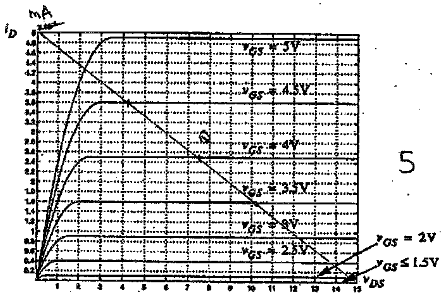
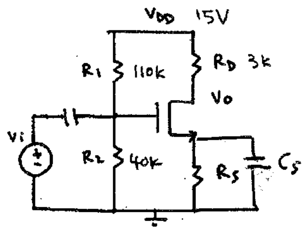
3. In the circuit, the MOSFET has the following output characteristic curves. If $R_D = 3\ k\Omega$, $V_{DD} = 15V$, $R_1 = 110\ k\Omega$, $R_2 = 40\ k\Omega$, $R_S = 0\ \Omega$, find V_{GS}, sketch the AC loadline, locate the Q-point on the loadline, and find V_{DS} at Q-point ($=V_{DSQ}$). (b) Estimate the transconductance gm ($= \partial i_{DS} / \partial v_{GS}$ at V_{DSQ}), sketch the mid-frequency small signal equivalent circuit, and find the voltage gain Vo/Vi. Given r_O of transistor $= \infty$. (24)



5

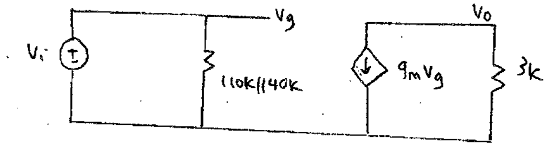


$$V_{GS} = 15 \frac{40k}{110k + 40k} = 4V$$ 3

$$V_{DSQ} \simeq 7.5V$$ 2

$$g_m = \frac{\partial i_D}{\partial V_{GS}}\Big|_{V_{DSQ}} \simeq \frac{3.6 - 1.6}{1V}$$

$$= 2mS$$ 6



$$\therefore \frac{V_o}{V_i} = -g_m\, 3K$$ 8

$$= -2m(3K) = -6$$

4. In an n-channel MOSFET, $V_T = 2V$, $I_{DS} = 1mA$ when $V_{GS} = 4V$ and $V_{DS} = 4V$. (a) Find K in the I_{DS} equation. (b) Find I_{DS} when $V_{GS} = 3V$ and sketch I_{DS} versus V_{GS} for $0V \le V_{GS} \le 4V$. (c) Estimate r_{on} (the resistance when the MOSFET is turned on, $= \cancel{\frac{\partial I_{DS}}{\partial V_{DS}}}$ ~~at $V_{DS}=0$~~ in the ohmic region). Given that $I_{DS} = K [\,2(V_{GS} - V_T)V_{DS} - V_{DS}^2\,]$ in the ohmic region. (20) $\rightarrow \frac{\partial V_{DS}}{\partial I_{DS}}\Big|_{V_{DS}=0}$ when $V_{GS} = 4V$

$$V_D = 4V > V_G - V_T = 4 - 2 = 2V$$ 2

$$\therefore I_{DS} = k(V_{GS} - V_T)^2$$

$$I_m = k(4-2)^2$$

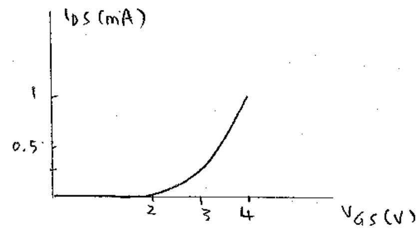
$$\therefore k = 0.25\ mA/V^2$$ 5

$V_G = 3V$

$$I_D = k(V_G - V_T)^2$$

$$= 0.25m(3-2)^2$$

$$= 0.25m$$



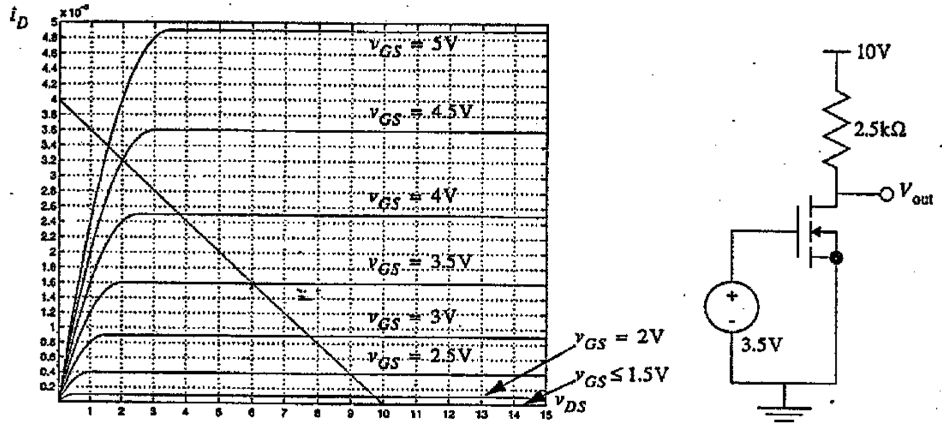
6

$$r_{on} = \frac{\partial V_{DS}}{\partial I_{DS}}\Big|_{V_{DS}=0} = \frac{1}{2K(V_G - V_T)}$$ 7

$$= \frac{1}{2(0.25m)(4-2)}$$

$$= 1K\Omega$$

(a) Assume that the transistor in the circuit below has the transfer characteristics shown. Find the value of V_{out}. (4 pts)



2

$\because V_{GS} = 3.5V$, $V_{out} = V_{DS} = 6V$ (graphically)

or analytically

$I_{DS} = k(V_{GS} - V_T)^2$ 1

$V_T = 1.5V$ since $I_D = 0$ for $V_{GS} < V_T$ 1

When $V_{GS} = 2.5V$ $I_D = 0.4mA$

$\therefore k = \frac{0.4mA}{(2.5-1.5)^2} = 0.4 \times 10^{-3}$

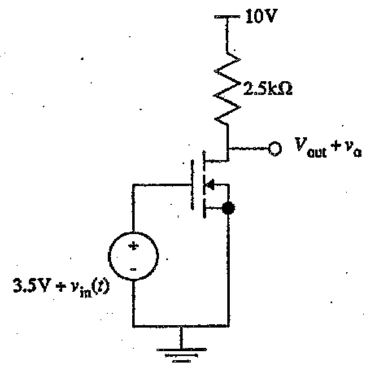
$\therefore V_{out} = 10V - 2.5k\Omega\,[k(V_{GS} - V_T)^2]$

$= 10 - 2.5k\,(0.4\times10^{-3})(3.5-1.5)^2$

$= 6V$

2

(b) Estimate the small signal voltage gain $A = v_{out}/v_{in}$ for the circuit below assuming the transistor is the sar that in part (a) and that v_{in} and v_{out} are small AC signals. (6 pts)



From load line (graphical)

if $V_{in}(t) = 0.5V$

$V_{GS} = 4V$ $V_{DS} = 3.8V$

$\therefore V_{out}(t) = 3.8 - 6$

$= 2.2V$

if $V_{in}(t) = -0.5V$

$V_{GS} = 3V$ $V_{DS} = 7.8V$

$\therefore V_{out}(t) = 7.8 - 6 = 1.8V$

$\therefore A_v = \frac{(-2.2) - 1.8}{0.5 - (-0.5)} = -4$

6

Analytically

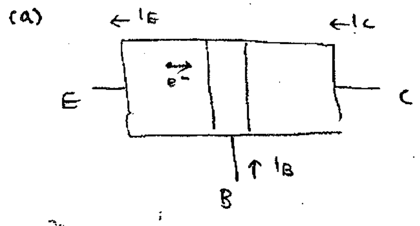
$A = \left.\frac{\partial V_{out}}{\partial V_{in}}\right|_{V_{GS}=3.5} = \frac{\partial}{\partial V_{GS}}\left[10 - 2.5k(0.4\times10^{-3})(V_{GS}-1.5\right.$

$= -2(2500)(0.4\times10^{-3})(3.5-1.5)$

$= -4$

3. (a) Sketch the cross section of a NPN transistor operated in the active region, describe the movement of electrons and explain briefly why $I_C \sim \alpha I_E$ and $I_C \sim \beta I_B$ where $\beta = \alpha / (1-\alpha)$.
(b) In the following transistor circuit, if $R_1 = 20\ k\Omega$, find I_C, V_{CE} and the forced β.
Given that $V_{BE} = 0.8V$, $\beta = 30$ and $V_{CEsat} = 0.2V$. (20)

(a)



EB fb   CB rb

e^- E to B

B thin

most e^- → C

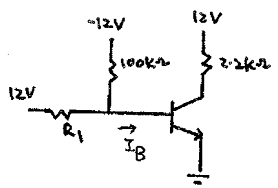
$I_C \sim \alpha I_E$

$I_C = I_E - I_B$

$= \frac{I_C}{\alpha} - I_B = \frac{\alpha}{1-\alpha} I_B$ 8

$= \beta I_B$

(b)



$I_B = \frac{12 - 0.8}{20k} + \frac{-12 - 0.8}{100K}$

$= 0.56m - 0.128m$

$= 0.432m$

if $I_C = \beta I_B = 0.432m\ (30)$

$= 12.96\ mA$

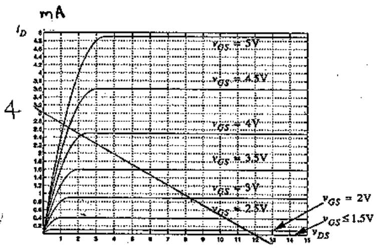
But $I_C max = \frac{12V}{2.2k\Omega} = 5.45m$ only

$\therefore I_C \doteqdot 5.45\ mA$ or $= \frac{12-0.2}{2.2K}$ 4

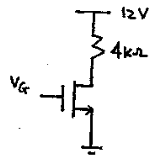
$V_{CE} = V_{CEsat} = 0.2V$ 4

$\beta_{forced} = \frac{5.45m}{0.432m} = 12.6$ 4

2. (a) Explain very briefly the difference of large signal and small signal.
(b) In the transistor circuit, if $V_G = 3V$, sketch the DC loadline on the output curves shown, find the Q-point, and estimate I_{DS}, V_{DS}, and the voltage gain A_V (= $\Delta V_{DS} / \Delta V_{GS}$).
(c) Find V_T and K.
(d) If $V_G = 5V$, show analytically the transistor is operating in the ohmic region and estimate the on resistance (r_{on}) of the transistor.
Given that $I_{DS} = 2K(V_{GS} - V_T)V_{DS}$ in the ohmic region and $I_{DS} = K(V_{GS} - V_T)^2$ in the saturation region.
(30)



4



(a) large signal : V swing ~ V   3

small signal : V swing ~ mV

use linear model

(b) $I_{DS} \sim 0.9\ mA$ 2

$V_{DS} \sim 8.2\ V$ 2

$A_V \sim \frac{\Delta V_{DS}}{\Delta V_{GS}} \sim \frac{10.3 - 5.4}{-1} \sim -4.9$ 5

(c) $V_T = 1.5\ V$ 3

$K = \frac{I_{DS}}{(V_{GS} - V_T)^2} = \frac{0.9\ mA}{(3 - 1.5)^2}$ 4

$= 0.4\ mA/V^2$

(d) $I_{DS} \sim 2K(V_{GS} - V_T)V_{DS}$

$\sim 2(0.4m)(5 - 1.5)1 \sim 2.8\ mA$ 4

$r_{ON} \sim \frac{1V}{2.6m} \sim 400\Omega$ 3

DEPARTMENT OF ELECTRICAL & ELECTRONIC ENGINEERING
HONG KONG UNIVERSITY OF SCIENCE OF TECHNOLOGY
ELEC 102 ELECTRONIC CIRCUITS
EXAM 1235-1515 25 May 1999 HALL ANSWER ALL QUESTIONS

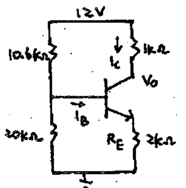
Try your best to answer all questions. Write down clearly all steps to get marks. Marking will be based mainly on steps. Total marks is 320 (2 marks ~ 1 min work). Make best use of your time!

Name: Department: Seat number:

Student ID: Email address:

Question	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Total	23	26	24	20	21	25	17	28	26	22	25	34	29	320
Mark														320

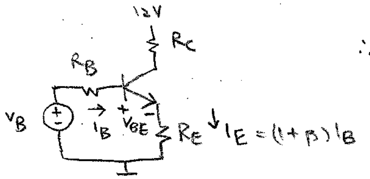
1. In the transistor circuit, find I_B and V_O. Explain also very briefly how R_E can stabilize I_C. Given that $V_{BE} = 0.7V$, $\beta = 100$. (23)



$V_B = 12 \frac{20k}{20k + 10.6k}$ 3

$= 7.84V$

$R_B = \frac{20k(10.6k)}{20k + 10.6k} = 6.93k\Omega$ 3



$\therefore I_B = \frac{7.84 - 0.7}{6.93k + (1+100)2k}$ 7

$= 34.2 \mu A$

$I_B = \frac{V_B - V_{BE}}{R_B + (1+\beta)R_E}$

$\therefore V_o = 12 - (100)(34.2\mu)1k$ 4

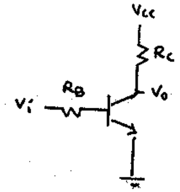
$= 8.58V$

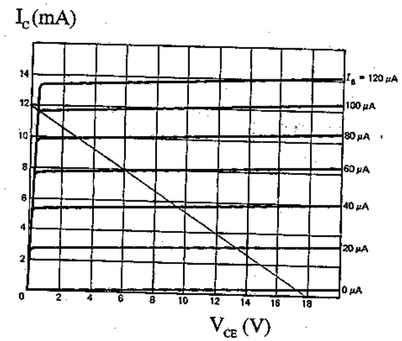
$I_C \uparrow$ $V_E = I_E R_E \uparrow$ $V_B \approx V_{BE} + V_E \sim const$ 6

$\downarrow$ $\uparrow$

$V_{BE} \downarrow$ $I_B \downarrow$ $I_C \downarrow$

2. The following BJT circuit has the output characteristic curves and loadline as shown. (a) From th load line, find Vcc and Rc. (b) From the output curves, estimate β, α and V_{CEsat} of the BJT. (c) If R_B = 10kΩ, sketch Vo versus Vi for 0 ≤ Vi ≤ 3V and label clearly all the voltages. Hence estimate the voltage gain A_V (= ΔVo /ΔVi) of the circuit in the linear region. Given that V_{BE} = 0.7V for the BJT. (26)





2 $V_{CC} = 18V$

2 $R_C = \frac{18V}{12mA} = 1.5k\Omega$

4 $\beta \sim \frac{10 - 3 \ mA}{60 \ \mu A} \sim 120$

4 $\alpha = \frac{\beta}{1+\beta} \sim \frac{120}{121}$

2 $V_{CEsat} \sim 0.4V$

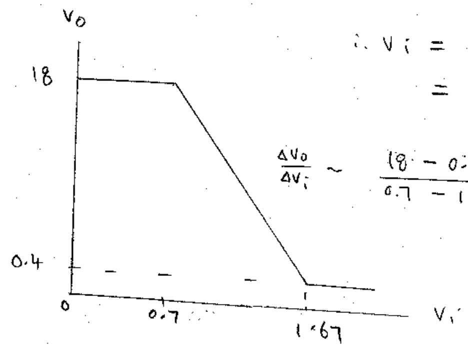
max $I_C = \frac{18 - 0.4}{1.5k} \sim 11.7mA$

$I_B \sim \frac{11.7m}{120} \sim 98 \mu A$

$\therefore V_i = 98\mu(10k) + 0.7$

$= 1.67V$

12



$\frac{\Delta V_o}{\Delta V_i} \sim \frac{18 - 0.4}{0.7 - 1.67} \sim -18$