Spring 2002

EEE598D: Analog Filters & Signal Processing Circuits

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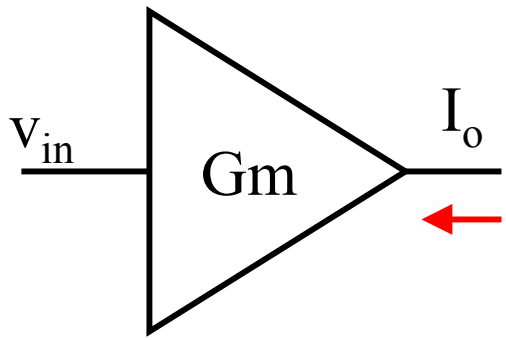
Today: Gm-C Filter Design

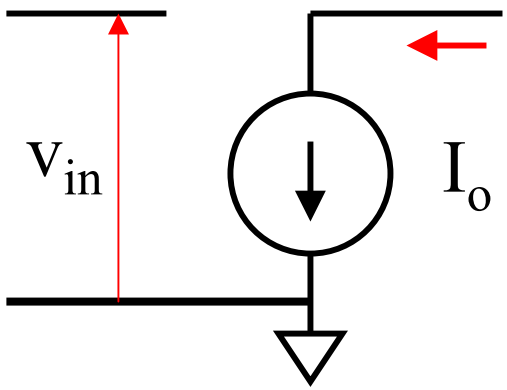
- Basic building blocks
- First-order Gm-C filters
- Second-order Gm-C filters
- High order Gm-C filters

Gm-C filters

- Basic building blocks:
  - Transconductor
  - Capacitor
- Driving application: disk drive read-channel filters
- Now used in many other applications:
  - Telecommunication,
  - Wireless communication
  - Anti-aliasing. etc

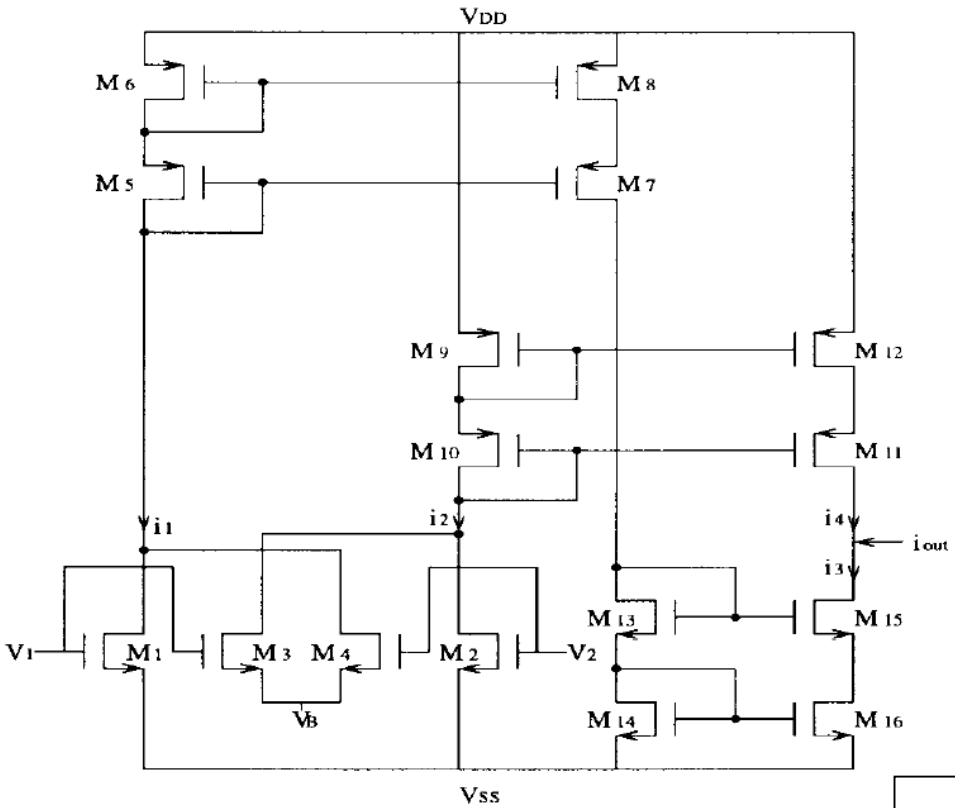
Transconductor

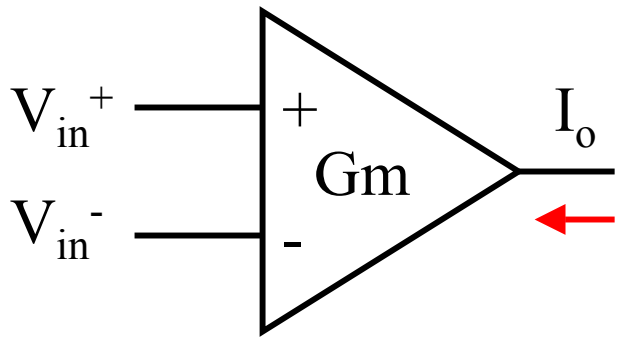




$$i_o = g_m v_{in}$$

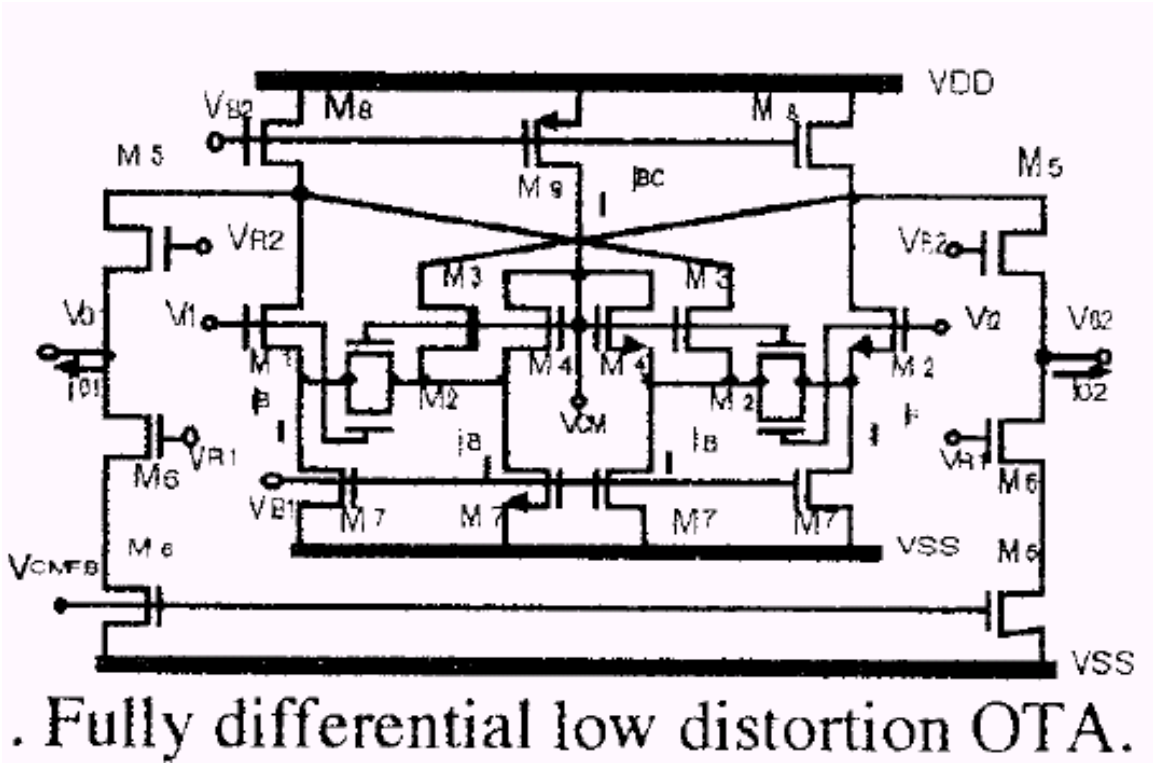
Transconductor



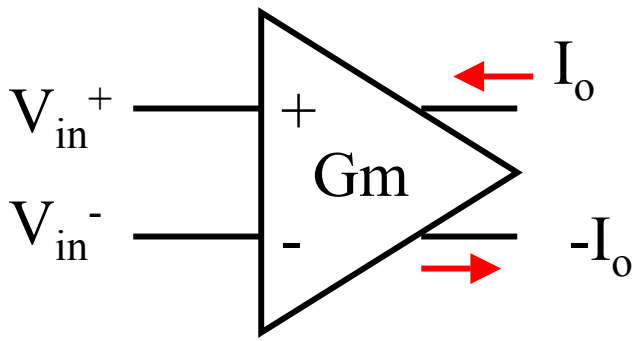


$$i_o = g_m\left(v_{in}^{+} - v_{in}^{-}\right)$$

Transconductor



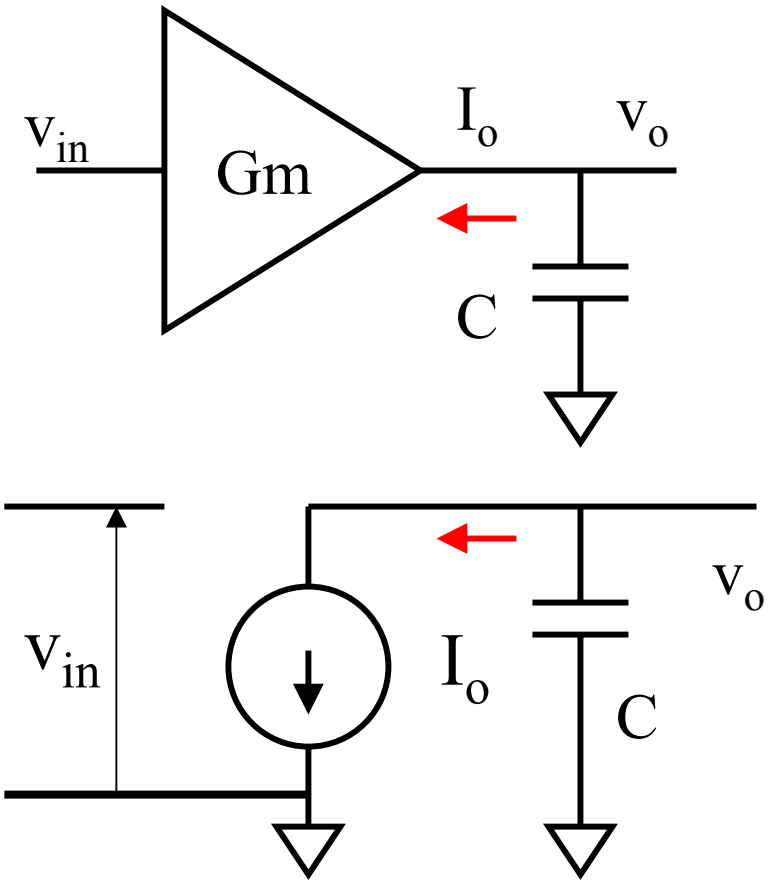
. Fully differential low distortion OTA.



$$i_o = g_m(v_{in}^+ - v_{in}^-)$$

Gm-C Integrator Structures

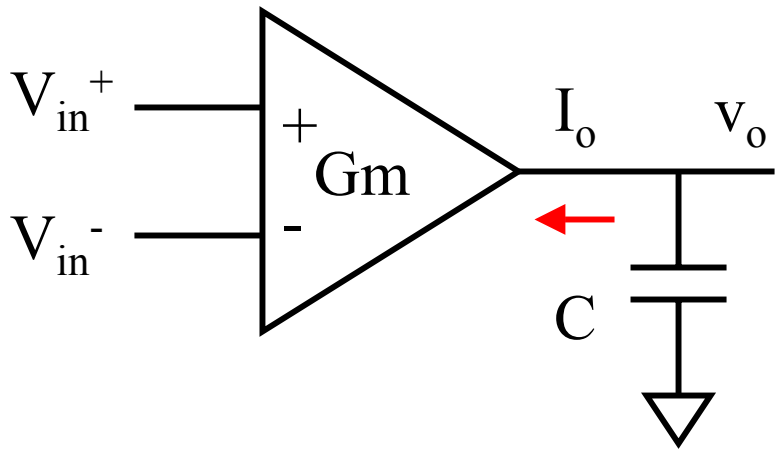
- Single-ended



$$H(s) = \frac{V_o(s)}{V_{in}(s)} = -\frac{g_m}{Cs}$$

Gm-C Integrator Structures

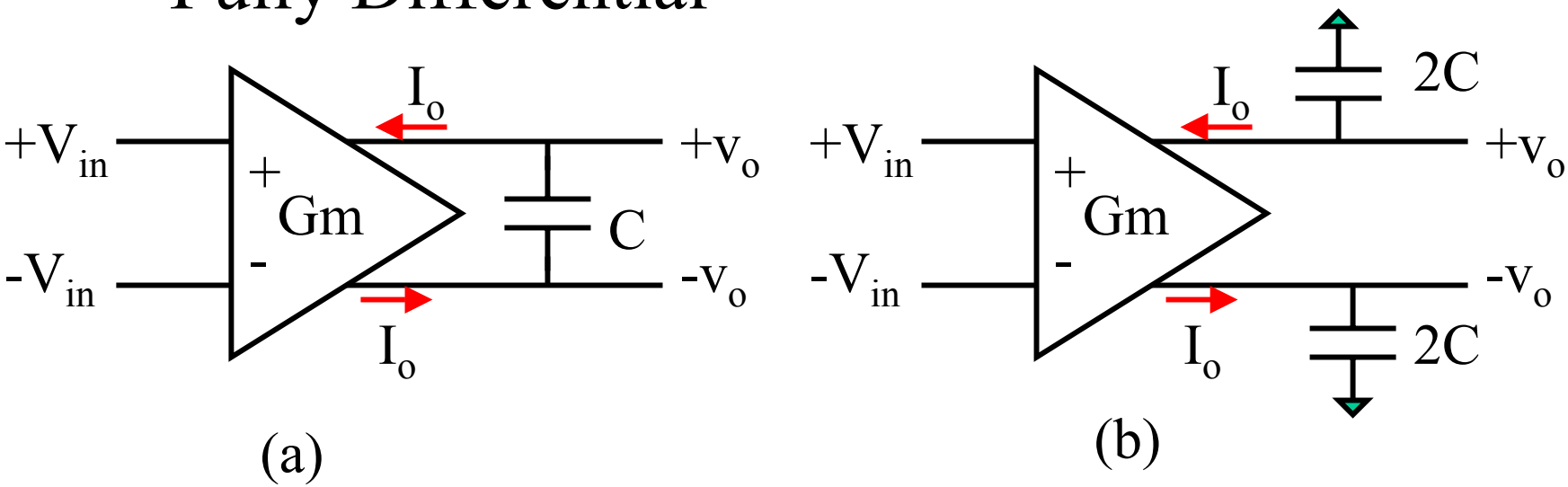
- Differential inputs



$$H(s) = \frac{V_o(s)}{V_{in}^{+}(s) - V_{in}^{-}(s)} = -\frac{g_m}{Cs}$$

Gm-C Integrator Structures

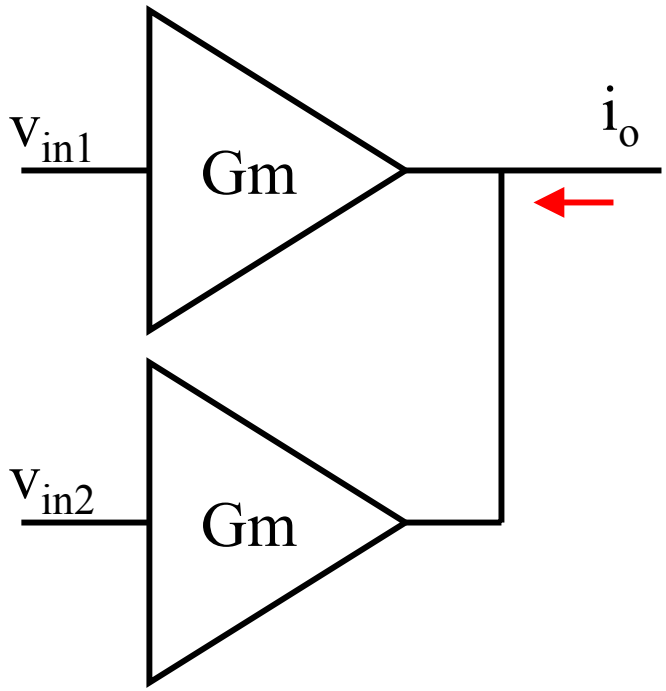
- Fully Differential



$$H(s) = \frac{V_o(s)}{V_{in}(s)} = -\frac{g_m}{Cs}$$

Gm-C Adder Structures

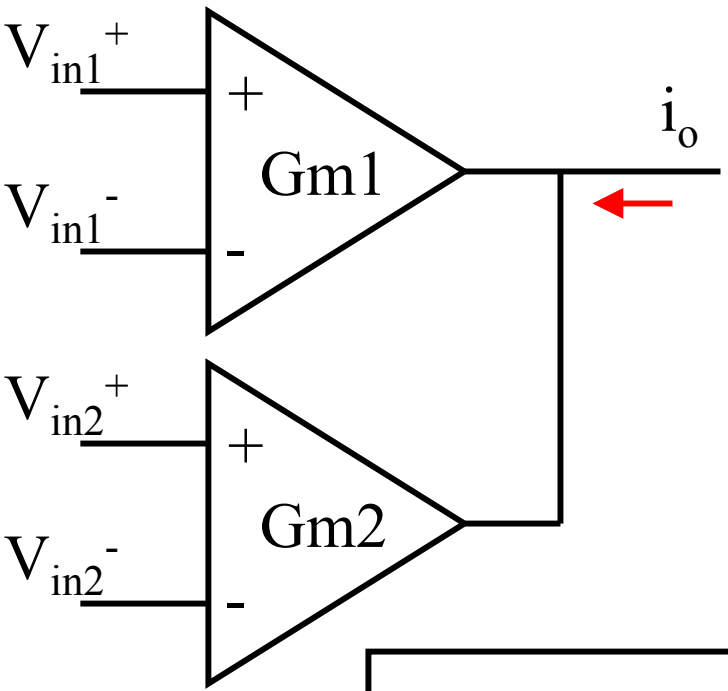
- Single-ended inputs



$$i_o = g_m(v_{in1} + v_{in2})$$

Gm-C Adder Structures

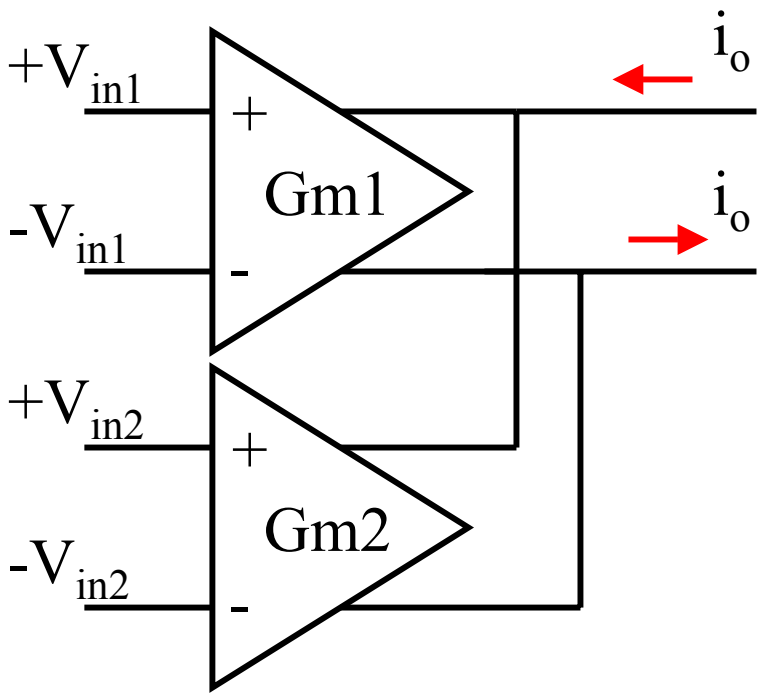
- Differential inputs



$$i_o = g_{m1}(v_{in1}^{+} - v_{in1}^{-}) + g_{m2}(v_{in2}^{+} - v_{in2}^{-})$$

Gm-C Adder Structures

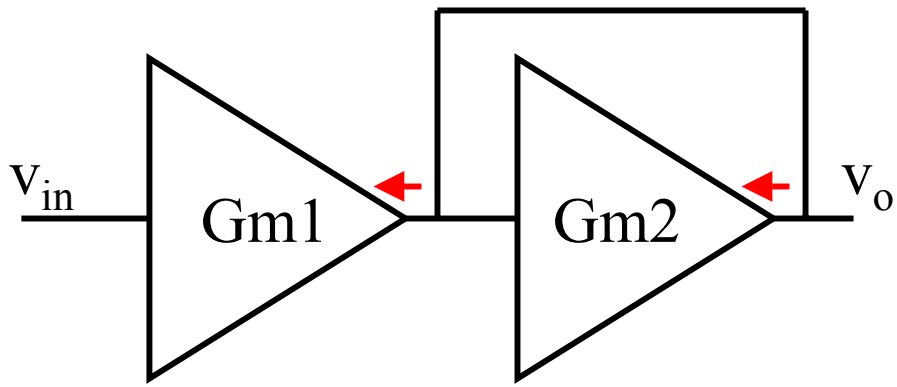
- Fully Differential



$$i_o = g_{m1} v_{in1} + g_{m2} v_{in2}$$

Gm-C Scaler Structures

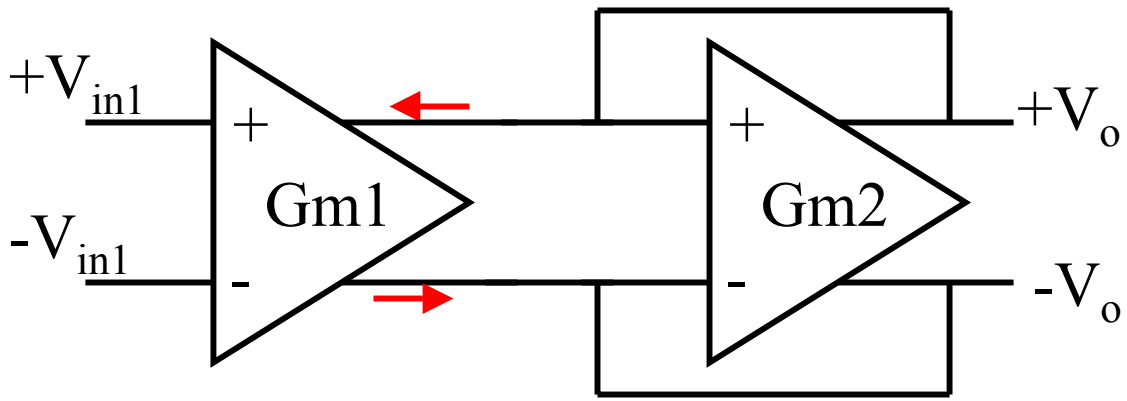
- Single-ended



$$v_o = -\frac{g_{m1}}{g_{m2}} v_{in}$$

Gm-C Scaler Structures

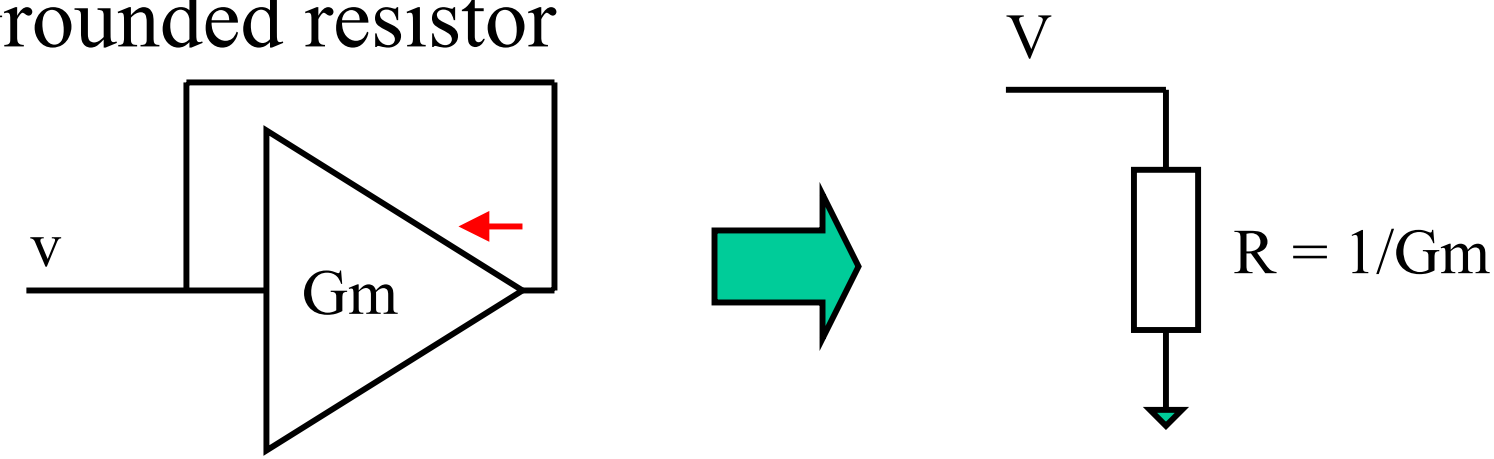
- Fully Differential



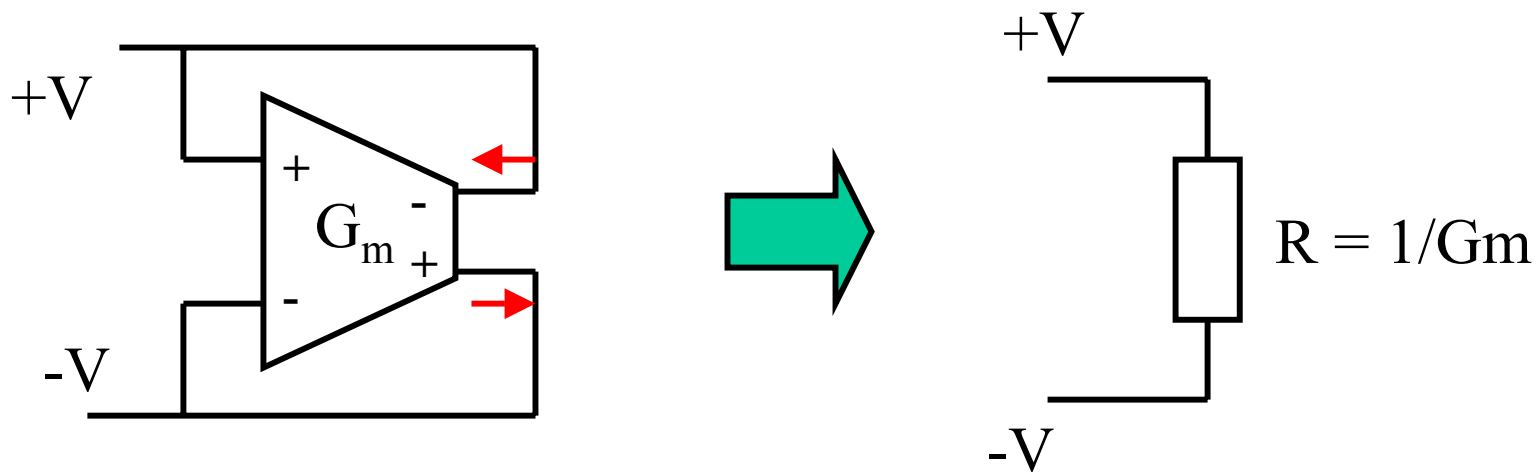
$$v_o = -\frac{g_{m1}}{g_{m2}} v_{in}$$

Gm-C Simulation of Resistors

- Grounded resistor

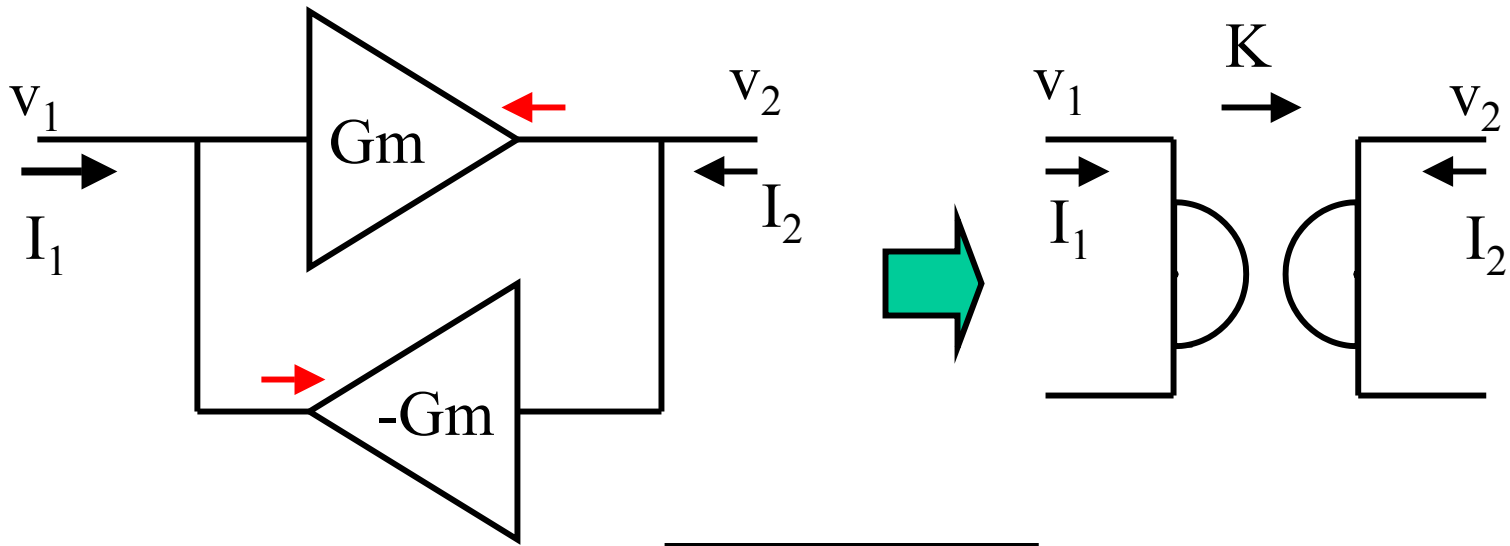


- Floating resistor



Gm-C Simulation of GIC

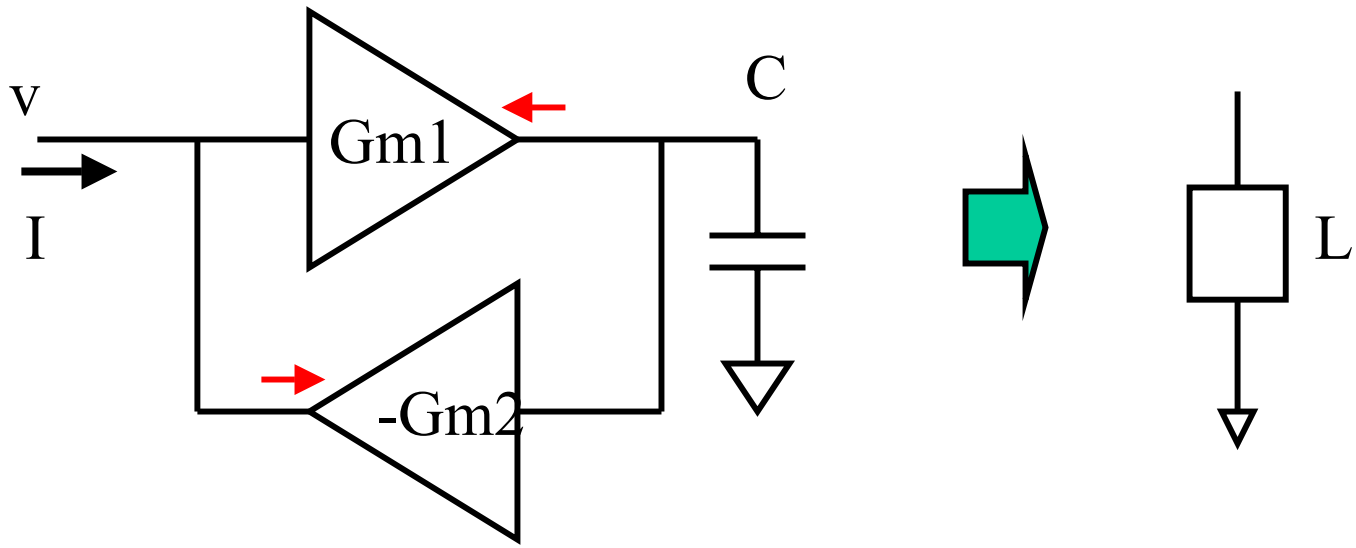
- General Impedance Converter (GIC)



$$V_1 = K\, I_2$$
$$V_2 = -K\, I_1$$

Gm-C Simulation of Inductors

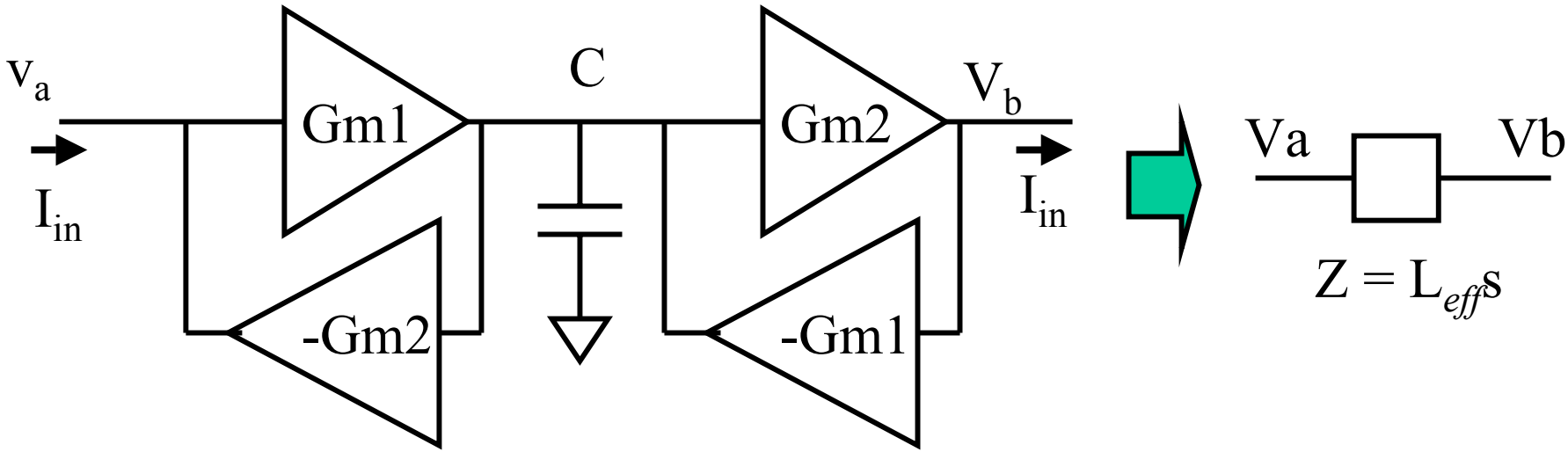
- Grounded Inductor



$$L = \frac{C}{g_{m2} g_{m1}}$$

Gm-C Simulation of Inductors

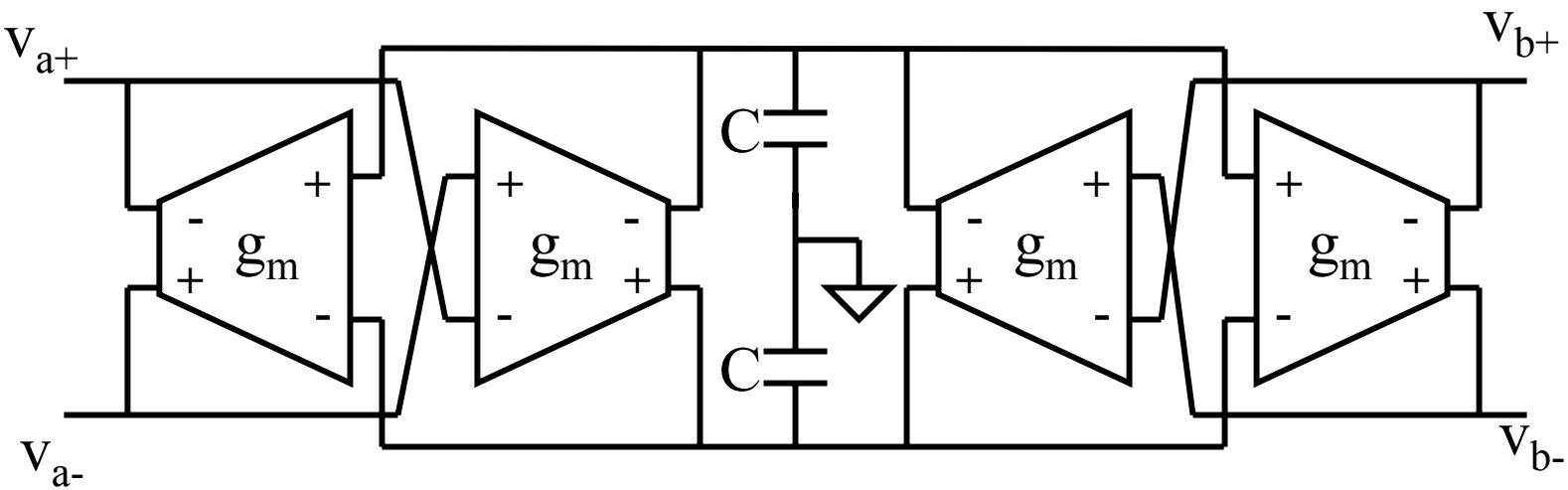
- Floating inductor

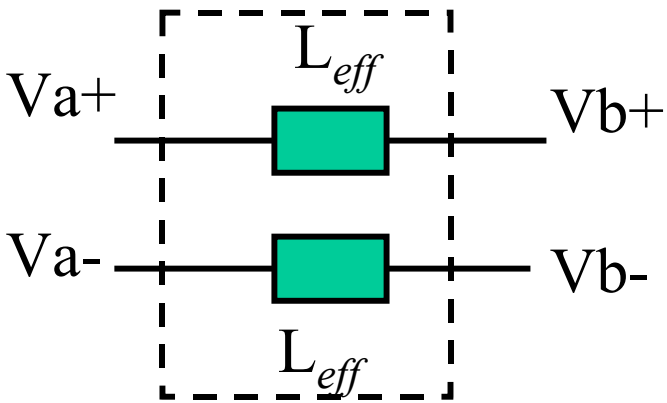


$$L = \frac{C}{g_{m2}g_{m1}}$$

Gm-C Simulation of Inductors

- Fully Differential Inductor (Gyrator)

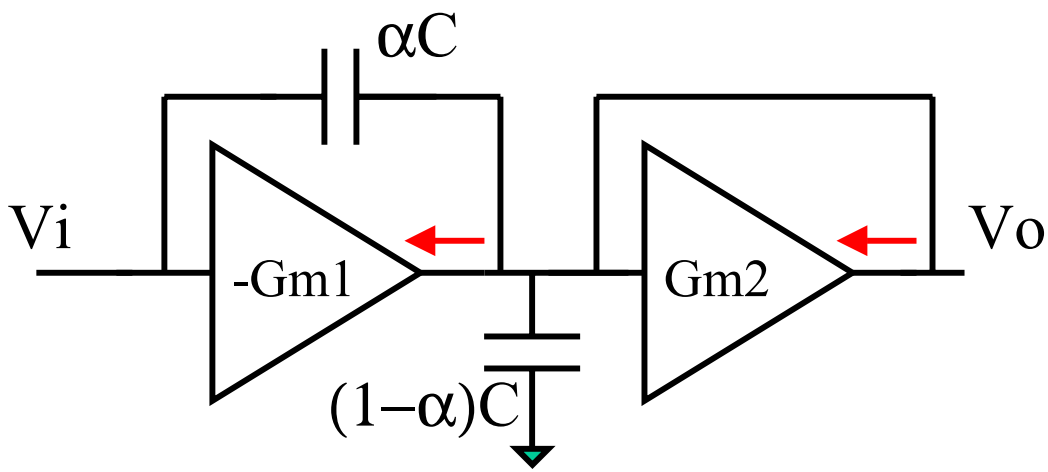




$$L_{eff} = \frac{C}{g_m^2}$$

First Order Gm-C Filters

- Single-ended

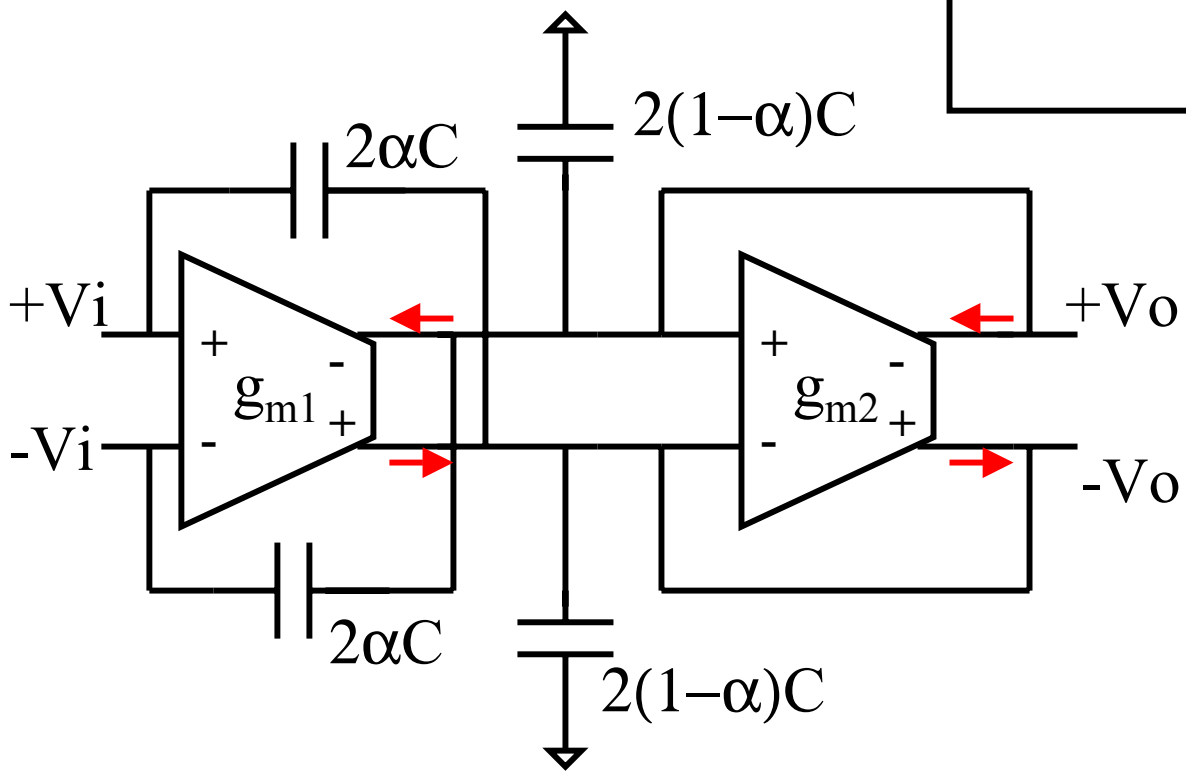


$$H(s) = \frac{V_o(s)}{V_i(s)} = \alpha \frac{s + \frac{g_{m1}}{\alpha C}}{s + \frac{g_{m2}}{C}}$$

First Order Gm-C Filters

- Fully Differential

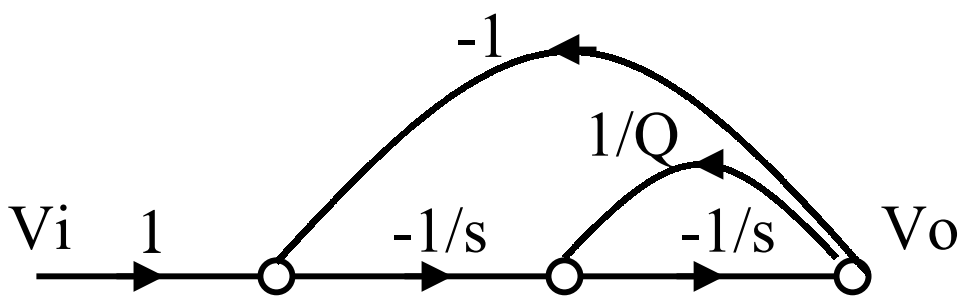
$$H(s) = \frac{V_o(s)}{V_i(s)} = \alpha \frac{s + \frac{g_{m1}}{\alpha C}}{s + \frac{g_{m2}}{C}}$$



Second Order Gm-C Filters

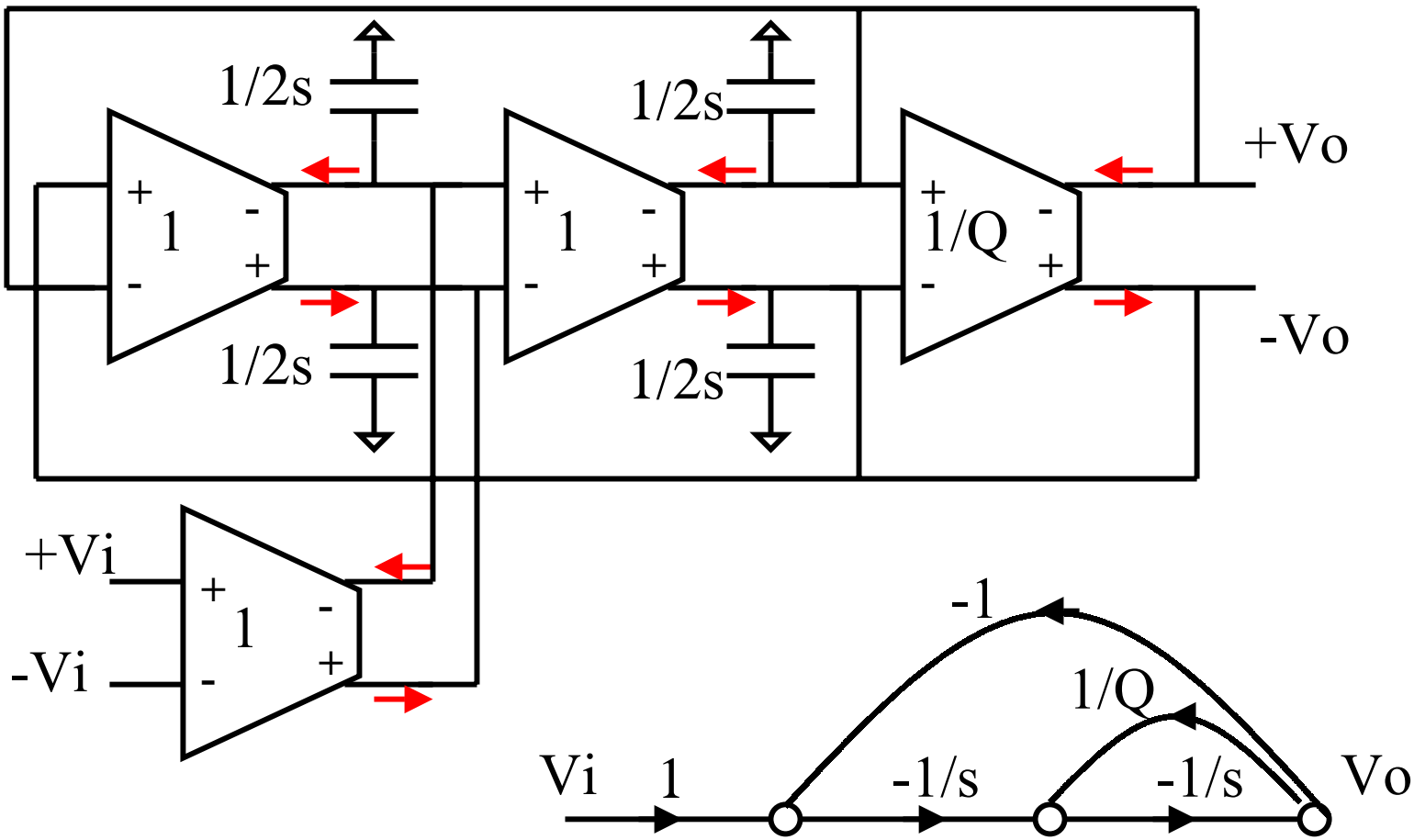
- LP

$$H(s) = \frac{V_o(s)}{V_i(s)} = \frac{1}{s^2 + \frac{1}{Q}s + 1}$$



Second Order Gm-C Filters

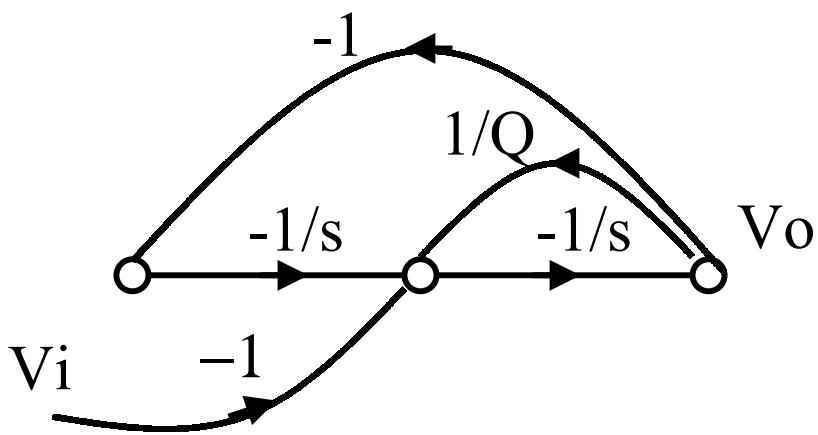
- LP



Second Order Gm-C Filters

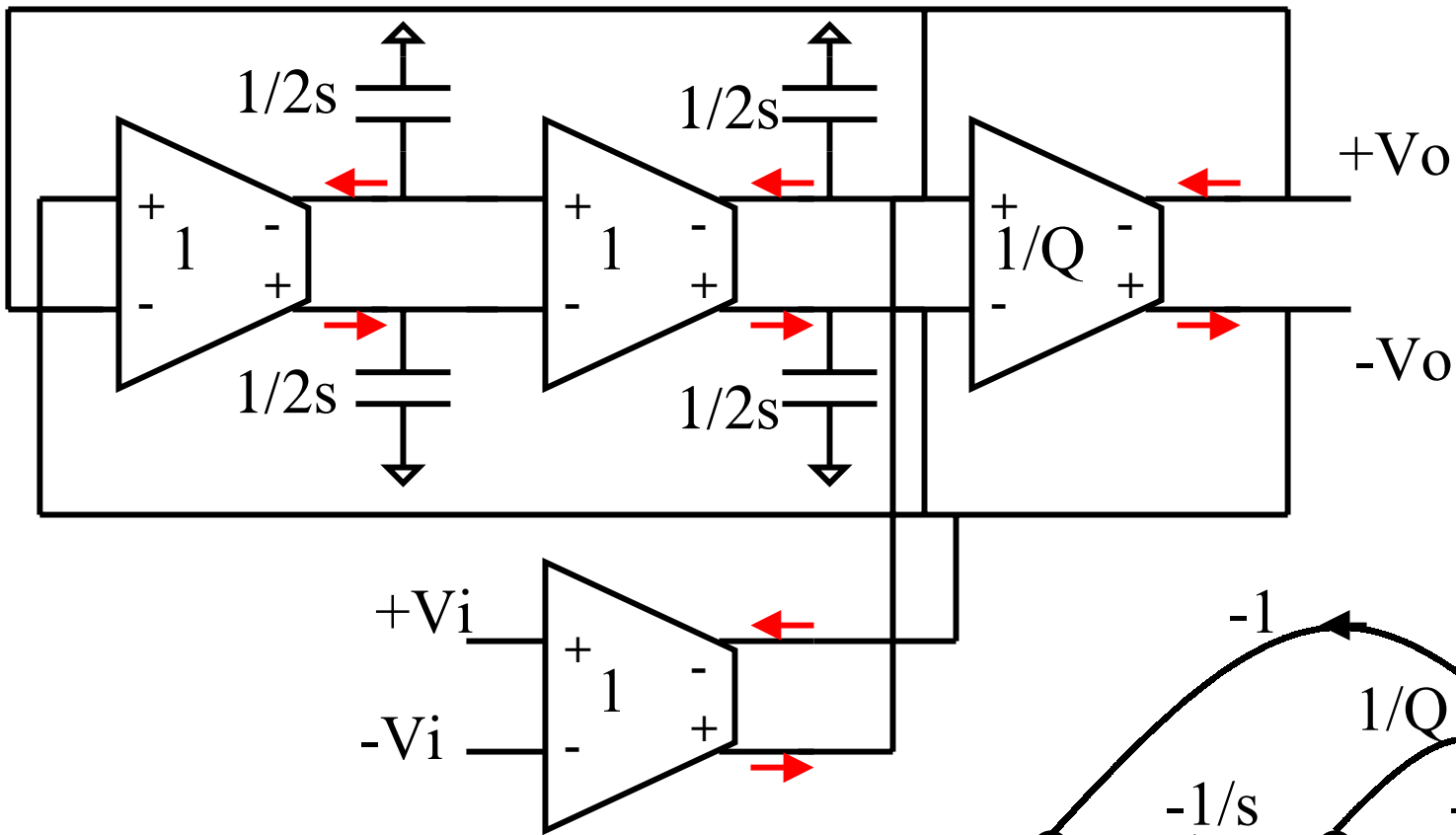
- BP

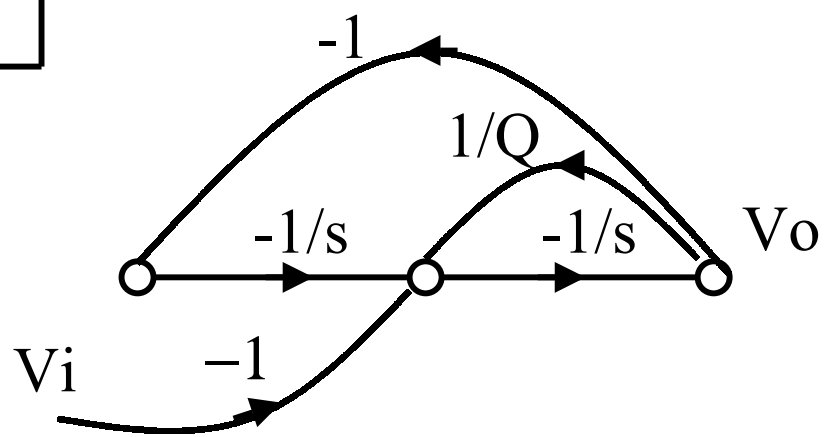
$$H(s) = \frac{V_o(s)}{V_i(s)} = \frac{s}{s^2 + \frac{1}{Q}s + 1}$$



Second Order Gm-C Filters

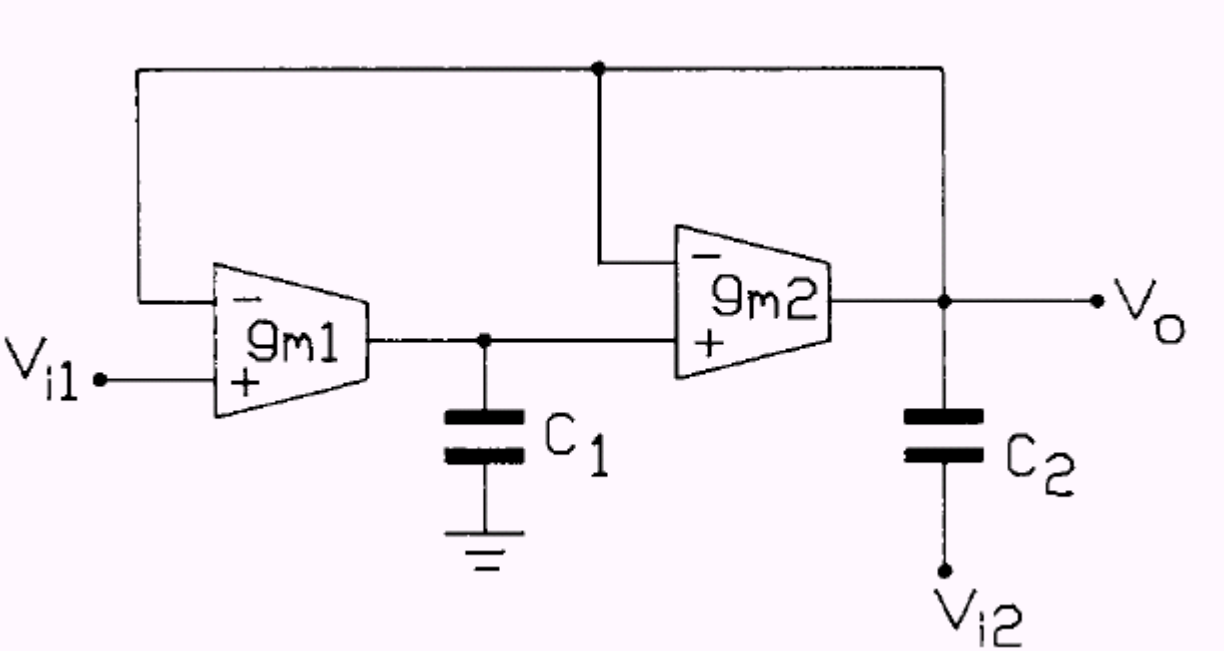
- BP





Second Order Gm-C Filter Structures

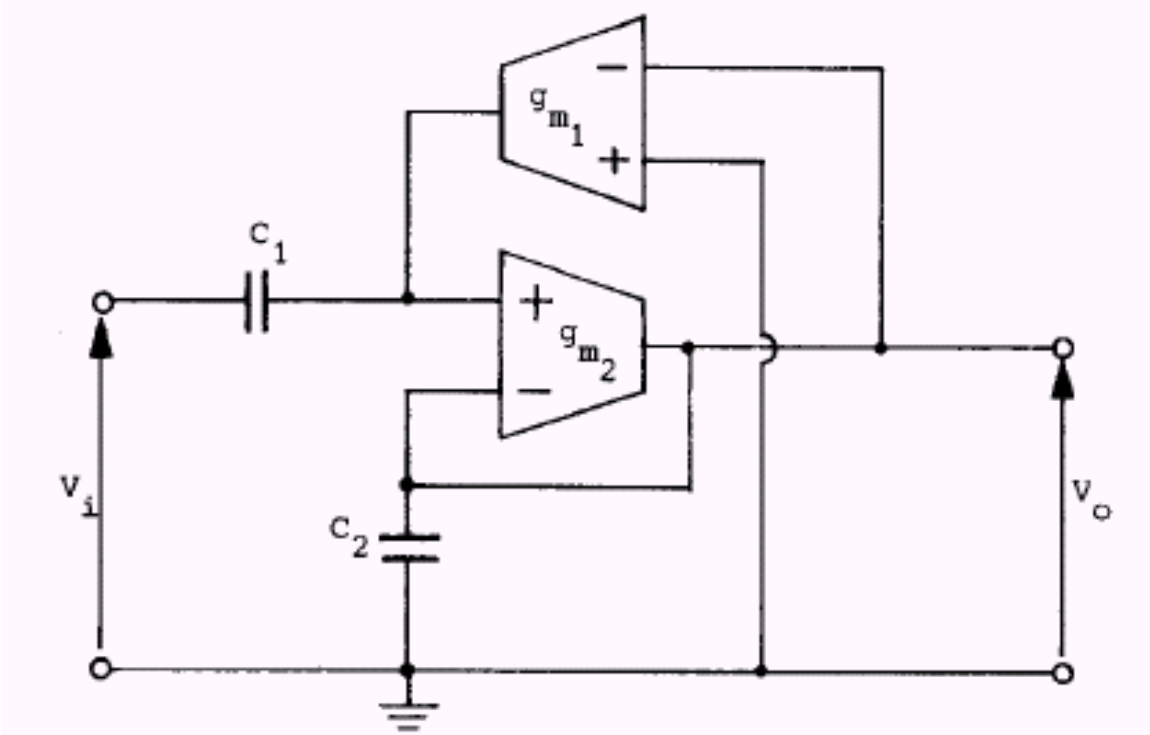
- LP, HP, and BS



$$V_o = \frac{s^2 V_{i2} + \omega_o V_{i1}}{s^2 + \frac{\omega_o}{Q_o} s + \omega_o^2}$$

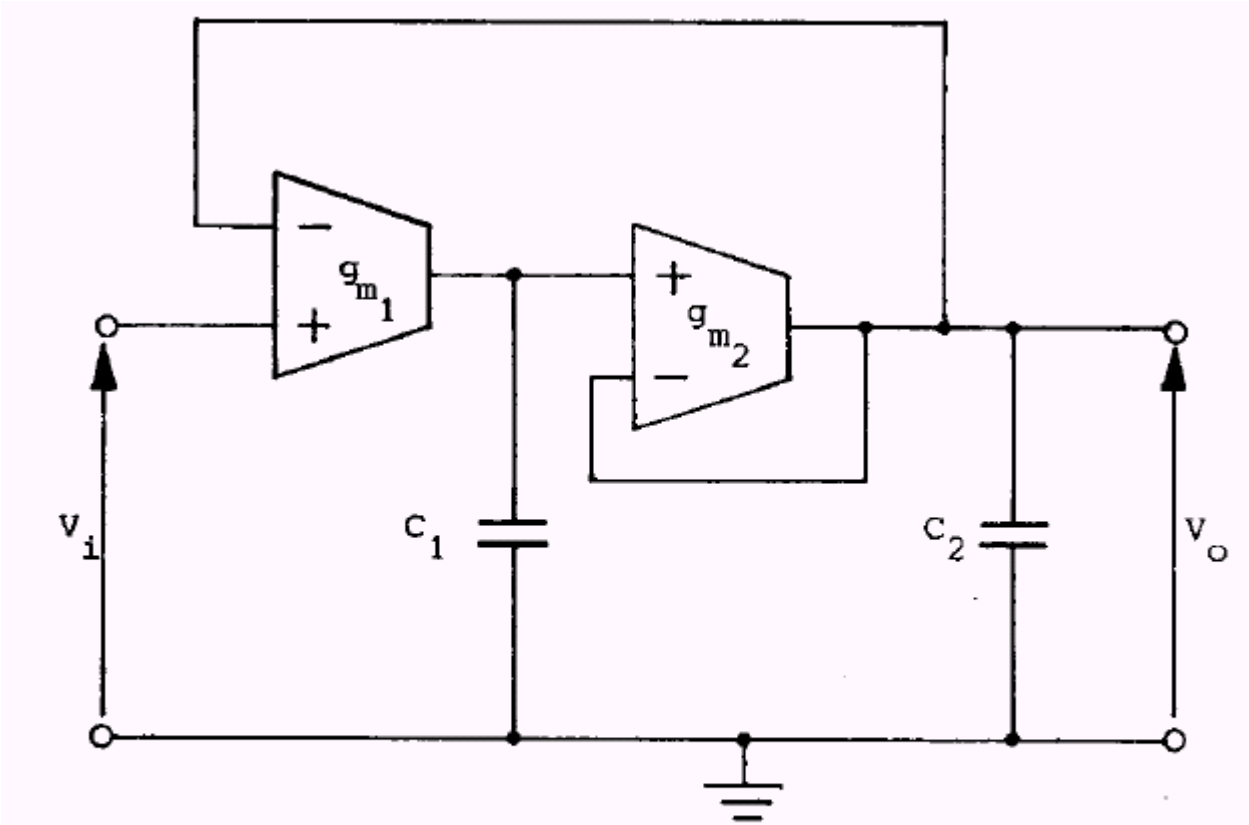
$$\omega_o = \sqrt{\frac{g_{m1} g_{m2}}{C_1 C_2}} \quad \text{and} \quad Q_o = \sqrt{\frac{g_{m1} C_2}{g_{m2} C_1}}$$

Second Order Gm-C Filter Structures



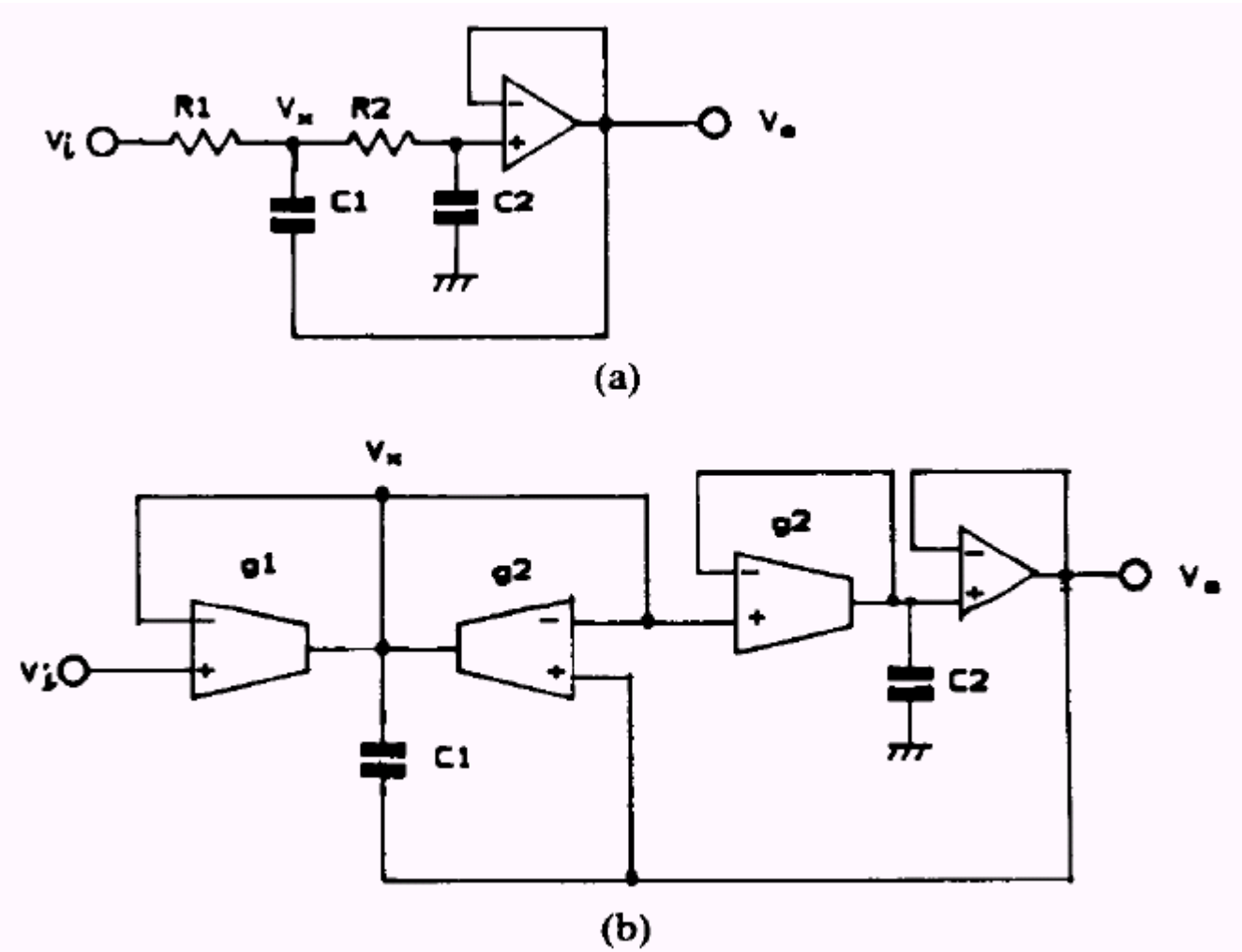
Canonical bandpass filter circuit with a floating capacitor

Second Order Gm-C Filter Structures

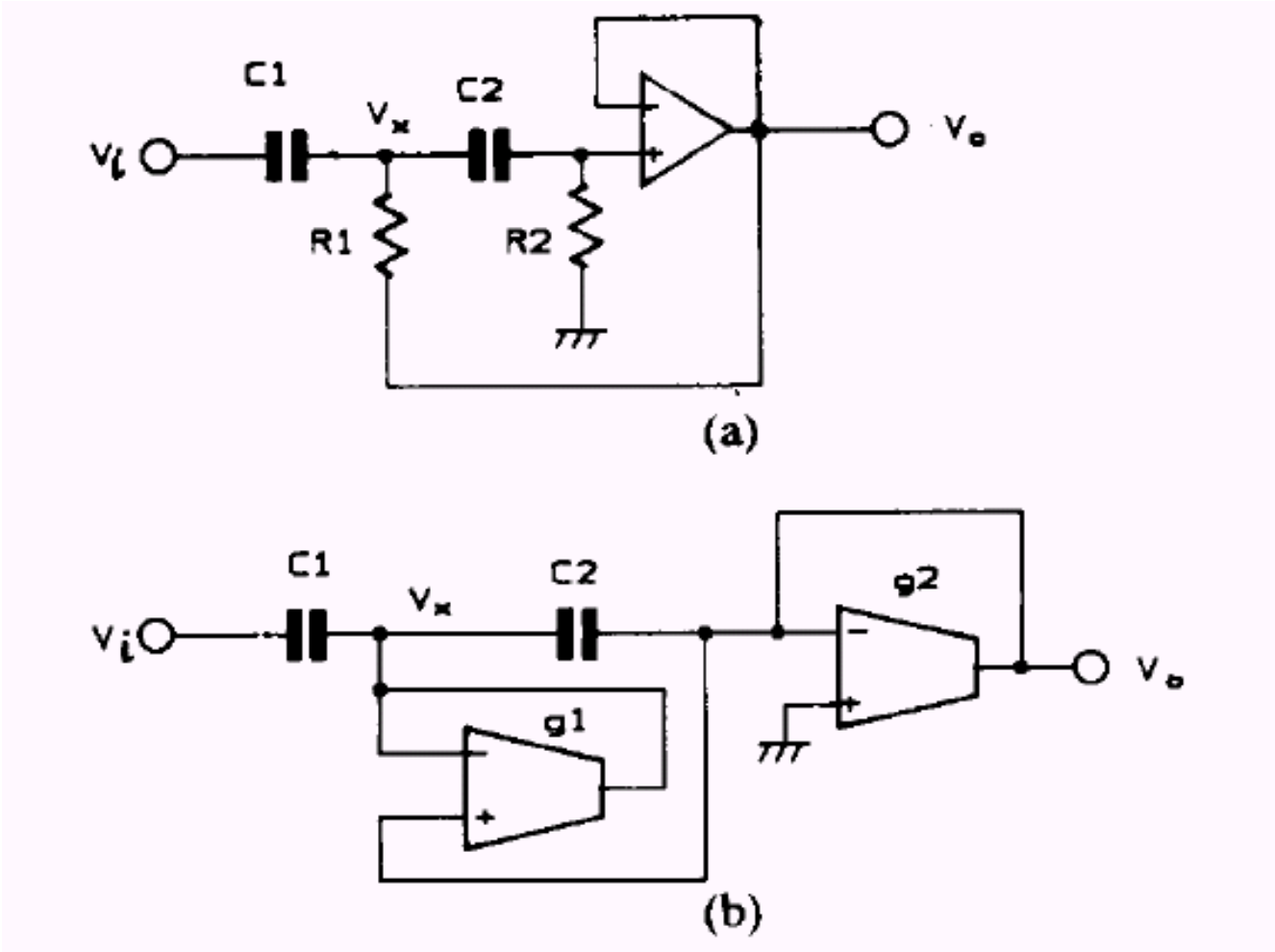


Canonical bandpass/lowpass filter with earthed capacitors

Second Order Gm-C Filter Structures



Second Order Gm-C Filter Structures



Cascade Design of High Order Filters

- In general, a high order filter can be implemented by cascading of the first- and second-order filters:

$$H(s) = \frac{\sum_{i=0}^{m} b_i s^i}{\sum_{i=0}^{n} b_i s^i} = \left(\prod_{i=1}^{l} \frac{\alpha_{2i} s^2 + \alpha_{1i} s + \alpha_{0i}}{s^2 + s\frac{\omega_{oi}}{Q_i} + \omega_{oi}^2}\right)\left(\frac{as+b}{s-p}\right)$$

$$= \prod_{i=1}^{l+1} H_i(s)$$