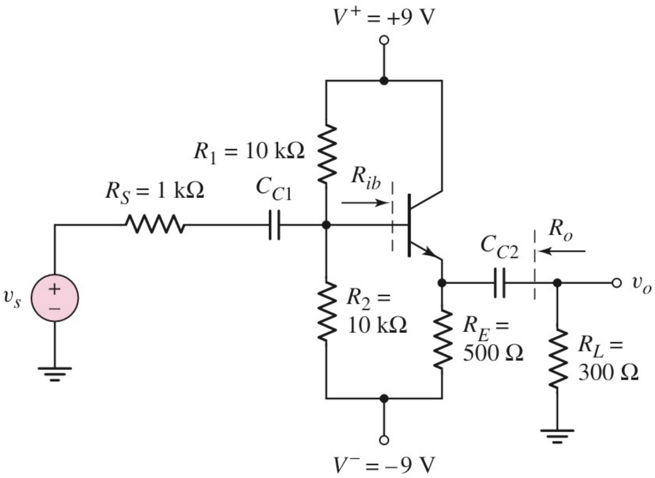
[1] The transistor parameters for the circuit in Figure 1 are $\beta = 180$ and $V_A = \infty$.

(a) Find $I_{CQ}$ and $V_{CEQ}$.

(b) Calculate the small-signal voltage gain.

(c) Determine the input and output resistances $R_{ib}$ and $R_o$.




Solution:

(a) For dc analysis, the capacitors *CC*1 and *CC*2 act as *open circuit*.

$$V_{TH} = \frac{R_2}{R_1 + R_2}\left(V^+ - V^-\right) + V^- = \left(\frac{10}{10+10}\right)(18) + (-9) = 0 \text{ (V)}$$

$$R_{TH} = R_1 \| R_2 = \frac{(10)(10)}{10+10} = 5.0 \text{ (k}\Omega\text{)}$$

$$I_{BQ} = \frac{V_{TH} - V_{BE(\text{on})} - V^-}{R_{TH} + (1+\beta)R_E} = \frac{0 - 0.7 - (-9)}{5 + (181)(0.5)} = 86.91 \ (\mu\text{A})$$

$$I_{CQ} = \beta I_{BQ} = 15.644 \text{ (mA)}$$

$$I_{EQ} = (1+\beta) I_{BQ} = 15.731 \text{ (mA)}$$

$$V_{CEQ} = V^+ - V^- - I_{EQ} R_E = 9 - (-9) - (15.731)(0.5) = 10.13 \text{ (V)}$$

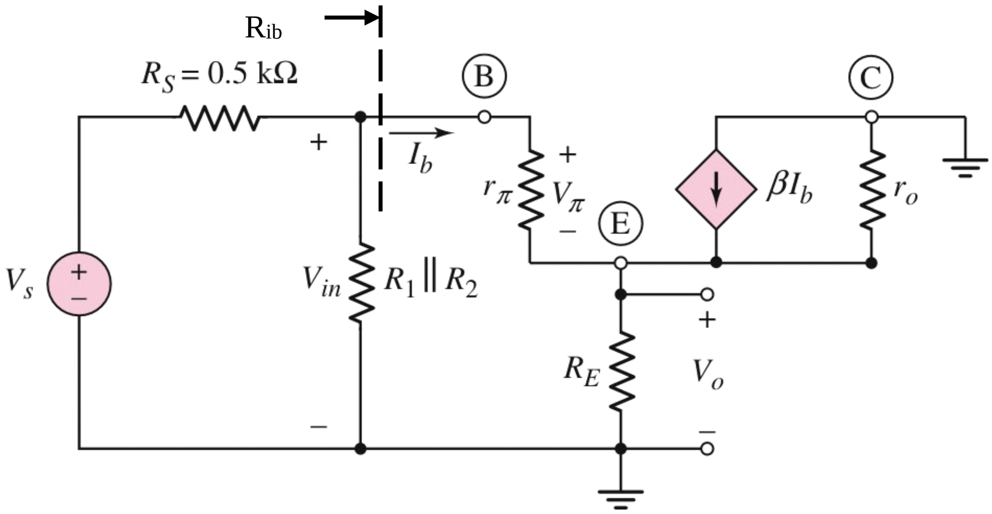
(b) The small-signal parameters are:

$$r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{(180)(0.026)}{15.644} = 0.299 \text{ (k}\Omega\text{)}$$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{15.644}{0.026} = 601.692 \text{ (mA/V)}$$

$$r_o = \frac{V_A}{I_{CQ}} = \infty$$

The small-signal ac equivalent circuit becomes:






$$v_o = (1+\beta)i_b(R_E \parallel R_L)$$

$$\Rightarrow \frac{v_o}{i_b} = (1+\beta)(R_E \parallel R_L) = (181)(0.1875) = 33.9375$$

$$v_b = V_\pi + v_o = i_b r_\pi + (1+\beta)i_b(R_E \parallel R_L)$$

$$\Rightarrow \frac{v_b}{i_b} = R_{ib} = r_\pi + (1+\beta)(R_E \parallel R_L) = 0.299 + 33.9375 = 34.2365$$

$$v_b = \frac{R_{ib} \parallel R_1 \parallel R_2}{R_S + R_{ib} \parallel R_1 \parallel R_2} v_s$$

$$\Rightarrow \frac{v_b}{v_s} = \frac{R_{ib} \parallel R_1 \parallel R_2}{R_S + R_{ib} \parallel R_1 \parallel R_2} = \frac{4.3628}{1+4.3628} = 0.8135$$

$$\frac{v_o}{v_s} = \frac{v_o}{i_b} \times \frac{i_b}{v_b} \times \frac{v_b}{v_s}$$

$$= (1+\beta)(R_E \parallel R_L) \times \frac{1}{R_{ib}} \times \frac{R_{ib} \parallel R_1 \parallel R_2}{R_S + R_{ib} \parallel R_1 \parallel R_2}$$

$$= \frac{(1+\beta)(R_E \parallel R_L)}{R_{ib}} \left( \frac{R_{ib} \parallel R_1 \parallel R_2}{R_S + R_{ib} \parallel R_1 \parallel R_2} \right)$$

$$= (33.9375)\left( \frac{1}{34.2365} \right)(0.8135) = 0.8064$$

(c) The input resistance $R_{ib}$ is:

$$R_{ib} = r_\pi + (1+\beta)(R_E \parallel R_L)$$
$$= 0.299 + 33.9375 = 34.24\ (\text{k}\Omega)$$

To calculate the output resistance $R_o$, the signal source vs is short-circuited and the following equations can be written by KCL at node $v_o$ and node $v_b$:

$$v_b = v_o + r_\pi i_b$$

$$\frac{v_b}{R_S \parallel R_1 \parallel R_2} + i_b = 0 \text{ (KCL at node } v_b\text{)}$$

$$\frac{v_o + r_\pi i_b}{R_S \parallel R_1 \parallel R_2} + i_b = 0 \Rightarrow \frac{v_o}{i_b} = -\left(r_\pi + R_S \parallel R_1 \parallel R_2\right)$$

$$i_o + (1+\beta) i_b = \frac{v_o}{R_E} \text{ (KCL at node } v_o\text{)}$$

$$i_o - (1+\beta)\left(\frac{v_o}{r_\pi + R_S \parallel R_1 \parallel R_2}\right) = \frac{v_o}{R_E}$$

$$\Rightarrow \frac{v_o}{i_o} = R_o = R_E \parallel \left(\frac{r_\pi + R_S \parallel R_1 \parallel R_2}{1+\beta}\right) = 6.18\ (\Omega)$$

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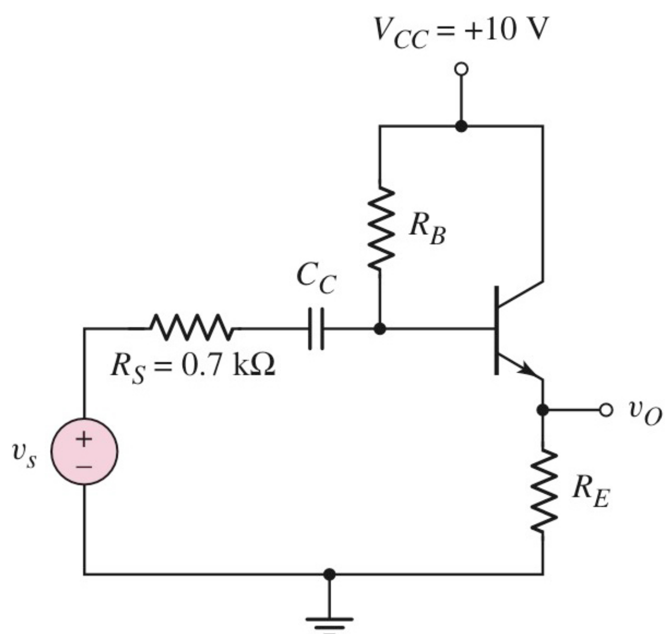
[2] For the transistor in Figure 2, the parameters are $\beta = 100$ and $V_A = \infty$.

(a) Design the circuit such that $I_{EQ} = 1$ mA and the Q-point is in the center of the dc load line.

(b) If the peak-to-peak sinusoidal output voltage is 4 V, determine the peak-to-peak sinusoidal signals at the base of the transistor and the peak-to-peak value of vs.

(c) If the load resistor $R_L = 1$ kΩ is connected to the output through a coupling capacitor, determine the peak-to-peak value in the output voltage, assuming vs is equal to the value determined in part (b).



*Solution:*

(a) For dc analysis, the capacitor *CC* acts as *open circuit*.

$$V_{CC} = I_{BQ}R_B + V_{BE(\text{on})} + I_{EQ}R_E$$

$$= \left(\frac{R_B}{1+\beta} + R_E\right) I_{EQ} + V_{BE(\text{on})}$$

$$\frac{R_B}{101} + R_E = \frac{V_{CC} - V_{BE(\text{on})}}{I_{EQ}} = \frac{10-0.7}{1} = 9.3\ (\text{k}\Omega) \qquad ...(1)$$

$$V_{CC} = V_{CEQ} + I_{EQ}R_E\ \left(V_{CEQ} = \frac{V_{CC}}{2} \text{ for } Q\text{-point is in the center of the dc load line}\right)$$

$$10 = 5 + (1)R_E$$

$$R_E = 5\ (\text{k}\Omega) \qquad ...(2)$$

$$\Rightarrow R_B = (101)(9.3 - R_E) = 434.3\ (\text{k}\Omega)$$

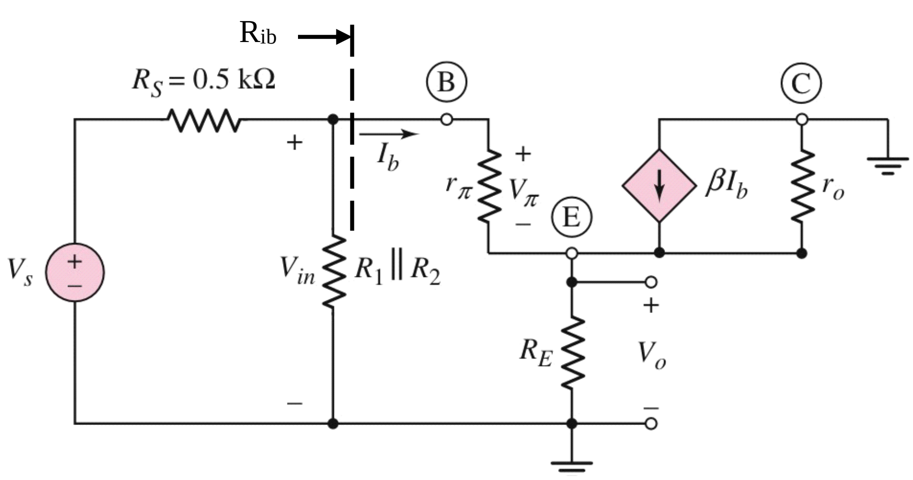
$$I_{CQ} = \left(\frac{\beta}{1+\beta}\right) I_{EQ} = \left(\frac{100}{101}\right)(1) = 0.990\ (\text{mA})$$

$$r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{(100)(0.026)}{0.990} = 2.6263\ (\text{k}\Omega)$$

$$g_m = \frac{I_{CQ}}{V_T} = \frac{0.990}{0.026} = 38.0769\ (\text{mA/V})$$

$$r_o = \frac{V_A}{I_{CQ}} = \infty$$

(b) The small-signal ac equivalent circuit is given by:



$$v_o = (1+\beta)R_E i_b$$

$$\Rightarrow \frac{v_o}{i_b} = (1+\beta)R_E = (101)(5) = 505$$

$$v_b = V_\pi + v_o = i_b r_\pi + (1+\beta)R_E i_b$$

$$\Rightarrow \frac{v_b}{i_b} = R_{ib} = r_\pi + (1+\beta)R_E = 2.6263 + 505 = 507.6263$$

$$v_b = V_\pi + v_o = i_b r_\pi + (1+\beta)R_E i_b$$

$$\Rightarrow \frac{v_b}{i_b} = R_{ib} = r_\pi + (1+\beta)R_E = 2.6263 + 505 = 507.6263$$

$$v_b = \frac{R_B \parallel R_{ib}}{R_S + R_B \parallel R_{ib}} v_s$$

$$\Rightarrow \frac{v_b}{v_s} = \frac{R_B \parallel R_{ib}}{R_S + R_B \parallel R_{ib}} = \frac{234.0545}{0.7+234.0545} = 0.9970$$

$$\frac{v_b}{v_o} = \frac{v_b}{i_b} \times \frac{i_b}{v_o}$$

$$= \frac{r_\pi + (1+\beta)R_E}{(1+\beta)R_E}$$

$$= \frac{507.6263}{505} = 1.0052 \qquad ...(3)$$

$$\frac{v_o}{v_s} = \frac{v_o}{i_b} \times \frac{i_b}{v_b} \times \frac{v_b}{v_s}$$

$$= (1+\beta)R_E \times \frac{1}{R_{ib}} \times \frac{R_B \parallel R_{ib}}{R_S + R_B \parallel R_{ib}}$$

$$= 505 \times \frac{1}{507.6263} \times 0.9970 = 0.9918 \qquad ...(4)$$

If the peak-to-peak output voltage $v_{o(\text{peak-peak})}$ is 4 V,

$$\text{Eq.(3)} \Rightarrow v_{b(peak-peak)} = 1.0052 v_{o(peak-peak)} = 4.021 \text{ (V)}$$

$$\text{Eq.(4)} \Rightarrow v_{s(peak-peak)} = \frac{v_{o(peak-peak)}}{0.9918} = 4.033 \text{ (V)}$$

(c) If the load resistor *RL* = 1 kΩ is added in parallel to *RE*, Eq. (4) must be modified accordingly:

$$\frac{v_o}{v_s} = \frac{(1+\beta)(R_E \,\|\, R_L)}{r_\pi + (1+\beta)(R_E \,\|\, R_L)}\left(\frac{R_B \,\|\, R_{ib}}{R_S + R_B \,\|\, R_{ib}}\right)$$

$$= \frac{(101)(0.8333)}{2.6263 + (101)(0.8333)}(0.9970) = 0.9668$$

$$\Rightarrow v_{o(peak-peak)} = 0.9668 v_{s(peak-peak)} = (0.9668)(4.033) = 3.90 \text{ (V)}$$

Therefore $v_{o(peak\text{-}peak)}$ becomes smaller due to the loading effect by $R_L$.

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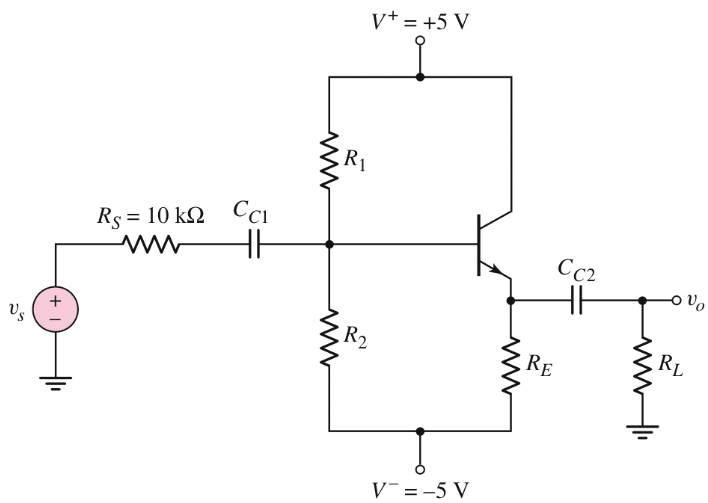
[3] An emitter-follower amplifier, with the configuration shown in Figure 3, is to be designed such that an audio signal given by $v_s = 5 \sin(3000t)$ V but with a source resistance of $R_S = 10\ \Omega$ can drive a small speaker. Assume the supply voltages are $V_+ = +12$ V and $V_- = -12$ V and β = 50. The load, representing the speaker, is $R_L = 12\ \Omega$. The amplifier should be capable of delivering approximately 1 W of average power to the load. What is the signal power gain of your amplifier?




*Solution:*

To deliver 1 W of average power to the load, the peak-to-peak output voltage should be:

$$\frac{v_{o(rms)}^2}{R_L} = \frac{v_{o(peak)}^2}{2R_L} = 1$$

$$\Rightarrow v_{o(peak)} = 4.899 \text{ (V)}$$

$$\Rightarrow i_{o(peak)} = \frac{4.899}{12} = 0.408 \text{ (A)}$$

$$\Rightarrow v_{o(peak-peak)} = 9.798 \text{ (V)}$$

The required voltage gain $A_v$ is:

$$A_v = \frac{v_{o(peak)}}{v_{s(peak)}} = \frac{4.899}{5.0} = 0.9798$$

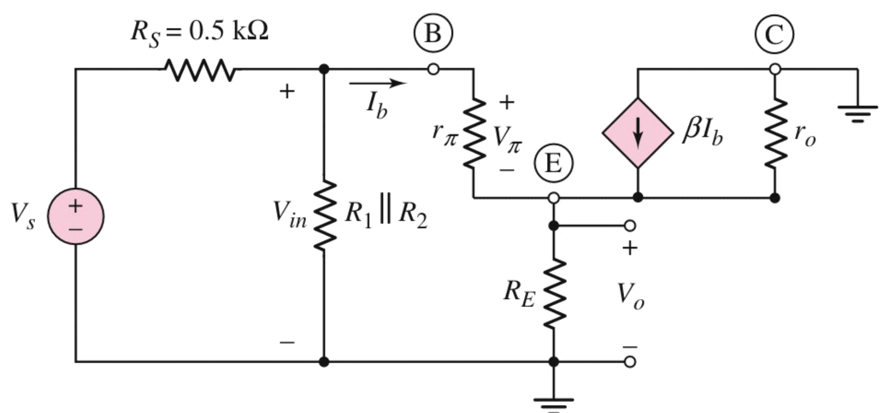
Choose $I_{EQ}$ = 0.8 A and $V_{CEQ}$ = 12 V,

$$R_E = \frac{V^+ - V^- - V_{CEQ}}{I_{EQ}} = \frac{12-(-12)-12}{0.8} = 15\ (\Omega)$$

$$R_{TH} = \frac{1}{10}(1+\beta)R_E = \left(\frac{51}{10}\right)(15) = 76.5\ (\Omega)\ \text{(for bias-stable circuit)}$$

$$\begin{aligned} V_{TH} &= V^- + I_{EQ}R_E + V_{BE(\text{on})} + I_{BQ}R_{TH} \\ &= -12 + (0.8)(15) + 0.7 + \left(\frac{0.8}{51}\right)(76.5) = 1.9\ (\text{V}) \\ &= \frac{R_1}{R_1+R_2}(V^+ - V^-) + V^- = \frac{1}{R_1}(R_1 \parallel R_2)(V^+ - V^-) + V^- \\ &\Rightarrow R_1 = 132\ (\Omega) \qquad R_2 = 182\ (\Omega) \end{aligned}$$

The small-signal ac equivalent circuit is given by:




Choosing $I_{EQ}$ = 0.5 A gives:

$$I_{CQ} = \frac{\beta}{1+\beta} I_{EQ} = \left(\frac{50}{51}\right)(0.8) = 0.784\ (\text{A})$$

$$r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{(50)(0.026)}{0.784} = 1.658\ (\Omega)$$

The small-signal voltage gain is taken from Q.2 with some modifications:

$$\frac{v_o}{v_s}=\frac{(1+\beta)(R_E \parallel R_L)}{r_\pi+(1+\beta)(R_E \parallel R_L)}\left(\frac{R_1 \parallel R_2 \parallel R_{ib}}{R_S+R_1 \parallel R_2 \parallel R_{ib}}\right)$$
$$=\frac{(51)(6.667)}{1.658+(51)(6.667)}\left(\frac{62.5116}{10+62.5116}\right)$$
$$=0.8579$$

Due to the presence of the source resistance $R_S$ (loading effect) the required voltage gain of $A_v$ = 0.9798 cannot be achieved. Note that $A_v = 0.9951$ if $R_S = 0$.
Therefore the maximum achievable peak output voltage is:

$$\frac{v_{o(peak)}}{v_{s(peak)}}=0.8579 \Rightarrow v_{o(peak)}=4.290\ (\text{V})$$

Hence the output power delivered to the load $R_L$ is:

$$P_L=\frac{v_{o(peak)}^2}{2R_L}=0.767\ (\text{W})$$

The input power delivered by the signal source $v_s$ is:

$$P_S=v_{s(rms)}i_{s(rms)}$$

$$i_{s(rms)}=\frac{v_{s(rms)}}{R_i}=\frac{v_{s(rms)}}{R_S+R_1 \parallel R_2 \parallel R_{ib}}=\frac{5/\sqrt{2}}{10+62.5116}=48.758\ (\text{mA})$$
$$\Rightarrow P_S=v_{s(rms)}i_{s(rms)}=\left(\frac{5}{\sqrt{2}}\right)(48.758)=172.386\ (\text{mW})$$

Hence the signal power gain of the amplifier is:

$$G_{power}=\frac{P_L}{P_S}=\frac{0.767}{172.386\times10^{-3}}=4.45$$