EE 435

Lecture 10:

Current-Mirror Op Amps
Properties of OTA-Based Circuits

• Can realize arbitrarily complex functions
• Circuits are often simpler than what can be obtained with Op Amp counterparts
• Inherently offer excellent high frequency performance
• Can be controlled with a dc voltage or current
• Often used open-loop rather than in a feedback configuration (circuit properties depend directly on $g_m$)
• Other high output impedance op amps can also serve as OTA
• Linearity is limited
• Signal swing may be limited but can be good too
• Circuit properties process and temperature dependent
Current Mirror Op Amp W/O CMFB

Can use higher output impedance current mirrors to decrease $g_{OEQ}$

$g_{OEQ} = g_{O6} + g_{O8}$

$g_{mEQ} = Mg_{m1}$

$A_{vo} = -\frac{M \cdot g_{m1}}{g_{O6} + g_{O8}}$

$SR = \frac{MI_T}{C_L}$
Fully Differential Current Mirror Op Amp with Improved Slew Rate

Need CMFB circuit and requires modest circuit modification to provide CMFB insertion point
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Fully Differential Current Mirror Op Amp with Improved Slew Rate

\[ SR = \frac{MI_T}{C_L} \]

\[ SR_{CMOpAmp} = \frac{M \cdot I_T}{2C_L} \]

Improved a factor of 2!

but ...

Need CMFB circuit and requires modest circuit modification to provide CMFB insertion point
Fully Differential Current Mirror Op Amp with Improved Slew Rate

\[
SR = \frac{MI_T}{C_L}
\]

\[
SR_{CM\text{Op Amp}} = \frac{M \cdot I_T}{2C_L}
\]

Improved a factor of 2!

But …

\[
P_{CM\text{Op Amp}} = V_{DD} I_T (1 + M)
\]

\[
P = V_{DD} I_T (1 + 2M)
\]

\[
SR_{CM\text{Op Amp}} = \left( \frac{P}{V_{DD} C_L} \right) \left[ \frac{M}{2[1+M]} \right]
\]

\[
SR = \left( \frac{P}{V_{DD} C_L} \right) \left[ \frac{M}{1 + 2M} \right]
\]

SR actually not as good for the “improved SR circuit”
Comparison of Current-Mirror Op Amps with Previous Structures

Does the simple mirror gain really provide an “almost free” gain enhancement?

\[ A_{vo} = -\frac{M \cdot g_{m1}}{2} \frac{g_{o6} + g_{o8}}{g_{o6} + g_{o8}} \]

\[ M = \frac{W_6 L_4}{W_4 L_6} \]
Reference Op Amp

Consider single-ended output performance:

\[
A(s) = \frac{g_{m1}}{2 \left( sC_L + g_{o1} + g_{o3} \right)}
\]

\[
A_{v0} = \frac{1}{2} \frac{g_{m1}}{g_{o1} + g_{o3}}
\]

\[
A_{v0} = \left[ \frac{1}{\lambda_1 + \lambda_3} \right] \left[ \frac{1}{V_{EB1}} \right]
\]

\[
G_B = \frac{g_{m1}}{2C_L}
\]

\[
G_B = \left( \frac{P}{2V_{DD}C_L} \right) \cdot \left[ \frac{1}{V_{EB1}} \right]
\]

\[
S_R = \frac{I_T}{2C_L}
\]

\[
S_R = \frac{P}{2V_{DD}C_L}
\]
Comparison of Current-Mirror Op Amps with Previous Structures

Does the simple mirror gain really provide an “almost free” gain enhancement?

\[ A_{vo} = - \frac{M \cdot g_{m1}}{2} \frac{2}{g_{o6} + g_{o8}} \]

\[ M = \frac{W_6 L_4}{W_4 L_6} \]

\[ M = \frac{g_{m6}}{g_{m4}} \]

\[ A_{vo} = - \frac{g_{m6} \cdot g_{m1}}{2} \frac{2}{g_{o6} + g_{o8}} \]

Gain Enhancement Potential Less Apparent but still Improved by \( g_{m6}/g_{m4} \) ratio
Comparison of Current-Mirror Op Amps with Previous Structures

Does the simple mirror gain really provide an “almost free” gain enhancement?

\[ A_{VO} = - \frac{M \cdot g_{m1}}{2} \frac{2}{g_{o6} + g_{o8}} \]

Consider how the gain appears in the practical parameter domain:

\[ A_{V0} = \frac{1}{2} \left( 2 \frac{I_1}{M} \right) \frac{\lambda_{M6} + \lambda_{M8}}{\lambda_{M6}} M \frac{I_1}{2} = \frac{1}{2 \lambda V_{EB1}} \]

This is exactly the same as was obtained for the simple differential amplifier! For a given \( V_{EB1} \), there is NO gain enhancement!
Comparison of Current-Mirror Op Amps with Previous Structures

How does the GB power efficiency compare with previous amplifiers?

\[ GB = \frac{g_{mEQ}}{C_L} = \frac{M g_{m1}}{2} = \frac{M I_T}{2V_{EB1} C_L} \]

\[ P = V_{DD} I_T (1 + M) \]

GB efficiency decreased for small M!!
Comparison of Current-Mirror Op Amps with Previous Structures

How does the SR compare with previous amplifiers?

\[
\begin{align*}
\text{SR}_{\text{Ref Op Amp}} &= \frac{I_T}{2C_L} \\
\text{SR} &= \frac{M \cdot I_T}{2C_L} \\
\text{SR Improved by factor of M!}
\end{align*}
\]

but ...

\[
\begin{align*}
P &= V_{\text{DD}} I_T (1 + M) \\
\text{SR} &= \frac{P}{2V_{\text{DD}} C_L} \left[ \frac{M}{1 + M} \right] \\
\text{SR}_{\text{Ref Op Amp}} &= \frac{P}{2V_{\text{DD}} C_L}
\end{align*}
\]

SR Really Less than for Ref Op Amp!!
Comparison of Current-Mirror Op Amps with Previous Structures

How does the Current Mirror Op Amp really compare with previous amplifiers or with reference amplifier?

Perceived improvements may appear to be very significant

Actual performance is not as good in almost every respect!
Current-Mirror Op Amps – Another Perspective!

Differential Half-Circuit
Current-Mirror Op Amps – Another Perspective!

Differential Half-Circuit

Cascade of n-channel common source amplifier with p-channel common-source amplifier!
Current-Mirror Op Amps – Another Perspective!

Differential Half-Circuit

From Current Mirror Analysis:

\[ A_v = -\frac{1}{2} \left( \frac{g_{m2}}{g_{m4}} \right) \left( \frac{g_{m6}}{g_{o6} + g_{o8}} \right) \]

\[ A_{vo} = -\frac{M \cdot g_{m1}}{2} = -\frac{g_{m6} \cdot g_{m1}}{g_{o6} + g_{o8}} \]

Cascade of n-channel common source amplifier with p-channel common-source amplifier!
Current-Mirror Op Amps – Another Perspective!
Differential Half-Circuit

Are there stability issues or concerns?

\[ p_2 \approx -\frac{g_{o6} + g_{o8}}{C_2} \]

\[ p_1 \approx -\frac{g_{m4}}{C_1} \]

\[ |p_1| >> |p_2| \]

No stability problems provided \( C_2 \) is sufficiently large!