\[ \frac{(V_{op} + V_{om})}{2} \]
Differential Half Circuit:

\[
\frac{(V_{op} + V_{sm})}{2}
\]

Assume loop is stable.

\[
\frac{V_c}{V_a} = g_m \left( \frac{r_o_1 || r_o_3 || R_{cm}}{r_o_2} \right)
\]
Common-mode Equivalent Circuit

\[
\frac{(V_{op} + V_{sm})}{2}
\]
CM Equivalent Circuit

Break the loop here

Error Amplifier
The overall circuit

$C_{GCM} = \frac{C_{GCM}}{2}$

$V_{CMFB}$

$V_{CM, ref}$

$V_{bias} = \frac{1}{M_0} \frac{V_I}{2}$

$V_{bias}$

$V_{CM}$

$M_1$, $M_2$

$M_{C2}$

$-C_{GCM}$ loads the differential pair.

We ignored this!
Let's place \( \frac{R_{cm}}{2} \) back into the CMFB circuit.

\[ V_{cm} \]

\[ V_{bias} \]

\[ V_{op} \]

\[ V_{op} + V_{cm} \]

\[ \frac{1}{C_1} \]

Excess delay in the loop

works at smaller frequencies

but at larger frequencies

\( \rightarrow \) phase lag \( \rightarrow \) delay
So we may have instability in the CMFB loop as the CM detector doesn't "work" at high frequencies.

\[ V_{op} \left( \frac{C_{cm}}{2C_{on} + C_1} \right) + V_{om} \left( \frac{C_{cm}}{2C_{cm} + C_1} \right) \]

\[ = \left( \frac{V_{op} + V_{om}}{2} \right) \left( \frac{2 \times C_{cm}}{2C_{cm} + C_1} \right) \]  

Parasitic cap causes attenuation but no phase lag at high frequencies.
Typical \( C_{cm} \leq C_1 \)

Either of these preferred

\[ V_{CMFB} \]

\[ V_{supply} \]
when the CMFB loop stabilizes

the node $V_{\text{cmfb}}$ goes from

$$(V_{DD} - V_{SG_{3,4}}|\frac{I_{C0}}{2})$$

to

$$(V_{DD} - V_{SG_{3,4}}|\frac{I_{C0}}{2})$$
\[
\left| \frac{V_{GQ} + V_{Com}}{2} - V_{CM_{ref}} \right| \rightarrow \frac{(V_{DD} - V_{SG_{c3,c4}})}{I_o} - \left( \frac{V_{DD} - V_{SG_{c3,c4}}}{I_o} \right)
\]

\text{loop-gain}

\text{system offset}