ECEN474: (Analog) VLSI Circuit Design
Fall 2011

Lecture 23: OTA-C Filters

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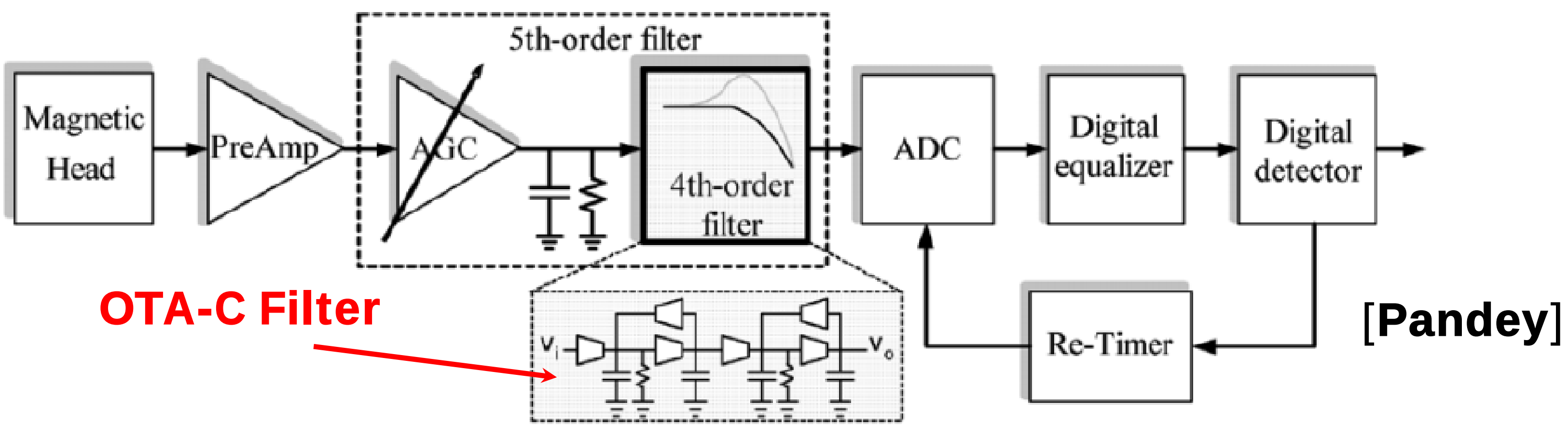
Agenda

- OTA-C Filters
- Material is related primarily to Project #3
- Full class on filters offered (458, 622)

OTA-C Filter Applications

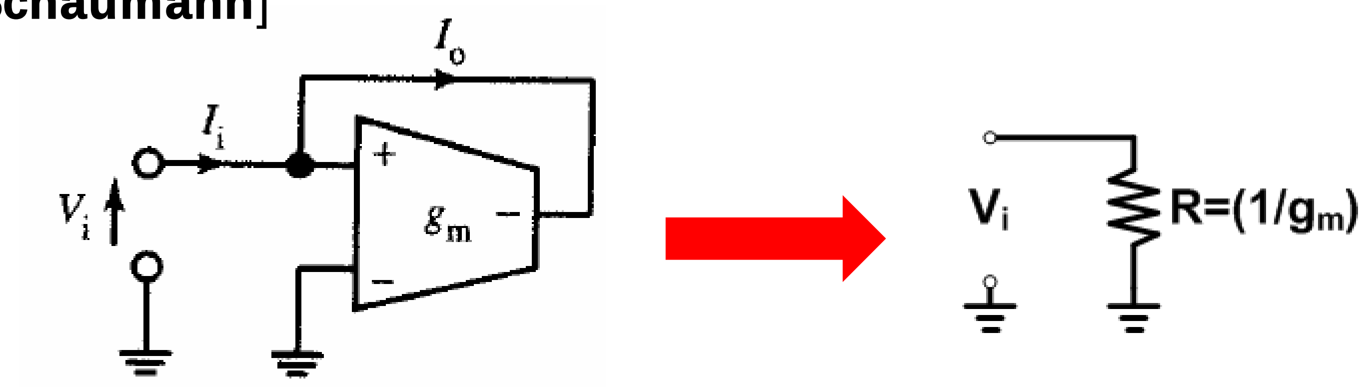
- Hard-disk drives require linear phase filters (>100MHz)
- RF systems require filters in the GHz range
- Wireless xcvrs intermediate frequency (IF) filters (>100MHz)
- Often used with variable gain amplifiers (VGAs) for automatic-gain control (AGC) to maximize dynamic range
- Low noise, low power, and high linearity are required



Hard-Disk Drive Receiver Front-End

OTA-Based Active Resistor

[**Schaumann**]

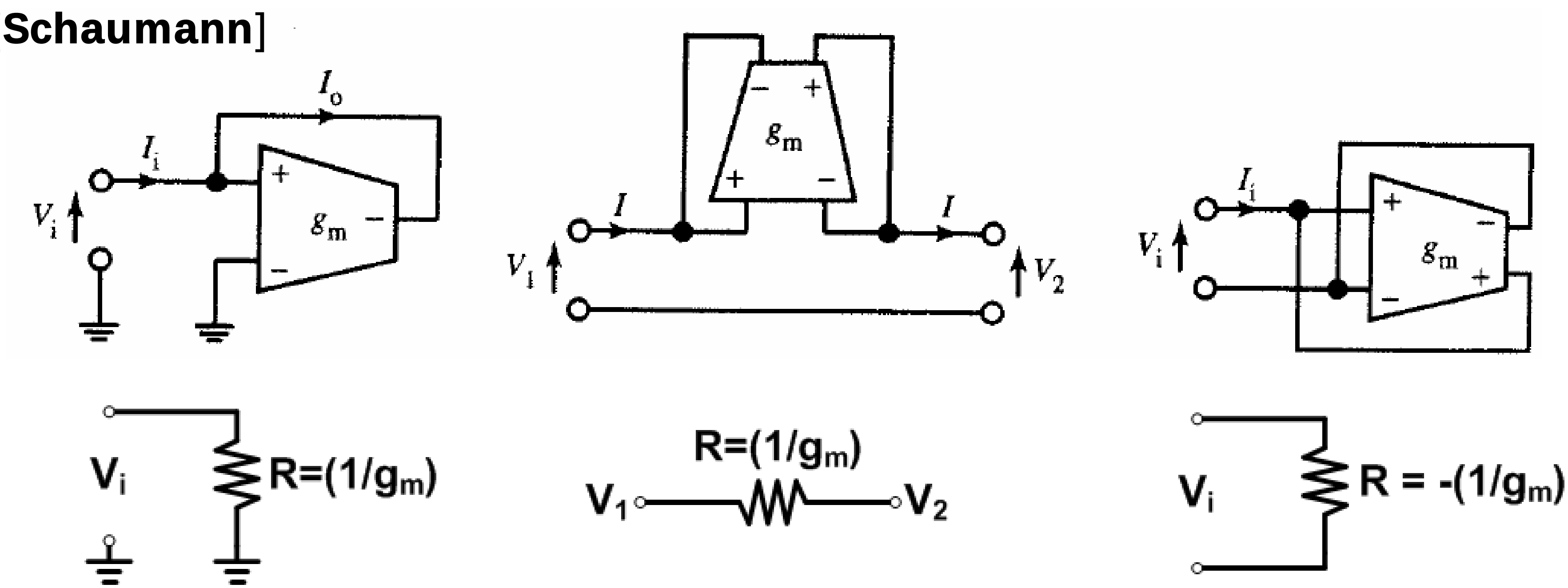


$$I_i = I_o = g_m V_i$$

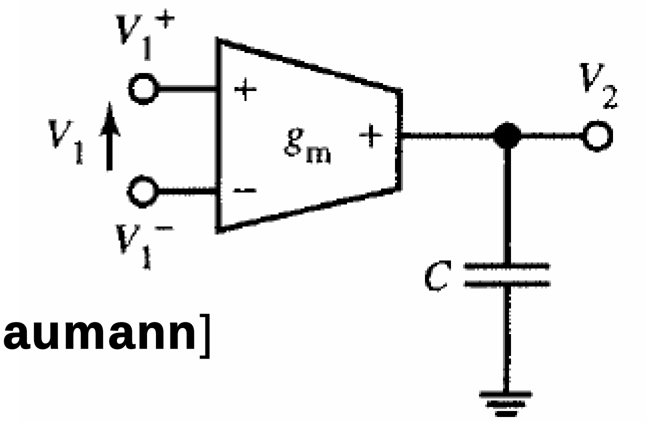
$$R = \frac{V_i}{I_i} = \frac{1}{g_m}$$

OTA-Based Active Resistors

[**Schaumann**]



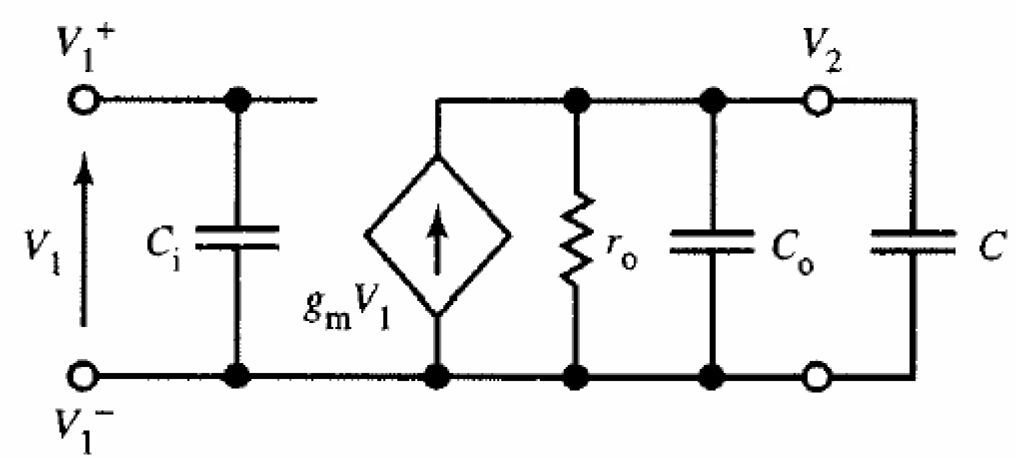
OTA-Based Integrator



[**Schaumann**]

Ideally $\frac{V_2}{V_1} = \frac{g_m}{sC}$

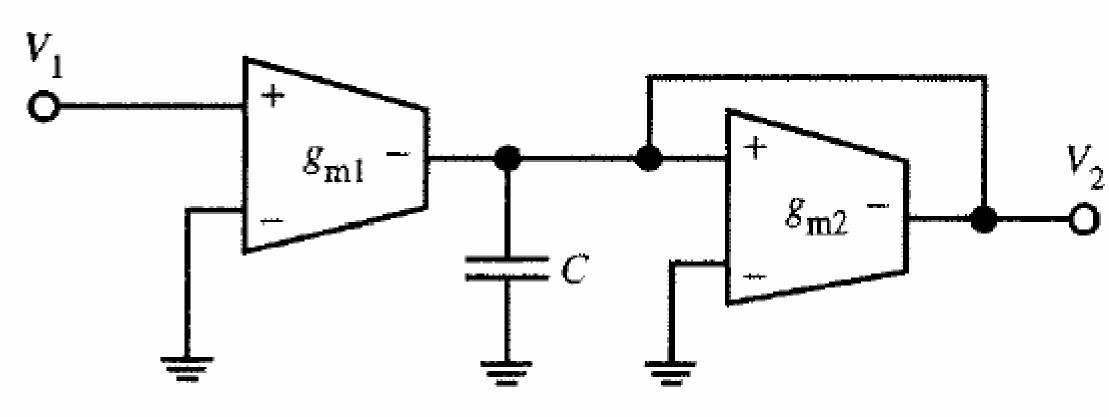
- Finite OTA r_o causes a non-zero pole
- OTA C_o reduces integration constant



$$\frac{V_2}{V_1} = \frac{g_m}{s(C + C_o) + g_o}$$

Lossy g_m-C Integrator (1st-Order LPF)

[**Schaumann**]

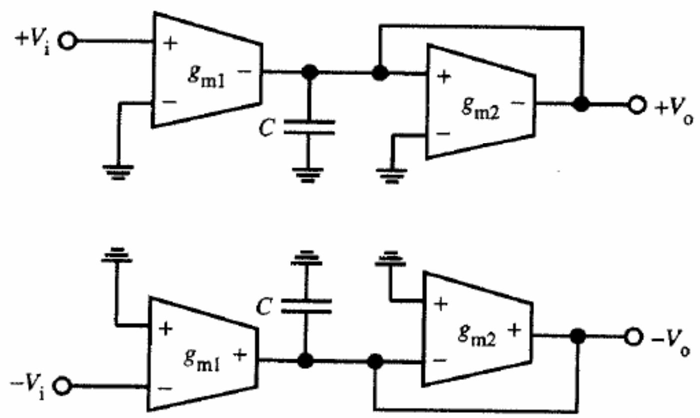


Ideally $$\frac{V_2}{V_1} = -\frac{g_{m1}}{sC + g_{m2}}$$

Considering finite OTA output resistance and non - zero input and output capacitance

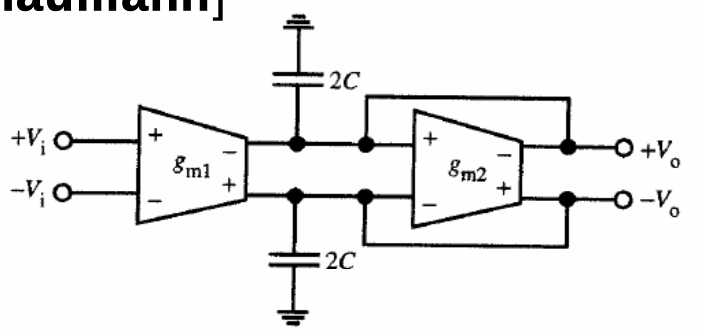
$$\frac{V_2}{V_1} = -\frac{g_{m1}}{s\left(C + 2C_o + C_i\right) + g_{m2} + 2g_o}$$

Fully Differential Lossy g_m-C Integrator

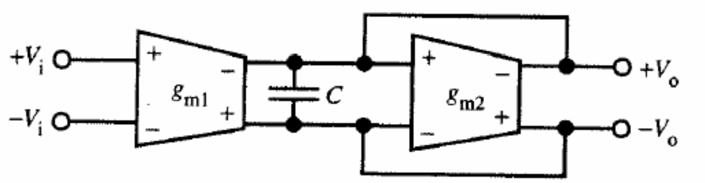


(a)

[**Schaumann**]



(b)

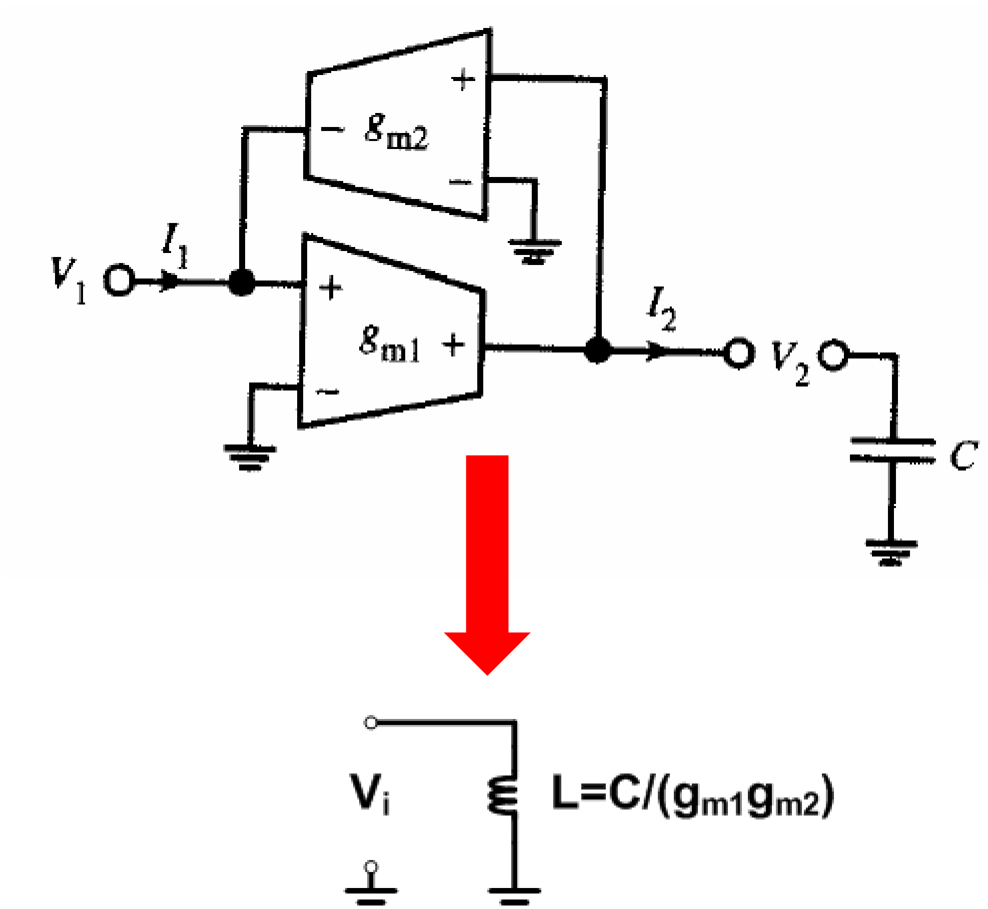


(c)

- Pseudo-Differential
- Fully Differential
  - 2C because full gm current goes to each side
- Why just C here?

OTA-Based Inductor

[**Schaumann**]



$$I_1 = g_{m2}V_2$$

$$I_2 = g_{m1}V_1$$

From these two equations

$$\frac{V_1}{I_1} = \frac{1}{g_{m1}g_{m2}}\frac{I_2}{V_2}$$

$$Z_1 = \frac{1}{g_{m1}g_{m2}}Y_2$$

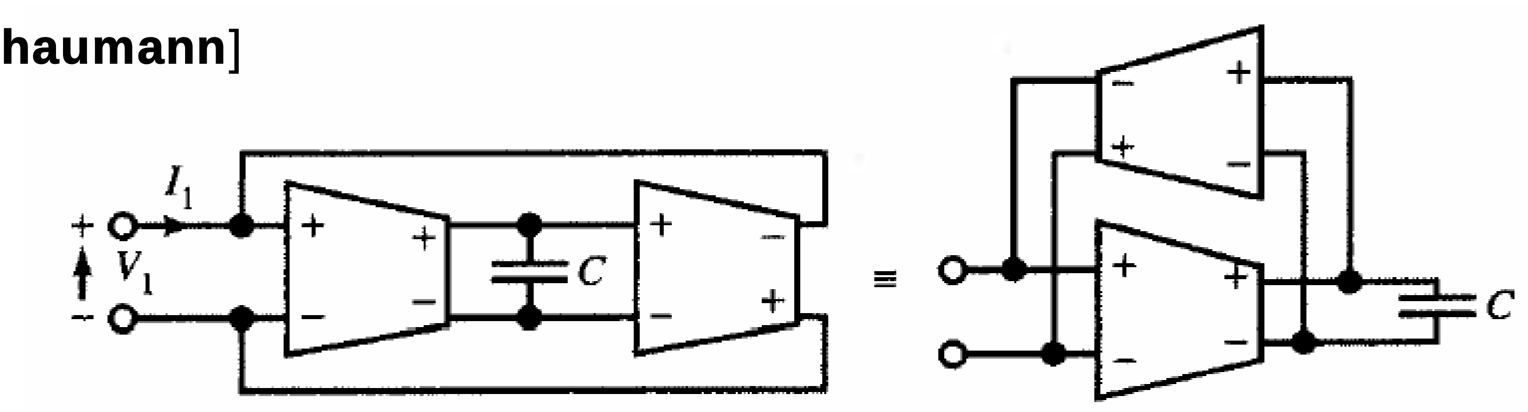
If $Y_2 = sC$

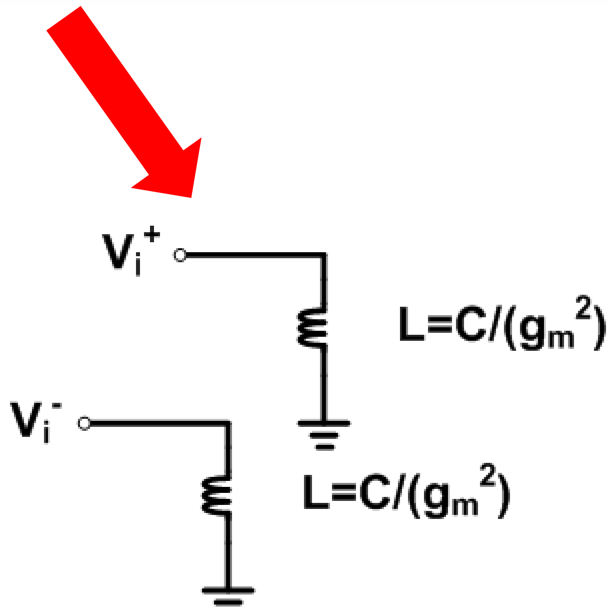
$$Z_1 = \frac{sC}{g_{m1}g_{m2}} = sL_{eff}$$

$$L_{eff} = \frac{C}{g_{m1}g_{m2}}$$

Differential Grounded Inductor

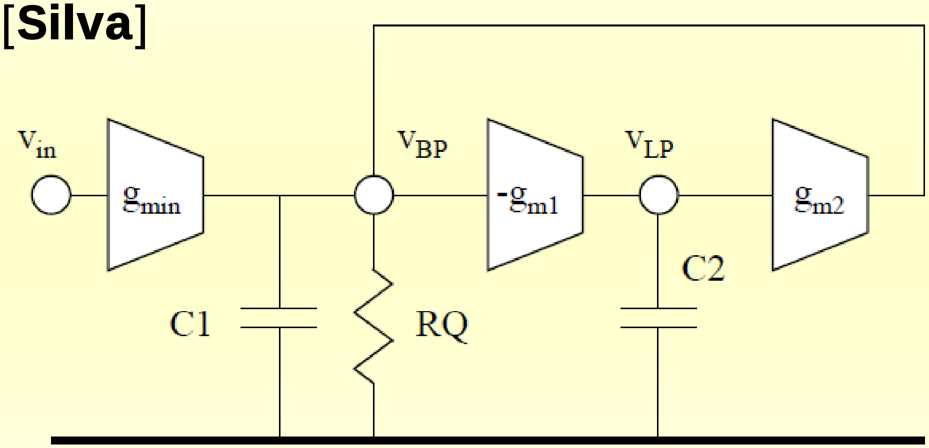
[**Schaumann**]



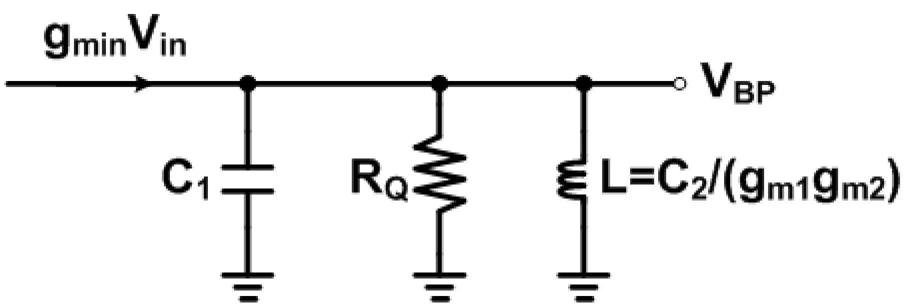


Second-Order Filter

[Silva]



Continuous-time biquad



$$\frac{V_{BP}}{V_{in}} = \frac{s\left(\frac{g_{\min}}{C_1}\right)}{s^2 + s\left(\frac{1}{R_Q C_1}\right) + \frac{g_{m1}g_{m2}}{C_1 C_2}} = \frac{s\left(\frac{g_{\min}}{C_1}\right)}{s^2 + s\left(\frac{\omega_o}{Q}\right) + \omega_o^2}$$

$$\frac{V_{LP}}{V_{in}} = -\frac{\left(\frac{g_{\min}g_{m1}}{C_1 C_2}\right)}{s^2 + s\left(\frac{1}{R_Q C_1}\right) + \frac{g_{m1}g_{m2}}{C_1 C_2}} = -\frac{\left(\frac{g_{\min}g_{m1}}{C_1 C_2}\right)}{s^2 + s\left(\frac{\omega_o}{Q}\right) + \omega_o^2}$$

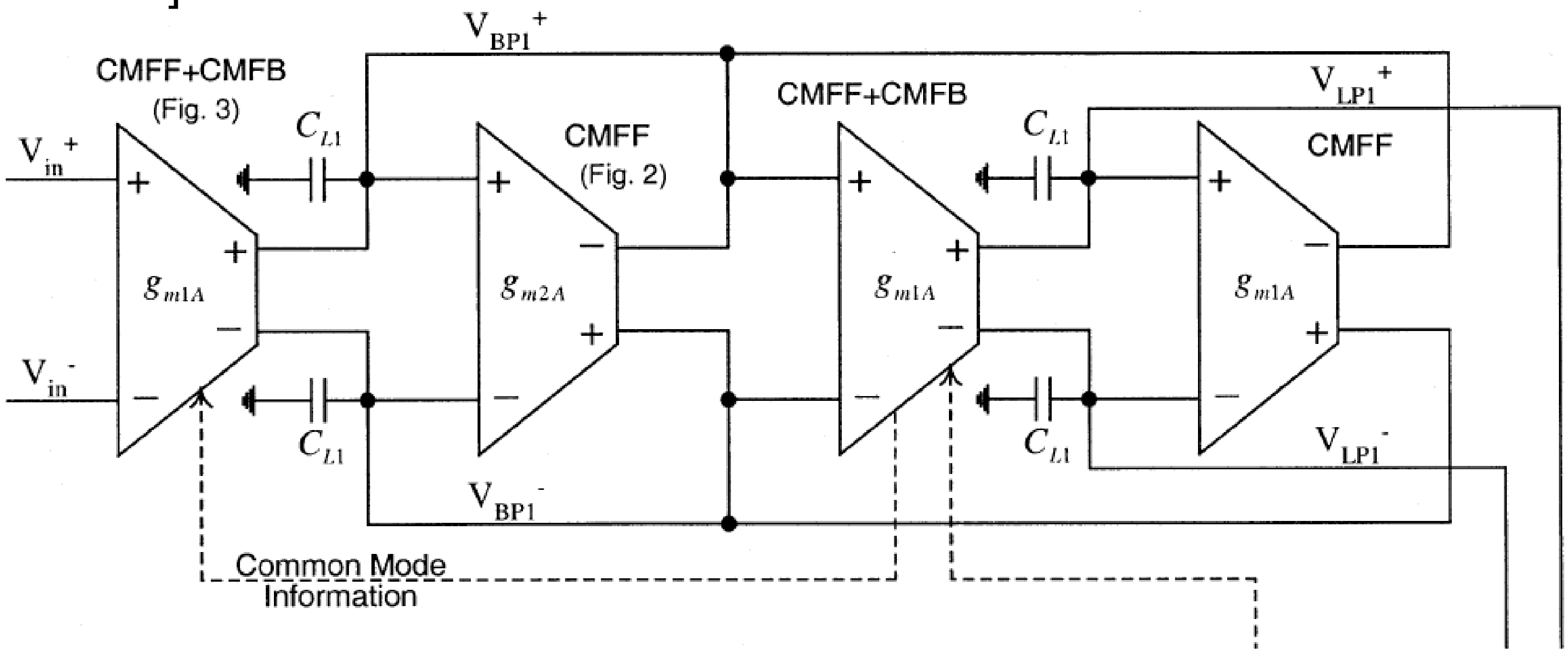
$$\omega_0 = \sqrt{\frac{g_{m1}g_{m2}}{C_1 C_2}}$$

$$Q = \sqrt{\frac{C_1}{C_2}\left(g_{m1}g_{m2}R_Q{}^2\right)}$$

$$A_{Vpeak} = g_{\min}R_Q$$

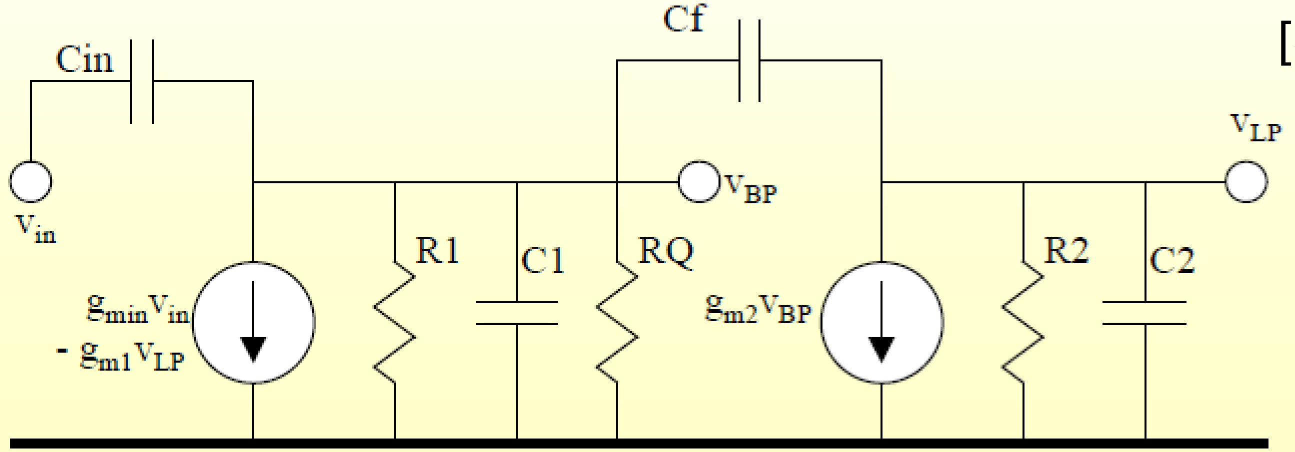
Differential Second-Order Filter

[**Mohieldin**]



OTA Output Resistance Effects

[Silva]



$$\omega_0 \cong \omega_{0ideal}\sqrt{1+\frac{1}{Q_{ideal}A_V}}$$

CENTER FREQUENCY IS LITTLE SENSITIVE TO A_V

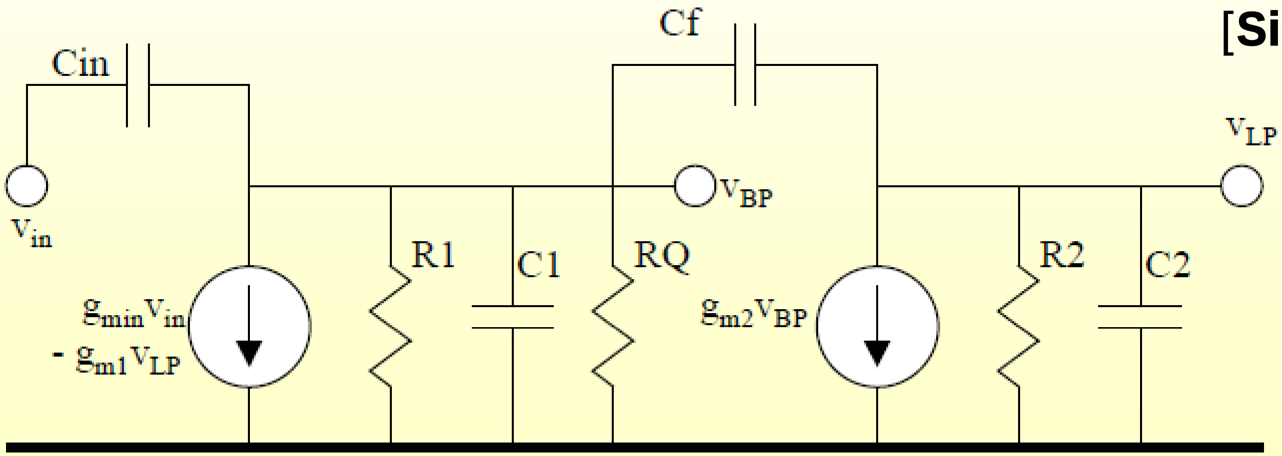
$$BW \cong BW_{ideal}\left(1+2\frac{Q_{ideal}}{A_V}\right)$$

BW IS QUITE SENSITIVE TO A_V

$Av=g_{m1}R_1$ ($R_1=R_2$ OTA output resistance)

OTA Non-Dominant Pole Effects

[Silva]



Single pole model:

$$g_m \cong \frac{g_{m0}}{1+\frac{s}{\omega_{p1}}}$$

$$\omega_0 = \omega_{0ideal}\sqrt{\frac{1}{1+\frac{2BW_{ideal}}{\omega_{P1}}}}$$

$$error \cong -\frac{BW_{ideal}}{\omega_{P1}}$$

Sensitive

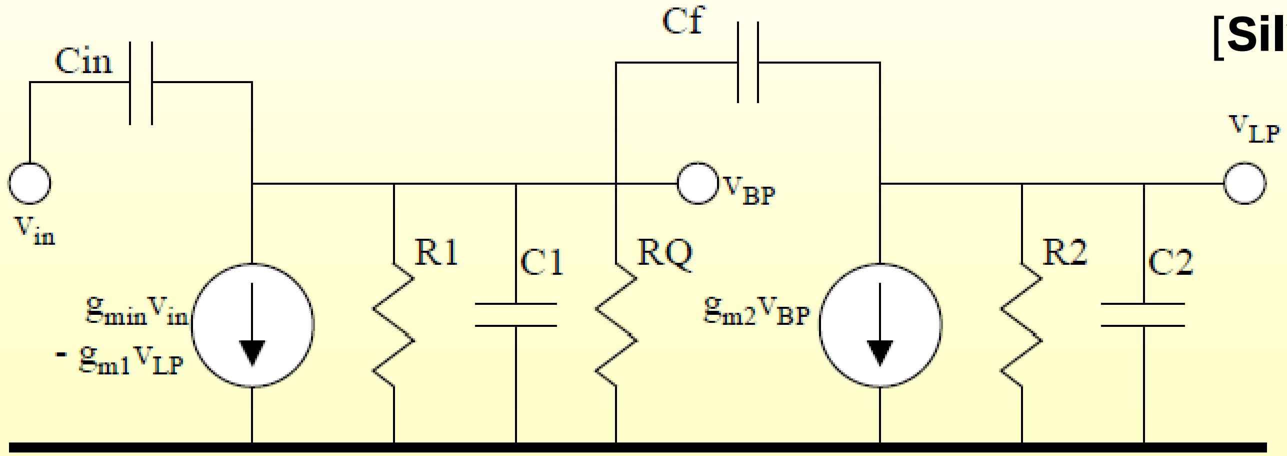
$$BW \approx BW_{ideal}\left(1 - 2Q_{ideal}\frac{\omega_{0ideal}}{\omega_{P1}}\right)$$

$$error \approx -2Q_{ideal}\frac{\omega_{0ideal}}{\omega_{P1}}$$

Quite sensitive !!!

OTA Parasitic Capacitor Effects

[Silva]



$$\omega_0 = \omega_{0ideal}\sqrt{\frac{1}{1+\frac{C_f}{C_1}+\frac{C_f}{C_2}+\frac{C_{in}(C_2+C_f)}{C_1C_2}}}$$

Little sensitive

$$BW = BW_{ideal}\frac{1+\left(1+\frac{g_{m2}-g_{m1}}{g_1}\right)\frac{C_f}{C_2}}{1+\frac{C_{in}}{C_1}+\frac{C_f}{C_1}+\frac{C_f}{C_2}\left(1+\frac{C_{in}}{C_1}\right)}$$

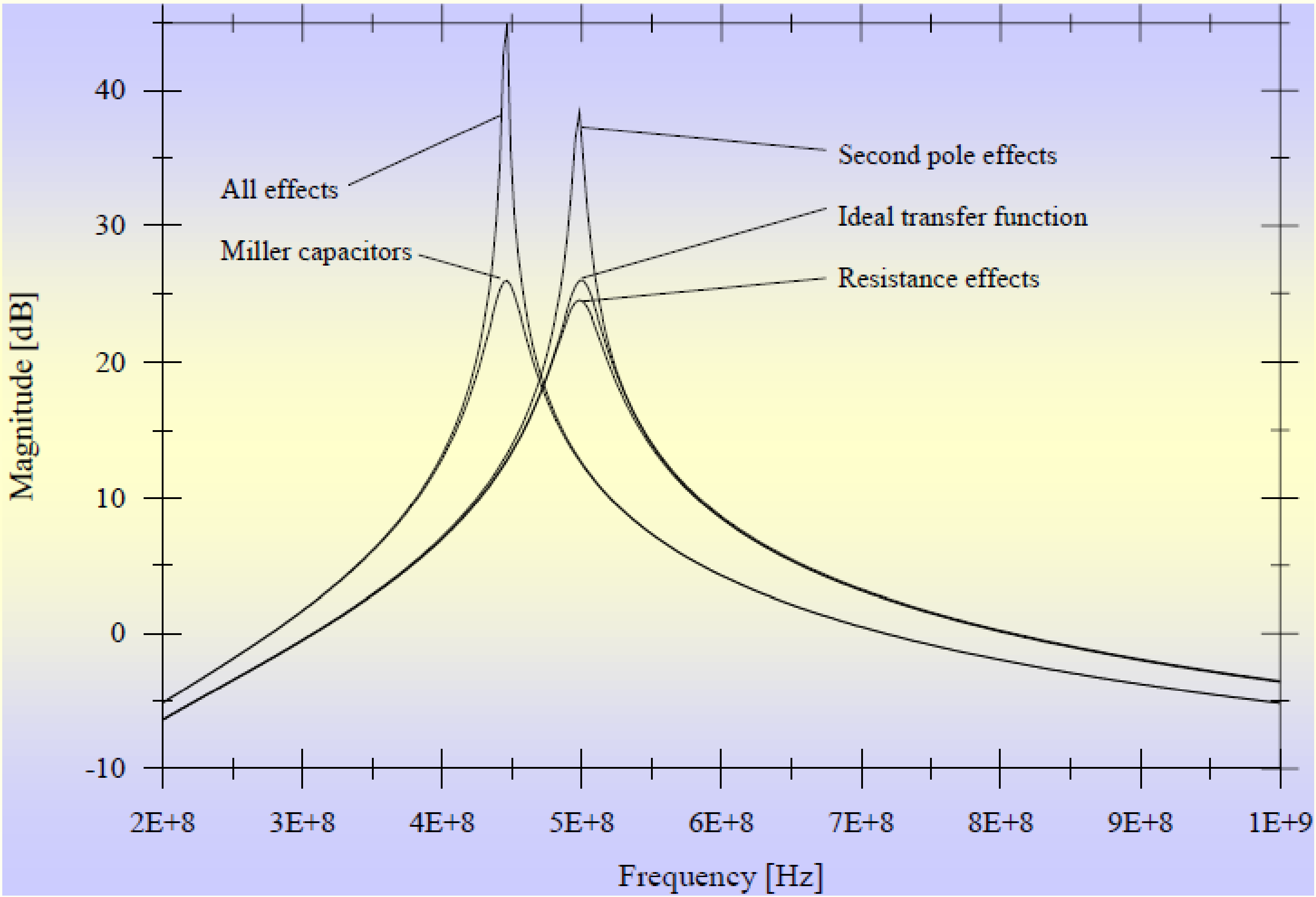
Little sensitive

C1 and C2 are affected by the grounded parasitic capacitors (partially corrected by the automatic tuning system).

Cin introduces a high frequency zero.

Filters are little sensitive to miller effects !!!

OTA-C BPF Modeling Simulations



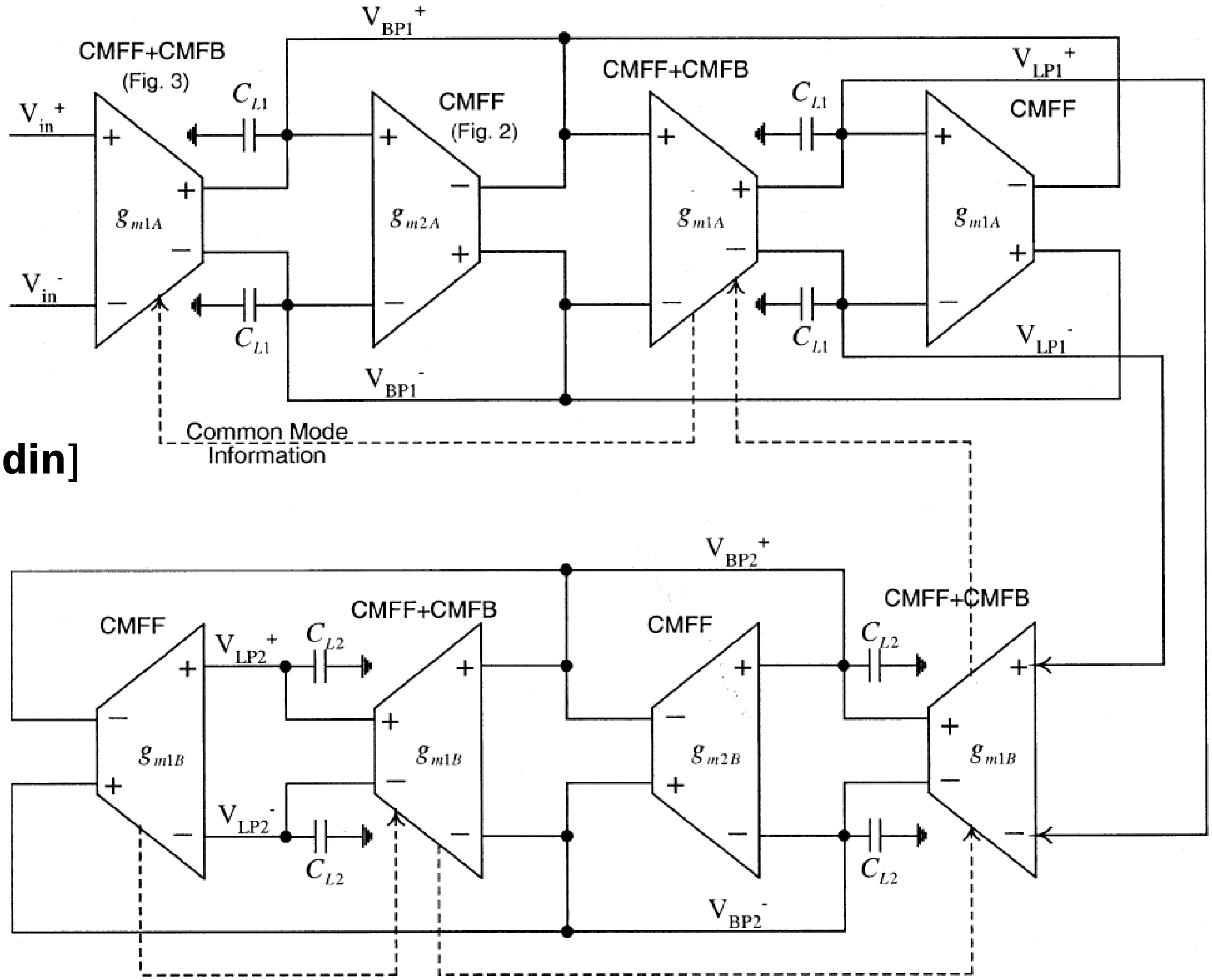
4th-Order BPF

[**Silva**]

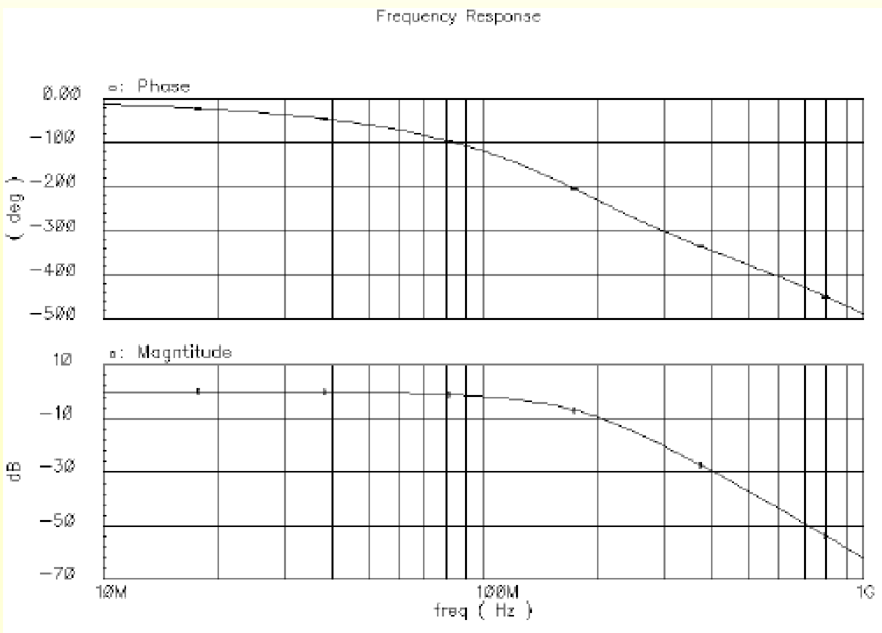
- **Little sensitve to OTA output resistances**
- **Very sensitive to second poles**
- **Parasitic capacitors should be accounted in the ATS (matching)**

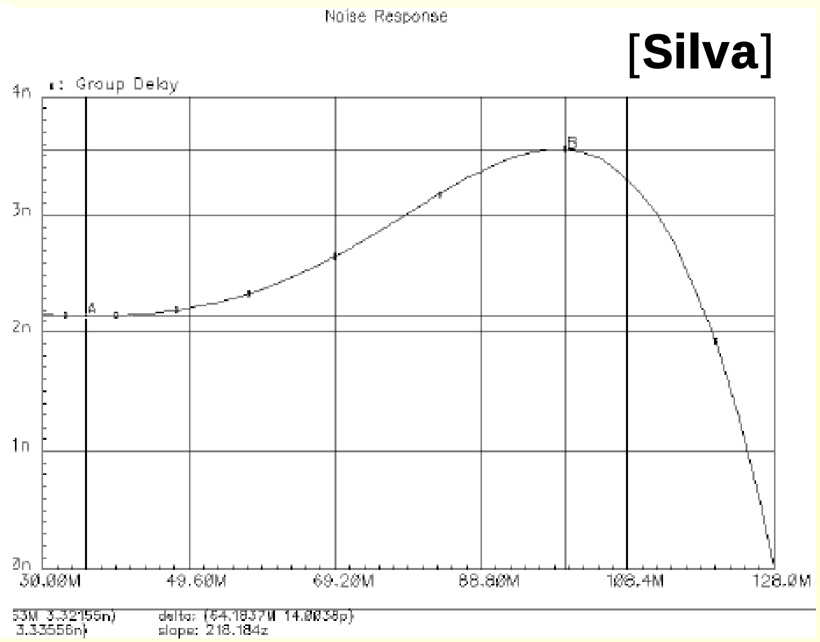
4th-Order Filter Example

[**Mohieldin**]



Magnitude, Phase, and Group Delay



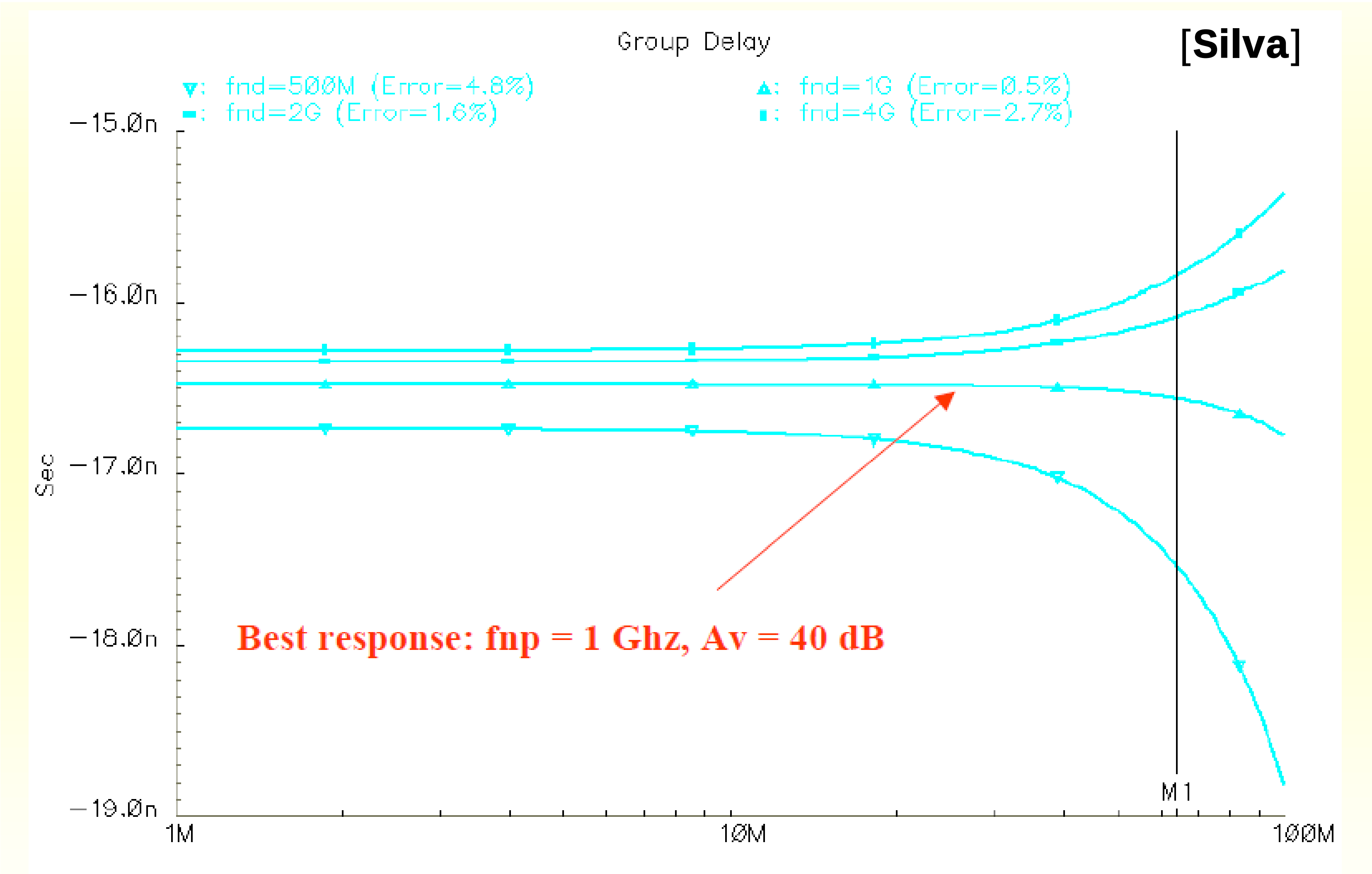


[Silva]

Magnitude and phase response for the 4th order filter

Group delay: Effects of the parasitic poles

Optimization: Non-Dominant Pole & DC Gain



Useful References

IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS—I: REGULAR PAPERS, VOL. 53, NO. 4, APRIL 2006 811

A CMOS 140-mW Fourth-Order Continuous-Time Low-Pass Filter Stabilized With a Class AB Common-Mode Feedback Operating at 550 MHz

Pankaj Pandey, Jose Silva-Martinez, and Xuemei Liu

IEEE JOURNAL OF SOLID-STATE CIRCUITS, VOL. 38, NO. 4, APRIL 2003 663

Brief Papers

A Fully Balanced Pseudo-Differential OTA With Common-Mode Feedforward and Inherent Common-Mode Feedback Detector

Ahmed Nader Mohieldin, *Student Member, IEEE*, Edgar Sánchez-Sinencio, *Fellow, IEEE*, and José Silva-Martínez, *Senior Member, IEEE*

- “Design of Analog Filters” by R. Schauman (Filters Textbook)

Next Time

- Analog Applications
  - Variable-Gain Amplifiers
  - Switch-Cap Filters, Broadband Amplifiers
- Bandgap Reference Circuits
- Distortion