Transistors applications: AC amplifiers

Eugeni E. Mikhailov

The College of William & Mary

Week 7
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
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.
Real life signal

In real life signals usually swing around zero.

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
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

\[ V_{cc} \]
\[ V_{in} \]
\[ V_{out} \]
\[ R_e \]
NPN and PNP emitter follower

NPN emitter follower

\[ V_{cc} \]

\[ V_{in} \]

\[ V_{out} \]

\[ R_e \]

\[ V_0 \]

\[ V_{0.6V} \]

\[ V_0 \]

\[ V_{in(t)} \]

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

NPN emitter follower

PNP emitter follower
NPN and PNP emitter follower

NPN emitter follower

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

PNP emitter follower

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

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

Eugeniy Mikhailov (W&M)
Push-Pull emitter follower

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

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

Eugeniy Mikhailov (W&M)
Push-Pull emitter follower

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

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

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

\[ V_0 \quad V_0-0.6V \quad -V_0+0.6V \]

\[ t \quad -10 \quad -5 \quad 0 \quad 5 \quad 10 \]

Eugeniy Mikhailov (W&M)
Push-Pull follower crossovers

$V_{in}(t)$  $V_{out}(t)$

Eugeniy Mikhailov (W&M)  Electronics 1  Week 7
Push-Pull follower crossovers

\[ V_0, V_0 - 0.6V, -V_0, -V_0 + 0.6V \]

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

-10, -5, 0, 5, 10

Electronics 1
Week 7
Push-Pull follower crossovers
Push-Pull emitter follower improved
Push-Pull emitter follower improved
AC-coupled emitter follower

Design rules
maximum output swing
\[ V_{cc} = \frac{V_{cc}}{2} \]
disregarding \( V_{be} = 0.6 \) 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 \( I_{R1+R2} \gg I_b \) factor of 10 for a safe margin.
\[ I_{R1+R2} = 10 \times I_b = 10 \frac{I_e}{\beta} \]
thus \( R_1 = R_2 = R_e \frac{\beta}{10} \).
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 \( R_1 = R_2 = R_e\beta/10 \)
AC-coupled emitter follower: capacitors choice

From AC point of view

For unloaded filter $R_L \gg R_e$ factor of 10 for a safe margin

$R_L = 10R_e$
From AC point of view
- Input is RC high-pass
  - \( C = C_1 \)
  - \( R = R_1 \parallel R_2 \parallel \beta R_e \)
  - \( f_{3\text{db}} = \frac{1}{2\pi C_1 (R_1 \parallel R_2 \parallel \beta R_e)} \)
- with above rules \( R \approx R_1 / 2 \)

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

\[ V_{cc} \]
\[ V_{in} \]
\[ V_{out} \]
\[ C_1 \]
\[ R_1 \]
\[ R_2 \]
\[ \beta R_e \]
From AC point of view

- **Input is RC high-pass**
  - \( C = C_1 \)
  - \( R = R_1 \parallel R_2 \parallel \beta R_e \)
  - \( f_{3\text{db}} = \frac{1}{2\pi} \frac{1}{C_1(R_1 \parallel R_2 \parallel \beta R_e)} \)
    - with above rules \( R \approx R_1/2 \)

- **Output is also RC high-pass**
  - \( C = C_2 \)
  - \( R = R_L \)
  - \( f_{3\text{db}} = \frac{1}{2\pi} \frac{1}{C_2 R_L} \)
    - for unloaded filter \( R_L \gg R_e \)
    - factor of 10 for a safe margin
      - \( R_L = 10R_e \)
Common emitter (inverting) amplifier

\[ V_{\text{out}} = V_{\text{cc}} - \frac{R_c}{R_e} \left( V_{\text{in}} - 0.6 \, \text{V} \right) \]

\[ V_{\text{out}} = V_{\text{cc}} - \frac{R_c \left( V_{\text{in}} - 0.6 \, \text{V} \right)}{R_e} \]

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

\[ \text{attractive to put } R_e = 0 \]

Transistor model fails

Transistor emitter resistance 
\[ r_e = 25 \, \text{mV} / I_c \]
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 $r_e = 25\, mV/I_c$
  - gain $G = -R_c/r_e$
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
  $I_{R1} + R_2 = 10I_b = 10I_c / \beta$
- $R_2 / (R_1 + R_2) = \frac{V_b}{V_{cc}}$
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
    - $I_{R_1+R_2} = 10I_b = 10I_c/\beta$
    - $R_1 + R_2 = \frac{V_{cc}\beta}{(10I_c)}$
- $V_b = V_e + 0.6$
- $\frac{R_2}{(R_1 + R_2)} = \frac{V_b}{V_{cc}}$