

$$\Delta I_C = S_\beta \Delta \beta + S_V \cdot \Delta V_{BE}$$

$$S_\beta = \frac{I_C}{\beta_1} \times \frac{R_t + R_E}{R_t + (1 + \beta_1) R_E} \Delta \beta - \frac{1}{R_E} \Delta V_{BE} \rightarrow \boxed{\Delta I_C = \frac{I_C}{R_E} + \frac{V}{\Delta}}$$

$$R_t \ll (1 + \beta) R_E \xrightarrow{\text{فرض}} R_t = \frac{\beta_{min} \cdot R_E}{1}$$

$$I, II \rightarrow R_E = 4.4 \Omega, \quad \boxed{R_E = 1.75 \Omega}$$

$$\rightarrow R_t = 2.9 \text{ k}\Omega, \quad I_{C1} = 0.5 \text{ mA}$$

$$I_{C2} = 0.41 \text{ mA}$$

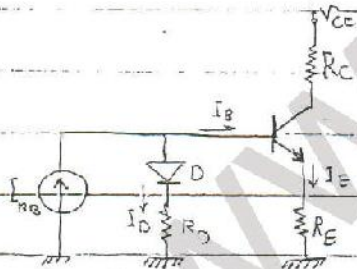
$$\rightarrow 0 < I_C < 0.41 \text{ mA}$$

$$\rightarrow \Delta < \frac{V_E - V_{BE}}{R_E + \frac{R_t}{\beta}} < 0.41 \text{ mA} \xrightarrow{\text{فرض}} 4.1 \text{ V} < V_E < 4.17 \text{ V}$$

$$\boxed{V_E = 4.1 \text{ V}}$$

$$\boxed{R_B = 2.1 \text{ k}\Omega}$$

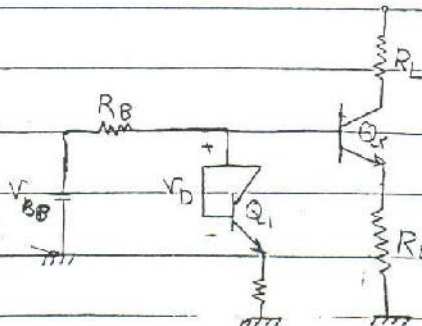
$$\boxed{R_E = 1.75 \Omega}$$



$$\begin{cases} I_{BB} = I_D + I_B \\ V_D + R_D I_D = V_{BE} + R_E I_E \end{cases}$$

$$I_E = \frac{V_D - V_{BE} + I_{BB} R_D}{R_E + \frac{R_D}{1 + \beta}}$$

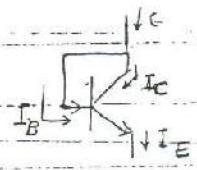
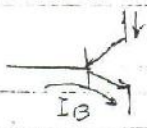
$$\frac{\Delta I_E}{\Delta T} = \frac{\frac{\Delta V_D}{\Delta T} - \frac{\Delta V_{BE}}{\Delta T}}{R_E + \frac{R_D}{1 + \beta}} \rightarrow \frac{\Delta V_D}{\Delta T} - \frac{\Delta V_{BE}}{\Delta T} = K$$



استفاده از ترانزیستور  $Q_1$  به منم روبرو به جای دیود مدار را

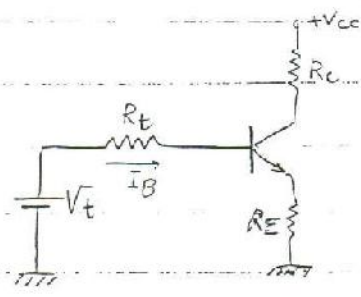
این مزیت را دارد که امپدانس ورودی ترانزیستور کم است

۴۰



$$h_{ie} = \frac{2V_T}{I_C}$$

$$\frac{h_{ie}}{1+h_{fe}}$$



$$R_t = R_D \parallel R_B$$

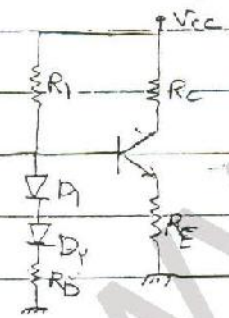
$$V_t = \frac{R_D V_{BB} + R_B V_D}{R_D + R_B}$$

$$V_t = R_t I_B + V_{BE} + R_E I_E$$

$$I_E = \frac{(V_{BB} R_D + V_D R_B) / R_B + R_D}{R_E}$$

$$\frac{\Delta I_E}{\Delta T} = \frac{1}{R_E} \left[ \frac{\Delta V_D}{\Delta T} \frac{R_B}{R_B + R_D} + \frac{\Delta V_{BE}}{\Delta T} \right]$$

$$\frac{\Delta V_D}{\Delta T} = \frac{\Delta V_{BE}}{\Delta T} = -K \rightarrow \frac{\Delta I_E}{\Delta T} = \frac{K}{R_E} \left[ \frac{1}{1 + \frac{R_B}{R_D}} \right]$$

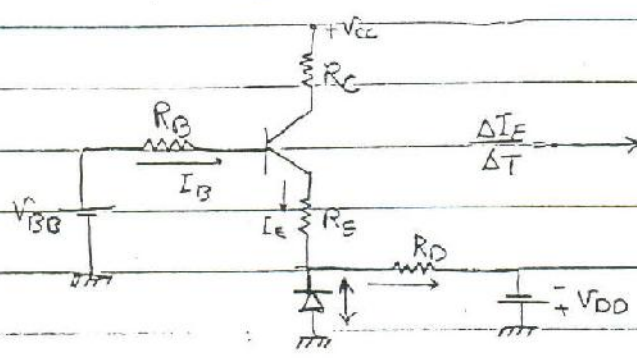


$$V_t = \frac{V_{CC} R_D + V_D R_B}{R_D + R_B}$$

$$R_t = R_D \parallel R_B$$

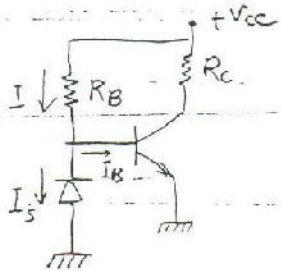
$$I_E = \frac{(V_{CC} R_D + V_D R_B) / R_B + R_D - V_{BE}}{R_E}$$

$$\frac{\Delta V_D}{\Delta T} = \frac{\Delta V_{BE}}{\Delta T} \rightarrow \frac{\Delta I_E}{\Delta T} \rightarrow R_B = R_D$$



$$\frac{\Delta I_E}{\Delta T} \rightarrow \frac{\Delta V_{BE}}{\Delta T} = \frac{\Delta V_D}{\Delta T}$$

نیل کی کتاب = ۱۰۳



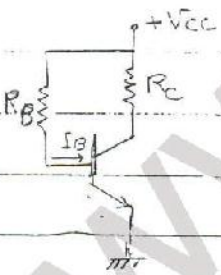
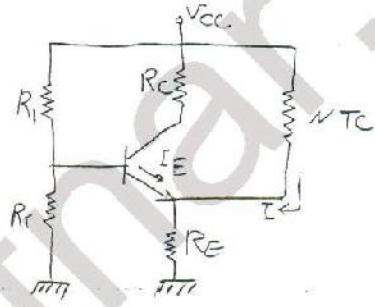
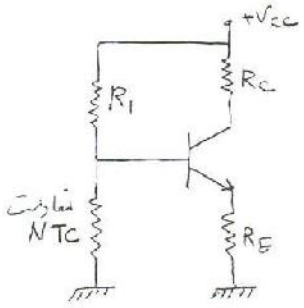
حیران اثر جری  $I_{CBO}$  :

$$\begin{cases} I_C = \beta I_B + (1 + \beta) I_{CBO} \\ I_C = \beta (I - I_S) + (1 + \beta) I_{CBO} \end{cases}$$

با فرض دما برابر و دوتر از استور و  $\beta \gg 1$

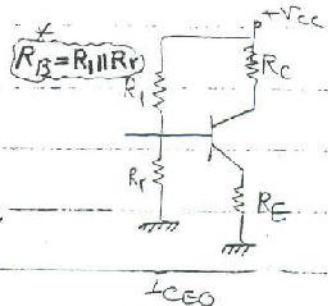
$$\rightarrow \frac{\Delta I_C}{\Delta T} = -\beta \frac{\Delta I_S}{\Delta T} + (1 + \beta) \frac{\Delta I_{CBO}}{\Delta T} \approx 0$$

تثبیت کنندگی حرارتی با استفاده از مقاومتهای PTC, NTC :



$$\Delta I_C = S_I \frac{\Delta I_C}{\Delta I_{CBO}} + \dots$$

$$S_o = \frac{\Delta I_C}{\Delta I_C} = \text{موردیون پایه ای}$$



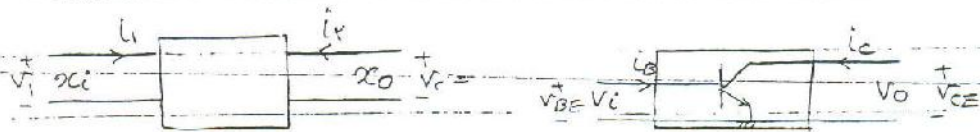
$$\frac{\Delta I_C}{\Delta I_{CBO}} \approx 1 \rightarrow I_C = \beta I_B + (1 + \beta) I_{CBO}$$

$$S_o = \frac{1}{\left(\frac{R_B + R_E(1 + \beta)}{R_B + R_E}\right)} = \frac{R_E(1 + \beta)}{R_B + R_E}, \quad R_B \ll (1 + \beta) R_E$$

$$S_o = \frac{(1 + \beta) R_E}{R_B + R_E}$$

$$S_o = 1 + \frac{\beta R_E}{R_E + R_B}, \quad \beta \gg 1$$

$$S_o > 1$$



$$Z \begin{cases} V_1 = Z_{11} i_1 + Z_{12} i_2 \\ V_2 = Z_{21} i_1 + Z_{22} i_2 \end{cases}$$

$$Y \begin{cases} i_1 = y_{11} V_1 + y_{12} V_2 \\ i_2 = y_{21} V_1 + y_{22} V_2 \end{cases}$$

$$h \begin{cases} V_1 = h_{11} i_1 + h_{12} V_2 \\ i_2 = h_{21} i_1 + h_{22} V_2 \end{cases}$$

$$Z_{11} = \frac{V_1}{i_1} \Big|_{i_2=0} \text{ امیدانس ورودی خروجی باز}$$

$$Z_{22} = \frac{V_2}{i_2} \Big|_{i_1=0} \text{ امیدانس خروجی ورودی باز}$$

$$Z_{12} = \frac{V_1}{i_2} \Big|_{i_1=0} \text{ امیدانس انتقالی معکوس}$$

$$Z_{21} = \frac{V_2}{i_1} \Big|_{i_2=0} \text{ امیدانس انتقالی مستقیم}$$

$$y_{11} = \frac{i_1}{V_1} \Big|_{V_2=0} \text{ ادمیتانس ورودی}$$

$$y_{22} = \frac{i_2}{V_2} \Big|_{V_1=0} \text{ ادمیتانس خروجی}$$

$$y_{12} = \frac{i_1}{V_2} \Big|_{V_1=0} \text{ ادمیتانس انتقالی معکوس}$$

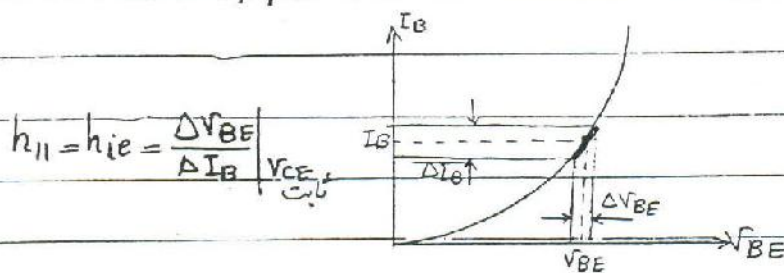
$$y_{21} = \frac{i_2}{V_1} \Big|_{V_2=0} \text{ ادمیتانس انتقالی مستقیم}$$

$$h_{11} = \frac{V_1}{i_1} \Big|_{V_2=0} \text{ امیدانس ورودی } (h_{ie})$$

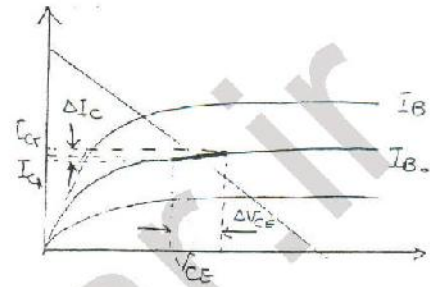
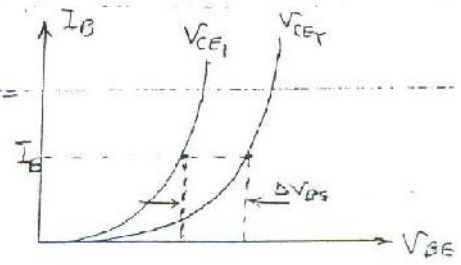
$$h_{22} = \frac{i_2}{V_2} \Big|_{i_1=0} \text{ ادمیتانس خروجی } (h_{oe})$$

$$h_{12} = \frac{V_1}{V_2} \Big|_{i_1=0} \text{ بهره ولتاژ انتقالی معکوس } (h_{re})$$

$$h_{21} = \frac{i_2}{i_1} \Big|_{V_2=0} \text{ بهره جریان انتقالی مستقیم } (h_{fe})$$



$$h_{re} = h_{re} = \left. \frac{\Delta V_{BE}}{\Delta V_{CE}} \right|_{I_B \text{ const}}$$



مدار هیبرید:

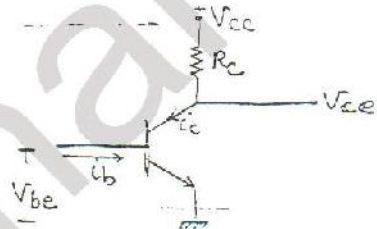
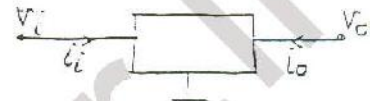


پارامترهای h

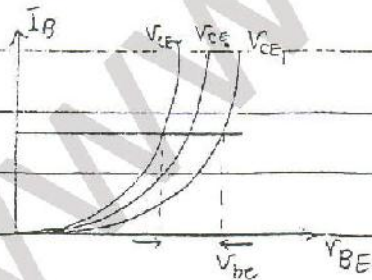
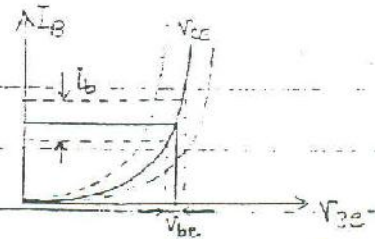
$$\begin{cases} V_1 = h_{11} i_1 + h_{12} V_2 \\ i_2 = h_{21} i_1 + h_{22} V_2 \end{cases}$$

$$\begin{cases} V_i = h_{ie} i_i + h_{re} V_o \\ i_o = h_{fe} i_i + h_{oe} V_o \end{cases}$$

$$\begin{cases} V_{be} = h_{ic} i_b + h_{re} V_{ce} \\ i_c = h_{fe} i_b + h_{oe} V_{ce} \end{cases}$$

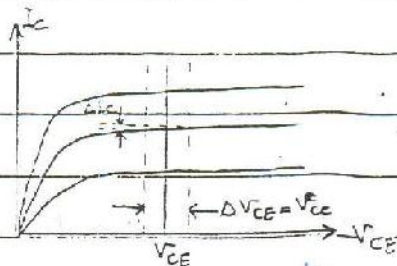
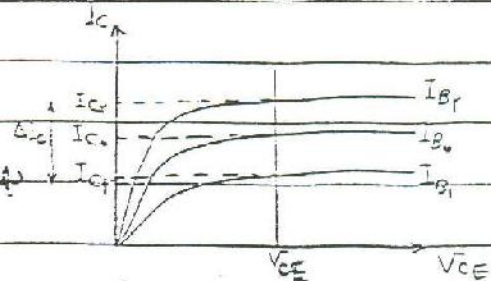


$h_{ie} = \left. \frac{V_{be}}{i_b} \right|_{V_{ce}=0}$  امیدانش ورودی



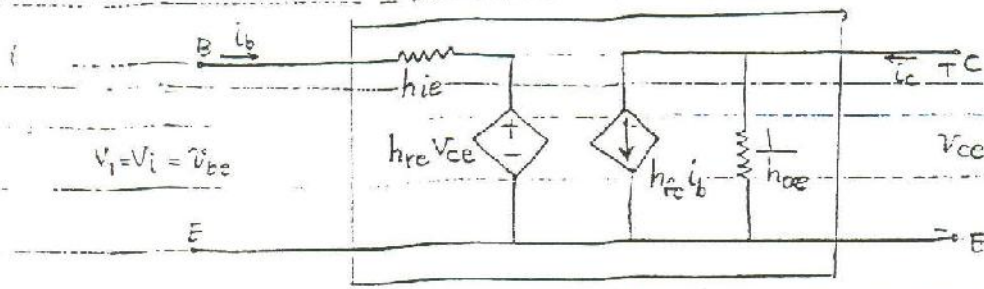
$h_{re} = \left. \frac{V_{be}}{V_{ce}} \right|_{i_b=0}$  بهره ولتاژ معکوس

$h_{fe} = \left. \frac{i_c}{i_b} \right|_{V_{ce}=0}$  بهره جریان مستقیم

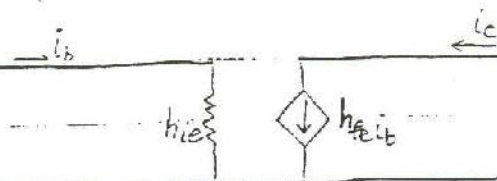


$$\begin{cases} i_b = \Delta i_b = I_{B2} - I_{B1} \\ i_c = \Delta i_c = I_{C2} - I_{C1} \end{cases}$$

$h_{oe} = \left. \frac{i_c}{V_{ce}} \right|_{i_b=0}$  امیدانش خروجی

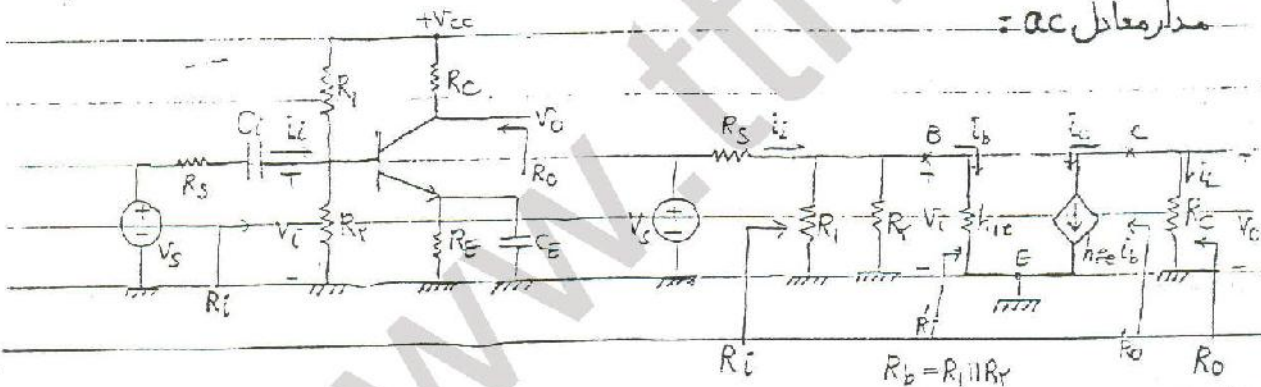


مدل هیبرید C.E (دقیق)



مدل تقریبی

مدل معادل ac =



گین ولتاژ  $A_v = \frac{V_o}{V_i}$

گین جریان  $A_i = \frac{i_L}{i_i}$

$$A_v = \frac{V_o}{V_i} = \frac{-R_c i_c}{h_{ie} i_b} A_i$$

$$A_v = \frac{h_{fe} R_o}{h_{ie}} = \frac{R_o}{R_i} A_i$$

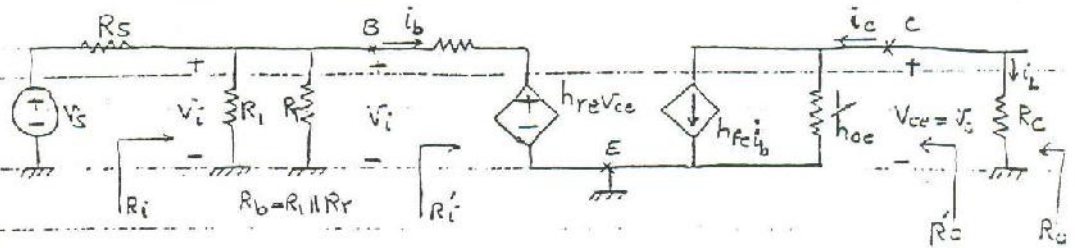
$$A_i = \frac{i_L}{i_i} = \frac{-i_c}{i_b} \times \frac{i_b}{i_i} = -h_{fe} \times \frac{R_b}{R_b + h_{ie}}$$

$$A_i = -h_{fe} \frac{R_b}{R_b + h_{ie}}$$

اینها را در فرمول جایگزین می‌کنیم

$$R_i = \frac{V_i}{i_i} = R_1 || R_2 || R_i' = R_1 || R_2 || \left( \frac{V_i}{i_b} \right) = R_1 || R_2 || h_{ie} \rightarrow R_i = R_1 || R_2 || h_{ie}$$

$$R_o = \left. \frac{V_o}{i_o} \right|_{V_s=0} = R_o' || R_c = \infty || R_c = R_c \rightarrow R_o = R_c$$



$$A_v = \frac{V_o}{V_i} \rightarrow \begin{cases} V_o = -R_c \cdot i_c = -R_c (h_{fe} i_b + V_o h_{oe}) \\ V_i = h_{ie} i_b + h_{re} V_o = h_{ie} i_b + h_{re} V_o \end{cases}$$

$$\rightarrow A_v = \frac{-h_{fe} (R_c \parallel \frac{1}{h_{oe}})}{h_{ie} - h_{re} h_{fe} (R_c \parallel \frac{1}{h_{oe}})}$$

$$R_i = \frac{V_i}{i_b} = R_1 \parallel R_r \parallel R_i' = R_1 \parallel R_r \parallel \frac{V_i}{i_b} = R_1 \parallel R_r \parallel R_i'$$

$$\rightarrow R_i' = h_{ie} - h_{re} h_{fe} (R_c \parallel \frac{1}{h_{oe}})$$

$$\rightarrow R_i = R_1 \parallel R_r \parallel (h_{ie} - h_{re} h_{fe} (R_c \parallel \frac{1}{h_{oe}}))$$

$$A_i = \frac{i_c}{i_b} = A_v \cdot \frac{R_o}{R_i'} \times A_i'$$

$$A_i = \frac{i_c}{i_b} = \frac{i_c}{h_{fe} i_b} \times \frac{h_{fe} i_b}{i_b} = \frac{1}{h_{oe} + R_c} \times h_{fe} \rightarrow A_i = \frac{h_{fe}}{h_{oe} + R_c}$$

$$A_{i_s} = \frac{i_c}{i_i} = \frac{i_c}{i_b} \times \frac{i_b}{i_i} = A_i \times \frac{R_b}{R_b + R_i'} \rightarrow A_{i_s} = A_i \frac{R_b}{R_b + R_i'}$$

$$R_o = \left. \frac{V_o}{i_o} \right|_{V_s=0} = R_c \parallel R_o'$$

$$R_o' = \left. \frac{V_o}{i_c} \right|_{V_s=0} = i_c = h_{fe} i_b + V_o h_{oe} \rightarrow h_{re} V_o = i_b (h_{ie} + R_s \parallel R_b)$$

$$\rightarrow Y_o = \frac{1}{R_o'} = h_{oe} \frac{h_{fe} h_{re}}{h_{ie} + R_s \parallel R_b}$$



مثال عددی:  $R_c = 1 \text{ k}\Omega$ ,  $R_s = 100 \Omega$ ,  $R_b \gg h_{ie}$

$h_{fe} = \beta = 50$ ,  $h_{ie} = 1100 \Omega$ ,  $h_{re} = 2.5 \times 10^{-4}$ ,  $h_{oe} = 25 \mu\text{S}$

$\frac{1}{h_{oe}} = 40 \text{ k}\Omega$

الف) مقادیر  $A_v$ ,  $R_o$ ,  $R_i$  و  $A_i$  را به طور دقیق بدست آورید. ب) با فرض  $h_{re}$  و  $h_{oe}$

تقریباً مقادیر قسمت الف را بدست آورید

$A_v = \frac{-h_{fe}(R_c \parallel h_{oe})}{h_{ie} - h_{re}h_{fe}R_c} = -44$  الف)

$R_i = R_b \parallel h_{ie} = 1.1 \text{ k}\Omega$

$A_i = -\beta \frac{-i_c}{i_b} = -50 \times 4 = -200$

$Y_o = h_{oe} + \frac{h_{fe}h_{re}}{h_{ie} + R_s \parallel R_b} = 114 \mu\text{S}$   $R_o = \frac{1}{Y_o} = 8.8 \text{ k}\Omega$

$R_o = R_c \parallel R_o = 1 \text{ k}\Omega$

$R_i = R_b \parallel h_{ie} = 1.1 \text{ k}\Omega$

$R_o = R_c \parallel R_o = 1 \text{ k}\Omega$

$A_v = \frac{-h_{fe}R_c}{h_{ie}} = -45.5$

$A_i = -\beta = -50$



$$\begin{cases} V_i = h_{ii} i_i + h_{ir} V_r \\ i_r = h_{ri} i_i + h_{rr} V_r \end{cases}$$

Common Collector  
C.C

$$\begin{cases} V_{bc} = h_{ic} i_b + h_{rc} V_{ec} \\ i_e = h_{fc} i_b + h_{oc} V_{ec} \end{cases}$$

$$h_{ic} = \left. \frac{V_{bc}}{i_b} \right|_{V_{ec}=0}$$

امپدانس ورودی

$$h_{rc} = \left. \frac{V_{bc}}{V_{ec}} \right|_{i_b=0}$$

بهره ولتاژ انتقالی معکوس

$$h_{fc} = \left. \frac{i_e}{i_b} \right|_{V_{ec}=0}$$

بهره جریان مستقیم

$$h_{oc} = \left. \frac{i_e}{V_{ec}} \right|_{i_b=0}$$

امپدانس خروجی

$$V_{bc} = V_{be} + V_{ec} = V_{be} = h_{ie} \times i_b$$

$$h_{ic} = \left. \frac{V_{bc}}{i_b} \right|_{V_{ec}=0} = \frac{h_{ie} \times i_b}{i_b} = h_{ie} \rightarrow \boxed{h_{ic} = h_{ie}}$$

$$h_{rc} = \left. \frac{V_{be} + V_{ec}}{V_{ec}} \right|_{i_b=0} = \frac{-h_{re} \cdot V_{ec} + V_{ec}}{V_{ec}} = 1 - h_{re}$$

$$V_{be} = h_{ie} i_b + h_{re} V_{ec} = -h_{re} V_{ec}$$

$$\rightarrow \boxed{h_{rc} = 1 - h_{re}}$$

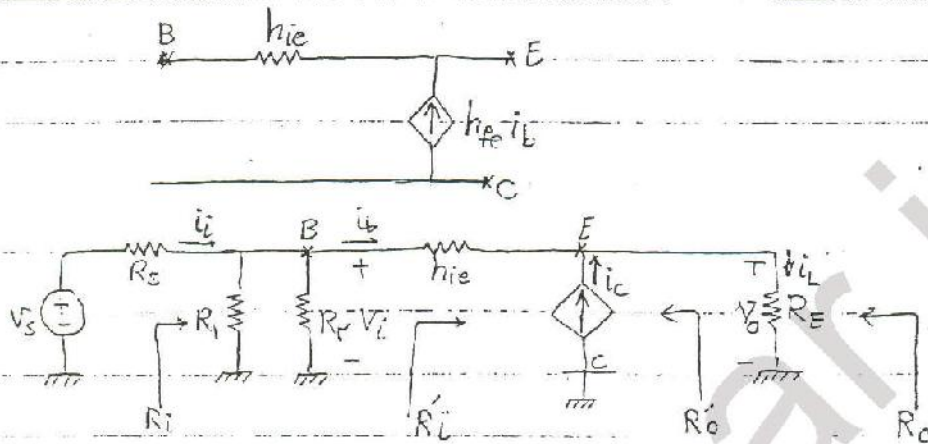
$$h_{fc} = \left. \frac{i_e}{i_b} \right|_{V_{ec}=0} = \frac{-(1 + h_{fe}) i_b}{i_b} = -(1 + h_{fe})$$

$$V_{ec}=0 \rightarrow i_e = h_{fe} i_b$$

$$\rightarrow \boxed{h_{fc} = -(1 + h_{fe})}$$

f<sub>o</sub>

$$h_{oc} = \left. \frac{i_e}{V_{ec}} \right|_{i_b=0} = \frac{-i_c}{-i_c \times \frac{1}{h_{oe}}} = h_{oe} \rightarrow \boxed{h_{oc} = h_{oe}}$$



$$A_i = \frac{I_L}{I_i} = \frac{I_L}{I_b} \cdot \frac{I_b}{I_i} = \frac{I_b + h_{fe} I_b}{I_b} \cdot \frac{R_b}{R_b + R'_i}$$

$$A_v = \frac{V_o}{V_i} = \frac{(1+h_{fe}) I_b \cdot R_E}{(1+h_{fe}) I_b \cdot R_E + h_{ie} \cdot I_b} = \frac{(1+h_{fe}) R_E}{h_{ie} + (1+h_{fe}) R_E} \approx 1$$

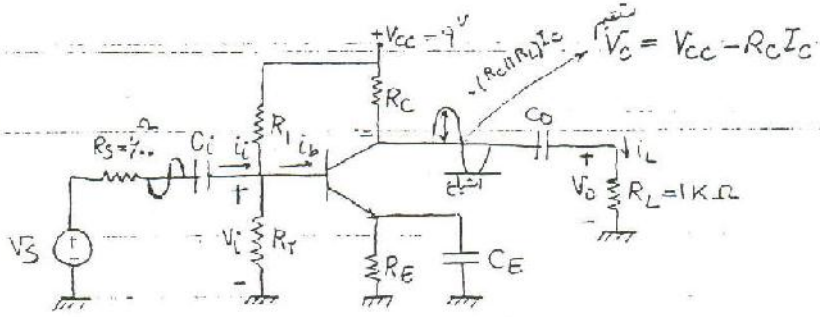
$$\rightarrow A_v = \frac{(1+h_{fe}) R_E}{h_{ie} + (1+h_{fe}) R_E}$$

$$R_i = \frac{V_i}{I_i} = R_1 \parallel R_2 \parallel R'_i$$

$$R'_i = \frac{V_i}{I_b} = \frac{(1+h_{fe}) I_b \cdot R_E + h_{ie} \cdot I_b}{I_b} = (1+h_{fe}) R_E + h_{ie}$$

$$R_o = \left. \frac{V_o}{I_o} \right|_{V_s=0} = R'_o \parallel R_E$$

$$R'_o = \left. \frac{V_o}{I_o} \right|_{V_s=0} = \frac{-I_b \cdot h_{ie} - I_b \cdot R_1 \parallel R_2 \parallel R_s}{-(1+h_{fe}) I_b} = \frac{h_{ie} + R_1 \parallel R_2 \parallel R_s}{(1+h_{fe})}$$

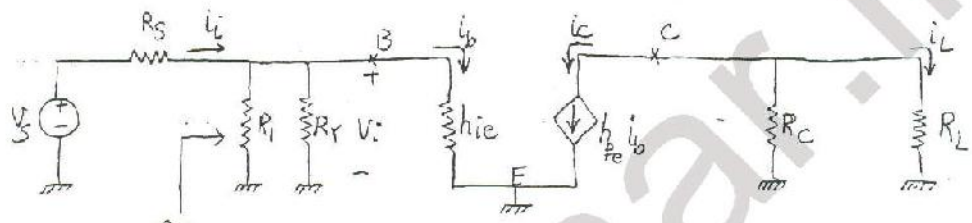


گسار مقابل را با داده های

زیر طراحی کنید.

داده ها:

$\beta = h_{fe} = 200$  ,  $\frac{i_L}{i_i} = A_i \gg 10$  ,  $R_i \gg 1K\Omega$  ,  $V_{opp} \gg 1V$



برای راحتی کار از تقریب مقابل استفاده می کنیم:

$A_i \gg 10 \rightarrow \frac{i_L}{i_i} = \frac{i_L}{i_b} = \frac{i_L}{i_c} \times \frac{i_c}{i_b} = \frac{-R_c}{R_c + R_L} \times h_{fe} \gg 10$

$R_c \gg 1.5 K\Omega$  مقاومت استاندارد  
 $R_c = \frac{1.8 K}{1.5 V} = 1.2 K$

$R_i \approx h_{ie} \gg 1 K\Omega$  ,  $h_{ie} = \frac{2V_T}{I_c} \beta \gg 1 K\Omega \rightarrow I_c \leq 1.5 mA$  ①

$(R_c || R_L) I_c \gg 1V \rightarrow I_c \geq 1.5 V mA \leftarrow V_{op}^+$  ②

$V_{cc} = R_c I_c + V_{CE} + R_E I_c$  چون  $V_{CE_{sat}}$  را ندوده آن را صفر می گیریم

$V_{CE} = V_{cc} - I_c (R_c + R_E) \gg 1V \rightarrow I_c \leq \frac{1}{R_c + R_E}$

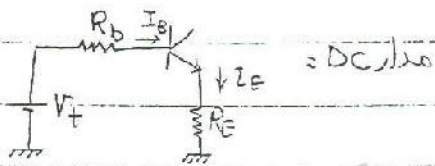
if  $R_E = 0 \rightarrow I_c \leq 1.99 mA \leftarrow V_{op}^-$  ③

① , ② , ③  $\rightarrow I_c = 1 mA$

ع ۱

$$I_c \leq \frac{\Delta}{R_E + R_C} \xrightarrow{I_c = 1 \text{ mA}} R_E = 1 \text{ k}\Omega$$

$$R_b = \frac{\beta_{min} R_E}{I_0} = 10 \text{ k}\Omega$$



$$\begin{cases} R_1 = R_b \frac{V_{CC}}{V_T} \\ R_2 = \frac{R_b}{1 - \frac{V_T}{V_{CC}}} \end{cases}$$

$$V_T = R_b I_B + V_{BE} + R_E I_E = 2.19 \text{ V}$$

$$R_1 = 43 \text{ k}\Omega$$

$$R_2 = 219.9 \text{ k}\Omega$$

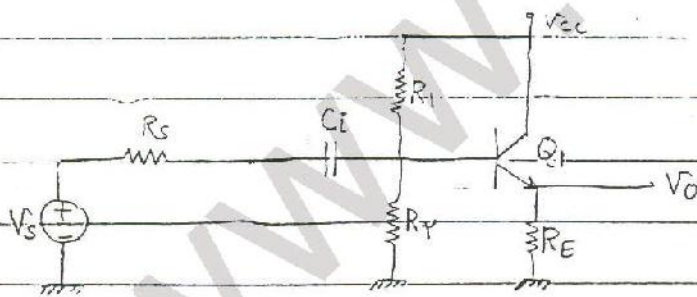
استاندارد

استاندارد

اگر اعداد نیست آمده را در مسئله قرار داده و یکبار دیگر تحلیل کنیم خواهیم دید که:

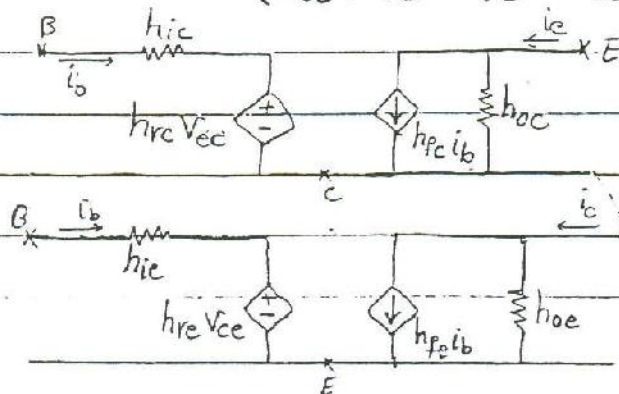
$$\rightarrow R_i = R_1 \parallel R_2 \parallel h_{ie} = 2.19 \text{ k}\Omega, A_i = -124.2, V_{CE} = 1.4 \text{ V}$$

تقویت کننده کلکتور مشترک:



با فرض اینکه پارامترهای هیبرید را در تقویت کننده امیتر مشترک داریم، پارامترهای هیبرید

کلکتور مشترک را بدست می آوریم ( $h_{oc}, h_{rc}, h_{fc}, h_{ic}$ )



$$R_E = 1K, R_S = 10 \Omega$$

سوال: تقویت کننده بیس مشترک با بیس شده:

$$h_{ib} = 214 \Omega, R_L = 1K, h_{fb} = 2,5 \times 10^{-9}, h_{fb} = -198$$

$$h_{ob} = 2,5 \times 10^{-9} S$$

$$\rightarrow A_i = -h_{fb} = 198$$

$$A_v = \frac{-h_{fb} R_L}{h_{ib}} = 920, R_o = \frac{1}{h_{ob}} \parallel R_c = R_c = 1K \Omega$$

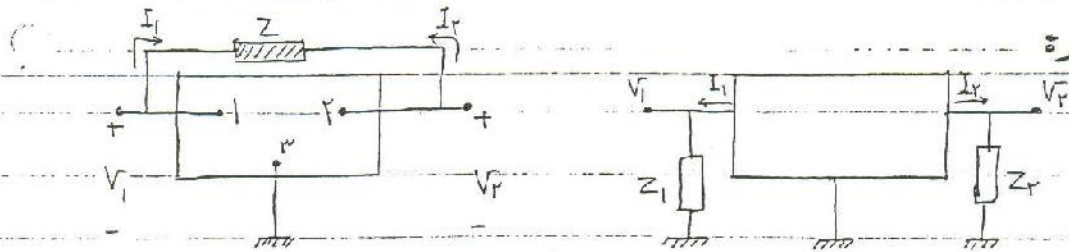
$$R_i = h_{ib} \parallel R_E = h_{ib} = 214 \Omega$$

$$A_{v_s} = \frac{V_o}{V_s} = \frac{V_o}{V_i} \cdot \frac{V_i}{V_s}$$

$$A_{v_s} = A_v \cdot \frac{R_i}{R_i + R_s} = 31,7$$

نوع تقویت کننده	$A_i$	$A_v$	$R_i$	$R_o$
C.E یا خازن با بیس	بالا $h_{fe}$	بالا $\frac{-h_{fe} R_c}{h_{ie}}$	متوسط	بالا
C.E بدون خازن	متوسط	پائین	بالا	بالا
C.C	متوسط	$\approx 1$	بالا	پائین
C.B یا خازن بیس	$\approx 1$	بالا	پائین	بالا

قضیه میلر

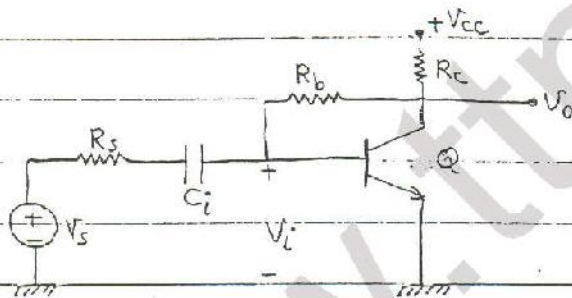


$$\begin{cases} \frac{V_2}{V_1} = k \\ I_1 = -I_2 = \frac{V_1 - V_2}{Z} \end{cases} \rightarrow Z_1 = \frac{V_1}{I_1}, \quad Z_2 = \frac{V_2}{I_2} = \frac{kV_1}{V_2}$$

$$\rightarrow Z_1 = \frac{Z}{1-k}$$

$$Z_2 = \frac{Z}{1-\frac{1}{k}} = \frac{kZ}{k-1}$$

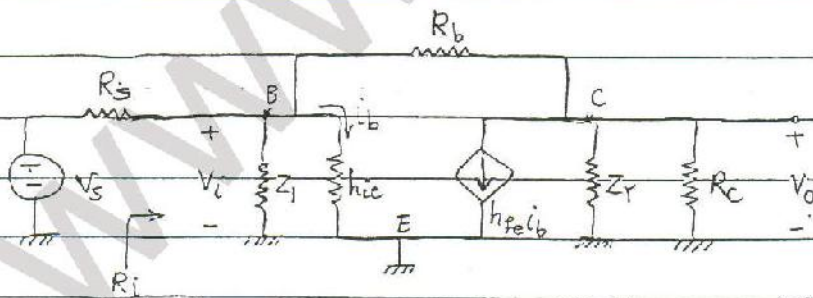
مثال



$A_V = ?$

$A_{V_s} = ?$

$R_i = ?$



$Z_1 = \frac{Z}{1-k}$

$Z_2 = \frac{kZ}{k-1}$

$h_{ie} = 1.5 \text{ K}\Omega$

$h_{fe} = 100$

$(h_{oe})^{-1} = 10 \text{ K}$

$R_b = 200 \text{ K}$

$R_c = 10 \text{ K}$

$R_s = 10 \text{ K}$

$|A_V|$

$A_V = \frac{V_o}{V_i} = \frac{-h_{fe} i_b (\frac{1}{h_{oe}} \parallel Z_r \parallel R_c)}{i_b h_{ie}} \approx -11.4$

$R_i = Z_1 \parallel h_{ie} = 130.119 \Omega$

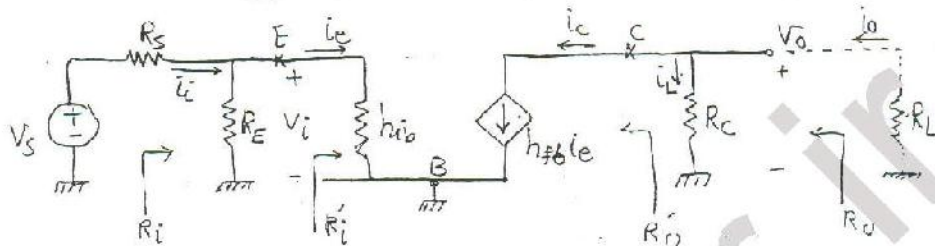
$A_{V_s} = \frac{V_o}{V_s} = \frac{V_o}{V_i} \cdot \frac{V_i}{V_s} = A_V \cdot \frac{R_i}{R_i + R_s} = -10.4$

$$h_{ib} = \frac{V_{eb}}{i_e} = \frac{h_{ie}}{1+h_{fe}}$$

$$h_{rb} = \frac{V_{eb}}{V_{cb}} = \frac{h_{ie} h_{oe} - h_{re}}{1+h_{fe}}$$

$$h_{fb} = \frac{i_c}{i_e} = \frac{-h_{fe}}{1+h_{fe}}$$

$$h_{ob} = \frac{i_c}{V_{cb}} = \frac{h_{oe}}{1+h_{fe}}$$



$$A_i = \frac{i_L}{i_i} = \frac{i_L}{i_c} \cdot \frac{i_c}{i_e} \cdot \frac{i_e}{i_i} = -1 \times h_{fb} \times \frac{R_E}{R_E + h_{ib}}$$

$$\rightarrow A_i = \frac{-h_{fb} R_E}{R_E + h_{ib}} \approx -h_{fb}$$

$$R_i = \frac{V_i}{i_i} = R_E \parallel R'_i$$

$$R'_i = \frac{V_i}{i_e} = \frac{i_e h_{ib}}{i_e} = h_{ib} \rightarrow R'_i = h_{ib}$$

$$\rightarrow R_i = R_E \parallel h_{ib} \approx h_{ib}$$

$$A_v = \frac{V_o}{V_i} = \frac{-R_C i_c}{h_{ib} i_e} = \frac{h_{fb} R_C}{h_{ib}} = \frac{h_{fe} R_C}{h_{ie}} \rightarrow A_v = \frac{-h_{fe} R_C}{h_{ie}}$$

$$A_v = A_i \frac{R_C}{R_i}$$

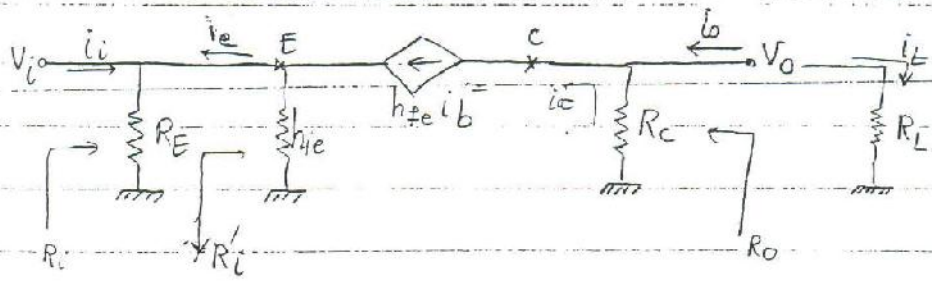
راه دیگر برای بدست آوردن  $A_v$ :

$$R_o = \frac{V_o}{i_o} \Big|_{V_s=0} = R_C \parallel R'_o = R_C \rightarrow R_o = R_C$$

$$R'_o = \frac{V_o}{i_c} \Big|_{V_s=0} = \infty \rightarrow R'_o = \infty$$

فقط





$$A_i = \frac{i_c}{i_i} = \frac{i_c}{i_e} \cdot \frac{i_e}{i_i} = \frac{h_{fe} i_b}{(1+h_{fe}) i_b} \times \frac{-R_E}{R_E + R'_i} = \frac{-h_{fe}}{1+h_{fe}}$$

$$\rightarrow A_i = -\frac{h_{fe}}{1+h_{fe}}$$

$$R_i = \frac{V_i}{i_i} = R_E \parallel R'_i = R_E \parallel \frac{V_i}{-i_e} = R_E \parallel \frac{h_{ie}}{1+h_{fe}} \approx \frac{h_{ie}}{1+h_{fe}}$$

$$\rightarrow R_i = R_E \parallel \frac{h_{ie}}{1+h_{fe}} \approx \frac{h_{ie}}{1+h_{fe}}$$

$$R'_i = \frac{-i_b h_{ie}}{-(1+h_{fe}) i_b} = \frac{h_{ie}}{1+h_{fe}} \rightarrow R'_i = \frac{h_{ie}}{1+h_{fe}}$$

$$A_v = \frac{V_o}{V_i} = \frac{-R_C i_c}{-i_b h_{ie}} = \frac{h_{fe} R_C}{h_{ie}} \rightarrow A_v = \frac{h_{fe} R_C}{h_{ie}}$$

$$R_o = \left. \frac{V_o}{i_o} \right|_{V_s=0} = R_C \parallel R'_o = R_C \parallel \frac{V_o}{i_i} = R_C, \quad R_o = R_C$$

اگر خازن  $C_b$  و  $C_e$  را از مدار برداریم آن گاه...

$$R_i = \frac{V_i}{i_i} = R_E \parallel R'_i = R_E \parallel \frac{V_i}{-i_e} = R_E \parallel \frac{h_{ie} + R_b}{1+h_{fe}} = \frac{h_{ie} + R_b}{1+h_{fe}}$$

$$R'_i = \frac{-i_b h_{ie} - i_b (R_b)}{-(1+h_{fe}) i_b} = \frac{h_{ie} + R_b}{1+h_{fe}}$$

$$A_v = \frac{V_o}{V_i} = \frac{-R_C i_c}{-i_b h_{ie} - i_b R_b} = \frac{h_{fe} R_C}{h_{ie} + R_b}$$

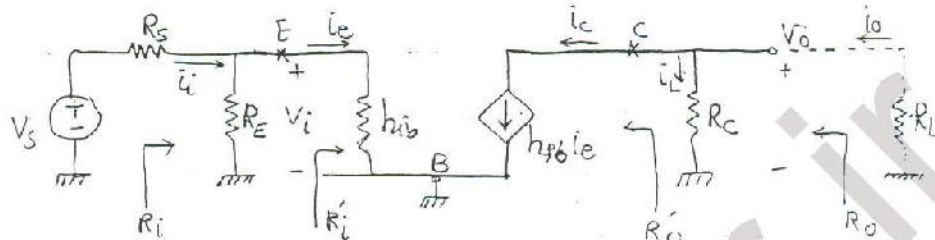
L

$$h_{ib} = \frac{V_{eb}}{i_e} = \frac{h_{ie}}{1+h_{fe}}$$

$$h_{rb} = \frac{V_{eb}}{V_{cb}} = \frac{h_{ie}k_{oc}}{1+h_{fe}} - h_{re}$$

$$h_{fb} = \frac{i_c}{i_e} = \frac{-h_{fo}}{1+h_{fe}}$$

$$h_{ob} = \frac{i_c}{V_{cb}} = \frac{k_{oc}}{1+h_{fe}}$$



$$A_i = \frac{i_L}{i_i} = \frac{i_L}{i_c} \cdot \frac{i_c}{i_e} \cdot \frac{i_e}{i_i} = -1 \times h_{fb} \times \frac{R_E}{R_E + h_{ib}}$$

$$\rightarrow A_i = \frac{-h_{fb} R_E}{R_E + h_{ib}} \approx -h_{fb}$$

$$R_i = \frac{V_i}{i_i} = R_E \parallel R'_i$$

$$R'_i = \frac{V_i}{i_e} = \frac{i_e h_{ib}}{i_e} = h_{ib} \rightarrow R'_i = h_{ib}$$

$$\rightarrow R_i = R_E \parallel h_{ib} \approx h_{ib}$$

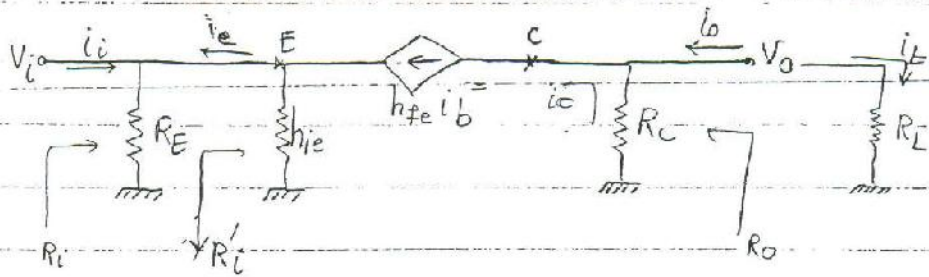
$$A_v = \frac{V_o}{V_i} = \frac{-R_C i_c}{h_{ib} i_e} = \frac{h_{fb} R_C}{h_{ib}} = \frac{h_{fe} R_C}{h_{ie}} \rightarrow A_v = -\frac{h_{fe} R_C}{h_{ie}}$$

$$A_v = A_i \frac{R_C}{R_i}$$

راه دیگر برای بدست آوردن  $A_v$ :

$$R_o = \left. \frac{V_o}{i_o} \right|_{V_s=0} = R_C \parallel R'_o = R_C \rightarrow R_o = R_C$$

$$R'_o = \left. \frac{V_o}{i_c} \right|_{V_s=0} = \infty \rightarrow R'_o = \infty$$



$$A_i = \frac{i_c}{i_i} = \frac{i_c}{i_e} \cdot \frac{i_e}{i_b} = \frac{h_{fe} i_b}{(1+h_{fe}) i_b} \times \frac{-R_E}{R_E + R'_i} = \frac{-h_{fe}}{1+h_{fe}}$$

$$\rightarrow A_i = -\frac{h_{fe}}{1+h_{fe}}$$

$$R_i = \frac{V_i}{i_i} = R_E \parallel R'_i = R_E \parallel \frac{V_i}{-i_e} = R_E \parallel \frac{h_{ie}}{1+h_{fe}} \approx \frac{h_{ie}}{1+h_{fe}}$$

$$\rightarrow R_i = R_E \parallel \frac{h_{ie}}{1+h_{fe}} \approx \frac{h_{ie}}{1+h_{fe}}$$

$$R'_i = \frac{-i_b h_{ie}}{-(1+h_{fe}) i_b} = \frac{h_{ie}}{1+h_{fe}} \rightarrow R'_i = \frac{h_{ie}}{1+h_{fe}}$$

$$A_v = \frac{V_o}{V_i} = \frac{-R_C i_c}{-i_b h_{ie}} = \frac{h_{fe} R_C}{h_{ie}} \rightarrow A_v = \frac{h_{fe}}{h_{ie}} R_C$$

$$R_o = \frac{V_o}{i_o} \Big|_{V_s=0} = R_C \parallel R'_o = R_C \parallel \frac{V_o}{i_b} \approx R_C \rightarrow R_o = R_C$$

اگر خازن \$C\_b\$ را از مدار برداریم آن گاه...

$$R_i = \frac{V_i}{i_i} = R_E \parallel R'_i = R_E \parallel \frac{V_i}{-i_e} = R_E \parallel \frac{h_{ie} + R_b}{1+h_{fe}} = \frac{h_{ie} + R_b}{1+h_{fe}}$$

$$R'_i = \frac{-i_b h_{ie} - i_b (R_b)}{-(1+h_{fe}) i_b} = \frac{h_{ie} + R_b}{1+h_{fe}}$$

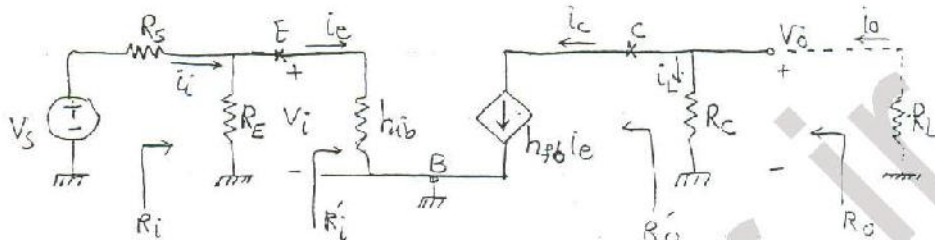
$$A_v = \frac{V_o}{V_i} = \frac{-R_C i_c}{-i_b h_{ie} - i_b R_b} = \frac{h_{fe} R_C}{h_{ie} + R_b}$$

$$h_{ib} = \frac{V_{eb}}{i_e} = \frac{h_{ie}}{1+h_{fe}}$$

$$h_{rb} = \frac{V_{eb}}{V_{cb}} = \frac{h_{ie}k_{oe}}{1+h_{fe}} - h_{re}$$

$$h_{fb} = \frac{i_c}{i_e} = \frac{-h_{fe}}{1+h_{fe}}$$

$$h_{ob} = \frac{i_c}{V_{cb}} = \frac{k_{oe}}{1+h_{fe}}$$



$$A_i = \frac{i_L}{i_i} = \frac{i_L}{i_c} \cdot \frac{i_c}{i_e} \cdot \frac{i_e}{i_i} = -1 \times h_{fb} \times \frac{R_E}{R_E + h_{ib}}$$

$$\rightarrow A_i = \frac{-h_{fb} R_E}{R_E + h_{ib}} \approx -h_{fb}$$

$$R_i = \frac{V_i}{i_i} = R_E \parallel R'_i$$

$$R'_i = \frac{V_i}{i_e} = \frac{i_e h_{ib}}{i_e} = h_{ib} \rightarrow R'_i = h_{ib}$$

$$\rightarrow R_i = R_E \parallel h_{ib} \approx h_{ib}$$

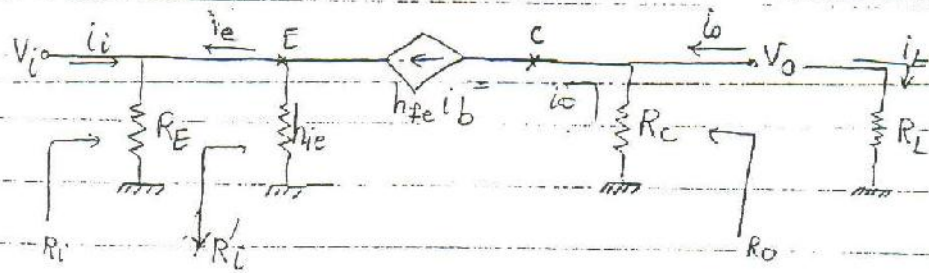
$$A_v = \frac{V_o}{V_i} = \frac{-R_c i_c}{h_{ib} i_e} = \frac{h_{fb} R_c}{h_{ib}} = \frac{h_{fe} R_c}{h_{ie}} \rightarrow A_v = -\frac{h_{fe} R_c}{h_{ie}}$$

$$A_v = A_i \frac{R_c}{R_i}$$

راه دیگر برای بدست آوردن  $A_v$ :

$$R_o = \left. \frac{V_o}{i_o} \right|_{V_{S_s}=0} = R_c \parallel R'_o = R_c \rightarrow R_o = R_c$$

$$R'_o = \left. \frac{V_o}{i_c} \right|_{V_{S_s}=0} = \infty \rightarrow R'_o = \infty$$



$$A_i = \frac{i_c}{i_i} = \frac{i_c}{i_e} \cdot \frac{i_e}{i_b} = \frac{h_{fe}i_b}{(1+h_{fe})i_b} \times \frac{-R_E}{R_E+R'_i} = \frac{-h_{fe}}{1+h_{fe}}$$

$$\rightarrow A_i = \frac{h_{fe}}{1+h_{fe}}$$

$$R_i = \frac{V_i}{i_i} = R_E \parallel R'_i = R_E \parallel \frac{V_i}{-i_e} = R_E \parallel \frac{h_{ie}}{1+h_{fe}} \approx \frac{h_{ie}}{1+h_{fe}}$$

$$\rightarrow R_i = R_E \parallel \frac{h_{ie}}{1+h_{fe}} \approx \frac{h_{ie}}{1+h_{fe}}$$

$$R'_i = \frac{-i_b h_{ie}}{-(1+h_{fe})i_b} = \frac{h_{ie}}{1+h_{fe}} \rightarrow R'_i = \frac{h_{ie}}{1+h_{fe}}$$

$$A_v = \frac{V_o}{V_i} = \frac{-R_C i_c}{-i_b h_{ie}} = \frac{h_{fe} R_C}{h_{ie}} \rightarrow A_v = \frac{h_{fe} R_C}{h_{ie}}$$

$$R_o = \frac{V_o}{i_o} \Big|_{V_s=0} = R_C \parallel R'_o = R_C \parallel \frac{V_o}{i_c} = R_C \rightarrow R_o = R_C$$

اگر خازن \$C\_b\$ و الزم داریم داریم آن گاه

$$R_i = \frac{V_i}{i_i} = R_E \parallel R'_i = R_E \parallel \frac{V_i}{-i_e} = R_E \parallel \frac{h_{ie} + R_b}{1+h_{fe}} = \frac{h_{ie} + R_b}{1+h_{fe}}$$

$$R'_i = \frac{-i_b h_{ie} - i_b (R_b)}{-(1+h_{fe})i_b} = \frac{h_{ie} + R_b}{1+h_{fe}}$$

$$A_v = \frac{V_o}{V_i} = \frac{-R_C i_c}{-i_b h_{ie} - i_b R_b} = \frac{h_{fe} R_C}{h_{ie} + R_b}$$

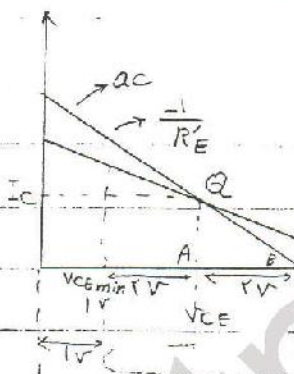
$$A_v = \frac{(1+h_{fe})(R_E \parallel R_L)}{h_{ie} + (1+h_{fe})(R_E \parallel R_L)} > 100 \rightarrow \frac{h_{fe}(R_E \parallel R_L)}{\frac{26V_T \beta}{I_C} + h_{fe}(R_E \parallel R_L)} > 100$$

$$\rightarrow 1 + \frac{1}{R_E} < \beta \Delta I_C$$

$$V_{CC} = R_E I_C + V_{CE}$$

$$I_C = \frac{V_{CC} - V_{CE}}{R_E}$$

$$R_E + \beta \Delta V_{CE} < \beta V_T$$



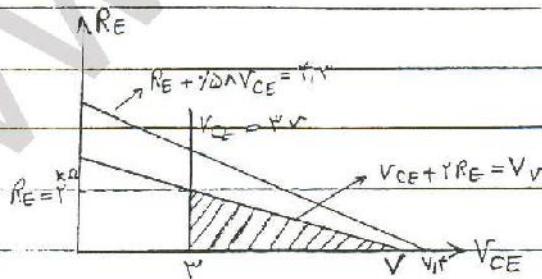
$$\rightarrow V_{CE} \geq 2V$$

$$AB = I_C \cdot R'_E > 2V$$

$$R'_E = \frac{R_E \cdot R_L}{R_E + R_L}$$

$$\rightarrow I_C \frac{R_E}{1 + R_E} > 2V$$

$$\rightarrow \beta R_E + V_{CE} < \beta V_T$$



$$\rightarrow R_E = 10 \text{ k}\Omega$$

$$V_{CE} = 2V$$

$$I_C = \frac{V_{CC} - V_{CE}}{R_E} = 1 \text{ mA}$$

$$R_i = R'_i \parallel R_b = [h_{ie} + (1+h_{fe})(R_E \parallel R_L)] \parallel R_b > 10 \text{ k}\Omega$$

$$h_{ie \text{ min}} = \frac{26V_T \beta_{\text{min}}}{I_C} = 1.4 \text{ k}\Omega$$

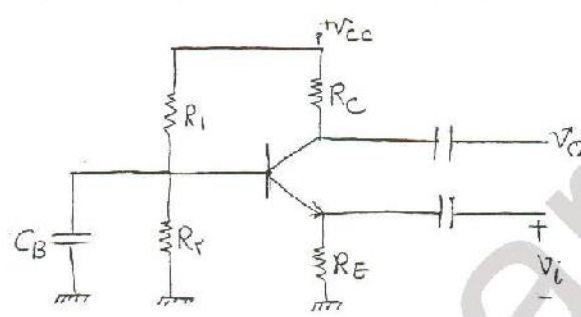
$$\rightarrow R_b > 10 \text{ k}\Omega$$

$$R_b = \frac{\beta_{min} \cdot R_E}{10} \approx 1 \text{ k}\Omega \rightarrow R_1 \parallel R_2 = 1 \text{ k}\Omega$$

با نظریه تقویت کننده

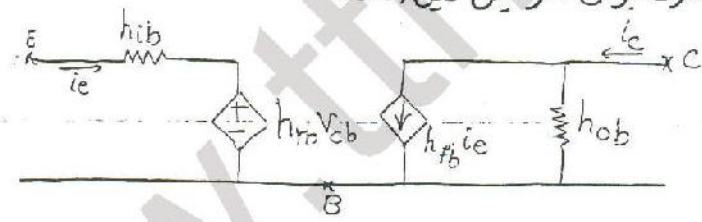
$$R_1 = 40 \text{ k}\Omega, R_2 = 50 \text{ k}\Omega$$

$\downarrow$  انتخابی       $\downarrow$  انتخابی  
 $33 \text{ k}\Omega$        $54 \text{ k}\Omega$



تقویت کننده بیس مشترک =

استفاده از خازن CB صرفاً برای افزایش گین است.



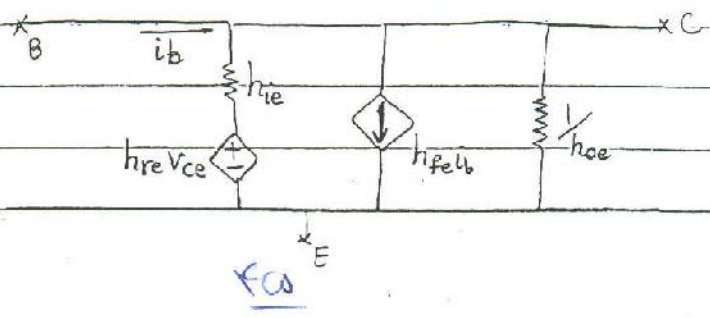
$$\begin{cases} V_{eb} = h_{ib} \cdot i_e + h_{rb} V_{cb} \\ i_c = h_{fb} i_e + V_{cb} h_{ob} \end{cases}$$

$$h_{ib} = \left. \frac{V_{eb}}{i_e} \right|_{V_{cb}=0}$$

$$h_{rb} = \left. \frac{V_{eb}}{V_{cb}} \right|_{i_e=0}$$

$$h_{fb} = \left. \frac{i_c}{i_e} \right|_{V_{cb}=0}$$

$$h_{ob} = \left. \frac{i_c}{V_{cb}} \right|_{i_e=0}$$



تمرین: پارامترهای هیبرید را محاسبه کنید.

جواب:

$$h_{ib} = \frac{h_{ie}}{h_{ie}h_{oe} + (1+h_{fe})(1-h_{r_e})}$$

$$h_{fb} = \frac{-h_{fe}(1-h_{r_e}) - h_{oe}h_{ie}}{(1+h_{fe})(1-h_{r_e}) - h_{oe}h_{ie}}$$

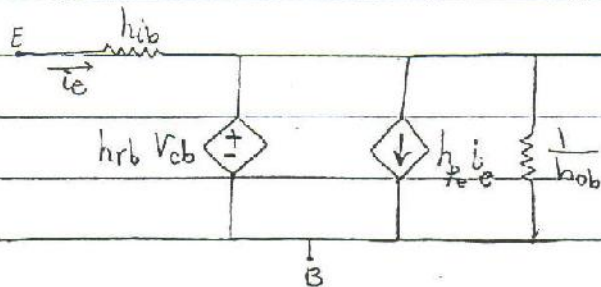
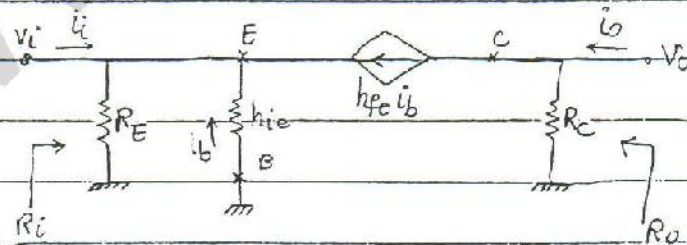
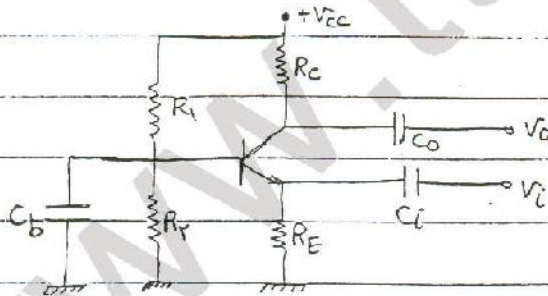
$$h_{rb} = \frac{h_{ie}h_{oe}}{1+h_{fe}} - h_{r_e}$$

$$h_{ob} = \frac{h_{oe}}{h_{ie}h_{oe} + (1+h_{fe})(1-h_{r_e})}$$

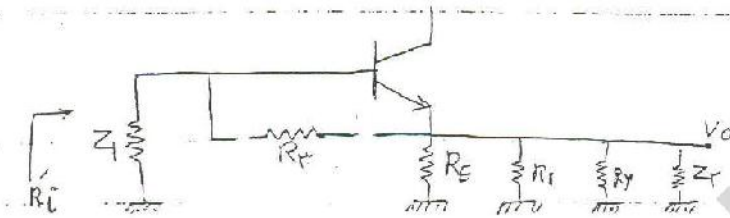
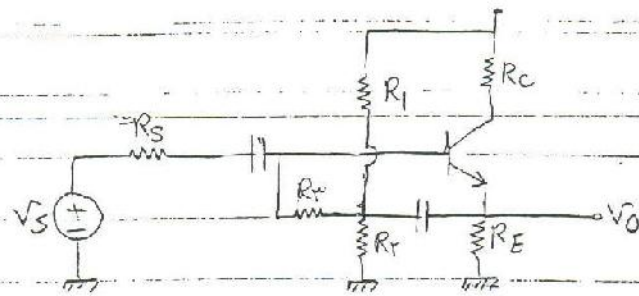
می توان از تقریبهای  $h_{fe} \gg h_{ie}h_{oe}$

$$\rightarrow h_{ib} = \frac{h_{ie}}{1+h_{fe}}, \quad h_{fb} = \frac{-h_{fe}}{1+h_{fe}}, \quad h_{ob} = \frac{h_{oe}}{1+h_{fe}}$$

تقویت کننده بیس مشترک:



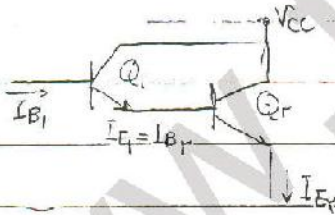




مدار معادل AC

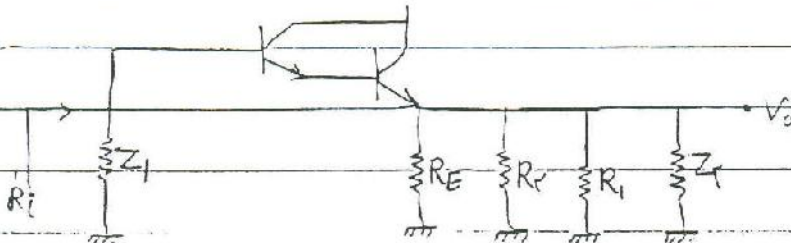
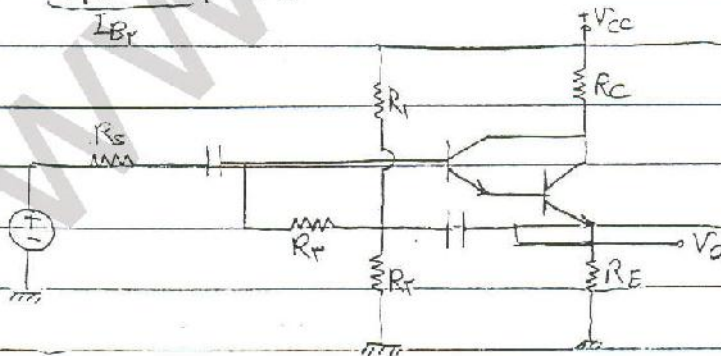
$$R'_i = R_i \parallel Z_i \parallel [h_{ie} + (1 + \beta_{ie})(R_E \parallel R_1 \parallel R_2 \parallel Z_T)]$$

$$Z_i = \frac{R_{\pi}}{1 - A_v}, \quad Z_T = \frac{R_T}{A_v}$$



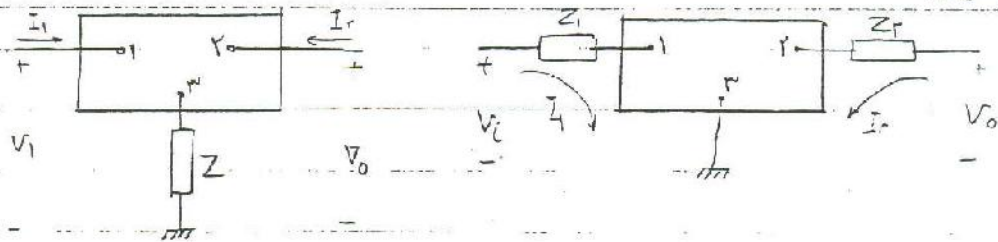
دارلینگتون

$$I_{E2} = \frac{I_{B1}(1 + \beta_1)(1 + \beta_2)}{I_{B2}}$$



←

قضیه دوم میله:



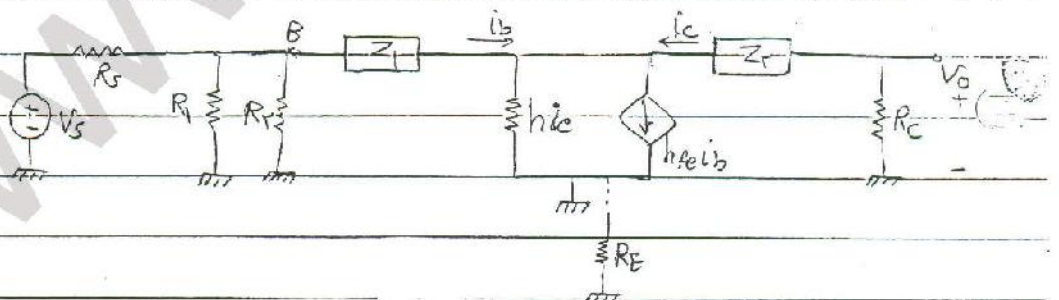
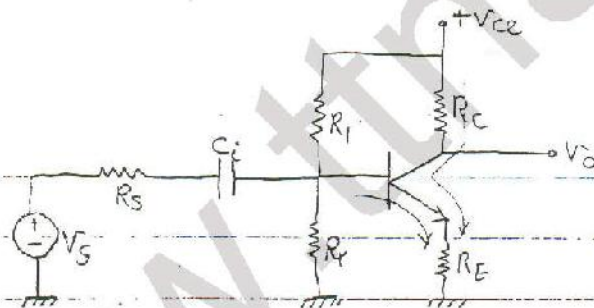
$$\frac{I_r}{I_1} = K$$

$$\begin{cases} V_i = V_{1r} + Z(I_1 + I_r) \\ V_o = V_{r} + Z(I_1 + I_r) \end{cases}$$

$$\begin{cases} V_i = Z_1 I_1 + V_{1r} \\ V_r = Z_r I_r + V_{r} \end{cases}$$

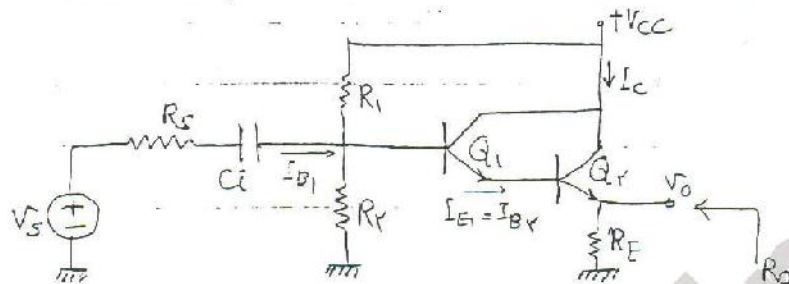
$$\rightarrow \begin{cases} Z_1 = Z(1+K) \\ Z_r = \frac{K+1}{K} Z \end{cases}$$

مثال:

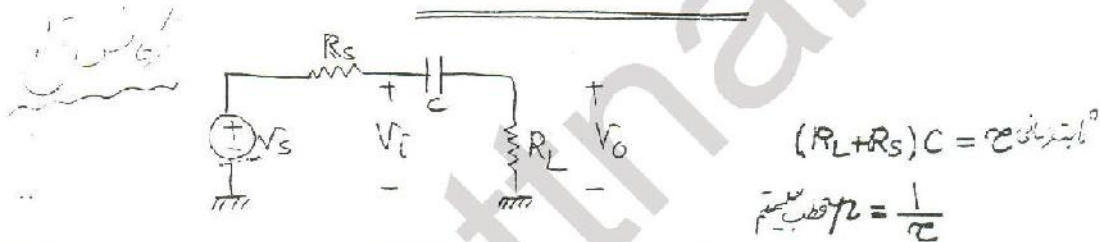


$$Z_r = R_E(1+h_{fe}) \rightarrow Z_r = \frac{1+h_{fe}}{h_{fe}} R_E \approx R_E, \quad (h_{oe})^{-1} \gg (R_E + R_C)$$

$$R_i = Z_i \parallel [h_{ie1} + (1+h_{fe1})[h_{ier} + (1+h_{fer})(R_E \parallel R_r \parallel R_z)]]$$



$$R_o = R_E \parallel \frac{1}{1+h_{fer}} [h_{ier} + \frac{1}{1+h_{fe1}} [h_{ie1} + R_1 \parallel R_2 \parallel R_S]]$$



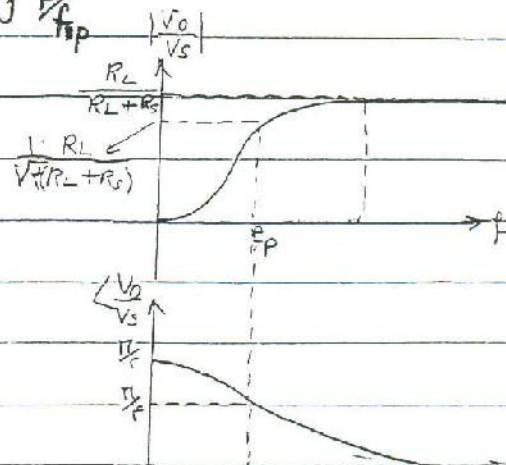
$$\frac{V_o}{V_s} = \frac{R_L}{R_L + R_S + \frac{1}{Cs}} = \frac{R_L C s}{(R_L + R_S) C s + 1} = \frac{R_L}{R_L + R_S} \cdot \frac{s}{s + \tau_c}$$

$$\frac{V_o(j\omega)}{V_s(j\omega)} = \frac{jR_L C \omega}{1 + j(R_L + R_S)\omega C} \quad \text{if } \omega_{\tau_c} = \frac{1}{(R_L + R_S)}$$

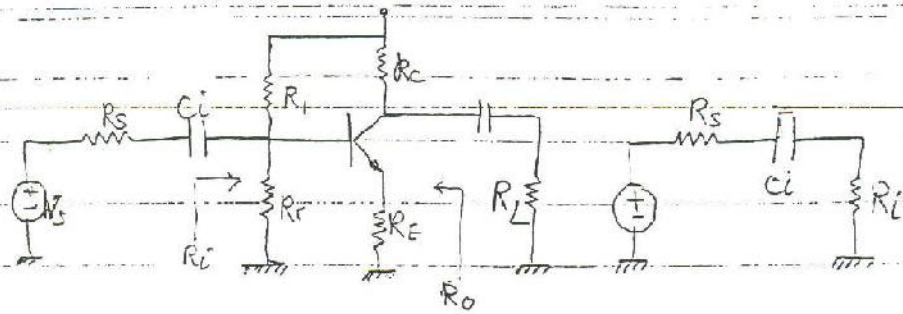
$$\frac{V_o(j\omega)}{V_s(j\omega)} = \frac{jR_L C \omega}{1 + j\frac{\omega}{\omega_p}} = \frac{j\pi R_L C f}{1 + j\frac{f}{f_p}}$$

$$\left| \frac{V_o}{V_s} \right| = \frac{\pi R_L C f}{\sqrt{1 + \left(\frac{f}{f_p}\right)^2}} = \frac{1}{\sqrt{r}}$$

$$\angle \frac{V_o}{V_s} = \frac{\pi}{2} - \text{Arctg} \frac{f}{f_p} = \frac{\pi}{4}$$



FL



$$f_L = \frac{1}{\pi(R_i + R_s)C_i}$$

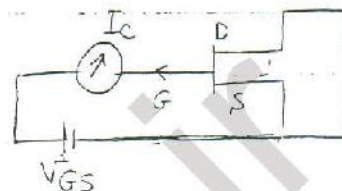
www.ttnar.ir

$$V_{GS} = 0 \rightarrow I_{DS} = I_{DSS} = 11 \text{ mA}$$

$$V_{GS} = -1.1 \text{ V} \rightarrow I_{DS} = 11 \left( 1 - \frac{-1.1}{-2} \right)^2 = 0.11 \text{ mA}$$

$$V_{GS} = 2 \rightarrow I_{OS} = 4 \text{ mA}$$

$$\begin{cases} I_{GSS} = 10 \text{ nA} \\ P_D = 10 \text{ W} \\ T = -40t + 100 \end{cases}$$

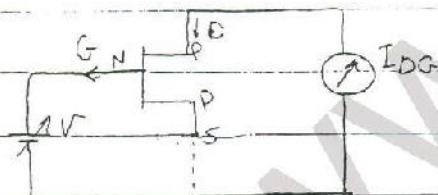


$$I_{GSS} = 0.01 \text{ } \mu\text{A}$$

$$V_{GS} = 1.1 \text{ V}$$

$$T = 100^\circ \rightarrow I_{GSS} = 1 \text{ } \mu\text{A}$$

$$V_{GS} = 1.1 \text{ V}$$



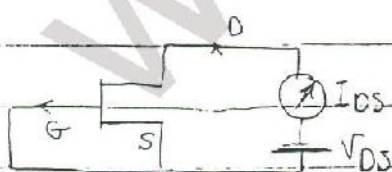
در حالتی که خط صاف نیست

$$BV_{DG} = -10 \text{ V}$$

$$2 \text{ mA} \times 1 \text{ V}$$

$$10 \text{ } \mu\text{A}$$

در حالتی که خط صاف وجود دارد:  $BV_{DG} = -BV_{GS}$



$$V_{GS} = 0 \rightarrow I_{DSS} = I_{DS}$$

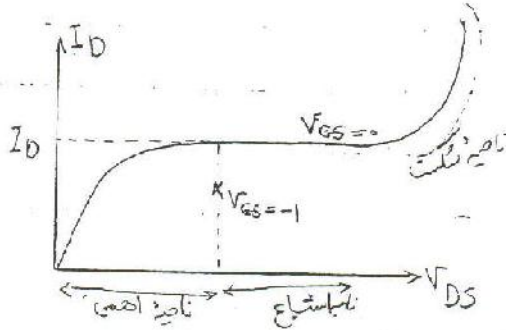
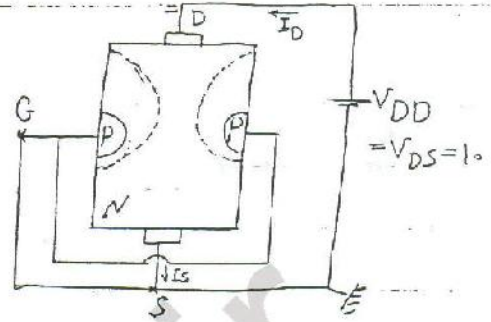
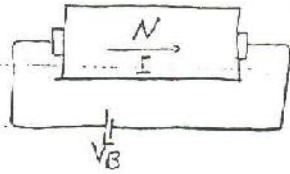


$$V_{DS} = 10 \text{ V}$$

$$V_{GS} = 1.1 \text{ V}$$

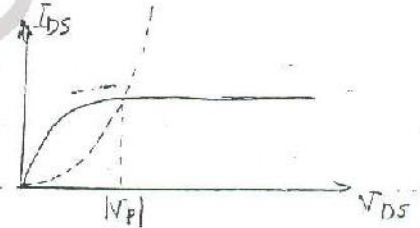
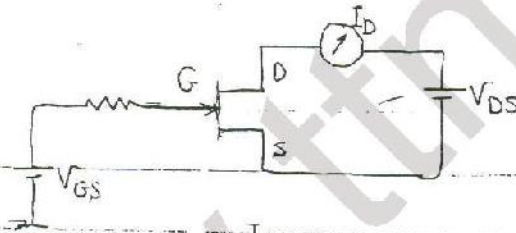
FA

(فترانزیستور اثر میدانی) (field effect transistor) FET

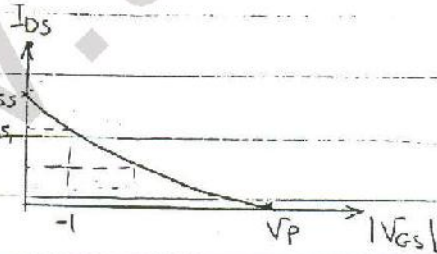


$I_{DSS} \rightarrow V_{GS} = 0$

$V_{GS} = V_p \rightarrow I_D = 0$



مشخصه انتقال



$V_{GS} = 0 \rightarrow I_{DS} = I_{DSS}$

$V_{GS} = V_p \rightarrow I_{DS} = 0$

$$I_{DS} = I_{DSS} \left(1 - \left|\frac{V_{GS}}{V_p}\right|\right)^2$$

$V_p = -2V$

$I_{DSS} = 12mA$

$$\rightarrow \begin{cases} V_{GS} = 0 \\ V_{GS} = -1V \\ V_{GS} = -2V \end{cases}$$

مسئله عددی:

$$\rightarrow \frac{-V_{GS}}{R_S} = I_{DSS} \left(1 - \frac{V_{GS}}{V_P}\right)^2 \rightarrow V_{GS} = \begin{cases} -3.2 \\ -1.8 \end{cases}$$

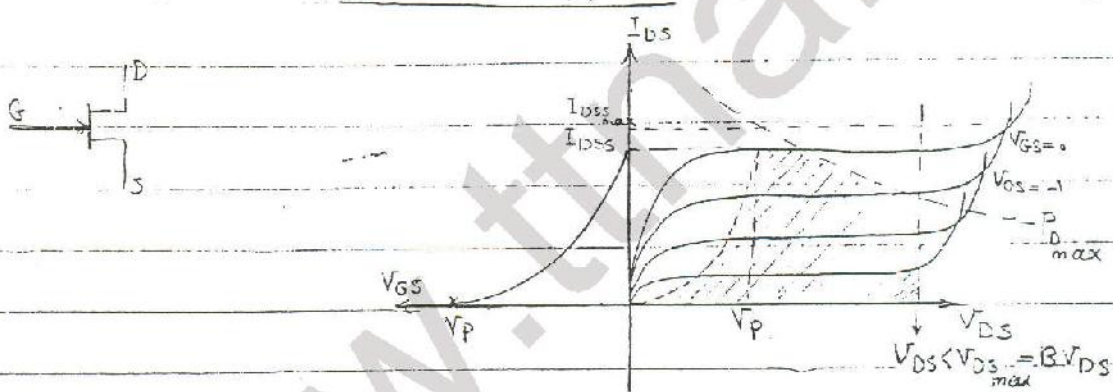
$$\begin{cases} I_{DS} < I_{DSS} \\ |V_{GS}| < |V_P| \end{cases} \begin{array}{l} \text{شرایطی که باید حتماً در} \\ \text{مدارها چک شود.} \end{array}$$

$$V_{DS} = V_D - V_S = V_{DD} - R_D I_{DS} = R_S \cdot I_{DSS}$$

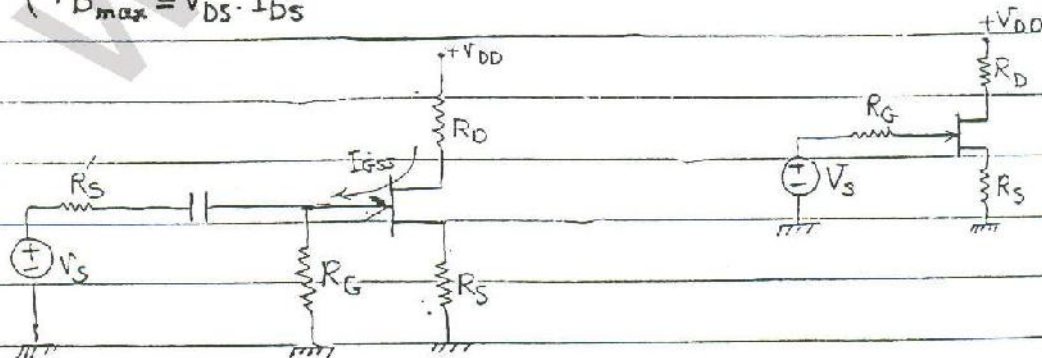
$$\rightarrow V_{DS} = 5.18 \text{ V}$$

$$V_{DS} \geq V_{GS} - V_P \rightarrow V_{DS} \geq -3.2 - (-5) = 1.8 \text{ V}$$

چون که در این برای ما صاف می آید



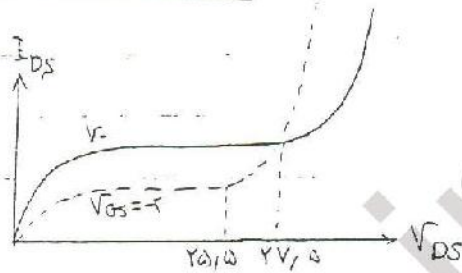
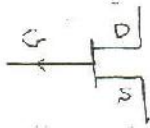
$$\begin{cases} V_{DS} \geq V_{GS} - V_P \\ BV_{DS} \\ I_{DSmax} \\ P_{Dmax} = V_{DS} \cdot I_{DS} \end{cases} \begin{array}{l} \text{پارامترهای} \\ \text{محدودکننده} \end{array} \quad \begin{cases} I_{DS} = I_{DSS} \left(1 - \left|\frac{V_{GS}}{V_P}\right|\right)^2 \\ I_{DS} < I_{DSS} \end{cases}$$



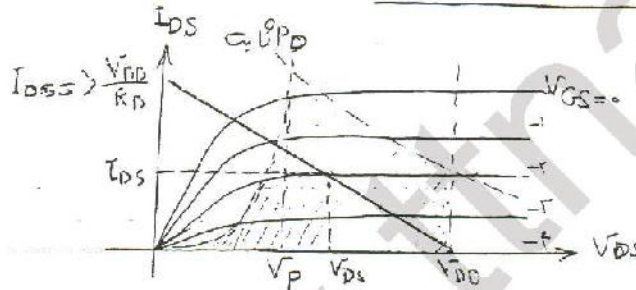
$$I_{D,off} = 1 \mu A \rightarrow V_{GS} = 1^V \approx V_P$$

$$V_{DS} = 12 V$$

$BV_{DS}$

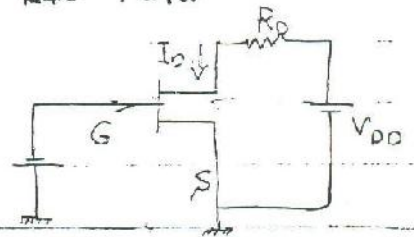


$$BV_{DS} = -2V_P, \quad V_{DS} = V_{DG} + V_{GS}$$



$$P_D = I_{DS} V_{DS}$$

$$T = 25^\circ$$

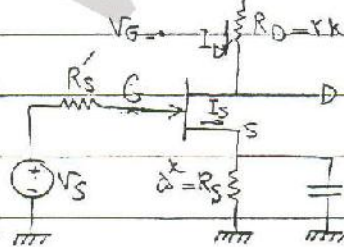


ماتریس بار  $V_{DD} = R_D I_D + V_{DS}$

$$V_{GS} = 0 \leftarrow V_{DS} = |V_P| \quad \text{نامی اشباع}$$

$$V_{DS} \geq V_{GS} - V_P$$

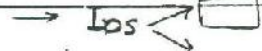
مثال:  $V_P, I_{DSS}$  و  $V_{GS}$  را برای مدارات زیر داشته باشید



$$I_{DSS} = 5 mA, \quad V_P = -5 V$$

$$\begin{cases} V_{GS} = V_G - V_S = -V_S = -R_S I_{DS} \\ I_{DS} = I_{DSS} \left(1 - \frac{V_{GS}}{V_P}\right)^2 = I_{DSS} \left(1 + \frac{R_S I_{DS}}{V_P}\right)^2 \end{cases}$$

$$I_{DS} = \frac{-V_{GS}}{R_S} = 1.24$$





$$\begin{cases} I_{GSS} \\ \textcircled{1} V_G = I_{GSS} \times R_G = 10^{-9} \times 10^9 = 1 \text{ V} \\ I_{GSS} = 10 \text{ nA} \\ \textcircled{2} V_{GS} = V_G - V_S = V_G - R_S I_S \\ = 1 - 4 = -3 \end{cases} \quad \textcircled{3} I_{DS} - I_{GSS} = I_S$$

$R_G$  اگر کوچک باشد دیگر آمپدانس ورودی آن خیلی بزرگ نخواهد بود و اگر خیلی بزرگ باشد با

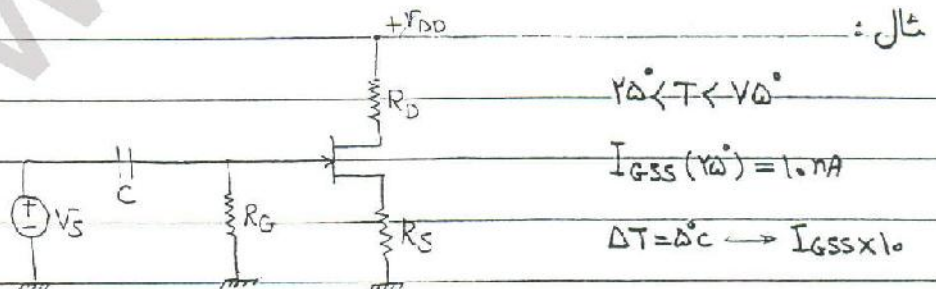
تغییرات دما که  $I_{GSS}$  تغییر می‌کند  $V_G$  تغییر خواهد کرد و احتمال این است که FET از ناحیه اشباع خارج

شود. همچنین با توجه به اینکه در ورودی سیگنال‌های noise وجود دارند اگر  $R_G$  خیلی بزرگ باشد

این سیگنال به خروجی منتقل می‌شود و در خروجی با توان بالایی تقویت و ظاهر می‌شود اما اگر  $R_G$

مناسب باشد noise توسط  $R_G$  به زمین منتقل می‌شود و در خروجی ظاهر نخواهد شد.

$$\textcircled{1}, \textcircled{2}, \textcircled{3} \rightarrow V_{GS} = R_S I_{DS} + (R_S + R_G) I_{GSS}$$



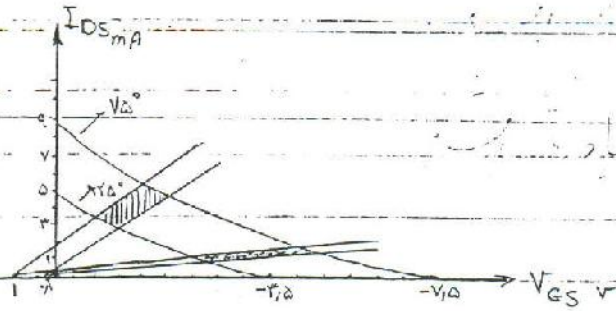
$$I_{DS} = I_{DSS} \left(1 - \left|\frac{V_{GS}}{V_P}\right|\right)^2 \quad \begin{matrix} 25^\circ \left\{ \begin{array}{l} I_{DSS} = 5 \text{ mA} \\ V_P = -4.5 \text{ V} \end{array} \right. & 75^\circ \left\{ \begin{array}{l} I_{DSS} = 9 \text{ mA} \\ V_P = -7.5 \text{ V} \end{array} \right. \end{matrix}$$

a)  $R_S = 500 \Omega$

b)  $R_S = 5 \text{ k}\Omega$

مشخصات انتقالی را رسم کنید.

de



a)  $R_S = \infty \Omega$

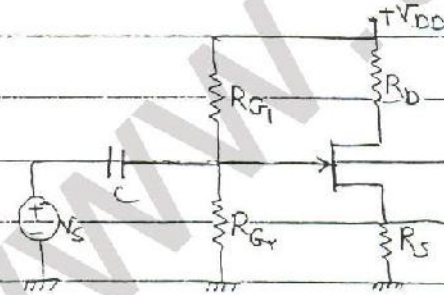
$$V_{D^0} \longrightarrow V_{GS} = -\infty \cdot I_{DS} + V_{DD}$$

$$V_{D^0} \longrightarrow V_{GS} \approx -\infty \cdot I_{DS} + V_{DD}$$

b)  $R_S = \infty \text{ k}\Omega$

$$V_{D^0} \longrightarrow V_{GS} = -\infty \cdot I_{DS} + V_{DD}$$

$$V_{D^0} \longrightarrow V_{GS} = -\infty \cdot I_D + V_{DD}$$

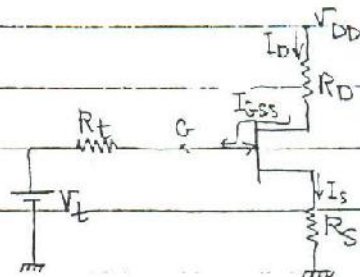


$$V_{GS} = V_G - V_S$$

$$V_{GS} = V_{DD} \times \frac{R_{G2}}{R_{G1} + R_{G2}} - R_S I_S$$

$$V_t = \frac{R_{G2}}{R_{G1} + R_{G2}} V_{DD}$$

$$R_t = R_{G1} \parallel R_{G2}$$

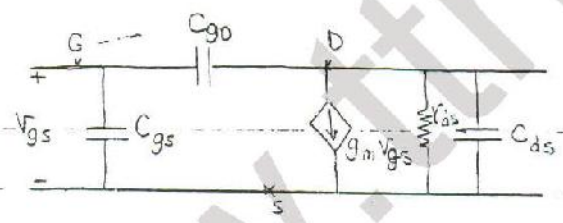


$$\begin{cases} I_D = I_S + I_{GSS} \\ V_G = R_t \times I_{GSS} + V_t \\ V_S = -R_S I_S \end{cases} \quad \bullet \quad V_{GS} = V_G - V_S$$

تحلیل AC و تقویت کننده ها =

C.S	G ورودی	D خروجی	$ A_V  > 1$
C.D	G ورودی	S خروجی	$A_V \approx 1$
C.G	S ورودی	D خروجی	$A_V > 1$ ← کاربرد چندانی ندارد

مدار معادل =



$C_{gs}, C_{gd} \approx PF$

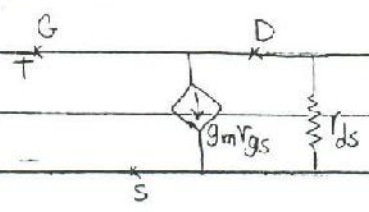
$C_{ds} \ll C_{gs}, C_{gd}$

$C_{iss} = C_{gs} + C_{gd}$  (مقادیری که در

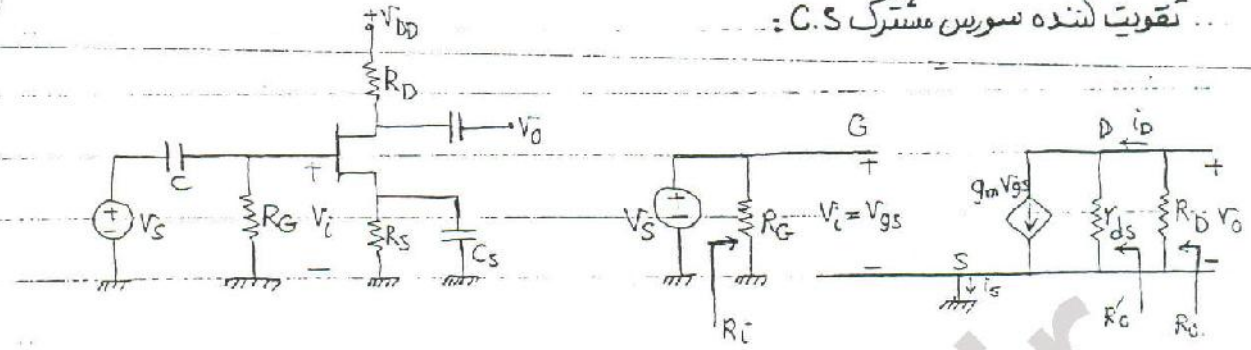
$C_{rss} = C_{gd}$  (مقادیری که در

کاتالوگ FET داده می شود)

مدل سیگنال کوچک FET =



تقویت کننده سورس مشترک C.S.:

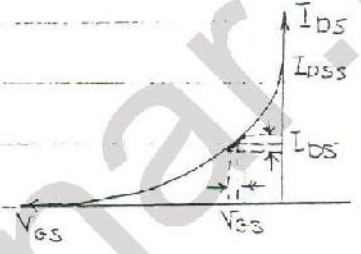


$$A_V = \frac{V_o}{V_i} = \frac{-g_m V_{gs} (R_D \parallel R_{ds})}{V_{gs}} = -g_m (R_D \parallel R_{ds})$$

$$g_m = \frac{\Delta I_{DS}}{\Delta V_{GS}} = g_{m0} \left(1 - \frac{V_{GS}}{V_P}\right)$$

$$g_{m0} = \frac{2 I_{DSS}}{|V_P|}$$

*نسبت تغییر در ولتاژ به تغییر در جریان*



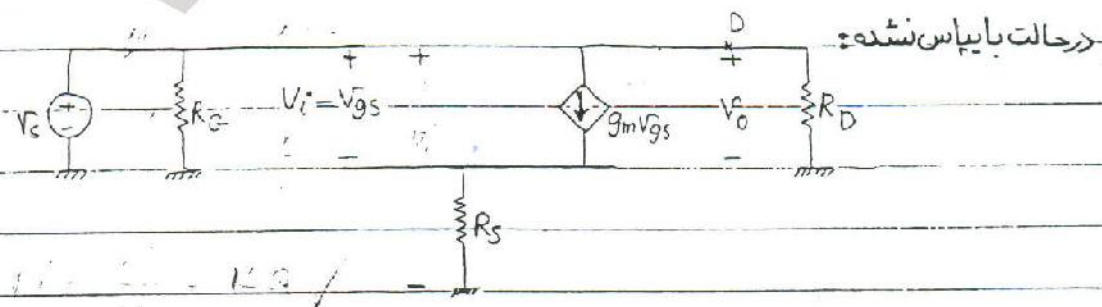
$$R_i = R_G$$

$$R_o = \left. \frac{V_o}{i_o} \right|_{V_s=0}, \quad R_o = R_D \parallel R_o'$$

$$R_o' = \frac{V_o}{i_o} = r_{ds} \rightarrow R_o = R_D \parallel r_{ds}$$

با توجه به اینکه  $V_s$  از نظر ازمین است در نتیجه  $V_i = V_{GS}$  لذا در این نوع تقویت کننده ها علاوه

بر پارامترهای بالا باید  $V_{i,pp}$  را نیز محاسبه و محدود کنیم

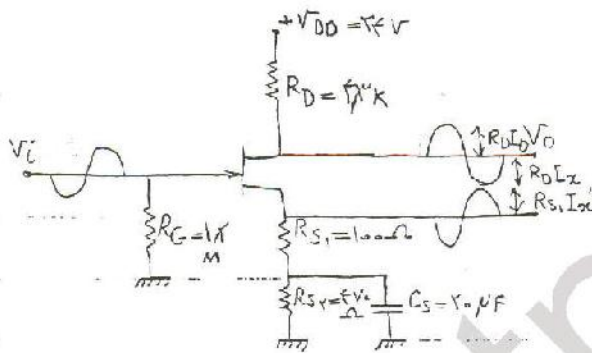
$$V_{i,pp} = \frac{V_{opp}}{A_V}$$


$$A_V = \frac{V_o}{V_i} = \frac{-g_m V_{gs} R_D}{V_{gs} + V_{gs} g_m R_S} = \frac{-g_m R_D}{1 + g_m R_S}$$

$$\rightarrow A_V = \frac{-g_m R_D}{1 + g_m R_S}$$

$$R_i = R_G$$

$$R_o = R_D$$



$$I_{DSS} = 4 \text{ mA}$$

مثال =

$$V_P = -4 \text{ V}$$

$$R_i, R_o, A_V, V_{opp}, P_L = ?$$

$$I_{DS} = I_{DSS} \left(1 - \left|\frac{V_{GS}}{V_P}\right|\right)^2$$

$$V_{GS} = V_G - V_S = 0 - I_{DS} (R_{S1} + R_{Sr}) = -1.5V I_{DS}$$

$$\rightarrow I_{DS} = 1.9 \text{ mA}$$

$$\rightarrow V_{GS} = -1.14 \text{ V}$$

$$g_m = \frac{2 I_{DSS}}{|V_P|} \left(1 - \frac{V_{GS}}{V_P}\right) = 1.13 \text{ mS}$$

$$A_V = \frac{-g_m R_D}{1 + g_m R_{S1}} = -0.15, \quad R_i = R_G = 1 \text{ k}\Omega$$

$$R_o = R_D = 1 \text{ k}\Omega$$

$$V_D = V_{DD} - R_D I_D$$

$$V_{op}^+ = R_D I_D \rightarrow V_{op}^+ = 1.9 \text{ V}$$

$$(dc) V_S = R_{S1} I_{DS} + R_{Sr} I_{DS}$$

$$(ac) V_S = R_{S1} I_D$$

$$V_{op}^- = V_{DS} \times \frac{R_D}{R_{S1} + R_D}$$

$$\rightarrow V_{op}^- = 9.14 \text{ V}$$

$$(dc) V_{DS} = V_D - V_S = V_{DD} - R_D I_D - I_D (R_{S1} + R_{Sr}) = 9.15 \text{ V}$$

at

$$\rightarrow V_{opp} = 1.9 \times 9.14 = 1.7 \text{ V}$$

تقویت کننده درین حالت

$$R_{cs} = R_{sr} \parallel (R_{s1} + r_s)$$

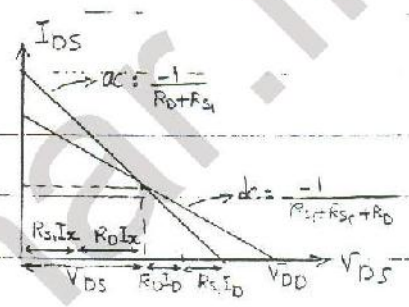
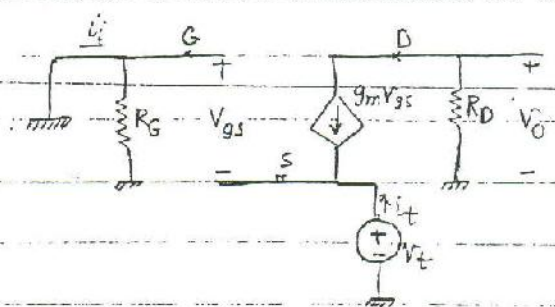
$$i_t = -g_m V_{gs}$$

$$V_t = -V_{gs} \rightarrow r_s = \frac{V_t}{i_t} = \frac{1}{g_m}$$

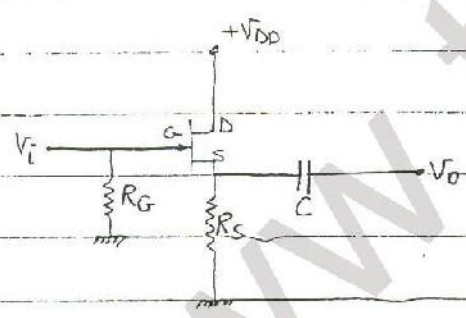
$$\rightarrow R_{cs} = r_s \parallel (100 + 1718) = 300 \Omega$$

$$\rightarrow f_L = \frac{1}{2\pi R_{cs} C_{cs}} = 2415 \text{ Hz}$$

روش دیگر یافتن  $V_{app}$  از روی خط بار dc و ac



تقویت کننده درین مشترک C.D. :



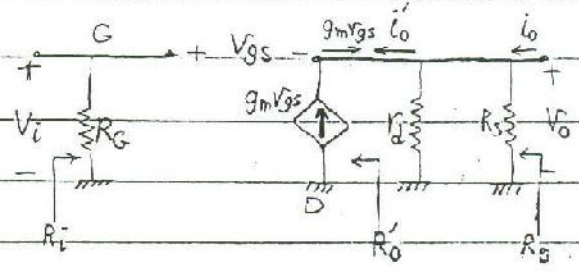
$$A_v = \frac{V_o}{V_i} = \frac{g_m V_{gs} (r_d \parallel R_s) R_L}{V_{gs} + g_m V_{gs} (r_d \parallel R_s)}$$

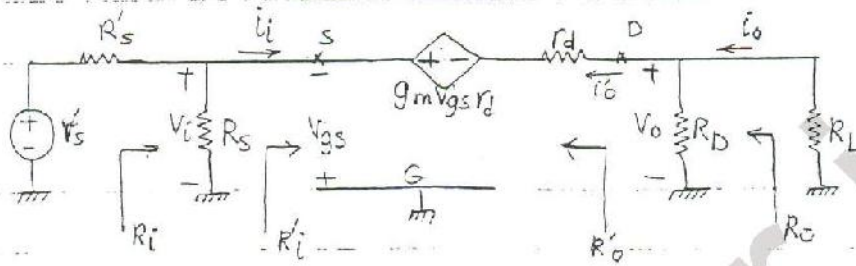
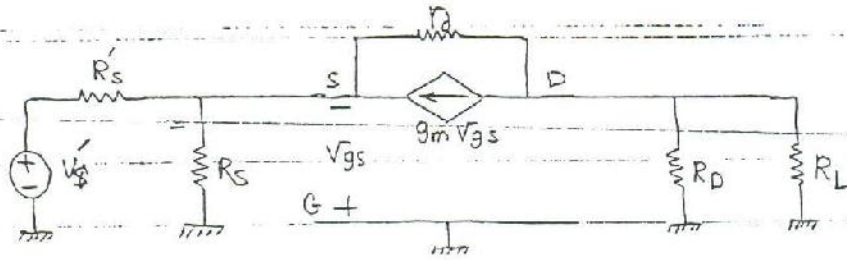
$$\rightarrow A_v = \frac{g_m R_L}{1 + g_m R_L} < 1, \quad R_i = R_G$$

$$R_o = \left. \frac{V_o}{i_o} \right|_{V_i=0} = R_o' \parallel (r_d \parallel R_s)$$

$$R_o' = \frac{V_o}{i_{R_o'}} = \frac{-V_{gs}}{-g_m V_{gs}} = \frac{1}{g_m}$$

$$\rightarrow R_o = \left( \frac{1}{g_m} \right) \parallel (r_d \parallel R_s) = \frac{1}{g_m} \parallel R_s$$





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

$$V_o = (R_D \parallel R_L) i_i$$

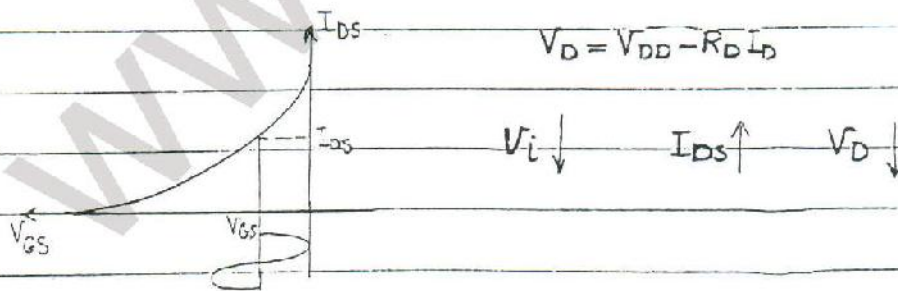
$$\text{KVL: } +V_{gs} + g_m V_{gs} r_d + r_d i_i + (R_D \parallel R_L) i_i = 0$$

$$V_i = -V_{gs}$$

$$i_i = -V_{gs} \frac{1 + g_m r_d}{r_d + (R_D \parallel R_L)}$$

$$\rightarrow A_V = \frac{V_o}{V_i} = \frac{(R_D \parallel R_L) \left[ \frac{V_{gs} (1 + g_m r_d)}{r_d + (R_D \parallel R_L)} \right]}{-V_{gs}}$$

$$\rightarrow A_V = \frac{(R_D \parallel R_L) (1 + g_m r_d)}{r_d + (R_D \parallel R_L)}$$



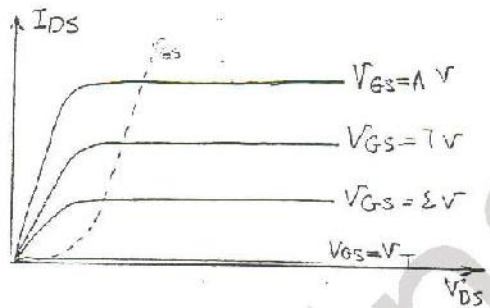
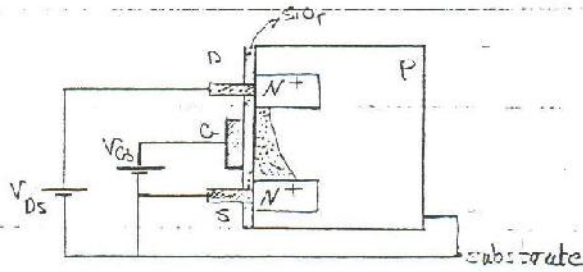
$$A_V = \frac{(R_D \parallel R_L) (g_m r_d)}{r_d} \approx g_m (R_D \parallel R_L) \rightarrow A_V \approx g_m (R_D \parallel R_L)$$

$$R_{oi} = \frac{V_i}{i_i} = R_s \parallel R'_i, \quad R'_i = \frac{V_i}{i_i} = \frac{-V_{gs}}{-V_{gs} \frac{1 + g_m r_d}{r_d + (R_D \parallel R_L)}} \approx \frac{1}{g_m}$$

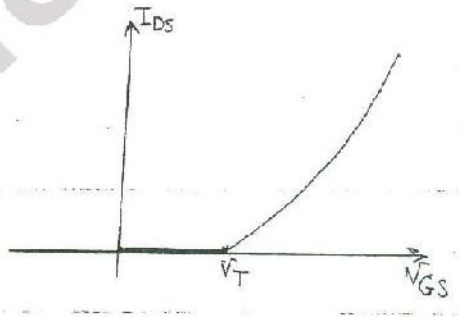
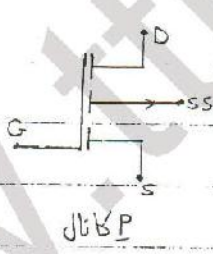
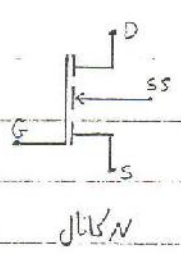
$$\rightarrow R'_i = \frac{r_d + (R_D \parallel R_L)}{1 + g_m r_d} \approx \frac{1}{g_m}$$

or

۲-نوع افزایشی :



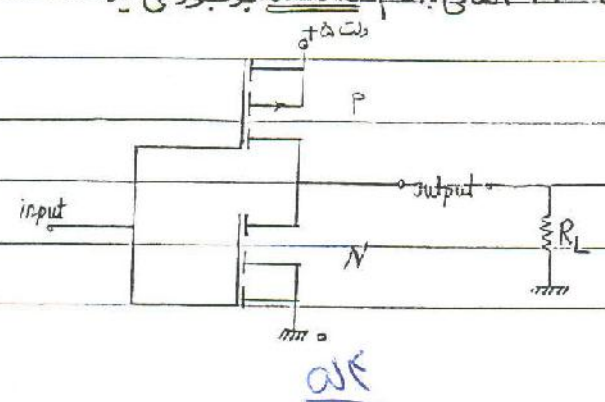
ت  
 $V_T = V_{GD} = 1.3$   
 ولتاژ آستانه تشکیل کانال



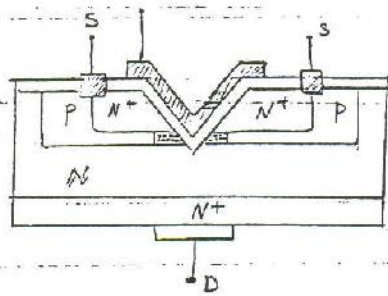
$$I_D = \frac{1}{2} \beta (V_{GS} - V_T)^2, \quad V_{GS} \geq V_T, \quad \beta = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} \frac{A}{V^2}$$

$$V_{DS_{sat}} = V_{GS} - V_T$$

از ترکیب NMOS (ن کانال) و PMOS (پ کانال) به نام CMOS بوجود می آید







: VMOS

کاربرد VMOS در مدارهای سوئیچینگ با جریان بالا است چون مقاومت کمی دارد.

www.ttnar.ir

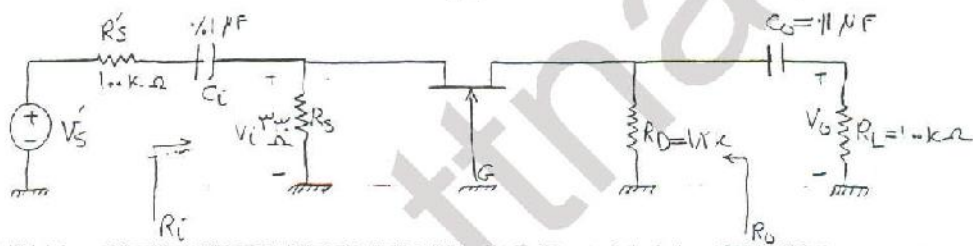
$$\rightarrow R_i = R_s \parallel \left( \frac{r_d + (R_D \parallel R_L)}{1 + g_m r_d} \right) \approx R_s \parallel \frac{1}{g_m}$$

$$R_o = \left. \frac{V_o}{i_o} \right|_{V_{gs}=0} = R_D \parallel R'_o$$

$$R'_o = \frac{V_o}{i_o} = \frac{r_d i_o + g_m (V_{gs}) r_d + i_o (R_s \parallel R'_s)}{i_o} = r_d + g_m r_d (R_s \parallel R'_s) + (R_s \parallel R'_s)$$

$$\text{Since } r_d \rightarrow R'_o = r_d (1 + g_m (R_s \parallel R'_s))$$

$$\rightarrow R_o = R_D \parallel [r_d (1 + g_m (R_s \parallel R'_s))] \approx R_D$$



مثال

$$V_{gs} = -1 \text{ V}, \quad g_m = 2 \text{ mA/V}, \quad r_d = \infty$$

$$R_i, R_o, A_v, f_L = ?$$

$$A_v = \frac{(1 + g_m r_d)}{r_d + R_L} \times R'_L \approx R'_L \left( \frac{1}{r_d} + g_m \right) \rightarrow A_v = g_m R'_L = g_m (R_L \parallel R_D) = 2 \text{ V/V}$$

$$R_i = R_s \parallel \frac{1}{g_m} = 100 \text{ k}\Omega, \quad R_o = R_D = 1 \text{ k}\Omega$$

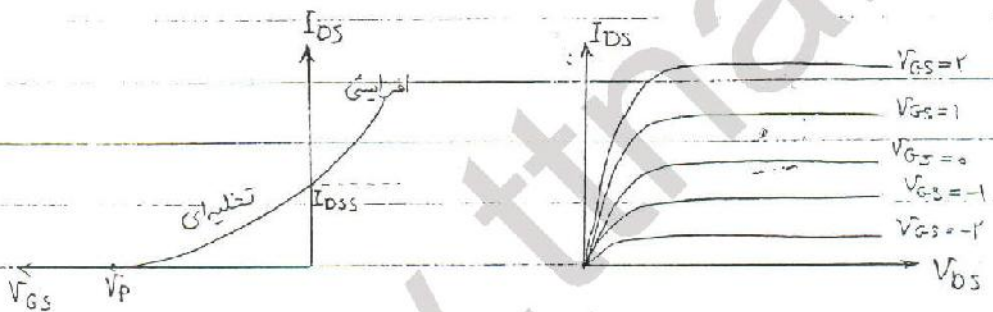
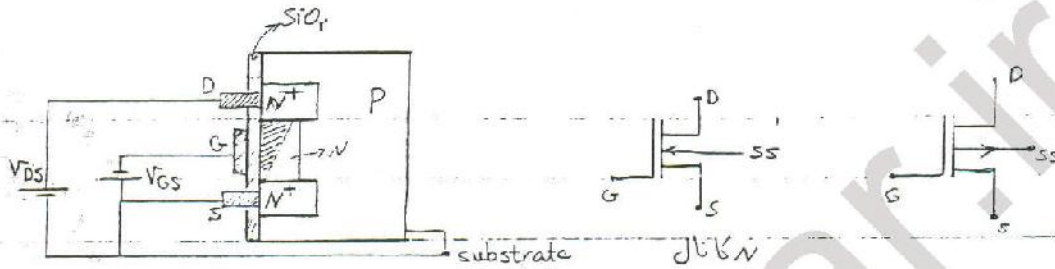
$$R_{ci} = R_i + R_s \approx 100 \text{ k}\Omega, \quad \tau_{ci} = R_{ci} \times C_c = 100 \text{ }\mu\text{s}$$

$$R_{co} = R_D + R_L \approx 100 \text{ k}\Omega, \quad \tau_{co} = R_{co} \times C_o = 100 \text{ }\mu\text{s}, \quad f_{ci} = \frac{1}{2\pi\tau_{ci}} = 1.59 \text{ kHz}$$

# MOS FET : دو نوع از این تقویت کننده داریم .

1- تخلیه ای Depletion      2- افزایشی Enhancement

نوع تخلیه ای :



$$I_{DS} = I_{DSS} \left(1 - \frac{V_{GS}}{V_P}\right)^2, \quad g_m = g_{m_0} \left(1 - \frac{V_{GS}}{V_P}\right)$$

$$g_{m_0} = \frac{2 I_{DSS}}{|V_P|}$$

مثال :  $I_{DSS} = 1 \text{ mA}$  ,  $V_P = -5 \text{ V}$

الف - کانال  $V_{GS} = -3 \text{ V} \rightarrow I_{DS} = 1 \left(1 - \frac{-3}{-5}\right)^2 = 0.16 \text{ mA}$

$V_{GS} = 2.5 \text{ V} \rightarrow I_{DS} = 1 \left(1 - \frac{2.5}{-5}\right)^2 = 1.6 \text{ mA}$

$V_{GS} = -3 \text{ V} \rightarrow I_{DS} = 0.16 \text{ mA}$

$V_{GS} = 2.5 \text{ V} \rightarrow I_{DS} = 1.6 \text{ mA}$

ب - P-کانال  $I_{DSS} = 1 \text{ mA}$   
 $V_P = 5 \text{ V}$