1) Draw the small-signal equivalent circuit. (4 marks)
2) Find the mid-band gain $A_v$. (4 marks)
3) Find the mid-band $R_{in}$. (2 marks)
4) Find the mid band $R_{out}$ (include $r_{o2}$). (3 marks)
5) Find the $\omega_L$'s for the circuit. For the $\omega_L$ associated with $C_2$, assume that $R_s = 0$. (4 marks)
6) Find the $\omega_H$'s for the circuit. Do not include $c_{\pi1}$. (4 marks)
7) Given that $V_{cc} = 15V$, $\beta_1 = \beta_2 = 100$, $R_E = 700\Omega$, the voltage on the emitter of $Q_1$ is about 11V and the voltage on the collector of $Q_2$ is about 5V, determine resistor values for $R_{B1}$, $R_{B2}$, $R_{B3}$ and $R_C$ such that the collector current of $Q_1$ is about 1 mA and the current through $R_{B1}$ is about 10 times the base current of $Q_1$. (4 marks)

$$r_\pi = \frac{\beta}{g_m}, \quad r_m = (\beta + 1)r_e, \quad m = \frac{\beta}{\beta + 1}, \quad g_m = \frac{I_C}{V_T}, \quad V_T = 25mV @ 20^\circ C.$$  

$$\omega_L = \omega_{L1} + \omega_{L2} + \omega_{L3} + \ldots \quad \text{and} \quad \frac{1}{\omega_H} \approx \frac{1}{\omega_{H1}} + \frac{1}{\omega_{H2}} + \frac{1}{\omega_{H3}} + \ldots$$

Miller’s Theorem: $Y_1 = Y \left(1 - \frac{v_2}{v_1}\right), \quad Y_2 = Y \left(1 - \frac{v_1}{v_2}\right)$
1. With T models (pi model is also acceptable)

2. \[ \frac{v_o}{v_{\pi 2}} = -g_{m2} \left( \frac{g_m}{R_L} \right), \quad \frac{v_{\pi 2}}{v_{bl}} = -\frac{r_{e2}}{r_{e1} + R_E + r_{e2}}, \quad \frac{v_{bl}}{v_s} = \frac{R_{in}}{R_s + R_{in}}, \quad \text{with } R_{in} \text{ as in 3.} \]

Thus:

\[
\frac{v_s}{v_{\pi 2}} = \frac{-g_m}{R_L} \left( R_s + R_{in} \right) \left( r_{e1} + R_E + r_{e2} \right) \left( 1 + \beta_1 \right) \]

3. As above, \[ R_{in} = R_{B1} \parallel R_{B2} \parallel (r_{e1} + R_E + r_{e2})(1 + \beta_1) \]

4. \( r_{e2} \) goes from C to E will turn on the transistor. Need to apply \( v_x \) measure \( i_x \). Then \( R_{out} = \frac{v_x}{i_x} \)

Thus:

\[
\frac{v_x}{R_C} + \frac{v_s}{r_{e2} + r_{e2}} \left( \frac{R_{B2}}{R_{E} + r_{e1} + \frac{R_{B1}}{1 + \beta_1}} \right) - g_m \left( \frac{R_{B1}}{R_s + R_{in}} \right) \frac{v_x}{r_{e2} + r_{e2}} \left( \frac{R_{B2}}{R_{E} + r_{e1} + \frac{R_{B1}}{1 + \beta_1}} \right) \]

5. \( R_C = R_s + R_{in} \) where \( R_{in} \) is from 3, \( R_{C2} = (r_{e2} + R_E + r_{e1})(1 + \beta_1) \parallel R_{B2} \parallel R_{B3} \parallel R_{C3} = R_L + R_C \)

\[ \omega_C = \frac{1}{R_C C_1}, \quad \omega_{C2} = \frac{1}{R_{C2} C_2}, \quad \omega_{C3} = \frac{1}{R_{C3} C_3}, \quad \omega_L = \omega_C + \omega_{C2} + \omega_{C3} \]

6. \[ \omega_1 = \frac{1}{\left( \frac{R_{B2}}{R_{E} + r_{e1} + \frac{R_{B1}}{1 + \beta_1}} \right) c_{\pi 1}}, \quad \omega_2 = \frac{1}{\left( \frac{R_{E} + r_{e1} + \frac{R_{B1}}{1 + \beta_1}}{R_{B2} \parallel R_{E} \parallel R_{B3}} \right) c_{\pi 2}}, \quad \omega_3 = \frac{1}{\left( \frac{R_{E} \parallel R_{B2}}{R_{E} \parallel R_{B3}} \right) c_{\mu 2}} \]

\[ \frac{1}{\omega_3} = \frac{1}{\omega_1} + \frac{1}{\omega_2} + \frac{1}{\omega_3} \]

7. DC \( I_{C1} = 1 \text{ mA}, \beta = 100, I_{B1} = 10 \mu A, I_{RB1} = 100 \mu A. V_{E1} = 11 \text{ V}, V_{B1} = 11.7 \text{ V}, \text{ and } R_{B1} = (15-11.7)/100 \mu A = 33 \text{ k} \Omega, \text{ with } 1 \text{ mA}, V_{RE} = 0.7 \text{ V}, \text{ so } V_{E2} = 10.3 \text{ V}, \text{ and } V_{B2} = 9.6 \text{ V.} \]

then \( R_{B3} = (11.7-9.6)/100 \mu A = 23.33 \text{ k} \Omega, \)
and \( R_{B3} = (9.6)/100 \mu A = 96 \text{ k} \Omega. \)
Finally, \( R_C = (5)/1 \text{ mA} = 5 \text{ k} \Omega \)

Notes: \( I_{E1} = I_{E2} = 1.01 \text{ mA}, 1 \text{ mA} \) is close enough. It is acceptable if bias current is rounded off to 100\( \mu A \) for all three resistors. Note the actual currents through \( R_{B1}, R_{B2}, \text{ and } R_{B3}, \) are 100\( \mu A, 90 \mu A, \) and 100\( \mu A, \) respectively.