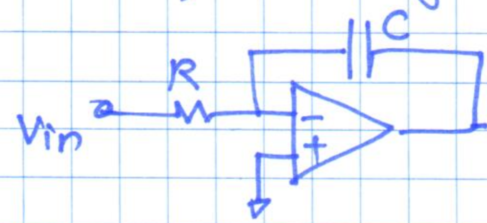
* Key Element in filter design (ladder) → Integrator

Example

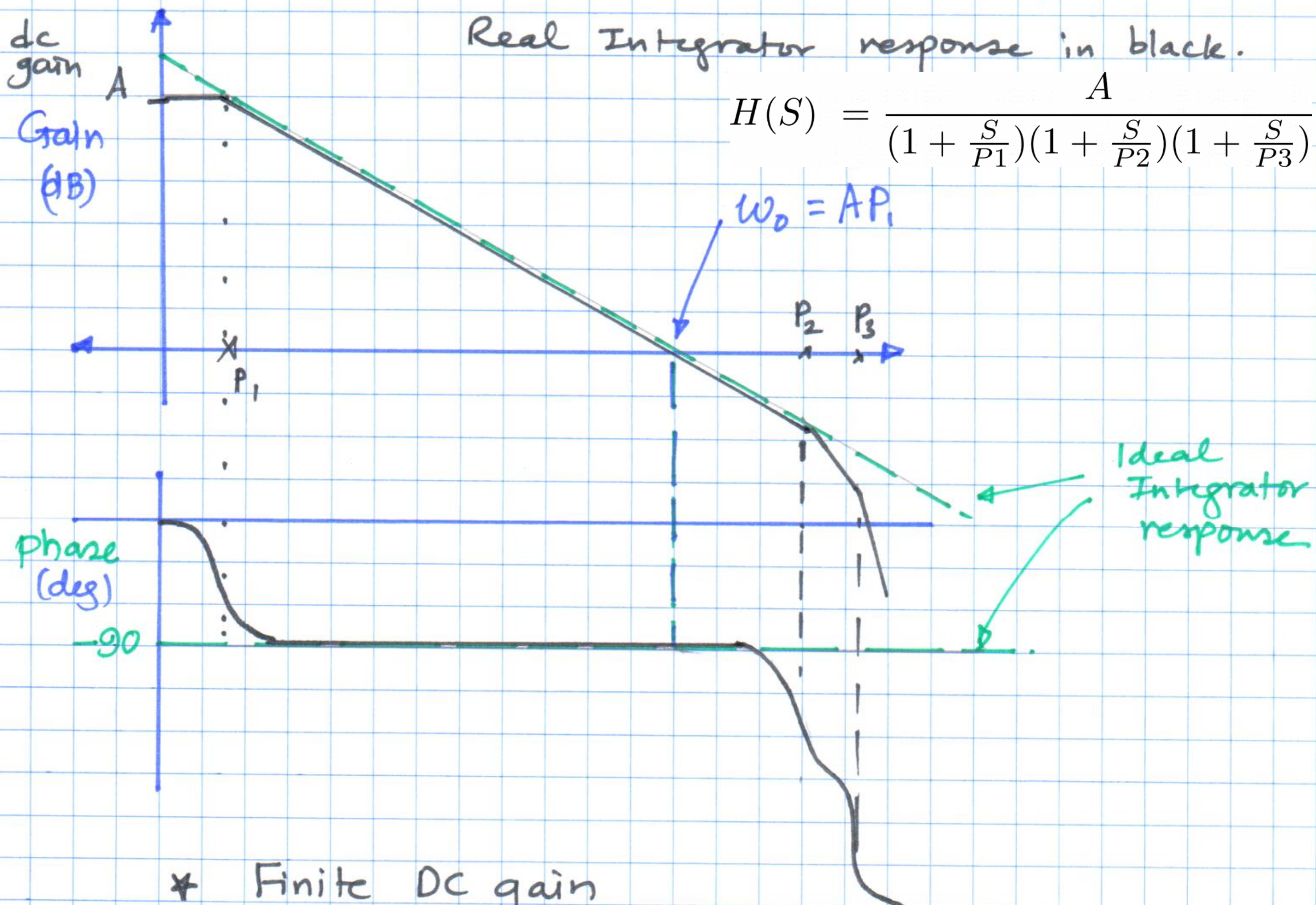


$$V_{out} = \frac{-V_{in}}{s(RC)}$$

Ideal Integrator Response shown in green. $H(S) = \frac{\omega_0}{S}$

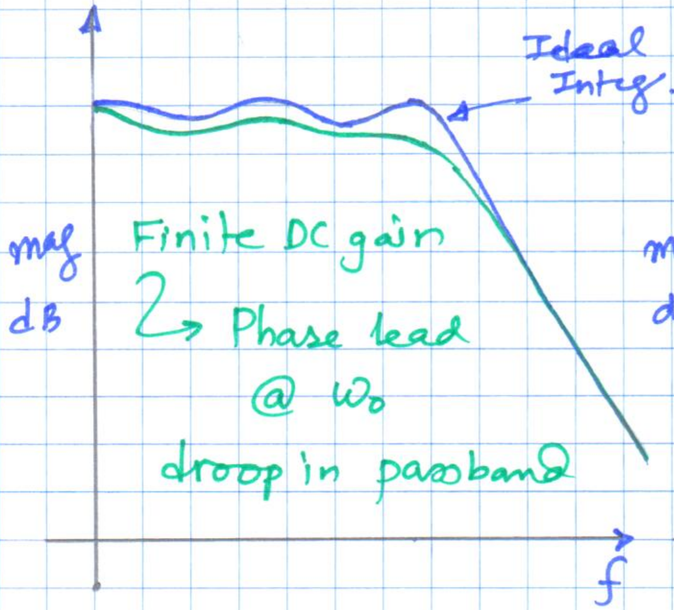
Real Integrator response in black.

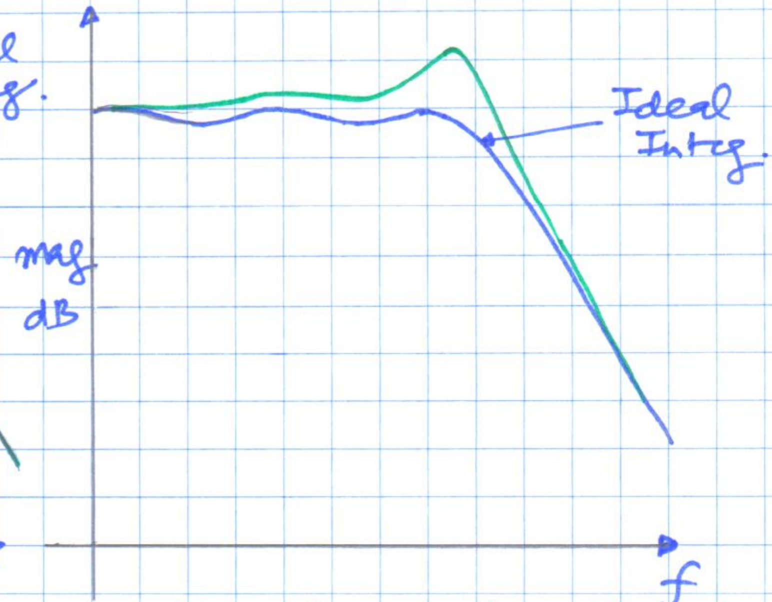
$$H(S) = \frac{A}{(1+\frac{S}{P1})(1+\frac{S}{P2})(1+\frac{S}{P3})}$$



* Finite DC gain

* Phase shift @ unity gain frequency due to Non-dominant poles P_2, P_3 etc.





Non-dom poles close to integrator UG.F ω_o.
→ phase lag @ ω_o
→ peaking - could be oscillatory. → careful.

Integrator Quality factor

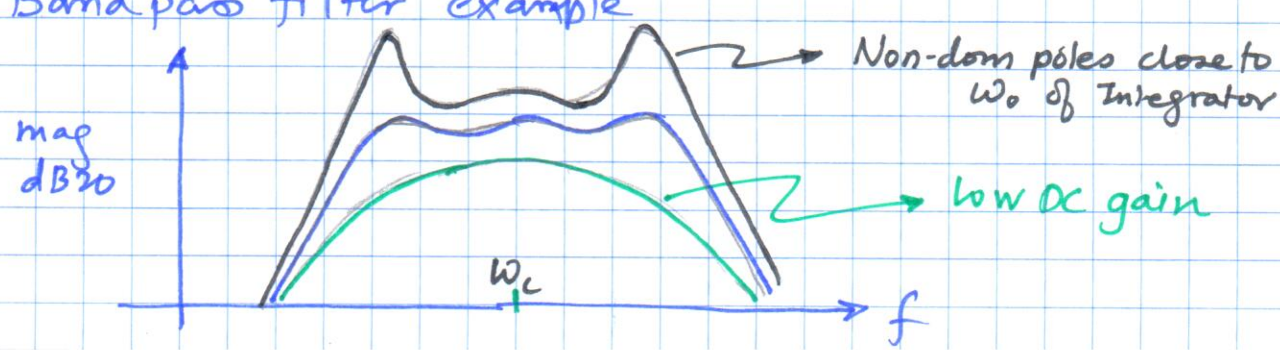
$$\text{Ideal integrator} = \frac{K}{s} = \frac{1}{j\omega RC}$$

$$\text{Non Ideal Integrator} = \frac{1}{(\text{Real}) + j(\text{Imag})}$$

$$Q_{\text{integrator}}(\omega) = \frac{\text{Imaginary}}{\text{Real}}$$

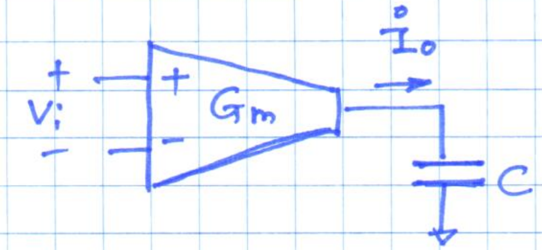
Real → $=0$ $Q = \infty$ @ ω_o

Bandpass filter example



Gm-C Filters

Gm – transconductance

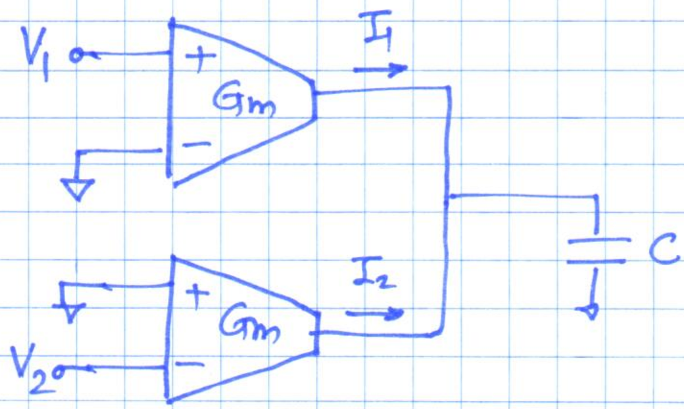


$i_o = G_m V_i$

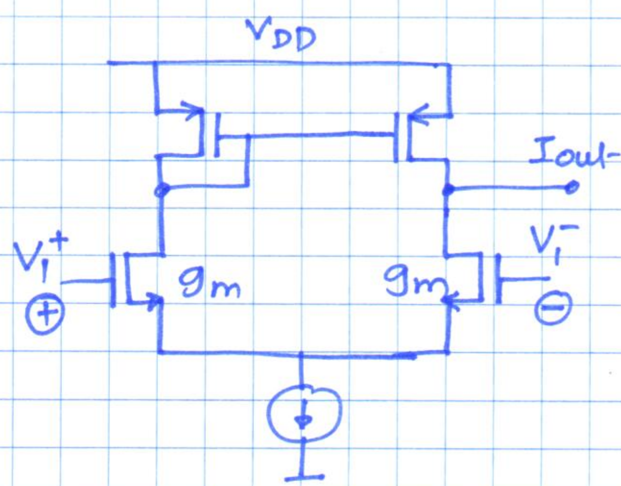
$$V_o = \frac{i_o}{sC} = \frac{G_m V_i}{sC}$$

$$\frac{V_o}{V_i} = \frac{\omega_o}{\omega} \rightarrow \left(\frac{G_m}{C}\right)$$

Multi input integrator / summer



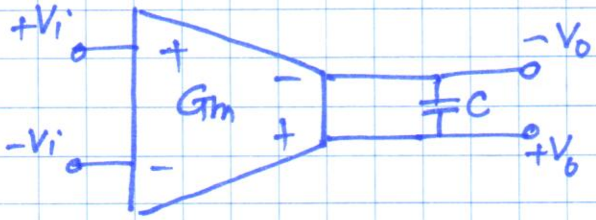
$$V_o = \frac{G_m}{sC}\left(V_1 - V_2\right)$$

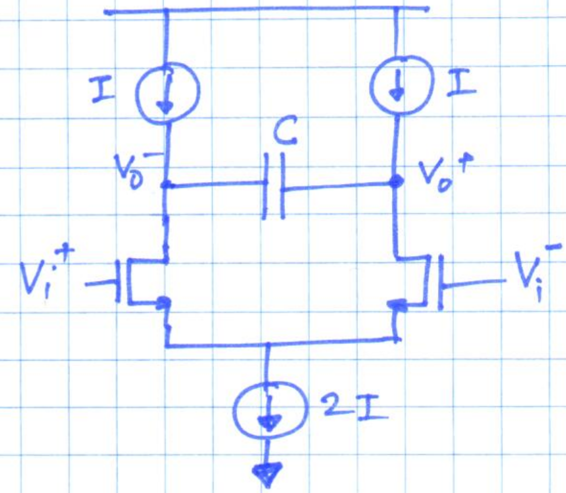


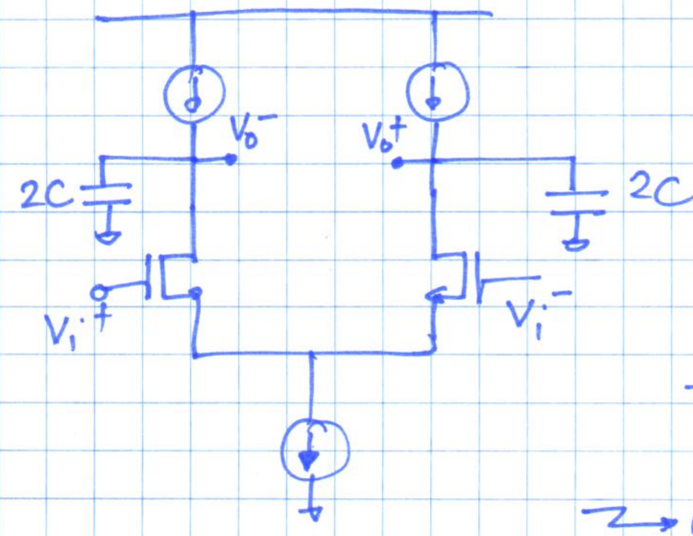
Gm-C filters

- \+ Simple circuit
- \+ Lends to high frequency performance
- – Linearity.
  - ↳ can be improved by source degeneration
- ⓞ Tuning Required due to Gm variations.

Fully-Differential Gm-C integrator





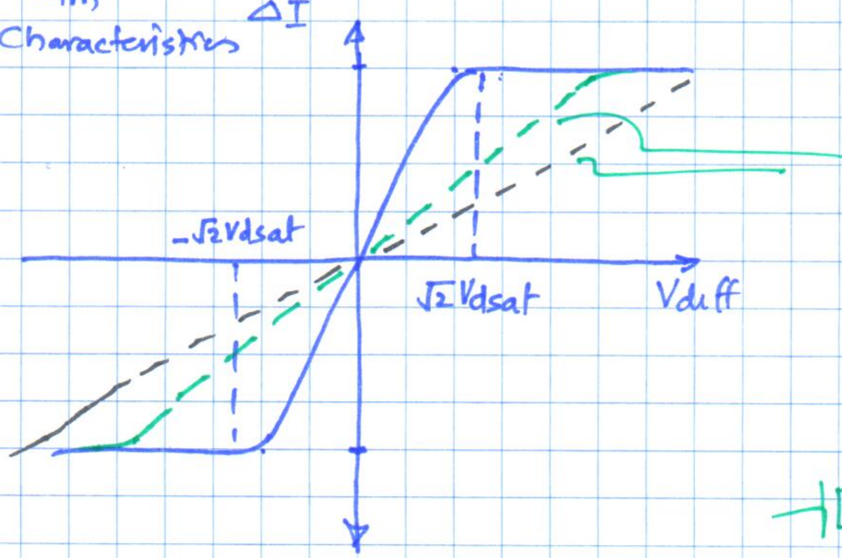


Better since common-mode path also has capacitors.

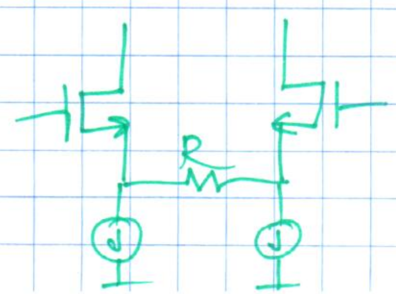
→ Although larger size.

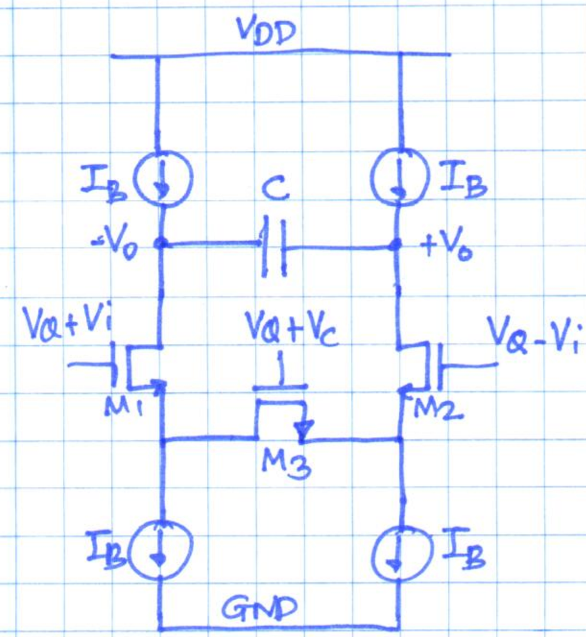
→ Reference H. Khorramabadi "High Freq. CMOS filters" JSSC DEC 84.

Gm Characteristics



Source degeneration to improve linearity of Gm cell.



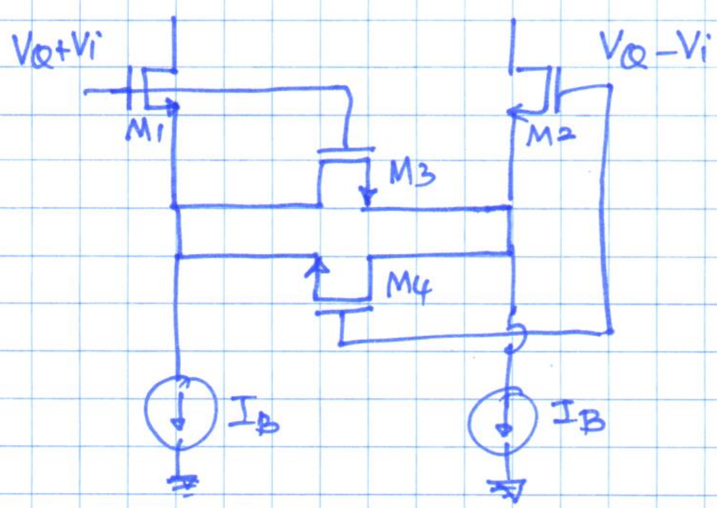


source degeneration using MOS Transistor M3 in triode region

V_c – used for tuning G_m & filter corner frequency

→ J.M. Khoury JSSC Dec. 91

Another variation



M3, M4 in triode region

They are biased from i/p signal.

Better distortion performance.

$$G_m = \frac{4K_1K_3}{(K_1+4K_3)}\sqrt{\frac{2I_B}{K_1\mu_n C_{ox}}}$$

$$K_1 = \left(\frac{W}{L}\right)_1 \quad K_3 = \left(\frac{W}{L}\right)_3$$

→ Reference F. KRUMMENACHER.

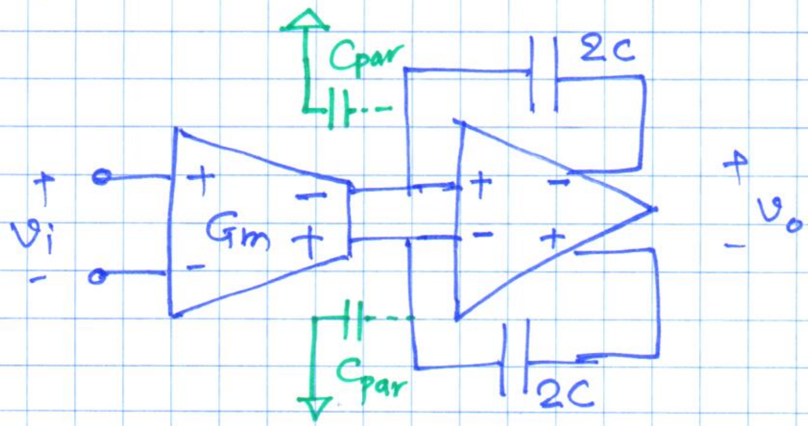
A 4MHz CMOS. Cont. time filter with on-chip Automatic tuning. JSSC – JUNE 1988.

Key issue in design of High Frequency Gm-C filter

* Parasitic caps. (top plate parasitics, interconnect caps
Next stage loading.)
→ appear in parallel with integration cap. affecting frequency response accuracy.
→ can't be compensated & matched.

Goal – Parasitic Insensitive topology.

* Gm-C OPAMP Filters



* Parasitic caps @ o/p of Gm – connected to virtual gnd.
* Gm o/p doesn't handle large swings
* Higher Integrator gain
* wideband OTA can be used instead of OPAMP.

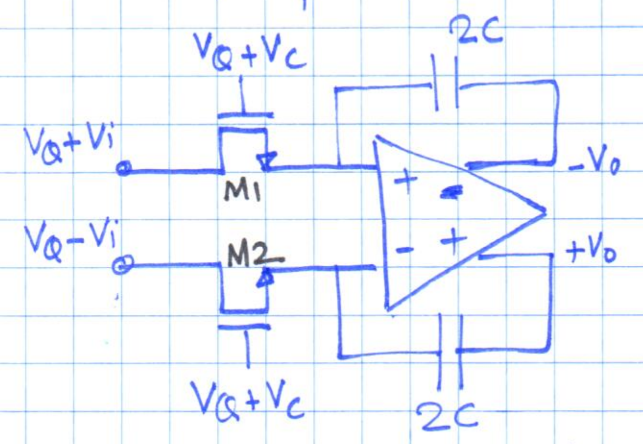
Ref: 1. K.S. TAN & P. GRAY JSSC DEC 78

2. C. Laber & P. GRAY JSSC April 93

- Overall higher power

MOSFET-C Filters

→ Replace Gm transconductor with MOS in triode region.
→ Lower power.



M1 & M2 in triode region.

$$\omega_o = \frac{1}{RC} \quad \text{UGF of Integrator.}$$

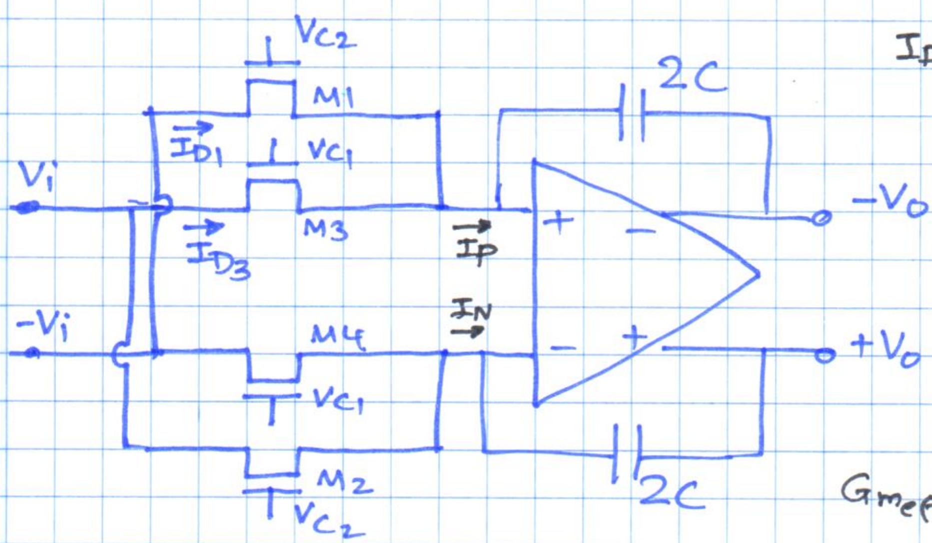
$$R = \frac{1}{\mu C_{ox}\left(\frac{W}{L}\right)(V_C - V_T)}$$

* Fully-balanced operation - MOS even-order non-linearities are cancelled.
* Third order (odd) non-linearities - keep signal amplitude low

Ref: Fully Integrated Active RC filters in MOS tech"
M. Banu, Y. Tsividis - JSSC Dec 1983.

Improving Linearity further

TRIODE EQ. $I_D = \underbrace{K}_{\mu_n C_{ox}(W/L)}\left(V_{gs} - V_T - \frac{V_{ds}}{2}\right)V_{ds}$



$$I_{D1} = -K\left(V_{gs_1} - V_T + \frac{V_i}{2}\right)V_i$$

$$I_{D3} = K\left(V_{gs_3} - V_T - \frac{V_i}{2}\right)V_i$$

$$I_P = I_{D1} + I_{D3}$$
$$= KV_i\left(V_{gs_3} - V_{gs_1} - V_i\right)$$

$$I_N = KV_i\left(V_{gs_1} - V_{gs_3} - V_i\right)$$

$$I_P - I_N = 2KV_i\left(V_{gs_3} - V_{gs_1}\right)$$

$$G_{m_{eff}} = \frac{\partial(I_P - I_N)}{\partial(2V_i)} = \mu_n C_{ox}\left(\frac{W}{L}\right)\underbrace{\left(V_{C_1} - V_{C_2}\right)}_{\text{Const}}$$

Ref: Z. Czarnul IEEE. Tran CAS JULY 1986.
M. Ismail JSSC Feb 88.

Large Signal Linear behavior
→ : 50-70dB linearity.