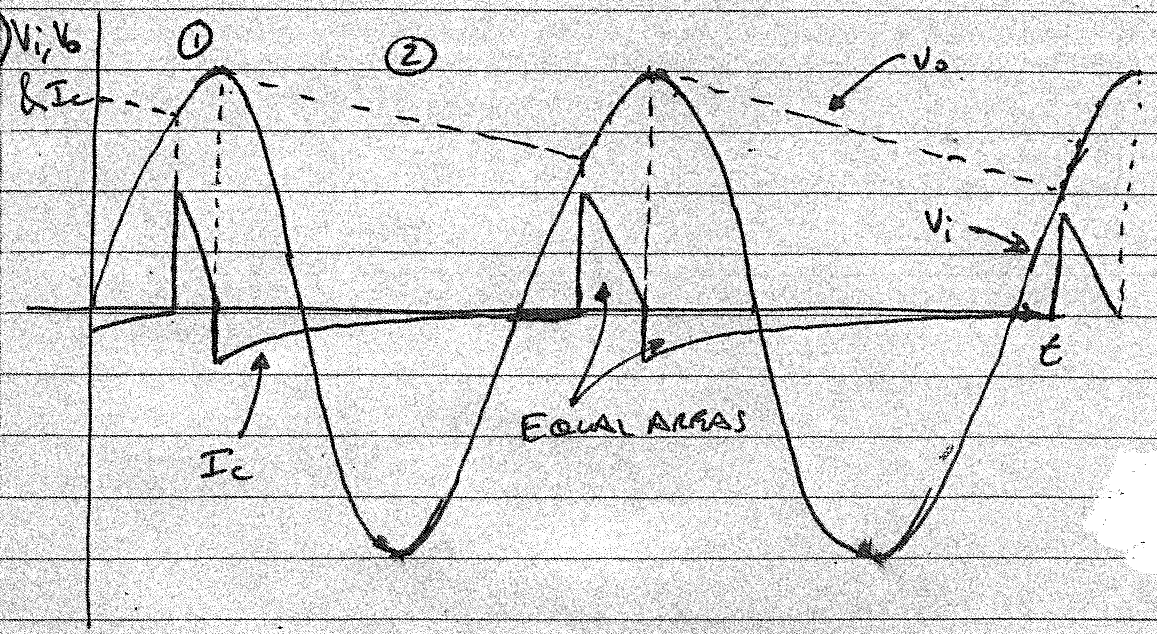
EEE 118 2014 – 2015

1(a.i)



1 – MARK FOR NEARLY RIGHT

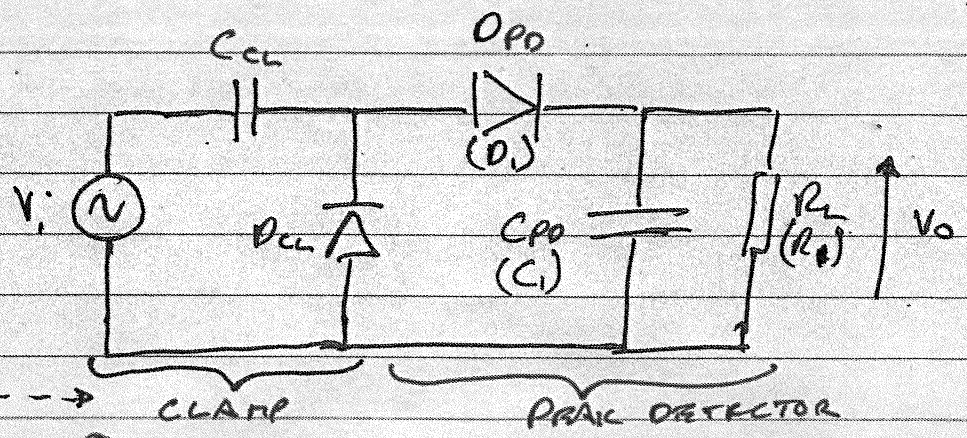
2 – FOR "PERFECT". PERFECT ONLY IF SHAPE <u>AND</u> TIME ALIGNMENT DEMONSTRATE UNDERSTANDING.

ii) ① – $V_i > V_o$ ∴ DIODE CONDUCTS AND C_1 CHARGES THROUGH DIODE, D_1. CONDUCTION STOPS WHEN V_i STARTS TO FALL AS THE DIODE CURRENT FALLS TO ZERO BECAUSE THE CAPACITOR IS NO LONGER CHARGING FROM THE INPUT SIGNAL.

AT LEAST 2 GOOD POINTS FROM THIS OR SIMILAR SENSIBLE COMMENTS.

② – $V_i < V_o$. THE DIODE IS REVERSE BIASED. ONLY A SMALL LEAKAGE CURRENT FLOWS IN D_1. C_1 DISCHARGES THROUGH R_1. PROVIDED C_1 IS CAPABLE OF STORING MUCH MORE CHARGE THAN R_1 WILL CONDUCT OVER THE PERIOD OF THE INPUT WAVEFORM, THE CHANGE IN V_o DUE TO C_1 DISCHARGING CAN BE APPROXIMATED AS LINEAR ALTHOUGH IT IS ACTUALLY EXPONENTIAL.

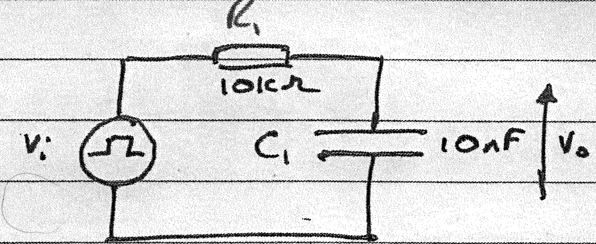
1b i)

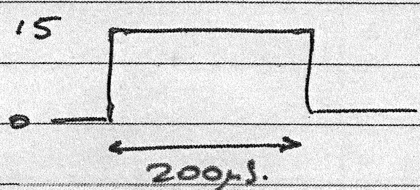


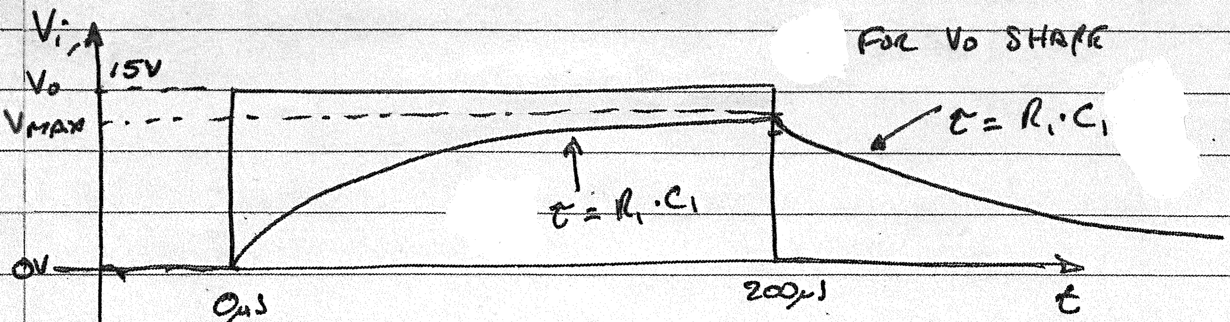
① - FOR CAPACITOR IN CORRECT PLACE
① - " DIODE " " "
① - " PEAK DETECTOR CORRECTLY PLACED.

iii) THE ADDITIONAL CIRCUIT IS A VOLTAGE CLAMP

1c)







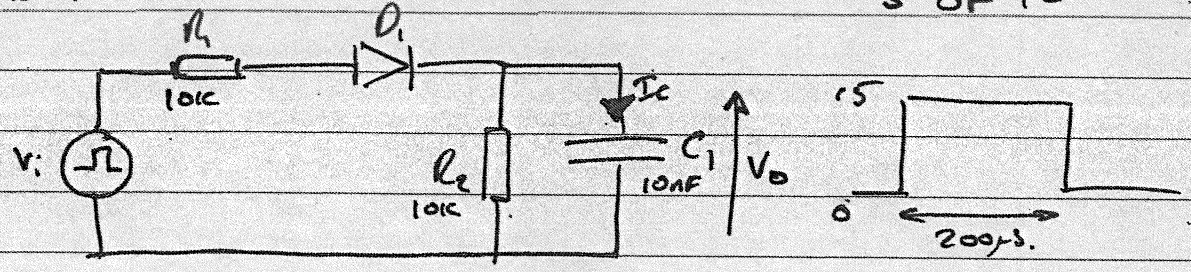
V_{MAX} ... $V_o = V_i\left(1 - e^{-t/\tau}\right)$

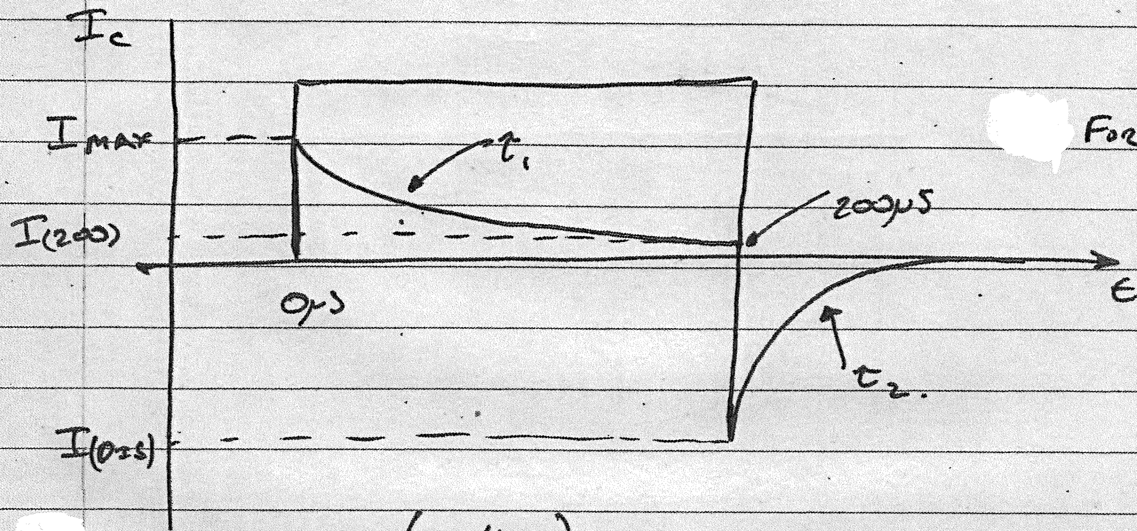
$= 15\left(1 - e^{\left(-\frac{200\times10^{-6}}{10\times10^{3}\cdot10\times10^{-9}}\right)}\right)$

$= 15\left(1 - 0.13533\right)$

$= \underline{12.9696\ V} \sim \underline{12.97V}$

1d.





FOR I_C SHAPE

$$\tau_1 = (R_1 // R_2) \cdot C_1 = \frac{10K \cdot 10K}{10K + 10K} \cdot 10nF = \underline{\underline{50\mu S}}$$

$$\tau_2 = R_2 \cdot C_1 = 10K \cdot 10nF = \underline{\underline{100\mu S}}$$

$$I_{MAX} = \frac{V_{in}}{R_1} = \frac{15}{10K} = \underline{\underline{1.5mA}}$$

BECAUSE C_1 LOOKS LIKE A SHORT CIRCUIT WHEN IT IS FULLY DISCHARGED AND BEFORE IT HAS CHARGED APPRECIABLY.

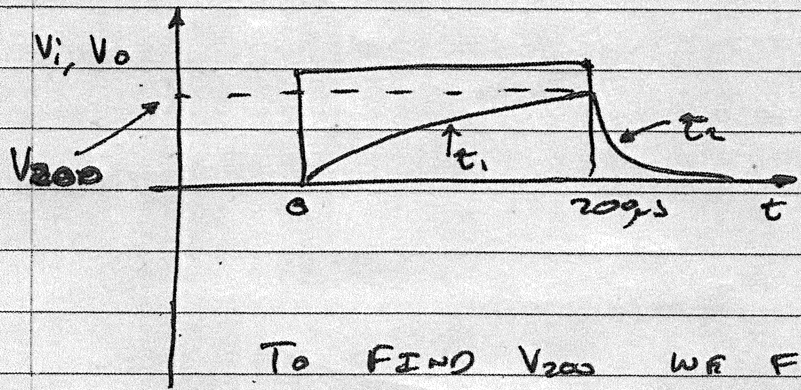
$$I_{(200)} = I_{MAX} \cdot e^{-t/\tau_1}$$

$$= 1.5 \times 10^{-3} \cdot e^{\left(-\left(\frac{200 \times 10^{-6}}{50 \times 10^{-6}}\right)\right)}$$

$$= \underline{\underline{27.47 \mu A}}$$

I_{DIS} ... IS HARDER, WE NEED TO KNOW THE VOLTAGE V_O GOT TO @ 200µS. IT IS NOT THE SAME AS PART c.

1d) CONTINUED...



TO FIND V_{200} WE FIRST NEED V_{MAX}. V_{MAX} IS THE BIGGEST VOLTAGE V_o CAN GET TO IN FIGURE 1b. IT IS THE POTENTIAL DIVISION OF V_i BY R_1 & R_2.

$$V_{MAX} = V_i \cdot \frac{R_2}{R_1+R_2} = 15 \cdot \frac{10}{10+10} = \underline{\underline{7.5V}}$$

$$\therefore \; V_{200} = V_{MAX} \cdot \left(1 - e^{-t/\tau_1}\right)$$

$$= 7.5 \cdot \left(1 - e^{-\left(\frac{200\times10^{-6}}{50\mu s}\right)}\right)$$

$$= 7.5 \cdot 0.9817$$

$$= \underline{\underline{7.363V}}$$

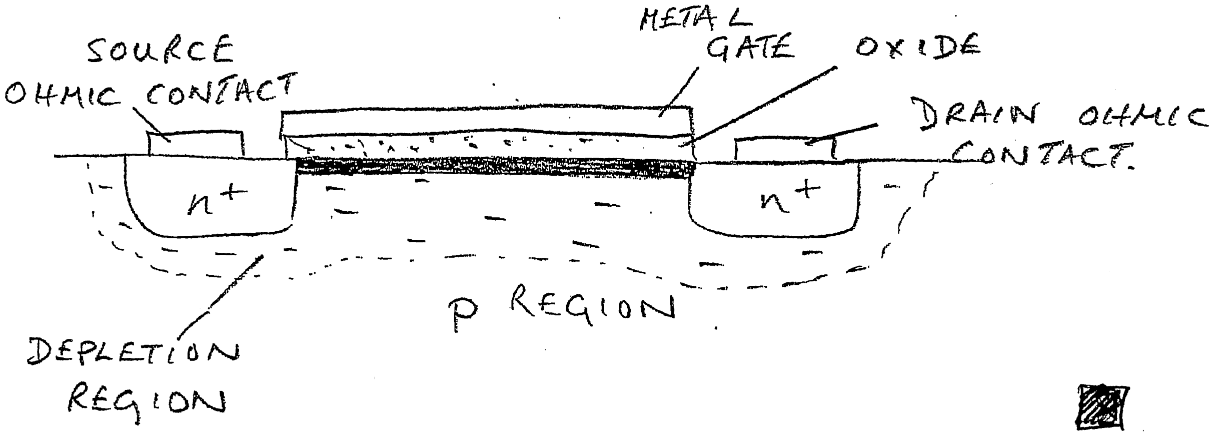
← SO IT NEARLY MAKES IT ALL THE WAY, BUT NOT QUITE.

$$\text{SO } I_{(DIS)} = \frac{7.363}{R_2} = \frac{7.363}{10k} = \underline{\underline{736.26\mu A}}$$

EEE118 SOLUTIONS

2014-15

2. (a) n-channel MOSFET

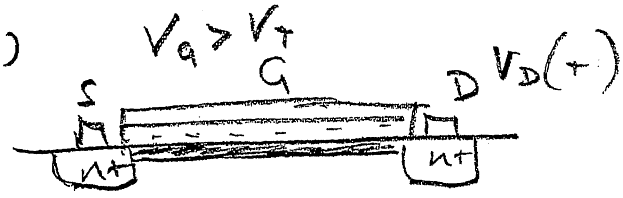


[redacted]

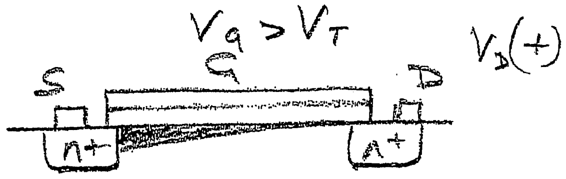
(b) With source and drain grounded, as gate voltage is increased (+) depletion region extends into p-region to uncover negative acceptor charge to balance positive gate charge. Eventually the depletion region can no longer supply enough balancing charge and electrons are formed at the oxide/semiconductor interface to form a conducting bridge between the source and drain

[redacted]

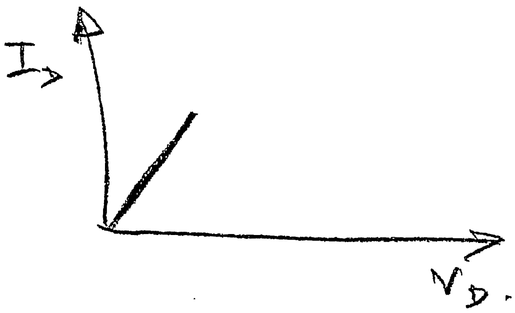
(c)

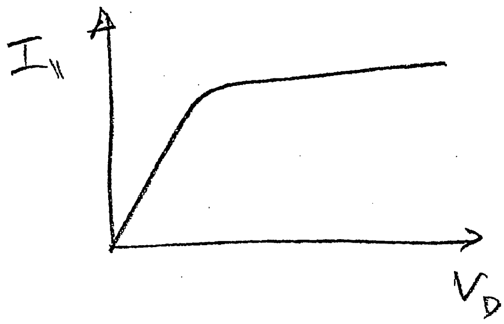


$V_D \sim 0$



$V_D >$ ~~threshold~~ voltage



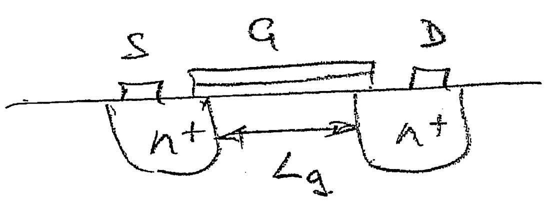


At $V_D \sim 0$, V_G exceeds the threshold voltage, V_T, and a conducting channel is formed.

2(c) (continued)

The current I_D rises linearly since the channel behaves as a resistor. As $(V_D - V_G) \simeq V_T$ the channel "pinches off" at the drain end and the resistance of the channel increases (slope reduces). Further increase in V_D pushes the pinch-off region ~~further~~ towards the source. Current saturates since it is now controlled by rate of lateral injection of electrons into the depletion region.

(d)



Cut-off frequency $= 15\,GHz = \dfrac{1}{2\pi\tau}$

$\therefore$ transit time under gate

$$= \tau = \frac{1}{2\pi \times 15 \times 10^9} = \underline{10.6 \times 10^{-12}\,s}$$

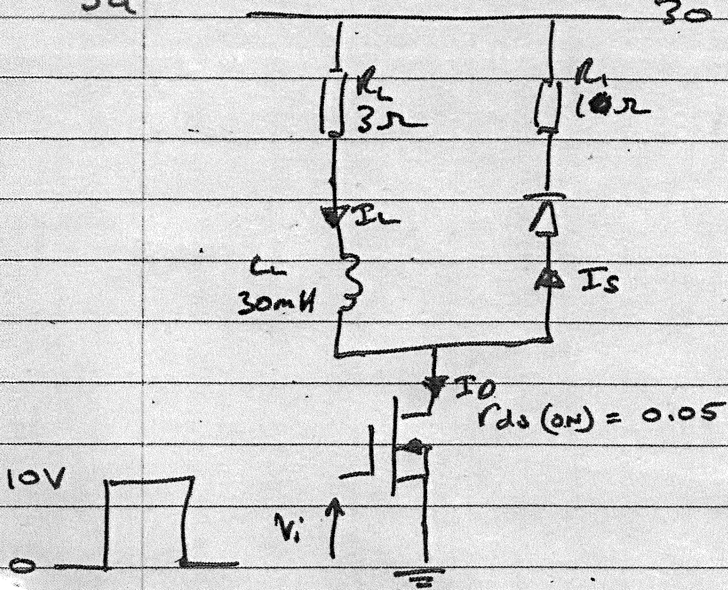
$\therefore$ gate length required

$$L_g = 1 \times 10^5 \times 10.6 \times 10^{-12}$$

$$= 1.06 \times^{-6}$$

$$= \underline{1.06\,\mu m}$$

3a



i) $I_L = \dfrac{V_S}{R_L + r_{ds(on)}} = \dfrac{30}{3.05}$

$I_L = \underline{9.8361\,A}$

ii) $E_{LL} = \frac{1}{2} L I^2$

$= \frac{1}{2} \cdot 30\times10^{-3} \cdot 9.8361\,A$

$= \underline{147.54\ mJ}$

iii) $P_{LOAD} = I^2 R_L = 9.8361^2 \cdot 3 = \underline{290.25\,W}$

iv) $P_{SWITCH} = I^2 r_{ds(on)} = 9.8361^2 \cdot 0.05 = \underline{4.837\ W}$

v) DIRECTLY AFTER SWITCH OFF $I_D \to 0$. AND I_L DOES NOT CHANGE SO $I_S = I_L$.

vi) $V_{DS} = 30 + I_S R_1 + 0.7$

POWER SUPPLY...

$V_{DS} = 30 + 9.8361 \cdot 1 + 0.7$

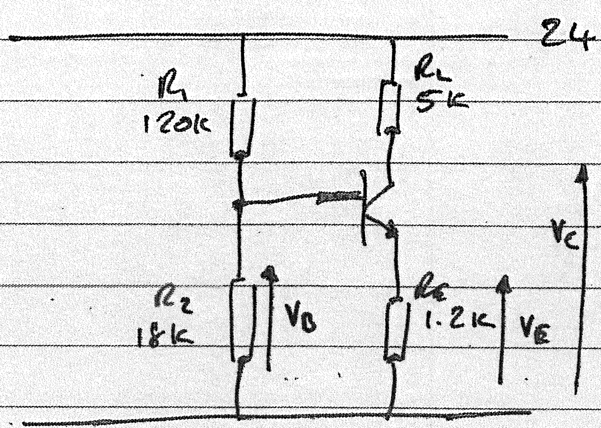
$= \underline{40.5361\,V}$

6i) $V_B = \dfrac{24 \cdot R_2}{R_1 + R_2} = \dfrac{24 \cdot 18k}{120k + 18k}$

$= \underline{3.1304\,V}$

$V_E = V_B - 0.7$

$= \underline{2.43043\ V}$



3b i) CONTINUED...

$$I_E = \frac{V_E}{R_E} = \frac{2.43043}{1.2\,k\Omega} = \underline{2.0254\ mA}$$

ASSUMING $I_B = 0$ ($h_{FE} \gg 1$), $I_C = I_E$

SO

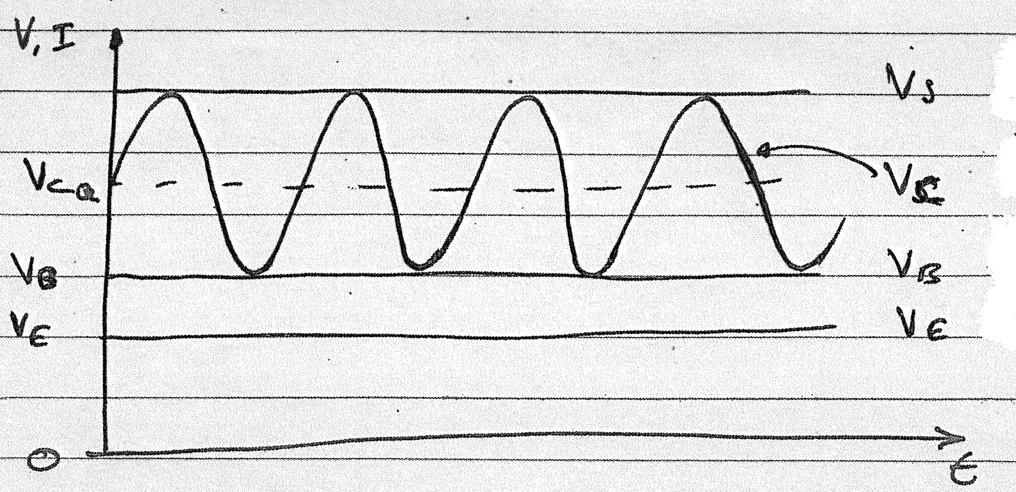
$$V_C = V_S - I_C \cdot R_L$$
$$= 24 - 2.0254 \cdot 5$$
$$= \underline{13.873\,V}$$

$$g_m = \frac{e\,I_C}{kT} = \frac{1.6\times10^{-19} \cdot 2.0254\times10^{-3}}{1.38\times10^{-23} \cdot 297.15}$$

$$= \underline{79.027\ mS}$$

$$r_{be} = \frac{\beta}{g_m} = \frac{700}{79.027\times10^{-3}} = \underline{8.858\,k\Omega}$$

ii)



3b iii)

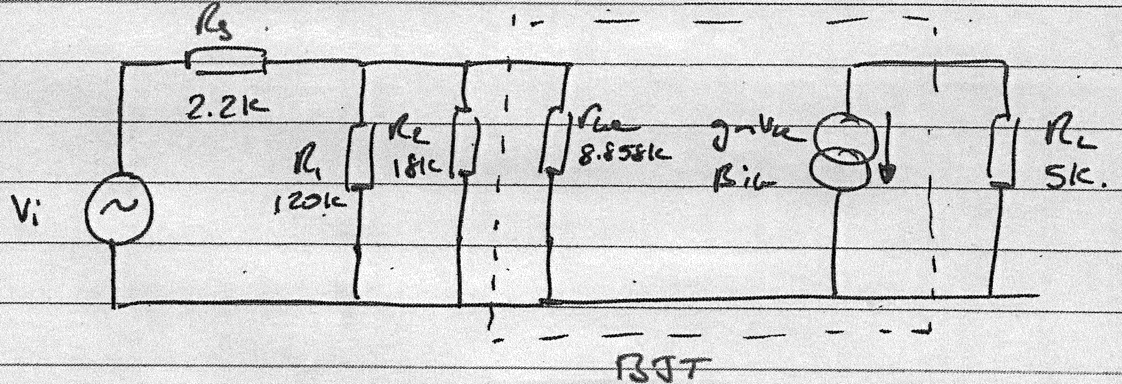
MANY WAYS TO DO THIS...

$$V_{CQ} = \frac{V_B + V_S}{2} = 13.57$$

$$= \frac{3.1304 + 24}{2} = \underline{\underline{13.57\ V}}$$

DEPENDS ON ASSUMPTIONS TOO. SAY V_C MUST NOT FALL BELOW V_B ...

c i)



① - FOR TRANSISTOR PLACEMENT.
① - FOR R_1 & R_2 TO GND.
① - FOR R_L TO GND
① - FOR V_i & R_S PLACEMENT.

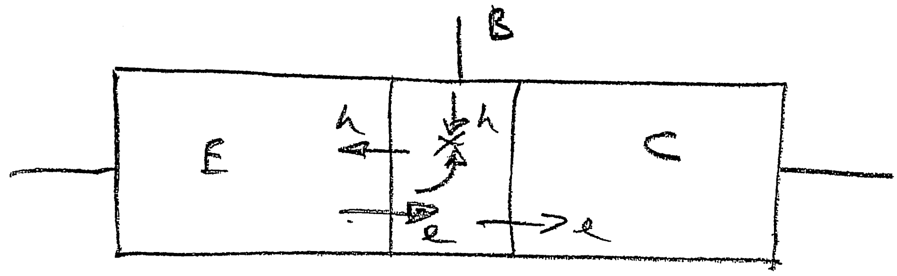
ii) INPUT RESISTANCE BY INSPECTION IS $R_1 // R_2 // r_{be}$

$$\text{So } \frac{1}{r_{in}} = \frac{1}{r_{be}} + \frac{1}{R_1} + \frac{1}{R_2}$$

$$\frac{1}{r_i} = \frac{1}{8.858} + \frac{1}{120} + \frac{1}{18}$$

$$r_i = \underline{\underline{5.6567\ k\Omega}}$$

4. (a) Emitter - base junction forward biased (3)
Base - collector junction reverse biased. [redacted]



At emitter - base junction electrons flow from emitter into base. They then diffuse through the base and are pulled into the reverse biased base - collector junction [redacted]

(i) Hole current from base to emitter reduces gain (current does not appear in collector)

(ii) Some electrons recombine with majority holes in the base. (lost to collector current. [redacted]

(i) - ensure emitter doping >> base doping

(ii) - base width << minority carrier diffusion length [redacted]

(b) current gain $= \frac{I_C}{I_B} = 60$

$\therefore \quad I_C = 60 \times 5\,mA = \underline{300\,mA}$ peak to peak

For $50\,\Omega$ load $V_c = 0.3 \times 50$

$= \underline{15\,V}$

4 (continued) ④

(c) First need α & B from data

$$\beta = \frac{\alpha}{1-\alpha} \qquad \alpha = B\gamma \quad \text{(from formula page)}$$

$$\beta = 100 \Rightarrow \alpha_{100} = \frac{1}{\frac{1}{100}+1} = 0.99$$ [redacted]

$$B_{100} = \frac{\alpha_{100}}{\gamma} = \frac{0.99}{0.997} = 0.993$$ [redacted]

$$= 1 - \frac{1}{2}\left(\frac{l_B}{L_e}\right)^2 \quad \text{(from formula page)}$$

$$\Rightarrow l_B = \sqrt{(1-0.993)\times 2 \times (1.5\times10^{-6})^2}$$

$$= 0.177 \times 10^{-6} \text{ m}$$

$$= \underline{0.177\ \mu m}$$ [redacted]

5. (a) Use diode equation from formulae

$$J = J_0\left(\exp\frac{eV}{kT} - 1\right)$$

In forward bias neglect "−1" term

$$\therefore \exp\frac{eV}{kT} = \frac{J}{J_0} = \frac{50\times10^{-3}}{1\times 1\times10^{-6}} = 5\times10^{4}$$

$$\Rightarrow V = \frac{kT}{e}\ln(5\times10^{4}) = 0.026 \times 10.81 \qquad \left(\frac{kT}{e} = 0.026\right)$$

$$= \underline{0.28\,V}$$ [redacted]

From formulas $R = \frac{L_n}{\sigma_n A}$ and $\frac{L_p}{\sigma_p A}$ for n and p regions respectively. [redacted]

$$R_n = \frac{1\times10^{-3}}{500\times1\times10^{-6}} = 2\,\Omega$$ [redacted]

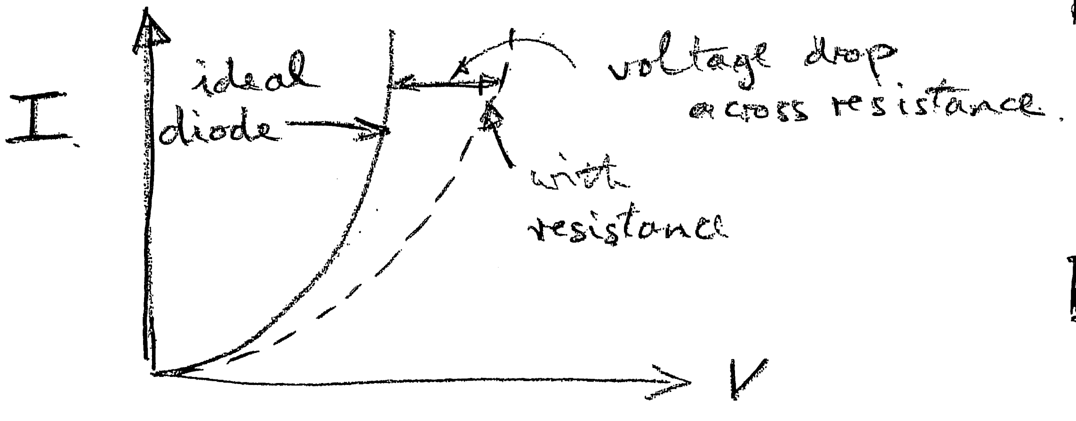
$$R_p = \frac{1\times10^{-3}}{2000\times1\times10^{-6}} = 0.5\,\Omega$$

$\therefore$ Total resistance $= \underline{2.5\,\Omega}$

Total voltage drop $= (50\times10^{-3}\times2.5) + 0.28\,V$

$= 0.125 + 0.28 = \underline{0.405\,V}$ [redacted]

(b)



[redacted]

5 (continued)

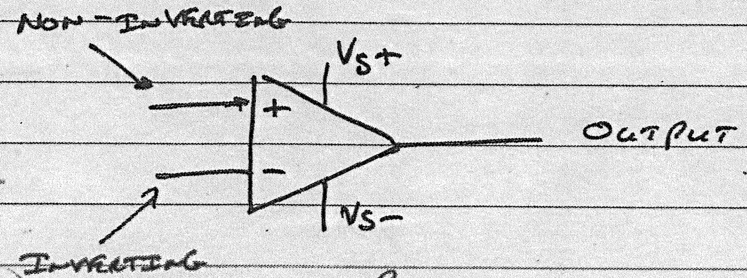
(c) Voltage would be lost to the output and efficiency would be reduced.

(d) $$J_0 = \frac{e L_p n_p}{\tau_e} + \frac{e L_h p_n}{\tau_h}$$

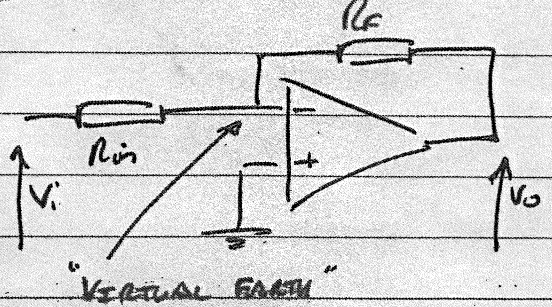
n_p and p_n are the minority carrier densities which depend on thermally generated electron-hole pairs ($\propto \exp \frac{W_g}{kT}$; W_g = band gap).
L and τ only have a weak temperature dependence

(e) LED - photons come from energy released as electons and holes recombine.
In non light emitting diodes recombination still occurs but energy released transfers to crystal as heat.

6ai)



b)



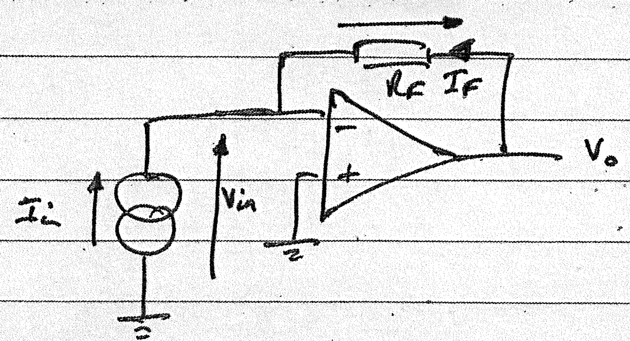
1 - FOR CCT

1 - FOR VE LABEL

THE VIRTUAL EARTH EXISTS DUE TO THE OPAMP OPPERATION AND THE USE OF NEGATIVE FEEDBACK. THE OPAMP IS DESCRIBED BY THE EQUATION $V_o = A_v(V^+ - V^-)$. ASSUMING A_v IS LARGE, THE OPAMP WILL, WHEN OPPERATED WITH NEGATIVE FEEDBACK, ATTEMPT TO BRING ITS INPUTS TOGETHER BY ADJUSTING ITS OUTPUT VOLTAGE. SINCE THE NON-INVERTING INPUT IS GROUNDED THE O/AMP TRIES TO MAKE THE INVERTING INPUT GROUND TOO.

ci) IT IS A CURRENT TO VOLTAGE CONVERTER.

ii)



SUM CURRENTS AT V^-

$$I_{in} + I_F = 0$$

$$I_{in} + \frac{V_O - V^-}{R_F} = 0$$

$$\text{IF } A_v \rightarrow \infty \quad V^+ = V^- = 0 \ldots$$

6c ii) CONTINUED...

$$\therefore \quad I_{in} + \frac{V_o}{R_F} = 0$$

SO $$\frac{V_o}{I_{in}} = -R_F$$

iii) FOR R_{IN} AND WITH $A_V \neq \infty$...
SUM CURRENTS AT V^-

$$I_{in} + I_F = 0$$

$$I_{in} + \frac{V_o - V^-}{R_F} = 0 \qquad (A)$$

$$V_o = A_V(V^+ - V^-) \qquad (B)$$

(B) $\rightarrow$ (A) :

$$I_{in} + \frac{A_V(V^+ - V^-)}{R_F} = 0$$

$$V^+ = 0$$

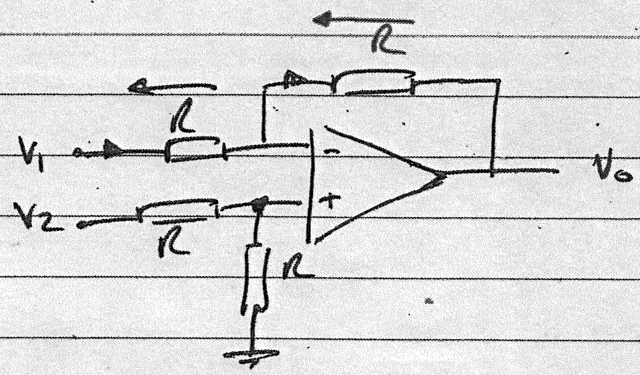
$\therefore$

$$I_{in} R_F - A_V V^- = 0 \qquad (V^- = V_{in})\ \ldots$$

$$R_{IN} = \frac{V_{in}}{I_{in}} \qquad \therefore \quad -A_V V_{in} = -I_{in} R_F$$

AND $$\frac{V_{in}}{I_{in}} = \frac{R_F}{A_V}$$

6d i)



Sum I @ V^-:

$$\frac{V_1 - V^-}{R} = \frac{V^- - V_0}{R} \quad (C)$$

And: $V^+ = \frac{V_2 \cdot R}{R+R}$ (D) $A_V \to \infty$ so $V^+ = V^-$

Get (C) in terms of V^-

$$V^- = \frac{V_1 + V_0}{2} \quad (E)$$

Substitute (D) & (E) into $V^+ = V^-$

$$\frac{V_1 + V_0}{2} = \frac{V_2}{2}$$

Simplify to:

$$\underline{\underline{V_0 = V_2 - V_1}}$$

ii) This is a <u>subtractor circuit</u> or a <u>difference amplifier</u>