Agenda

• Common-Mode Feedback Circuits
What is a common-mode feed-back correction circuit?

A common mode feed-back circuit is a circuit sensing the common-mode voltage, comparing it with a proper reference, and feeding back the correcting common-mode signal (both nodes of the fully-differential circuit) with the purpose to cancel the output common-mode current component, and to fix the dc outputs to the desired level.
Fully-Differential Filters: CMFB Principle

- A common-mode feedback loop must be used: Circuit must operate on the common-mode signals only!

- BASIC IDEA: CMFB is a circuit with very small impedance for the common-mode signals but transparent for the differential signals.

- Use a common-mode detector (eliminates the effect of differential signals and detect common-mode signals)

- Analyze the common-mode feedback loop: Large transconductance gain and enough phase margin

- Minimum power consumption

\[ v_{cm} = \frac{v_{01} + v_{02}}{2} \]
CMFB Principles: Analysis of the loop for common-mode signals only

- Analysis for common-mode noise; for instance noise due to power supplies:
  - \(i_{o1}=i_{o2}=i_{cm\_noise}\)

- The two outputs can be connected together for the analysis of the CMFB loop!

- **BASIC CONCEPTS:**
  - The common-mode input noise is converted into a common-mode voltage (common-mode voltage noise) by the common-mode transconductance of the CMFB = \(1/G_{m\_fb}\).

\[
Z_{cm} = \frac{1}{g_m}
\]

- \(v_{cm\_noise} = \frac{i_{cm\_noise}}{G_{m\_fb}}\)

  - **common-mode voltage variations**
    - \(v_{cm\_noise} = \frac{i_{cm\_noise}}{G_{m\_fb}} \uparrow\downarrow\)

  - **The larger** \(G_{m\_fb}\) **the smaller the effects of the common-mode noise!**
Fully-Differential Filters: CMFB

- CMFB Characteristics:
  - Transconductance gain = $g_m^2/2$ (no PMOS mirror in CMFB OTA)
  - Dominant pole at the output
  - At least 2 additional poles in the loop
  - $Z_{cm}$ reduces the OTA dc gain, affecting the differential gain
  - NOTE THAT $V_{cm}$ IS FORCED TO BE AROUND THE GROUND LEVEL.

- DC OFFSET VOLTAGE IS AROUND $2*I_{off}/g_{m2}$
Fully-Differential Filters: CMFB

- CMFB Characteristics:
  - DC Transconductance gain $= \frac{g_{m2}}{2}$
  - Loop gain (ignoring poles)
    $$\approx \left( \frac{g_{m2}}{2} \right) \left( \frac{1}{g_{m3}} \right) \left( 2 g_{m3} \left( \frac{Z_1}{2} \right) \right) = -\frac{g_{m2} Z_1}{2}$$
  - Dominant pole at the output
  - At least 2 additional poles in the loop

- DC OFFSET IS AROUND $2I_{off}/g_{m2}$
Fully-Differential Filters: CMFB Principles

Can be removed for CMFB analysis

- Common-mode stability: DC gain and most relevant poles
  - 1 pole at vcm (1/RC)
  - 1 pole at gate of M3 (g_{m3}/C_{P3})
  - 1 pole at the output (g_{01}/C_{1})

- \( \text{dc gain} = 0.5 \ g_{m2}R_{01} \)

- Be sure phase margin > 45°
Fig. 3 Common-mode feedback basic circuit concept. (a) Basic common-mode detector, (b) A CMOS CMFB Implementation.

Notice that the resistors $R$ reduce the differential gain!
**Fully-Differential Amplifiers: Common-mode pulse**

- **Differential Time Constant**: $5K \times 10P = 50\text{nsecs}$

- **A pulsed current is added to the tail current (common-mode pulse)**

- **This current must be absorbed by the CMFB**

- **Differential feedback does not reduce common-mode offsets and noise.**
Fully-Differential Amplifiers with CMFB
Differential input signals only

Seems to be that the system is working fine, isn’t it?
Fully-Differential Amplifiers with CMFB

Differential input signals + common-mode pulses

Single-ended outputs
Fully-Differential Amplifiers with CMFB
Differential input signals + common-mode pulses

Common-mode output

True pulse response of the CMFB
Evidently PM<45 degrees
GBW ~ 1/0.8us=1.2 MHz
DC-CMFB resistance ~ 10mV/Ioffset
The stability conditions are exactly the same for OTA’s and OPAMP’s:

- 1 pole at vcm (1/RC)
- 1 pole at gate of M3 ($g_m3/C_{P3}$)
- 1 pole at the output ($g_{o1}/C_1$)

In OPAMP’s you can use resistors as common-mode detector due to the presence of the output buffers

- dc gain = $0.5g_m2R_{o1}$
Isolated Common-Mode Sensing

- Source-Followers isolate the loading of the common-mode sensor resistors
- Need to have a replica source follower to set the appropriate reference level for the CMFB amplifier
Two Differential Pair CM Sensor

\[ I_{cms} = I_{20} + g_{m22}(V_{oc} - V_{CM}) \]

\[ G_{cmf} = g_{m22} \]
CMFB w/ Triode Devices in Tail Current Source

[Razavi]
Next Time

• Common-Mode Feedback Wrap-Up
• Variable Gain Amplifiers