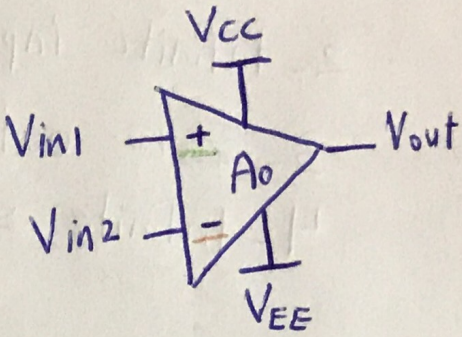
Electronics II discussion

Chapter 8: OP-Amp as a black box.

Eng. Ayman F. EL-Khuzundar

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*) The op-Amp is the circuit that amplifies the difference between the two inputs.



$$V_{out} = A_o (V_{in1} - V_{in2}) \quad -[1]$$

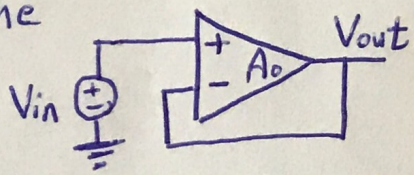
With: A_o : open-loop gain

V_{in1} : the input at the non-inverting terminal.

V_{in2} : the input at the inverting terminal.

*) Unity-gain buffer :-

when the inverting input is tied to the output, we get a unity-gain buffer.



Unity-gain

from [1] $V_{out} = A_o (V_{in} - V_{out})$

$$V_{out} = \left(\frac{A_o}{1+A_o}\right) V_{in}$$

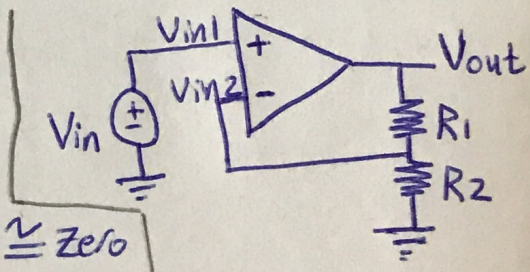
, and When A_o becomes very large then

$V_{out} \cong V_{in}$

*) OP-Amp. based Circuits :-

1- Non-inverting Amplifier:

from [1] $A_o = \dfrac{V_{out}}{V_{in1} - V_{in2}}$



Non-inverting Amp.

and when A_o is large then $V_{in1} - V_{in2} \cong$ zero

$$V_{in1} \cong V_{in2} = \frac{R_2}{R_1+R_2} V_{out}$$

$$\frac{V_{out}}{V_{in}} \cong \frac{R_1+R_2}{R_2} \cong 1 + \frac{R_1}{R_2} \quad -[2]$$

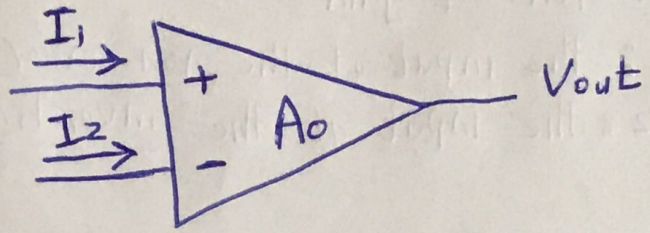
Ideal op-Amp. properties:-

1- Infinite Voltage gain: $A_o \rightarrow \infty$.

2- Infinite input impedences: I_1 and I_2 = Zero.

3- Zero output impedence.

4- Infinite speed.



*) Notes about the non-inverting amplifier:-

1- the name is due to the positive gain.

2- Eq. [2] is called "the closed-loop gain of the circuit".

*) Extreme Cases:-

1- When $\frac{R_1}{R_2} \to \infty$ (or R_2 = Zero) then $\frac{V_{out}}{V_{in}} \to \infty$.

2- When $\frac{R_1}{R_2} \to 0$ (or $R_2 = \infty$) then $\frac{V_{out}}{V_{in}} \to 1$.

*) $$\text{Gain-Error} = \frac{1+\frac{R_1}{R_2}}{A_o}$$ closed loop gain "actual" / open loop gain

---

Q/8.3: nominal gain = A_o = 2000

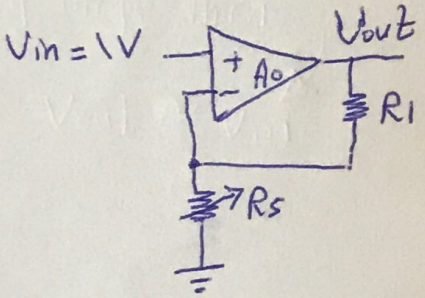
nominal closed-loop gain = $1+\frac{R_1}{R_2} = 8$

$$\text{Gain-Error} = \frac{1+\frac{R_1}{R_2}}{A_o} = \frac{8}{2000} = \boxed{0.0004 = 0.4\%}$$

Q/8.10:

$R_s = R_o + \alpha W$

$$\text{Gain} = ?? = \frac{\text{change } V_{out}}{\text{change } W} = \frac{d\,V_{out}}{dW}$$

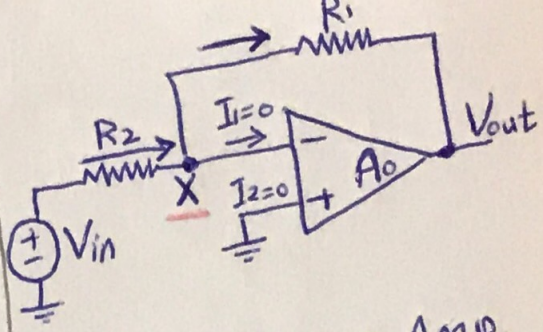


for the non-inverting Amp. $\frac{V_{out}}{V_{in}} = 1+\frac{R_1}{R_2}$

$\left(\frac{V_{out}}{1} = 1+\frac{R_1}{R_s} = 1+\frac{R_1}{R_o+\alpha W}\right)$ derivate the equation by dW

$$\frac{d\,V_{out}}{dW} = \frac{0-\alpha R_1}{(R_o+\alpha W)^2} \Rightarrow \boxed{\frac{d\,V_{out}}{dW} = \frac{-\alpha R_1}{(R_o+\alpha W)^2}}$$

2- Inverting Amplifier:



inverting op-Amp.

- the op-Amp. has a Very high ($\to\infty$) input impedence, this means that:

  $I_1 = I_2 = zero.$

- the op-Amp has a very high ($\to\infty$) gain and a finite output, this means that: $V_{in1} = V_{in2}$ and here $V_x = 0$ and X is called "Virtual ground".

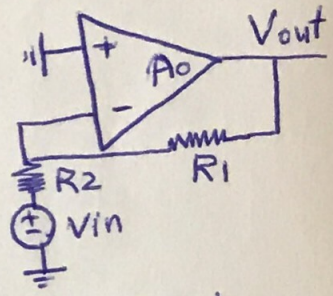
from the above informations, $I_{R2} = I_{R1}$

$$\frac{\cancel{V_x}^{0} - V_{in}}{R_2} = \frac{V_{out} - \cancel{V_x}^{0}}{R_1} \Rightarrow \boxed{\frac{V_{out}}{V_{in}} = \frac{-R_1}{R_2}} \quad -3$$

* Eq. 3 is called "the closed-loop gain" for infinite op-Amp gain ($A_o \to \infty$).

but for a finite op-Amp gain We get a gain Error.

$$\boxed{\frac{V_{out}}{V_{in}} \approx \frac{-R_1}{R_2}\left[1 - \frac{1}{A_o}\left(1 + \frac{R_1}{R_2}\right)\right]} \quad -4$$



another way to draw the circuit.

Example :- Design the inverting Amplifier for a nominal gain of 4, a gain error of 0.1 % and an input impedence of at least 10kΩ.

solution: to design this op-Amp we need to get A_o, R_1, R_2.

$\Rightarrow \frac{R_1}{R_2} = 4$ and the input impedence $\approx \boxed{R_2 = 10k\Omega}$ then $\boxed{R_1 = 40k\Omega}$

$\Rightarrow \frac{1}{A_o}\left(1 + \frac{R_1}{R_2}\right) = 0.1\%$ then $\boxed{A_o = 5000}$

Q/8.12 :- Nominal gain = 8 = $\frac{+R_1}{R_2}$

- gain Error = 0.2% = $\left[\frac{1}{A_0}\left(1+\frac{R_1}{R_2}\right)\right]$

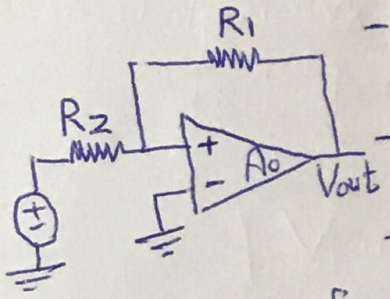
- find: the minimum required op-Amp gain = A_0 = ??

$$\frac{0.2}{100} = \frac{1}{A_0}(1+8)$$

$$0.002 = \frac{9}{A_0} \Rightarrow \boxed{A_0 = 4500}$$

Q/8.17 :- Nominal gain = 8 = $\frac{R_1}{R_2}$

- gain Error = 0.1% = $\frac{1}{A_0}\left(1+\frac{R_1}{R_2}\right)$



- op-Amp output impedence = 2kΩ

- input impedence of the circuit = 1kΩ = R2

- find: open-loop gain of the op-Amp = A_0 = ??
the value of the required R_1 = ??

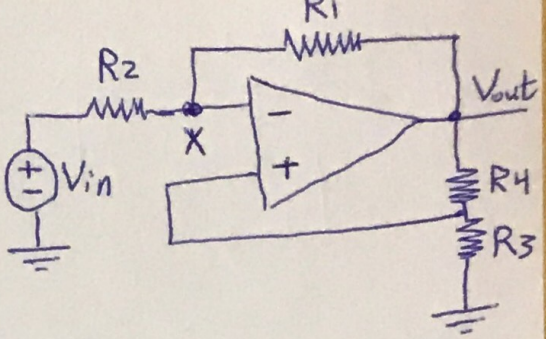
→ gain Error = 0.001 = $\frac{1}{A_0}[1+8] \Rightarrow \boxed{A_0 = 9000}$

→ nominal gain = $8 = \frac{R_1}{R_2} \Rightarrow \boxed{R_1 = 8R_2 = 8k\Omega}$

Continued

Q/8.18:

- Determine the closed-loop gain if $A_o = \infty$



starts from:

$$V^- = V^+ \Rightarrow \boxed{V_x = \frac{R_3}{R_3+R_4} V_{out}} \quad -\textcircled{*}$$

Note: $V_x \neq 0$ here

then:

$$I_{R1} = I_{R2} \Rightarrow \left[\frac{V_x - V_{in}}{R_2} = \frac{V_{out} - V_x}{R_1}\right] \text{ multiply by } -1$$

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

$$\frac{V_{in}}{R_2} = \frac{V_x}{R_1} - \frac{V_{out}}{R_1} + \frac{V_x}{R_2} \quad \Big| \text{ then, all of the following are MATH!}$$

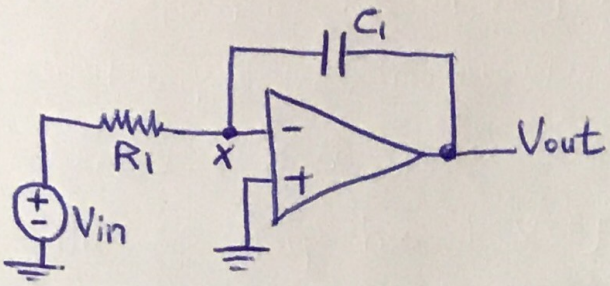
$$\frac{V_{in}}{R_2} = V_x\left[\frac{1}{R_1} + \frac{1}{R_2}\right] - \frac{V_{out}}{R_1} \quad \Big| \text{ from } \textcircled{*}$$

$$\frac{V_{in}}{R_2} = \left[\frac{R_3}{R_3+R_4}\right] V_{out}\left[\frac{1}{R_1} + \frac{1}{R_2}\right] - \frac{1}{R_1} V_{out}$$

$$\frac{V_{in}}{R_2} = \left(\left[\frac{R_3}{R_3+R_4}\right]\left[\frac{1}{R_1} + \frac{1}{R_2}\right] - \frac{1}{R_1}\right) V_{out}$$

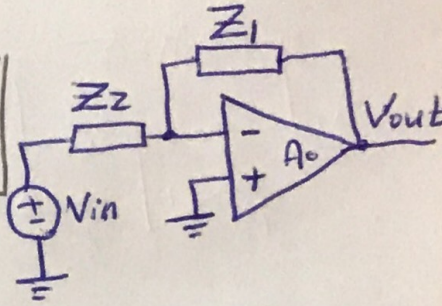
$$\boxed{\frac{V_{out}}{V_{in}} = \frac{1/R_2}{\left(\left[\frac{R_3}{R_3+R_4}\right]\left[\frac{1}{R_1} + \frac{1}{R_2}\right] - \left[\frac{1}{R_1}\right]\right)}}$$

3- Integrator :-



Integrator circuit

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



circuit with general impedances.

$$\frac{V_{out}}{V_{in}} = \frac{-\frac{1}{C_1 s}}{R_1} = \frac{-1}{R_1 C_1 s} \quad -[5]$$

for ideal op-Amp

and from V_x = Virtual ground, then :

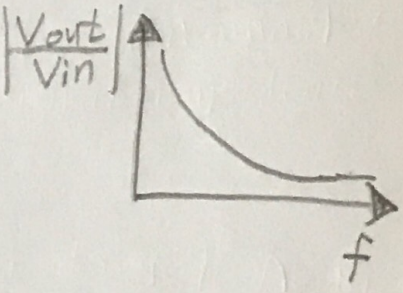
$$I_{R1} = I_{C1}, \quad \frac{V_{in}}{R_1} = -C_1 \frac{dv_{out}}{dt}$$

$$V_{out} = -\frac{1}{R_1 C_1} \int V_{in}\, dt. \quad -[6]$$

Notes :-

1- the output voltage equals the integral of the input voltage multiplied by a factor.

2- the circuit operates as a "low-pass filter".



Now, the gain of the integrator when $A_o < \infty$ is : "lossy integrator"

$$\frac{V_{out}}{V_{in}} = \frac{-1}{\frac{1}{A_o} + \left(1 + \frac{1}{A_o}\right) R_1 C_1 s} \quad -[7]$$

and here the pole frequency is :

$$S_p = \frac{-1}{(A_o + 1) R_1 C_1} \quad -[8]$$

Q/ 8.21 : - $S_p \leq 1\,Hz$

- $R_1 = 10\,K\Omega = 10 \times 10^3\,\Omega$
- $K_1 = 1nF = 1 \times 10^{-9}\,F$

_determine : the required gain of the op-Amp = ??

$$|S_p| = 1 = \frac{1}{(A_o+1) R_1 C_1} = \frac{1}{(A_o+1) \times 10 \times 10^3 \times 1 \times 10^{-9}}$$

$$A_o + 1 = 100{,}000 \Rightarrow \boxed{A_o = 99{,}999}$$

Integrator with pulse input:

See Example 8.5

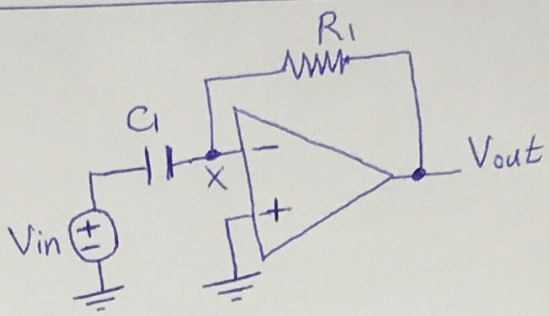
Electronics II discussion

Chapter 8 : op-Amp as a black box

Part 2

Eng. Ayman F. EL-khuzundar

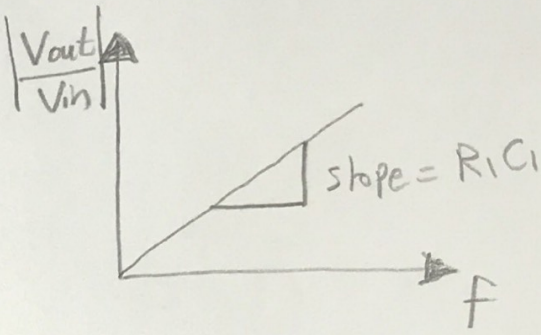
4- Differentiator :-



Differentiator circuit

$$V_{out} = -R_1 C_1 \frac{dV_{in}}{dt} \quad [1]$$

*) As we see from Eq. [1] the circuit Acts as a differentiator and a high-pass filter



Now, to calculate the gain of the circuit when $A_o < \infty$

$$I_{C1} = I_{R1} \quad \text{then}$$

$$\frac{V_{out}}{V_{in}} = \frac{-R_1 C_1 S}{1 + \frac{1}{A_o} + \frac{R_1 C_1 S}{A_o}} \quad [2]$$

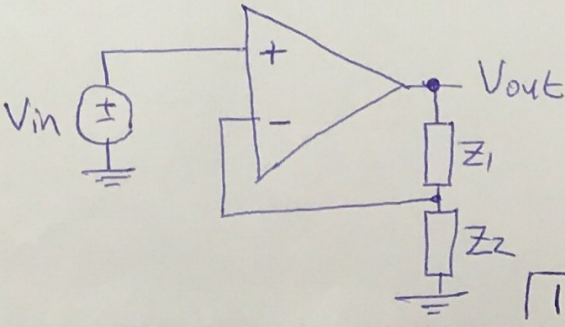
Notes :-

1- An important drawback of differentiators stems from the amplification of high frequency "noise".

2- We can build a non-inverting differentiator and integrator, but this yields to nonideal circuits.

*) The circuit contains a pole at :

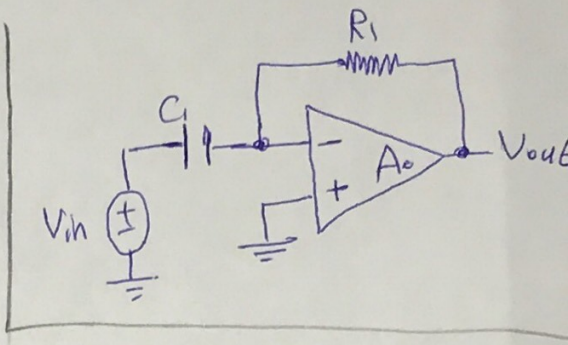
$$S_p = \frac{A_o + 1}{R_1 C_1} \quad [3]$$



Q/ 8.24 : - Freq. = 1MHz = 1×10^6 Hz and $\left|\frac{V_{out}}{V_{in}}\right| = 5$

- $A_o = \infty$ "Ideal deferentiator"

-determine : the Value of $R_1 C_1$.



Now, for the ideal deferntiator

$$\left|\frac{V_{out}}{V_{in}}\right| = \frac{Z_1}{Z_2} = \frac{R_1}{\frac{1}{C_1 S}}$$

but $C_1 S = C_1 W J$ and by ignoring J (it's not a real value)

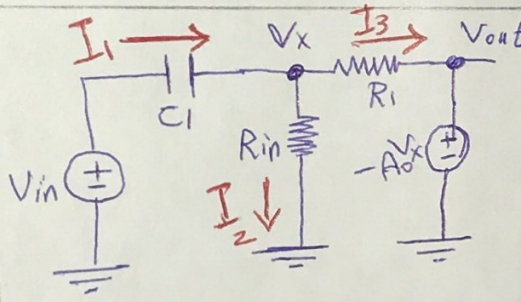
$$\left|\frac{V_{out}}{V_{in}}\right| = \frac{R_1}{\frac{1}{C_1 W}} = R_1 C_1 W \quad \text{and} \quad \boxed{W = 2\pi F}$$

$$5 = R_1 C_1 \times 2\pi \times 10^6$$

$$\boxed{R_1 C_1 = \frac{5}{2\pi \times 10^6} = 7.9577 \times 10^{-7} \text{ sec.}}$$

this Value is called "time constant"

Q/ 8.26 :



using KCL : $I_1 = I_2 + I_3$

$$\frac{(V_x - V_{in})}{\frac{1}{C_1 S}} = \frac{V_x}{R_{in}} + \frac{(-A_o V_x - V_x)}{R_1}$$

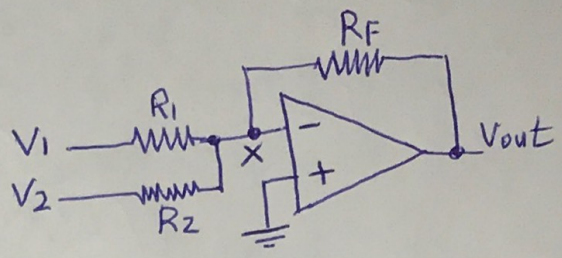
use your math skills to get

$$\left[\frac{V_x}{V_{in}} = \frac{C_1 S}{C_1 S + \frac{1}{R_{in}} + \frac{(A_o+1)}{R_1}}\right] \times -A_o$$

calling that $\boxed{V_{out} = -A_o V_x}$

$$\boxed{\frac{V_{out}}{V_{in}} = \frac{-A_o C_1 S}{C_1 S + \frac{1}{R_{in}} + \frac{(A_o+1)}{R_1}}}$$

5- Voltage Adder (summer) :-



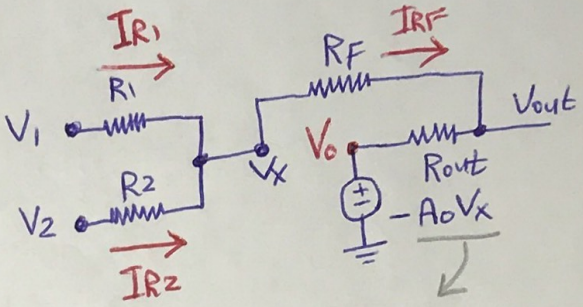
Voltage Adder

Calling that x is a virtual ground then,

$$I_{R1} + I_{R2} = I_{RF}$$ ②

$$V_{out} = -R_F \left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \text{----- (if there is more)} \right)$$

Q/ 8.32 :-



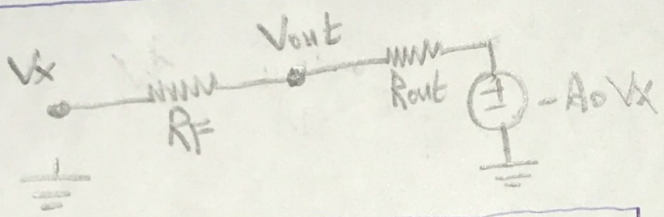
using KCL :- $I_{R1} + I_{R2} = I_{RF}$

$$\boxed{\frac{V_x - V_1}{R_1} + \frac{V_x - V_2}{R_2} = \frac{V_o - V_x}{R_{out} + R_F}}$$ ⊛

$$V_o = A_o(V_{in1} - V_{in2})$$

$$V_o = A_o(0 - V_x)$$

$$\boxed{V_o = -A_o V_x}$$



$$\boxed{V_{out} = I_{RF} \times R_F = \frac{V_o - V_x}{R_{out} + R_F} \times R_F}$$ ⊛⊛

from ⊛ in ⊛⊛

$$\boxed{V_{out} = \left(\frac{V_x - V_1}{R_1} + \frac{V_x - V_2}{R_2} \right) R_F = \left(\frac{1}{R_1} + \frac{1}{R_2} \right) [\quad]}$$ ⊛⊛⊛

Now, to get rid of V_x, from ⊛

$$\frac{V_x - V_1}{R_1} + \frac{V_x - V_2}{R_2} = \frac{V_x(-A_o - 1)}{R_{out} + R_F}$$

$$\frac{V_x}{R_1} - \frac{V_1}{R_1} + \frac{V_x}{R_2} - \frac{V_2}{R_2} - \frac{V_x(-A_o - 1)}{R_{out} + R_F} = 0$$

$$V_x \left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{(A_o + 1)}{R_{out} + R_F} \right] = \frac{V_1}{R_1} + \frac{V_2}{R_2}$$

Continued in Page 5

$$V_X = \frac{\frac{V_1}{R_1} + \frac{V_2}{R_2}}{\left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{(A_o+1)}{R_{out}+R_F}\right]}$$

Now, return to ~~xxxx~~

$$V_{out} = \left(\frac{V_X}{R_1} - \frac{V_1}{R_1} + \frac{V_X}{R_2} - \frac{V_2}{R_2}\right) R_F$$

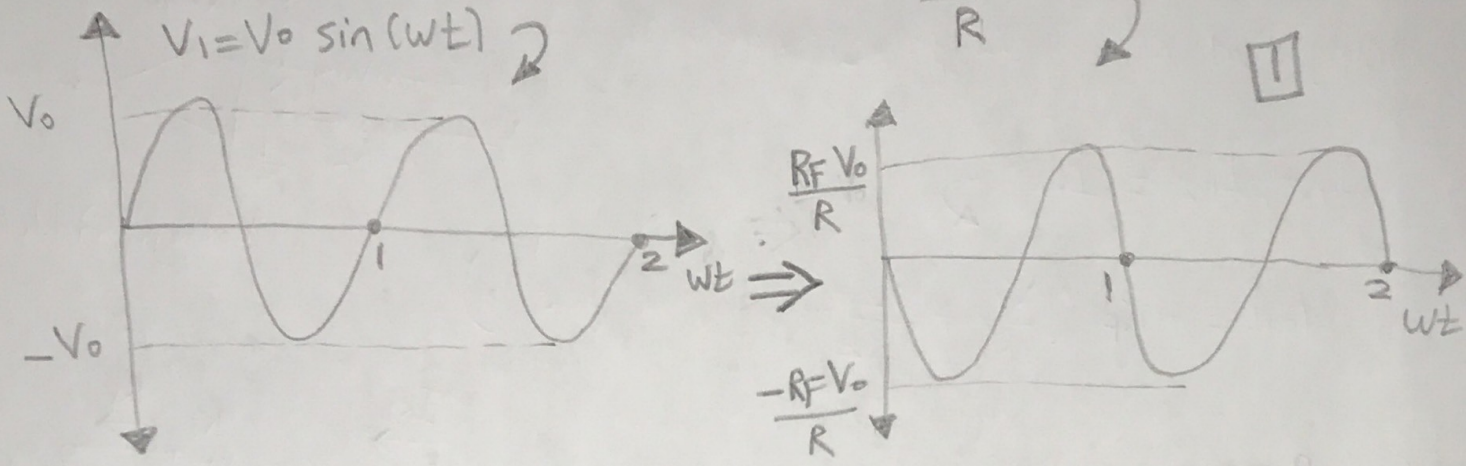
$$V_{out} = \left[\left(V_X\left[\frac{1}{R_1} + \frac{1}{R_2}\right] - \frac{V_1}{R_1} - \frac{V_2}{R_2}\right) R_F\right]$$

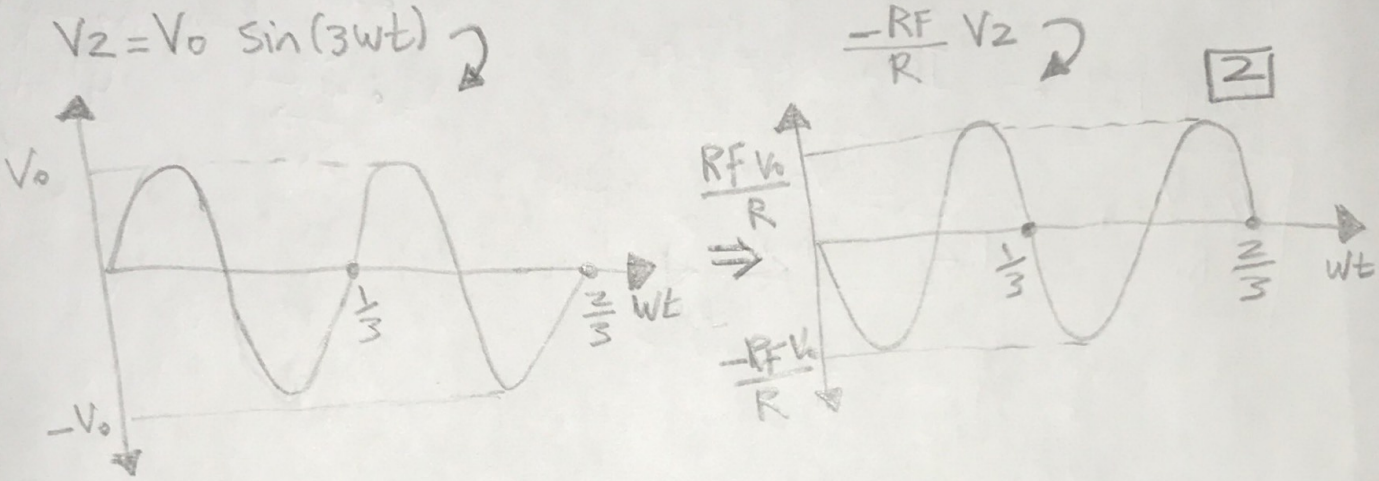
Now From ~~xxxx~~

$$V_{out} = \left[\frac{\left(\frac{V_1}{R_1} + \frac{V_2}{R_2}\right)\left(\frac{1}{R_1} + \frac{1}{R_2}\right)}{\left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{(A_o+1)}{R_{out}+R_F}\right.} - \frac{V_1}{R_1} - \frac{V_2}{R_2}\right] R_F$$

Note: this Question is very long, just understand how to model a circuit and how to find each equation.

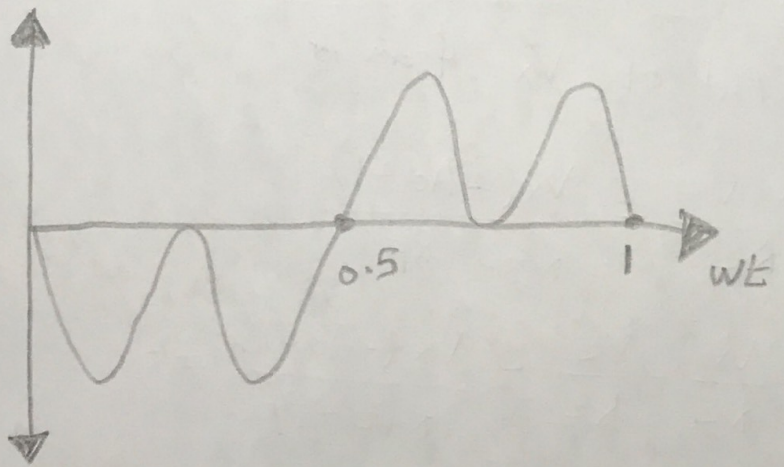
Q/ 8.30 :





$$V_{out} = \frac{-R_F}{R}(V_1 + V_2) = \left(\frac{-R_F}{R} V_1\right) + \left(\frac{-R_F}{R} V_2\right) = [1] + [2]$$

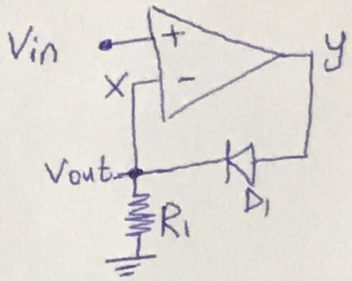
Using complex calculator



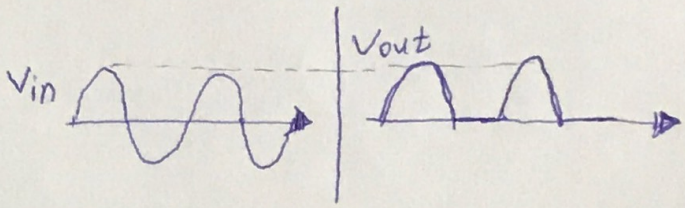
✳ Nonlinear Functions :

1- precision Rectifier :-

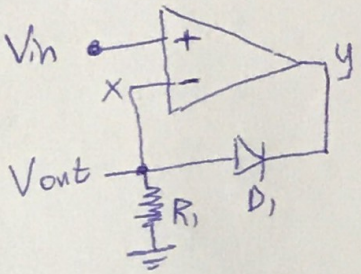
- this circuit is used when we need to Amplify and then rectify the input signal especially when deals with small signals.

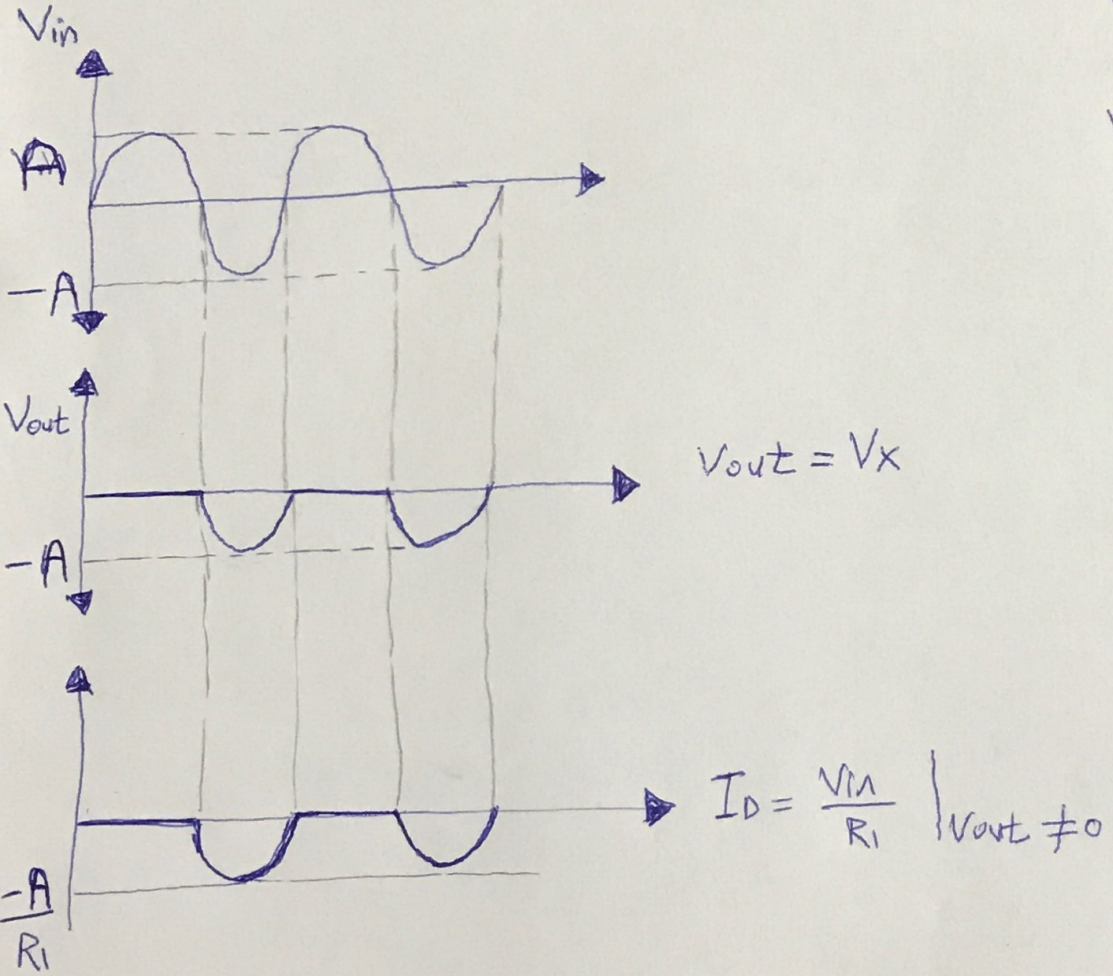


$$V_{out} = \begin{cases} V_{in} & V_{in} \geq 0 \\ 0 & V_{in} < 0 \end{cases}$$



Q/8.37 : plot V_x, V_y and I_D for a sinosoidal input.



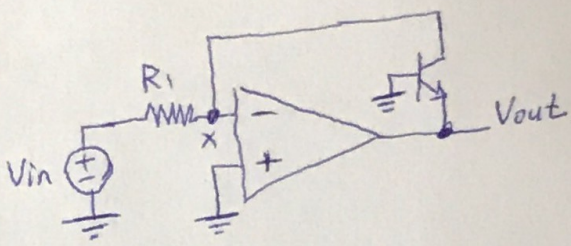


$V_{out} = V_x$

$I_D = \frac{V_{in}}{R_1} \Big|_{V_{out} \neq 0}$

2- logarithmic Amplifier:-

- the output of this circuit is proportional to the natural logarithm of Vin



$$V_{out} = -V_T \ln \frac{V_{in}}{R_1 I_s}$$

Where: I_s: the saturation current of the emitter-base diode.

V_T: the thermal Voltage.

Electronics II discussion

Chapter 8 : op-Amp as a black box

Eng. Ayman F. EL-Khuzundar

Part 3

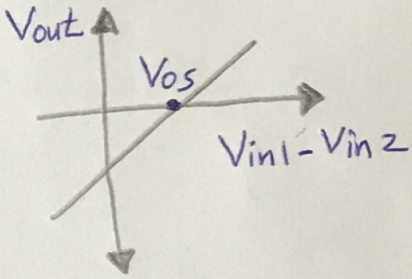
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*) op-Amp. non-idealities :-

1- Dc offsets :

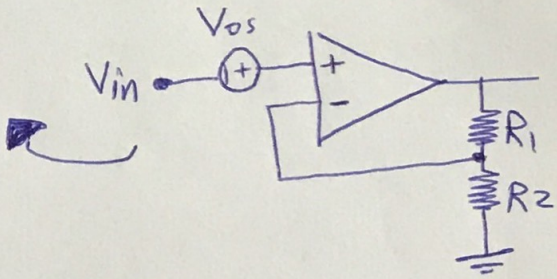
- in Ideal op-Amp. : Vout = 0 if Vin1 = Vin2.
- in reality : Vout = 0 if Vin1 - Vin2 = Vos "offset".

- في الواقع يجب أن يكون هناك فرق جهد بين "offset" يسمى Vin1 و Vin2 حتى يصبح Vout=0



- بعض آخر هناك قيمة جهد يتم تكبيرها بالإضافة إلى تكبير الإشارة ، وهذا يسبب مشاكل في الخرج .

$$Vout = \left(1 + \frac{R1}{R2}\right)(Vin + Vos)$$

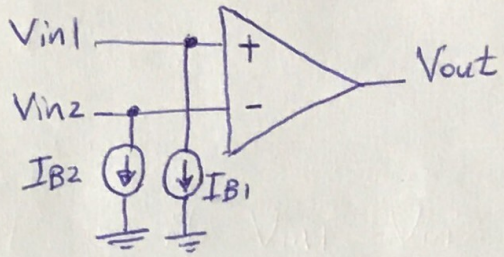


as an Example, offset in non-inverting op-Amp.

- See Example 8.10 and 8.11 in the book

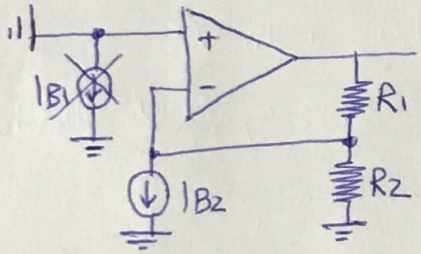
2- Input Bias current :-

- بعض أنواع الـ OP-Amp. تستهلك القليل من التيار (0.1 → 1 μA) وهذا التيار يؤثر على بعض الدوائر. ويتم تمثيله بمصدر تيار كما في الشكل

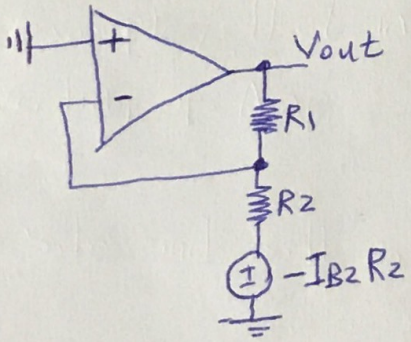


- lets take the non-inverting amplifier as an Example :

and set Vin = Zero,



then change the current source I_{B2} into Voltage source = $-I_{B2}R_2$

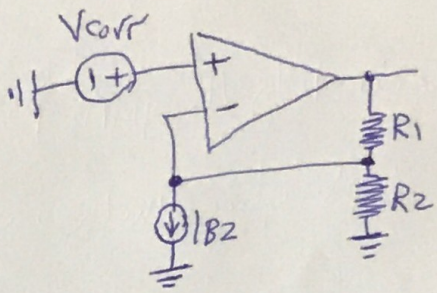


then derivate the output Voltage

$$\boxed{V_{out} = R_1 I_{B2}} \quad \text{When } V_{in} = \text{Zero}$$

- نستطيع التخلص على هذه المشكلة عن طريق إضافة مصدر فرق كما في الشكل

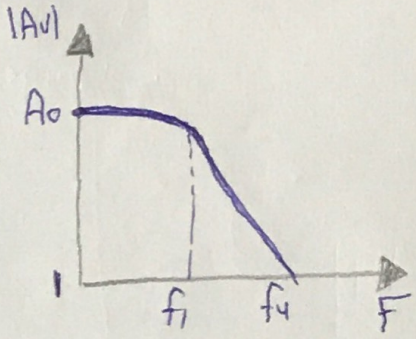
$$V_{corr} = -I_{B2}\left(R_1 R_2 \,/\, (R_1 + R_2)\right)$$



- See Example 8.12

3- Speed limitations :-

- in reality, op-Amps suffers from finite bandwidth.



Where :

f_1 : the frequency at which the gain begins to fall.
f_u : the frequency at which the gain equals unity.

and here, the gain of the non-inverting Amp. (for example) becomes :

$$\frac{V_{out}}{V_{in}}(s) = \frac{A_o}{\frac{s}{\omega_1} + \frac{R_2}{R_1+R_2}A_o + 1}$$

Where : $\omega_1 = 2\pi f_1$

and the closed-loop bandwidth is :

$$|\omega_{p,closed}| = \left(1 + \frac{R_2}{R_1+R_2}A_o\right)\omega_1 .$$

- See Example 8.14

End of chapter 8

Electronics II discussion

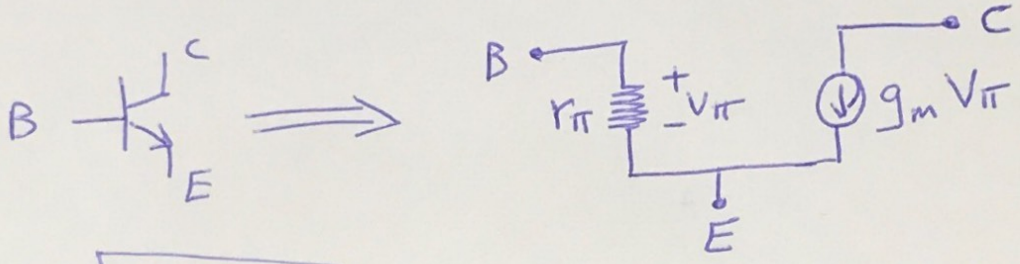
Chapter 9: Cascode Stages and current mirrors

Part 1

Eng. Ayman F. EL-khuzundar

Revision:

1- BJT small signal model :-



Where : $V_\pi = V_{BE}$

$$r_\pi = \frac{\beta}{g_m}$$

$$g_m = \frac{I_C}{V_T}$$

$$I_C = I_S\, e^{\frac{V_{BE}}{V_T}}$$

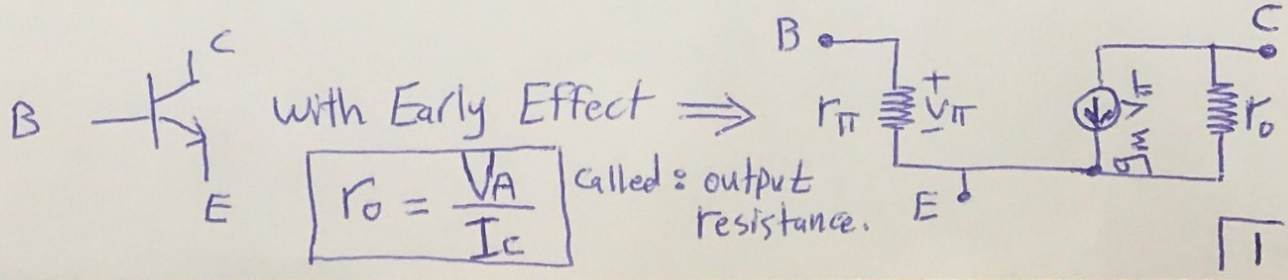
In small signal model:

- Dc Voltge supplies ⇒ shorted.
- AC Voltage supplies ⇒ remains the same

*) Early Effect : the effect that lets I_C depends on V_{CE} or the effect that limits the gain of an amplifier. "V_A"

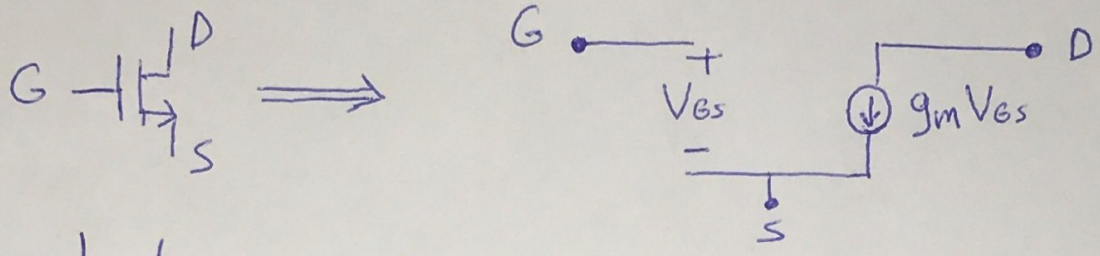
*) هو التأثير الذي يجعل I_C يعتمد على قيمة V_{CE} أو هو التأثير الذي يحد الـ gain الـ Amplifier

$$I_C = \left(I_S\, e^{\frac{V_{BE}}{V_T}}\right)\left(1 + \frac{V_{CE}}{V_A}\right)$$



$$r_o = \frac{V_A}{I_C}$$ called : output resistance.

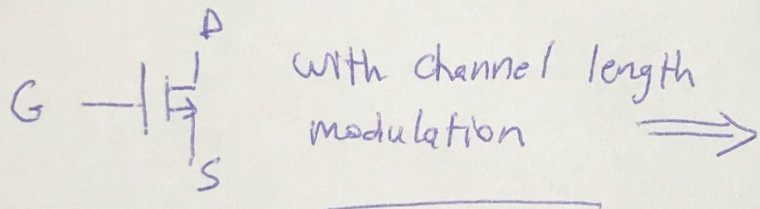
2- MOS small signal model :-

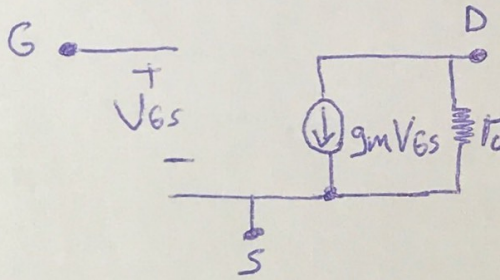


$$I_{D_{max}} = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{TH})^2$$

* Channel length modulation : the effect that lets I_D depends on V_{DS} and also limits the gain. "λ"

$$I_{D,max} = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{TH})^2 (1 + \lambda V_{DS})$$





$$r_o = \frac{1}{\lambda I_D}$$

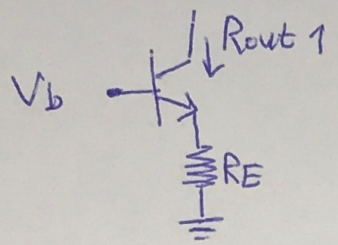
For MOS in saturation mode :-

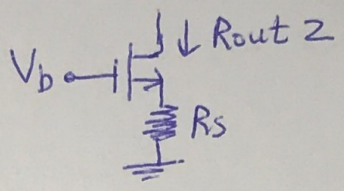
$$g_m = \begin{cases} 1- \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{TH}) \\ 2- \sqrt{2 \mu_n C_{ox} \frac{W}{L} I_D} \\ 3- \frac{2 I_D}{V_{GS} - V_{TH}} \end{cases}$$

Now, let's go to our subject ⇝

1- Cascode as a current source :-

*) The output impedence is limited due to → Early Effect
                                          → Channel-length modulation





المعادلات الأساسية:

$$R_{out1} = (1+g_m r_o)(R_E \| r_\pi) + r_o = \left[1+g_m(R_E \| r_\pi)\right] r_o + R_E \| r_\pi$$

$$R_{out2} = (1+g_m R_s)\frac{r_o}{} + R_s = (1+g_m r_o) R_s + r_o$$

*) RE and Rs can be increased to raise the output resistance.

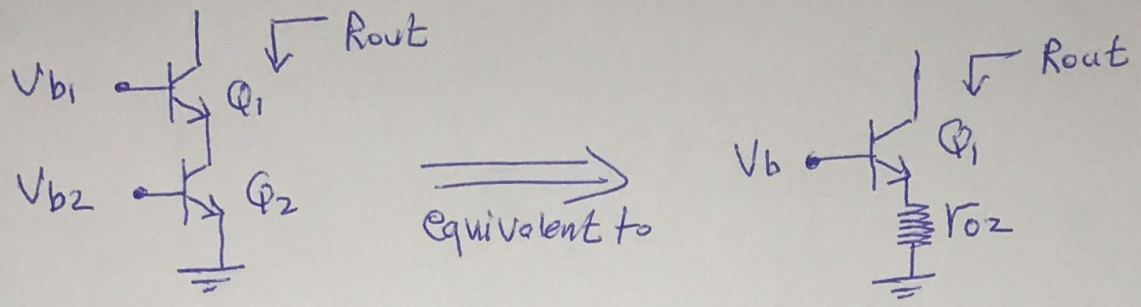
يمكننا زيادة قيم RE, Rs لزيادة الـ output impedance

<u>but</u> the voltage drop across the degeneration resistor increases also :C

وأيضاً قيمة الـ voltage drop تزداد مع زيادة قيم هذه المقاومة وبالتالي يزداد استهلاك التيار.

لذلك نريد طريقة لنزيد من ظاهرياً استهلاك التيار ونقوم بزيادة الـ output impedence وذلك من خلال دائرة Cascode

Bipolar Cascode :-



* V_{BE2} مباشرة وبالتالي ground بال Emitter موصول Q_2 لأن

ثابتة في هذه الحالة ، فإنه يمكننا اعتبار Q_2 كأنها مقاومة r_{o2}

*) draw the small signal model and don't forget the early effect, then you will find that :

$$R_{out} \cong g_{m1} \cdot r_{o1} \cdot (r_{o2} \,||\, r_{\pi 1})$$

and when $r_{o2} \gg r_{\pi 1}$ then

$$R_{out,max} = g_{m1} \cdot r_{o1} \cdot r_{\pi 1}$$

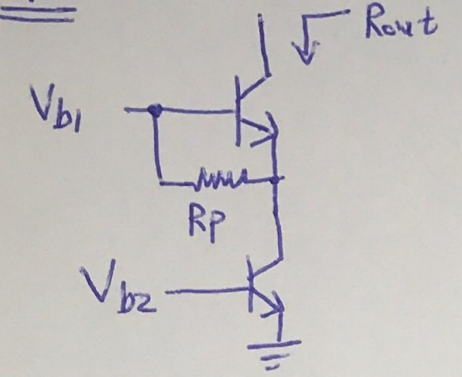
أو يمكن كتابتها بهذه الطريقة

$$R_{out} = \left[1 + g_{m1}(r_{o2} \,||\, r_{\pi 1})\right] r_{o1} + r_{o2} \,||\, r_{\pi 1}$$

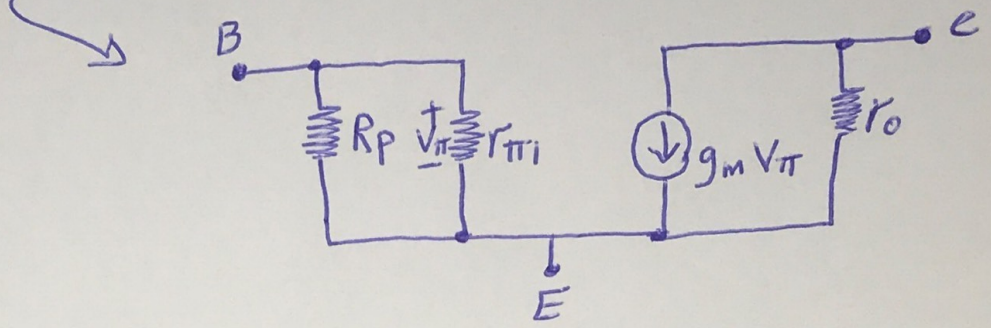
الصحيحة

Q/9.4 :- بيحكيلك في السؤال إنه نتيجة الأخطاء المصنعية ظهرت بعض المقاومات التطفيلية في الدوائر التالية ، اجب Rout في كل حالة.

a-



نلاحظ في أول حالة أنه المقاومة Rp ظهرت بالتوازي مع $r_{\pi 1}$ وبالتالي نقوم برسم الـ small signal model الخاصة بالمقاومة التي



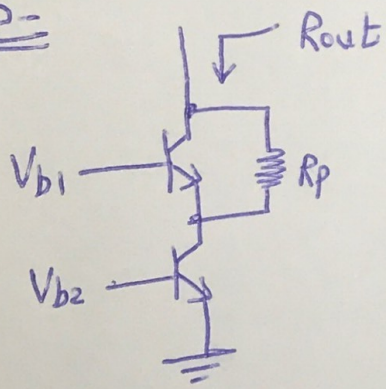
بالتعويض في المعادلات الأساسية (في صفحة 493)

$$R_{out} = \left[1 + g_{m1}(r_{o2} \| r_{\pi 1} \| R_p)\right] r_{o1} + (r_{o2} \| r_{\pi 1} \| R_p)$$

$$= (1 + g_{m1} r_{o1})(r_{o2} \| r_{\pi 1} \| R_p) + r_{o1}$$

طريقة أخرى ←

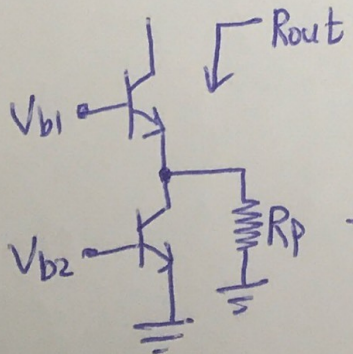
b-



نفس طريقة الحل وكأن Rp بالتوازي مع r_{o1}

$$\Longrightarrow R_{out} = \left[1 + g_{m1}(r_{o2} \| r_{\pi 1})\right](r_{o1} \| R_p) + (r_{o2} \| r_{\pi 1}$$

c-

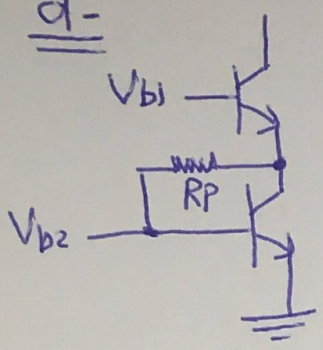


$R_p \| r_{o2}$

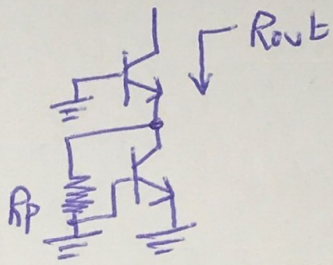
$$\Longrightarrow R_{out} = \left[1 + g_{m1}(r_{o2} \| R_p \| r_{\pi 1})\right] r_{o1} + (r_{o2} \| R_p \| r_{\pi 1})$$

نفس الناتج من الفرع a-

d-



زي ما حكينا في المراجعة في صفحة 1 انه المصدر الـ DC في التحليل Small Signal بصير كأنه Short و بالتالي Vb2 بتتوصل بالـ Ground والنتيجة نفس سؤال 9.4 c- و 9-

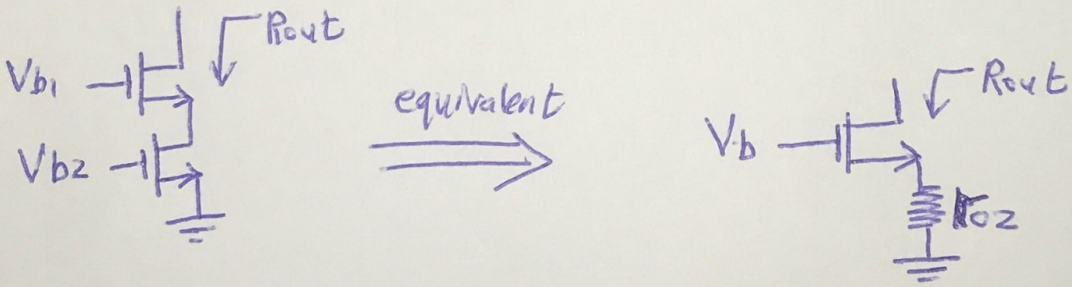


$$R_{out} = \left[1 + g_{m1}(r_{o2} \| R_p \| r_{\pi 1})\right] r_{o1} + (r_{o2} \| R_p \| r_{\pi 1})$$

ملاحظة: في حالة استعمال ترانزستورات PNP الخصائص تكون مشابهة وبنفس المعادلات في صفحة 4.

Mos Cascode:-

تماماً كما فعلنا مع Bipolar هي تصبح الدائرة كالتالي:



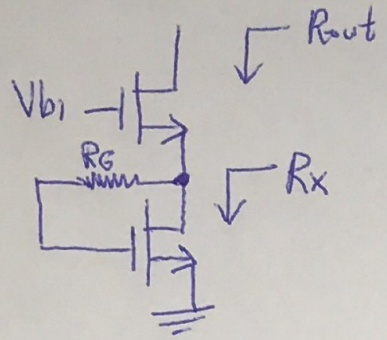
$$R_{out} = (1 + g_{m1} r_{o2}) r_{o1} + r_{o2} \approx g_{m1} r_{o1} r_{o2}$$

ملاحظة: بنفس الطريقة تماماً عند استعمال PMOS وبنفس المعادلات.

lets see @ 9.16 ⇝

Q/9.16 :-

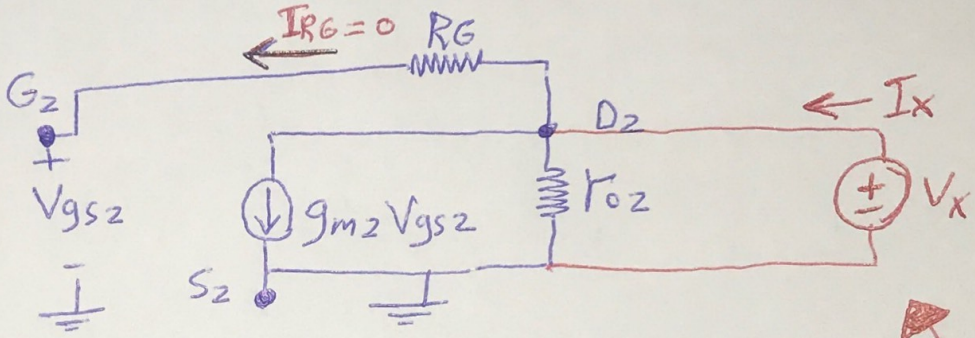
a-



في هذا السؤال بشكل الدائرة تغير 6 ولانه بنتعامل مع MOS بالتالي بنفس نفس خطوات المحاضرة الأولية ، فخلينا نقسم الرسمة ونشتغل خطوة خطوة ---

١- الخطوة الأولى : Find the equivalent Rx (Small signal model) رسم دائرة مكافئة

الجزء الضوئي فقط



* الهدف من الرسم هو حساب Rx المكافئة لهذا الـ MOS 6 إلى الطرف من استخدام Thevenins theorem أي :

$$R_x = \frac{V_x}{I_x}$$

وبالتالي نحتاج لتطبيق قانون عند العقدة المراد حساب المقاومة عندها (بين D2 و S2) وحساب التيار Ix

~~Using KCL at Node D2~~

Using KCL at Node D2 :-

$$I_x = g_{m2} V_{gs2} + \frac{V_x}{r_{o2}} + \text{Zero}$$

Zero ← I_{RG} / gate من تيار يمر خلال

ولانه $I_{RG} = 0$ بالتالي

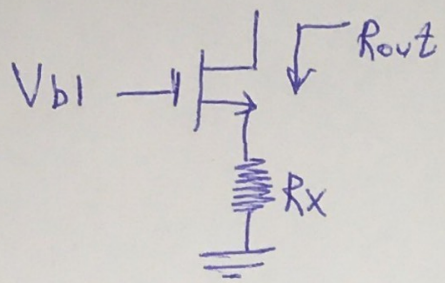
$$\boxed{V_x = V_{D2} = V_{gs2}}$$

$$I_x = g_{m2} V_x + \frac{V_x}{r_{o2}} = V_x \left(g_{m2} + \frac{1}{r_{o2}} \right)$$

$$\boxed{\frac{V_x}{I_x} = R_x = \frac{1}{g_{m2} + 1/r_{o2}}}$$

٢- الخطوة الثانية : نقوم باستبدال MOS2 مع RG بـ مقاومة متغير Rx

ليصبح الشكل :



٣- الخطوة الثالثة : نوضح الشكل الذي نفس الشكل الوارد في صفحة 6 وبالتالي بإمكاننا استخدام المعادلة والتعويض عن قيمة Rx بالرمز

$$R_{out} = (1 + g_{m1} R_x) r_{o1} + R_x \approx g_{m1} r_{o1} R_x$$

$$R_{out} = \left(1 + \frac{g_{m1}}{g_{m2} + 1/r_{o2}}\right) r_{o1} + \frac{1}{g_{m2} + 1/r_{o2}} \approx \frac{g_{m1} r_{o1}}{g_{m2} + 1/r_{o2}}$$

End of Par 1

Electronics II discussion

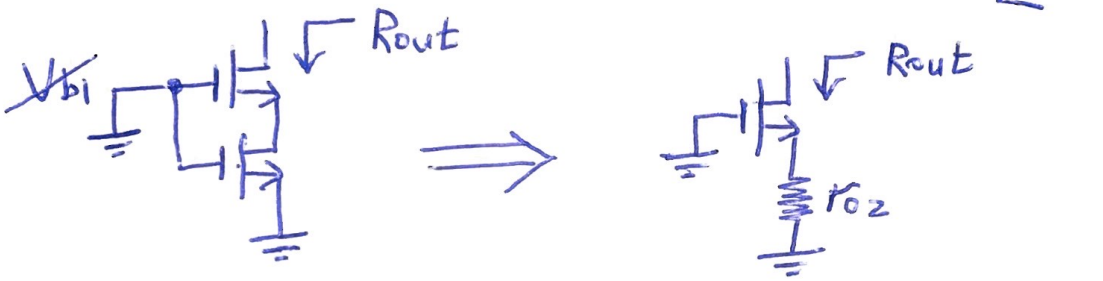
Chapter 9 : Cascode stages and current mirrors

Part 2

Eng. Ayman F. EL-Khuzundar

Q/ 9.16 : Continued ---

b- As we said earlier in part 1, we change every Dc source and short it, so the two gates are grounded here



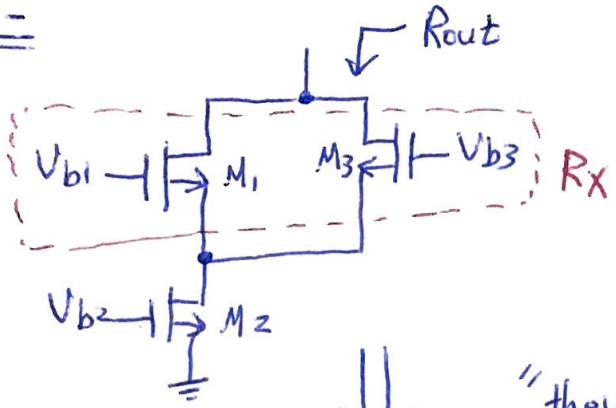
the same as the general Mos Cascode circuit,

$$R_{out} = \underbrace{(1+g_{m1}r_{o1})r_{o2}+r_{o1}}_{1} = \underbrace{(1+g_{m1}r_{o2})r_{o1}+r_{o2}}_{2}$$

ملاحظة / في مناقشاتي أعتمد مبدأ الإحكام بشرح الفكرة دون التطرق إلى طريقة الحل الكثيرة لنفس المسألة ، باختصار "افهم الفكرة وطبقها صح حتى لو طريقتك غير عني"

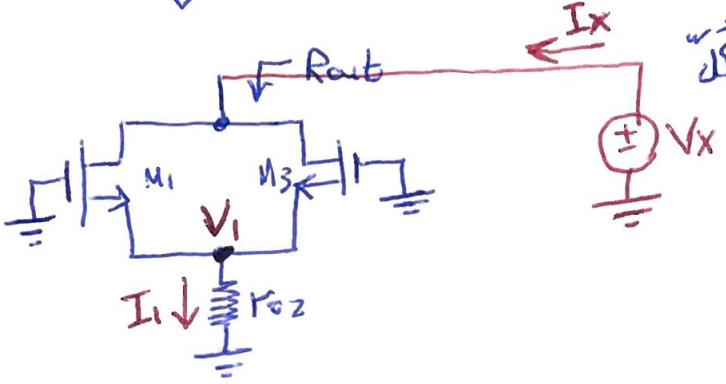
ملاحظة / في اختبار المادة اعتمد شكل القانون المعتمد لدى مدرس المادة ، في هذا السؤال مثلاً هناك شكلان مختلفان 1 و 2 ، اعتمد أحدهما بناءاً على توجيهات المدرس.

c-



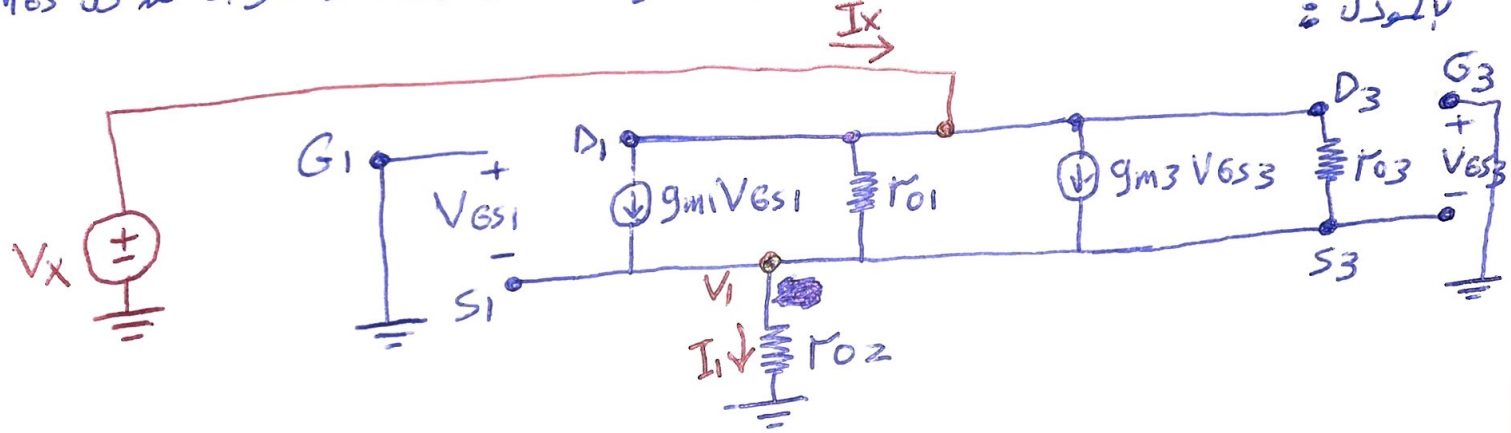
- طريقة حل هذا الفرع مشابهة للفرع a- ولكن هنا نقوم بإيجاد المقاومة المكافئة للجزء العلوي لأنه المقاومة المكافئة للجزء السفلي معروفة = r_{o2}.

- ولإيجاد نفس المقاومة المكافئة نقوم بتطبيق جهد V_x وإيجاد التيار I_x ثم $R_x = \frac{V_x}{I_x}$ ، كما في السابق "thevenin"



- ويمكننا تطبيق الجهد على الدائرة ككل وبالتالي لإيجاد المقاومة المكافئة للدائرة وليس الجزء العلوي فقط (طريقة الحل المتبعة)

- قبل ما نبدأ نوجد التيارات خلينا نرجع لدائرة Mos Small signal و نعوض عن كل Mos بالمودل :



والآن نحسب التيار بكل سهولة :

$$I_x = g_{m1} V_{GS1} + \frac{V_x - V_1}{r_{o1}} + g_{m3} V_{GS3} + \frac{V_x - V_1}{r_{o3}} \quad (*)$$

and $I_x = I_1 = \frac{V_1}{r_{o2}} \Rightarrow V_1 = I_x r_{o2}$ (**)

and $V_{GS1} = V_{GS3} = 0 - V_1 = -I_x r_{o2}$ (***)

Combine (*) + (**) + (***) together

$$I_x = -I_x r_{o2} g_{m1} + \frac{V_x}{r_{o1}} - \frac{I_x r_{o2}}{r_{o1}} - I_x r_{o2} g_{m3} + \frac{V_x}{r_{o3}} - \frac{I_x r_{o2}}{r_{o3}}$$

$$I_x\left(1+r_{o2}g_{m1}+\frac{r_{o2}}{r_{o1}}+r_{o2}g_{m3}+\frac{r_{o2}}{r_{o3}}\right)=V_x\left(\frac{1}{r_{o1}}+\frac{1}{r_{o3}}\right)$$

$$R_x=R_{out}=\frac{V_x}{I_x}=\frac{1+r_{o2}g_{m1}+\frac{r_{o2}}{r_{o1}}+r_{o2}g_{m3}+\frac{r_{o2}}{r_{o3}}}{\frac{1}{r_{o1}}+\frac{1}{r_{o3}}}$$

d- the same ideas so try to solve it by yourself :)

2- Cascode as an Amplifier :-

⇒ Short-circuit transconductance $\boxed{G_m=\frac{i_{out}}{V_{in}}\Big|_{V_{out}=0}}$

* this equation signifies the strength of a circuit in converting the input voltage to a current

⇒ Lemma : The voltage gain of a linear circuit can be expressed as : $\boxed{A_v=-G_m R_{out}}$

See the book Page (403-403) for the Proof

* Lemma serves as an alternative method of gain calculation, and indicates that the voltage gain of a circuit can be increased by raising the output impedence.

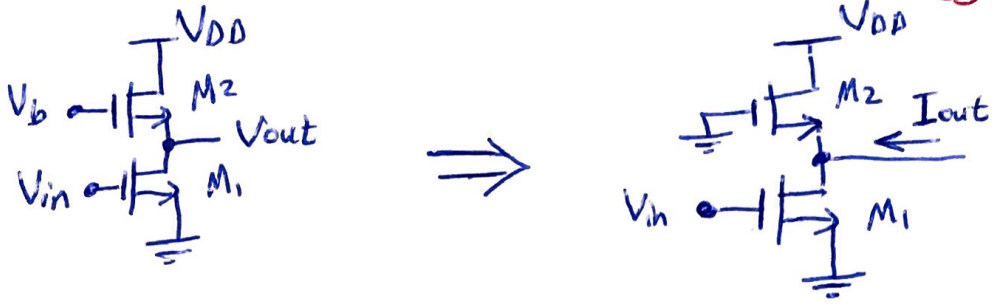
إحدى طرق زيادة الأكسالة عندما يطلب منك إيجاد Av كمية سلبية

زيادة Gm أو زيادة Rout للوصول إلى $A_v=-G_m R_{out}$

Q / 9.20 : Find the short-circuit transconductance and the voltage gain.

قم بدراسة وحل سؤال 9.25 ثم ارجع لحل هذه المسألة

a-



- Note that Vin isn't a DC source, so it remains in the model

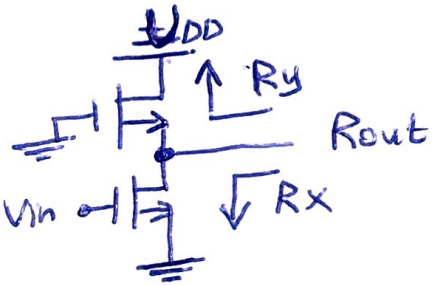
- now, we need to find a relation between Vin and Iout

$$I_{out} = G_m V_{in} \Rightarrow \boxed{G_m = \frac{I_{out}}{V_{in}} = \frac{I_D}{V_{GS}} = g_{m1}}$$

الاستنتاج الكامل موجود في أحد أمثلة الكتاب

- then, to find Av we need to find Rout

$$R_{out} = R_x \,||\, R_y$$

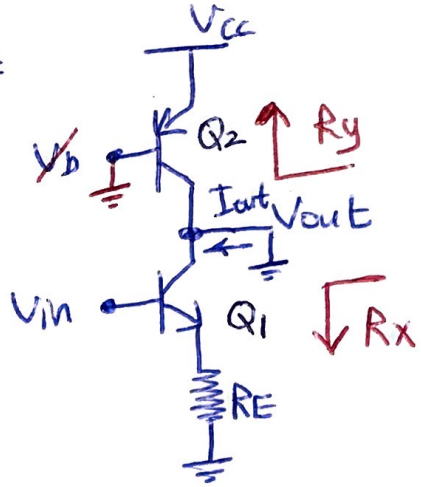


$$R_x = r_{o1}$$

and $R_y = 1/g_{m2}$

then, $$\boxed{A_v = -g_{m1}\left(r_{o1} \,||\, \frac{1}{g_{m2}}\right)}$$

c-



When we short the output node then the circuit is common-emitter stage with degeneration, and

$$\boxed{G_m = \frac{g_{m1}}{g_{m1}(R_E \,||\, r_{o1}) + 1}}$$

$$R_{out} = R_x \,||\, R_y$$

$$R_x = \left[1 + g_{m1}(R_E \,||\, r_{\pi 1})\right] r_{o1} + (R_E \,||\, r_{\pi 1})$$

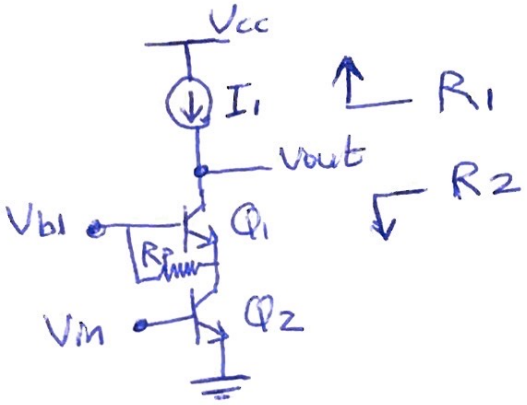
$$R_y = r_{o2}$$

نسمي الـ general

$$\boxed{A_v = \frac{-g_{m1}\left(\left[\left[1 + g_{m1}(R_E \,||\, r_{\pi 1})\right] r_{o1} + (R_E \,||\, r_{\pi 1})\right] \,||\, r_{o2}\right)}{g_{m1}(R_E \,||\, r_{o1}) + 1}}$$

Q / 9.25 : Find Av for :-

a-



$$A_V = -G_m R_{out} \quad , \quad R_{out} = R_1 \,||\, R_2$$

- في تحليل Small Signal model يصبح مصدر التيار كدارة مفتوحة open circuit وبالتالي نجد:

$$R_1 = \infty \Rightarrow \boxed{R_{out} = R_2} \quad -(1)$$

* Now let us find R_2 without the effect of R_p then add R_p in its place

$$\boxed{R_2 = \left[1 + g_{m1}(r_{\pi 1} \,||\, r_{o2})\right] r_{o1} + (r_{\pi 1} \,||\, r_{o2})} \quad -(*)$$

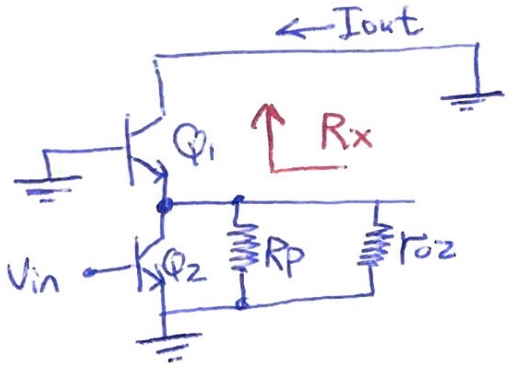
then, R_p is in parallel with $r_{\pi 1}$

$$\boxed{R_2 = \left[1 + g_{m1}(r_{\pi 1} \,||\, R_p \,||\, r_{o2})\right] r_{o1} + (r_{\pi 1} \,||\, R_p \,||\, r_{o2})} \quad (**)$$

الآن نريد إيجاد معادلة G_m لذلك نقوم بتصفير الدائرة عندها يكون $V_{out}=0$ و أيضاً $V_{b1}=0$

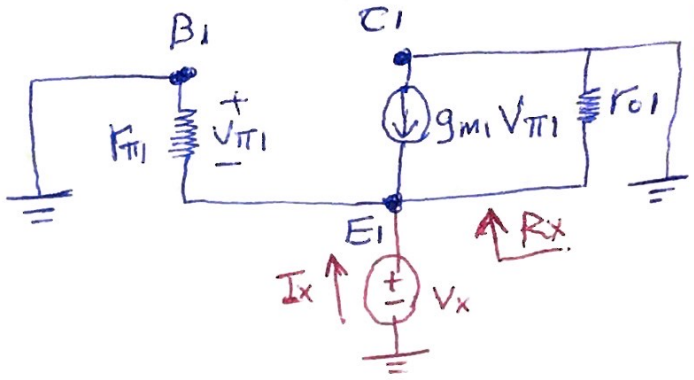
$$G_m = \left.\frac{I_o}{V_{in}}\right|_{V_{out}=0}$$

الآن لإيجاد I_o والذي يرتبط بـ V_{in} كلياً بتبسيط الدائرة و إيجاد المقاومة المكافئة الجزء العلوي R_x



نرسم المودل الخاص بالجزء العلوي

R_x لإيجاد thevenin نستعمل



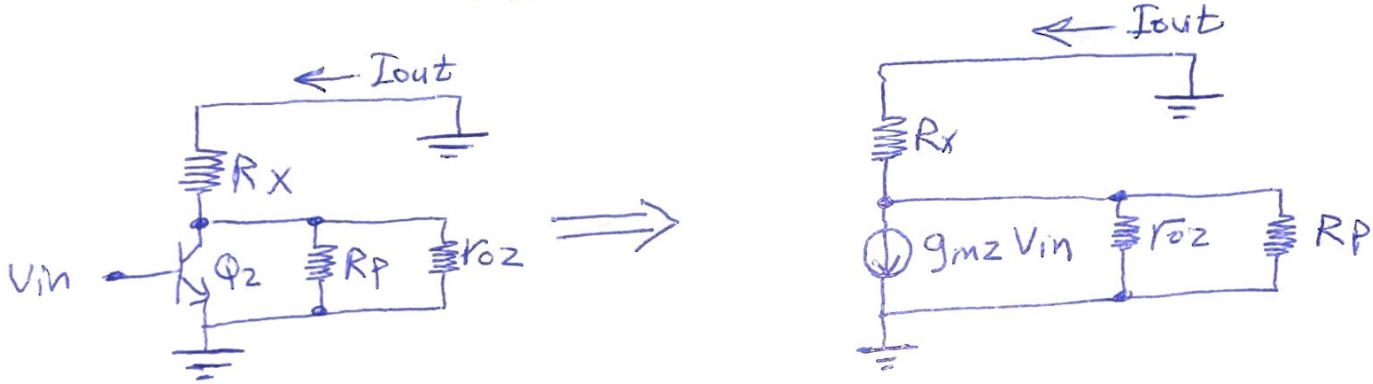
$$I_x = \frac{V_x}{r_{o1}} - g_{m1} V_{\pi 1} + \frac{V_x}{r_{\pi 1}}$$

$$\boxed{V_{\pi 1} = -V_x}$$

$$I_x = \frac{V_x}{r_{o1}} + g_{m1} V_x + \frac{V_x}{r_{\pi 1}} = V_x \left[\frac{1}{r_{o1}} + \frac{1}{r_{\pi 1}} + g_{m1} \right]$$

$$\boxed{\frac{V_x}{I_x} = R_x = \frac{1}{\frac{1}{r_{\pi 1}} + \frac{1}{r_{o1}} + g_{m1}} = r_{\pi 1} \,||\, r_{o1} \,||\, \frac{1}{g_{m1}}}$$

الآن يمكننا إستبدال الجزء العلوي بالمقاومة R_x



كما نلاحظ يجب معادلة تربط بين V_{in} ، I_{out} نستعمل current divider

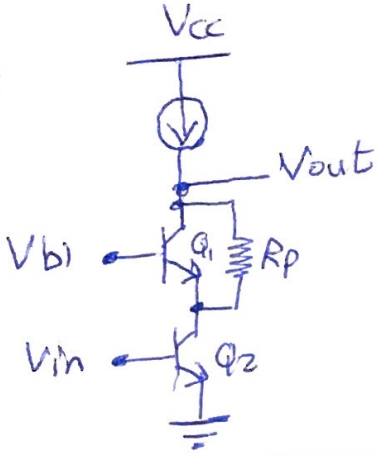
$$I_{out} = \frac{(r_{o2} \,||\, R_p)}{(r_{o2} \,||\, R_p) + R_x} g_{m2} V_{in} = \frac{(r_{o2} \,||\, R_p)\, g_{m2} V_{in}}{(r_{o2} \,||\, R_p) + (r_{\pi 1} \,||\, r_{o1} \,||\, \frac{1}{g_{m1}})}$$

$$\boxed{G_m = \frac{I_{out}}{V_{in}} = \frac{(r_{o2} \,||\, R_p)\, g_{m2}}{(r_{o2} \,||\, R_p) + (r_{\pi 1} \,||\, r_{o1} \,||\, \frac{1}{g_{m1}})}}$$

$$A_V = -G_m R_{out} = -G_m R_2$$

اضرب في

b-



- نلاحظ أن الشكل مختلف في النوع عن a وكذلك باختلاف قيمة Rp حيث أن $R_p \| r_{o1}$

$$R_{out} = \left[1 + g_{m1}(r_{\pi 1} \| r_{o2})\right](r_{o1} \| R_p) + (r_{\pi 1} \| r_{o2})$$

ولإيجاد Gm كما في النوع a تماماً

$$G_m = \frac{I_o}{V_{in}} = \frac{(r_{o2} \| R_p)\, g_{m2}}{(r_{o2} \| R_p) + (r_{\pi 1} \| r_{o1} \| \frac{1}{g_{m1}})}$$

هنا استعملنا نفس المعادلة لأن شكل الدارة لم يتغير بتغير قيمة Rp وكذلك في أسئلة أخرى يمكن تغير المعادلة "نخرج من خلال الرسمة المائلة للرسمة في محاضرة 5 أسفل الصفحة 11"

$$A_V = -G_m R_{out}$$

$$A_V = \frac{\left[-(r_{o2} \| R_p)\, g_{m2}\right]\left[\left[1 + g_{m1}(r_{\pi 1} \| r_{o2})\right](r_{o1} \| R_p) + (r_{\pi 1} \| r_{o}\right.}{(r_{o2} \| R_p) + (r_{\pi 1} \| r_{o1} \| \frac{1}{g_{m1}})}$$

End of Part 2

Electronics II discussion

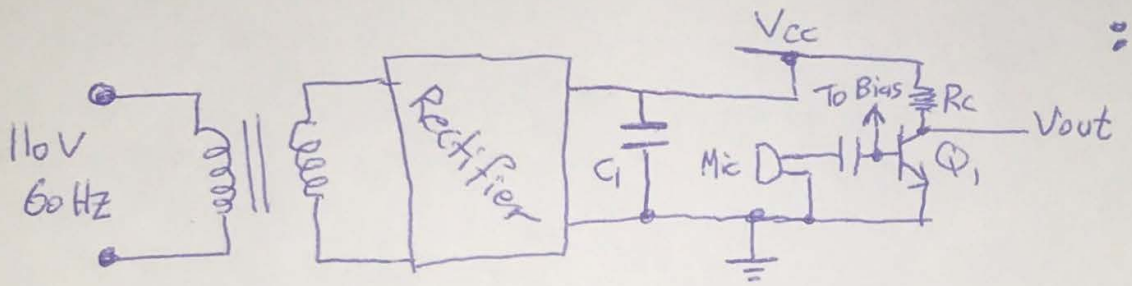
Chapter 10 : Differential Amplifiers

Part 1

Eng. : Ayman F. EL-Khuzundar

لماذا نحتاج هذا النوع من الـ Amplifiers ؟؟

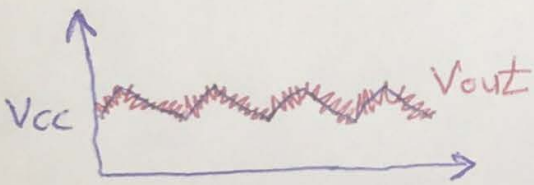
أنظر الدائرة المجاورة :



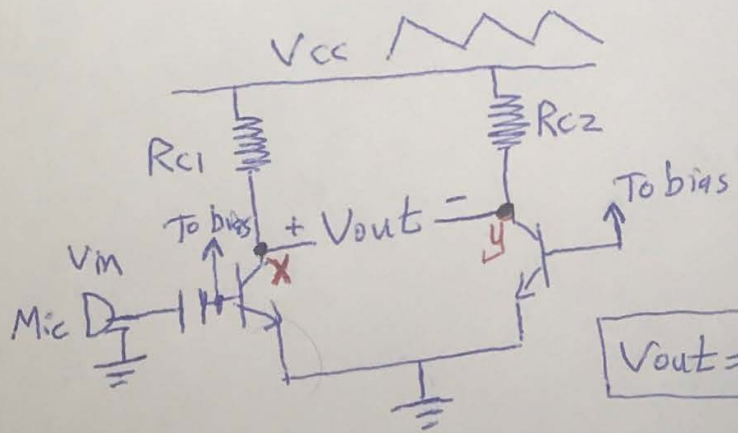
لو حاولنا إيجاد معادلة الخرج الناتج من هذه الدائرة (وهي دائرة تكبير الصوت Mic) نجد أنه :

$$Vout = Vcc - Ic\,Rc$$

الإشارة الناتجة (الصوت المكبّر) لها علاقة مباشرة مع مصدر التغذية Vcc ، وحيث أن مصدر التغذية تم الحصول عليه بواسطة دائرة Rectifier فإنه سيعاني من Ripple وبالتالي تشكل الإشارة الناتج سيعاني من نفس المشكلة .



هذه الظاهرة تسمى Humming ، ولتخلص منها نلجأ الى إيجاد حل يجعل Vout لا يعتمد على Vcc من خلال الدائرة التالية :



وبإيجاد معادلة Vx و Vy :

$$Vx = Av\,Vm + Vr$$

$$Vy = Vr$$

وبالتالي ⇐ $\boxed{Vout = Vx - Vy = Av\,Vin}$

نلاحظ أن Vout لا تربطه أي علاقة بالـ Vcc ، وكأننا عزلنا Vout عن Vcc .

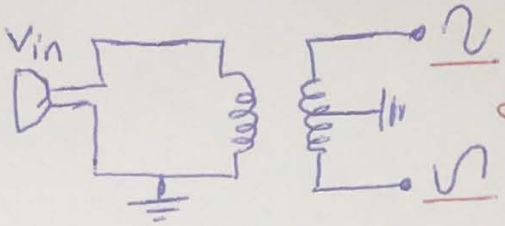
⇒ We made Vout, Relative to another ground.

↓ be

Differential Signals :-

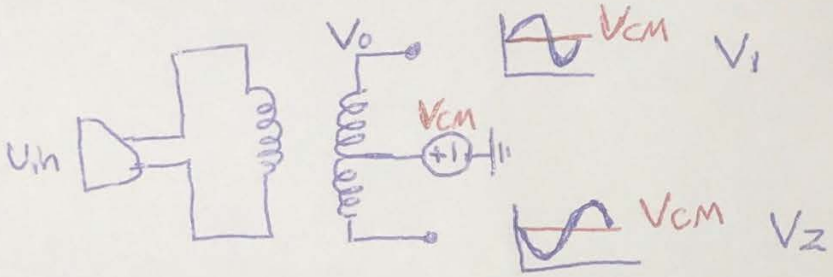
التعريف : هي إشارات لها فرق الصفة وبينها phase shift مقداره 180°.

يتم توليدها عن طريق استعمال "Center tapped" transformer كما في الشكل :



V_{CM} : Common-mode Voltage :

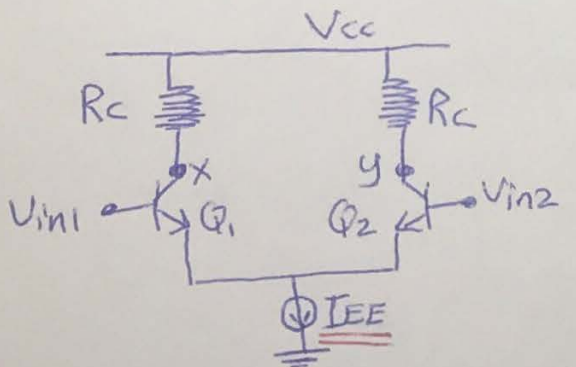
هي الصفة الـ dc التي يتم إضافتها إلى الـ differential signals ، ويتم ذلك عند الـ center tap الخاص بالـ transformer :



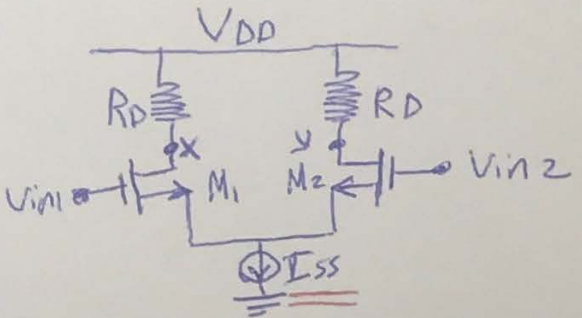
$$V_1 = V_o \sin \omega t + V_{cm}$$
$$V_2 = -V_o \sin \omega t + V_{cm}$$

$$V_{out} = V_1 - V_2 = 2V_o \sin \omega t$$ differential output

Differential Pair :-



Bipolar differential pair



Mos differential pair

IEE and Iss are called "tail current source"

Bipolar differential pair :-

1- Qualitative Analysis :-

بالرجوع لل الرسمة في الصفحة السابقة :

at $V_{in1} = V_{in2} = V_{CM}$

$$\begin{cases} V_{BE1} = V_{BE2} \\ I_{C1} = I_{C2} = \frac{I_{EE}}{2} \\ V_x = V_y = V_{CC} - R_C \frac{I_{EE}}{2} \end{cases}$$

but the collector voltages must not fall below the base voltages

$$V_{CC} - R_C \frac{I_{EE}}{2} \geq V_{CM}$$

and also V_{CM} cannot be arbitrarily high.

$V_{CC} - R_C \frac{I_{EE}}{2}$ is called "output CM level"

in the Qualitative analysis, we "Zoom in" around $V_{in1} - V_{in2} = 0$ and study the circuit's behaviour for a small input difference.

and then :-

$$I_{C1} = \frac{I_{EE}}{2} + \Delta I$$

$$I_{C2} = \frac{I_{EE}}{2} - \Delta I$$

$$A_V = \frac{\text{change in differential output}}{\text{change in differential input}}$$

$$= \frac{-2 g_m \Delta V R_C}{2 \Delta V}$$

$$\boxed{A_V = -g_m R_C}$$

مزيد من المعلومات حول الموضوع راجع الكتاب 446+447

Example 10.6:- Design a bipolar differential pair for a gain of 10 and a power budget of 1mW with a supply voltage of 2V. الطلوبة الباقية في السؤال هي R_{C1} R_{C2}

Solution:- $P = V_{CC} * I_{EE}$, $P = 1 \times 10^{-3}\ W$, $V_{CC} = 2V$

$$I_{EE} = 0.5mA$$

and $g_m = \frac{I_C}{V_T}$, $I_C = \frac{I_{EE}}{2} = 0.25mA$

$$g_m = \frac{0.25m}{0.026} = (104\ \Omega)^{-1} \quad \left| \quad = \frac{1}{104} = 9.615 \times 10^{-3} \right.$$

$$A_V = -g_m R_C \Rightarrow R_C = \left| \frac{A_V}{g_m} \right| = 10 \times 104 = 1040\ \Omega$$

$$R_{C1} = R_{C2} = 1040\Omega$$

2- Large-Signal Analysis:-

$$I_{C1} = \frac{I_{EE}}{1 + \exp \frac{V_{in2} - V_{in1}}{V_T}}$$

$$V_{out1} - V_{out2} = -R_C (I_{C1} - I_{C2})$$

$$I_{C2} = \frac{I_{EE}}{1 + \exp \frac{V_{in1} - V_{in2}}{V_T}}$$

$$V_{out1} - V_{out2} = -R_C I_{EE} \tanh \frac{V_{in1} - V_{in2}}{2V_T}$$

and (for example) if $I_{C1} \approx 0$ and $I_{C2} \approx I_{EE}$ then:

exactly: If $V_{in1} - V_{in2} = -10\ V_T$

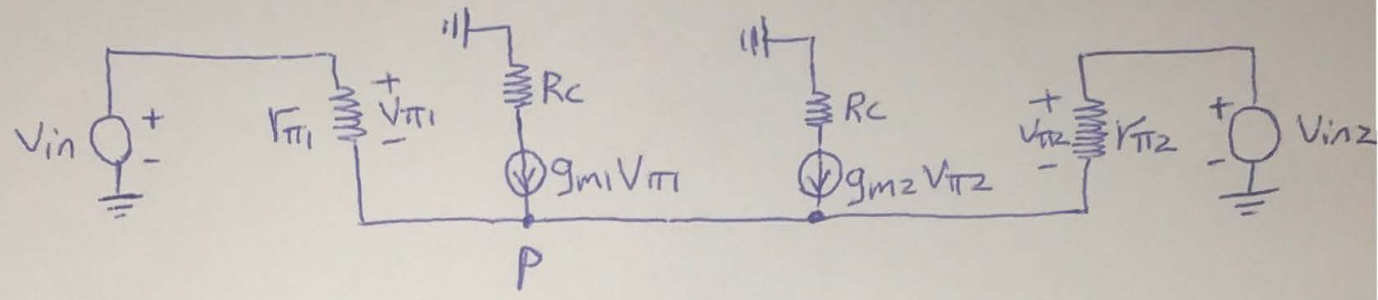
$I_{C1} \approx 4.54 \times 10^{-5}\ I_{EE}$ (very small)

$I_{C2} \approx (1 - 4.54 \times 10^{-5})\ I_{EE}$ (very large)

يتبع ... يتبع الصفحة مع الإشارة

3- Small Signal Analysis :-

By drawing the small signal model :- (for the same circuit)



Notes: ⇒ $V_{in1} = -V_{in2}$ (differential signals)

→ $r_{\pi 1} = r_{\pi 2}$, $g_{m1} = g_{m2}$ (identical transistors)

→ The Right and left side must be symmetrical.

by making KVL for the circuit, then :- أجزاء اليمين تشبه أجزاء اليسار والقيم لها نفس القيم.

→ V_P = Zero

→ $V_{out1} = -g_m R_c V_{in1}$

→ $V_{out2} = -g_m R_c V_{in2}$

and the differential Voltage gain :

→ $$\frac{V_{out1} - V_{out2}}{V_{in1} - V_{in2}} = -g_m R_c$$

*) input impedence (single-ended) $= r_{\pi 1} = r_{\pi 2}$ (by using thevinin theorem applied to the above model)

*) input impedence (differential) $= 2r_{\pi 1} = 2r_{\pi 2}$

*) output impedence (single-ended) $= R_c$

*) output impedence (differential) $= 2R_c$

Q/ 10.17 :-

a- Very easy. (the upper limit = $\frac{I_{EE}}{2}$ and Center = $\frac{I_{EE}}{4}$)

b- V_{cc} rises by ΔV.

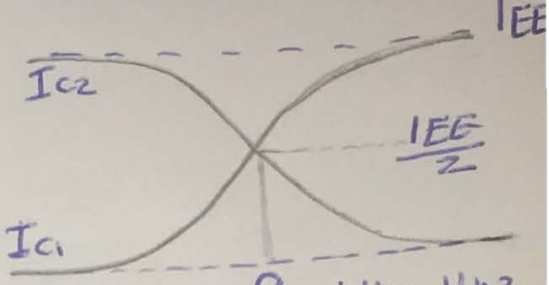
- طالما حيدت الرسم الجاور وصعوبة سؤال characteristic عندما نجيب V_{cc} نجيب $V_{cc}+\Delta V$ ؟؟

- بكل بساطة فولتية الكيلكتر لسه بتتغير (وهنا سبب استعمالنا لهذه الكلمة) أما بالنسبة لـ "Collector current" فهي بالنسبة للطرفين

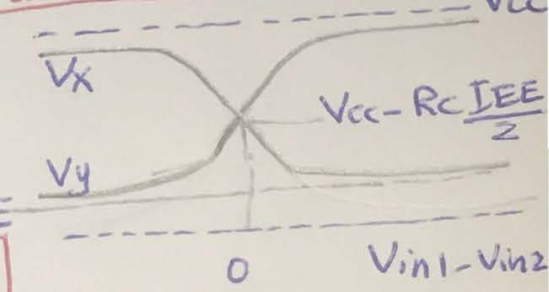
- سوف يحصل Shift للرسمة "output Voltages" لـ

$V_{out}=V_x-V_y$ بعطاء ΔV للأعلى، وهنا أيضاً لم يتغير صيغة V_{out} لكن الرسمة تم إزاحتها كلياً للأعلى فقط بالكمية ΔV

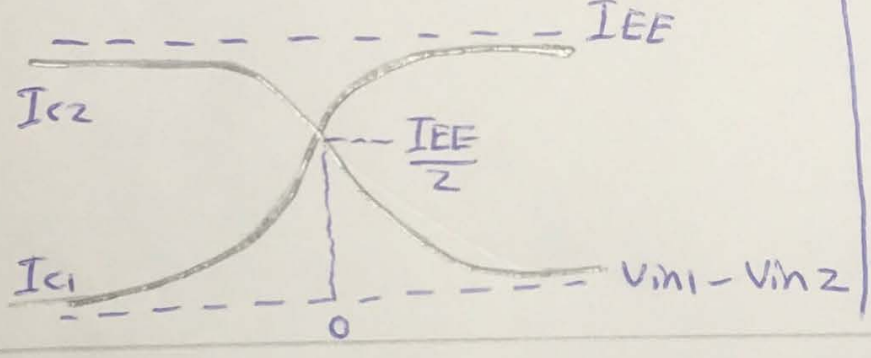
Figure 10.10 :- (original)

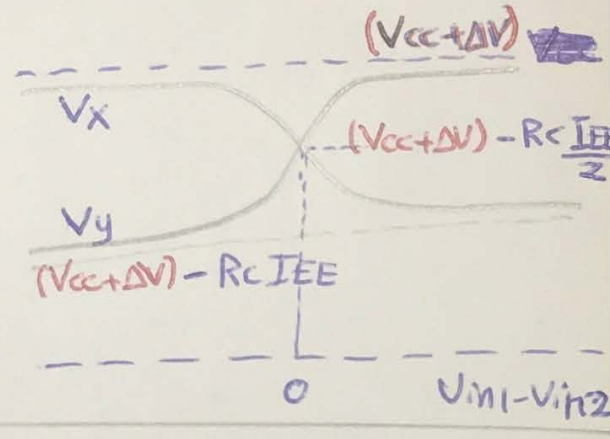


Collector currents



output Voltages as a function of input.



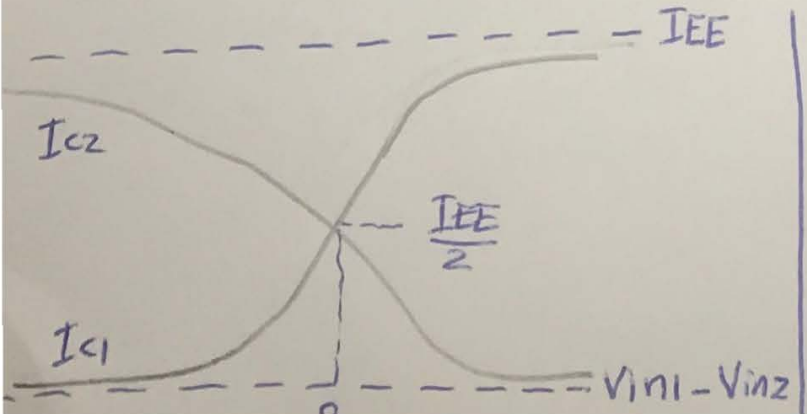


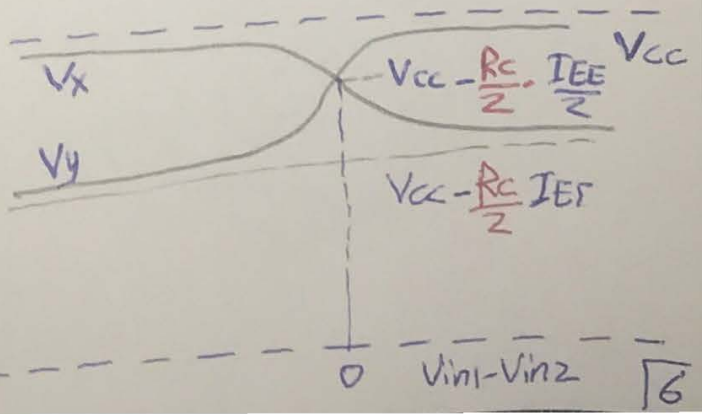
c- Rc is halved ?

- عندما تقل Rc للنصف فإن الكيلكتر الحالي سيظل له نفس القيمة = $\frac{I_{EE}}{2}$ حيث أن كلا المعادلتين تغيرتا معاً

- أما بالنسبة لرسمة output Volt. فسيحصل لها shift أيضاً ولكن يلزم تغيير الحد العلوي = V_{cc}.

- "يتقارع وسير في Rc ويقسمها على 2"

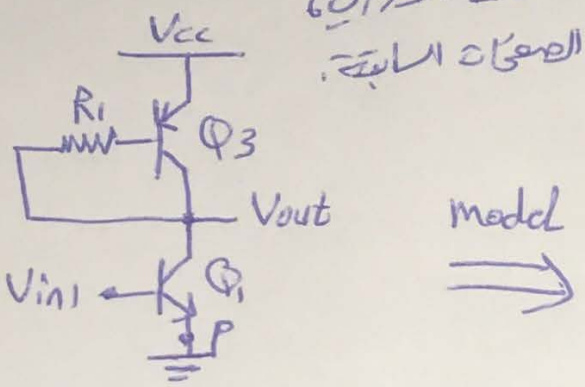




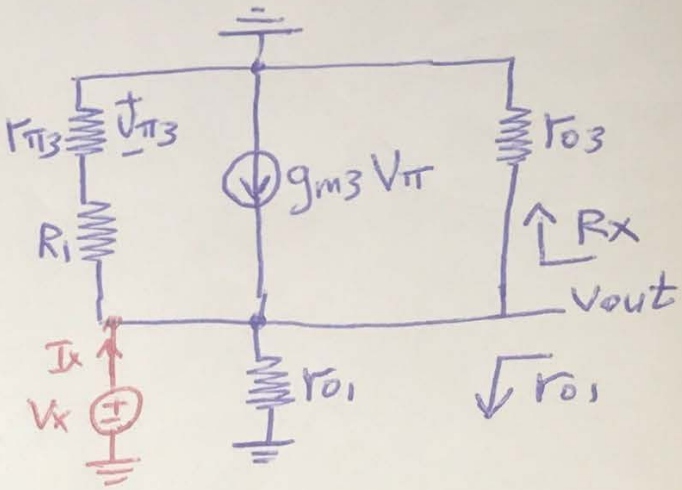
Q/ 10.32 e-

9- - عند طريقة الحل حيث تكون الدائرة Symmetrical فإن أخذ الجزء اليمين أو اليسار وتحليله ، وبالتالي نكمل خطوات الدائرة كاملة (لأنه اليمين نفس اليسار)

- نلاحظ (في الدائرة المجاورة) أن النقطة P تم توصيلها بـ الأرضي وهذا ما وجهنا إليه في التحليل Small-signal في الصفحات السابقة.



model ⟹



$$Av = -g_m R_{out}$$

but $R_{out} = (r_{o1} \parallel R_x)$

to find R_x use thevinin theorem e-

$$\boxed{I_x = \frac{V_x}{R_1 + r_{\pi 3}} - g_{m3} V_\pi + \frac{V_x}{r_{o3}}} \quad (*)$$

but $\boxed{V_\pi = -\frac{r_{\pi 3}}{r_{\pi 3} + R_1} \cdot V_x}$ in (*)

$$I_x = V_x \left[\frac{1}{R_1 + r_{\pi 3}} + \frac{1}{r_{o3}}\right] + \frac{r_{\pi 3} g_{m3} V_x}{r_{\pi 3} + R_1} = V_x \left[\frac{1}{R_1 + r_{\pi 3}} + \frac{1}{r_{o3}} + \frac{r_{\pi 3}\, g_{m3}}{r_{\pi 3} + R_1}\right]$$

$$\frac{V_x}{I_x} = R_x = \left[\frac{1}{\frac{1}{R_1 + r_{\pi 3}} + \frac{1}{r_{o3}} + \frac{r_{\pi 3}}{r_{\pi 3} + R_1}}\right]$$

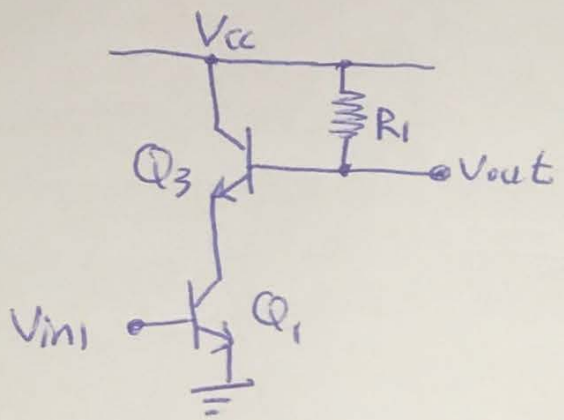
$$\boxed{Av = -g_{m1} (r_{o1} \parallel R_x)}$$

b- Very easy $\boxed{A_V = -g_{m1}(R_1 \| R_C \| r_{o1})}$ بنفس الآلية عادةً

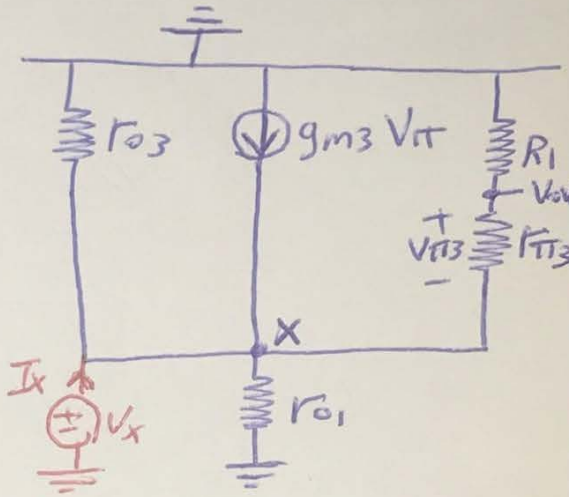
c- بنفس طريقة فرع q- نأخذ نصف الدائرة :

فكرة جديدة

half circuit :-



model ⟹



- في الأسئلة السابقة كنا سعوديه Rout نجيبها من طريق نصف الدائرة لـ $r_{o1} \| R_x$ مثلاً ، ولكن في هذه المسألة انظر إلى Rout من فرق Vout سنجد أنه إيجادها معقد للغاية
- لذلك سنستخدم طريقة مختلفة بإيجاد R_x للجزء العلوي كمثال ، بغض النظر ماذا يمثل هذا الجزء بالنسبة لـ Rout ، ثم نتابع ونرى ماذا يحصل من خلال هذا الحل ...

$$I_x = \frac{V_x}{r_{o3}} - g_{m3} V_\pi + \frac{V_x}{R_1 + r_{\pi 3}}$$ (نفس ناتج الفرع q- من السؤال)

$$R_x = \frac{V_x}{I_x} = \left[\frac{1}{\frac{1}{R_1 + r_{\pi 3}} + \frac{1}{r_{o3}} + \frac{r_{\pi 3}}{r_{\pi 3} + R_1}}\right] = \boxed{(R_1 + r_{\pi 3}) \| r_{o3} \| \left(1 + \frac{R_1}{r_{\pi 3}}\right) \frac{1}{g_{m3}}}$$

- لو بدنا نجيب الـ Av عند النقطة اللي حسبنا عندها R_x ، حتكون :

$$\boxed{A_V(\text{at } x) = -g_{m1}(r_{o1} \| R_x) = \frac{V_x}{V_{in}}} \quad -(1)$$

- علاقة Vout مع Vx هي : Voltage divider

$$V_{out} = \frac{R_1}{R_1 + r_{\pi 3}} V_x$$

$$\frac{V_{out}}{V_X} = \frac{R_1}{R_1 + r_{\pi 3}} \quad - [2]$$

$$\therefore A_V = \frac{V_{out}}{V_{in}}$$

$$A_V = \frac{V_{out}}{V_{in}} = \boxed{2}\ \frac{V_{out}}{V_x} \cdot \boxed{1}\ \frac{V_x}{V_{in}}$$

$$\boxed{A_V = -g_{m1}(r_{o1} \| R_x) \cdot \frac{R_1}{R_1 + r_{\pi 3}}}$$

the answer is reasonable -by sense- as the voltage gain is <u>divided</u> by the resistors (R_1 and $r_{\pi 3}$).

<u>d-</u> Very easy, similar to <u>a-</u> with the same answer.

The End of Part 1.

Electronics II discussion
Chapter 10 : Differential Amplifiers

Eng. Ayman F. EL-Khuzundar

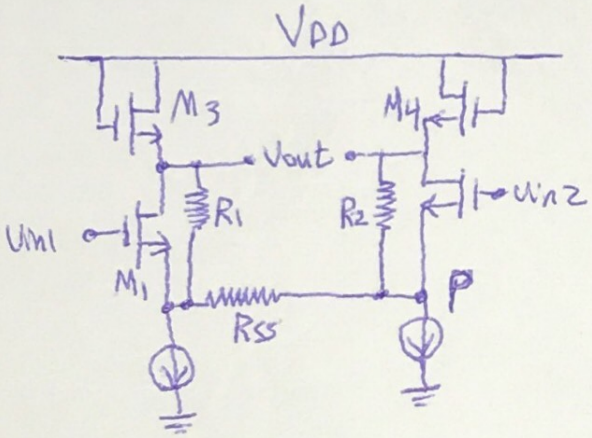
Part 2

Mos differential pair :-

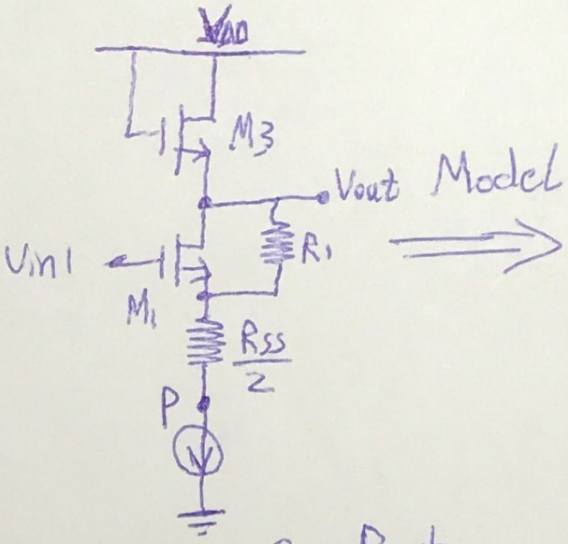
* نفس الشرح الوارد تماماً بالنسبة لـ Bipolar باختلاف الرمز للدلالة للـ Mos ، لذا سنتجه للأسئلة مباشرة.

Q/ 10.53 :-

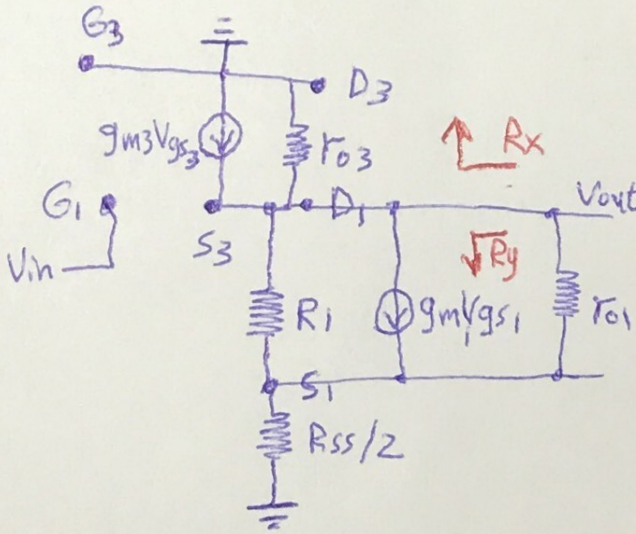
a-



- نلاحظ أن هناك مقاومة Rss تربط بين الجزء الأيمن والأيسار، ولتحقيق الـ symmetry نقوم بفصل هذه المقاومة إلى نصفين، $\frac{Rss}{2}$ في كل فرع، وبالتالي يصبح كل الدائرة الـ half circuit.



Model ⟹



$A_V = -G_m R_{out}$

$R_{out} = R_x \parallel R_y$

$R_x = (r_{o3} \parallel \frac{1}{g_{m3}})$ from Electronics I

$R_y = \left[g_{m1}(R_1 \parallel r_{o1}) \frac{R_{ss}}{2} + \frac{R_{ss}}{2} + (R_1 \parallel r_{o1}) \right]$ from ch 9

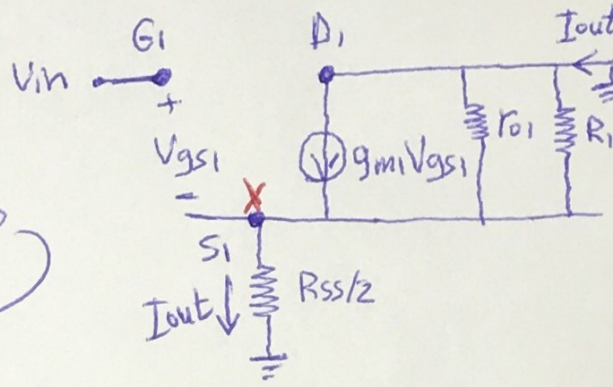
OR $R_y = (1 + g_{m1}\frac{R_{ss}}{2})(r_{o1} \| R_1) + \frac{R_{ss}}{2}$ بشكل آخر (لنفس الوجود في مناقشة شابة و ص 3)

$$R_{out} = (r_{o3} \| \frac{1}{g_{m3}}) \| \left[g_{m1}(R_1 \| r_{o1})\frac{R_{ss}}{2} + \frac{R_{ss}}{2} + (R_1 \| r_{o1}) \right] \quad -(1)$$

then, We need to find Gm, re-draw the circuit at $V_{out}=0$

M3 is shorted so it doesn't appear in the circuit

"اصبح أطراف M3 موصولة بال GND وبالتالي يختفي من الدائرة"



make KCL at point X :-

$$\frac{V_{s1}}{R_{ss}/2} + \frac{V_{s1}}{r_{o1}} + \frac{V_{s1}}{R_1} - g_{m1}V_{gs1} = 0$$

$$\frac{V_{s1}}{\frac{R_{ss}}{2} \| r_{o1} \| R_1} - g_{m1}V_{gs1} = 0 \quad -(*)$$

but $V_{gs1} = V_{in} - V_x$ in (*) $V_x = V_{s1}$

$$\frac{V_x}{\frac{R_{ss}}{2} \| r_{o1} \| R_1} + g_{m1}V_x = g_{m1}V_{in} \Rightarrow V_x = \frac{g_{m1}V_{in}}{\frac{1}{\frac{R_{ss}}{2} \| r_{o1} \| R_1} + g_{m1}}$$

now, let's find Iout :-

$$I_{out} = g_{m1}V_{gs1} + \frac{V_x}{r_{o1}} + \frac{V_x}{R_1} \quad \text{OR} \quad = \frac{V_x}{R_{ss}/2} = \frac{2g_{m1}V_{in}}{R_{ss}\left[\frac{R_{ss}}{2} \| r_{o1} \| R_1 + g_{m1}\right]}$$

then, $$G_m = \frac{I_{out}}{V_{in}}\Big|_{v_{out}=0} = \frac{2g_{m1}}{R_{ss}\left[\left(\frac{1}{R_{ss}/2} \| R_1 \| r_{o1}\right) + g_{m1}\right]} \quad [2]$$

$$A_v = -G_m R_{out} = [1] * [2]$$

[2]

58, 55 ملاحظة / يمكن الرجوع لنفس الحل بالإضافة إلى سؤال

Q/10.64: Voltage gain = $A_V = 200$

tail current = $I_{SS} = 1mA$

$\mu_n C_{ox} = 100\ \mu A/V^2$ $\quad \lambda_n = 0.1\ V^{-1}$

$\mu_p C_{ox} = 50\ \mu A/V^2$ $\quad \lambda_p = 0.2\ V^{-1}$

determine: $\left(\frac{W}{L}\right)_1 -- \left(\frac{W}{L}\right)_8$

half circuit الـ ا-ـحـ الـ

R_{out} ا-ـص

G_m م بنـ

$R_{out} = R_x \parallel R_y = (g_{m3} r_{o3} r_{o1}) \parallel (g_{m5} r_{o5} r_{o7})$

$G_m = g_{m1}$

$$|A_v| = 200 = g_{m1}\left[(g_{m3} r_{o3} r_{o1}) \parallel (g_{m5} r_{o5} r_{o7})\right] \quad (*)$$

$g_{m1} = g_{m3}$ (identical N-channel MOSs) $= \sqrt{\mu_n C_{ox} \left(\frac{W}{L}\right) I_{SS}}$

$$g_{m1} = g_{m3} = 3.16 \times 10^{-4} \left(\frac{W}{L}\right)^{\frac{1}{2}} \ \Omega^{-1} \quad -[1]$$

$$g_{m5} = \sqrt{\mu_p C_{ox} \left(\frac{W}{L}\right) I_{SS}} = 2.236 \times 10^{-4} \left(\frac{W}{L}\right)^{\frac{1}{2}} \ \Omega^{-1} \quad -[2]$$

$$r_{o1} = r_{o3} = \frac{2}{\lambda_n I_{SS}} = 20{,}000\ \Omega \quad -[3]$$

$$r_{o5} = r_{o7} = \frac{2}{\lambda_p I_{SS}} = 10{,}000\ \Omega \quad -[4]$$

back to (*) $\quad 200 = 3.16 \times 10^{-4} \left(\frac{W}{L}\right)^{\frac{1}{2}} \left[126400 \left(\frac{W}{L}\right)^{\frac{1}{2}} \parallel 22360 \left(\frac{W}{L}\right)^{\frac{1}{2}}\right]$

$$\frac{W}{L} = 33.31$$

Selected Design problems from Ch 9:-

Q 9.58

$P = 2mW$

$V_{CC} = 2.5V$ (from graph)

$V_{BC1} = V_{CB4} = 200mV$ find V_{b1}, V_{b2}??

$I_{S,n} = I_{S,p} = 6 \times 10^{-16} A$ (from the given information for all the design problems)

$\beta_n = 100$

$\beta_p = 50$

$V_{A,n} = V_{A,p} = 5\ V$

Voltage gain = ??

$I_{C,p} = I_{E,p} = I_{C,n} = I_{p,n} = I_{Bias}$

$$I_{Bias} = \frac{Power}{V_{CC}} = \frac{2 \times 10^{-3}}{2.5} = \boxed{0.8\ mA}$$

$A_V = -g_{m1} R_{out}$ "R_{out}" لإيجاد الـ ... على الدائرة أو إيجاد كمية لذلك نذهب للمناطق التي لها علاقة لحل كمية "R_{out}"

$$A_V = -g_{m1}\left[(g_{m2} r_{o2}(r_{o1} \| r_{in2})) \| (g_{m3} r_{o3}(r_{o4} \| r_{in3}))\right]$$

simplifying this equation using Electronics I

$$A_V \cong \frac{V_{A,n} \cdot V_{A,p}}{V_T^2\left(\frac{V_{A,p}}{V_{A,n}} + \frac{V_{A,p}}{\beta_n V_T} + \frac{V_{A,n}}{V_{A,p}} + \frac{V_{A,n}}{\beta_p V_T}\right)} \cong \boxed{4760}$$

continued →

$$V_{b1} = V_{BE,2} + V_{c,1}$$ —(*)

$$= V_{BE,1} = V_{in} = V_{EB,3} = V_{EB,4}$$

$$\Rightarrow V_{BE,2} = V_T \ln\left(\frac{I_{Bias}}{I_{S,n}}\right) = 0.026 \ln\left(\frac{0.8\times10^{-3}}{6\times10^{-6}}\right) = 0.726V$$

$$\Rightarrow V_{c,1} = V_{BE,1} - V_{BC,1} = 0.726 - 0.2 = 0.526V$$

$$\Rightarrow V_{b1} = 0.726 + 0.526 = 1.252V$$

$$V_{b2} = V_{c4} - V_{EB,3}$$ —(**)

$$\Rightarrow V_{c4} = V_{b3} + V_{CB,4} \quad \text{but } V_{b3} = V_{cc} - V_{EB,4}$$

$$= 2.5 - 0.726 = 1.774V$$

$$V_{c4} = 1.774 + 0.2 = 1.974V$$

$$\Rightarrow V_{b2} = 1.974 - 0.726 = 1.248V$$

Electronics II discussion

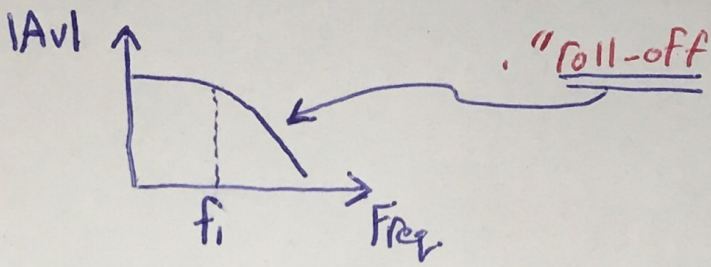
Chapter 11: Frequency Response

Eng. Ayman F. EL-Khuzundar

Part 1

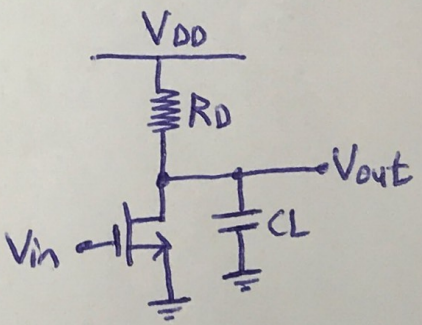
- في هذا الشابتر ندرس تأثير التغير في الـ input Frequency على دوائر الترانزستور والموسفت

- معظم الدوائر لها High gain في حالة الترددات المنخفضة ولكن مع زيادة الترددات نلاحظ إنخفاض في الـ gain "Roll-off".



- هناك نقطة معينة يتم إيجاد الـ Freq. عندها وهي "-3dB bandwidth" وتعتبر $\left|\frac{Vout}{Vin}\right|$ للدائرة في الـ high Freq. يساوي $\left|\frac{Vout}{Vin}\right|$ لـ "low Freq." مقسومة على $\sqrt{2}$ ، انظر المثال لتفهم الحل.

Example:- Determine the transfer function and frequency response of the CS stage shown.



- في الدائرة المجاورة وفي حالة low Freq. فإن المكثفة الخاصة بالكتف تكون دائرة مفتوحة وبالتالي مرحلة مسار الحساب (التوتر) وبالتالي فإن الـ gain:

$$Av = \frac{Vout}{Vin} = -g_m R_{out} = -g_m R_D$$ في حالة low Freq.

- في حالة high Freq. فإننا نحسب المكثفة الخاصة بالكتف وتصغر الحساب كالتالي:

$$Av = \frac{Vout}{Vin} = -g_m R_{out} = -g_m (R_D \| Z_c) = -g_m \left(R_D \| \frac{1}{C_L s}\right)$$

-- يتبع --

$$A_v = H(s) = \frac{V_{out}}{V_{in}}(s) = \frac{-g_m R_D}{R_D C_L s + 1}$$

*) When the input is a sinosoidal then we replace $\boxed{s = jw}$

then we compute the magnitude of $H(s)$

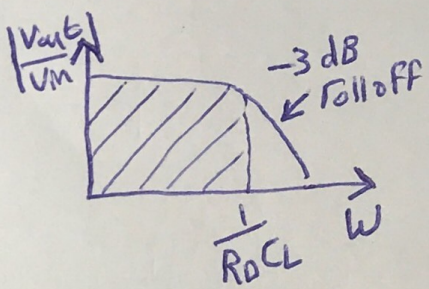
$$|H(s)|_{s=jw} = \frac{g_m R_D}{\sqrt{R_D^2 C_L^2 w^2 + 1}}$$

* نلاحظ أن $|H(s)|$ عند الترددات المنخفضة ($w=0$) تعطي نفس قيمة الـ gain في حالة الترددات المنخفضة.

$g_m R_D$ وهي تساوي

- النوع لإيجاد "-3dB bandwidth" نقوم بحساب القيمة التي تجعل عندها المقام = $\sqrt{2}$

$$\sqrt{R_D^2 C_L^2 w^2 + 1} = \sqrt{2} \Rightarrow \boxed{w = \frac{1}{R_D C_L}}$$

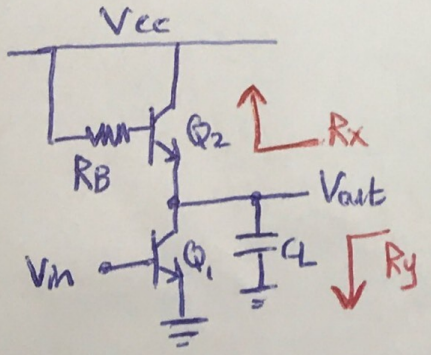


▨ -3 dB bandwidth.

Q/ 11.3 :- assume $V_A = \infty$ but $r > 0$

find -3 dB bandwidth.

b-



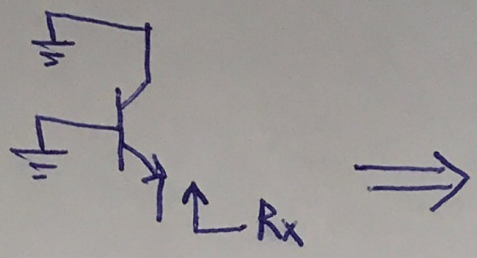
$R_{out} = R_x \parallel R_y$

but $R_y = r_{o1} = \infty$, as $V_A = \infty$

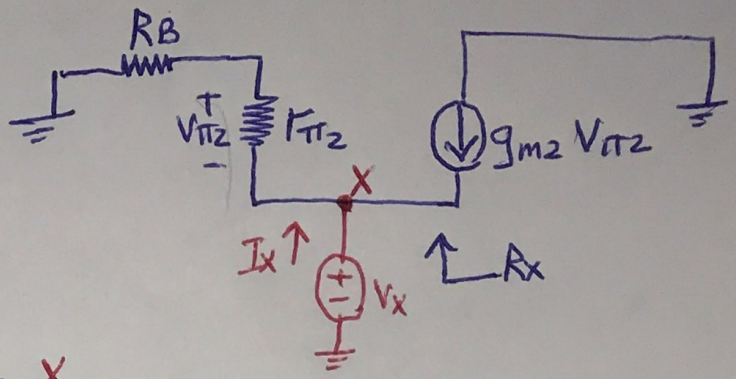
then $\boxed{R_{out} = (R_x \parallel C_L s)}$ *

to find R_x, draw small signal model at $R_{o2} = \infty$

$\Rightarrow$



$\Rightarrow$



$R_x = \frac{V_x}{I_x}$, Using KCL at node X

$$I_x = -g_{m2} V_{\pi 2} + \frac{V_x - 0}{R_B + r_{\pi 2}} \quad (**) \quad \text{or} \quad \frac{V_{\pi 2}}{r_{\pi 2}}$$

but $V_{\pi 2} = \frac{r_{\pi 2}}{r_{\pi 2} + R_B} \cdot V_x$ in (**)

$$I_x = \left[\frac{+g_{m2} r_{\pi 2}}{r_{\pi 2} + R_B} + \frac{1}{R_B + r_{\pi 2}} \right] V_x = \frac{1 + g_{m2} r_{\pi 2}}{r_{\pi 2} + R_B} \cdot V_x$$

$$\frac{V_x}{I_x} = R_x = \frac{r_{\pi 2} + R_B}{1 + g_{m2} r_{\pi 2}}$$

Now, $A_v = \left| \frac{V_{out}}{V_{in}} \right| = |H(s)| = -g_{m1} R_{out} = \left| -g_{m1} (R_x \| C_L s) \right|$

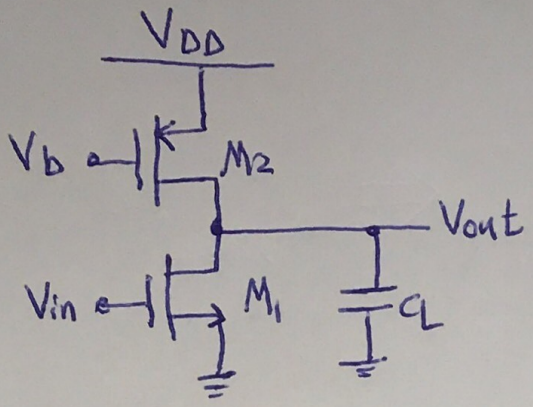
نفس خطوات حل المثال السابق

$$|H(s)|_{s=jw} = \frac{g_{m1} R_x}{\sqrt{R_x^2 C_L^2 w^2 + 1}}$$

*) -3 dB bandwidth $=$ at $\sqrt{R_x^2 C_L^2 w^2 + 1} = \sqrt{2}$

$$w = \frac{1}{R_x C_L} = \frac{1 + g_{m2} r_{\pi 2}}{(r_{\pi 2} + R_B) C_L}$$

c-



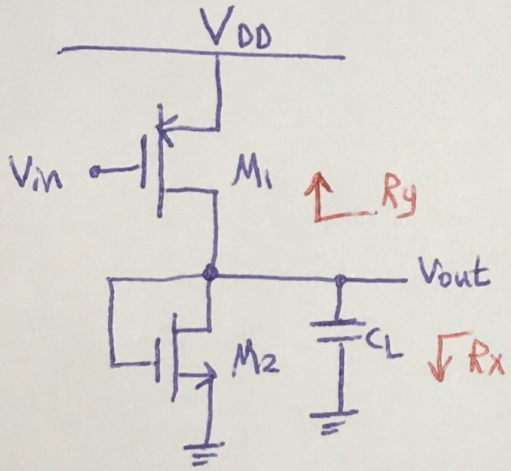
$$R_{out} = r_{o1} \,||\, r_{o2}$$ معروفة

$$H(s) = -g_m R_{out} = -g_{m1}\left[(r_{o1} \,||\, r_{o2}) \,||\, C_L\right]$$

نلاحظ أن الصيغة بنفس صيغة السؤالين السابقين وبالتالي:

$$-3dB \text{ band width} = \frac{1}{(r_{o1} \,||\, r_{o2})\, C_L}$$

d-



$$R_{out} = R_x \,||\, R_y$$

$$R_x = r_{o1}$$

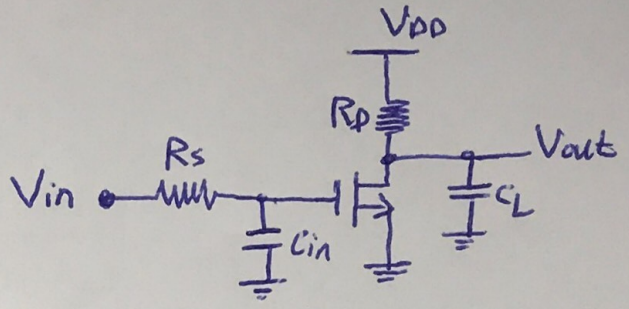
$$R_y = r_{o2} \,||\, \frac{1}{g_{m2}}$$ معروفة

$$R_{out} = r_{o1} \,||\, r_{o2} \,||\, \frac{1}{g_{m2}}$$

$$-3\,dB \text{ bandwidth} = W_{-3dB} = \frac{1}{\left(r_{o1} \,||\, r_{o2} \,||\, \frac{1}{g_{m2}}\right) C_L}$$

④ الـ Poles الخاصة بالدائرة تلعب دور مهم في الـ Freq. response وبالتالي كلما إيجادها لازم تعرفها ودراستها.

Example 11.8 :- Determine the poles of the circuit, Assume $\lambda = 0$



Solution :-

1- let Vin = Zero. لـ Pole
2- Short
3-

* Now, for Cin :- "to find input Pole"

V_{in} = Zero

C_L = short

R_1 (at the terminals of Cin) = R_s

Now, $|W_{p1}| = \frac{1}{R_1 \cdot C_{in}} = \boxed{\frac{1}{R_s C_{in}}}$ W_{p1} = input pole

* Now, for C_L :- "to find output Pole"

V_{in} = Zero

C_{in} = short

R_2 (at the terminals of C_L) = R_D

Now, $|W_{p2}| = \frac{1}{R_2 \cdot C_L} = \boxed{\frac{1}{R_D C_L}}$ W_{p2} = output Pole

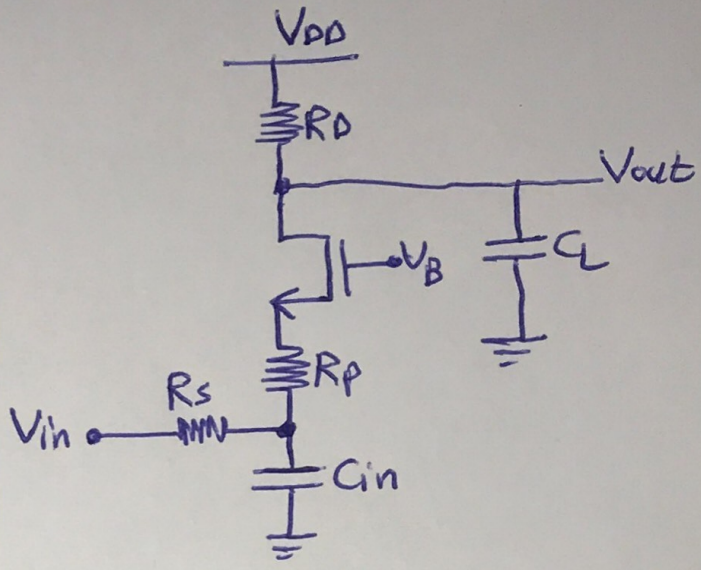
* low-frequency gain of the circuit = $-g_m R_D$, then

$$\boxed{H(s) = \left|\frac{V_{out}}{V_{in}}\right| = \frac{g_m R_D}{\sqrt{(1+\frac{w^2}{w_{p1}^2})(1+w^2 w_{p2}^2)}}}$$

Q / 11.11 :- $\lambda = 0$

find input and output poles.

Solution :-



*) for Cin :

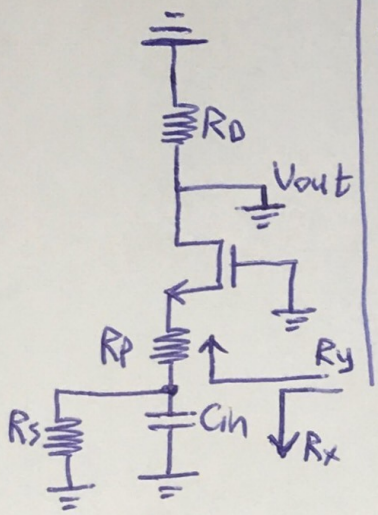
V_M = Zero

C_L = short

$R_1 = R_x \parallel R_y$

$\boxed{R_x = R_s}$

$\boxed{R_y = \frac{1}{g_m} + R_P}$



$\boxed{R_1 = R_s \parallel \left(\frac{1}{g_m} + R_P\right)}$

$$\boxed{\omega_{P_1} = \omega_P(\text{input}) = \frac{1}{\left[R_s \parallel \left(\frac{1}{g_m} + R_P\right)\right] C_{in}}}$$ input Pole

*) for CL :

V_{in} = Zero

C_{in} = short

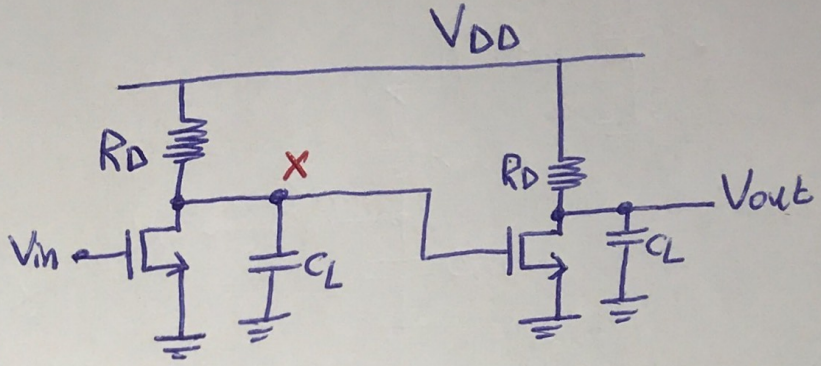
but $\lambda = \infty \Rightarrow R_2 = R_D \parallel \infty = \boxed{R_D}$

$$\boxed{\omega_{P_2} = \omega_P(\text{output}) = \frac{1}{R_D C_L}}$$ output Pole

Q/ 11.9 :- Neglecting channel-length modulation and other Capacitances, construct the bode plot of $\left|\frac{V_{out}}{V_{in}}\right|$

Note : $\left|\frac{V_{out}}{V_{in}}\right| = \frac{V_{out}}{V_x} \cdot \frac{V_x}{V_{in}}$

Solution :-



Cascade identical CS stages. الحل عبارة عن

⇒ the pole for the first stage
= the pole for the second stage
$= \frac{1}{R_D C_L}$ (here we don't have C_{in}, so there is just one pole)

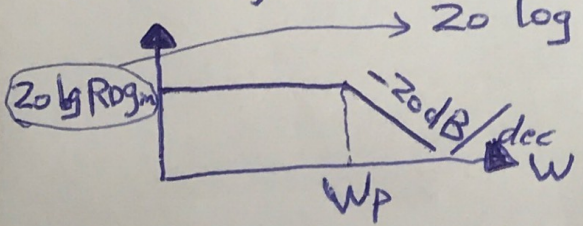
⇒ |dc gain| (at low frequency) $= g_m R_D$

⇒ T.F للدائرة المطلوب عمل bode plot لها نقوم بحساب

$\left|\frac{V_x}{V_{in}}\right| H(s) = \frac{|dc\ gain|}{\frac{s}{\omega_p} + 1} = \frac{g_m R_D}{(R_D C_L)s + 1}$ for the first stage

and also, $\left|\frac{V_{out}}{V_x}\right| = H(s) = \frac{g_m R_D}{(R_D C_L)s + 1}$ For the second stage

الآن نرسم bode plot للـ first stage وهي نفسها second stage

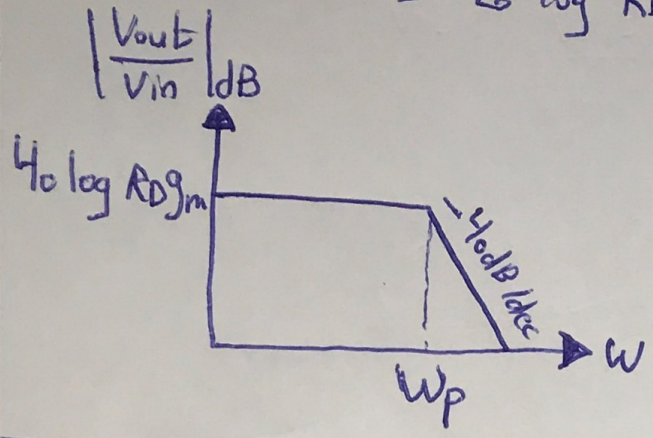


الآن نجمع الـ bode plot للـ Cascade حيث first في second

$\left|\frac{V_{out}}{V_{in}}\right|_{dB} = \left|\frac{V_x}{V_{in}}\right|_{dB} \cdot \left|\frac{V_{out}}{V_x}\right|_{dB}$ ⇒ تابع

$$20\log\left|\frac{V_{out}}{V_{in}}\right| = 20\log\left|\frac{V_x}{V_{in}}\right| + 20\log\left|\frac{V_{out}}{V_x}\right|$$

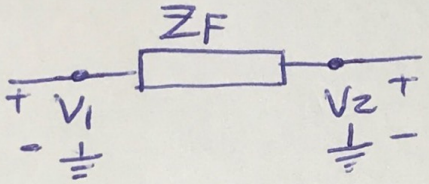
$$= 20\log R_D g_m + 20\log R_D g_m = 40\log R_D g_m$$



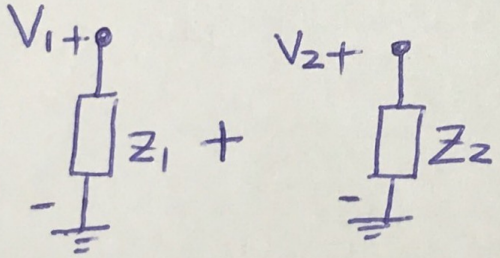
Miller's Theorem :-

ـ هي طريقة تستعمل لتحويل floating impedences والتي two grounded impedences

تستعمل المتفاعل عكسيا.



تتحول إلى ⇓



$$Z_1 = \frac{Z_F}{1-A_V}\ ,\ Z_2 = \frac{Z_F}{1-1/A_V} \qquad \text{Where: } A_V = \frac{V_2}{V_1}$$

ـ بتطبيق هذا الكلام على Capacitor :

$$Z_F = \frac{1}{C_f s} \Rightarrow Z_1 = \frac{1/C_f s}{1-A_V} = \frac{1}{C_f (1-A_V) s}$$

$$Z_2 = \frac{1/C_f s}{1-\frac{1}{A_V}} = \frac{1}{C_f (1-\frac{1}{A_V}) s}$$

Q/ 11.16 :- Apply Miller's theorem to Resistor R_F.

Estimate the Voltage gain.

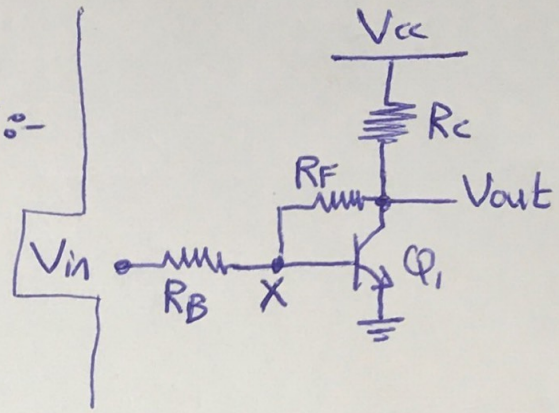
Asume $V_A = \infty$ and R_F is large enough so $\frac{V_{out}}{V_x} = -g_m R_c$

Solution :-

by applying Miller's theorem to R_F :-

$$R_1 = \frac{R_F}{1 - A_V} \quad , \quad A_V = \frac{V_2}{V_1} = \frac{V_{out}}{V_x}$$

$$R_2 = \frac{R_F}{1 - \frac{1}{A_V}} \quad , \quad A_V = \frac{V_2}{V_1} = \frac{V_{out}}{V_x}$$

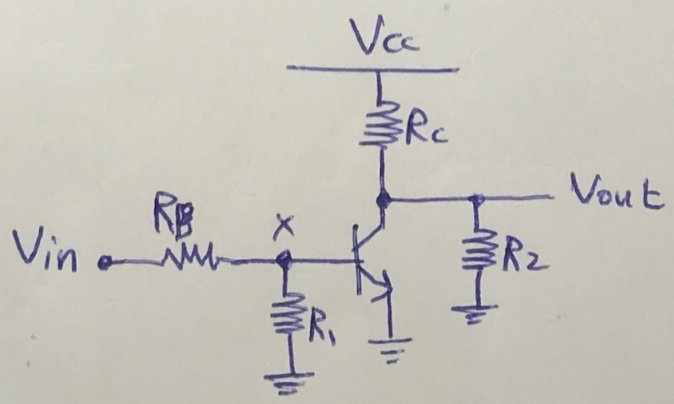


④ المطلوب نطلع الـ Voltage gain للدائرة وبالتالي كلنا عرفنا قيمة $A_V = \frac{V_{out}}{V_x}$ هي تقوم بحلها بإيجاد $A_{V(total)}$ للدائرة ككل.

but from the question above, $\frac{V_{out}}{V_x} = -g_m R_c = A_V$, then

$$\boxed{R_1 = \frac{R_F}{1 + g_{m1} R_c}} \quad \text{and} \quad \boxed{R_2 = \frac{R_F}{1 + (1/g_{m1} R_c)}}$$

ويصبح شكل الدائرة كالتالي :



⟹

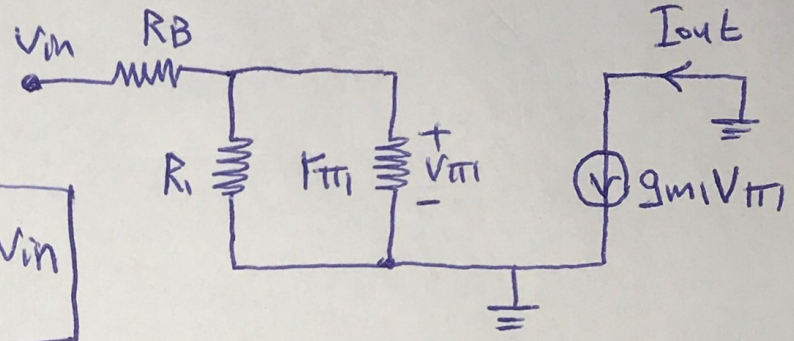
-: $A_{V(total)}$ والآن نأخذ

$$A_{V(total)} = -G_m \cdot R_{out}$$

$$\boxed{R_{out} = R_C \parallel R_2}$$ as $r_{o1} = \infty$ because $V_A = \infty$

$$G_m = \left.\frac{I_{out}}{V_{in}}\right|_{V_{out}=Zero}$$

$$\boxed{I_{out} = g_{m1} V_{\pi 1}} \quad -\text{II}$$



but $$\boxed{V_{\pi 1} = \frac{(r_{\pi 1} \parallel R_1)}{(r_{\pi 1} \parallel R_1) + R_B} \cdot V_{in}}$$

in II

$$\boxed{\left.\frac{I_{out}}{V_{in}}\right|_{V_{out}=Zero} = G_m = \frac{g_{m1}(r_{\pi 1} \parallel R_1)}{(r_{\pi 1} \parallel R_1) + R_B}}$$

Now, $A_{V(total)} = -R_{out} \cdot G_m$

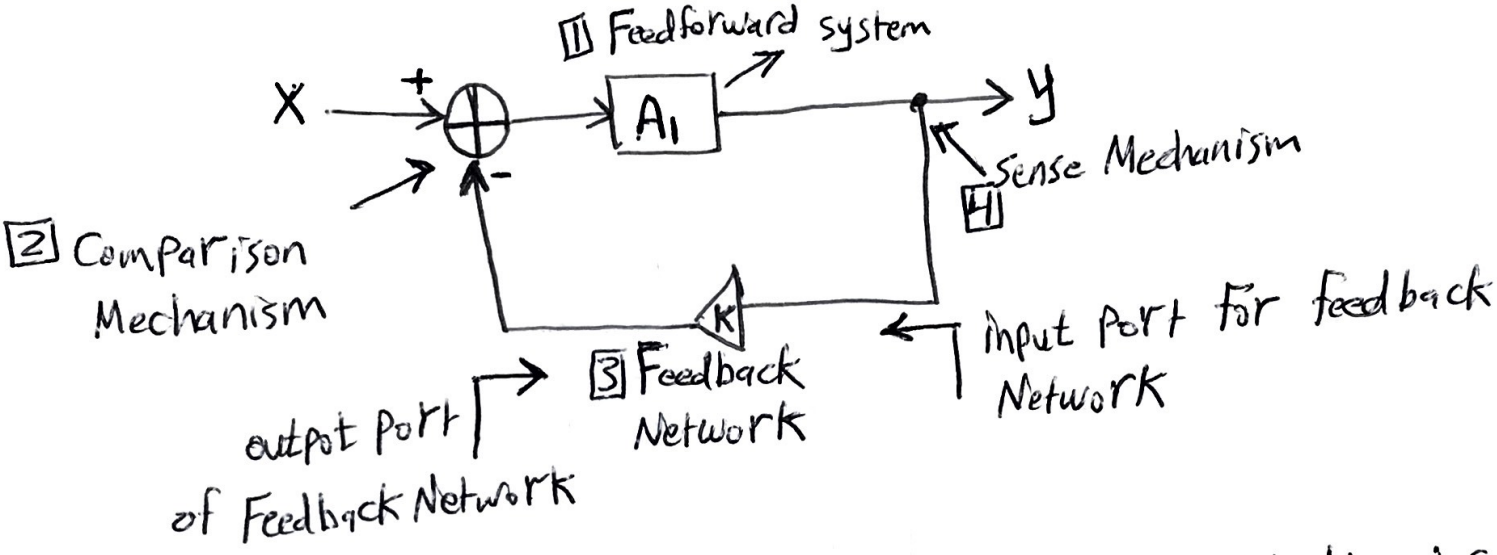
$$\boxed{A_{V(total)} = -(R_C \parallel R_2)\left[\frac{g_{m1}(r_{\pi 1} \parallel R_1)}{(r_{\pi 1} \parallel R_1) + R_B}\right]}$$

Electronics II Discussion

Chapter 12: Feedback

Part 1

Eng. Ayman F. EL-Khuzundar



* في هذا الشابتر سنتعامل مع الدوائر بصورة أخرى ، نتخيل الدائرة كما هي موجودة في الشكل أعلاه بغض النظر عن مكوناتها ، وبالتالي معادلتها كالتالي :-

$$\frac{y}{X} = \frac{A_1}{1+KA_1}$$

the closed loop T.F of the above system.

* المؤثرات التي تؤثر على "open-loop gain" يكون تأثيرها أقل بكثير في حالة "closed-loop gain"

* انظر الكتاب في Page 568 Example 12.4 لتوضيح الفكرة.

* بعض فوائد الـ Feedback :-

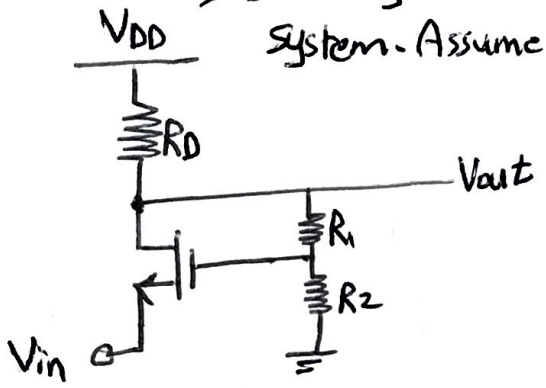
1- في حالة ارتفاع وزيادة تردد الإشارة ، فإن A_1 تقل وكذلك $\frac{A_1}{1+KA_1}$ تظل ثابتة تقريباً.

2- في حالة تغيير Load Resistance فإن A_1 تتغير كما في CS Stage ، وكذلك في حالة Feedback فإن الـ gain يصبح أقل حساسية للتغير في الـ load Resistance.

3- الـ "Feedback" يحسن من الـ "linearity" الخاصة بالنظام ويقلل من تأثير التغير في الـ "Signal Amplitude".

Example :-

⇒ Identify the four components of the feedback system. Assume $\lambda = 0$, $R_1 + R_2 \gg R_D$.



1- The forward system : M_1, R_D.

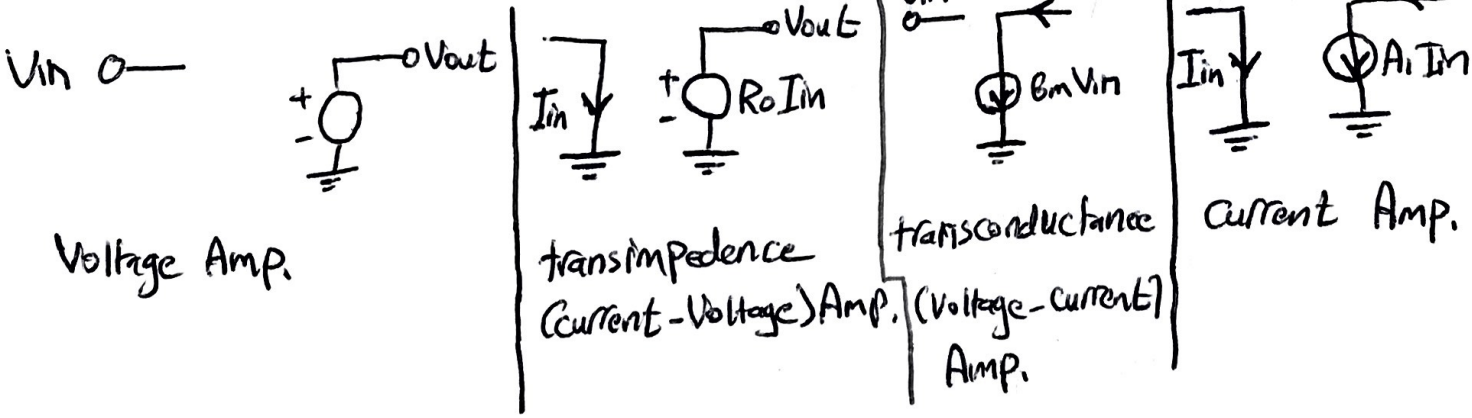
2- Comparison Mechanism : M_1.

3- Feedback Network : R_1, R_2.

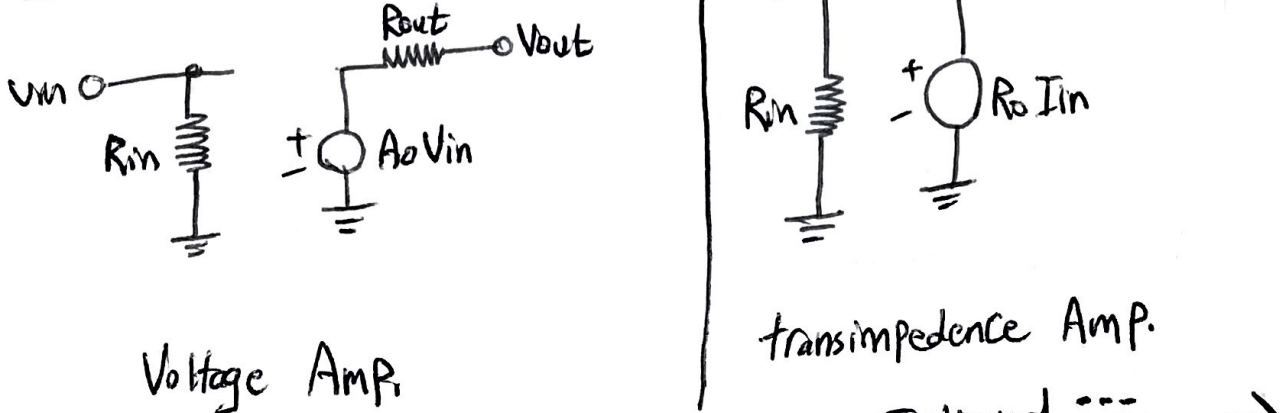
4- Sense Mechanism : R_1, R_2.

Simple Amplifier Models :-

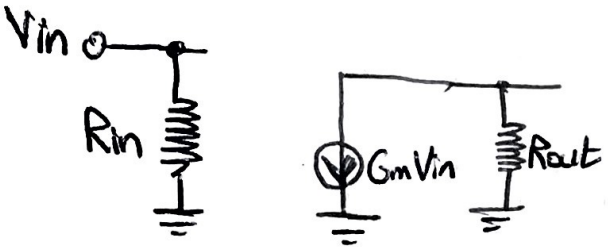
1- Ideal Models :-



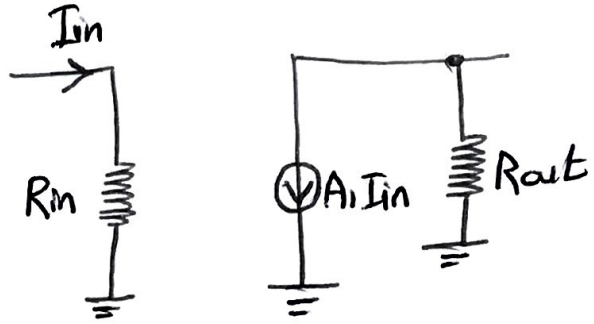
2- Realistic Models :-



Continued ⟶ 2

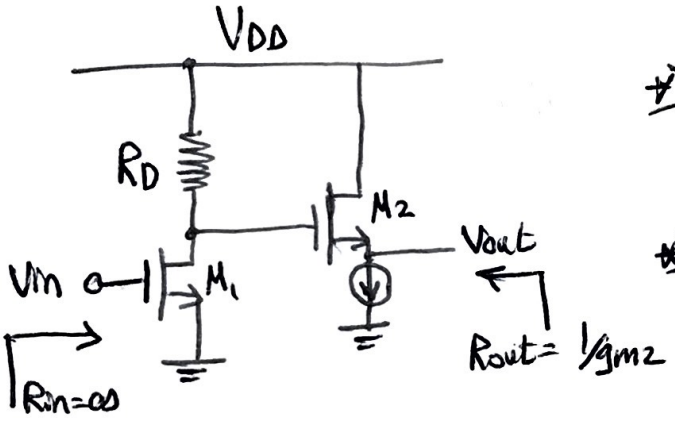


transconductance Amp.



current Amp.

Example of a Voltage Amp. Circuits—

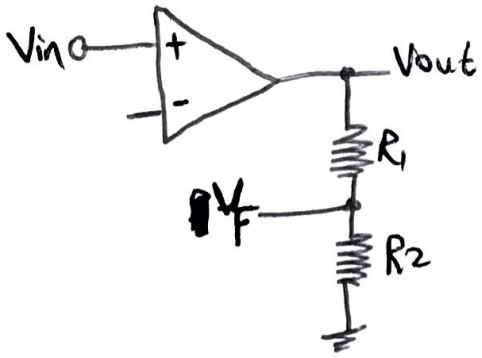


*) high input impedence such as the Voltemeter.

*) low output impedence such as the Voltage source.

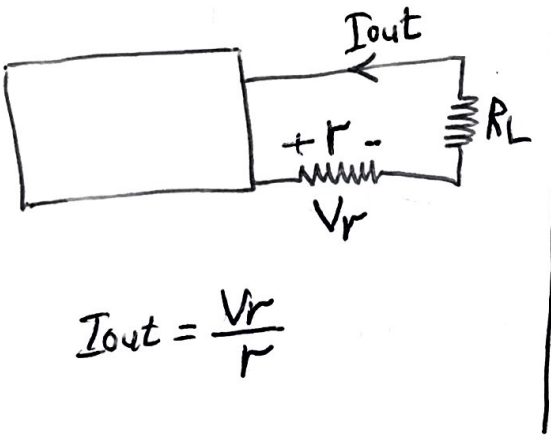
Sense and Return Techniques :—

i- Measure Voltage :- We can use two Resistors R_1 and R_2, and thrier Value (R_1+R_2) must be very large so that A_1 isn't affected.



$$V_{out} = \frac{R_1+R_2}{R_2} \cdot V_F$$

2- Measure current :- a small resistor replaced in serrese with the load, and by measure the voltage drop across it then we find the current passing through the load R_L.

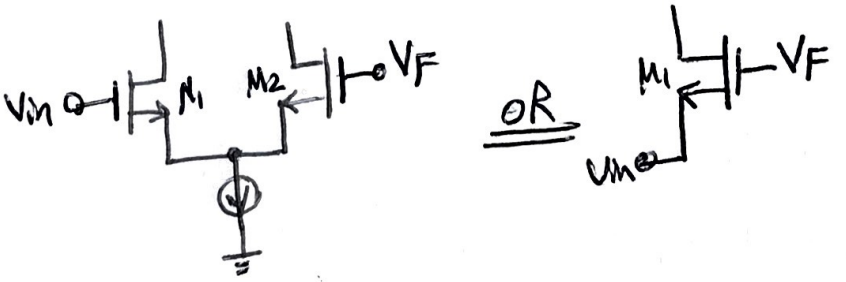


$$I_{out} = \frac{V_r}{r}$$

$$I_{out} = \frac{V_F}{R_S}$$

3- Addition Method :- to add (sum) two voltages, we can use the following circuit :-

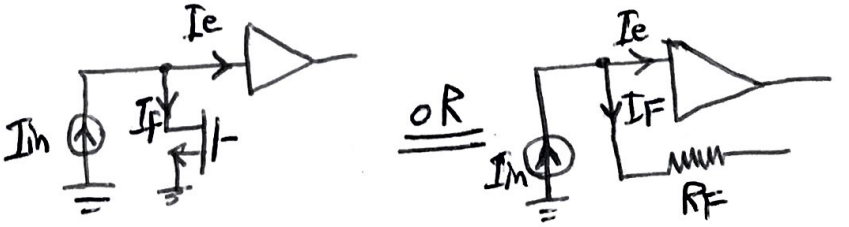
(Voltage)



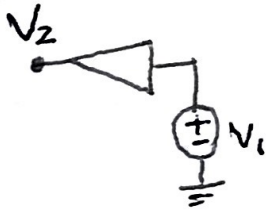
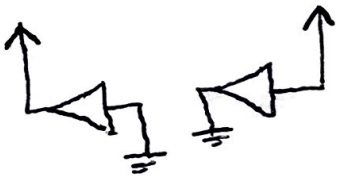
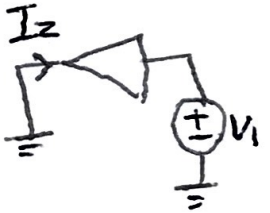
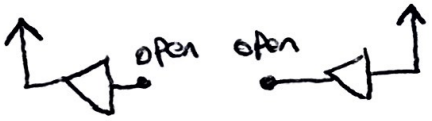
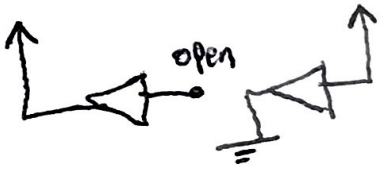
$$V_e = V_{in} - V_F$$

4- Addition Method :-

(current)

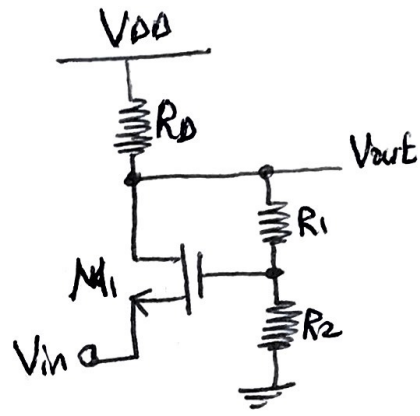


$$I_e = I_{in} - I_F$$

Topology	Closed-loop Parameters	Finding A_1	Finding k
V-V	$A_F = \frac{A_1}{1+kA_1}$ $R_{iF} = R_i(1+kA_1)$ $R_{oF} = \frac{R_o}{1+kA_1}$		 $k = \frac{V_2}{V_1}$
V-I	$A_F = \frac{A_1}{1+kA_1}$ $R_{iF} = \frac{R_i}{1+kA_1}$ $R_{oF} = \frac{R_o}{1+kA_1}$		 $k = \frac{I_2}{V_1}$
I-V	$A_F = \frac{A_1}{1+kA_1}$ $R_{iF} = R_i(1+kA_1)$ $R_{oF} = R_o(1+kA_1)$		 $k = \frac{V_2}{I_1}$
I-I	$A_F = \frac{A_1}{1+kA_1}$ $R_{iF} = \frac{R_i}{1+kA_1}$, $R_{oF} = R_o(1+kA_1)$		 $k = \frac{I_2}{I_1}$

Q/ 12.25 e-

- $R_1 + R_2 \gg R_D$
- Assume $\lambda = 0$
- Compute closed-loop gain and I/O impedences

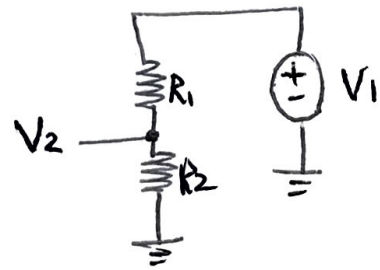


Solution:-

$$A_F = \frac{A_1}{1 + kA_1}$$

$$A_1 = A_v \text{ (open-loop)} = \frac{V_{out}}{V_{in}} = g_m R_D$$

to find k:-



$$V_2 = \frac{R_2}{R_1 + R_2} \cdot V_1$$

$$k = \frac{V_2}{V_1} = \frac{R_2}{R_1 + R_2}$$

then,

$$A_F = \frac{g_m R_D}{1 + \frac{g_m R_D R_2}{R_1 + R_2}}$$

$$R_{in,\ open\ loop} = \frac{1}{g_{m1}} \quad , \quad R_{out,\ open\ loop} = R_D$$

$$R_{IF} = \frac{1}{g_{m1}} \left(1 + g_m R_D \frac{R_2}{R_1 + R_2}\right)$$

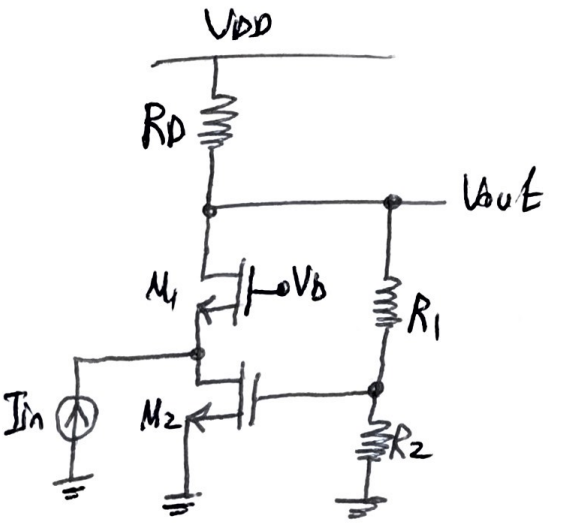
$$R_{OF} = \frac{R_D}{1 + \frac{g_m R_D R_2}{R_1 + R_2}}$$

From the table

Q/12.33 :- - $R_1 + R_2$ is very large

- Assume $\lambda = 0$.
- Compute the closed-loop gain and I/o impedances.

solution :-

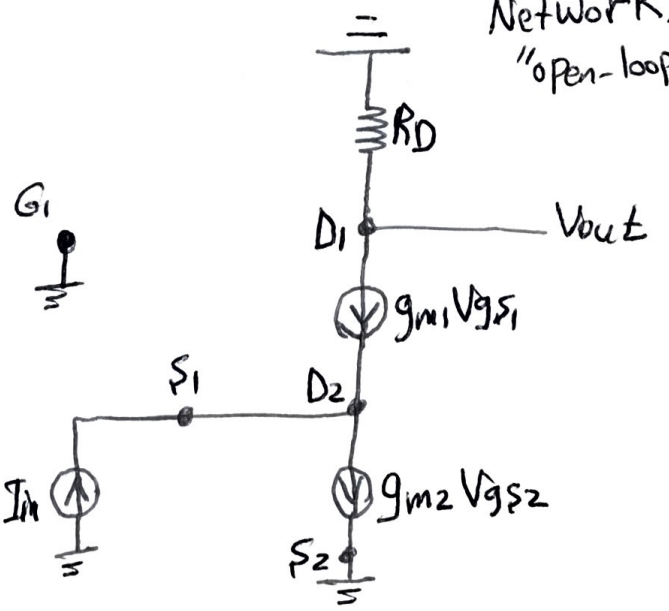


this circuit is V-I
- feedback
- input

So, $A_F = \dfrac{A_1}{1 + K A_1}$

$A_1 = A(\text{open-loop}) = \dfrac{V_{out}}{I_{in}}$

* to find it draw the small signal model :- (without feedback Network) "open-loop"



$I_{in} = -g_{m1} V_{gs1} + g_{m2} V_{gs2}$

but $\boxed{V_{gs2} = \text{Zero}}$

and $g_{m1} V_{gs1} = \dfrac{V_{out}}{R_D}$

then, $I_{in} = \dfrac{V_{out}}{R_D}$

$$\boxed{\frac{V_{out}}{I_{in}} = A_1 = R_D}$$

Now, we need to find K --- continued

$K = \frac{I_2}{V_1}$ from table While: $I_2 = I_{in}$

$V_1 = V_{out}$

but $I_{in} = g_{m2} V_{gs2}$

and $V_{gs2} = \frac{R_2}{R_1 + R_2} \cdot V_1$

$$I_{in} = g_{m2} \cdot \frac{R_2}{R_1 + R_2} \cdot V_1 \Rightarrow \boxed{K = \frac{I_2}{V_1} = g_{m2} \cdot \frac{R_2}{R_1 + R_2}}$$

$$\boxed{A_F = \frac{A_1}{1 + K A_1} = \frac{R_D}{1 + R_D g_{m2} \cdot \frac{R_2}{R_1 + R_2}}}$$

to find I/O impedences,

$\boxed{R_{in,\,open\,loop} = \frac{1}{g_{m1}}}$ and $\boxed{R_{out,\,open\,loop} = R_D}$

then From the table

$$\boxed{R_{iF} = \frac{R_{in,\,open\,loop}}{1 + K A_1} = \frac{1/g_{m1}}{1 + R_D \cdot g_{m2} \cdot \frac{R_2}{R_1 + R_2}}}$$

$$\boxed{R_{oF} = \frac{R_{out,\,open\,loop}}{1 + K A_1} = \frac{R_D}{1 + R_D \cdot g_{m2} \cdot \frac{R_2}{R_1 + R_2}}}$$