



Answer all the following questions:

1. Design a BJT differential amplifier to amplify a differential input signal of 5 mV and provide a differential output signal of 0.8 V. The differential input resistance must be at least 80 KΩ. The BJTs available are specified to have $\beta = 150$. Give the circuit configuration and specify the values of all its components.

2. The 4-stages direct coupled op-amp circuit shown in Fig.1 is operating at room temperature. Assuming all transistors have $\beta = 200$

- Perform an approximate dc analysis to calculate the current and voltage everywhere in the circuit (assuming $|V_{BE}|=0.7V$, neglect the Early effect). Note that Q_6 has four times the area of each of Q_9 and Q_3 .
- Compute the differential input resistant.
- Compute the overall voltage gain of the multistage amplifier.
- What is the input offset voltage if R_1 changed by 2%

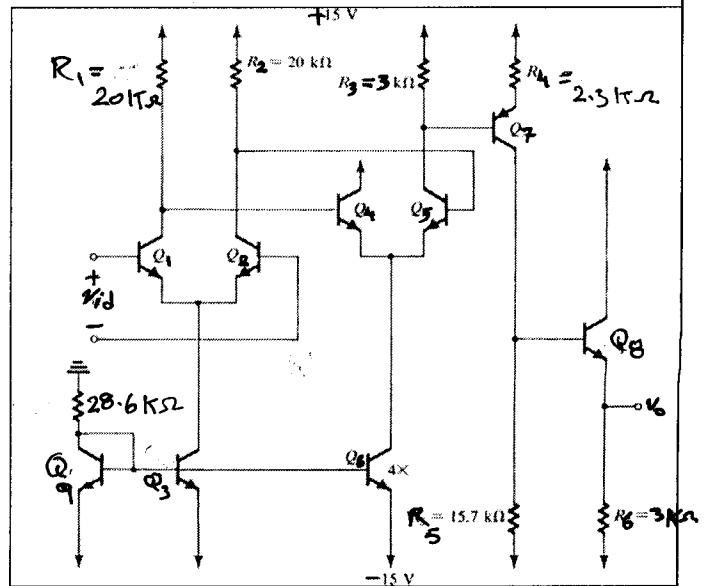


Fig. 1

3. For the BJT amplifier shown in fig. 2, find the input Resistance (R_{in}) and the frequency response for the following component values:

- $R_1=10k\Omega$; $R_2=10k\Omega$; $R_C=4.3k\Omega$; $R_E=6.8k\Omega$;
 $R_L=1k\Omega$; $R_{sig}=500\Omega$; $V_{CC}=15V$; $\beta = 100$
 $C_{C1}=0.47\mu F$; $C_{C2}=0.68\mu F$; $C_E=0.22\mu F$;
 $C_\mu=1pF$; $C_\pi=1nF$.

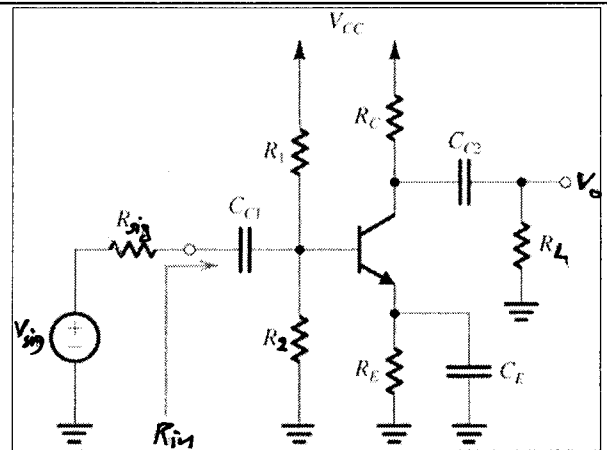


Fig. 2

4. Consider the complementary BJT class B output stage and neglect the effects of finite V_{BE} and V_{CEsat} . For $\pm 10V$ power supplies and a 100Ω load resistance,
- What is the maximum sine wave output power available?
 - What is the power-conversion efficiency?
 - Show how to reduce the zero-crossing distortion in class B power amplifier?
5. Design an RF amplifier shown in figure (3) for P_o (max) = 9 mW into $R_L = 100 \Omega$ at $\omega_o = 10^7$ rad/s and bandwidth of 10^6 rad/s. T_1 consists of $X_{L1} = 100 \Omega$ with $Q_u = 100$ at ω_o and $k = 1$. The transistor has $V_{be} = 0.7$, $\beta = 100$, $C_{bc} = 3$ pF, and $C_{be} = 27$ pF. For $V_{CC} = 10V$ determine:
- R_1 , R_2 , and R_E .
 - C_1 and Turns ratio of T_1 , given the bandwidth requirement.
 - Amplifier ac input resistance, R_{in} , and parallel capacitive reactance, X_{in} .

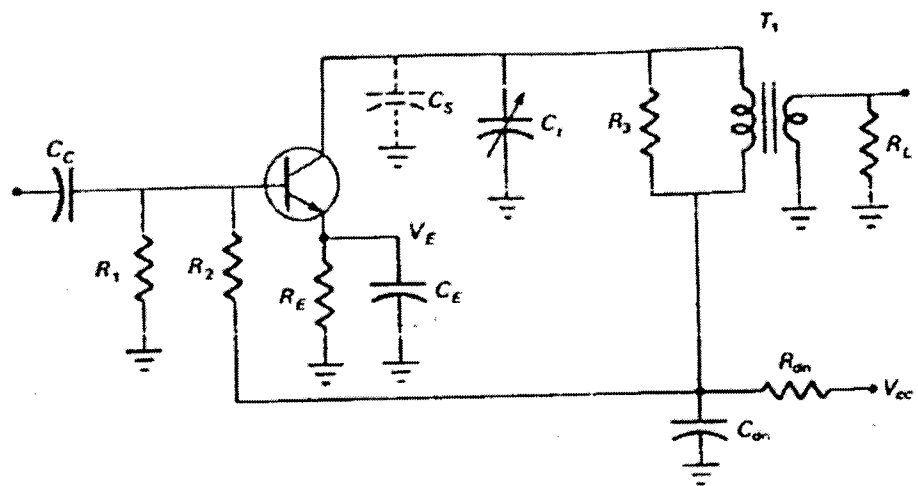


Fig.3

BEST WISHES

Q1:

Design a BJT differential amplifier to amplify a differential input signal of 5 mV and provide a differential output signal of 0.8 V. The differential input resistance must be at least 80 K Ω . The BJTs available are specified to have $\beta = 150$. Give the circuit configuration and specify the values of all its components.

Solution

given $I_E = 1 \text{ mA}$

$$r_e = \frac{V_T}{I_E} = \frac{25 \text{ mV}}{1 \text{ mA}} = 25 \Omega$$

$$\therefore R_{id} = 2(1 + \beta)(r_e + R_E)$$

$$80 \text{ K} = 2(1 + 150)(r_e + R_E)$$

$$r_e + R_E = \frac{80 \text{ K}}{2 \times 151} = 264.9 \Omega \approx 265 \Omega$$

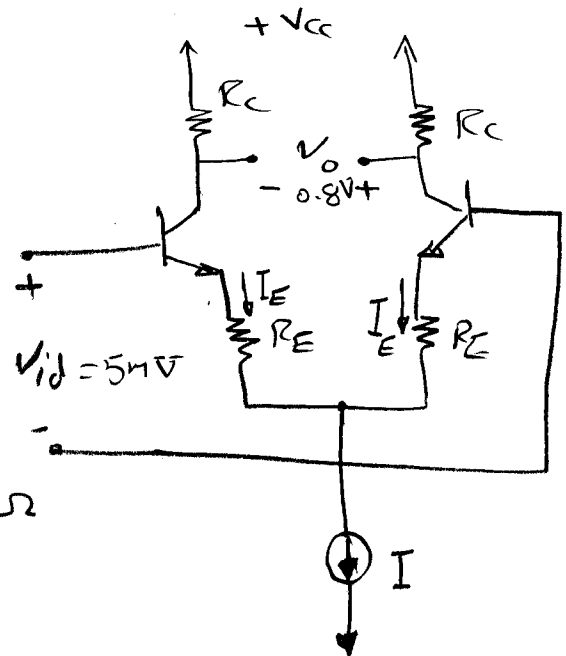
$$\therefore R_E = 265 - 25 = 240 \Omega$$

$$\therefore I_E = 1 \text{ mA} \Rightarrow I = 2I_E = 2 \text{ mA}$$

$$A_v = \frac{v_o}{v_{id}} = \frac{0.8}{5 \text{ m}} = \frac{2R_c}{2(r_e + R_E)} = \frac{R_c}{r_e + R_E}$$

$$\therefore 160 = \frac{R_c}{r_e + R_E}$$

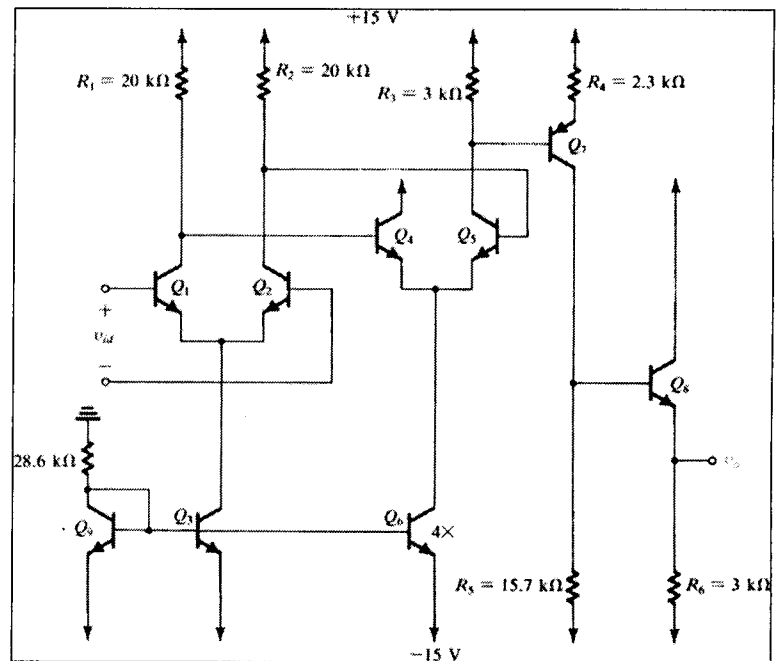
$$R_c = 160(r_e + R_E) = 160 \times 265 = 42.4 \text{ K}\Omega.$$



Q2:

The 4-stages direct coupled op-amp circuit shown in Fig.1 is operating at room temperature. Assuming all transistors have $\beta = 200$

- Perform an approximate dc analysis to calculate the current and voltage everywhere in the circuit (assuming $|V_{BE}|=0.7\text{V}$, neglect the Early effect). Note that Q_6 has four times the area of each of Q_9 and Q_3 .
- Compute the differential input resistant.
- Compute the overall voltage gain of the multistage amplifier.
- What is the input offset voltage if R_1 changed by 2%

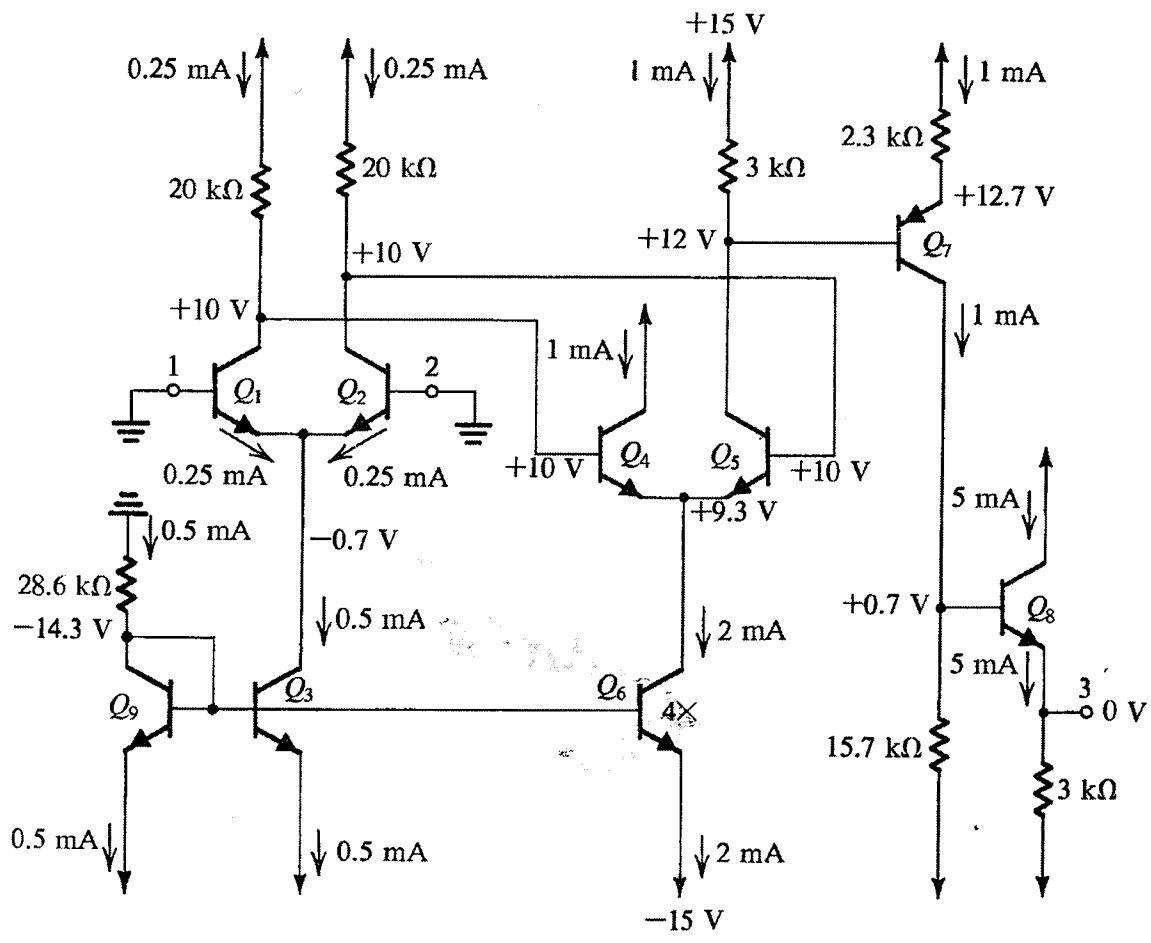


Solution:

(a) The values of all dc currents and voltages are indicated on the circuit diagram. These values were calculated by ignoring the base current of every transistor-that is, by assuming β to be very high. The analysis starts by determining the current through the diode-connected transistor Q_9 to be 0.5 mA. Then we see that transistor Q_3 conducts 0.5 mA and transistor Q_6 conducts 2mA. The current-source transistor Q_3 feeds the differential pair (Q_1, Q_2) with 0.5 mA. Thus each of Q_1 and Q_2 will be biased at 0.25 mA. The collectors of Q_1 and Q_2 will be at $[+15 - 0.25 \times 20] = +10 \text{ V}$.

Proceeding to the second differential stage formed by Q_4 and Q_5 , we find the voltage at their emitters to be $[+10 - 0.7] = 9.3 \text{ V}$. This differential pair is biased by the current-source transistor Q_6 , which supplies a current of 2 mA; thus Q_4 and Q_5 will each be biased at 1 mA. We can now calculate the voltage at the collector of Q_5 as $[+15 - 1 \times 3] = +12 \text{ V}$. This will cause the voltage at the emitter of the pnp transistor Q_7 to be $+12.7 \text{ V}$, and the emitter current of Q_7 will be $(+15 - 12.7)/2.3 = 1 \text{ mA}$. The collector current of Q_7 , 1 mA, causes the voltage at the collector to be $[-15 + 1 \times 15.7] = +0.7 \text{ V}$. The emitter of Q_8 will be 0.7 V below the base; thus output terminal 3 will be at 0 V.

Finally, the emitter current of Q_8 can be calculated to be $[0 - (-15)]/3 = 5 \text{ mA}$.



(b) The input differential resistance R_{id} is given by:

$$R_{id} = r_{\pi 1} + r_{\pi 2}$$

Since Q_1 and Q_2 are each operating at an emitter current of 0.25 mA, it follows that

$$r_{e1} = r_{e2} = 25 / 0.25 = 100 \Omega$$

for $\beta = 200$; then

$$r_{\pi 1} = r_{\pi 2} = 201 \times 100 = 20.1 \text{ k}\Omega$$

Thus $R_{id} = 40.2 \text{ k}\Omega$

(c) To evaluate the gain of the first stage we first find the input resistance of the second stage, R_{i2} ,

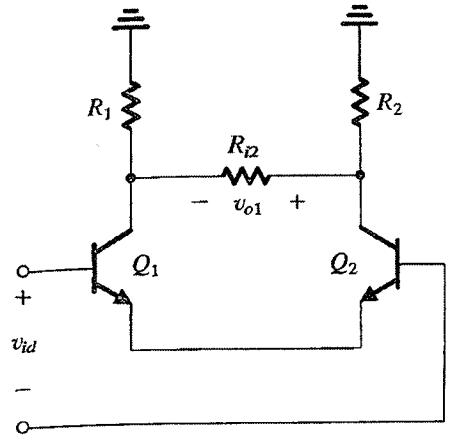
$$R_{i2} = r_{\pi 4} + r_{\pi 5}$$

Q_4 and Q_5 are each operating at an emitter current of 1 mA; thus

$$r_{e4} = r_{e5} = 25 \Omega$$

$$r_{\pi 4} = r_{\pi 5} = 201 \times 25 = 5.025 \text{ k}\Omega$$

Thus $R_{i2} = 10.05 \text{ k}\Omega$.



This resistance appears between the collectors of Q1 and Q2, as shown in - Fig. Thus the gain of the first stage will be

$$A_1 \equiv \frac{v_{o1}}{v_{id}} \cong \frac{\text{Total resistance in collector circuit}}{\text{Total resistance in emitter circuit}} = \frac{R_{i2} \parallel (R_1 + R_2)}{r_{e1} + r_{e2}}$$

$$= \frac{10.05k \parallel 40k}{200} = \frac{8031.97}{200} = 40.16 \text{ V/V}$$

Figure 2 shows an equivalent circuit for calculating the gain of the second stage. As indicated, the input voltage to the second stage is the input voltage of the first stage, v_{o1} . Also shown is the resistance R_{i3} which is the input resistance of the third stage formed by Q_7 . The value of R_{i3} can be found by multiplying the total resistance in the emitter of Q_7 by $(\beta + 1)$:

$$R_{i3} = (\beta + 1)(R_4 + r_{e7})$$

Since Q_7 is operating at an emitter current of 1 mA,

$$r_{e7} = 25/1 = 25\Omega$$

$$R_{i3} = 201 \times (2.3k + 25) = 467.325 \text{ k}\Omega$$

We can now find the gain A_2 of the second stage as the ratio of the total resistance in the collector circuit to the total resistance in the emitter circuit:

$$A_2 = \frac{v_{o2}}{v_{o1}} = - \frac{(R_3 \parallel R_{i3})}{r_{e4} + r_{e5}}$$

$$= - \frac{(3k \parallel 467.325k)}{50} = \frac{2980.86}{50} = -59.6 \text{ V/V}$$

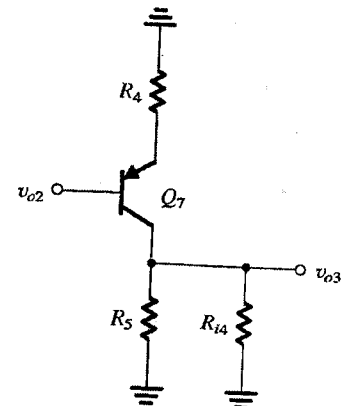
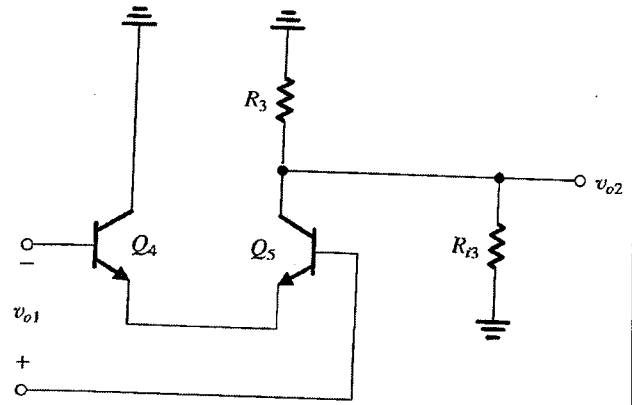
To obtain the gain of the third stage we refer to the equivalent circuit shown in Fig., where R_{i4} is the input resistance of the output stage formed by Q_8 . Using reflection resistance-reflection rule, we calculate the value of R_{i4} as

$$R_{i4} = (\beta + 1)(r_{e8} + R_6)$$

where

$$r_{e8} = 25/5 = 5\Omega$$

$$R_{i4} = 201(5 + 3000) = 604.005 \text{ k}\Omega$$



The gain of the third stage is given by

$$A3 \equiv \frac{v_{o3}}{v_{o2}} = -\frac{(R_5 \parallel R_{i4})}{r_{e7} + R_4} = -\frac{(15.7k \parallel 604.005k)}{25 + 2.3k}$$

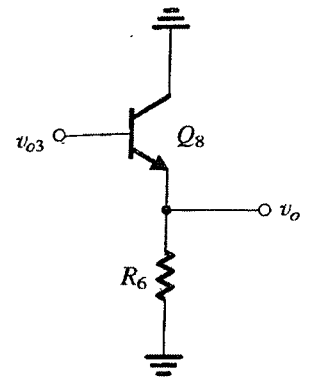
$$= -\frac{15.302k}{2.325k} = -6.58 \text{ V/V}$$

Finally, to obtain the gain $A4$ of the output stage we refer to the equivalent circuit in Fig. and write

$$A4 \equiv \frac{v_o}{v_{o3}} = \frac{R_6}{R_6 + r_{e8}} = \frac{3000}{3000 + 5} = 0.998 \approx 1$$

The overall voltage gain of the amplifier can then be obtained as follows:

$$\frac{v_o}{v_{id}} = A1A2A3A4 = 40.16 \times -59.6 \times -6.58 \times 1 = 15749.5$$



(d) The input offset voltage if R_1 changed by 2%

The input offset voltage V_{OS}

$$|V_{OS}| = V_T \left(\frac{\Delta R_c}{R_c} \right) = V_T \left(\frac{\Delta R_1}{R_1} \right) = 25m \times 0.02 = 0.5mV$$

Q3:

For the BJT amplifier shown in fig. 2, find the input Resistance (R_{in}) and the frequency response for the following component values:

$R_1=10k\Omega; R_2=10k\Omega; R_C=4.3k\Omega;$

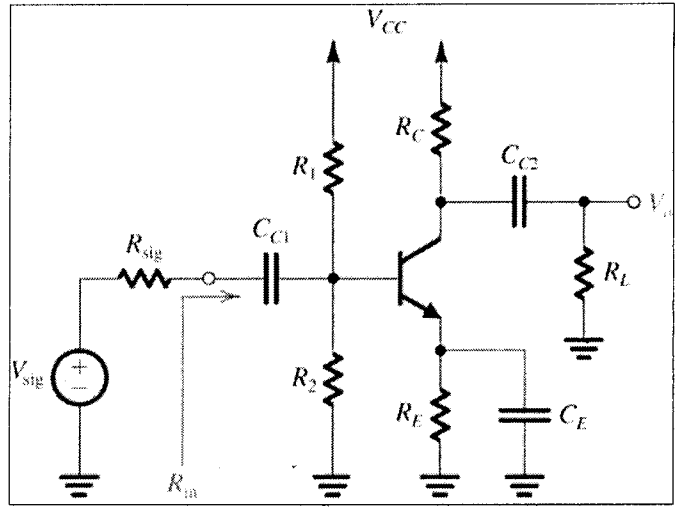
$R_E=6.8k\Omega;$

$R_L=1k\Omega; R_{sig}=500\Omega; V_{cc}=15V$

$C_{C1}=0.47\mu F; C_{C2}=0.68\mu F; C_E=0.22\mu F;$

$C_{\mu}=1pF; C_{\pi}=1nF. \beta = 100$

Solution



DC Analysis

- ALL capacitor are o.c

$R_B = R_{TH} = R_1 || R_2 = 10k || 10k = 5k\Omega.$

$V_{TH} = \frac{V_{cc} R_2}{R_1 + R_2} = \frac{15 \times 10}{10 + 10} = 7.5V$

Loop (I)

$V_{TH} = I_B R_B + V_{BE} + I_E R_E \quad ; \quad I_B = \frac{I_E}{1 + \beta}$

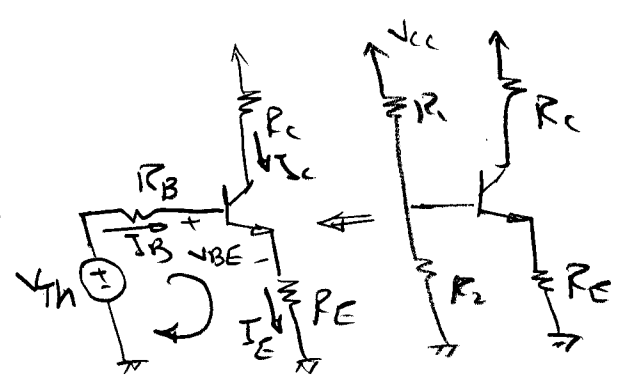
$I_E = \frac{V_{TH} - V_{BE}}{R_E + \frac{R_B}{1 + \beta}} = \frac{7.5 - 0.7}{6.8k + \frac{5k}{101}} = 0.993mA$

$I_C = \alpha I_E = \frac{\beta}{1 + \beta} I_E = \frac{100}{101} \times 0.993mA = 0.98mA$

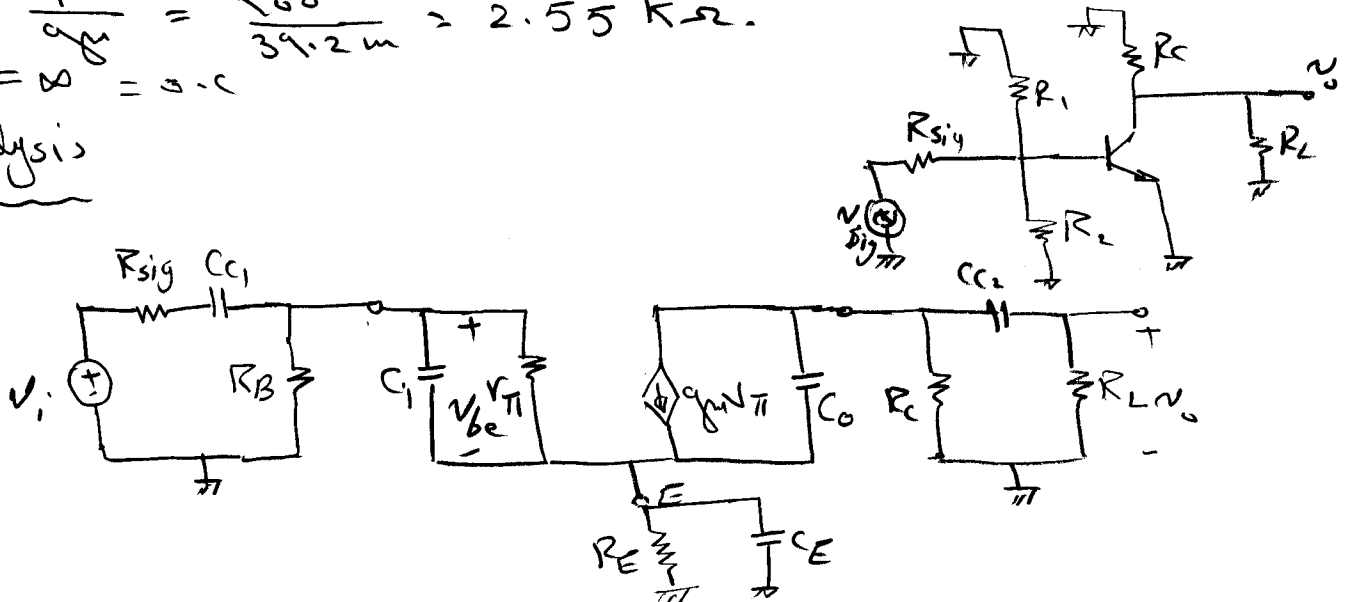
$g_m = \frac{I_C}{V_T} = \frac{0.98mA}{25mV} = 39.2 mA/V$

$r_{\pi} = \frac{\beta}{g_m} = \frac{100}{39.2mA} = 2.55k\Omega.$

$r_o = \infty = o.c$

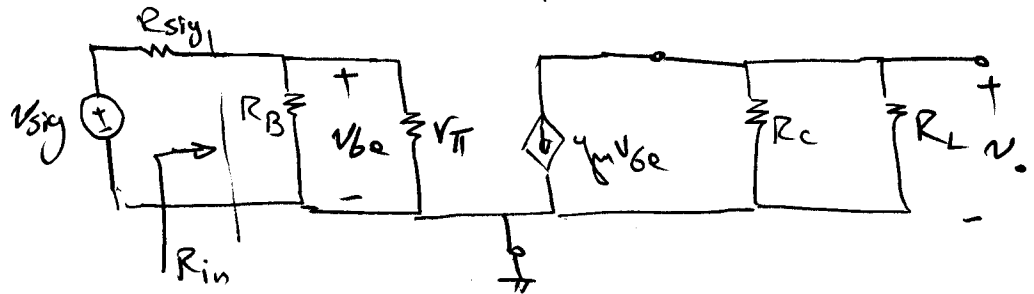


AC Analysis



For mid-band gain A_{vo} There is no effect of capacitors

$$C_{c1} = C_{c2} = C_E = s.c \quad \Rightarrow \quad C_i = C_o = 0.c$$



$$R_{in} = R_B \parallel r_{\pi} = 5K \parallel 2.55K = 1.69 K\Omega$$

$$\left| \frac{v_{ce}}{v_{be}} \right| = \beta \mu R_L' \quad ; \quad R_L' = R_C \parallel R_L$$

$$R_L' = R_C \parallel R_L = 4.3K \parallel 1K\Omega = 811.32 \Omega$$

$$\left| \frac{v_{ce}}{v_{be}} \right| = 39.2 \times 10^{-3} \times 811.32 = 31.8 \text{ V/V}$$

$$C_i = C_{\pi} + C_{Mi} \quad ; \quad C_{Mi} = C_{\mu} \left(1 + \left| \frac{v_{ce}}{v_{be}} \right| \right)$$

$$C_{Mi} = 1 \text{ pF} (1 + 31.8) = 32.8 \text{ pF}$$

$$C_{Mo} = C_{\mu} \left(1 + \left| \frac{v_{ce}}{v_{be}} \right| \right) = C_{\mu} = 1 \text{ pF} = C_o$$

- To find cutoff frequency $\Rightarrow v.s = s.c \text{ \& } c.s = 0.c$

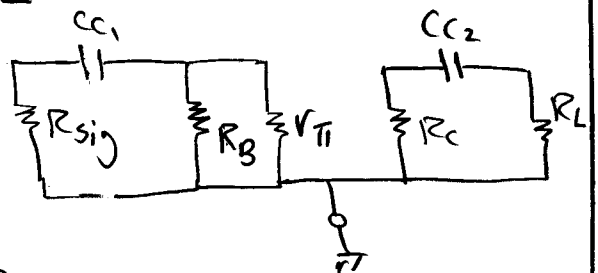
- For low frequency $\Rightarrow C_i = C_o = 0.c$

effect of C_{c1}

put $C_{c2} = C_E = s.c$

$$R_{cc1} = R_{sig} + R_B \parallel r_{\pi}$$

$$= 500 + 1.69K = 2.19 K\Omega$$



$$f_{cL1}|_{C_{c1}} = \frac{1}{2\pi (C_{c1} R_{cc1})} = \frac{1}{2\pi (0.47 \times 10^{-6} \times 2.19 \times 10^3)}$$

$$= 154.6 \text{ Hz}$$

effect of C_{c2}

put $C_{c1} = C_E = s.c$

$$R_{cc2} = R_C + R_L = 4.3K + 1K = 5.3 K\Omega$$

$$f_{cL2} \Big|_{C_c} = \frac{1}{2\pi (C_c R_{cC2})}$$

$$= \frac{1}{2\pi \times 0.68 \times 10^{-6} \times 5.3 \times 10^3} = 44.2 \text{ Hz}$$

effect of C_E

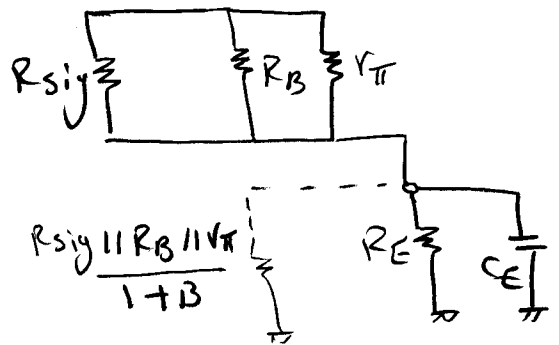
put $C_{c1} = C_{c2} = \text{s.c}$

$$R_{cE} = R_E \parallel \left[\frac{R_{sig} \parallel R_B \parallel r_{\pi}}{1+B} \right]$$

$$= 6.8 \text{ k} \parallel \left[\frac{500 \parallel 1.69 \text{ k}}{1+B} \right]$$

$$= 6.8 \text{ k} \parallel \frac{385.85}{101}$$

$$= 6.8 \text{ k} \parallel 3.82 \approx 3.82 \Omega$$



$$f_{cL3} \Big|_{C_E} = \frac{1}{2\pi (C_E R_{cE})} = \frac{1}{2\pi \times 0.22 \times 10^{-6} \times 3.82} = 189.4 \text{ kHz}$$

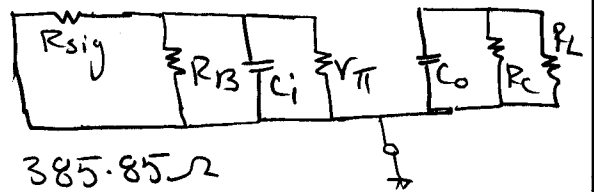
$$f_L = f_{cL1} + f_{cL2} + f_{cL3} = 189.6 \text{ kHz}$$

- for high frequency response $\Rightarrow C_{c1} = C_{c2} = C_E = \text{s.c}$

effect of C_i

put $C_o = \text{o.c}$

$$R_{c1} = R_{sig} \parallel R_B \parallel r_{\pi} = 500 \parallel 1.69 \text{ k} = 385.85 \Omega$$



$$f_{ch1} \Big|_{C_i} = \frac{1}{2\pi (C_i R_{c1})}$$

$$C_i = C_{\pi} + C_{M_i} = 1 \text{ nF} + 32.8 \text{ pF} = 1.0328 \text{ nF}$$

$$f_{ch1} \Big|_{C_i} = \frac{1}{2\pi \times 1.0328 \times 10^{-9} \times 385.85} = 399.4 \text{ kHz}$$

effect of C_o put $C_i = \text{o.c}$

$$R_{c0} = R_C \parallel R_L = R_L' = 811.32 \Omega$$

$$f_{ch2} \Big|_{C_o} = \frac{1}{2\pi (C_o R_{c0})} = \frac{1}{2\pi \times 1 \times 10^{-12} \times 811.32} = 196.17 \text{ MHz}$$

$$f_H = f_{ch1} + f_{ch2} = 196.564 \text{ MHz}$$

Q4:

Consider the complementary BJT class B output stage and neglect the effects of finite V_{BE} and V_{CEsat} . For $\pm 10V$ power supplies and a 100Ω load resistance,

- What is the maximum sine wave output power available?
- What is the power-conversion efficiency?
- Show how to reduce the zero-crossing distortion in class B power amplifier?

Solution

(a) The average load power: $P_L = \frac{1}{2} \frac{\hat{V}_o^2}{R_L}$

where \hat{V}_o is the peak amplitude of o/p sine wave.
 - The maximum sine-wave o/p power occurs when $\hat{V}_o = V_{CC}$ Then

$$P_{L|max} = \frac{1}{2} \frac{V_{CC}^2}{R_L} = \frac{1}{2} \frac{(10)^2}{100} = 0.5 \text{ W}$$

(b) The power conversion efficiency $\eta = \frac{P_L}{P_S}$
 where P_S is the total supply power

$$P_S = P_{S+} + P_{S-}$$

\therefore The average power drawn from each of the two power supplies will be the same. - Then

$$P_{S+} = P_{S-} = \frac{1}{\pi} \frac{\hat{V}_o}{R_L} V_{CC} = \frac{1}{\pi} \frac{(10)}{100} \times 10 = 0.318 \text{ W}$$

$$\therefore P_S = 2 \times 0.318 = 0.637 \text{ W}$$

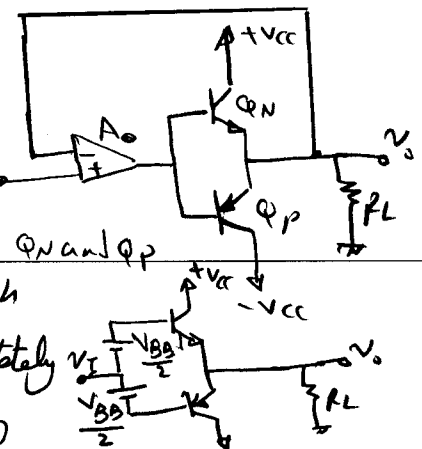
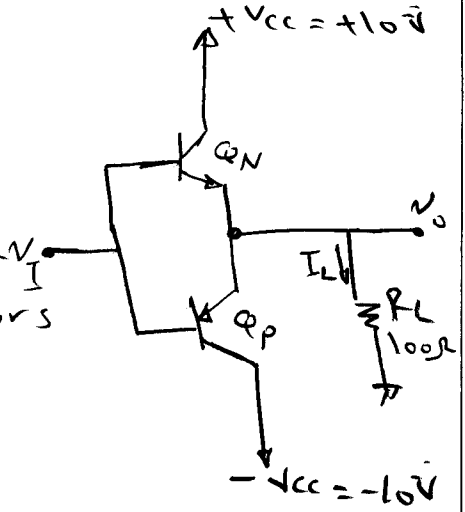
\therefore The power conversion efficiency η is

$$\eta = \frac{P_L}{P_S} \times 100 = \frac{0.5}{0.637} \times 100 = 78.5 \%$$

(c) - To reduce the zero-crossing distortion in class B Power Amp. by using a high-gain op-amp. and overall negative feedback as shown. The $\pm 0.7V$ dead band is reduced to $\pm 0.7/A$ volt.

where A_0 is the DC gain of op-amp.

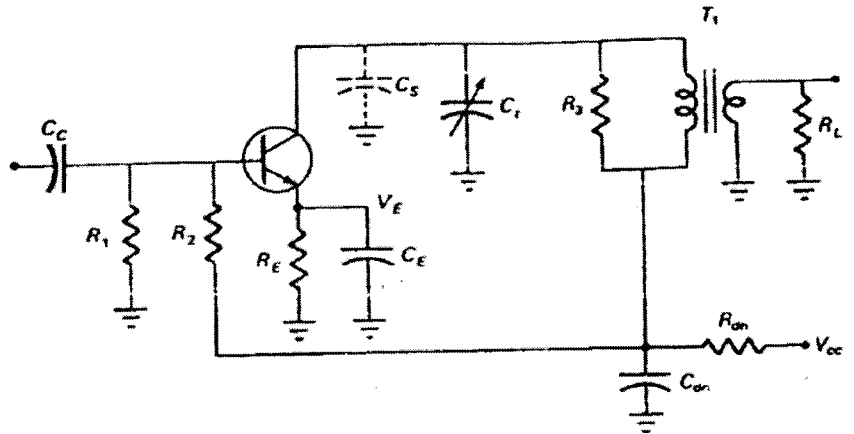
- OR by biasing the complementary transistors using bias voltage V_{BB} applied between the bases of Q_N and Q_P giving rise to bias current I_{ce} . Thus for small V_I , both transistors conduct and crossover distortion is almost completely eliminated. as shown in fig. (class AB o/p stage)



Q5:

Design an RF amplifier for P_o (max) = 9 mW into $R_L = 100 \Omega$ at $\omega_o = 10^7$ rad/s and bandwidth of 10^6 rad/s. T_1 consists of $X_{LI} = 100 \Omega$ with $Q_u = 100$ at ω_o and $k = 1$. The transistor has $V_{be} = 0.7$, $\beta = 100$, $C_{bc} = 3$ pF, and $C_{be} = 27$ pF. For $V_{CC} = 10$ V determine:

- $R_1, R_2,$ and R_E .
- C_i and Turns ratio of T_1 , given the bandwidth requirement.
- Amplifier ac input resistance, R_{in} , and parallel capacitive reactance, X_{in} .



Solution

DC Design

let $\eta = 50\%$; $\therefore P_o|_{max} = 9 \text{ mW}$

$$I_c = \frac{2P_o}{0.9V_{CC}}$$

$$= \frac{2 \times 9 \text{ m}}{0.9 \times 10} = 2 \text{ mA}$$

$$I_B = \frac{I_c}{\beta} = \frac{2 \text{ m}}{100} = 0.02 \text{ mA}$$

$$I_E = I_B + I_c = 2 \text{ m} + 0.02 \text{ m} = 2.02 \text{ mA}$$

let $V_E = 0.1 V_{CC} = 0.1 \times 10 = 1 \text{ V}$

$$R_E = \frac{V_E}{I_E} = \frac{1}{2.02 \text{ m}} = 495 \Omega$$

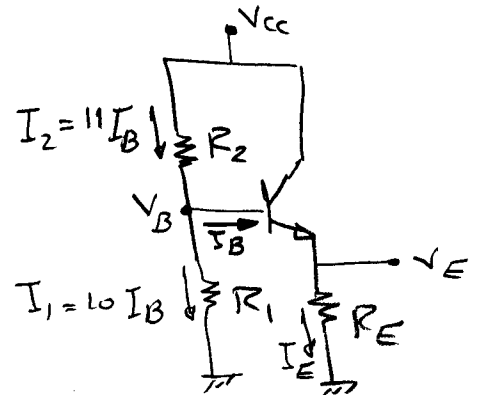
For hard potential divider let $I_1 = 10 I_B$; Then $I_2 = 11 I_B$

$$\therefore V_B = V_{BE} + V_E = 0.7 + 1 = 1.7 \text{ V}$$

$$\therefore R_1 = \frac{V_B}{I_1} = \frac{1.7}{10 \times 0.02 \text{ m}} = 8.5 \text{ k}\Omega$$

$$R_2 = \frac{V_{CC} - V_B}{I_2}$$

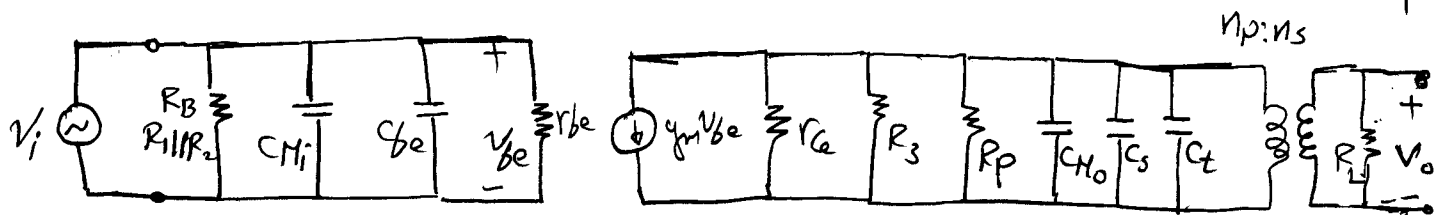
$$= \frac{10 - 1.7}{11 \times 0.02 \text{ m}} = 37.73 \text{ k}\Omega$$



AC Design

$$g_m = \frac{I_c}{V_T} = \frac{2 \text{ mA}}{25 \text{ mV}} = 0.08 \text{ A/V}$$

$$r_{be} = \frac{\beta}{g_m} = \frac{100}{0.08} = 1.25 \text{ k}\Omega$$



$$Q_L = \frac{f_o}{\text{BW}} = \frac{10^7 / 2\pi}{10^6 / 2\pi} = 10$$

$$\therefore Q_L = \frac{R_{eq}}{\omega_o L} = \frac{R_{eq}}{X_L} \Rightarrow R_{eq} = Q_L X_L$$

$$\therefore R_{eq} = 10 \times 100 = 1 \text{ k}\Omega$$

$$\text{For max. Power Transfer} \Rightarrow R_L' = r_o'$$

$$\therefore R_{eq} = 1 \text{ k}\Omega \Rightarrow R_L' = r_o' = 2 \text{ k}\Omega$$

$$\therefore R_L' = R_L \left(\frac{n_p}{n_s}\right)^2 \Rightarrow \frac{n_p}{n_s} = \sqrt{\frac{R_L'}{R_L}} = \sqrt{\frac{2 \text{ k}}{100}} = 4.47 \approx 5$$

$$r_o' = r_o \parallel R_3 \parallel R_P$$

$$R_P = \omega_o L Q_u = X_L Q_u = 100 \times 100 = 10 \text{ k}\Omega$$

$$\therefore f_o = \frac{1}{2\pi \sqrt{L_P C_{eq}}} \Rightarrow C_{eq} = \frac{1}{(2\pi f_o)^2 L_P}$$

$$\therefore X_L = \omega_o L_P \Rightarrow L_P = \frac{X_L}{\omega_o} = \frac{100}{10^7} = 10 \text{ }\mu\text{H}$$

$$C_{eq} = \frac{1}{(2\pi \times \frac{10^7}{2\pi})^2 \times 10 \times 10^{-6}} = 1000 \text{ pF}$$

$$\therefore C_{eq} = C_s + C_t + C_{M_o}$$

$$C_{M_o} \Rightarrow C_{bc} \quad ; \quad C_s = 0 \text{ (not given)}$$

$$\therefore C_t = C_{eq} - C_{M_o} = 1000 \text{ pF} - 3 \text{ pF} = 997 \text{ pF}$$

$$R_i = R_1 \parallel R_2 \parallel r_{be} = R_3 \parallel r_{be} = 8.5 \text{ k} \parallel 37.73 \text{ k} \parallel 1.25 \text{ k} = 1.059 \text{ k}\Omega$$

$$C_{in} = C_{Mi} \parallel C_{be} = C_{Mi} + C_{be}$$

$$C_{Mi} = (1 + |A_{vol}|) C_{bc}$$

$$|A_{vol}| = 1 \frac{V_{ce}}{V_{be}} = \beta_m R_{eq} = 0.08 * 1k\Omega = 80 \text{ V/V}$$

$$C_{Mi} = (1 + 80) * 3pF = 243 pF$$

$$\therefore C_{in} = C_{Mi} + C_{be}$$

$$= 243 pF + 27 pF = 270 pF$$

$$X_{Cin} = \frac{1}{\omega_0 C_{in}}$$

$$= \frac{1}{10^7 * 270 * 10^{-12}} = 370 \Omega.$$
