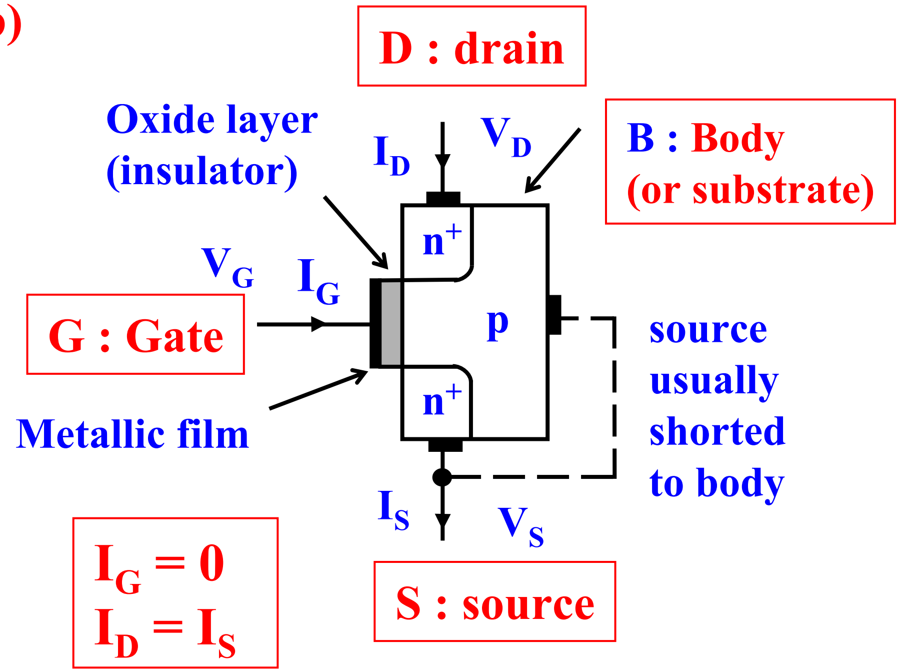
1

(a) Name two advantages of MOSFET. (b) Draw the cross sectional diagram for an enhancement NMOSFET and describe very briefly the structure.
(16)

(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.

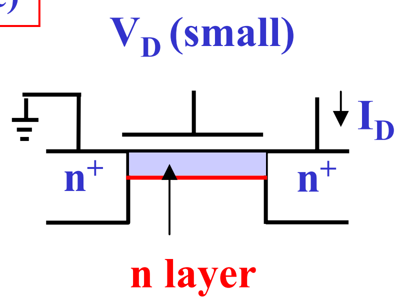
(12)

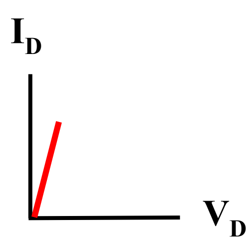
(12)

(c) Draw the cross sectional structure and draw the n-channel conditions when the NMOS is in Triode (VDS << VGS - VT) and Saturation (VDS > VGS - VT) mode. Sketch also the ID-VDS curve in each mode. (12)

(c)

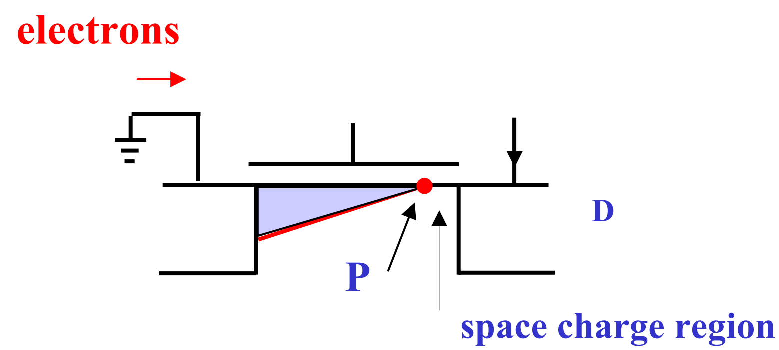
Triode (ohmic)

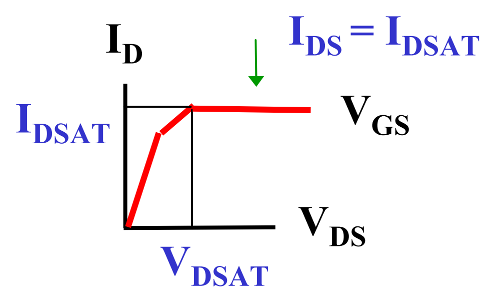




(5)

saturation





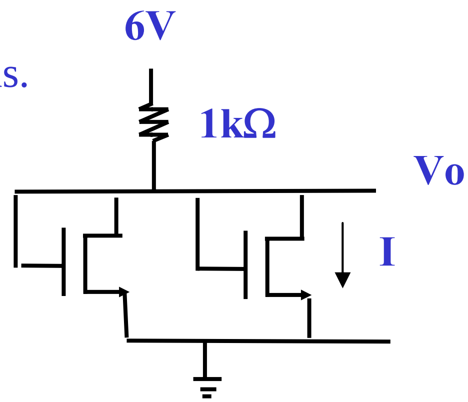
(7)

2

Find Vo . (20)

Show clearly your reasons.

Given the NMOS are all identical, $V_T = 1V$
$K = 0.25mA/V^2$.



Assume 2 NMOS are in <u>saturation</u> **(2)**

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]

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

$$\therefore I = 0.25m * (Vo - 1)^2 = \frac{6 - Vo}{1k\Omega} * \frac{1}{2}$$ **(8)**

$$0.5(1 - 2Vo + Vo^2) = 6 - Vo$$

$$1 - 2Vo + Vo^2 = 12 - 2Vo$$

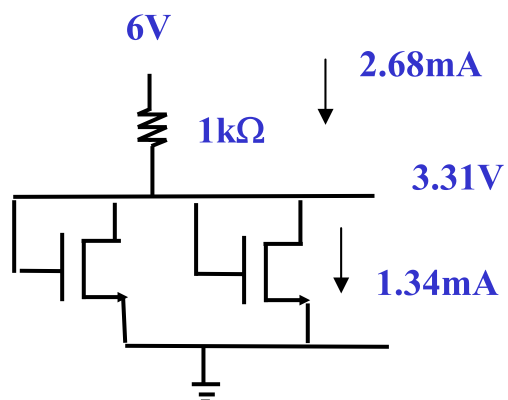
$$Vo^2 = 11$$

$$Vo = \sqrt{11} \cong 3.31V$$ **(8)**

NMOS is saturate since

1. $V_{GS} > V_T$ 3.31 > 1

2. $V_{DS} > V_{GS} - V_T$ 3.31 > 3.31 - 1 **(4)**

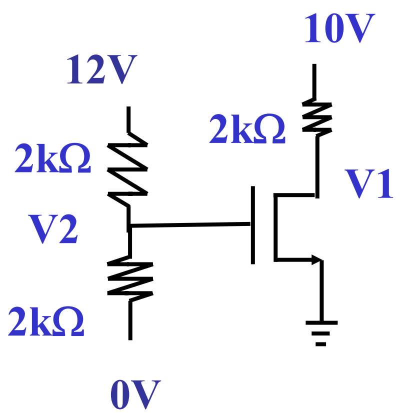


$I = 0.25\,(3.31 - 1)^2 \cong 1.34mA$

(22)

3

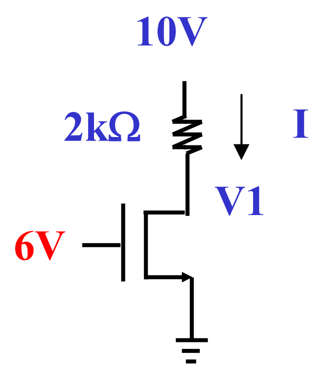
Show that V2 = 6V. Hence find V1 . Show clearly your reasons. (22)



Given

$V_T = 1V$

$K = 0.5mA/V^2$



V2 = 6V since IG = 0. **(4)**

Assume NMOS is triode

$$\therefore \mathbf{I} = \frac{10\mathbf{V} - \mathbf{V}1}{2\mathbf{k}\Omega} = 2 * 0.5\mathbf{m} * [(6\mathbf{V} - 1\mathbf{V})\mathbf{V}1 - \frac{\mathbf{V}1^2}{2})]$$

$$\therefore 10\mathbf{V} - \mathbf{V}1 = 2 * [5\mathbf{V}1 - \frac{\mathbf{V}1^2}{2}]$$

(8)

$$\therefore \mathbf{V}1^2 - 11\mathbf{V}1 + 10 = 0$$

$$\therefore \mathbf{V}1 = 10\mathbf{V} \quad \textbf{or} \quad 1\mathbf{V}$$

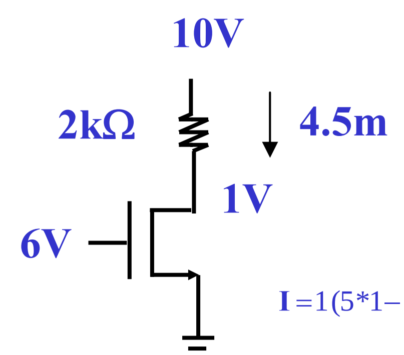
(6)

When Vo = 10V, MOS is OFF
But MOS is not OFF (VGS > VT) . Hence Vo = 1V **(2)**

NMOS is triode since

1. $V_{GS} > V_T$ 6 > 1
2. $V_{DS} < V_{GS} - V_T$ 1 > 6 - 1

(2)



$\mathbf{I} = 1(5*1 - 0.5) = 4.5\mathbf{mA}$

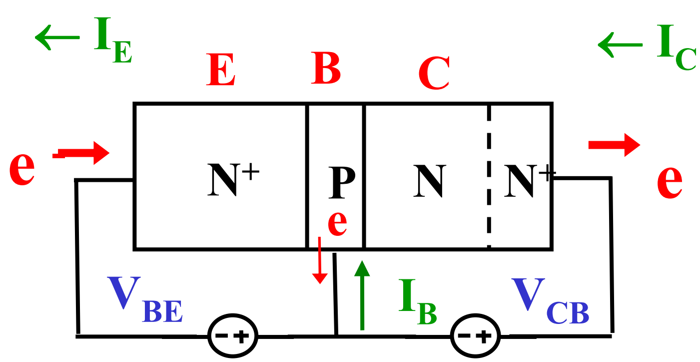
At triode region, VGS ≥ VT , VDS < VGS - VT , ID = 2K(VGS –VT)VDS – $KVDS^2$

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

4

Draw the cross sectional structure of a NPN BJT transistor operated in the amplifier mode, Describe the movement of electrons, the designs in the emitter/base/collector, and explain briefly the equation IE $\approx$ IC / α . If $I_C \cong \beta I_B$, find β in terms of α. (17)

(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

$$I_C \cong \alpha I_E \qquad (12)$$

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

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

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

$$\beta = \frac{\alpha}{1 - \alpha} \qquad (5)$$

5

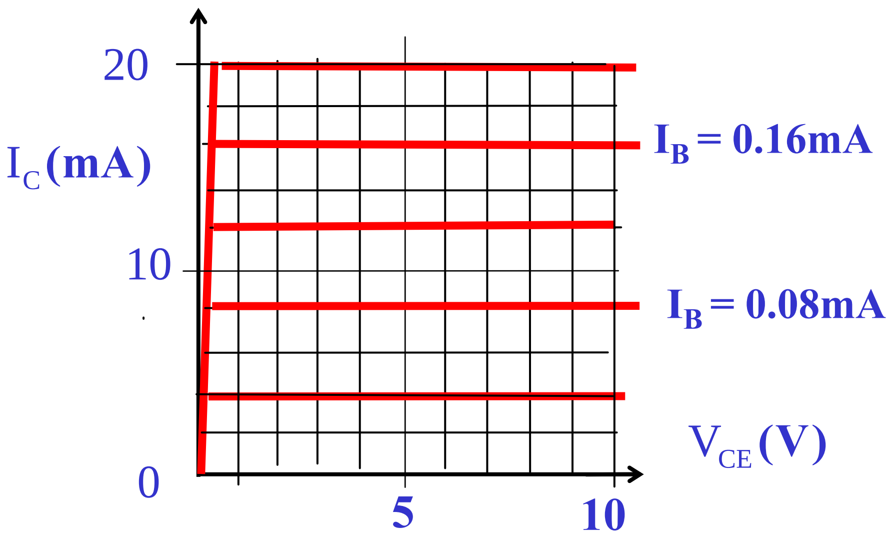
Given the BJT circuit below and the I_C-V_{CE} curve of the BJT. Given VCC = 9V, RC = 500Ω, RB = 1kΩ, Vi = 0.8V.

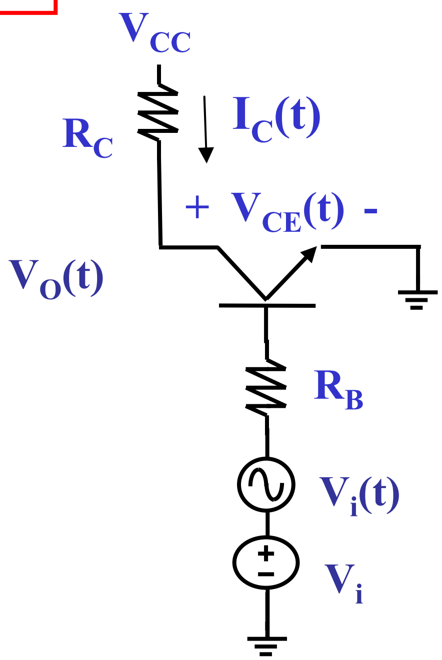
(a) Draw the load line $V_{CE} = V_{CC} - I_C R_C$, and locate the Q point on the load line.

(b) If Vi(t) = 0.02coswt V, sketch and label Ib(t), Ic(t) and Vo(t).

(c) If Vi is changed from 0.8V to 0.76V, sketch and label V_{CE}(t). Estimate also the voltage gain ΔVO / ΔVi . Vi(t) = 0.02coswt V (32)

For the BJT, given $V_{BE(ON)}$ = 0.7V , V_{CESAT} = 0.2V .

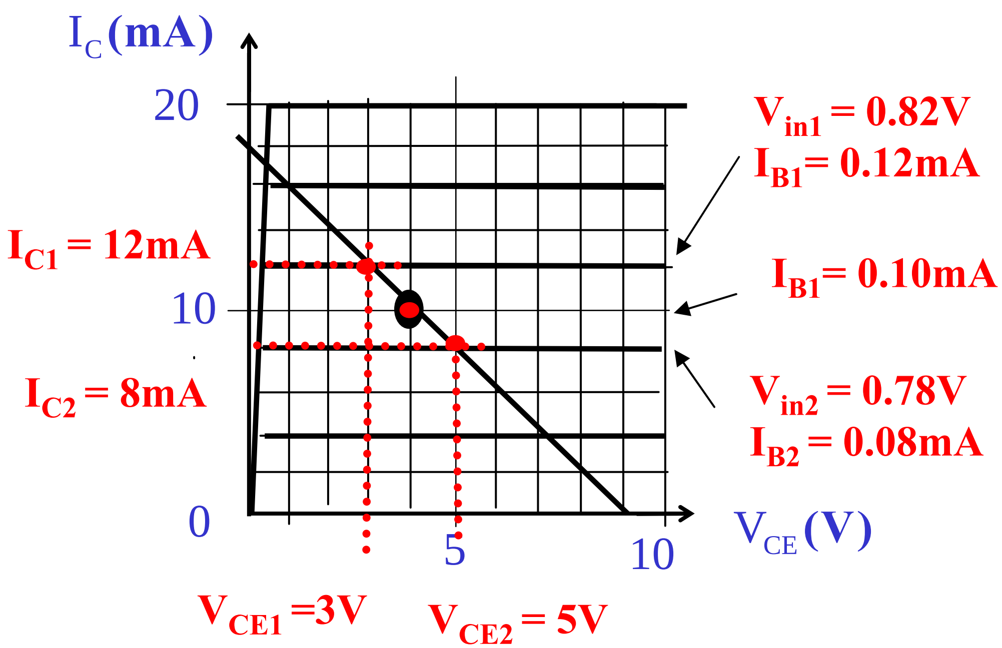




(a) Draw load line,

$$\therefore I_C = \frac{V_{CC}}{R_C} = \frac{9V}{500\Omega} = 18mA$$

(6)

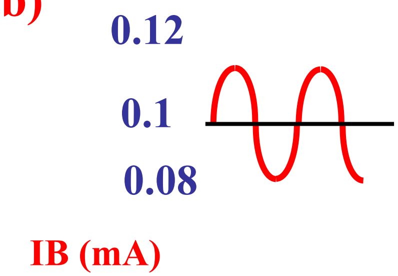


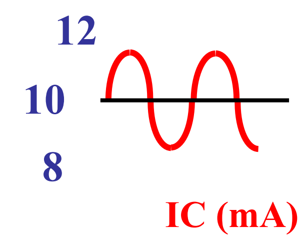
Draw Q point,

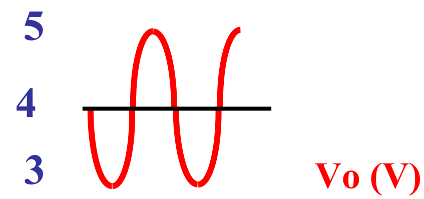
$$\therefore I_{BQ} = \frac{0.8V - 0.7V}{1k\Omega} = 0.1mA$$

(6)

(b)





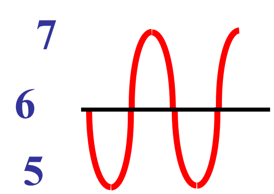


(9)

(c)

$$\therefore I_{BQ} = \frac{0.76V - 0.7V}{1k\Omega} = 0.06mA$$

VCE(t) roughly ~



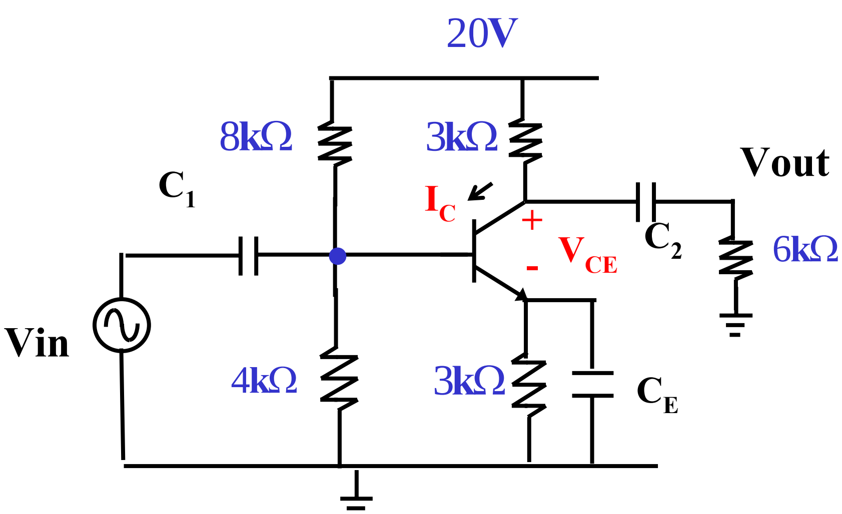
(6)

voltage gain A_v (5)

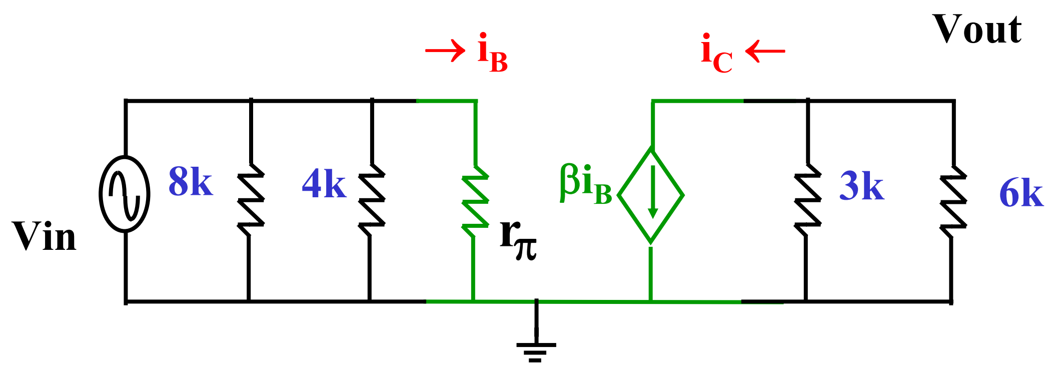
$$\cong \frac{7V - 5V}{0.74V - 0.78V} = -50$$

6

Sketch the small signal (AC) equivalent circuit of the BJT amplifier and find the voltage gain Av (= Vout / Vin). Given $r\pi = 1k\Omega$, $\beta = 100$, $V_{CESAT} = 0.2V$, $V_{BE(ON)} = 0.7V$. Assume C1, C2 and CE are very large in your calculation. . (17)



Replace BJT by model.



(10)

$$\frac{Vout}{Vin} = \frac{-\beta\, i_B (6k\Omega\,//\,3k\Omega)}{i_B r\pi}$$

$$= \frac{-\beta\,(2k\Omega)}{r\pi} = -\frac{100 * 2k\Omega}{1k\Omega} = -200$$

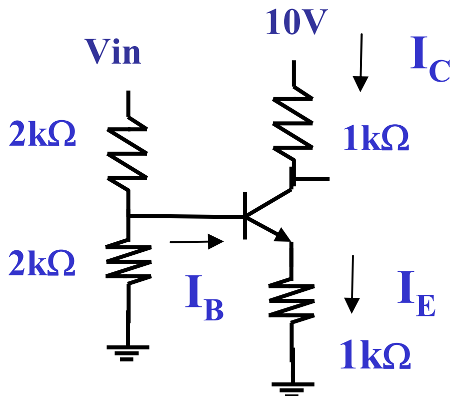
(7)

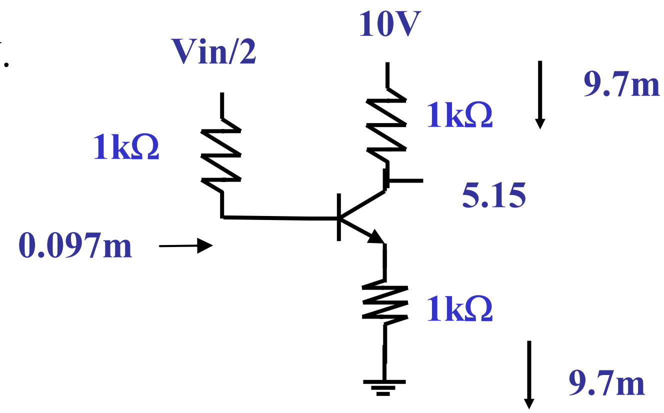
Answer with 3kohm (not 6k//3k) also accepted

(33)

7

If IB = 0.097mA, find Vin and IE. Show clearly your reasons.
For the BJT, given $V_{BE(ON)}$ = 0.7V, β = 100, V_{CESAT} = 0.2V.
(33)





$$\therefore V_B = \text{Vin} * \frac{2k\Omega}{2k\Omega + 2k\Omega} = \frac{\text{Vin}}{2}$$

$$\therefore R_B = 2k\Omega \,//\, 2k\Omega = 1k\Omega$$

(6)

$$\therefore I_C = \beta I_B = 100 * 97\mu A = 9.7mA$$

BJT is SAT, since Ic when VCE = 0.2V is only ~5mA

(7)

$$\because 10V = I_C R_C + V_{CE} + I_E R_E$$

$$= \beta I_B R_C + V_{CE} + (1+\beta) I_B R_E = (1+2\beta) 0.097m * 1k\Omega + 0.2V$$

$$\therefore \beta = \left(\frac{10V - 0.2V}{0.097m * 1k\Omega} - 1\right) * \frac{1}{2} \cong 50$$

(10)

$$\therefore I_C \cong \beta I_B \cong 50 * 97\mu A \cong 4.85mA$$

$$\therefore I_E \cong (1+\beta) I_B \cong 51 * 97\mu A \cong 4.95mA$$

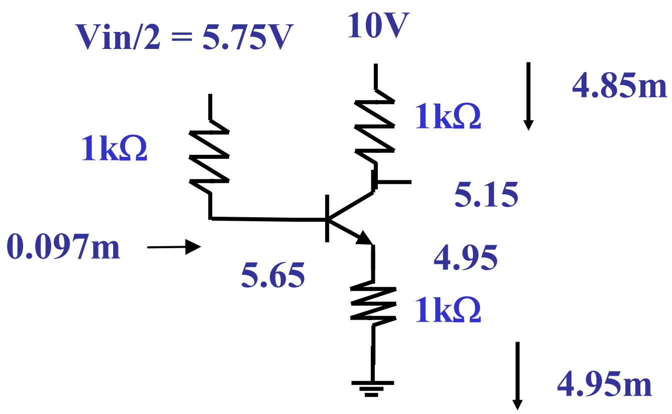
(3)

$$\therefore \frac{\text{Vin}}{2} = I_B R_B + V_{BE} + I_E R_E$$

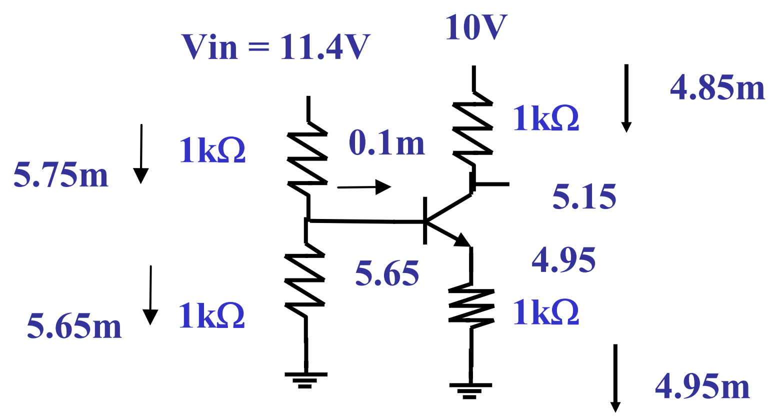
$$\cong 0.097m * 1k\Omega + 0.7V + 4.95V \cong 5.75V$$

(7)

$$\therefore \text{Vin} \cong 11.5V$$



Vin/2 = 5.75V
10V
4.85m
1kΩ
1kΩ
5.15
0.097m
4.95
5.65
1kΩ
4.95m

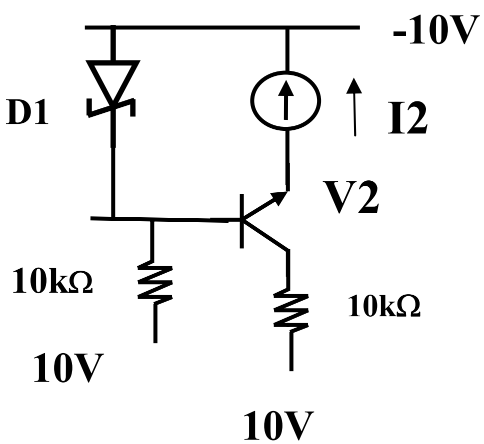


10V
Vin = 11.4V
4.85m
1kΩ
1kΩ
0.1m
5.75m
5.15
5.65
4.95
5.65m
1kΩ
1kΩ
4.95m

(16)

8

8. In the BJT circuit, if transistor is just in saturation and diode is at breakdown, find I2. Given V_{CESAT} = 0.1V, V_{BEON} = 0.7V, β is large for BJT, breakdown voltage = 5V for zener diode, rz = 0. (15)



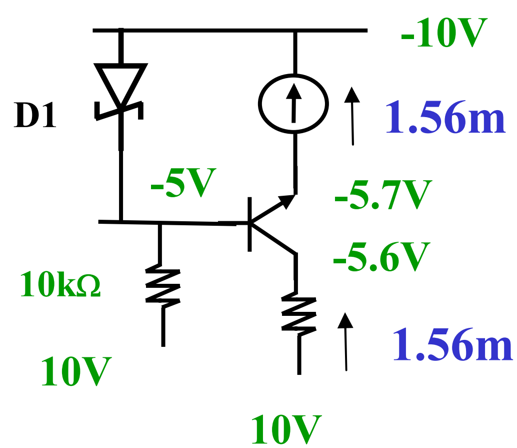
Base of BJT = -5V
Hence V2 = -5.7V

$$\therefore 10V \cong V2 + V_{CESAT} + I2 * 10k\Omega$$

$$= -5.7V + 0.1V + I2 * 10k\Omega$$

$$\therefore I2 \cong \frac{15.6V}{10k\Omega} = 1.56mA$$

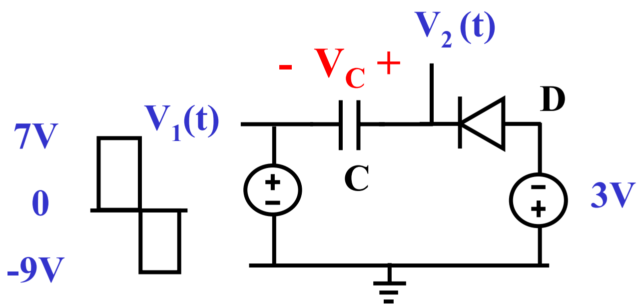
(15)



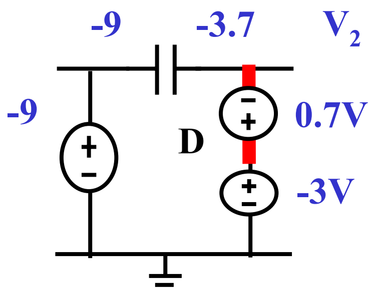
(15)

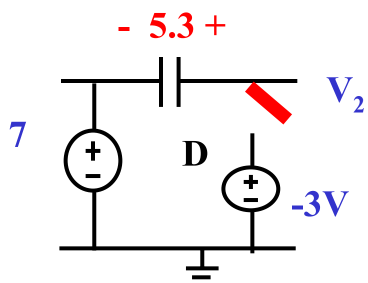
9

(a) In the diode circuit, find Vc. Hence sketch and label clearly V2(t). D is an <u>offset diode</u> with VF = 0.7V. (15)

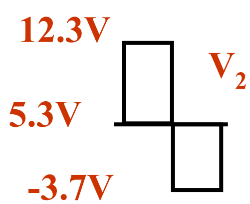


(a)





V_2 = V1+ Vc = V1 + 5.3V



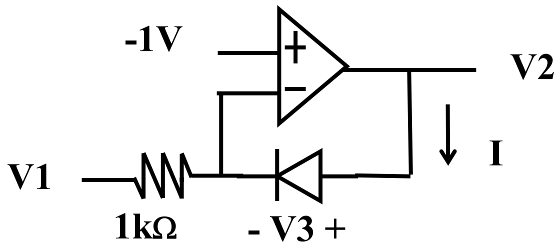
(15)

(22)

9

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

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



.
Find V3 if V1 = - 2V
Given that I = 0.135 mA when V2 = -0.35V. (22)

9(b)

$$V2 = -0.35V$$

$$\therefore V3 = -0.35 - -1V = 0.65V$$

$$\therefore I = 0.135mA = I_O\ (e^{\frac{0.65V}{25mV}} - 1)$$

(7)

$$\therefore V1 = -2V$$

$$\therefore I = 1mA$$

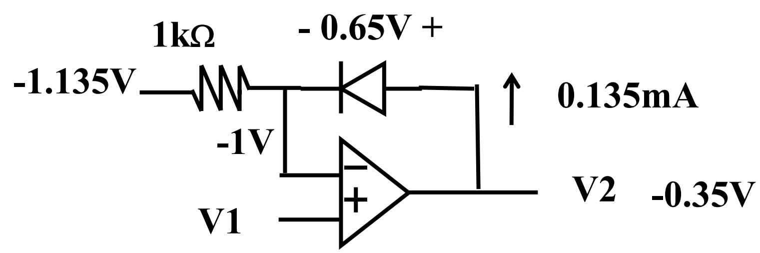
$$\therefore I = 1mA = I_O\ (e^{\frac{V3}{25mV}} - 1)$$

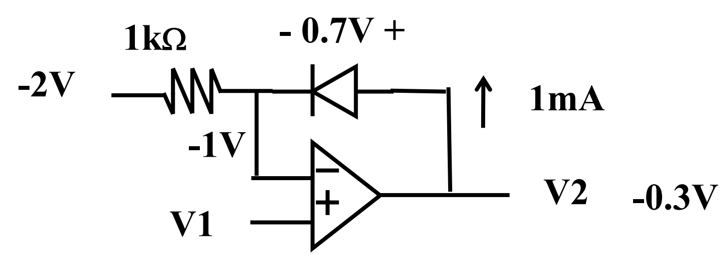
(7)

$$\frac{1mA}{0.135mA} = \frac{e^{\frac{V3}{25m}} - 1}{e^{\frac{650m}{25m}} - 1} \cong e^{(V3-650m)/25m} \cong 0.135$$

$$\therefore V3 = 650m + 25m \ln \frac{1}{0.135} = 700mV$$

(8)





10

In the diode circuit, the diode has the forward, reverse and breakdown characteristics as shown.

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

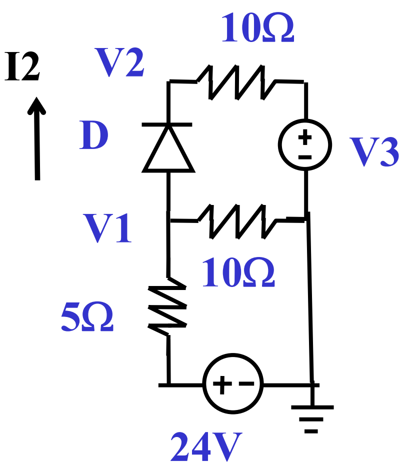
(b) Find I2 , V1 and V2 if V3 = 20V

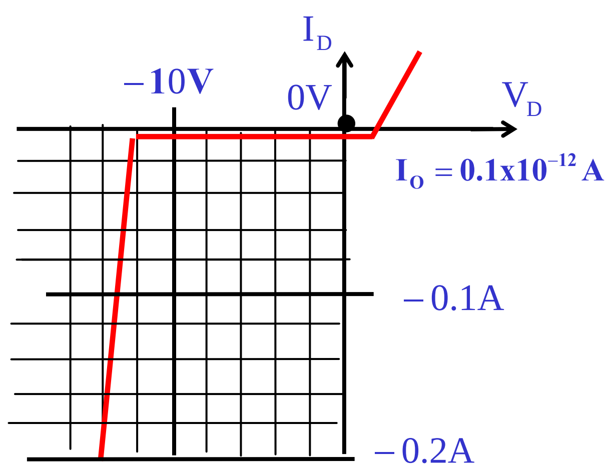
(c) Find V1 and I2 if V3 = 30V .

Show clearly your reasons. **(34)**

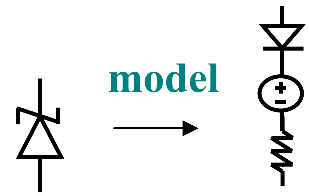
The diode equation is

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





(a)

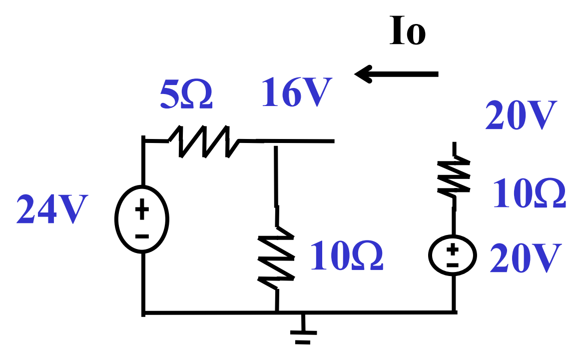


$V_{ZO} = 12V$ **(7)**

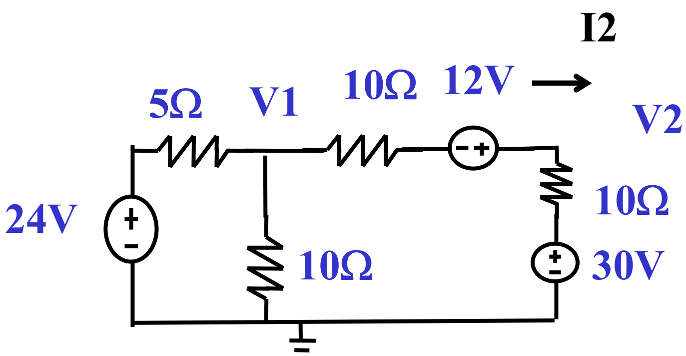
$r_Z = 2V/0.2A = 10\Omega$

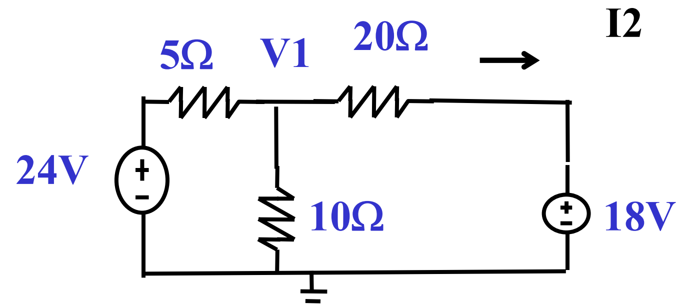
(b) If V3 = 20V , D is OFF , V1 = 16V, V2 = 20V **(6)**

$\therefore I2 = -I_O = -0.1x10^{-12}$ A **(4)**



(c) If V3 = 30V , D is breakdown, replace D by model



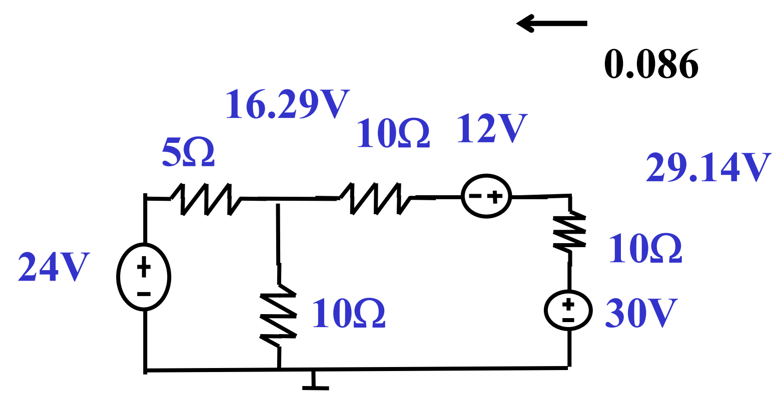


$$\frac{24V - V1}{5\Omega} = \frac{V1}{10\Omega} + \frac{V1 - 18V}{20\Omega} \quad (8)$$

$$\therefore 96V - 4V1 = 2V1 + V1 - 18V$$

$$V1 = \frac{114V}{7} \cong 16.29V \quad (5)$$

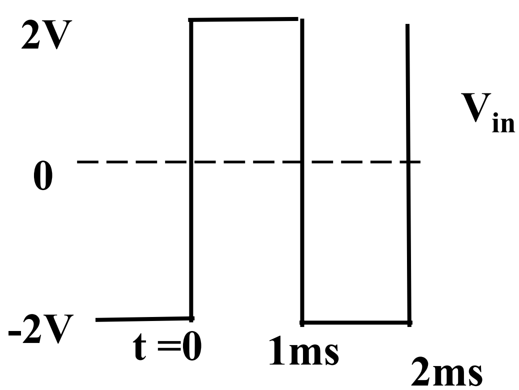
$$I2 \cong \frac{16.29V - 18V}{20\Omega} = -0.0857A \quad (4)$$

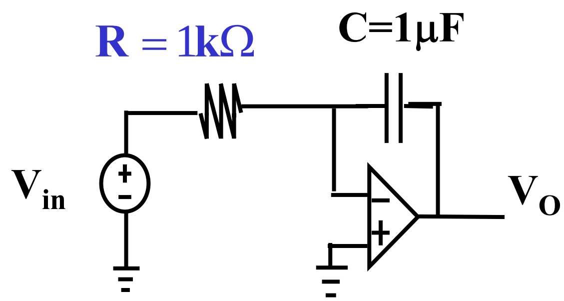


(18)

11

. An ideal op amp RC integrator circuit has the following input voltage V_{in} . Draw the integrator circuit, derive the equation for the output voltage V_O , and hence draw the waveform of V_O . Given R = 1kΩ and C = 1μF . (18)





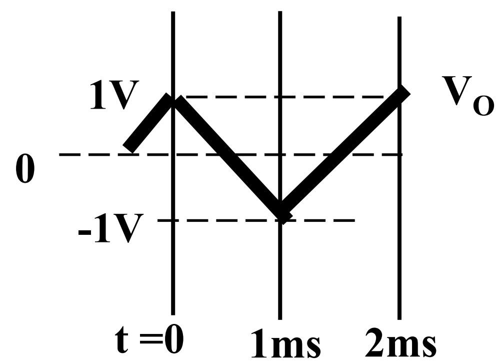
(6)

$$-C\frac{dV_O}{dt} \cong \frac{V_{in}}{R}$$

$$V_{in} \cong -CR\frac{dV_O}{dt}$$

(6)

$$V_{in} \cong -(1\mu F * 1k\Omega)\frac{\Delta V_O}{1ms} = 2V \Rightarrow \Delta V_O = -2V$$



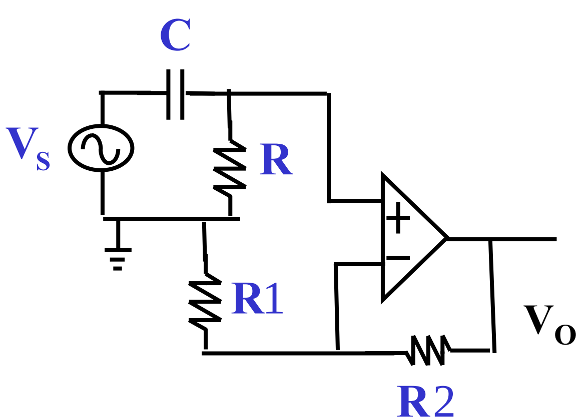
(6)

Can have other answers with ΔVo = -2V

(21)

12

Given the ideal op amp filter circuit .
(a) Find the complex transfer function G $(= V_O / V_S)$ in terms of R, C, R1, R2 and jw .
(b) Find the cut-off frequency . Estimate also Vo(t) if VS(t) = 2costV. Is the op amp circuit a low pass filter?
Given that R = 1kΩ, C = 1uF, R1 = 1kΩ, R2 = 20kΩ, and ωO = 1/CR . (21)



a

$$V_O = V_S * \frac{R}{R + \frac{1}{j\omega C}}\left(1 + \frac{R_2}{R_1}\right)$$

$$G = \frac{V_O}{V_S} = \left(1 + \frac{R_2}{R_1}\right)\frac{1}{1 + \frac{1}{j\omega CR}}$$

(8)

b ω_O = **cut-off frequency**

$$\omega_O = \frac{1}{RC} = \frac{1}{1k\Omega * 1\mu F} = 1krad/s$$

(4)

when ω = 1

$$\omega CR = \frac{1}{1k} \cong 0.001$$

$$V_O = Vi * |G| \cong 0.021Vi \cong 0$$

(6)

Circuit is a high pass filter

(3)

13

In an ideal op amp filter circuit, the complex transfer function G (= V_O / V_S) is given as. $\dfrac{-10}{1+2\mathbf{j}\omega\mathbf{CR}}$

(a) Plot the magnitude of G **in dB** (= |G| in dB) versus ω .
Given **|G| in dB = 20 $\log_{10}$ |G|** .
Show clearly the value of | G | when ω = 0 , cut-off frequency , and oo in your plot.
(b) If $\mathbf{V_S(t) = 1\cos 400kt\ V}$, find $V_O(t)$.
Given that 1/CR = 200krad/s . (28)

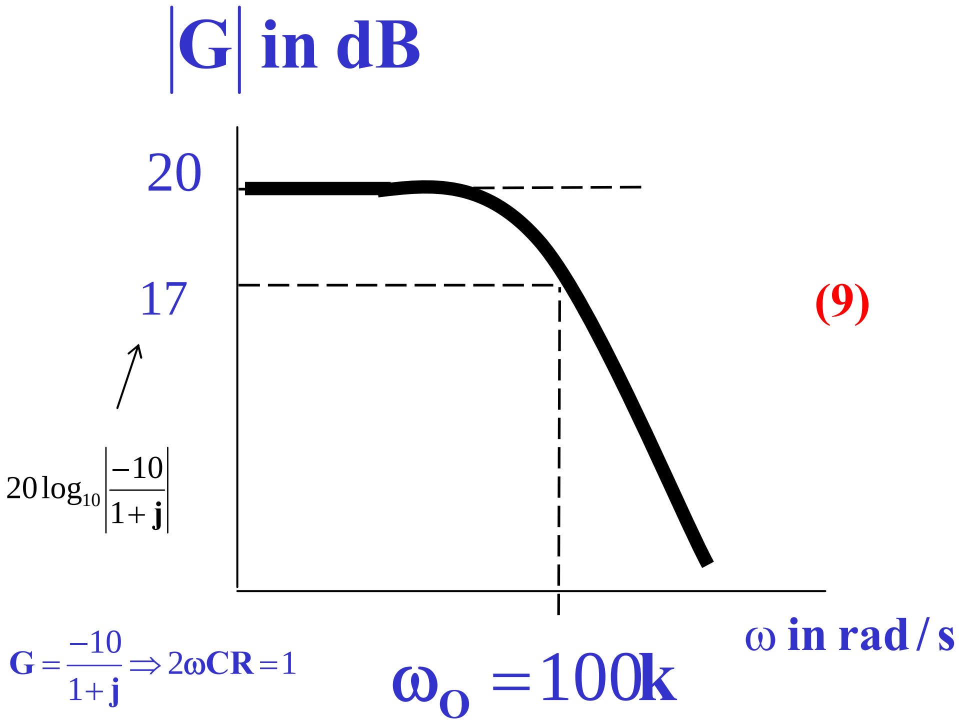
(a)

$$|\mathbf{G}|\ \mathbf{in\ dB} = 20\log_{10} 10 \cong 20.0\ \mathbf{dB} \qquad \mathbf{(4)}$$

At cut-off frequency, $|\mathbf{G}| = \dfrac{10}{\sqrt{2}}$

$$|\mathbf{G}|\ \mathbf{in\ dB} = 20\log_{10}\frac{10}{\sqrt{2}} \cong 17.0\ \mathbf{dB} \qquad \mathbf{(4)}$$

(a)



(9)

$\mathbf{G} = \dfrac{-10}{1+\mathbf{j}} \Rightarrow 2\omega\mathbf{CR} = 1$

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

$$\mathbf{G} = \frac{-10}{1+2\mathbf{j}*400\mathbf{k}*\mathbf{CR}} = \frac{-10}{1+\mathbf{j}4} \qquad \mathbf{(11)}$$

$$\therefore \mathbf{V_O} = 1\angle 0 * \frac{-10}{1+4\mathbf{j}} \cong \frac{-10}{\sqrt{17}\angle 76^o}$$

$$\mathbf{V_O(t)} = -\frac{10}{\sqrt{17}}\cos(400\mathbf{kt} - 76^o)\mathbf{V}$$