ECE 342
Electronic Circuits

Lecture 25
Frequency Response of CG, CB, SF and EF

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Common Gate Amplifier

Substrate is not connected to the source ➔ must account for body effect

Drain signal current becomes

\[ i_D = \left( g_m v_{gs} + g_{mb} v_{bs} \right) \]

And since \( v_{gs} = v_{bs} \)

Body effect is fully accounted for by using \( g_m \rightarrow (g_m + g_{mb}) \)
Common Gate Amplifier

\[ i_i = (g_m + g_{mb})v_i + i_{ro} \]

with \( v_i = v_s \)

\[ i_{ro} = \frac{v_i - v_o}{r_o} = \frac{v_i - i_iR_L}{r_o} \Rightarrow i_i = \frac{\left( g_m + g_{mb} + \frac{1}{r_o} \right) v_i}{\left( 1 + \frac{R_L}{r_o} \right)} \]
IC - Common Gate Amplifier

\[ R_{in} \equiv \frac{v_i}{i_i} = \frac{r_o + R_L}{1 + (g_m + g_{mb}) r_o} \]

As \( r_o \to \infty \), \( R_{in} \to \frac{1}{g_m + g_{mb}} \)

If \( R_L = \infty \), \( R_i \to \infty \)

\[ v_o = \left( g_m + g_{mb} \right) r_o v_i + v_i \]

\[ A_{vo} = 1 + \left( g_m + g_{mb} \right) r_o \]
IC - Common Gate Amplifier

\[
R_{in} = \frac{r_o + R_L}{A_{vo}} \approx \frac{l}{g_m + g_{mb}} + \frac{R_L}{A_o}, \quad \text{where } A_o \approx \left( g_m + g_{mb} \right) r_o
\]

Taking \( r_o \) into account adds a component \( (R_L/A_o) \) to the input resistance.

The open-circuit voltage gain is:

\[
A_{vo} = I + \left( g_m + g_{mb} \right) r_o
\]

The voltage gain of the loaded CG amplifier is:

\[
G_v = A_{vo} \frac{R_L}{R_L + r_o + A_{vo} R_s}
\]
CG Output Resistance

\[ v_x = \left[ i_x + \left( g_m + g_{mb} \right) v \right] r_o + v \quad \text{with} \quad v = i_x R_s \]

\[ R_{out} = r_o + \left[ 1 + \left( g_m + g_{mb} \right) r_o \right] R_s \quad \text{or} \quad R_{out} = r_o + A_{vo} R_s \]
CG Amplifier as Current Buffer

\[ G_{is} = G_{vo} \frac{R_s}{R_{out}} \approx 1 \]

\( G_{is} \) is the short-circuit current gain
High-Frequency Response of CG

- Include $C_L$ to represent capacitance of load
- $C_{gd}$ is grounded
- No Miller effect
High-Frequency Response of CG

2 poles:

\[
    f_{P1} = \frac{1}{2\pi C_{gs} \left( R_s \parallel \frac{1}{g_m + g_{mb}} \right)}
\]

\[
    f_{P2} = \frac{1}{2\pi \left( C_{gd} + C_L \right) R_L}
\]

• \( f_{P2} \) is usually lower than \( f_{P1} \)
• \( f_{P2} \) can be dominant
• Both \( f_{P1} \) and \( f_{P2} \) are usually much higher than \( f_p \) in CS case
Common Base (CB) Amplifier
CB Amplifier

\[ R_{in} = \frac{r_o + R_L}{1 + \frac{r_o}{r_e} + \frac{R_L}{(\beta + 1)r_e}} \]

\[ A_{vo} = 1 + g_m r_o \]

\[ r_e = \frac{r_\pi}{\beta + 1} \]

\[ R_{out} = r_o + (1 + g_m r_o) R_e' \]

\[ R_e' = R_e \parallel r_\pi \]
High-Frequency Analysis of CB Amplifier

Exact analysis is too tedious ➔ approximate

From current gain analysis

\[ \omega_{in-3dB} = \frac{1}{C_\pi \left( \frac{R_S \parallel R_E}{R_E} + \frac{r_x}{1+\beta} \right) \parallel \frac{r_\pi}{1+\beta}} \]

\[ \omega_{out-3dB} = \frac{1}{C_\mu R_L} \]

The amplifier’s upper cutoff frequency will be the lower of these two poles.
Source Follower

\[ R'_L = R_L \parallel r_o \parallel \frac{1}{g_{mb}} \]

\[ v_o = g_m v_{gs} R'_L \]
Source Follower

\[ v_{gs} = v_i - v_o \]

\[ A_v \equiv \frac{v_o}{v_i} = \frac{g_m R_L'}{1 + g_m R_L'} \]

\[ A_{vo} = \frac{g_m r_o}{1 + (g_m + g_{mb}) r_o} \]

\[ A_{vo} = \frac{g_m}{g_m + g_{mb}} = \frac{1}{1 + \chi} \]
Source Follower – Output Resistance

\[ R_o = \frac{1}{g_m + g_{mb}} \parallel r_o \]

\[ R_o \approx 1/\left[ (1 + \chi) g_m \right] \]
Frequency Response of Source Follower

• Determine location of transmission zeros
• Use method of open-circuit time constants to estimate 3-dB frequency
Determination of Zeros

- Three capacitances form a continuous loop
- Two transmission zeros

\[ \omega_{Z_{\infty}} = \infty \quad \omega_{Z} = \frac{g_m}{C_{gs}} \quad \Rightarrow \quad f_Z \cong f_T \]
Determination of Poles

\[ R_{gs} = R_{sig} \]

\[ R_{gd} = \frac{R_{sig} + R'_{L}}{1 + g_m R'_{L}} \]

\[ R_{CL} = R_{L} \parallel R_{o} \]

\[ f_{H} = \frac{1}{2 \pi \tau_{H}} = \frac{1}{2 \pi} \left( C_{gd} R_{gd} + C_{gs} R_{gs} + C_{L} R_{CL} \right) \]

The source follower has excellent high-frequency response
Emitter Follower
Emitter Follower
Emitter Follower High-Frequency

Exact analysis is too tedious $\Rightarrow$ approximate

$$A_v'(s) = \frac{g_m R_L}{1 + g_m R_L} \frac{1 + \frac{sC_\pi}{g_m}}{1 + \left(1 + g_m R_E\right)}$$

$$\omega_{3dB} = \frac{1 + g_m R_E}{R_E C_\pi} \simeq \frac{g_m}{C_\pi + C_\mu} = \omega_T$$
High-Frequency Analysis of Emitter Follower

\[ g_m V_{\pi} + \frac{V_{\pi}}{r_\pi} + s_Z C_\pi = 0 \]

leads to:

\[ \frac{g_m + \left(1 / r_\pi\right)}{C_\pi} = -\frac{1}{C_\pi r_e} \Rightarrow \omega_Z = \frac{1}{C_\pi r_e} \]
High-Frequency Analysis of Emitter Follower

\[
R_{\mu} = R'_{\text{sig}} \parallel \left[ r_{\pi} + (\beta + 1) R'_L \right]
\]

\[
R_{\pi} = \frac{R'_{\text{sig}} + R'_L}{1 + \frac{R'_{\text{sig}}}{r_{\pi}} + \frac{R'_L}{r_{e}}}
\]

\[
f_H = \frac{1}{2\pi} \left[ C_{\mu} R_{\mu} + C_{\pi} R_{\pi} \right]
\]