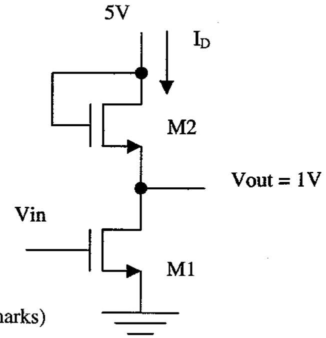
2. The MOS transistors M1 and M2 are identical.
Given : $K = 10\ mA/V^2$ and $V_T = 1V$.

$$I_D = K(V_{GS} - V_T)^2 \qquad \textit{Saturation}$$

$$I_D = 2K\left[(V_{GS} - V_T)V_{DS} - \frac{V_{DS}^{\ 2}}{2}\right] \qquad \textit{Ohmic}$$



a) Find and prove the operation mode of M2. (6 marks)
b) Calculate the current I_D. (4 marks)
c) Find Vin if M1 is in ohmic. (7 marks)
d) Estimate the ON resistance ron of M1 (ron = $\partial V_{DS} / \partial I_D$). (5 marks)

a) $V_{GS} > V_T$ $\quad V_{DS} > V_{GS} - V_T$

$5 - 1 > 1$ $\quad 4 > 4 - 1$

$\therefore$ M2 is saturate

6

b) $I_D = K(V_{GS} - V_T)^2 = 10m(4-1)^2 = 90mA$

4

c) $I_D = 2K\left[(V_{GS} - V_T)V_{DS} - \frac{V_{DS}^2}{2}\right]$

$90m = 2(10m)\left[(V_{in} - 1)1 - \frac{1}{2}\right]$

$4.5 = V_{in} - 1.5$

$\therefore V_{in} = 6V$

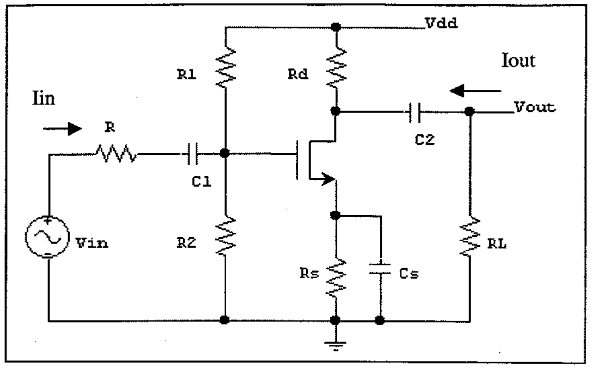
7

d) $r_{on} \doteq \frac{1}{2K(V_{GS} - V_T)} = \frac{1}{2(10m)(6-1)}$

$= 10\Omega$

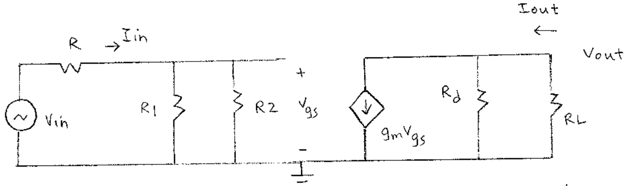
5

3. Given the following circuit diagram.



a) Draw the ac equivalent circuit for the whole circuit. Assume C1, C2 and Cs are large, and r_o of NMOS model is infinity. (7 marks)
b) Find the total input resistance Rin (Rin = Vin / Iin). (3 marks)
c) Find the total output resistance Rout (Rout = Vout / Iout). (3 marks)
d) Find the ac voltage gain of the amplifier (Av = Vout / Vin). The expression is required to be independent of Vin. (6 marks)

a)



7

b) $R_{in} = \frac{V_{in}}{I_{in}} = R + R_1 \parallel R2$

3

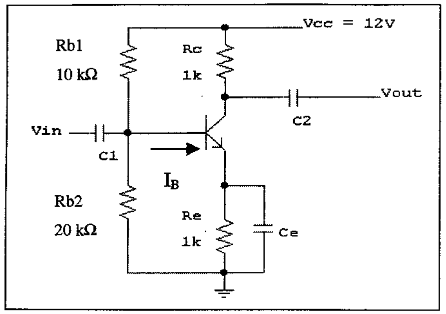
c) $R_{out} = R_L$

3

d) $A_V = \frac{V_{out}}{V_{in}} = \frac{-g_m V_{gs}(R_d \parallel R_L)}{\frac{V_{gs}}{R1 \parallel R2}(R + R1 \parallel R2)}$

6

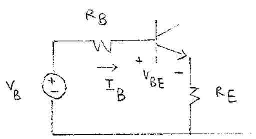
12. Given the following circuit diagram.



$\beta = 50$
$V_{CE}\text{ (sat)} = 0.2\text{ V}$
$V_{BE} = 0.7\text{ V}$

a) Show that the base current I_B is 0.127 mA. (Hint : Use Thevenin's Theorem) (13 marks)
b) Show that the Q-point is in the saturation region. (8 marks)
c) Show that the forced β is 29.7 (18 marks)
d) Suggest a method to move the Q-point to the active region. (4 marks)
e) Give two advantages of this circuit connection. (4 marks)
f) Briefly explain the function of C1, C2 & Ce. (5 marks)

a)



$$V_B = V_{cc}\frac{R_{b2}}{R_{b1}+R_{b2}} = 12\,\frac{20K}{10K+20K} = 8V$$ 3

$$R_B = R_{b1} \parallel R_{b2} = 10K \parallel 20K = \frac{20K\Omega}{3}$$ 3

$$I_B = \frac{V_B - V_{BE}}{R_B + (1+\beta)R_E} = \frac{8-0.7}{\frac{20K}{3} + (1+50)1k}$$

$$= 0.127\text{ mA}$$ 7

b) If BJT active, $I_c = \beta I_B = 50\,(0.127\,m)$

$= 6.33\text{ mA} \approx I_E$

but $I_c R_c + I_E R_E \approx 6.33\,m\,(2k)$

$> 12\,V$

$\therefore$ BJT saturates 8

c) BJT saturates

$$V_{cc} = I_c R_c + V_{CESAT} + I_E R_E$$

$$12 = \beta_f I_B\,1K + 0.2 + (1+\beta_f)I_B\,1K$$

$$\therefore I_B = \frac{11.8}{1K\,(2\beta_f + 1)}$$

But I_B also $= \dfrac{V_B - V_{BE}}{R_B + (1+\beta_f)R_E} = \dfrac{8-0.7}{\frac{20k}{3} + (1+\beta_f)1k}$

$$\therefore 7.3K\,(1+2\beta_f) = 11.8K\left(\frac{20}{3} + 1 + \beta_f\right)$$

$$\therefore \beta_f = 29.7$$ 18

d) BJT active, $I_B \downarrow$

or $R_B + (1+\beta)R_E \uparrow$ 4

e) single supply (V_{cc})

stable Q point 4

f) C_1 C_2 : block DC and

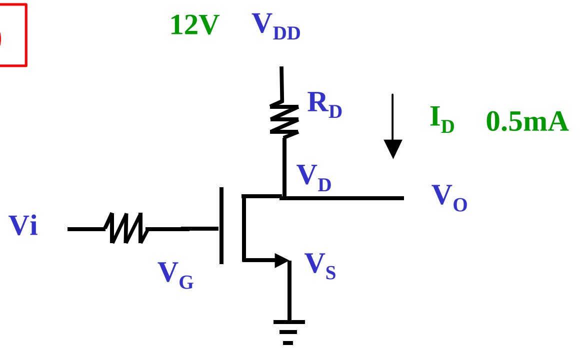
pass AC current 5

C_e : short R_E at AC

increase A_V

11 **(30)**

Given
$V_T = 1V$
$K = 0.02mA/V^2$



Find R_D such that $Vi = V_O$,
i.e. $V_{GS} = V_{DS}$ and NMOS saturates

$$\because I_{DS} = K\,(V_{GS} - V_T)^2 = 0.02m(V_{GS} - 1)^2 = 0.5mA$$

$$\therefore V_{GS} = \sqrt{\frac{0.5m}{0.02m}} + 1 = 6V$$

$$\because V_{DD} = I_{DS}R_D + V_{DS}$$

$$\therefore R_D = \frac{V_{DD} - V_{DS}}{I_{DS}} = \frac{12 - 6}{0.5m} = 12k\Omega$$

Find V_O such that $Vi = V_{DD}$
i.e. $V_{GS} = 12V$, hence $V_{GS} - V_T > V_{DS}$ and NMOS in triode

$$\therefore I_{DS} = 2K[(V_{GS} - V_T)V_{DS} - \frac{V_{DS}^{\ 2}}{2}]$$

$$= 2(0.02m)[(12 - 1)V_{DS} - \frac{V_{DS}^{\ 2}}{2}]$$

$$\therefore I_{DS} = \frac{V_{DD} - V_{DS}}{R_D} = \frac{12 - V_{DS}}{12.5k} = 0.04m(11V_{DS} - \frac{V_{DS}^{\ 2}}{2})$$

$$\therefore 12 - V_{DS} = 0.5[11V_{DS} - \frac{V_{DS}^{\ 2}}{2}]$$

$$\therefore 12 - 6.5V_{DS} + 0.25V_{DS}^{\ 2} = 0$$

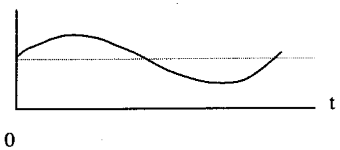
$$\therefore V_{DS}^{\ 2} - 26V_{DS} + 48 = 0$$

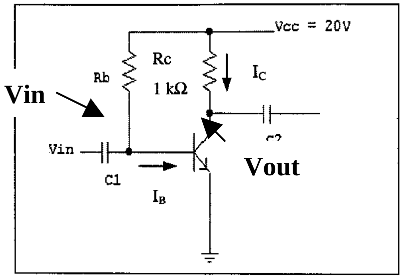
$$\therefore V_{DS} = 24V \quad \text{or} \quad 2V$$

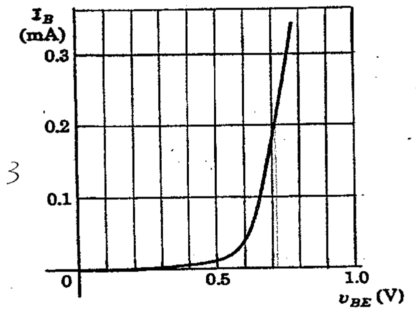
hence $V_O = V_{DS} = 2V$ ($24\,V > V_{DS}$ is impossible)

13. Given the following circuit diagram. The input (base) and output (collector) characteristics of the BJT are given.

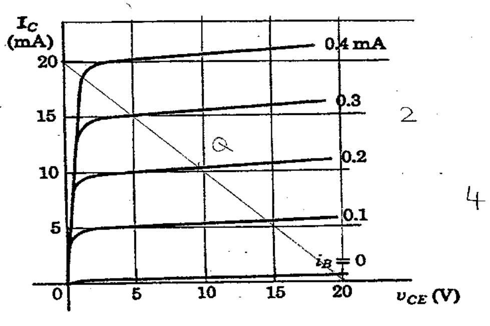
Vin = 0.71 + 0.05 sin ωt V







(a) Base characteristics



(b) Collector characteristics

a) Plot the dc load line in the output characteristics. Show clearly your calculations. (4 marks)
b) Show that the base current I_B is 0.2 mA. (3 marks)
c) Calculate Rb. (3 marks)
d) Show the location of the Q-point in the output characteristics. (2 marks)
e) Find Ic and V_{CE} at the Q-point. (4 marks)
f) Sketch the base current I_B, the collector current I_C and the output voltage Vout. Show clearly the dc level, the maximum and the minimum values in your sketch. (15 marks)
g) Calculate the ac voltage gain (Av = Δ Vout / ΔVin). (3 marks)
h) Calculate the ac current gain (Ai = ΔIc / ΔI_B). (3 marks)

a) $V_{cc} = I_c R_c + V_{CE}$

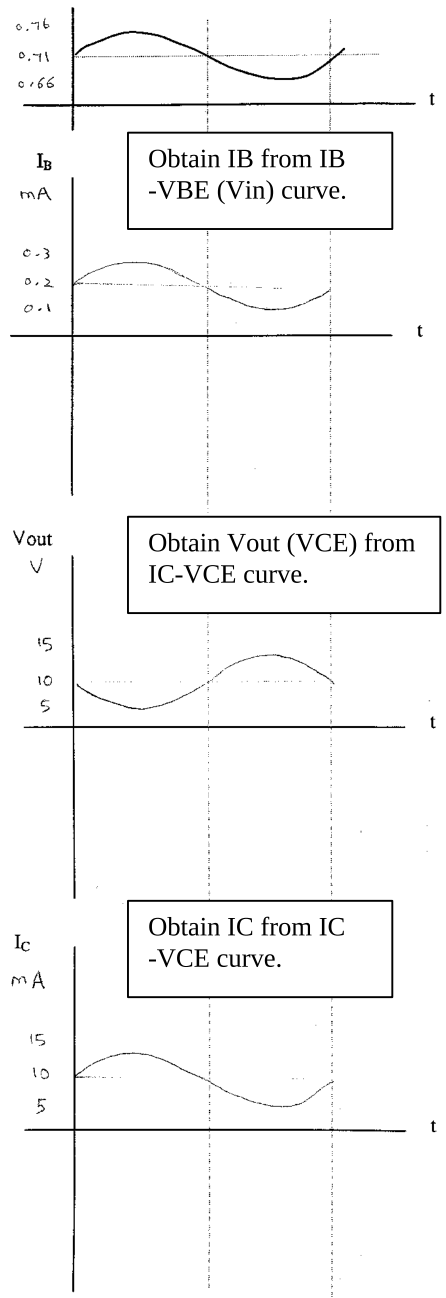
$I_c = 0 \qquad V_{CE} = V_{cc} = 20\text{ V}$

$V_{CE} = 0 \qquad I_c = \frac{V_{cc}}{R_c} = \frac{20\text{ V}}{1k} = 20\text{ mA}$

b) $V_{BE} \approx 0.7\text{ V}$ 3

$I_B = 0.2\text{ mA}$

Vin = 0.71 + 0.05 sin ωt V



c) $R_b = \frac{V_{cc} - V_{BE}}{I_B}$

$= \frac{20 - 0.7}{0.2\text{ m}}$

$= 96.5\text{ k}\Omega$ 3

d) Q point

e) $I_c \approx 10\text{ mA}$ 4

$V_{CE} \approx 10\text{ V}$

f) 15

g) $A_V = \frac{\Delta V_{out}}{\Delta V_{in}}$

$\approx \frac{5 - 15}{0.76 - 0.66}$ 3

$= -100$

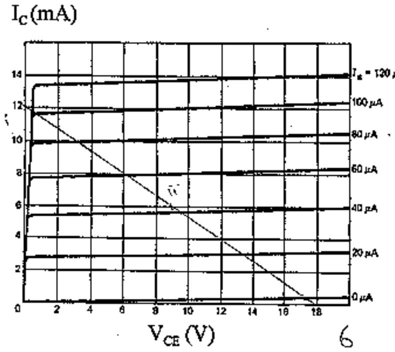
$A_I = \frac{\Delta I_c}{\Delta I_B}$

$\approx \frac{15 - 5}{0.3 - 0.1}$ 3

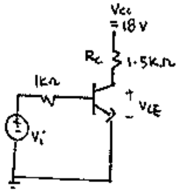
$= 50$

END

12. The BJT in the circuit has the output characteristic curves as shown.
(a) Sketch the load line $V_{CC} = I_C R_C + V_{CE}$. (6)
(b) Locate the Q-point on the loadline and find the operating modes of the BJT (i) if Vi = 0.8V, and (ii) if the circuit is to give maximum symmetric V_{CE} output. (14)
(c) Show that the voltage gain A_V (= ΔVo /ΔVi) of the circuit is -90. (11)
Given that for the BJT, V_{BE} = 0.7V, β = 120, r_π = 1 kΩ, ro = ∞.



6



(i) Vi = 0.8V

$I_B = \frac{0.8 - 0.7}{1K} = 0.1m$ 4

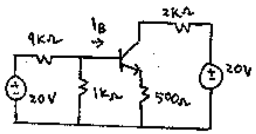
BJT ON. 3

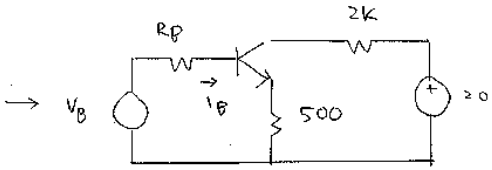
(ii) middle of loadline 4

BJT active 3

C:\

11. In the circuit, (a) show that $I_B \sim 25$ μA. (19)
(b) Explain briefly why the circuit can have stable Ic. (7)
For the BJT, given V_{BE} = 0.7V and β = 100.





$V_B = 20 \frac{1K}{10K} = 2V$ 5

$R_B = 1K \| 9k = 900\,\Omega$ 4

$\therefore 2 = I_B R_B + V_{BE} + I_E 500$

$= I_B 900 + 0.7 + (101) I_B 500$

$\therefore I_B = \frac{2 - 0.7}{900 + 101(500)} = 25\mu A$ 10

$I_C \uparrow$ $V_E \uparrow$ $V_{BE} \downarrow$ $I_B \downarrow$ $I_C \downarrow$ 7