ECEN325: Electronics
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Common-Collector Amplifier Graphical Approach Design

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Common Collector Amp

\[ A_v = \frac{R_E \| R_L}{r_e + R_E \| R_L} \]

\[ R_{in} = R_B \| \left( r_\pi + (\beta + 1)R_E \| R_L \right) \]

\[ R_{out} = R_E \left[ r_e + \frac{R_S \| R_B}{\beta + 1} \right] \]
Typical Design Specifications

• Loaded voltage gain, $A_v$

• Max output swing, $V_{omax}$
  • This must be satisfied at a given linearity (total harmonic distortion)

• Input and output resistance, $R_{in}$ & $R_{out}$
  • If you know $R_L$, then $R_{out}$ spec is somewhat redundant with $A_v$ spec

• Power Supply, $V_{CC}$
How to set DC Biasing Conditions?

• In order to meet all design specifications, the DC biasing conditions \((I_E, R_E)\) must be set appropriately.

• Can transform design specifications into functions of \(I_E\) & \(R_E\) and graph them to find acceptable solution space.
R_{in} Specification

- **R_{in} Spec**

\[ R_{in} = R_B \parallel (r_\pi + (\beta + 1)R_E \parallel R_L) \approx \beta (R_E \parallel R_L) \]

\[ R_E \geq \left( \frac{\beta}{R_{in,spec}} - \frac{1}{R_L} \right)^{-1} \]

- Input resistance is primarily set by \( R_E \) and somewhat independent of \( I_E \)
Neg. $v_{o_{\text{max}}}$ Specification

- Need to insure with a negative swing that the output signal doesn’t clip the power supply

$$I_E R_E - v_{o_{\text{max}}} \geq 0V$$

$$I_E \geq \frac{v_{o_{\text{max}}}}{R_E}$$

- Negative AC Swing constraint sets a lower bound on $I_E$
- Additional linearity constraint (harmonic distortion) generally sets a tighter bound
Pos. $v_{o\text{max}}$ & $V_{CC}$ Specifications

• Need a minimum $V_{CE}$ to keep transistor in active mode with maximum positive swing

\[
\text{Set } V_{CE\text{min}} = 500\text{mV}
\]
(w/ 200mV design margin)

• $V_{CC}$ Spec (w/ max positive swing)

• Maximum positive AC swing constraint sets an upper bound on $I_E$

\[
V_{CC} = I_E R_E + v_{o\text{max}} + V_{CE\text{min}}
\]

\[
V_{CE\text{min}} = V_{CC} - I_E R_E - v_{o\text{max}} \geq 500\text{mV}
\]

\[
I_E \leq \frac{V_{CC} - v_{o\text{max}} - 0.5V}{R_E}
\]
Gain Specification

\[ A_v = \frac{R_E \parallel R_L}{r_e + R_E \parallel R_L} = \frac{R_E \parallel R_L}{V_{th} + R_E \parallel R_L} \]

\[ I_E \geq \frac{A_v V_{th}}{(R_E \parallel R_L)(1 - A_v)} \]

- Gain constraint sets a lower bound on \( I_E \)
Harmonic Distortion Specification

- Need a minimum amount of bias current to insure that the AC swing doesn’t distort

\[ \text{Total } i_C = I_s \left( \frac{V_{BE} + v_{be}}{V_{th}} - 1 \right) \approx I_s \left( \frac{V_{BE}}{V_{th}} + \frac{v_{be}}{V_{th}} \right) = I_{CQ} \left( \frac{v_i}{V_{th}} \right) \approx I_{CQ} \left( e^{\frac{v_i}{V_{th} \left( 1 + g_m R_E R_L \right)}} \right) \]

with a Taylor Expansion of the exponential term

\[ i_C = I_{CQ} + I_{CQ} \left( \frac{v_i}{V_{th} \left( 1 + g_m R_E R_L \right)} \right) + \frac{I_{CQ}}{2} \left( \frac{v_i}{V_{th} \left( 1 + g_m R_E R_L \right)} \right)^2 + \frac{I_{CQ}}{6} \left( \frac{v_i}{V_{th} \left( 1 + g_m R_E R_L \right)} \right)^3 + \ldots \]

- DC term
- “linear” AC term
- “non-linear” AC distortion terms

\[ HD2 = \frac{1}{4} \frac{v_{i_{\text{max}}}}{V_{th} \left( 1 + g_m R_E R_L \right)} \]
Harmonic Distortion Specification

- Can relate the HD2 specification to the ratio of AC current $i_c$ to $I_{CQ}$

$$i_c \leq 4(\text{HD2})\left(1 + g_m \left( R_E \parallel R_L \right) \right) I_{CQ}$$

Now, assuming a high $\beta$ or $\alpha \approx 1$

$$i_e \leq 4(\text{HD2})\left(1 + g_m \left( R_E \parallel R_L \right) \right) I_{EQ}$$

$$I_{EQ} \geq \frac{\frac{V_{o\text{max}}}{R_E \parallel R_L}}{4(\text{HD2})\left(1 + g_m \left( R_E \parallel R_L \right) \right)} \approx \frac{\frac{V_{o\text{max}}}{R_E \parallel R_L}}{4(\text{HD2})\left( \frac{I_{EQ}}{V_{th}} \right) \left( R_E \parallel R_L \right)}$$

$$I_{EQ} \geq \frac{1}{2(R_E \parallel R_L)} \sqrt{\frac{V_{th} V_{o\text{max}}}{\text{HD2}}}$$

- HD2 will dominate the distortion terms
- For a -30dB THD, perhaps set HD2 to -40dB or (0.01)
Design Example - Specifications

- $A_v \geq 0.95$
- $R_{in} \geq 1\,k\Omega$
- $V_{omax} = 500mV_{pk}$ w/ THD $\leq -30\,dB$
  - Here I set HD2=40dB or 0.01
- $V_{CC} = 5V$
- $R_L = 50\,\Omega$
• Pick a low $I_E$ design point to save power
• $I_E=20\text{mA}$, $R_E=100\Omega$
DC bias points must be reasonable for the circuit to work as designed!
Transient & Distortion

- Achieved a gain $0.95V/V$
- Output with swing $> v_{\text{omax}}$

<table>
<thead>
<tr>
<th>HARMONIC FREQUENCY</th>
<th>FOURIER NORMALIZED</th>
<th>PHASE NORMALIZED</th>
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<td>(DEG)</td>
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<td>1.410E-04</td>
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TOTAL HARMONIC DISTORTION = 1.088050E+00 PERCENT