HW-14

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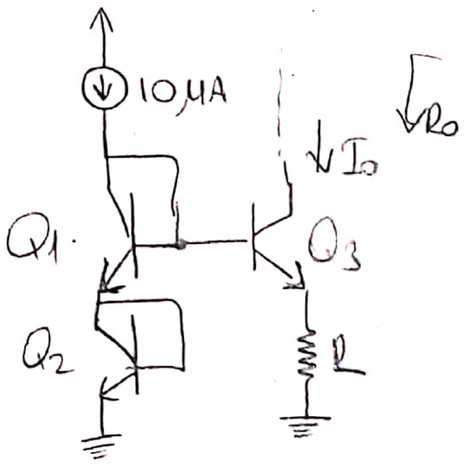
(a) For the circuit in Fig P6.144, Assume BJTs with high β and $V_{BE} = 0.7V$ at $1mA$. Find the value of R that will result in $I_o = 10\mu A$ (b) For the design in (a), find R_o assuming $\beta = 100$ and $V_A = 100V$



$$I_{C_1} = I_S \cdot \exp\left(\frac{V_{BE1}}{V_T}\right)$$

$$I_{C_2} = I_S \exp\left(\frac{V_{BE2}}{V_T}\right)$$

$$I_{C_3} = I_S \exp\left(\frac{V_{BE3}}{V_T}\right)$$

$I_{C1} = I_{C2} = 10\mu A$ $\quad I_{C3} = 10\mu A$

$I_{S1} = I_{S2} = I_{S3}$

$V_{T1} = V_{T2} = V_{T3}$

$V_{BE1} = V_{BE2} = V_{BE3} = V_{BE}$

$$V_{BE} = V_T \ln \frac{I_C}{I_S} \rightarrow 0.7V = 26mV \cdot \ln\left(\frac{1mA}{I_S}\right)$$

$$\frac{0.7}{26\times10^{-3}} = \ln\left(\frac{10^{-3}}{I_S}\right) \rightarrow \boxed{I_S = 2.02\times10^{-15} A}$$

$(V_{BE}, I_C) = (0.7V, 1mA)$

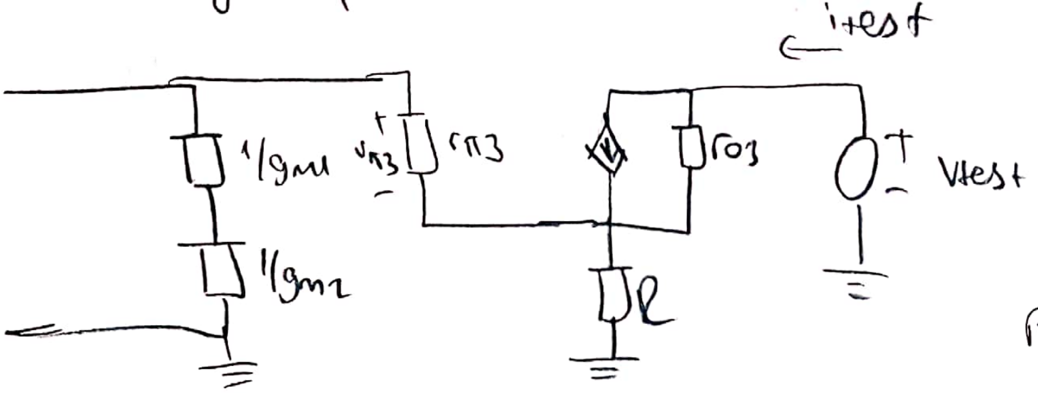
$$V_{BE_2} = 26\times10^{-3} \cdot \ln\left(\frac{10\mu A}{2.02\times10^{-15}}\right) = 0.58V$$

$V_{BE1} = V_{BE3}$

$V_{BE2} + V_{BE1} - V_{BE3} - RI_o = 0$

$$R = \frac{V_{BE2}}{10\mu A} = \frac{0.58V}{10\mu A} = 58.039 k\Omega$$

Small sig. eq. cir.



$$r_{\pi 3} \gg \frac{1}{g_{m1}} + \frac{1}{g_{m2}}$$

$$R_o \approx \frac{V_{test}}{i_{test}} = (1 + g_{m3} r_{o3})(R \| r_{\pi 3}) + r_{o3}$$

$$r_{o3} = \frac{V_A}{I_{C3}} = \frac{100V}{10\mu A} = 10\,M\Omega$$

$$g_{m3} = \frac{I_{C3}}{V_T} = \frac{10\mu A}{25mV} = \frac{10 \times 10^{-3}}{25} = 4 \times 10^{-4}\,S$$

$$r_{\pi 3} = \frac{\beta}{g_{m3}} = \frac{100}{4 \times 10^{-4}} = \frac{100 \times 10^{4}}{4} = 25 \times 10^{4}\,\Omega$$

250 kΩ

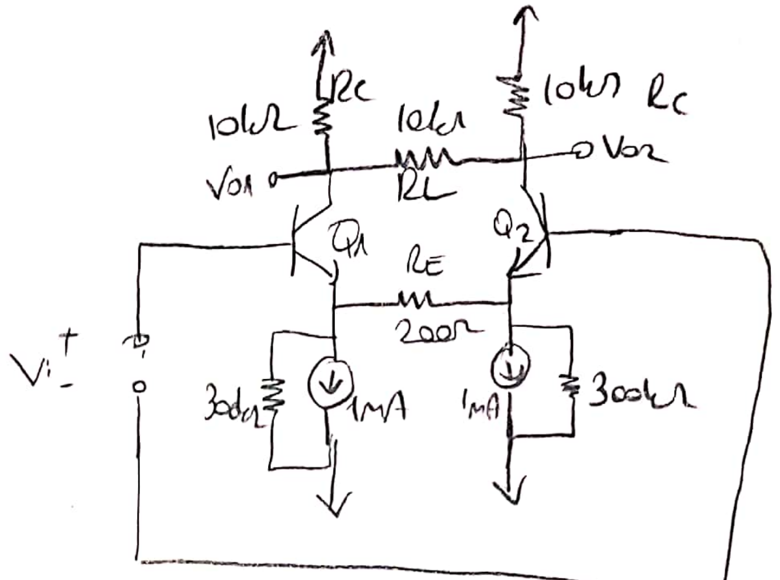
$$R_o = (1 + 4\times 10^{-4} \cdot 10 \times 10^{6})(58.039\,k\Omega \| 25 \times 10^{4}\,\Omega) + 10 \cdot 10^{6}\,\Omega$$

$$R_o = (4001) \cdot (47.10\,k\Omega) + 10^{7}\,\Omega$$

$$\boxed{R_o = 10.188\,M\Omega}$$

CamScanner ile tarandı

Q2. For the differential amplifier shown in Fig. P7.41, identify and sketch the differential half circuit and the common mode half circuit. Find the differential gain, the differential input resistance, the common mode input resistance. For the transistors $\beta = 100$ and $V_A = 100V$



DC analysis

when $V_i = 0$ $\rightarrow$ $I_{RL} = I_{RE} = 0$ $\qquad I_{C1} = I_{C2} \cong 1mA$

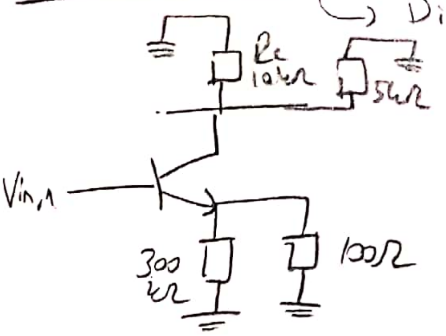
$$g_m = \frac{I_C}{V_T} = \frac{1mA}{25mV} = 40mS$$

$$r_o = \frac{V_A}{I_C} = \frac{100V}{1mA} = 100k\Omega$$

$$r_\pi = \frac{\beta}{g_m} = \frac{100}{40mS} = 2.5k\Omega$$

S.S. analysis

$\hookrightarrow$ Diff. Mode - half. circ $\Rightarrow$ virtual gnd R_L ve R_E

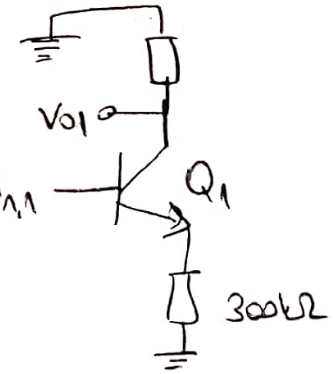


Common Emit. config.

$$A_d = \frac{V_{o1}}{V_{in1}} \cong \left\{ -\frac{g_m}{1+g_m(R_{cs} \| \frac{R_E}{2})} \right\} \left\{ R_C \| \frac{R_L}{2} \| \left[1+g_m \left[R_{cs} \| \frac{R_E}{2} \right] r_o \right] \right\}$$

$$R_{i,d} \cong r_{\pi 1}\left[1+g_m\left(R_{cs} \| R_E/2\right)\right]$$

Common Mode Half Cir



$$A_c = \frac{v_{o1}}{v_{in,1}} \cong \left[-\frac{g_m}{1+g_m R_{es}} \right] \cdot \left[R_c // [1+g_m R_{es}] r_o \right]$$

$$R_{i,c} = r_\pi [1 + g_m R_{es}]$$

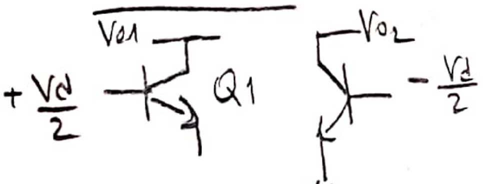
$$CMRR = \left| \frac{A_d}{A_c} \right|$$

$$V_{b1} = V_c + \frac{V_d}{2} \longrightarrow V_c = \frac{V_{B1}+V_{B2}}{2} = 0.1 \sin(2\pi 60 t) V$$

$$V_{b2} = V_c - \frac{V_d}{2} \longrightarrow V_d = V_{B1} - V_{B2} = 0.01 \sin(2\pi 1000 t) V$$

superposition

diff mode



$$V_{o1} = A_d \frac{V_d}{2}$$

$$V_{o2} = -A_d \frac{V_d}{2}$$

common mode only

$$V_{o1} = A_c V_c$$

$$V_{o2} = A_c V_c$$

superposition $V_{o1} = A_d \frac{V_d}{2} + A_c V_c$, $V_{o2} = -A_d \frac{V_d}{2} + A_c V_c$

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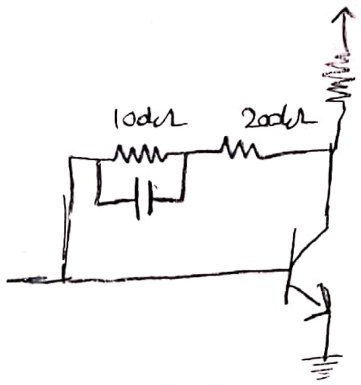
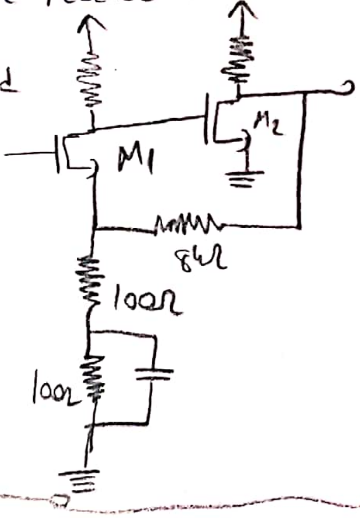
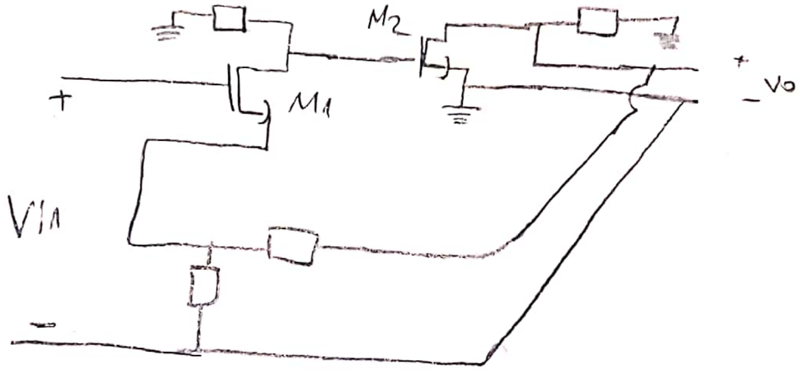
Q3. For each circuit of Fig. P9.29, identify the type of feedback and find the numerical value of β using the appropriate two port parameters of the feedback circuit. State whether the feedback is dc or ac. If both, find the two-port parameter values for both.

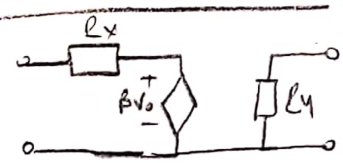




Voltage-series feedback
voltage amplifier



Two Port parameters



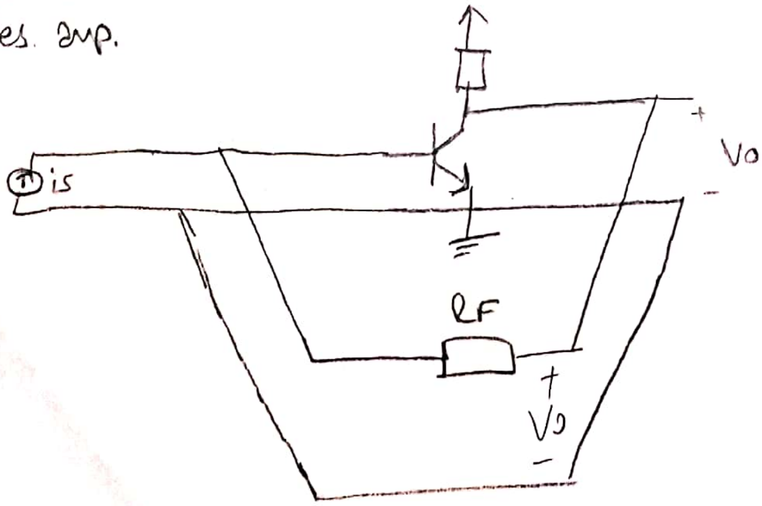
AC feedback

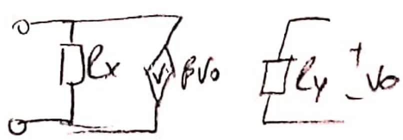
$\beta = \frac{100}{8k} = \frac{1}{80}$

$R_x = 100\Omega \parallel 8k\Omega = 98.7\,\Omega$

$R_y = 8.2k\Omega$

Voltage-Shunt
Trans res. amp.



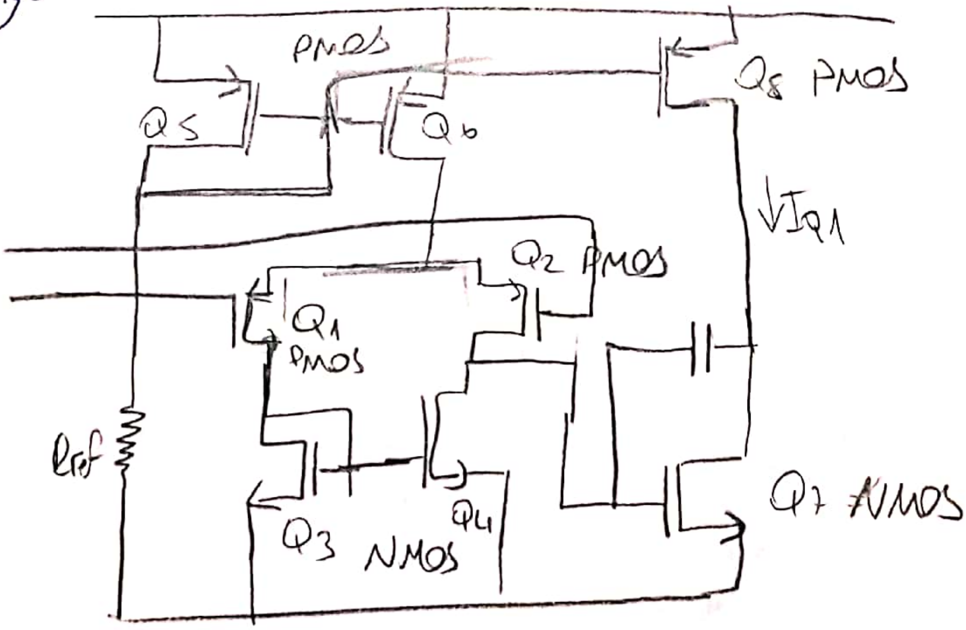


(a)

	ac feed.	dc feed
$B = -\frac{1}{R_F}$	$-\frac{1}{200k\Omega}$	$-\frac{1}{300k\Omega}$
$R_x = R_F$	$200k\Omega$	$300k\Omega$
$R_y = R_F$	$200k\Omega$	$300k\Omega$

Q4. The CMOS amplifier in Fig 14.20 is operated at a biasing current of $I_Q = 50\mu A$. The parameters of the MOSFET's are $k_x = 10\mu A/V^2$, $|V_A(NMOS)| = V_A(PMOS) = 60V$, $V_t = 1V$, $W/L = 80\mu m/10\mu m$ except for Q_7, for which $W/L = 160\mu m/10\mu m$.
Assume $V_{DD} = V_{SS} = 5V$

(a) Find V_{GS}; g_m and r_o for all MOSFETs.
(b) Find the low-frequency voltage gain of the amplifier A_{vo}
(c) Find the value of the external resistance R_{ref}.
(d) Find the value of Compensation capacitance C_x that gives a unity-gain bandwith of 1MHz and the corresponding slew rate.
(e) Find the value of resistance R_x to be connected in series with C_x in order to move the zero frequency to infinity.
(f) Find the common-mode input voltage range
(g) Find the voltage range



ⓐ Systematic DC offset cancellation

$$2\frac{(\frac{W}{L})_8}{(\frac{W}{L})_6} = \frac{(\frac{W}{L})_7}{(\frac{W}{L})_4}$$

$I_{D5} = I_{D6} = I_Q = I_{ref} = 50\mu A$

$I_{D1} = I_{D2} = I_{D3} = I_{D4} = \frac{I_Q}{2} = 25\mu A$

$I_{D8} = I_{D7} = I_Q = 50\mu A$

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

$I_D = \frac{1}{2}\mu_p C_{ox}\frac{W}{L}(V_{SG}-|V_t|)^2$ $\quad k_x = \frac{1}{2}\mu_n C_{ox} = \frac{1}{2}\mu_p C_{ox} = 10\mu A/V^2$

$\frac{W}{L} = \frac{80\mu m}{10\mu m}$ $\quad Q_7 \; \frac{160\mu m}{10\mu m}$

$I_{D1} = \dots 25\mu A = \underbrace{\frac{1}{2}\cdot\mu_n C_{ox}}_{10\mu A/V^2}\underbrace{\frac{W}{L}}_{8}(V_{GS}-V_t)^2$

$Q_1 = Q_2 = Q_5 = Q_6 = Q_8 = PMOS$

$Q_3 = Q_4 = Q_7 = NMOS$

$25\mu A = \underbrace{\frac{1}{2}\mu_n C_{ox}}_{10\mu A/V^2}\cdot\underbrace{\frac{W}{L}}_{8}(V_{GS}-V_t)^2 \rightarrow \boxed{V_{GS}-V_t = 0.790}$

$\rightarrow Q_1 = Q_3 = Q_4 = Q_2$

$50\mu A = 10\mu A/V^2 \cdot 8\cdot(V_{GS}-V_t)^2$

$\rightarrow V_{GS}-V_t = 0.790 \rightarrow Q_5, Q_6$

$50\mu A = 10\mu A/V^2 \cdot 16(V_{GS}-V_t)^2 = 0.559 \rightarrow Q_7$

$\rightarrow V_{GS}-V_T$

$$\boxed{r_o = \frac{60V}{50\mu A} = 1.2M\Omega}$$

$Q_1 \rightarrow \underbrace{\frac{1}{2}\mu_p C_{ox}}_{10\mu A/V}\underbrace{\frac{W}{L}}_{8}(V_{SG}-V_t)^2 = 25\mu A$

$g_m = \frac{2I_D}{V_{GS}-V_T}$

$Q_1 \rightarrow (V_{SG}-V_t)^2 = \frac{25}{80}$

$Q_2 \rightarrow (V_{SG}-V_t)^2 = \frac{25}{80}$

$Q_3 \rightarrow (V_{GS}-V_t)^2 = \frac{25}{80}$

$Q_4 \rightarrow (V_{GS}-V_t)^2 = \frac{25}{80}$

$Q_5 \rightarrow (V_{SG}-V_t)^2 = \frac{50}{80}$

$Q_6 \rightarrow (V_{SG}-V_t)^2 = \frac{50}{80}$

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$Q_7 = 10\mu A/V\cdot 16\cdot(V_{GS}-V_t)^2 = 50\mu A$

$\rightarrow (V_{GS}-V_t)^2 = \frac{25}{80}$

$$r_{o1} = \frac{|V_A|}{I_D} = \frac{60}{25\mu A} = 2.4\,M\Omega$$

$I_{D1} = I_{D2} = I_{D3} = I_{D4} = 25\mu A$

$I_{D5} = I_{D6} = I_{D7} = I_{D8} = 50\mu A$

$r_{o1} = r_{o2} = r_{o3} = r_{o4} = 2.4\,M\Omega$

$r_{o5} = r_{o6} = r_{o7} = r_{o8} = \frac{r_{o1}}{2} = 1.2\,M\Omega$

$(V_{GS}-V_t)_{1,2,3,4,7} = \frac{25}{80}$

$(V_{GS}-V_t)_{5,6,8} = \frac{50}{80}$

$$g_{m1} = g_{m2} = g_{m3} = g_{m4} = \frac{2I_D}{\substack{(V_{GS}-V_t)\\(V_{SG}-V_t)}} = \frac{50\mu}{25/80} \simeq 0.16\,mS$$

$$g_{m7} = \frac{100\mu}{25/80} = 0.32\,mS \qquad g_{m5} = g_{m6} = g_{m8} = \frac{400\mu}{50/80} = 0.16\,mS$$

(b)

gain of diff. stage $\rightarrow$ $\frac{V_{g7}}{V_{in}^+ - V_{in}^-} \cong -g_{m1}(r_{o2} \| r_{o4}) = \underbrace{-0.16\,mS\,(1.2\,M\Omega)}_{-192}$

gain of the common source $\rightarrow$ $\frac{V_{d7}}{V_{g7}} = -g_{m7}(r_{o8} \| r_{o7}) = \underbrace{-0.32\,mS \cdot 0.6\,M\Omega}_{-192}$

$$A_{vo} = \frac{V_{d7}}{V_{in}^+ - V_{in}^-} = \underbrace{\frac{V_{g7}}{V_{in}^+ - V_{in}^-}}_{-192} \cdot \underbrace{\frac{V_{d7}}{V_{g7}}}_{-192} = +36864$$

$V_{dd} - V_{SG,5} - I_{Ref} \cdot R_{ref} = -V_{ss}$

$10 - 0.764 = 50\mu A \cdot R_{ref}$

$\boxed{R_{ref} = 184.70\,k\Omega}$

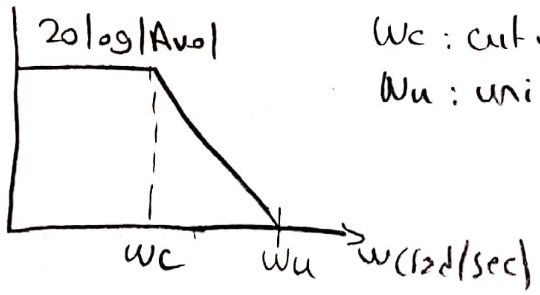
$V_{dd} = V_{ss} = 5V$

$(V_{GS,5} - V_t)^2 = \frac{50}{80} \rightarrow V_{GS,5} = 0.764V$

$V_{GS,5} = 0.764V$

$I_{ref} = 50\mu A$

(c)

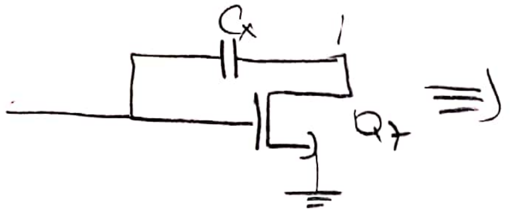


W_c : cut off freq
W_u : unity gain freq.

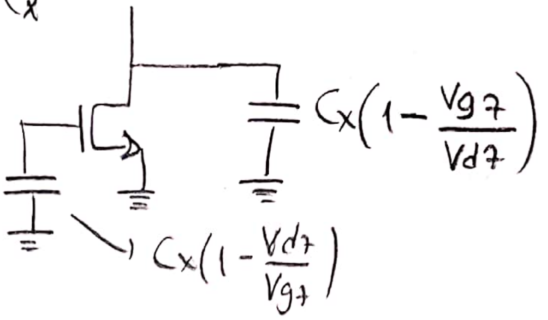
(d)

$$A_{vo} \cdot W_c = W_u \longrightarrow W_c = \frac{W_u}{A_{vo}}$$

Miller theorem to transform C_x



$\Longrightarrow$



$$W_c = \frac{1}{C_x\left(1 - \frac{V_{d7}}{V_{g7}}\right) \cdot \underbrace{(r_{o2} \| r_{o4})}_{\text{thevenin eq. res.}}}$$

$W_u = 1MHz$

$$W_u = A_{vo} \cdot W_c$$

$$1\times10^6 = 36864 \cdot \frac{1}{\underbrace{C_x(1 + \underset{0.32M}{g_{m7}} \underset{0.6M\Omega}{(r_{o6} \| r_{o7})}) \cdot \underset{1.2M\Omega}{(r_{o2} \| r_{o4})}}_{231.6\times10^6}}$$

$$27.12 = \frac{1}{C_x \cdot 231.6\times10^6} \longrightarrow C_x = \frac{1}{27.12 \times 231.6\times10^6} = 1.592\times10^{-10}$$

$$= 15.92nF$$

$$\boxed{C_x = 15.92nF}$$

$$\boxed{\text{Slew rate} = \frac{I_Q}{C_x} = \frac{50\mu A}{15.92nF} = 3140.70}$$

(9)

~~Vsg~~ f

$$V_{CM,max} = V_{DD} - [V_{SG6} - |V_t|] - V_{SG1} \rightarrow V_{SD6} \geq V_{SG6} - |V_t|$$

$$V_{CM,max} = 5 - \underbrace{(0.765 - 0.025)}_{0.74} - 0.533$$

$$\boxed{V_{SG1} = 0.533V}$$

$$\boxed{V_{SG6} = 0.765V}$$

$$\boxed{V_{CM,max} = 3.727V}$$

$$V_{SD,1} \geq V_{SG1} - |V_t|$$

$$|V_t| \geq V_{SG,1} - V_{SD,1} = V_{DG1}$$

$$V_{GD,1} \geq -|V_t| \longrightarrow (V_{G1} - V_{D1}) \geq -|V_t|$$

$$V_{GS,3} = 0.765V$$

$$V_{G1} \geq -|V_t| + (-V_{SS}) + V_{GS,3}$$

$$V_{G1} \geq -0.025 - 5 + 0.765$$

$$\boxed{V_{CM,min} = -4.26V}$$

$$V_{o,max} = V_{DD} - (V_{SG,8} - |V_t|)$$

$$V_{o,min} = -V_{SS} + (V_{GS,7} - V_t)$$

$$V_{o,max} = 5 - (0.765 - 0.025)$$

$$\boxed{V_{omax} = 4.26V}$$

$$V_{o,min} = -5 + (0.533V - 0.025)$$

$$\boxed{V_{omin} = -4.492V}$$

g

$V_{SD,8} \geq V_{SG,8} - |V_t| \rightarrow$ Q8 satürasyonda

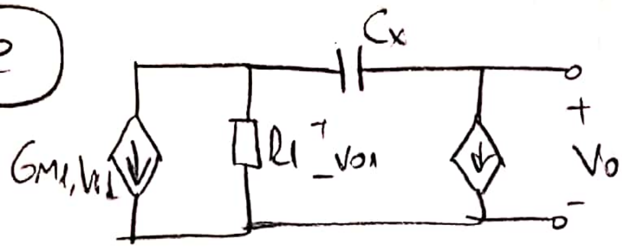
$V_{DS,7} \geq V_{GS,7} - V_t \rightarrow$ Q7 satürasyon

$$V_{GS7} = 0.533V$$

$$V_{SG,8} = 0.765V$$

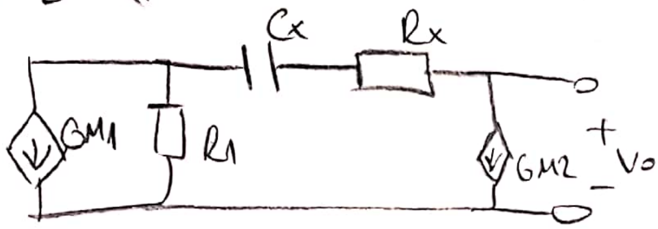
10

e



$G_{M2}, V_{o1} = (V_{o1} - V_o)\, w C_x$ $\quad W_z =$ zero $\quad V_o = 0$

$G_{M2} \cancel{V_{o1}} = \cancel{V_{o1}} W_z C_x$ $\quad W_z = \frac{G_{M2}}{C_x}$

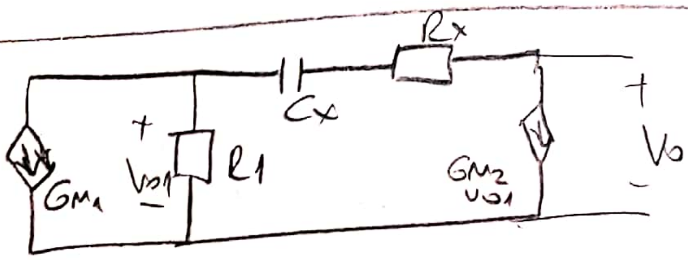


$G_{M2} V_{o1} = \frac{V_{o1} - V_o}{R_x + \frac{1}{jwC_x}}$ $\quad G_{M2} V_{o1} = \frac{V_{o1}\, j w_z C_x}{1 + j w_z R_x C_x}$

$G_{M2} + j w_z R_x C_x G_{M2} = j w_z C_x \Rightarrow G_{M2} + j w_z C_x (R_x G_{M2} - 1) = 0$

$G_{M2}\left[1 + j \frac{w_z}{\frac{1}{C_x\left(R_x - \frac{1}{G_{M2}}\right)}}\right] \rightarrow$ zero freq. $\frac{1}{C_x\left(R_x - \frac{1}{G_{M2}}\right)}$

$R_x = \frac{1}{G_{M2}}$ ise zero freq $\rightarrow +\infty$



$G_{M1}, V_d + \frac{V_{o1}}{R_1} + \underbrace{\frac{V_{o1} - V_o}{Z_x}}_{G_{M2} V_{o1}} = 0$

$G_{M1}, V_d + \frac{V_{o1}}{R_1 \parallel \frac{1}{G_{M2}}} = 0$

$V_o = -G_{M2} V_{o1} [Z_x] + V_{o1}$

$= V_{o1} [1 - G_{M2} Z_x]$

$\frac{V_o}{V_d} = \frac{V_{o1}}{V_d} [1 - G_{M2} Z_x]$

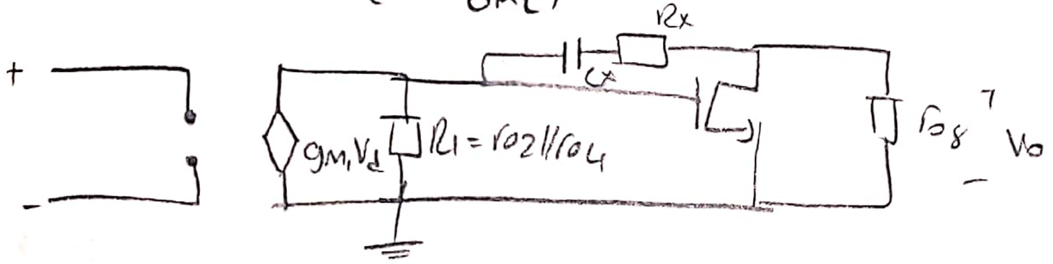
$\frac{V_o}{V_d} = -\frac{G_{M1} R_1}{1 + G_{M2} R_1} [1 - G_{M2} Z_x]$

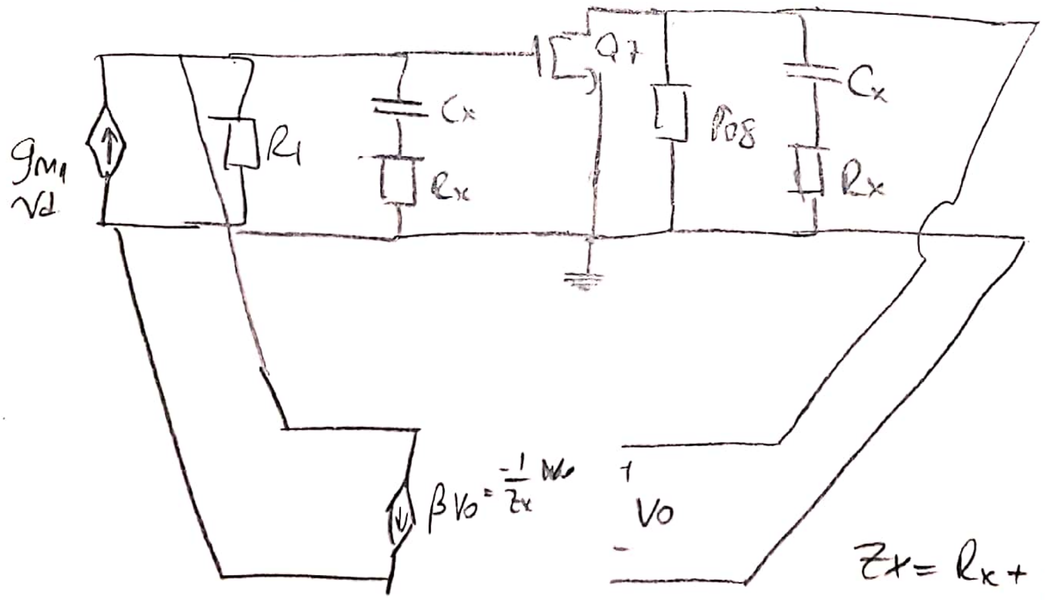
$$\frac{V_o}{V_d} = -\frac{G_{M1}R_1}{1+G_{M2}R_1}\left[1 - G_{M2}\left[R_x + \frac{1}{jwC_x}\right]\right]$$

$$= \frac{G_{M1}R_1}{1+G_{M2}R_1}\left[(G_{M2}R_x - 1) + \frac{G_{M2}}{jwC_x}\right]$$

$$= \frac{G_{M1}R_1}{1+G_{M2}R_1}\left[\frac{1 + jwC_x\left(R_x - \frac{1}{G_{M2}}\right)}{jwC_x}\right] G_{M2}$$

$$w_z = \frac{1}{C_x\left(R_x - \frac{1}{G_{M2}}\right)} \qquad R_x = \frac{1}{G_{M2}} \text{ ise zero freq} \to +\infty$$





$$Z_x = R_x + \frac{1}{jwC_x}$$

$\beta = 0 \quad A_{TRA} = ?$

$$A_{TRA} = \frac{V_o}{i_s} = [R_1 // Z_x][-g_{m7}][R_2 // Z_x]$$

$$A_f = \frac{A_{TRA}}{1+\beta A_{TRA}} = \frac{V_o}{i_s} = \frac{-g_{m7}[R_1 // Z_x][R_2 // Z_x]}{1 + g_{m7}[R_1 // Z_x][R_2 // Z_x]\frac{1}{Z_x}}$$

$$i_s = -g_{m1} V_d$$

$$\frac{V_o}{i_s} = \frac{V_o}{-g_{m1} V_d} \qquad \frac{V_o}{V_d} = \frac{g_{m1} \cdot g_{m7} \cdot [R_1 \| Z_x][R_2 \| Z_x]}{1 + g_{m7}[R_1 \| Z_x][R_2 \| Z_x]\frac{1}{Z_x}}$$

$$\frac{V_o}{V_d} = \frac{g_{m1} g_{m7} \frac{R_1 Z_x}{R_1+Z_x} \cdot \frac{R_2 Z_x}{R_2+Z_x}}{1 + g_{m7} \frac{R_1 Z_x}{R_1+Z_x} \cdot \frac{R_2 Z_x}{R_2+Z_x} \cdot \frac{1}{Z_x}}$$

$$= \frac{g_{m1} g_{m7} R_1 R_2 Z_x^2}{(R_1+Z_x)(R_2+Z_x) + g_{m7} R_1 R_2 Z_x}$$

$$= \frac{g_{m1} g_{m7} R_1 R_2 Z_x^2}{R_1 R_2 + Z_x(R_1 + R_2 + g_{m7} R_1 R_2) + Z_x^2}$$

$\longrightarrow g_{m7} R_1 R_2 >> R_1 + R_2$

$$= \frac{g_{m1} g_{m7} R_1 R_2 Z_x^2}{R_1 R_2 + Z_x g_{m7} R_1 R_2 + Z_x^2} \longrightarrow \text{root}$$

$$\frac{-b \mp \sqrt{\Delta}}{2a}$$

$g_{m7} R_1 R_2 - 2 r_{SM}$

$$\frac{-g_{m7} R_1 R_2 \mp \sqrt{(g_{m7} R_1 R_2)^2 - 4 R_1 R_2}}{2}$$

$(g_{m7} R_1 R_2)^2 >> 4 R_1 R_2$

$r_1 = -g_{m7} R_1 R_2 + r_{SM}$

$r_2 = -r_{SM}$

$$\frac{V_o}{V_d} = \frac{g_{m1} g_{m7} R_1 R_2 Z_x^2}{(Z_x + r_{SM}) \cdot (Z_x + g_{m7} R_1 R_2)}$$

$$Z_x = R_x + \frac{1}{j\omega C_x}$$

$$\frac{Z_x^2}{(Z_x + r_{SM}) \cdot (Z_x + g_{m7} R_1 R_2)} = \frac{(1 + j\omega C_x R_x)^2}{[1 + j\omega C_x (R_x + r_{SM})] \cdot [1 + j\omega C_x (R_x + g_{m7} R_1 R_2)]}$$

CamScanner ile tarandı

$$\frac{(1+j\omega C_x R_x)^2}{1+j\omega C_x(R_x+r_{SM})} \approx \frac{(1+j\omega 2C_x R_x)(1-j\omega C_x(R_x+r_{SM}))}{1+\omega^2[C_x(R_x+r_{SM})]^2}$$

$$\approx 1+j\omega C_x(R_x-r_{SM})$$

$$\frac{V_o}{V_d} = \underbrace{g_{m1} g_{m7} . R_1 . R_2}_{A} . \frac{1+j\omega C_x(R_x-r_{SM})}{1+j\omega C_x(R_x+g_{m7}R_1R_2)}$$

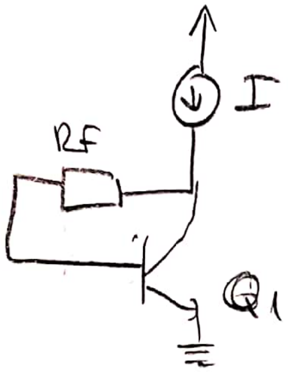
$$w_z = \frac{1}{C_x(R_x-r_{SM})} \qquad w_p = \frac{1}{C_x(R_x+g_{m7}R_1R_2)}$$

$$w_p = \frac{1}{\underbrace{C_x(1+g_{m7}R_2)}_{\text{miller}} \cdot R_1}$$ ↳ thevenin eq. res

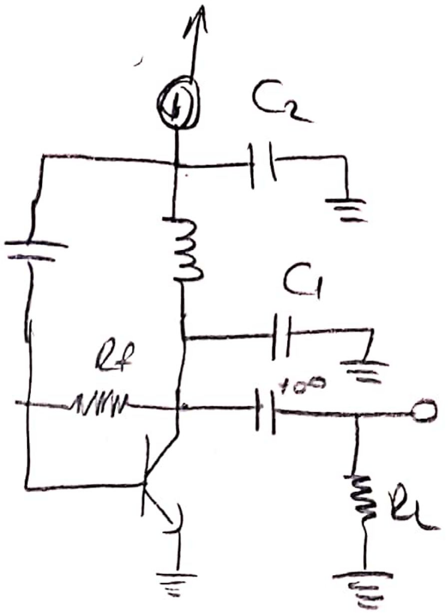
R_2: $r_{o8} \| r_{o7}$ $\quad$ R_1: $r_{o2} \| r_{o4}$

$w_z \to +\infty \qquad R_x \approx r_{SM}$ olur.

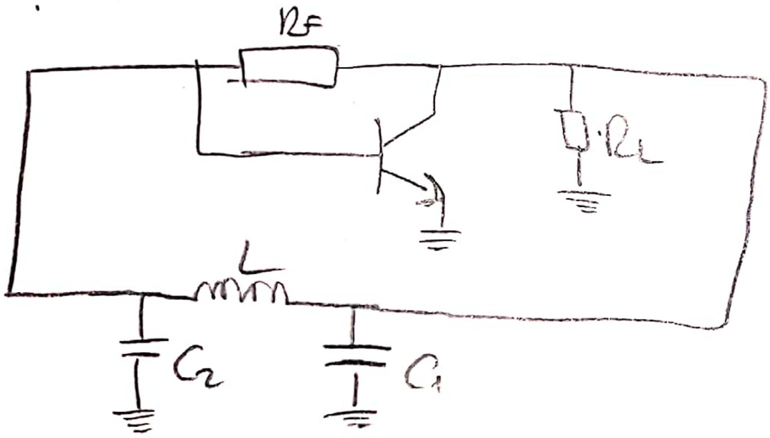
Q5. Figure P.13.21 shows four oscillator circuits of the Colpitts type, complete with bias detail. For each circuit, derive an equation governing circuit operation and find the frequency of oscillation and the gain condition that ensures that oscillation start.



C: open
← L: short



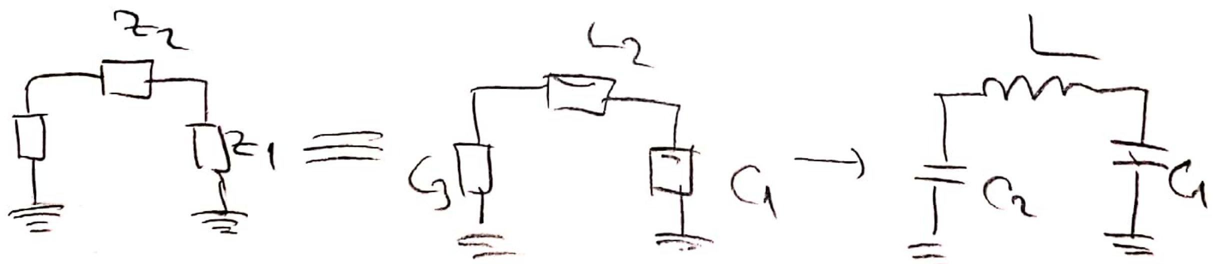
S.S equivalent



$R_f >> w_0 L$

$R_f // jw_0 L \approx jw_0 L$

$R_f \to$ open circuit davranır.



$$W_0 = \frac{1}{\sqrt{L \cdot \frac{C_1 C_2}{C_1 + C_2}}}$$

$$g_m R_L \geq \frac{C_2}{C_1}$$