- **FULLY CURRENT-MODE**

Input Signal: Current

Output Signal: Current

Basic Building Blocks are:

Inverting Integrators

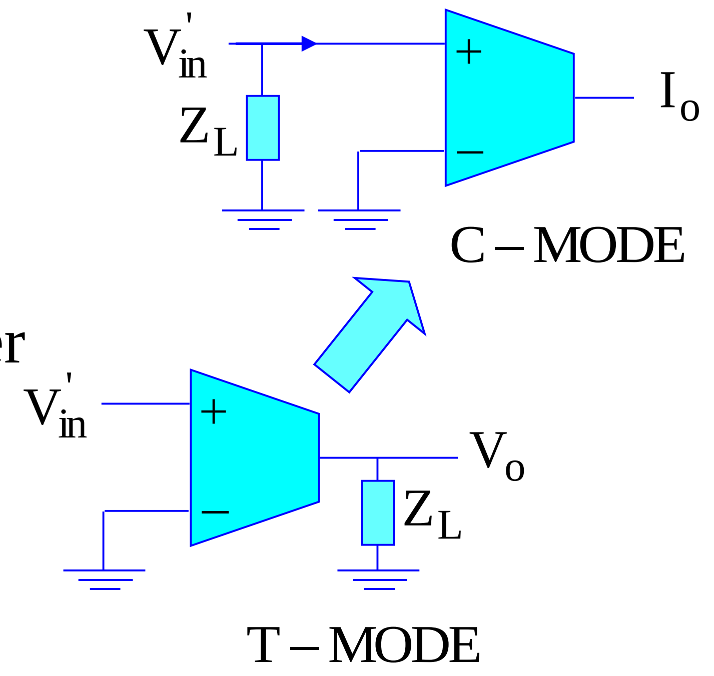
Inverting (Current Amplifiers)

Primitive Circuit Implementations:

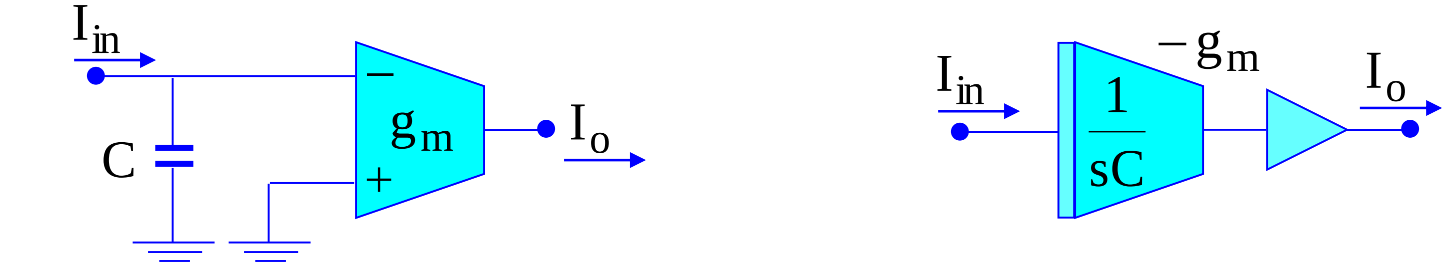
Single Transistor Inverting Amplifier

Simple Current Mirror

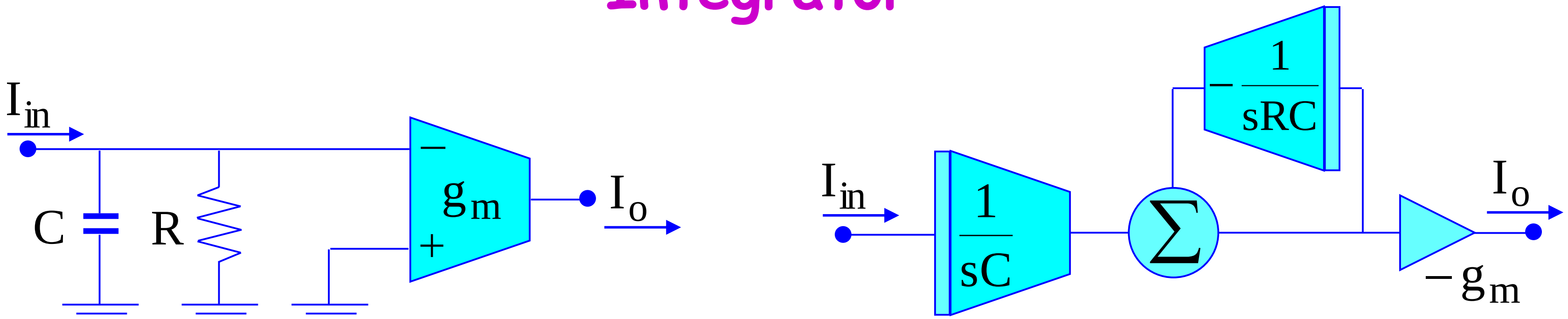
Capacitor



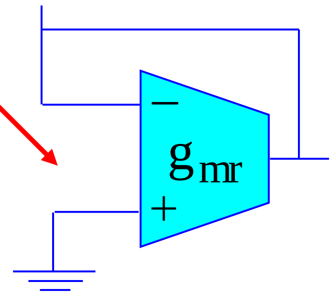
Current-Mode Implementation using OTA's



Integrator



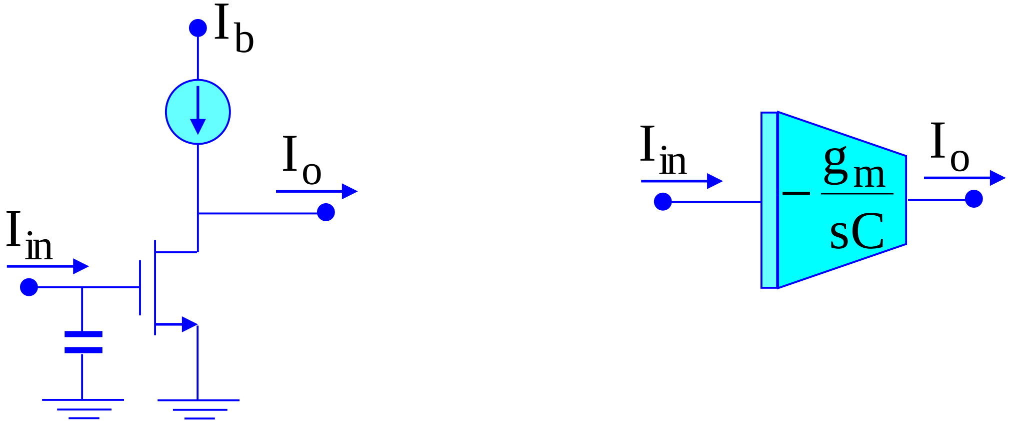
Self Loop Integrator



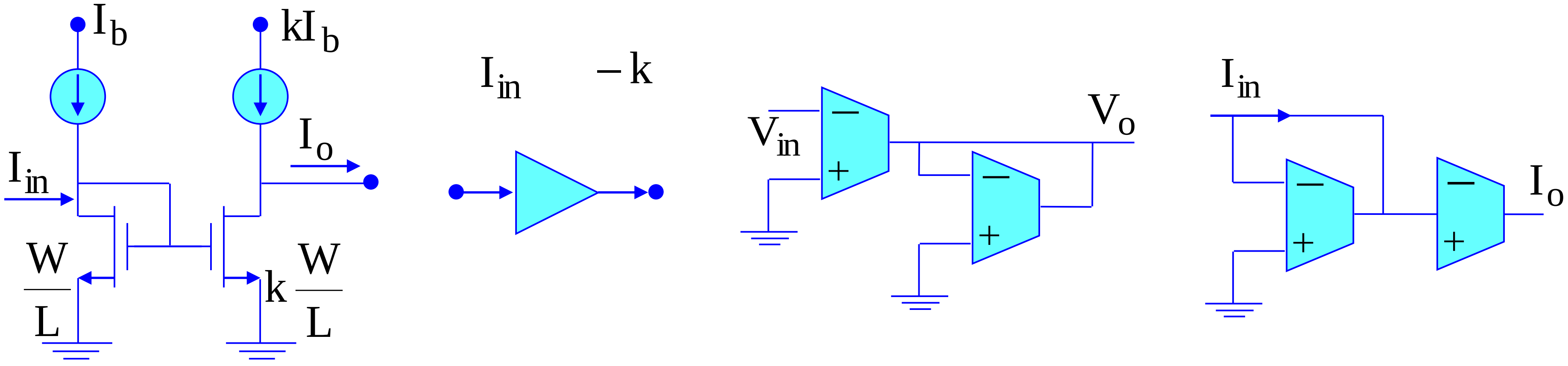
$$R = \frac{1}{g_{mr}}$$

In order to fully obtain the benefits of current-mode techniques simpler circuits with reduced parasitics are desireable.

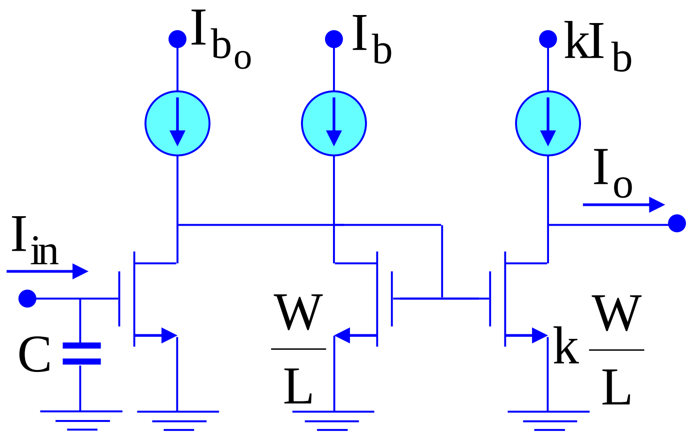
Primitive CM Circuits

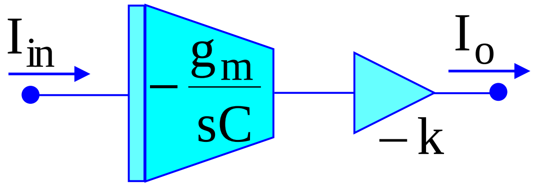


Inverting Integrator



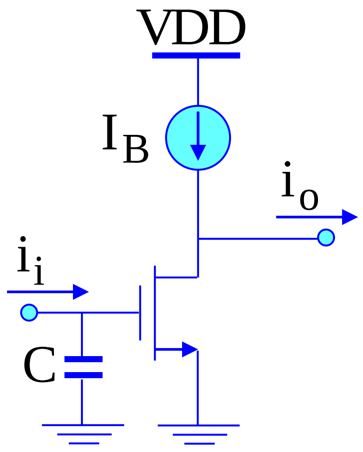
Amplifier (Multiplier by a constant)



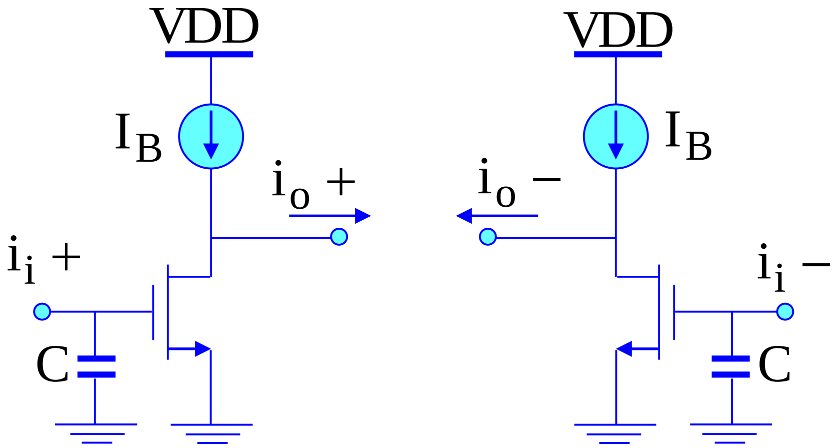


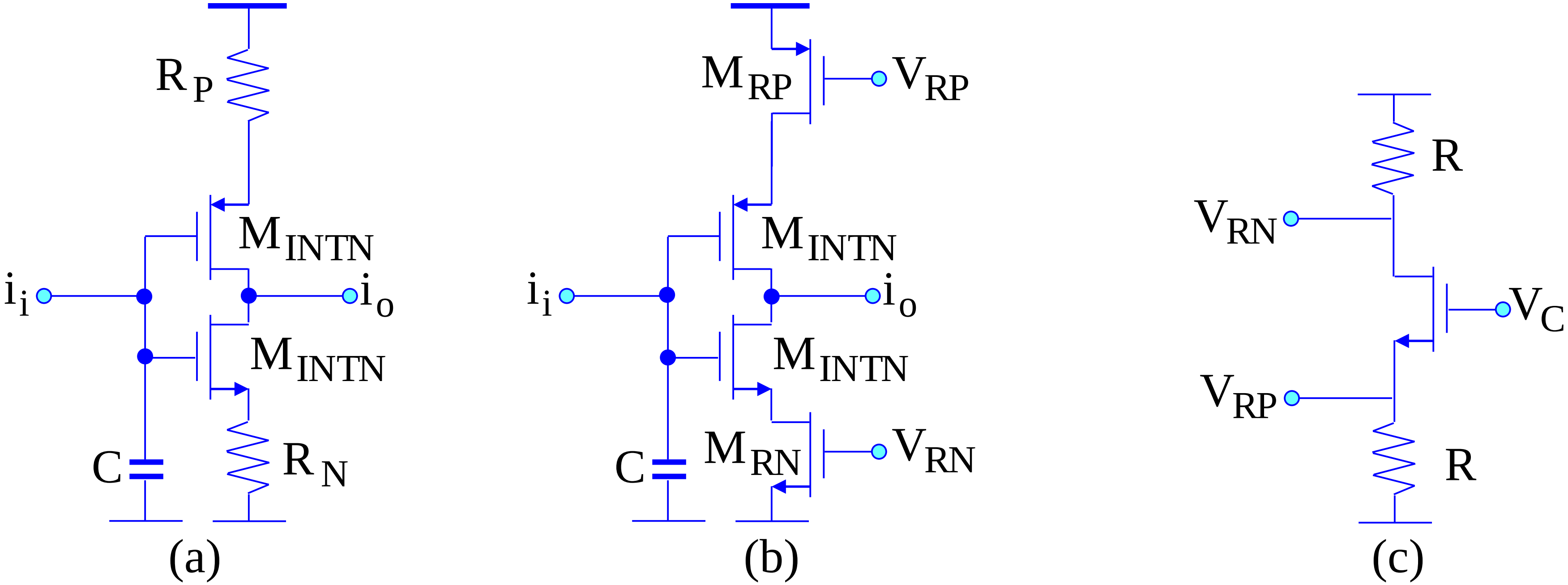
Non-Inverting Integrator

3.3V Power supply
High frequency
Low area
Suitable for digital process
Good PSR
Poor linearity, efficiency (1% THD => η < 4%)
Poor voltage gain



Low power supply (3.3V)
High frequency
Low area
Suitable for digital process
Very good PSR
Good Linearity (differential)
Excellent efficiency ($\approx$ 100%)
Poor common mode rejection





(a) Tunable CMOS class AB integrator (b) Transistor Implementation with Mrn and Mrp operating in triode region (c) Bias implementation (diffusion or poly resistors).

Linearity sufficient

Very high efficiency (> 100%) => AB, low power

Very high frequency

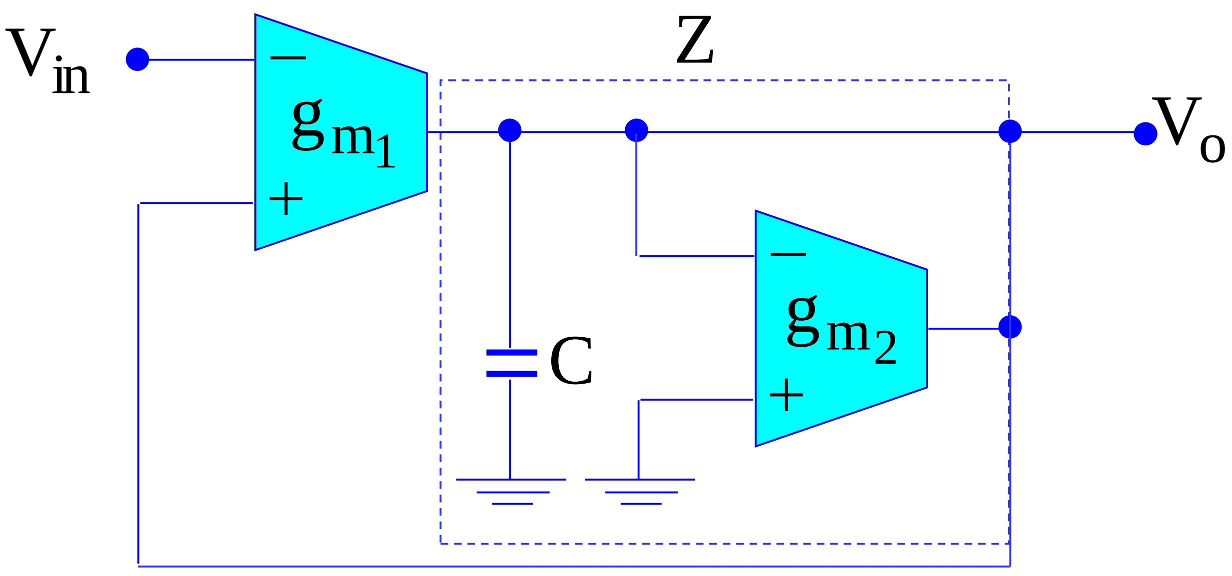
Small area

Low Power Supply

Linearity dep. on process variations

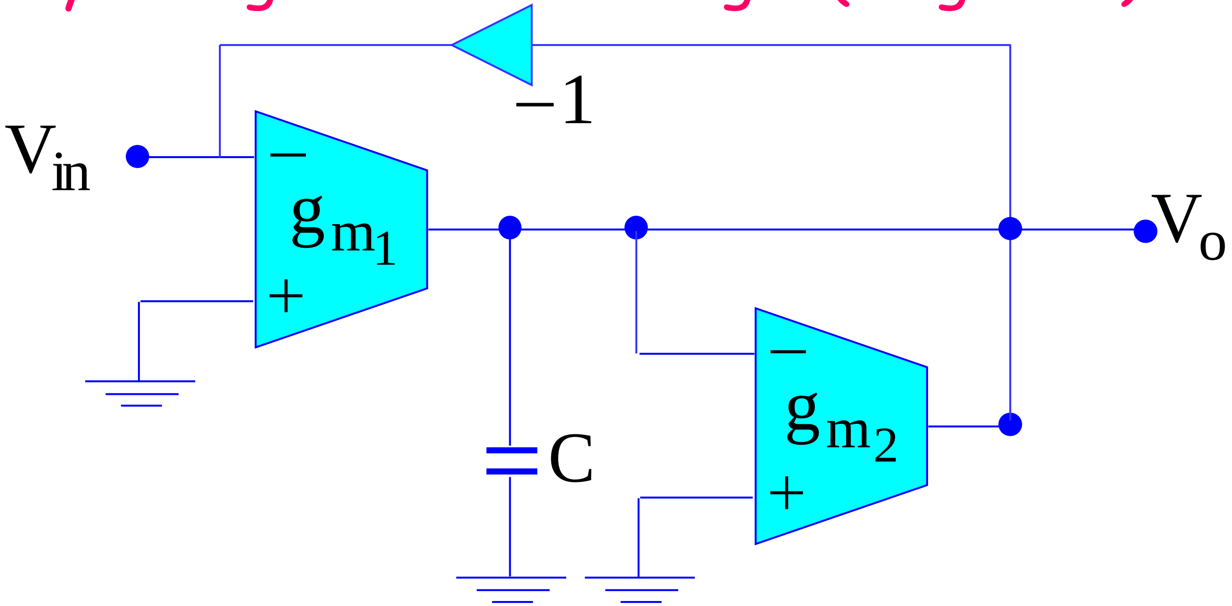
PSR poor

How to convert a Lossy Transconductance Integrator With Positive Feedback into a Current-Mode Lossy Integrator

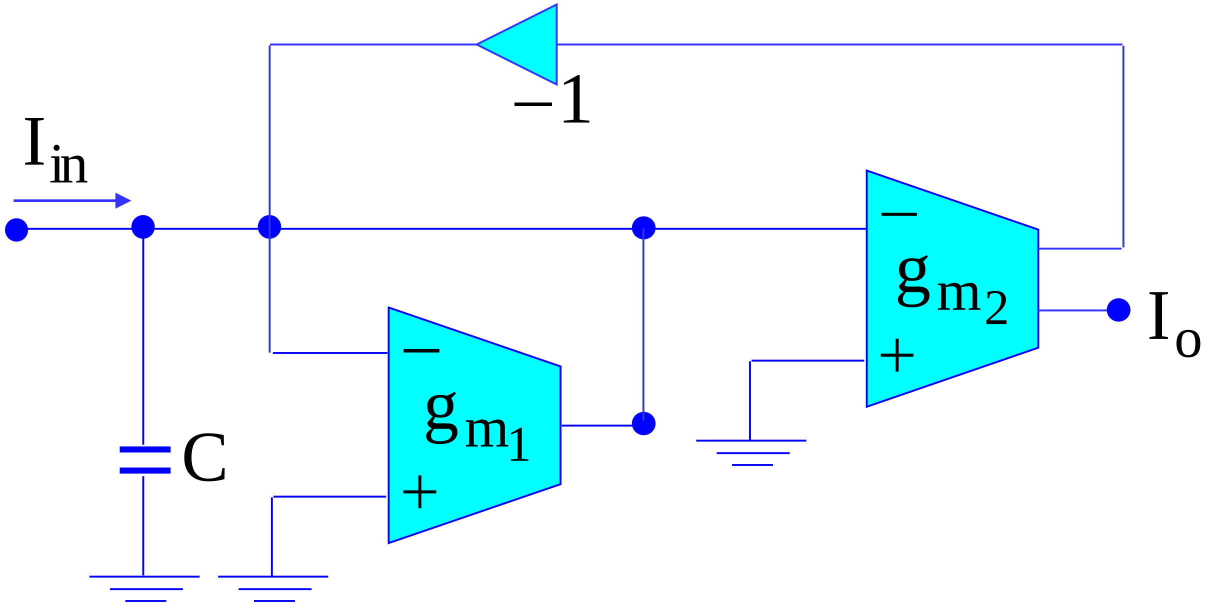


$$\frac{V_o}{V_{in}} = \frac{-g_{m_1} Z}{1 - g_{m_1} Z} = -\frac{g_{m_1}}{sC_2 + (g_{m_2} - g_{m_1})}$$

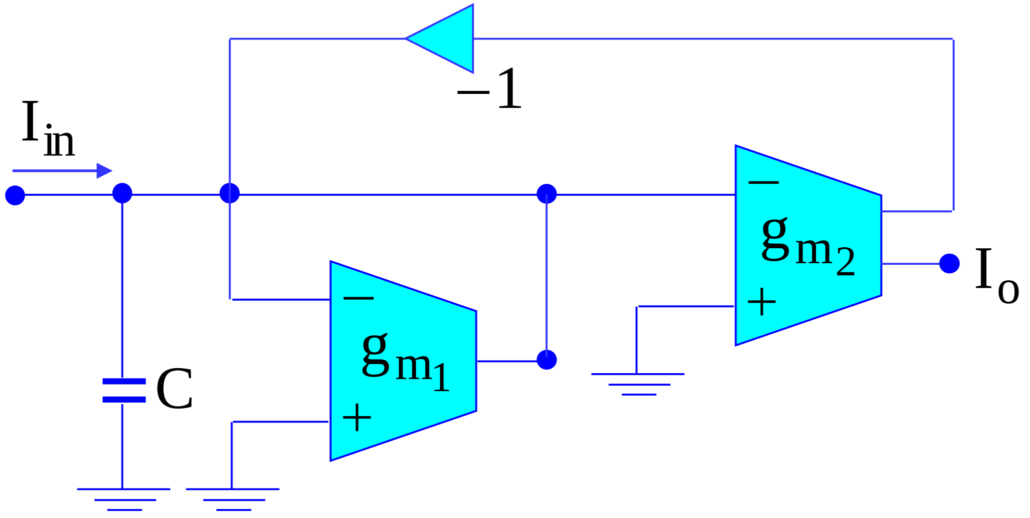
OTA-C Lossy Integrator With Single (Negative) Input OTA's



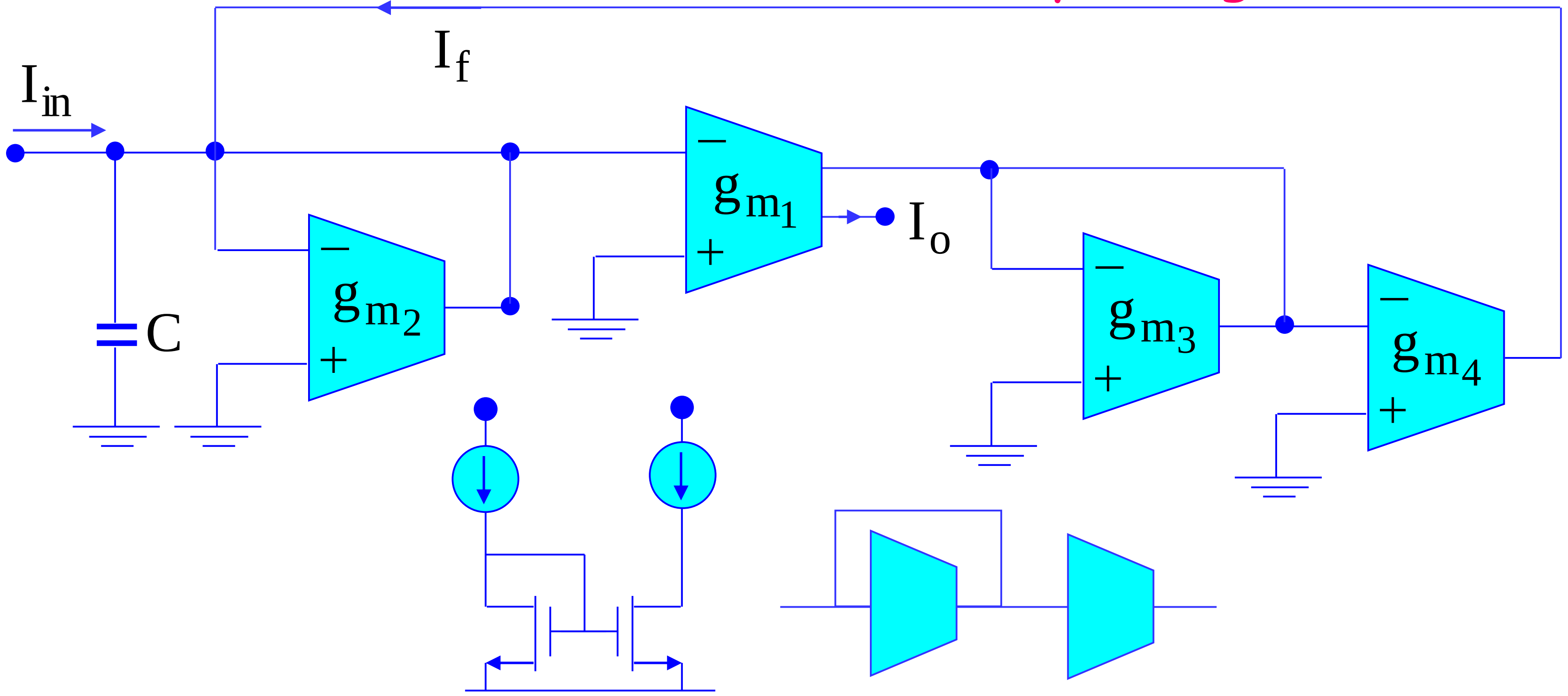
Current-Mode Version

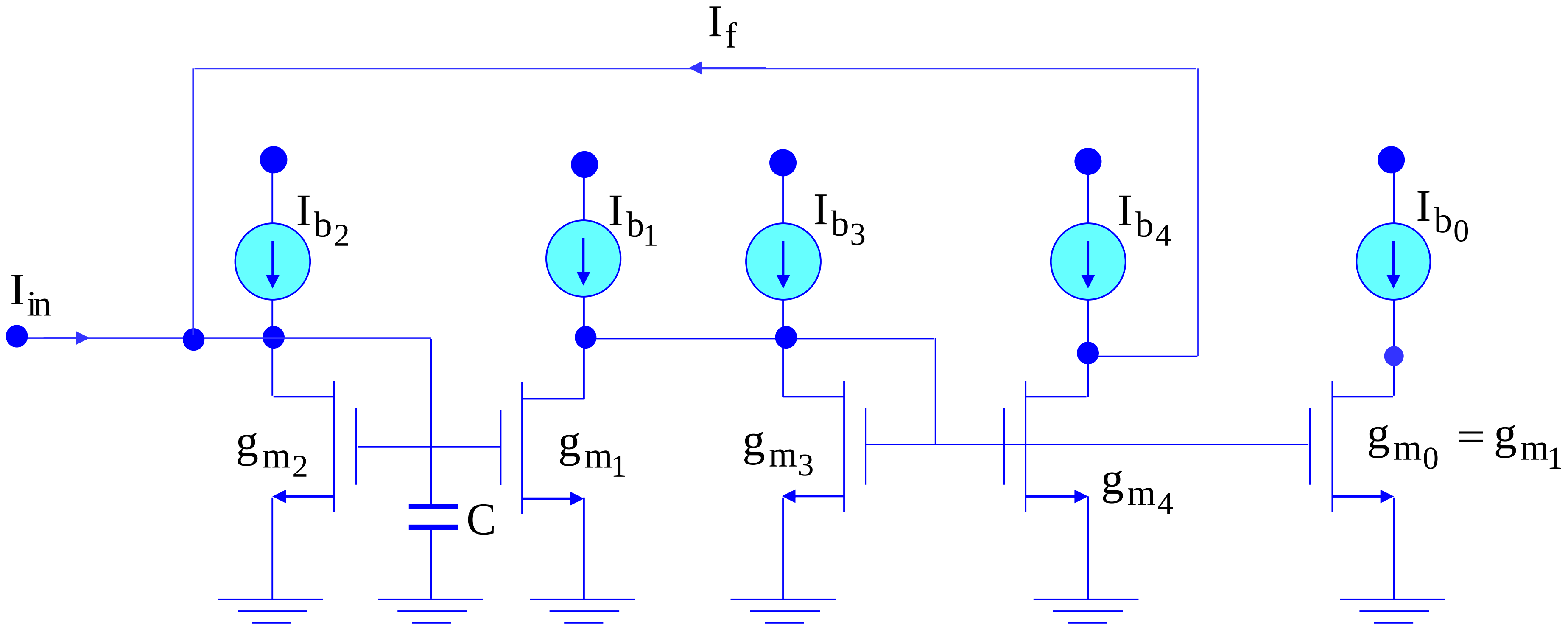


Current-Mode Version

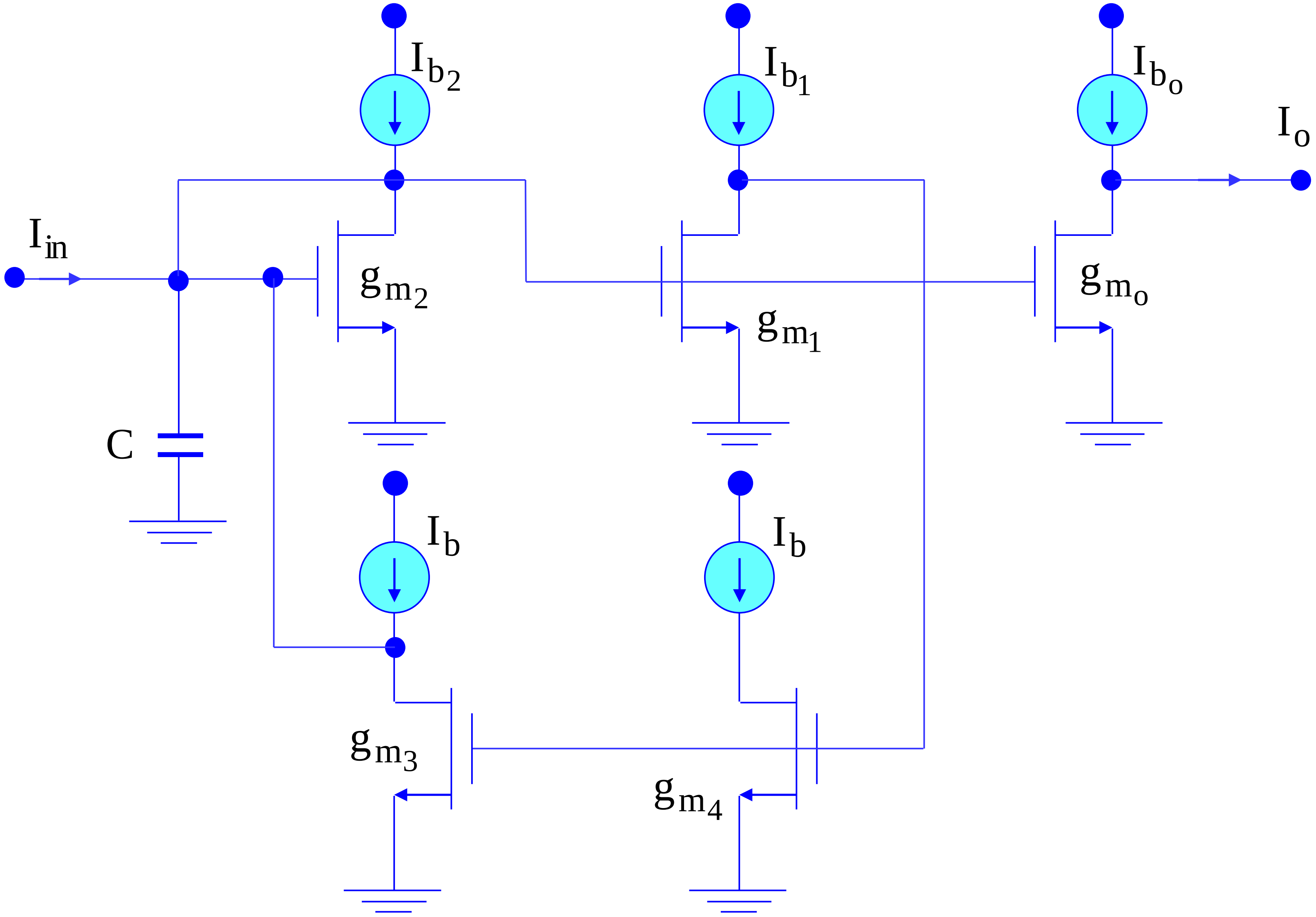


Generalized Current-Mode Lossy Integrator



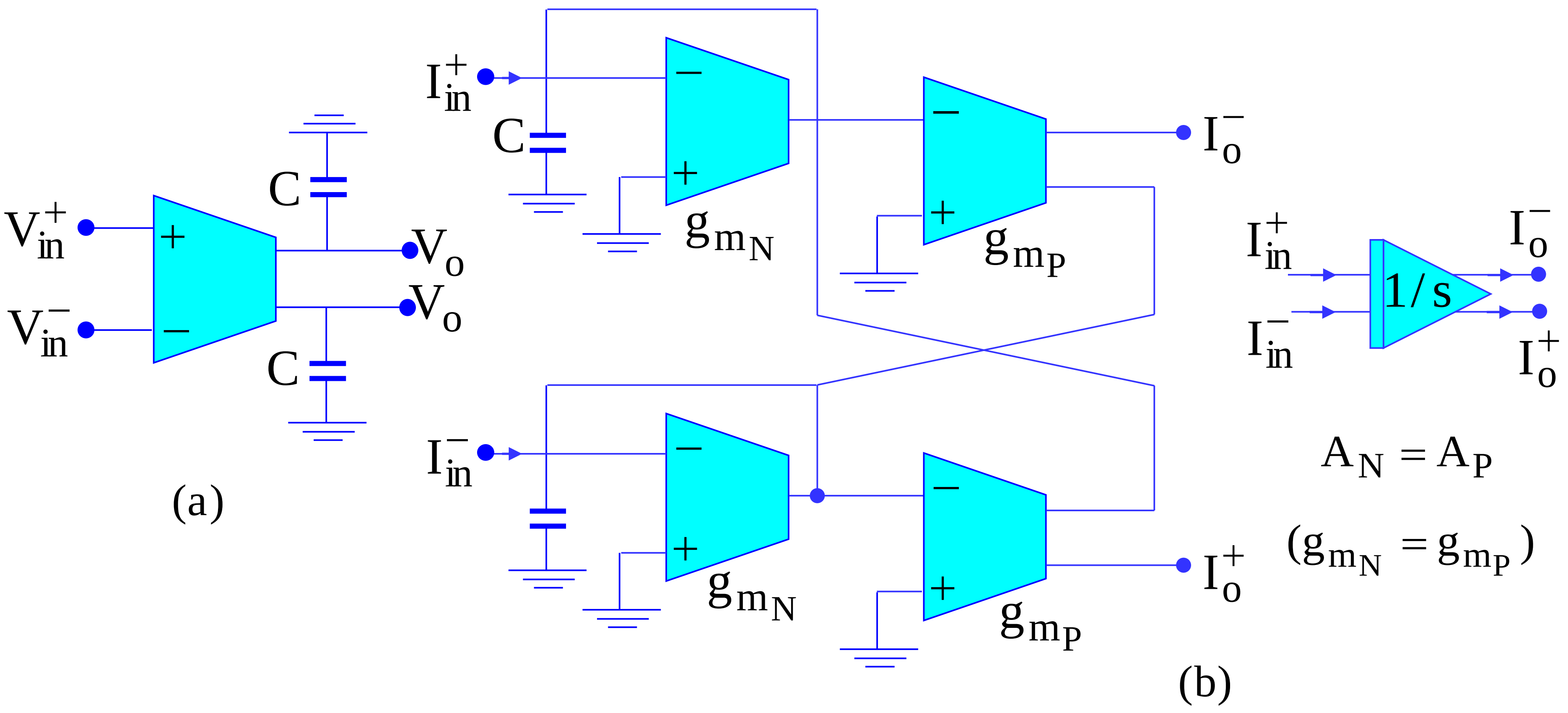


Transistor Level Implementation
CM Lossy (Lossless) Integrator



Redrawing the CM Integrator

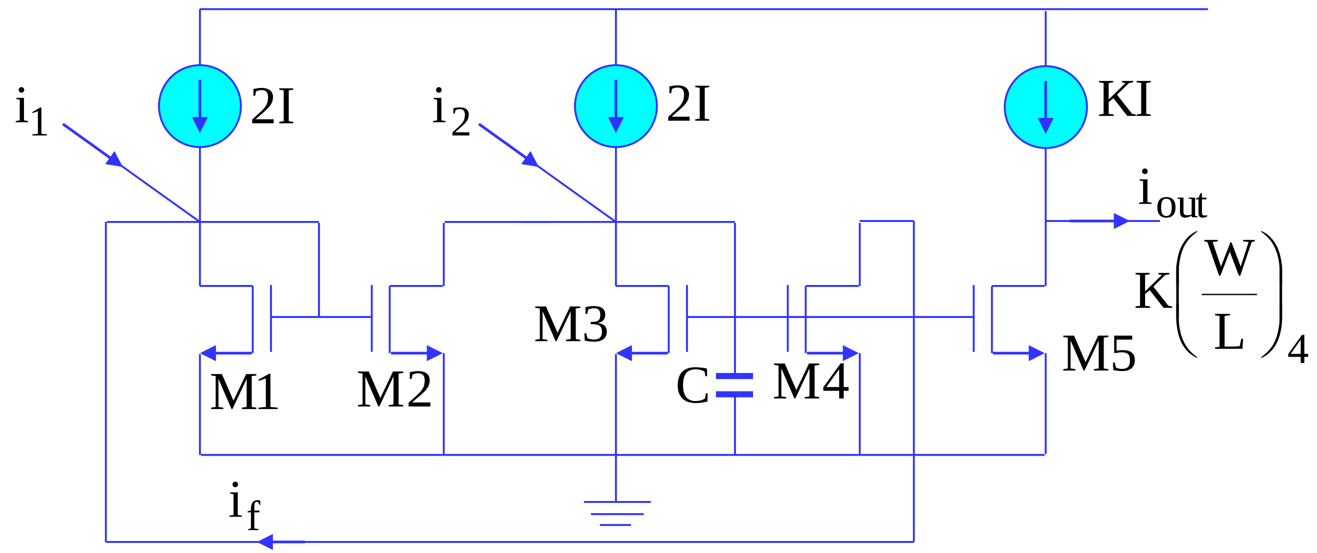
Fully Pseudo Differential Integrator

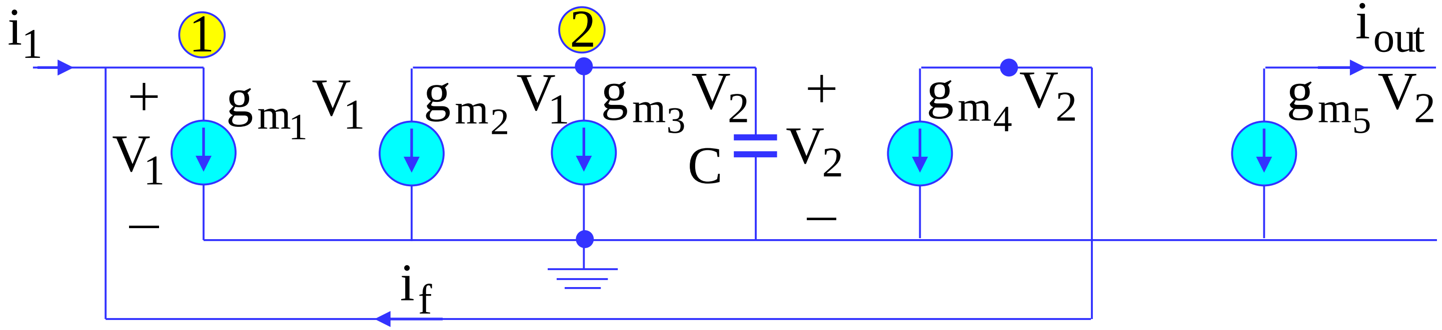


$$A_{d_m} = \frac{I^{+}I_{o}^{-}}{I_{in}^{+} - I_{in}^{-}} = \frac{-\omega_u}{s + (A_N + A_p)\omega_u}$$

$$A_{c_m} = \frac{I_{o}^{+} + I_{o}^{-}}{I_{in}^{+} + I_{in}^{-}} = \frac{-\omega_u}{s + (A_N + A_p)\omega_u}$$

Continuous - Time Current-Mode Integrator Based On Current-Mirrors.





$$i_f = \frac{i_1 \frac{g_{m_2}}{g_{m_1}} - i_2}{g_{m_1}\left(g_{m_3} + sC\right) - g_{m_2} g_{m_4}} \bullet g_{m_1} g_{m_4}$$

$$i_f = g_{m_1} g_{m_4} \frac{i_1 \frac{g_{m_2}}{g_{m_1}} - i_2}{g_{m_1} g_{m_3} - g_{m_2} g_{m_4} + g_{m_1} sC}$$

a) Lossless Integrator

$$g_{m_1} = g_{m_2} \quad \text{and} \quad g_{m_3} = g_{m_4}$$

$$i_f = \frac{g_{m_4}}{sC}(i_1 - i_2)$$

$$i_{out} = K \frac{g_{m_4}}{sC}(i_1 - i_2)$$

b) Lossy Integrator

$$g_{m_1} g_{m_3} > g_{m_2} g_{m_4} \quad , \quad g_{m_1} = k g_{m_2} \; , \; g_{m_3} = k g_{m_4}$$

$$i_f = \frac{k}{k^2 - 1} \frac{k i_1 - i_2}{1 + \frac{sC}{g_{m_4}} \frac{k^2 - 1}{k}} \quad , \quad k > 1$$

$$\text{i.e.} \quad k = 2$$

$$i_f = \frac{2}{3} \frac{2 i_1 - i_2}{1 + \frac{sC}{g_{m_4}} \frac{3}{2}}$$

If the parasitic capacitances and the output conductances are considered, then

$$i_f = \frac{-k_1 (s - z_1) i_1}{(s + p_1)(s + p_2)} - \frac{k_2 (s + z_2)}{(s + p_1)(s + p_2)}$$

Where

$$k_1 = g_o / C_1 \quad , \quad k_2 = g_m / C_2$$

$$p_1 = 4g_o / C_2 \quad , \quad p_2 = g_m / C_1$$

$$z_1 = \frac{g_m}{C_2}\frac{g_m}{g_o} \quad , \quad z_2 = \frac{g_m + g_o}{C_1}$$

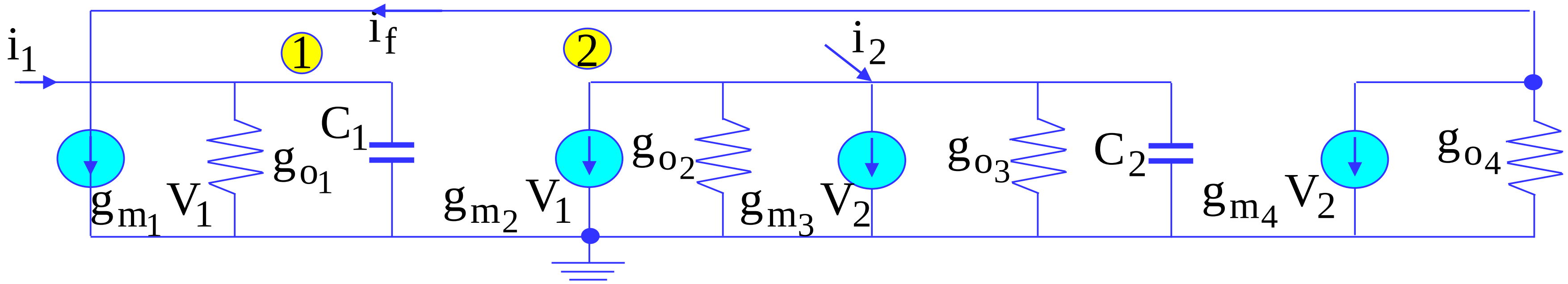
All transistors are equal, and C_1 and C_2 are the lumped nodal capacitances associated with nodes 1 and 2. Note that p_1 moves from the origin to

$$p_1 \rightarrow \frac{\omega_o}{\alpha} = \frac{\frac{g_{m_3}}{C_2}}{\frac{g_m}{4g_o}} = \frac{g_{m_3}}{g_m}\frac{4g_o}{C_2}$$

And

$$Q = -\frac{g_{m_1}}{g_{m_3}}\frac{C_2}{C_1}$$

Let's consider the input and output impedance,



$$z_{in} = \left.\frac{V_1}{i_1}\right|_{i_2=0} = \frac{g_{m_3} + g_{o_2} + g_{o_3} + sC_2}{-g_{m_4} g_{m_2} + (g_{m_1} + g_{o_1} + g_{o_4} + sC_1)(g_{m_3} + g_{o_2} + g_{o_3} + sC_2)}$$

$$z_{in} = \left.\frac{V_1}{i_1}\right|_{i_2=0} \cong \frac{g_{m_3}(1 + sC_2/g_{m_3})}{-g_{m_4} g_{m_2} + g_{m_1} g_{m_3} + s(C_2 g_{m_1} + C_1 g_{m_3}) + s^2 C_1 C_2}$$

a) Lossless Integrator

$$z_{in}(0) \cong \frac{g_{m_3}}{-g_{m_4} g_{m_2} + g_{m_1} g_{m_3}} \Bigg|_{\substack{g_{m_1}=g_{m_2} \\ g_{m_3}=g_{m_4}}} \to \infty$$

b) Lossy Integrator

$$z_{in}(0) \cong \frac{k^2}{k^2 - 1} \frac{1}{g_{m_1}} \quad , \quad k > 0$$

$$z_o(0) \cong \frac{1}{g_{o_5}}$$