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
Real life signal

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

In real life signals usually swing around zero.

We need to do something with our simple emitter follower.

Solution 1: Push-Pull follower
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

\[ \text{V}_{\text{cc}} \]
\[ \text{V}_{\text{in}} \]
\[ \text{V}_{\text{out}} \]
\[ \text{R}_{e} \]
NPN and PNP emitter follower

NPN emitter follower

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

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

PNP emitter follower

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

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

NPN emitter follower

PNP emitter follower

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NPN and PNP emitter follower

NPN emitter follower

PNP emitter follower

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

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

\[ V_0 \]
\[ V_0 - 0.6V \]

\[ V_0 \]
\[ V_0 + 0.6V \]

\[ -V_0 \]
\[ -V_0 \]

\[ -10 \]
\[ -5 \]
\[ 0 \]
\[ 5 \]
\[ 10 \]
Push-Pull emitter follower

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

- \( V_{in} \)
- \( V_{out} \)
- \( R_L \)
- \( V_{cc} \)
- \( -V_{ee} \)
Push-Pull emitter follower

\[ V_{cc} \]

\[ R_L \]

\[ V_{in} \]

\[ V_{out} \]

\[ -V_{ee} \]

\[ V_{in}(t) \]

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

\[ V_0 \pm 0.6V \]

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

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Push-Pull follower crossovers

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

- \( V_{in}(t) \) is the input voltage.
- \( V_{out}(t) \) is the output voltage.

Input range: \(-10\) to \(10\) Volts.
Output range: \(-5\) to \(5\) Volts.

The graph shows the superposition of the input and output signals, demonstrating the operation of a push-pull follower circuit.
Push-Pull follower crossovers

$V_{in}(t)$ $V_{out}(t)$
Push-Pull emitter follower improved

\[ V_{cc} \]

\[ R_{L} \]

\[ V_{in} \]

\[ V_{out} \]

\[ -V_{ee} \]
Push-Pull emitter follower improved
AC-coupled emitter follower

Design rules
maximum output swing
\[ V_e = \frac{V_{cc}}{2} \]
disregarding \[ V_{be} = 0.6 \text{ V} \].

\[ V_b = V_e = \frac{V_{cc}}{2} \]
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
\[ I_{R_1 + R_2} = 10 I_b = 10 \frac{I_e}{\beta} \]
thus
\[ R_1 = R_2 = R_e \frac{\beta}{10} \]

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AC-coupled emitter follower

Design rules

- maximum output swing
  - $V_e = V_{cc}/2$
- disregarding $V_{be} = 0.6$ V
  - $V_b = V_e = V_{cc}/2$
  - thus $R_1 = R_2$
- quiescent current $I_e = V_e/R_e$
- we want $I_{R_1+R_2} \gg I_b$
  - factor of 10 for a safe margin
    - $I_{R_1+R_2} = 10I_b = 10I_e/\beta$
  - thus $R_1 = R_2 = R_e\beta/10$
From AC point of view

\[
\begin{align*}
V_{cc} & \quad V_{in} \\
V_{cc} & \quad C_1 \quad R_1 \quad V_{out} \\
C_1 & \quad R_1 \quad R_2 \quad C_2 \\
R_1 & \quad R_2 \quad R_e \quad R_L \\
V_{out} & \quad V_{cc} \\
R_L & \quad R_e \\
\end{align*}
\]
From AC point of view
- Input is RC high-pass
  - \( C = C_1 \)
  - \( R = \frac{1}{2} \frac{1}{R_1||R_2||\beta R_e} \)
- \( f_{3\text{db}} = \frac{1}{2\pi} \frac{1}{C_1(R_1||R_2||\beta R_e)} \)
- with above rules \( R \approx \frac{R_1}{2} \)
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 \( R \approx R_1 / 2 \)
- 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 \( R_L = 10R_e \)
Common emitter (inverting) amplifier

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

\[ I_c = \frac{V_{in} - 0.6V}{R_e} \]

\[ V_{out} = V_{cc} - \frac{R_c I_c}{R_e} \]

\[ V_{out} = (V_{cc} + \frac{0.6V R_c}{R_e}) - V_{in} \frac{R_c}{R_e} \]

\[ \text{gain } G = -\frac{R_c}{R_e} \]

Attractive to put \( R_e = 0 \)

Transistor model fails

Transistor emitter resistance \( r_e = 25 \text{ mV/I} \)

\[ \text{gain } G = -\frac{R_c}{r_e} \]
Common emitter (inverting) amplifier

- $I_c = I_e = (V_{in} - 0.6V)/R_e$
- $V_{out} = V_{cc} - R_c I_c$
- $V_{out} = V_{cc} - R_c(V_{in} - 0.6V)/R_e$
- $V_{out} = (V_{cc} + (0.6V)R_c/R_e) - V_{in}R_c/R_e$
- gain $G = -R_c/R_e$
- attractive to put $R_e = 0$
  - transistor model fails
  - transistor emitter resistance
    - $r_e = 25mV/I_c$
  - gain $G = -R_c/r_e$
Design rules

\( \text{chose gain} \quad G = \frac{R_c}{R_e} \)

maximum output swing
\( V_{cc} = \frac{V_{cc}}{2} \)

quiescent current
\( I_c = \frac{(V_{cc} - V_c)}{R_c} = \frac{V_{cc}}{2R_c} \)

\( R_c = \frac{V_{cc}}{2I_c} \)

\( R_e = R_c / G \)

we want
\( I_{R1} + R_2 \gg I_b \)

factor of 10 for a safe margin
\( I_{R1} + R_2 = 10I_b = \frac{10I_c}{\beta} \)

\( R_1 + R_2 = \frac{V_{cc}}{\beta} / (10I_c) \)

\( V_{b} = V_e + 0.6 \)

\( \frac{R_2}{(R_1 + R_2)} = \frac{V_{b}}{V_{cc}} \)
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
  - \( I_c = \frac{(V_{cc} - V_c)}{R_c} = \frac{V_{cc}}{2R_c} \)
  - \( R_c = \frac{V_{cc}}{(2I_c)} \)
  - \( R_e = R_c/G \)
- we want \( I_{R_1+R_2} \gg I_b \)
  - factor of 10 for a safe margin
    - \( I_{R_1+R_2} = 10I_b = 10I_c/\beta \)
    - \( R_1 + R_2 = \frac{V_{cc}\beta}{(10I_c)} \)
- \( V_b = V_e + 0.6 \)
- \( R_2/(R_1 + R_2) = V_b/V_{cc} \)
AC-coupled (inverting) amplifier signal output impedance

In the pass band we can neglect capacitors:

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

\[ V_{th} = \left( V_{cc} - I_{ce} R_c \right) - I_L R_{th} \]

Thévenin's equivalent:

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

\[ R_{th} = R_c \]

Rule of 10 must be satisfied:

\[ R_L \geq 10 R_c \]
AC-coupled (inverting) amplifier signal output impedance

In the pass band we can neglect capacitors

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

\[ V_{th} = V_{cc} - I_{ce} R_c \]
\[ R_{th} = R_c \]
AC-coupled (inverting) 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

\[ R_L \geq 10 R_c \]
AC-coupled (inverting) amplifier capacitors choice

Input equivalent

Output equivalent

See notes about AC-coupled emitter follower
AC-coupled (inverting) amplifier capacitors choice

Input equivalent

See notes about AC-coupled emitter follower
AC-coupled (inverting) amplifier capacitors choice

Input equivalent

Output equivalent

See notes about AC-coupled emitter follower
AC-coupled (inverting) amplifier capacitance 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