CE Amplifier Example

Given:
- Supply Voltage 10V
- \( R_L = 10k\Omega \)

Required:
- \(|A_v| > 100\)
- 100Hz - 100kHz Passband

Topology

Transistor:
- \( 100 < \beta < 400 \)
- \( V_{BEa} \approx 0.7V \)
- \( n \ V_T \approx 30mV \)
- \( V_A \approx 80V \)

Note: \( C_f, C_o \) and \( C_E \) are dc decoupling caps. Their values will depend on the required frequency band of the amplifier and the operating point (A-point) values of the transistor.

To simplify the analysis, we will first assume that they act as shorts for all frequencies of interest. Subsequently, we will determine their proper values.
Step 1  Select Q-point
  e.g. \[ I_{CA} = 1 \text{mA} \]
  \[ V_{CES} = 5 \text{V} \]

Step 2  Determine values of biasing resistors.

\[
I_{CA} = \frac{\frac{V_{CC}}{\frac{1}{R_1} + \frac{1}{R_2}} - V_{I_{B}}}{\frac{1}{R_1} + \frac{1}{R_2} + (1 + \frac{1}{\beta})R_E}
\]

\[
V_{CE} = V_{CC} - I_{CA} \left[ R_C + (1 + \frac{1}{\beta})R_E \right]
\]

Since you have 4 free parameters, namely \( R_1, R_2, R_C \) and \( R_E \), there exists no unique solution. We will use the 2 degrees of freedom to optimize the circuit performance with regard to Q-point stability and (possibly) power dissipation. The first objective requires \( R_1 \approx \frac{1}{\beta}R_2 \) to be much smaller than \( R_E \); the second would require \( R_1 \) to be large (less current).
Practical Compromise:

<table>
<thead>
<tr>
<th>$R_1 = 10,k\Omega$</th>
<th>$R_2 = 47,k\Omega$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{T} \approx 8.2,k\Omega$</td>
<td></td>
</tr>
<tr>
<td>$R_{L} = 1,k\Omega$</td>
<td></td>
</tr>
</tbody>
</table>

$$I_{C6}(\beta=100) = 0.97\,mA$$
$$I_{C6}(\beta=400) = 1.03\,mA$$

$$I_{C6} = 1.00 \pm 0.05\,mA$$

Select $R_C = 4.7\,k\Omega$

$$V_{CEa}(\beta=100) = 4.45\,V$$
$$V_{CEa}(\beta=400) = 4.11\,V$$

$$V_{CEa} = 4.28 \pm 0.17\,V$$

---

**Step 3: Small Signal Analysis**

Linear equivalent circuit (capacitors shorts)

![Schematic Diagram]

Where $r_i = \beta \frac{V_i}{I_C}$

$V_o = \frac{V_A}{I_C}$

Note: $r_i e = \delta_m V_i$

$s_m = \frac{I_C}{n V_i}$

Simplify: $V_o \approx R_C \approx R_L = \frac{V_o}{R_L} = 3.07\,k\Omega$
\[
V_i = \beta V_i' = \frac{\beta}{g_m} \quad \quad \quad \quad \quad \quad \quad V_c = -\beta V_i' \tilde{V}_c \\
\text{or} \quad \quad \quad \quad \quad \quad \quad V_c = -g_m V_i' \tilde{V}_c
\]

\[
\Delta v = \frac{V_c}{V_i'} = -g_m \tilde{V}_c = -\frac{2ca}{nV_i'} \tilde{V}_c
\]

\[
I_{ca} = 1.00\text{mA} \\
V_i' = 50\text{mV} \\
\tilde{V}_c = 7.07\text{k}\Omega \\
\text{Note: If magnitude of voltagepairs would have been too small, we could have increased the bias current, } I_{ca}. \\
\]

C. S. \[
I_{ca} \approx 2\text{mA} \\
\tilde{V}_c = 2.2\text{k}\Omega \\
\tilde{V}_E = 500\text{V} \\
\tilde{V}_L \approx 1.73\text{k}\Omega \\
\text{or} \quad \quad \quad \quad \quad \quad \quad V_{ce} = 5.9V
\]

\[
I_{ca} \approx 5\text{mA} \\
\tilde{V}_c = 1\text{k}\Omega \\
\tilde{V}_E = 200\text{V} \\
\tilde{V}_L \approx 860\text{V} \\
\text{or} \quad \quad \quad \quad \quad \quad \quad V_{ce} = 3.3V
\]

\[
\Delta v \approx -115V \\
\Delta v \approx -144V
\]

To keep A-point \( \beta \text{-independent, } R_1 \text{ and } R_2 \text{ have to be reduced accordingly in the latter 2 cases.} \]
Step 4. Determine values of decoupling caps

All 3 decoupling caps form a highpass filter with their respective resistor counterpart, that is

\[
\begin{align*}
C_p \text{ and } R_{in} & \approx 2.2 \text{ to } 5.2 \text{ k}\Omega \\
C_0 \text{ and } R_L & \approx 10 \text{ k}\Omega \\
C_E \text{ and } R_E & = \frac{1}{\frac{1}{g_m} \approx \frac{1}{g_m} = 33 \Omega}
\end{align*}
\]

for \( I_{eq} = 1 \text{ mA} \)

Since \( C_E \) turns out to have the smallest resistor counterpart, we select it to set the low frequency corner at 100 kHz

\[
C_E = \frac{g_m}{2 \pi f_L} = 48 \mu F
\]

To avoid overlap with the corner frequency \( f_L \), we select the values of \( C_p \) and \( C_0 \) such that they form a corner at around \( \frac{1}{10} \) of \( f_L \). Hence

\[
\begin{align*}
C_p & \approx \frac{10}{2 \pi f_L R_{in}} \approx 5.3 \mu F \\
C_0 & = \frac{10}{2 \pi f_L R_L} \approx 1.6 \mu F
\end{align*}
\]
CE Amplifier Design Example

Frequency Response

Transient Response

(Mag(V)) : f(Hz)
vm(7)

(V) : t(s)
v(7)
v(5)

VL
VS
CE Amplifier with Emitter Degeneration

Transistor
\[ \beta = 150 \]
\[ V_A = 60 \]
\[ V_{T_E E} = 0.7V \]
\[ n V_T = 50mV \]

\[ V_{cc} = 10V \]
\[ R_1 = 10k\Omega \]
\[ R_C = 10k\Omega \]
\[ R_L = 10k\Omega \]

Find:
1. G-point \((I_{CA}, V_{CEA})\) DC Analysis
2. \(A_V = \frac{V_L}{V_i}\) AC Analysis

Step 1: DC Analysis

\[ R_A = 8.8k\Omega \]
\( R_A = R_C \parallel R_2 \)
\( I_{CA} = \frac{V_{CC} R_1}{R_C R_2 + \frac{1}{\beta}} \approx 0.52mA \)
\( V_{CEA} = V_{cc} \cdot I_{CA} \left( \frac{1}{\beta} + \frac{1}{R_L} \right) = 4.5V \)
Step 2: AC Analysis (Capacitor as shorts)

**Small Signal eq. Circuit**

Equations:

1. \[ V_i = \frac{C_i}{C_m} + (1+\alpha) C_i \pi_E \]
2. \[ V_L = -\beta C_L \tilde{\pi}_L \]

\[ \tilde{\pi}_L = \pi_C \pi_R = 5 \Omega \]

\[ A_V = -\frac{\pi_L}{\pi_c + (1+\alpha) \pi_E} \]

\[ = -\frac{\tilde{\pi}_L}{\tilde{\pi}_C + (1+\alpha) \tilde{\pi}_E} \]

\[ \left| A_V \right| = -\frac{\pi_L}{\pi_c + \pi_E} = -4.7 \]

**Note:** The emitter resistor \(\pi_E\) significantly reduces the gain. In return, it keeps the output voltage \(V_L\) more linear since the denominator of the voltage gain varies less with \(I_{CA}\).