Lecture 23

OUTLINE

• BJT Differential Amplifiers (cont’d)
  – Cascode differential amplifiers
  – Common-mode rejection
  – Differential pair with active load

• Reading: Chapter 10.4-10.6.1

Cascode Differential Pair

\[ R_{out} = \left[ 1 + g_{m3} \left( r_{\pi 3} \| r_{D3} \right) \right] r_{O3} + r_{D1} \| r_{\pi 3} \]

\[ R_{out} \approx g_{m3} \left( r_{\pi 3} \| r_{O3} \right) r_{O3} + r_{D1} \| r_{\pi 3} \]

Half circuit for ac analysis

\[ A_v = -g_m \frac{R_{out}}{g_{m1}} \approx -g_{m1} \left[ g_{m3} \left( r_{\pi 3} \| r_{O3} \right) r_{O3} + r_{D1} \| r_{\pi 3} \right] \]
Telescopic Cascode Differential Pair

\[ A_v \approx -g_{m1} \left[ g_{m3}r_{O3} \left( r_{O1} \parallel r_{\pi 3} \right) \right] \| \left[ g_{m5}r_{O5} \left( r_{O7} \parallel r_{\pi 5} \right) \right] \]

Example

\[ R_{op} = \left[ 1 + g_{m5} \left( r_{O7} \parallel r_{\pi 5} \parallel \frac{R_1}{2} \right) \right] \left( r_{O5} + r_{O7} \parallel r_{\pi 5} \parallel \frac{R_1}{2} \right) \]

\[ A_v = -g_{m1} \left[ g_{m3}r_{O3} \left( r_{O1} \parallel r_{\pi 3} \right) \right] \| R_{op} \]
Effect of Finite Tail Impedance

• If the tail current source is not ideal, then when an input common-mode voltage is applied, the currents in $Q_1$ and $Q_2$ and hence the output common-mode voltage will change.

\[
\frac{\Delta V_{\text{out,CM}}}{\Delta V_{\text{in,CM}}} = \left(\frac{R_s}{2}\right) = \frac{R_c}{2g_m} + R_{EE} = \frac{R_c}{g_m + 2R_{EE}} \quad \text{Common-mode gain should be small}
\]

Effect of Input CM Noise

Ideal Tail Current

• There is no effect of the input CM noise at the output.
Effect of Input CM Noise
Non-Ideal Tail Current

• The single-ended outputs are corrupted by the input CM noise.

\[ I_{TAIL} = I_{EE} + \frac{V_p}{R_E} \]

• Tail current, \( I_{TAIL} \), now changes with \( V_p \)
  and \( V_p \) is affected by \( V_{CM} \)

Comparison

• The differential output voltage signal is the same for both cases.

→ For small input CM noise, the differential pair is not affected.
CM to DM Conversion; gain $A_{CM-DM}$

- If finite tail impedance and asymmetry (e.g. in load resistance) are both present, then the differential output signal will contain a portion of the input common-mode signal.

\[
\Delta V_{CM} = \Delta V_{ex} + 2\Delta I_c R_{ex} = \frac{\Delta I_c}{g_m} + 2\Delta I_c R_{ex}
\]

\[
\Rightarrow \Delta I_c = \frac{\Delta V_{CM}}{2 R_{ex} g_m}
\]

\[
\Delta V_{out1} = -\Delta I_c R_C
\]

\[
\Delta V_{out2} = -\Delta I_c (R_C + \Delta R_C)
\]

\[
\Delta V_{out} = \Delta V_{out1} - \Delta V_{out2} = -\Delta I_c \Delta R_C
\]

\[
\left| \frac{\Delta V_{out}}{\Delta V_{CM}} \right| = \frac{\Delta R_C}{\left( \frac{1}{g_m} \right) + 2 R_{ee}}
\]
Common-Mode Rejection Ratio

- CMRR is the ratio of the wanted amplified differential input signal to the unwanted converted input common-mode noise that appears at the output.

\[
CMRR = \frac{A_{DM}}{A_{CM-DM}}
\]

Differential to Single-Ended Conversion

- Many circuits require a differential to single-ended conversion.

- This topology is not very good; its most critical drawback is supply noise corruption, since no common-mode cancellation mechanism exists. Also, we lose half of the voltage signal.
... A Better Alternative

- This circuit topology performs differential to single-ended conversion with no loss of gain.

\[
\frac{v_{out}}{v_{in1} - v_{in2}} = g_m \left( R_{o,NPN} \parallel R_{o,PNP} \right)
\]

Active Load

- With a current mirror as the load, the signal current produced by \( Q_3 \) can be replicated onto \( Q_4 \).
- This type of load is different from the conventional “static load” and is called an “active load.”
Differential Pair with Active Load

- The input differential pair decreases the current drawn from $R_L$ by $\Delta I$, and the active load pushes an extra $\Delta I$ into $R_L$ by current mirror action; these effects enhance each other.

Active Load vs. Static Load

- The load in the circuit on the left responds to the input signal and enhances the single-ended output, whereas the load in the circuit on the right does not.