(16)

1

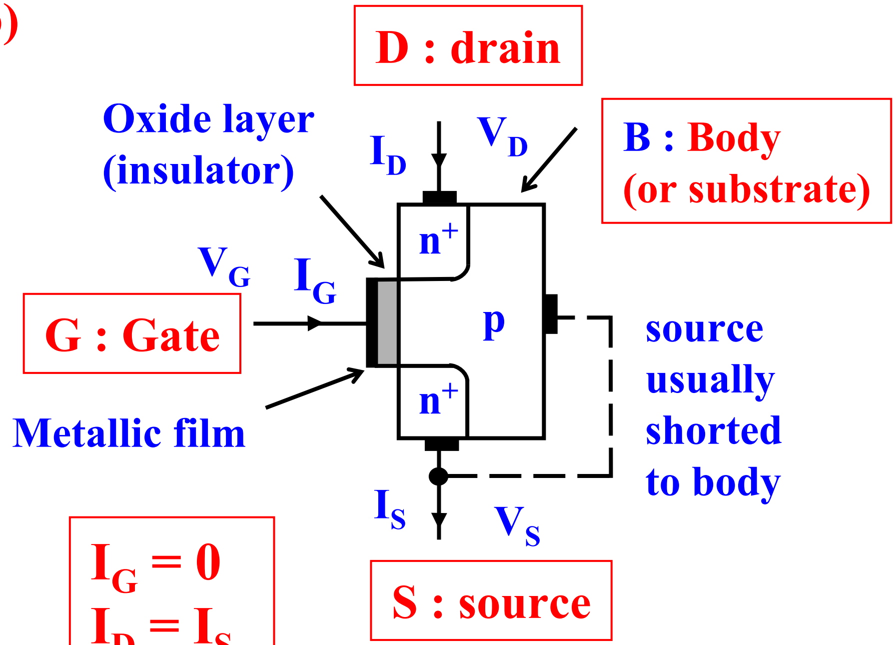
(a) Name two advantages of MOSFET. (b) Draw the cross sectional diagram for an enhancement NMOSFET and describe very briefly the structure. Are IG = 0 and ID = IS?
(16)

(a)

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

(4)

(b)



$I_G = 0$
$I_D = I_S$

(1)

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.

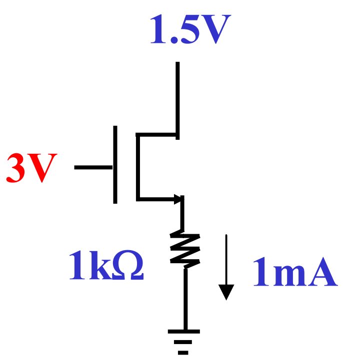
(11)

1

In the circuit, find the MOSFET constant K . Show clearly your reasons . (14)

(c)

Given that VT = 1V.
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]



$V_{GS} = 2V$ $V_{DS} = 0.5V$ **(4)**

Hence NMOS is triode since
1. $V_{GS} > V_T$
2. $V_{DS} < V_{GS} - V_T$

(2)

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

$$\therefore 1\mathbf{mA} = 2\mathbf{K}(1*0.5 - \frac{0.5^2}{2}]$$

$$\therefore \mathbf{K} = \frac{1\mathbf{mA}}{0.75} = \frac{4}{3}\mathbf{mA/V}^2$$

(8)

(23)

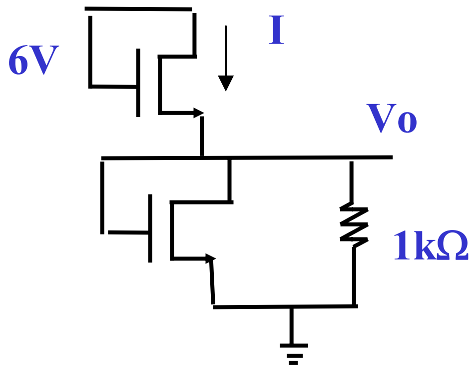
2 Find Vo . Show clearly your reasons. (23)

Given the NMOS are identical,

$V_T = 1V$, $K = 0.25m\ A/V^2$.

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]



Assume 2 NMOS are in <u>saturation</u>

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

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

(8)

$$0.25 * (5 - Vo)^2 = 0.25 * (Vo - 1)^2 + Vo$$

$$(5 - Vo)^2 = (Vo - 1)^2 + 4Vo$$

$$25 - 10Vo + Vo^2 = Vo^2 - 2Vo + 1 + 4Vo$$

$$24 - 12Vo = 0$$

$$Vo = 2V$$

(9)

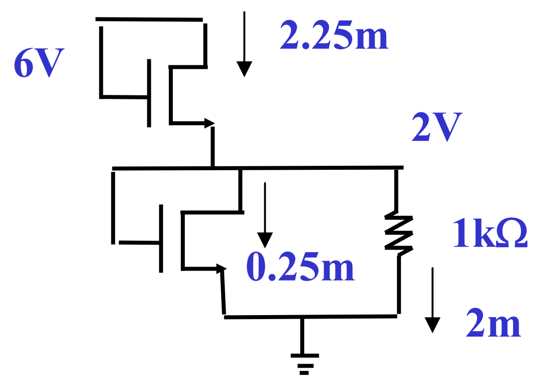
$V_{GS1} = 4V$ $V_{DS1} = 4V$

$V_{GS2} = 2V$ $V_{DS2} = 2V$

Hence NMOS is saturate since

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

(6)



(40)

3

(a) Find the conductivity of intrinsic (pure) silicon (Si). Find also the resistivity.

(b) The pure silicon is doped to n-type Si with a conductivity of 20 / Ωm , suggest a dopant atom . Find also the electron concentration (in atoms / m3) .

(c) 1 x 1021 / m3 boron atoms are used to dope the pure Si . Find the electron density n, hole density p , and conductivity σ . Is the doped Si n-Si or p-Si ?

(d) Name two III-V compound semiconductors.

Given that $\sigma = e(n\mu_n + p\mu_p)$, $\rho = 1/\sigma$, $np = n_i^2$, $n_i = 1.5 \times 10^{16}$ /m³, $\mu_p = 0.048$ m²/Vs, $\mu_n = 0.135$ m²/Vs , $e = 1.6 \times 10^{-19}$ C. Some atoms : group 3 (boron B, gallium Ga, indium In) ; group 5 (nitrogen N, phosphorus P, arsenic As) (40)

(a) The conductivity of intrinsic (pure) Si

$$\sigma_i = e(\mu_N n_i + \mu_P n_i) = en_i(\mu_P + \mu_N)$$
$$= 1.6x10^{-19} x1.5x10^{16} x(0.048 + 0.135) \cong 4.39x10^{-4} / \Omega m$$

(6)

$$\rho_i = \frac{1}{\sigma_i} = \frac{1}{4.39x10^{-4}} \cong 2277 \Omega m$$

(4)

(b)

$$\therefore \sigma_N = e(\mu_P p + \mu_N n) \cong e(\mu_N n) = 20 / \Omega m$$
$$\therefore n = \frac{20}{1.6x10^{-19} * 0.135} \cong 9.26x10^{20} / m^3$$

(6)

P or As. (3)

(c) P-type (2)

$$\therefore p \cong 1x10^{21} \text{ holes} / m^3$$

(4)

$$\therefore n = \frac{n_i^2}{p} = \frac{(1.5x10^{16})^2}{1x10^{21}}$$
$$\cong 2.25x10^{11} \text{ electrons} / m^3$$

(6)

$$\therefore \sigma_N = e(\mu_P p + \mu_N n) \cong e(\mu_P p)$$
$$= 1.6x10^{-19} * 0.048 * 1x10^{21}$$
$$= 7.68 / \Omega m$$

(5)

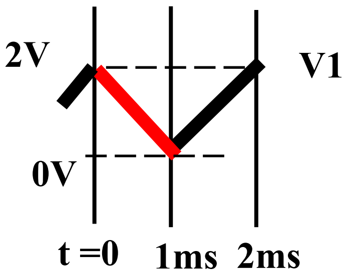
(d) III-V compound GaAs, InP etc (4)

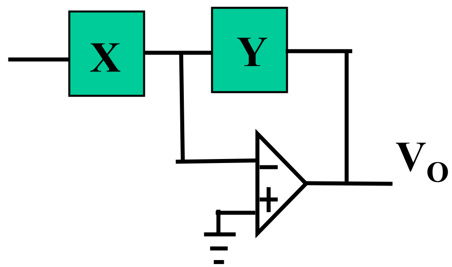
4 **(a)**

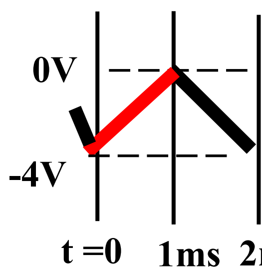
(i) If X = 1kΩ, Y = 2kΩ, draw the waveform of Vo .

(ii) If X = 1μF , Y = 1kΩ . derive the equation for the output voltage V_O , and hence draw the waveform of V_O .

Assume the op amp is ideal. (21)

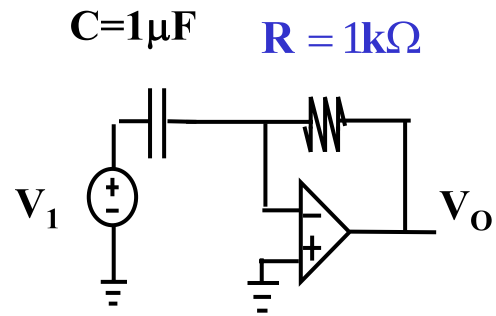






Vo

(7)

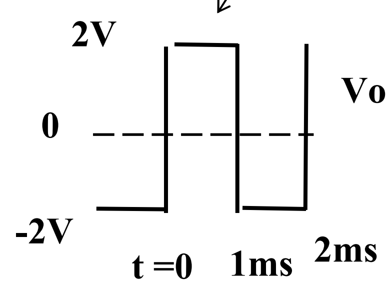


$$-\frac{Vo}{R} = C\frac{dV1}{dt}$$

$$Vo = -CR\frac{dV1}{dt}$$

$$Vo = -1ms * \frac{-2V}{1ms} = 2V$$

(9)

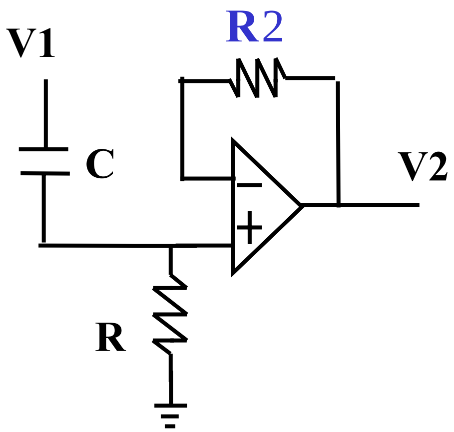


(5)

(11)

4 (b)

Find the complex transfer function G (= V2 / V1) in terms of R, C, R2 and jw .
Is the ideal op amp circuit a low pass filter?
(11)



(b)

$$V2 = V1 * \frac{R}{R + \frac{1}{j\omega C}}$$

$$G = \frac{V2}{V1} = \frac{1}{1 - j/\omega CR}$$ (8)

Circuit is a high pass filter (3)

(22)

5

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

(a) If $V_S(t) = 1\cos 400kt\ V$, find Vo(t) .

(b) Plot the magnitude of G (|G|) versus ω . Show clearly the value of |G| when ω = 0 , ω = ∞ , and ω = ωO (cut-off frequency) in your plot . Find also ωO .

.

Given that 1/CR = 800krad/s . (22)

(a)

$$G = \frac{-20}{1+2j*400k*CR} = \frac{-20}{1+j} \quad \textbf{(5)}$$

$$\therefore V_O = 1\angle 0 * \frac{-20}{1+j} \cong \frac{-20}{\sqrt{2}\angle 45^o} \quad \textbf{(5)}$$

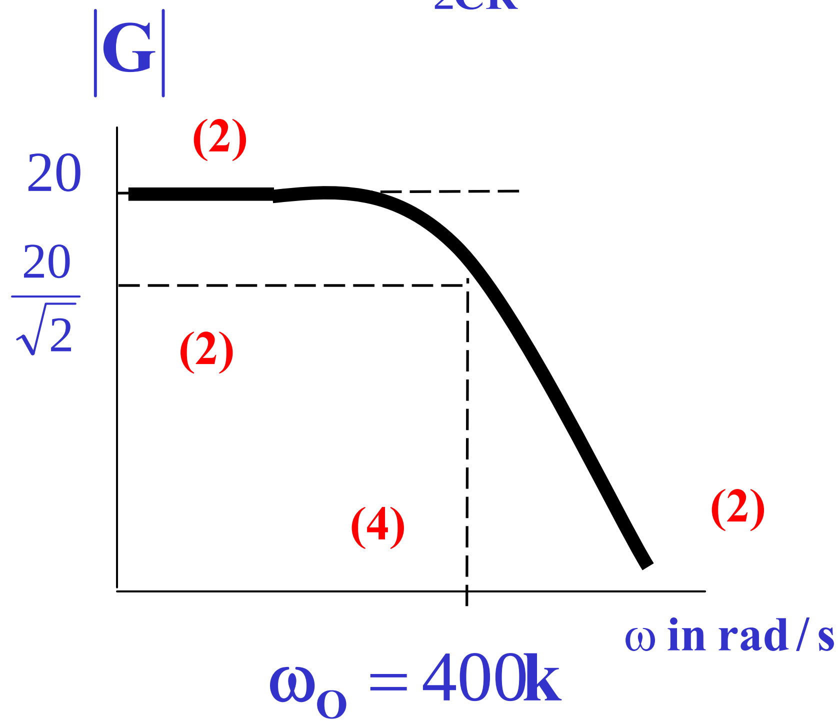
$$V_O(t) = -\frac{20}{\sqrt{2}}\cos(400kt - 45^o)V \quad \textbf{(2)}$$

(b) $|G| = 20$

At cut-off frequency, $|G| = \frac{20}{\sqrt{2}}$

$$G = \frac{-20}{1+j} \Rightarrow 2\omega CR = 1$$

$$\omega = \omega_O = \frac{1}{2CR} = 400krad/s$$

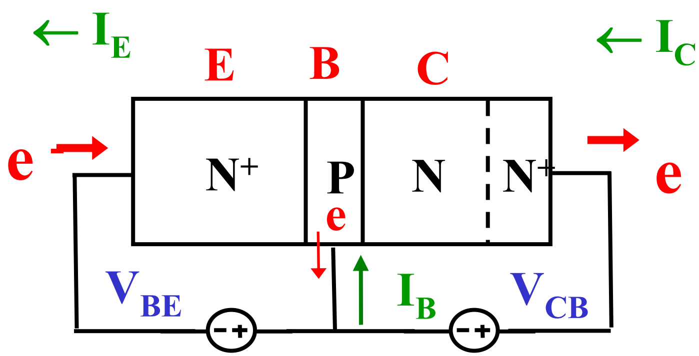


(16)

6

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 . Given $I_C \cong \beta I_B$, find β in terms of α. (16)

(a)



(4)

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

$$I_C \cong \alpha I_E$$

(7)

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

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

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

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

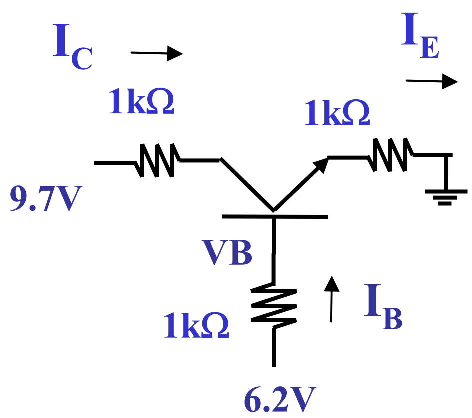
(5)

(24)

7

(a) Find the mode of the BJT.
(b) If VB = 5.7V, find IC/IB.

Show clearly your reasons. For the BJT, given
$V_{BE(ON)} = 0.7V$, $\beta = 100$, $V_{CESAT} = 0.2V$. (24)



(a)

$$\text{when } V_{CE} = V_{CESAT}$$

$$I_C \cong I_E = \frac{9.7V - 0.2V}{2k\Omega} = 4.75mA$$

$$\text{Now } 6.2V = I_B R_B + V_{BE} + I_E R_E$$

$$\cong 0.7V + I_E 1k\Omega$$

$$\therefore I_E \cong \frac{5.5V}{1k\Omega} \cong 5.5mA$$

Hence BJT is SAT

(11)

(b) **IB = 0.5mA** **(2)**

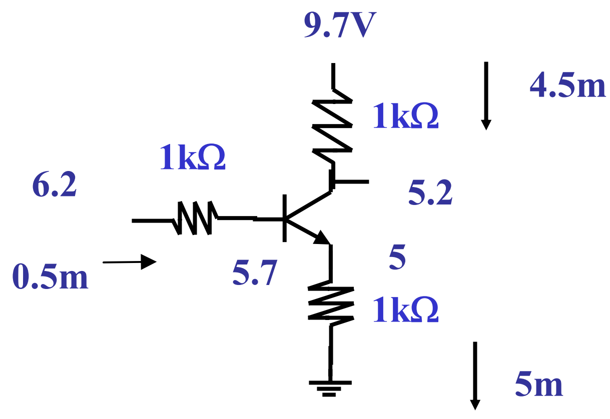
$$\because 9.7V = I_C R_C + V_{CE} + I_E R_E$$

$$= \beta' I_B R_C + V_{CE} + (1+\beta') I_B R_E$$

$$= (1 + 2\beta')0.5mA * 1k\Omega + 0.2V$$

$$\therefore \beta' = \left(\frac{9.7V - 0.2V}{0.5mA * 1k\Omega} - 1\right) * \frac{1}{2} = 9$$

(11)



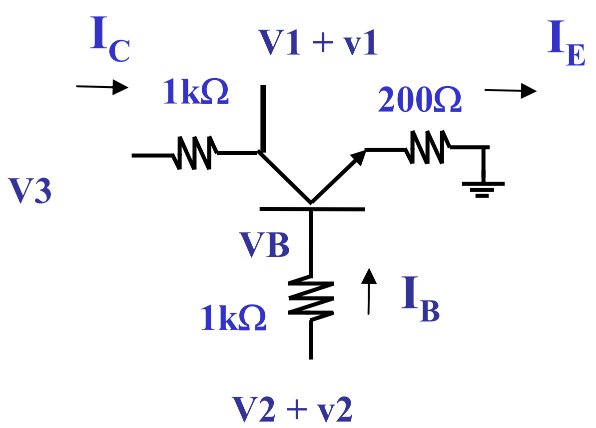
(20)

8

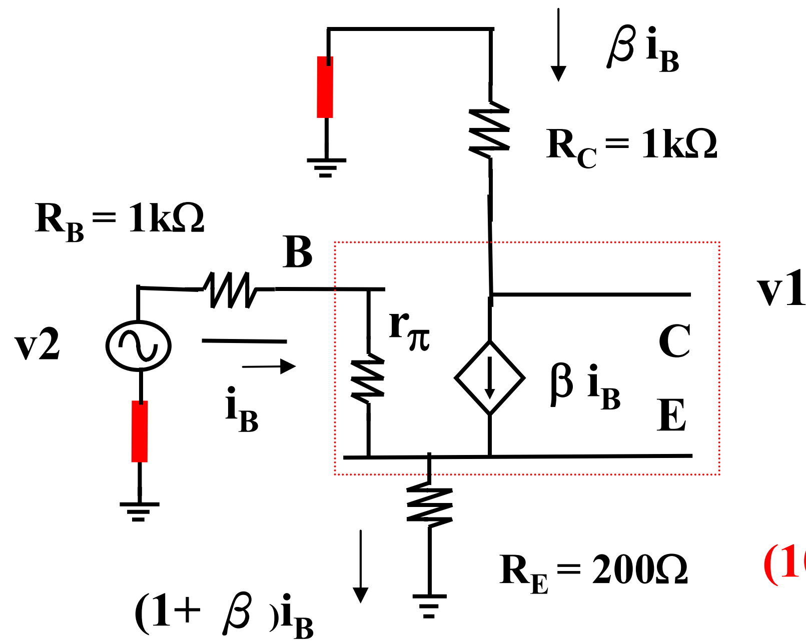
(a) Draw the small signal (AC) equivalent circuit of the BJT amplifier and find the voltage gain Av (= v1 / v2).

(b) The circuit is also a self bias BJT circuit. Explain very briefly why the circuit can have a stable Q point.

Given $r\pi = 0\Omega$, $\beta = 100$, and $V_{CESAT} = 0.2V$, $V_{BE(ON)} = 0.7V$. (28)



(a)



(10)

$$\therefore Av = \frac{v1}{v2} = \frac{-\beta\, i_B R_C}{i_B(R_B + r_\pi) + (1+\beta) i_B R_E} \qquad (6)$$

$$= \frac{-\beta R_C}{R_B + r_\pi + (1+\beta) R_E}$$

$$= \frac{-(100)(1k\Omega)}{1000\Omega + 101 * 200\Omega} \cong -4.7 \qquad (4)$$

(8)

8

(b)

Since V_B ~ constant

Hence $I_C \uparrow$, $I_E * R_E \uparrow$, $V_{BEON} \downarrow$, $I_C \downarrow$

I_C is almost a constant

OR

(8)

$$V_2 = I_B R_B + V_{BE(ON)} + I_E R_E$$

$$\sim V_{BE(ON)} + \beta\, I_B R_E \sim \text{ constant } (= V_B)$$

Hence $I_C = \beta\, I_B$ is almost a constant

9

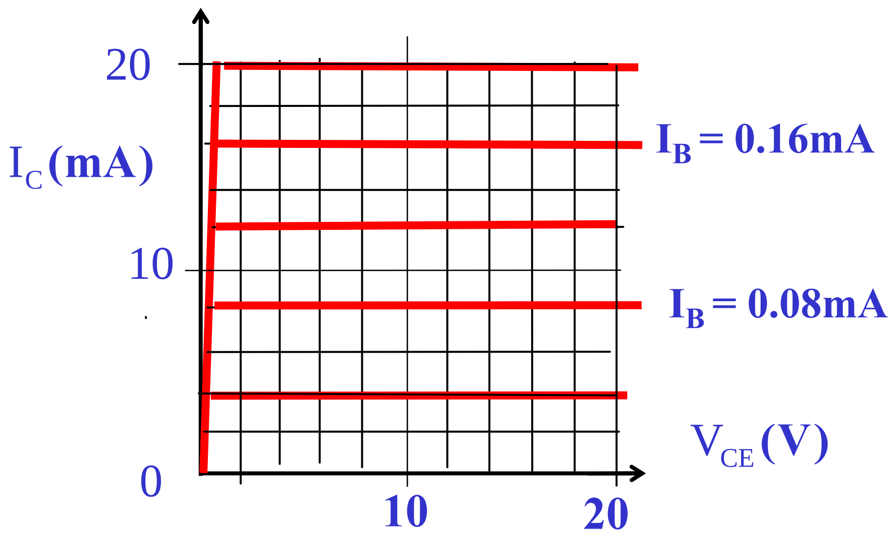
Given the BJT circuit below and the I_C-V_{CE} curve of the BJT. If the Q point is chosen to be VCEQ = 8V, ICQ = 10mA.

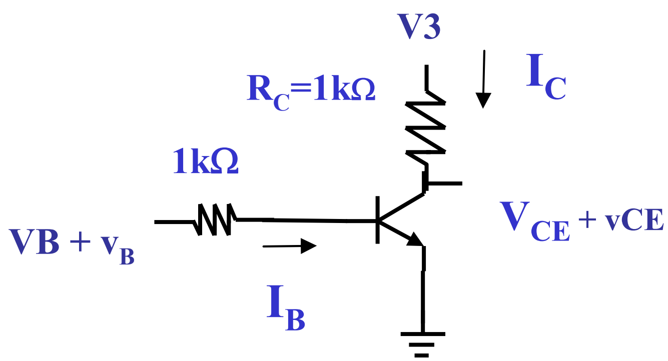
(a) Find V3, VB, draw the load line $V_{CE} = V3 - I_C R_C$ and locate the Q point on the load line.

(b) If vB = 0.02cosωt V, estimate the voltage gain vCE / vB from the load line and IC -VCE curves. Show also on the load line the range of movement of the bias point.

(c) If VBE(ON) of BJT is changed from 0.7V to 0.68V, sketch and label $V_O(t)$. (34)

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





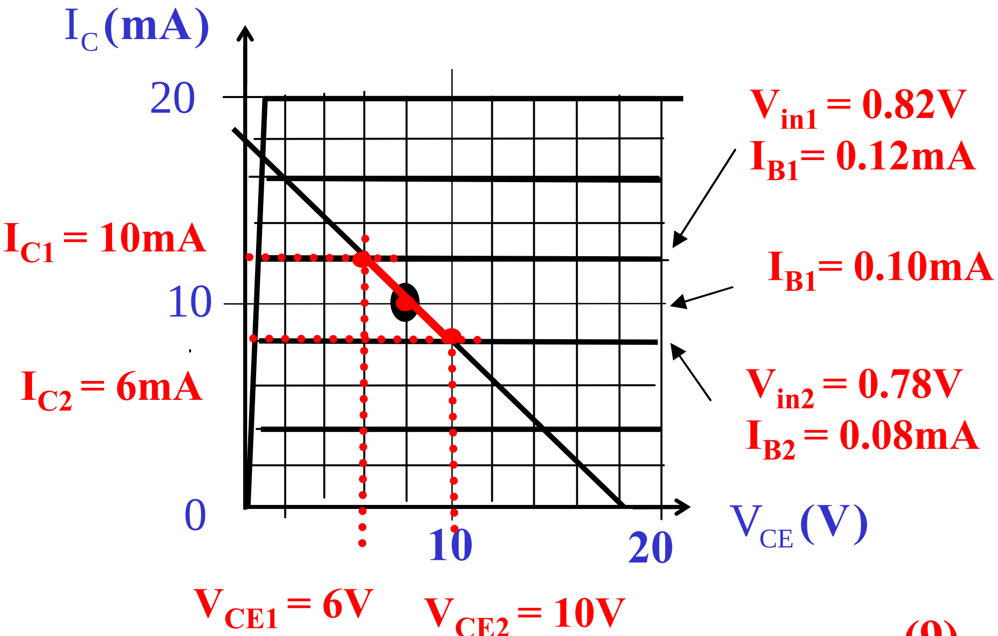
(a)

Draw load line, Draw Q point,

$\therefore V3 = 8V + 10mA * 1k\Omega = 18V$ **(4)**

$\therefore I_{BQ} = 0.1mA$ **(2)**

$\therefore VB = 0.7V + 0.1mA * 1k\Omega = 0.8V$ **(4)**



(9)

(b)

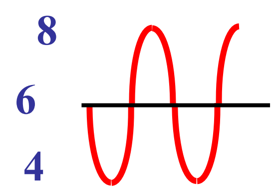
$$\text{voltage gain } A_v = \frac{v_{CE}}{v_B} = \frac{V_{CE2} - V_{CE1}}{V_{in2} - V_{in1}}$$

$$\cong \frac{10V - 6V}{0.78V - 0.82V} = -100$$ **(7)**

(c) **Q point shifts to**

$$\therefore I_B = \frac{0.8V - 0.68V}{1k\Omega} = 0.12mA$$

v_{CE} **roughly ~**



(8)

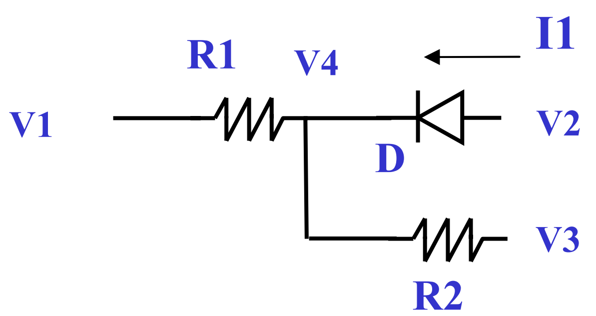
(22)

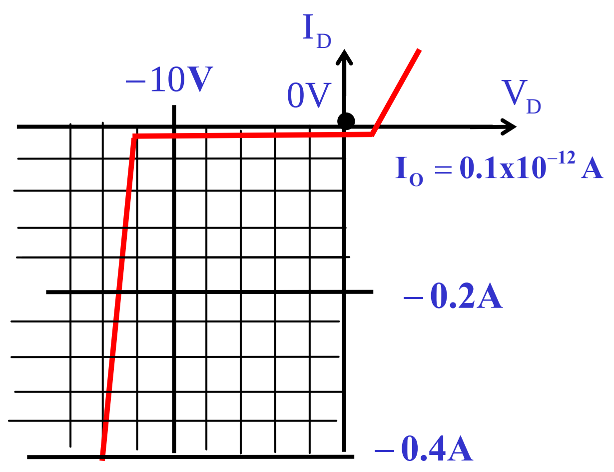
10

(i) Find the model of the diode at breakdown.
(ii) Find V4 if I1 = -0.1A, R1 = R2 = 10Ω, V2=V3 = 1V.
(iii) Find I1 if V1 = 20V, R1 = R2 = 10Ω, V2=V3 = 0V.

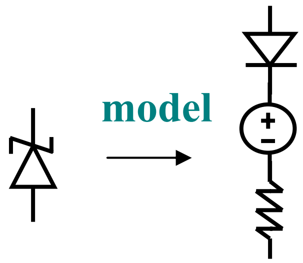
(a)

Show clearly your reasons . (22)
Given that the diode equation is $I_D = I_O * [e^{\frac{V_D}{25mV}} - 1]$
and the diode has the I-V curve as shown.





(i)

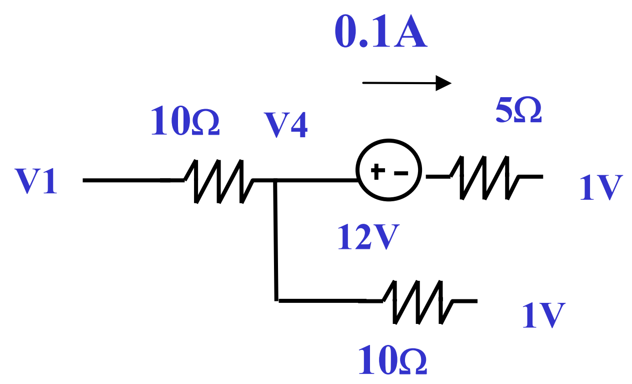


$V_{ZO} = 12V$

$r_Z = 2V/0.4A = 5\Omega$

(7)

(ii)



(7)

V4 = 13.5V (2)

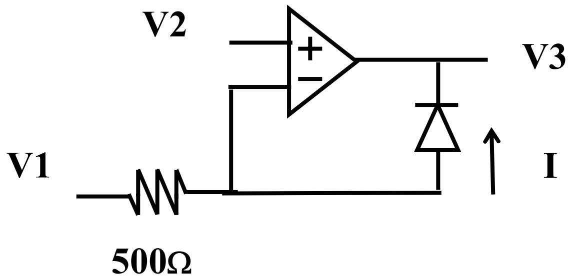
(iii)

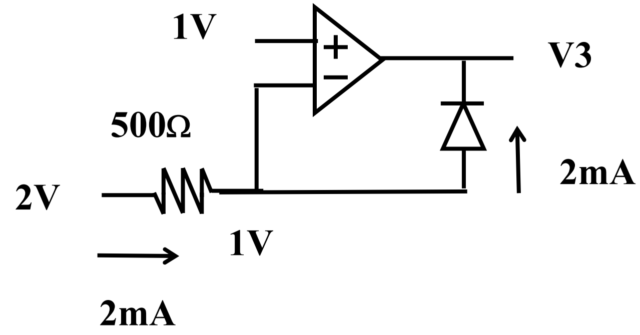
V4 = 10V, D is OFF,
I1 = - 0.1pA (6)

(14)

10

(b) (The diode in part (a) is used in the ideal op amp circuit, find V3 if V1 = 2V, V2 = 1V . (14)





$$\therefore 2\text{mA} = I_O\left(e^{\frac{VD}{25\text{mV}}} - 1\right) \cong 0.1\text{x}10^{-12}\left(e^{\frac{VD}{25\text{mV}}}\right) \qquad (7)$$

$$\therefore VD \cong 25\text{mV} * \ln \frac{2\text{mA}}{0.1\text{x}10^{-12}\,\text{A}} \cong 0.593\text{V} \qquad (3)$$

$$\therefore V3 \approx 1\text{V} - 0.593\text{V} = 0.407\text{V} \qquad (4)$$

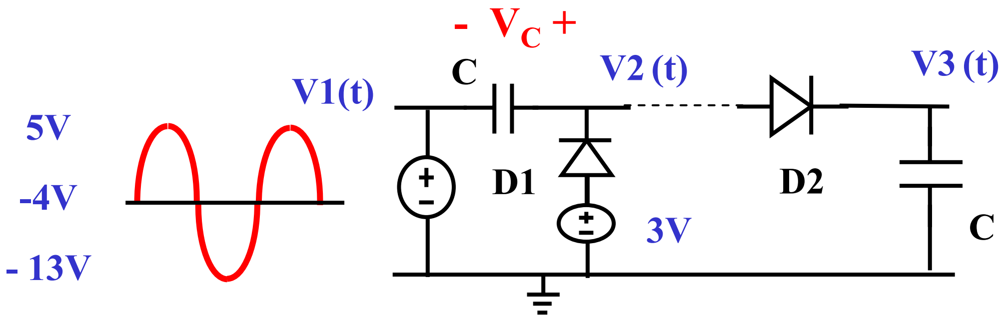
(21)

11

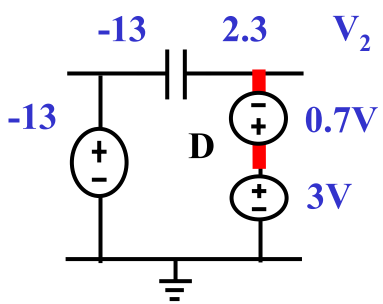
(a) In the diagram circuit, find Vc. Hence sketch and label clearly V2(t) .

(b) If the capacitor filter (D2 and C circuit) is connected to V2, sketch V3(t).

D1 and D2 are <u>offset diodes</u> with VF = 0.7V . (21)



(a)



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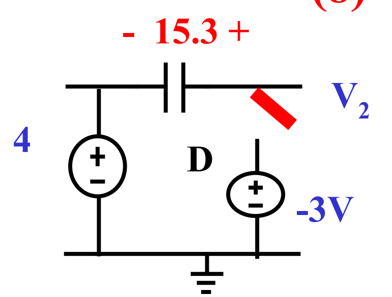
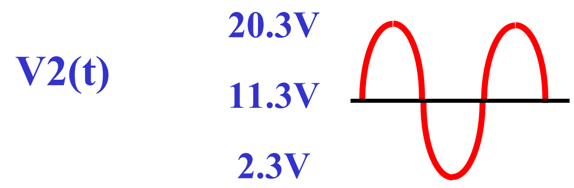


V2

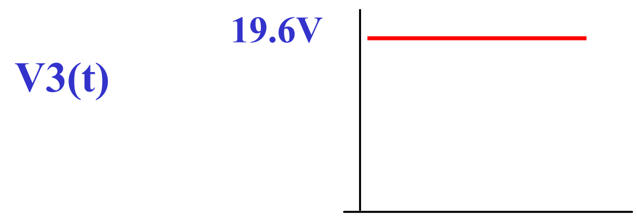
$$\boxed{V2 = V1 + Vc = V1 + 15.3V}$$

(4)



(3)

(b)

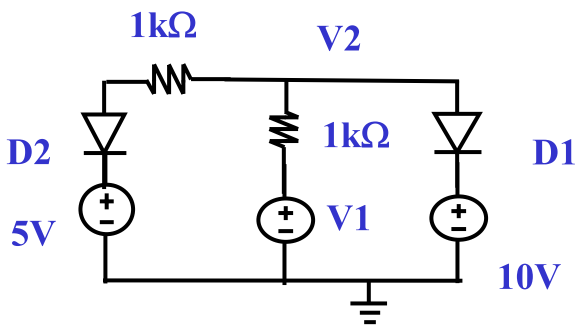


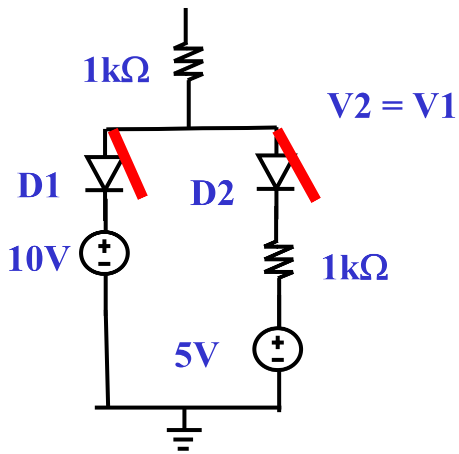
(6)

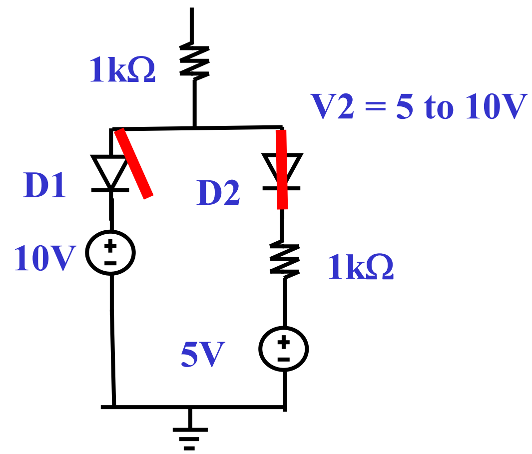
11

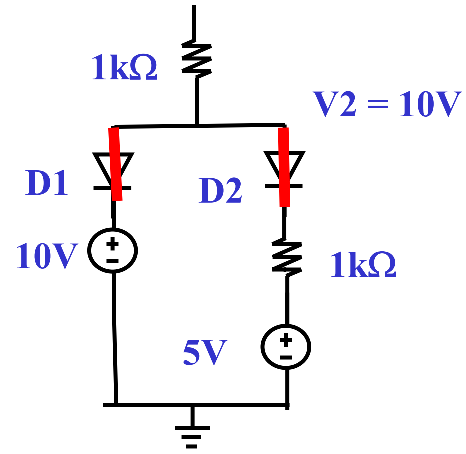
In the ideal diode circuit, plot V2 versus V1 for $20V \geq V1 \geq 0V$. (22)

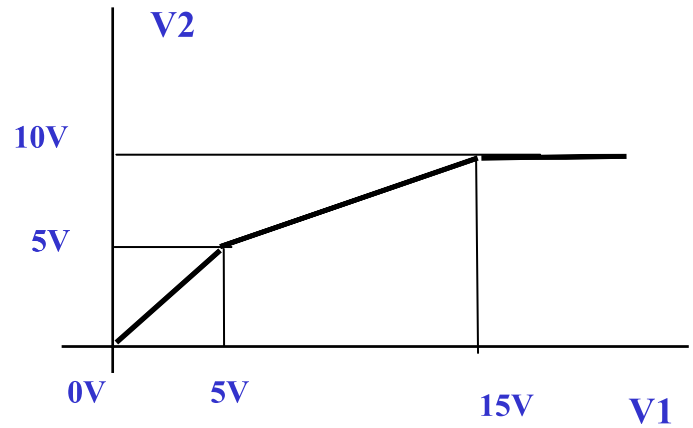
(c)











(7) (8) (7)