

Note Title

The diagram illustrates a differential-mode two-stage CMOS op-amp and its half-circuit analysis.

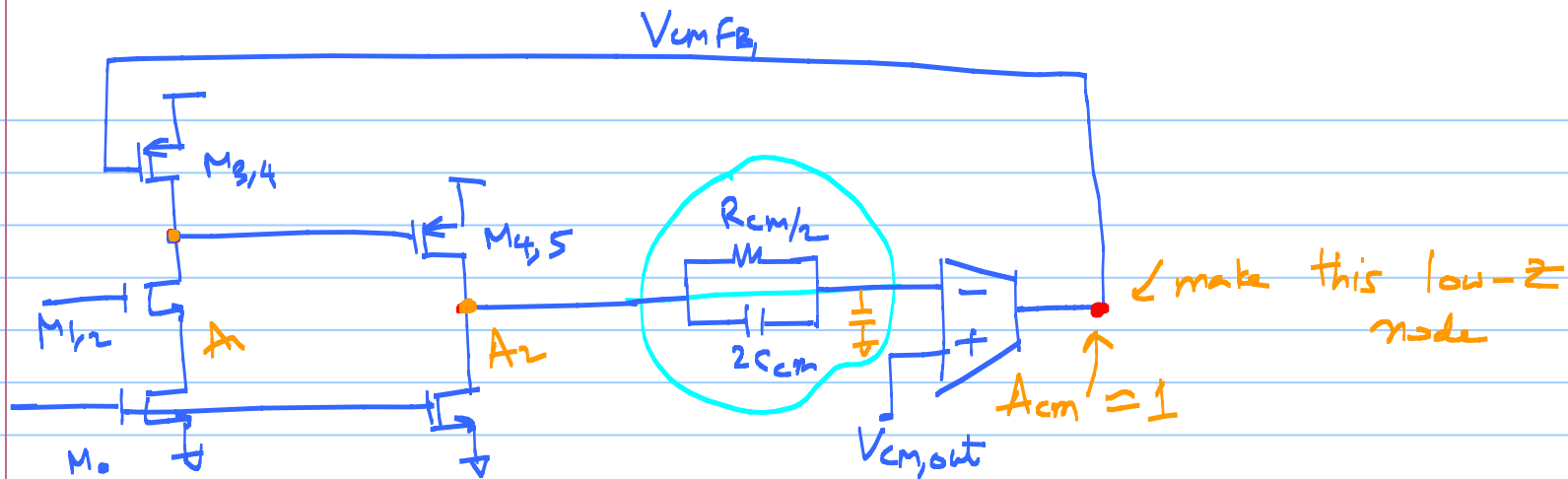
Op-amp Schematic:

- Input Stage:** A differential pair of NMOS transistors (M_1, M_2) with a Wilson current source load (M_3, M_4, M_5). The input is V_{in} , and the output is V_{op} . The Wilson current source is biased with V_{GS1} and V_{GS2} . The output current is I_2 .
- Output Stage:** A common-source stage with NMOS transistor M_6 and PMOS load M_7 . The input is V_{op} , and the output is $V_{cm, out}$. The output current is $2I_1$.
- Common-Mode Feedback (CMFB):** A feedback loop labeled $V_{cm FB}$ that senses the common-mode output voltage and provides a bias voltage V_{bias1} to the gates of M_1 and M_2 .

Differential-Mode Half-Circuit Analysis:

- The half-circuit is shown on the right, with input V_{in} and output $V_{cm, out}$.
- The input signal is split into two paths, each with a resistor R_a and a capacitor C_{cm} .
- The output is taken from the common-mode output node, which is connected to ground through a capacitor C_{cm} .
- The feedback loop $V_{cm FB}$ is shown as a pink line connecting the output node to the input node.

CM-equivalent circuit.



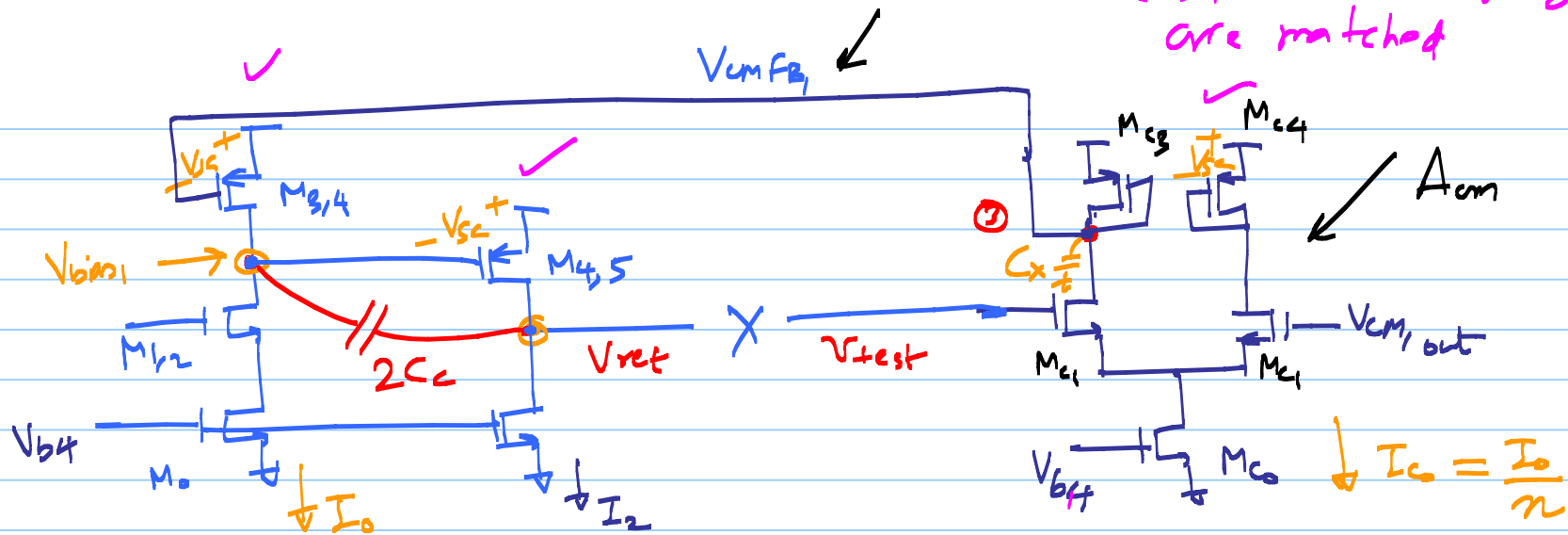
* 3 Low-freq poles

↳ need to compensate like a 3-stage opamp

OR

* Convert to two-pole system

• ensure current densities are matched



$$@ V_{cmFB}, \Rightarrow V_{ret} = \frac{A_{cm} g_{m3,4}}{s \cdot 2C_c} \cdot V_{test}$$

$$\frac{V_{ret}}{V_{test}} \Big|_{s=j\omega} = 1 \Rightarrow \omega_{u,cm} = \frac{A_{cm} g_{m3,4}}{2C_c}$$

$$\omega_{u,CM} = \frac{A_{cm} \cdot g_{m3,4}}{2C_c} = \frac{1}{2} \left(\frac{g_{mc1}}{g_{mc3}} \right) \cdot \left(\frac{g_{m3,4}}{2C_c} \right) \quad \leftarrow 2g_{m3}$$

$$= \frac{1}{2} \cdot \frac{g_{mc1}}{g_{mc3}} \cdot \frac{g_{m3}}{C_c}$$

$$= \frac{1}{2} \cdot g_{mc1} \cdot \left(\frac{n}{C_c} \right) \quad \because g_{mc1} = \frac{g_{m1}}{n}$$

$$= \frac{1}{2} \cdot \frac{g_{m1}}{C_c} \quad \text{if } M_{c1,c2} \text{ \& } M_1 \text{ \& } M_2 \text{ have the same current density}$$

$$\omega_{u,opamp} = \frac{g_{m1}}{C_c}$$

$$\boxed{\omega_{u,CM} = \frac{1}{2} \cdot \omega_{u,opamp}}$$

$$n \Rightarrow \frac{I_{co}}{I_o}$$

$$f_{3\omega} = \frac{g_{mcs}}{C_x}$$

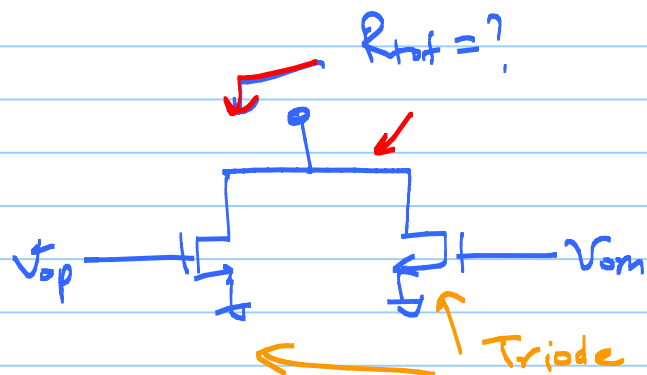
$$\rightarrow \underline{C_{gs_m3}} + C_{gs_{err-amp}}^n$$

for $n \uparrow$

$\Rightarrow g_{mcs} \downarrow$

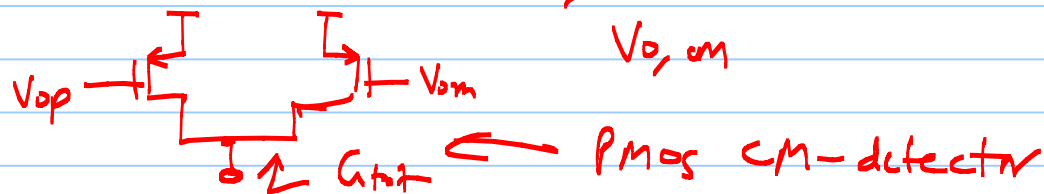
$f_{3\omega} \downarrow$

CMFB using Triode Devices



$$g_{tot} = 2\beta_n \left[\frac{V_{op} + V_{om}}{2} - V_{THN} \right]$$

$$g_{tot} = f(V_{o,cm})$$



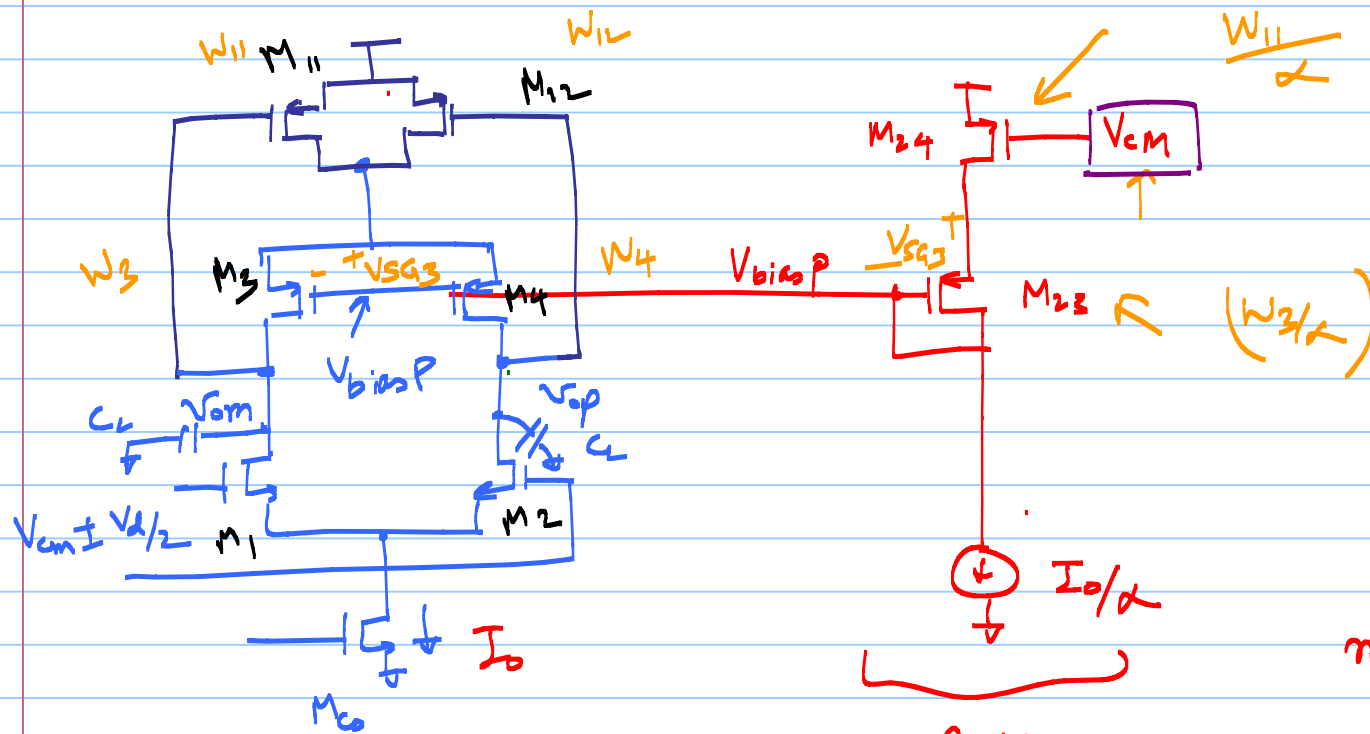
$$\begin{aligned} R_{tot} &= R_{on1} \parallel R_{on2} \\ &= \frac{1}{k\beta_n \frac{W}{L} (V_{op} - V_{THN})} \parallel \frac{1}{k\beta_n \frac{W}{L} (V_{om} - V_{THN})} \\ &= \frac{1}{k\beta_n \frac{W}{L} (V_{op} + V_{om} - 2V_{THN})} \\ &= \frac{1}{2\beta_n \left[\left(\frac{V_{op} + V_{om}}{2} \right) - V_{THN} \right]} \end{aligned}$$

$$R_S = R_{on1} \parallel R_{on2} = \frac{(V_{DD} - V_{bias1} - V_{SG3,4})}{2I_D} = \frac{1}{2k_{p2} \left(\frac{W}{L}\right)_{1,2} \left(\frac{V_{op} + V_{om}}{2} - V_{THP}\right)}$$

Solve

$$V_{o,cm} = \frac{V_{op} + V_{om}}{2} = \frac{I_D}{k_{p2} \left(\frac{W}{L}\right)_{3,4}} \cdot \frac{1}{V_{DD} - V_{bias1} - V_{SG3,4}} + V_{THP}$$

depends on $\uparrow$ device parameters



$$\left(\frac{V_{opt} + V_{cm}}{2} \right) \triangleq V_{cm}$$

* See Razavi Sec 9.6 for details

Replica
Biasing circuit

match the (W/I)

$$\frac{W_{11,12}}{I_0} = \frac{W_{34}}{I_0/\alpha}$$

Class-AB output stage

