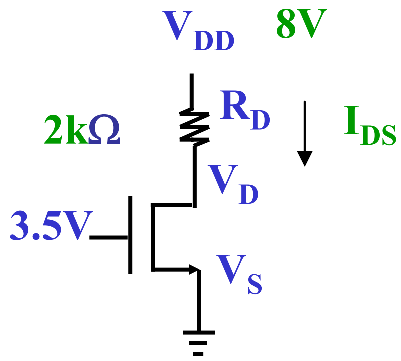
2

Given $V_T = 1V$
$K = 0.25mA/V^2$



Find V_{DS} and I_{DS} for $V_G = 3.5V$

MOS is in saturation mode

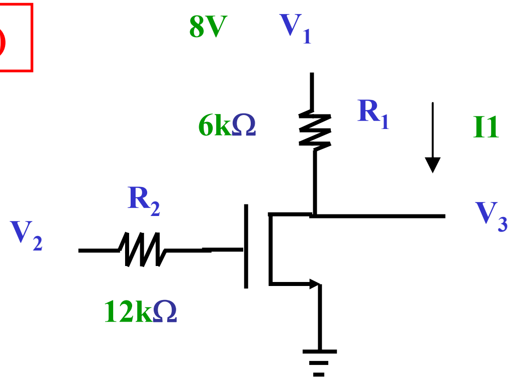
$$\therefore I_{DS} = K\,(V_{GS} - V_T)^2 = 0.25\text{m}(3.5-1)^2 = 1.5625\text{mA}$$

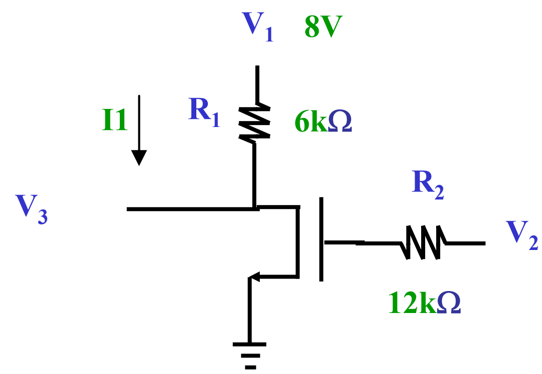
$$\therefore V_{DS} = V_{DD} - I_{DS}R_D = 8-(1.5625\text{m})2\text{k} \cong 4.875\text{V}$$

$$\therefore I_{DS} = \frac{8-4.875}{2\text{k}} = 1.5625\text{mA}$$

4 **(18)**

Given
$V_T = 1V$
$K = 0.25mA/V^2$





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a **If $V_2 = 0.5V$**

$V_{GS} < V_T$

$0.5 < 1$

NMOS cut off

$$\therefore \mathbf{I}_1 = 0$$

$$\therefore \mathbf{V}_3 = 8\mathbf{V}$$

---

b **If $V_2 = 3V$**

Assume NMOS is in saturation

$$\therefore \mathbf{I}_1 = \mathbf{K}\,(\mathbf{V}_{GS} - \mathbf{V}_T)^2 = 0.25\mathbf{m}(3-1)^2 = 1\mathbf{mA}$$

$$\therefore \mathbf{V}_3 = 8 - \mathbf{I}_1\mathbf{R}_1 = 8 - 1\mathbf{m}(6\mathbf{k}) = 2\mathbf{V}$$

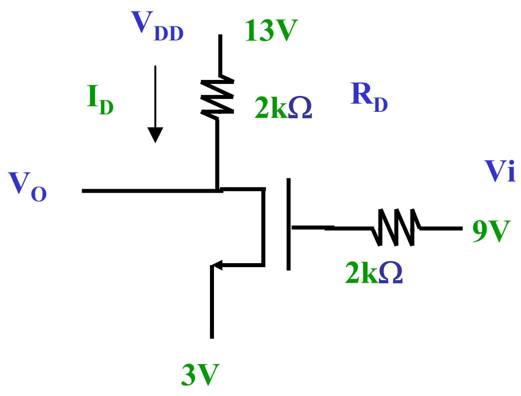
NMOS is saturated since
1. 3 > 1
2. 2 = 3 - 1

NMOS is saturated since
1. $V_{GS} > V_T$
2. $V_{DS} = V_{GS} - V_T$

4. (a) If V_2 = 0.5V, find I_1 and V_3. (b) If V_2 = 2V, find I_1 and V_3. State clearly the reasons for your answer.
Given V_T = 1V, K = 0.25mA/V^2.
Given that
at triode region, $I_{DS} = 2K[(V_{GS} - V_T)V_{DS} - V_{DS}^2 / 2]$

at saturation region, $I_{DS} = K[(V_{GS} - V_T)^2]$ (19).

5 **(26)**



Given
$V_T = 1V$
$K = 0.5mA/V^2$

$$\therefore I_D = \frac{V_{DD} - V_{DS}}{R_D} = \frac{10 - V_{DS}}{2k}$$

$$= 2K[(V_{GS} - V_T)V_{DS} - \frac{V_{DS}^{\ 2}}{2}] = 1m[(8 - 2 - 1)V_{DS} - \frac{V_{DS}^{\ 2}}{2})]$$

$$\therefore \frac{10 - V_{DS}}{2k} = 1m[5V_{DS} - \frac{V_{DS}^{\ 2}}{2}]$$

$$\therefore 10 - V_{DS} = 2[5V_{DS} - \frac{V_{DS}^{\ 2}}{2}]$$

$$\therefore V_{DS}^{\ 2} - 11V_{DS} + 10 = 0$$

$$\therefore V_{DS} = 10V \quad \text{or} \quad 1V$$

hence $V_O = 3 + 1 = 4V$
$V_{DS} = 12\ V = V_{DD}$ is impossible since MOS is not cut off ($V_{DGS} > V_T$)

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

NMOS is triode since
1. $6 > 1$
2. $1 < 6 - 1$

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

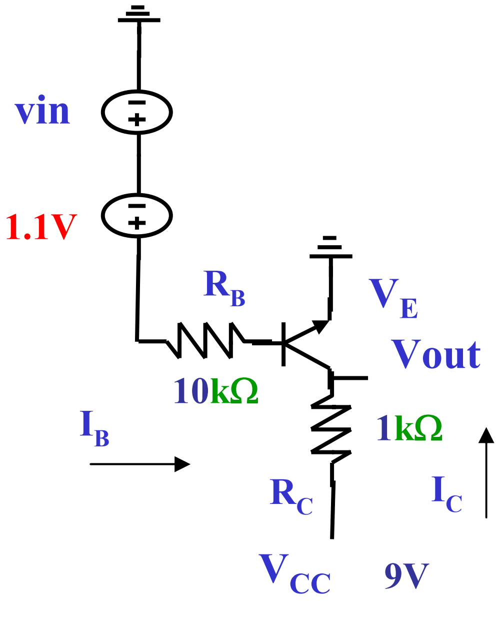
$$= 1m[(6 - 1)1 - \frac{1}{2})] = 4.5mA$$

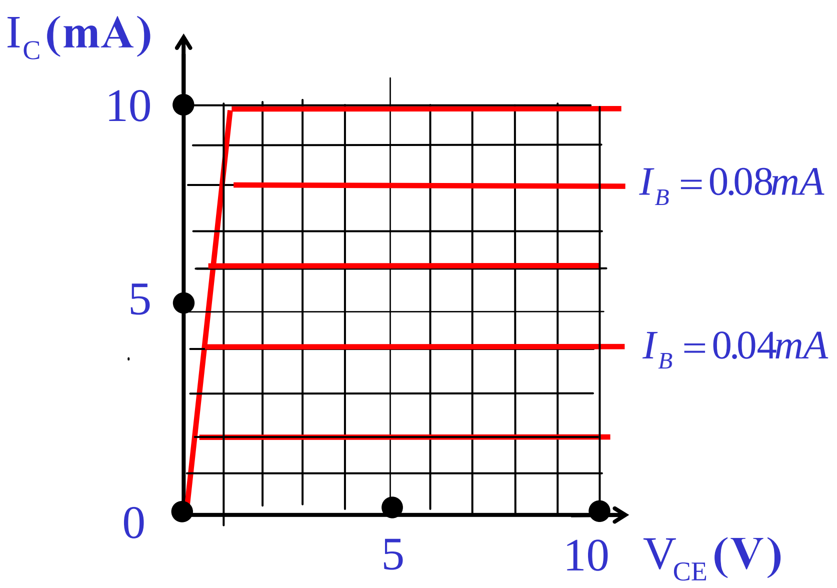
5. In the circuit, find V_O . State clearly the reasons for your answer.
Given $V_T = 1V$, $K = 0.5mA/V^2$.
Given that
at triode region, $I_{DS} = 2K[(V_{GS}-V_T)V_{DS} - V_{DS}^{\ 2} / 2]$

at saturation region, $I_{DS} = K[(V_{GS}-V_T)^2]$ (26).

8

8. A BJT with the following I_C-V_{CE} characteristics is used in the following circuit. (a) Sketch the load line $V_{CE} = V_{CC} - I_C R_C$ and the Q point on the graph.
(b) If vin = 0.1 cos ωt V, sketch the base current I_B , the collector current I_C and the output voltage Vout. Show clearly the DC value, the maximum and minimum value in your sketch. Estimate also the current gain dI_C / dI_B and voltage gain dVout / dVin.
(c) Sketch the small signal (AC) equivalent circuit of the amplifier and find the voltage gain Av (= Vout/Vin). For the BJT, given $r\pi = 0\Omega$, $V_{BE(ON)} = 0.7V$. (49)

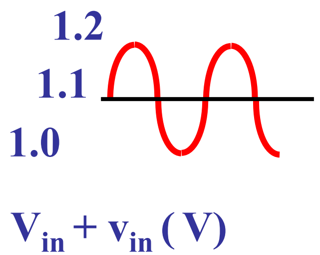


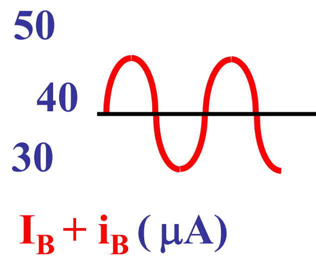


a **Find I_B from equation**

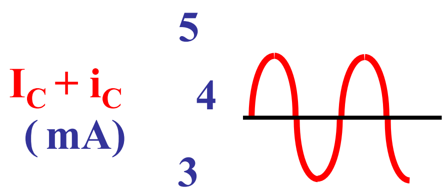
$$\therefore I_B = \frac{V_{in} - V_{BE}}{R_B} = \frac{1.1V - 0.7V}{10k\Omega} = 0.04mA$$

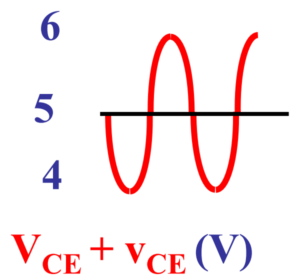
b **Find I_C from graph**



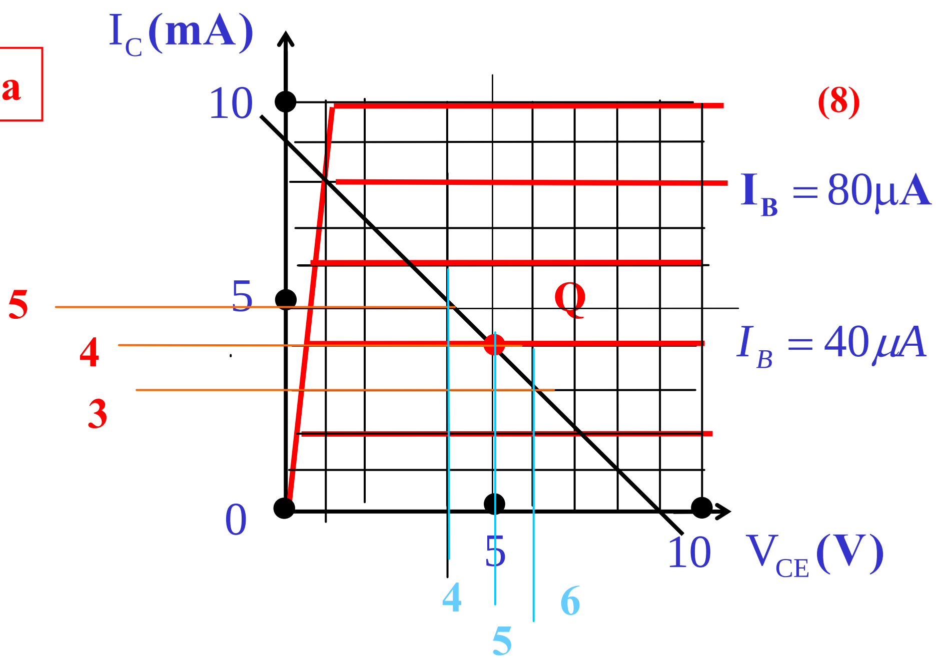


c **Find V_{CE} from graph**





a



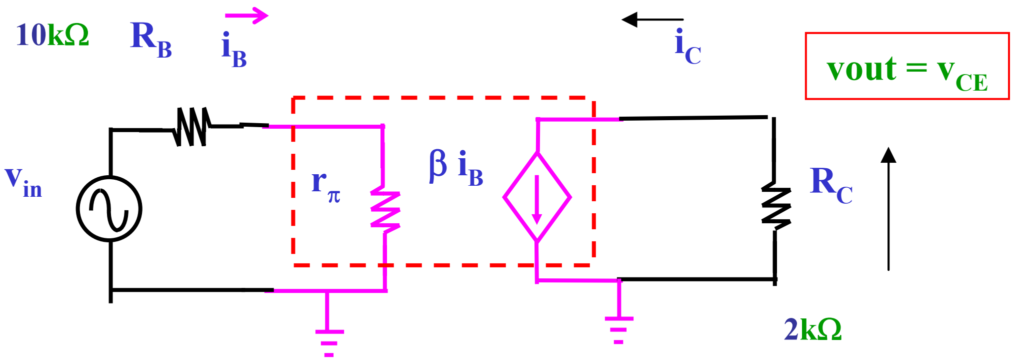
(8)

Estimate current and voltage gain

$$\therefore A_I = \beta_F = \frac{\Delta I_C}{\Delta I_B} \approx \frac{5m - 3m}{50\mu - 30\mu} = \frac{2mA}{20\mu A} = 100$$

$$\therefore A_V = \frac{\Delta V_{out}}{\Delta V_{in}} = \frac{6V - 4V}{1.0V - 1.2V} = \frac{2V}{-0.2V} = -10$$

c

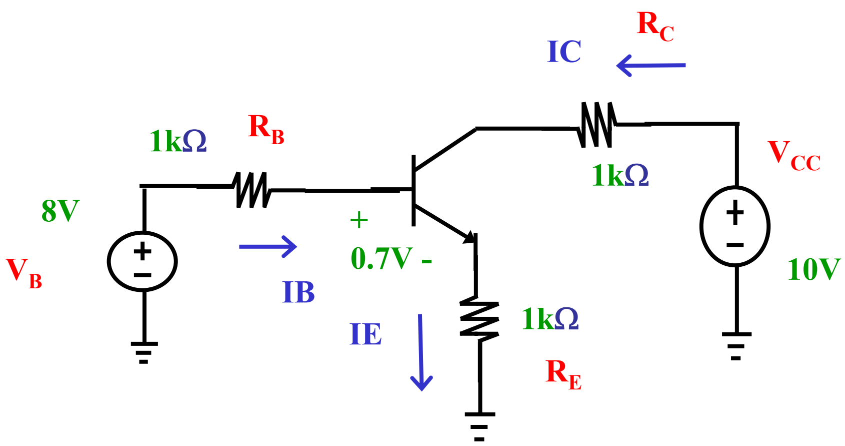


$$\therefore Av = \frac{v_{OUT}}{v_{in}} = \frac{-\beta\, i_B R_C}{i_B(R_B + r_\pi)} = \frac{-\beta R_C}{R_B + r_\pi} = \frac{-(100)(1k)}{10k} \cong -10$$

(30)

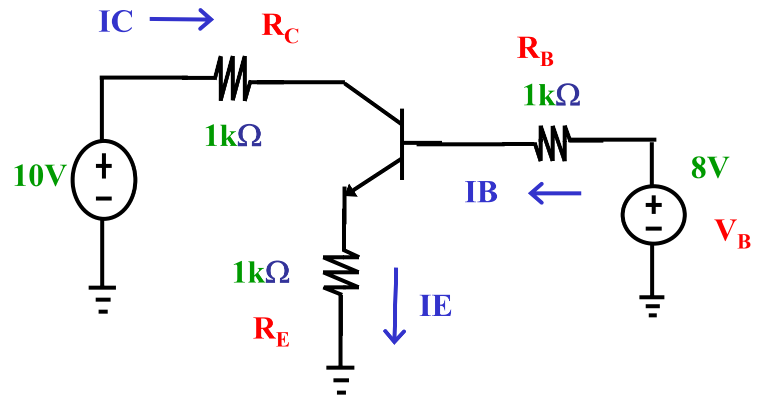
9

9. Given the BJT circuit.
Given that IB is about 1.57mA. Show that the BJT is in saturation.
Hence show that the forced beta is about 2.7.
For the BJT, given V_{BE} = 0.7V, β = 100, V_{CESAT} = 0.1V . (30)



$$\therefore\ I_C = \beta I_B = 100(1.57\mathrm{m}) = 157\mathrm{mA}$$

$$>> I_C\ (\text{when } V_{CE} = 0\mathrm{V}) = \frac{10\mathrm{V}}{2\mathrm{k}\Omega} = 5\mathrm{mA}$$



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

$$\therefore\ I_B = \frac{8-0.7}{1\mathrm{k} + (1+\beta^*)1\mathrm{k}} = \frac{10-0.1}{1\mathrm{k}(1+2\beta^*)}$$

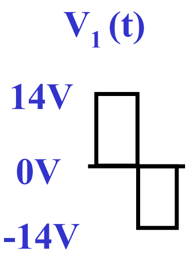
$$\therefore 7.3(1+2\beta^*) = 9.9(2+\beta^*)$$

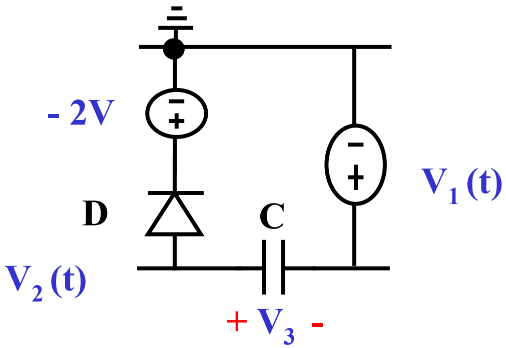
$$\therefore 14.6\beta^* + 7.3 = 9.9\beta^* + 19.8$$

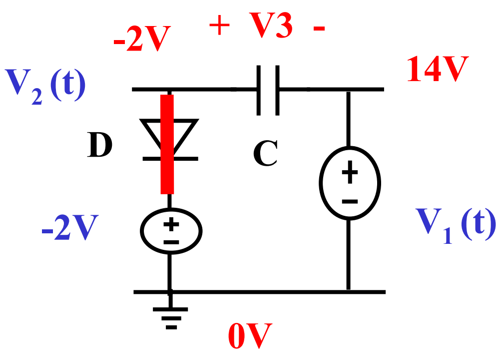
$$\therefore \beta^* = \frac{19.8-7.3}{14.6-9.9} \cong 2.66$$

11

11. (a) In the ideal diode circuit, find V3 and sketch V2(t). (15)

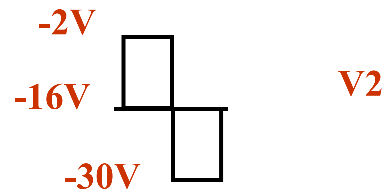






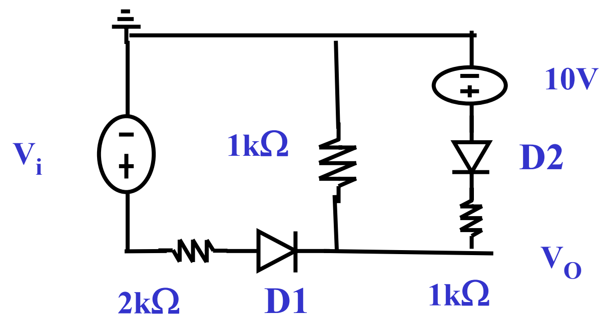
Hence V3 = - 16V

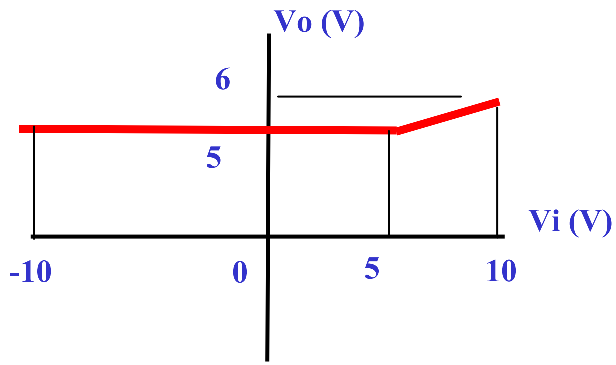
Hence V_2 = V1 + V3 = V1 - 16V



11

(b) In the ideal diode circuit, plot Vo versus Vi for
-10V ≤Vi ≤ 10V.
Show clearly all voltages in your sketch. (20)





(6)

Vi < 5V, D1 OFF and D2 ON $\quad \therefore \mathrm{Vo} = 5\mathrm{V}$

Vi > 5V, D1 and D2 ON,

$$\therefore \frac{\mathrm{Vi}-\mathrm{Vo}}{2\mathrm{k}} + \frac{10-\mathrm{Vo}}{1\mathrm{k}} = \frac{\mathrm{Vo}}{1\mathrm{k}}$$

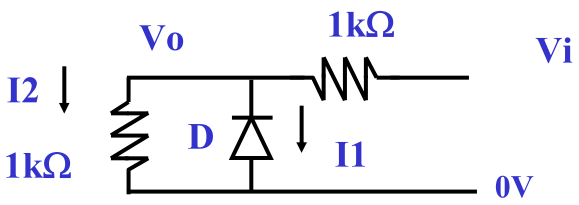
$$\therefore \mathrm{Vi}-\mathrm{Vo}+20-2\mathrm{Vo} = 2\mathrm{Vo}$$

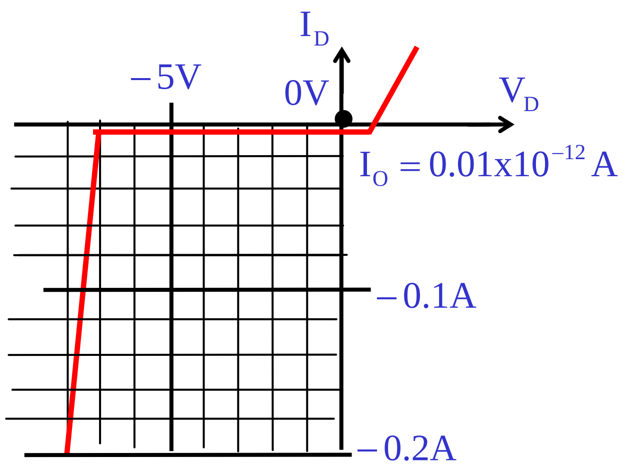
$$\therefore \mathrm{Vo} = \frac{\mathrm{Vi}+20}{5}$$

(35)

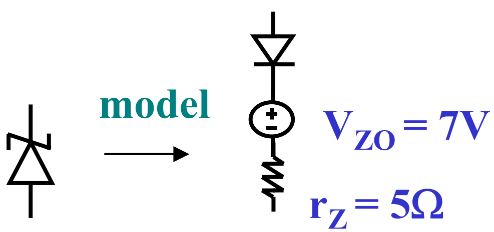
12

12. In the diode circuit, the diode has the reverse characteristics as shown. The diode equation is I = Io exp [(V/25mV) – 1].
(a) Sketch the circuit model of the diode at breakdown.
(b) Find I1 if Vi = – 1V.
(c) Find I1 if Vi = 2V.
(d) Find I2 if Vi = 16V. (35)





a



b

$$\mathbf{Vi = -1V,\ \therefore Vo = -0.5V}$$

$$\therefore \mathbf{I_1 = -I_O\,(e^{\frac{0.5V}{25mV}} - 1)}$$

$$= \mathbf{-0.01x10^{-12}\,A\,(e^{\frac{500m}{25m}} - 1)} = -4.85x10^{-6}\,\mathbf{A}$$

c

$$\therefore I_1 = I_O = 0.01x10^{-12}\,A$$

d

$$Vi = 16V,\ \therefore Vo = 8V, D\ \ breakdown$$

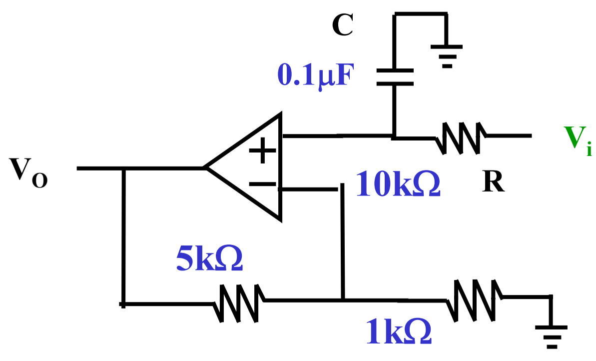
$$\frac{16 - \mathbf{Vo}}{\mathbf{1k}} = \frac{\mathbf{Vo} - 7}{5} + \frac{\mathbf{Vo}}{\mathbf{1k}}$$

$$16 - \mathbf{Vo} = 200(\mathbf{Vo} - 7) + \mathbf{Vo}$$

$$\mathbf{Vo} = \frac{1400 + 16}{202} \cong 7.01\mathbf{V}$$

$$\therefore \mathbf{I2} = \frac{\mathbf{Vo}}{\mathbf{R_L}} \cong \frac{7.01}{\mathbf{1k}} = 7.01\mathbf{mA}$$

13



a

$$V_2 = Vi\frac{1/j\omega C}{R + 1/j\omega C} = \frac{Vi}{1 + j\omega CR}$$

$$\therefore V_O = V_2(1 + \frac{5k}{1k}) = 6V_2 = 6\frac{Vi}{1 + j\omega CR}$$

$$\therefore G = \frac{V_O}{V_i} = \frac{6}{1 + j\omega CR}$$

13. Given the filter circuit. The op amp is ideal.
(a) Obtain the complex transfer function G (=Vo/Vi) in terms of jω, C and R .
(b) Find the cut-off frequency (in rad/s) and the DC gain (value of G when Vi is a DC voltage) of the filter.
(c) Sketch |Vo/Vi| in dB versus angular frequency ω . Label clearly all intercepts. Given |G| in dB = $20\log_{10}|G|$.
(d) Is it a low pass filter? Find also the pole and zero of the filter.
(38)

b

At cut off frequency $\therefore G = \frac{V_O}{V_i} = \frac{6}{1 + j}$

$$\omega_O CR = 1$$

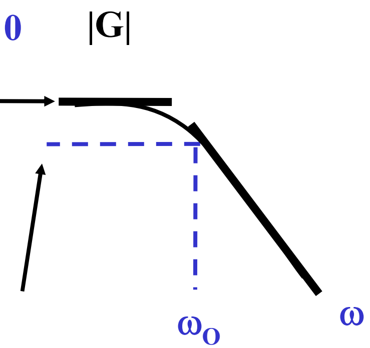
$$\therefore \omega_O = \frac{1}{CR} = \frac{1}{0.1\mu(10k)} = 1\text{krad/s}$$

DC gain $G = 6$

c

At low frequency, ω ~ 0

$$|G| \text{ in dB} = 20\log_{10} 6 \cong 15.6\text{ dB}$$



At cut-off frequency,

$$|G| \text{ in dB} = 20\log_{10}\frac{6}{\sqrt{2}} \cong 12.6\text{ dB}$$

d

low pass filter

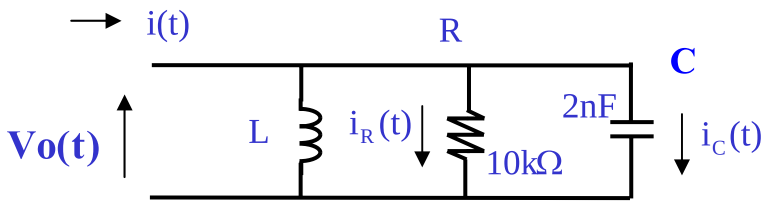
(36)

15

15. In the following LCR circuit,
(a) find the resonant frequency (in rad/s and in Hz), Q-factor , bandwidth, upper and lower cut-off frequencies (all in rad/s) of the LCR circuit.
(b) If $i(t)=\sqrt{8}\cos\omega t\ \mathrm{mA}$ find Vo(t) and iC(t) at resonance. (36)

Lower f $\therefore \omega_1 = \omega_O - \frac{BW}{2} = 4950k\ rad/s$

Upper f $\therefore \omega_2 = \omega_O + \frac{BW}{2} = 5050k\ rad/s$



If i is 2mA rms

a

$$\therefore \omega_O = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{L*2n}} = 5M\ rad/s\ \text{and}\ 795.78kHz$$

$$\text{Hence } L = \frac{1}{(5M)^2 * 2n} = 0.02mH$$

$$\therefore Q\,factor = \frac{Q}{P} = \frac{R}{\omega_O L} = \frac{10k}{5M(0.02m)} = 100$$

$$\therefore BW = \frac{\omega_O}{Q\,factor} = \frac{5M}{100} = 50k\ rad/s\ \text{or}\ 7.96kHz$$

b

$$\therefore i_R = 2m\ Arms$$
$$\therefore Vo = 2mA * 10k\Omega = 20\ Vrms$$
$$\therefore i_C = Q\,factor * i_R = 200\ mArms$$

$$\therefore Vo(t) = 20\sqrt{2}\cos 5Mt\ V$$

$$\therefore i_C(t) = 200\sqrt{2}\cos(5Mt + 90^o)\ mA$$