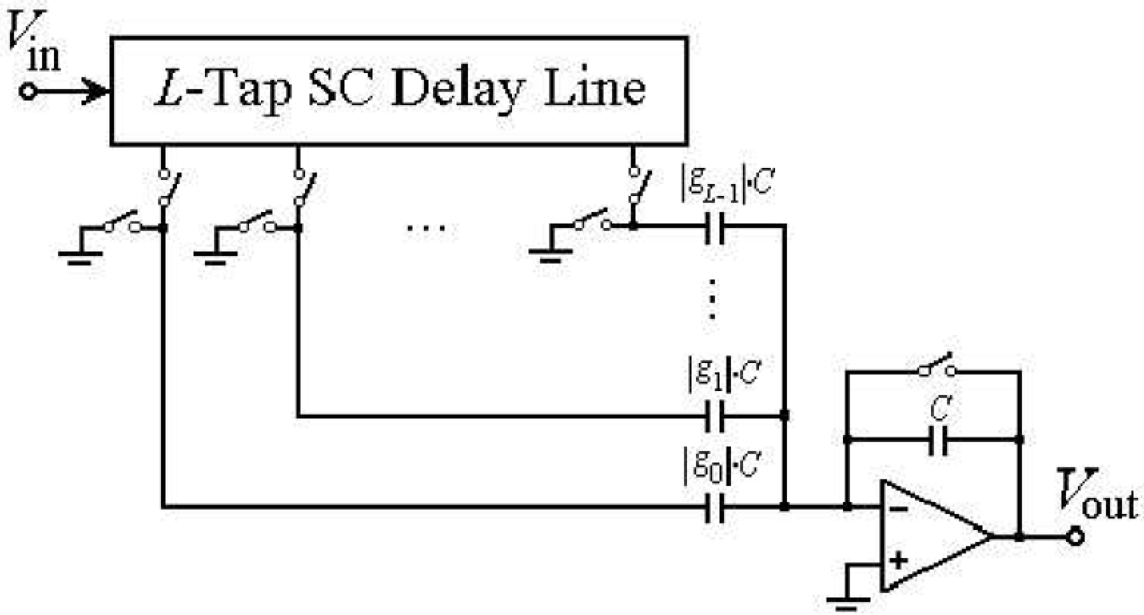
Direct-Form SC Filters

Direct-Form FIR SC Filter Realization

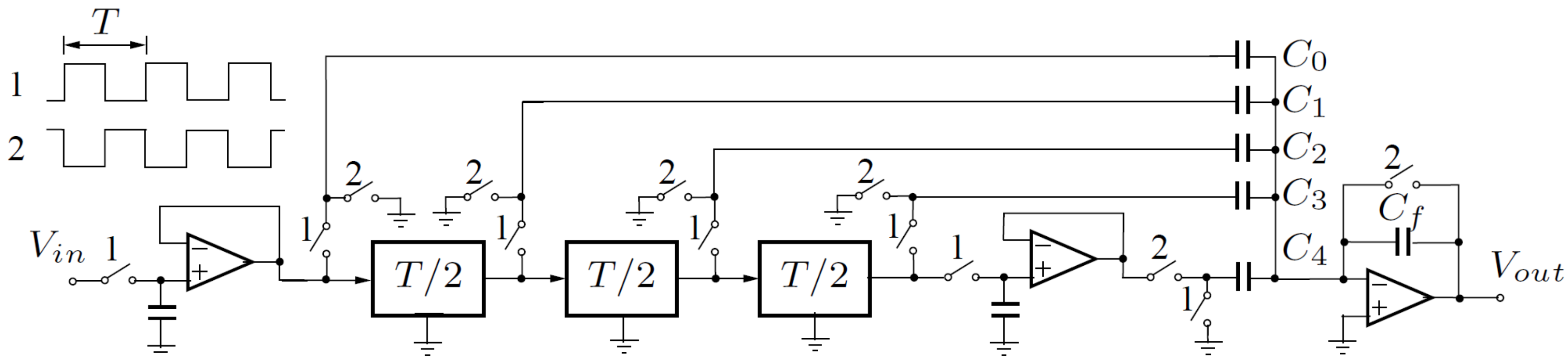
(L-1)th-order FIR SC filter:

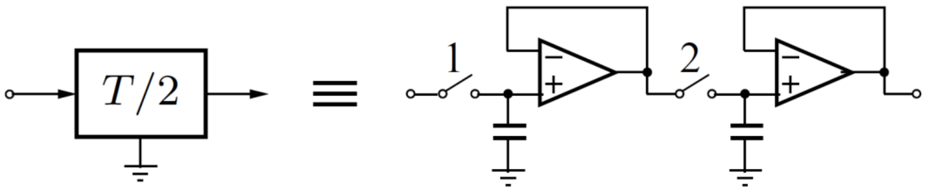


$$\frac{V_{out}}{V_{in}}(z) = \sum_{k=0}^{L-1} g_k z^{-k}$$

Direct-Form FIR SC Filter Realization

Ex.: 4th-order SC FIR filter

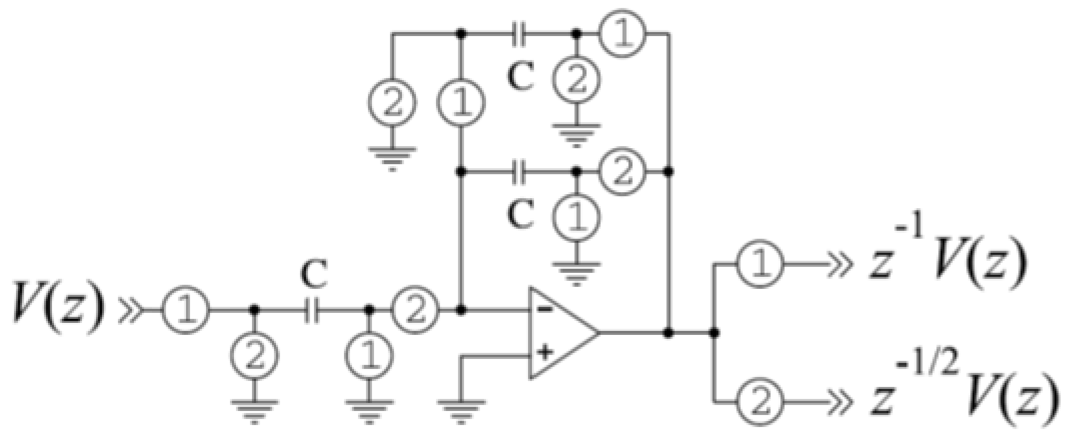




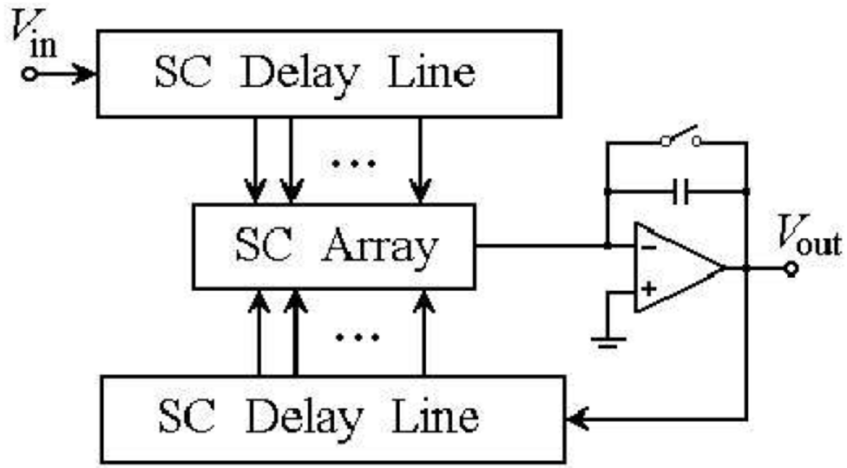
$$\frac{V_{out}}{V_{in}}(z) = -\frac{C_0}{C_f} - \frac{C_1}{C_f}z^{-1} - \frac{C_2}{C_f}z^{-2} - \frac{C_3}{C_f}z^{-3} + \frac{C_4}{C_f}z^{-4}$$

Direct-Form FIR SC Filter Realization

Reduction of the number of amplifiers by a multiplexing technique



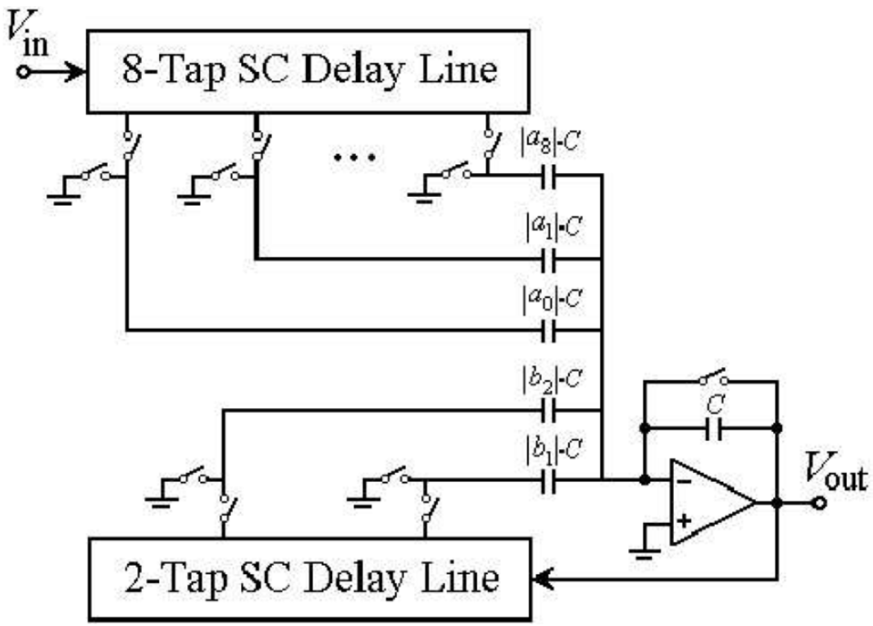
Direct-Form IIR SC Filter Realization



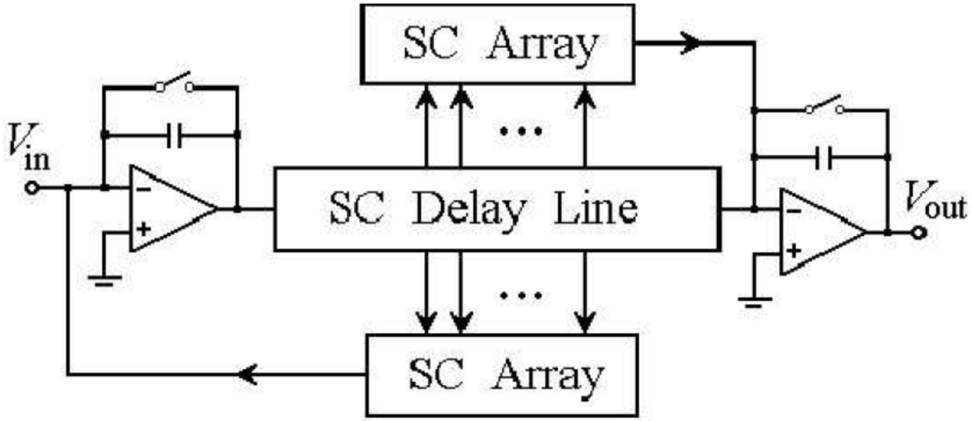
Direct Form I

2 SC delay lines sharing the same SC array

Ex.: $$\frac{V_{out}}{V_{in}}(z) = \frac{a_0 + a_1 z^{-1} + \cdots + a_8 z^{-8}}{1 - b_1 z^{-1} - b_2 z^{-2}}$$



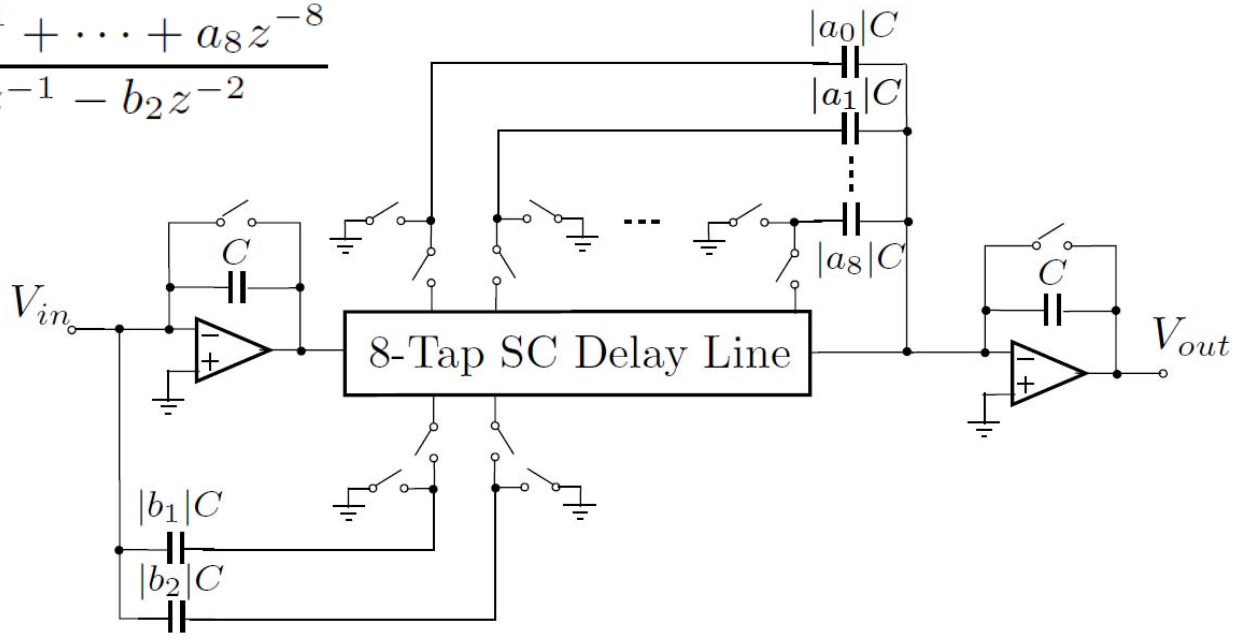
Direct-Form IIR SC Filter Realization



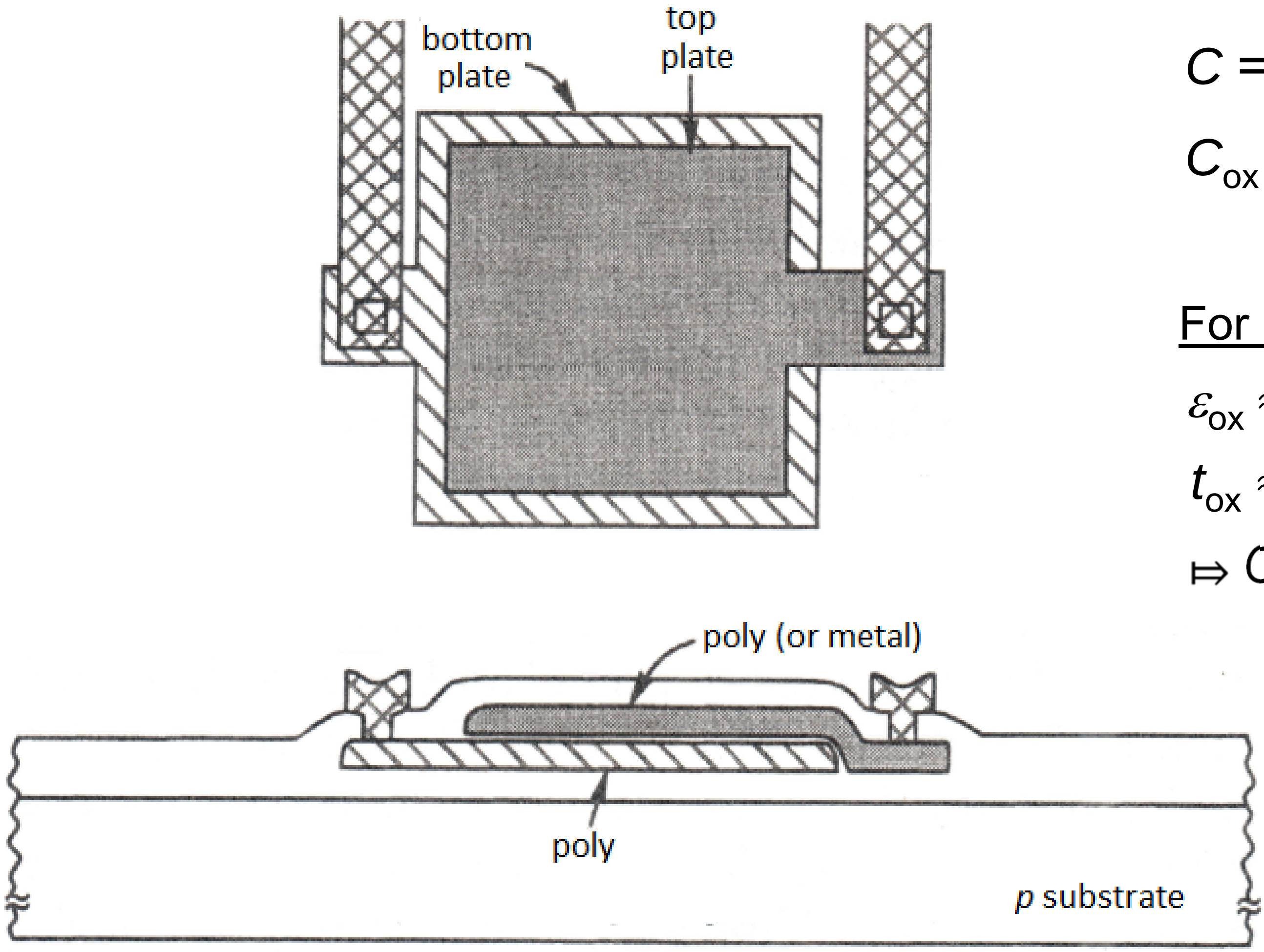
Direct Form II

2 SC arrays sharing the same SC delay line

Ex.: $$\frac{V_{out}}{V_{in}}(z) = \frac{a_0 + a_1 z^{-1} + \cdots + a_8 z^{-8}}{1 - b_1 z^{-1} - b_2 z^{-2}}$$



CMOS Capacitors



$C = AC_{ox}$

$C_{ox} = \varepsilon_{ox}/t_{ox}$

For 0.35 μm CMOS:

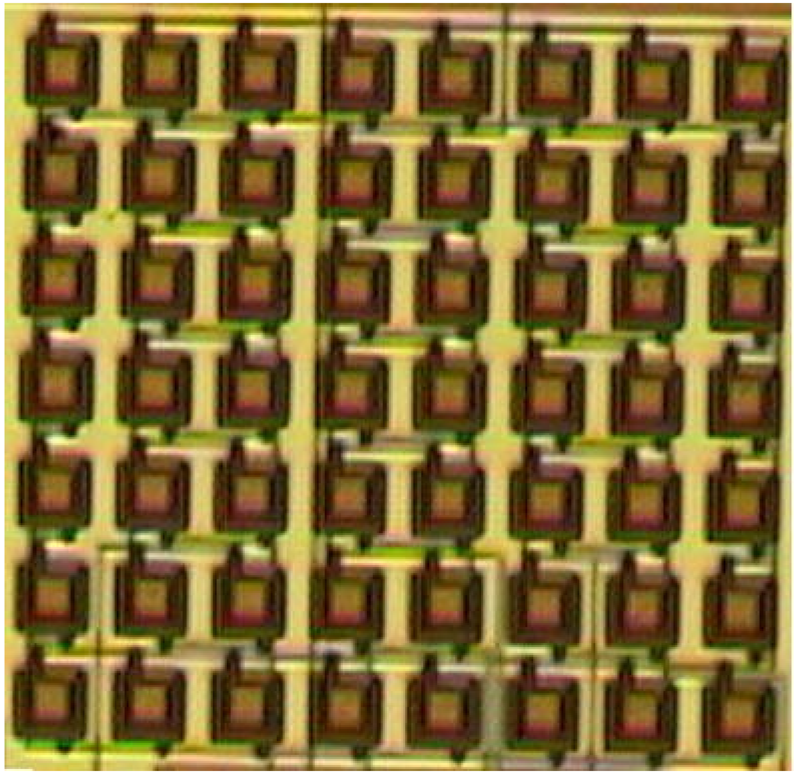
$\varepsilon_{ox} \approx 3.5 \times 10^{-13}$ F/cm

$t_{ox} \approx 10$ nm

$\Rightarrow C_{ox} \approx 3.5$ fF/μm^2

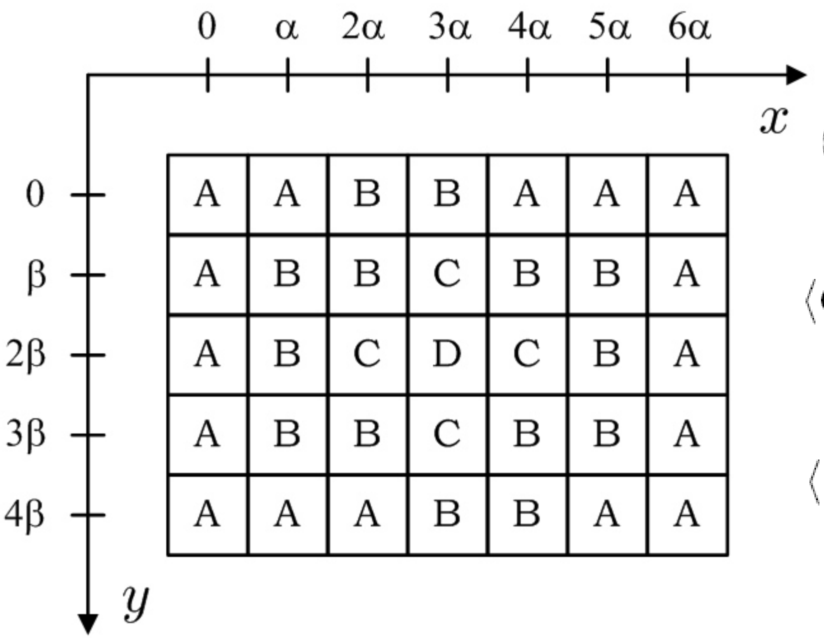
Capacitance Mismatch Effects

Capacitances implemented by parallel associations of identical 0.1 pF units



Capacitance Mismatch Effects

Mismatch caused by process gradients:



Average capacitances assuming linear process gradient:

$$\langle C_{xy} \rangle_A = \frac{1}{16} \cdot [16\,C + 48\,\alpha + 32\,\beta] = C + 3\,\alpha + 2\,\beta$$

$$\langle C_{xy} \rangle_B = \frac{1}{14} \cdot [14\,C + 42\,\alpha + 28\,\beta] = C + 3\,\alpha + 2\,\beta$$

$$\langle C_{xy} \rangle_C = \frac{1}{4} \cdot [4\,C + 12\,\alpha + 8\,\beta] = C + 3\,\alpha + 2\,\beta$$

$$\langle C_{xy} \rangle_D = C + 3\,\alpha + 2\,\beta$$

Capacitance Mismatch Effects

Mathematical model commonly used in computer aided analysis of SC filters:

$$\hat{\gamma}_k = \gamma_k + \epsilon_{\gamma_k}$$

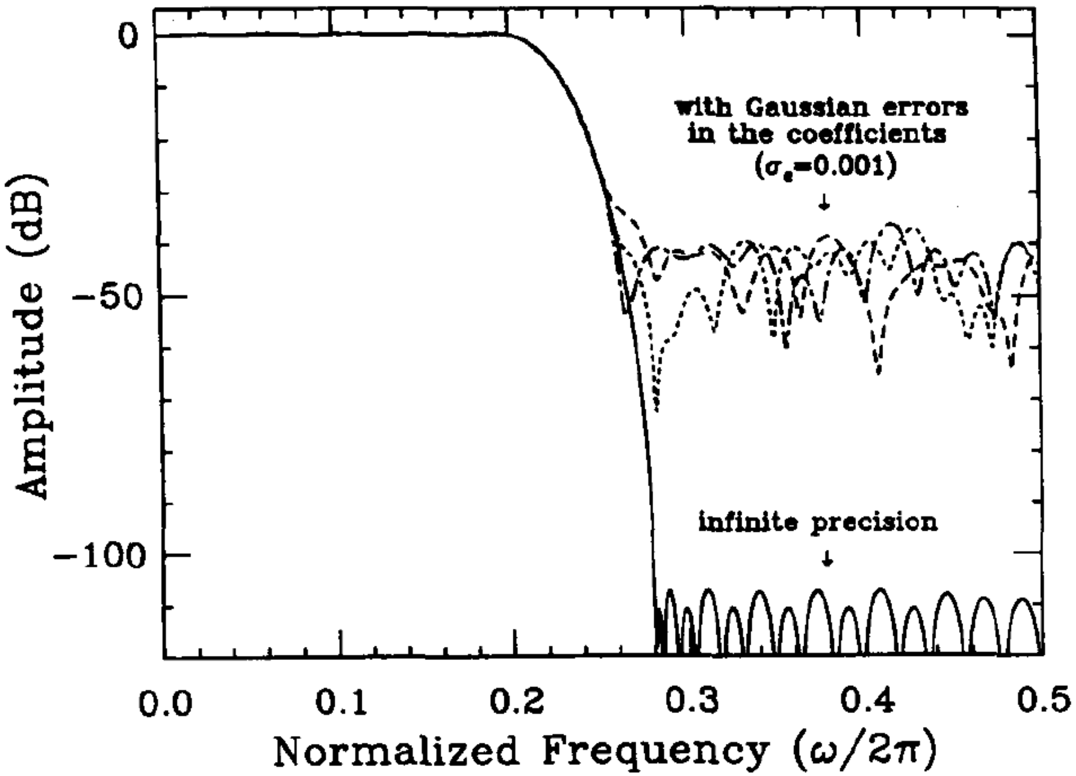
were $\epsilon_{\gamma_k} = \gamma_k \epsilon_k$

γ_k : capacitance ratios

ϵ_k : uncorrelated zero-mean Gaussian random variables

Capacitance Mismatch Effects

Ex.: Frequency responses of 3 FIR filters having 50 coefficients and σ_{ϵ}= 0.001



Capacitance Mismatch Effects

a) FIR SC Filters

$$G(e^{j\omega}) = \sum_{k=0}^{L-1} g_k e^{-j\omega k}$$

Each coefficient is implemented as a ratio between two capacitances

Because of random capacitance errors, the actual frequency response is:

$$\hat{G}(e^{j\omega}) = \sum_{k=0}^{L-1} (g_k + \epsilon_{g_k}) e^{-j\omega k}$$

$$= G(\omega) + \sum_{k=0}^{L-1} \epsilon_{g_k} e^{-j\omega k}$$

Capacitance Mismatch Effects

Deviation in the frequency response:

$$\Delta G(e^{j\omega}) = \hat{G}(e^{j\omega}) - G(e^{j\omega})$$
$$= \sum_{k=0}^{L-1} \epsilon_{g_k} e^{-j\omega k}.$$

where $\epsilon_{g_k} = \overline{g}\epsilon_{k},\quad \overline{g} = \sum_{k=0}^{L-1} |g_k|/L$

(i) ϵ_k are random Gaussian mismatches with zero mean and standard deviation σ_ϵ

(ii) $|\Delta G(e^{j\omega})|$ is a Raileygh random variable with a mean (average) value

$$\overline{|\Delta G|(e^{j\omega})} = \frac{\sigma_g \sqrt{\pi L}}{2}, \quad \forall\omega$$

where $\sigma_g = \overline{g}\sigma_\epsilon$

Capacitance Mismatch Effects

b) IIR SC Filters

$$H(z) = \frac{A(z)}{B(z)} = \frac{\sum_{k=0}^{M-1} a_k z^{-k}}{1 - \sum_{k=1}^{N-1} b_k z^{-k}}$$

Each coefficient is implemented as a ratio between two capacitances

The average deviation in frequency response is:

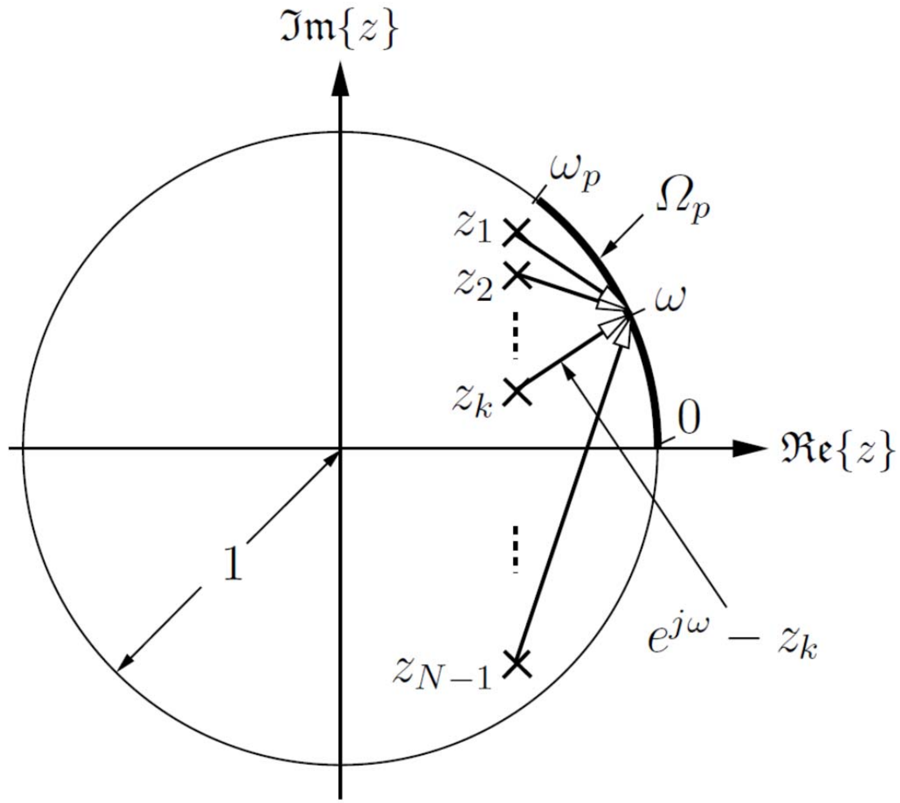
$$\overline{|\Delta H|(e^{j\omega})} = \begin{cases} \dfrac{\sigma_b \sqrt{\pi(N-1)}}{2|B(e^{j\omega})|}, & \omega \in \Omega_p \\ \\ \dfrac{\sigma_a \sqrt{\pi M}}{2|B(e^{j\omega})|}, & \omega \in \Omega_s \end{cases}$$

where $\sigma_a = \sigma_\epsilon \sum_{k=0}^{M-1} |b_k|/M$, $\sigma_b = \sigma_\epsilon \sum_{k=1}^{N-1} |b_k|/(N-1)$

Capacitance Mismatch Effects

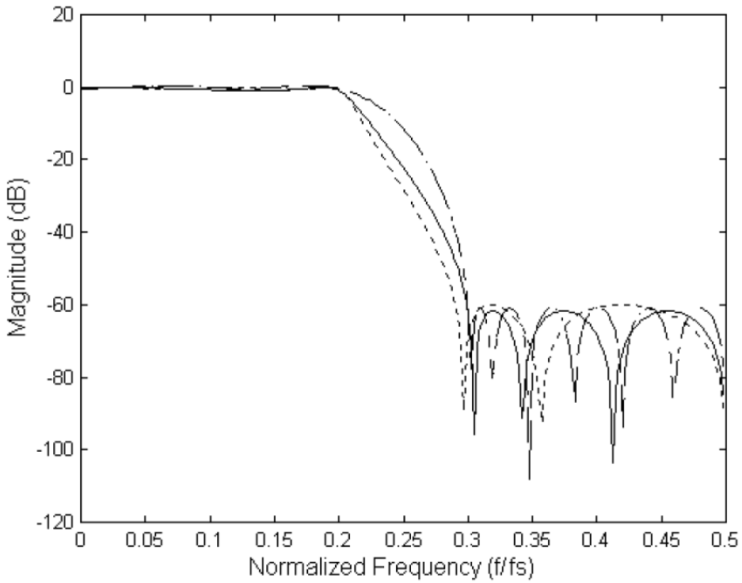
Letting z_1, z_2, …, z_{N-1} be the poles of H(z):

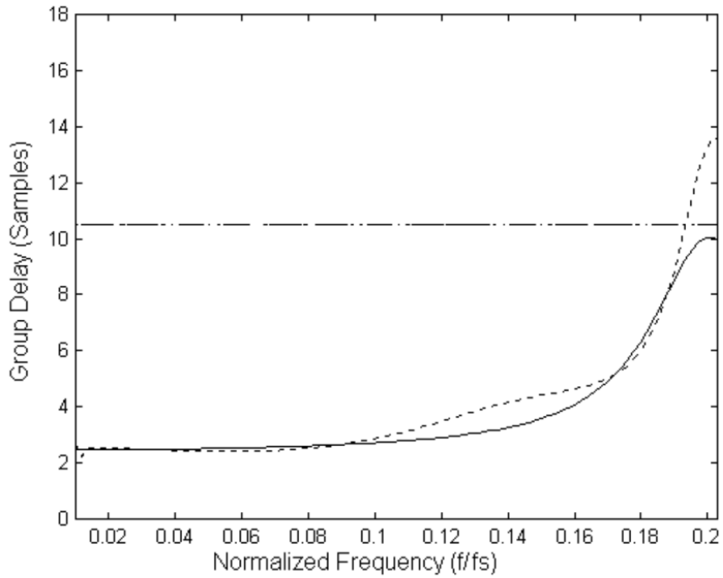
$$|B(e^{j\omega})| = |e^{j\omega} - z_1||e^{j\omega} - z_2|...|e^{j\omega} - z_{N-1}|$$



Capacitance Mismatch Effects

Example: ωp = 0.2; ωs = 0.3; Rp < 1dB; Rs > 60 dB





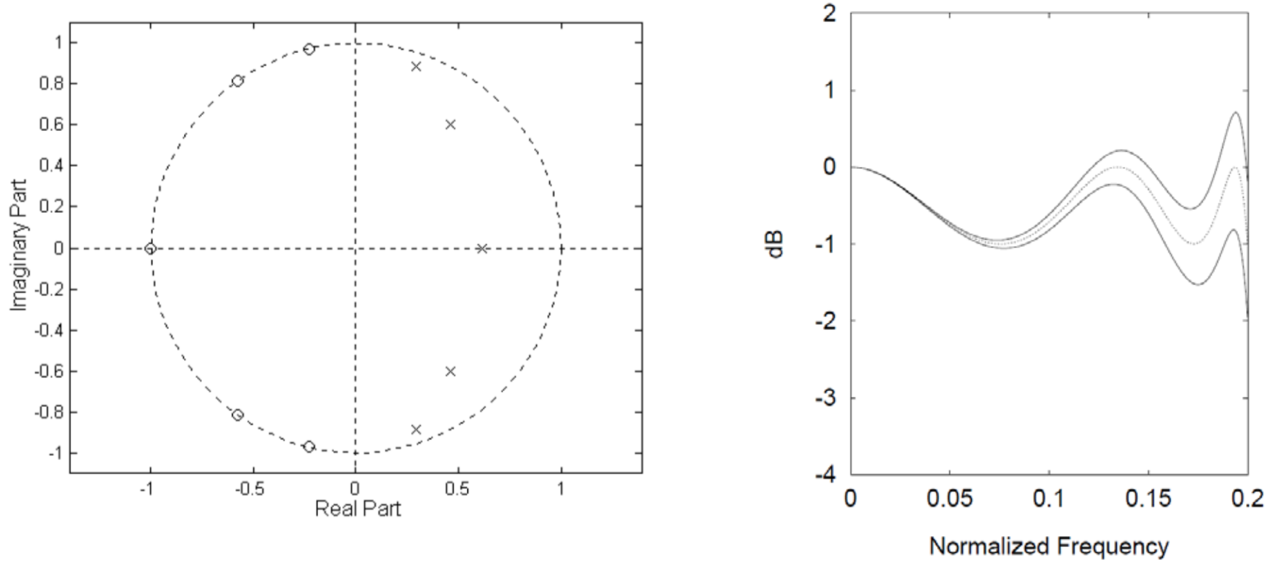
--- Eliptic: M=N=6

__ Two-pole design: M=9, N=3

_._ FIR: M=22, N=1

Capacitance Mismatch Effects

Eliptic:
M=N=6



Two-pole design:
M=9, N=3