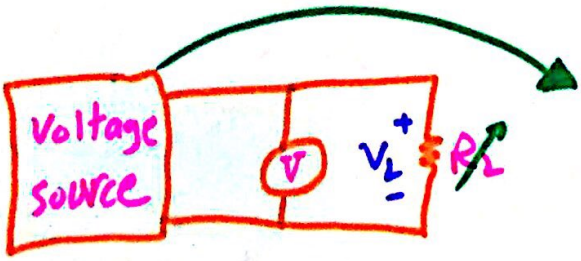
$V_2 = V_1 = V_s = V_L$

$\Rightarrow$ $V_s = V_L$ even if R_L is changed.

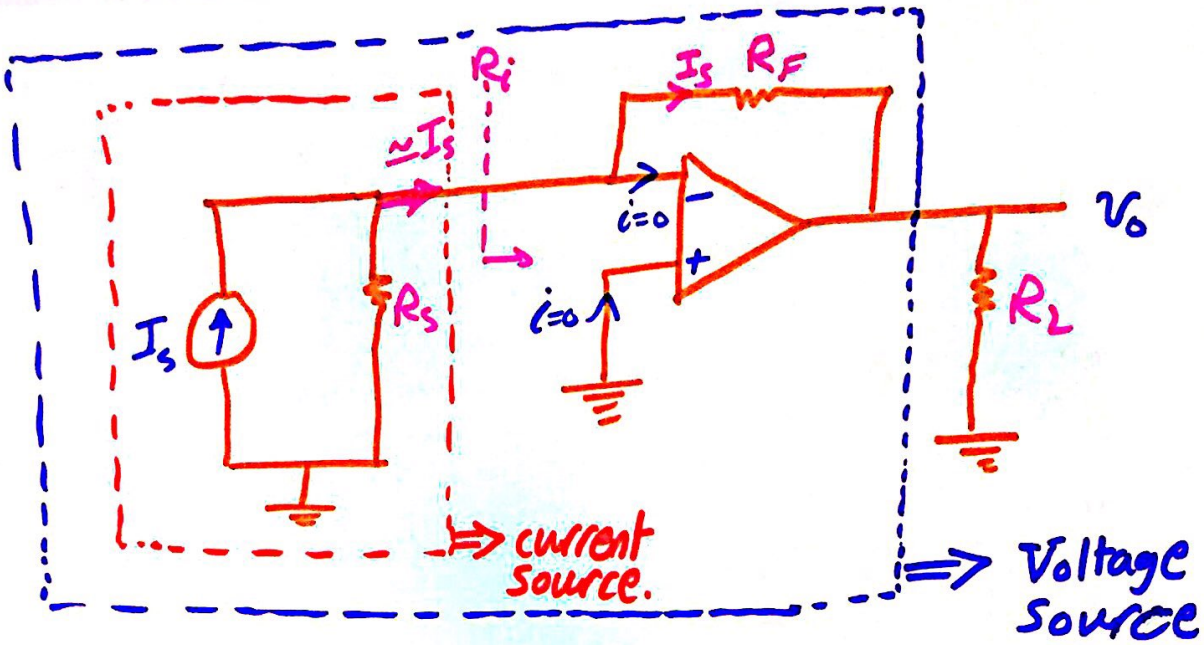
⑥ Current-to-Voltage Converter:



it is current source if I_s is fixed and independent on R_L.



it is voltage source if V_L is fixed and independent on R_L.



$\Downarrow$

$V_1 = V_2 = 0$

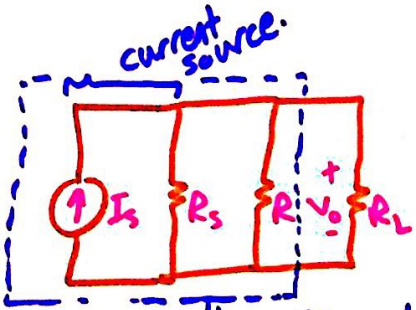
$R_i = 0$

$\Rightarrow I_s = \frac{0 - V_o}{R_F}$

$\hookrightarrow$ $V_o = -R_F I_s$

independent on R_L

so, yes it it voltage source.

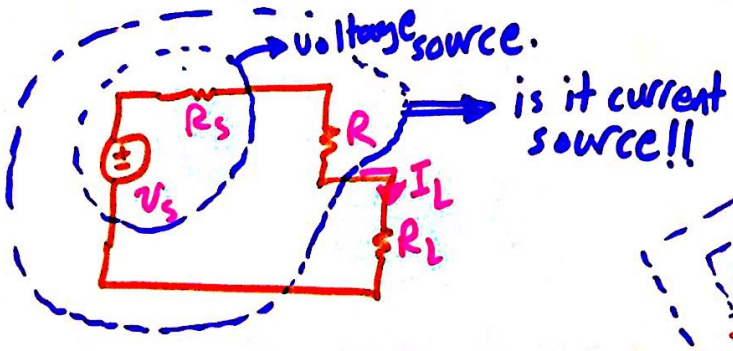


$\Rightarrow$ it is not voltage source.

since: $V_o = I_s(R_s // R // R_L)$

$\rightarrow V_o$ depend on R_L so it is not voltage source.

(7) Voltage-to-Current Source:

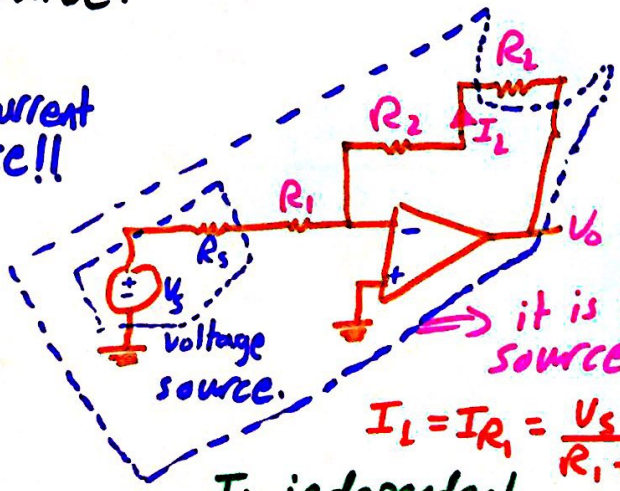


$\rightarrow$ is it current source!!

$$I_L = \frac{V_s}{R_s + R + R_L}$$

$\Rightarrow I_L$ depends on R_L

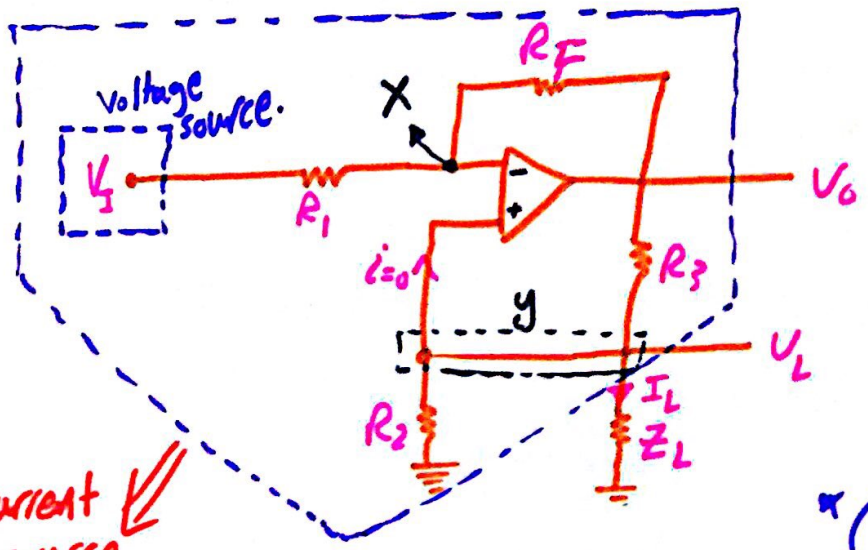
so Not a current source.



$\Rightarrow$ it is current source.

$I_L = I_{R_1} = \frac{V_s - 0}{R_1 + R_s}$

I_L independent on R_L.



current source * under the condition *

$$i_i = -\frac{V_I}{R_2}$$

so under this condition.

→ so always check for the condition to use this relation.

⇒ Do KCL @ x & y:

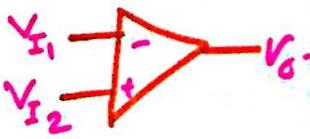
$$i_i = -V_I \frac{R_F}{R_1 R_3}$$

⇒ we choose

$$\frac{R_F}{R_1 R_2} = \frac{1}{R_2}$$

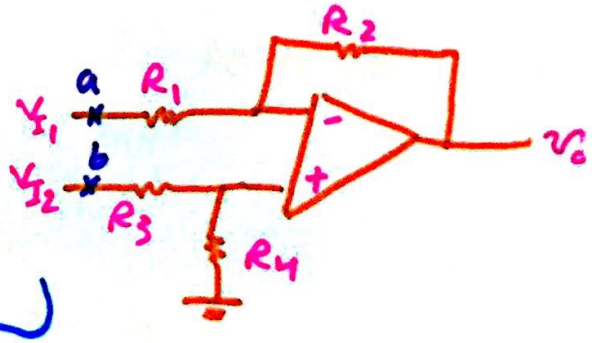
⇒ To cancel Z_L

⑧ Difference Amplifier:



↳ Problem that Aod fixed

solution. ⟹



use super position.

$$V_o = \left(1+\frac{R_2}{R_1}\right)\left(\frac{R_4/R_3}{1+R_4/R_3}\right)V_{I2} - \frac{R_2}{R_1}V_{I1}$$

we choose: $\frac{R_4}{R_3} = \frac{R_2}{R_1}$ ⟹ $v_o = \frac{R_2}{R_1}(V_{I2} - V_{I1})$

↳ The easiest to select:

$R_3 = R_1$

$R_4 = R_2$

R_i between a & b:

$R_i = R_1 + R_3$ if the condition true

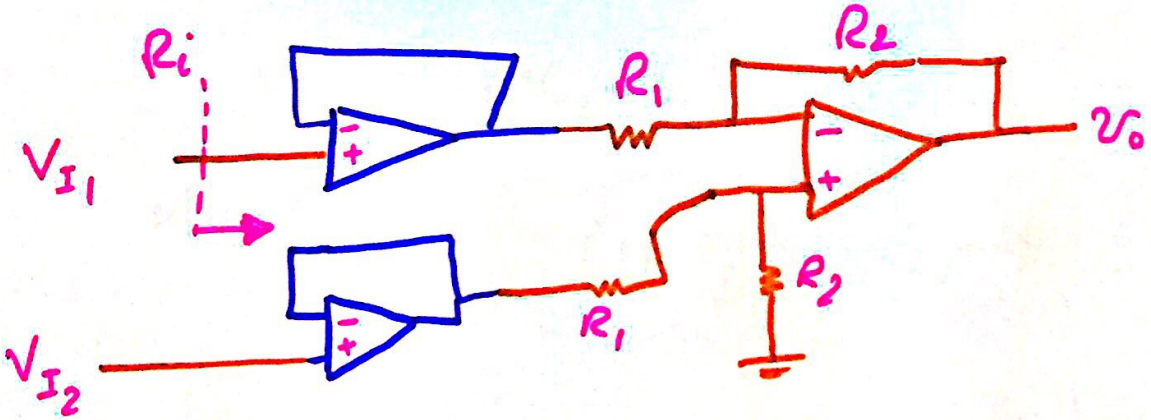
⇒ $R_i = 2R_1$

Note: if he asked to find R_i between two points
⇒ put voltage source V_x with I_x between these two points.
if he asked to find R_i @ some point
⇒ put V_x with I_x between this point and the ground.

* Two problems face application number ⑧:

① if we want to change the gain $V_o = \frac{-R_2}{R_1}(V_{I_2} - V_{I_1})$
we take R_1 fixed & change R_2 but there is (two R_2) ⇒ we should keep them equal (practical problem)
⇒ we solve this By Application ⑨.
↳ Instrumentation Amplifier.

② $A_V = \frac{R_2}{R_1}$, we need $R_i = 2R_1$ to be High
⇒ This will cause A_V to be low
⇒ we solve this by **Buffer**.



⇒ $R_i = \frac{V_x}{I_x}$ where $I_x = 0$

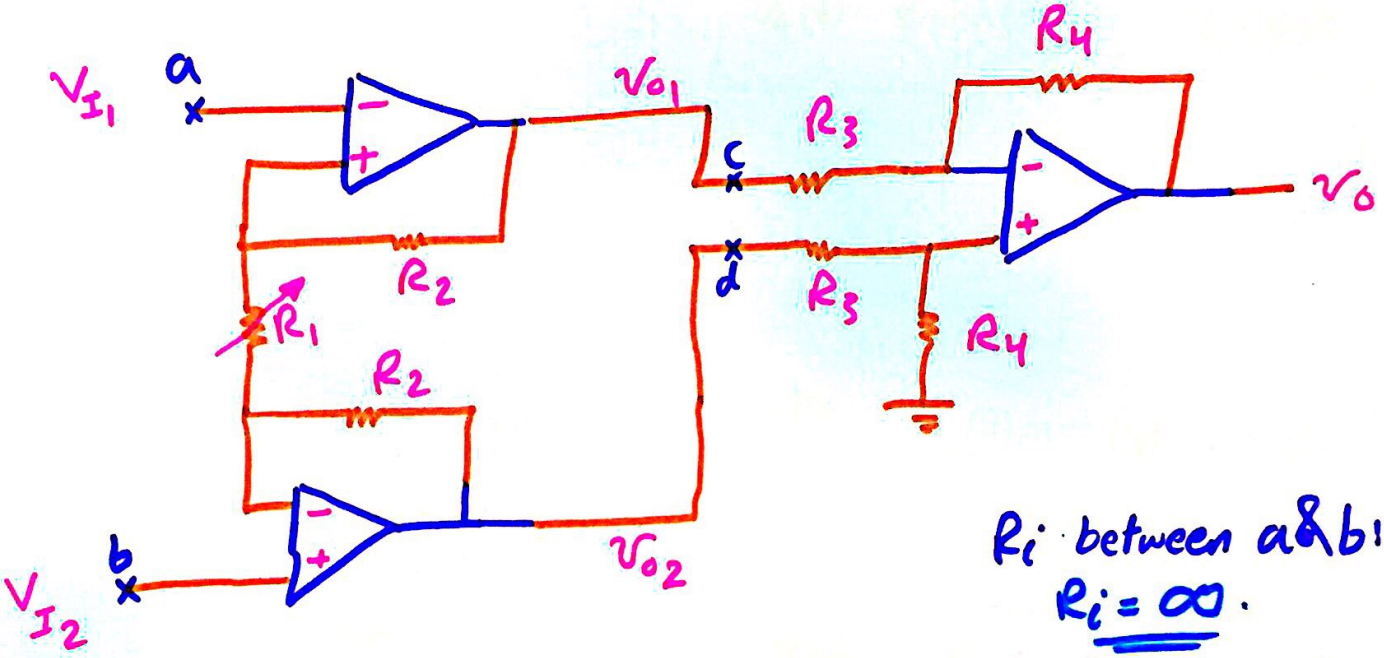
so $R_i = \infty$ (High value)

⑨ Intrumentation Amplifier:

* Advantages:

① $R_i = \infty$.

② We can change the gain via one resistor.



R_i between a & b:
$R_i = \infty$.

R_i between c & d:
$R_i = 2R_3$

⇒ After doing the analysis:

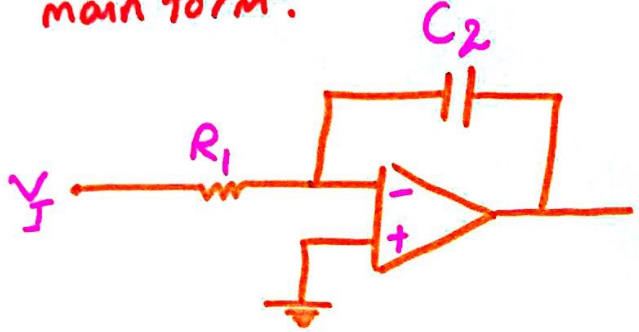
$$v_o = \frac{R_4}{R_3}(v_{o_2} - v_{o_1})$$

also *
$$v_o = \frac{R_4}{R_3}\left(1 + \frac{2R_2}{R_1}\right)(V_{I_2} - V_{I_1})$$ *

* Note: You have to know how to find R_i between any two points or @ any point.

⑩ Integrator:

main form:

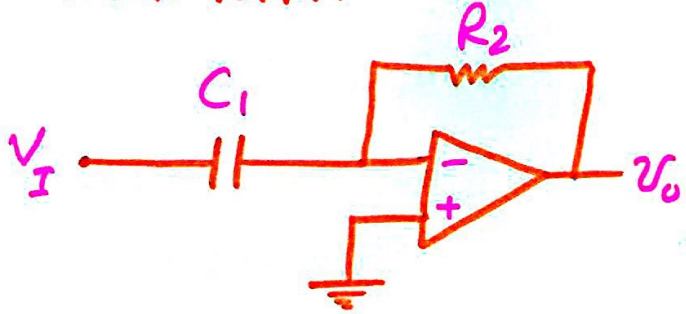


$$V_o(s) = \frac{-1}{sR_1C_2} V_I(s)$$

$$v_o(t) = v_c(t=0) - \frac{1}{R_1C_2}\int_0^t v_I(t')dt'$$

⑪ Differentiator:

main form:



$$V_o(s) = -R_2C_1 s V_I(s)$$

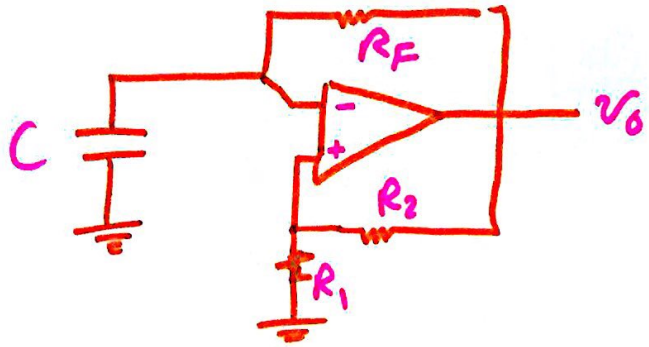
$$v_o(t) = -R_2C_1 \frac{dV_I(t)}{dt}$$

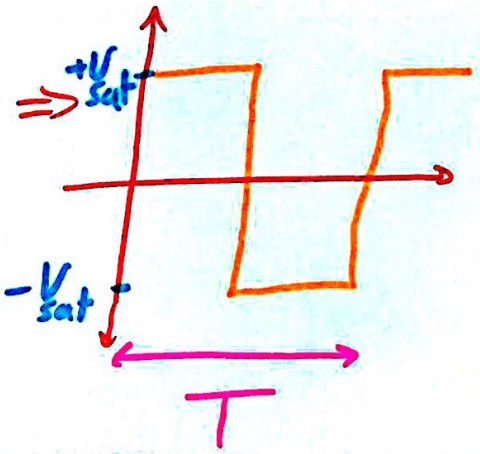
* An important NOTE on both applications ⑩ & ⑪:

You have to know the main condition that make a ckt Integrator or differentiator so if he add any component to the ckt and ask what will make it integrator or differentiator just find $\frac{V_o(s)}{V_i(s)} = ?$ Then compare between (?) & the main condition. ⇒ Then find the new condition.

- $\frac{-1}{sR_1C_2}$ → Integrator.
- $-sR_2C_1$ → Differentiator.

(12) Square-Wave Generator:





if $V_2 > V_1 \Rightarrow V_o = +V_{sat}$

if $V_1 > V_2 \Rightarrow V_o = -V_{sat}$

if $V_o > V_c \Rightarrow$ C is charged.

if $V_c > V_o \Rightarrow$ C is discharged.

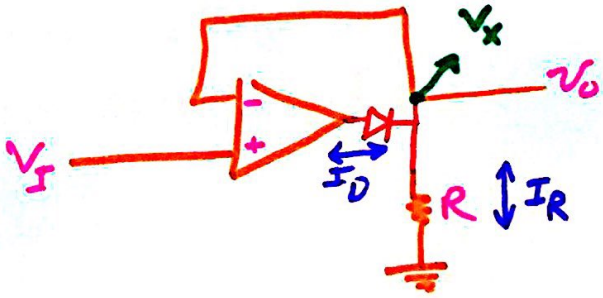
$$T = 2R_F C \ln\left(\frac{1+\lambda}{1-\lambda}\right)$$

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

(13) Precision Half-wave Rectifier:

Why we use it ?

To save the 0.7 voltage that was lost in Diode half-wave rectifier.



we have two assumptions:

$V_I < 0$ or $V_I > 0$

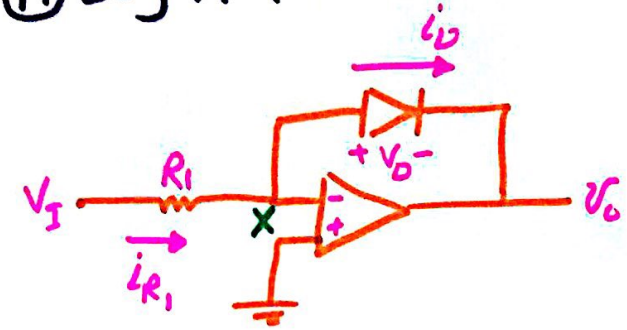
Case ($V_I < 0$):

- if the diode ON: $\Rightarrow$ voltage follower ($V_o = V_I$) $\Rightarrow V_x < 0 \Rightarrow I_R \uparrow = I_D$ (wrong assumption).
- if the diode OFF: $\Rightarrow$ No feedback ($V_o = 0$)

Case ($V_I > 0$):

- if the diode ON: $\Rightarrow$ voltage follower $\Rightarrow V_x > 0 \Rightarrow I_R \downarrow = I_D$ (correct assumption).

(14) Log Amplifier:



remember:

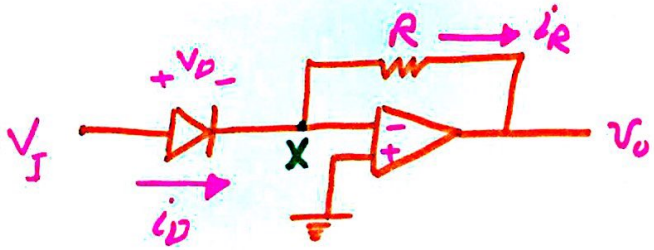
$$i_D \simeq I_S\, e^{v_D/N_T}$$

@X: $i_{R_1} = i_D$

$$\frac{V_I}{R_1} = I_S\, e^{v_D/N_T} \quad ; v_D = -V_o$$

$$\Rightarrow \boxed{V_o = -V_T \ln\left(\frac{V_I}{I_S R_1}\right)}$$

(15) Antilog or Exponential Amplifier:



Kcl @x:

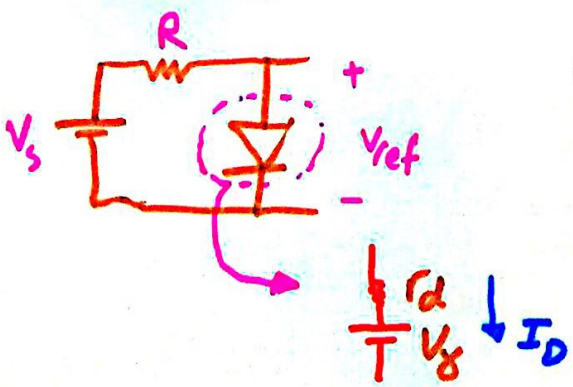
$$\Rightarrow \boxed{V_o = -I_S R\, e^{V_I/N_T}}$$

(16) Reference Voltage Source Design:

- Tempreture effect on the typical voltage source
  ⇒ So we use this application to have a fixed reference voltage.

* We have 3 solutions:

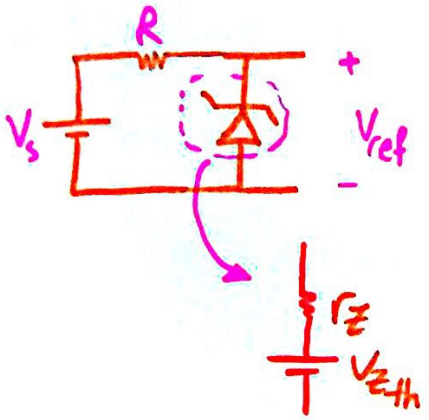
Solution(1): using pn Diode.



$$\Rightarrow V_{ref} = V_\gamma + r_d\left(\frac{V_s - V_\gamma}{r_d + R}\right)$$

* NOT a strong solution
Need another one.

solution(2): using Zener diode.



$$\Rightarrow V_{ref} = V_{z_{th}} + r_z \left(\frac{V_s - V_{z_{th}}}{r_z + R} \right)$$

r_z is very small so however V_s changes it won't effect a lot in V_{ref}

$\Rightarrow$ so solution 2 better than solution 1.

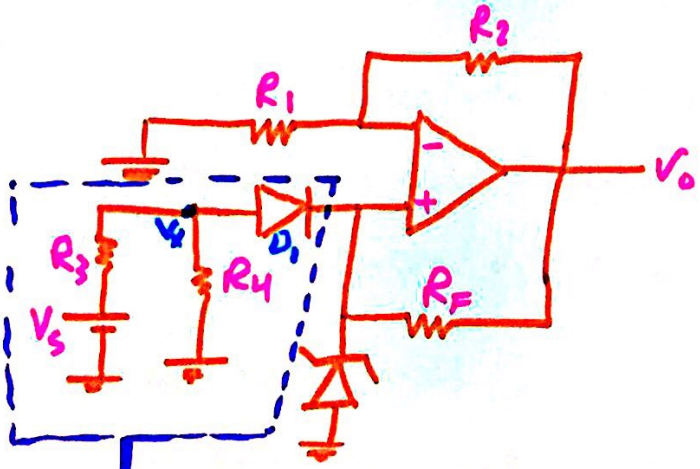
*Disadvantages of solution(2):

① V_s changes slightly with V_{ref}.

② in some cases, we need $V_{ref} >$ or $<$ than $V_{z_{th}}$.

solution (3):

using op-amp, pn diode & Zener diode.



we use this part:
To start-up the circuit.

*when D_1 is on.

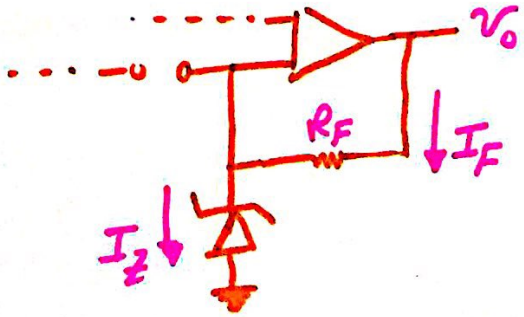
$$(V_x - V_z) > V_\gamma$$

$$V_s \frac{R_4}{R_3 + R_4} - V_z > V_\gamma$$

$\Rightarrow$ we decrease V_s such that D_1 is off (open ckt)

$$V_o = V_z \left(1 + \frac{R_2}{R_1}\right)$$

$$I_z = \frac{R_2 V_z}{R_1 R_F}$$



※ Feedback & Stability:

* Types of feedback:

① Positive Feedback: a portion of the output signal is added to the input signal
⇒ used in the design of oscillators
e.g. square-wave-generator.

② Negative Feedback: a portion of the output signal is subtracted from the input signal.

* Advantages of (-ve) Feedback:

① Gain Stability: the gain is independent on the parameters of the transistor or the op-amp (ex. β)
e.g: Inverting Amplifier.

② Bandwidth Extension: increase the bandwidth.

③ Increase Signal-to-Noise Ratio. (SNR).

④ Reduce the Non-Linear Distortion.

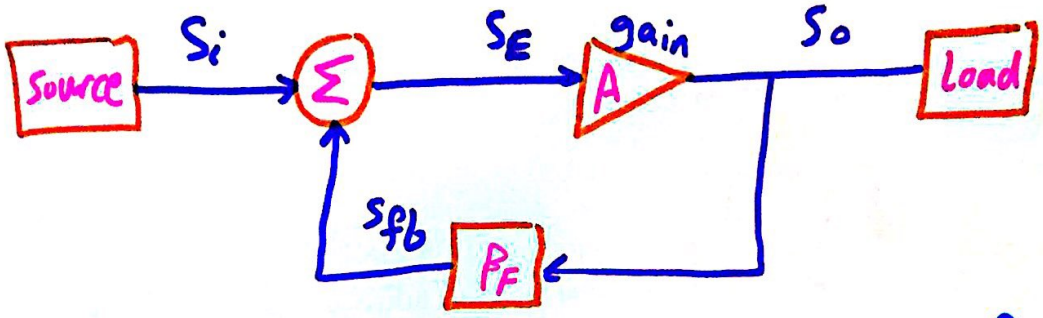
⑤ Control the Input & Output Impedances.

* Disadvantages:

① Reduce the Gain.

② There is a possibility that the feedback ckt may become unstable (oscillate) @ high frequancy.

* Basic Feedback Concepts:



$$A_f = \frac{S_o}{S_i} = \frac{A}{1+\beta_f A}$$

gain with feedback.

gain without feedback

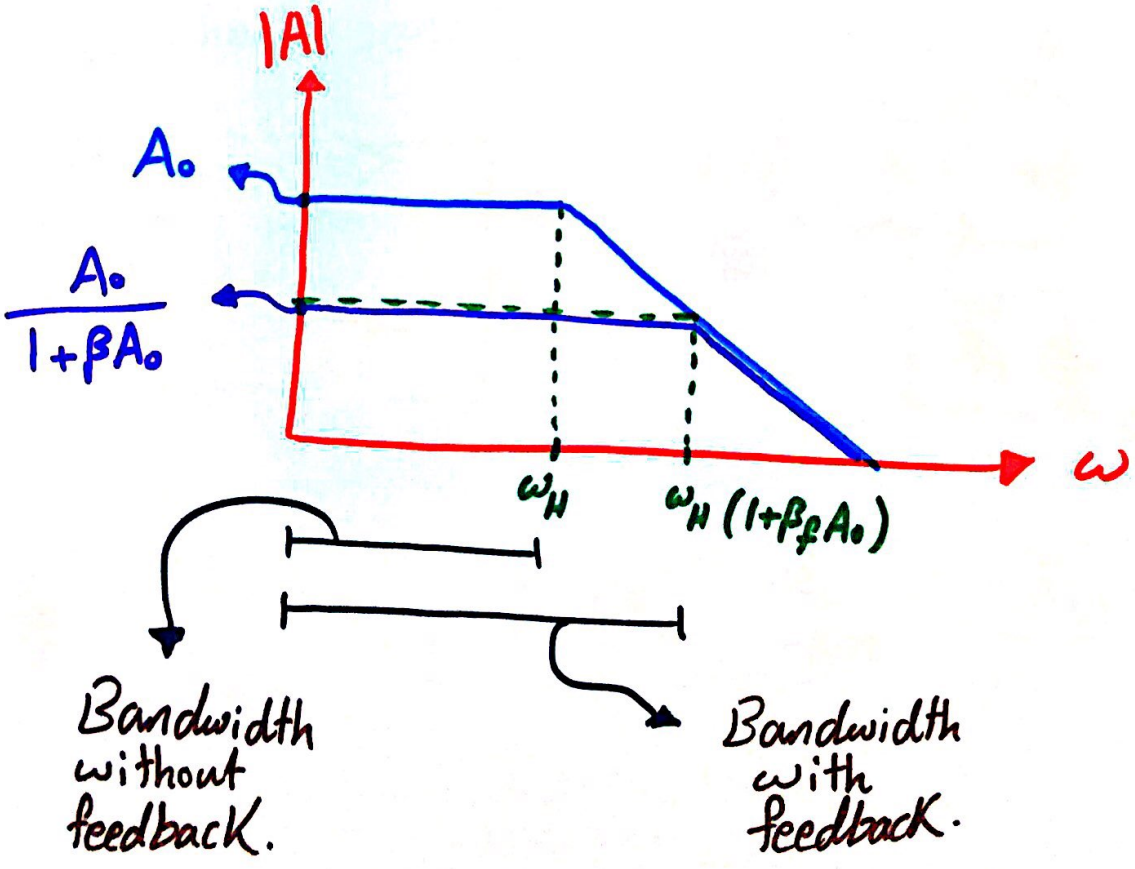
usually $\beta_f A >> 1$

$$A_f = \frac{1}{\beta_f}$$

"stable gain"

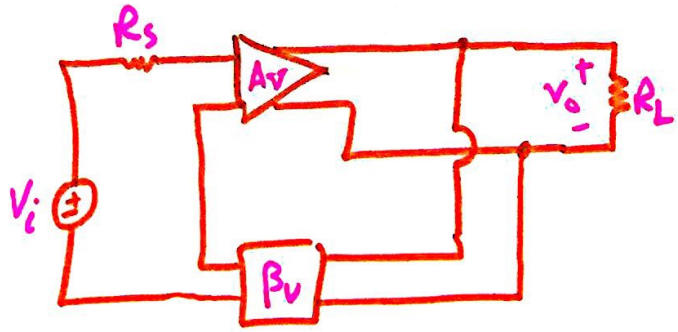
* Bandwidth Extension:

Gain * Bandwidth = Constant



※ 4- Topologies (Configuration):

① Series - Shunt.



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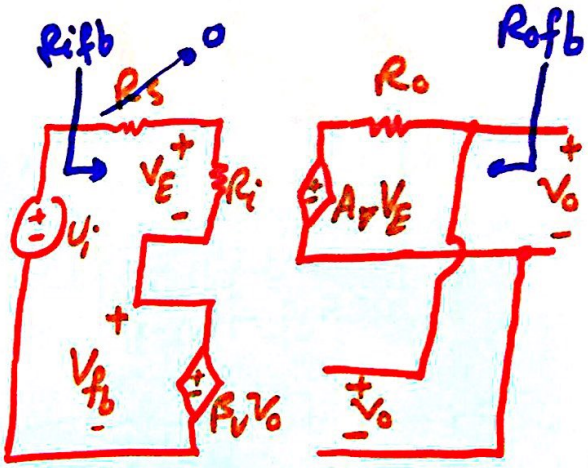


$$\frac{v_o}{v_i}\quad A_{v_{fb}} = \frac{A_v}{1+A_v\beta_v}$$

reduce the voltage gain.

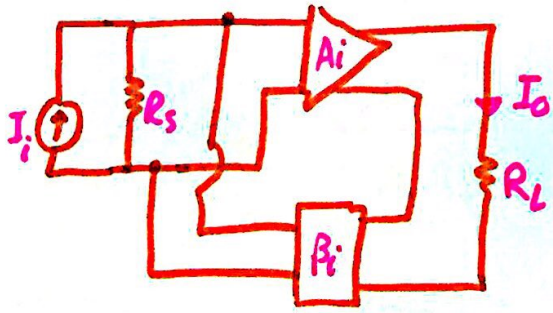
$$R_{i_{fb}} = R_i(1+\beta_v A_v)$$

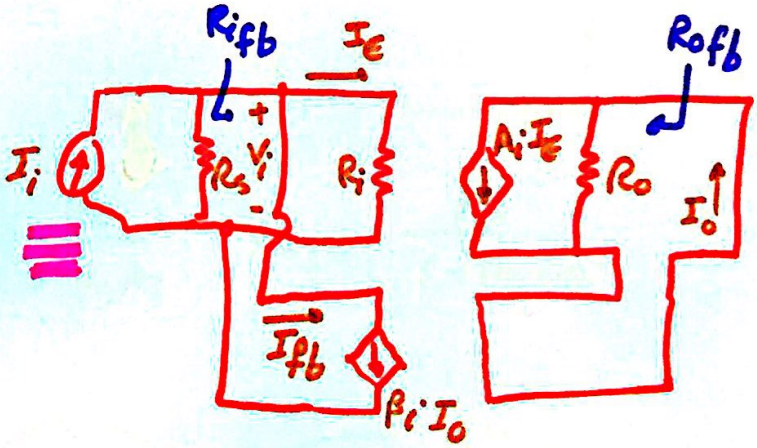
increase the input impedance.

$$R_{o_{fb}} = \frac{R_o}{1+A_v\beta_v}$$

reduce the output impedance.

② Shunt - Series.





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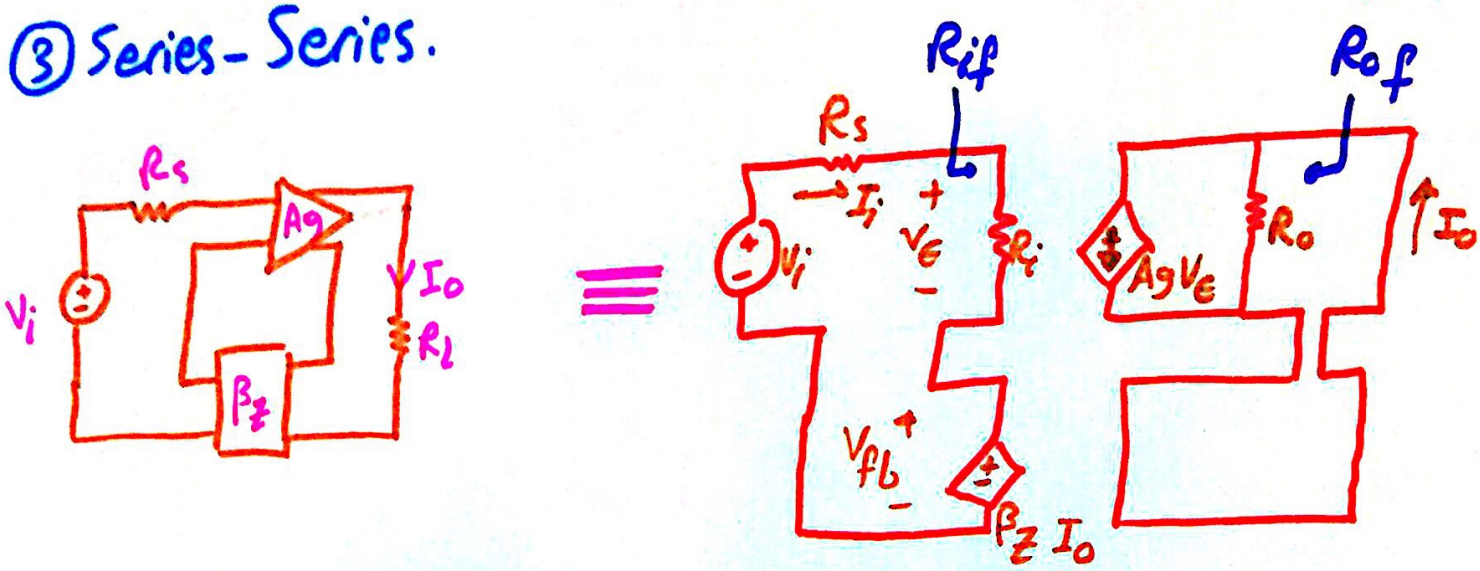
$$\frac{I_o}{I_i}\quad A_{if} = \frac{A_i}{1+\beta_i A_i}$$

$$R_{if} = \frac{R_i}{1+\beta_i A_i}$$

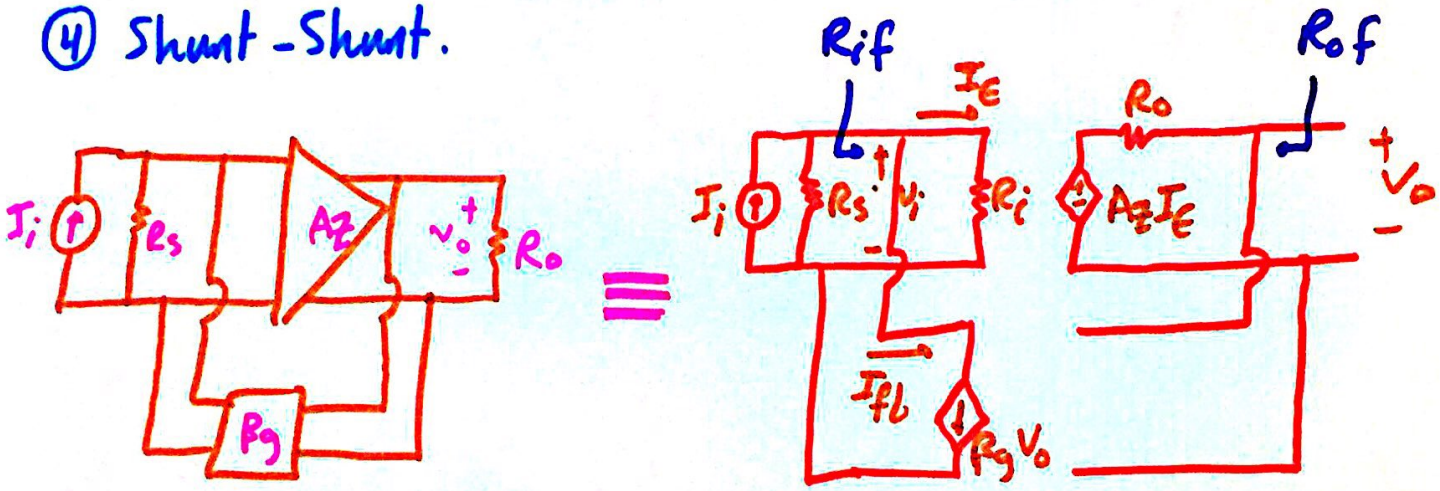
$$R_{of} = (1+\beta_i A_i)R_o$$

③ Series - Series.



$$\frac{I_o}{V_i} \leftarrow A_{gf} = \frac{A_g}{1+\beta_z A_g} \qquad R_{if} = R_i(1+\beta_z A_g) \qquad R_{of} = R_o(1+\beta_z A_g)$$

④ Shunt - Shunt.



$$\frac{V_o}{I_i} \leftarrow A_{zf} = \frac{A_z}{1+\beta_g A_z} \qquad R_{if} = \frac{R_i}{1+\beta_g A_z} \qquad R_{of} = \frac{R_o}{1+\beta_g A_z}$$

End of Final Material.

* * * * *

GOOD LUCK