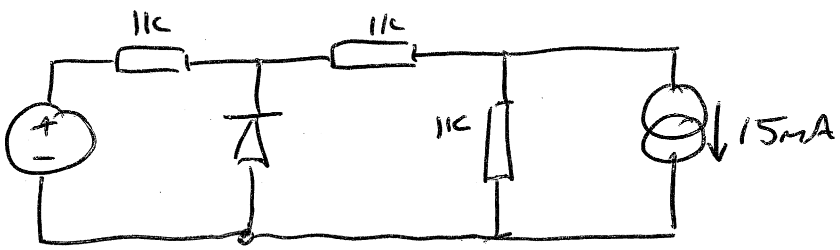
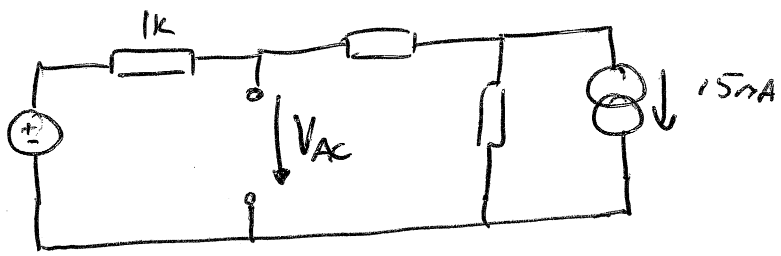
2013/14. ①

1a i

BY SUPERPOSITION:



IF DIODE NOT CONDUCTING...



FOR 6V SOURCE (15mA IS O/C)

$$\therefore \quad V_{AC} = -6 \cdot \frac{2K}{3K}$$

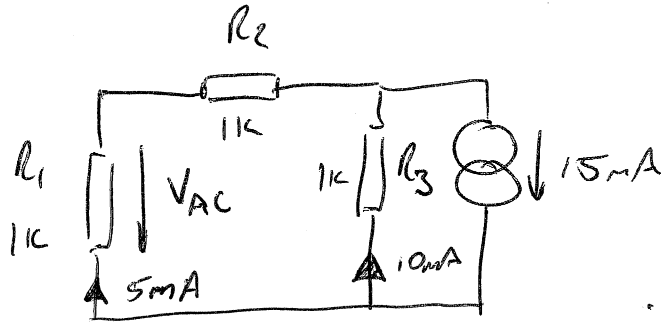
$$= \underline{\underline{-4V.}}$$

FROM $\left[-\left(6 \cdot \frac{R_2 + R_3}{R_1 + R_2 + R_3}\right) \right]$

FOR 15mA SOURCE (6V IS S/C)

$$\therefore \quad V_{AC} = 15 \times 10^{-3} \cdot \frac{1}{3} \cdot 1K\Omega = \underline{\underline{5V}}$$

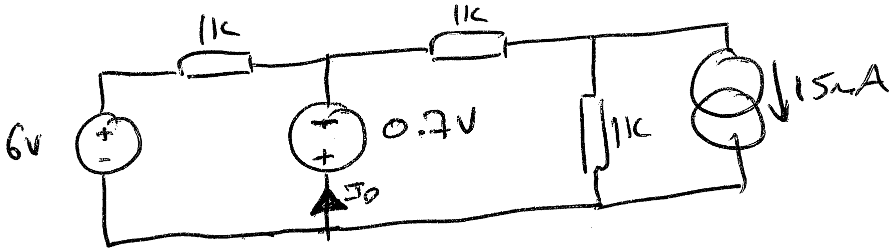
THIS IS BECAUSE WITH THE 6V S/C THE CCT BECOMES...



...WHICH IS A CURRENT DIVIDER CIRCUIT.

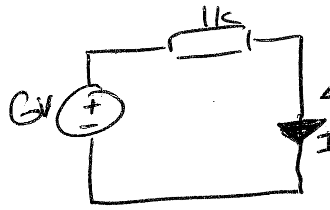
TOTAL $V_{AC} = 5V - 4V = 1V$. $1V > 0.7V \therefore$ DIODE CONDUCTS.

1a ii) CONDUCTION CURRENT...



BY SUPERPOSITION...

FOR 6V (V_0 & 15mA S/C & O/C RESPECTIVELY)

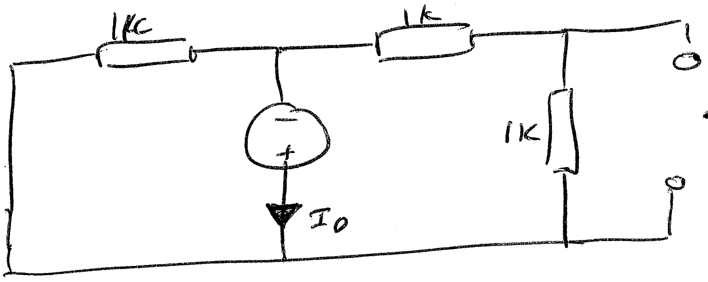


V_D IS S/C...

$I_D = \underline{6mA}$ (BUT LOOK AT THE DIRECTION)

FOR 0.7V (6V & 15mA S/C & O/C RESPECTIVELY).

6V S/C

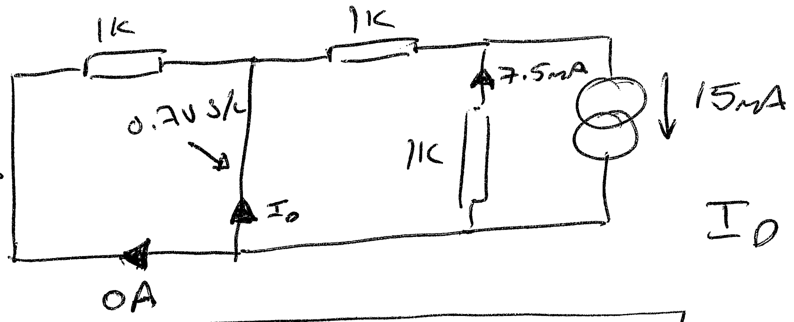


15mA O/C

$$I_D = \frac{0.7}{1K // (1K+1K)} = \frac{0.7}{0.66\dot{6}} = \underline{1.05mA}$$

FOR 15mA (6V & 0.7V BOTH S/C)

6V S/C



THIS IS A CURRENT DIVIDER TOO.

$$I_D = 15mA \times \frac{1}{2} = \underline{7.5mA}$$

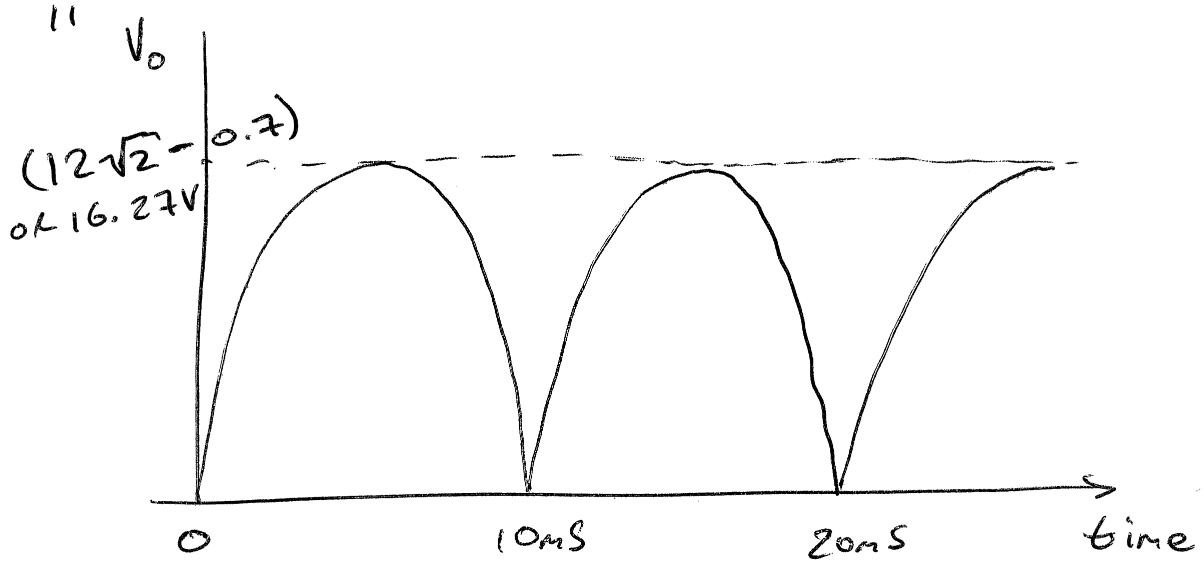
$$I_D = -6 - 1.05 + 7.5 \quad (mA)$$

$$= 0.45mA.$$

THESE SIGNS ARE FOUND BY LOOKING AT THE DIRECTION OF I_D IN EACH SUPERPOSITION CIRCUIT. THE CURRENT FLOWING ANODE TO CATHODE IS CONSIDERED POSITIVE.

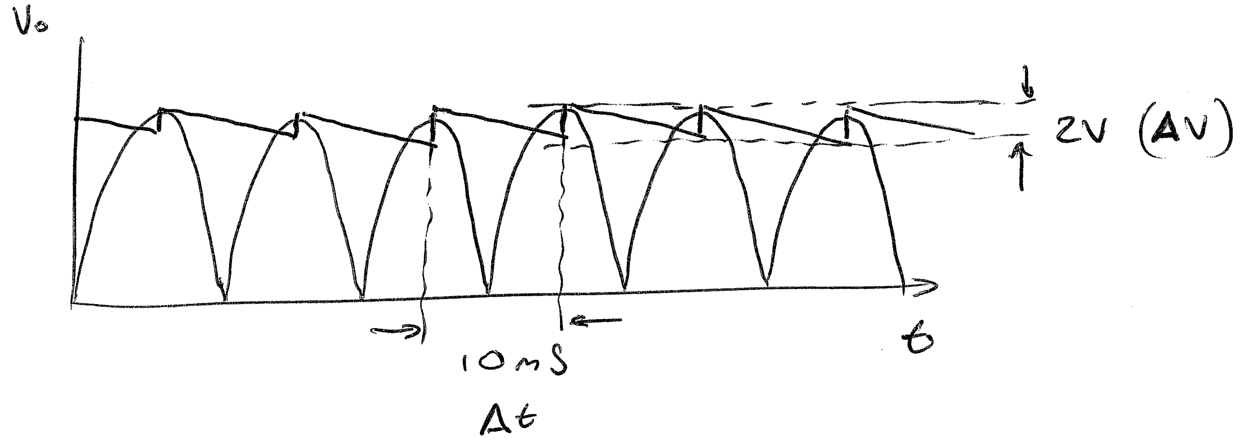
16 i FULL WAVE. ③

ii



iii From ii $16.27/30 = \underline{542.\dot{3}\ mA}$

iv LOOKS LIKE



ASSUMING WORST CASE (PEAK CURRENT FLOWS ALWAYS)

$$I = C\frac{dv}{dt} \quad \therefore \quad C = \frac{I\,dt}{dV} = \frac{542.3 \times 10^{-3} \times 10 \times 10^{-3}}{2}$$

$$= \underline{2{,}711.5\ mF}$$

④

IF AVERAGE CURRENT IS USED...

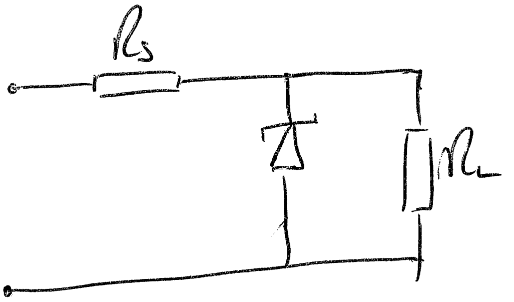
$$I_{MIN} = \frac{16.27 - 2}{30} = \underline{475.\dot{6}\,mA}$$

$$I_{AV} = \frac{542.\dot{3} + 475.\dot{6}}{2} = \underline{509\,mA}$$

$$C = \frac{I\,dt}{dV} = \frac{0.509A \times 10mS}{2V} = \underline{2545\mu F}$$

ALL OTHER ANSWERS VALID AS LONG AS ASSUMPTIONS ARE REASONABLE AND STATED.

d i)

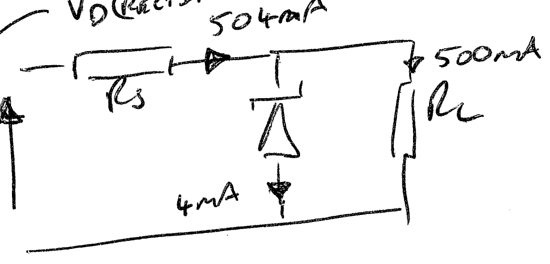


ii) MUST USE SMALLEST I/P VOLTAGE & LARGEST O/P CURRENT.

Rms → pk.

V_D (RECTIFIER)

$$\left(\sqrt{2}\cdot 12\right) - 0.7 - 2$$



Ripple

$$I_{RS} = 500mA + 4mA = \underline{504mA}$$

$$V_{RS} = 14.27 - 9 = \underline{5.27}$$

$$\therefore R_S = \frac{5.27}{504mA} = \underline{10.46\Omega}$$

iii) $P = I^2R = \underline{2.65}$ WATTS

$\therefore$ $>3W$ BUT <10 WATT. WOULD BE OK.

iv) $P_D = V_D \times I_D$

V_D: 9V (ZENER)

- WHEN CCT IS FULLY ON I_D IS A MINIMUM AT 4mA SO:

  $P = 9 \cdot 4 \times 10^{-3} = \underline{36mW}$

- WHEN CCT IS ON STANDBY I_D IS A MAXIMUM (ASSUMING THAT "NO LOAD" IS NOT A VALID OPTION)

  $P = 9 \cdot (504 - 20)mA = \underline{4.356}$ WATTS

3a i)

$$I_{R_L} = \frac{V_S - V_{CE(SAT)}}{R_L} = \frac{48 - 1.1}{10} = \underline{4.69\,A}$$

ii) $$E = \frac{1}{2} L I^2 = \frac{1}{2} \cdot 80 \times 10^{-3} \cdot 4.69^2$$

$$= \underline{0.88\,J}$$

iii) $$P = I^2 R = 4.69^2 \cdot 10 = \underline{219.96 \text{ WATTS}}$$

iv) $$P = IV = 4.69 \times 1.1(V) = \underline{5.159 \text{ WATTS}}$$

IT IS OK TO INCLUDE B-E DISSIPATION IF IT'S DONE CORRECTLY.

v) $$I_B = I_C / h_{FE} = \frac{4.69}{100} = \underline{46.9\,mA}$$

$$V_B = V_i - \underbrace{0.7}_{V_{BE(SAT)}}$$

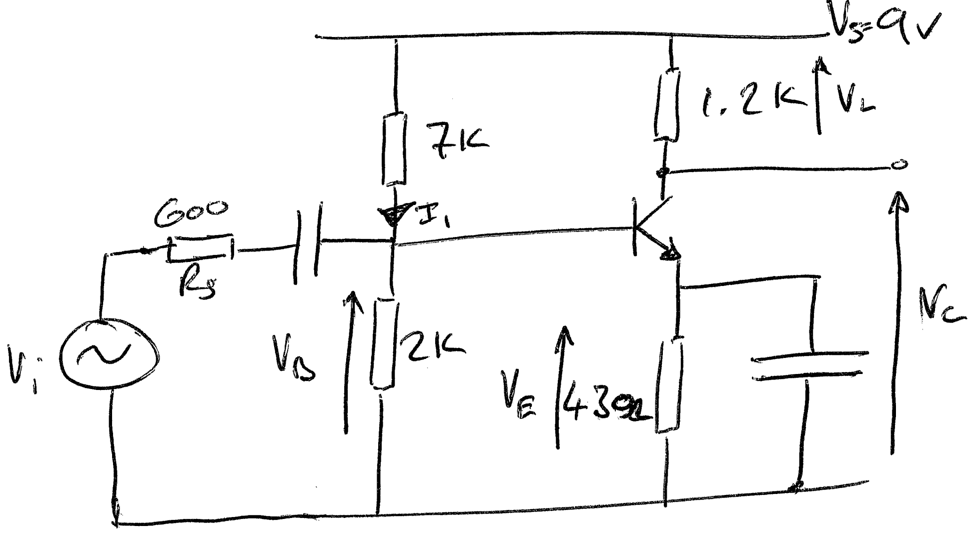
$$R_B = V_B / I_B = \frac{5 - 0.7}{46.9\,mA} = \underline{91.68\,\Omega}$$

vi) POWER IN THE SWITCH SHOULD BE CONSTANT SO

$$\underbrace{I^2}_{4.69\,A} r_{ds(ON)} = \underline{5.159\,W}$$

$$r_{ds(ON)} = \frac{5.159}{4.69^2} = \underline{0.235\,\Omega}$$

c)



$- V_B = V_S \cdot \frac{2K}{7K + 2K} = \cancel{9} \cdot \frac{2.}{\cancel{9}} = \underline{2V.}$

$- I_1 = \frac{V_S - V_B}{7K} = \frac{9 - 2}{7K} = \underline{1mA}$

$- V_E = V_B - 0.7 = \underline{1.3V}$

$- I_E = V_E / 430 = \frac{1.3V}{430} = \underline{3.02mA}$

Assume $I_B = 0$..

$\therefore I_C = I_E$

$\therefore V_L = 1.2k \cdot 302\ mA = \underline{3.624V}$

And $V_C = V_S - V_L = 9 - 3.624 = \underline{5.376V}$

<u>OR</u> Assuming $I_B = 150$ (say)...

$I_C + I_B = I_E$

$I_C + I_C/\beta = I_E$

$$1.00\dot{6}\, I_C = I_E$$

$$I_C = \frac{3.02\text{mA}}{1.006} = \underline{\underline{3\text{mA}}}$$

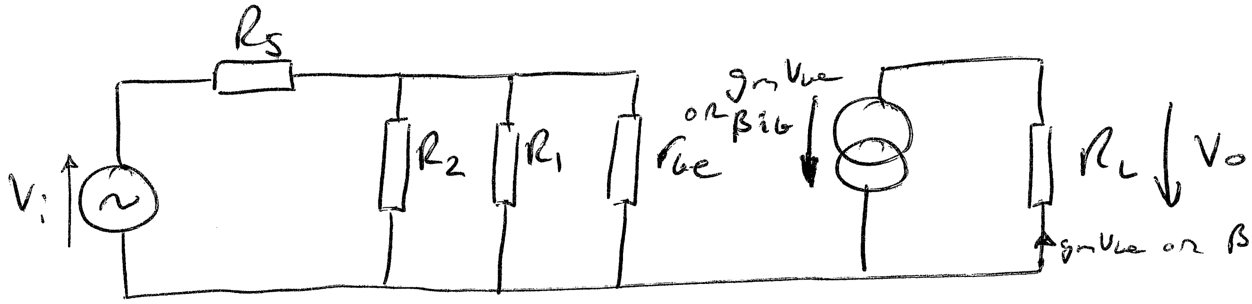
$$\therefore\ I_B = I_E - I_C = 3.02 - 3\ (\text{mA})$$

$$= \underline{\underline{20\mu A}}$$

THEN $V_L = 1.2 \cdot 3 = \underline{\underline{3.6V}}$

AND $V_C = V_S - V_L = 9 - 3.6 = \underline{\underline{5.4V}}$

c)



$$V_{be} = V_i \cdot \frac{r_{be} // R_1 // R_2}{R_S + r_{be} // R_1 // R_2}$$

$$V_o = g_m v_{be} \cdot R_L$$

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

$$g_m = \frac{eI_C}{KT} = \frac{1.6\times10^{-19} \cdot 3\text{mA}}{1.38\times10^{-23} \cdot 300}$$ (OR 3.02 mA..)

$$= 0.1159\ A/V$$

$$r_{be} = \beta / g_m = 150/0.1159 = \underline{\underline{1.294k\Omega}}$$

$$\frac{V_o}{V_i} = 0.1159 \cdot 1.2k \cdot \frac{(1.294k // 7k // 2k)}{600 + (1.294k // 7k // 2k)}$$

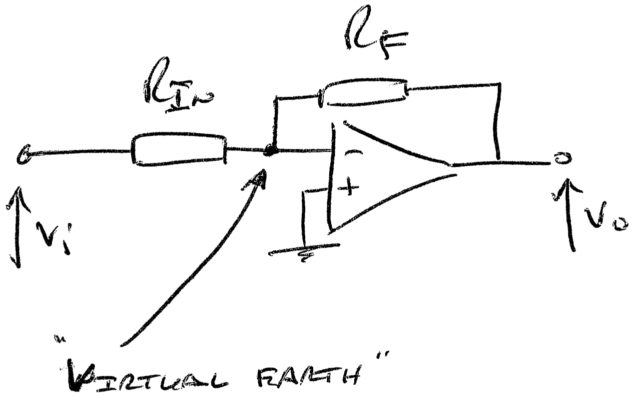
$$= 0.1159 \cdot 1.2k \cdot \frac{706.387}{1,306.4}$$

$$= \underline{\underline{75.202}}\ V/V.$$

(DEPENDS ON ASSUMPTIONS)

6a i)

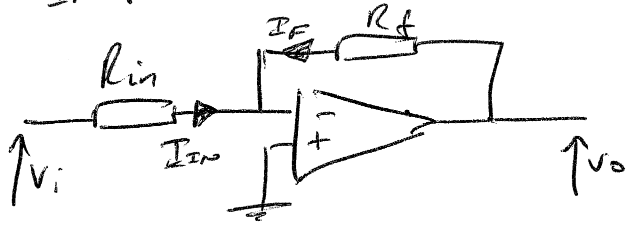
10



iii) THE VIRTUAL EARTH EXISTS DUE TO THE OPAMP OPPERATION. THE OPAMP IS DESCRIBED BY ITS 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 OPAMP WILL ATTEMPT TO MAKE THE INVERTING INPUT GROUND TOO.

iv) BY INSPECTION THE INPUT RESISTANCE IS R_{IN}.

v)



$$I_{IN} = I_F$$

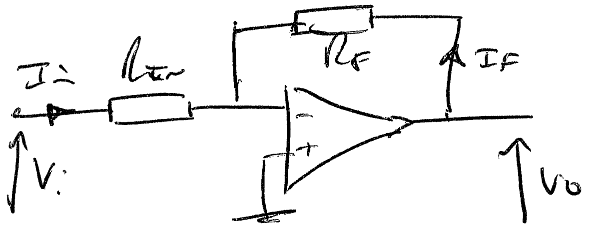
$$\frac{V_i - V^-}{R_{in}} = \frac{V^- - V_o}{R_F}$$

$$V^- = V^+ = 0$$

$$V_i/R_{in} = -V_o/R_F$$

$$-V_o/V_i = R_F/R_{in}$$

$$\therefore \underline{\underline{V_o/V_i = -R_F/R_{in}}}$$



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

$$\frac{V_o - V^-}{R_F} + \frac{V_i - V^-}{R_{in}} = 0$$

SOLVE FOR V^-

$$(V_o - V^-) R_{in} + (V_i - V^-) R_F = 0$$

$$V^- = \frac{V_o R_{in} + V_i R_F}{R_{in} + R_F}$$

USE V^- IN $V_o = A_V(V^+ - V^-)$ AND $\underline{V^+ = 0}$

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

... DO SOME TRANSPOSITION...

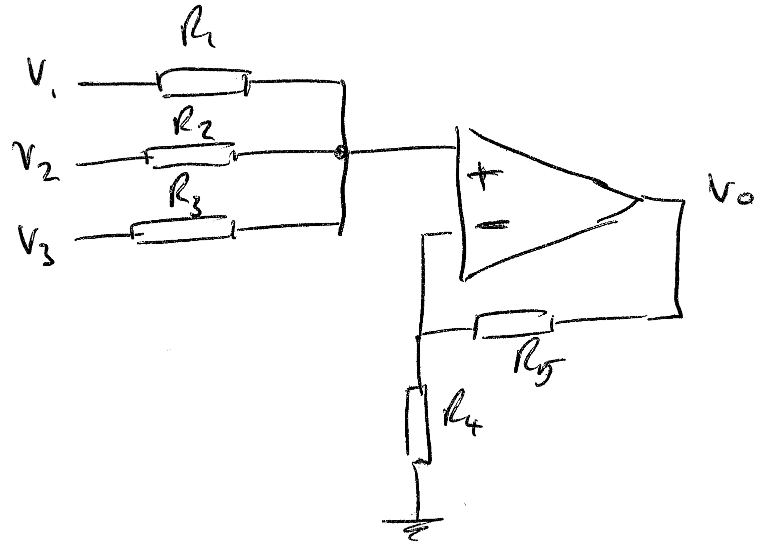
$$V_o/V_i = \frac{-A_V R_F}{R_i + R_F + A_V R_{in}}$$

÷ BY A_V...

$$V_o/V_i = \frac{-R_F}{\frac{1}{A_V}\left[R_{in} + R_F\right] + R_{in}}$$

6b i) SEVERAL POSSIBLE METHODS...

FIRST



$$V_o\big|_{V_1} = V_1 \cdot \frac{R_2 /\!/ R_3}{R_1 + R_2 /\!/ R_3} \cdot \frac{R_5 + R_4}{R_4}$$

$$V_o\big|_{V_2} = V_2 \cdot \frac{R_1 /\!/ R_3}{R_2 + R_1 /\!/ R_3} \cdot \frac{R_5 + R_4}{R_4}$$

$$V_o\big|_{V_3} = V_3 \cdot \frac{R_1 /\!/ R_2}{R_3 + R_1 /\!/ R_2} \cdot \frac{R_5 + R_4}{R_4}$$

$$V_o = \left(V_1 \cdot \frac{R_2 /\!/ R_3}{R_1 + R_2 /\!/ R_3} + V_2 \frac{R_1 /\!/ R_3}{R_2 + R_1 /\!/ R_3} + V_3 \frac{R_2 /\!/ R_1}{R_3 + R_2 /\!/ R_1}\right)\left(\frac{R_5 + R_4}{R_4}\right)$$

ii) THIS IS A KIND OF SUMMING AMPLIFIER. MORE SPECIFIC-ALLY IF $R_1 = R_2 = R_3$ V_o/V_i IS THE AVERAGE OF THE THREE INPUTS MULTIPLIED BY A GAIN OF $\frac{R_5 + R_4}{R_4}$.

6bi) SECOND METHOD

$$\frac{V_1 - V^+}{R_1} + \frac{V_2 - V^+}{R_2} + \frac{V_3 - V^+}{R_3} = 0$$

$$V_o = V^+ \cdot \frac{R_4 + R_5}{R_4}$$

$$(V_1 - V^+) R_2 R_3 + (V_2 - V^+) R_1 R_3 + (V_3 - V^+) R_1 R_2 = 0$$

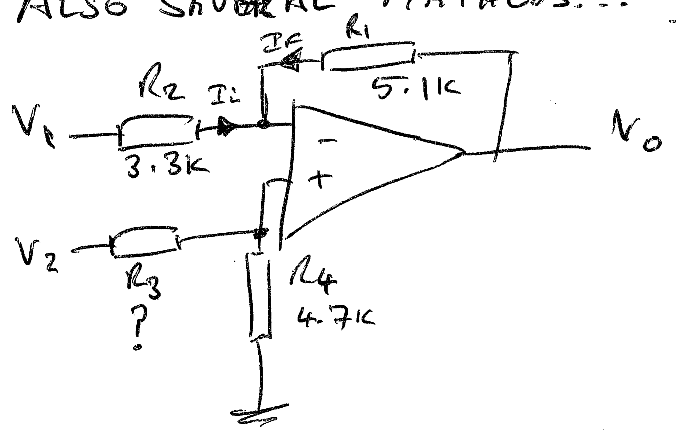
$$V_1 R_2 R_3 - V^+ R_2 R_3 + V_2 R_1 R_3 - V^+ R_1 R_3 + V_3 R_1 R_2 - V^+ R_1 R_2 = 0$$

$$-V^+ (R_2 R_3 + R_1 R_3 + R_1 R_2) + V_1 R_2 R_3 + V_2 R_1 R_3 + V_3 R_1 R_2 = 0$$

$$V^+ = \frac{V_1 R_2 R_3 + V_2 R_1 R_3 + V_3 R_1 R_2}{R_2 R_3 + R_1 R_3 + R_1 R_2}$$

$$V_o = \left(\frac{V_1 R_2 R_3 + V_2 R_1 R_3 + V_3 R_1 R_2}{R_2 R_3 + R_1 R_3 + R_1 R_2}\right)\left(\frac{R_4 + R_5}{R_4}\right)$$

6ci) ALSO SEVERAL METHODS... FIRST.



$$I_{IN} = I_F$$

$$\frac{V_1 - V^-}{R_2} + \frac{V_o - V^-}{R_1} = 0 \quad (1)$$

$$V^+ = V^- \quad (2)$$

$$V^+ = \frac{V_2 R_4}{R_3 + R_4} \quad (3)$$

$((3 \to 2) \to 1)$

$$\frac{V_1 - \frac{V_2 R_4}{R_3 + R_4}}{R_2} + \frac{V_0 - \frac{V_2 R_4}{R_3 + R_4}}{R_1} = 0$$

$$V_0 = \frac{-\left(V_1 - \frac{V_2 R_4}{R_3 + R_4}\right) R_1}{R_2} + \frac{V_2 R_4}{R_3 + R_4} \quad (4)$$

SOLVE (4) FOR R_3 TO GET...

$$R_3 = \frac{-R_4 \left(-R_1 - R_2\right) V_2}{R_1 V_1 + R_2 V_0} - R_4$$

$$= \frac{-4.7\left(-5.1 - 3.3\right) \cdot -8}{5.1 \cdot (-6) + 3.3 \cdot 0} = \underline{5.621\,k\Omega}$$

SECOND METHOD

$$V_0 \big|_{V_1} = V_1 \cdot -R_1/R_2 \qquad V_0 \big|_{V_2} = V_2 \cdot \frac{R_4}{R_3 + R_4} \cdot \frac{R_1 + R_2}{R_2}$$

$$V_0 = V_1 - R_1/R_2 + V_2 \frac{R_4}{R_3 + R_4} \cdot \frac{R_1 + R_2}{R_2} \quad (V^+ = V^- \ldots)$$

SUB $V_0 = 0$...

$$\therefore \quad V_1 - R_1/R_2 = -\frac{V_2 R_4}{R_3 + R_4} \cdot \frac{R_1 + R_2}{R_2}$$

SOLVE FOR R_3 ...

$$R_3 = \frac{V_2(R_4 R_1 + R_4 R_2) R_2 - V_1 R_1 R_4 R_2}{V_1 R_1 R_2}$$

SUBSTITUTE VALUES.

$$R_3 = \frac{-8(4.7 \cdot 5.1 + 4.7 \cdot 3.3) 3.3 - (-6) 5.1 \cdot 4.7 \cdot 3.3}{(-6) 5.1 \cdot 3.3}$$

$$= \underline{\underline{5.621\ k\Omega}}$$

THIRD METHOD

$$\frac{V_1 - V^-}{R_2} + \frac{V_o - V^-}{R_1} = 0$$

$$V_1 R_1 - V^- R_1 + V_o R_2 - V^- R_2 = 0$$

$$-V^-(R_1 + R_2) = -V_1 R_1 - V_o R_2$$

$$V^- = \frac{V_1 R_1 + V_o R_2}{R_1 + R_2} \quad (1)$$

$$\frac{V_2 - V^+}{R_3} = V^+/R_4 \quad (2) \rightarrow (V_2 - V^+) R_4 = V^+ R_3$$

$$V^+ = V^- \quad (3)$$

$$((1) \ \& \ (2)) \rightarrow (3)$$

$$\left(V_2 - \frac{V_1 R_1 + V_o R_2}{R_1 + R_2}\right) R_4 = \frac{V_1 R_1 + V_o R_2}{R_1 + R_2} \cdot R_3$$

16

$$R_4 V_2 (R_1 + R_2) - V_1 R_1 R_4 + V_o R_2 R_4 = V_1 R_1 R_3 + V_o R_2 R_3$$

$$V_o (R_2 R_4 - R_2 R_3) = V_1 R_1 R_3 - V_2 (R_1 + R_2) R_4 + V_1 R_1 R_4$$

$$V_o = \frac{V_1 R_1 R_3 - R_4 V_2 (R_1 + R_2) + V_1 R_1 R_4}{R_2 R_4 - R_2 R_3}$$

$$V_o = \frac{V_1 (R_1 R_3 + R_1 R_4) - V_2 (R_1 + R_2) R_4}{R_2 (R_4 - R_3)}$$

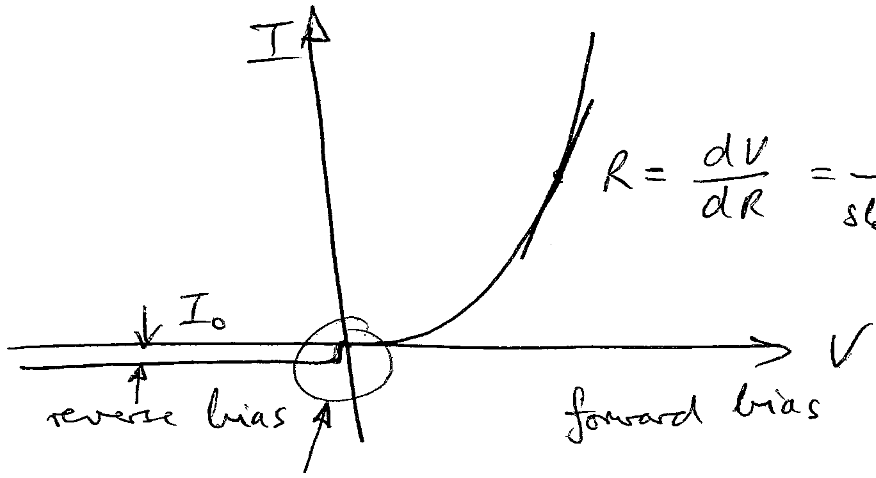
$$= \frac{-6(5.1(5.621 + 4.7)) - (-8)(5.1 + 3.3) 4.7}{3.3(4.7 - 5.621)}$$

$$= \sim \underline{\underline{0.0174 V}}$$

So 5.621 kΩ IS CORRECT (MORE OR LESS...)

EEE 118 2014 Solutions

Q2 (a)



$R = \dfrac{dV}{dR} = \dfrac{1}{\text{slope}}$ 2

1

note current = 0 at V = 0 1

As I increases slope increases and R decreases.
2

(b) hole current $\propto \sigma_p = p e \mu_h$

electron current $\propto \sigma_n = n e \mu_e$.

Injection efficiency $\gamma = \dfrac{I_p}{I_p + I_e}$ 2

$$= \frac{\sigma_p}{\sigma_p + \sigma_n} = \frac{1}{1 + \frac{\sigma_n}{\sigma_p}} = \frac{1}{1 + \frac{7\times10^{23} \times 0.07}{7\times10^{25} \times 0.045}}$$

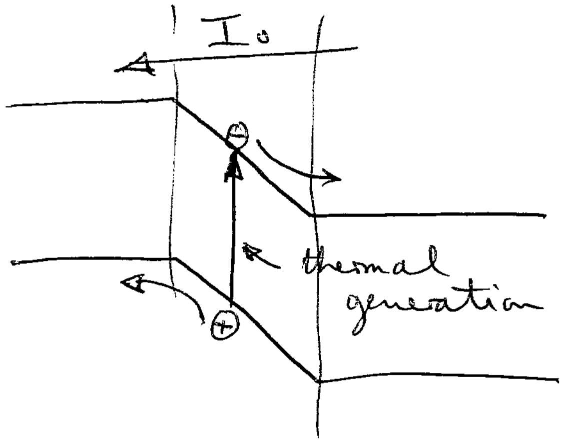
$= \underline{0.985}$ 2

from page 1 $\alpha = \gamma \beta = 0.985$

current gain $\beta = \dfrac{\alpha}{1-\alpha} = \dfrac{0.985}{1-0.985}$

$= \underline{65.6}$ 2

(c)



In reverse bias the depletion region is extended and the barrier to diffusion is increased. Latter is cut off but thermally generated carriers produce small reverse current as shown. 3

(i) Increased band-gap reduces the possibility of electron-hole thermal generation hence I_0 would decrease. 2

(ii) Lower temperature provides less energy hence reduced I_0. 2

(d) $$I = I_0 \left(\exp \frac{eV}{kT} - \cancel{1} \right)$$

ignore

$$\therefore \exp \frac{eV}{kT} = \frac{I}{I_0}.$$ 2

$$V = \frac{kT}{e} \ln \frac{I}{I_0} = \frac{1.38 \times 10^{-23} \times 300 \ln \frac{10^{-2}}{10^{-6}}}{1.6 \times 10^{-19}}$$

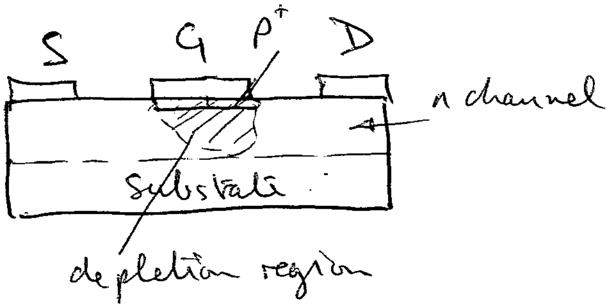
$$= \underline{0.24 \text{ V}}$$ 2

Actual terminal voltage greater than this due to voltage drop across semiconductor either side of junction. 2

Q4

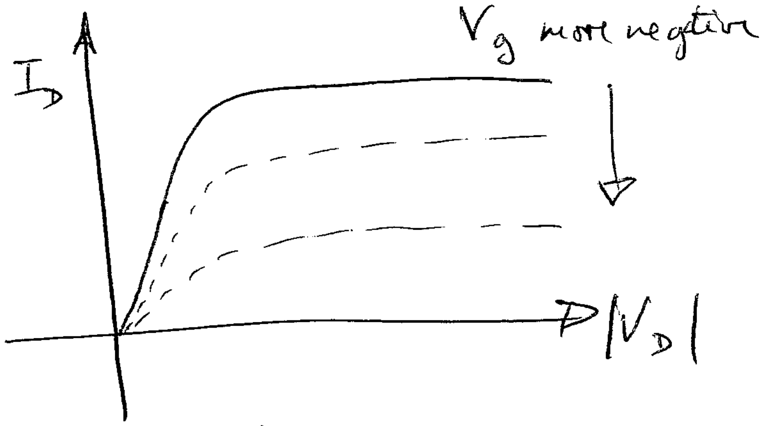
(a)

(i) JFET



Reverse biased (negative) gate depletes channel and restricts electron flow from S to D (I_D).

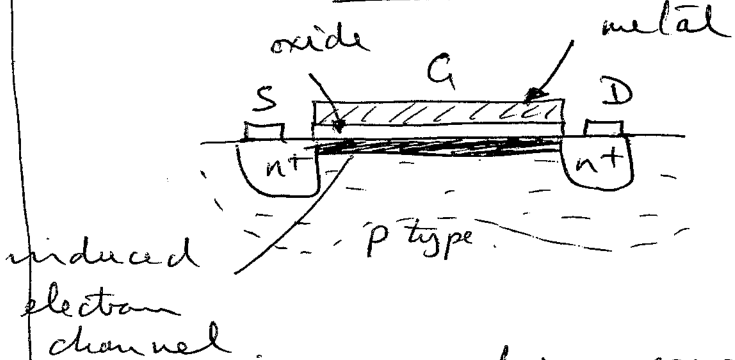
Initial current at low drain bias due to resistance of the channel



As V_D becomes more negative channel resistance increases until it is pinched off – I_D then saturates

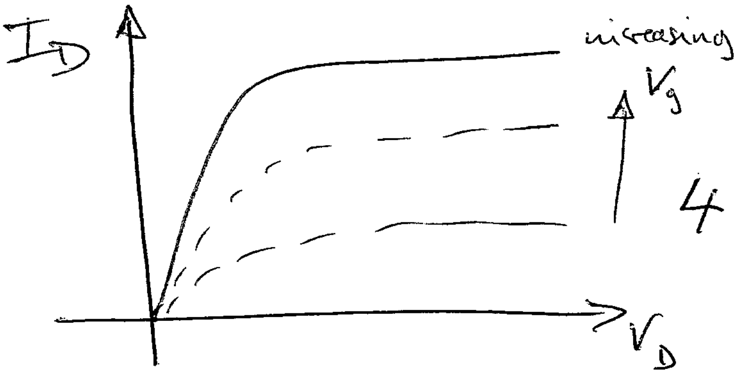
ii) Device is "on" when no gate bias is applied ("normally-on"). "Off" when $V > V_{pinch-off}$.

MOSFET



6

Positive gate bias causes depletion of p-type region. No channel or current initially. As gate bias increases, electron channel is induced under the gate and get conduction between S + D. at $V_G = V_{th}$ 2



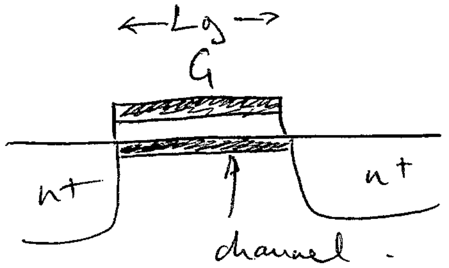
4

As V_D increases, voltage between G + D at drain end reduces until $V_G - V_D < V_{th}$ and channel is pinched off – I_D saturates. 2

(ii) Device is "off" with no gate bias ("normally off"). "On" when $V_g > V_{th}$.

4

(b) (i)



Assume channel is fully depleted.

velocity $v = \mu E = 0.07 \times 5 \times 10^{6}\ ms^{-1}$ 2

$= \underline{3.5 \times 10^{5}\ ms^{-1}}$

Time to travel under gate $= \frac{L_g}{v} = \frac{1 \times 10^{-6}}{3.5 \times 10^{5}}$

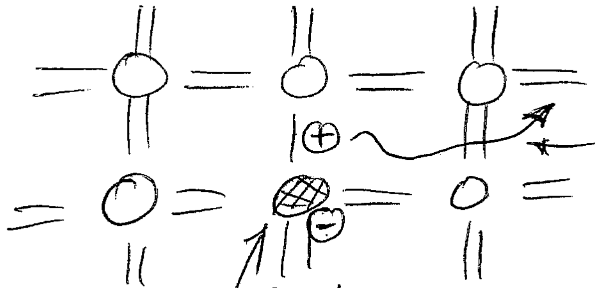
$= \underline{2.86\ ps}$ 2

$\left(2.86 \times 10^{-12}\ s\right)$

(ii) The transit time under the gate determines how quickly charge can be removed from the channel or gate. Hence the device cannot change state (eg "on" or "off") faster than this and switching speed is limited by this delay. 3

Q5.

(a)



hole can easily move away from the boron atom.

B atom

The boron atom has 3 outer electrons and when it bonds to a Si lattice there is 1 electron too few for a complete bond. Hence the missing electron represents a hole with a net (+) ve charge. The boron atom appears to have a net negative charge when the hole moves away. 6

(b) Since the hole concentration is dependent on the boron concentration only at room temperature and above, it will not change significantly. 2

In undoped material there is much less electrons and holes but these will increase in concentration as the temperature is increased giving rise to a larger fractional increase. 2

(c) From page 1 $n_p p_p = n_i^2$ 3

$$\therefore n_p = \frac{n_i^2}{p_p} = \frac{1 \times 10^{32}}{1 \times 10^{24}} = \underline{1 \times 10^{8} \, m^{-3}}$$

(d) From page 1 $\sigma = n_p e \mu_e + p_p e \mu_h$.

ignore electron contribution since this is very small 3

$$\therefore \sigma = 1 \times 10^{24} \times 1.6 \times 10^{-19} \times 0.045$$

$$= \underline{7.2 \times 10^{3} \, S m^{-1}}$$

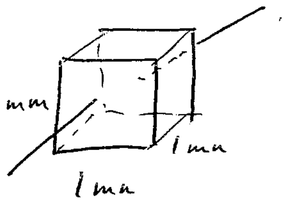
(e) for electrons $\sigma_e = n_p e \mu_e$

$$= 1\times10^{8}\times1.6\times10^{-19}\times 0.07$$

$$= \underline{1.12\times10^{-12}\ S\,m^{-1}} \qquad 3$$

ie. it is indeed negligible

(f)



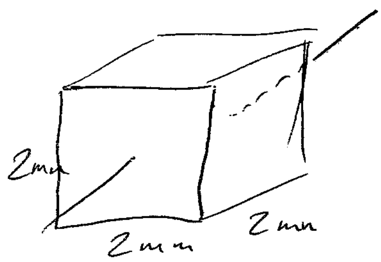
$$R_{1mm} = \frac{l}{\sigma A} \quad \text{from page 1.}$$

$$= \frac{1\,mm}{7.2\times10^{3}\times(1\,mm)^2} = \frac{\cancel{10^{-3}}}{7.2\times\cancel{10^{3}}\times1\times\cancel{10^{-6}}} \qquad 3$$

$$= \underline{0.138\ \Omega}$$

(g) $$R_{2mm} = \frac{2\times10^{-3}}{7.2\times10^{3}\times4\times10^{-6}}$$

$$= \underline{0.069\ \Omega}$$



3