* Field Effect transistor Amplifiers (FET-Amp.)

14-10-2018

* advantage of Field Effect Transi. over BJT:-

① small size.

② High Input Impedance.

③ low power dissipation.

* dis advantage $g_{m(BJT)} \gg g_{m(FET)} \Rightarrow A_{v(BJT)} \gg A_{v(FET)}$

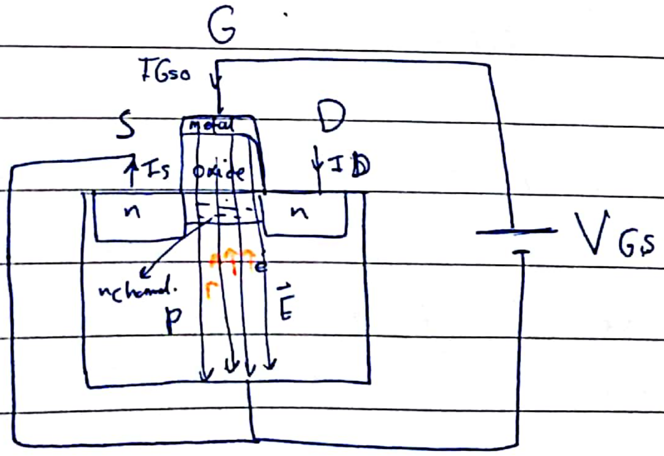
Types of field effect trans.

① MOSFET : Metal-oxide semiconductor FET.

- ↳ n-channel (NMOS FET). → enhancement mode / → depletion mode.
- ↳ p-channel (PMOS FET). → " " / → " "

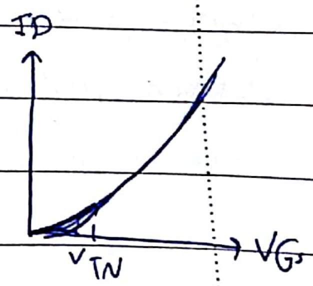
② JFET.

* NMOSFET :



If $V_{GS} > V_{TN} \Rightarrow$ n-channel $\longrightarrow I_D > 0.$

$I_G = 0, \; I_D = I_S.$



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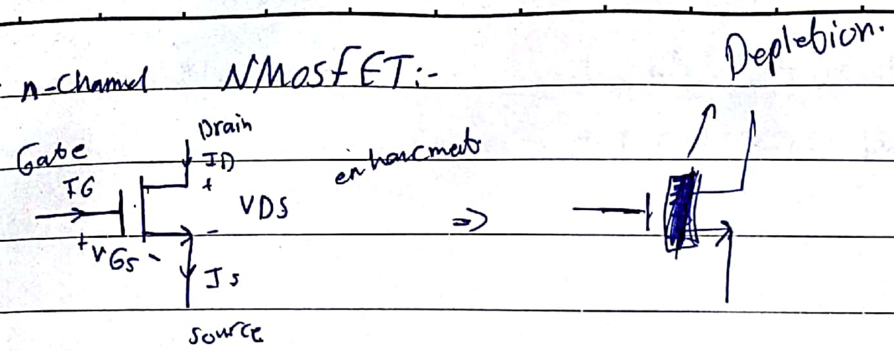
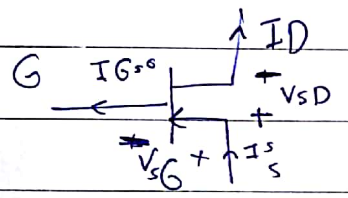
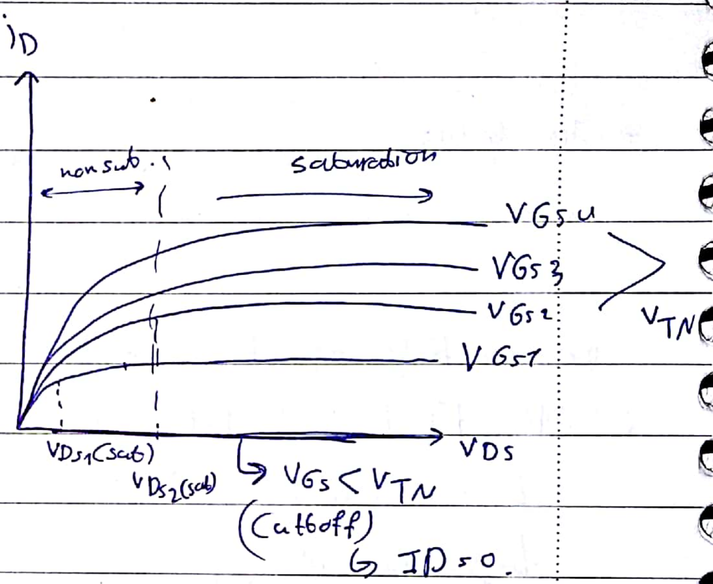
* n-channel NMOSFET:-



VGS ← IB ↓~

* p-MosFet





4 modes of operation.

* ① saturation mode (VDS > VDS(sat)). ⟹ (Amp).

② non-saturation mode ⟹ (switches & logic gates).

③ cutoff. ⟹

* $V_{DS(sat)} = V_{GS} - V_{TN}$.

* Basic Configurations:- for (FET)

① common Source. CS.

② common Drain CD.

③ common Gate CG.

* Analysis of FET Amp.

(*) Dc analysis ⇒ Qpoint points (I_{DQ}, V_{GSQ}, V_{DSQ}), Dc load line ($I_D \propto V_{DS}$).

(*) Ac analysis ⇒ A_v, A_i, R_i, R_o.

* Dc analysis:-

* capacitors open ckt.
* AC sources ⇒ Kill all Ac sources.

⇒ NMOSFET

* Saturation mode
* $V_{DS} > V_{DS(sat)}$
* $I_D = K_n(V_{GSQ} - V_{TN})^2$
* $V_{DS(sat)} = V_{GSQ} - V_{TN}$.

* Non saturation

$V_{DS} < V_{DS(sat)}$

$I_D = K_n(2(V_{GS} - V_{TN}) V_{DS} - V_{DS}^2]$

pMOSFET.

* Saturation mode.
* $V_{SD} > V_{SD(sat)}$.
* $I_D = K_p(V_{SGQ} + V_{TP})^2$

$V_{SD(sat)} = V_{SGQ} + V_{TP}$.

* Non saturation.

$V_{SD} < V_{SD(sat)}$.

$I_D = K_p(2(V_{SG} + V_{TP}) V_{SD} - V_{SD}^2]$

* K_n oR K_p ⇒ conduction parameter. (A/V^2).

$V_{TN} > 0$, $V_{TP} < 0$ ⇒ enhancment.

$V_{TP} > 0$
$V_{TN} < 0$ } depletion.

N O T E B O O K

Finding Mode of operation:-

① Assume saturation mode.

Inputloop ⇒ find V_{GS} ⇒ If ($V_{GS} < V_{TN}$) Then cutoff.

↳ $I_D = K_n(V_{GS} - V_{TN})^2$

↳ output loop : find V_{DS}.

Check If $V_{DS} > V_{DS(sat)}$ ⇒ then saturation mode.

other wise:- non-saturation mode.

Input loop:- V_{GS}

$I_D = K_n(2(V_{GS} - V_{TN})V_{DS} - V_{DS}^2)$.

output loop : I_D & V_{DS}.

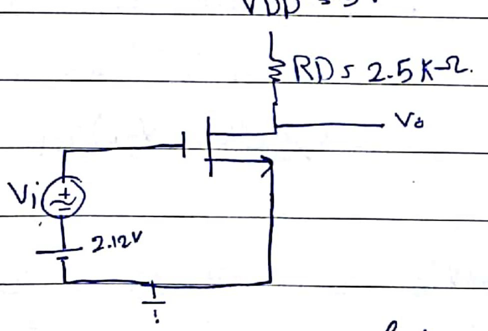
} I_D & V_{DS}.

21-10-2018.

NMOSFET.

Ex:-

CS without Rs.

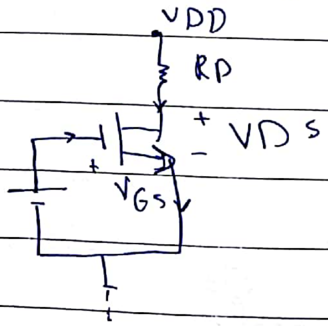


Given : $V_{TN} = 1V$, $K_n = 0.8 mA/V^2$

$\lambda = 0.02 V^{-1}$

find $A_V = \frac{V_o}{V_i}$

* DC analysis



$I_D = I_S$.

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Input loop :=)

$V_{GS} = 2.12\,V > V_{TN}$ Not cuttoff mode.

$I_D = K_n (V_{GS} - V_{TN})^2 = 1\,mA$.

(K_n = 0.8, V_{GS} = 2.12, V_{TN} = 1)

output loop:-

$-V_{DD} + I_D R_D + V_{DS} = 0$

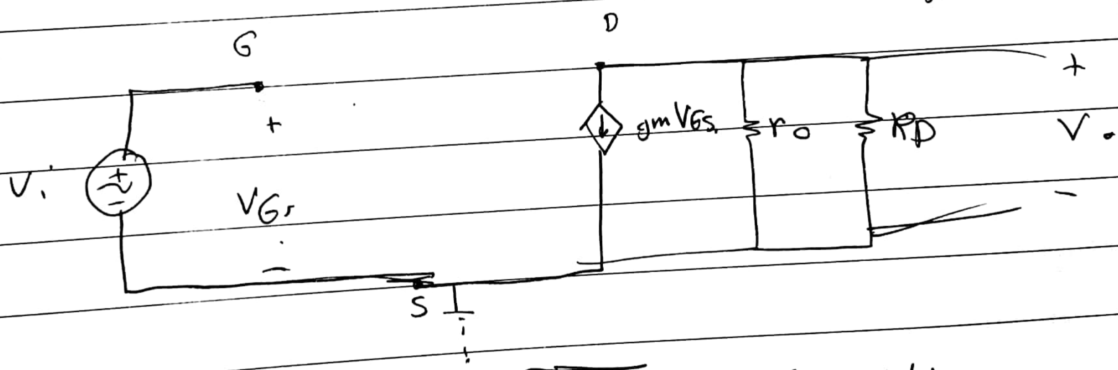
$V_{DS} = 2.5\,V$

$V_{DS} > V_{DS(sat)}$ yes, saturation mode.

($V_{DS(sat)} = V_{GS} - V_{TN}$)

Ac analysis.

early effect ← λ is

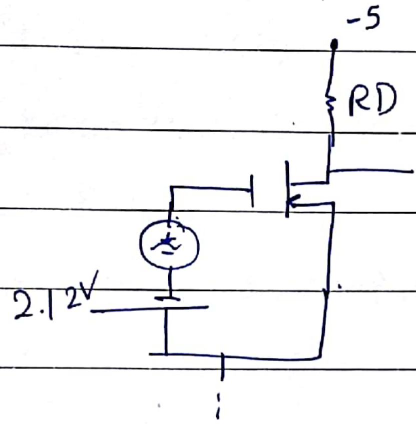


$g_m = 2K_n(V_{GS} - V_{TN}) = 2\sqrt{K_n I_{DQ}} = 1.79\,mA/V$.

$r_o = \frac{1}{\lambda I_{DQ}} = 50\,K\Omega$.

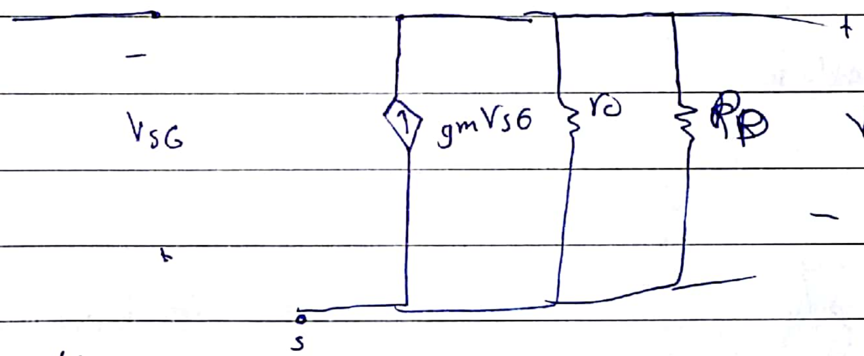
$V_o = -g_m V_{GS} (r_o \| R_D)$ (V_{GS} → V_i) $= A_{vs} - g_m (r_o \| R_D) = -4.26$

Ex:- For the previous example use PMOSFET instead NMOSFET, then Find Av.



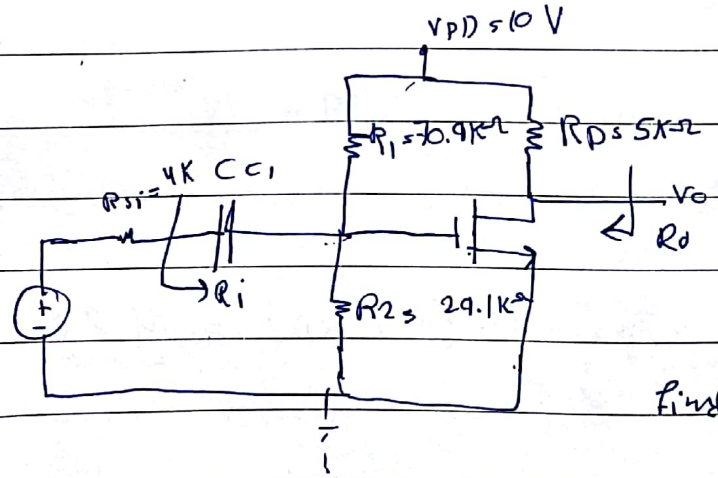
هون بنحطه نفس دز gain.

in Ac



Av = -4.26

Ex:-



Given $V_{TN} = 1.5V$,

$K_n = 0.5m\ A/V^2$

$\lambda = 0.01V^{-1}$

Find ① Q-point values.

② Dc load line.

③ Av

④ Ri

⑤ Ro.

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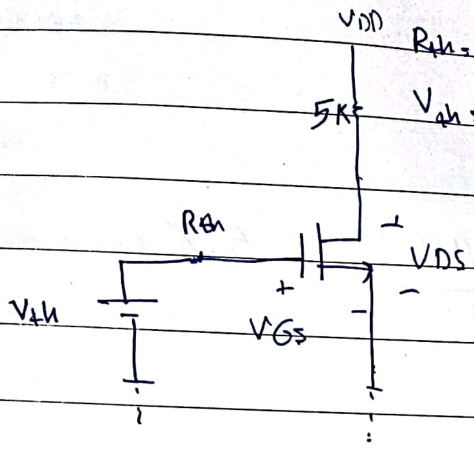
Dc analysis:-



$R_{th} = R_1 || R_2$

$V_{th} = VDD \frac{R_2}{R_1 + R_2}$

Input loop : VGs.

$V_{GS} = V_{TN} = 2.41$ V

outploop

$I_D = K_n (V_{GS} - V_{TN})^2 = 1mA.$

VDS ⇒ $-VDD + R_D I_D + V_{DS} = 0.$

$V_{DS} = 5$ V $> V_{GS} - V_{TN}$ yes.(sat mode).

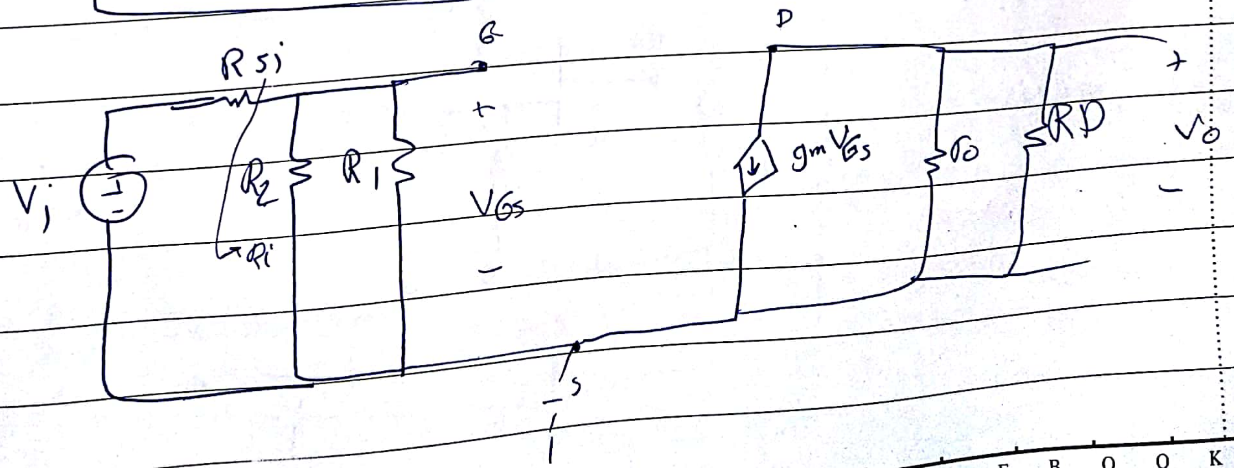
① Qpoint Values

$V_{GSQ} = 2.41$, $I_{DQ} = 1mA$, $V_{DSQ} = 5$ V.

② Dc load line.

$$I_D = \frac{VDD}{RD} - \frac{V_{DS}}{R_D}$$

AC analysis:-



N O T E B O O K

$V_o = -g_m V_{GS} (r_o \| R_D)$

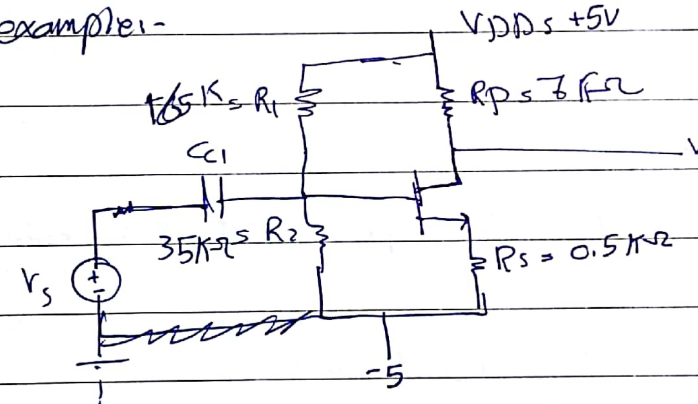
$V_{gs} = \dfrac{v_s (R_1 \| R_2)}{R_{si} + (R_1 \| R_2)}$

$A_v = \dfrac{-g_m (r_o \| R_D)(R_1 \| R_2)}{R_{si} + (R_1 \| R_2))} = -5.62.$

(4) $R_i = R_1 // R_2 = 20.6 K\Omega.$

(5) $R_o = r_o // R_D = 4.76 K\Omega$

example:-



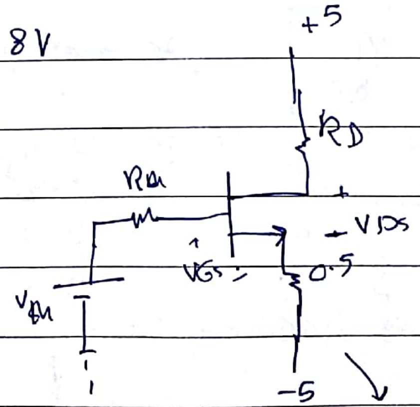
Given :- $K_n = 1 mA/V^2$

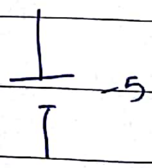
$\lambda = 0 V^{-1}$

$V_{TN} = 0.8V$

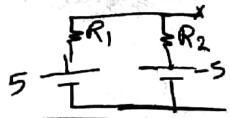
find $A_v = \dfrac{V_o}{V_s}$

Dc analysis:-

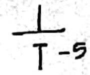




Subject



⇐ Vth.



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$R_{th} = R_1 // R_2 = 28.4 k\Omega$

$V_{th} = \frac{V_{th} - 5}{R_1} + \frac{V_{th} - (-5)}{R_2} = -3.25 V.$

VGS ⇒ Input loop

$-V_{th} + V_{GS} + I_D R_S - 5 = 0$ --- ①

$I_D = K_n (V_{GS} - V_{TN})^2$ ---- ②

Sub ① in ②

↳ $V_{GSQ}^2 + 0.4 V_{GS} - 2.86 = 0$

$V_{GS} = 1.5$ or ~~$-1.9 V$~~.

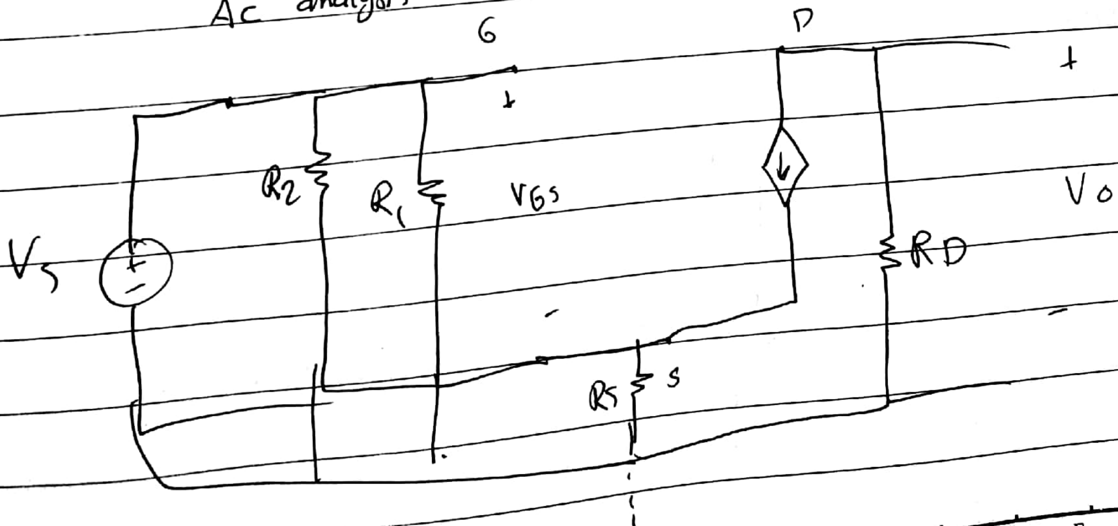
V_{TN} ...

$V_{GS} = 1.5 V$

$I_{DQ} = 0.5 mA.$

output loop ⇒ $V_{DSQ} =$ ☐ V.

Ac analysis



$v_o = -g_m V_{GS} R_D$ --- ①

$-V_s + V_{GS} + R_S\, g_m V_{GS} = 0$

~~$V_{GS} = V_s / 1 + g_m R_S$~~ --- ②

$V_{GS} = \dfrac{V_s}{1 + g_m R_S}$

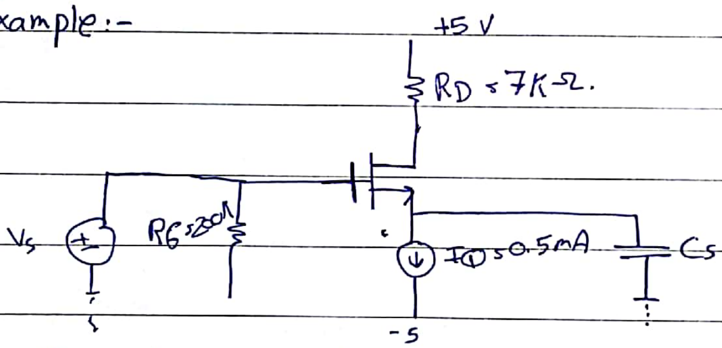
~~$A_v = \frac{V_o}{V_s} = -g_m R_S$~~

$A_v = \dfrac{v_o}{v_s} = \dfrac{-g_m R_D}{1 + g_m R_S}$

$= -5.8$

~~$V_{GS}\, g_m\, R_D$~~

Example:-



n-channel common source.

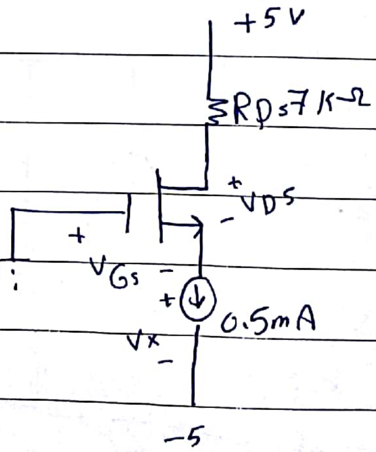
Given $K_n = 1\,mA/V^2$

$V_{TN} = 0.8\,V$

$\lambda = 0$

Find : $A_v = \dfrac{V_o}{V_s}$

* DC analysis:-



$I_D = K_n (V_{GS} - V_{TN})^2$ (0.5mA, 1 mA/V^2, 0.8)

$V_{GSQ} = 1.51\,V.$

V_x

$\Rightarrow V_{GS} + V_x - 5 = 0$

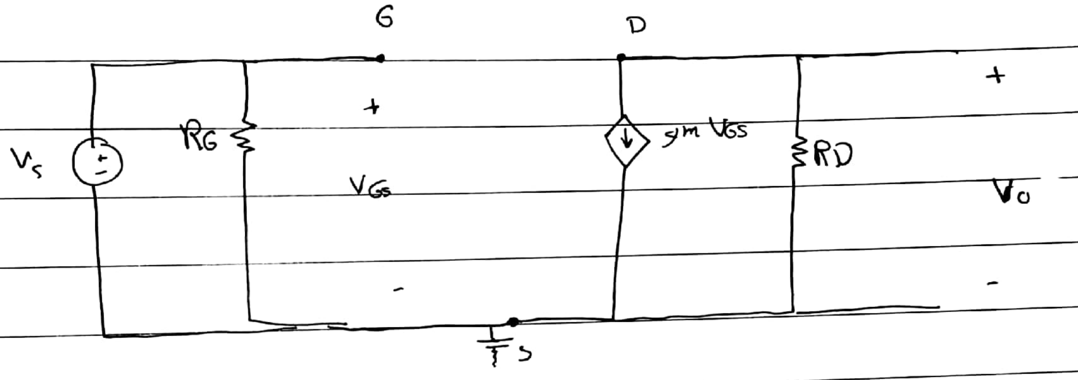
$1.51 + V_x - 5 = 0$

$V_x = 3.49\,V.$

output loop $-5 + R_D I_D + V_{DS} + V_X - 5 = 0$

$V_{DS} = \boxed{3V}$

Ac analysis:-



$A_V = \frac{V_o}{V_s}$

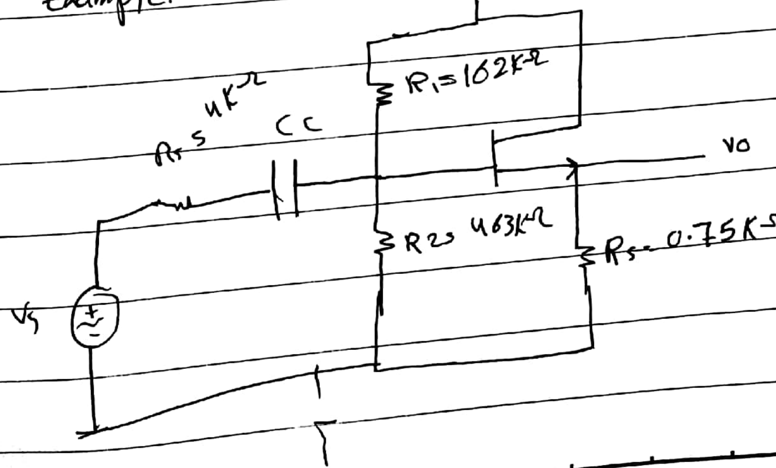
$V_o = -g_m V_{GS} \cdot R_D \Rightarrow A_V = -g_m R_D = -10.$

$V_{gs} = V_s$

$g_m = 2\sqrt{I_{DQ} K_n} = 1.414 mA/V.$

$R_i = R_G$, $R_o = R_D.$

Example:



Given $V_{TN} = 1.5V.$

$K_n = 4 mA/V^2$

$\lambda = 0.01 V^{-1}$

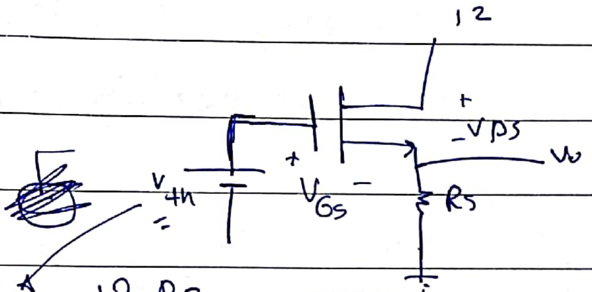
find ① A_V

② R_i

③ R_o.

DC

$R_{th} = R_1 // R_2 = 120 K\Omega$.



$V_{th} = \frac{12 R_2}{R_1 + R_2} = 8.89 V$

Input loop ⇒ $-8.89 + V_{GS} + R_S I_D = 0$ --- ①.

$I_D = K_n (V_{GS} - V_{TN})^2$ --- ②.

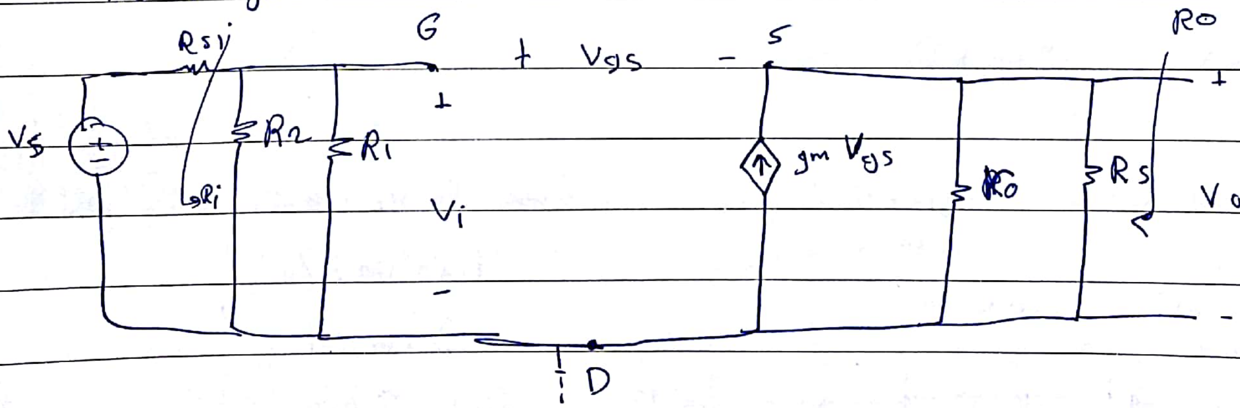
Solve ① & ②

$V_{GS}^2 - 2.67 V_{GS} - 6.713 = 0$

$V_{GS} = 2.91 V$ OR ~~$-6.245 V$~~

$I_{DQ} = 8 mA$.

Ac analysis:-



$g_m = 2\sqrt{K_n I_{DQ}} = 11.28 mA/V$

$r_o = \frac{1}{\lambda I_{DQ}} = 12.5 K\Omega$.

$A_{vs} = \frac{V_o}{V_s} =$

$V_o = g_m V_{gs} (r_o // R_s)$

$V_{gs} = V_i - V_o$

$V_{gs} = V_s \frac{R_1 // R_2}{R_1 // R_2 + R_s} - V_o = ?$

Solve ① & ②

$A_{vs} = \frac{g_m (r_o // R_s)(R_1 // R_2)}{[(R_1 // R_2) + R_{si}] [1 + g_m (r_o // R_s)]} = 0.86$

* $R_i = R_1 // R_2 = 120K\Omega$.

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

↳ KCL at S: ⇒ $I_x + g_m V_{gs} = \frac{V_x}{r_o // R_s}$

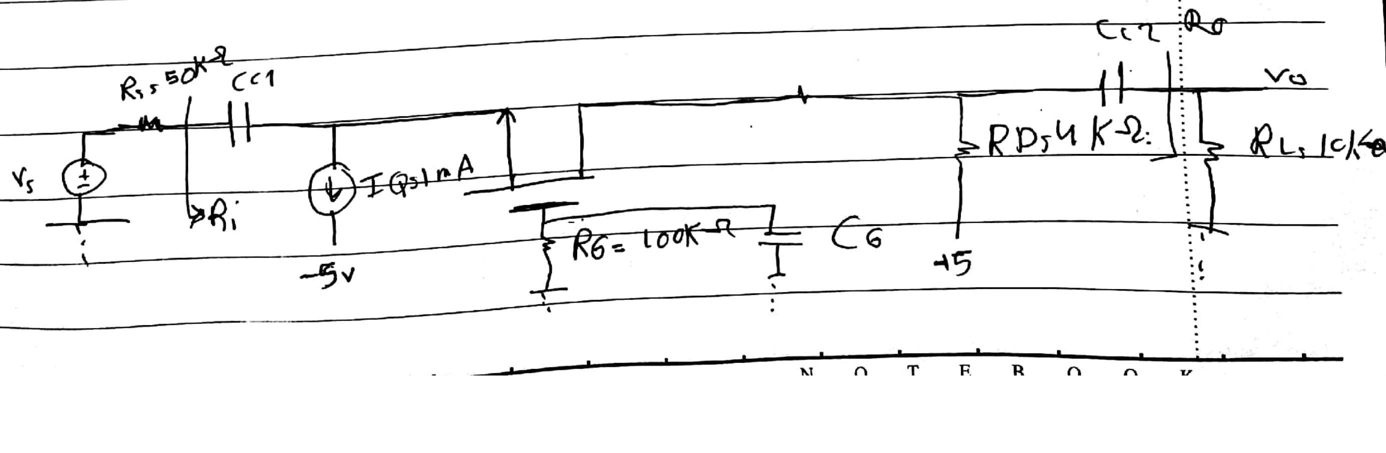
$V_{gs} = -V_x$

$I_x = V_x \left[g_m + \frac{1}{r_o // R_s} \right]$.

$R_o = \frac{V_x}{I_x} = \frac{1}{g_m + \frac{1}{r_o // R_s}} = 78.8\ \Omega$.

H.W

Example : common Gate.



Given $V_{TN} = 1V$

$K_n = 1mA/V^2$

$\lambda = 0$

Find ① A_v =

② R_i =

③ R_o =

DC analysis:-

$I_{DQ} = 1mA$.

$V_{GSQ} = 2V$.

AC analysis:-

$g_m = 2m/V$

$r_o = \infty$

$A_v = 0.06$

$R_i = 500\Omega$

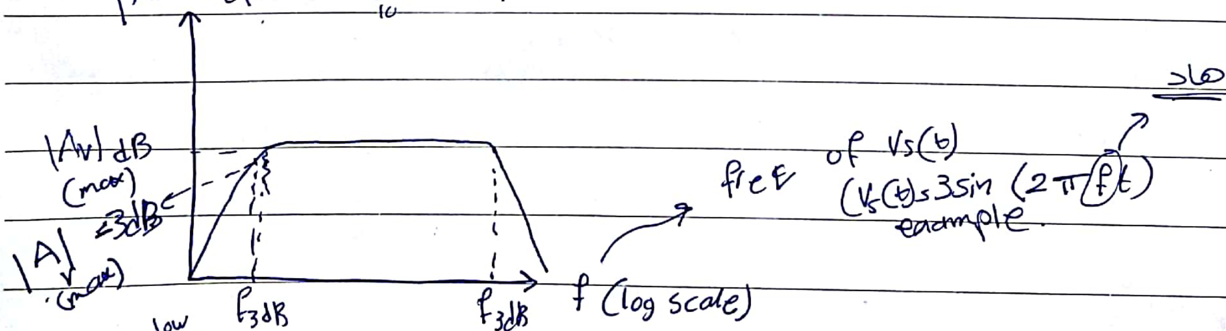
$R_o = 2.86 K\Omega$.

* Frequency Response:- (Transfer function). $T(s) = \frac{S_o(f)}{S_i(f)}$

⇒ Frequency Response for Amp CKT:- $\underset{\sim}{A}(f) = \frac{V_o(f)}{V_i(f)}$.

In General

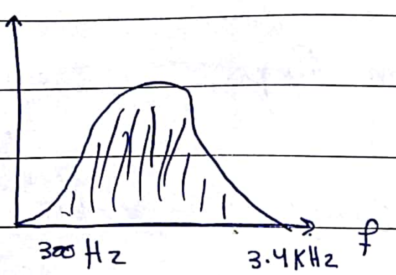
$|A_v(f)|_{dB} = 20\log_{10}|A(f)|$



low 3db freq (f_L)
break point freq
OR
corner freq.

High 3db freq. (f_H)
break point freq. OR
corner freq

* Voice signal



* Band width of Amp. = $f_H - f_L$

كل ما دا BW أكبر أحسن.

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

τ_L → Time constant

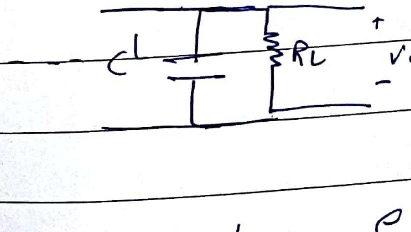
* $\tau_{Low} = R_{eq} * C_{eq}$ for low freq. Range.
* $\tau_{High} = R_{eq} * C_{eq}$ for High freq. Range.

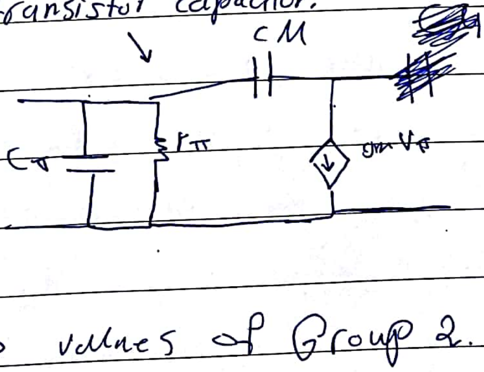
f_L & f_H are due to the capacitors in the Amp CKT. ($Z = \frac{1}{j2\pi fC}$)

* Types of capacitor in Amp. CKT:

① Group 1, Coupling capacitor & Bypass Capacitors.

② Group 2, load capacitors & transistor capacitor.





* values of Group 1 > values of Group 2.

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* any capacitor could be represeted as open CKT, Short CKT OR Impedance.

$$Z_c = \frac{1}{j2\pi fc}$$ based on freq.

* for DC ($f=0$): Group 1 = open CKT, Group 2 = ~~short~~ open CKT.

* for low freq. Rang ($0 < f < f_L$):-
Group 1: Impedance. $= \frac{1}{j2\pi f_c}$
Group 2: open CKT.
$Z_c = \frac{1}{j2\pi fC} = \frac{1}{0} = \infty$

} τ lows Req Ceq.
$f_L = \frac{1}{2\pi\tau_L}$

* for midband freq Range ($f_L < f < f_H$):-
Group 1: short CKT
Group 2: ~~Short~~ open CKT.

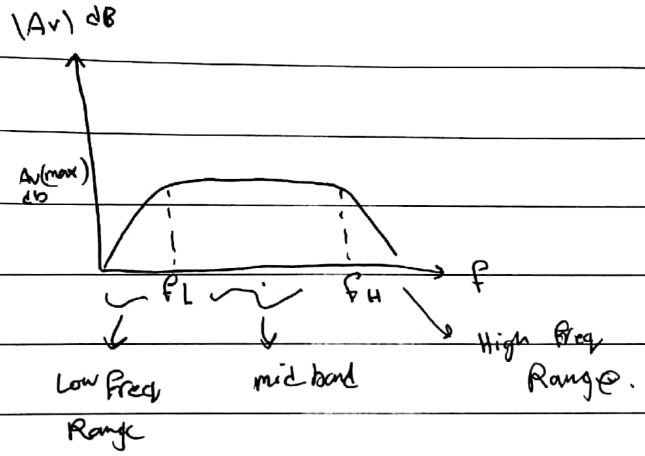
} $|A_{v(max)}|$

* for High freq Range ($f > f_H$):-
Group 1: short CKT
Group 2: $Z = \frac{1}{j2\pi fc}$

} τ_H
$f_H = \frac{1}{2\pi\tau_H}$.

* f_{low} is due to Group 1.
* f_H is " " Group 2.

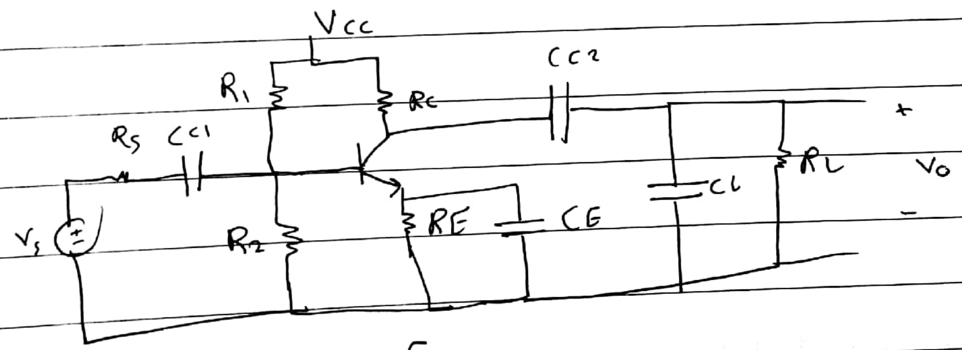
Scanned by CamScanner



$f_{low} = \frac{1}{2\pi \tau_L}$ → $\tau = R_{eq} C_{eq}$

$f_H = \frac{1}{2\pi \tau_H}$ → $\tau = R_{eq} C_{eq}$.

Ex:-



$C_\pi = 5$ nf, $C_\mu = 2$ pf

Draw the equ CKT :-

① dc DC → To find I_{CQ} → r_π, gm

② in the low freq range → $f_L = \frac{1}{2\pi \tau_L}$ → $R_{eq} * C_{eq}$.

③ in the mid band range → $|A_{v(max)}|$

④ in High freq. range. → $f_H = \frac{1}{2\pi \tau_H}$ → $R_{eq} * C_{eq}$

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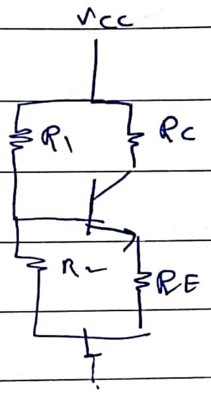
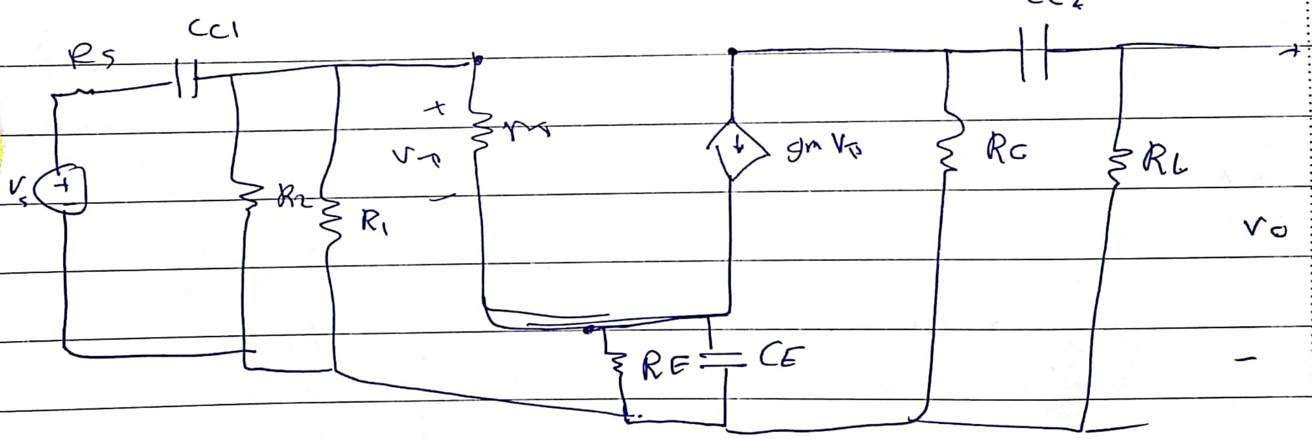
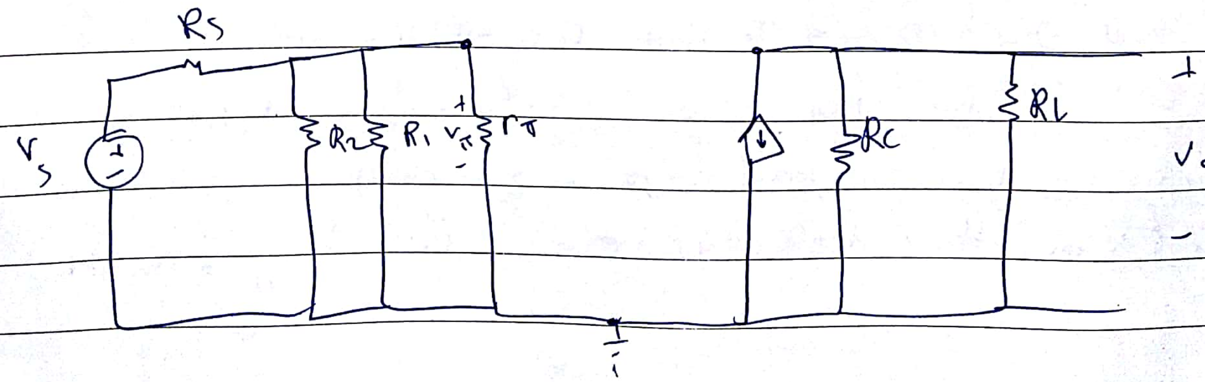
① Dc ($f = 0$ Hz) C_1 & C_2 ⇒ open ckT.



② low freq range.



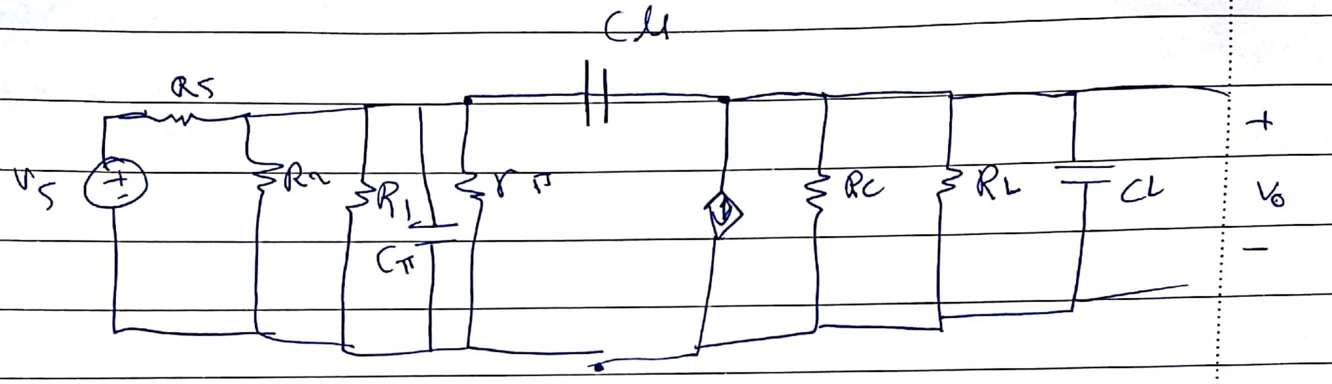
③ Mid band freq Range.



Group 1 => إلها فتحة كبيرة .

Subject   Date   No.

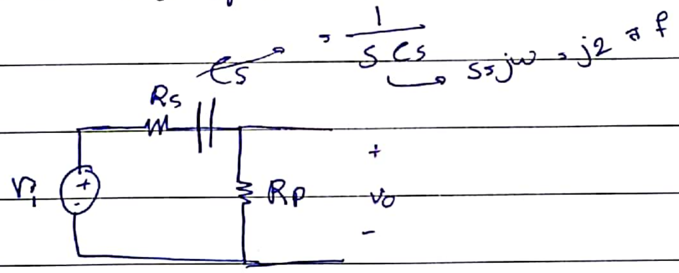
(4) High freq Range.



* $f_L = \frac{1}{2\pi \tau_L}$, $f_H = \frac{1}{2\pi \tau_H}$. why ?

Answer: Consider two special circuits :-

CKT (1)



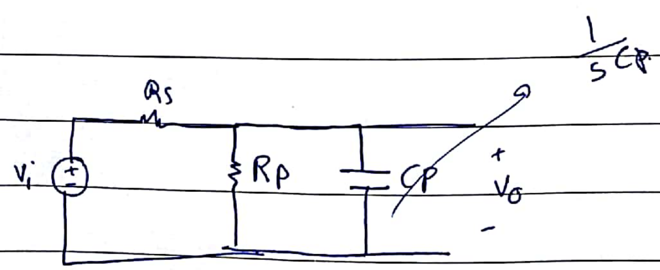
Find transfer function of this circuit:- $T_1(s) = \frac{V_o(s)}{V_i(s)}$

$V_o(s) = V_i(s) * \frac{R_p}{R_p + (R_s + \frac{1}{sC_s})}$

$\tau = (R_p + R_s) C_s$ ← time constant.

$T_1(s) = \frac{R_p}{R_p + R_s} \cdot \frac{s(R_p + R_s)C_s}{1 + s(R_p + R_s)C_s} = \frac{R_p}{R_p + R_s} \cdot \frac{s\tau}{1 + s\tau}$

circuit (2)



$T_2(s) = \frac{V_o(s)}{V_i(s)}$

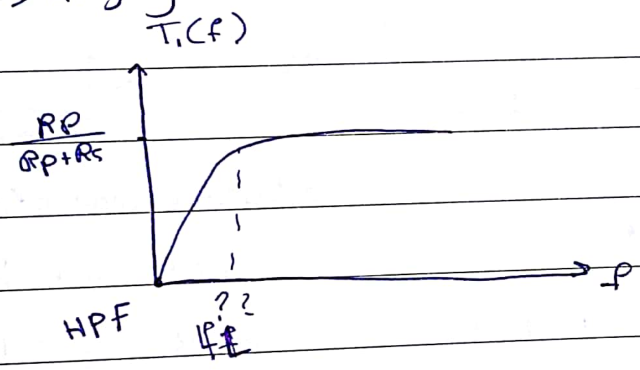
$V_o(s) = V_i(s) \frac{R_p \parallel \frac{1}{sC_p}}{R_s + R_p \parallel \frac{1}{sC_p}}$

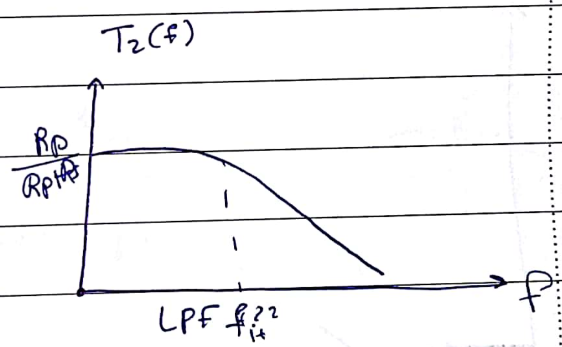
$T(s) = \frac{R_p}{R_p + R_s} \cdot \frac{1}{1 + s(R_p \parallel R_s) C_p} = \frac{R_p}{R_p + R_s} \cdot \frac{1}{1 + s\tau}$

$\tau = (R_p \parallel R_s) C_p$ time constant.

Draw $T_1(s)$ & $T_2(s)$

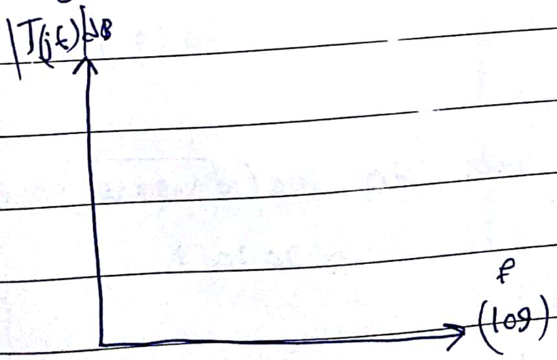
⇒ Roughly:





→ Use the Bode plots:-

Bode plots: it is a simplify Teq. used to Approximitly draw the magnitude & the phase of a transfer function.



Subject

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draw $T_1(s)$ Using Bode plots..

$$T_1(s) = \frac{R_p}{R_p+R_s} \cdot \frac{s\tau}{1+s\tau}$$

$$T_1(jf) = \frac{R_p}{R_p+R_s} \cdot \frac{j2\pi f\tau}{1+j2\pi f\tau}$$

$$X = a+jb$$

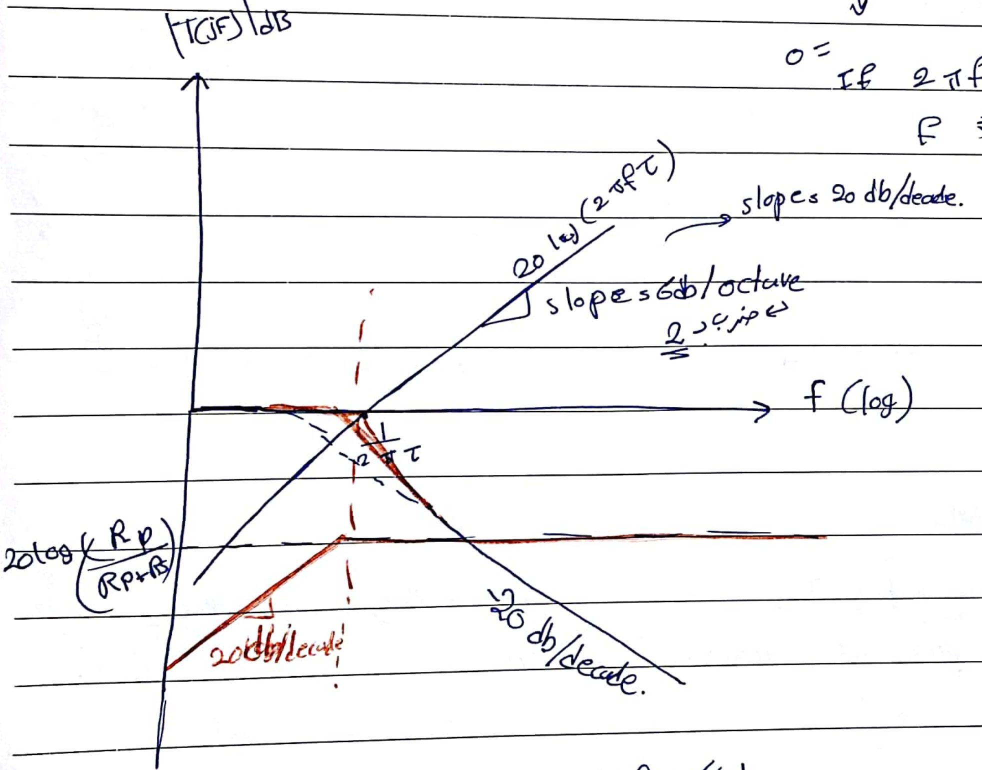
$$|X| = \sqrt{a^2+b^2}$$

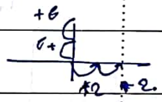
$$|T_1(jf)| = \frac{R_p}{R_p+R_s} \; \frac{2\pi f\tau}{\sqrt{1+(2\pi f\tau)^2}}$$

$$|T_1(jf)| = 20\log\left(\frac{R_p}{R_p+R_s}\right) + 20\log(2\pi f\tau) - 20\log\left(\sqrt{1+(2\pi f\tau)^2}\right)$$

$0 =$ If $2\pi f\tau = 1$

$f \Rightarrow \frac{1}{2\pi\tau}$





octave $= 20\log 2 = 6db$

$= 20\log 4 = 12dB$

$20\log 8 = 18db$

decade

$20\log 10 = 20$

$20\log 100 = 40$

$20\log 1000 = 60$

If $2\pi f\tau \ll 1$

$f \ll \frac{1}{2\pi\tau}$ then $20\log\left(\sqrt{1+(2\pi f\tau)^2}\right) \approx 0$

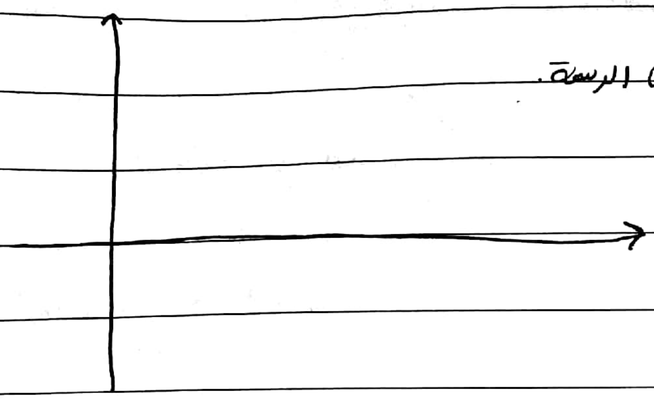
$\approx 20\log 1 = 0$

If $2\pi f\tau \gg 1$

$f \gg \frac{1}{2\pi\tau}$ then $20\log\sqrt{1+(2\pi f\tau)^2}$

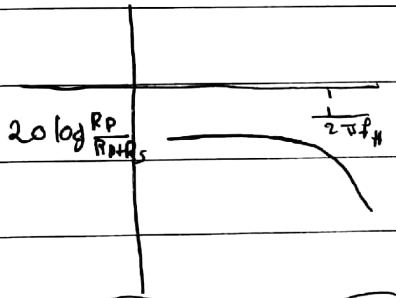
$= 20\log 2\pi f\tau$

N O T E B O O K



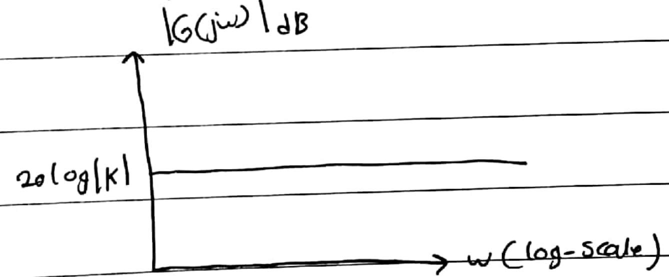
$f_L = \frac{1}{2\pi \tau_L}$ ← من الرسمة.

H.w ⇒ Use Bode plot to Draw $|T_2(jf)|_{dB}$

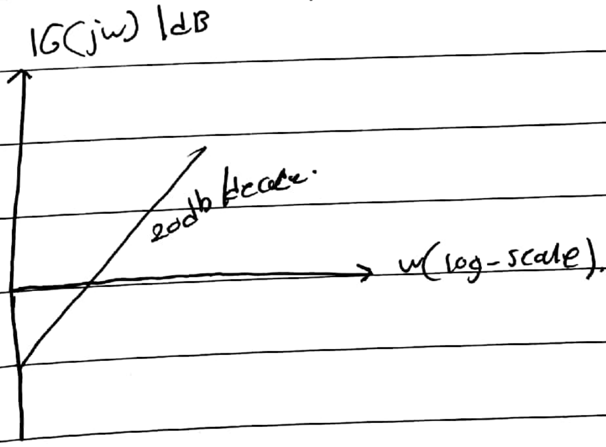


Short Method for Bode plot:-

* $G(j\omega) = K$ ⇒
  (K: constant)



* $G(j\omega) = j\omega$



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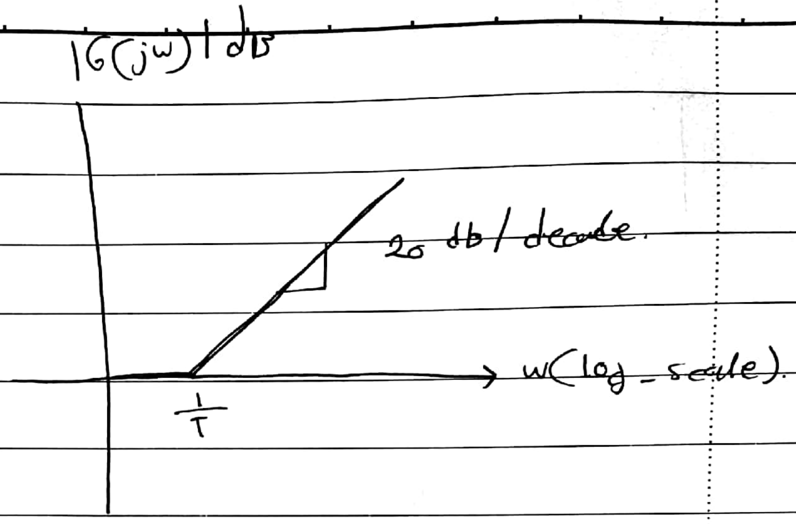
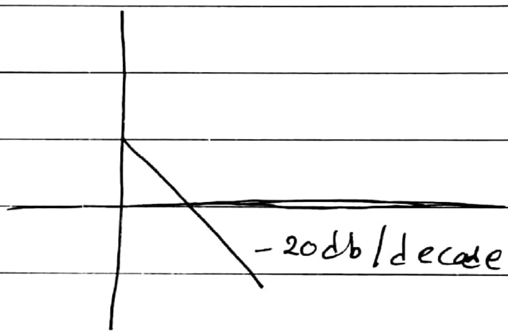
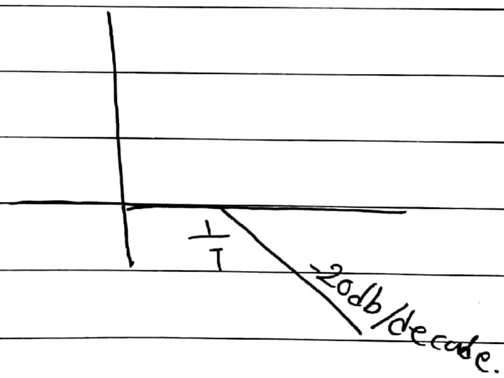
$G(j\omega) = 1 + j\omega T$



$G(j\omega) = \frac{1}{j\omega}$



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



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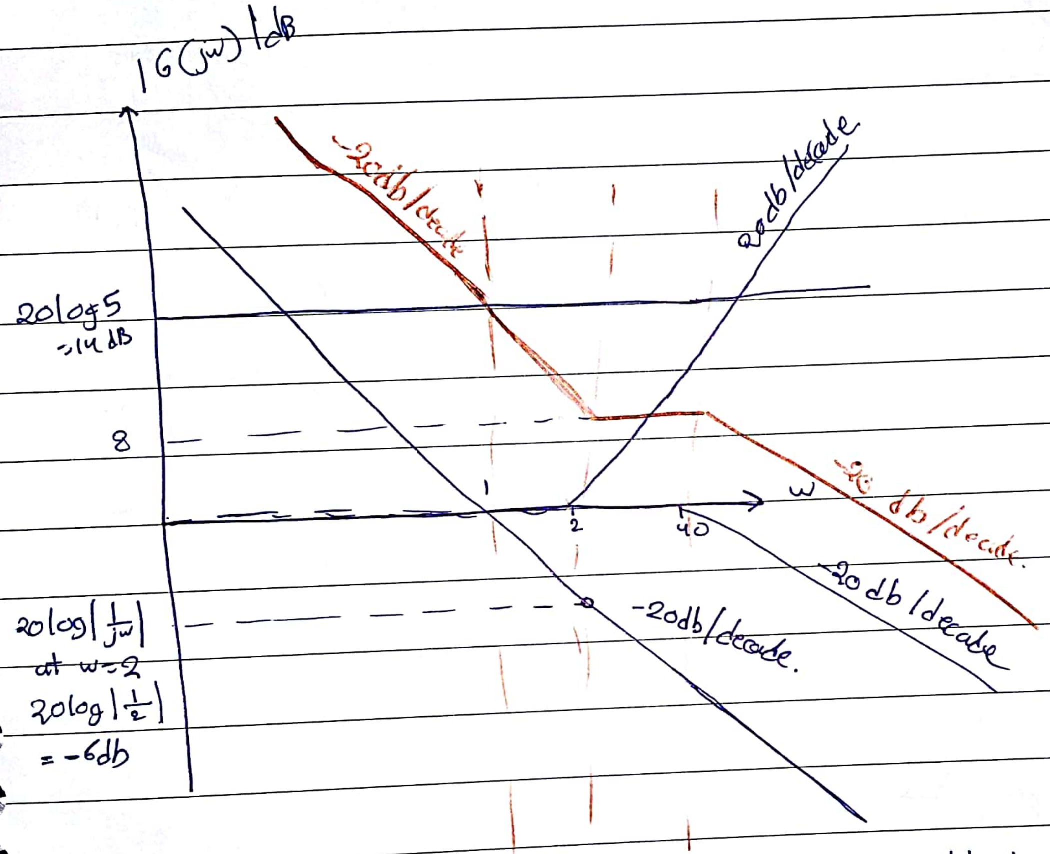
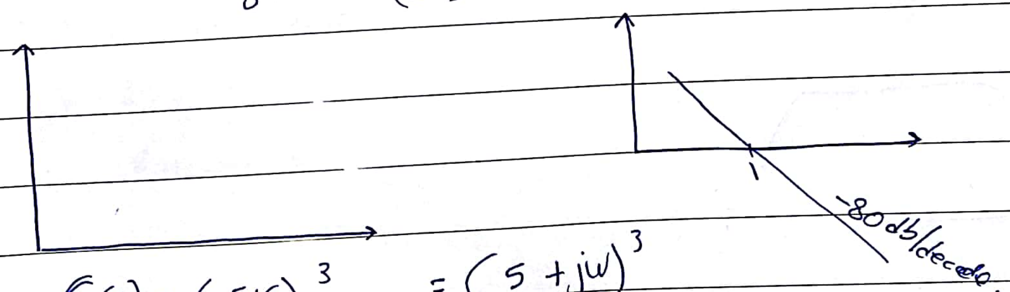
Ex: $G(s) = \frac{100(s+2)}{s(s+40)}$ Plot $|G(j\omega)|_{dB}$.

$G(j\omega) = \frac{100(j\omega+2)}{j\omega(j\omega+40)} = \frac{100 * 2(1+\frac{j\omega}{2})}{j\omega * 40(1+\frac{j\omega}{40})} = 5 * (\frac{1}{j\omega}) * (1+\frac{j\omega}{2}) * \frac{1}{1+\frac{j\omega}{40}}$



Ex (H.W) ⇒ $G(s) = \frac{1}{s^4} = \frac{1}{(j\omega)^4} = 20 * 4 \log\left|\frac{1}{j\omega}\right| = \frac{1}{j\omega} \cdot \frac{1}{j\omega} \cdot \frac{1}{j\omega} \cdot \frac{1}{j\omega}$



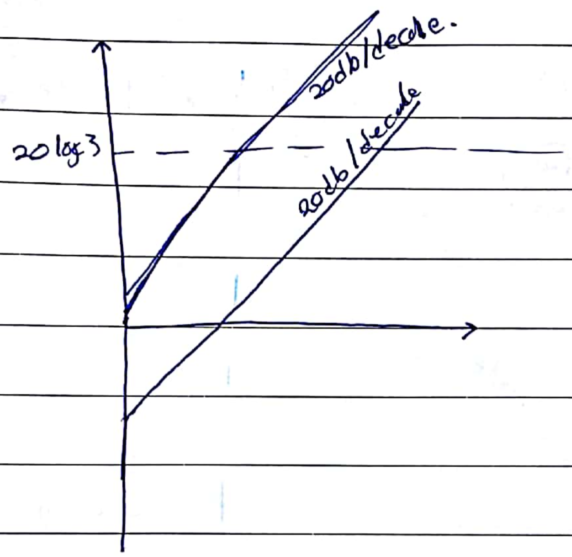
Ex: $G(s) = (5+s)^3 = (5+j\omega)^3$

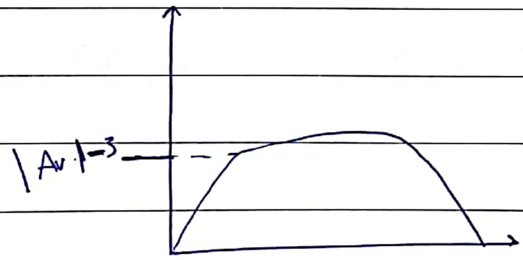
$= (5+j\omega)(5+j\omega)(5+j\omega)$

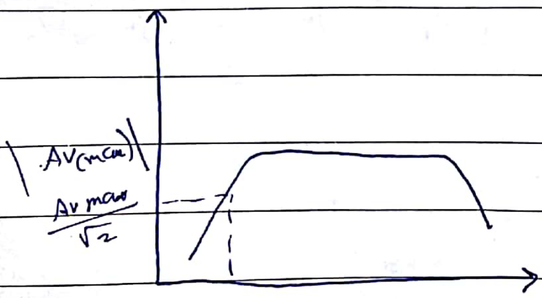
$= 5(1+\frac{j\omega}{5})\, 5(1+\frac{j\omega}{5})\, 5(1+\frac{j\omega}{5}) = 125 (1+\frac{j\omega}{5}) \cdot (1+\frac{j\omega}{5}) \cdot (1+\frac{j\omega}{5})$

NOTEBOOK

Ex:- $G(S) = -3S \Rightarrow -3(j\omega) = -3 * j\omega$





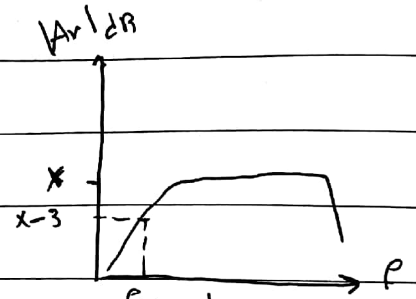


How to find τ

① from a plot.

dB إزامش

$\frac{X}{\sqrt{2}}$



$f_{dB} = \frac{1}{2\pi\tau}$

↓

?

② from a function.

→ simplyfy the function to $T_1(s)$ OR $T_2(s)$

$T_1(s) = K \frac{s\tau}{1+s\tau}$

$T_2(s) = K \frac{1}{1+s\tau}$

example:- $T(s) = \frac{5s}{3+4s}$

Find $\tau = ?$

$= \frac{5}{3} \frac{\frac{3}{4} \cdot \frac{4}{3} s}{(1 + \frac{4}{3} s)}$

$\Rightarrow \frac{5}{4} \frac{\frac{4}{3} s}{1 + \frac{4}{3} s}$

$\tau = \frac{4}{3}$ sec.

③ from a CKT:-

Case 1:-

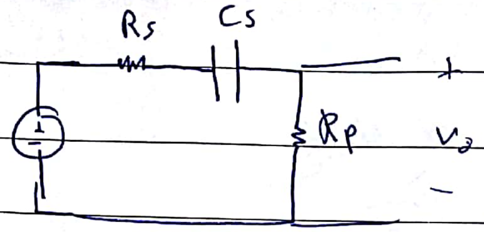
If There is one capacitor.

$\tau = R_{eq} C_{eq}$

↓

R_{th} seen by C

* example.

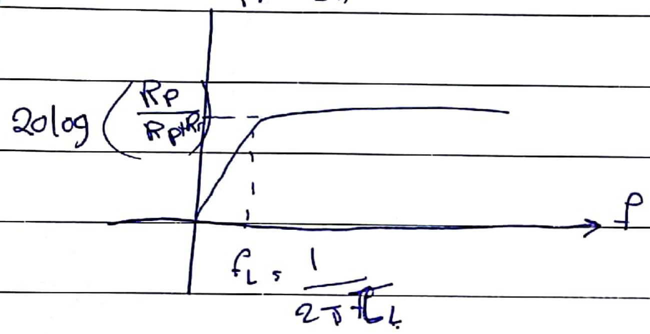


Find τ and draw the freq. Response $|A_v|$

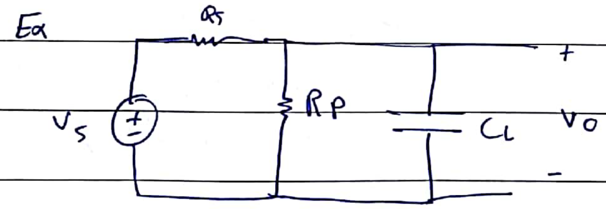
$\tau = R_{eq}\, C_s$

$= (R_s + R_p)\, C_s$

بعوض zero
آو ∞



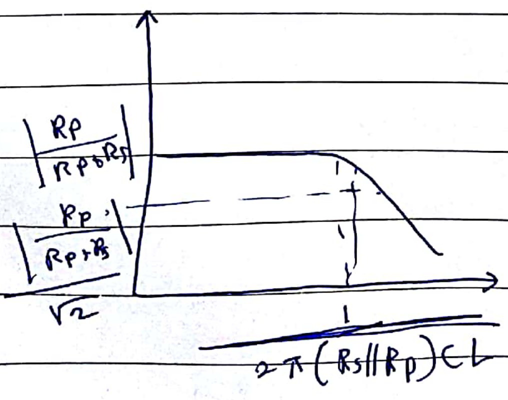
Ex



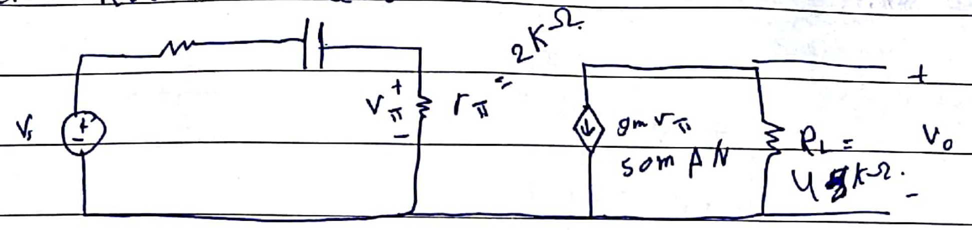
Find τ.

$\tau = R_{eq}\, C_L$

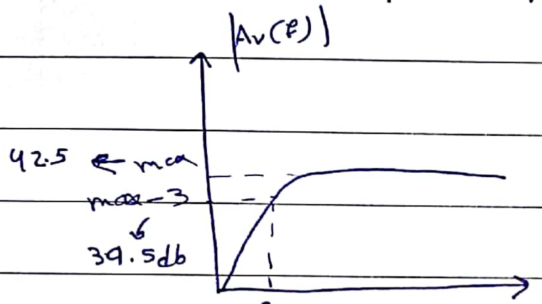
$= (R_s // R_p)\, C_L$



example: $R_s = 1k\Omega$ $C_c = 1\mu F$



Draw the $|A_v(f)|_{dB}$



$f_L = \frac{1}{2\pi \tau_L} = 53.1\ Hz.$

$\tau = R_{eq}\ C_c$

$= (r_s + r_\pi)\ C_c$

$= 3k\Omega * 1\mu = 3m\ sec.$

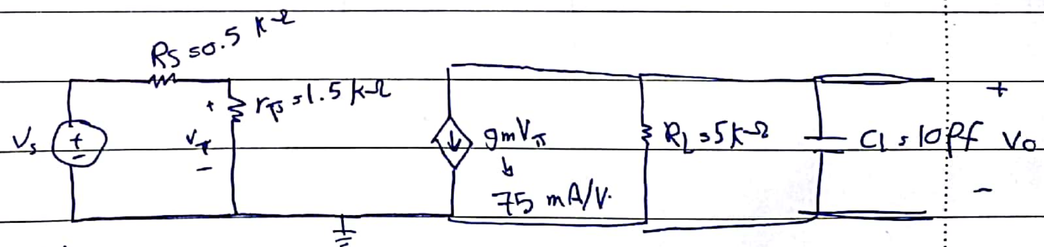
$A_v = -g_m \frac{R_L\ r_\pi}{r_\pi + R_s}$

$= -133.$

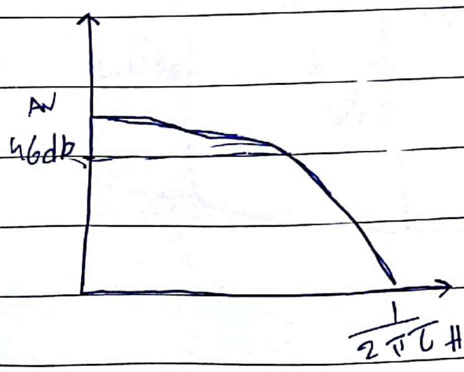
$|A_v|_{db} = 20 \log 133$

$= 42.5\ db$

Ex:



Draw $|A_v(f)|_{dB}$



$\frac{1}{2\pi\tau_H}.$

$A_v = -g_m \frac{R_L\ r_\pi}{r_\pi + R_s} = -281$

$|A_v\ db| = 20 \log 281 =$ 44 db

$\tau_H = R_{eq}\ C_L = R_L\ C_L =$

$= 50\ n\ sec.$

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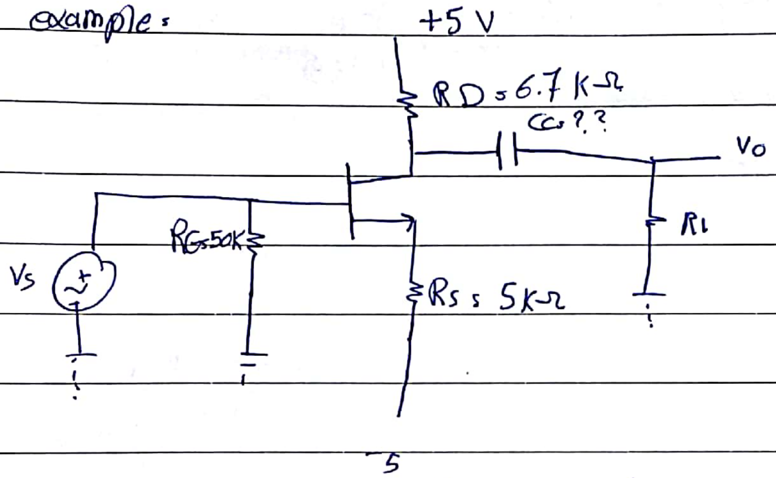
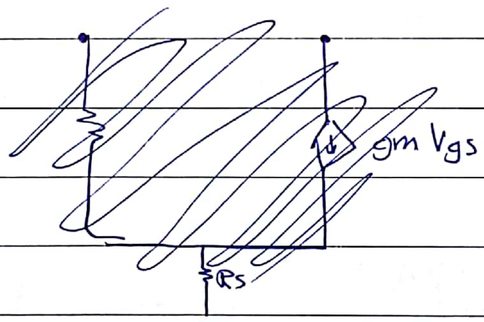
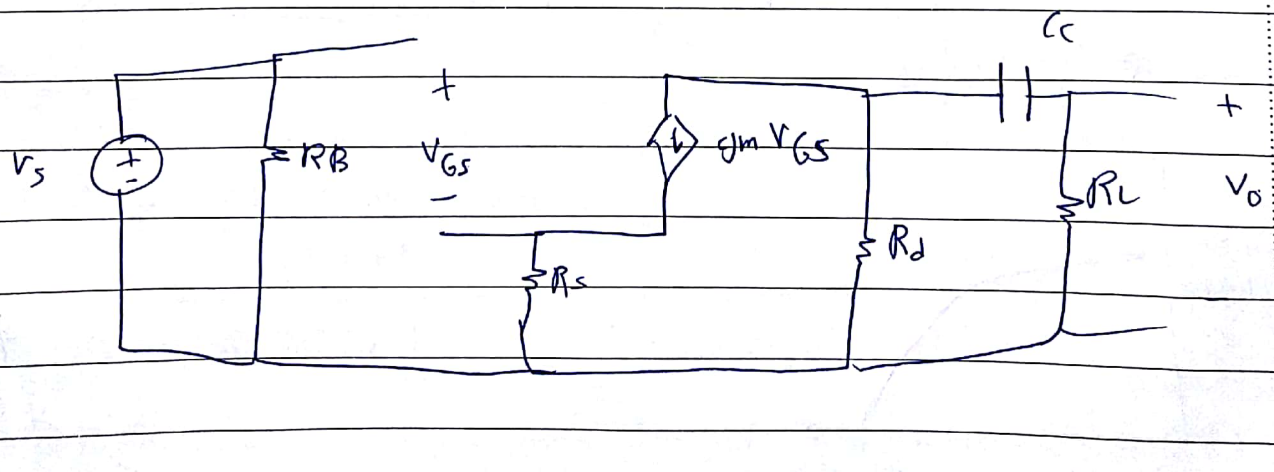
$f_H = 3.18\ MHz$

example:



find Cc such $f_{3db} = 20\ Hz$.

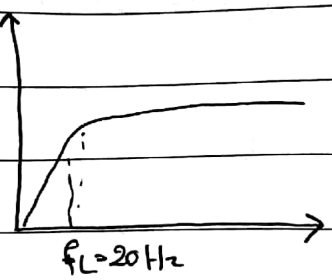




KCL:- $g_m V_{gs} + \frac{V_{gs}}{R_s} \Rightarrow V_{GS}\left(g_m + \frac{1}{R_s}\right) = 0$

$\downarrow$

zero



$20 Hz = \frac{1}{2\pi\tau} \Rightarrow \tau = 7.96$ m sec $\Rightarrow R_{eq} C_E$

$\downarrow$

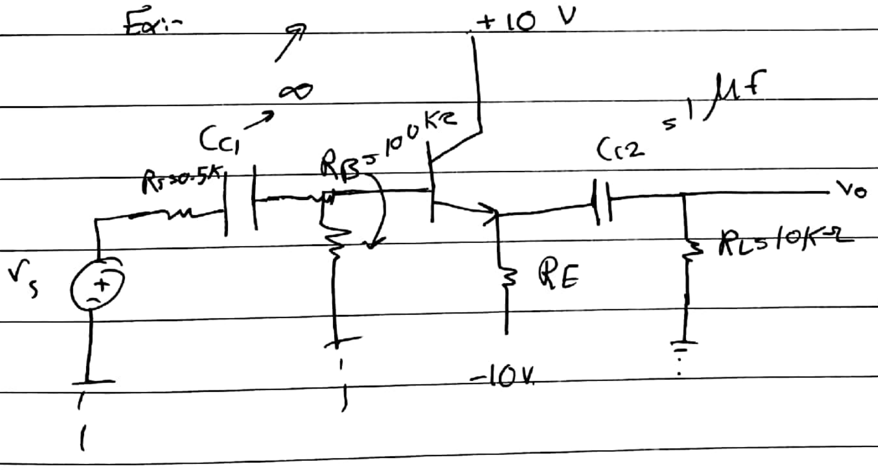
$(R_D + R_L) C_C$

$= 16.7K * C_c$

$C_c = 0.477 \mu F$

short CKT.

Ex:-



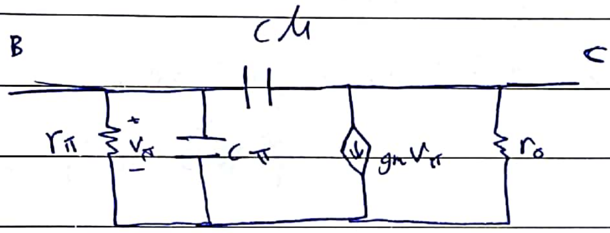
$\beta = 100$, $V_A = 120V$

find f_{3dB}.

Answer: ⇒ 15.4 Hz.

Case 2: more than one capacitor we use open CKT-short CKT time constant. (later).
↳ If there are

* Transistor capacitors (for bipolar Junction capacitor)

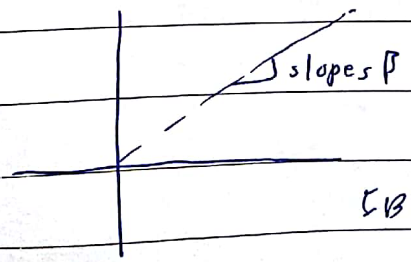


* C_π & C_μ are Transistor capacitors.
* The effect of these capacitors ~~appeared~~ can be found at High frequency.
* $C_\mu \ll C_\pi$, but we cannot ignore the effect of C_μ due to <u>Miller effect</u>.

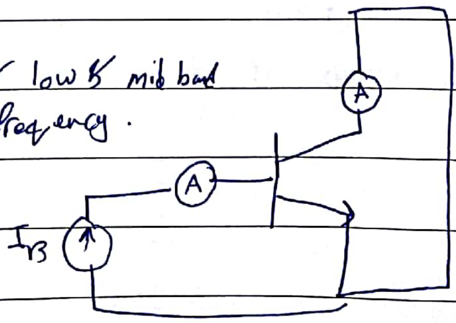
* The effect of C_π & C_μ on short CKT current Gain.
* Transistor is a current Amplifier because $I_C = \beta I_B$ ($I_C \to I_o$, $I_B \to I_i$)

β is called short-circuit current gain. $A_i = \frac{I_C}{I_o} = \beta$

in DC & low & mid band frequency.



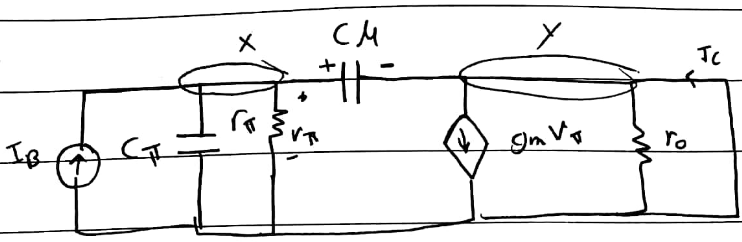
←



I_B	I
-	-
-	-
-	-

Subject Date No.

In High Frequency



find $A_i = \frac{i_c}{i_b}$

KCL at X:

$$i_b = \frac{V_\pi}{r_\pi} + \frac{V_\pi}{\frac{1}{j\omega C_\pi}} + \frac{V_\pi}{\frac{1}{j\omega C_\mu}} \quad \text{--- (1)}$$

$$i_b = V_\pi \left[\frac{1}{r_\pi} + j\omega(C_\pi + C_\mu)\right] \quad \text{--- (1)}$$

KCL at Y:

$$g_m V_\pi = i_C + \frac{V_\pi}{\frac{1}{j\omega C_\mu}}$$

$$i_C = V_\pi (g_m - j\omega C_\mu) \quad \text{--- (2)}$$

$$A_i = \frac{i_C}{i_b} = \frac{g_m - j\omega C_\mu}{\left[\frac{1}{r_\pi} + j\omega(C_\pi + C_\mu)\right]}$$

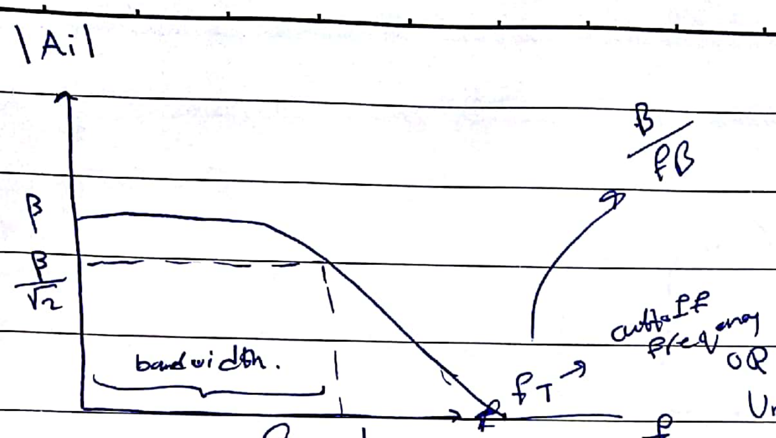
Typically, $C_\mu = 0.2\,pf$, $g_m = 50\,mA/V$, $f_{max} = 100\,MHz$

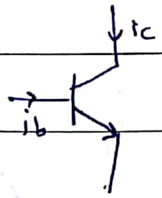
$\omega C_\mu \ll g_m$, so $A_i = \frac{i_C}{i_b} = \frac{\beta}{1 + j\omega r_\pi (C_\pi + C_\mu)}$

⇓

$I_b = K \frac{1}{1+s\tau}$

NOTEBOOK





Unity gain bandwidth.
$(I_C = I_B)$

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

β cutoff frequency OR bandwidth of the transistor.

[illegible] (قانون).

*Unity gain bw (f_T) :-

$$|A_i(f_T)| = 1$$

$$= \left|\frac{\beta}{1 + j2\pi f_T r_\pi(C_\pi + C_\mu)}\right| = 1$$

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

$$= \frac{\beta}{\sqrt{1 + \left(\frac{f_T}{f_\beta}\right)^2}} = 1$$

but $\frac{f_T}{f_\beta} \gg 1$

$$\frac{\beta}{\frac{f_T}{f_\beta}} = 1 \Rightarrow \boxed{f_T = \frac{\beta}{f_\beta}}$$

example: Find the 3dB frequency of the short CKT current gain (A_i) of BJT given $r_\pi = 2.6\,k\Omega$, $C_\pi = 2\,pF$, $C_\mu = 0.1\,pF$.

$$f_\beta = \frac{1}{2\pi r_\pi (C_\pi + C_\mu)} = 29.1\,MHz.$$

* Note: High frequency BJT has small sizes. becase f_β High it means C_π, C_μ have small values

⇓

So small size.

Ex:. Consider BJT that has $f_T = 500\,MHz$ at $I_C = 1\,mA$. $\beta = 100$, $C_\mu = 0.3\,pF$, find C_π.

$$f_\beta = \frac{f_T}{\beta} = \frac{500\,MHz}{100} = 5\,MHz.$$

$$f_\beta = \frac{1}{2\pi r_\pi (C_\pi + C_\mu)}$$ (f_β = 5M)

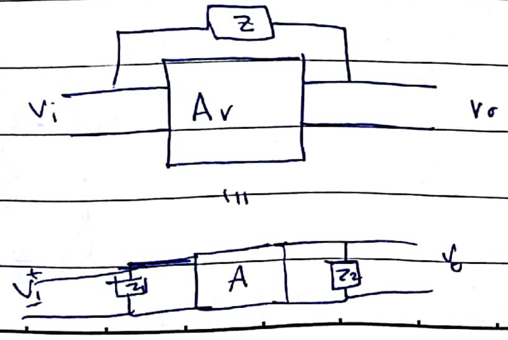
$r_\pi = \frac{\beta}{g_m}$, $g_m = \frac{I_{CQ}}{V_T}$, $\frac{100}{\,}$, $V_T = 0.026$, $I_{CQ} = 1\,mA$ ⇒ r_π = ▭

$C_\pi = 11.4\,pF$.

* Miller effect & Miller capacitance.

⇒ $C_\mu \ll C_\pi$ but we cannot ignore C_μ due to Miller effect.

⇒ Miller theorem



$Z_1 = \frac{Z}{1-A_v}$, $Z_2 = \frac{Z}{1-\frac{1}{A_v}}$

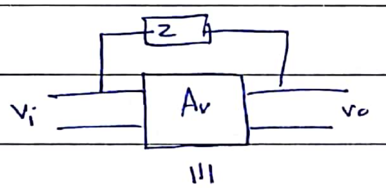
$C_\mu \ll C_\pi$

↓

$\frac{1}{j\omega C_\mu} \approx \infty \text{ (o.c)}$

0

* Miller Theorem



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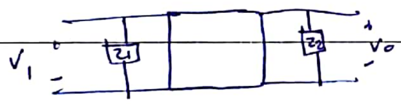
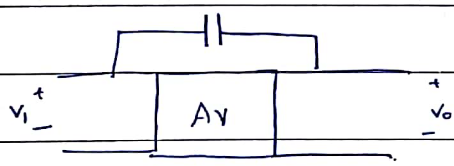


$Z_1 = \frac{Z}{1-A_{v(max)}}$ in mid band

$Z_2 = \frac{Z}{1-\frac{1}{A_{v\,max}}}$

for Amp. CKTs (at High Frequency)



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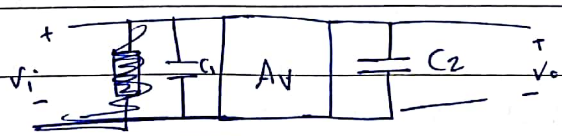
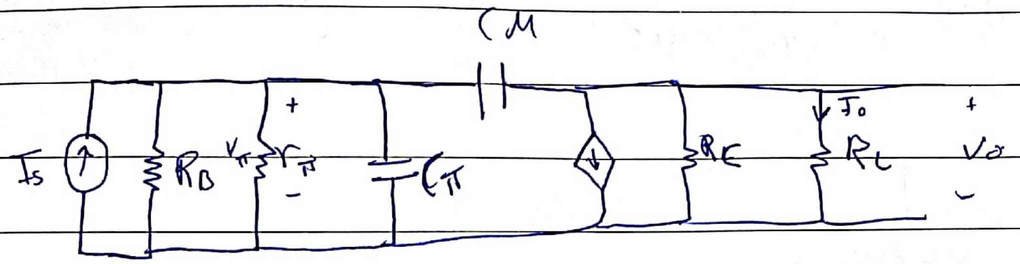


$C_1 = C_\mu(1-A_{v\,max})$

$C_2 = C_\mu\left(1-\frac{1}{A_{v\,max}}\right)$ → small value. we can Ignore it.

$C_1 \Rightarrow$ it's called $C_M \Rightarrow$ Miller capacitance.

Example:-



Given :- $R_C = R_L = 4K\Omega$, $r_\pi = 2.6\ K\Omega$, $R_B = 200K\ \Omega$.

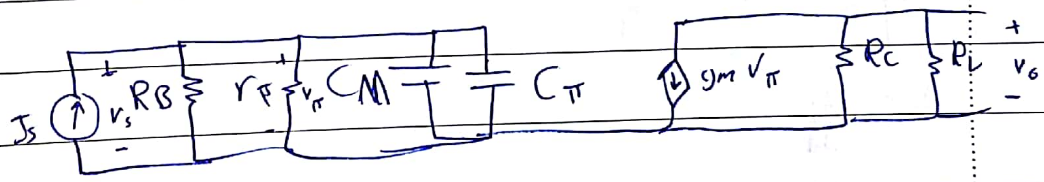
$gm = 38.5\ mA/V$, $C\mu = 0.2pf$, $C_\pi = 4\ pF$

find f_{3dB}:

(1) if we consider miller effect.

(2) " " donot consider " " .

1. $f_{3db} = \dfrac{1}{2\pi\ \tau}$



$C_M = C\mu(1 - A_{v\,mid})$

$= C\mu(1 + gm(R_L // R_C))$

$= 15.6\ PF$

Av in mid band $= \dfrac{V_o}{V_s} = \dfrac{-gm\ V_\pi (R_L // R_C)}{V_\pi}$

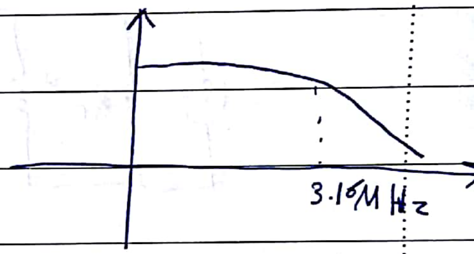
$= -gm\ (R_L // R_C)$

$=$

$\tau = R_{eq} C_{eq} = R_{eq}(C_M + C_\pi)$

$(R_B \| R_\pi)(C_M + C_\pi) =$

$$f_{3dB} = \frac{1}{2\pi (R_B \| r_\pi)(C_M + C_\pi)} = 3.16\ MHz$$



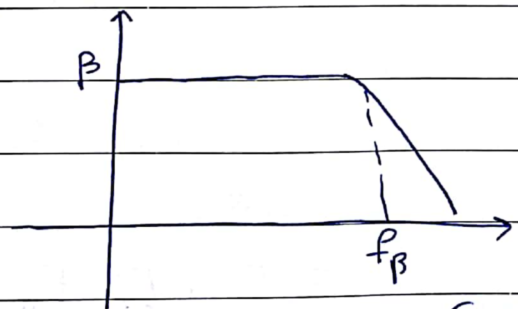
② $$f_{3db} = \frac{1}{2\pi (R_B \| r_\pi) C_\pi} = 15.5\ MHz$$

↓

BW زادت

الاصح اهمل Miller effect.

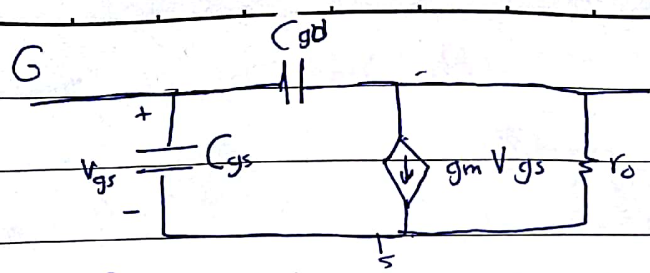
f_{3dB} without Miller effect ≥ $5 * f_{3dB}$ (with~~out~~ Miller)



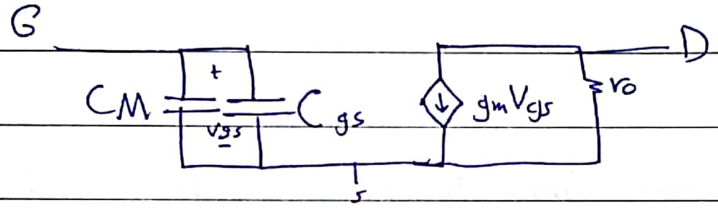
C_J & C_M

$A_i = \frac{I_c}{I_B}$

FET at High frequency:-

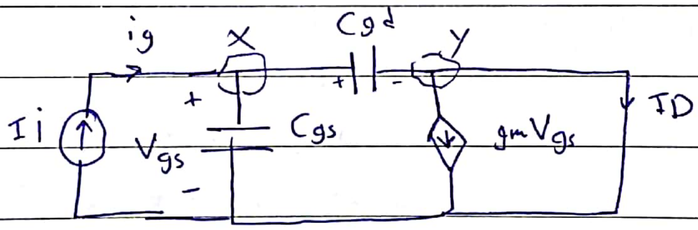


$C_{gd} \ll C_{gs}$ but we cannot Ignor C_{gd} due to Miller effect where:-



$C_M = C_{gs}(1 - A_v)$.

* effect of C_{gd} & C_{gs} on short-circuit current Gain.



* In DC & low & Mid band frequency. $I_G = 0$ A

$$A_i = \frac{I_d}{I_g} = \infty$$

* In High frequency Range

$$A_i = \frac{I_d}{I_G} =$$

KCL at X:-

$$I_g = \frac{V_{gs}}{\frac{1}{j\omega C_{gs}}} + \frac{V_{gs}}{\frac{1}{j\omega C_{gd}}} = V_{gs}\left[j\omega(C_{gs} + C_{gd})\right] \quad \text{---} (1)$$

KCL at y:-

$$i_d + \frac{V_{gs}}{\frac{1}{j\omega C_{gd}}} = g_m V_{gs} \quad \text{---} (2)$$

use (1) and (2)

$$A_i = \frac{g_m - j\omega C_{gd}}{j\omega (C_{gs} + C_{gd})}$$

Typically, at High frequency: $g_m = 1 mA/V$, $C_{gd} = 0.5 pf$,

$f_{H_{max}} = 100 MHz$

$\Downarrow$

$g_m \gg |j\omega C_{gd}|$

So $A_i = \frac{g_m}{j\omega (C_{gd} + C_{gs})}$

unity gain BW

A_i at $f_T \Rightarrow |A_i(f_T)| = 1$

$$\frac{g_m}{2\pi f_T (C_{gd} + C_{gs})} = 1$$

$$\boxed{f_T = \frac{g_m}{2\pi (C_{gd} + C_{gs})}}$$

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example: Consider an n-channel MOSFET with parameters

$K_n = 0.25\ mA/V^2$

$V_{TN} = 1V$, $\lambda = 0$, $C_{gs} = 0.2pF$, $C_{gd} = 0.04pF$

Assume the Transistor is biased at $V_{GSQ} = 3V$, find the Unity gain bw (f_T)

$$f_T = \frac{g_m}{2\pi(C_{gs}+C_{gd})}$$

$$g_m = 2K(V_{GS} - V_{TN}) = 1mA/V$$

$$= 663\ MHz.$$

finding τ:-

1. from plot
2. from function
3. from circuit.

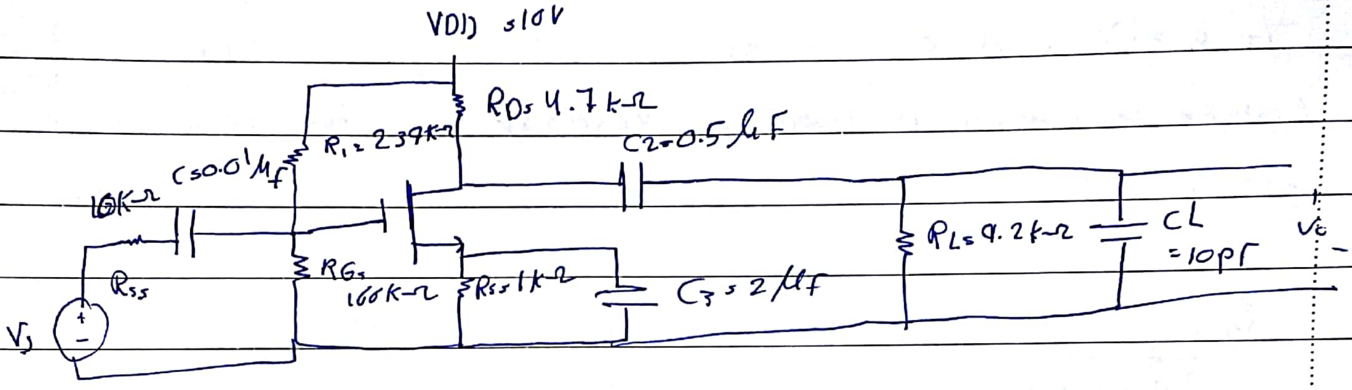
Case 1: one capacitor. $\tau = R_{eq} C$

Case 2: more than one capacitor.

We use open-CKT and Short-CKT time constant.

Ex:

Ex: Draw Frequency Response of the following Amp. CKT



Given: $K_n = 0.4\ mA/V^2$

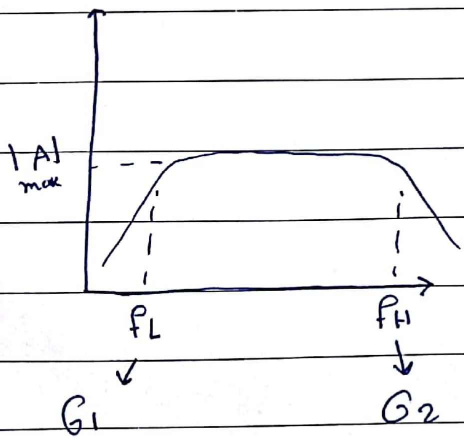
$V_{TN} = 1\ V$, $g_m = 1.56\ mA/V$

$\lambda = 0$

$C_{gd} = 0.1\ pF$, $C_{gs} = 1\ pF$

common source

CS



Dc analysis: $V_{GSQ} = 2.96\ V$

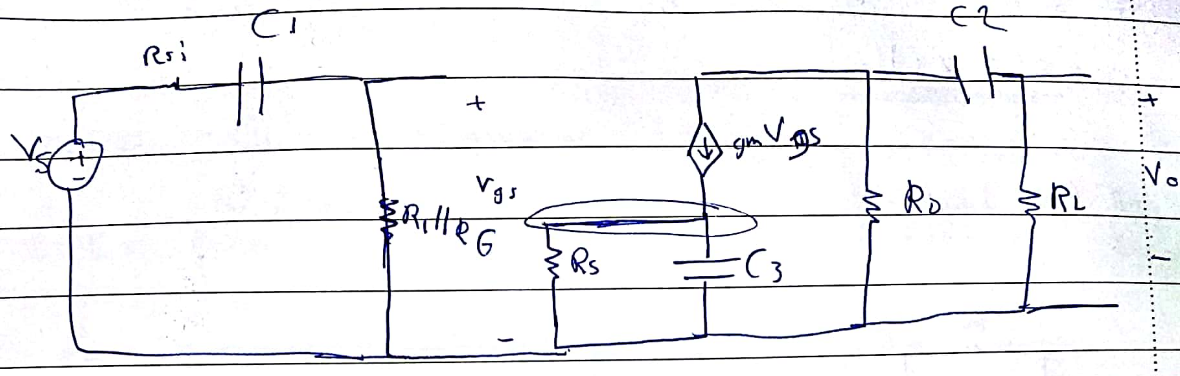
$I_{DQ} = 1.54\ mA$

$V_{DSQ} = 1.24\ V$

low frequency Range.

$G_1 = Z_c$

$G_2 = O.C.$



$\Rightarrow C_1$ only , C_2 & C_3 = S.C

$\tau_1 = R_{eq}\, C_1$

$\downarrow$

$((R_1 \| R_G) + R_{si}) * C_1$

$$f_{L_1} = \frac{1}{2\pi\tau_1} = 148.6\, Hz.$$

C_2 only , C_1 & C_3 : S.C

$\tau_2 = R_{eq}\, C_2 = (R_L + R_o)\, C_2$

$$f_{L_2} = \frac{1}{2\pi\tau_2} = 46.13\, Hz.$$

C_3 only , C_1 & C_2 : S.C

$\tau_3 = R_{eq}\, C_3 =$

$V_{gs} = -V_x$

$$KCL = g_m V_{gs} + I_x = \frac{V_x}{R_s} \Rightarrow \frac{V_x}{I_x} = \frac{1}{g_m + \frac{1}{R_s}}$$

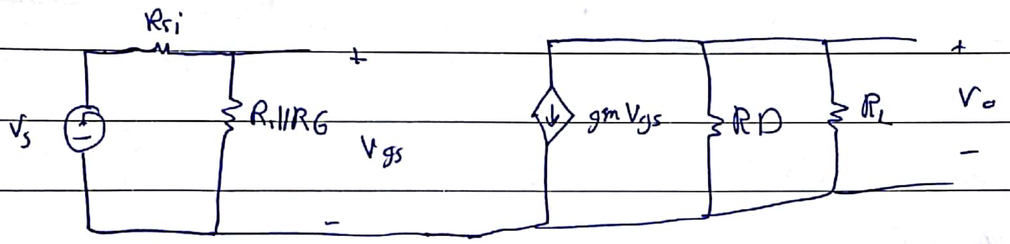
($V_{gs} \to -V_x$)

$$f_L = \frac{1}{2\pi\tau_3} = 238.73\, Hz$$

f_L = Max of f_{L1}, f_{L2}, f_{L3}

$= 238.73\ Hz$

at Mid band :-



$A_{vs} = \frac{V_o}{V_s}$

$V_o = -g_m V_{gs} (R_L // R_D)$ —— ①

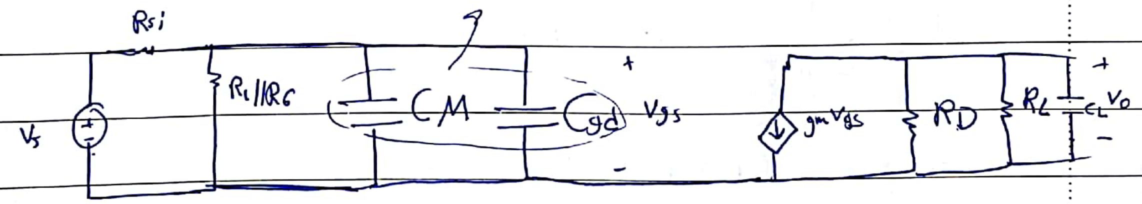
$V_{gs} = V_s \frac{R_1 // R_G}{R_1 // R_G + R_{si}}$ —— ②

$A_{vs} = \frac{-g_m (R_L // R_D)(R_1 // R_G)}{R_1 // R_G + R_{si}}$

$= -2.32$

* High frequency Range:

$C_{eq} = C_M + C_{gs} = 1.33\ pF.$



$C_M = C_{gd}(1 - A_v)$

$= C_{gd}[1 - (-2.32)]$

$C_M = 0.332\ pF.$

C_{eq} only , C_L = open.

$\tau_1 = R_{eq}\ C_{eq} = R_{si} // R_1 // R_G\ \ C_{eq} = 1.2 * 10^{-8}$ sec.

$f_{H1} = \frac{1}{2\pi \tau_1} = 13.2\ MHz$

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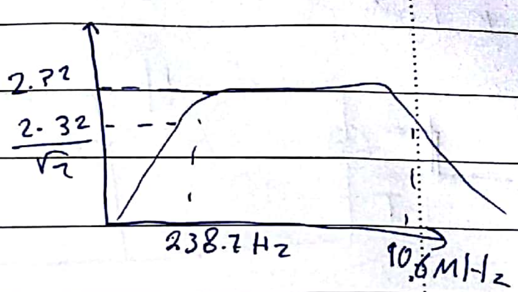
C_L only, & C_{eq} s.o.c

$T_2 = R_{eq} C_L$

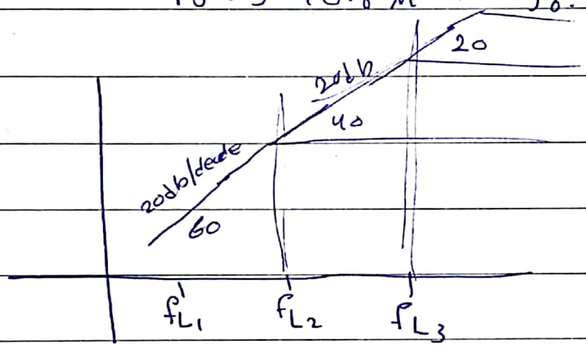
$= R_D \| R_L \quad C_L = 15$ n Second.

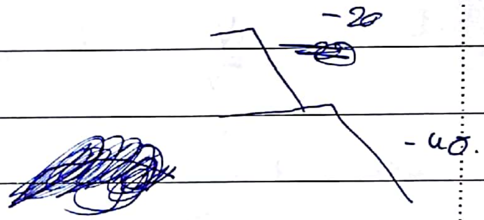
$f_H = \frac{1}{2\pi T_2} = 10.6$ MHz.



So f_H = minimum of f_{H_1} & f_{H_2} = 10.6 MHz

BW = 10.6 M − 238.7 = 10.6 MHz

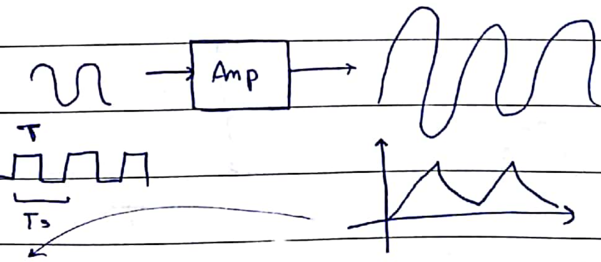




* Time Response:-

⇒ We consider the time Response if input signal is a non sinusoidal signal.

[Example : Square wave].



⇒ Distortion : The reson is due to coupling Capacitor & load capacitors.

(input CKT & output CKT).

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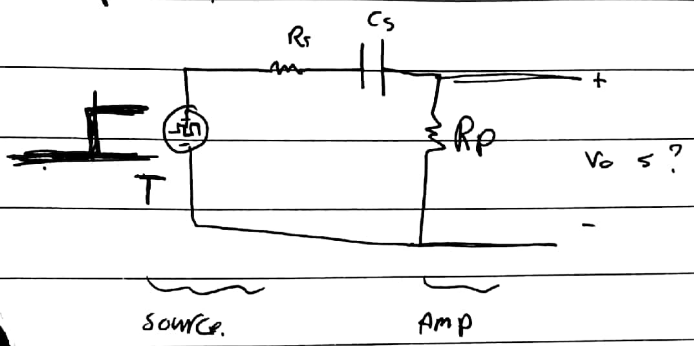
* Input ckT :- -



S-Domain : $\frac{V_o(s)}{V_s(s)} = K \frac{s\tau}{1+s\tau}$

where $K = \frac{R_p}{R_p+R_s}$, $\tau = (R_s + R_p) C_s$.

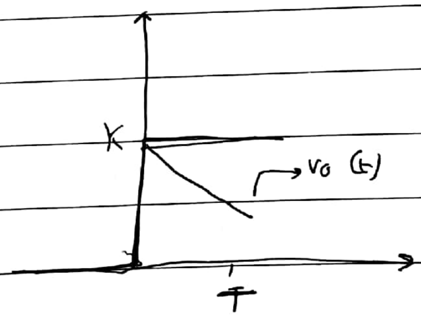
$V_o(s) = V_s(s) * K \frac{s\tau}{1+s\tau}$

if $V_s(t) = u(t)$ then $V_s(s) = \frac{1}{s}$

$V_o(s) = \frac{1}{s} * K \frac{s\tau}{1+s\tau}$

$V_o(s) = \frac{K\tau}{1+s\tau}$

→ inverse laplace = $V_o(t) = K e^{-\frac{t}{\tau}}$



we need , $V_o(t=T) = K$

$K e^{-\frac{T}{\tau}} = K$

So we need $e^{-\frac{T}{\tau}} \approx 1$

so we need $\frac{T}{\tau} = 0$, $\tau \gg T$

(Rule $\tau \geq 10 T$)

T ↓ $\frac{1}{2}$ Ts → period of Vs $T_s = \frac{1}{f_s}$

NOTEBOOK

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$\tau \geq 10T$

$(R_s+R_p)C_s \geq 10\ T$

we need C_s (coupling capacitor to be high value).