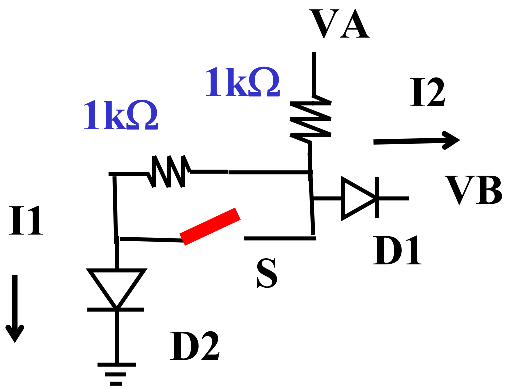
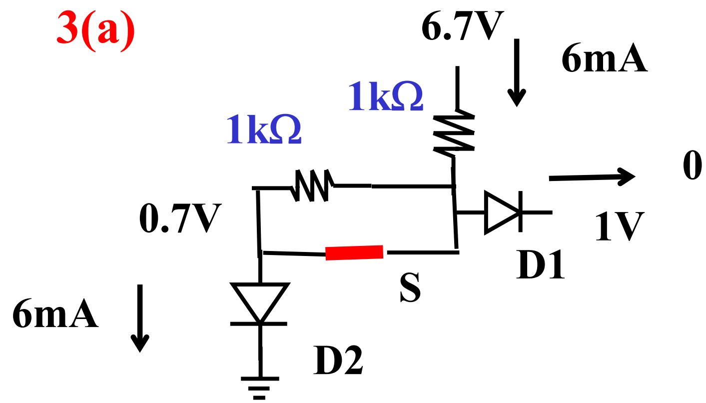
(12)

3

(a) Given VA = 6.7V, VB = 1V. If S is closed, find I1 and I2. Assume D1 and D2 are offset diodes with VF = 0.7V. (12)



3(a)



I1 = 6mA

I2 = 0mA

(12)

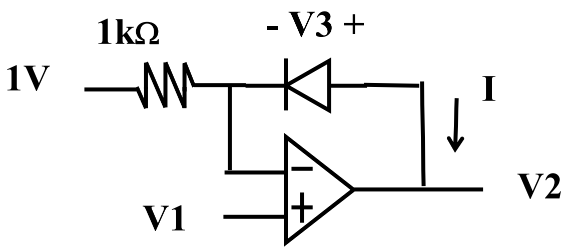
(12)

3

3. (b) In the ideal op amp circuit, the diode equation is

$$I_D = 10^{-13} A * [e^{\frac{V_D}{25mV}} - 1]$$

Find I if V2 = V1 + 0.6V. (12)



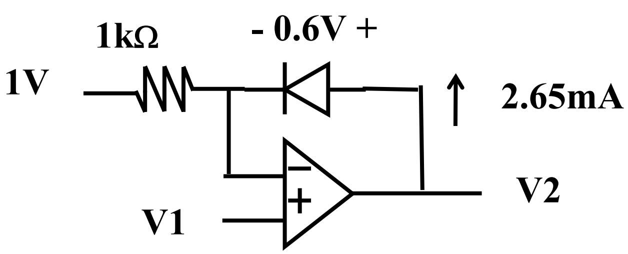
3(b)

$$\therefore V3 = 0.6V$$

$$\therefore I = -I_O\,(e^{\frac{0.6V}{25mV}} - 1)$$

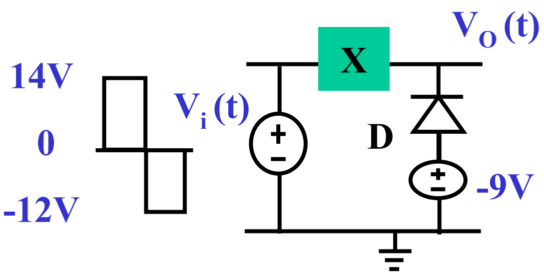
$$= -10^{-13} A * (e^{\frac{600m}{25m}} - 1) \cong -2.65mA$$

(12)

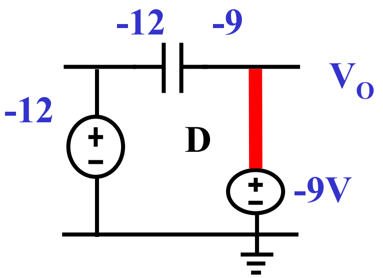


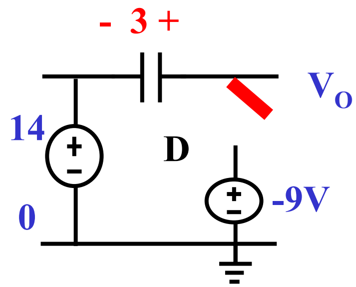
4

In the ideal diode circuit, sketch Vo(t) .
(a) If X = C.
(b) If X = R . (19)

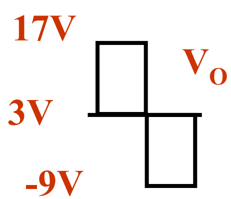


(a)



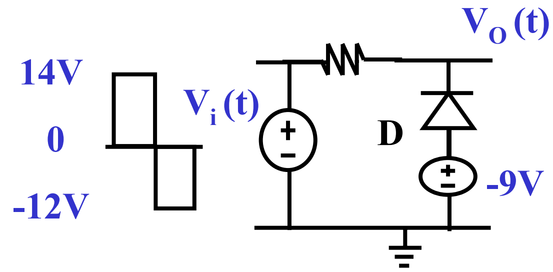


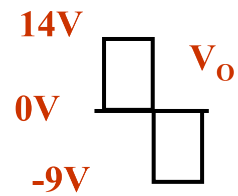
$\boxed{V_O = Vi + Vc = Vi + 3V}$



(11)

(b)





(8)

(17)

5

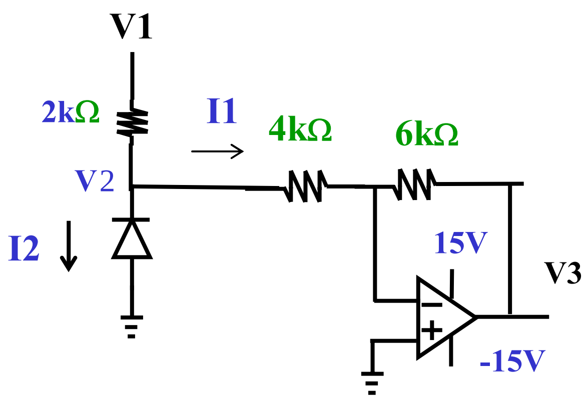
In the ideal op amp circuit, the diode has the reverse characteristics as shown.

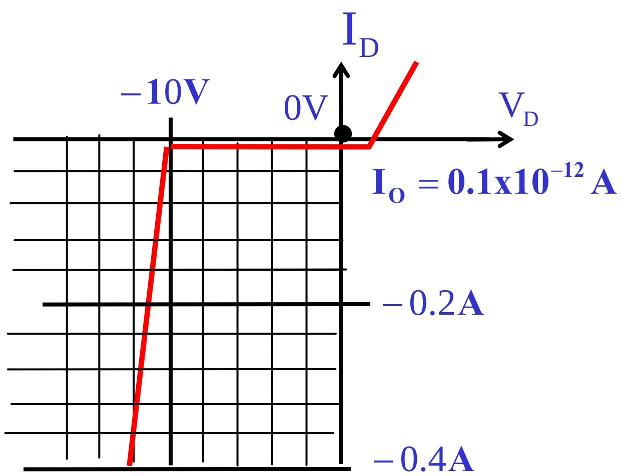
(a) Find the model of the diode at breakdown.

(b) If V1 = 10V, find V3 and I2.

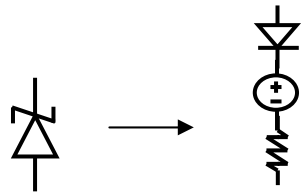
(c) If V1 = 25V, find V3 .

(31)





(a) **Model at breakdown**



$V_{ZO} = 10V$

$r_Z = 5\Omega$

(7)

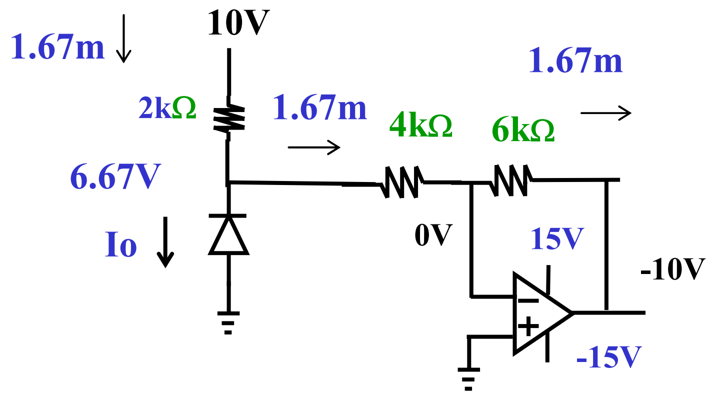
(b) V1 = 10V diode is not breakdown and is an off diode (open)

$$\therefore V3 = -\frac{6k\Omega}{4k\Omega + 2k\Omega} 10V = -10V$$

(6)

$$\therefore I2 = 0.1x10^{-12}\ A$$

(4)



(14)

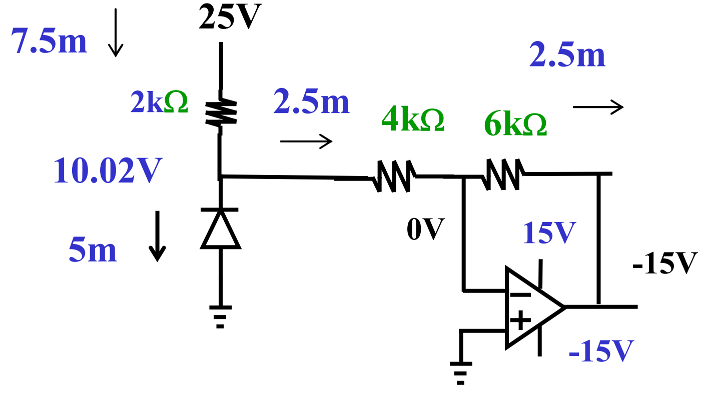
V1= 25V   Zener is breakdown

$$\therefore \frac{25-\mathbf{V}2}{2\mathrm{k}\Omega} \cong \frac{\mathbf{V}2-10}{5\Omega} + \frac{\mathbf{V}2}{4\mathrm{k}\Omega}$$

$$2(25-\mathbf{V}2) \cong 800(\mathbf{V}2-10) + \mathbf{V}2$$

$$\therefore \mathbf{V}2 \cong \frac{8000+50}{803} \cong 10.02\mathbf{V} \qquad \textbf{(10)}$$

$$\therefore \mathbf{V}3 = -\frac{6\mathbf{k}}{4\mathbf{k}} * 10.02 = -15\mathbf{V} \qquad \textbf{(4)}$$

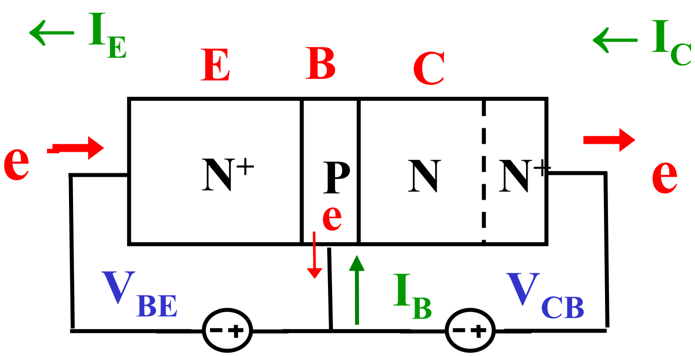


(16)

6

Draw the cross sectional structure of a NPN BJT transistor operated in the amplifier mode, describe the movement of electrons, and explain briefly the equation $I_C / \alpha \cong I_E$.
If $I_C \cong \beta I_B$, find β in terms of α. (16)

(a)



1. EB Junction is a forward bias (on) diode and BC is reverse bias (off) diode

2. E is very heavily doped (N^+ for NPN). E has many electrons,

3. B is very thin. So most electrons injected from E (to B) are attracted to C and

$$I_C \cong \alpha I_E \qquad (10)$$

$$I_E \cong \frac{I_C}{\alpha} = I_B + I_C = \frac{I_C}{\beta} + I_C$$

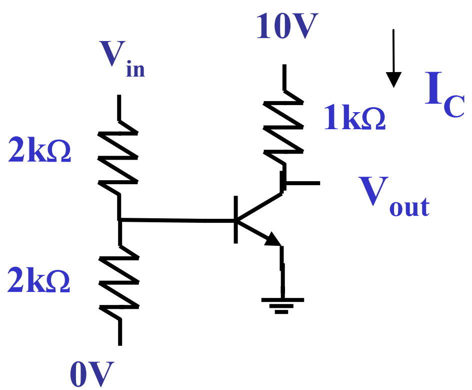
$$\text{hence } \frac{1}{\alpha} = \frac{1}{\beta} + 1$$

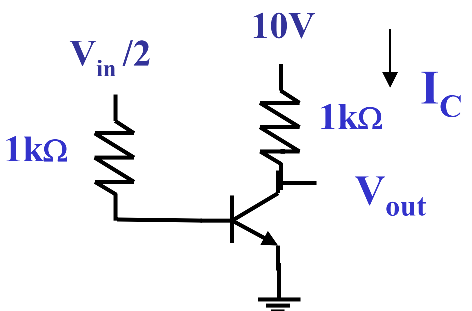
$$\alpha = \frac{\beta}{\beta + 1}$$

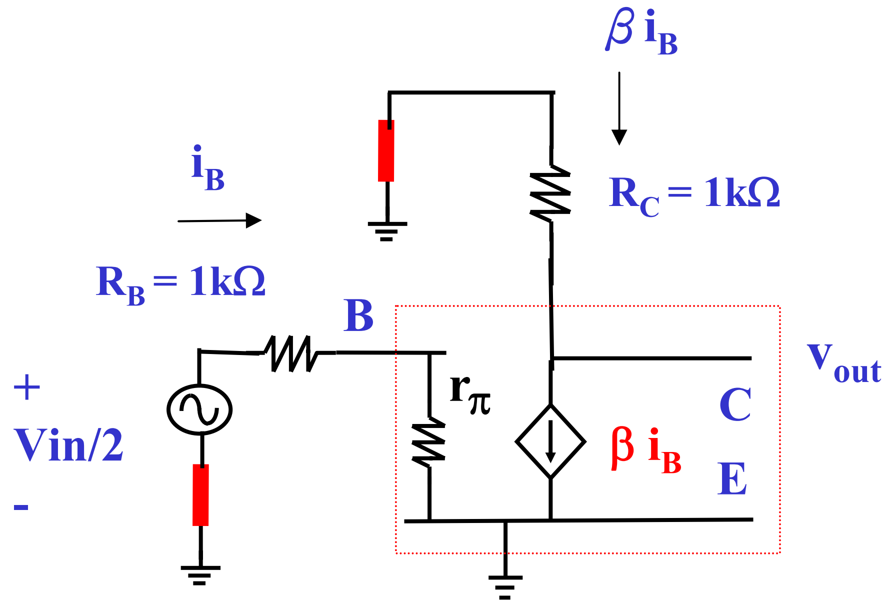
$$\beta = \frac{\alpha}{1 - \alpha} \qquad (6)$$

7

Sketch the small signal (AC) equivalent circuit of the BJT amplifier and find the voltage gain Av (= V_{out} / V_{in}). Given $r\pi$ = 0Ω, β = 100 , and V_{CESAT} = 0.2V , $V_{BE(ON)}$ = 0.7V . (16)







(8)

$$\therefore Av = \frac{V_{OUT}}{V_{in}} = \frac{-\beta\, i_B R_C}{2 i_B (R_B + r_\pi)}$$

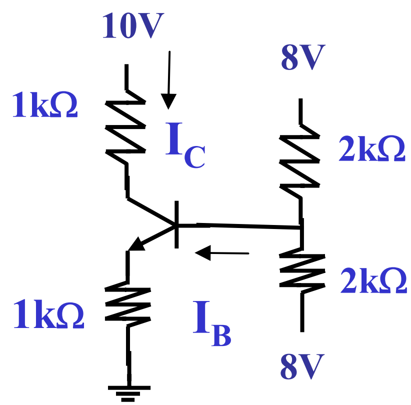
$$= \frac{-\beta R_C}{2R_B + 2r_\pi} = \frac{-(100)(1k\Omega)}{2k\Omega} \cong -50$$

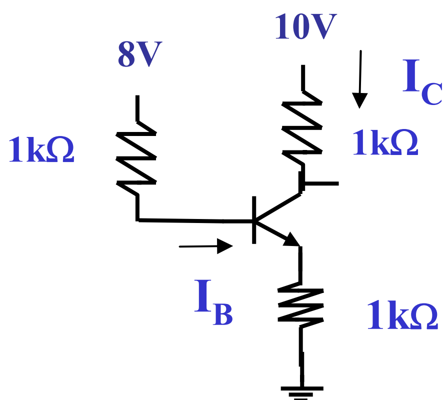
(8)

(24)

8

Find I_C / I_B . Show clearly your reasons.
For the BJT, given $V_{BE(ON)}$ = 0.7V, β = 100, V_{CESAT} = 0.2V. (24)





$$I_B \cong \frac{10V - 0.2V}{1k\Omega + 1k\Omega} * \frac{1}{\beta} = 0.049mA \quad \text{when } V_{CE} = 0.2V$$

$$\text{But } I_B \cong \frac{8V - 0.7V}{\beta * 1k\Omega + 1k\Omega} \cong 0.072mA$$

$\therefore$ BJT is in saturation

$$\therefore\ I_B = \frac{V_B - V_{BE}}{R_B + (1+\beta^*)R_E} = \frac{V_{CC} - V_{CESAT}}{\beta^* R_C + (1+\beta^*)R_E}$$

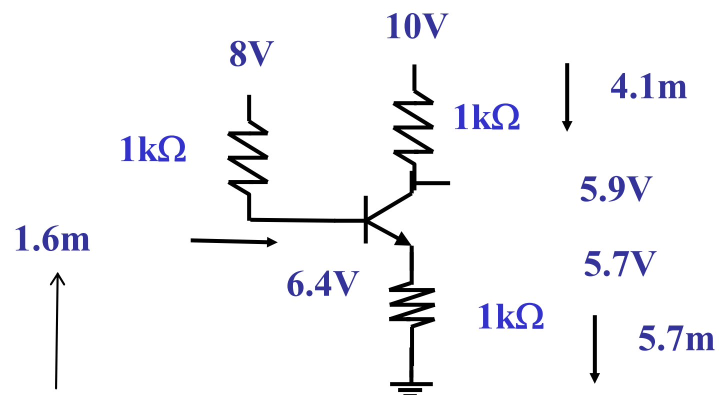
$$\therefore\ I_B = \frac{8V - 0.7V}{1k\Omega + (1+\beta^*)1k\Omega} = \frac{10V - 0.2V}{1k\Omega(1+2\beta^*)}$$

$$\therefore 7.3V(1+2\beta^*) = 9.8V(2+\beta^*)$$

$$\therefore 7.3V + 14.6\beta^* = 19.6V + 9.8\beta^*$$

$$\therefore \beta^* = \frac{19.6V - 7.3V}{14.6 - 9.8} = 2.5625$$

(24)

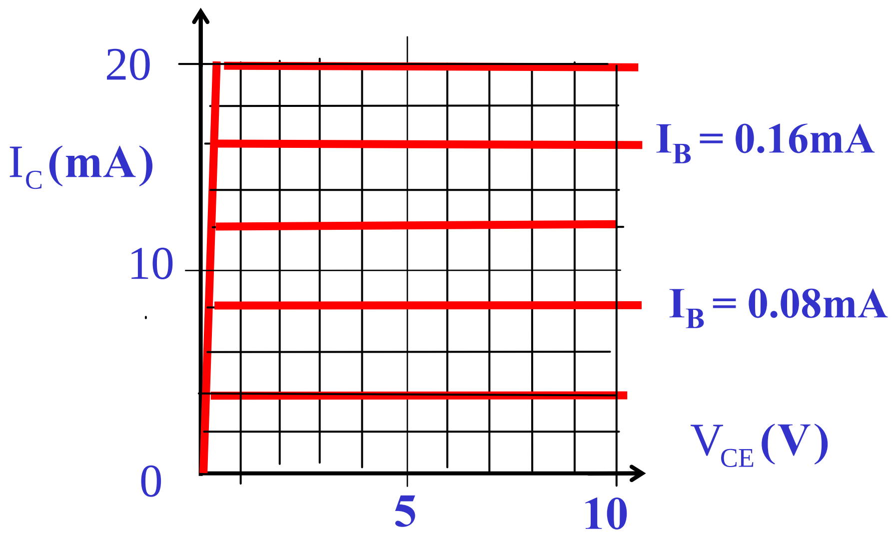


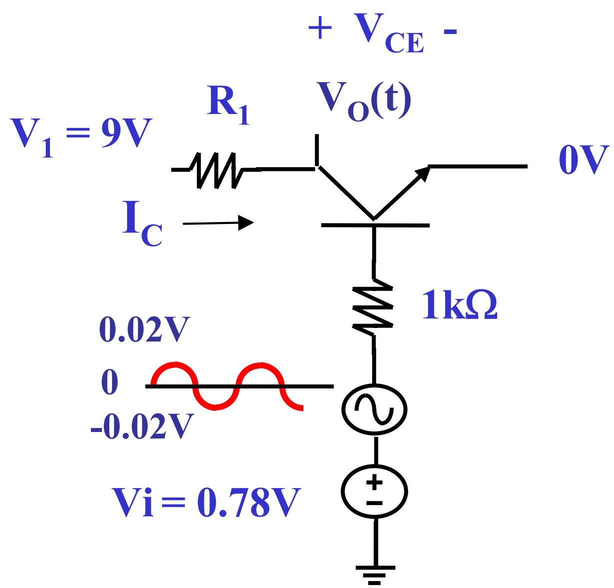
$$I_B = \frac{8V - 0.7V}{(2.5625 + 1) * 1k\Omega + 1k\Omega} = 1.6mA$$

9

Given the BJT circuit below and the I_C -V_{CE} curve of the BJT. V_{CEQ} = 5V. (a) Draw the load line $V_{CE} = V_1 - I_C R_1$, and locate the Q point on the load line. Find also R1

(b) Estimate the voltage gain $\Delta VO / \Delta Vi$ from the IC -VCE curves and sketch $V_O(t)$.
(30)
For the BJT, given $V_{BE(ON)}$ = 0.7V , V_{CESAT} = 0.2V .





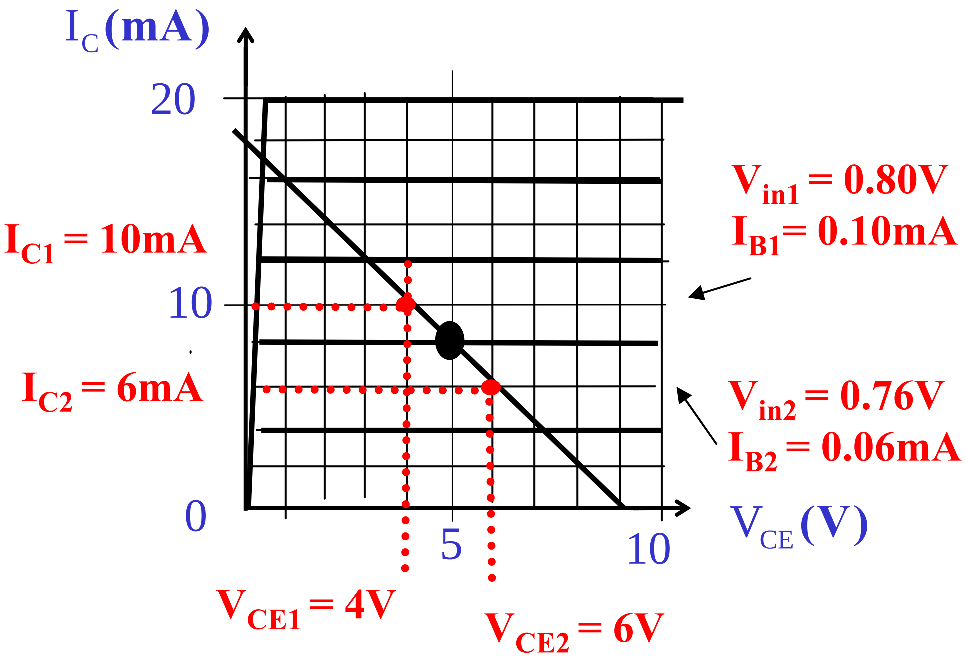
(30)

(a)

Draw load line,

$$\therefore I_B = \frac{0.78V - 0.7V}{1k\Omega} = 0.08mA$$ (5)

$$\therefore R_1 = \frac{V_{CC}}{I_C} = \frac{9V}{18mA} = 500\Omega$$ (5)

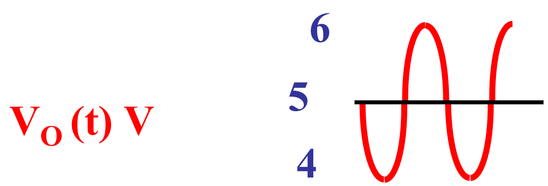


(8)

$$\text{voltage gain } A_v = \frac{dV_{CE}}{dV_{in}} = \frac{V_{CE2} - V_{CE1}}{V_{in2} - V_{in1}}$$

$$\cong \frac{6V - 4V}{0.76V - 0.8V} = -50$$

(8)



(4)

(15)

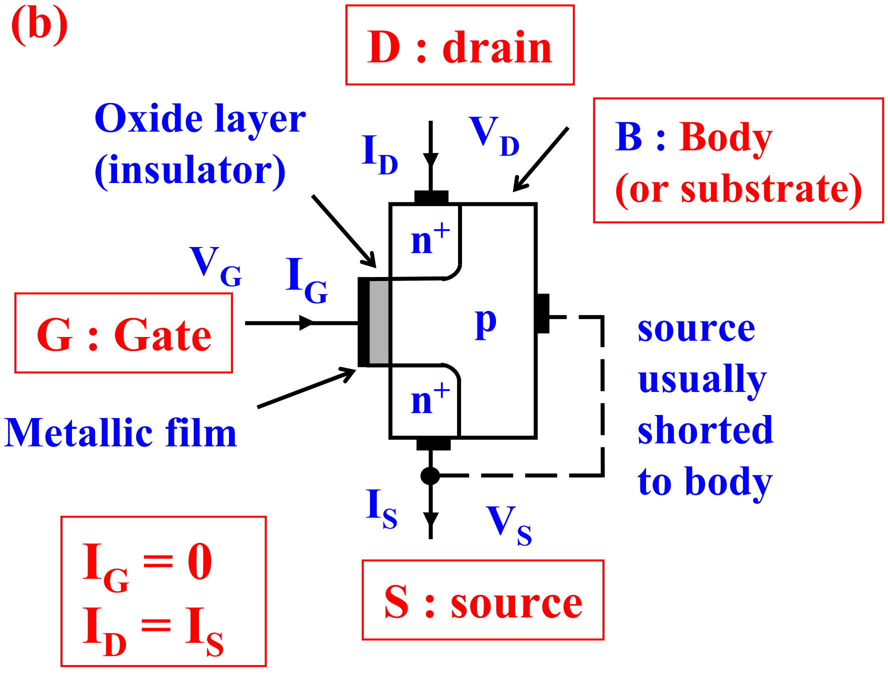
10

(a) Name two advantages of MOSFET. (b) Draw the cross sectional diagram for an enhancement NMOSFET and describe very briefly the structure.
(15)

(a)

small size (scaled down easily) and low power consumption. **(4)**

(b)



An NMOSFET consists of a metal gate insulated from a p-type semiconductor substrate (or body) by an insulating layer of silicon dioxide. On either side of the gate there are n type regions forming the drain and source.

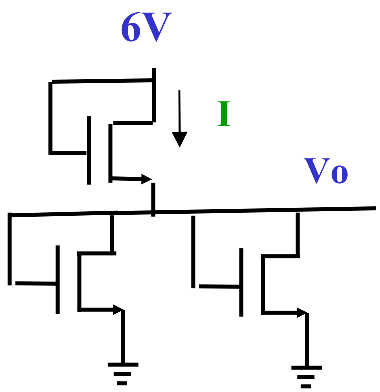
(11)

(22)

11

Find Vo .

Given the NMOS are all identical, $V_T = 2V$ $K = 1mA/V^2$.



Since $V_{DS} = V_{GS}$ **Since $V_{GS} > V_T$**

Hence $V_{DS} > V_{GS} - V_T$

If $V_{GS} < V_T$ for any 1 MOS (MOS off) the other MOS will be saturated Which is not possible

Hence only possibility is all 3 NMOS are in saturation (6)

$$\therefore I_D = K\,(V_{GS} - V_T)^2$$

$$I = 1(6 - Vo - 2)^2 = 1(Vo - 2)^2 + 1(Vo - 2)^2 \qquad (7)$$

$$(4 - Vo)^2 = 2(Vo - 2)^2$$

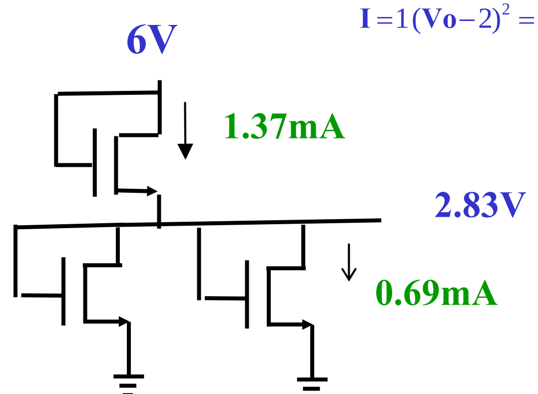
$$16 - 8Vo + Vo^2 = 2Vo^2 - 8Vo + 8$$

$$Vo^2 - 8 = 0$$

$$Vo = \sqrt{8}V \cong 2.83V \qquad (9)$$

$$I = 1(6 - Vo - 2)^2 = 1(6 - 2.83 - 2)^2 \cong 1.37mA$$

$$I = 1(Vo - 2)^2 = 1(2.83 - 2)^2 \cong 0.689mA$$



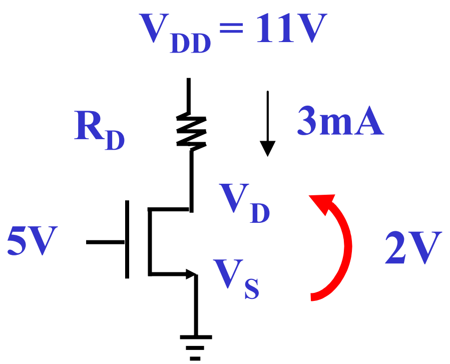
11. Find Vo . Show clearly the reasons for your answers. (22)
Given that the three NMOS are identical and VT = 2V , K = 1 mA/V2 .
At triode region , VGS ≥ VT , VDS < VGS - VT , ID = 2K(VGS –VT)VDS – KVDS2
At saturation region , VGS ≥ VT , VDS ≥ VGS - VT , ID = K[(VGS –VT)2]

(15)

12

Find K and RD.

Given $V_T = 1V$.



$$\therefore R_D = \frac{11V - 2V}{3mA} = 3k\Omega$$ **(4)**

$V_{GS} = 5V$, $V_{DS} = 2V$, MOS is Triode.

Since $V_{DS} < V_{GS} - V_T$ $\quad V_{GS} > V_T$ **(3)**

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

$$3mA = 2K[(5V - 1V)2V - \frac{4V^2}{2}] = 2K[6V^2]$$

$$\therefore K = 0.25mA / V^2$$ **(8)**

$$3mA = 2*0.25[(5V - 1V)2V - \frac{4V^2}{2}] = 2*0.25[6V^2]$$

Find K and RD . Show clearly the reasons for your answers. (15)

Given that VT = 1V .

At triode region, VGS ≥ VT , VDS < VGS - VT , ID = 2K(VGS –VT)VDS – KVDS^2

At saturation region, VGS ≥ VT , VDS ≥ VGS - VT , ID = K [(VGS –VT)^2]

(5)

13

(a) Explain very briefly the meaning of gain bandwidth product of a real op amp.

(a) Gain Bandwidth Product (GBP)

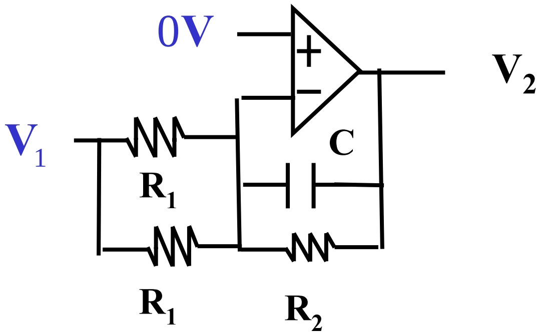
Gain of op amp circuit x bandwidth of op amp circuit = constant

(5)

(22)

13 **(b)**

Find the voltage gain V2 / V1 in terms of R1 , R2, C and jω . If ω_O is 1krad/s, find C. Estimate V2(t) if V1(t) = 2cos5tV. Given that R2 = 10kΩ , R1 = 5k Ω , and ω_O = 1/CR2 . Is the op amp circuit a low pass filter? Assume the op amp is ideal. (22)



(b) In the ideal op amp circuit, find the voltage gain V2 / V1 in terms of R1 , R2 , C and jω . If ωO = 1krad/s , find C . Estimate also V2(t) if V1(t) = 2cos5t V . Given that R2 = 10kΩ , R1 = 5kΩ , **and** ωO = 1/C*R2 . Is the op amp circuit a low pass filter? (27)

$$\therefore Z_2 = \frac{R_2 \dfrac{1}{j\omega C}}{R_2 + \dfrac{1}{j\omega C}} = \frac{R_2}{j\omega C R_2 + 1}$$

$$G = \frac{V2}{V1} = -\frac{Z_2}{Z_1} = -\frac{\dfrac{R_2}{j\omega C R_2 + 1}}{R_1/2} = -\frac{2R_2}{R_1}\frac{1}{1 + j\omega C R_2}$$

(10)

$$\therefore C = \frac{1}{\omega_O R_2} = \frac{1}{1\text{krad}/s * 10k\Omega} = 0.1\mu F$$

(3)

When frequency = 5rad/s,

$$V2 \cong \frac{-2*10k}{5k}\frac{1}{1 + j5/1k} * V1$$

$$V2(t) \cong -8\cos(5t)V$$

(6)

Circuit is a low pass filter **(3)**

(24)

14

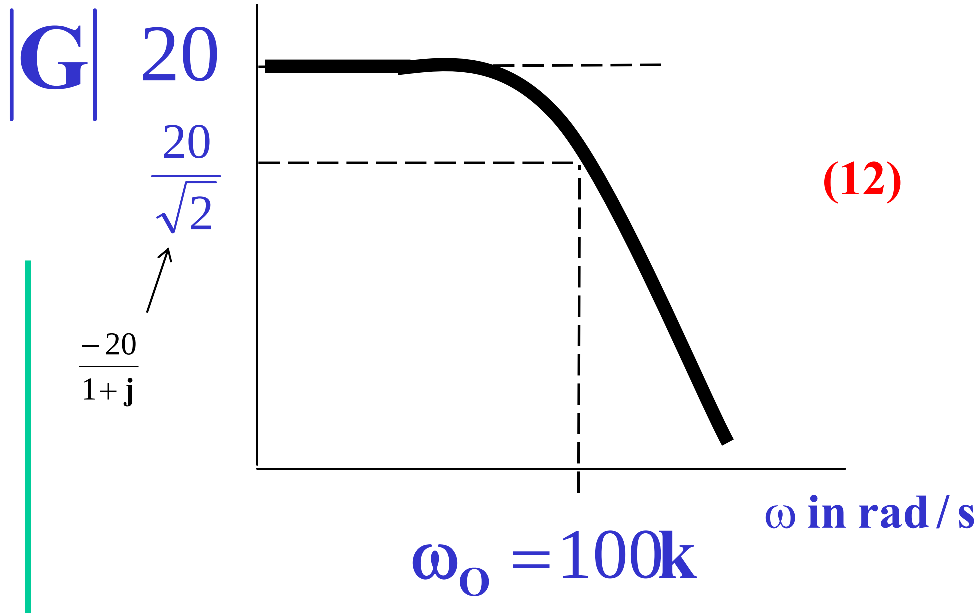
In an ideal op amp filter circuit, the complex transfer function G (= V_O / V_S) is given as. $\dfrac{-20}{1+2\mathbf{j}\omega\mathbf{CR}}$

Given that 1/CR = 200krad/s

(a) Plot the magnitude of G (| G |) versus ω . Show clearly the value of | G | when ω = 0 , cut-off frequency , and oo in your plot.

(b) If $\mathbf{V_S}(\mathbf{t}) = 2\cos 200\mathbf{kt}\ \mathbf{V}$, find $V_O(t)$.
(24)

(a)



(12)

$$2\omega\mathbf{CR} = 1$$

$$\omega = \omega_O = \frac{1}{2\mathbf{CR}} = 100\mathbf{krad/s}$$

(b)

$$\mathbf{G} = \frac{-20}{1+2\mathbf{j}*200\mathbf{k}*\mathbf{CR}} = \frac{-20}{1+\mathbf{j}2}$$

$$\therefore \mathbf{V_O} = 2\angle 0 * \frac{-20}{1+2\mathbf{j}} = \frac{-40}{\sqrt{5}\angle 63.4^o}$$

$$\mathbf{V_O}(\mathbf{t}) = -\frac{40}{\sqrt{5}}\cos(200\mathbf{kt} - 63.4^o)\mathbf{V} \qquad \textbf{(12)}$$