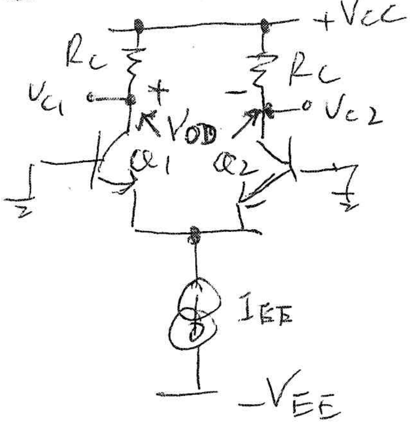
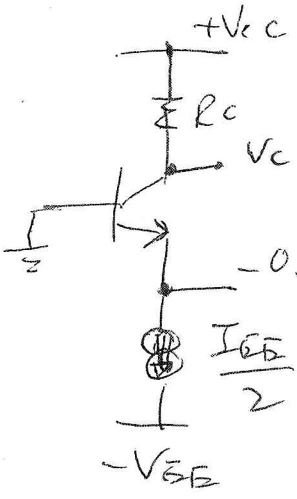
EE2002 Tutorial 8

1(a) DC Analysis



⟹ DC half circuit



$$I_C = \alpha I_E = \alpha \frac{I_{EE}}{2} = \left(\frac{\beta}{\beta+1}\right)\frac{I_{EE}}{2} = \frac{100}{101} \times \frac{400\mu A}{2} = 198\mu A$$

$$V_{CE} = V_{CC} - I_C \cdot R_C - (-0.7V) = 12 - 39K \times 198\mu A - (-0.7)$$

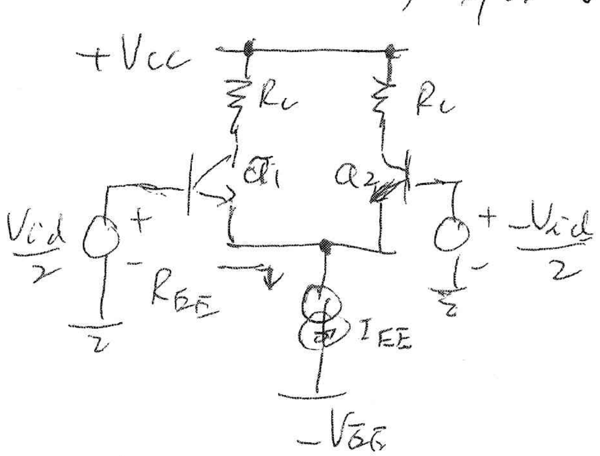
$$= 4.98V$$

∴ Q point is $198\mu A$ and $4.98V$ #

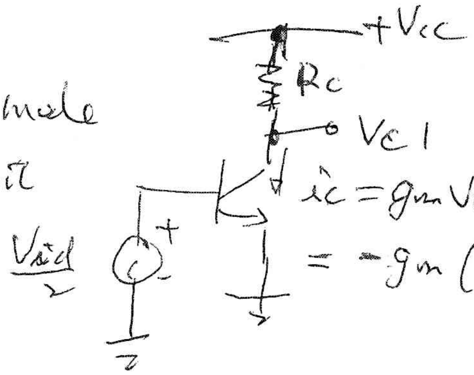
1(b) $g_m = \frac{I_C}{nV_T} = 40 \cdot I_C = 7.92mS$ where $nV_T = 25mV$ — Differential-Mode Analysis

$$r_\pi = \frac{\beta}{g_m} = \frac{100}{7.92m} = 12.6K\Omega$$

$$r_o = \infty, \text{ for } V_A = \infty$$



⟹ Differential-mode half circuit



$i_c = g_m V_{be} = -g_m\left(\frac{V_{id}}{2}\right)$

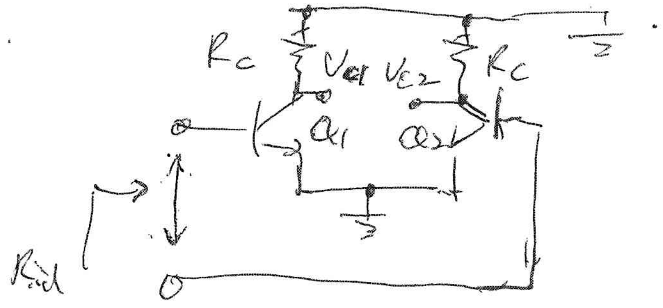
$$v_{c1} = -g_m\left(\frac{V_{id}}{2}\right)R_C, \quad v_{c2} = g_m\left(\frac{V_{id}}{2}\right)R_C$$

$$V_{od} = V_{c1} - V_{c2} = -g_m V_{id} R_C$$

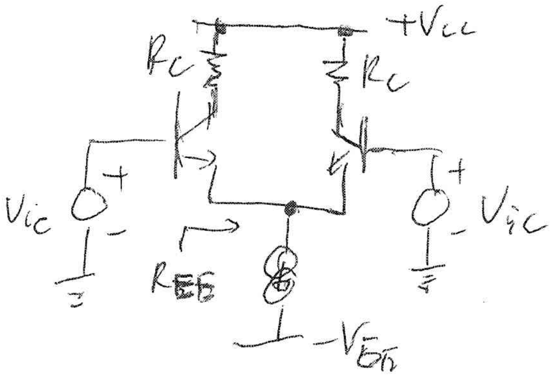
$$A_{dm\_diff} = \frac{v_{od}}{v_{id}} = -g_m R_C = -7.92m \times 39k = -309$$

$$A_{dm\_sel} = \frac{v_{c1}}{v_{id}} = \frac{-g_m R_C}{2} = -154.5$$

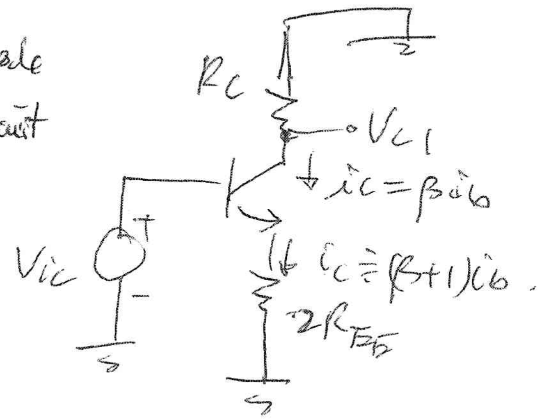
$R_{id} = 2r_\pi = 25.2k\Omega$.



Common-Mode Analysis



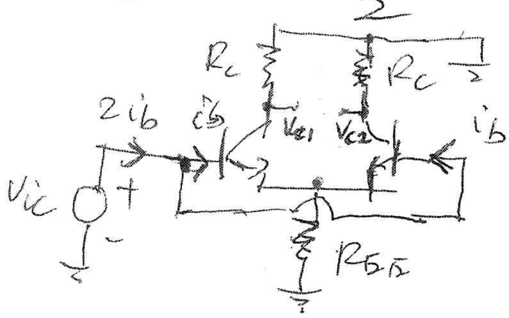
Common-Mode Half Circuit ⟹



$\because v_{od} = v_{c1} - v_{c2} = 0$, Therefore, $A_{cm\_diff} = 0$

$$A_{cm\_sel} = \frac{v_{c1}}{v_{ic}} = \frac{-\beta \cancel{i_b} R_C}{\cancel{i_b}[r_\pi + (\beta+1) \cdot 2R_{EE}]} = -0.0965$$

$$R_{ic} = \frac{v_{ic}}{i_{b1} + i_{b2}} = \frac{v_{ic}}{2i_b} = \frac{r_\pi + (\beta+1) 2 \cdot R_{EE}}{2} = \underline{\underline{20.2M\Omega}}$$



CMRR at differential output

$$CMRR = \frac{A_{dm\_diff}}{A_{cm\_diff}} = \frac{-309}{0} = \infty$$

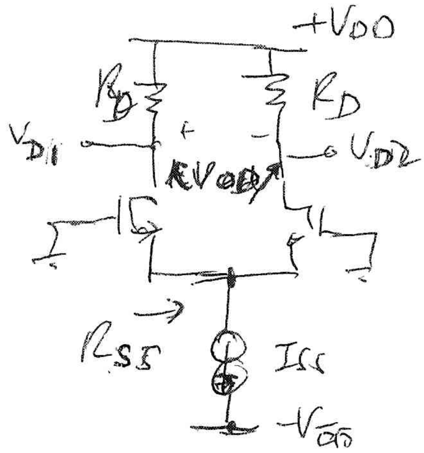
CMRR at single-ended output

$$CMRR = \frac{A_{dm\_sel}}{A_{cm\_sel}} = \frac{-154.5}{-0.0965} = 1600 \text{ or } 64.1dB$$

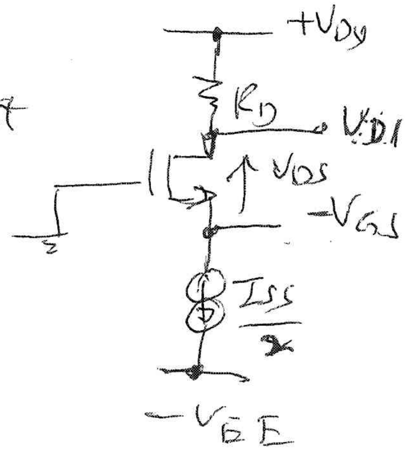
output resistance: $R_{o1} = R_{o2} = r_o // R_C = 39k\Omega$

$R_{od} = R_{o1} + R_{o2} = 2R_C = 78K$

2(a) DC Analysis



DC half circuit $\Rightarrow$



$I_D = \frac{I_{SS}}{2} = 150\,\mu A$, $V_{GS} = V_{TN} + \sqrt{\frac{2 I_D}{K_n}} = 1.866\,V$

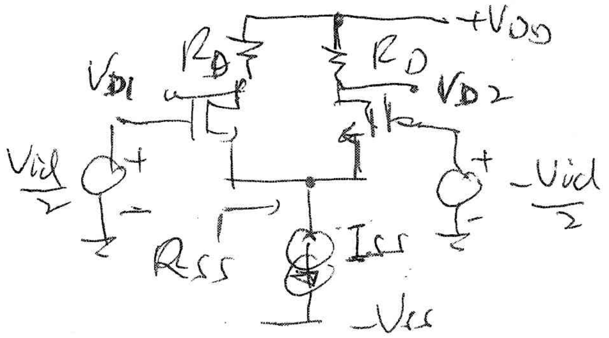
$V_{DS} = V_{DD} - I_D \times R_D - (-V_{GS}) = 5.62\,V$

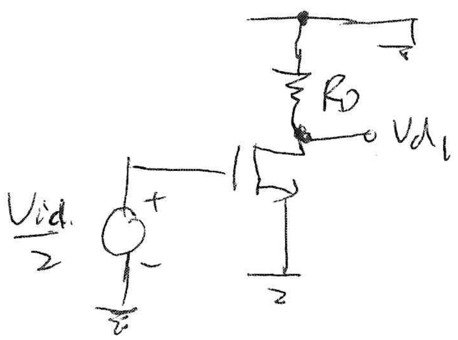
$\therefore V_{DS} = 5.62 > V_{GS} - V_{TN} = 0.866\,V$

The MOSFETs are in saturation region

2(b) $g_m = \sqrt{2 K_n I_D} = 0.346\,mS$

Differential-Mode Analysis





$V_{d1} = -g_m\left(\frac{V_{id}}{2}\right)R_D$, $V_{d2} = -g_m\left(\frac{-V_{id}}{2}\right)R_D$

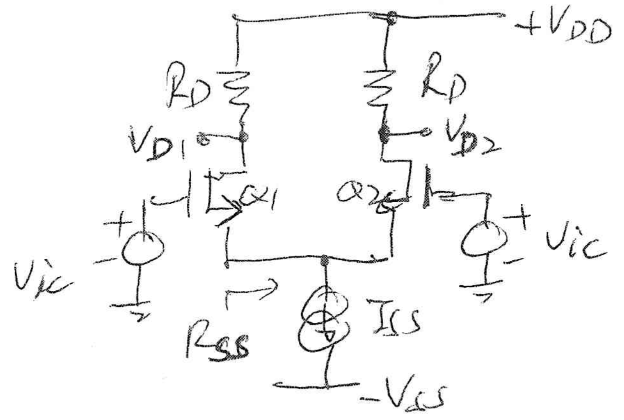
$V_{od} = V_{d1} - V_{d2} = -g_m V_{id} R_D$

$\therefore A_{dm\_dif} = \frac{V_{od}}{V_{id}} = -0.346m \times 75k = -26$

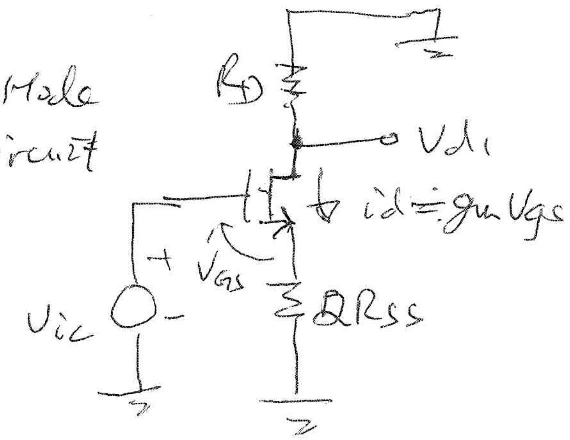
$A_{d\_sel} = \frac{V_{d1}}{V_{id}} = \frac{-g_m R_D}{2} = \frac{-26}{2} = -13$

$R_{id} = \infty$

Common Mode Analysis



Common-Mode half circuit



$\because V_{od} = V_{d1} - V_{d2} = 0, \quad \therefore A_{cm\_diff} = 0$

$$A_{cm\_se1} = \frac{V_{d1}}{V_{ic}} = \frac{-g_m V_{gs} R_D}{V_{gs} + g_m V_{gs}(2R_{SS})} = \frac{-g_m R_D}{1 + 2g_m R_{SS}}$$

$$= -0.232$$

$R_{ic} = \infty$

CMRR

Differential Output

$$CMRR = \left|\frac{-26}{0}\right| = \infty$$

Single-Ended Output

$$CMRR = \left|\frac{-13}{-0.232}\right| = 56$$

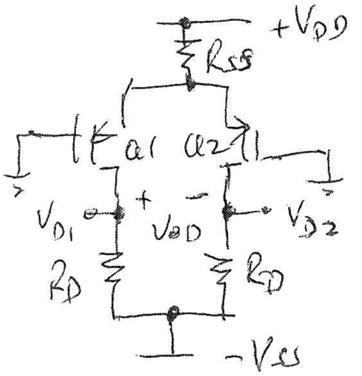
or 35dB

Output Resistance

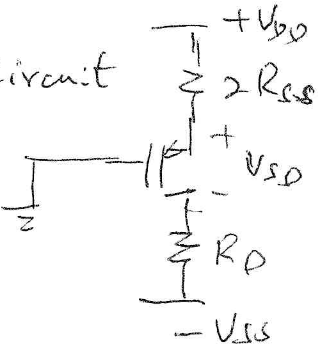
$R_{o1} = R_{o2} = R_D \parallel r_o \approx R_D = 75k\Omega$

$R_{o2} = 2(R_D \parallel r_o) \approx 2R_D = 150k\Omega$

3(a) DC Analysis



DC half circuit



$$I_D = \frac{|K_p|}{2}(V_{SG} - |V_{TP}|)^2 = \frac{18 - V_{SG}}{112k}$$

$$I_D = \frac{18 - V_{SG}}{2 \times 56K} \Rightarrow 11.2V_{SG}^2 - 21.4\,V_{SG} - 6.8 = 0$$

$\therefore V_{SG} = +2.19V$ or $V_{SG} = -0.28V$ (rejected)

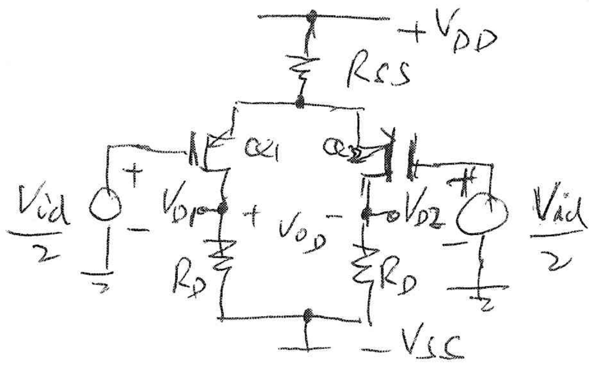
$$\therefore I_D = \frac{18 - V_{SG}}{112k} \doteqdot 141\mu A$$

and $V_{SD} = V_{SG} - I_D R_D - (-V_{SS}) = 2.19 - 141\mu \times 91k + 18$

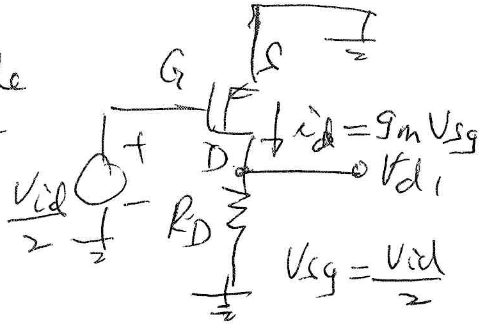
$= 7.34V$

3(b) $g_m = \sqrt{2|K_p| I_D} = \sqrt{2 \times (2 \times 10^{-4}) \times (1.41 \times 10^{-4})} = 0.237mS$

Differential-mode Analysis



Differential-Mode half circuit



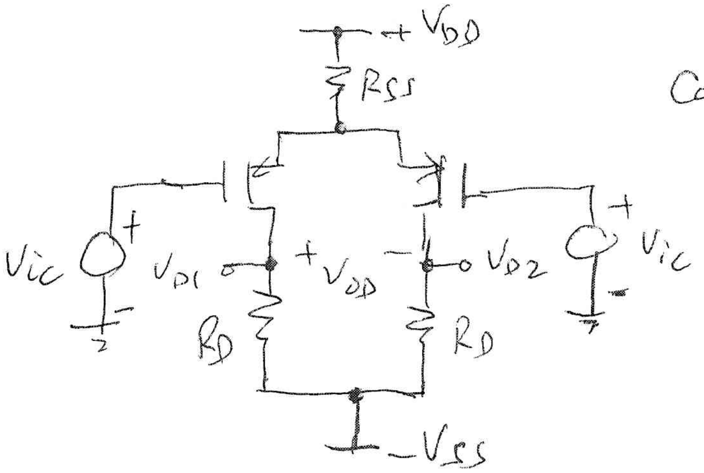
$$V_{d1} = -g_m\left(\frac{V_{id}}{2}\right)R_D, \quad V_{d2} = -g_m\left(-\frac{V_{id}}{2}\right)R_D$$

$$\therefore V_{od} = V_{d1} - V_{d2} = -g_m V_{id} R_D$$

$$\therefore A_{dm\_diff} = \frac{V_{od}}{V_{id}} = -g_m R_D = -0.237m \times 91k = -21.57$$

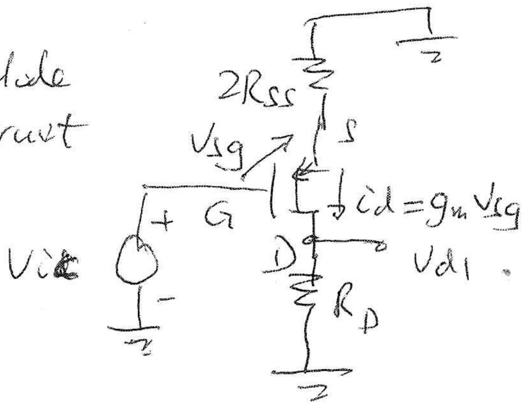
$$A_{dm\_sel} = \frac{A_{dm\_diff}}{2} = -10.78, \quad R_{ic} = \infty$$

Common-Mode Analysis



Common-Mode half circuit

$\Rightarrow$



Since $v_{od} = v_{d1} - v_{d2} = 0$, $\Rightarrow$ $A_{cm\text{-}diff} = 0$

$$A_{cm\text{-}se} = \frac{v_{d1}}{v_{ic}} = \frac{-g_m v_{sg} R_D}{v_{sg} + g_m v_{sg}(2R_{SS})} = \frac{-g_m R_D}{1 + 2g_m R_{SS}}$$

$$= \underline{-0.783}$$

$R_{ic} = \infty$

CMRR

Differential Output

$$CMRR = \left|\frac{-21.57}{0}\right| = \infty$$

Single-Ended Output

$$CMRR = \left|\frac{-10.78}{0.78}\right| = 13.82 \text{ or } 22.81\,dB$$

Output Resistances

$R_{o1} = R_{o2} = R_D \| r_{o2} \simeq R_D \cong 91\,k\Omega$

$R_{od} = 2(R_D \| r_o) \simeq 2R_D = 182\,k\Omega$