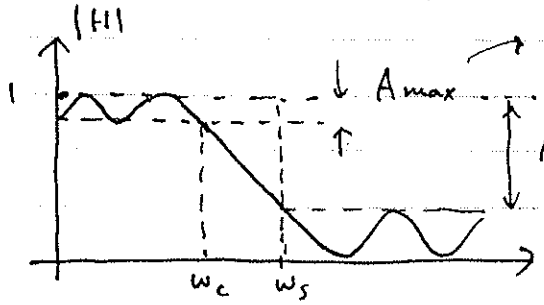
Chapter 4 Active filters : Part II

- Sharp cutoff ⇒ higher order filter (continuous-time)
  - Cascade design
  - direct synthesis
- Switched capacitor filter & sampled data system and dis signal processing

4.1 Filter Approximations



→ max. passband ripple

→ min. stopband attenuation

w_c : cutoff freq.

w_s/w_c : selectivity factor

passband ↕ stopband

transition band (skirt)

$$A(w) = -20 \log_{10} |H(jw)| \quad : \text{attenuation}$$

polynomial approximation
- Butterworth
- Chebyshev
- Cauer elliptic
- Bessel

Design procedure

① filter spec. (w_c, w_s, A_{max}, A_{min})

② Find required order n (handbook on $s(w)$)

③ (Cascade approach, OR
RLC Ladder approach

③ (ω_0, Q for each stage, OR
R, L, C

* Butterworth approximation (maximally flat)

$$H(j\omega) = \frac{1}{\sqrt{1+\varepsilon^2(\omega/\omega_c)^{2n}}}$$

- n : order
- ω_c : cutoff freq.
- $A_{max} = A(\omega_c) = 20\log_{10}\sqrt{1+\varepsilon^2} = 10\log_{10}(1+\varepsilon^2)$
- maximally flat, slow roll-off
- roll-off : $-20n$ dB/dec (stopband)
- Fig 4.4 (a)
- Example 4.1

* Chebyshev approximation

$$H(j\omega) = \frac{1}{\sqrt{1+\varepsilon^2 C_n^2(\omega/\omega_c)}}$$

Chebyshev polynomial ← $C_n(\omega/\omega_c)$

$C_n(\omega/\omega_c \le 1) = \cos[n\cos^{-1}(\omega/\omega_c)]$

$C_n(\omega/\omega_c \ge 1) = \cosh[n\cosh^{-1}(\omega/\omega_c)]$

- max. & roll-off } ripple↑ → roll-off↑
- passband ripple
- ω_c : cutoff freq.
- $A_{max} = 10\log_{10}(1+\varepsilon^2)$
- ultimate roll-off = $-20n$ dB/dec. → ultimate
- Fig 4.4 (b)

* Cauer approximation
  - Cauer filter or elliptic filter
  - ripples in both passband and stopband
  - sharper roll-off
  - Fig 4.5

* Bessel approximation
  - Bessel filter or Thomson filter
  - maximize passband delay ⇒ linear phase in passband
  - less sharp roll-off
  - Fig. 4.6

4.2 Cascade Design

$$H(s) = H_1(s)\ H_2(s) \cdots H_{n/2}(s) \quad : \text{짝수 } n$$

* Lowpass filter design

Table 4.1

f_0 : normalized freq. (1 Hz)

$\begin{cases} f_0 = -3\,\text{dB cutoff freq. for Butterworth \& Bessel} \\ f_0 = \text{edge of ripple band for Chebyshev \& Cauer} \end{cases}$

실제의 필터 설계 시

$\begin{cases} f_0 = f_{0(\text{table})} \times f_c \\ f_z = f_{z(\text{table})} \times f_c \end{cases}$

◎ Example 4.2 : 해설. (Fig 4.7, 4.8)

◎ Example 4.3 : 해설. (Fig 4.9)

p141 → p149

* Highpass filter Design

- $s/\omega_0 \longrightarrow 1/(s/\omega_0)$.

  (LP용의 H(s) 에서 s대신 대치)

- LP와 동일 Table 사용

- $\begin{cases} f_0 = f_c / f_{0(table)} \\ f_z = f_c / f_{z(table)} \end{cases}$

  ◎ Example 4.4 (Fig 4.10)

* Bandpass filter Design

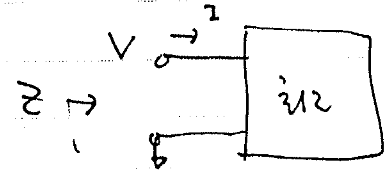
  ◎ Example 4.5 (Fig 4.11)

  ◎ Example 4.6 (Fig 4.12)

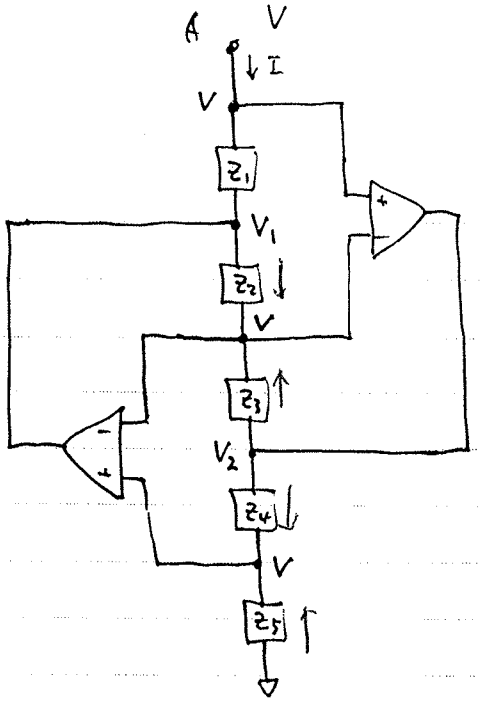
* Band reject filter Design

  ◎ Example 4.7

4.3 Generalized Impedance Converters (GIC)



$Z = \dfrac{V}{I}$



$$I = \frac{V - V_1}{Z_1}$$

$$\frac{V_1 - V}{Z_2} + \frac{V_2 - V}{Z_3} = 0$$

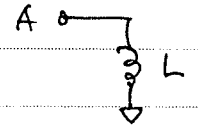
$$\frac{V_2 - V}{Z_4} + \frac{0 - V}{Z_5} = 0$$

$$Z = \frac{V}{I} = \frac{Z_1 Z_3 Z_5}{Z_2 Z_4}$$

① $Z_1 = R_1$, $Z_2 = 1/j\omega C_2$, $Z_3 = R_3$, $Z_4 = R_4$, $Z_5 = R_5$

$$Z = \frac{R_1 R_3 R_5}{(1/j\omega C_2) R_4} = j\omega \frac{R_1 R_3 R_5 C_2}{R_4} = j\omega L$$

⇒ grounded inductance.



② $Z_1 = 1/j\omega C_1$, $Z_2 = R_2$, $Z_3 = R_3$, $Z_4 = R_4$, $Z_5 = 1/j\omega C_5$

$$Z = -\frac{1}{\omega^2 D} \qquad D = \frac{R_2 R_4 C_1 C_5}{R_3}$$

⇒ grounded FDNR (freq-dependent negative resistance)

OR D element.

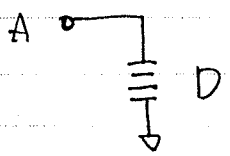


Fig 4.16 ⇒ D-element 의 회로를 구현

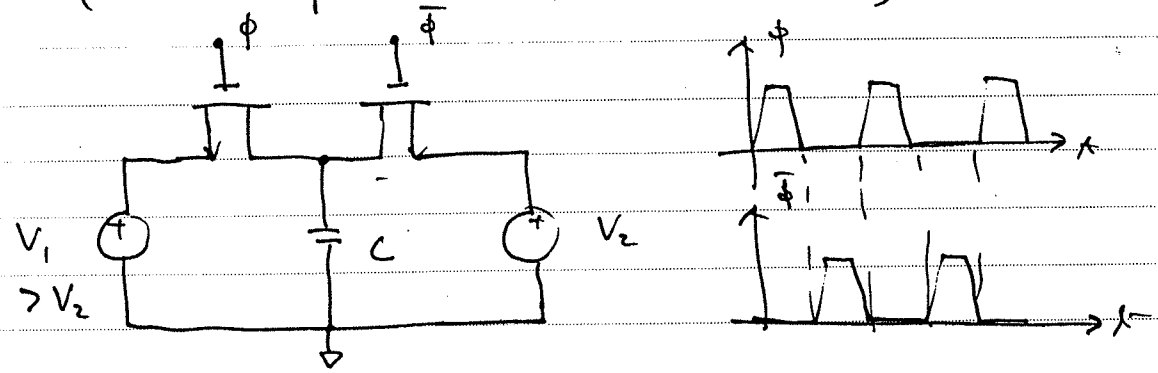
* Synthesis using grounded inductances
  Example 4.8 (Fig 4.17)

* Synthesis using FDNR

4.4 Direct Design

4.5 Switched Capacitor filter (SC Filters)

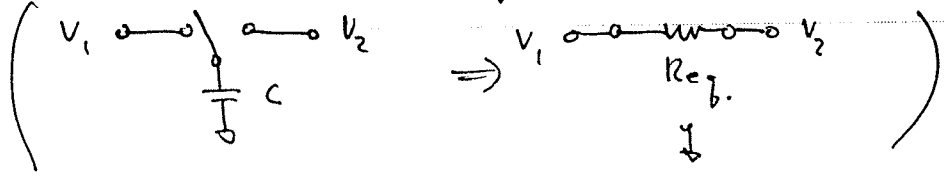
{ MOS cap. + MOSFET switch } simulate cap.



$$\Delta Q = C(V_1 - V_2)$$

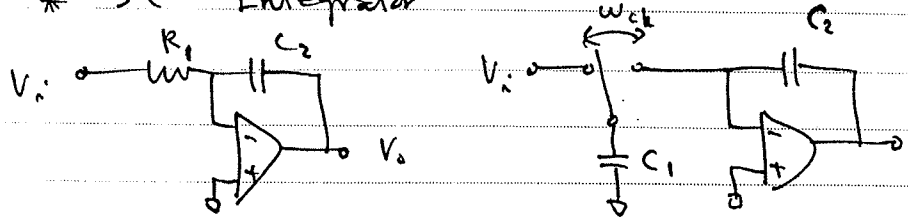
$$I_{avg} = C f_{CK}(V_1 - V_2) = \Delta Q \cdot f_{CK} = \frac{\Delta Q}{\Delta t}$$

$$\Rightarrow \quad R_{eq} = \frac{V_1 - V_2}{I_{avg}} = \frac{1}{C f_{CK}}$$

(

)

* SC Integrator



$$H(jw) = \frac{-1}{jw/w_o} \qquad w_{ck} \gg w \text{ (input signal freq.)}$$

$$w_o = \frac{1}{R_1 C_2} \qquad w_o = \frac{1}{R_{eq} C_2} = \frac{C_1}{C_2} f_{ck}$$

< SC 의 특징 >

① R 이 필요없다 → 집적도 증가 가능

② C_1/C_2 는 0.1% 로 제어 가능

③ w_o 가 f_{clk} 에 비례하므로 w_o 의 제어가 쉽다.

- C 는 주로 0.1pf ~ 100pf 사용. (1pf ~ 10pf 가 가장 많이 사용됨)
- 실제 구조 : Fig 4.26

4.6 Switched Capacitor filter

Fig 4.29

Fig 4.30

H/W 4-6, ~~4-8~~, 4-10, 4-18, 4-19

4-22,