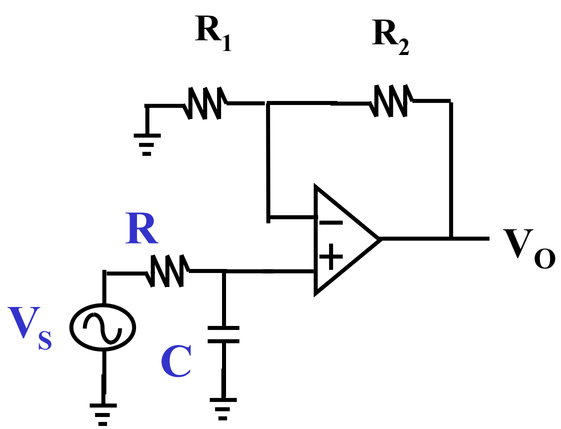
(300) (20)

1

Find the voltage gain V_O / V_S in terms of R, R_1, R_2, C and $j\omega$. If the maximum voltage gain is 11 and the bandwidth ω_O is 1krad/s, find R_2 and C. Given that $R = R_1 = 1\text{k}\Omega$ and $\omega_O = 1/CR$. Is the op amp circuit a low pass filter? Assume the op amp is ideal.
(20)



$$V_+ = V_S * \frac{\frac{1}{j\omega C}}{R + \frac{1}{j\omega C}} = V_S * \frac{1}{1 + j\omega CR}$$

$$V_O = (1 + \frac{R_2}{R_1})V_+ = V_S * (1 + \frac{R_2}{R_1})\frac{1}{1 + j\omega CR} \qquad \textbf{(9)}$$

$$\therefore 1 + \frac{R_2}{R_1} = 11$$

$$\therefore R_2 = 10\text{k}\Omega \qquad \textbf{(5)}$$

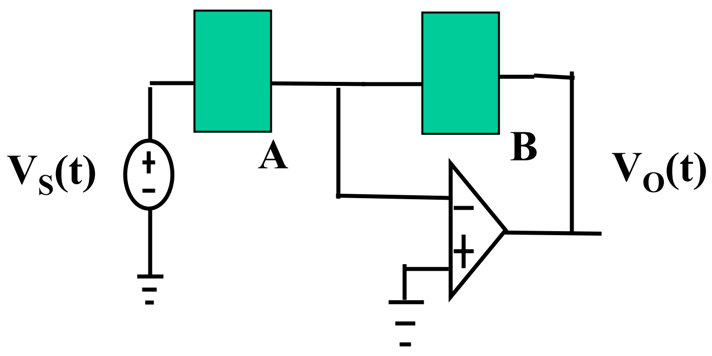
$$\therefore C = \frac{1}{\omega_O R} = \frac{1}{1\text{krad/s} * 1\text{k}\Omega} = 1\mu\text{F} \qquad \textbf{(3)}$$

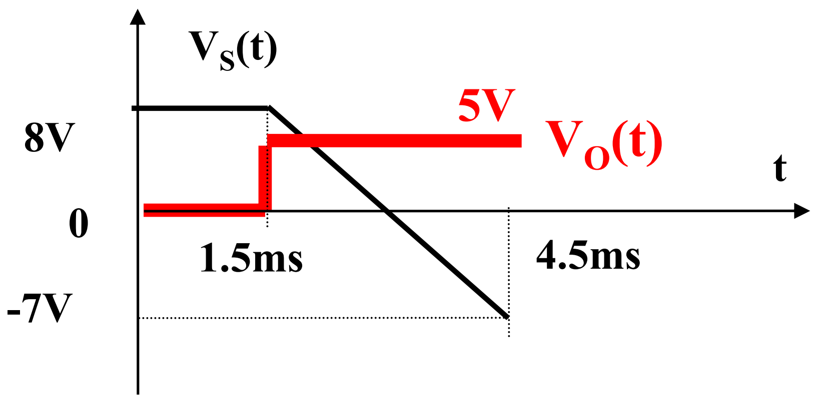
Circuit is a low pass filter **(3)**

(19)

1

(b) Find the elements and values of A and B. Given that one element is 1kΩ resistor . Show clearly your steps and assume the op amp is ideal. (19)





Circuit is a differentiator, B is 1kΩ **(5)**

$$\text{apply KCL} \Rightarrow C\frac{dV_S}{dt} \cong \frac{-V_O}{R}$$

$$\therefore V_O \cong -CR\frac{dV_S}{dt} = -C(1k\Omega) * \frac{-7V-8V}{3ms} = 5V \quad \textbf{(10)}$$

A is 1uF **(4)**

(19)

2

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

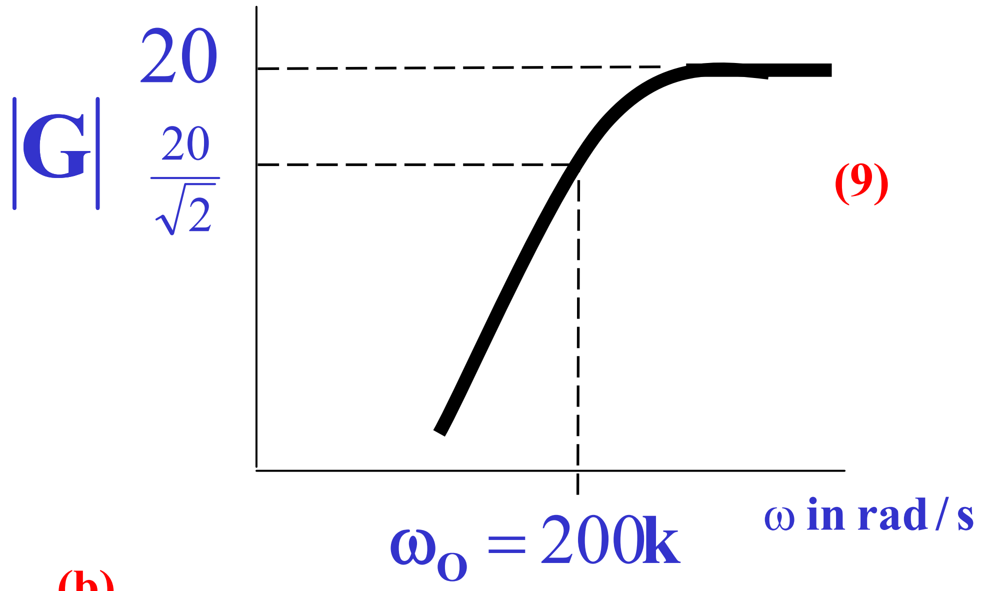
Given that ωo = 200krad/s

(a) Plot the magnitude of G ($|G|$) versus ω. Show clearly the value of $|G|$ when ω = oo and $\omega = \omega_O$ in your plot.

(b) If $\mathbf{V_S(t) = 2\cos 0.5\omega_O t\ V}$, find $V_O(t)$.

(19)

(a)



(9)

(b)

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

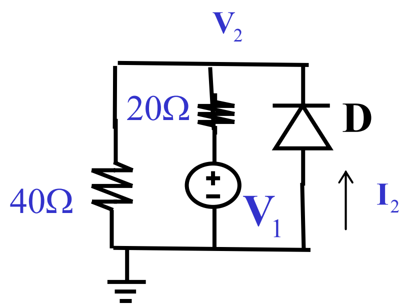
(10)

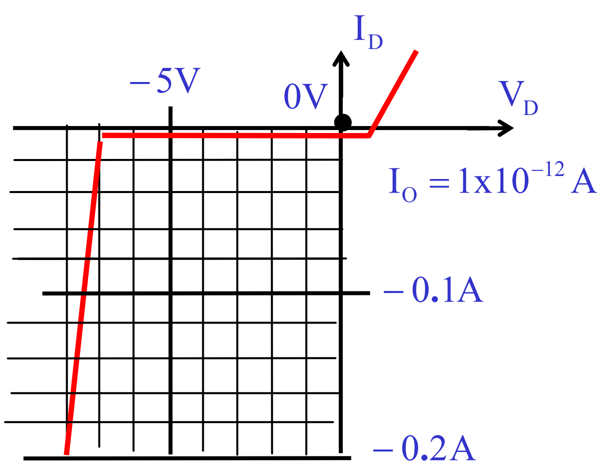
$$V_O(t) = -\frac{20}{\sqrt{5}}\cos(100\mathbf{k}t + 63.4^o)V$$

(7)

3 . In the ideal op amp circuit, the diode has the reverse characteristics as shown. Given that the diode equation is $I_D = I_O[e^{\frac{V_D}{n*25mV}} - 1]$ and n = 1.

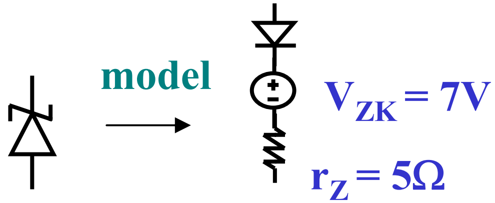
(a) Find the model of the diode at breakdown.
(b) If V_2 = -0.62V , find the diode mode and V1 .
(c) If V1 = 13V , find the diode mode and V2 .
Show clearly your steps and reasons. (33)





(a)

Model of zener diode



(7)

(26)

(b) **If V2 = - 0.62V D is a ON diode**

$$\therefore \mathbf{I}_2 \cong \mathbf{I_O} \exp\left(\frac{\mathbf{V}_2}{25\mathbf{mV}}\right)$$

$$= (1\mathbf{pA})\exp\left(\frac{620\mathbf{mV}}{25\mathbf{mV}}\right) \cong 59\mathbf{mA}$$

(8)

$$\therefore \mathbf{V}_1 = -\left(59\mathbf{mA} + \frac{0.62\mathbf{V}}{40\Omega}\right) * 20\Omega - 0.62\mathbf{V}$$

$$= -2.11\mathbf{V}$$

(6)

(c)

If V1 = 13V, D is a breakdown diode

$$\frac{13\mathbf{V} - \mathbf{V}_2}{20\Omega} = \frac{\mathbf{V}_2 - 7\mathbf{V}}{5\Omega} + \frac{\mathbf{V}_2}{40\Omega}$$

$$\therefore 26\mathbf{V} - 2\mathbf{V}_2 = 8\mathbf{V}_2 - 56\mathbf{V} + \mathbf{V}_2$$

(12)

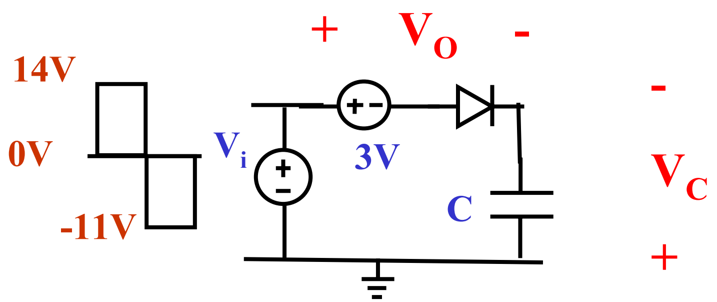
$$\therefore \mathbf{V}_2 = \frac{82\mathbf{V}}{11} \cong 7.45\mathbf{V}$$

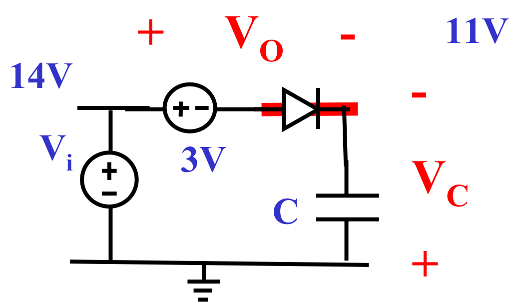
(14)

4

(a)

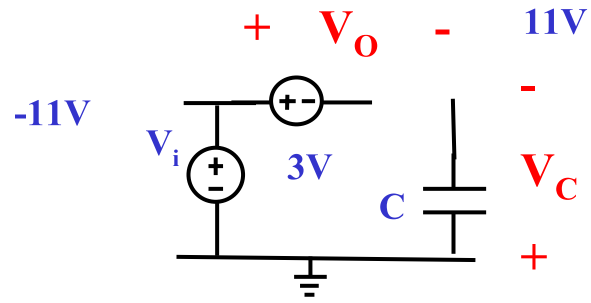
(a) In the diode circuit, find Vc . Hence sketch Vo(t). Label clearly $V_O(t)$. Assume the diode is ideal. (14)



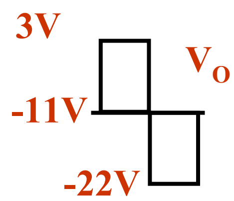


Vc = -11V

Vo = 3V



Vo = -22V



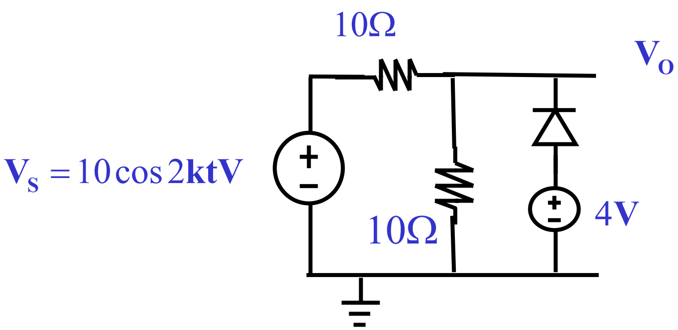
(14)

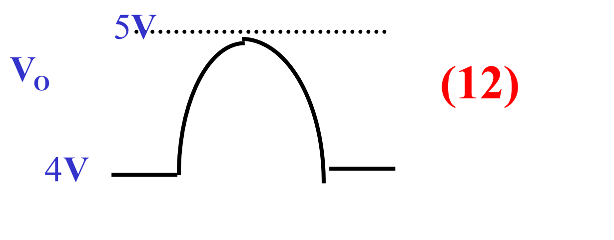
(26)

4

(b) In the diagram circuit, sketch and label clearly Vo(t). Assume the diode is ideal. (12)

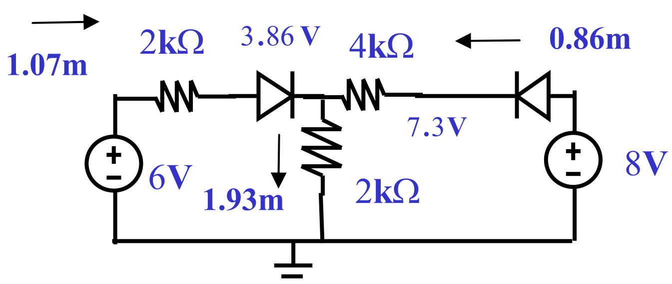
(b)



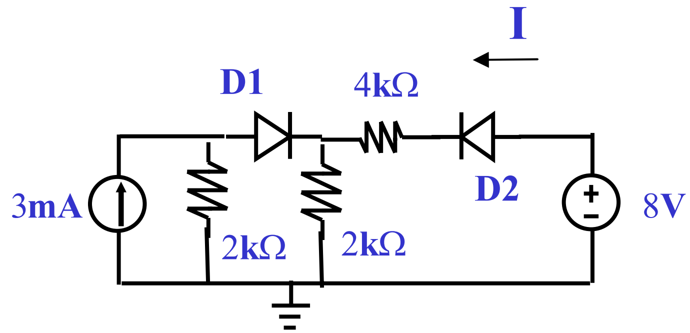


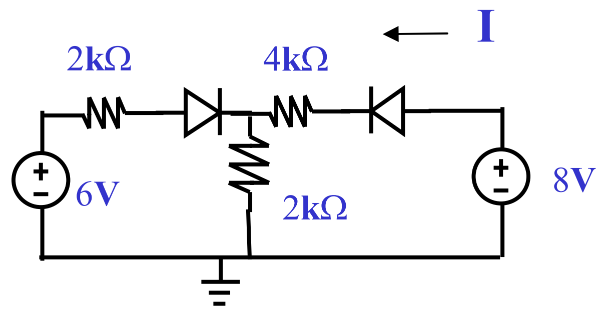
(12)

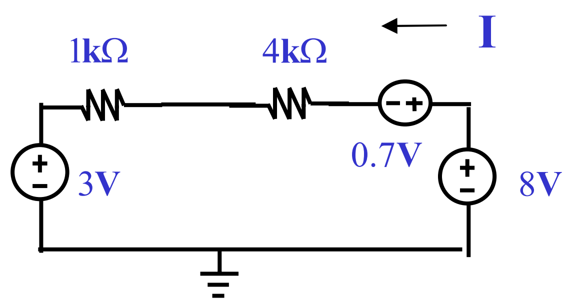
(c) In the diode circuit, find I . D1 is an ideal and diode and D2 is an offset diode with $V_F = 0.7V$ . . (14)



(c)







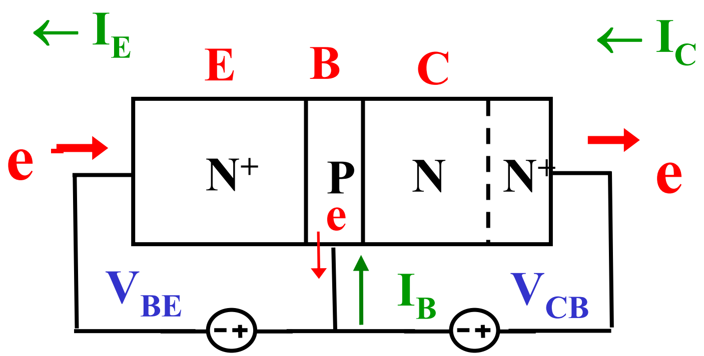
$$I = \frac{8V - 3V - 0.7V}{5k\Omega} = 0.86mA$$

(14)

(16)

5

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



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**

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

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

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

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

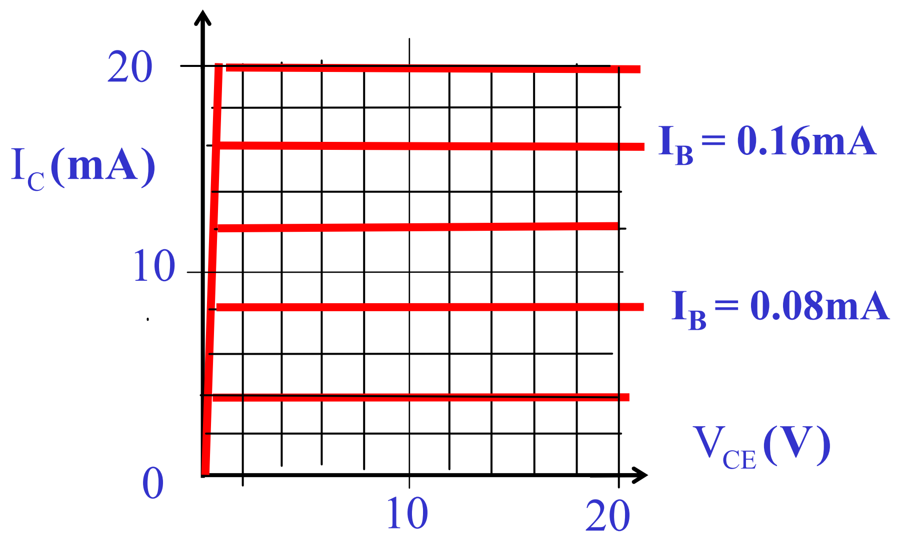
$$\beta = \frac{\alpha}{1 - \alpha} \qquad (6)$$

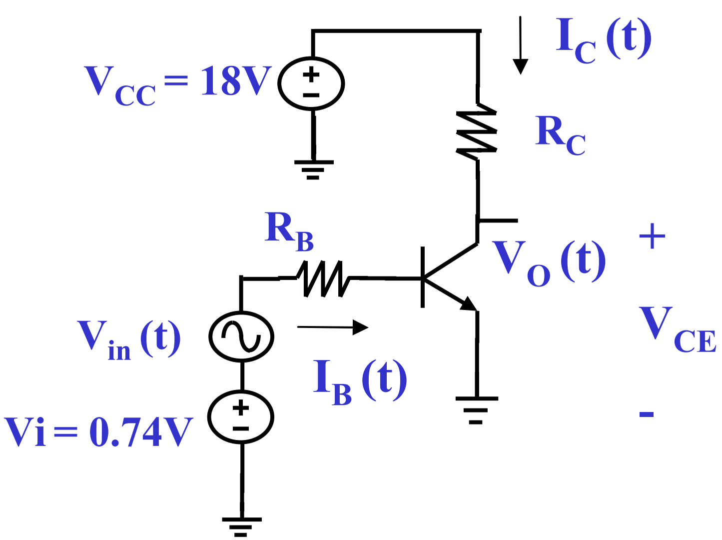
6

Given the BJT circuit and the I_C - V_{CE} curves of the BJT.

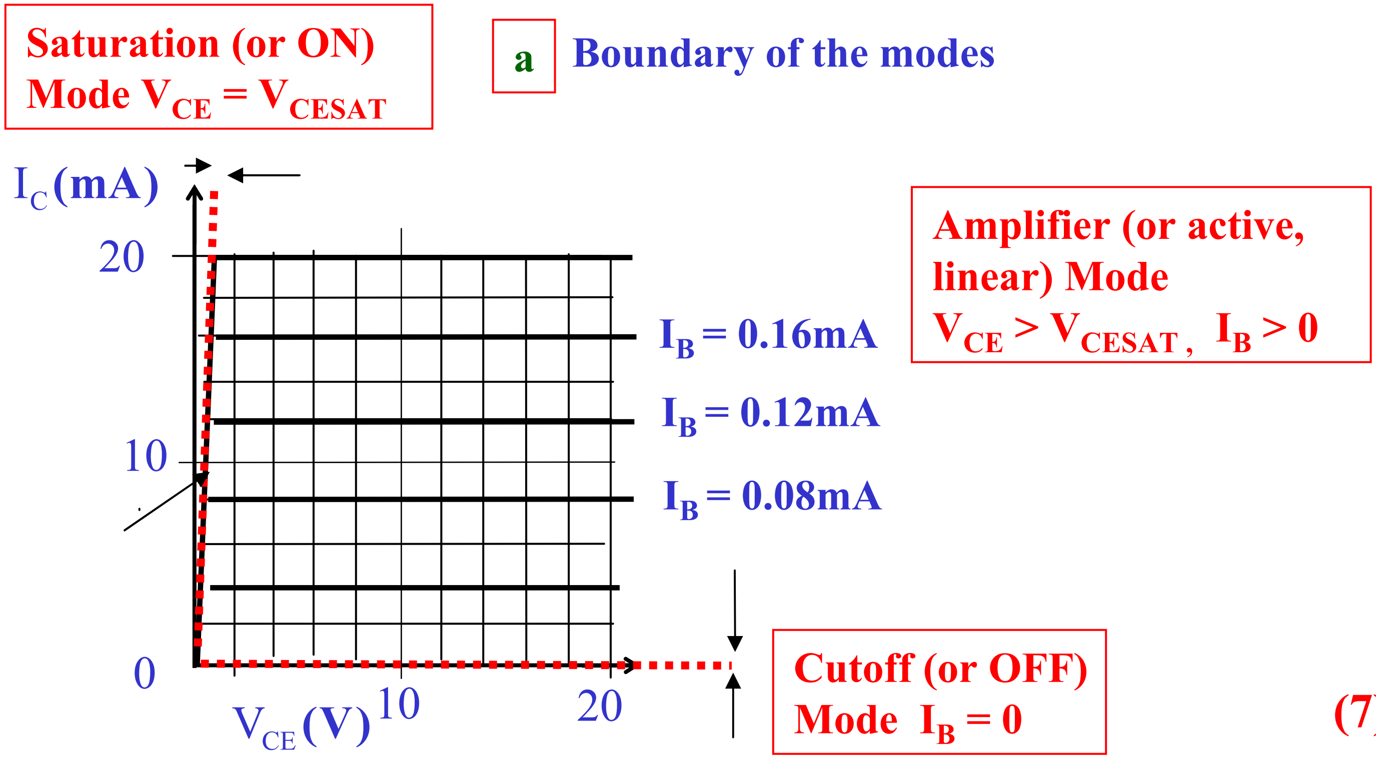
(a) Draw the boundary of the cut-off, amplifier and saturation modes of the BJT in the I_C - V_{CE} curves.
(b) If the Q point is chosen to be $I_C = 8mA$ and $V_{CE} = 10V$, $\mathbf{V_{in}(t)} = 0.02\cos 1\mathbf{kt\ V}$
(i) draw the load line $V_{CE} = V_{CC} - I_C R_C$ and locate the Q point on the I-V curve.
(ii) Calculate the value of R_B and R_C.
(iii) Find also from the I_C - V_{CE} curves the voltage gain $\Delta V_O / \Delta Vi$.
(iv) Hence find $V_O(t)$, $I_B(t)$ and $I_C(t)$.
(c) If R_B is changed to $1k\Omega$ and R_C is unchanged, estimate the maximum amplitude of $V_O(t)$.

For the BJT, given that $V_{BE(ON)} = 0.7V$, $V_{CESAT} = 0.2V$. (44)





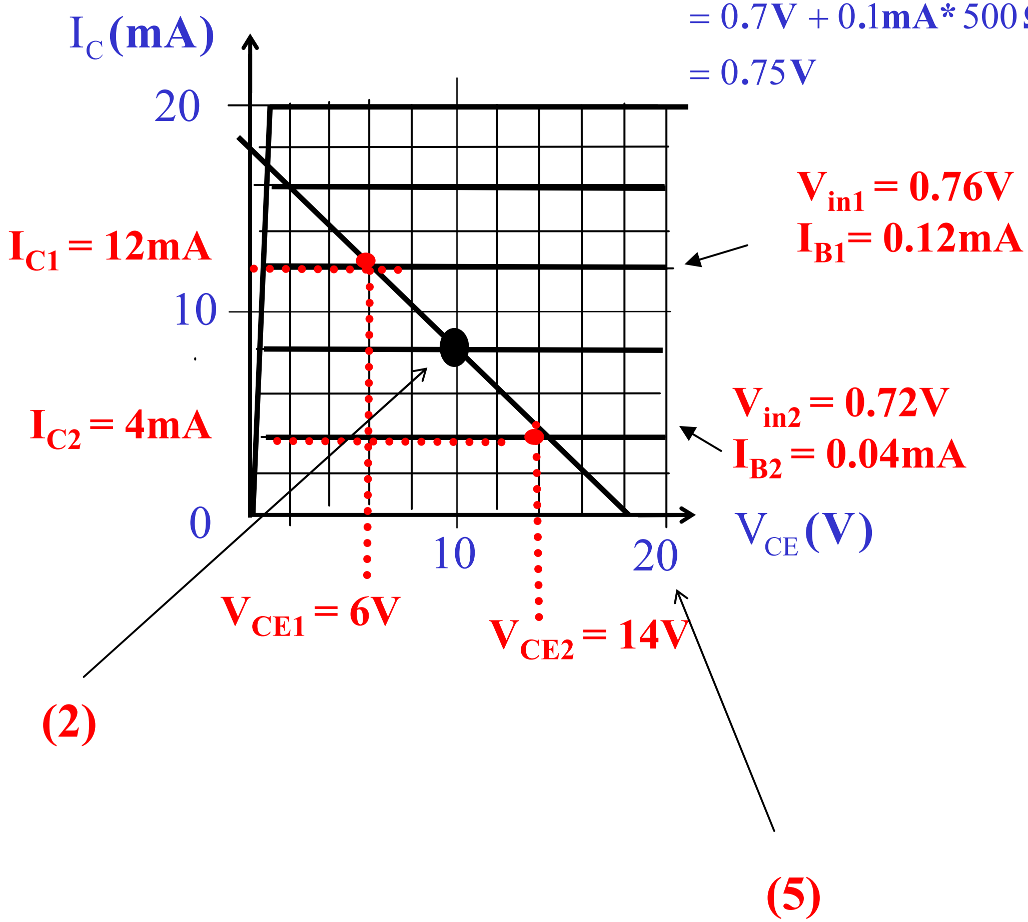
(a)


Saturation (or ON) Mode $V_{CE} = V_{CESAT}$
a
Boundary of the modes
I_C (mA)
20
10
0
V_{CE} (V)
10
20
$I_B = 0.16$mA
$I_B = 0.12$mA
$I_B = 0.08$mA
Amplifier (or active, linear) Mode
$V_{CE} > V_{CESAT}$, $I_B > 0$
Cutoff (or OFF) Mode $I_B = 0$

(7)

(b) Draw load line, Q point,
and find voltage gain

$$V_{in2} = V_{BE(ON)} + I_B R_B$$
$$= 0.7V + 0.1mA * 500\,\Omega$$
$$= 0.75V$$



(30)

(c)

$$\therefore R_C = \frac{V_{CC}}{I_C} = \frac{18V}{18mA} = 1k\Omega$$ **(5)**

$$\therefore R_B = \frac{0.74V - 0.7V}{0.08mA} = 500\Omega$$ **(5)**

(d)

$$\text{voltage gain } A_v = \frac{\Delta V_O}{\Delta V_i} = \frac{V_{CE2} - V_{CE1}}{V_{in2} - V_{in1}}$$

$$\cong \frac{14V - 6V}{0.72V - 0.76V} = -200$$

(9)

$$\therefore V_O(t) = 10V - 4\cos(1kt)V$$ **(4)**

(e)

$$\therefore I_B = \frac{0.74V - 0.7V}{R_B} = \frac{0.04V}{1k\Omega} = 0.04mA$$

Q point = 14V

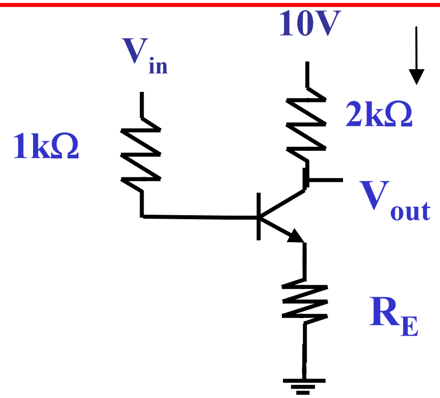
(7)

Maximum amplitude of Vo = 4V

(25)

7

(a) Explain briefly why the circuit can have stable IC if V_{in} is a constant .
(b) Sketch the small signal (AC) equivalent circuit of the BJT amplifier and find the voltage gain Av (= V_{out} / V_{in}).
Given $R_E = 0\Omega$, and $r\pi = 0\Omega$.
Given $\beta = 100$, and $V_{CESAT} = 0.2V$, $V_{BE(ON)} = 0.7V$.
(25)



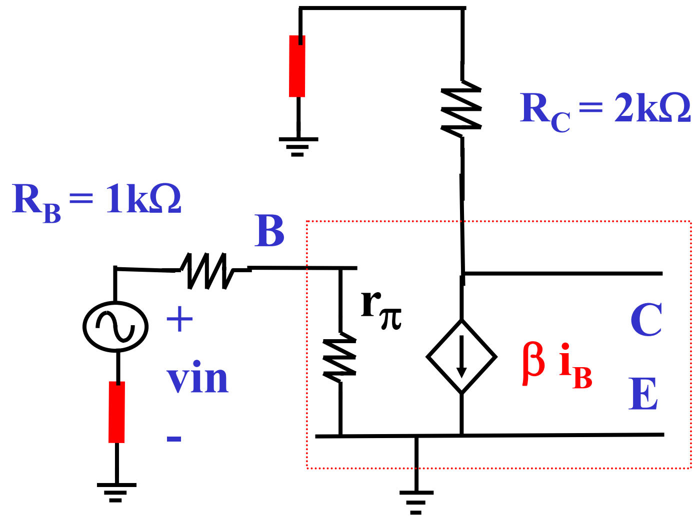
(a)

Circuit can maintain stable I_C (Q-point).

$I_C \uparrow$ (∵ β or T↑) → $V_E \uparrow$ (∵ $V_E = I_E R_E \sim I_C R_E$) → $V_{BE} \downarrow$ (∵ V_{BE} = Vin - V_E) → $I_B \downarrow$ → $I_C \downarrow$ (∵ $I_C = \beta I_B$)

(9)

(b)



(8)

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

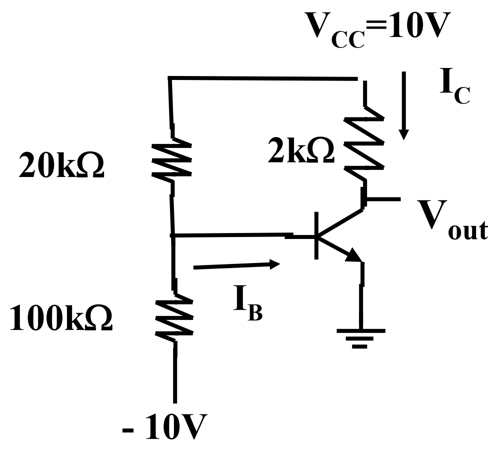
$$= \frac{-\beta R_C}{R_B + r_\pi} = \frac{-(100)(2k\Omega)}{1k\Omega} \cong -200$$

(8)

(20)

8

. In the BJT circuit, $\beta = 30$, $V_{BE(ON)} = 0.7V$, $V_{CESAT} = 0.2V$
Find I_C/I_B. Show clearly your reasons. (20)



$$\therefore I_B = \frac{10V - 0.7V}{20k\Omega} + \frac{-10V - 0.7V}{100k\Omega}$$

$$= 0.465mA - 0.107mA = 0.358mA$$

$$\therefore I_C = \beta I_B = 30(0.358mA) = 10.74mA$$

But $\quad I_C = \frac{10V}{2k\Omega} = 5mA$ only

when $V_{CE} = 0V$

Hence BJT in saturation

$$\therefore I_C = \frac{10V - 0.2V}{2k\Omega} = 4.9mA$$

$$\therefore \frac{I_C}{I_B} = \frac{4.9mA}{0.358mA} \cong 13.7$$

(20)

9

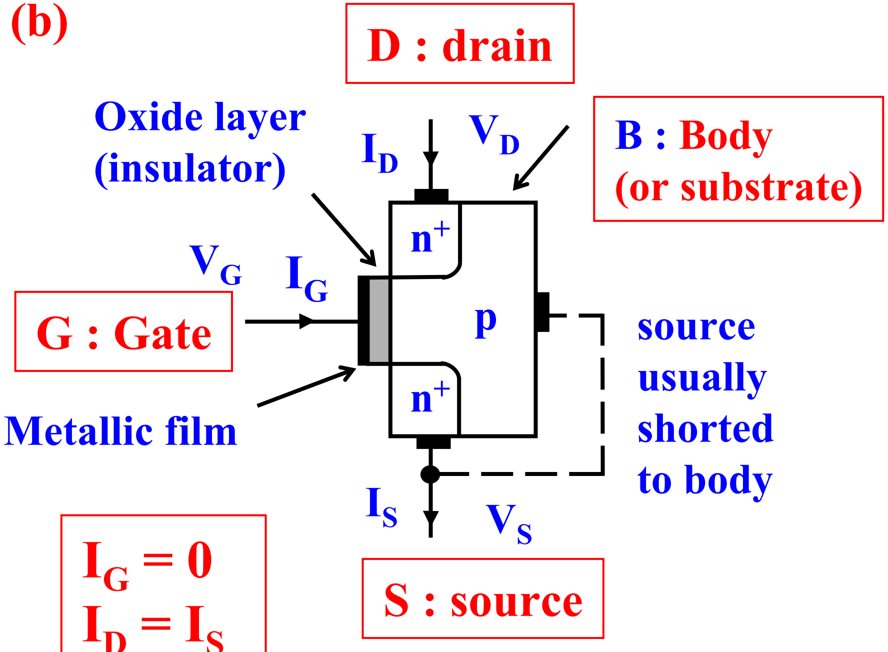
(a) Name two advantages of MOSFET. (b) Draw the cross sectional diagram for an enhancement NMOSFET and describe very briefly the structure.
(15)

(a)

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

(5)

(b)



$I_G = 0$
$I_D = I_S$

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.

(10)

(25)

10

M1 is saturate since

$V_{GS} = 4V > V_T$ $\quad V_T = 1V$

and $V_{DS} = V_{GS}$

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

$$\therefore I_{DS} = K\,(V_{GS1} - V_T)^2 = 10mA(4-1)^2$$
$$= 90mA$$

(10)

As I > 0, M2 is not off, and is triode or saturate

If M2 is saturate $\quad V_T = 1V$

then $V_{GS} > V_T$ and $V_{DS} > V_{GS} - V_T$

But $1V > V_{GS} - 1V$ is not possible

since $V_{GS} = 6V$

Hence M2 is triode

(7)

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

$$90mA = 2(10m)[(V_S - 1V)1V - \frac{1V^2}{2})]$$

$$4.5 = V_S - 1.5V$$

$$\therefore V_S = 6V$$

(8)

Find the mode of the M1 and M2 MOSFET. Find also I and VS. Show clearly the reasons for your answers.
(25)

Given that $V_T = 1V$, $K = 10mA/V^2$.
At triode region, $V_{GS} \geq V_T$, $V_{DS} < V_{GS} - V_T$, $I_{DS} = 2K[(V_{GS} - V_T)V_{DS} - V_{DS}^{\ 2}/2]$
At saturation region, $V_{GS} \geq V_T$, $V_{DS} \geq V_{GS} - V_T$, $I_{DS} = K[(V_{GS} - V_T)^2]$