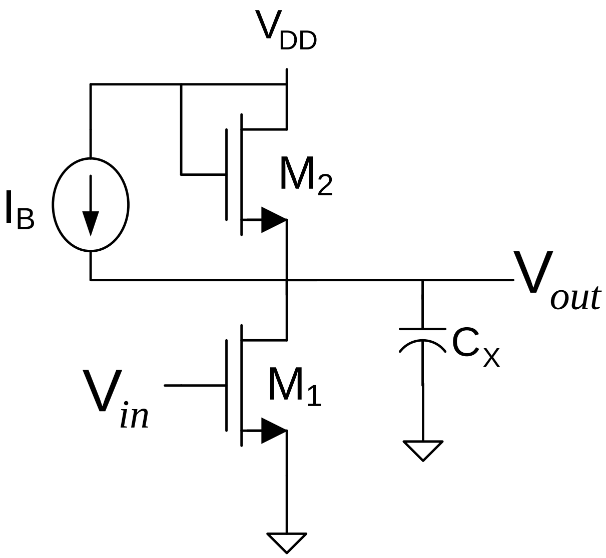
EE 508

Lecture 37

High Frequency Filters

A lossy integrator stage

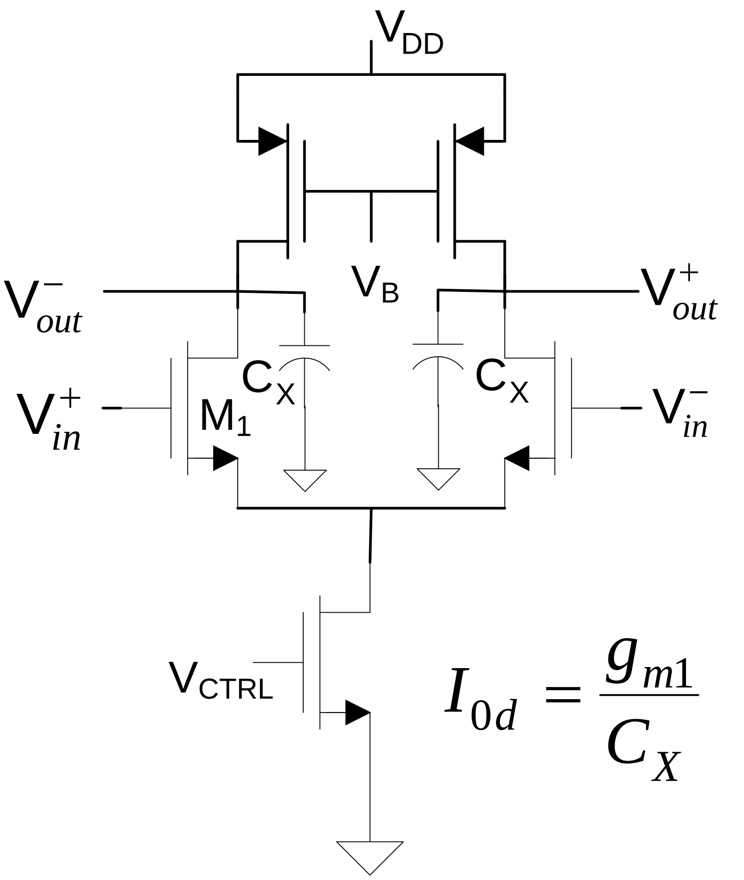


$$I(s) = \frac{-g_{m1}/C_X}{s+g_{m2}/C_X}$$

$$I_0 = g_{m1}/C_X$$

$$\alpha_L = g_{m2}/C_X$$

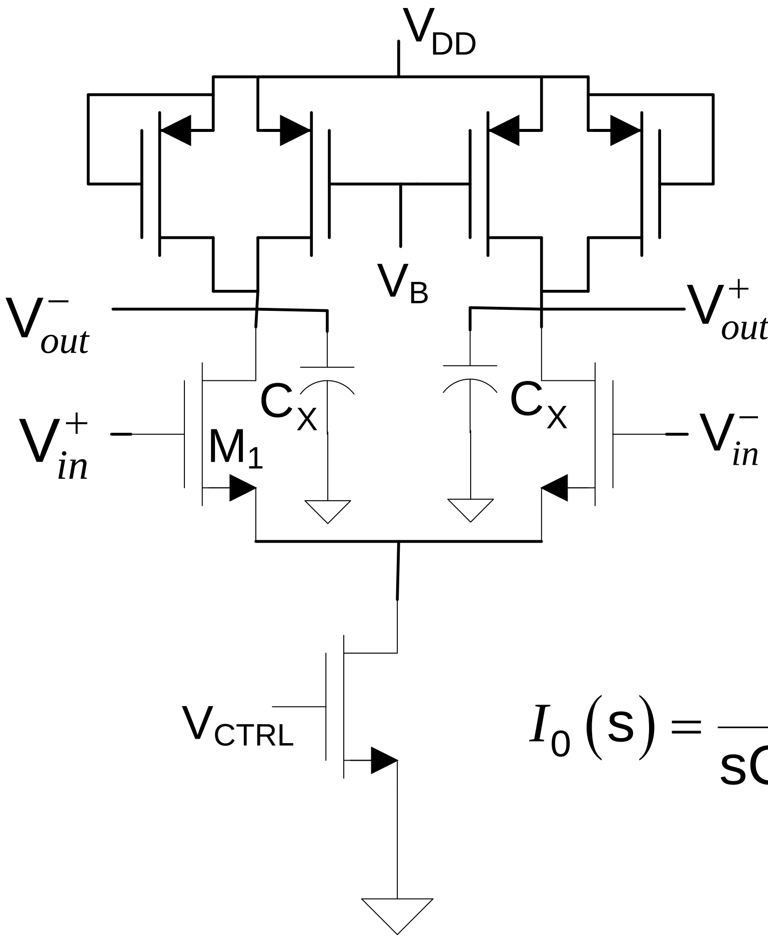
A fully-differential voltage-controlled integrator stage



$$I_{0d} = \frac{g_{m1}}{C_X}$$

Will need CMFB circuit

A fully-differential voltage-controlled integrator stage with loss



$$I_0(s) = \frac{g_{m1}}{sC_X + g_{m3}}$$

Will need CMFB circuit

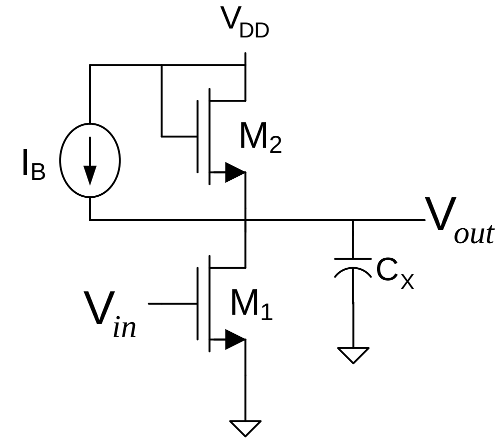
Example:

Using the single-stage lossy integrator, design the integrator to meet a given ω_0 and Q requirement

Recall:

$$I_0 = \frac{\omega_0}{(\sin\theta)2Q}\sqrt{4Q^2-1} \quad (1)$$

$$\alpha_L = \frac{\omega_0}{2Q} + \frac{\omega_0}{2Q(\tan\theta)}\sqrt{4Q^2-1} \quad (2)$$



Substituting for I_0 and α_L we obtain:

$$I_0 = g_{m1}/C_X$$

$$\alpha_L = g_{m2}/C_X$$

$$\frac{g_{m1}}{C_X} = \frac{\omega_0}{(\sin\theta)2Q}\sqrt{4Q^2-1} \quad (3)$$

$$\frac{g_{m2}}{C_X} = \frac{\omega_0}{2Q} + \frac{\omega_0}{2Q(\tan\theta)}\sqrt{4Q^2-1} \quad (4)$$

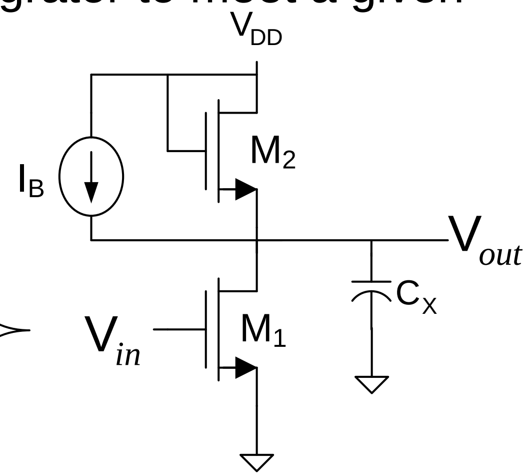
Example:

Using the single-stage lossy integrator, design the integrator to meet a given ω_0 and Q requirement

Expressing g_{m1} and g_{m2} in terms of design parameters:

$$\frac{\mu C_{OX} W_1 V_{EB1}}{L_1 C_X} = \frac{\omega_0}{(\sin\theta) 2Q}\sqrt{4Q^2 - 1} \qquad (5)$$

$$\frac{\mu C_{OX} W_2 V_{EB2}}{L_2 C_X} = \frac{\omega_0}{2Q} + \frac{\omega_0}{2Q(\tan\theta)}\sqrt{4Q^2 - 1} \qquad (6)$$



$$I_0 = g_{m1}/C_X$$

$$\alpha_L = g_{m2}/C_X$$

If we assume I_B=0, equating drain currents obtain:

$$V_{EB2} = V_{EB1}\sqrt{\frac{W_1 L_2}{W_2 L_1}} \qquad (7)$$

Thus the previous two expressions can be rewritten as :

$$\frac{\mu C_{OX} V_{EB1}}{C_X}\left[\frac{W_1}{L_1}\right] = \frac{\omega_0}{(\sin\theta) 2Q}\sqrt{4Q^2 - 1} \qquad (8)$$

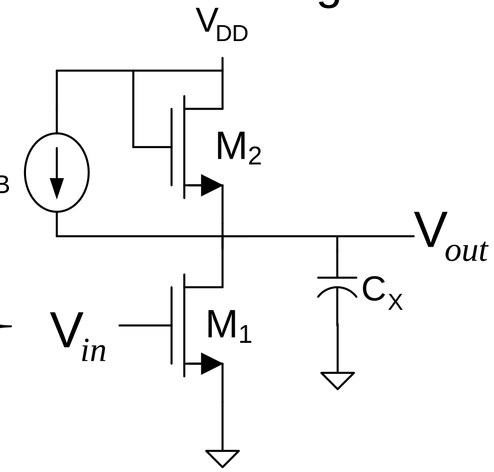
$$\frac{\mu C_{OX} V_{EB1}}{C_X}\left[\frac{W_1 W_2}{L_1 L_2}\right] = \frac{\omega_0}{2Q} + \frac{\omega_0}{2Q(\tan\theta)}\sqrt{4Q^2 - 1} \qquad (9)$$

Example:

Using the single-stage lossy integrator, design the integrator to meet a given ω_0 and Q requirement

$$\frac{\mu C_{OX} V_{EB1}}{C_X}\left[\frac{W_1}{L_1}\right]=\frac{\omega_0}{(\sin\theta)2Q}\sqrt{4Q^2\text{-}1} \qquad (8)$$

$$\frac{\mu C_{OX} V_{EB1}}{C_X}\left[\frac{W_1 W_2}{L_1 L_2}\right]=\frac{\omega_0}{2Q}+\frac{\omega_0}{2Q(\tan\theta)}\sqrt{4Q^2\text{-}1} \qquad (9)$$



$$I_0 = g_{m1}/C_X$$

$$\alpha_L = g_{m2}/C_X$$

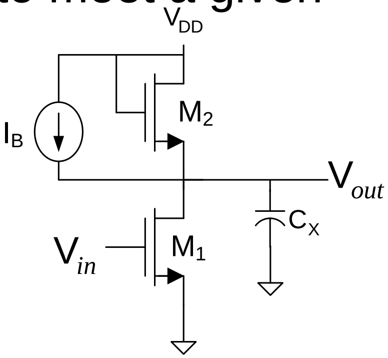
Taking the ratio of these two equations we obtain:

$$\frac{W_2}{L_2}=\frac{\sin\theta+\cos\theta\sqrt{4Q^2\text{-}1}}{\sqrt{4Q^2\text{-}1}} \qquad (10)$$

Observe that the pole Q is determined by the dimensions of the lossy device !

Example:

Using the single-stage lossy integrator, design the integrator to meet a given ω_0 and Q requirement



$$\frac{\mu C_{OX} V_{EB1}}{C_X}\left[\frac{W_1}{L_1}\right]=\frac{\omega_0}{(\sin\theta)2Q}\sqrt{4Q^2\text{-}1} \qquad (8)$$

$$\frac{W_2}{L_2}=\frac{\sin\theta+\cos\theta\sqrt{4Q^2\text{-}1}}{\sqrt{4Q^2\text{-}1}} \qquad (10)$$

Still must obtain W_1/L_1, V_{EB1}, and C_X from either of these equations

Although it appears that there might be 3 degrees of freedom left and only one constraint (one of these equations), if these integrators are connected in a loop, the operating point (Q-point) will be the same for all stages and will be that value where $V_{out}=V_{in}$. So, this adds a second constraint.

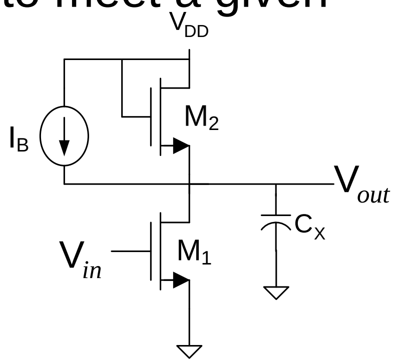
Setting $V_{out}=V_{in}$, and assuming $V_{T1}=V_{T2}$, we obtain from KVL

$$V_{DD}=V_{EB1}+V_{EB2}+2V_T \qquad (11)$$

But V_{EB1} and V_{EB2} are also related in (7)

Example:

Using the single-stage lossy integrator, design the integrator to meet a given ω_0 and Q requirement



$$\frac{\mu C_{OX} V_{EB1}}{C_X}\left[\frac{W_1}{L_1}\right]=\frac{\omega_0}{(\sin\theta)2Q}\sqrt{4Q^2\text{-}1} \qquad (8)$$

$$\frac{W_2}{L_2}=\frac{\sin\theta+\cos\theta\sqrt{4Q^2\text{-}1}}{\sqrt{4Q^2\text{-}1}} \qquad (10)$$

Still must obtain W_1/L_1, V_{EB1}, and C_X from either of these equations

$$V_{DD}=V_{EB1}+V_{EB2}+2V_T \qquad (11)$$

$$V_{EB2}=V_{EB1}\sqrt{\frac{W_1L_2}{W_2L_1}} \qquad (7)$$

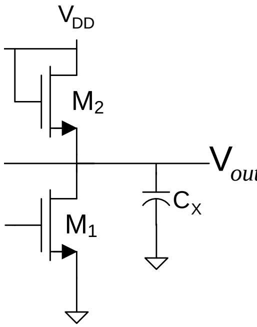
$$\rightarrow \quad V_{EB1}=\frac{V_{DD}\text{-}2V_T}{1+\sqrt{\frac{W_2L_1}{W_1L_2}}} \qquad (12)$$

Substituting (10) into (12) and then into (8) we obtain

$$\frac{\mu C_{OX}}{C_X}\left[\frac{W_1}{L_1}\right]\left(\frac{V_{DD}-2V_T}{1+\sqrt{\left(\frac{W_1}{L_1}\right)^{-1}\left(\frac{\sin\theta+\cos\theta\sqrt{4Q^2\text{-}1}}{\sqrt{4Q^2\text{-}1}}\right)}}\right)=\frac{\omega_0}{(\sin\theta)2Q}\sqrt{4Q^2\text{-}1} \qquad (13)$$

Example:

Using the single-stage loss … iven ω_0 and Q requirement



$$\frac{W_2}{L_2}=\frac{\sin\theta+\cos\theta\sqrt{4Q^2\text{-}1}}{\sqrt{4Q^2\text{-}1}}$$

$$\frac{\mu C_{OX}}{C_X}\left[\frac{W_1}{L_1}\right]\left(\frac{V_{DD}-2V_T}{1+\sqrt{\left(\frac{W_1}{L_1}\right)^{-1}\left(\frac{\sin\theta+\text{co}\ldots}{\sqrt{4Q^2\text{-}1}}\right)}}\right)$$

There is still one degree of freedom remaining. Can either pick W_1/L_1 and solve for C_X or pick C_X and solve for W_1/L_1.

Explicit expression for W_1/L_1 not available

Tradeoffs between C_X and W_1/L_1 will often be made

Since $V_{OUTQ}=V_T+V_{EB1}$, it may be preferred to pick V_{EB1}, then solve (12) for W_1/L_1 and then solve (13) for C_X

Adding I_B will provide one additional degree of freedom and will relax the relationship between V_{OUTQ} and W_1/L_1 since (7) will be modified

High Frequency Filter Design

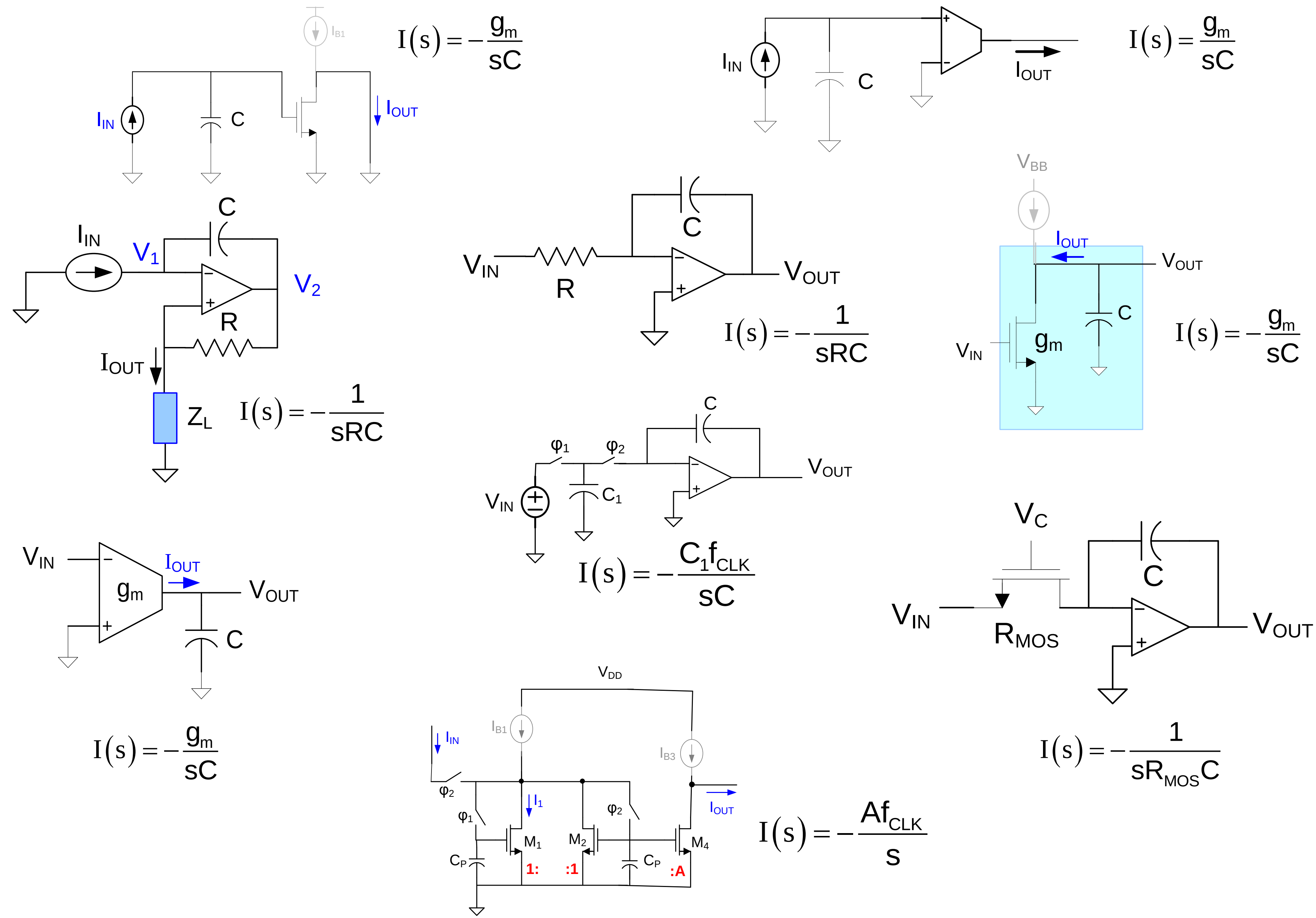
- Architecture selection is critical
- At high frequencies, simplicity of the structures is important
- Parasitic capacitances and their relationship to the time constants that can be achieved provide the ultimate limit on speed
- Will limit discussions to "inductorless" structures

High Frequency Filter Design

Following two methods will provide highest frequency of operation

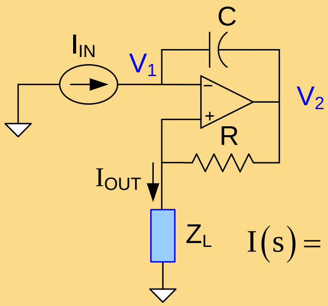
- Degenerate VCOs
- Simple high-frequency integrator-based filters

Integrator Architecture Selection

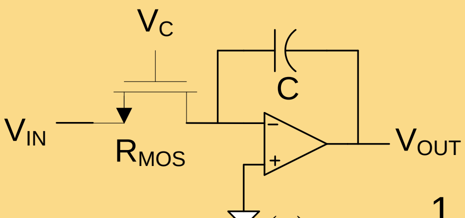


Integrators for High-Speed Operation

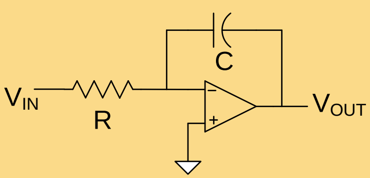
Slow



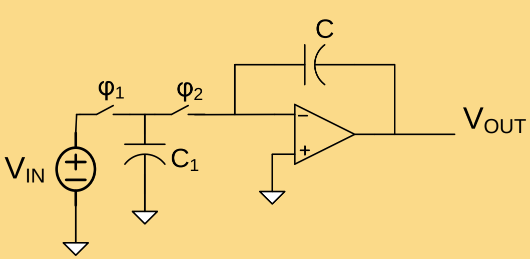
$$I(s) = -\frac{1}{sRC}$$



$$I(s) = -\frac{1}{sR_{MOS}C}$$

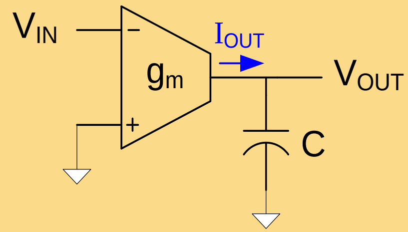


$$I(s) = -\frac{1}{sRC}$$

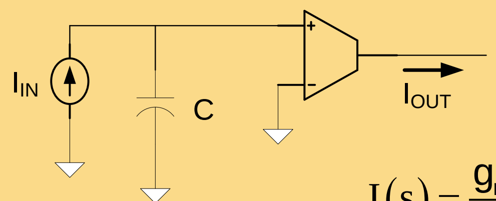


$$I(s) = -\frac{C_1 f_{CLK}}{sC}$$

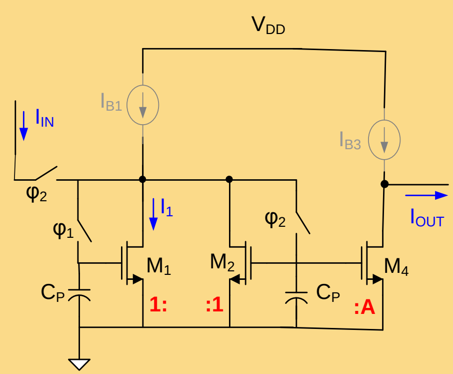
Reasonably Fast



$$I(s) = -\frac{g_m}{sC}$$

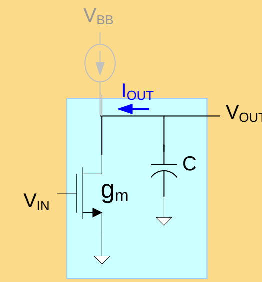


$$I(s) = \frac{g_m}{sC}$$

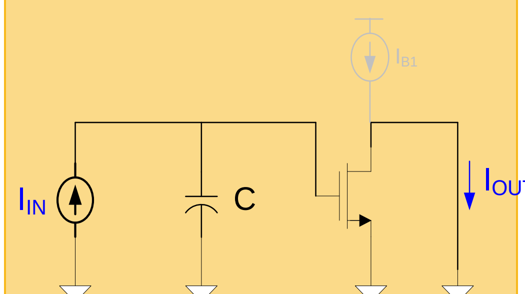


$$I(s) = -\frac{Af_{CLK}}{s}$$

Very Fast



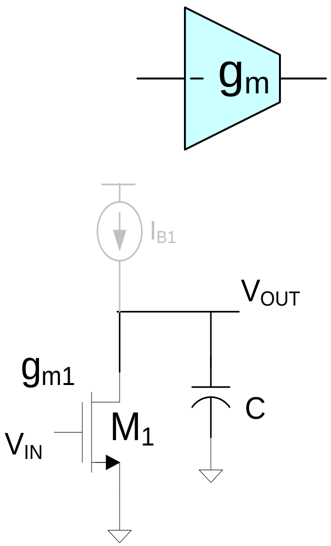
$$I(s) = -\frac{g_m}{sC}$$



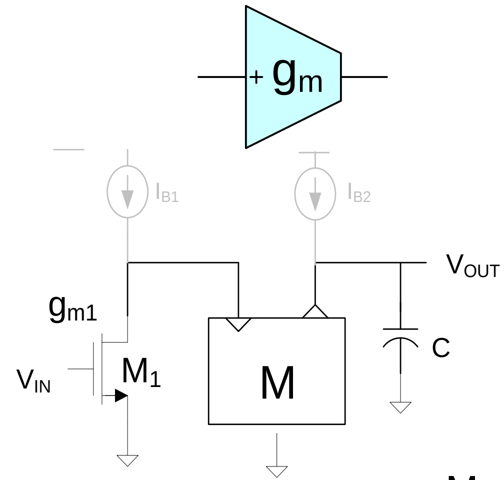
$$I(s) = -\frac{g_m}{sC}$$

Single-ended High-Frequency TA Integrators

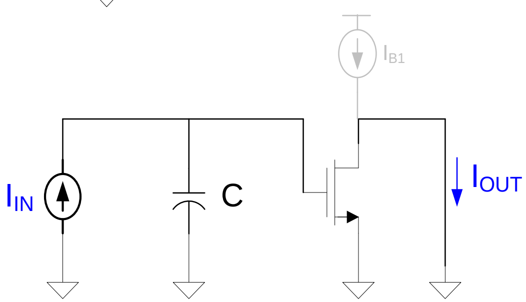
Structures of choice for highest-frequency of operation



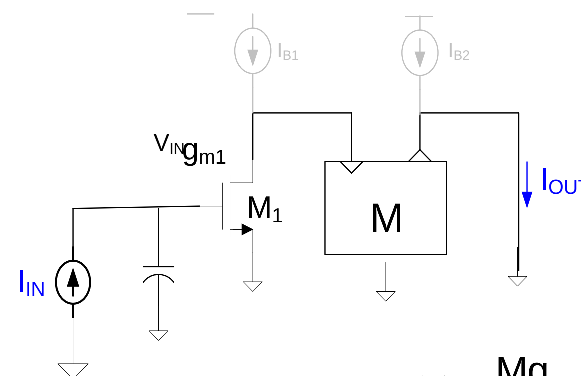
$$I(s) = -\frac{g_m}{sC}$$



$$I(s) = \frac{Mg_m}{sC}$$



$$I(s) = -\frac{g_m}{sC}$$

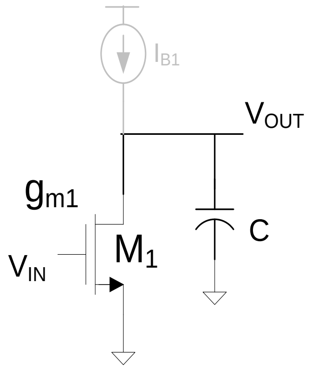


$$I(s) = \frac{Mg_m}{sC}$$

Some authors focus on voltage mode and others on current mode

But overall structures and performance appears to be identical

Single-ended High-Frequency TA Integrators



$$I(s) = -\frac{g_m}{sC}$$

$$I_0 = \frac{g_m}{C}$$

Recall: ω_0 for integrator-based filters generally port ional to I_0

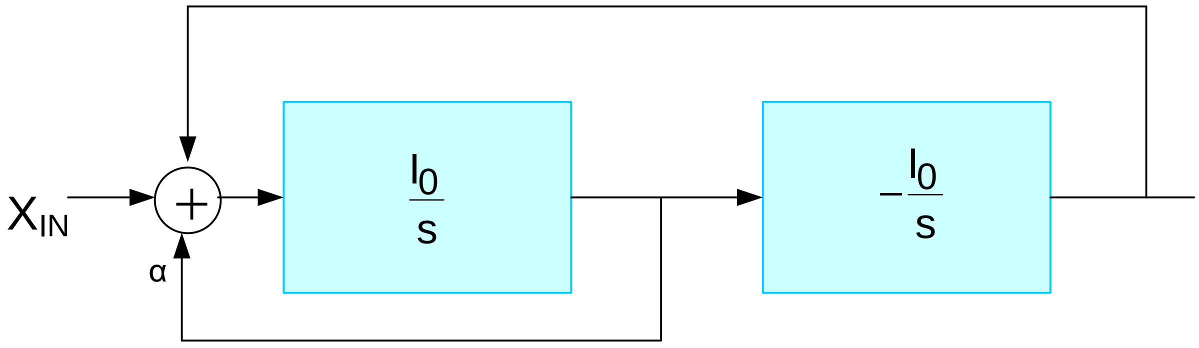
How high can I_0 be?

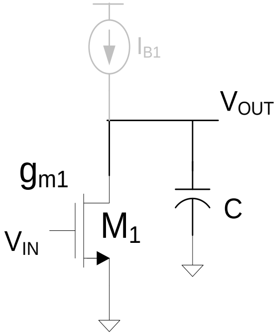
$$I_0 = \frac{\mu C_{OX} W / L V_{EB}}{C}$$

Looks like we can make I_0 as large as we want by making V_{EB} large, C small, L small, and W large

Single-ended High-Frequency TA Integrators

How high can I_0 be?

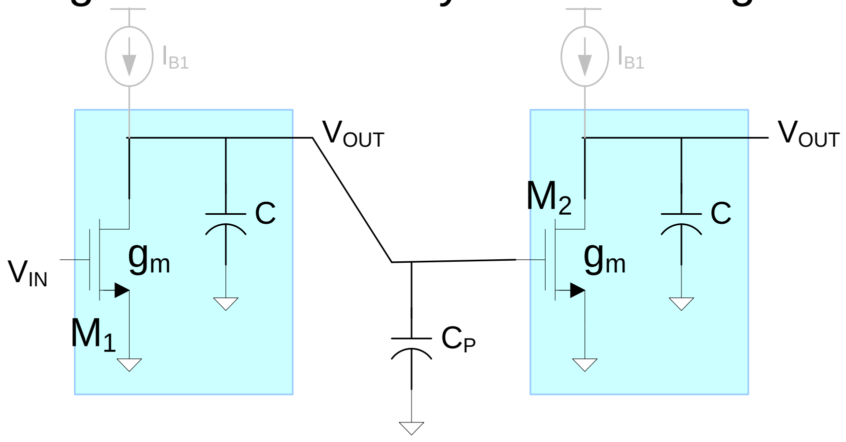




Consider a typical filter – the two integrator loop

$$I_0 = \frac{\mu C_{OX} W / L V_{EB}}{C}$$

Integrator is loaded by another integrator!



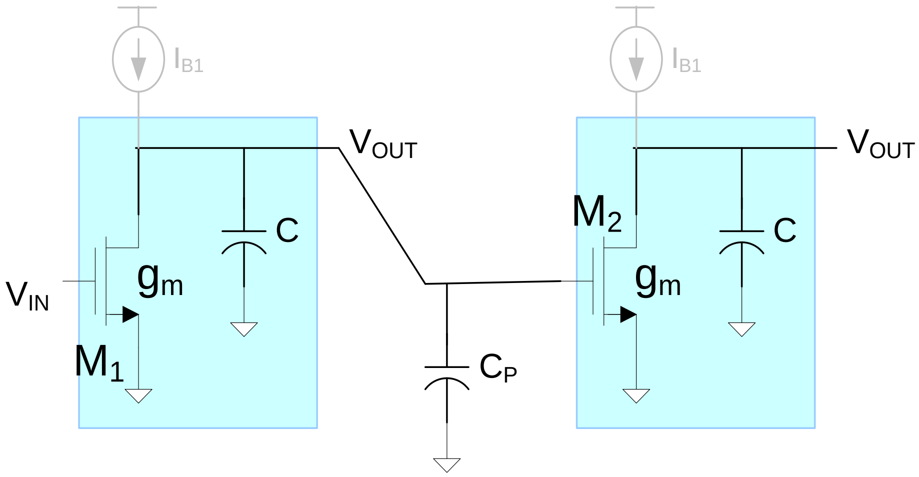
$$I_0 = \frac{\mu C_{OX} W_1 / L_1 V_{EB1}}{C + C_P + C_{OX} W_2 L_2}$$

Even if C goes to 0, I_0 is limited!

C_P is the parasitic capacitances on the output node

Single-ended High-Frequency TA Integrators

How high can I_0 be?



$$I_0 = \frac{\mu C_{OX} W_1 / L_1 V_{EB1}}{C + C_P + C_{OX} W_2 L_2}$$

Setting C to 0 and assuming C_p is small,

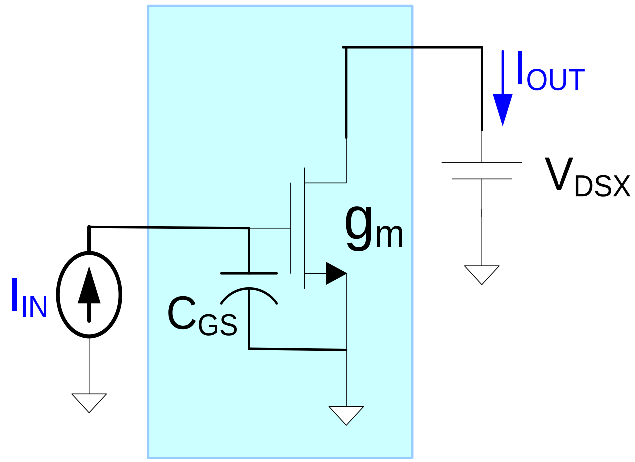
$$I_0 = \frac{\mu C_{OX} W_1 / L_1 V_{EB1}}{C_{OX} W_2 L_2}$$

$$I_0 = \frac{\mu W_1 V_{EB1}}{W_2 L_1 L_2}$$

Assuming the integrator stages are identical, it follows that

$$I_0 = \frac{\mu V_{EB1}}{L_{min}^2}$$

Transition (transit) frequency (f_T) of a process



The transit frequency of a process is the frequency where the short-circuit current gain of the common-source configuration drops to 1.

$$i_{OUT} = g_m v_{gs}$$

$$i_{IN} \bullet \frac{1}{sC_{GS}} = v_{gs}$$

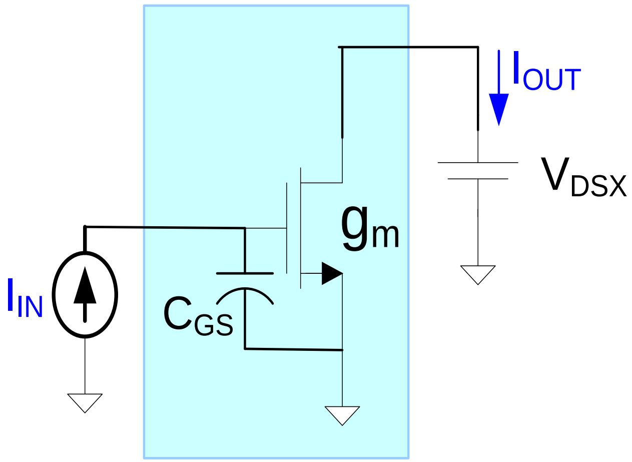
$$\frac{i_{OUT}}{i_{IN}} = \frac{g_m}{sC_{GS}}$$

$$1 = \frac{g_m}{C_{GS}\omega_T}$$

$$\omega_T = \frac{g_m}{C_{GS}} = \frac{\left(\mu C_{OX}\frac{W}{L}V_{EB}\right)}{C_{OX}WL} = \frac{\mu V_{EB}}{L^2}$$

$$\omega_T = \frac{\mu V_{EB}}{L_{min}^2}$$

Transition (transit) frequency (f_T) of a process



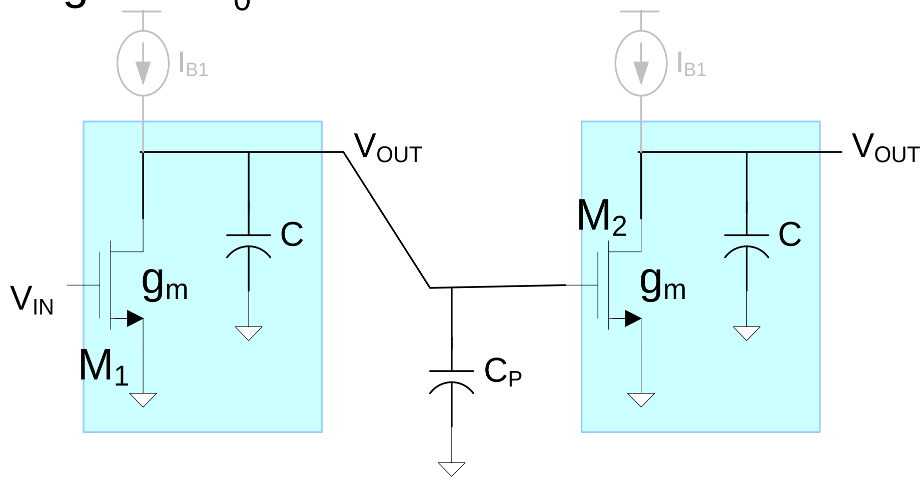
The transit frequency of a process is the frequency where the short-circuit current gain of the common-source configuration drops to 1.

$$\omega_T = \frac{\mu V_{EB}}{L_{min}^2}$$

This is dependent upon V_{EB}
Does not include effects of diffusion capacitances or overlap capacitances
f_{MAX} is another figure that characterizes the speed of a process

Single-ended High-Frequency TA Integrators

How high can I_0 be?



$$I_{0M} = \frac{\mu V_{EB1}}{L_{min}^2}$$

$$I_{0M} = \omega_T$$

Speed of operation increases with V_{EB1}

V_{EB1} is limited by signal swing requirements and V_{DD}

Signal Swing:

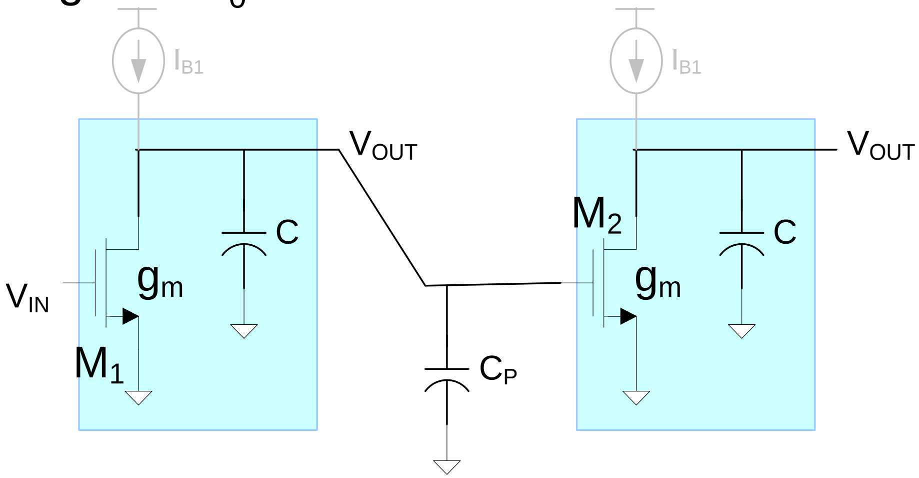
$$V_{SW\text{-}0P} \simeq \min\{V_{DD} - V_{OQ}, V_{OQ} - (V_T + 100mV)\}$$

$$V_{OQ} = V_T + V_{EB}$$

$$V_{SW\text{-}0P} \simeq \min\{V_{DD} - V_T - V_{EB}, V_T + V_{EB} - (V_T + 100mV)\}$$

Single-ended High-Frequency TA Integrators

How high can I_0 be?



$$I_{0M} = \frac{\mu V_{EB1}}{L_{min}^2}$$

$$I_{0M} = \omega_T$$

Speed of operation increases with V_{EB}

V_{EB} is limited by signal swing requirements and V_{DD}

Signal Swing:

$$V_{DD} - V_T - V_{EB} = V_T + V_{EB} - (V_T + 100mV)$$

$$V_{EB} = \frac{V_{DD} + 100mV - V_T}{2}$$

$$I_{OMAX} \simeq \frac{\mu\left(V_{DD} + 100mV - V_T\right)}{2L_{min}^2}$$