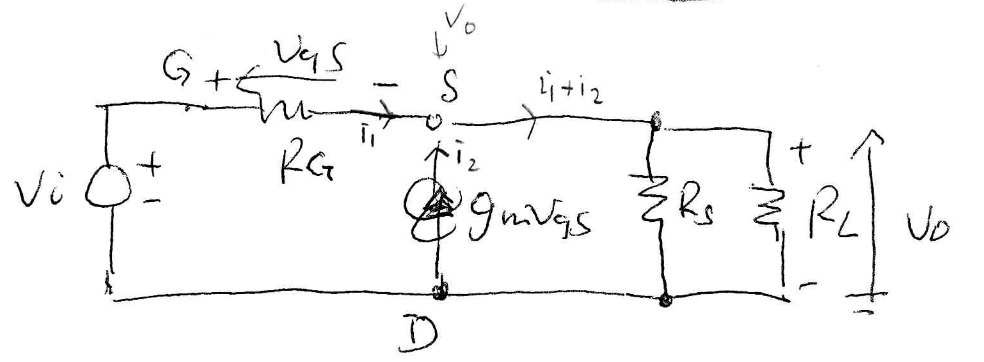
EE 2002 Tutorial 7

1 (a)



$g_m = 3.54\,mS$

r_o is ignored

$R_G = 1M\Omega$

$R_S = 2k\Omega$

$R_L = 100k\Omega$

$V_{DD} = 10V$

$-V_{SS} = -10V$

KCL at node S,

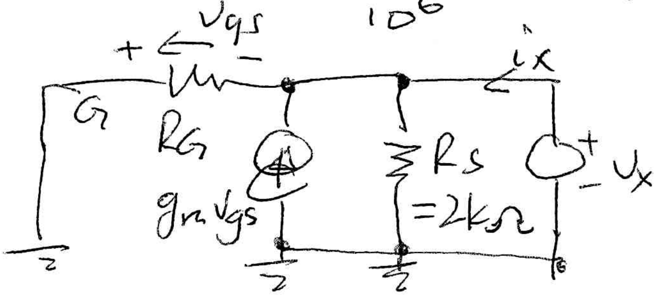
$$\underbrace{\frac{V_i - V_o}{R_G}}_{i_1} + \underbrace{g_m (V_i - V_o)}_{i_2} = \frac{V_o}{R_S \parallel R_L}$$

$$\frac{V_i - V_o}{1\times 10^6} + 3.54\times 10^{-3}(V_i - V_o) = \frac{V_o}{1960}$$

$$\Rightarrow V_o = 0.874\, V_i$$

$$\therefore A_v = \frac{V_o}{V_i} = \underline{\underline{0.874}}$$

$$R_{in} = \frac{V_i}{i_i} = \frac{V_i}{\frac{(V_i - V_o)}{10^6}} = \frac{10^6 V_i}{V_i - \underbrace{0.874 V_i}_{V_o}} = \underline{\underline{7.94 M\Omega}}$$



$$V_{gs} = -V_x$$

$$i_x = \frac{V_x}{R_G} + \frac{V_x}{R_S} + g_m V_x = \frac{V_x}{10^6} + \frac{V_x}{2000} + 3.54\times 10^{-3} V_x$$

$$\therefore R_{out} = \frac{V_x}{i_x} = \underline{\underline{247\Omega}}$$

1 (b) If $A_v = 1$, $R_{in} \to \infty$. #

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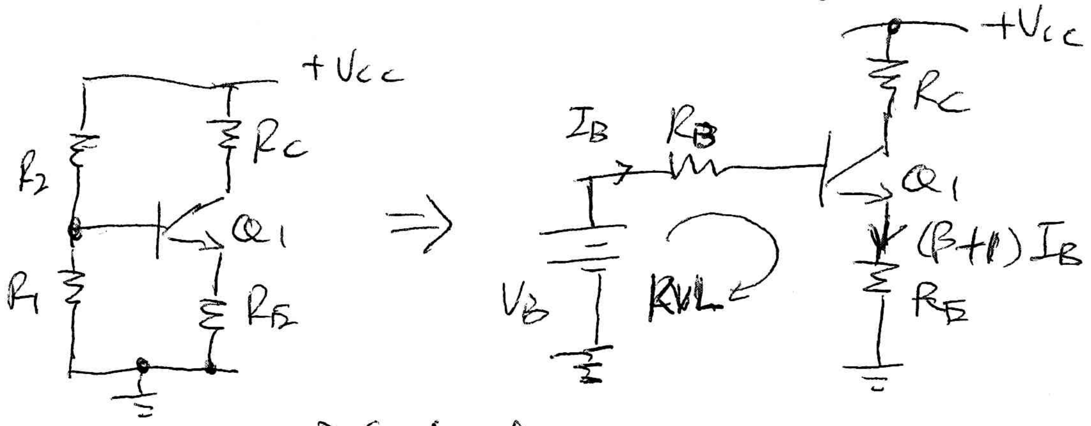
2



DC Analysis

$$V_B = 15 \times \frac{180k}{300k + 180k} = 5.63V, \quad R_B = 300k // 180k = 113k\Omega$$

$$I_B = \frac{V_B - V_{BE}}{R_B + (\beta+1)R_E} = \frac{5.63 - 0.7}{113k + 101 \times 20k} = 2.31\,\mu A$$

$$I_C = \beta I_B = 100 \times 2.31\,\mu A = 232\,\mu A, \quad I_E = (\beta+1) I_B = 101 \times 2.31\,\mu A$$
$$= 234\,\mu A$$

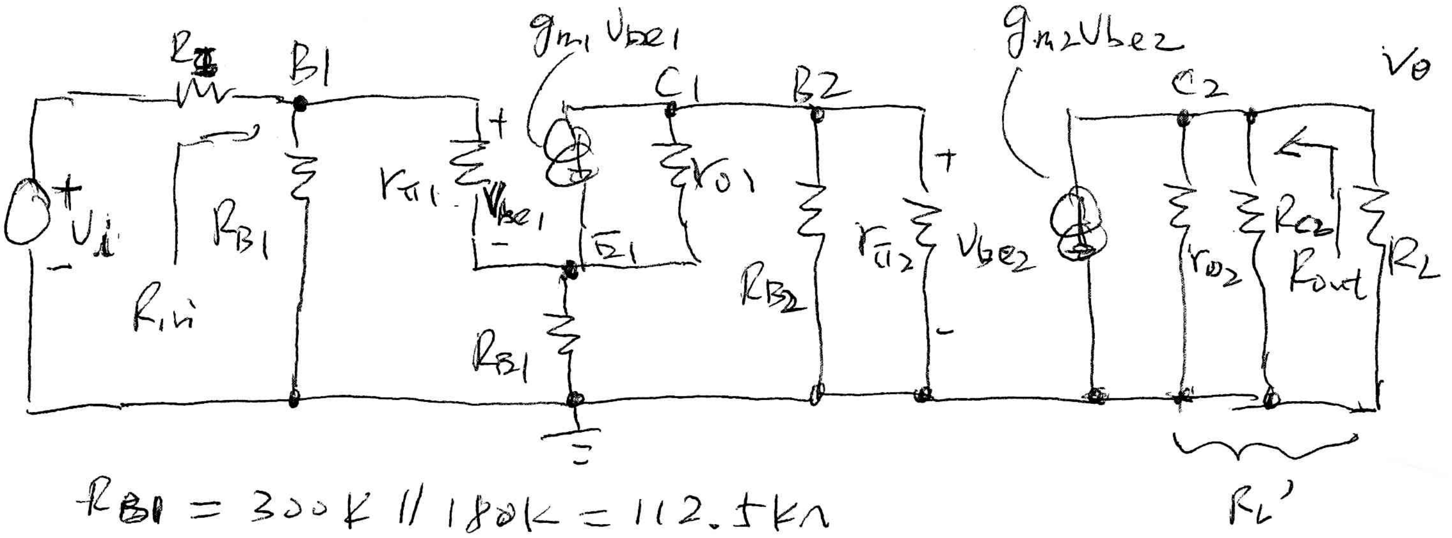
$$V_{CE} = V_{DD} - I_C \cdot R_C - I_E R_E = 15V - I_C (20k) - I_E (20k)$$
$$= 5.71V$$

$$\therefore g_m = \frac{I_C}{V_T} = \frac{232\,\mu A}{0.025V} = 9.28\,mS$$

$$r_\pi = \frac{\beta}{g_m} = 10.8\,k\Omega$$

$$r_o = \frac{V_A + V_{CE}}{I_C} = \frac{(70 + 5.71)V}{232\,\mu A} = 326\,k\Omega$$

AC analysis



$R_{B1} = 300K \,//\, 180K = 112.5k\Omega$

$R_{B2} = 20K \,//\, 300k \,//\, 180K = 16.98k\Omega$

$\therefore R_{in} = R_{B1} \,//\, [r_{\pi 1} + (\beta+1)R_{E1}) = 112.5k \,//\, [10.8K + 101 \times 2K]$
$= \underline{\underline{73.6k\Omega}}$

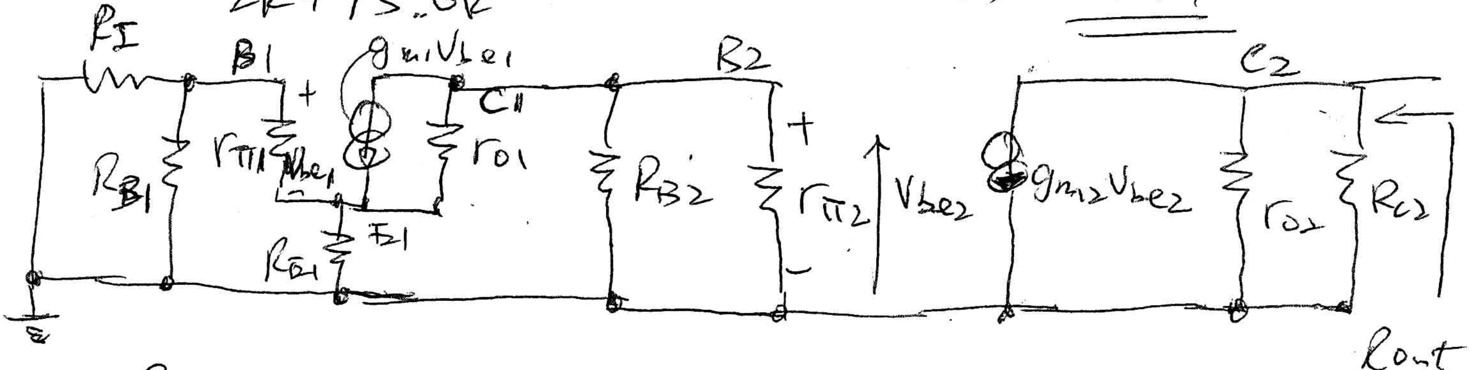
$$A_V = \left(\frac{R_{in}}{R_I + R_{in}}\right) \times A_{V1}' \times A_{V2}'$$

$$A_{V1}' = \frac{V_{C1}}{V_{b1}} = \frac{-i_{b1} \cdot \beta_1 (R_{B2} \,//\, r_{\pi 2})}{i_{b1}[r_{\pi 1} + (\beta_1+1)R_{E1}]} = -3.10$$ (2kΩ in stage 1 is not bypassed)

$$A_{V2}' = \frac{V_o}{V_{B2}} = \frac{-g_{m2}V_{be2}R_L'}{V_{be2}} = -g_{m2}R_L' = -147$$

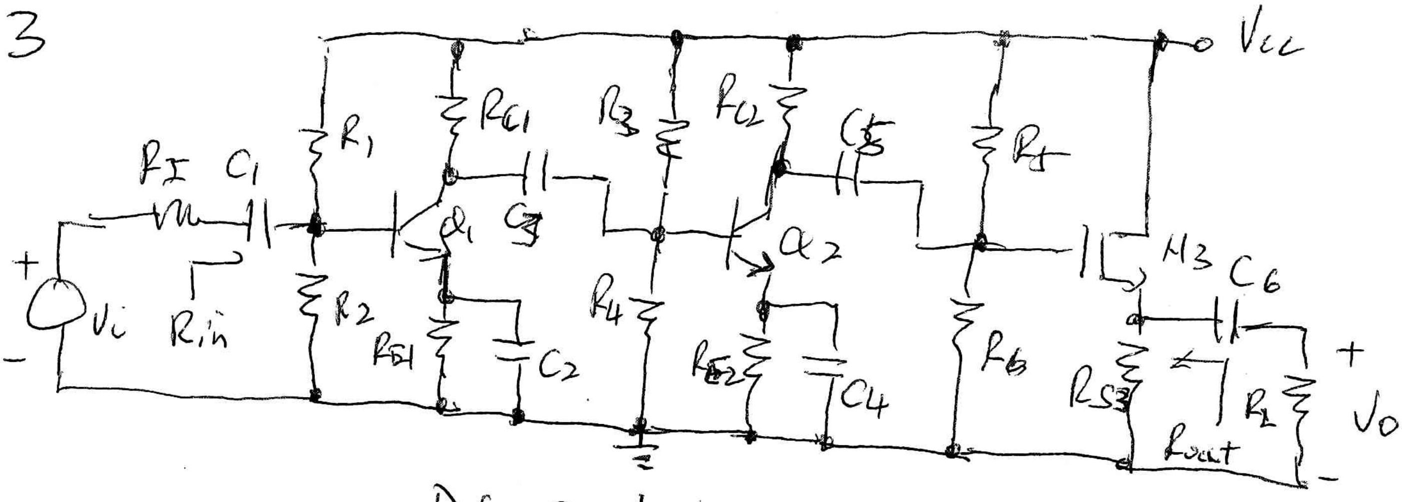
where $R_L' = r_{o2} \,//\, R_{C2} \,//\, R_L = 326K \,//\, 20K \,//\, 100K$

$$\therefore A_V = \frac{73.6K}{2K + 73.6K} \times (-3.10) \times (-147) = \underline{\underline{444}}$$



$R_{out} = 20K \,//\, r_{o2} = 20K \,//\, 326K = \underline{\underline{18.8k\Omega}}$

3



DC analysis

Q1	Q2	M3
V_{B1}, R_{B1}	V_{B2}, R_{B2}	See Q5 of Tutorial 5.
I_{C1}, V_{CE1}	I_{C2}, V_{CE2}	
g_{m1}, $r_{\pi1}$, r_{o1}	g_{m2}, $r_{\pi2}$, r_{o2}	

Note: $I_C = \dfrac{\beta(V_B - V_{BE})}{R_B + (\beta+1)R_E}$, $V_{CE} = V_{cc} - I_C R_C - I_E R_E = V_{cc} - I_C\left(R_C + \dfrac{R_E}{\alpha}\right)$

$$\boxed{R_{in} = R_{B1} \,//\, r_{\pi1}}$$

$$\boxed{A_V = \left(\frac{R_{in}}{R_I + R_{in}}\right) \times A_{V1}' \times A_{V2}' \times A_{V3}'}$$

A_{V1}' and A_{V2}' are the ac gain of stage 1 & stage 2 CE amplifier with full-bypassed emitter resistor.

A_{V3}' is the ac gain of common drain amplifier (same as Q2 of Tutorial 6).

$$\boxed{R_{out} = r_{o3} \,//\, R_{S3} \,//\, \frac{1}{g_{m3}}}$$

Input signal range

M3	Q2
① $v_{gs3} \le 0.2(V_{GS3} - V_{TN3})$	$v_{be2} \le 0.005\ V$
② Relate v_i and v_{gs3}	Relate v_i & v_{be2}

③ Find the worst case v_i