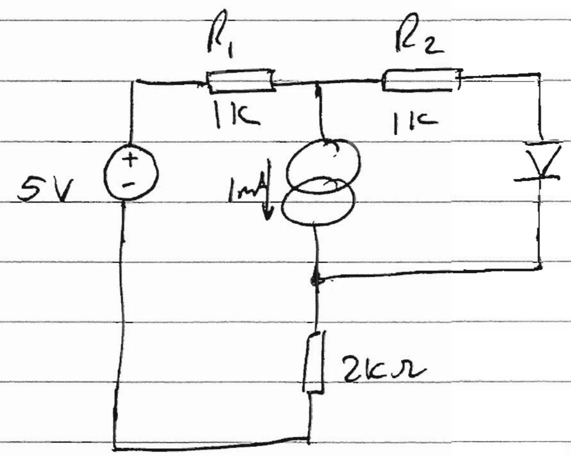
EEE118 2012 - 2013 SOLUTION 8/4/13

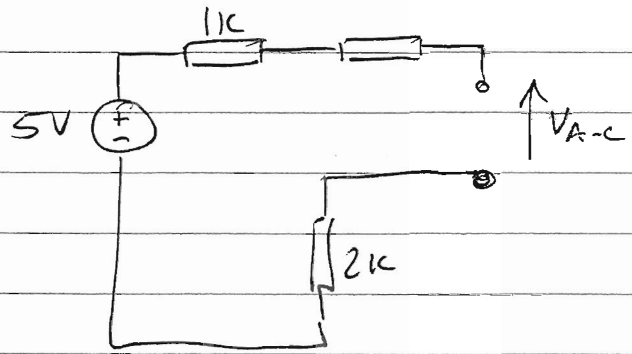
1.

a.



USE SUPERPOSITION: ASSUME DIODE NOT CONDUCTING.

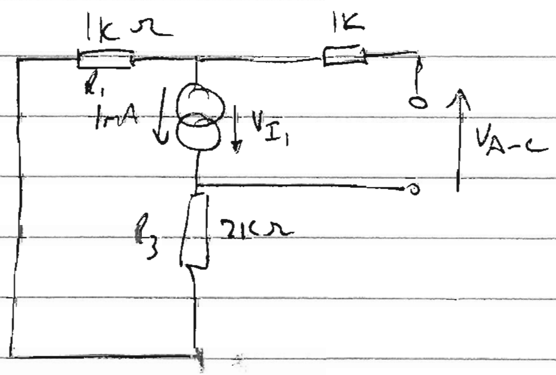
- FOR THE 5V SOURCE:



BY INSPECTION, NO CURRENT AS NO PATHWAY

$V_{AC} = 5V.$

- FOR THE 1mA SOURCE:



$V_{A-C} = -V_{I_1}$

R_1 R_3

$V_{I_1} = -1mA * (1k\Omega + 2k\Omega)$

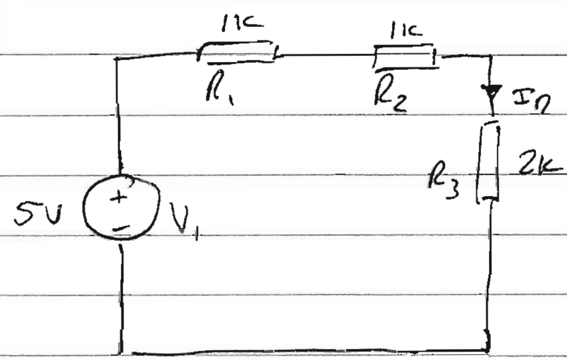
$= -3V.$

- TOTAL $V_{AC} = 5 + (-3)\ V = 2V.$

$\therefore$ DIODE CONDUCTS!

NOW DIODE IS CONDUCTING: FIND DIODE CURRENT DUE TO V_1, I_1 & V_0

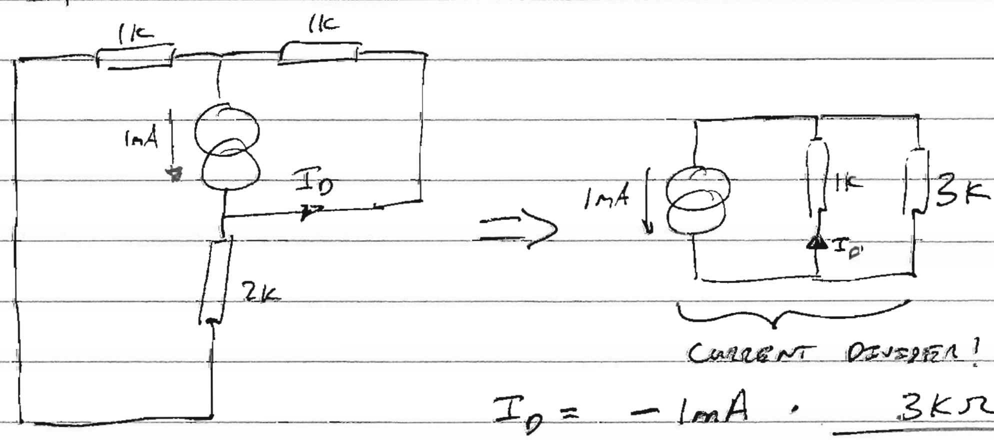
- FOR V_1, BY SUPERPOSITION.



$$I_D = \frac{V}{R_T} = \frac{5}{(1K+1K+2K)}$$

$$= \underline{\frac{5}{4}\ mA}$$

- FOR I_1:

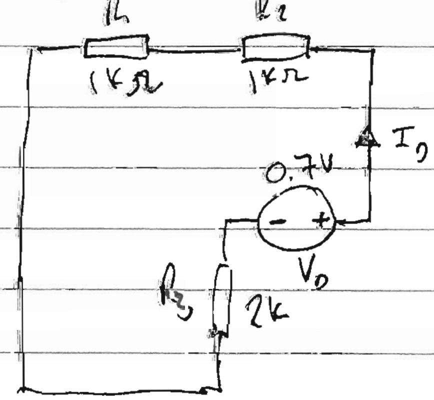


$$I_D = -1mA \cdot \frac{3K\Omega}{1K\Omega + 3K\Omega}$$

$$= \underline{-\frac{3}{4}\ mA}$$

- DIODE CURRENT DUE TO I_1 IS OPPOSITE TO DIODE CURRENT DUE TO V_1 ∴ NEGATIVE.

- FOR V_0:



$$I_D = -\frac{V_D}{1K\Omega + 1K\Omega + 2K\Omega}$$

$$= -\frac{0.7}{4K\Omega}$$

$$= \underline{-0.175mA}.$$

THEREFOR TOTAL CURRENT IN DIODE :

$$I_D = I_{D(V_1)} + I_{D(V_2)} + I_{D(V_3)}$$

$$= 1.25mA + (-0.75mA) + (-0.175mA)$$

$$= \underline{\underline{0.325mA}}$$

1b. $I_D = 0$ ... So I_1 (NOW VARIABLE IS USED TO CANCEL THE 0.325mA FROM PART A.

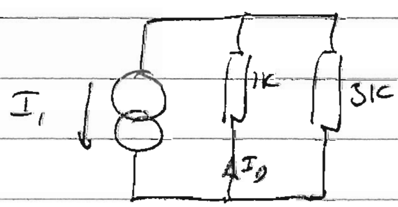
THE CURRENT THAT MUST BE CANCELED IS

$$I_{D\,(CANC)} = I_{D(V_1)} + I_{D(V_3)}$$

$$= 1.25mA + (-0.175mA).$$

$$= 1.075mA.$$

FOR SUPERPOSITION OF I_1 WITH DIODE CONDUCTING...



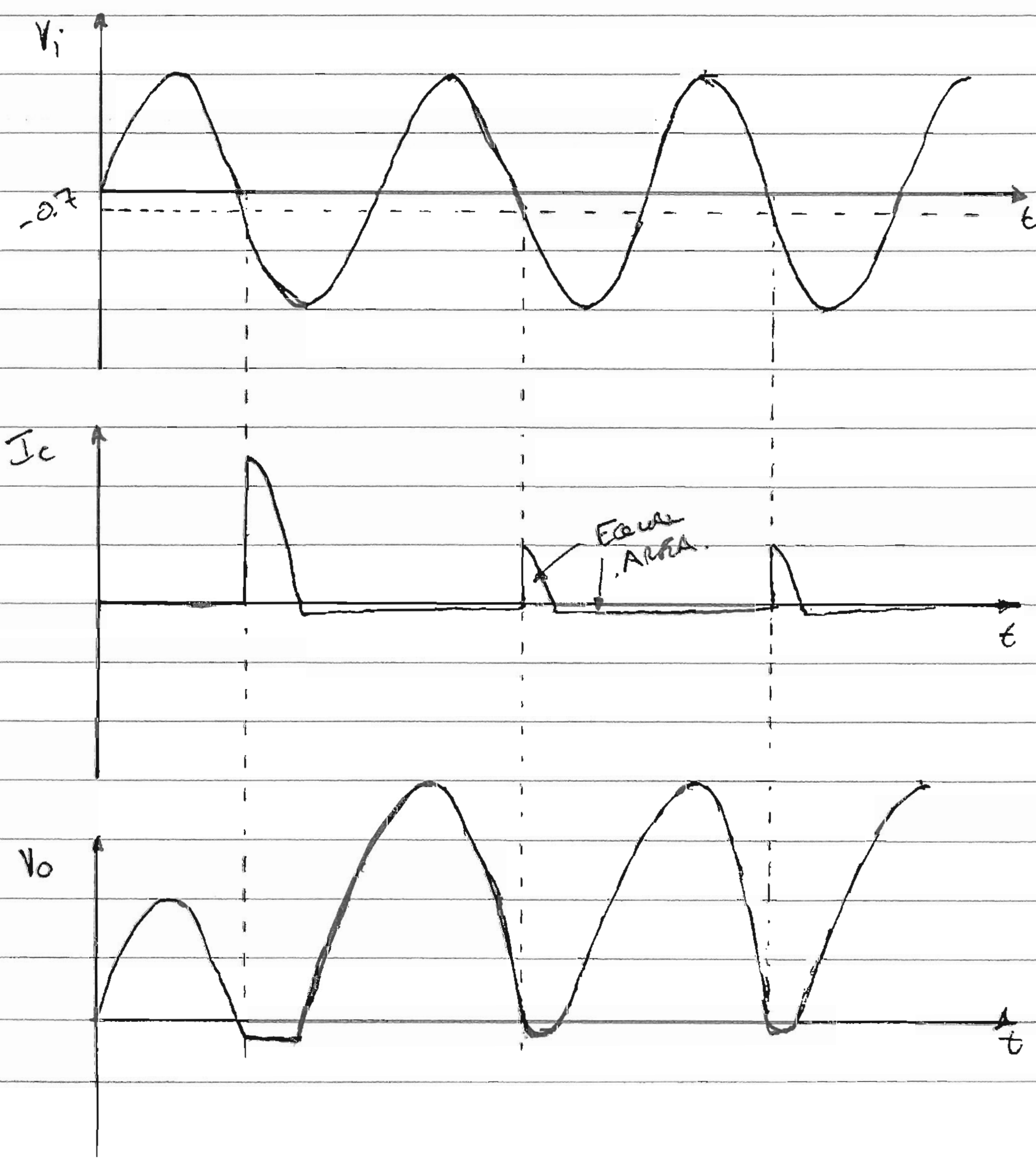
I_D DUE TO I_1 = 1.075mA
BUT ONLY $\frac{3}{4}$ OF I_1 IS FLOWING AS I_D SO...

$$I_1 = \frac{4}{3}(1.075mA)$$

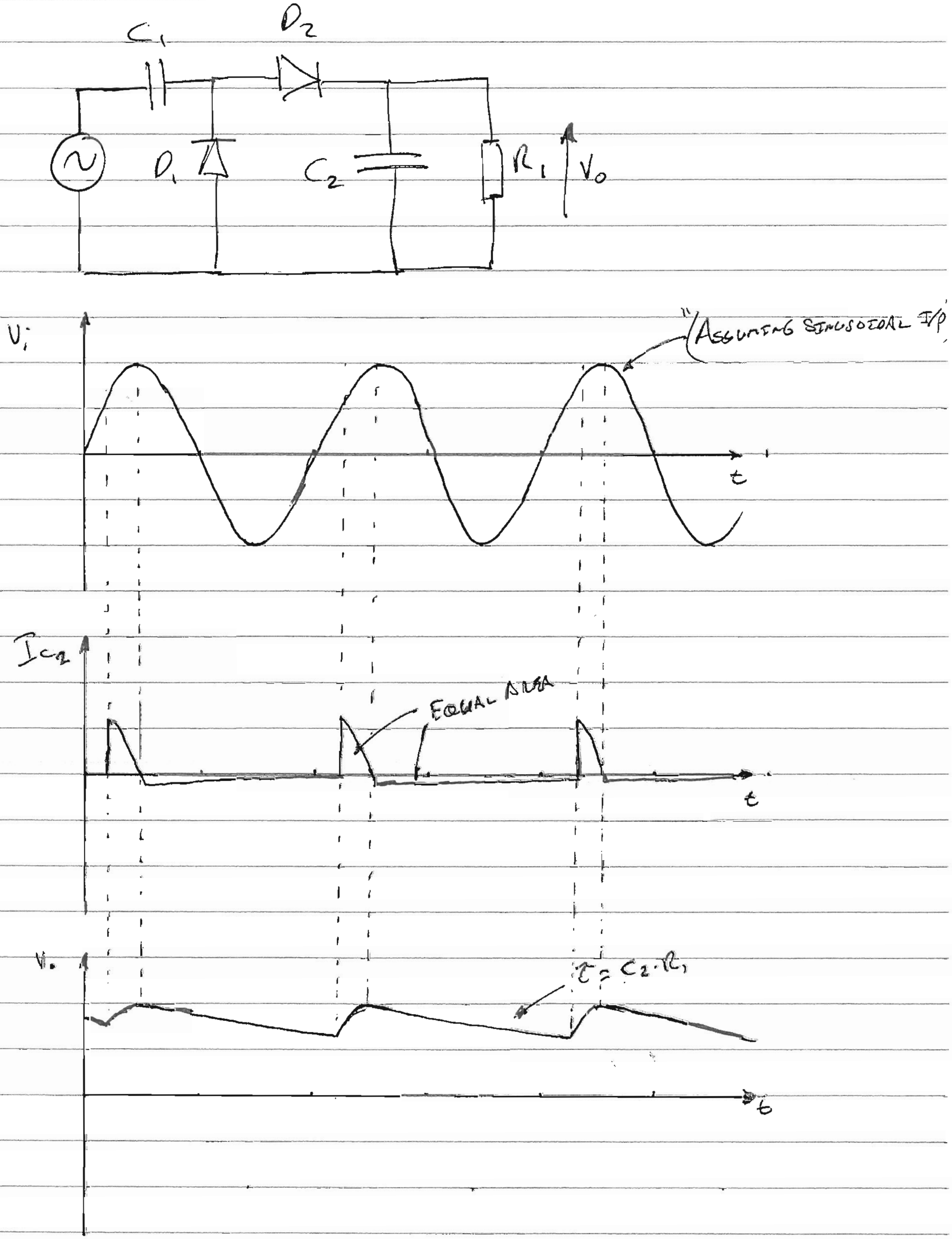
$$= \underline{\underline{1.43\,mA}}$$

C.i)
- POSITIVE VOLTAGE CLAMP.
- INPUT V_1 IS SINUSOID CENTERED ON ZERO V.
- OUTPUT VOLTAGE V_o TAKEN ACROSS R_1
  - MIN. −0.7V (CAUSED BY CLAMPING ACTION OF DIODE IN THIS CIRCUIT.
- WHEN I/P TRIES TO FALL BELOW −0.7V DIODE CONDUCTS AND CHARGE ACCUMULATES ONTO R.H. PLATE OF C_1 INCREASING ITS POTENTIAL W.R.T THE LEFT PLATE.
- BECAUSE R_1 IS LARGE C_1 DISCHARGES SLOWLY THROUGH IT. CONSEQUENTLY CAPACITOR VOLTAGE CANNOT CHANGE QUICKLY
- AS V_i RISES V_o RISES TOO BUT $V_o > V_i$ BY WHATEVER VALUE THE CAPACITOR HAS CHARGED UP TO.

ii)



1d.



IF SOLUTION GIVEN WITH
CLAMP O/P AS I/P TO P.D
FULL MARKS MAY BE OBTAINED
FOR A CONSISTENT ANSWER.

2 (a) <u>Saturation regime</u> – both emitter-base and base-collector junctions are forward biased which inject minority charge into the base. This results in a large base current and no gain.

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<u>Normal regime</u> – emitter-base forward biased which injects electrons into the base. The base-collector is reverse biased in order to collect the electrons from the emitter

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(b)

4

Minimum V_{CE} at $I_c = 2\,mA$ is $\sim 0{\cdot}8\,V$ (edge or normal operation).

(c) Current gain $= \dfrac{\Delta I_c}{\Delta I_B} = \dfrac{2\,mA}{20\,\mu A} = 100$

(from figure 2).

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(d) From the equations given

$$\text{gain} = \beta = \frac{\alpha}{1-\alpha} \quad \text{and} \quad \alpha = \gamma B$$

where B is the base transport factor and γ is the emitter injection efficiency.

$$B = 1 - \frac{1}{2}\left(\frac{l_B}{L_e}\right)^2 , \qquad \gamma = 0.997$$

$$\beta = 100 = \frac{\alpha}{1-\alpha}$$

$$\therefore \quad 100 - 100\alpha = \alpha \quad \Rightarrow \quad \alpha = \frac{100}{101} = \underline{0.99}$$

$$\text{hence} \quad \gamma B = 0.99 \quad \Rightarrow \quad B = \frac{0.99}{0.997} = \underline{0.993}$$

$$\therefore \quad 0.993 = 1 - \frac{1}{2}\left(\frac{l_B}{L_e}\right)^2$$

$$\frac{1}{2}\left(\frac{l_B}{L_e}\right)^2 = 7 \times 10^{-3}$$

$$\therefore \quad l_b = \left(2 \times 7 \times 10^{-3}\right)^{\frac{1}{2}} \times 1.5 \times 10^{-6}$$

$$= \underline{0.18\ \mu m}$$

8

(e) $$\text{new } \alpha' = 0.992 \times 0.993$$ (base transport factor not affected).

$$= 0.985$$

$$\text{new gain } \beta' = \frac{0.985}{1-0.985}$$

$$= \underline{65.9}$$

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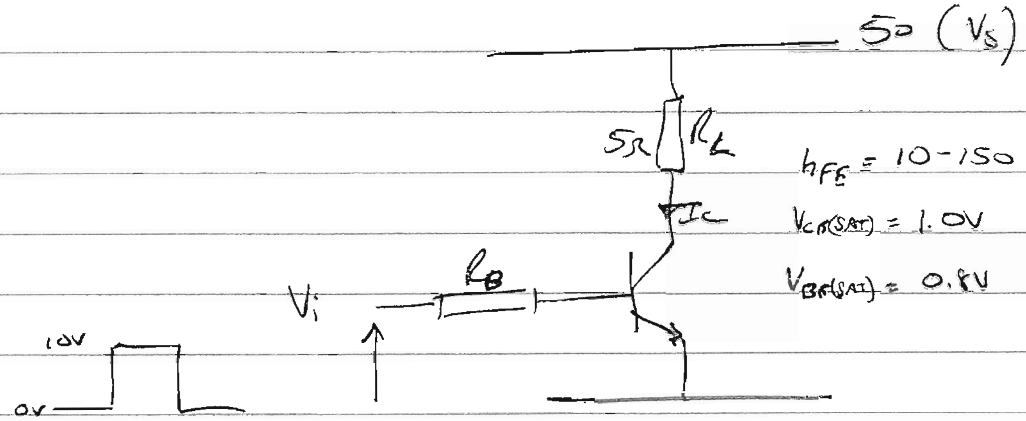
3a.



$h_{FE} = 10 - 150$

$V_{CE(SAT)} = 1.0V$

$V_{BE(SAT)} = 0.8V$

i) LOAD CURRENT:

$$I_C = \frac{V_S - V_{CE(SAT)}}{R_L} = \frac{50 - 1.0}{5} = \underline{\underline{9.8A}}$$

ii) POWER IN LOAD:

$$P_L = I^2 R_L = (9.8^2) \cdot 5 = \underline{\underline{480.2 \text{ WATTS}}}$$

iii) POWER IN SWITCH:

$$P_S = V_{CE(SAT)} \cdot I_C = 1.0 \times 9.8 = \underline{\underline{9.8 \text{ WATTS}}}$$

iv) POSSIBLE BASE CURRENTS

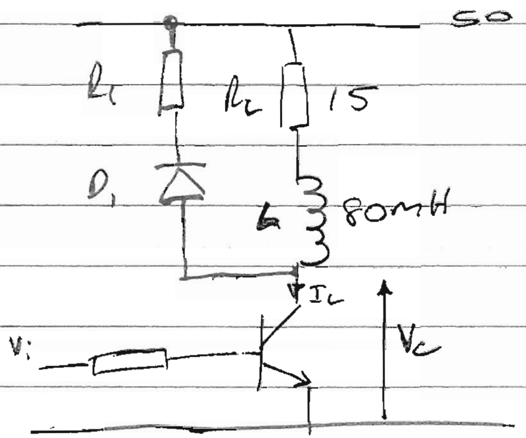
$$I_{B(MAX)} = \frac{I_C}{h_{FE(MIN)}} = \frac{9.8A}{10} = \underline{\underline{0.98A}}$$

$$I_{B(MIN)} = \frac{I_C}{h_{FE(MAX)}} = \frac{9.8A}{150} = \underline{\underline{65.3\dot{3} mA}}$$

v) R_B MAX:

$$R_B = \frac{V_i - V_{BE(SAT)}}{I_{B(MAX)}} = \frac{10 - 0.8}{0.98} = \underline{\underline{9.38\Omega}}$$

3b i)



ADDITIONS IN 26 iv ARE IN RED.

ii) INDUCTOR CURRENT:

I_L BEFORE = I_L AFTER SO..

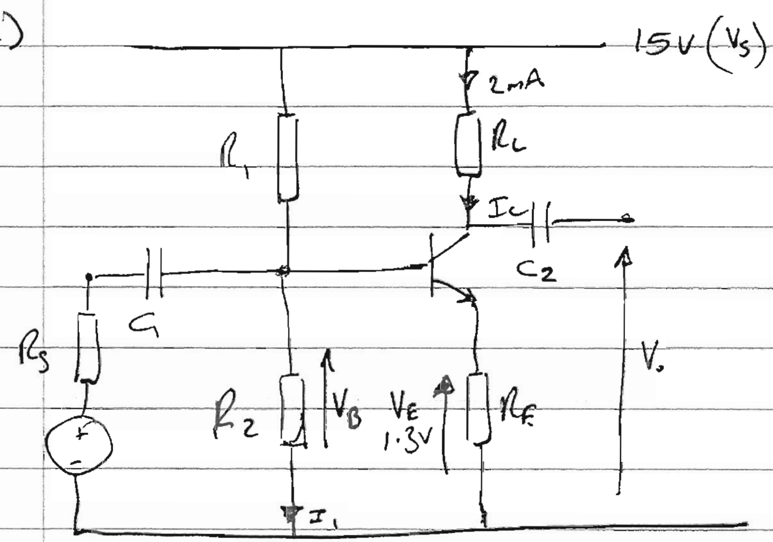
$$I_L = \frac{V_S - V_{CE(SAT)}}{R_L} = \frac{50 - 1}{15} = \underline{3.266\dot{6}\,A}$$

iii) ENERGY STORED:

$$E = \frac{1}{2} L I^2 = \frac{1}{2} \cdot 80 \times 10^{-3} \cdot (3.266\dot{6})^2$$

$$= \underline{0.4266 \text{ JOULES.}}$$

c)



- MAX SIGNAL SWING ON COLLECTOR.
- $f_{-3dB(\text{low})} = 15Hz$.

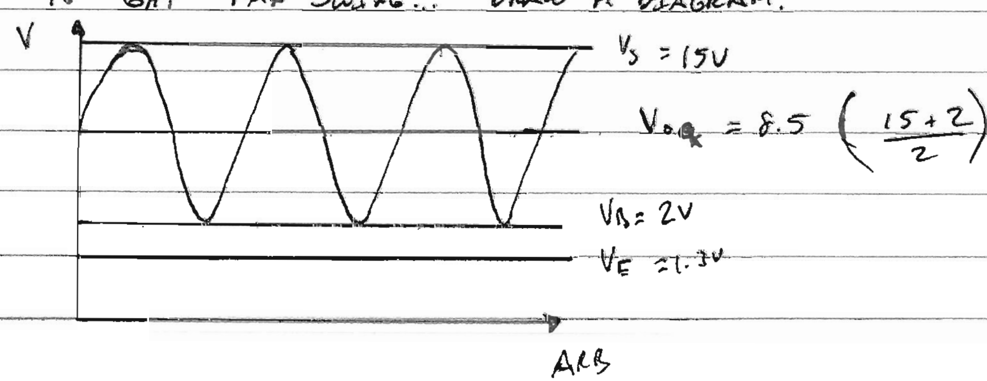
- $V_{BE} = 0.7V$
- $h_{FE} >> 1 \therefore I_C = I_E$
- $I_B = 0$.

- IF $I_C = I_E$ AND $I_C = 2mA$ THEN $R_E = V/I = \frac{1.3}{2mA} = \underline{\underline{650\Omega}}$
- $V_{R_2} = 2V \because V_E + V_{BE} = 1.3 + 0.7 = 2V$.
- CHOOSE $I_1 = 1mA$ (SAY)

  - $R_2 = V/I = \frac{2V}{1mA} = \underline{\underline{2k\Omega}}$

  - $R_1 = \frac{V_S - V_B}{I_1} = \frac{15-2}{1mA} = \underline{\underline{13k\Omega}}$

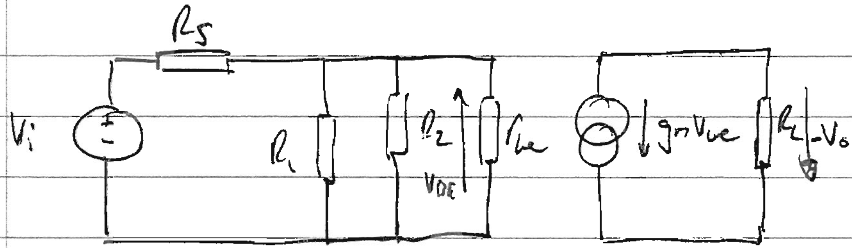
- TO GET MAX SWING... DRAW A DIAGRAM.



$V_{OQ} = 8.5$ FROM DIAGRAM. SO

$$R_L = \frac{V_S - V_{OQ}}{I_C} = \frac{15 - 8.5}{2mA} = \underline{\underline{3.25k\Omega}}$$

d) SINCE R_E IS BYPASSED IT IS IGNORED.



$//$ = IN PARALLEL

$$V_{BE} = V_i \cdot \frac{R_1 // R_2 // r_{be}}{R_S + R_1 // R_2 // r_{be}} \qquad (1)$$

$$V_o = -g_m V_{be} R_L \qquad (2)$$

(1) → (2)

$$V_o = -g_m V_i \frac{R_1 // R_2 // r_{be}}{R_S + R_1 // R_2 // r_{be}} \cdot R_L$$

$$V_o / V_i = -g_m \frac{R_1 // R_2 // r_{ce}}{R_S + R_1 // R_2 // r_{ce}} \cdot R_L .$$

4 (a)

(i) Conductors – There are many free electrons which are able to conduct current when an electric field is applied (e.g. metals)

Insulators – The electrons are tightly bound into the crystal lattice and are not free to move. Therefore no conduction is possible (e.g. ceramics, plastics.) 2 2

(ii) Motion of electrons is random, due to thermal energy. The electrons scatter from imperfections but no net movement in any direction occurs. 1

(b)

Drift – charge carriers receive a force from an applied electric field and move or "drift" causing a current to flow. 2

Diffusion – carriers can move from a high concentration to a low concentration due to their random thermal motion. No electric field is required but system must be above 0K. 2

(c) From the equations given

$$R = \frac{\rho l}{A} = \frac{1{\cdot}8 \times 10^{-8} \times 1}{1{\cdot}5 \times 10^{-6}}$$

3

$$= \underline{0{\cdot}012\ \Omega}$$

(d) As the temperature is increased the lattice atoms vibrate more and more. The electrons scatter from these vibrations (phonons) reducing their mobility and increasing the resistivity and resistance

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(e) $\alpha = 4\times10^{-11}\ \Omega m K^{-1}$

change in resistivity $\rho_2(620K) - \rho_1(300K) = \alpha\Delta T$

$= 4\times10^{-11} \times 320 = 1.28\times10^{-8}\ \Omega m$

fractional increase $= \dfrac{\rho_1 - \rho_2}{\rho_1} = \dfrac{1.28\times10^{-8}}{1.8\times10^{-8}}$

$= 0.71$

This represents the same fractional change in resistance

$\therefore$ Change in resistance $= 0.012 * 0.71$

$= \underline{8.52\times10^{-3}\ \Omega}$

6

(f) An intrinsic semiconductor has almost no carriers at low temperature. As the temperature is increased electron hole pairs are produced by breaking the bonds of the crystal. This causes more carriers and hence reduced resistance. The effect is far stronger than the reduced mobility experienced at high temperatures.

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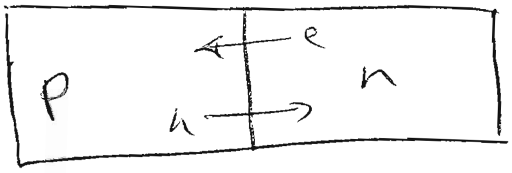
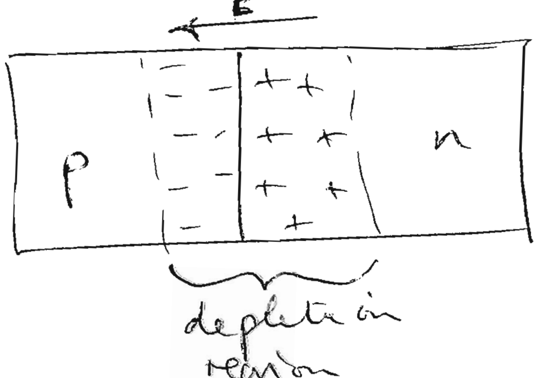
5 (a)



When the two regions are brought together electrons from the n-region diffuse into the p region. Similar for holes from the p-region. The diffusing carriers leave behind positive donors and negative acceptors in the n and p regions respectively near ~~the~~ junction.



The region close to the junction is "depleted" of free carriers giving rise to the "space charge" as shown. This space charge causes an electric field which sets up a drift flow of the carriers to exactly balance the diffusion and an equilibrium is set up. A built-in potential arises from this field. 8

(b) $$W = \left[\frac{2\epsilon V_0}{q}\left(\frac{N_a + N_d}{N_a N_d}\right)\right]^{\frac{1}{2}} = \left[\frac{2\epsilon V_0}{q}\left(\frac{1 + \frac{N_d}{N_a}}{N_d}\right)\right]^{\frac{1}{2}}$$

for $N_a \gg N_d$ $$W = \left[\frac{2\epsilon V_0}{q}\left(\frac{1}{N_d}\right)\right]^{\frac{1}{2}}$$ 4

For overall charge neutrality the donors and acceptors in each depletion region must be equal. If $N_a \gg N_d$ then a smaller depletion distance is required to uncover the same charge as the lower doped side. 2

(c) V_o is the built-in potential in (b) above. Since reverse bias adds to this potential, the equation simply becomes.

$$W = \left[\frac{2\epsilon (V_o + V_r)}{q} \left(\frac{N_a + N_d}{N_a N_d}\right)\right]^{\frac{1}{2}}$$

where V_r is the applied reverse bias. 3

(d) Use the simplified version (since $N_d >> N_a$)

$$\therefore \quad W = \left(\frac{2\epsilon (V_o + V_r)}{q} \cdot \frac{1}{N_a}\right)^{\frac{1}{2}}$$

at pinch-off $W = 0.8\ \mu m$

$$\therefore \quad (V_o + V_r) = \frac{(0.8\times10^{-6})^2 \times 1.6\times10^{-19} \times 1\times10^{22}}{2 \times 12 \times 8.85 \times 10^{-12}}$$

$$= \underline{4.8\,V}$$

Assuming $V_o \approx 0.7\,V$, A applied gate voltage would be $\underline{\approx 4.1\,V}$

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(e) Higher electron mobility will mean higher velocity which results in higher frequency operation. Also higher current results for the same geometry as a Si FET.

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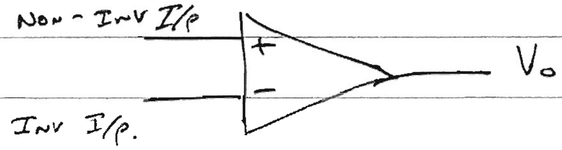
6ai)



ii)

$Z_{in} \sim 10^{6} \rightarrow 10^{12}\ \Omega$

$Z_{out} \sim < 50\ \Omega$

$A_v \sim 10^{5} \rightarrow 10^{9}$

iii) $V_o = A_v (V^+ - V^-)$

V_o - OUTPUT VOLTAGE TERMINAL

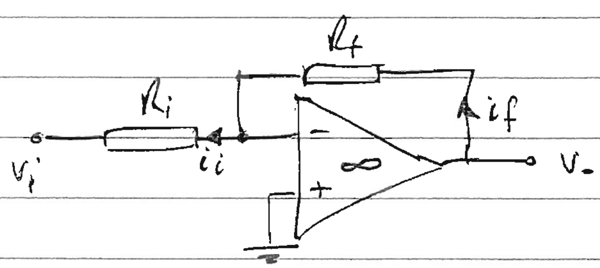
A_v - OPEN LOOP GAIN.

V^+ - NON INV I/P TERMINAL

V^- - INV " " .

bi) INVERTING VOLTAGE AMPLIFIER.

ii)



SUM CURRENTS AT V^-:

$$i_f = i_i$$

$$\frac{V_o - V^-}{R_f} = \frac{V^- - V_i}{R_i}$$

$V^+ = 0$ & $V^+ = V^-$ $\therefore$ $(\because A_v \rightarrow \infty)$

$$\frac{V_o - 0}{R_f} = \frac{0 - V_i}{R_i}$$

$$\frac{V_o}{R_f} = \frac{-V_i}{R_i}$$

$$V_o R_i = -V_i R_f$$

$$V_o/V_i = -R_f/R_i$$

iii) FROM ii :

$$\frac{V_o - V^-}{R_f} = \frac{V^- - V_i}{R_i}$$

NOW $A_V \neq \infty$ SO $V^- \neq V^+$ FIND V^+

$$(V_o - V^-) R_i = (V^- - V_i) R_f$$

$$V_o R_i - V^- R_i = V^- R_f - V_i R_f$$

$$-V^-(R_i + R_f) = -V_i R_f - V_o R_i$$

$$V^- = \frac{V_i R_f + V_o R_i}{R_i + R_f} \quad (1)$$

$$(1) \rightarrow \quad V_o = A_V(V^+ - V^-) \qquad (V^+ = 0 \ldots)$$

$$V_o = A_V\left(0 - \frac{V_i R_f + V_o R_i}{R_i + R_f}\right)$$

AFTER SOME TRANSPOSITION...

$$V_o/V_i = \frac{-A_V R_f}{R_i + R_f + A_V R_i}$$

TO GET FINAL FORM... $\div$ TOP AND BOTTOM BY A_v.

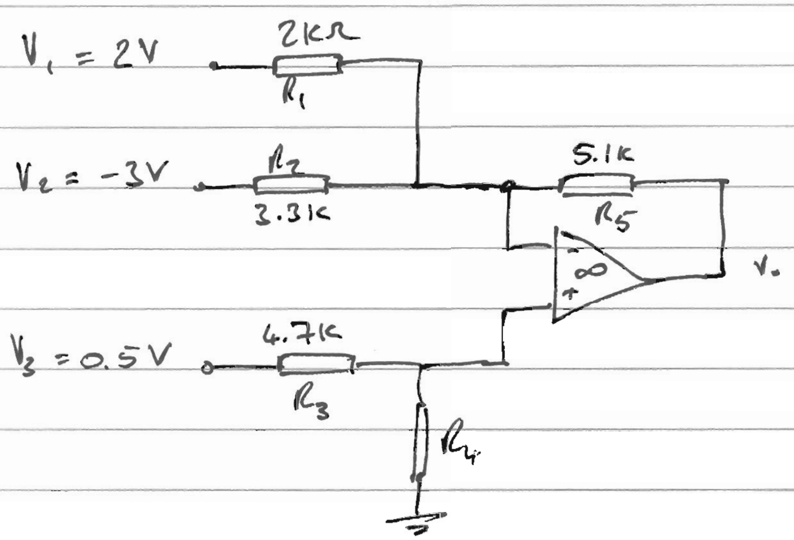
$$V_o/V_i = \frac{-R_f}{\frac{1}{A_v}\left[R_i + R_f\right] + R_i} \qquad \text{Q.E.D}$$

ii) USE ① ON Pg 13 TO FIND V_o IF $R_4 = \cancel{1}k\Omega$

$$V_o = -0.0166 + 4.469\sin(\omega t + \phi)$$

- O/P DUE TO AC = 4.469 V (MAGNITUDE)
- O/P DUE TO AC = $\phi°$ (PHASE)
  - THE AC INPUT IS TO THE NON INVERTING PIN SO NO PHASE SHIFT IS EXPECTED.

6c i)



V_o DUE TO V_1 :

$$V_o = -\frac{R_5}{R_1} \cdot V_1 = \frac{-5.1}{2} \cdot 2 = \underline{\underline{-5.1V}} \quad 1$$

V_o DUE TO V_2 :

$$V_o = -\frac{R_5}{R_2} \cdot V_2 = \frac{-5.1}{3.3} \cdot -3 = 4.63\dot{6} \quad 1$$

V_o DUE TO V_3 (DC. ONLY).

$$V_o = V_3 \cdot \frac{R_4}{4.7 + R_4} \cdot \frac{5.1 + 2/\!/3.3}{2/\!/3.3} \; 1 = -(-5.1 + 4.63\dot{6}) \quad 1^*$$

$$0.5 \cdot \frac{R_4}{4.7+R_4} \cdot \frac{5.1 + 1.2453}{1.2453} = +0.464.$$

$$\frac{R_4}{4.7+R_4} \cdot 2.547 = 0.464$$

$$2.547 R_4 = 2.1808 + 0.464 R_4$$

$$2.547 R_4 - 0.464 R_4 = 2.1808$$

$$R_4 = \frac{2.1808}{2.083} = \underline{\underline{1.0469\ k\Omega}}$$

1

* THIS MARK IS FOR FIGURING OUT THAT V_o DUE TO V_1 AND V_o DUE TO V_2 MUST SUM TO EQUAL V_o DUE TO V_3. IT IS NOT NECESSARILY RELATED TO THIS EQUATION AS MANY WAYS OF SHOWING THIS UNDERSTANDING EXIST.

ii) USE:

$$V_o = -\frac{R_5}{R_1} V_1 + -\frac{R_5}{R_2} V_2 + V_3 \cdot \frac{R_4}{R_3 + R_4} \cdot \frac{R_5 + R_1 // R_2}{R_1 // R_2}$$

WITH $R_4 = 1k\Omega$. TO YIELD (FOR DC)

$$V_o = \frac{-5.1}{2} \cdot 2 + \frac{-5.1}{3.3} \cdot -3 + 0.5 \cdot \frac{1}{4.7+1} \cdot \frac{5.1 + 1.2453}{1.2453}$$

$$= (-5.1) + (+4.63\dot{6}) + (0.44696)$$
$$= \underline{\underline{-0.01704\ V}}$$

(FOR AC.)

$$V_o = 5 \cdot \frac{1}{4.7+1} \cdot \frac{5.1 + 1.2453}{1.2453} = \underline{\underline{4.4696\ V}}$$

$$\therefore \quad V_o = -0.01704 + 4.4696 \sin(\omega t + \phi)$$

- O/P DUE TO AC = 4.4696 V (MAG)
- O/P DUE TO AC = $\phi°$ (PHASE)
- AC IS I/P TO NON-INV SO NO PHASE SHIFT.