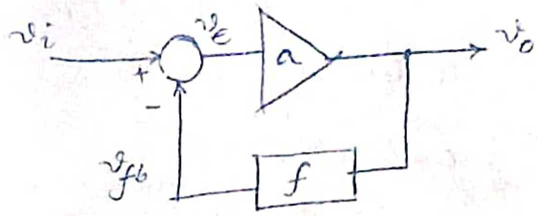
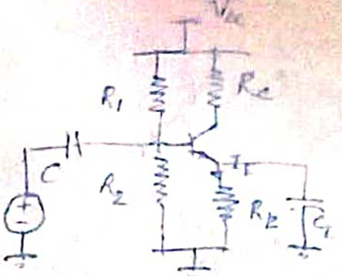
EC301

Ideal feedback configuration:





$$I_E = \frac{V_{BB} - V_{BE}}{R_E + \frac{R_B}{\beta+1}}$$

$$R_E \gg \frac{R_B}{\beta+1}$$

$V_{BB} \gg V_{BE}$

$V_{BB} = \frac{R_2}{R_1+R_2} V_{cc}$

$v_E = v_i - v_{fb}, \quad v_{fb} = f \cdot v_o$

$= v_i - f v_o$

$v_o = a v_E$

$= a(v_i - f v_o)$

$= a v_i - a f v_o \quad \Rightarrow \quad v_o(1+af) = a v_i$

$I = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_T$

$\Rightarrow \frac{v_o}{v_i} = \frac{a}{1+af} = A \rightarrow$ closed loop gain

$af = T \rightarrow$ loop gain

2.5

100 K

$R_D = 10\,K\Omega$

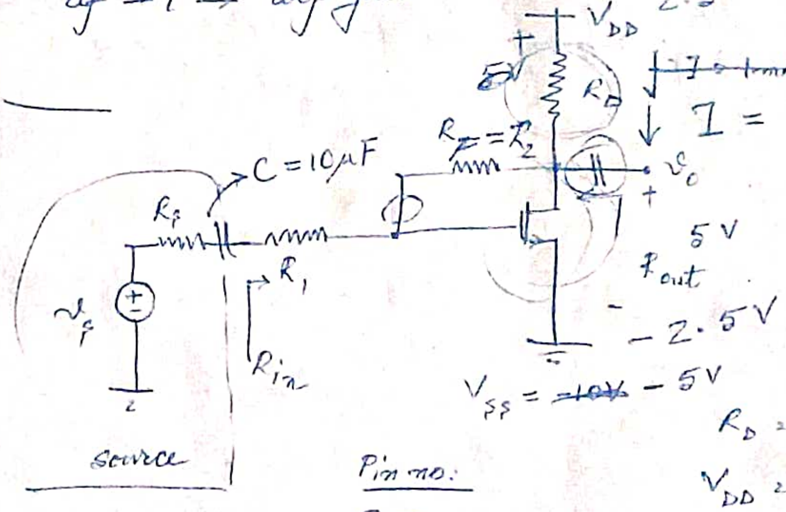
$V_{RD} = 2.5\ldots$

$V_{RD} =$

~~I = 1mA~~ ~~I =~~

$I =$

p.



shunt-shunt feedback amplifier

$R_D, R_1, R_2 \rightarrow$

$V_{SS} = \cancel{-10V}\ -5V$

~~I = 1mA~~

$R_D = 5K\Omega$

$V_{DD} = 10V$

Pin no:

G →

D →

S →

$R_1 = 10K\Omega$

$R_2 = 10K\Omega$

	In	f	Out
Input: (w/ f.b)	~~10 mV~~ 1.08 V	1 KHz	700 mV
(w/o f.b)	1.08 V	1 KHz	900 mV

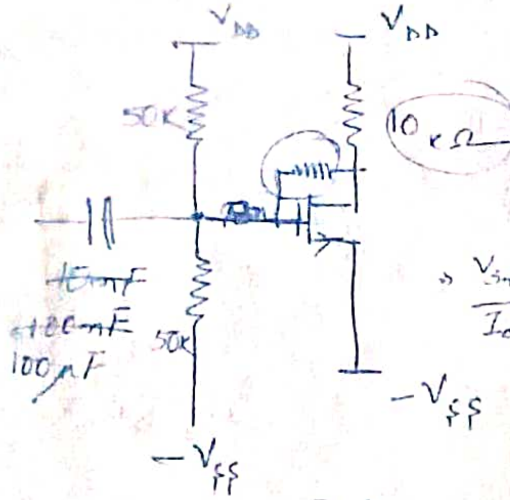
with $R_D = \cancel{10K}\ 100K\Omega$

$R_D = 1M\Omega$, 0.8V

with $R_D = 10K\Omega$

	In	f	out
(w/ fb)	~~0.830 mV~~ 800 mV	1KHz	
(w/o fb)	800 mV	1KHz	

$$\frac{I_D}{2.5} = \frac{76\mu A}{2.5} =$$

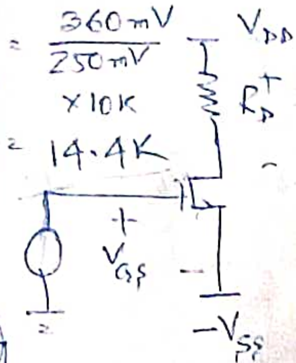


$v_s = 1.08\,V\,p\text{-}p$

$v_{s\,rms} = 360\,mV \quad v_R =$

$$\frac{V_{s\,rms}}{I_{o\,rms}} = \frac{360\,mV}{250\,mV} \times 10K = 14.4K$$

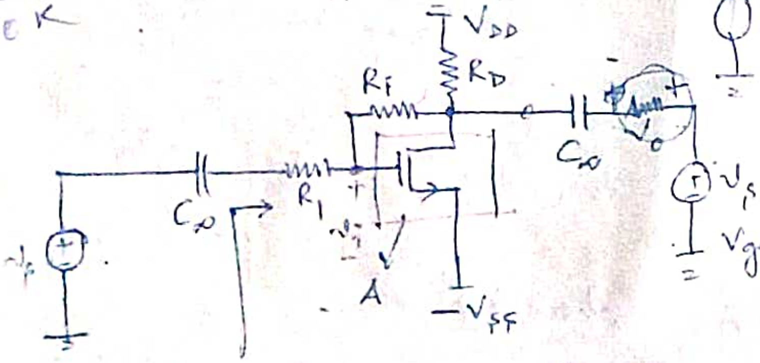
$$\frac{250\,mV}{10K}$$



$V_{DD} = 2.5$

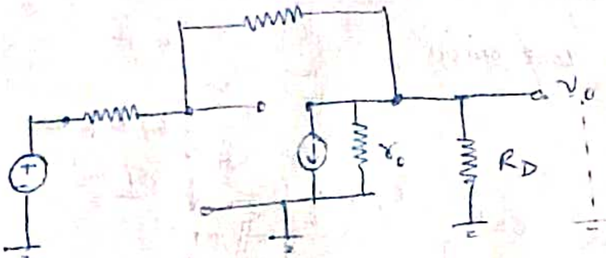
$$\frac{V_{RD}}{R_D} = \frac{0.955}{10K} = 95.5\,\mu A$$

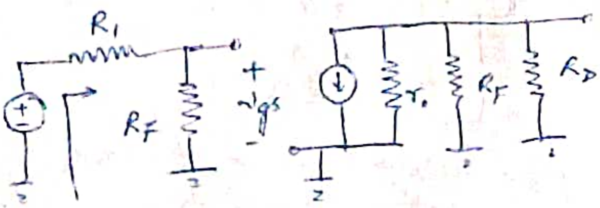
-2.5



$$v_{gs} = 2.5\,V \quad g_m = \frac{I_D}{V_{gs}} = \frac{95\,\mu A}{2.5} = ~~38.2~~\,A/V = 38.4$$

A ckt





$R_D = R_F = R_1 = 10\,K\Omega$

$g_m = ?$

R_i

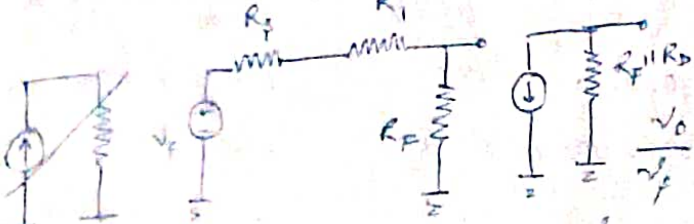
$r_o \to \infty$

$$v_{gs} = v_s \times \frac{R_F}{R_1 + R_F}$$

$$R_i = \frac{(R_1 + R_F)}{(1 + A\beta)}$$

$$v_o = -g_m \times r_o \,||\, R_F \,||\, R_D \times v_{gs}$$

$$\simeq -g_m\, R_F \,||\, R_D \times v_s \times \frac{R_F}{R_1 + R_F}$$



$$\frac{v_o}{v_s} = -g_m \times$$

$$v_o = -g_m \times (R_F \,||\, R_D) \times v_{gs}$$

$$v_{gs} = I_s' \times R_F \,||\, (R_s + R_1)$$

$$v_o = -g_m (R_F \,||\, R_D) \times$$

$\Rightarrow \quad v_0 = -g_m (R_F \| R_D) \times (R_F \| R_X) \times I_f'$

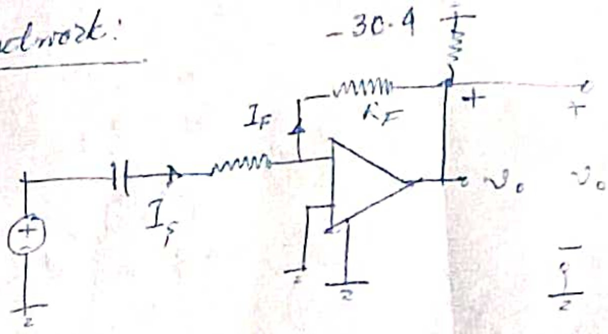
$R_X = R_s + R_1$

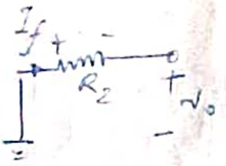
$\Rightarrow \quad \frac{v_0}{I_f'} = A = -g_m (R_F \| R_D) \times (R_F \| R_X)$

$= \cancel{-38.2}\mu \times 50K \times (50K) = \cancel{-955} = -95{,}500$ for $R_F = R_D = R_1 = 50K$

-30.4

<u>β network:</u>





$I_f \cdot R_2 = -v_0 \quad \frac{I_f}{v_0} = -\frac{1}{R_2}$

$\cancel{\beta = 1}$

$\beta = \frac{I_f}{V_0} = -\frac{1}{R_2}$

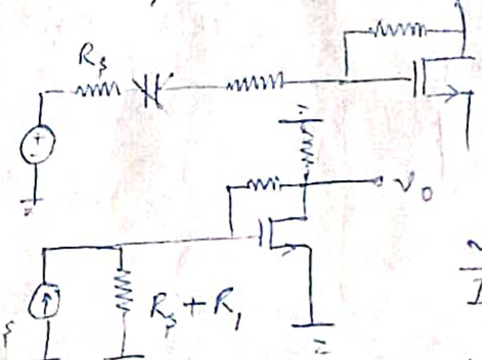
$\Rightarrow \quad A\beta = + g_m (R_F \| R_D) \times (R_F \| R_X) \times \frac{1}{R_2} = + \frac{955}{10K} = \cancel{0.0955}$

$\Rightarrow \quad A\beta = \cancel{1.91}\ 1.52$

$\Rightarrow \quad \frac{v_0}{I_f} = \frac{A}{1 + A\beta} \simeq \frac{1}{\beta} = \cancel{-R_2}$

$R_1 = R_2 = R_D = 50K$

<u>v_0</u>



$A_F = \frac{95500}{2.91} = 32{,}817$

$\frac{v_0}{I_f} = A_F$

$A_F = \frac{76000}{2.52} = 30{,}158$

$\Rightarrow \quad \frac{v_0}{I_f \times (R_s + R_1)} = -\frac{R_2}{R_s + R_1} \cong -\frac{R_2}{R_1}$

<u>$\cancel{v_0}$</u> $\quad \frac{v_0}{I_f} = -\frac{955}{1 + 0.0955} = -871$

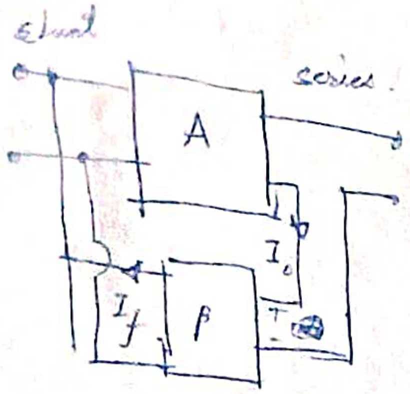
$\frac{32{,}817}{50K} = 0.65$

$\Rightarrow \quad \frac{v_0}{I_f \times (R_s + R_1)} = -\frac{871}{10K}$

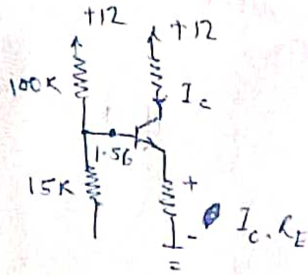
$R_D \| R_F$
$= 50K \| 50K$
$= \frac{25K}{2.52} = 10K$.

$\frac{30{,}158}{50K} = 0.6$

shunt-series feedback



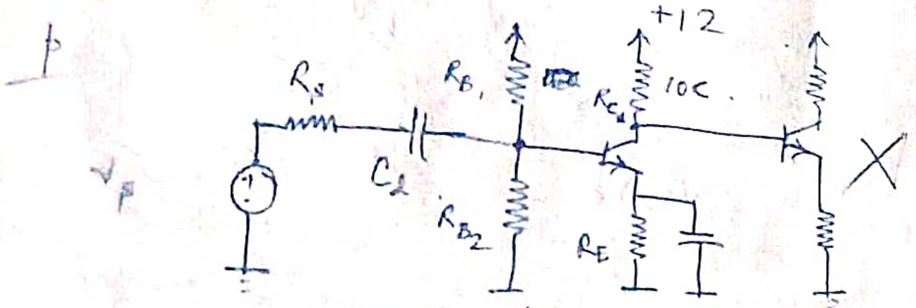
$$\beta = \frac{I_f}{I_o}$$

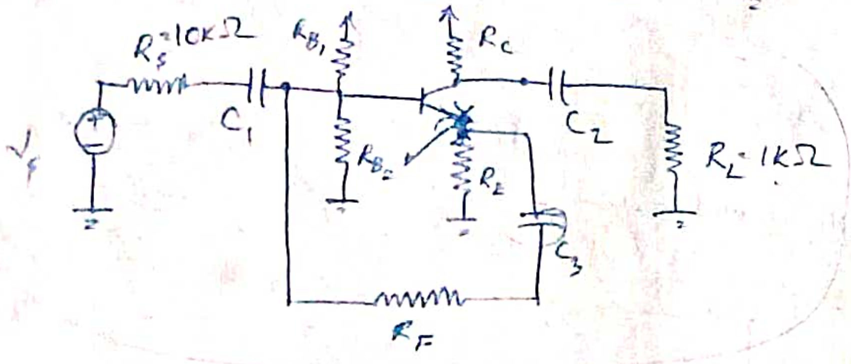


$1.56 = 0.7 + I_c \cdot 1K$

$\Rightarrow I_c = 865\mu A$

$= 0.865 \, mA$





$R_{B_1} = 100K$ $\quad V_{BE} = 0.7$

$R_{B_2} = 15K$

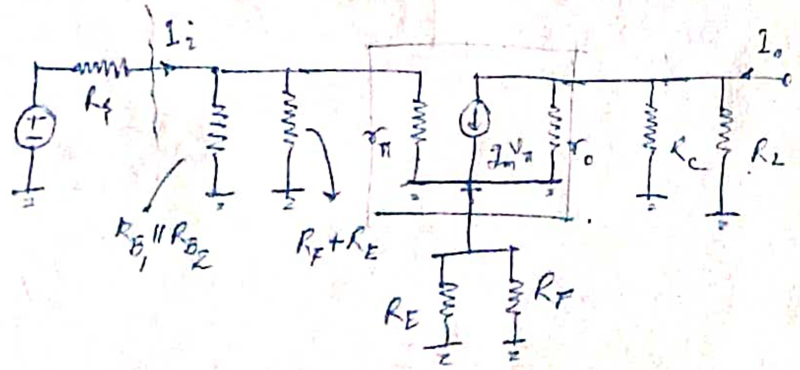
$R_{C_1} = 10K$

$R_E = 1K$ $\quad R_F = 10K$

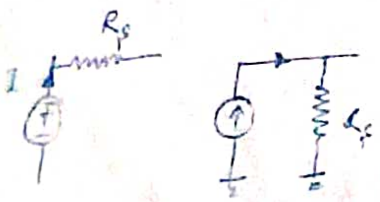
$C_1 = C_2 = C_3 = 1\mu F / 10\mu F$

$\beta = 120$

A ckt



$\beta = g_m r_\pi$



with $R_{B_1} = R_{B_2}$

$I_c = \frac{6 - 0.7}{1K}$

$= 5.3m$

$g_m = \frac{I_c}{V_T} = \cancel{33.27m}$ $203.8m$

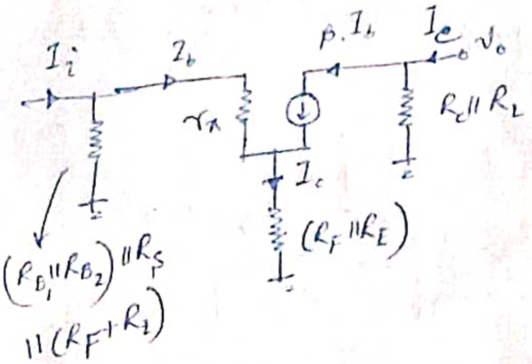
$\Rightarrow r_\pi = \frac{120}{33.27m}$

$= 3.6K$

$\Rightarrow g_m =$

$\Rightarrow r_\pi = \frac{120}{203.8m} = 588$

find I/P & O/P resistance



$\frac{I_e}{I_i} \simeq \cancel{\;} 3$

$\frac{I_o \times (R_c \parallel R_L)}{I_i \times 10K} = \frac{3 \times 1K}{10K}$

$(I_i - I_b)\left\{(R_{B_1} \parallel R_{B_2}) \parallel R_S \parallel (R_F + R_E)\right\} = I_b . r_\pi + \beta . I_b (R_F \parallel R_E)$

$i_c \simeq I_o$

$\cancel{I_o =} \quad \cancel{(I_c - \beta I_b) R_c \parallel R_L =}$

$I_e = \beta I_b + I_b = (\beta+1) I_b$

$I_i \left\{(R_{B_1} \parallel R_{B_2}) \parallel R_S \parallel (R_F + R_E)\right\} = I_b \left\{ r_\pi + \beta (R_F \parallel R_E) + (R_{B_1} \parallel R_{B_2}) \parallel R_S \parallel (R_F + R_E)\right\}$

$\Rightarrow I_b = \frac{I_i \times \{(13.0K) \parallel 10K \parallel 11K\}}{r_\pi + 120 \times (1K \parallel 10K) + 3.73K}$

$13.0K \parallel 5.24K =$

with $R_{B_1} = R_{B_2} = 50K$,

$= 25K \parallel 5.24K$

$= 4.33K$

$= \frac{I_i . 3.73K}{r_\pi + 109K + 3.73K}$

$1.3 \mu A$

$0.02 \mu A$

$= \frac{I_i . 3.73K}{r_\pi + 112.73K}$

$\Rightarrow I_o = (\beta+1) \times I_i \times \frac{(3.73K)}{(116.33K)}$

$= \frac{I_i (3.73K)}{(116.33K)} = \frac{I_i \times 4.33K}{0.58K + 109K + 4.33K}$

$\frac{I_o}{I_i} = \cancel{121 \times} \; 3.87 = \frac{121 \times 4.33}{113.9}$

$= 4.6$

$\beta = 0.09$

$\beta = \frac{R_E}{R_E + R_f} = \frac{1K}{11K}$

$= \frac{I_i \times 4.33K}{113.9K}$

$1 + A\beta = 1 + 0.35 = 1.35$

$= 1.42 \; (R_{B_1} = R_{B_2}$

$\Rightarrow A =$

$A = \frac{7.64K}{0.58K + 109K + 7.64K}$

$= \frac{7.64}{117.22}$

$\Rightarrow A_f = \frac{3.87}{1.35} = 2.86.$

$\Rightarrow A_f = \frac{4.6}{1.42} = 3$

$V_{R_f} = 287 mV$ $\Rightarrow A = 3.97$

$A_f = 3.97$ $i_f = \frac{287m}{10K} = 28.7\mu A$ $\Rightarrow 1 + A\beta = 1 + 3.97 \times$

$\frac{A}{1+A\beta} = 3.97$ $V_{R_L} = 114 mV$

$\Rightarrow A = 3.97(1 + A \cdot 0.09)$ $i_L = \frac{114 mV}{1K} = 114\mu A$

$A - 3.97$

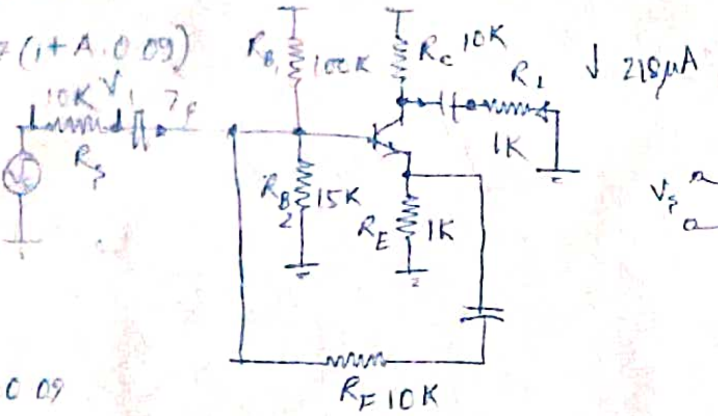
$A \cdot 0.36$

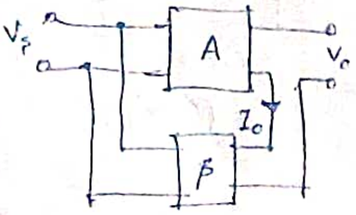
$A = 6.2$

$1 + A\beta$

$= 1 + 6.2 \times 0.09$

1.56





$R_F = 10K = R_C$
$R_L = R_E = 1K$

A ckt: (small signal ckt.)

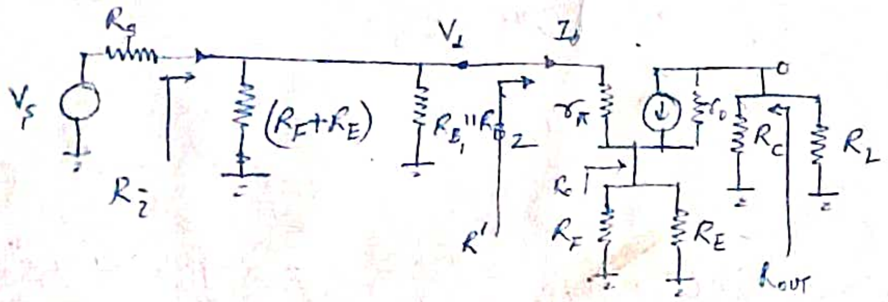
$V_{cc} = 12$

$V_c = 9.82V$

$I_c = 218\mu A$

$g_m = \frac{218\mu}{26m}$

$= 8.38m$



$V \cdot 140 mV$

$i_o R_L = i_o' R_C$

$$R_i = (R_F + R_E) \| (R_{B_1} \| R_{B_2}) \| R'$$ $r_o \to \infty$ $\Rightarrow i_c' = i_o \frac{R_L}{R_C}$

$= i_o \times \left(\frac{1}{10}\right)$

$$R' = \frac{V_1}{I_b}$$

$$V_1 = I_b \cdot r_\pi + (\beta+1) I_b (R_F \| R_E)$$

$$= I_b \left\{ r_\pi + (\beta+1)(R_F \| R_E) \right\}$$

$$\Rightarrow R_i = (R_F + R_E) \| (R_{B_1} \| R_{B_2}) \| \left\{ r_\pi + (\beta+1)(R_F \| R_E) \right\}$$

$$= 11K \| 13K \| \{3.6K + 121 \times 0.9K\}$$

$$= 11K \| 13K \| 112.5K$$

$$= 11K \| 11.65K = 5.65K$$

$$\Rightarrow R_{if} = \frac{5.65K}{1.35} = 4.19K$$

$-I_f R_f = (I_f + I_o)$

$I_f R_f + (I_f + I_o) R_E = 0$

$\Rightarrow I_f (R_f + R_E) = -I_o R_E$

$\Rightarrow \frac{I_f}{I_o} = \beta = -\frac{R_E}{R_F + R_E}$

$R_i = 5.087 K\Omega$

Exp

Output Resis:

$R_o = R_C$

$R_{of} = R_o(1+A\beta)$ $\quad r_o \approx 86\,k\Omega$

$R_o = (R_E \parallel R_F) + \frac{r_\pi}{\beta+1} + \frac{R_C \parallel r_o}{\beta+1}$

$= 0.9K + \frac{3.6K + 8.9K}{121}$

$= 0.9K + 103 = 1K$

$R_{of} = 1K \times (1+A\beta) = 1.35K$

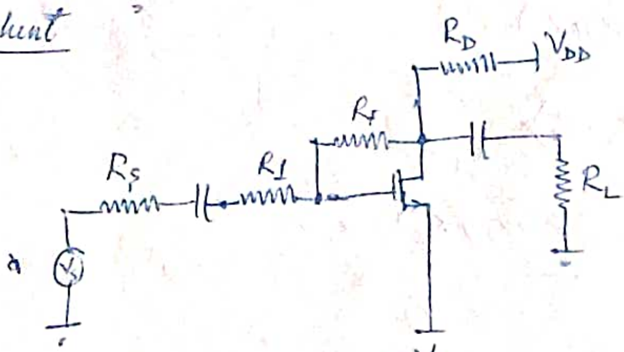
$R_{OUT} = r_o\left[1 + 33.27m \times (r_\pi \parallel R_{of})\right]$

$= 86K\left[1 + 33.27m \times 0.98K\right]$

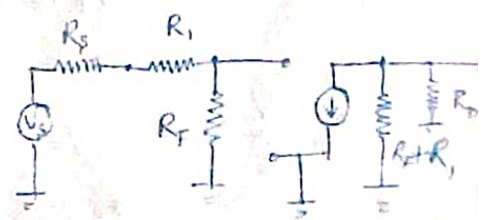
$= 2.8M\Omega$

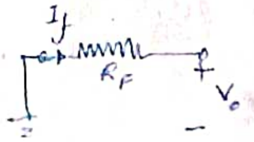
$\Rightarrow R_{OUT,net} = 2.9M \parallel 10K$

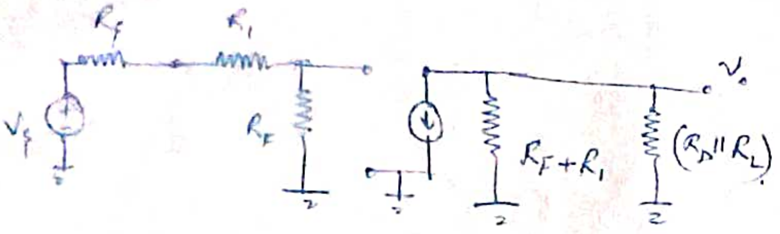
Shunt-shunt

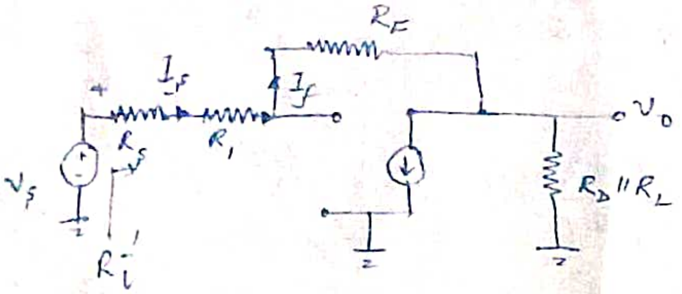


A ckt:



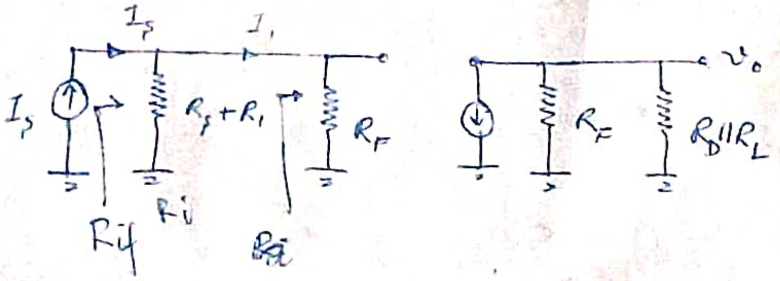






Let, $R_D = R_L = 10K$
$R_s = 10K$
$R_1 = R_F = 50K$

A ckt.



$R_s' = R_s + R_1$

$V_{GS} = (I_s - I_1)(R_s + R_1) = I_1 R_F$

$\Rightarrow (I_s - I_1) R_s' = I_1 R_F$

$\Rightarrow I_1 (R_s' + R_F) = I_s R_s'$

$\Rightarrow I_1 = \frac{I_s R_s'}{R_s' + R_F}$

$v_o = -g_m \times (R_F \| R_D \| R_L) V_{GS}$ $\qquad g_m = 38.2 \mu A/V$

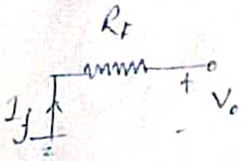
$\frac{v_o}{I_s} = -g_m \times (R_F \| R_D \| R_L) \times \frac{R_s' R_F}{R_s' + R_F}$

$\frac{v_o}{I_s} = -g_m \times \frac{(R_F \| R_D \| R_L) \times R_s' R_F}{R_s' + R_F} = A$

$= -38.2 \times 4.5K \times (60K \| 50K)$

$= -38.2\mu \times 4.5K \times 27.27K$

$= -4075.7$ V/A



$\beta = \frac{I_f}{V_o}$

$V_o = -I_f R_f$

$\Rightarrow \beta = \frac{I_f}{V_o} = -\frac{1}{R_f}$

$\Rightarrow A\beta = -4675.7 \times -\frac{1}{R_F}$

$= -4675.7 \times -\frac{1}{50K}$

$= 0.0935$

$\Rightarrow 1 + A\beta = 1.0935$

$\Rightarrow A_f = \frac{A}{1+A\beta} = -4276$

$R_i = \frac{R_F}{1+A\beta} = \frac{50K}{1.09} = 45.87K$

$\Rightarrow R_i' = R_s + R_1 + R_i = 60K + 45.87K$

$= 105.87K$

$R_{if} = \frac{R_i}{1+A\beta}$ $R_i = (60K \parallel 50K)$

$= 27.27K$

$\Rightarrow R_{if} = \frac{27.27K}{1.09} = 25.02K$

if $R_D = R_L = R_s = R_1 = R_F = 10K$,

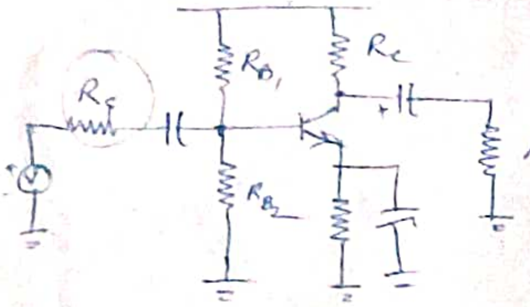
$\frac{V_o}{I_s} = -38.2u \times 3.33K \times 6.67K$

$= -848.46$

$\beta = -\frac{1}{R_F}$ $\Rightarrow$ $A\beta = 0.085$ $R_{if} = \frac{6.67K}{1.08} = 6.15K$

$\Rightarrow 1 + A\beta = 1.085$

series series



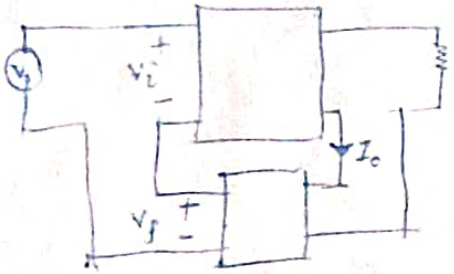
$R_{B_1} = 100K$

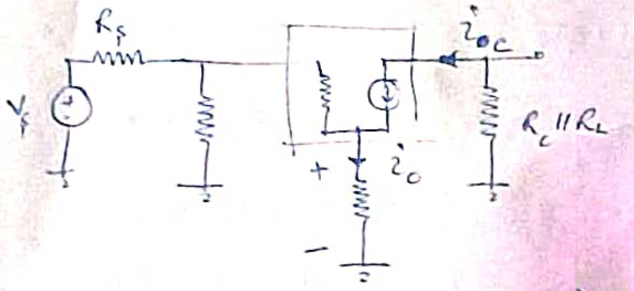
$R_{B_2} = 15K$

$R_C = 10K$

$R_E = 1K$, $R_L = 1K$

$R_s = 10K$

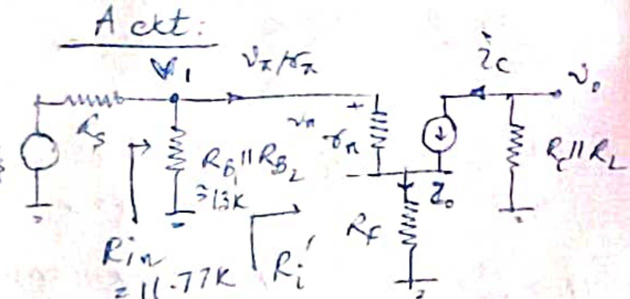




$i_c \simeq i_o$

$$\beta = \frac{V_f}{I_o}$$

A ckt:



$$A = \frac{i_c}{V_s}$$

$= r_\pi + (\beta+1)R_F \simeq 124.6K$

$$i_c = g_m v_\pi \qquad \& \qquad i_o = \frac{v_\pi}{r_\pi} + \beta\frac{v_\pi}{r_\pi}$$

$$= (\beta+1)\frac{v_\pi}{r_\pi}$$

$$\frac{V_s - V_1}{R_s} = \frac{V_1}{R_{B_1} \| R_{B_2}} + \frac{v_\pi}{r_\pi} \qquad \&$$

$\Rightarrow$ $\&$ $V_1 = v_\pi + i_o R_F$

$$\Rightarrow \frac{v_s}{R_s} = V_1\left(\frac{1}{R_s} + \frac{1}{R_{B_1} \| R_{B_2}}\right) + \frac{v_\pi}{r_\pi}$$

$$= (v_\pi + i_o R_F)\left(\frac{1}{R_s} + \frac{1}{R_{B_1} \| R_{B_2}}\right) + \frac{v_\pi}{r_\pi}$$

$$\Rightarrow \frac{v_s}{R_s} = \left(\frac{i_o r_\pi}{(\beta+1)} + i_o R_F\right)\left(\frac{1}{R_s} + \frac{1}{R_{B_1} \| R_{B_2}}\right) + \frac{i_o}{\beta+1}$$

$$= i_o \left\{ \left(\frac{r_\pi}{\beta+1} + R_F\right)\left(\frac{1}{R_s} + \frac{1}{R_{B_1} \| R_{B_2}}\right) + \frac{1}{\beta+1} \right\}$$

$$\Rightarrow \cancel{\frac{v_s}{i_o} = A = R_s \times \Big\{}$$

$$= i_o \left\{ (29.75 + 1K)\left(\frac{1}{10K} + \frac{1}{12K}\right) + \frac{1}{121} \right\}$$

$$\Rightarrow \frac{i_o}{v_s} = \frac{1}{R_s \times}$$

$$= i_o \times \left\{ \cancel{(1029.75)\times}\ 0.182 + 8.26 \times 10^{-3} \right\}$$

$r_\pi = 3.6K$

$$= i_o \times 0.19$$

$$\Rightarrow \frac{i_o}{v_s} = \frac{1}{R_s \times 0.19} = \frac{1}{10K \times 0.19} = 526.3\mu$$

$$\Rightarrow A = 526.3\mu.$$

$$\beta = \frac{V_f}{I_o} = R_F = 1K.$$

$$\Rightarrow A\beta = 0.526 \Rightarrow 1 + A\beta = 1.526.$$

$$\Rightarrow A_f = \frac{A}{1+A\beta} = \frac{526.3\mu}{1.526} = 345\mu = \frac{i_c}{v_s}$$

$$\cancel{i_o = A_f \times}$$

$$A_f = \frac{i_c}{V_s},\ i_c \simeq i_o$$

$$= A_f \cdot v_s$$

$$i_c \simeq i_o, \ \& \ v_o = -i_o \times (R_C \| R_L)$$

$$\cancel{= -i_o \times r_o}$$

$$\frac{v_o}{v_s} = -A_f \cdot (R_C \| R_L)$$

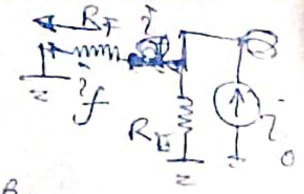
$$= -345\mu \times 0.9K$$

$$= -0.3105$$

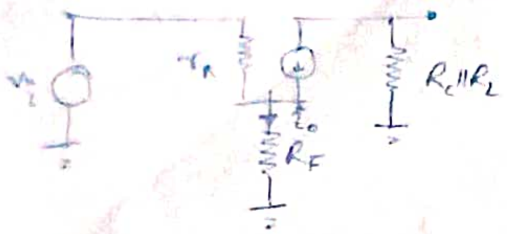
$$A' \ G_{vf} = \frac{v_o}{v_s}$$

$$= -\frac{R_C \| R_L}{R_F} \times \frac{R_{in}}{R_{in} + R_s}$$

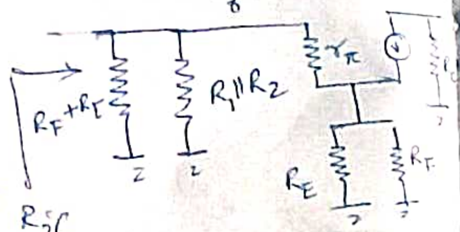
$$= -\frac{0.9K}{1K} \times \frac{11.77K}{11.77K + 10K} = -0.48$$



$$\frac{i_f}{i_o} = \beta$$



$$\frac{i_f}{i_o} =$$



$$\cancel{V_i} = \frac{\cancel{v_\pi}}{r_\pi} \qquad V_i = v_\pi + i_o R_F$$

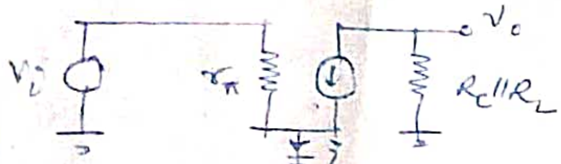
R_{if} -

$$\& \quad i_o = \frac{v_\pi}{r_\pi} + \beta \cdot \frac{v_\pi}{r_\pi} = (\beta+1)\frac{v_\pi}{r_\pi}$$

$$R_i = (R_F + R_E) \| (R_1 \| R_2) \| \; r_\pi + (\beta+1)\{R_E \| R_F\}$$

$\Rightarrow v_i =$

A ckt



$$R_{if} = \frac{R_i}{1 + A\beta}$$

$$\Rightarrow i_o = \frac{v_\pi}{r_\pi} + \beta \cdot \frac{v_\pi}{r_\pi}$$

$$= (\beta+1)\frac{v_\pi}{r_\pi} = (\beta+1)\frac{v_i}{r_\pi}$$

$$\frac{i_i}{i_f}$$

$$\Rightarrow \frac{i_o}{v_i} = \frac{1}{r_\pi/(\beta+1)} = 33.6m$$

$$\beta = \frac{i_f}{i_o}$$

$$i_o R_F = V_f \Rightarrow \frac{V_f}{i_o} = \beta = R_F$$

$$\Rightarrow A\beta = \frac{1}{r_\pi/(\beta+1)} \times R_F =$$

$$= \frac{1}{3.6K/121} \times 1K$$

$$= \frac{1000}{29.75} = 33.61$$

$$\Rightarrow 1 + A\beta = 1 + 33.61 = 34.61$$

$$\Rightarrow A_f = \frac{i_o}{v_i} = \frac{A}{1+A\beta} = \frac{33.6m}{34.61} = 971\mu$$

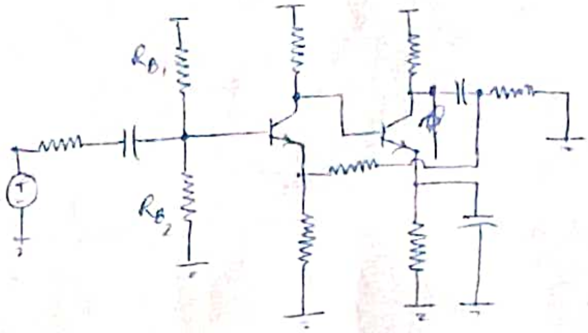
$$\Rightarrow \text{as } i_o \simeq i_c, \quad \frac{v_o}{v_i} \simeq -\frac{R_C \| R_L}{R_F} = \frac{0.9K}{1K} = -0.9$$

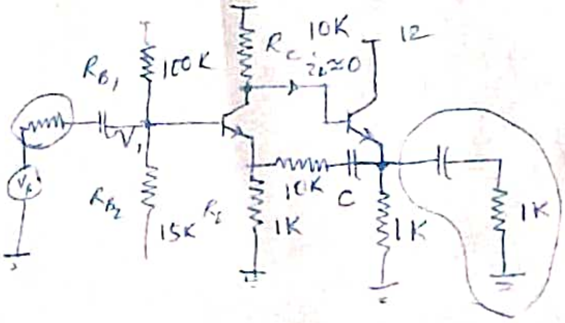
$$\& \quad v_o = -i_o \times (R_C \| R_L)$$

$$= -A_f \cdot v_i (R_C \| R_L)$$

$$\Rightarrow \frac{v_o}{v_i} = -A_f (R_C \| R_L) = -971\mu \times 0.9K = -0.874$$

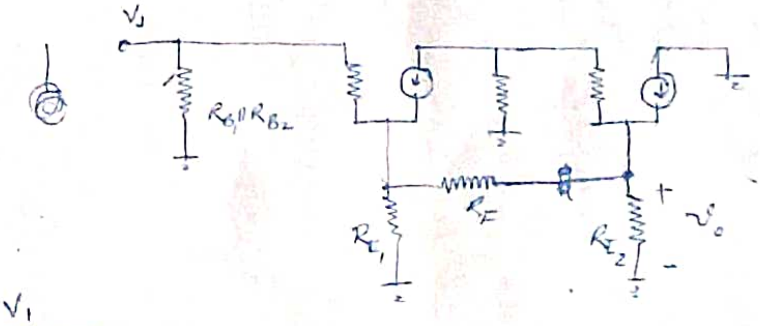
series-shunt

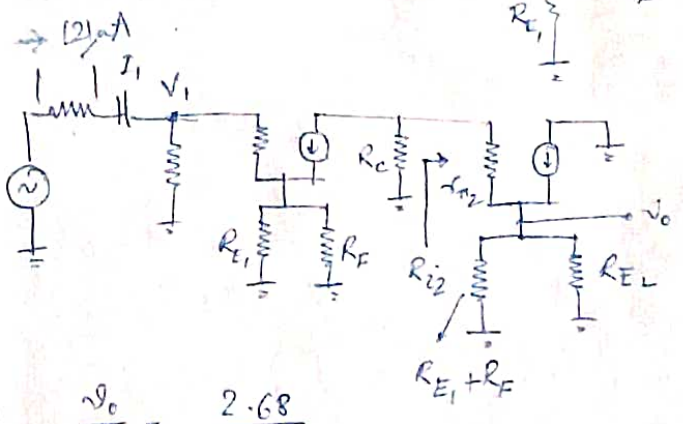




$v_{C_1} = 5.4$

$v_{E_2} = 2.65\text{ V}$





$R_{i_2} = r_{\pi_2} + (\beta+1)\left[(R_{E_1} + R_F) \| R_{E_2} \right]$

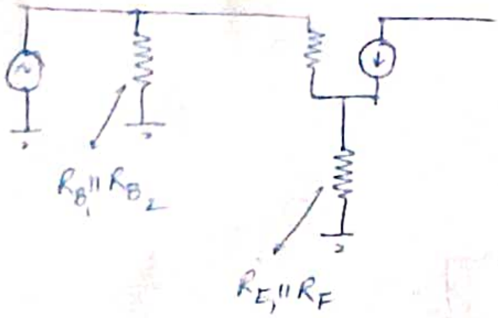
$= r_{\pi_2} +$

$\dfrac{v_o}{v_1} = \dfrac{2.68}{20.5m}$

$= 130$

$V_1 = 658\text{ mV}$

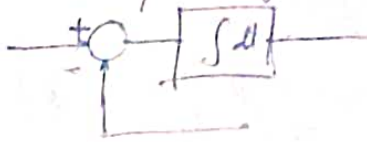
$\dfrac{V_1}{I_1} = \dfrac{658m}{121\mu} = 5.43\text{ K}\Omega$



$R_{B_1} \| R_{B_2}$
$R_{E_1} \| R_F$

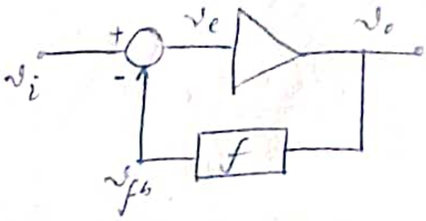
class note

Car speed example



$-ve$

A typical $_\wedge$ feedback ckt



$v_e = v_i - v_{fb}$

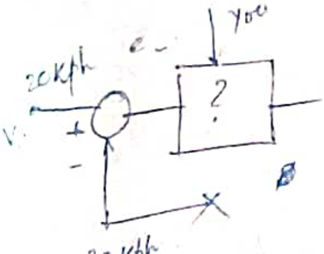
$= v_i - f \cdot v_o$

$v_o = a v_e \quad = v_i - f \cdot a v_e$

$\Rightarrow v_e(1+af) = v_i$

$v_e = \frac{v_i}{1+af}$

$\Rightarrow v_e = \frac{v_i}{af}$



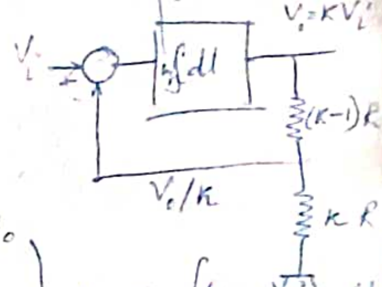
$\frac{v_o}{v_i} = \frac{a}{1+af}$ $\quad T = af =$ loop gain

most often, it is found that $af \gg 1$,

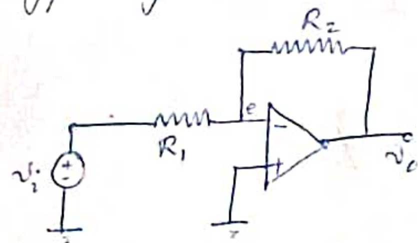
in such cases, closed loop gain: $\frac{v_o}{v_i} \simeq \frac{a}{af} = \frac{1}{f}$

as objective is $v_{fb} \simeq v_i$

to make dimension const



a typical feedback ckt: inverting amplifier

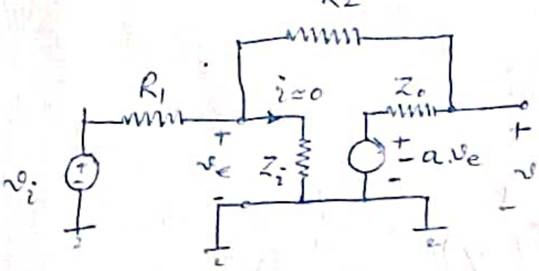


$\frac{v_i - e}{R_1} = \frac{e - v_o}{R_2}$

$\rightarrow v_i$ as $e \simeq 0$

$\frac{v_i}{R_1} = -\frac{v_o}{R_2} \Rightarrow \frac{v_o}{v_i} = -\frac{R_2}{R_1}$

$V_o = \omega_n \int \left(V_i - \frac{V_o}{K}\right) dt$



$\Rightarrow \frac{dV_o}{dt} = \omega_n V_i - \frac{\omega_n}{K}$

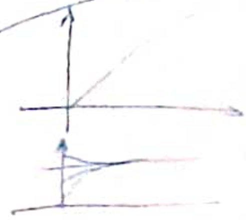
$Z_i \rightarrow \infty$

$Z_o \rightarrow 0$

dV_o

$V_o(t) = KV_i\left(1 - e^{-\frac{\omega_n t}{K}}\right) + V_o(0) e^{-\frac{t}{K}}$

$\Rightarrow \frac{v_i - v_e}{R_1} = \frac{v_e - v_o}{R_2}$ & $v_o = -a \cdot v_e$ $\quad \Rightarrow v_e = -\frac{v_o}{a}$



$\Rightarrow$ ~~$v_i + a$~~ $\Rightarrow \frac{v_i + \frac{v_o}{a}}{R_1} = \frac{-\frac{v_o}{a} - v_o}{R_2}$

$\Rightarrow \frac{v_i}{R_1} = -\frac{v_o}{aR_1} - \frac{v_o}{aR_2} - \frac{v_o}{R_2}$

$= -v_o\left\{\frac{1}{R_2} + \frac{1}{a}\left(\frac{1}{R_1} + \frac{1}{R_2}\right)\right\}$

$$\frac{v_i}{R_1} = -v_o\left\{\frac{1}{R_2} + \frac{1}{a}\left(\frac{1}{R_1}+\frac{1}{R_2}\right)\right\}$$

$$\Rightarrow \cancel{\frac{v_o}{v_i}} = -\frac{v_o}{R_2}\left\{1 + \frac{1}{a}\left(1+\frac{R_2}{R_1}\right)\right\}$$

$$\Rightarrow \frac{v_o}{v_i} = -\frac{R_2}{R_1} \times \frac{1}{\left\{1+\frac{1}{a}\left(1+\frac{R_2}{R_1}\right)\right\}} = A$$

now, closed loop gain of ~~an amplif~~ a feedback ckt

$$A = \frac{a}{1+af}.$$

. determination of gain sensitivity

$$\frac{dA}{da} = \frac{1}{1+af} - \frac{af}{(1+af)^2}$$

$$= \frac{1+af-af}{(1+af)^2} = \frac{1}{(1+af)^2}.$$

$$\Rightarrow \Delta A = \frac{\Delta a}{(1+af)^2}.$$

in terms of % change,

$$\frac{\Delta A}{A} = \frac{\Delta a}{(1+af)^2} \times \frac{1}{\frac{a}{(1+af)}}$$

$$= \frac{\Delta a}{a} \times \frac{1}{(1+af)}.$$

now, $\frac{v_o}{v_i}$ of the inverting ckt:

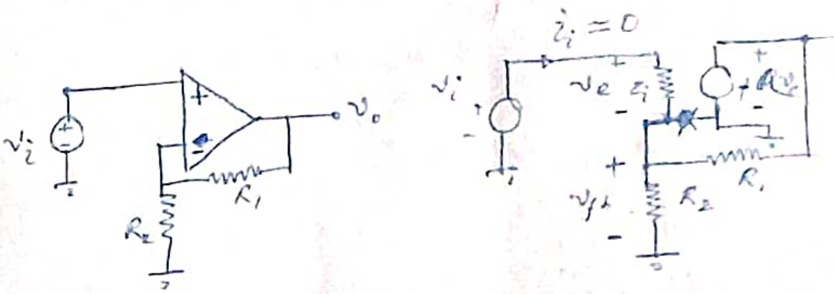
$$\frac{v_o}{v_i} = -\frac{R_2}{R_1} \times \frac{a}{\left\{a + \left(1+\frac{R_2}{R_1}\right)\right\}}$$

$$= -\frac{a}{\left\{\frac{a}{\left(1+\frac{R_2}{R_1}\right)} + 1\right\}} \times \frac{R_2}{R_1}$$

$$= \frac{a}{\quad}$$

consider,

$r_i \simeq \infty$



442.57μ

$\Rightarrow \; v_i - v_e - v_{fb} = 0.$ $\qquad v_{fb} = \frac{R_2}{R_1+R_2} \times v_o$ $\qquad v_o = Av_e$

$= \frac{R_2}{R_1+R_2} \times \cancel{Av_e}\, v_o$ $\qquad \Rightarrow v_e = \frac{v_o}{A}$

$$\Rightarrow v_i - \frac{v_o}{A} - v_o \cdot \frac{R_2}{R_1+R_2}$$

$$\Rightarrow v_i = \frac{v_o}{a} + v_o \cdot \frac{R_2}{R_1+R_2} = v_o\left\{\frac{1}{a} + \frac{R_2}{R_1+R_2}\right\}$$

$\frac{900}{900 \times \frac{1}{2}+1} = \frac{900}{451}$

$$\Rightarrow \frac{v_o}{v_i} = \frac{1}{\left\{\frac{1}{a} + \frac{R_2}{R_1+R_2}\right\}} = \frac{a}{\left\{a \times \frac{R_2}{R_1+R_2} + 1\right\}} = A_{cl}$$

$\frac{1000}{1000 \times \frac{1}{2}+1} = \frac{1000}{501}$

$$\text{as } a \to \infty, \quad \frac{v_o}{v_i} = A_{cl} = \frac{R_1+R_2}{R_2} = \left(1+\frac{R_1}{R_2}\right)$$

Let, $a \times \frac{R_2}{R_1+R_2} = 100$, find $\frac{\Delta A}{A}$ if $\frac{\Delta a}{a}$ is

Let, $a = 200 \Rightarrow \frac{R_2}{R_1+R_2} = 0.5$

change of 10% $\Rightarrow$ $a_1 = 200 + 20 = 220$.

$$A_{CL_1} = \frac{200}{200\times0.5+1} = \frac{200}{101} = 1.98$$

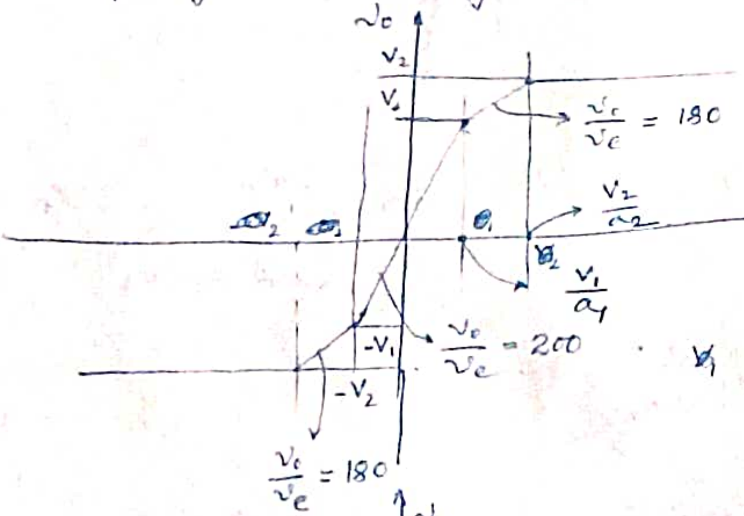
$$A_{CL_2} = \frac{220}{220\times0.5+1} = \frac{220}{111} = 1.982$$

$$\therefore \left|\frac{A_{CL_1} - A_{CL_2}}{A_{CL_1}}\right| \times 100 = \frac{1.982 - 1.98}{1.98} \times 100 = 0.1\%$$

$\rightarrow$ advantage of having feedback.

Leads to another advantage: less distortion:

Let, the op amp has following I/P – O/P char:

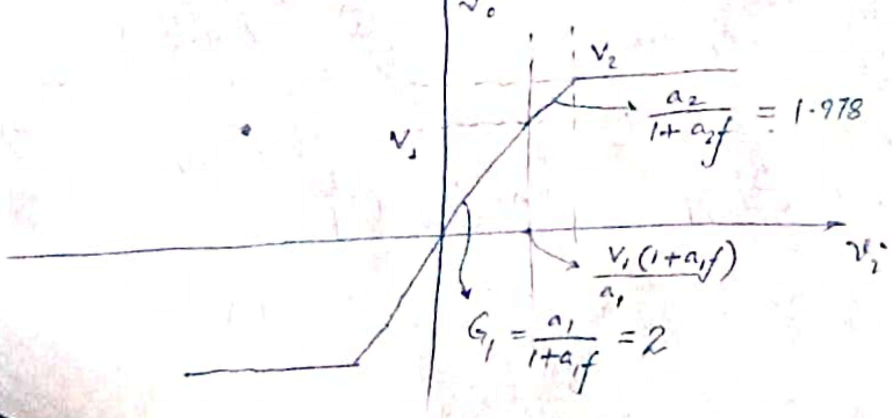


$a_1 = 200$

$a_2 = 180$

V_1 at $v_e = V_1$, $v_o = a_1 V_1$

$f = 0.5$



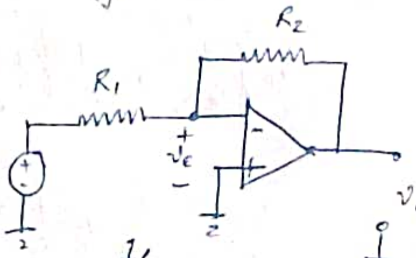
$\frac{V_2(1+a_2 f)}{a_2}$

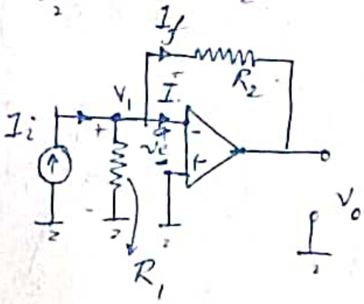
distortion can not be removed beyond V_2

as ~~gain~~ open loop gain $a \to 0 \Rightarrow A_{CL} = 0$

Different feedback configurations:

inverting amplifier:





$V_1 = -\frac{V_o}{a}$

$\Rightarrow I_i = \frac{V_1}{R_1} + \frac{V_1 - V_o}{R_2}$

$I_i = \frac{V_i}{R_1}$

$(I_i - I_f)R_1 =$

$= I_f R_2 + V_o$

$\Rightarrow I_i R_1 = I_f (R_1 + R_2) + V_o$

$V_o = -aV_1$

$= -a(I_i - I_f)R_1$

$\Rightarrow I_i R_1 =$

$V_1 = -\frac{V_o}{a} = (I_i - I_f)R_1$

$= \frac{1}{R_1}\left(I_i R_1 + \frac{V_o}{a}\right) \times (R_1 + R_2) + V_o$

$\Rightarrow I_i R_1 - I_f R_1 = -\frac{V_o}{a}$

$\Rightarrow I_f R_1 = I_i R_1 + \frac{V_o}{a}$

$\Rightarrow I_f = \frac{1}{R_1}\left(I_i R_1 + \frac{V_o}{a}\right)$

$\Rightarrow I_i R_1 - \frac{1}{R_1} \cdot I_i R_1 (R_1 + R_2)$

$= \frac{1}{R_1} \cdot \frac{V_o}{a} \cdot (R_1 + R_2) + V_o$

$\Rightarrow \cancel{I_i R_1} - \cancel{I_i R_1} - I_i R_2$

$= \frac{1}{R_1} \cdot \frac{V_o}{a}(R_1 + R_2) + V_o$

$\Rightarrow V_o \left\{ \frac{R_1 + R_2}{R_1} \times \frac{1}{a} + 1 \right\} = -I_i R_2$

$\Rightarrow \frac{V_o}{I_i} = -\frac{R_2}{\left\{1 + \frac{1}{a} \times \frac{R_1 + R_2}{R_1}\right\}} = -\frac{a}{\left\{a + \frac{R_1 + R_2}{R_1}\right\}} R_2$

$$I_i = \frac{V_1}{R_1} + \frac{V_1 - V_0}{R_2}, \quad V_1 = -\frac{V_0}{a}$$

$$\Rightarrow I_i = -\frac{V_0}{R_1} + \frac{-\frac{V_0}{a} - V_0}{R_2} \qquad = -\frac{V_0}{aR_1} + \frac{-\frac{V_0}{a} - V_0}{R_2}$$

$$= -V_0\left\{\frac{1}{R_1} + \frac{1}{R_2}\cdot\left(\frac{1}{a}+1\right)\right\} \qquad = -V_0\left\{\frac{1}{aR_1} + \frac{1}{R_2}\left(\frac{1}{a}+1\right)\right\}$$

$$= -V_0\left\{\frac{1}{R_1} + \frac{1}{R_2}\left(\frac{1+a}{a}\right)\right\} \qquad = -V_0\left\{\frac{1}{aR_1} + \frac{1}{R_2}\left(\frac{1+a}{a}\right)\right\}$$

$$= \cancel{-V_0\{\quad\}}$$

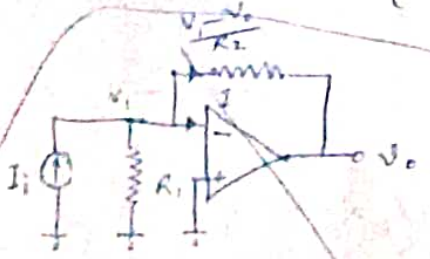
$$= -V_0\left\{\frac{1}{R_1} + \frac{1}{R_2}\frac{(1+a)}{a}\right\} \qquad = -\frac{V_0}{a}\cdot\left\{\frac{1}{R_1} + \frac{1+a}{R_2}\right\}$$

$$= -V_0\left\{\frac{aR_2 + R_1(1+a)}{R_1R_2a}\right\}$$

$$\Rightarrow \frac{V_0}{I_i} = -\frac{aR_1R_2}{R_1 + a(R_1+R_2)}$$

$$= -\frac{a}{\quad}$$

$$\cancel{= -V_0\{}$$



$$I = -\frac{v_0}{a}$$

$$I_i = \frac{V_1}{R_1} + \frac{V_1 - V_0}{R_2} + I$$

$$\frac{V_1 - V_0}{R_2}$$

$$I = -\frac{v_0}{a}.$$

$$\Rightarrow \frac{V_0}{I_i} = -\frac{a}{\left\{\frac{1}{R_1} + \frac{1+a}{R_2}\right\}}$$

$$= -\frac{a}{\left\{\frac{R_2 + R_1(1+a)}{R_1R_2}\right\}} = -\frac{a}{\left\{\frac{R_2 + R_1 + aR_1}{R_1R_2}\right\}}$$

$$\rightarrow \frac{v_o}{i_i} = \frac{a}{\left(\frac{R_2+R_1}{R_1R_2}\right)\{1+a}$$

$$\rightarrow \frac{v_o}{I_i} = -\frac{a}{\left\{\frac{R_2+R_1}{R_1R_2} + \frac{a}{R_2}\right\}}$$

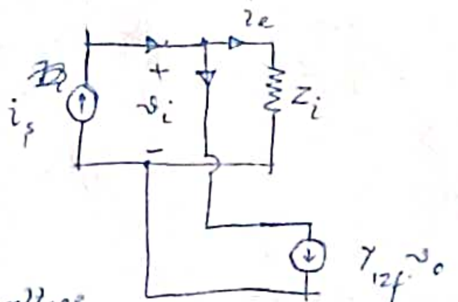
$$= -\frac{a}{\left\{\frac{1}{R_1 \| R_2} + \frac{a}{R_2}\right\}}$$

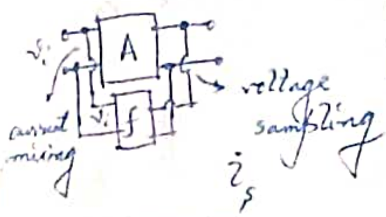
$$= -\frac{a \times (R_1 \| R_2)}{\left\{1 + \frac{a \times (R_1 \| R_2)}{R_2}\right\}}$$

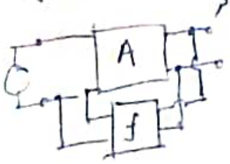
$$\frac{R_1 \| R_2}{R_2} = \frac{R_1}{R_1+R_2}$$

as $\frac{v_o}{v_e} = -a$, actual gain should come in terms of Resistance (V/I), not voltage ratio

Feedback ckts practical considerations
i.e, where feedback ckts load the amplifier ckt







$$z_{if} = \frac{v_i}{i_s}$$

$$i_s = i_e + y_{12f}\, v_o$$

$$\frac{v_o}{i_s} = \frac{a}{1+af} \cdot \frac{a}{1+a}$$

$$\frac{v_o}{i_e} = a \quad a = -\frac{y_{21o}}{y_i\, y_o}$$

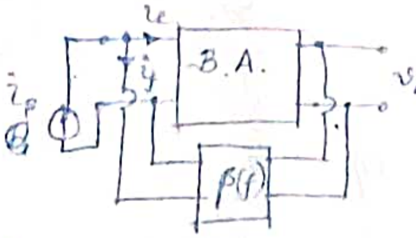
$$i_s = \frac{v_o}{\left(-\frac{y_{21o}}{y_i y_o}\right)} + y_{12f}\, v_o$$

$$\rightarrow \frac{v_o}{i_s} =$$

$$= v_o\left\{\frac{1}{a} + y_{12f}\right\}$$

$$= v_o\left\{\frac{1}{a} + f\right\}$$

shunt shunt



$y_p \rightarrow I_1 = Z_{11}V_1 + Z_{12}V_2$
$\quad\quad I_2 = Z_{21}V_1 + Z_{22}V_2$

$z_p \rightarrow V_1 = I_1 + I_2$
$\quad\quad V_2 = I_1 + I_2$

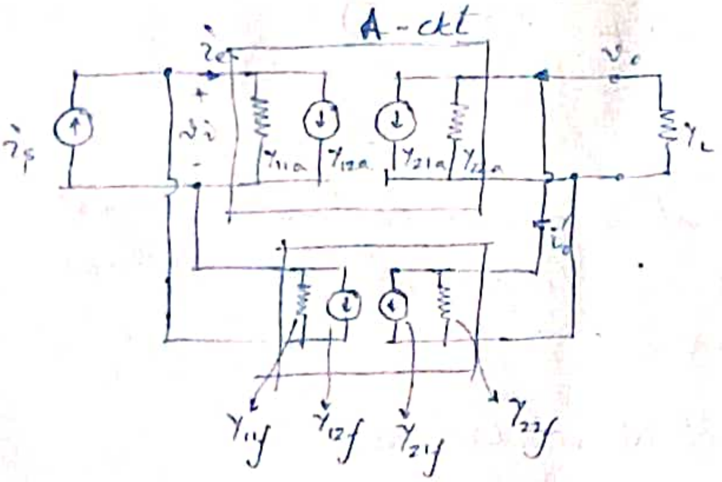
$h_p \rightarrow V_1 = I_1 + V_2$
$\quad\quad I_2 = I_1 + V_2$

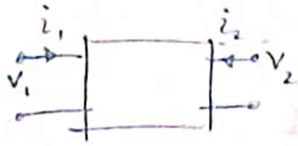
$g_p \rightarrow I_1 = V_1 + I_2$
$\quad\quad V_2 = V_1 + I_2$

mixing → current mixing
sampling → voltage sampling

i/p → current
o/p → voltage

Both B.A. & f.b n/w are replaced with y parameters.





$i_1 = y_{11}v_1 + y_{12}v_2$
$i_2 = y_{21}v_1 + y_{22}v_2$

$y_{11} = \left.\frac{i_1}{v_1}\right|_{v_2=0}$

$y_{12} = \left.\frac{i_1}{v_2}\right|_{v_1=0}$
= return signal

$y_{21} = \left.\frac{i_2}{v_1}\right|_{v_2=0}$
forward signal

clearly, for A-ckt,

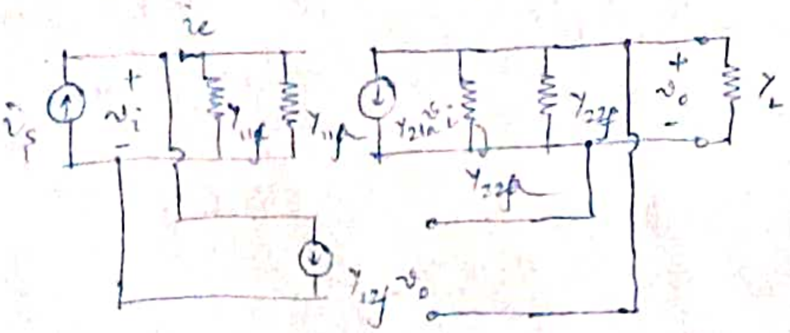
$y_{21a} \gg y_{12a}$,

so, y_{12a} neglected,

|||ly, for f ckt., $y_{21f} \ll y_{12f}$.

$y_{11f} = \left.\frac{i_f}{v_i}\right|_{v_2=0}$

$y_{22f} =$



⇒ $i_s = v_i(y_{11a} + y_{11f}) + y_{12f} v_o$

& $y_{21a} v_i + v_o(y_{22a} + y_{22f} + y_L) = 0$

Let, $y_{11a} + y_{11f} = y_i$

$y_{22a} + y_{22f} + y_L = y_o$

⇒ $i_s = v_i \cdot y_i + y_{12f} v_o$

$0 = y_{21a} v_i + y_o \cdot v_o$

$v_i = -\dfrac{y_o v_o}{y_{21a}}$

⇒ $i_s = -\dfrac{y_o y_i v_o}{y_{21a}} + y_{12f} \cdot v_o$

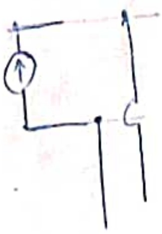
$= v_o\left(y_{12f} - \dfrac{y_o y_i}{y_{21a}}\right)$

$= v_o\left(\dfrac{y_{12f}\, y_{21a} - y_o y_i}{y_{21a}}\right)$

⇒ $\dfrac{v_o}{i_s} = \dfrac{y_{21a}}{y_{12f}\, y_{21a} - y_o y_i} = \dfrac{\dfrac{y_{21a}}{y_o y_i}}{\dfrac{y_{12f} \cdot y_{21a}}{y_o y_i} - 1}$

$= \dfrac{\left(-\dfrac{y_{21a}}{y_o y_i}\right)}{1 + \left(-\dfrac{y_{21a}}{y_o y_i}\right) \cdot y_{12f}} = \dfrac{a}{1+a}$

$= \dfrac{A}{1 + Af}$



$i_s = v_i y_i + y_{12f} v_o$

$y_{21a} v_i + v_o y_o = 0$

⇒ $v_i = -v_o \dfrac{y_o}{y_{21a}}$

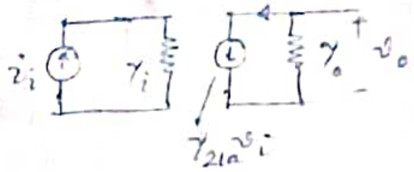
⇒ $i_s = \cancel{v_i y_i + y_{12f}}$

$i_s = -v_o \dfrac{y_o y_i}{y_{21a}} + y_{12f} v_o$

for the amplifier ckt,

without feedback,

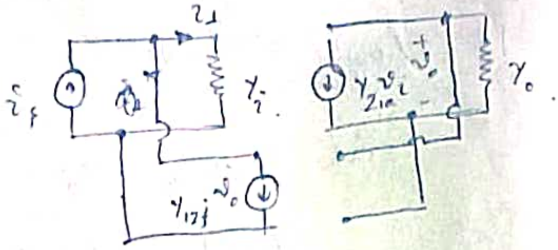
gain: $\dfrac{v_o}{i_s}$



$v_o = -\dfrac{y_{21a} v_i}{y_o} = -\dfrac{y_{21a} i_i}{y_o y_i}$

$v_i = \dfrac{i_i}{y_i}$ ⇒ $\dfrac{v_o}{i_i} = -\dfrac{y_{21a}}{y_o y_i}$

i/p impedance with feedback:



$$i_s = i_1 + y_{12f} \cdot v_0$$

$$i_1 = v_i Y_i$$

$$\Rightarrow i_s = v_i Y_i + y_{12f} \cdot v_0$$

$$v_0 = \frac{A}{1+Af} \times i_s$$

$$\Rightarrow i_s = v_i Y_i + \frac{y_{12f} \times y_{21a}}{y_{12f} \times y_{21a} - Y_i Y_0} i_s$$

$$\Rightarrow i_s \left\{ 1 - \frac{y_{12f} \times y_{21a}}{y_{12f} \times y_{21a} - Y_i Y_0} \right\} = v_i Y_i$$

$$\Rightarrow \cancel{i_s \left\{ 1 - y_{12f} \right.}$$

$$\Rightarrow i_s \left\{ \frac{y_{12f} y_{21a} - Y_i Y_0 - y_{12f} y_{21a}}{y_{12f} y_{21a} - Y_i Y_0} \right\} = v_i Y_i$$

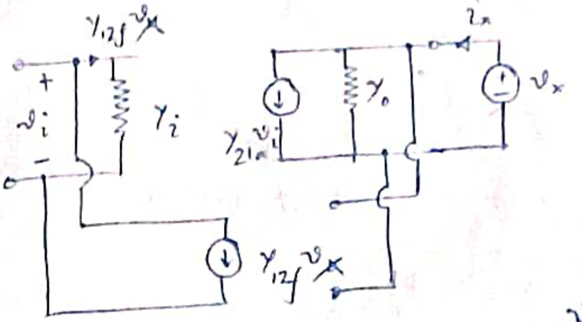
$$\Rightarrow i_s \left\{ \frac{\cancel{-Y_i Y_0} \; 1}{-\frac{y_{12f} y_{21a}}{Y_i Y_0} + 1} \right\} = v_i Y_i$$

$$\Rightarrow \frac{v_i}{i_s} = Z_{if} = \frac{1}{Y_i} \times \frac{1}{1 + \left(-\frac{y_{21a}}{Y_i Y_0}\right) \times y_{12f}}$$

$$= \frac{1}{Y_i} \times \frac{1}{1+Af}.$$

O/P impedance with feedback:

$$\cancel{Z_{of} = v_o} \qquad Z_{of} = ?$$



$$v_i = -\frac{Y_{12f}\,v_x}{Y_i}$$

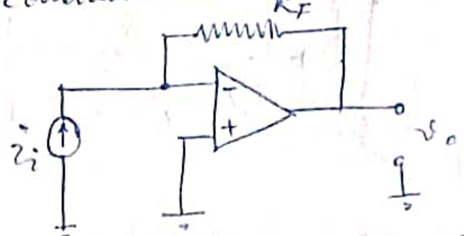
$$i_x = v_x \cdot Y_o + Y_{21a} \cdot v_i$$

$$= v_x Y_o - Y_{21a} \times \frac{Y_{12f}}{Y_i} \cdot v_x$$

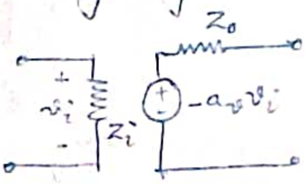
$$= v_x Y_o \left\{ 1 + \left(\frac{-Y_{21a} Y_{12f}}{Y_o Y_i} \right) \right\}$$

$$\frac{v_x}{i_x} = \frac{1}{Y_o} \times \frac{1}{1 + \left(\frac{-Y_{21a}}{Y_o Y_i}\right) \times Y_{12f}}$$

p. consider the ckt



model the op-amp as



$Z_i = 2M\Omega$

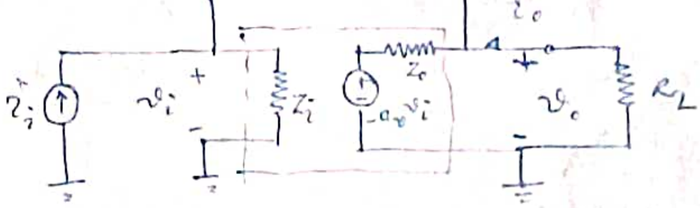
$Z_o = 75\,\Omega$

$a_v = 200{,}000$

$R_L = 10k\Omega$

$R_F = 1M\Omega$

find the closed loop gain $\frac{v_o}{i_i}$



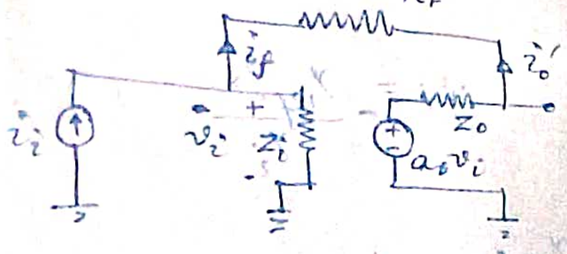
$$i_o = -\frac{v_o}{R_L}$$

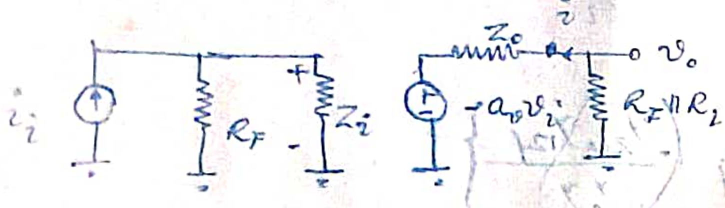
$$i_i = \frac{v_i}{Z_i} + \frac{v_i - v_o}{R_F}$$

$$-a_v v_i + \left\{ i_o - \left(\frac{v_o - v_i}{R_F}\right) \right\} \times R_i$$

$y_{11f} = \frac{i_f}{v_i}\Big|_{v_o=0}$ → o/p shorted

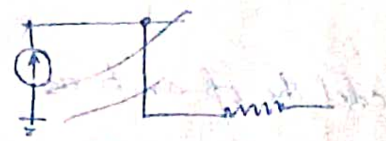
$y_{22f} = \frac{i_o'}{v_o}\Big|_{v_i=0}$ → i/p shorted

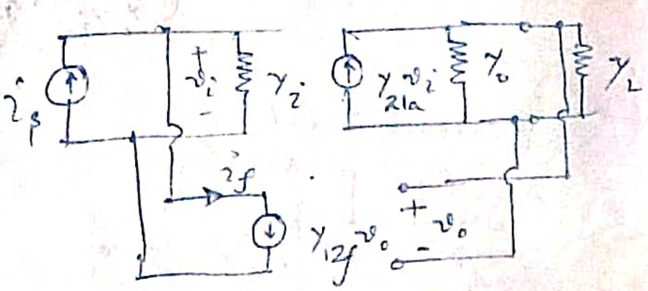




formation of amplifier with feedback loading.

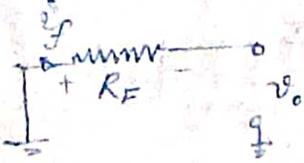
& feedback ckt





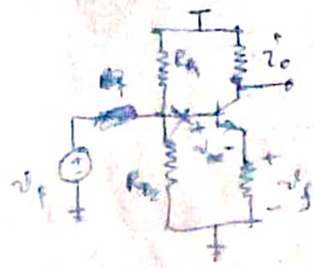
$y_{12f} = \frac{i_f}{v_o}\Big|_{v_i=0}$ → i/p shorted

i.e,

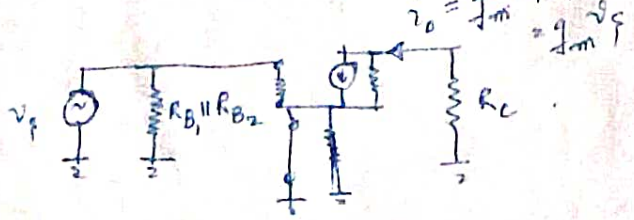


$i_f R_F + v_o = 0$

$\Rightarrow \frac{i_f}{v_o}\Big|_{v_i=0} = y_{12f} = -\frac{1}{R_F}$



$i_o = g_m v_\pi = g_m v_f$



$\frac{i_o}{v_f} = g_m$

$\frac{g_m R_E}{1 + g_m R_E}$

→ ~~[illegible]~~

$$i = \frac{v_o + a_v v_i}{Z_o}$$

$$\Rightarrow v_o = -i R_F' = -\frac{v_o + a_v v_i}{Z_o} \times R_F'$$

$$v_i = i_i \times (R_F \| Z_i) \qquad R_F' = R_F \| R_L$$

$$\Rightarrow v_o = -v_o \times \frac{R_F}{Z_o} - a_v v_i \times \frac{R_F}{Z_o}$$

$$\Rightarrow v_o \left(1 + \frac{R_F}{Z_o}\right) = -a_v \times i_i (R_F \| Z_i) \times \frac{R_F'}{Z_o}$$

$$\Rightarrow \frac{v_o}{i_i} = -\frac{a_v \times (R_F \| Z_i) \times \frac{R_F'}{Z_o}}{\left(1 + \frac{R_F'}{Z_o}\right)}$$

$$\Rightarrow \frac{v_o}{i_i} = -\frac{a_v \times (R_F \| Z_i) \times \frac{R_L \| R_F}{Z_o}}{\left(1 + \frac{R_L \| R_F}{Z_o}\right)}$$

$$= -\frac{200{,}000 \times (2M \| 1M) \times \frac{(10K \| 1M)}{75}}{\left(1 + \frac{10K \| 1M}{75}\right)}$$

$$= -\frac{200{,}000 \times 667K \times 132}{133}$$

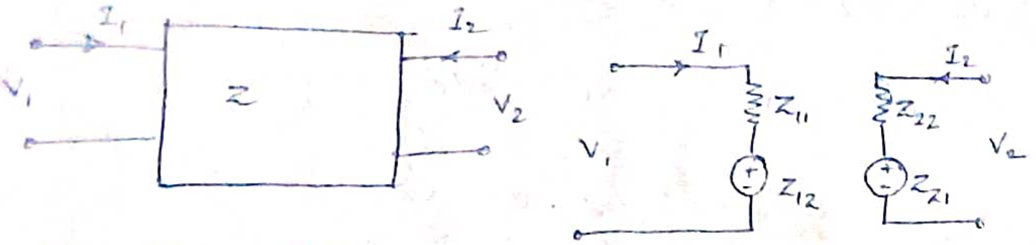
$$= -1.324 \times 10^{11}\ \Omega \qquad f = -\frac{1}{R_F}$$

$$\Rightarrow A_{CL} = \frac{A}{1 + A \cdot f} = \frac{-1.324 \times 10^{11}}{1 + \frac{1.324 \times 10^{11}}{1M}}$$

$$= 999.97\ K\Omega$$

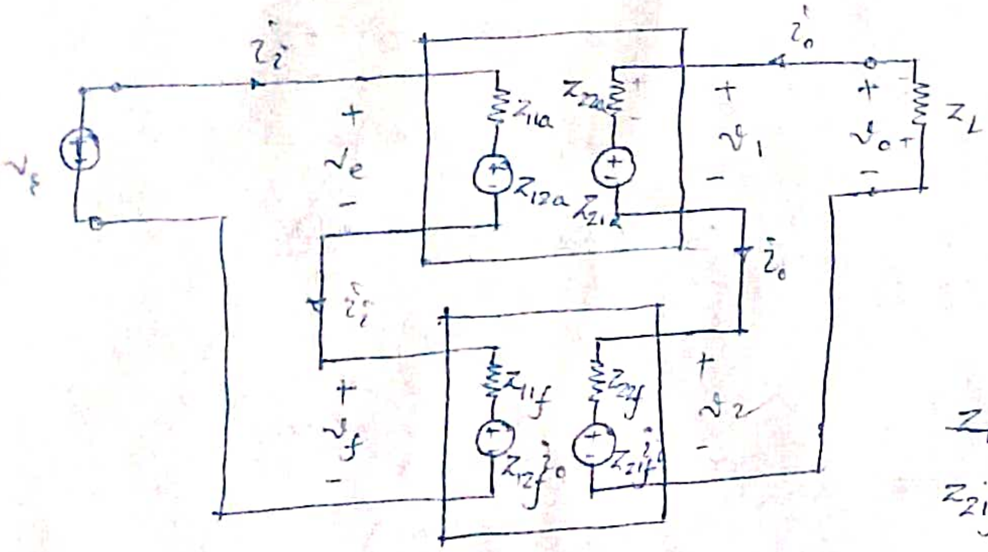
series - series feedback

representation with z parameters



$$V_1 = Z_{11} I_1 + Z_{12} I_2$$

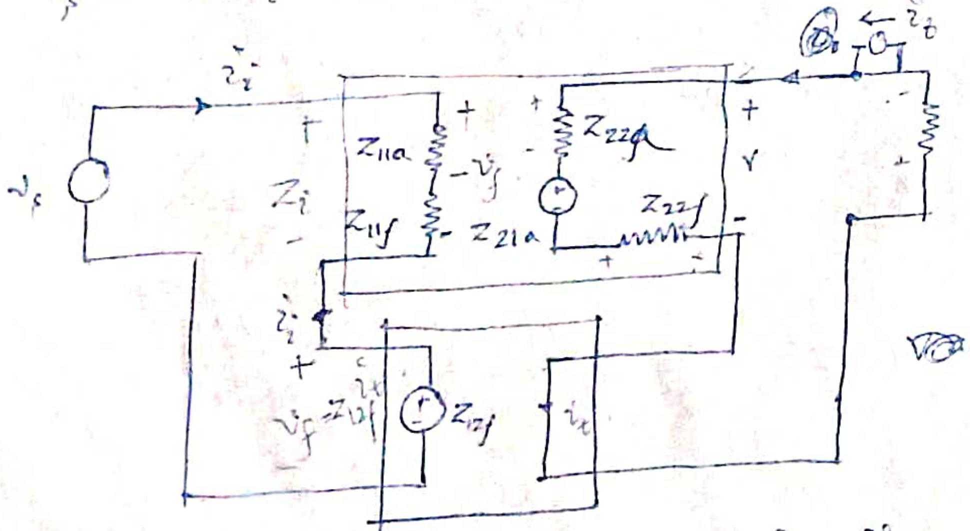
$$V_2 = Z_{21} I_1 + Z_{22} I_2$$



~~$Z_{12f} = Z$~~

$$Z_{21f} = Z_{12a} \simeq 0$$

~~$v_s = Z_{11a} i_i + Z_{12a} v_o + Z_{11f} i_i + Z$~~



$$V = Z_o \cdot i_t + Z_{21a} \cdot i_i$$

$$= Z_o i_t \pm \frac{Z_{21a} Z_{1}}{Z_i}$$

$$Z_{oi} = Z_o i_t (1 + A_f)$$

$$V = Z_{22a} i_t + Z_{22f} i_t + Z_{21a} \cdot i_i$$

$$i_i = \frac{v_f}{Z_i} = \frac{Z_{12f} i_t}{Z_i}$$

$$v_s = i_i (Z_{11a} + Z_{11f}) + Z_{12f} \cdot i_o$$

$$i_o (Z_L + Z_{22a} + Z_{22f}) + Z_{21a} \cdot i_i = 0$$

$$\Rightarrow i_o (Z_L + Z_{22a} + Z_{22f}) + Z_{21a} \times i_i \cancel{(Z_{11a} + Z_{11f})} = 0$$

Let, $Z_{11a} + Z_{11f} = Z_i$, $\quad Z_L + Z_{22a} + Z_{22f} = Z_o$

$$\Rightarrow v_s = i_i Z_i + Z_{12f}\, i_o$$

$$0 = i_o Z_o + Z_{21a} \cdot \cancel{Z_i}\, i_i \cancel{=0}$$

$$\Rightarrow \cancel{i_i = -\frac{i_o Z_o}{Z_{21a} \cdot Z_i}} \qquad \Rightarrow i_i = -\frac{i_o Z_o}{Z_{21a}}$$

$$\Rightarrow v_s = -\frac{i_o Z_o}{Z_{21a} \cdot \cancel{Z_i}} \cdot Z_i + Z_{12f} \cdot i_o$$

$$= -\frac{i_o Z_o Z_i}{Z_{21a}} + Z_{12f} \cdot i_o$$

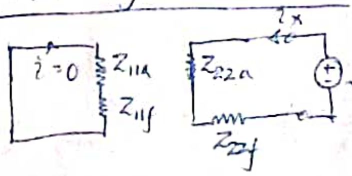
$$\Rightarrow = i_o \left(-\frac{Z_o Z_i}{Z_{21a}} + Z_{12f} \right)$$

$$\Rightarrow \frac{i_o}{v_s} = A_{CL} = \frac{Z_{21a}}{Z_{21a} Z_{12f} - Z_o Z_i} = \frac{\left(-\frac{Z_{21a}}{Z_o Z_i}\right)}{1 + \left(-\frac{Z_{21a}}{Z_o Z_i}\right) Z_{12f}}$$

$Z_o = Z_{22a} + Z_{22f}$

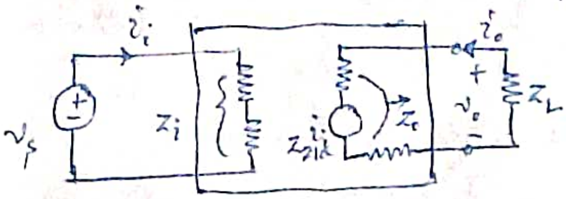
$$= \frac{a}{1 + af} = \frac{A}{1 + Af}$$

<u>how to form A ckt :</u>



$$Z_{11f} = \left.\frac{v_f}{i_i}\right|_{i_o = 0} \qquad Z_{22f} = \left.\frac{v_2}{i_o}\right|_{i_i = 0}$$

i.e., o/p open ckt. $\qquad$ i.e. i/p open ckt.



$$i_o \cdot Z_o + Z_{21a}\, i_i = 0$$

$$\Rightarrow i_o = -\frac{Z_{21a}\, i_i}{Z_o} = -\frac{Z_{21a}}{Z_o Z_i} v_s$$

$$\& \quad i_i = \frac{v_s}{Z_i} \qquad \Rightarrow \frac{i_o}{v_s} = -\frac{Z_{21a}}{Z_o Z_i}$$

I/P & O/P impedance

$$\frac{v_s}{i_i} = ?$$

$$v_s = i_i Z_i + Z_{12f}\, i_o$$

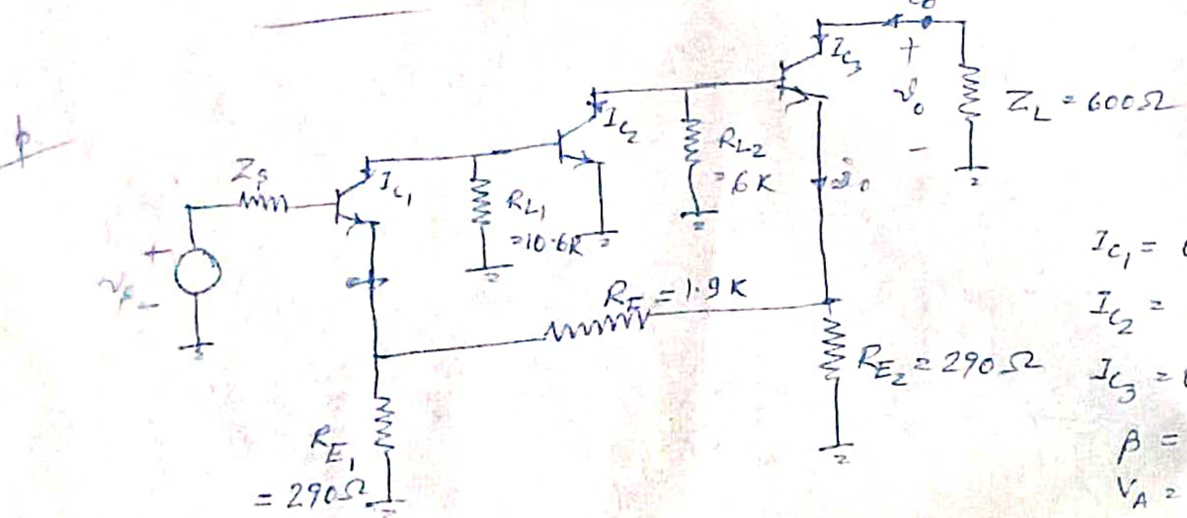
$$\& \; i_o = -\frac{Z_{21a}\, i_i}{Z_o}$$

$$\Rightarrow v_s = i_i Z_i - Z_{12f} \cdot \frac{Z_{21a}}{Z_o}\, i_i = i_i\left(\frac{Z_i Z_o - Z_{12f} Z_{21a}}{Z_o}\right)$$

$$\Rightarrow \frac{v_s}{i_i} = \left(\frac{Z_o}{Z_i Z_o - Z_{12f} Z_{21a}}\right)^{-1} = \frac{Z_i Z_o\left(1 - \frac{Z_{12f} \cdot Z_{21a}}{Z_i Z_o}\right)}{Z_o} = Z_i\left(1 + \left(-\frac{Z_{21a}}{Z_i Z_o}\right) Z_{12f}\right) = Z_i(1 + A\beta)$$

how to form fb ckt:

$$Z_{12f} = \left.\frac{v_f}{i_o}\right|_{i_i = 0}$$



$I_{C_1} = 0.5\,mA$

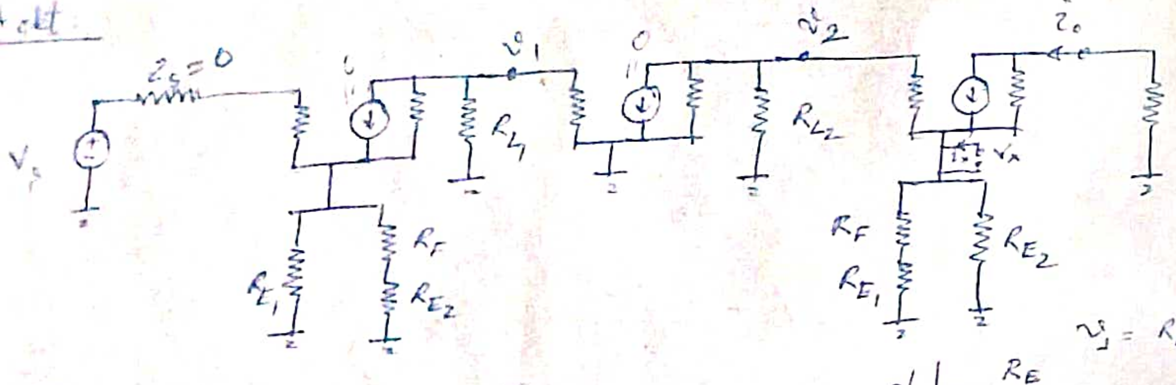
$I_{C_2} = 0.77\,mA$

$I_{C_3} = 0.73\,mA$

$\beta = 120,$

$V_A = 40$

A ckt

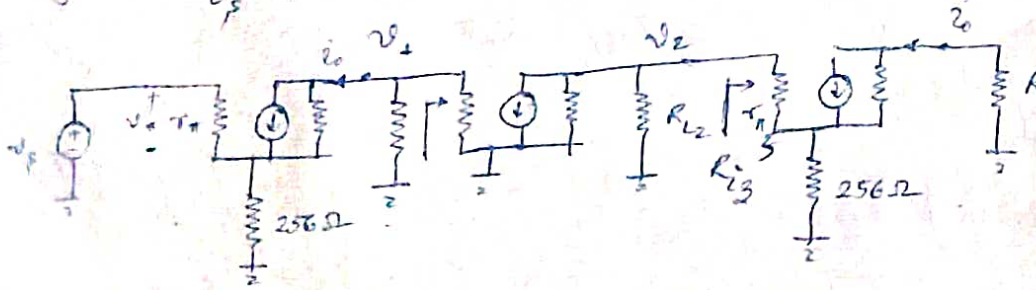


$$v_f = R_{E_2} \| (R_F + R_{E_1}) \times i_o$$

$$\left. v_f \right|_{i_i = 0} = \frac{R_{E_1}}{R_{E_1} + R_F} \times R_{E_2} \| (R_F + R_{E_1}) \times i_o$$

$$= \frac{R_{E_1} \times R_{E_2} (R_F + R_{E_1})}{(R_{E_1} + R_F)(R_F + R_{E_1} + R_{E_2})} = \frac{R_{E_1} R_{E_2}}{R_{E_1} + R_{E_2} + R_F}$$

$$\text{gain} = \frac{i_o}{v_s}$$



$$r_{\pi_1} = \frac{\beta}{g_{m_1}} = \frac{120}{\left(\frac{0.5m}{26m}\right)} = 6.24K$$

$$r_{\pi_2} = \frac{\beta}{g_{m_2}} = \frac{120}{\left(\frac{0.77m}{26m}\right)} = 4.05K$$

$$r_{\pi_3} = \frac{120}{\frac{0.73m}{26m}} = 4.27K\Omega$$

$$r_{o_1} = \frac{40}{0.5m} = 80K\Omega$$

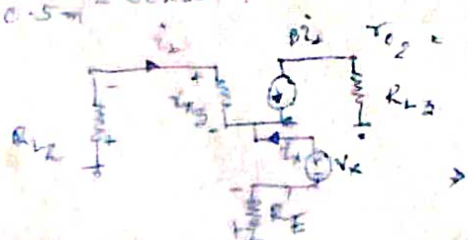
$$r_{o_2} = 52K\Omega \qquad r_{o_3} = 54K\Omega$$

o/p imp

$$i_s + \beta i_s + i_x = 0$$

$$i_x = -(\beta+1) i_s$$

$$i_s = \frac{i_x}{\beta+1}$$



$$-i(R_{L_2} + r_{\pi_3}) - v_x + i_x R_E' = 0$$

$$\Rightarrow \frac{(R_{L_2} + r_{\pi_3})\, i_x}{\beta + 1} + i_x R_E' = v_x$$

out put aces :

$v_1 = -i_0 (R_{L_1} \| r_{\pi_2})$

$v_s = v_\pi + \left(i_0 + \frac{v_\pi}{r_\pi}\right) \times R_E'$

$i_0 = g_m v_\pi + \dfrac{v_1 - \left(i_0 + \frac{v_\pi}{r_\pi}\right) \times R_E'}{r_{o_1}}$

$v_\pi = v_\pi + \frac{v_\pi R_E'}{r_\pi} + i_c R_E'$

$= g_m v_\pi +$

$= v_\pi \left(1 + \frac{R_L'}{r_\pi}\right) + i_0 R_E'$

$\frac{v_1}{v_s} \simeq \frac{(R_{L_1} \| r_{\pi_2})}{R_E'} = \frac{10.6K \| 4.05K}{256}$

$= \frac{2.93K}{256} = -11.44 \text{ V/V}$.

$a = 4.5 \text{ A/V}$

$\left.\frac{i_0}{v_s}\right|_{c_2} = 29 \text{ mA/V}$

$R_{i_3} = r_{\pi_3} + (\beta+1) R_E''$

$= 4.27K + 121 \times 256$

$= 35.25K$.

$R_i = 5.73 M\Omega$

$R_o = 355.5 M\Omega$

$\cancel{\frac{i_c}{v_s} = 6.03}$

$\Rightarrow \frac{v_2}{v_1} = -g_{m_2} \times (r_{o_2} \| R_{i_3} \| R_{L_2})$

$f =$

$= -g_{m_2} \times (52K \| 30K \| 6K)$

$= -g_{m_2} \times (19K \| 6K)$

$= -g_{m_2} \times 4.56K$

$= -135 \text{ V/V}$.

$r_{\pi_1} = 6.24K \quad g_{m_1} =$

$r_{\pi_2} = 4.05K \quad g_{m_2} =$

$r_{\pi_3} = 4.27K \quad g_{m_3} =$

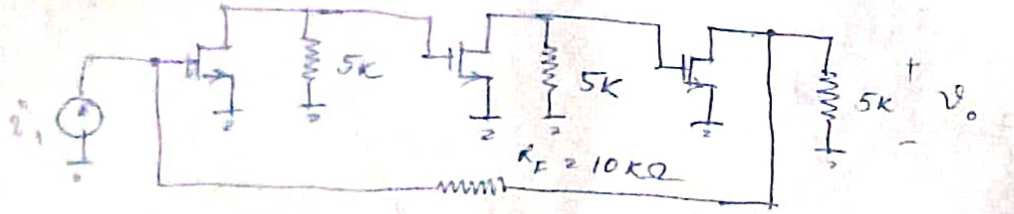
$\cancel{v_0 = -i_0 R_L}$

$\frac{v_0}{v_2} \simeq -\frac{R_L}{R_E''} = -\frac{600}{256} = -2.34 \text{ V/V}$

$\frac{v_0}{v_2} = -2.34 = -\frac{i_c \cdot R_L}{v_2} \Rightarrow \frac{i_c}{v_2} = \frac{2.34}{R_L}$

$\Rightarrow \frac{i_0}{v_s \times 11.44 \times 135} = \frac{2.34}{600}$

$\Rightarrow \frac{i_0}{v_s} = \frac{2.34 \times 11.44 \times 135}{600} \cong 6.03$



$I_D = 1mA,\ W/L = 100,\ k' = 60\mu A/V^2,\ \lambda = \frac{1}{50} V^{-1}$

$a_{CL} \simeq -10k\Omega$

$Z_{if} = 16.4\Omega$

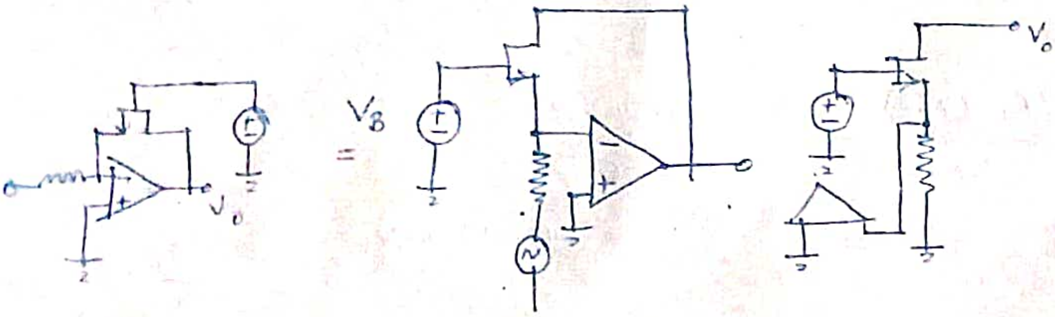
$Z_{of} = 1.13\Omega$

$R_{in} \times 2$

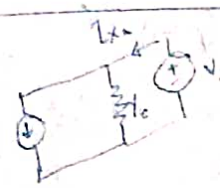
$R_{out} \times 2$

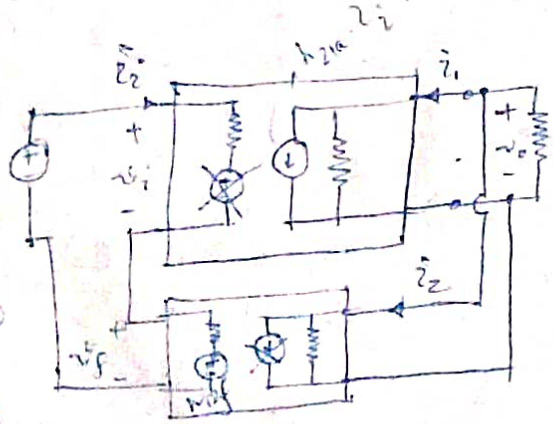
$\frac{V_2}{V_1} \times 2$

$\frac{V_o}{V_2} \times 2$



Series shunt feedback:





h parameters

for BA ckt

$v_i = h_{11a} i_i + h_{12a} v_o$

$i_1 = h_{21a} i_i + h_{22} v_o$

for feedback ckt

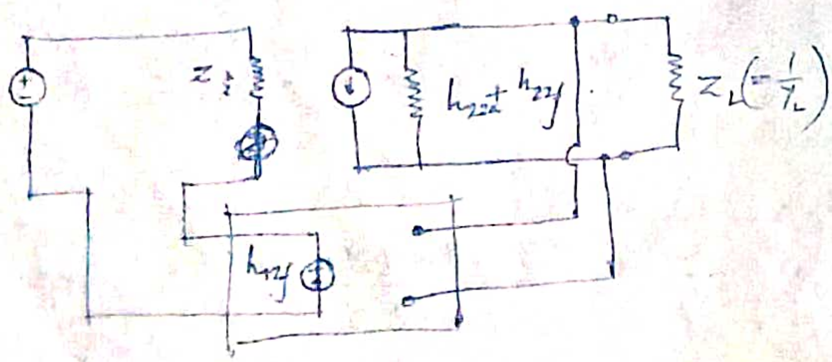
$v_f = h_{11f} i_i + h_{12f} \cdot v_o$

$i_2 = h_{21f} i_i + h_{22f} \cdot v_o$

assumption: $h_{12a} \ll h_{21a}$

& $h_{21f} \ll h_{12f}$.

modified ckt



$$v_s = i_i . z_i + h_{12f} . v_o$$

& $$v_o = -h_{21a} . i_i \times \frac{1}{h_{22a} + h_{22f} + \gamma_L} \Rightarrow = -\frac{h_{21a} i_i}{\gamma_o}$$

Let, $h_{22a} + h_{22f} + \gamma_L = \gamma_o$ $\Rightarrow i_i = -\frac{v_o \gamma_o}{h_{21a}}$

$$\Rightarrow v_s = i_i z_i + h_{12f} \times v_o$$

$$= -\frac{v_o \gamma_o}{h_{21a}} \times z_i + h_{12f} v_o$$

$$= v_o \left(\frac{-\gamma_o z_i + h_{12f} h_{21a}}{h_{21a}} \right)$$

$$\Rightarrow \frac{v_o}{v_s} = \frac{h_{21a}}{-\gamma_o z_i + h_{12f} h_{21a}}$$

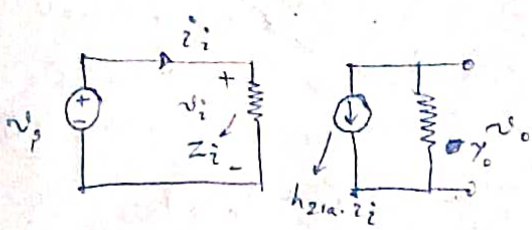
$$= \frac{\left(-\frac{h_{21a}}{\gamma_o z_i}\right)}{1 + \left(-\frac{h_{21a}}{\gamma_o z_i}\right) . h_{12f}}$$

$$h_{12f} = \left.\frac{v_f}{v_o}\right|_{i_i = 0}$$

$$h_{11f} = \left.\frac{v_f}{i_i}\right|_{v_o = 0}$$

$$h_{22f} = \left.\frac{i_2}{v_o}\right|_{i_i = 0}$$

BA ckt with feedback load:



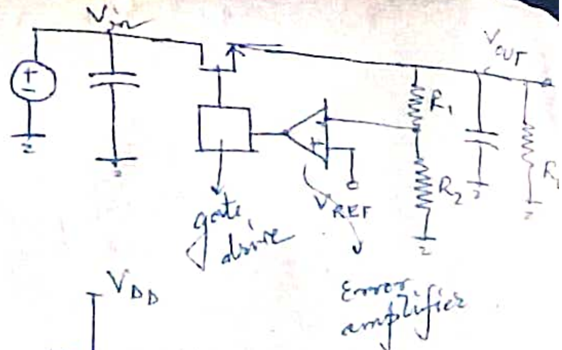
$$v_s = i_i z_i \quad \& \quad v_o = -\frac{h_{21a} . i_i}{\gamma_o}$$

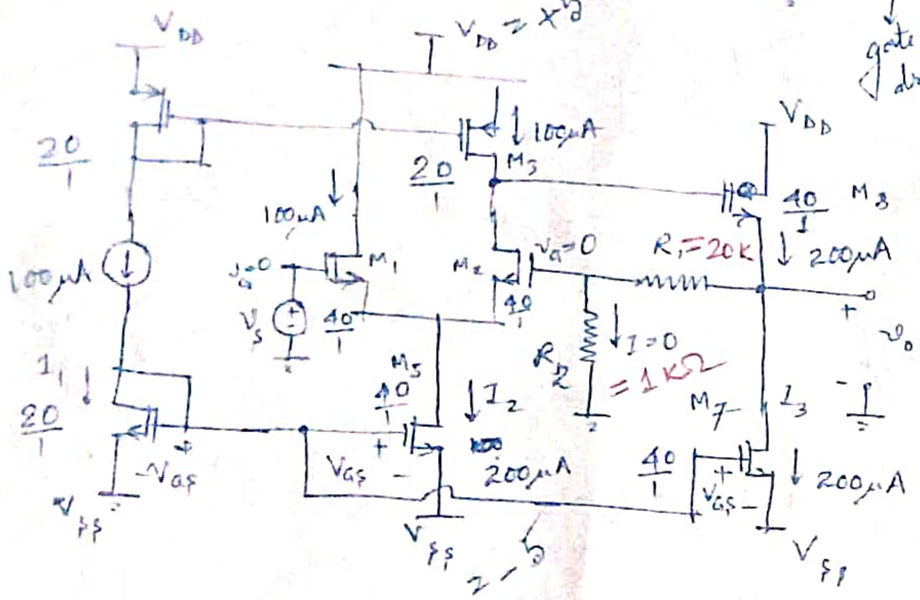
$$f = h_{12f} = \left.\frac{v_f}{v_o}\right|_{i_i = 0}$$

$$\Rightarrow v_s = -\frac{v_o \gamma_o z_i}{h_{21a}} \quad \Rightarrow i_i = -\frac{v_o \gamma_o}{h_{21a}}$$

$$\Rightarrow \frac{v_s}{v_o} = -\frac{h_{21a}}{\gamma_o z_i} = a \qquad A_{CL} = \frac{v_o}{v_s} = \frac{a}{1 + af}$$

(P)





$\mu_n C_{ox} = 60\ \mu A/V^2$

$\mu_p C_{ox} = 30\ \mu A/V^2$

$V_{tn} = |V_{tp}| = 0.8V$,

$\lambda_n = |\lambda_p| = 0.03\ V^{-1}$

assume all the transistors are in saturation region.

neglect r_{o_1}, r_{o_2} of M_1 & M_2, i.e., assume $r_o \to \infty$

$I_{D_1} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS}-V_{tn})^2$

$I_1 = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\cdot(V_{GS}-V_{tn})^2\cdot(1+\lambda_n V_{DS})$

$\Rightarrow V_{GS}-V_{tn} = \sqrt{\frac{2\times 100}{60\times 40\times}}$

for I_1, $V_{GS} = V_{DS}$

$\Rightarrow V_{GS_1} = 1.1V$

$\Rightarrow V_{S_1} = -1.1V$

$\Rightarrow \frac{I_1\times 2}{\mu_n C_{ox}\left(\frac{W}{L}\right)} = (V_{DS}-0.8)^2\cancel{(1+\lambda_n V_{DS})}$

for M_2,

$I_{D_2} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{GS_2}-V_{t}$

$\Rightarrow V_{GS} = \sqrt{\frac{2.I_1}{\mu_n C_{ox}\left(\frac{W}{L}\right)}} + 0.8 = 1.21V$

$\Rightarrow V_{GS} = -1.1V$.

$\cancel{\Rightarrow V_G = V_{GS}}$ $\cancel{V_{GS} = V_G - V_S}$

$\Rightarrow V_{G_2} = 0$

$\cancel{\Rightarrow V_G =}$

$\Rightarrow I = 0$

$200\mu A = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)\times(V_{GS}-V_{tn})^2(1+\lambda_n V_{DS})$

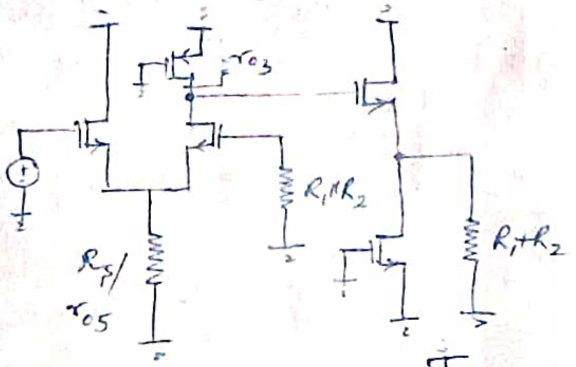
$= \frac{1}{2}\times 60\mu\times 40\times(1.21-0.8)^2(1+0.03.V_{DS})$

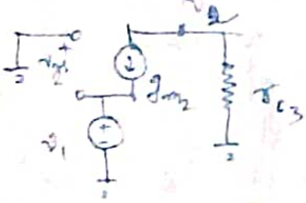
$\Rightarrow \frac{200\times 2}{60\times 40\times 0.168} = (1+0.03V_{DS})$

$\Rightarrow$ ~~$V_{DS} =$~~ $1+0.03V_{DS} = 0.992$

~~$\Rightarrow 0.03V_{DS} =$~~ $\Rightarrow V_{DS} = -0.267$

• basic amplifier ckt :



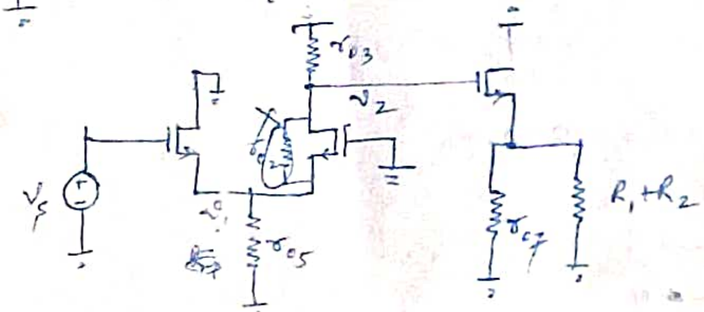


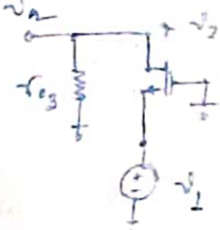
$v_2 = -g_{m_2} v_{gs} \times r_{o3}$

$= -g_{m_2}(-v_1) \times r_{o3}$

$\Rightarrow v_2 = + g_{m_2} r_{o3} \times v_1$

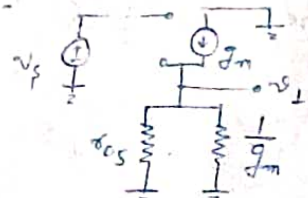
R_S

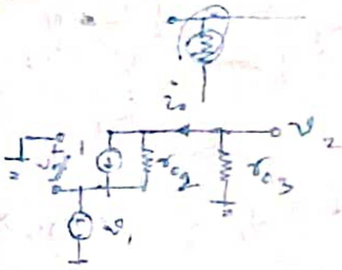




Consider $r_{o1}, r_{o2} \to \infty$, for M_1 & M_2.

$\Rightarrow$ now.





$v_1 = g_m v_{gs} \times \left(r_{o5} \| \frac{1}{g_m}\right)$ $\qquad v_S = v_{gs} + v_1$

$\Rightarrow v_1 = g_m (v_S - v_1) \left(r_{o5} \| \frac{1}{g_m}\right)$ $\qquad \Rightarrow v_{gs} = v_S - v_1$

$\Rightarrow v_1 = g_m v_S \left(r_{o5} \| \frac{1}{g_m}\right) - v_1 g_m \left(r_{o5} \| \frac{1}{g_m}\right)$

$\Rightarrow v_1 (1 + g_m r) = v_S \cdot g_m r$

$\Rightarrow \frac{v_1}{v_S} = \frac{g_m r}{1 + g_m r} \simeq 1$

$v_{gs} + v_1 = 0 \quad \Rightarrow v_2 = -i_o r_{o3}$

$i_o = g_m v_{gs} + \frac{v_2 - v_1}{r_{o2}}$

$\Rightarrow i_o = -g_m v_1 + \frac{v_2 - v_1}{r_{o2}}$

$= -g_m v_1 - \frac{v_1}{r_{o2}} + \frac{v_2}{r_{o2}}$

$\Rightarrow i_o = -g_m v_1 - \frac{v_1}{r_{o2}} + \frac{v_2}{r_{o2}}$

$= -v_1 \left(g_m + \frac{1}{r_{o2}}\right) + \frac{v_2}{r_{o2}}$

$\Rightarrow v_2 = -\left\{-v_1 \left(g_m + \frac{1}{r_{o2}}\right) + \frac{v_2}{r_{o2}}\right\} \times r_{o3}$

$= v_1 \left(g_m + \frac{1}{r_{o2}}\right) r_{o3} - \frac{v_2 r_{o3}}{r_{o2}}$

$\Rightarrow v_2 \left(1 + \frac{r_{o3}}{r_{o2}}\right) = v_1 \left(g_m + \frac{1}{r_{o2}}\right) r_{o3}$

$\Rightarrow v_2 \left(\frac{r_{o2} + r_{o3}}{r_{o2}}\right) = v_1 \left(\frac{g_m r_{o2} + 1}{r_{o2}}\right) r_{o3}$

$\Rightarrow \frac{v_2}{v_1} = \frac{(1 + g_m r_{o2}) r_{o3}}{r_{o2} + r_{o3}}$ $\qquad \left(g_m + \frac{1}{r_{o2}}\right)(r_{o3} \| r_{o2})$

$\simeq g_m ($ $\qquad r_{o2} \gg r_{o3}$

$v_1 \simeq v_s$

$\therefore v_2 = g_m \cdot r_{o_3}$

$\therefore v_o \cong v_2 \Rightarrow v_o = g_m \cdot r_{o_3} \cdot v_s$

$\Rightarrow a = g_m \cdot r_{o_3}$

$= 693\mu \times 333K$

$= 230.7$

$i_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(v_{GS}-V_T)^2$

$\Rightarrow \frac{\partial i_D}{\partial v_{gs}} = \mu_n C_{ox}\frac{W}{L}(v_{GS}-V_T)$

$= \mu_n C_{ox}\frac{W}{L} \times \frac{\sqrt{2 i_D}}{\sqrt{\mu_n C_{ox}\frac{W}{L}}}$

$= \sqrt{2\mu_n C_{ox}\frac{W}{L} \times i_D}$

$r_{o_3} = \frac{1}{\lambda I_D}$

$= \frac{1}{0.03 \times 100\mu}$

$= 333 k\Omega$

$r_{o_5} = \frac{1}{\lambda I_D}$

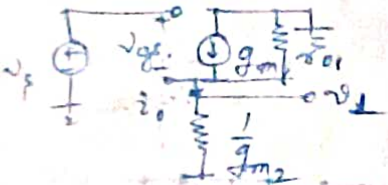
$= \frac{1}{0.03 \times 200\mu}$

$= 166.7 k\Omega$

$\therefore \frac{1}{g_m} = \frac{1}{693\mu}$

$= 1.443 k\Omega$

$\Rightarrow \frac{1}{g_m} << r_{o_5}$



$v_s = v_{gs} + v_1$

$\Rightarrow v_{gs} = v_s - v_1$

$\Rightarrow v_1 = g_{m_1} \times v_{gs_1} \times \frac{1}{g_{m_2}}$

$= g_{m_1}(v_s - v_1) \times \frac{1}{g_{m_2}}$

$\Rightarrow v_1 = \frac{g_{m_1}}{g_{m_2}} v_s - v_1 \times \frac{g_{m_1}}{g_{m_2}}$

$\Rightarrow v_1\left(1 + \frac{g_{m_1}}{g_{m_2}}\right) = \frac{g_{m_1}}{g_{m_2}} \cdot v_s \Rightarrow v_1 = \frac{v_s}{2}$

$\frac{v_2}{v_1} \cong \left(g_{m_2} + \frac{1}{r_{o2}}\right) \times (r_{o2} \| r_{o3})$

$v_s = v_{gs_1} + v_1$

$\Rightarrow v_{gs_1} = v_s - v_1$

$i_o = g_m v_{gs} + \frac{0 - v_1}{r_{o1}} \Rightarrow v_1 = i_o \times \frac{1}{g_{m2}}$

$= g_{m_1}(v_s - v_1) - \frac{v_1}{r_{o_1}}$

$= g_{m_1} v_s - v_1\left(g_{m_1} + \frac{1}{r_{o_1}}\right)$

$= \left\{g_{m_1} v_s - v_1\left(g_{m_1} + \frac{1}{r_{o_1}}\right)\right\}\frac{1}{g_m}$

$= v_s - v_1\left(g_{m_1} + \frac{1}{r_{o_1}}\right)\frac{1}{g_{m_2}}$

$= v_s - v_1\left(1 + \frac{1}{g_{m_2} r_{o_1}}\right)$

$\Rightarrow v_1\left(\cancel{1}+1+\frac{1}{g_{m_2}r_{o_1}}\right) = v_f$

$\Rightarrow \frac{v_1}{v_f} = \frac{1}{2+\frac{1}{g_{m_2}r_{o_1}}}$

$= \frac{1}{2+\frac{1}{693\mu\times}}$

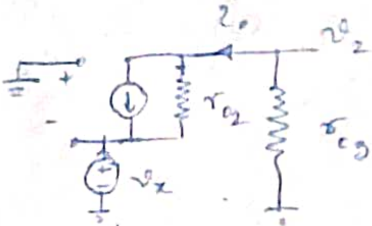
$\Rightarrow \frac{v_2}{v_x} = \frac{(g_m r_{o_2}+1)\, r_{o_3}}{(r_{o_2}+r_{o_3})}$

$= \frac{g_m\, r_{o_2} r_{o_3}}{r_{o_2}+r_{o_3}}$

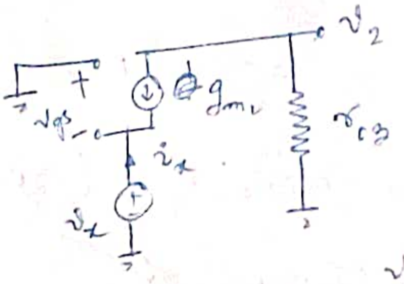
$\Rightarrow a = \frac{1}{2} g_m r_{o_3} = 109.25$

$f = \frac{1}{21}$ $\Rightarrow A_{CL} = \frac{a}{1+af} = \frac{109.25}{1+109.25\times\frac{1}{21}} = \frac{109.25}{6.2}$

$= 17.62$



$\frac{v_2}{v_x} =$



$v_{gs}+v_x = 0$ $\quad v_2 = -g_{m_2}v_{gs}\, r_{o_3}$

$\frac{v_x}{i_x} =$

$\Rightarrow v_{gs} = -v_x$ $\quad \Rightarrow v_2 = +g_{m_2}r_{o_3}v_x$

$\Rightarrow i_x = -g_{m_2}\cdot v_{gs} = +g_{m_2}\cdot v_x$ $\quad \Rightarrow \frac{v_2}{v_x} = g_{m_2}r_{o_3}$

$\Rightarrow \frac{v_x}{i_x} = \frac{1}{g_{m_2}}$

$\Rightarrow a = \frac{1}{2} g_{m_2} r_{o_3}$

$v_x + v_{gs} = 0$ $\quad = \frac{1}{2}\; 693\mu \times 333K$

$v_2 = -i_o\cdot r_{o_3}$

$\Rightarrow v_2 = \left\{+\left(g_m+\frac{1}{r_{o_2}}\right)v_x - \frac{v_2}{r_{o_2}}\right\} r_{o_3}$

$\Rightarrow v_2\left(1+\frac{r_{o_3}}{r_{o_2}}\right) = v_x\cdot\left(g_m+\frac{1}{r_{o_2}}\right) r_{o_3}$

$i_o = g_m v_{gs} + \frac{v_2 - v_x}{r_{o_2}}$

$= g_m(-v_x) + \frac{v_2}{r_{o_2}} - \frac{v_x}{r_{o_2}}$

shunt-shunt amp using feedback topologies

series-shunt

$$i_f = \frac{v_i}{r_i} + \frac{v_i - v_o}{R_F}$$

$$\Rightarrow i_f = v_i\left(\frac{1}{r_i}+\frac{1}{R_F}\right) - \frac{v_o}{R_F}$$

$$\Rightarrow v_i\left(\frac{1}{r_i}+\frac{1}{R_F}\right) = i_f + \frac{v_o}{R_F}$$

$$\Rightarrow v_i\left(\frac{r_i + R_F}{r_i R_F}\right) = \frac{i_f R_F + v_o}{R_F}$$

$$\Rightarrow v_i = \frac{(i_f R_F + v_o)\, r_i}{(r_i + R_F)}$$

$$i + \frac{v_i - v_o}{R_F} + \left(-\frac{v_o}{r_o}\right) = 0$$

$$\Rightarrow i = \frac{v_o}{r_o} + \frac{v_o - v_i}{R_F} = v_o\left(\frac{1}{r_o}+\frac{1}{R_F}\right) - \frac{v_i}{R_F}$$

$$-a_v v_i - \left\{v_o\left(\frac{1}{r_o}+\frac{1}{R_F}\right) - \frac{v_i}{R_F}\right\} r_o - v_o = 0$$

$$\Rightarrow -a_v v_i + \frac{v_i}{R_F} r_o = v_o\left\{1 + r_o\left(\frac{1}{r_o}+\frac{1}{R_F}\right)\right\}$$

$$\Rightarrow -a_v v_i R_F + v_i r_o = v_o \frac{(r_o R_F + R_F r_o + r_o \ldots}{r_o}$$

$$\Rightarrow (-a_v R_F + r_o) \frac{(i_f R_F + v_o)\, r_i}{(r_i + R_F)} = \frac{v_o (r_o R_F + R_F r_o \ldots}{R_F}$$

$$\Rightarrow (-a_v R_F + r_o)\left\{ i_f (R_F r_i) + \frac{v_o r_i}{r_i + R_F}\right\}$$

$$= v_o \{$$

$$\left(-a_v + \frac{r_o}{R_F}\right) v_i = v_o \left\{1 + \frac{r_o}{(r_i + R_F)}\right\}$$

$$\Rightarrow \left(\frac{-a_v R_F + r_o}{R_F}\right) v_i = v_o \left\{\frac{(r_o + R_F) + r_o}{(r_o + R_F)}\right\}$$

$$v_i = i_f (R_s \| Z_i) + \frac{v_o Z_i}{(Z_i + R_f)}$$

$$\Rightarrow \left(-a_v + \frac{Z_o}{R_F}\right)\left\{ i_f (R_s \| Z_i) + \frac{v_o Z_i}{Z_i + R_f}\right\} = v_o \left\{1 + \frac{Z_o}{Z_i \| R_f}\right\}$$

$$\Rightarrow -a_v\, i_f (R_s \| Z_i) - \frac{a_v v_o Z_i}{Z_i + R_f}$$

$$+ \frac{Z_o}{R_F}(R_s \| Z_i)\, i_f + \frac{Z_o}{R_F}\frac{Z_i}{Z_i + R_f}\, v_o$$

$$= v_o \left\{1 + \frac{Z_o}{Z_i \| R_f}\right\}$$

~~$\Rightarrow -a_v \{ i_f (R_s \| Z_i)$~~

$$\Rightarrow i_f \left\{-a_v (R_s \| Z_i) + \frac{Z_o}{R_F}(R_s \| Z_i)\right\}$$

$$= v_o \left\{1 + \frac{Z_o}{Z_i \| R_f} - \frac{Z_o Z_i}{R_F (Z_i + R_f)} + \frac{a_v Z_i}{(Z_i + R_f)}\right\}$$

$Z_i \| R_s = Z_i =$ [illegible] Ω

$Z_i \| R_f =$ [illegible] M

$$\Rightarrow i_f \{ - [illegible] + \frac{[illegible]}{[illegible]} [illegible] \}$$

$$= v_o \{ 1 + \frac{[illegible]}{[illegible]} + \frac{[illegible]}{[illegible]} + \frac{[illegible]}{[illegible]} \}$$

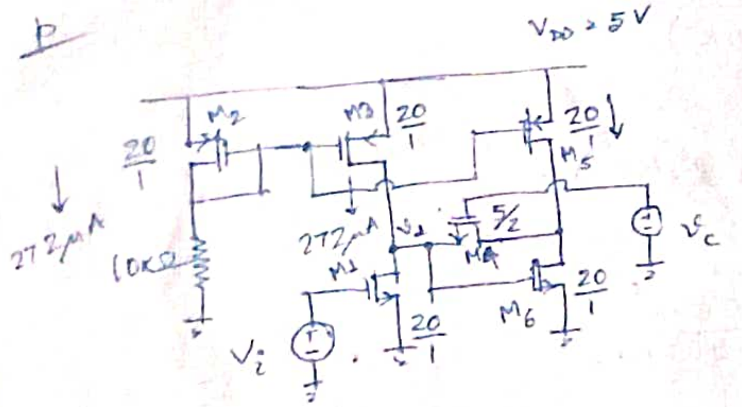
$$\Rightarrow i_f \{ -[illegible] + [illegible] \} = v_o \{ 1 + [illegible] + [illegible] + [illegible] \}$$

$$\Rightarrow \frac{v_o}{i_f} \approx -1\,\text{M}$$

Variable gain Amplifier

$\mu_n C_{ox} = 60\mu A/V^2$
$\mu_p C_{ox} = 30\mu A/V^2$
$V_{tn} = |V_{tp}| = 0.8V$
$\lambda_n = \lambda_p = 0$
$V_{tn4} = 1.14V$ λ

P



$I_D = \frac{1}{2}\mu_p C_{ox}\frac{W}{L}(V_{SG} - V_{TH})^2$

$I_D = \frac{V_{DD} - V_{SG}}{10K\Omega}$

$\Rightarrow I_D = \frac{5 - V_{SG}}{10K\Omega}$

$\Rightarrow \frac{5 - V_{SG}}{10K} = \frac{1}{2} \cdot 30\mu \times \frac{20}{1}(V_{SG} - 0.8)^2$

$\Rightarrow 5 - V_{SG} = 3(V_{SG} - 0.8)^2$
$= 3(V_{SG}^2 - 1.6V_{SG} + 0.64)$

$\Rightarrow 3V_{SG}^2 - 4.8V_{SG} + 1.92 = 5 - V_{SG}$

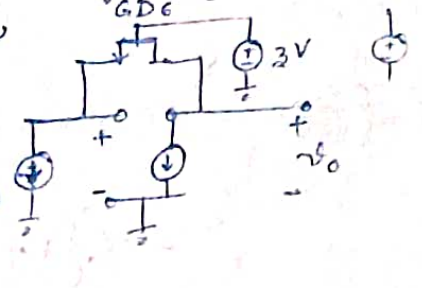
$\Rightarrow 3V_{SG}^2 - 3.8V_{SG} - \cancel{6.92}\,3.08 = 0$

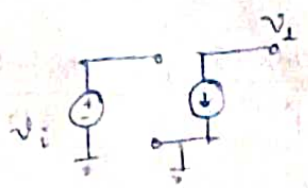
$\Rightarrow V_{SG} = \frac{3.8 \pm \sqrt{3.8^2 + 4.3.\cancel{6.92}\,3.08}}{2.3} = \frac{3.8 + 7.16}{6}$
$= 1.83V$

$\cancel{= \frac{3.8 \pm 9.87}{6} = 2.28V}$

$\Rightarrow I_D = \frac{5 - \cancel{2.28}\,1.83}{10K} = \cancel{272\mu A},$
$= 317\mu A$

$V_{GD6} = 0$





$\cancel{g_{m4}} =$

now, $\cancel{602\mu}\,317\mu = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)(V_{GS6} - V_{tn})^2$
$= \frac{1}{2}\, 60\mu . 20\,(V_{GS6} - 0.8)^2$

$\Rightarrow V_{GS6} = 1.53V \Rightarrow$

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

In linear region,

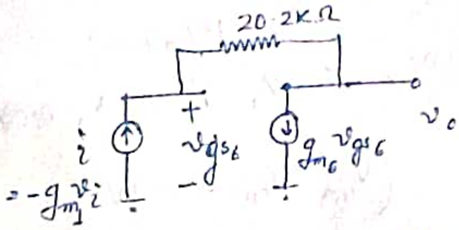
$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left\{2(V_{GS4} - V_{TH})V_{DS4} - V_{DS4}^2\right\}$

$\Rightarrow \frac{\partial I_D}{\partial V_{DS}} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left\{2(V_{GS} - V_{TH}) - 2V_{DS}\right.$
$= \mu_n C_{ox}\frac{W}{L}(V_{GS} - V_{TH}) - \mu_n C_{ox}\frac{W}{L}V_{DS}$

$\Rightarrow g_{ds4} = \mu_n C_{ox} \frac{W}{L}.(V_{GS4} - V_{T4})$

$= 60\mu \times \frac{5}{2}.(V_c - 1.53 - 1.14)$

$= 60\mu \times \frac{5}{2}(3 - 1.53 - 1.14) = (20.2\,k\Omega)^{-1}$



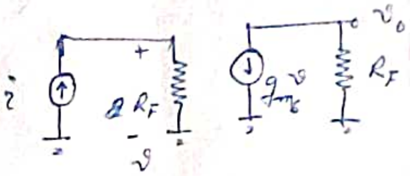
$g_{m1} = g_{m6} = g_m$

$= \sqrt{2\mu_n C_{ox} \frac{W}{L}.I}$

$= \sqrt{2.60\mu.20 \times 317\mu}$

$= 872\mu A/V$

BA $\rightarrow$



$v_o = -g_{m6}.v.R_F$

$= -g_{m6}.i.R_F.R_F \Rightarrow \frac{v_o}{i} = -g_m \times R_F^2$

$\cancel{= -g_{m6}.(-g_{m1}v_i)R_F}$

$\cancel{= + g_{m6}^2 R_F^2 =}$

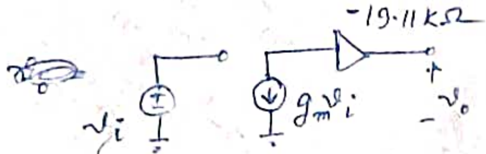
$= -872\mu \times (20.2K)^2$

$= -355.81 \times 10^3$

$\cancel{f =}\ f = -\frac{1}{20.2K} =$

$\Rightarrow \left(\frac{v_o}{i}\right)_{CL} = \frac{-355.81\times10^3}{1 + \frac{355.81\times10^3}{20.2\times10^3}} = -19.11\,k\Omega$

$\Rightarrow$



$v_o = -g_m v_i \times (-19.11\,k\Omega)$

$\Rightarrow \left(\frac{v_o}{v_i}\right)_{CL} = 872\mu \times 19.11k$

$= 16.66\ V/V$

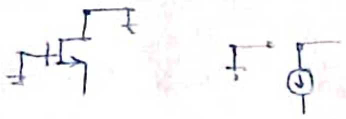
& $R_{of} = \frac{R_F}{(1+af)} = \frac{R_F}{18.61} = \frac{20.2\,k\Omega}{18.61}$

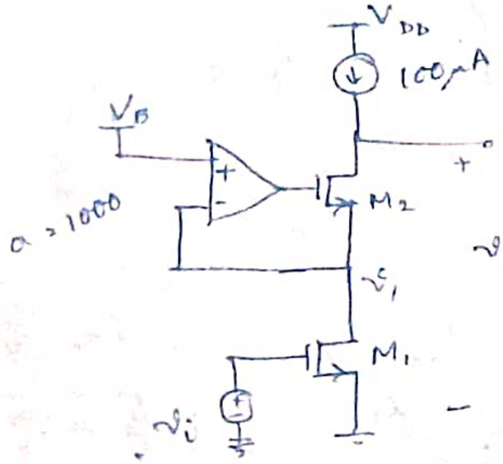
$= 1.085\,k\Omega$

|| ROUGH ||

b

active cascode





$K_n' = \mu_n C_{ox} = 140 \mu A/V^2$

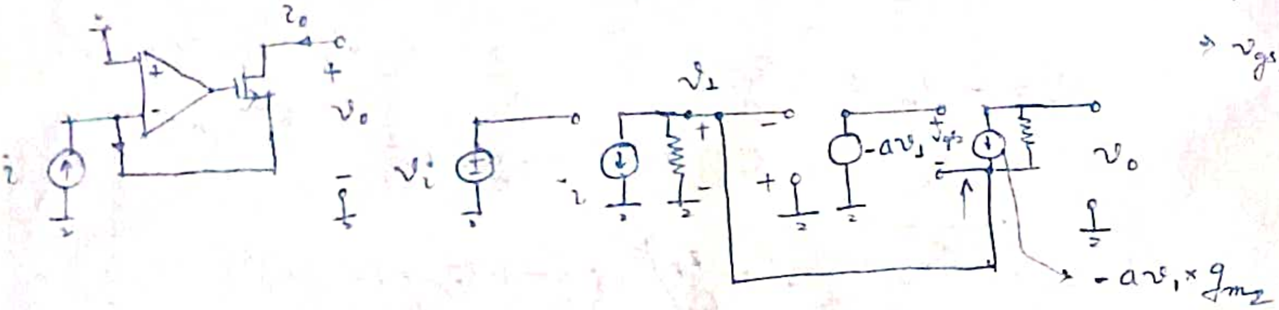
$V_{OV} = 0.3V, \quad \gamma = 0, \quad \lambda_n = 0.03 V^{-1}$

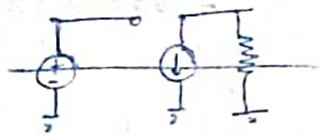
$(V_{GS_1} - V_{TH}) = 0.3V$

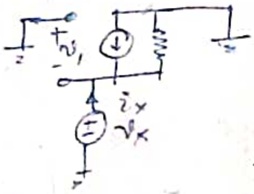
$-av_1 - v_{gs_2} - v_1 = 0$

$\Rightarrow v_{gs_2} = -(a+1)v_1$

$\approx -av_1$







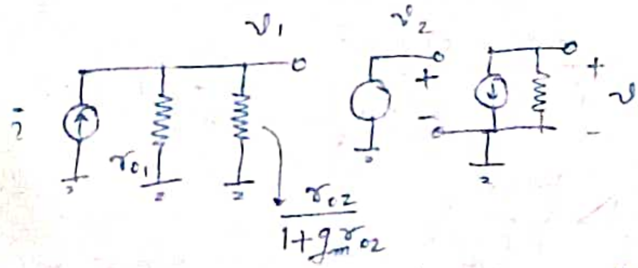
$i_x + g_m v_1 + \frac{(-v_x)}{r_o} = 0$

$v_1 + v_x = 0$

$\Rightarrow i_x - g_m v_x - \frac{v_x}{r_o} = 0$

$\Rightarrow v_x \left(g_m + \frac{1}{r_o}\right) = i$

$\Rightarrow \frac{v_x}{i_x} = \frac{r_o}{1+g_m r_o}$



$r_o \approx r_{o1} \times \left(\frac{1}{g_{m2}} \| r_{o2}\right)$

$\approx r_{o1} \times \frac{\frac{1}{g_{m2}} r_{o2}}{\frac{1}{g_{m2}} + r_{o2}}$

$\approx r_{o1} \times \frac{r_{o2}}{1+g_{m2} r_{o2}}$

$v_1 = i \times r_{o1} \| \frac{r_{o2}}{1+g_{m_2} r_{o2}}$

$\Rightarrow v_1 = i \times \frac{r_{o1} \| r_{o2}}{1+g_{m_2}(r_{o1} \| r_{o2})}$

$$\frac{\frac{r_{o1} r_{o2}}{1+g_{m_2} r_{o2}}}{r_{o1} + \frac{r_{o2}}{1+g_{m_2} r_{o2}}} = \frac{r_{o1} r_{o2}}{r_{o1} + g_{m_2} r_{o1} r_{o2} + r_{o2}} = \frac{r_{o1} \| r_{o2}}{1+g_{m_2}(r_{o1} \| r_{o2})}$$

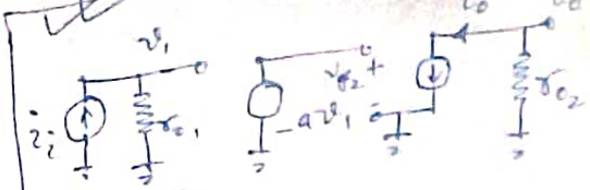
$v_2 = -a \times v_1 = -\frac{a \times i \times (r_{o1} \| r_{o2})}{1+g_{m_2}(r_{o1} \| r_{o2})}$

$v_o = -g_{m_2} \times r_{o2} \times v_2$

$= + \frac{a \times g_{m_2}(r_{o1} \| r_{o2}) \times r_{o2}}{1+g_{m_2}(r_{o1} \| r_{o2})} \times i$

$\Rightarrow \frac{v_o}{v_i} \times \frac{r_{o2}}{g_{m_1} r_{o2}} = \frac{\cancel{}}{1 + g_{m_2} a r_{o1}}$

||ROUGH||



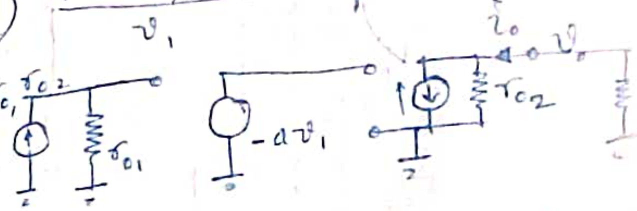
$i_o = -\frac{v_o}{r_{o2}}$ $\Rightarrow \frac{\frac{v_o}{r_{o2}}}{g_{m_1} v_i}$

$i_i = -g_{m_1} v_i$

$\frac{v_o}{i} = - \frac{a r_{o2} \times g_{m_2} (r_{o1} \| r_{o2})}{1 + g_{m_1} (r_{o1} \| r_{o2})}$

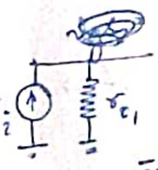
$\cancel{\frac{i_o}{i_i}} =$

$\Rightarrow \left(\frac{i_o}{i_i}\right)_{CL} = \frac{-g_{m_2} a r_{o1}}{\cancel{1 + g_{m_2} a r_{o1}}}$ $\Rightarrow \frac{v_o}{v_i} = -g_{m_1} g_{m_2} a r_{o1} r_{o2}$



$\therefore \left(\frac{v_o}{i}\right)_{CL} \simeq - a r_{o2} g_{m_1}$

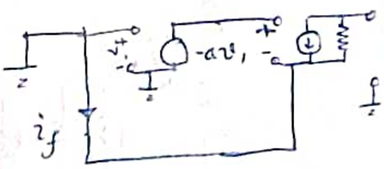
$= -a g_{m_1} r_{o2}$



$i_o = + g_{m_2} v_{gs_2}$
$= g_{m_2}(-a v_1)$
$= -g_{m_2} a v_1$
$= -g_{m_2} a . i_i . r_{o1}$

$i_o = g_m v_{gs_2} a + \frac{v_o}{r_{o2}}$
$= g_{m_2}(-a v_1) + \frac{v_o}{r_{o2}}$
$= g_{m_2}(-a) \times i_i r_{o1} + \frac{v_o}{r_{o2}}$

feedback ckt :

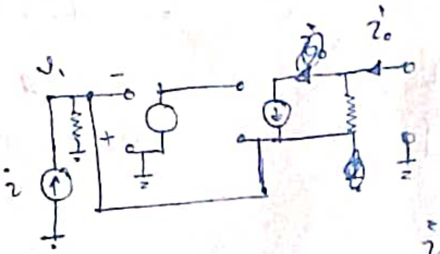


r_{o2}

$\frac{i_o}{i_i} = -g_{m_2} a r_{o1} R_{of} = \frac{R_o}{1+0}$

$\Rightarrow i_o \left(1 + \frac{R_L}{r_{o2}}\right) = g_{m_2}(-a) \times i_i r_{o1}$

$\left(\frac{v_o}{i}\right)$



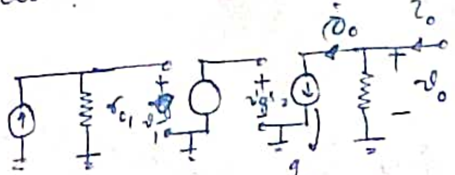
$\Rightarrow \frac{i_o}{i_i} = A_{ol} = \frac{-a g_{m_2} r_{o1}}{\left(1 + \frac{R_L}{r_{o2}}\right)}$

$i_c =$

$i_o = \frac{v_o}{r_{o2}} + g_{m_2} v_{gs_2}$

$i_o = g_{m_2} (-a v_1)$
$= -a g_{m_2} i_i r_{o1}$
$= -a g_{m_2} r_{o2} (1 + af)$ $f = 1$
$r_{o2}(1 + a g_{m_2} r_{o1})$

BA ckt .

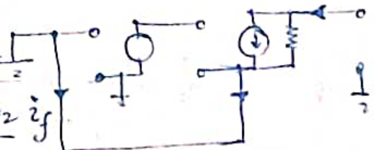


$i_o = g_{m_2} v_{gs_2}$
$= -g_{m_2} \times a v_1$
$= -g_{m_2} \times a \times r_{o1} \times i$

$-\frac{a g_{m_2} r_{o1} r_{o2}}{R_L}$ $\frac{i_o}{i_i} = -\frac{a g_{m_2} r_{o1} r_{o2}}{R_L}$ $v_1 = i \times r_{o1}$

f.B. ckt :

$\Rightarrow \frac{i_o}{i} = -g_{m_2} a r_{o1}$



$\frac{i_o}{i_1} = \frac{(-a g_{m_2} r_{o1} r_{o2}) / R_L}{1 + \frac{a g_{m_2} r_{o1} r_{o2}}{R_L} i_f}$

$\cancel{\frac{i_f}{i_o} = 1}$ $i_f = 0$

$\Rightarrow = -\frac{a g_{m_2} r_{o1} r_{o2}}{R_L}$

$\left(\frac{i_o}{i}\right)_{CL} = \frac{-g_{m_2} a r_{o1}}{1 + \cancel{g_{m_2} a r_{o1}} 0} = -g_{m_2} a r_{o1}$

$i_o = -\frac{v_o}{R_L}$ & $i = -g_{m_1} v_1$

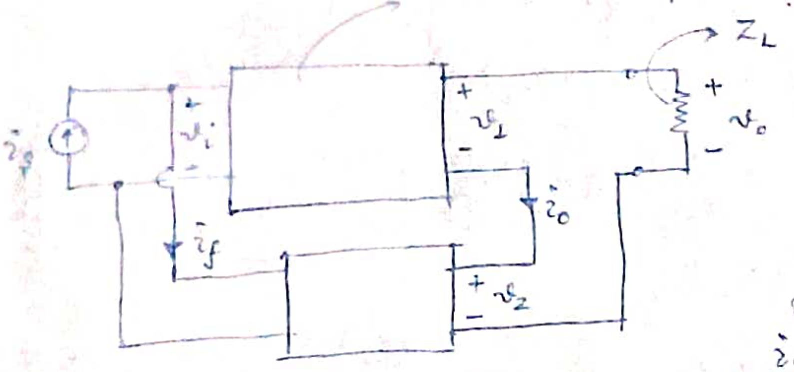
$\Rightarrow \frac{v_o}{v_i \, g_{m_1} R_L} \Rightarrow \frac{v_o}{v_i} = -a g_{m_1} g_{m_2} r_{o1} r_{o2}$ $\frac{i_o}{-g_{m_1} v_1} = -g_{m_2} a r_{o1}$

$\Rightarrow v_o = -i_o r_{o2}$

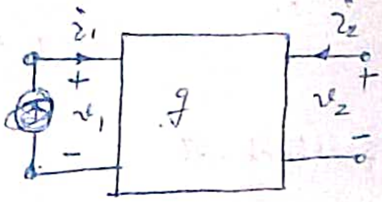
$\Rightarrow \frac{i_o}{v_1} = + g_{m_1} g_{m_2} a r_{o1}$ $\Rightarrow \frac{v_o}{v_1} = -g_{m_1} g_{m_2} r_{o1} r_{o2}$

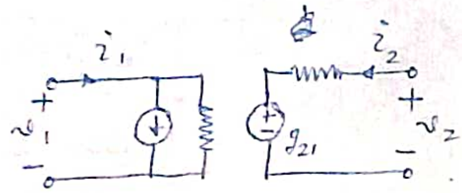
shunt - series:

g parameter representation:



g parameter:





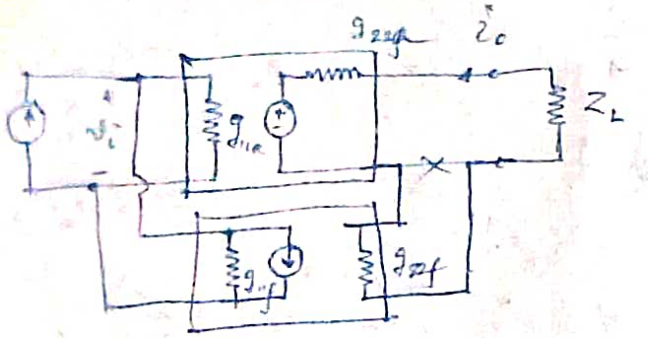
$$i_1 = g_{11} v_1 + g_{12} \cdot i_2$$

$$v_2 = g_{21} v_1 + g_{22} i_2 .$$

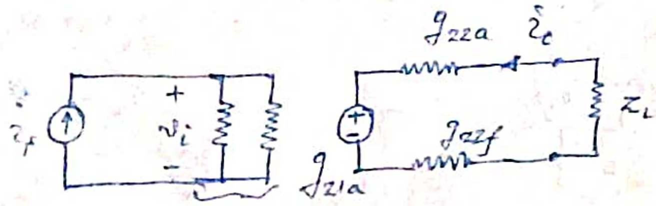
now, for the feedback amplifier.

$$g_{12a} << g_{21a}$$

$$\& \quad g_{12f} >> g_{21f}$$



Basic Amplifier ckt:



$$g_{11a} + g_{11f} = g_i$$

$$v_i = \frac{i_s}{g_i} \quad \& \quad i_o = -\frac{g_{21a} v_i}{g_o}$$

$$\Rightarrow i_o = -\frac{g_{21a} \cdot i_s}{g_o g_i}$$

$$\Rightarrow \frac{i_o}{i_s} = a = -\frac{g_{21a}}{g_o g_i}$$

$$= 20\log \frac{a_0}{a_0\beta}$$

$$20\log\frac{a_0}{1+a_0\beta} \approx -20\log\beta \qquad 20\log 10^5 = 100$$

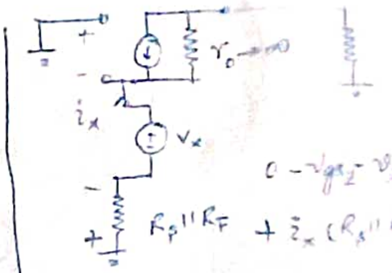
10^5, $\quad 20\log\beta = -3$

feedback ckt : g_{12f} $\quad 10\log 10^{10} =$ $\quad \log\beta = \frac{3}{20} \Rightarrow \beta = 1.4125$

$\beta = 0.707$

$$g_{12f} = \left.\frac{i_f}{i_o}\right|_{v_i=0}$$

O/P resistance at X



$$\left(\frac{i_o}{i_s}\right)_{CL} = \frac{\left(-\frac{g_{21a}}{g_o g_i}\right)}{1+\left(-\frac{g_{21a}}{g_o g_i}\right)g_{12f}}$$

$0 - v_{gs_2} - v_x$

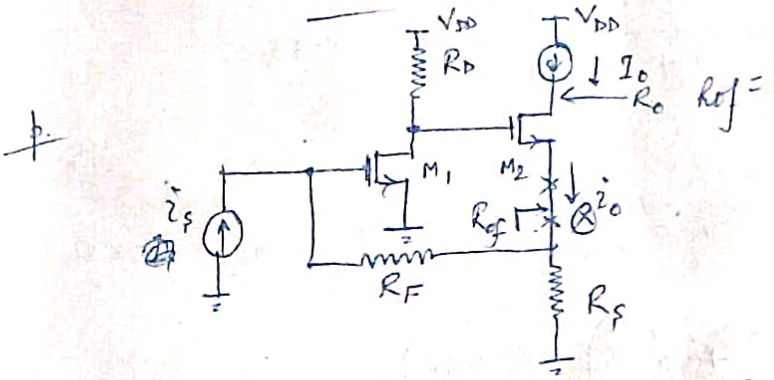
$+ i_x(R_s \| R_F) =$

$\Rightarrow i_x + g_{m_2} v_{gs_2} = 0$

$\Rightarrow i_x = -g_{m_2} \times (-v_x + i_x(R_s\|R_F)$

$\Rightarrow i_x(1+g_{m_2} R_s\|R_F$

$= g_{m_2} v_x$



$R_{of} =$

$g_{m_1} = g_{m_2} = 5\,mA/V$,

$R_D = 10\,K\Omega$, $R_s = 10\,K\Omega$

$R_F = 90\,K\Omega$

$r_o \to \infty$

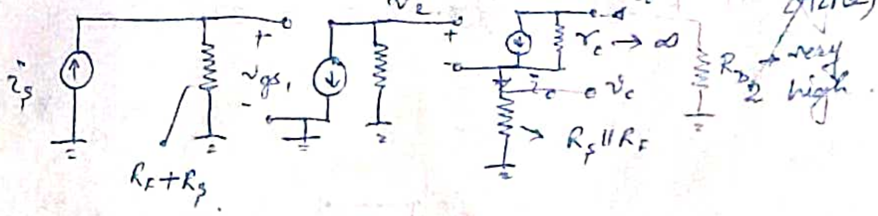
$\Rightarrow \frac{v_x}{i_x} = \frac{1+g_{m_2}(R_s\|R_F)}{g_{m_2}}$

$\simeq R_s \| R_F$

$r_{o2} = 20\,K\Omega$, find R_o (Ans: 2.42 MΩ)

~~feedback ckt~~

Basic amplifier



alternate method

$v_o = v_2$

$v_o = i_o R_s \| R_F$

$$v_{gs_1} = i_s(R_F+R_s) \qquad v_2 = -g_{m_1} v_{gs_1} \times R_D \qquad i_o = g_m v_{gs_2} + \frac{(-i_o R_{D_2} - v_o)}{r_o}$$

$$i_o = g_{m_2} v_{gs_2} \qquad \Rightarrow i_o\left(1+\frac{R_{D_2}}{r_o}\right) = g_m v_{gs_2} - \frac{v_o}{r_o}$$

$\cancel{v_{gs_2}} =$ $\quad v_2 = v_{gs_2} + i_o(R_s\|R_F)$ $\quad \Rightarrow i_o\left(1+\frac{R_{D_2}}{r_o}+\frac{R_s\|R_F}{r_o}\right)$

$i_o(1+g_{m_2}\times R_s\|R_F)$ $\quad \Rightarrow v_{gs_2} = v_2 - i_o(R_s\|R_F)$ $\quad = g_m(v_2 - i_o R_s\|R_F$

$= -g_{m_1} g_{m_2} R_D \times i_s(R_F+R_s)$

$\Rightarrow i_o = g_{m_2}(v_2 - i_o R_s\|R_F)$

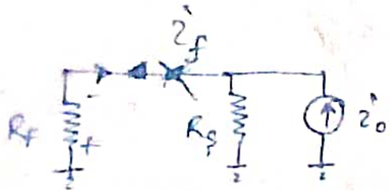
$$\frac{i_o}{i_s} = \frac{-g_{m_1} g_{m_2} R_D(R_F+R_s)}{1+g_{m_2}\times(R_s\|R_F)} \qquad \Rightarrow i_o(1+g_{m_2} R_s\|R_F) = g_{m_2} v_2$$

$$= g_{m_2}\times(-g_{m_1}) v_{gs_1} \times R_D$$

$$\simeq -\frac{g_{m_1} R_D(R_F+R_s)}{R_s\|R_F}$$

$$= -\frac{5m \times 10K \times 100K}{9K} = -555.5\ A/A$$

feedback ckt :



$$\Rightarrow -i_f \cdot R_F - (i_f + i_o) R_S = 0$$

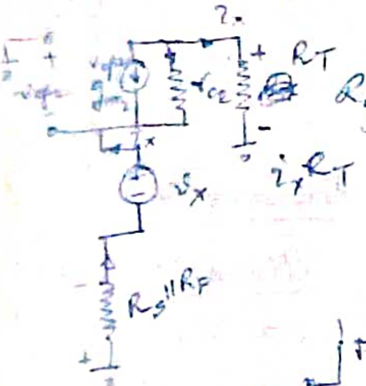
$$\Rightarrow -i_f (R_F + R_S) = i_o R_S$$

$$\Rightarrow \frac{i_f}{i_o} = f = -\frac{R_S}{R_F + R_S} = \frac{10K}{100K} = ($$

$$\Rightarrow \left(\frac{i_o}{i_s}\right)_{CL} = \frac{-555.5}{1 + 55.5} = -9.83$$

$$\Rightarrow R_{if} = \frac{R_F + R_S}{(1 + af)} = \frac{100K}{56.5} =$$

$r_{o2} = 20K\Omega$

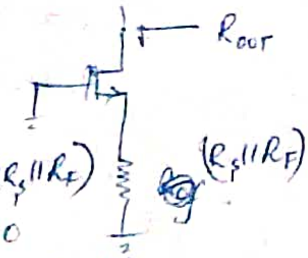


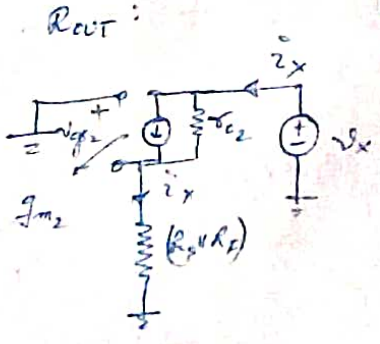
$$R_{of} = \left((R_F \| R_S) + r_{o2} \right) \times (1 + af)$$

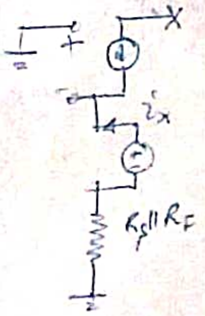
$i_x R_T$

$$= (9K + 20K) \times 56.5 = 519.8 K\Omega$$

R_{OUT} :







$$v_{gs_2} - v_x + i_x (R_S \| R_F) = 0$$

$$\Rightarrow v_{gs_2} = v_x - i_x (R_S \| R_F)$$

$$\Rightarrow i_x = g_{m_2} v_{gs_2} + \frac{i_x R_T - v_x + i_x (R_S \| R_F)}{r_{o2}} \quad 0 - v_{gs_2} - i_x (R_S \| R_F) = 0$$

$$\Rightarrow v_{gs_2} = -i_x (R_S \| R_F)$$

$$i_x r_{o2} = g_{m_2} r_{o2} (v_x - i_x (R_S \| R_F)) + i_x R_T - v_x + i_x (R_S \| R_F)$$

$$\Rightarrow i_x = g_{m_2} v_{gs_2} + \frac{v_x - i_x (R}{r_{o2}}$$

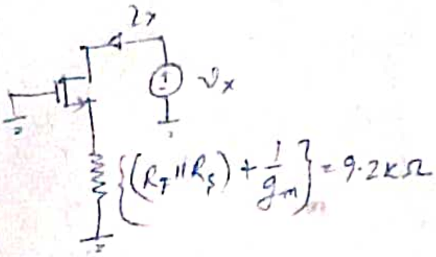
$$\Rightarrow i_x (1 + \quad = -g_{m_2} i_x (R_S \| R_F) + \frac{v_x}{r_{o2}} - \frac{i_x (R_S \|}{r_o}$$

$$\Rightarrow i_x \left(1 + g_{m_2} (R_S \| R_F) + \frac{R_S \| R_F}{r_{o2}}\right) = \frac{v_x}{r_{o2}}$$

$$\Rightarrow i_x \left(r_{o2} + g_{m_2} r_{o2} (R_S \| R_F) + R_S \| R_F\right) = v_x$$

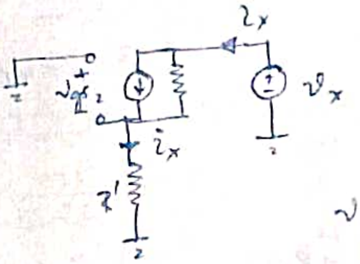
$$\Rightarrow v_x = 20K + 9K + 5m \times 20K \times 9K$$

$$\Rightarrow \frac{v_x}{i_x} \times (1 + af) = 52 M\Omega .$$



$i_x r_{o2}$

$= g_{m_2} r_{o2} v_x$



$i_x = g_m v_{gs_2} + \frac{v_x - i_x R'}{r_{o2}}$

$v_{gs_2} + i_x R' = 0$

$\Rightarrow i_x = -g_m R' i_x - i_x \frac{R'}{r_{o2}} + \frac{v_x}{r_{o2}}$

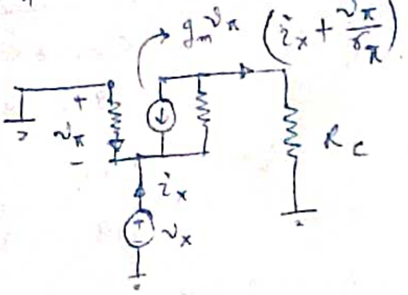
$\Rightarrow i_x \left(1 + g_m R' + \frac{R'}{r_{o2}}\right) = \frac{v_x}{r_{o2}}$

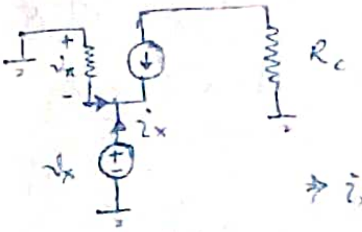
$\Rightarrow \frac{v_x}{i_x} = r_{o2} + g_m r_{o2} R' + \underline{R'}$

$= 20K + 9.2K + 5m \times 20K \times 9.2K$

$=$

|| ROUGH ||





$i_x + \frac{v_\pi}{r_\pi} + g_m v_\pi = 0$

$\Rightarrow i_x = -v_\pi \left(g_m + \frac{1}{r_\pi}\right)$

$v_\pi + v_x = 0$

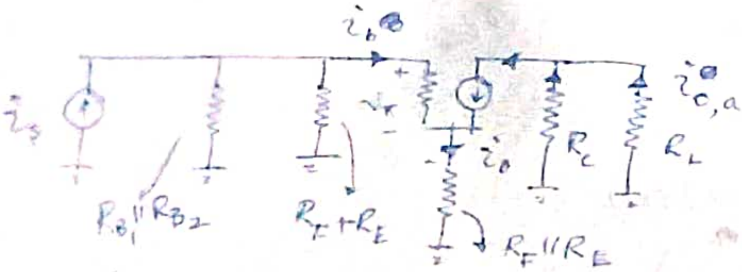
$i_x + g_m v_\pi + \frac{v_\pi}{r_\pi} - \frac{v_x - \left(i_x + \frac{v_\pi}{r_\pi}\right) R_C}{r_o} = 0$

$\Rightarrow i_x + \frac{i_x R_C}{r_o} = \left(g_m + \frac{1}{r_\pi} + \frac{1}{r_o} + \frac{R_C}{r_\pi r_o}\right) v_x$

$\Rightarrow i_x \frac{(r_o + R_C)}{\cancel{r_o}} = \left(\frac{g_m r_\pi r_o + r_o + r_\pi + R_C}{r_\pi \cancel{r_o}}\right) v_x$

$\Rightarrow \frac{v_x}{i_x} = \frac{r_\pi (r_o + R_C)}{g_m r_\pi r_o + r_o + r_\pi + R_C} = \frac{r_\pi (r_o + R_C)}{(\beta+1) r_o + (r_\pi + R_C)}$

$= \frac{r_\pi}{1 + \frac{r_\pi (1 + g_m r_o)}{r_o + R}} = \frac{\left(\frac{r_\pi}{\beta+1}\right)(r_o + R_C)}{r_o + \frac{r_\pi + R_C}{\beta+1}}$



$R_F = 10K, \ R_E = 1K$

$$(i_s - i_b)\left\{(R_{B_1} \| R_{B_2}) \| (R_F + R_E)\right\}$$
$$= i_b\left(r_\pi + (\beta+1)(R_F \| R_E)\right)$$

$$i_o = g_m v_\pi + \frac{v_\pi}{r_\pi} \qquad v_\pi = i_b r_\pi$$
$$= \left(g_m + \frac{1}{r_\pi}\right) i_b \cdot r_\pi$$
$$= \frac{\beta+1}{r_\pi} \cdot i_b \cdot r_\pi = (\beta+1)\, i_b$$

$$i_o = (\beta+1) \times i_s \times \frac{6}{119.6}$$
$$= \frac{121 \times i_s \times 6}{119.6}$$
$$\Rightarrow \frac{i_o}{i_s} = 6.07$$

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

$= \frac{865 \mu A}{26 m}$

$= 33.27 mA/V$

$\beta = 120 = g_m r_\pi$

$\Rightarrow r_\pi = \frac{120}{33.27 m}$

$= 3.6 K\Omega$

$$\Rightarrow i_b = \frac{i_s \times \{(R_{B_1} \| R_{B_2}) \| (R_F + R_E)\}}{\{(R_{B_1} \| R_{B_2}) \| (R_F + R_E) + r_\pi + (\beta+1)(R_F \| R_E)\}}$$
$$= i_s \times \frac{13K \| 11K}{\{6K + 3.6K + 121 \times 909\}}$$
$$= i_s \times \frac{6K}{119.589K}$$

now, $i_{o,a} R_L = (i_o - i_{o,a}) R_C$

$$\Rightarrow i_{o,a}(R_L + R_C) = i_o R_C$$
$$\Rightarrow i_{o,a} = i_o \times \frac{R_C}{R_L + R_C}$$
$$= i_o \times \frac{10}{11}$$
$$i_o = i_{o,a} \times \frac{11}{10}$$

$$\Rightarrow \frac{i_{o,a} \times 11}{i_s \times 10} = 6.07$$

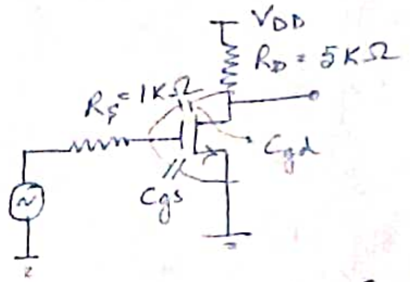
$$\Rightarrow \frac{i_{o,a}}{i_s} = \frac{6.07 \times 10}{11}$$
$$= 5.5$$

$$a_{CL} = \frac{6.07}{1 + 6.07 \times \frac{1}{11}} = 3$$

$\frac{(R_s \|}{r_{c,}}$

High frequency analysis

Consider a CS amplifier:



$f_T = 400MHz$

f_T = unity gain freq. / unity short ckt current gain frequency.

$i_o = -g_m v_{gs}$

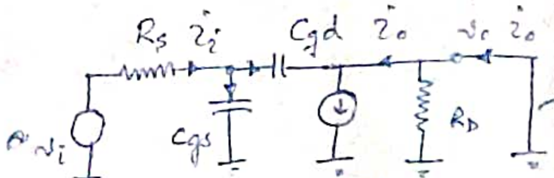
$g_m =$

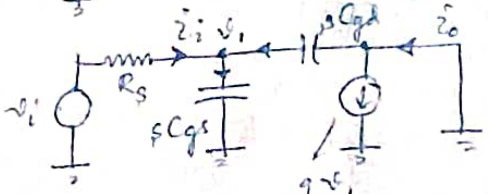
$\frac{i_o}{v_s} =$

$C_{gs} = ?$

$C_{gd} = 0.5pF$ $\quad \mu C_{ox}\frac{W}{L} = 100m\,A/V^2$

$I_D = 1mA$, let $\lambda = 0$





$14m$ $\quad .933\mu$

$g_m = \sqrt{2\mu_n C_{ox}\frac{W}{L}\times I_D}$

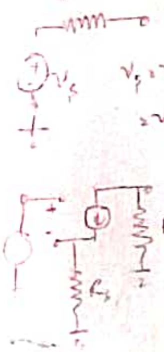
$= \sqrt{} = 14.14m$

$= \sqrt{2\times 60n\times 10\times 1m}$

$\frac{1.09m}{2\pi(5f)}$

$g_m = 14m$

$g_m R_D = 70$



$v_s = v_{gs} + g_m v_{gs} R_{S_1}$

$= v_{gs}(1 + g_m R_{S_1})$

$v_o = -i_o R_D$

$= -g_m v_{gs} R_D$

$= -\frac{g_m R_D}{1 + g_m R_{S_1}}$

$= -\frac{14m\times 5K}{1 + 14m\,1K}$

$= \frac{70}{15}$

$$i_o = g_m v_1 + (0 - v_1)\times sC_{gd}$$

$$= g_m v_1 - v_1 . sC_{gd} = v_1(g_m - sC_{gd}) = \sqrt{}$$

& $\cancel{i_i = v_1 \times sC_{gs} + v_1}$ $\quad \cancel{i_i + v_1\times sC_{gd} = v_1 sC_{gs}}$

$\Rightarrow i_i = v_1(sC_{gs} - sC_{gd})$ $\quad i_i = v_1(sC_{gs} + sC_{gd})$

$\Rightarrow i_o = \frac{i_i(g_m - sC_{gd})}{(sC_{gs} - sC_{gd})}$ $\quad$ & $\cancel{i_o = g_m v_1 +}$

$i_o + v_1 C_{gd}s = g_m v_1$

$\Rightarrow i_o = (g_m - sC_{gd})v_1$

$$i_o = \frac{g_m - sC_{gd}}{sC_{gs} + sC_{gd}} \times i_i$$

$500M = \frac{g_m}{2\pi(C_{gs}+C_{gd})}$ $\quad g_m = \frac{1}{100} = 0.01$

$\Rightarrow \frac{\sqrt{2\times 100\times 0.5m}}{2\pi\times 500M}$

$C_{gs}+C_{gd} = 3.183p$

$\Rightarrow C_{gs}$ $3.18pF - 0.1pF = 3.08pF$

$\frac{1}{2\pi(3.08p)\times 1K + 0.1p(1K + 5K)}$

$$\left|\frac{i_o}{i_i}\right| = \frac{\sqrt{g_m^2 + \omega^2 C_{gd}^2}}{\omega_T(C_{gs}+C_{gd})} = 1 \Rightarrow$$

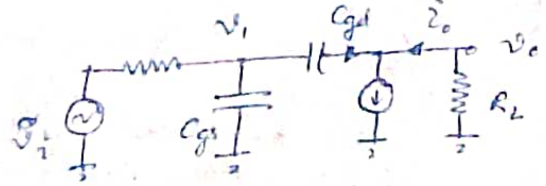
$C_{gs} + C_{gd} = \frac{\sqrt{g_m^2 + \omega_T^2 C_{gd}^2}}{2\pi f_T}$

$= \frac{\sqrt{2\times 10^{-4} + (2\pi f_T)^2 C_{gd}^2}}{2\pi f_T}$

$$= \frac{\sqrt{2\times 10^{-4} + 1.58\times 10^{-6}}}{2\pi f_T} = 5.65pF$$

$C_{gs} + C_{gd} = 5.65 pF$

$C_{gs} = 5.65 - 0.5 = 5.15 pF$



$v_o = -i_o R_D$ $\quad$ ~~$i_o = g_m v_1 + (v_o - v_1)$~~

$i_o = -\frac{v_o}{R_D}$ $\quad$ $i_o + (v_1 - v_o) s C_{gd} = g_m v_1$

$\Rightarrow i_o - v_o s C_{gd} = v_1 (g_m - s C_{gd})$

$$\frac{v_i - v_1}{R_s} = v_1 (s C_{gs} + s C_{gd})$$

$$\Rightarrow \frac{v_i}{R_s} = v_1 \left\{ (s C_{gs} + s C_{gd}) + \frac{1}{R_s} \right\}$$

$$\Rightarrow v_1 = \{1 + s R_s (C_{gs} + C_{gd})\}^{-1} v_i$$

$$= \frac{v_i}{1 + s R_s (C_{gs} + C_{gd})}$$

$$\Rightarrow -\frac{v_o}{R_D} - v_o s C_{gd} = \frac{(g_m - s C_{gd}) v_i}{\{1 + s R_s (C_{gs} + C_{gd})\}}$$

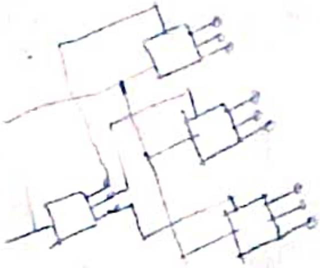
$$\Rightarrow v_o (1 + s R_D C_{gd}) = -\frac{R_D (g_m - s C_{gd})}{\{1 + s R_s (C_{gs} + C_{gd})\}} v_i$$

$$\Rightarrow \frac{v_o}{v_i} = -\frac{R_D (g_m - s C_{gd})}{\{1 + s R_s (C_{gs} + C_{gd})\}(1 + s R_D C_{gd})}$$

$$\omega_z = \frac{g_m}{C_{gd}} = \frac{14.14m}{0.5p} \Rightarrow f_z = 4.5 \text{ GHz}$$

$$f_{P_1} = \frac{1}{R_s(C_{gs}+C_{gd})\times 2\pi} = 28.17 \text{ MHz}$$

$$f_{P_2} = \frac{1}{2\pi R_D C_{gd}} = 63.6 \text{ MHz}$$



$$\frac{v_i - v_1}{R_s} = v_1 s C_{gs} + (v_1 - v_o) \times s C_{gd}$$

$$= v_1 (s C_{gs} + s C_{gd}) - v_o s C_{gd}.$$

$$\Rightarrow v_i = v_1 \{1 + s R_s (C_{gs} + C_{gd})\} - v_o s R_s C_{gd}.$$

$$\Rightarrow v_1 = \frac{v_i + v_o s R_s C_{gd}}{\{1 + s R_s (C_{gs} + C_{gd})\}}$$

$$\Rightarrow -\frac{v_o(1 + s R_D C_{gd})}{R_D} = \frac{(g_m - s C_{gd})(v_i + v_o s R_s C_{gd})}{\{1 + s R_s (C_{gs} + C_{gd})\}}$$

$$\Rightarrow -v_o \left\{ \frac{1}{R_D} + s C_{gd} + \frac{(g_m - s C_{gd}) s R_s C_{gd}}{\{1 + s R_s (C_{gs} + C_{gd})\}} \right\} = \frac{(g_m - s C_{gd})}{\{1 + s R_s (C_{gs} + C_{gd})\}}$$

$$\Rightarrow -v_o \left\{ \frac{1 + s R_s (C_{gs} + C_{gd}) + s C_{gd} R_D + s^2 R_s C_{gd} (C_{gs} + C_{gd})}{R_D} + \frac{s R_s C_{gd} g_m - s^2 R_s C_{gd}^2}{R_D} \right\} = g_m - s C_{gd}.$$

$$\Rightarrow -v_o \left\{ 1 + s R_s (C_{gs} + C_{gd}) + s C_{gd} R_D + s^2 R_s C_{gd} C_{gs} R_D + s R_s C_{gd} R_D g_m \right\} = (g_m - s C_{gd}) R_D v_i$$

$$\Rightarrow v_o \left\{ 1 + s \{ R_s (C_{gs} + C_{gd}) + C_{gd} R_D + g_m R_s R_D C_{gd} \} + s^2 R_s R_D C_{gd} C_{gs} \right\} = -(g_m - s C_{gd}) R$$

$$v_o\left\{ s^2 R_S R_D C_{gd} C_{gs} + s\left\{ R_S(C_{gs}+C_{gd}) + C_{gd}R_D + g_m R_S R_D C_{gd} \right\} + 1 \right\} = R_D\,(g_m - sC_{gd})\,v_i$$

$$\Rightarrow v_o\left\{ s^2 \times 1.29\times10^{-17} + s \times 4.35\times10^{-8} + 1 \right\} = R_D.(g_m - sC_{gd})\,v_i$$

$\Rightarrow$

$$s = \frac{-4.35\times10^{-8} \pm \sqrt{(4.35\times10^{-8})^2 - 4.1.29\times10^{-17}}}{2\times1.29\times10^{-17}}$$

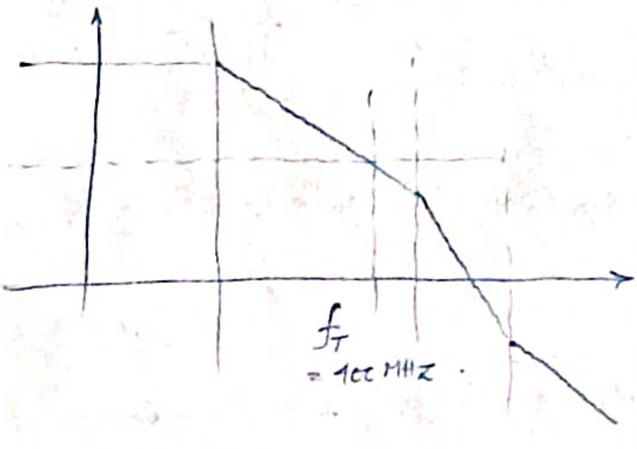
$$= \frac{-4.35\times10^{-8} \pm 4.29\times10^{-8}}{2.58\times10^{-17}}$$

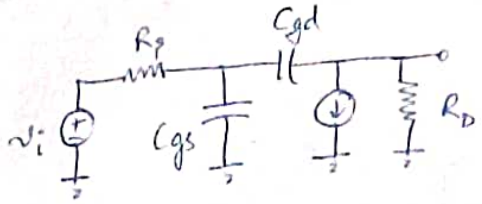
$$\Rightarrow v_o\left\{s - 23.25\times10^6\right\}\left\{s - 3.34\times10^9\right\} = R_D.(g_m - sC_{gd})\,v_i$$

$$\Rightarrow \quad p_1 = \frac{23.25\times10^6}{2\pi} = 3.7\,MHz.$$

$$p_2 = \frac{3.34\times10^9}{2\pi} = 531.5\,MHz$$

$$z_1 = \frac{g_m}{2\pi C_{gd}} = 4.5\,GHz.$$





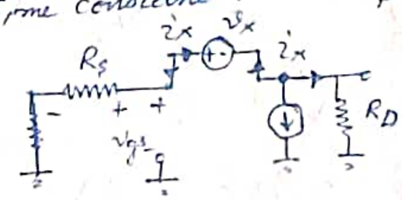
dominant pole :

Resistance associated with C_{gs} : R_s

open C_{gd},
open cur.
short v_i

Resistance associated with C_{gd} : $(R_s + R_D)$

⇒ Time constant : $\cancel{R_s C_{gs} + C_{gd}(R_s + R_D)}$.



$v_{gs} = i_x R_s$

$$\frac{i_x R_s - v_x}{R_D} + g_m v_{gs} + i_x = 0$$

$$\Rightarrow i_x \frac{R_s}{R_D} - \frac{v_x}{R_L} + g_m R_s i_x + i_x = 0$$

$$\Rightarrow \frac{v_x}{R_D} = i_x \left(1 + g_m R_s + \frac{R_s}{R_D}\right)$$

$$\Rightarrow \frac{v_x}{i_x} = R_D + g_m R_s R_D + R_s.$$

⇒ time constant =

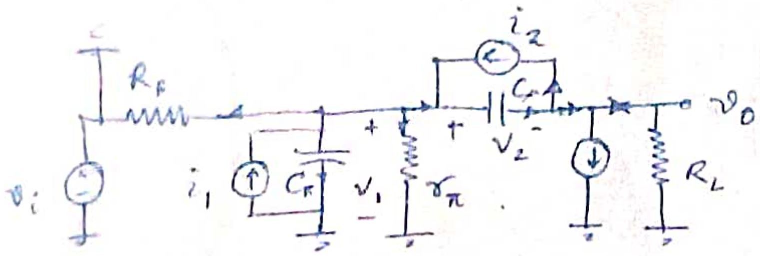
$$R_s C_{gs} + (R_D + g_m R_s R_D + R_s) C_{gd}$$

4.5 MHz

$$= 5.15 \times 10^{-9} + 3.835 \times 10^{-8} = 4.35 \times 10^{-8}.$$

$$\Rightarrow f_{P1} = \frac{1}{2\pi\tau} = \frac{1}{2\pi \times 4.35 \times 10^{-8}} = 3.66\ \text{MHz}.$$

short ckt & open ckt time constant.



$v_1 - v_2 - v_0$

$v_1 - v_0 = v_2$

$v_0 = v_1 - v_2$

$$i_1 = v_1 \cdot sC_\pi + \frac{v_1}{r_\pi} + \frac{v_1}{R_s} + v_2\, sC_\mu$$

$$\cancel{i_2 = v_2\, sC_\mu +}$$

$$v_2 sC_\mu + g_m v_1 + \frac{v_1 - v_2}{R_L} = i_2$$

$$\Rightarrow \quad i_2 = v_2\left(sC_\mu - \frac{1}{R_L}\right) + v_1\left(g_m + \frac{1}{R_L}\right)$$

$$i_1 = v_1\left(sC_\pi + \frac{1}{r_\pi} + \frac{1}{R_s}\right) + v_2\, sC_\mu$$

$$i_2 = v_1\left(g_m + \frac{1}{R_L}\right) + v_2\left(sC_\mu - \frac{1}{R_L}\right)$$

$$\begin{bmatrix} i_1 \\ i_2 \end{bmatrix} = \begin{bmatrix} sC_\pi + \frac{1}{r_\pi} + \frac{1}{R_s} & sC_\mu \\ g_m + \frac{1}{R_L} & sC_\mu - \frac{1}{R_L} \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \end{bmatrix}$$

$$\Delta = \left(sC_\pi + \frac{1}{R_{11}}\right) \times \left(sC_\mu - \frac{1}{R_L}\right) - sC_\mu\left(g_m + \frac{1}{R_L}\right) = 0$$

$$\Rightarrow s^2 C_\pi C_\mu - s\frac{C_\pi}{R_L} + s\frac{C_\mu}{R_{11}} - sC_\mu g_m - s\frac{C_\mu}{R_L} - \frac{1}{R_{11}R_L} = 0$$

$$\Rightarrow \frac{s^2 C_\pi C_\mu R_{11} R_L - sC_\pi R_{11} + sC_\mu R_L - sC_\mu g_m R_{11} R_L - sC_\mu R_{11} - 1}{R_{11} R_L} = 0$$

$$\Rightarrow s^2 C_\pi C_\mu R_{11} R_L - s\left\{C_\pi R_{11} \pm C_\mu R_L + g_m R_{11} R_L C_\mu + C_\mu R_{11}\right\} - 1 = 0$$

~~Cascode amplifier:~~

$$\Delta(s) = K_3 s^3 + K_1 s^2 + K_2 s + \cancel{K_3} K_0$$
$$= K_3\left(s^3 + \frac{K_1}{K_3}s^2 + \frac{K_2}{K_3}s + \frac{K_0}{K_3}\right)$$

$$= K_3(s-p_1)(s-p_2)(s-p_3)$$
$$= K_3\left\{\left(s^2-(p_1+p_2)s+p_1p_2\right)(s-p_3)\right\}$$
$$= K_3\left\{s^3 - s^2(p_1+p_2) + s p_1 p_2 - s^2 p_3 + p_3(p_1+p_2)s - p_1p_2p_3\right\}$$
$$= K_3\left\{s^3 - s^2(p_1+p_2+p_3) + s(p_1p_2+p_2p_3+p_3p_1) - p_1p_2p_3\right\}$$

Denominator : Δ

$$\Delta(s) = \left\{s^2 R_s R_D C_{gd} C_{gs} + s\left\{R_s(C_{gs}+C_{gd}) + C_{gd}R_D + g_m R_s R_D C_{gd}\right\} + 1\right\} = 0$$

$$\Rightarrow s^2 + s\,\frac{\left\{R_s C_{gs} + (R_s + R_D + g_m R_s R_D)C_{gd}\right\}}{R_s R_D C_{gd} C_{gs}} + \frac{1}{R_s R_D C_{gs} C_{gd}} = 0$$

$$\Rightarrow (s-p_1)(s-p_2) = 0 \longrightarrow$$ non dominant pole

$$\Rightarrow \left(1-\frac{s}{p_1}\right)\left(1-\frac{s}{p_2}\right) = 0 \rightarrow$$ dominant pole

$$1 + \frac{s^2}{p_1p_2} - s\left(\frac{1}{p_1}+\frac{1}{p_2}\right) = 0$$

$$\frac{1}{p_1p_2} = R_s R_D C_{gd} C_{gs}$$
$$\Rightarrow p_2 = \frac{R_s C_{gs} + (R_s + R_D + g_m R_s R_D)C_{gd}}{R_s R_D C_{gd} C_{gs}}$$

if $p_2 \gg p_1 \Rightarrow \dfrac{1}{p_1} \simeq R_s C_{gs} + (R_s + R_D + g_m R_s R_D)C_{gd}$

$$= \sum R_i C_i$$

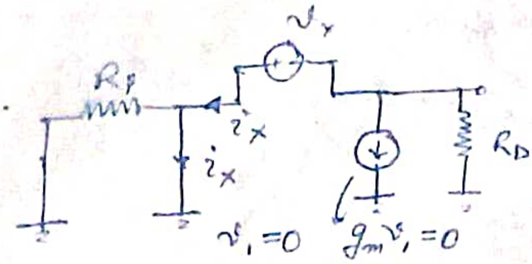
for non dominant pole,

$$s^2 - s(p_1+p_2) + p_1p_2 = 0 \Rightarrow p_2 \simeq \frac{1}{R_D C_{gd}} + \frac{1}{C_{gs} \times \frac{R_s R_D}{R_s + R_D + g_m R_s R_D}}$$

$$= \frac{1}{R_D C_{gd}} + \frac{1}{C_{gs} \times \frac{(R_s \| R_D)}{1 + g_m (R_s \| R_D)}}$$

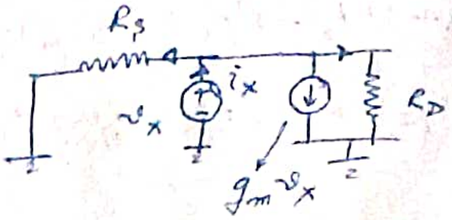
short ckt time constant :

(1)



$\Rightarrow R_{cgd} = R_D$

(2)



$R_D = 5K$
$R_s = 1K$

$g_m = 14.14 mA/V$

$R_s \| R_D = 0.83K$

$$i_x = \frac{v_x}{R_s} + g_m v_x + \frac{v_x}{R_D}$$

$$= v_x\left(\frac{g_m R_s R_D + R_s + R_D}{R_s R_D}\right)$$

$$\Rightarrow \frac{v_x}{i_x} = \frac{R_s \| R_D}{1 + g_m R_s \| R_D}$$

$\Rightarrow p_2$ = non-dominant pole : $\sum \frac{1}{R_i C_i}$

$$\Rightarrow p_2 = \frac{1}{R_D C_{gd}} + \frac{1}{C_{gs} \times \frac{R_s \| R_D}{1 + g_m R_s \| R_D}}$$

$$= \frac{1}{5K \times 0.5p} + \frac{1}{5.15p \times 65}$$

$$= \frac{1}{2.5ns} + \frac{1}{3.34 \times 10^{-10}}$$

$$\Rightarrow f_{p_2} = \frac{3.39 \times 10^9}{2\pi}$$

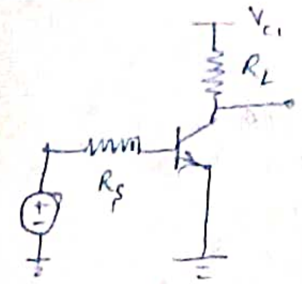
$$= 540 \text{ MHz}$$

$$\frac{1/g_m \cdot R_s \| R_D}{1/g_m + R_s \| R_D}$$

$1/g_m \| (R_s \| R_D)$

CE stage with emitter degeneration.

p



find $\frac{v_o}{v_i}$, f_{-3dB}

$R_s = 10K\Omega$

$R_L = 5K\Omega$

$K_n' \frac{W}{L} = 10 \times 60\mu = 600\mu$

$R_1 = 40K$

$R_2 = 20K$

$\frac{20}{60} = \frac{1}{3} \times 6 = 2V$

$I_D = \frac{1}{2} K_n' \frac{W}{L}(V_{GS} - V_{TN})^2 = \frac{1}{2} 600\mu \; 1^2 = 300\mu A$

$\left(\frac{v_o}{v_i}\right)_{W/O} = 192.5$

given $\beta = 200$, ~~$f_T = 600\,MHz$~~, $I_C = 1mA$, $C_\mu = 0.2pF$, $C_{je} = 2pF \simeq C_\pi$, $C_{cs} = 1pF$.

$\frac{v_o}{v_s} = \cancel{g_m} \frac{r_i}{r_i + R_s} \times \frac{R_L}{R_E}$

$=$

$g_m = \frac{I_C}{V_T} = \frac{1m}{26m} = 38.5\,mA/V$.

$\left(\frac{v_o}{v_i}\right)_{w} = 16.67 = \frac{a}{1+af}$

$\Rightarrow 1 + af = 11.54$

$\frac{v_o}{v_s} = \frac{r_\pi}{r_\pi + R_s} \times g_m \times R_L$

$= \frac{5.2K}{5.2K + 10K} \times 38.5m \times 5K$

$= -66 \Big|_{W/O\ R_E}$

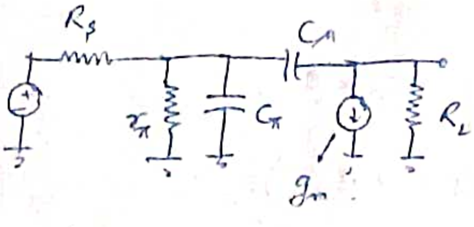
$f_T = \frac{g_m}{2\pi(C_\pi + C_\mu)} = \frac{38.5m}{2\pi(C_\pi + 0.2pF)}$

$\Rightarrow$ ~~$f_T\ 600M$~~ $C_\pi + 0.2pF = \frac{38.5m}{2\pi \times 600M} =$ ~~$10pF$~~ $10.2pF$

$\Rightarrow C_\pi = 10pF$

$g_m = \frac{0.3mA}{6 - 0.3m \times 10K} = 6 - 3 = 3V$

$\sqrt{K_n' \frac{W}{L} \times 0.3m} = \sqrt{2 \times 0.3m \times 0.6m} = \sqrt{0.6m \times 0.6m} = 0.6\,mA/V$



$r_\pi = \frac{\beta}{g_m} = \frac{200}{38.5m} = 5.2K$.

$R_{C_\pi} = r_\pi \| R_s = 10K \| 5.2K = 3.42K$

$\Rightarrow R_\pi C_\pi = 3.42K \times 10pF = 34.2\,ns$.

$R_{C_\mu} = (R_s \| r_\pi) + R_L + g_m R_L \times (R_s \| r_\pi)$

$= 3.42K + 5K + 38.5m \times 5K \times 3.42K$

$= 666.77K$

$\Rightarrow R_\mu C_\mu = 666.77K \times 0.2p = 133.35\,ns$

$\frac{40}{\cancel{600M}}$ $\cancel{60}K$

3 $\frac{40K}{3}$

13.33K

$\Rightarrow f_{p_1} = \frac{1}{2\pi(34.2n + 133.35n)} = 949.9\,KHz$.

23.6 KHz ?.

$\frac{1}{(13.33K \times 100f + 103.33K \times 20f)\,2\pi} = 46.8\,MHz$.

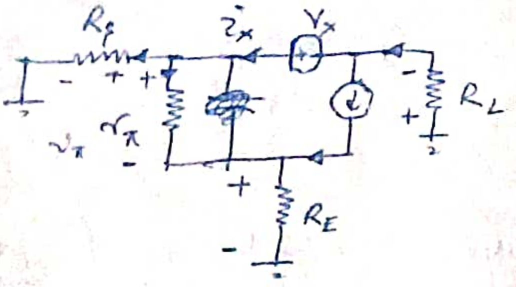
13.33K + 10K + ~~10K~~ + 0.6m × 10K × 13.33K

= 23.33K + 6 × 13.33K

= 23.33K + 80K = 103.33K

with emitter degeneratn:

$R_a = ?$ $\qquad R_E = 300\,\Omega$



$R_L = 5K$

$R_E = 300\,\Omega$

$\therefore\ G_1 = -\frac{R_L}{R_E} = -\frac{5K}{300} = -16.7$

$G_2 = -g_m R_L = -38.5m \times 5K$

$= 192.5$

$$\left(i_x - \frac{v_\pi}{r_\pi}\right) R_s - v_\pi - \left(\frac{v_\pi}{r_\pi} + g_m v_\pi\right) R_E = 0$$

$$\Rightarrow\ i_x = v_\pi \left(\frac{R_s}{r_\pi} + 1 + \frac{R_E}{r_\pi} + \frac{g_m R_E}{r_\pi}\right)$$

$$= \frac{v_\pi}{r_\pi} \cdot \left(R_s + R_E + r_\pi + g_m R_E\right)$$

$$= v_\pi \frac{(10K + 0.3K + 3.42K + 38.5m \times 0.3K)}{3.42K}$$

also, $\cancel{\left(i_x - \frac{v_\pi}{r_\pi}\right)}$ $\Rightarrow v_\pi = i_x \times 0.25$

also, $v_\pi \left(\frac{1}{r_\pi} + g_m\right) R_E + v_\pi - v_x + (i_x + g_m v_\pi) R_L = 0$

$$i_x\, 0.25 \left(\frac{\beta+1}{r_\pi}\right) . R_E + i_x \cdot 0.25 + i_x R_L + g_m i_x\, 0.25 \times R_L = v_x$$

$$\Rightarrow\ i_x \left\{ 4.4 + 0.25 + 5K + 48.125 \right\} = v_x$$

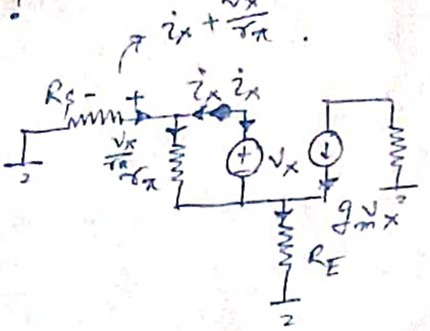
$$\Rightarrow\ \frac{v_x}{i_x} \simeq 5K.$$

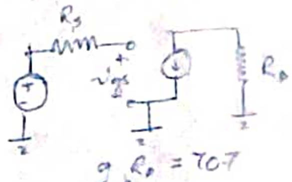
$\therefore\ R_a C_a = 5K \times 0.2p$

$= 1ns$

$$\Rightarrow\ f_{P_1,new} = \frac{1}{2\pi\, 35.2n} = 4.52\,MHz$$

Q $R_\pi = ?$





$\cancel{i_x + \frac{v_x}{r_\pi}}$

i_x

$g_m R_D = 707$

5 14×3.67

$\Rightarrow$ ~~$\left(i_x + \frac{v_x}{r_\pi}\right) R_S - v_x - \left(g_m v_x + i_x +\right.$~~

$R_S \times i_x - v_x - (g_m v_x - i_x) R_E = 0$

$\Rightarrow i_x (R_S + \cancel{g_m} R_E) = (1 + g_m R_E) v_x$

$\Rightarrow \frac{v_x}{i_x} = \left(\frac{1 + g_m R_E}{R_S + R_E}\right)^{-1}$

$\Rightarrow R_\pi = r_\pi \parallel \frac{R_S + R_E}{1 + g_m R_E} = 3.42K \parallel 820$
$= 661\Omega$.

$\Rightarrow R_\pi C_\pi = 10pF \times 661\Omega = 6.61ns$.

$\Rightarrow$ ~~$f_{p_1} = \frac{1}{7.61ns} = 20.9\ MHz$~~.

$R_{cgs} = \frac{R_S + R_{S_1}}{1 + g_m R_{S_1}}$

$= 132$

$C_{gs} = 5.15pF$

$R_{cgd} =$
$R_S + R_D + G_m R_S R_D$

$G_m = \frac{g_m}{1 + g_m R_{S_1}}$
$= 933\mu$

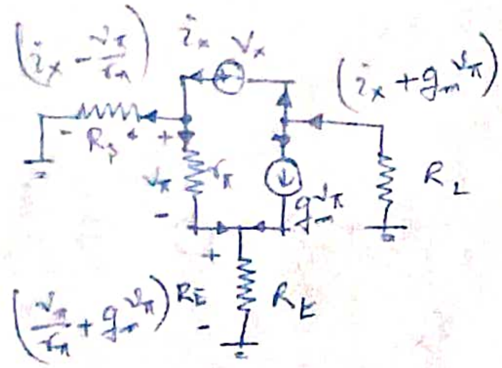
$= 1K + 5K + 4.67K$
$= 10.67K$

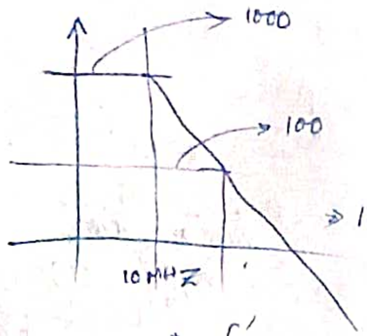
Q. $\frac{2K}{1+14} =$

$\tau = 6.8 \times 10^{-10} + 5.335 \times 10^{-9}$
$= 6.015 \times 10^{-9}$

$\Rightarrow f_{p_1} = \frac{1}{2\pi 6.015 \times 10^{-9}}$

Calculation of R_x:





$\Rightarrow f' = 10$

$f_T =$

$100 = \frac{1}{1+\ldots}$

$= \frac{100}{1+\ldots}$

$\Rightarrow 1 + Af = \ldots$

$= 10$

$$\left(i_x - \frac{v_\pi}{r_\pi}\right) R_s - v_x + (i_x + g_m v_\pi) R_L = 0$$

$$\Rightarrow i_x(R_s + R_L) - \left(v_\pi \cdot \frac{R_s}{r_\pi} - v_\pi g_m R_L\right) = v_x$$

&

$$\left(i_x - \frac{v_\pi}{r_\pi}\right) R_s - v_\pi - \left(\frac{v_\pi}{r_\pi} + g_m v_\pi\right) R_E = 0$$

$$\Rightarrow i_x R_s = v_\pi \left(\frac{R_s}{r_\pi} + 1 + \left(\frac{1}{r_\pi} + g_m\right) R_E\right)$$

$$= v_\pi \left\{ \frac{R_s + r_\pi + (\beta+1) R_E}{r_\pi} \right\}$$

$$\Rightarrow v_\pi = \frac{R_s r_\pi \times i_x}{R_s + r_\pi + (\beta+1) R_E}$$

$$\Rightarrow i_x (R_s + R_L) - v_\pi \left(\frac{R_s}{r_\pi} - g_m R_L\right) = v_x$$

$$\Rightarrow i_x (R_s + R_L) - \frac{R_s \cancel{r_\pi} i_x}{R_s + r_\pi + (\beta+1) R_E} \left(\frac{R_s - \beta R_L}{\cancel{r_\pi}}\right) = v_x$$

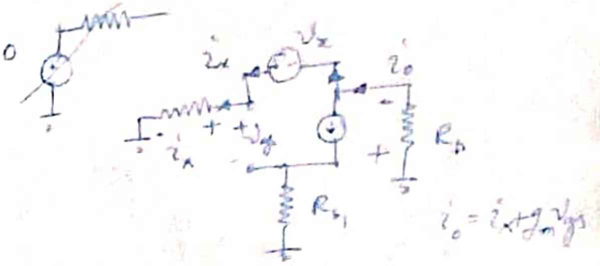
$$\Rightarrow \frac{(R_s + R_L)(R_s + r_\pi + (\beta+1) R_E) - R_s (R_s - \beta R_L)}{R_s + r_\pi + (\beta+1) R_E} = \frac{v_x}{i_x}$$

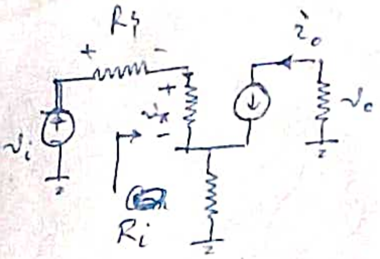
$$\Rightarrow \frac{\cancel{R_s^2} + R_s r_\pi + R_s R_E (\beta+1) + R_L R_s + R_L r_\pi + R_L R_E (\beta+1) - \cancel{R_s^2} - \beta R_s R_L}{R_s + r_\pi + (\beta+1) R_E} = \frac{v_x}{i_x}$$

$$\Rightarrow \frac{(\beta+1)(R_s R_E + R_L R_E) + R_L R_s + R_L r_\pi + R_s r_\pi - \beta R_s R_L}{R_s + r_\pi + (\beta+1) R_E}$$

$i_x R_s - v_x + i_o R_D = 0$

$\Rightarrow i_x R_s - v_x + \left(i_x + \frac{g_m i_x R_s}{1+g_m R_{s_1}}\right) R_D = 0$





$\frac{i_o}{v_i} =$

$i_o = g_m v_\pi$

$i_x R_s - v_{gs} - g_m v_{gs} R_{s_1} = 0$

$\Rightarrow v_{gs}(1+g_m R_{s_1}) = i_x R_s \Rightarrow v_{gs} = \frac{i_x R_s}{(1+g_m R_{s_1})}$

$v_i - \left(\frac{v_\pi}{r_\pi}\right) R_s - v_\pi - \left(\frac{v_\pi}{r_\pi} + g_m v_\pi\right) R_E = 0$

$\Rightarrow i_x R_s + i_x \left\{\frac{1+g_m R_{s_1} + g_m R_s}{1+g_m R_{s_1}}\right\} R_D = v_x$

$\Rightarrow v_i - v_\pi \left\{\frac{R_s}{r_\pi} + 1 + \left(\frac{1}{r_\pi} + g_m\right) R_E\right\} = 0$

$\Rightarrow \frac{v_x}{i_x} = R_s + \left\{1 + \frac{g_m R_s}{1+g_m R_{s_1}}\right\} R_D$

$\Rightarrow v_i = v_\pi \left\{\frac{R_s + r_\pi + (\beta+1) R_E}{r_\pi}\right\}$

$= R_s + R_D + \frac{g_m R_s R_D}{1+g_m R_{s_1}}$

$\Rightarrow i_o \cong \frac{g_m \times r_\pi \times v_i}{R_s + r_\pi + \beta R_E}$

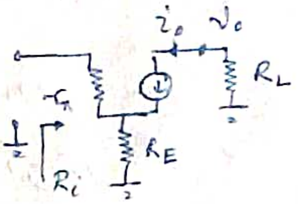
$\Rightarrow \frac{i_o R_L}{v_i} = -\frac{g_m r_\pi R_L}{R_s + r_\pi + \beta R_E}$

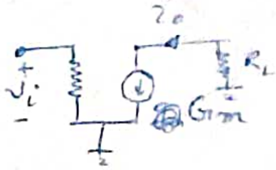
$\frac{v_o}{v_i} = -\frac{g_m R_L}{1 + \frac{R_s}{r_\pi} + g_m R_E}$

follow this procedure

$\frac{v_o}{v_i} = G_m R_L$

$v_o = -g_m v_\pi R_L$





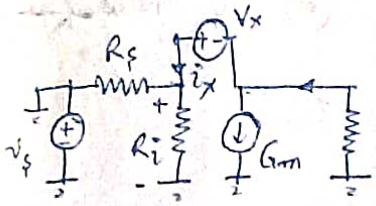
$r_\pi + (\beta+1) R_E$

$= R_i$

$= 5.2K + (201) \times 0.3K$

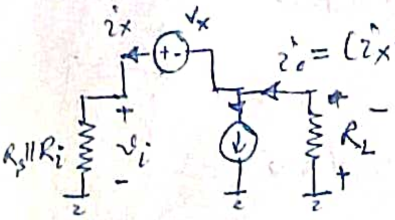
$= 65.5K$

$G_m \cdot v_i$



$v_o = -i_o R_L$

$= -g_m v_\pi R_L = -\frac{g_m R_L}{1+g_m R_E}$



$i_o = (i_x + g_m i_x (R_s \| R_i))$

$= -\left(\frac{g_m}{1+g_m R_E}\right) R_L$

$\Rightarrow G_m = \frac{38.5m}{1+38.5m \times 0.3K}$

$= 3.06 \ mA/V$

$i_o = -G_m \cdot v_i$

$v_i = i_x (R_s \| R_i)$

$i_x (R_s \| R_i) - v_x + \{i_x + G_m i_x (R_s \| R_i)\} R_L = 0$

$\Rightarrow v_x = i_x \{R_s \| R_i + R_L + G_m R_L (R_s \| R_i)\}$

$\Rightarrow \frac{v_x}{i_x} = \{8.67K + 5K + \cancel{38.5m}\ 3.06m \times 5K \times 8.67K\}$

$= 146.32K$

⇒ $R_\mu = 146.3K$

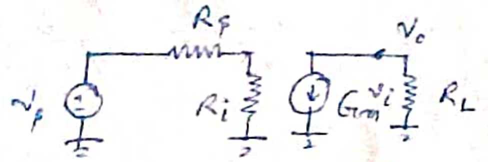
$C_\mu = 0.2pF$

⇒ $\tau_\mu = R_\mu C_\mu = 29.3ns$.

⇒ $\tau_\mu + \tau_\pi = 6.61ns + 29.3ns$
$\cong 36ns$

⇒ $f_{p_1} = \dfrac{1}{2\pi(\tau_\mu + \tau_\pi)} = 4.42MHz$.

Gain:



⇒ $\dfrac{v_o}{v_s} = -G_m \times \dfrac{R_i}{R_i + R_s} \times R_L$

$= -3.07m \times \dfrac{65.5}{75.5} \times 5K$

$= -13.31$

$= \dfrac{a}{1+af}$.

$\left|\dfrac{v_o}{v_s}\right| = 5 = \dfrac{a}{1+af}$

$(a) = 70, \quad 1+af = $

$-G_m$

⇒

& $a = -66$ ⇒ $T = 1 + af = 4.96$.

⇒ & $\dfrac{f_{p_1\,w/o\,C_E}}{f_{p_1\,w\,C_E}} = \dfrac{4.42MHz}{949kHz} \simeq 4.66$

$$g_{m_1} = \frac{\cancel{10}\,1\,mA}{25\,mV} = \cancel{400mS}\ 40\,mS \qquad \beta_1 = \beta_2 = 100$$

$$g_{m_2} = \frac{0.1\,mA}{25\,mV} = 4\,mS \qquad r_{\pi_1} = \frac{\beta_1}{g_{m_1}} = \frac{100}{40\,mS} \qquad r_{\pi_2} = \frac{\beta_2}{g_{m_2}} = \frac{100}{4\,mS}$$

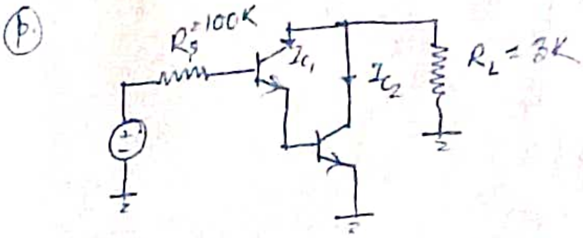
$2.5K + 25K$

Frequency response of a Darlington ~~stage~~ pair

$2.5K + 101 \times 25K$ $\quad C_\pi = C_b + C_{je}$

$=$

(b)



$\beta = 100$,

$f_T = 500\,MHz$ at $I_c = 1\,mA$.

$C_\mu = 0.4\,pF$, $r_o \to \infty$, $C_{je} = 2\,pF$

$I_{C_1} = 10\,\mu A$, $I_{C_2} = 1\,mA$.

at $I_{C_2} = 10\,\mu A$,

$$g_{m_1} = \frac{10\mu}{26m} = 384\,\mu A/V.$$

$$\Rightarrow r_{\pi_1} = \frac{100}{g_{m_1}} = 260\,K\Omega.$$

$$g_{m_2} = \frac{1}{26} = 38.4\,mA/V$$

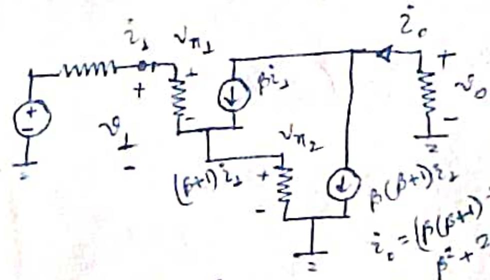
$$r_{\pi_2} = \frac{100}{g_{m_2}} = 2.6\,K\Omega$$

$$f_T = \frac{g_m}{2\pi(C_\mu + C_\pi)} = 500\,M$$

with $I_{C_1} = 10\,\mu A$,

$$\Rightarrow \frac{1/26}{2\pi \times 500M} = C_\mu + C_\pi \qquad \Rightarrow C_\pi + C_\mu = \frac{384\mu}{2\pi \times 500M}$$

$$\Rightarrow C_\pi = 12.24p - 0.4p = 11.84\,pF \qquad \Rightarrow C_\pi =$$



$$i_o = g_{m_1} v_{\pi_1} + g_{m_2} v_{\pi_2}$$

$$v_o = -i_o R_L \qquad g_{m_1} \neq g_{m_2}$$

$$i_o = g_{m_1} v_{\pi_1} + g_{m_2} v_{\pi_2}$$

$$v_{\pi_2} = \left(\frac{v_{\pi_1}}{r_{\pi_1}} + g_m v_{\pi_1}\right) r_{\pi_2}$$

$$= v_{\pi_1}\left(\frac{1}{r_{\pi_1}} + g_m\right) r_{\pi_2}$$

$$\Rightarrow i_o = g_{m_1} v_{\pi_1} + v_{\pi_1}\left(\frac{1}{r_{\pi_1}} + g_m\right) r_{\pi_2}$$

$$= v_{\pi_1}\left\{g_{m_1} + g_{m_2}(\beta+1) \times \frac{r_{\pi_2}}{r_{\pi_1}}\right\}$$

$$v_{\pi_1} + v_{\pi_2} = v_1$$

$$\Rightarrow i_o = \left[\frac{\{r_{\pi_1} g_{m_1} + g_{m_2}(\beta+1) r_{\pi_2}\}}{r_{\pi_1}}\right] \times \frac{r_{\pi_1}}{r_{\pi_1} + (\beta+1) r_{\pi_2}}\, v_1$$

$$\& \ v_{\pi_2} = \left(\frac{v_{\pi_1}}{r_{\pi_1}} + g_m v_{\pi_1}\right) r_{\pi_2}$$

$$= v_{\pi_1} \times (\beta+1)\frac{r_{\pi_2}}{r_{\pi_1}}$$

$$= \frac{\beta + \beta(\beta+1)}{r_{\pi_1} + (\beta+1) r_{\pi_2}}$$

$$\Rightarrow v_{\pi_1} + v_{\pi_1}(\beta+1)\frac{r_{\pi_2}}{r_{\pi_1}} = v_1$$

$$\Rightarrow G_m = \frac{\beta^2 + 2\beta}{r_{\pi_1} + (\beta+1) r_{\pi_2}} = \frac{10{,}200}{523K} = 19.5\,mA/V$$

$$\Rightarrow v_{\pi_1}\left(\frac{r_{\pi_1} + (\beta+1) r_{\pi_2}}{r_{\pi_1}}\right) = v_1$$

$$R_i = r_{\pi_1} + (\beta+1) r_{\pi_2}$$

$$= 260K + 101 \times 2.6K$$

$$= 523\,K\Omega$$

$$v_{\pi_1} = \frac{r_{\pi_1}}{r_{\pi_1} + (\beta+1) r_{\pi_2}}\, v_1$$

$$\Rightarrow \frac{v_o}{v_i} = -G_m \cdot R_L \times \frac{R_i}{R_i + R_s} = -19.5m \times 3K \times \frac{523}{623}$$

$$= -49\,V/V$$