EEE 3571 ELECTRONIC ENGINEERING I
TERM 1 TEST [SOLUTIONS] – 2016/2017 ACADEMIC YEAR – MARCH 30, 2017

[QUESTION 1]

(a)

(i) Determine the thermal voltage for a diode at a temperature of $T = 100\,^{\circ}\mathrm{C}$ (boiling point of water). **[4 Marks]**

(ii) For the same diode of part (i), find the diode current if $I_s = 5\,\mu\mathrm{A}$, $n = 2$ (low value of V_D), and the applied bias voltage is $0.5\,\mathrm{V}$. **[4 Marks]**

[SOLUTION]:

(i) To start with we convert the given temperature to absolute value in kelvins, i.e.,

$$T_K = 273 + T\left({}^{\circ}\mathrm{C}\right);\ T_K = 273 + 100 = 273\,\mathrm{K};$$

Thus, thermal voltage is, $V_T = \dfrac{kT_K}{q} = \dfrac{\left(1.38\times10^{-23}\,\mathrm{J/K}\right)\left(373\,\mathrm{K}\right)}{1.602\times10^{-19}\,\mathrm{C}} = 0.03213\,\mathrm{V}$;

$\therefore\ V_T = \mathbf{32.13\,mV}$. **[4 Marks]**

(ii) The diode current for the aforesaid diode given, $I_s = 5\,\mu\mathrm{A}$, $n = 2$, and the applied bias voltage is $V_D = 0.5\,\mathrm{V}$; is determined using Shockley's eq., i.e.,

$$I_D = I_s\left(e^{V_D/nV_T} - 1\right) = \left(5\times10^{-6}\,\mathrm{A}\right)\left(e^{0.5/2(0.03213)} - 1\right) = 0.011967\,\mathrm{A};\quad I_D = \mathbf{11.967\,mA}.$$

[4 Marks]

(b) Given a diode current of $6\,\mathrm{mA}$, $V_T = 26\,\mathrm{mV}$, $n = 1$, and $I_s = 1\,\mathrm{nA}$, find the applied voltage V_D. **[4 Marks]**

[SOLUTION]:

Given $I_D = 6\,\mathrm{mA}$, $V_T = 26\,\mathrm{mV}$, $n = 1$, and $I_s = 1\,\mathrm{nA}$, V_D is found as follows:

$$I_D = I_s\left(e^{V_D/nV_T} - 1\right);\ \Rightarrow\ e^{V_D/nV_T} = \left(\frac{I_D}{I_s}\right) + 1,\ \text{thus,}$$

$$V_D = nV_T\ln\left[\left(\frac{I_D}{I_s}\right) + 1\right] = (0.026)\ln\left[\left(\frac{6\times10^{-3}}{10^{-9}}\right) + 1\right] = 0.405789;\ V_D = \mathbf{405.789\,mV}.$$

[4 Marks]

(c) The network shown in Figure Q1 is a fixed input voltage V_i and variable load R_L

(i) Determine V_L, I_L, I_Z, and I_R for the network of Figure Q1(a) if $R_L = 180\,\Omega$. **[7 Marks]**

(ii) Determine the value of R_L that will establish maximum power conditions for the Zener diode. **[3 Marks]**

(iii) Determine the minimum value of R_L to ensure that the Zener diode is in the "on" state. **[3 Marks]**

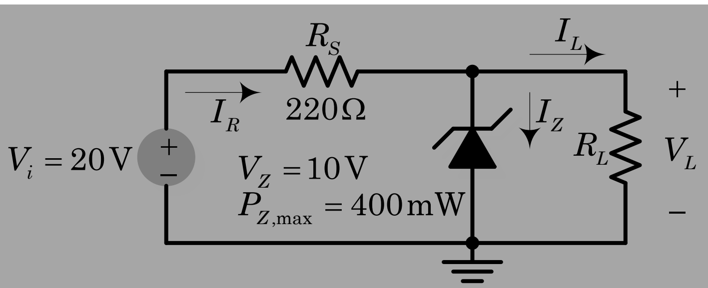
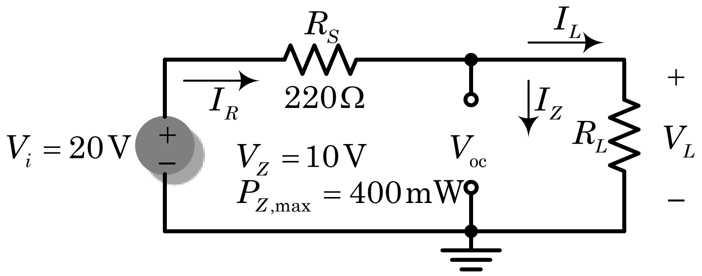


Figure Q1.

[Total 25 Marks]

[SOLUTION]:

(i) **Step 1:** Remove Zener diode and determine open circuit voltage with $R_L = 180\,\Omega$, i.e.,



[1 Mark]

$$V_{oc} = V_L = \frac{R_L}{R_S + R_L} V_i = \frac{180}{180+220}(20\,\text{V}) = 9\,\text{V}\text{, Thus, } V_L = \mathbf{9\,V}.$$ **[2 Marks]**

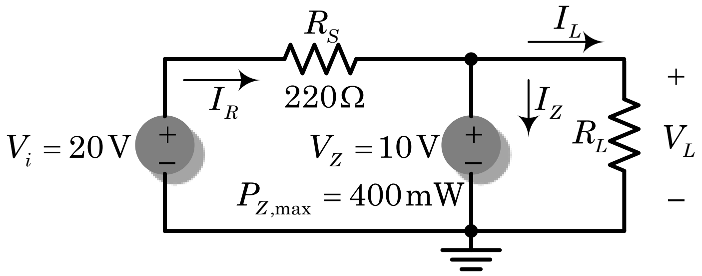
Notice that $V_L < V_Z = 10\,\text{V}$, thus the diode is OFF the equivalent circuit is an open circuit.

It follows that, $I_L = \dfrac{V_L}{R_L} = \dfrac{9\,\text{V}}{180\Omega} = 0.05$; $I_L = \mathbf{50\,mA}$. **[2 Mark]**

Vividly, $I_Z = \mathbf{0\,V}$. **[1 Mark]**

Finally, $I_R = I_L + I_Z = \mathbf{50\,mA}$. **[1 Mark]**

(ii) For maximum power condition the diode should be ON and its equivalent circuit is as shown,



$P_{Z,\max} = I_{Z,\max} V_Z$, thus, $I_{Z,\max} = \dfrac{P_{Z,\max}}{V_Z} = \dfrac{400\,\text{mW}}{10\,\text{V}} = 40\,\text{mA}$; it follows that,

$I_R = \dfrac{V_i - V_Z}{R_s} = \dfrac{20\,\text{V} - 10\,\text{V}}{220\Omega} = 0.0454545\,\text{A}$; $I_R = 45.4545\,\text{mA}$, and $I_{L,\min} = I_R - I_{Z,\max}$;

Thus, $R_{L,\max} = \dfrac{V_L}{I_{L,\min}} = \dfrac{10\,\text{V}}{(45.4545 - 40)\,\text{mA}} = 1833.33\Omega$, $R_{L,\max} = \mathbf{1.833\,k\Omega}$ **[3 Marks]**

(iii) For the diode to be ON, $R_{L,\min}$ ought to be, $R_{L,\min} = \dfrac{R_s V_Z}{V_i - V_Z} = \dfrac{(220\Omega)(10\,\text{V})}{20\,\text{V} - 10\,\text{V}} = 220\Omega$;

[3 Marks]

$R_{L,\min} = \mathbf{220\Omega}$.

[Total 25 Marks]

[QUESTION 2]

(a)

(i) Use your knowledge of differential calculus to find the derivative dI_D/dV_D of the diode characteristics function $I_D = I_s\left(e^{V_D/nV_T} - 1\right)$. **[5 Marks]**

(ii) Hence, by assuming $I_D \gg I_s$ in the vertical-slope section of the diode characteristics, show that the dynamic resistance (ac resistance) is given by $r_d = dV_D/dI_D = nV_T/I_D$.

[5 Marks]

[SOLUTION]:

(i) The derivative of the diode characteristic eq. is found using the calculus as

$$\frac{dI_D}{dV_D} = \frac{d}{dV_D} I_s\left(e^{V_D/nV_T} - 1\right) = \frac{I_s e^{V_D/nV_T}}{nV_T}\text{; but } I_s e^{V_D/nV_T} = I_D + I_s;$$

This implies that, $\dfrac{dI_D}{dV_D} = \dfrac{I_s e^{V_D/nV_T}}{nV_T} = \dfrac{I_D + I_s}{nV_T}$. **[5 Marks]**

(ii) Assuming $I_D \gg I_s$, we have $I_D + I_s \cong I_D$; i.e., $I_s e^{V_D/nV_T} \cong I_D$; thus,

$$\frac{dI_D}{dV_D} = \frac{I_D}{nV_T}\text{; inverting this results yields}$$

$r_d = \dfrac{dV_D}{dI_D} = \dfrac{nV_T}{I_D}$. Hence shown. **[5 Marks]**

(b) For the emitter follower network of Figure Q2,

(i) Find I_B, I_C, and I_E. **[6 Marks]**

(ii) Find V_B, V_C, and V_E. **[6 Marks]**

(iii) Calculate V_{BC} and V_{CE}. **[3 Marks]**

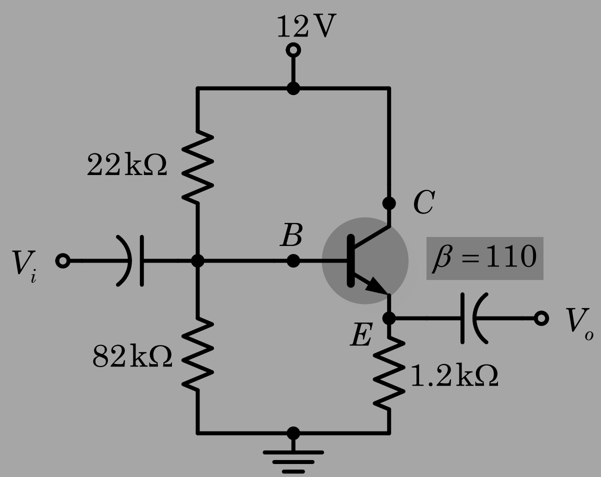
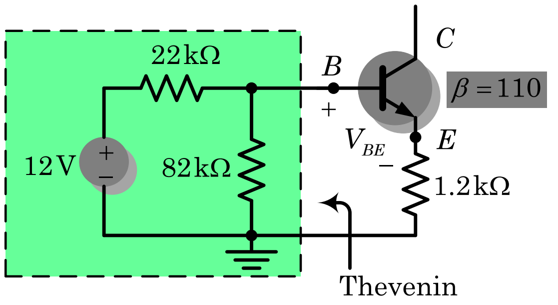


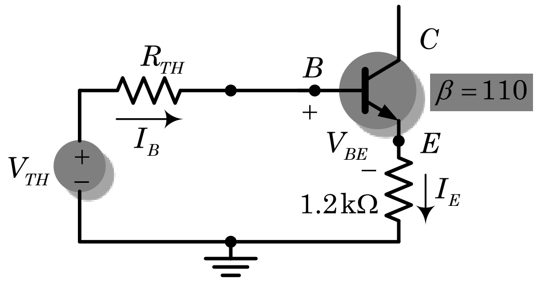
Figure Q2.

[Total 25 Marks]

[SOLUTION]:

(i) To do dc analysis, the ac sources are swithed OFF. Thus, the input circuit becomes





Where, $R_{TH} = 22\,\text{k}\Omega \| 82\,\text{k}\Omega = 17.34615\,\text{k}\Omega$, $V_{TH} = \dfrac{82\,\text{k}\Omega}{82\,\text{k}\Omega + 22\,\text{k}\Omega}(12\,\text{V}) = 9.461538\,\text{V}$;

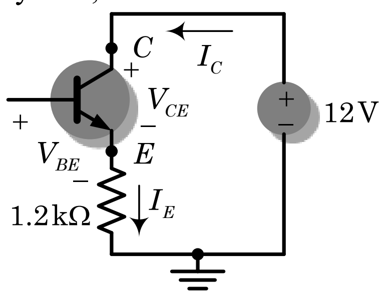
Applying KVL to the resultant input circuit yields, $V_{TH} - I_B R_{TH} - V_{BE} - I_E R_E = 0$;

But, $I_E = (\beta + 1) I_B$; thus, $V_{TH} - V_{BE} - (R_{TH} + (\beta+1) R_E) I_B = 0$; from which we get

$$I_B = \frac{V_{TH} - V_{BE}}{R_{TH} + (\beta+1)R_E} = \frac{9.461538\,\text{V} - 0.7\,\text{V}}{17.346154\,\text{k}\Omega + (111)(1.2\,\text{k}\Omega)} = 5.81984 \times 10^{-5};$$

$I_B = \mathbf{58.1984}\ \mu\mathbf{A}$ **[4 Marks]**

Applying KVL to the output circuit yields,



$I_E R_E + V_{CE} - 12 = 0$; since $I_E \cong I_C$; we have

$I_E = (\beta+1) I_B = 111(58.1984 \times 10^{-6}\,\text{A}) = 0.006460\,\text{A}$; $I_C = \beta I_B = 0.0064018\,\text{A}$;

$I_E = \mathbf{6.460\,mA}$; $I_C = \mathbf{6.4018\,mA}$. **[2 Marks]**

(ii) To determine V_B, we us

$V_B = V_{TH} - I_B R_{TH} = 9.461538\,\text{V} - (5.81984 \times 10^{-5}\,\text{A})(17.34615 \times 10^{3}\,\Omega) = 8.4520\,\text{V}$;

$V_B = \mathbf{8.4520\,V}$. **[2 Marks]**

Vividly, $V_C = \mathbf{12\,V}$. **[2 Marks]**

Furthermore, $V_E = V_B - V_{BE} = 8.4520\,\text{V} - 0.7\,\text{V} = 7.7520\,\text{V}$; $V_E = \mathbf{7.7520\,V}$. **[2 Marks]**

Alternatively, $V_E = I_E R_E = (0.006460\,\text{A})(1200\,\Omega) = \mathbf{7.7520\,V}$.

(iii) Thus, $V_{BC} = V_B - V_C = 8.4520\,\text{V} - 12\,\text{V} = \mathbf{-3.5480\,V}$; which confirms the base collector junction being reverse biased. **[1.5 Marks]**

Finally, $V_{CE} = V_C - V_E = 12\,\text{V} - 7.7520\,\text{V} = \mathbf{4.2480\,V}$. **[1.5 Marks]**

[Total 25 Marks]

[QUESTION 3]

(a) Determine the level of voltage V_o for network of Figure Q3(a). **[5 Marks]**

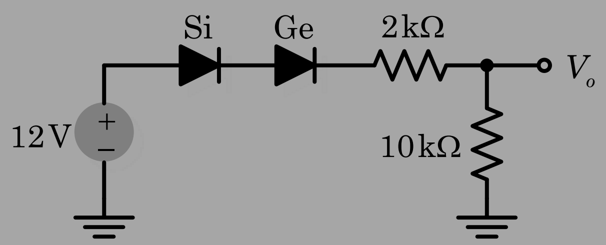
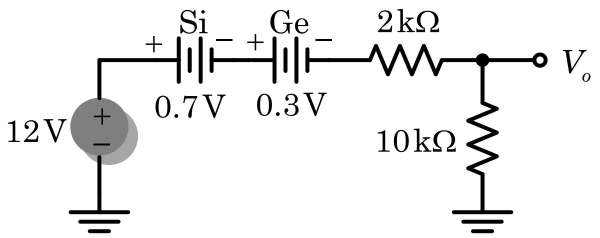


Figure Q3(a).

[SOLUTION]:

By exploiting the constant diode voltage drop model for both diodes the equivalent circuit is;



[2 Marks]

Using potential divider we have,

$$V_o = \frac{10\,\text{k}\Omega}{2\,\text{k}\Omega + 10\,\text{k}\Omega}(12\,\text{V} - 0.7\,\text{V} - 0.3\,\text{V}) = \frac{5}{6}(11\,\text{V}) = 9.16667\,\text{V}\;;\quad V_o = \mathbf{9.1667\,V}.$$ **[3 Marks]**

(b) For the network of Figure Q3(b):

(i) Calculate I_B, I_C, and r_e. **[6 Marks]**

(ii) Determine Z_i and Z_o. **[8 Marks]**

(iii) Calculate A_v. **[4 Marks]**

(iv) Determine the effect of $r_o = 30\,\text{k}\Omega$ on A_v. **[2 Marks]**

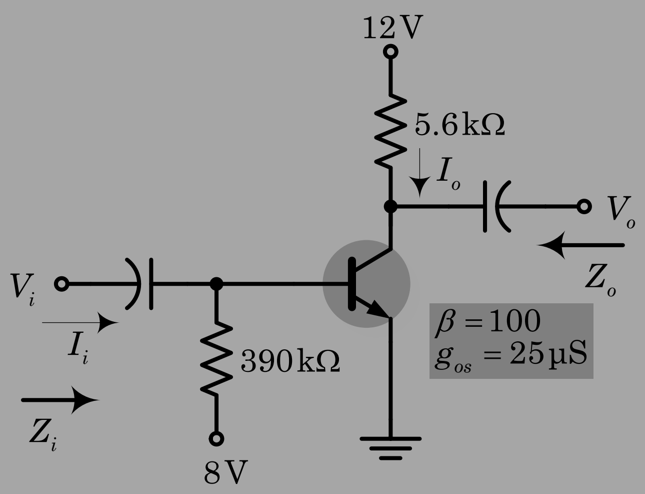
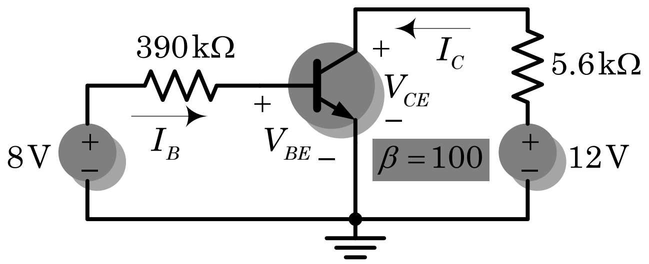


Figure Q3(b).

[Total 25 Marks]

[SOLUTION]:

(i) First we perform dc analysis by switching OFF ac voltage sources, i.e.,



[1 Mark]

Clearly, $V_B = V_{BE} = 0.7\,\text{V}$ since the emitter is connected to the ground.

Thus, $I_B = \dfrac{8\,\text{V} - 0.7\,\text{V}}{390\text{k}\Omega} = 1.871795 \times 10^{-5}$; $I_B = \mathbf{18.718\,\mu A}$. **[2 Marks]**

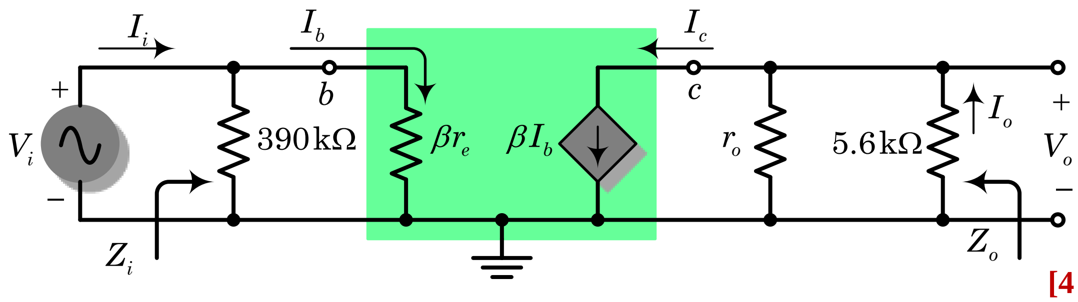
Furthermore, $I_C \cong I_E = (\beta + 1) I_B = 101(18.1795 \times 10^{-6}\,\text{A}) = 0.00189051\,\text{A}$;

$I_C \cong I_E = \mathbf{1.8905\,mA}$. **[1 Mark]**

Thererfore,

$r_e = \dfrac{26\,\text{mV}}{I_E} = \dfrac{26\,\text{mV}}{1.8905\,\text{mA}} = 13.752975\,\Omega$;. $r_e = \mathbf{13.753\,\Omega}$ **[2 Marks]**

(ii) We now conduct ac analysis in order to determine Z_i and Z_o, that is, substituting the r_e model yields



[4 Marks]

From the ac equivalent circuit above,

$Z_i = 390\text{k}\Omega \| \beta r_e = 390\text{k}\Omega \| (100)(13.753\Omega) = 390\text{k}\Omega \| 1.3753\text{k}\Omega = 1.3705\text{k}\Omega$;

$Z_i = \mathbf{1.3705k\Omega}$. **[2 Marks]**

Clearly, if $V_i = 0$, $I_i = I_b = 0$; $r_o = 1/g_{os} = 1/25\mu\text{S} = 40\,\text{k}\Omega$;

$Z_o = 5.6\text{k}\Omega \| 40\text{k}\Omega = \mathbf{4.9123k\Omega}$. **[2 Marks]**

(iii) To determine the voltage gain A_v, we start by formulating equations, i.e.,

$I_b = \dfrac{V_i}{\beta r_e}$; also $V_o = -\beta I_b (r_o \| 5.6\text{k}\Omega)$, thus, $V_o = -\beta \left(\dfrac{V_i}{\beta r_e}\right)(r_o \| 5.6\text{k}\Omega)$;

Therefore, with $r_o = 40\,\text{k}\Omega$, $Z_o = 5.6\text{k}\Omega \| 40\text{k}\Omega = 4.912281\text{k}\Omega$, so that ,

$A_v = \dfrac{V_o}{V_i} = -\dfrac{5.6\text{k}\Omega \| 40\text{k}\Omega}{r_e} = -\dfrac{4.912281\text{k}\Omega}{13.752975\Omega} = \mathbf{-357.18}$. **[4 Marks]**

(iv) With $r_o = 30\,\text{k}\Omega$, $Z_o = 5.6\text{k}\Omega \| 30\text{k}\Omega = 4.7191\text{k}\Omega$, so that ,

$A_v = \dfrac{V_o}{V_i} = -\dfrac{5.6\text{k}\Omega \| 30\text{k}\Omega}{r_e} = -\dfrac{4.7191\text{k}\Omega}{13.752975\Omega} = \mathbf{-343.13}$. **[2 Marks]**

Notice that $r_o = 30\,\text{k}\Omega$ causes the voltage gain A_v to reduce slightly.

[Total 25 Marks]

[QUESTION 4]

(a) Determine V_o and I_D for the network of Figure Q4(a). **[7 Marks]**

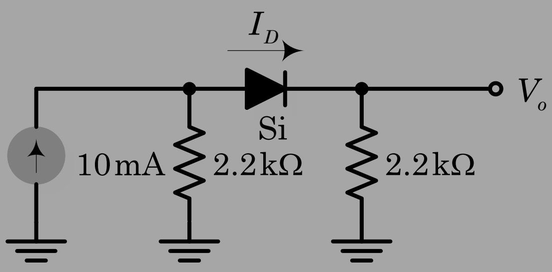
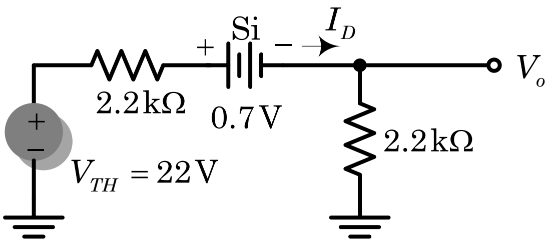


Figure Q4(a).

[SOLUTION]:

The circuit is redrawn with the Thevenin equivalent circuit replacing the Norton current source and resistance. Also the diode is replaced with a battery. That is,

$V_{TH} = I_N R_N = (10\,\text{mA})(2.2\,\text{k}\Omega) = 22\,\text{V}$, and $R_{TH} = R_N = 2.2\,\text{k}\Omega$,



[2 Marks]

Thus, by potential divider, $V_o = \left(\dfrac{2.2\,\text{k}\Omega}{2.2\,\text{k}\Omega + 2.2\,\text{k}\Omega}\right)(22\,\text{V} - 0.7\,\text{V}) = \mathbf{10.65\,V}$. **[3 Marks]**

It follows that, $I_D = \dfrac{10.65\,\text{V}}{2.2\,\text{k}\Omega} = \mathbf{4.8409\,mA}$. **[2 Marks]**

(b) For the cascaded system of Figure Q4(b), determine:

(i) The loaded voltage gain of each stage. **[4 Marks]**

(ii) The total gain of the system, $A_{v,\text{L}}$ and $A_{v,\text{S}}$. **[4 Marks]**

(iii) The loaded current gain of each stage. **[4 Marks]**

(iv) The total current gain of the system. **[2 Marks]**

(v) How Z_i is affected by the second stage and R_L. **[1 Mark]**

(vi) How Z_o is affected by the first stage and R_S. **[1 Mark]**

(vii) The phase relationship between V_o and V_i. **[2 Marks]**

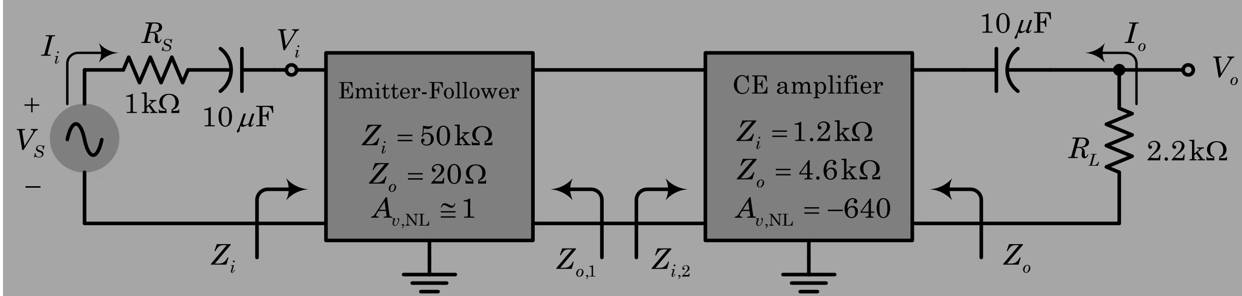


Figure Q4(b).

[Total 25 Marks]

[SOLUTION]:

(i) The loaded gain of each stage is obtained as follows,

For the Emitter follower: $V_{o,1} = \dfrac{Z_{i,2}}{Z_{i,2}+Z_{o,1}} A_{v,NL} V_{i,1} = \left(\dfrac{1.2\text{k}\Omega}{1.2\text{k}\Omega + 0.02\,\text{k}\Omega}\right)(1) V_{i,1} = 0.9836 V_{i,1}$;

Thus, $A_{v_1,\text{L}} = \dfrac{V_{o,1}}{V_{i,1}} = \mathbf{0.9836}$. **[2 Marks]**

Furthermore, $V_{o,2} = \dfrac{R_L}{R_L + Z_{o,2}} A_{v,NL} V_{i,2} = \left(\dfrac{2.2\text{k}\Omega}{2.2\text{k}\Omega + 4.6\,\text{k}\Omega}\right)(-640) V_{i,1} = -207.05882 V_{i,1}$

$A_{v_2,\text{L}} = \dfrac{V_{o,2}}{V_{i,2}} = \mathbf{-207.0588}$. **[2 Marks]**

(ii) The total gain of the system is,

$A_{v,\text{T}} = \left(\dfrac{V_{o,1}}{V_{i,1}}\right)\left(\dfrac{V_{o,2}}{V_{i,2}}\right) = (0.9836)(-207.0588) = \mathbf{-203.6630}$. **[2 Marks]**

The total gain of the system with source resistance included,

$V_{o,2} = \dfrac{Z_{i,1}}{Z_{i,1}+R_S} A_{v,\text{T}} V_S$; so that,

$A_{v,S} = \dfrac{V_{o,2}}{V_S} = \dfrac{Z_{i,1}}{Z_{i,1}+R_S} A_{v,\text{T}} = \left(\dfrac{50\,\text{k}\Omega}{50\,\text{k}\Omega + 1\,\text{k}\Omega}\right)(-203.6630) = -199.6630$;

$A_{v,s} = \dfrac{V_{o,2}}{V_S} = \mathbf{-199.6630}$. **[2 Marks]**

(iii) It follows that the loaded current gain is,

For the emitter-follower,

$A_{i_1,\text{L}} = \dfrac{I_{o,1}}{I_{i,1}} = -A_{v_1,\text{L}} \dfrac{Z_{i,1}}{Z_{i,2}} = -(0.9836)\left(\dfrac{50\text{k}\Omega}{1.2\text{k}\Omega}\right) = \mathbf{-40.9833}$. **[2 Marks]**

$A_{i_2,\text{L}} = \dfrac{I_{o,2}}{I_{i,2}} = A_{v_2,\text{L}} \dfrac{Z_{i,2}}{R_L} = (-207.05882)\left(\dfrac{1.2\text{k}\Omega}{2.2\text{k}\Omega}\right) = \mathbf{-112.9412}$. **[2 Marks]**

(iv) Thus the overall current gain is,

$A_{i,\text{T}} = \dfrac{I_{o,2}}{I_{i,1}} = -A_{v,\text{S}} \dfrac{R_S + Z_{i,1}}{R_L} = -(-199.6630)\left(\dfrac{1\,\text{k}\Omega + 50\,\text{k}\Omega}{2.2\text{k}\Omega}\right) = \mathbf{4628.55}$. **[2 Marks]**

(v) Z_i is NOT affected by the second stage and R_L . **[2 Marks]**

(vi) Z_o is NOT affected by the first stage and R_S .

(vii) The output voltage V_o is 180° out of phase from the input voltage V_i . **[2 Marks]**

[Total 25 Marks]