Transistors applications: AC amplifiers

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Lecture 07
Summary of simple emitter follower

Advantages
- input impedance increase $Z_{in} = \beta R_e$
- power/current gain
- output does not depend on $\beta$
- simple
Summary of simple emitter follower

Advantages
- input impedance increase $Z_{in} = \beta R_e$
- power/current gain
- output does not depend on $\beta$
- simple

Disadvantages
- input signal must be positive
- even more it should be above 0.6 V
- no voltage gain
In real life signals usually swing around zero.
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We need to do something with our simple emitter follower.
Real life signal

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Solution 1: Push-Pull follower
Real life signal

In real life signals usually swing around zero.

We need to do something with our simple emitter follower.

Solution 1: Push-Pull follower
Solution 2: AC-coupled biased-amplifier
NPN and PNP emitter follower

NPN emitter follower

\[ V_{cc} \quad \text{V}_{in} \quad \text{V}_{out} \quad \text{R}_e \]

\[ V_0 - 0.6 \quad V_0 \quad -10 -5 0 5 10 \]

\[ V_{in}(t) \quad V_{out}(t) \]

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NPN and PNP emitter follower

NPN emitter follower

\[ V_{cc} \]
\[ R_e \]
\[ V_{in} \]
\[ V_{out} \]

-\[ V_0 \]
-\[ V_0 + 0.6 \]

-10 -5 0 5 10

\[ t \]
\[ V_{in}(t) \]
\[ V_{out}(t) \]
NPN and PNP emitter follower

NPN emitter follower

PNP emitter follower
NPN and PNP emitter follower

NPN emitter follower

\[ V_{cc} \]
\[ V_{in} \]
\[ R_e \]
\[ V_{out} \]

\[ V_{0} - 0.6V \]
\[ V_{0} \]
\[ t \]

PNP emitter follower

\[ -V_{ee} \]
\[ R_e \]
\[ V_{in} \]
\[ V_{out} \]

\[ -V_{0} + 0.6V \]
\[ -V_{0} \]
Push-Pull emitter follower

\[ V_{cc} \]

\[ R_L \]

\[ V_{in} \]

\[ V_{out} \]

\[ V_{ee} \]

\[ V_{0} - V_{0} + 0.6V \]

\[ V_{0} - 0.6V \]

\[ V_{0} \]

-10 -5 0 5 10

\[ V_{in}(t) \]

\[ V_{out}(t) \]
Push-Pull emitter follower

\[ V_{cc} \]
\[ R_L \]
\[ V_{in} \]
\[ V_{out} \]
\[ -V_{ee} \]

\[ V_{0} - 0.6V \]
\[ V_{0} + 0.6V \]
\[ -V_{0} \]

\[ V_{in}(t) \]
\[ V_{out}(t) \]
Push-Pull follower crossovers

\[ V_0 - 0.6V \]

\[ V_0 + 0.6V \]

\[ V \]

\[ -V_0 \]

\[ V_{in}(t) \]

\[ V_{out}(t) \]

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Push-Pull follower crossovers

\[ V_{in}(t) \quad V_{out}(t) \]

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Push-Pull follower crossovers

\[ V_{in}(t) = V_0 - 0.6V \]

\[ V_{out}(t) = V_0 + 0.6V \]
Push-Pull emitter follower improved
Push-Pull emitter follower improved
AC-coupled emitter follower

Design rules
maximum output swing

\[ V_e = \frac{V_{cc}}{2} \]

disregarding \( V_{be} = 0.6 \) V

\[ V_b \approx V_e = \frac{V_{cc}}{2} \]

thus \( R_1 = R_2 \)

quiescent current
\[ I_e = \frac{V_e}{R_e} \]

we want \( I_{R_1 + R_2} \gg I_b \) factor of 10 for a safe margin

\[ I_{R_1 + R_2} \geq 10I_b = 10I_e / \beta \]

thus \( R_1 = R_2 \leq R_e \beta / 10 \)
AC-coupled emitter follower

Design rules

- maximum output swing
  - $V_e = V_{cc}/2$
- disregarding $V_{be} = 0.6$ V
  - $V_b \approx V_e = V_{cc}/2$
  - thus $R_1 = R_2$
- quiescent current $I_e = V_e/R_e$
- we want $IR_1+R_2 \gg I_b$
  - factor of 10 for a safe margin
    - $IR_1+R_2 \geq 10I_b = 10I_e/\beta$
  - thus $R_1 = R_2 \leq R_e\beta/10$
AC-coupled emitter follower: capacitors choice

From AC point of view
Input is RC high-pass
\[ C = C_1, \quad R = R_1 || R_2 || \beta R_e \]
\[ f_{3db} = \frac{1}{2\pi C_1 (R_1 || R_2 || \beta R_e)} \]
with above rules
\[ R \approx \frac{R_1}{2} \]
Output is also RC high-pass
\[ C = C_2, \quad R = R_L \]
\[ f_{3db} = \frac{1}{2\pi C_2 R_L} \]
for unloaded filter
\[ R_L \gg R_e \]
factor of 10 for a safe margin
\[ R_L = 10 R_e \]
AC-coupled emitter follower: capacitors choice

From AC point of view

- **Input is RC high-pass**
  - \( C = C_1 \)
  - \( R = R_1 || R_2 || \beta R_e \)
  - \( f_{3db} = \frac{1}{2\pi} \frac{1}{C_1 (R_1 || R_2 || \beta R_e)} \)
  - with above rules \( R \approx R_1 / 2 \)
From AC point of view
- Input is RC high-pass
  - $C = C_1$
  - $R = R_1 \parallel R_2 \parallel \beta R_e$
  - $f_{3db} = \frac{1}{2\pi} \frac{1}{C_1(R_1 \parallel R_2 \parallel \beta R_e)}$
    - with above rules $R \approx R_1 / 2$
- Output is also RC high-pass
  - $C = C_2$
  - $R = R_L$
  - $f_{3db} = \frac{1}{2\pi} \frac{1}{C_2 R_L}$
    - for unloaded filter $R_L \gg R_e$
      - factor of 10 for a safe margin
      - $R_L = 10 R_e$
Common emitter (inverting) amplifier

\[ V_{in} \]
\[ V_{cc} \]
\[ R_e \]
\[ V_{out} \]
\[ V_{out} = V_{cc} - R_c I_c \]
\[ V_{out} = V_{cc} - \frac{(V_{in} - 0.6V)}{R_e} R_c \]
\[ I_c = I_e = \frac{(V_{in} - 0.6V)}{R_e} \]
\[ \text{gain } G = -\frac{R_c}{R_e} \]

Transistor model fails when \( R_e \) is attractive to put \( R_e = 0 \).
Common emitter (inverting) amplifier

- \( I_c = I_e = \frac{(V_{in} - 0.6\,V)}{R_e} \)
- \( V_{out} = V_{cc} - R_c I_c \)
- \( V_{out} = V_{cc} - R_c (V_{in} - 0.6\,V)/R_e \)
- \( V_{out} = (V_{cc} + (0.6\,V) R_c/R_e) - V_{in} R_c/R_e \)
- gain \( G = -R_c/R_e \)
- attractive to put \( R_e = 0 \)
  - transistor model fails
  - transistor emitter resistance
  - \( r_e = 25\,mV/I_c \)
  - gain \( G = -R_c/r_e \)
In the pass band we can neglect capacitors

\[ V_{out} = V_{cc} - I_c R_C = V_{cc} - (I_{ce} + I_L) R_C = (V_{cc} - I_{ce} R_C) - I_L R_C = V_{th} - I_L R_{th} \]

Thévenin’s equivalent

\[ V_{th} = V_{cc} - I_{ce} R_C \]

\[ R_{th} = R_C \]

Rule of 10 must be satisfied

\[ R_L \geq 10 R_C \]
In the pass band we can neglect capacitors

\[
V_{out} = V_{cc} - I_c R_c = V_{cc} - (I_{ce} + I_L) R_c
\]

\[
= (V_{cc} - I_{ce} R_c) - I_L R_c
\]

\[
= V_{th} - I_L R_{th}
\]
In the pass band we can neglect capacitors

\[ V_{out} = V_{cc} - I_c R_c = V_{cc} - (I_{ce} + I_L) R_c \]
\[ = (V_{cc} - I_{ce} R_c) - I_L R_c \]
\[ = V_{th} - I_L R_{th} \]

Thévenin’s equivalent

\[ V_{th} = V_{cc} - I_{ce} R_c \]
\[ R_{th} = R_c \]
Common emitter amplifier signal output impedance

In the pass band we can neglect capacitors

\[ V_{out} = V_{cc} - I_c R_c = V_{cc} - (I_{ce} + I_L) R_c \]
\[ = (V_{cc} - I_{ce} R_c) - I_L R_c \]
\[ = V_{th} - I_L R_{th} \]

Thévenin’s equivalent

\[ V_{th} = V_{cc} - I_{ce} R_c \]
\[ R_{th} = R_c \]

Rule of 10 must be satisfied

\[ R_L \geq 10R_c \]
AC-coupled common emitter (inverting) amplifier

Design rules
- chose gain: $G = \frac{R_c}{R_e}$
- maximum output swing: $V_c = \frac{V_{cc}}{2}$
- quiescent current: $I_c = \frac{(V_{cc} - V_c)}{R_c} = \frac{V_{cc}}{2R_c}$
- $R_c = \frac{V_{cc}}{2I_c}$
- $R_e = \frac{R_c}{G}$

We want $I_R1 + R_2 \gg I_b$ factor of 10 for a safe margin:
- $I_R1 + R_2 \geq 10I_b = 10\frac{I_c}{\beta}$
- $R_1 + R_2 \leq \frac{V_{cc}}{\beta} \left( \frac{10I_c}{10} \right)$

$V_b = V_e + 0.6V$

$\frac{R_2}{R_1 + R_2} = \frac{V_b}{V_{cc}}$
AC-coupled common emitter (inverting) amplifier

Design rules

- chose gain $G = \frac{R_c}{R_e}$
- maximum output swing
  - $V_c = \frac{V_{cc}}{2}$
- quiescent current
  - $I_c = \frac{(V_{cc} - V_c)}{R_c} = \frac{V_{cc}}{2R_c}$
  - $R_c = \frac{V_{cc}}{2I_c}$
  - $R_e = \frac{R_c}{G}$
- we want $I_{R_1 + R_2} \gg I_b$
  - factor of 10 for a safe margin
    - $I_{R_1 + R_2} \geq 10I_b = 10I_c/\beta$
    - $R_1 + R_2 \leq \frac{V_{cc}\beta}{10I_c}$
- $V_b = V_e + 0.6\,\text{V}$
- $R_2/(R_1 + R_2) = \frac{V_b}{V_{cc}}$
AC-coupled (inverting) amplifier capacitors choice

\[ V_{cc} \]
\[ V_{in} \]
\[ R_e \]
\[ V_{out} \]
\[ R_1 \]
\[ R_2 \]
\[ C_1 \]
\[ C_2 \]
\[ R_L \]

See notes about AC-coupled emitter follower

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AC-coupled (inverting) amplifier capacitors choice

Input equivalent

\[ \begin{align*}
V_{cc} & \quad \text{Input equivalent} \\
\beta R_e & \quad \text{Output equivalent}
\end{align*} \]
AC-coupled (inverting) amplifier capacitors choice

Input equivalent

Output equivalent

See notes about AC-coupled emitter follower

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AC-coupled (inverting) amplifier capacitors choice

Input equivalent

Output equivalent

See notes about AC-coupled emitter follower
AC-coupled (inverting) amplifier with HF gain boost

Think what happens with equivalent impedance of $R_e$ at high frequencies