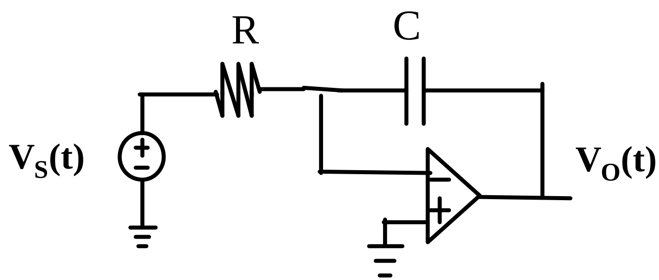
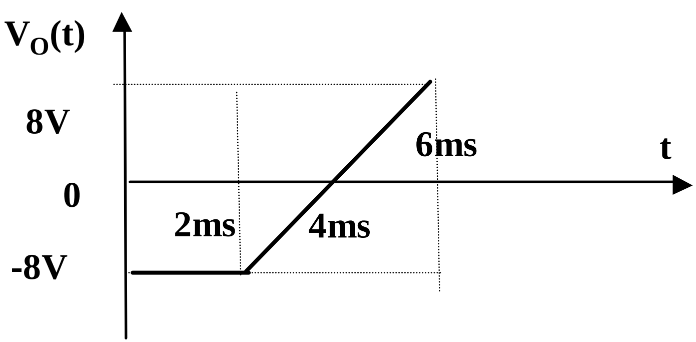
1

Find Vs(t) in terms of C, R, and Vo(t).

If C = 1μF and R = 2kΩ, find and plot Vs(t) . Assume the op amp is ideal.

(17)





$$\text{apply KCL} \Rightarrow \frac{V_S}{R} \cong -C\frac{dV_O}{dt}$$ (6)

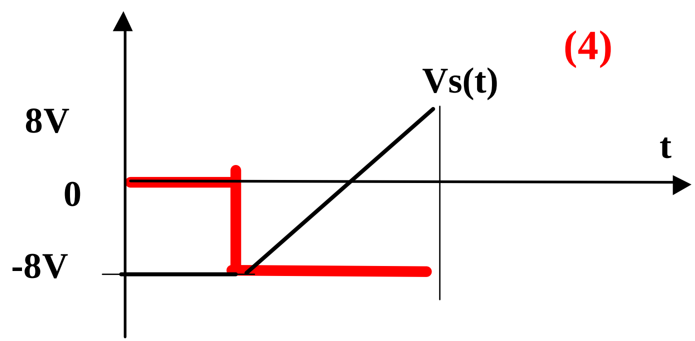
$$CR = 0.5mF * 2k\Omega = 1ms$$

$$\therefore V_S \cong -CR\frac{dV_O}{dt} = -2ms * \frac{8V - -8V}{4ms} = -8V$$

(7)

$V_S(t)$

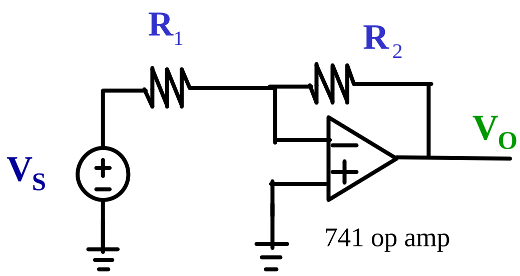
(4)

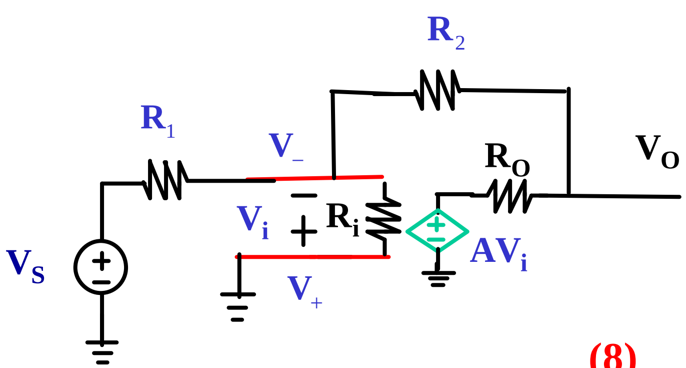


(17)

2

a. In the circuit, replace the 741 op amp by the op amp circuit model and redraw the circuit. Given that Ri = 2MΩ, Ro = 75Ω, A = 200k. (8)

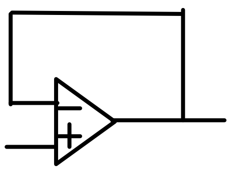




(8)

2

b. Draw the circuit of an op amp **voltage follower** and name two advantages of the circuit. (9)



(4)

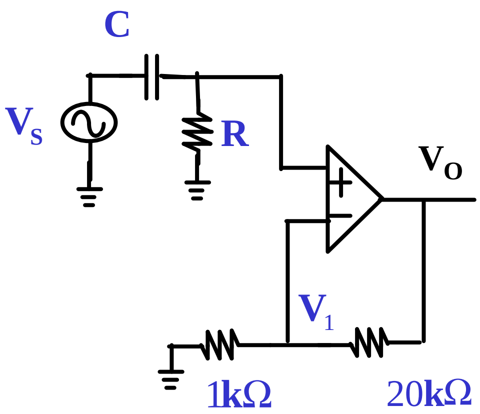
voltage follower

1. Very high input resistance
2. Very low output resistance

(5)

3

Given that $V_S(t) = V_m \cos wt\ V$ and $V_O / V_1 = 21$, find V_1 / V_S in terms of R, C and jw. If C = 1μF and R = 1kΩ, find the complex transfer function G (= V_O / V_S). Is the op amp circuit a low pass filter? Assume the op amp is ideal.
(13)



$$V_1 = V_S * \frac{R}{R + \frac{1}{jwC}} = V_S * \frac{1}{1 + \frac{1}{jwCR}}$$

$$V_O = 21V_1 = 21 * V_S \frac{1}{1 + \frac{1}{jwCR}} = \frac{21V_S}{1 + \frac{1}{jw(1mF * 1k\Omega)}}$$

$$G = \frac{V_O}{V_S} = \frac{21}{1 + \frac{1}{jw * 1ms}}$$

(10)

Circuit is a high pass filter (3)

(21)

4

In an ideal op amp filter circuit, the complex transfer function G (= V_O / V_S) is given as. $\frac{-11}{1+\mathbf{j}w\mathbf{CR}}$

C = 1x10^{-8} F and R = 1kΩ.

(a) Show that the cut off frequency ω_O is 100k rad/s.

(b) Plot the magnitude of G (| G |) versus ω . Show clearly the value of | G | when ω = 0 and $\omega = \omega_O$ in your plot.

(c) If $\mathbf{V_S(t)} = 2\cos 100\mathbf{kt},\mathbf{V}$ find $V_O(t)$.

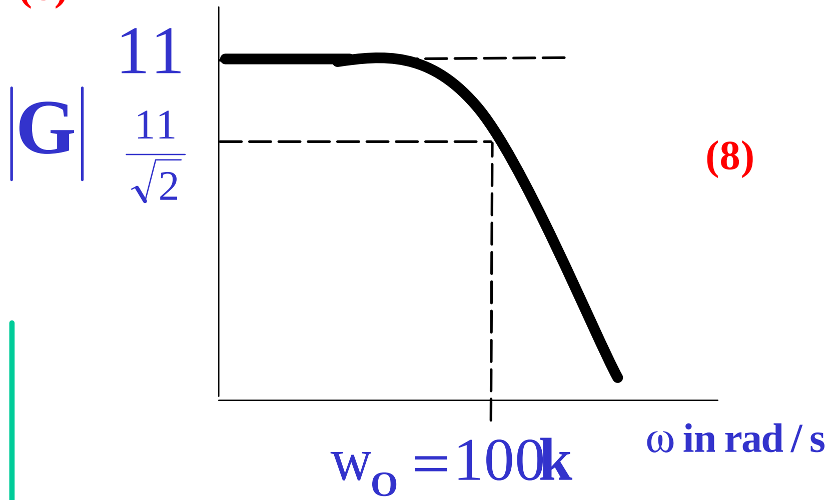
(21)

(a)

$$w_O = \frac{1}{\mathbf{CR}} = \frac{1}{10\mathbf{nF} * 1\mathbf{k}\Omega} = 100\mathbf{krad/s}$$

(5)

(b)



(8)

(c)

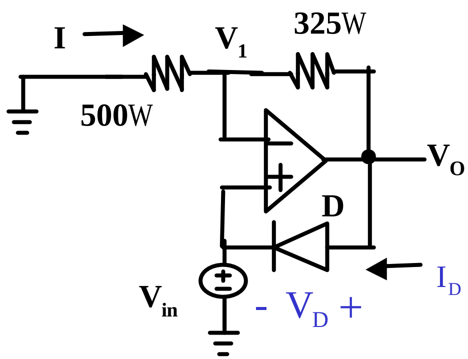
$$\mathbf{V_o} = 2\angle 0 * \frac{-11}{1+\mathbf{j}} = \frac{-11}{\sqrt{2}\angle 45^{\mathbf{o}}}$$

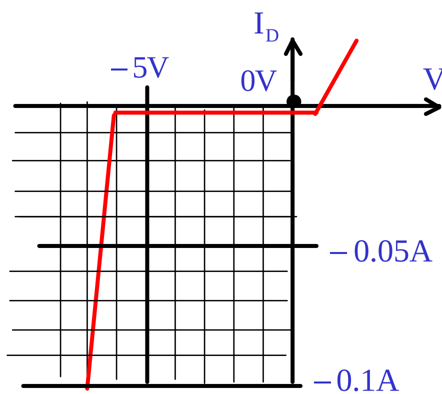
(8)

$$\mathbf{V_o(t)} = -\frac{22}{\sqrt{2}}\cos(100\,\mathbf{kt} - 45^{\mathbf{o}})\,\mathbf{V}$$

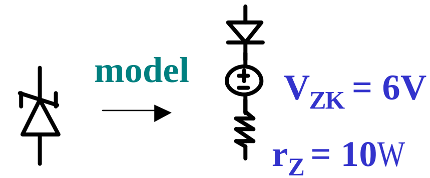
(22)

5 In the ideal op amp circuit, the diode has the forward, reverse and breakdown characteristics as shown.
(a) Draw the circuit model of the diode at breakdown.
(b) If I = 20mA, show that Vo = -16.5V. Hence find I_D.
(22)





(a)



(7)

(b) **When I = 10mA**

$$V_O = -\mathbf{I} * (500\Omega + 325\Omega) = -16.5\text{V}$$ **(3)**

$$\therefore V_{in} = V_1 = -10\text{V}$$ **(4)**

D is breakdown **(2)**

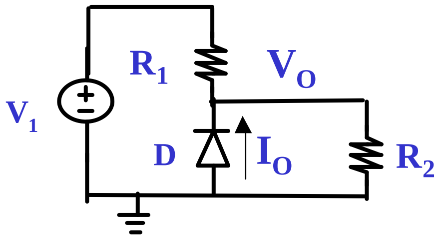
$$I_D = -\frac{-10\text{V} - -16.5\text{V} - 6\text{V}}{10\text{O}} = -0.05\text{A}$$ **(6)**

(13)

6

(a) In the diode circuit, if $V_1 = -7V$, $R_1 = 18k\Omega$, $R_2 = 2k\Omega$, find I_O.
Given that the diode equation is

I = (1pA) exp [(VD/25mV) – 1]. (13)



$$V_O = \mathbf{V_1} * \frac{\mathbf{R_2}}{\mathbf{R_1} + \mathbf{R_2}} = -7V * \frac{2k\Omega}{18k\Omega + 2k\Omega} = -0.7V$$

diode is ON

(5)

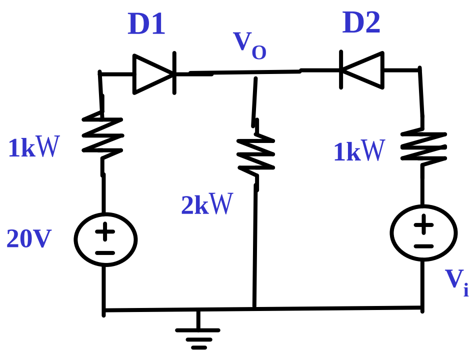
$$\therefore I_O = I_S \left(e^{\frac{0.7V}{25mV}} - 1\right)$$

$$= 1x10^{-12} A \left(e^{\frac{700m}{25m}} - 1\right) \cong 1.45A$$

(8)

6

(b) In the diode circuit, find Vo when Vi = 18V. Assume the diodes are ideal. (15)



Vi = 18V, D1 and D2 ON, (4)

$$\therefore \frac{Vi - Vo}{1k\Omega} + \frac{20 - Vo}{1k\Omega} = \frac{Vo}{2k\Omega}$$

$$\therefore Vi - Vo + 20 - Vo = 0.5Vo$$

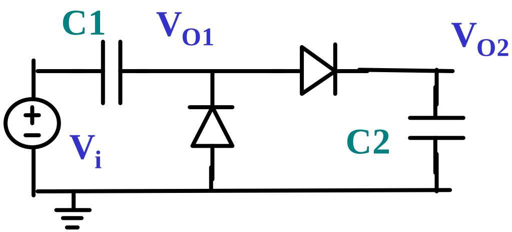
$$\therefore Vo = \frac{Vi + 20}{2.5} = \frac{18\mathbf{V} + 20}{2.5} = 15.2\mathbf{V}$$

(11)

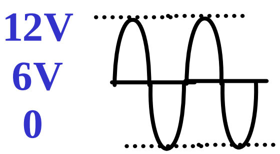
(10)

7

(a) Given that $V_i(t) = 6 \cos 2\pi 1kt$ V, plot and label clearly VO1 and V02. Assume the diodes are ideal. (10)

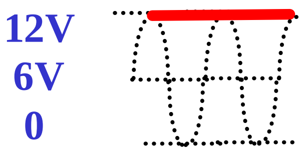


V_{O1}



(5)

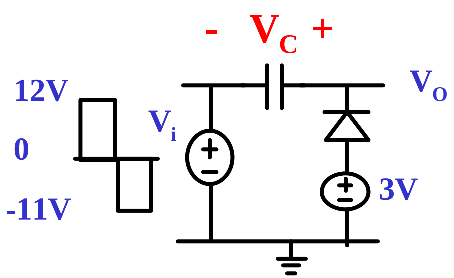
V_{O2}

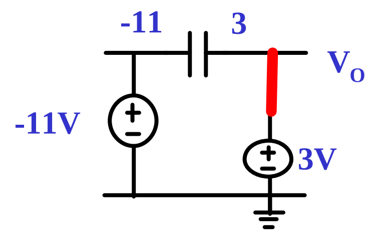


(5)

7

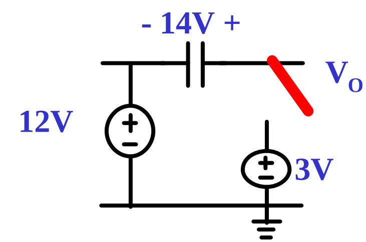
(b) In the diode circuit, find Vc and sketch Vo(t). Label clearly $V_O(t)$. Assume the diode is ideal. (12)



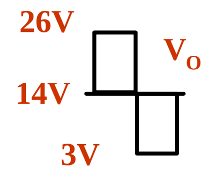


Vc = 3 - -11
= 14V

(6)



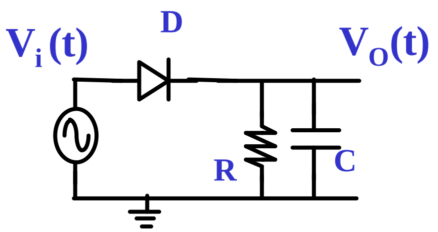
V_O = Vi + Vc
= 12 + 14
= 26 V



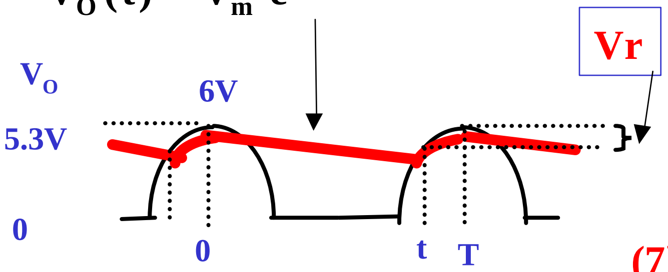
(6)

8

. If $V_i(t) = 6\cos 2\pi 1kt$ V, sketch the waveform of $V_i(t)$ and $V_O(t)$. Find also the ripple voltage V_r of $V_O(t)$. Given that $R = 30k\Omega$, $C = 1\mu F$ and diode is an <u>offset diode</u> where $V_F = 0.7V$. Given also that $V_r \cong V_m T / CR$. (14)



$$V_O(t) = V_m\, e^{-t/CR}$$



(7)

$$V_r \cong V_m(T/CR)$$

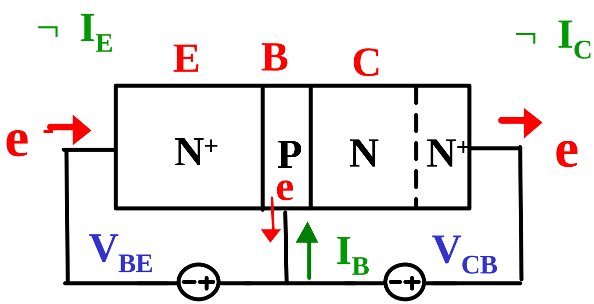
$$= (6V - 0.7V)(1ms/30ms) \cong 0.18V$$

(7)

(16)

9

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

$$I_C \cong a I_E$$

(10)

$$I_E \cong \frac{I_C}{a} = I_B + I_C = \frac{I_C}{\text{ß}} + I_C$$

$$\text{hence } \frac{1}{a} = \frac{1}{\text{ß}} + 1$$

$$a = \frac{\text{ß}}{\text{ß}+1}$$

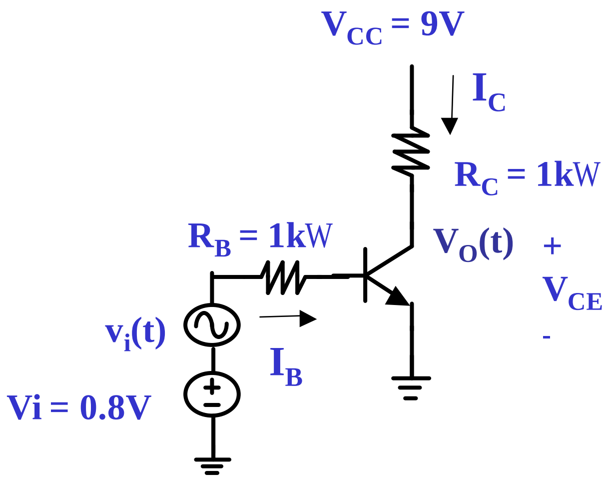
(6)

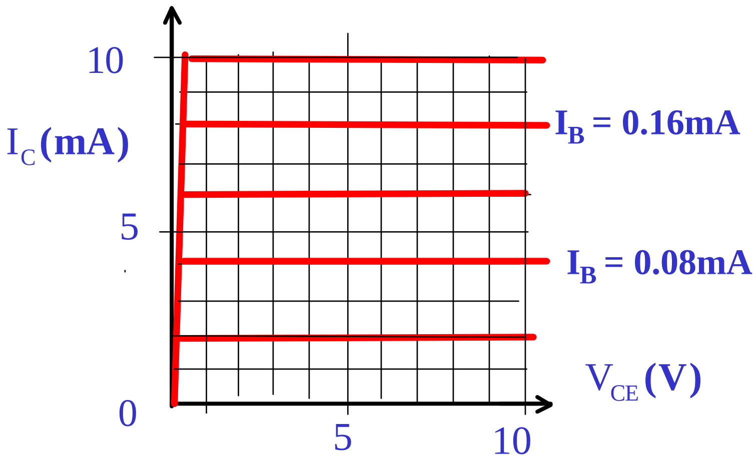
10

Given the BJT circuit below and the I_C - V_{CE} curve of the BJT. (a) Draw the load line $V_{CE} = V_{CC} - I_C R_C$ and locate the Q point on the load line. (b) If $v_i(t) = 0.02 \sin \omega t$ V, estimate the voltage gain from the I-V curve and sketch $V_O(t)$.

(22)

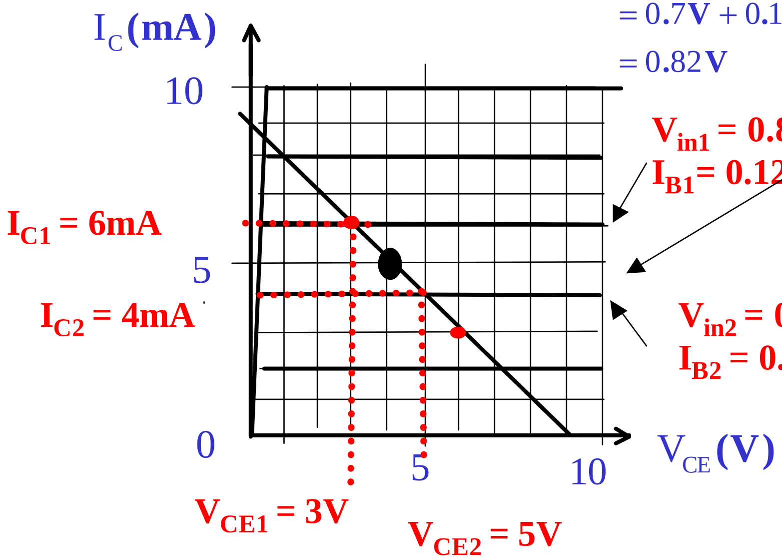
For the BJT, given $\beta = 50$, $V_{BE(ON)} = 0.7V$, $V_{CESAT} = 0.2V$, $r\pi = 0\Omega$





(a) Draw load line, Q point,

$$V_{in2} = V_{BE(ON)} + I_B R_B = 0.7V + 0.12mA*1kO = 0.82V$$



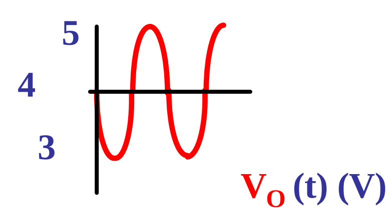
(11)

$$I_B = \frac{Vi - V_{BE(ON)}}{R_B} = \frac{0.8V - 0.7V}{1k\Omega} = 0.1mA$$

(b) and find voltage gain

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

$$\cong \frac{5V - 3V}{0.78V - 0.82V} = -50$$



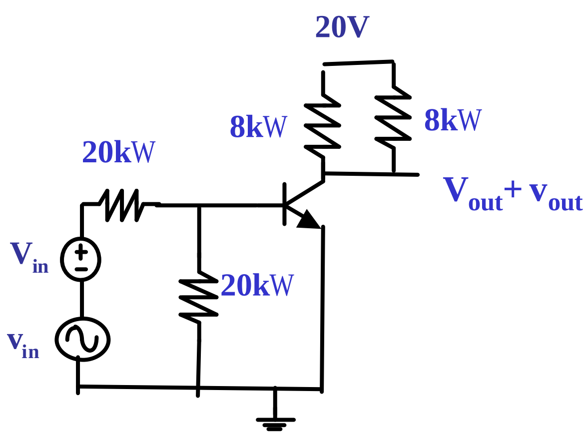
(11)

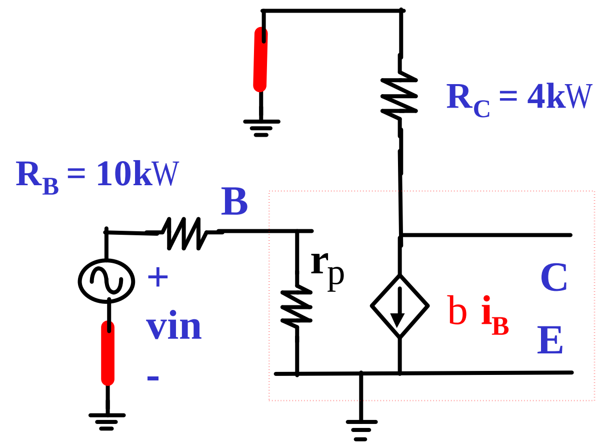
(16)

11

.
Draw the small signal (AC) equivalent circuit of the BJT amplifier and find the voltage gain A_V ($= v_{out} / v_{in}$) .

Given $\beta = 100$, and $V_{CESAT} = 0.2V$, $V_{BE(ON)} = 0.7V$, $r\pi = 0\Omega$. (16)





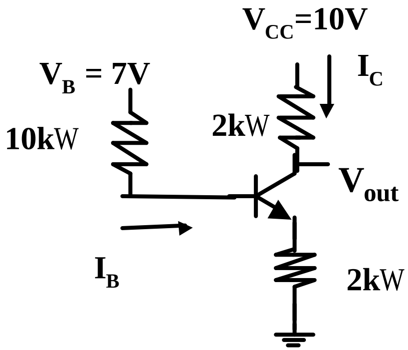
(8)

$$\therefore Av = \frac{v_{OUT}}{v_{in}} = \frac{-ß\, i_B R_C}{i_B (R_B + r_p)}$$

$$= \frac{-ßR_C}{R_B + r_p} = \frac{-(100)(4k\Omega)}{10k\Omega + 0\Omega} = -40$$ **(8)**

12

.
Given that the BJT is in saturation. Write down the equation relating IB and VB, and the equation relating IB and VCC, and show that the forced beta β* (= IC / IB) is about 18.8. Given that $V_{CESAT} = 0.2V$, $V_{BE(ON)} = 0.7V$. (17)



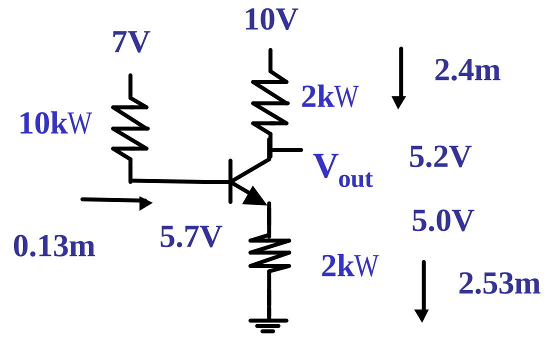
$$\therefore I_B = \frac{V_B - V_{BE}}{R_B + (1+b^*)R_E} = \frac{V_{CC} - V_{CESAT}}{b^* R_C + (1+b^*)R_E}$$

$$\therefore I_B = \frac{7-0.7}{10k + (1+b^*)2k} = \frac{10-0.2}{2k(1+2b^*)} \qquad \text{(10)}$$

$$\therefore 6.3(1+2b^*) = 9.8(6+b^*)$$

$$\therefore 12.6b^* + 6.3 = 9.8b^* + 58.8$$

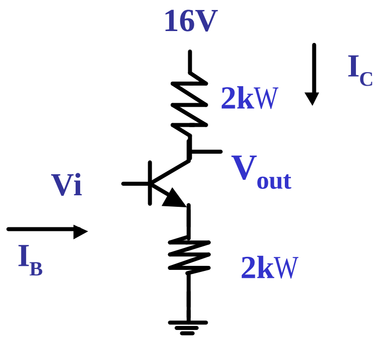
$$\therefore b^* = \frac{58.8-6.3}{12.6-9.8} \cong 18.75 \qquad \text{(7)}$$



13

.

(a) If Vi = 8V, find IB, Ic, Vout and the mode of BJT.
(b) If Vi = 10V, find Vout
Show clearly your reasons.
Given $\beta = 100$, and $V_{CESAT} = 0.2V$, $V_{BE(ON)} = 0.7V$.
(31)



BJT is not OFF since V_{BE} can be 0.7V

$$\therefore I_B = \frac{8V - 0.7V}{(100+1)(2k\Omega)} \cong 36mA \quad (6)$$

$$\therefore I_C = bI_B \cong 100 * 36mA = 3.6mA \quad (3)$$

Ic < max I_C = ~ 15.8V/4kW ~ 4mA (3)

Hence BJT is in amplifier mode (2)

$$\therefore V_{out} = 16V - I_C(2k\Omega) = 16V - 7.2V = 8.8V$$

(4)

Vi = 10V, IB ~ 46 uA
hence Ic > max Ic (6)

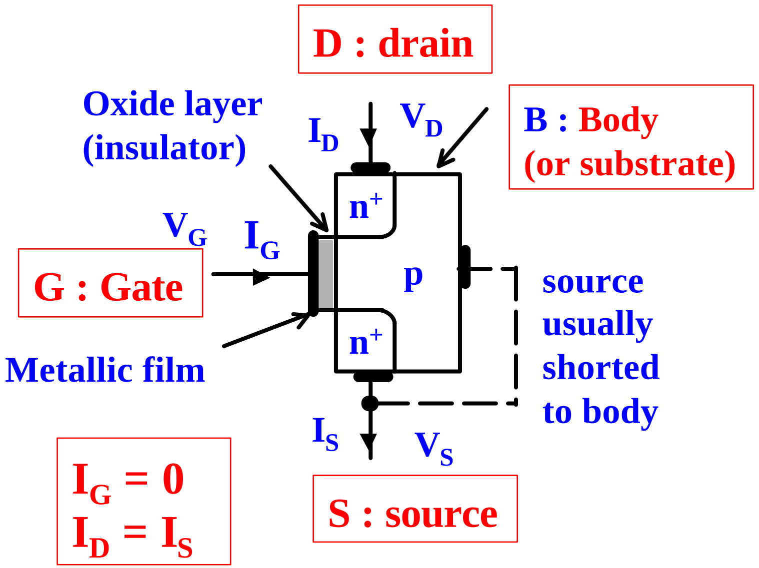
Hence BJT is in saturation mode (2)

$$\therefore V_{out} = 9.3V + 0.2V = 9.5V \quad (5)$$

14

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

small size (scaled down easily) and low power consumption. **(5)**



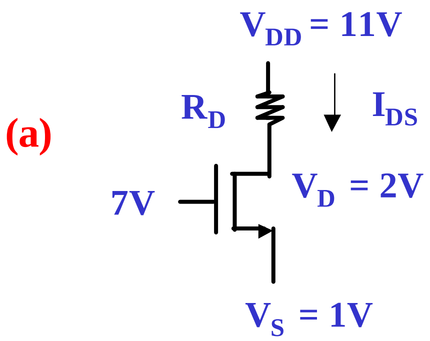
An NMOSFET consists of a metal gate insulated from a p-type semiconductor substrate (or body) by an insulating layer of silicon dioxide. On either side of the gate there are n type regions forming the drain and source.

(10)

15

(a) Find the mode of the MOSFET. Find also I_{DS} . Show clearly the reasons for your answers. (14)

Given that $V_T = 1V$, $K = 0.5\ mA/V^2$.
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, $V_{GS} \geq V_T$, $V_{DS} \geq V_{GS} - V_T$, $I_{DS} = K[(V_{GS} - V_T)^2]$



$$V_{GS} = V_G - V_S = 7V - 1V = 6V$$

$$V_{GS} > V_T$$

K= 0.5mA/V2
V_T= 1V

$$V_{DS} = V_D - V_S = 2 - 1 = 1V$$

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

(6)

NMOSFET is in <u>triode</u> mode **(2)**

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

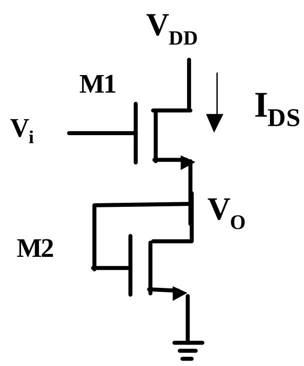
$$= 1m[(6V - 1V)1V - \frac{1V^2}{2})]$$

$$= 1m(\frac{9}{2}) = 4.5mA$$

(6)

15. (b) Show that $V_O = 0.5\ V_i$. (15)

Given that
M1 and M2 are in saturation .
$V_T = 1V$, $K = 0.5\ mA/V^2$.
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 $V_{GS} \geq V_T$, $V_{DS} > \mathbf{V}_{GS} - V_T$, $I_{DS} = K[(V_{GS} - V_T)^2]$.
.



$$\therefore \mathbf{I_{DS}} = \mathbf{K}\,(\mathbf{V_{GS1}} - \mathbf{V_T})^2 = \mathbf{K}\,(\mathbf{V_{GS2}} - \mathbf{V_T})^2$$ **(6)**

$$\therefore (\mathbf{V_{GS1}} - \mathbf{V_T}) = (\mathbf{V_{GS2}} - \mathbf{V_T})$$

$$\therefore \mathbf{V_{GS1}} = \mathbf{V_{GS2}}$$

$$\therefore \mathbf{Vi} - \mathbf{Vo} = \mathbf{Vo}$$

$$\therefore \mathbf{Vo} = \frac{\mathbf{Vi}}{2}$$ **(9)**