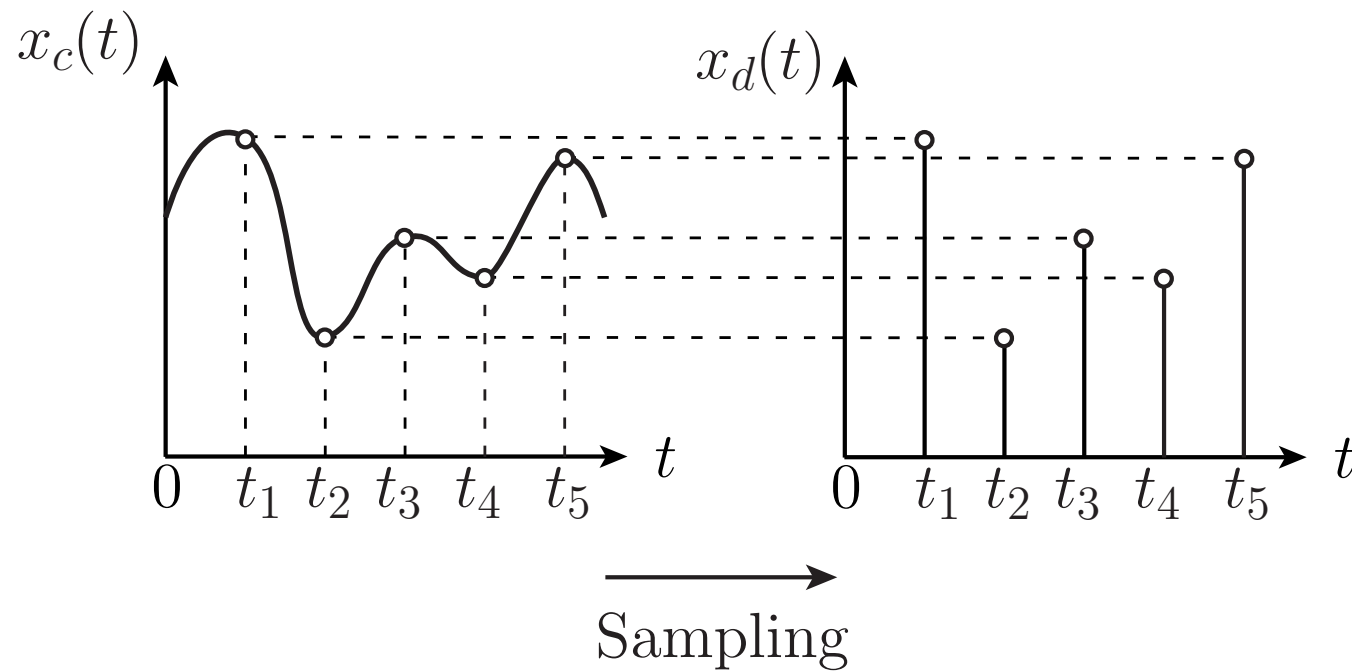


離散時間系フィルタの構成

スイッチトキャパシタフィルタ

連続時間系回路と離散時間系回路 (ラプラス変換からz変換へ)



$x_c(t)$: 連続時間信号
 $x_d(t)$: 離散時間信号

理想サンプリング

$\delta(t)$: デルタ関数

$$x_d(t) = \sum_{n=-\infty}^{\infty} x_c(t) \delta(t-nT) = x_c(t) \delta_T(t)$$

$$\delta_T(t) = \sum_{n=-\infty}^{\infty} \delta(t-nT)$$

$x_c(t)$ のフーリエ変換 $\rightarrow X_c(j\omega)$

$x_d(t)$ のフーリエ変換 $\rightarrow x_c(t)\delta_T(t)$ のフーリエ変換

$\delta_T(t)$ は周期関数 $\rightarrow$ フーリエ級数展開による表現

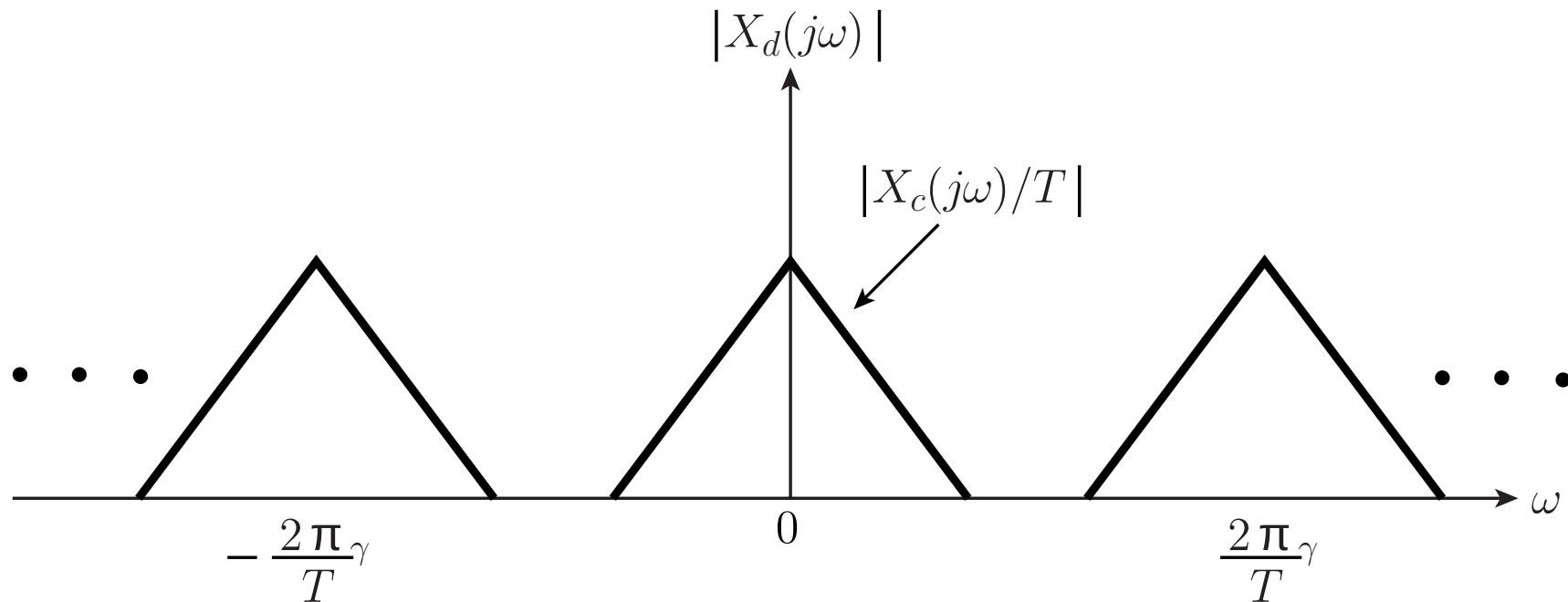
$$\delta_T(t) = \sum_{n=-\infty}^{\infty} c_n e^{jn\frac{2\pi}{T}t}$$

$$c_n = \frac{1}{T} \int_{-T/2}^{T/2} \delta_T(t) e^{-jn\frac{2\pi}{T}t} dt = \frac{1}{T} \longrightarrow \delta_T(t) = \frac{1}{T} \sum_{n=-\infty}^{\infty} e^{jn\frac{2\pi}{T}t}$$

$$X_d(j\omega) = \int_{-\infty}^{\infty} x_c(t) \frac{1}{T} \sum_{n=-\infty}^{\infty} e^{jn\frac{2\pi}{T}t} e^{-j\omega t} dt = \frac{1}{T} \sum_{n=-\infty}^{\infty} \int_{-\infty}^{\infty} x_c(t) e^{j(n\frac{2\pi}{T} - \omega)t} dt$$

$$= \frac{1}{T} \sum_{n=-\infty}^{\infty} X_c(j\omega - jn\frac{2\pi}{T})$$

周期的



$$\begin{aligned}
 x_d(t) &= \sum_{n=-\infty}^{\infty} x_c(t) \delta(t-nT) \\
 &= x_c(0)\delta(t) + x_c(T)\delta(t-T) + x_c(2T)\delta(t-2T) + \dots
 \end{aligned}$$

ただし, $t < 0$ では $x_c(t) = 0$ と仮定

$$X_d(s) = x_c(0) + x_c(T)e^{-sT} + x_c(2T)e^{-s2T} + \dots = \sum_{n=0}^{\infty} x_c(nT)e^{-snT}$$

e^{sT} を z で置き換えると

$$X_d(z) = \sum_{n=0}^{\infty} x_c(nT)z^{-n}$$

(片側) z 変換

z 変換

$$H(z) = \sum_{n=-\infty}^{\infty} h(n)z^{-n} \quad \text{(両側) } z \text{変換}$$

z 変換の性質(1)

$$\sum_{n=-\infty}^{\infty} h(n-1)z^{-n} = \sum_{l=-\infty}^{\infty} h(l)z^{-(l+1)} = \left(\sum_{l=-\infty}^{\infty} h(l)z^{-l} \right) z^{-1} = H(z)z^{-1}$$

z 変換の性質(2)

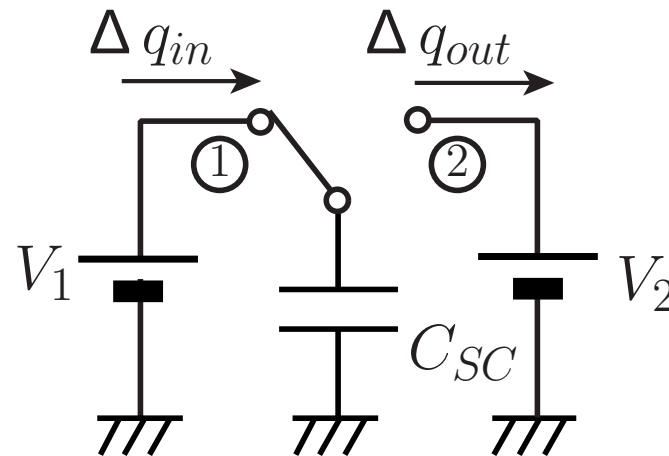
$H(z)$ の周波数特性

$z=e^{j\omega T}$ を代入

z 変換の性質(3) $s_i=\sigma_i+j\omega_i$ と置いたとき $\sigma_i<0$ なら安定

$$|z_i| = \left| e^{s_i T} \right| \text{に } s_i = \sigma_i + j\omega_i \text{を代入すると } |z_i| = \left| e^{\sigma_i + j\omega_i} \right| = \left| e^{\sigma_i} \right| \left| e^{j\omega_i} \right| = \left| e^{\sigma_i} \right| < 1$$

スイッチトキャパシタ回路の動作原理



$$q_1 = C_{SC} V_1$$

$$q_2 = C_{SC} V_2$$

$$q_2 + (q_1 - q_2) = q_1 \quad \longrightarrow \quad \Delta q_{in} = q_1 - q_2 = C_{SC} (V_1 - V_2)$$

$$q_1 - (q_1 - q_2) = q_2 \quad \longrightarrow \quad \Delta q_{out} = q_1 - q_2 = C_{SC} (V_1 - V_2)$$

$$\Delta q = \Delta q_{out} = \Delta q_{in}$$

近似モデル

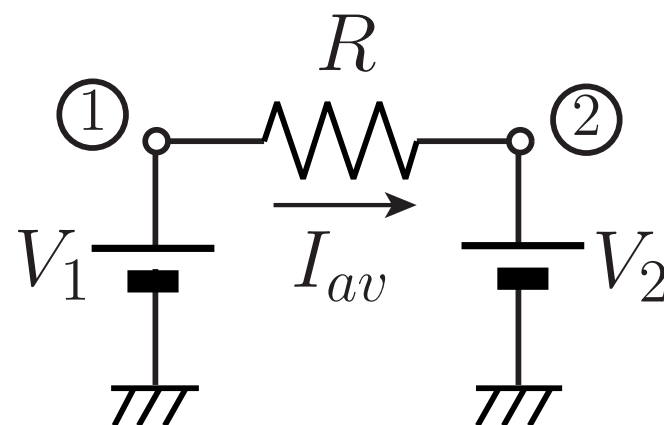
$$\Delta q = \Delta q_{out} = \Delta q_{in}$$

スイッチング周期: T

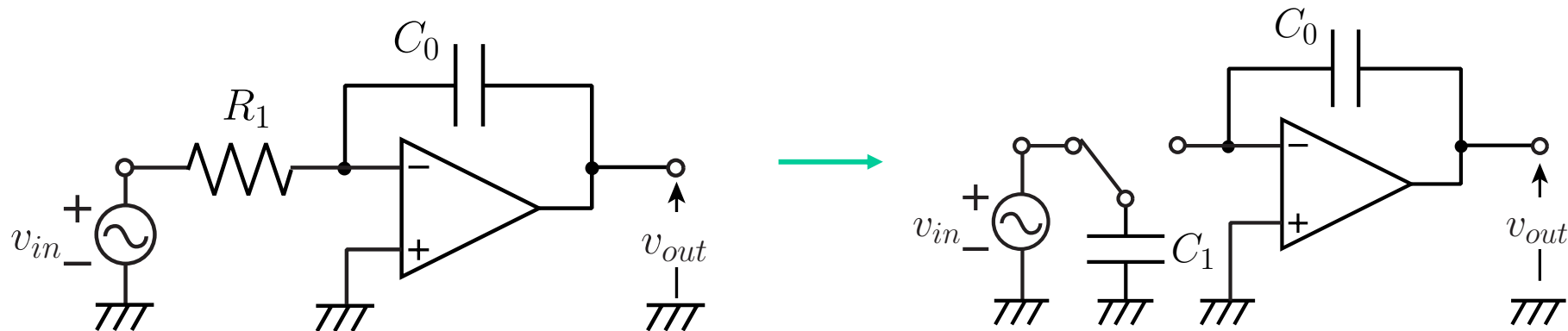
T 秒間に Δq の電荷が移動

平均電流:
$$I_{av} = \frac{\Delta q}{T} = \frac{C_{SC}(V_1 - V_2)}{T}$$

等価抵抗:
$$R = \frac{T}{C_{SC}}$$



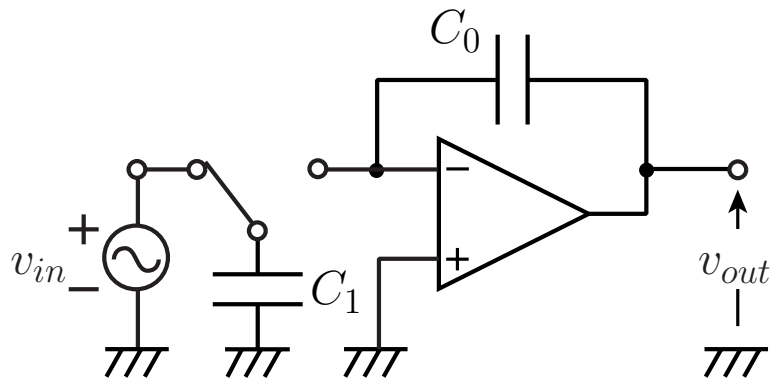
基本スイッチトキャパシタ積分回路



$$R_1 = \frac{T}{C_1}$$

$$T(s) = \frac{v_{out}}{v_{in}} = \frac{-1}{sC_0R_1}$$

$$T(s) = \frac{v_{out}}{v_{in}} = \frac{-C_1}{sC_0T}$$



$$T(s) = \frac{v_{out}}{v_{in}} = \frac{-C_1}{sC_0T}$$

特性： 容量比 & スイッチング周期

$$C_0=1\text{nF} , C_1=1\text{nF}$$

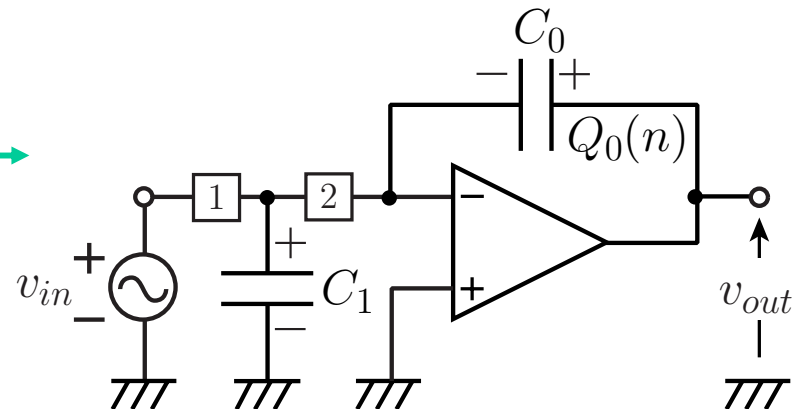
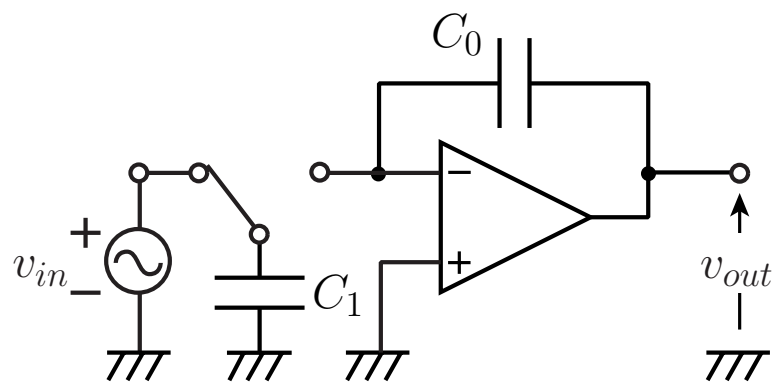
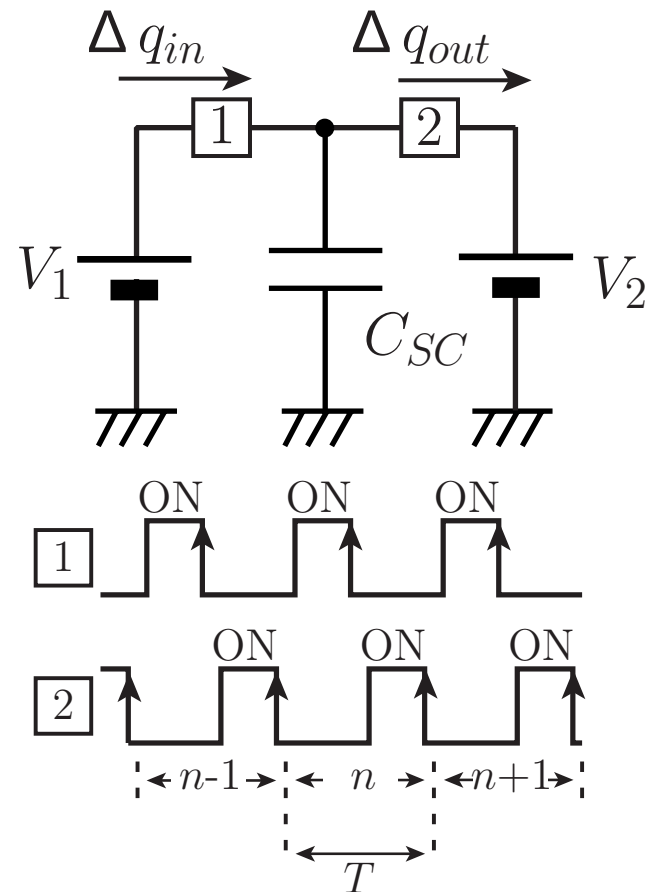
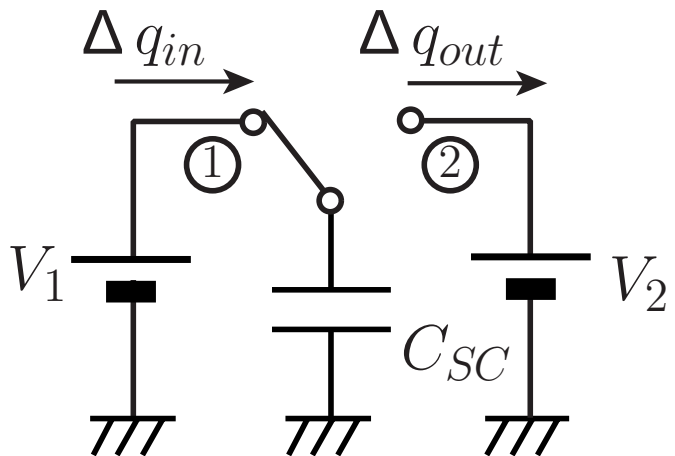
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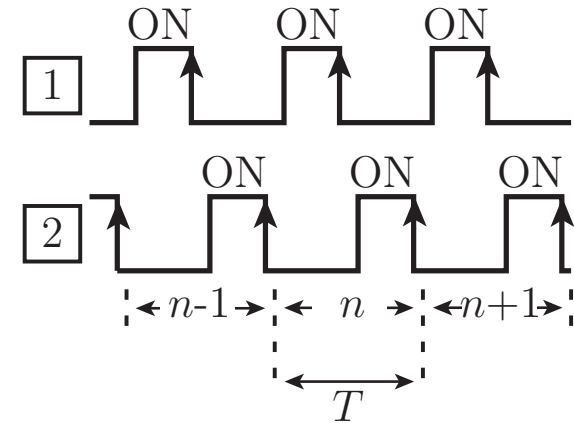
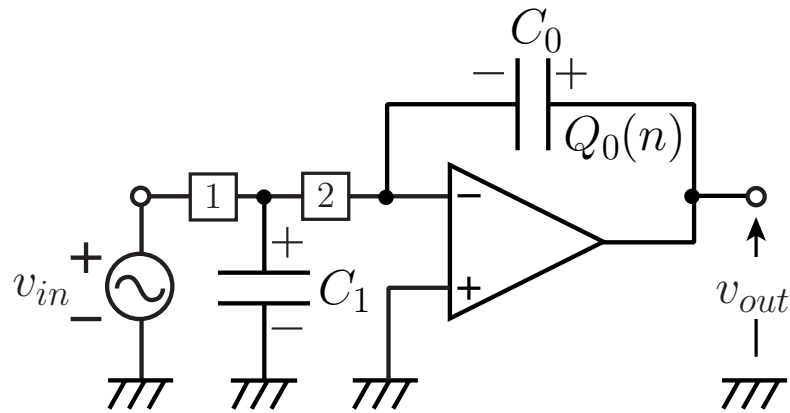
$$C_0=1\text{pF} , C_1=1\text{pF}$$

T: 水晶発振回路により正確

容量, 演算増幅器, スイッチ: 実現容易

スイッチトキャパシタ回路の解析





$$Q_0(n) = C_0 v_{out}(n)$$

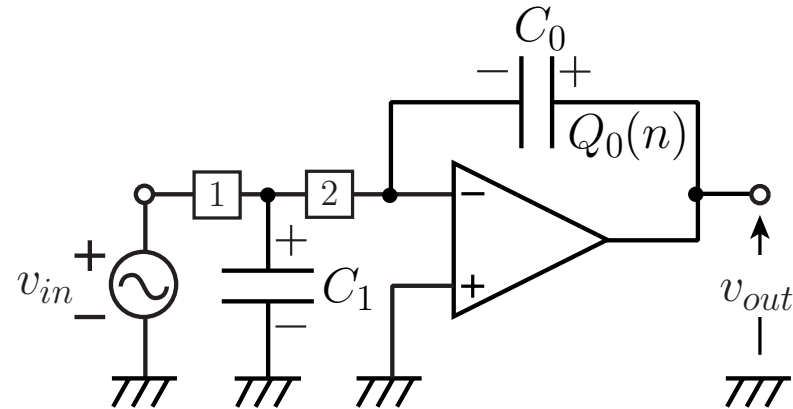
$$Q_0(n) = Q_0(n-1) - Q_1(n-1)$$

$$C_0 v_{out}(n) = C_0 v_{out}(n-1) - C_1 v_{in}(n-1)$$

$$C_0 V_{out}(z) = C_0 V_{out}(z) z^{-1} - C_1 V_{in}(z) z^{-1}$$

$$\boxed{\frac{V_{out}(z)}{V_{in}(z)} = \frac{-C_1 z^{-1}}{C_0(1 - z^{-1})}}$$

$$\frac{V_{out}(z)}{V_{in}(z)} = \frac{-C_1 z^{-1}}{C_0(1-z^{-1})}$$



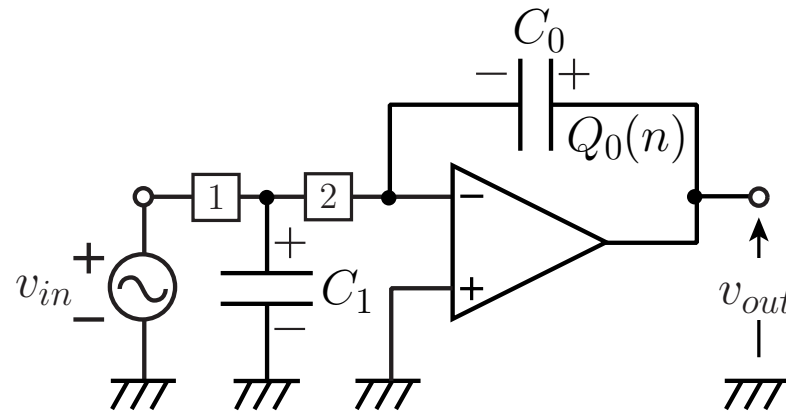
$z=e^{j\omega T}$ を代入

$$\begin{aligned} H(j\omega) &= \frac{-C_1 e^{-j\omega T}}{C_0(1-e^{-j\omega T})} = \frac{-C_1 e^{-j\omega T/2}}{C_0(e^{j\omega T/2} - e^{-j\omega T/2})} \\ &= \frac{-C_1 e^{-j\omega T/2}}{C_0 \{ \cos(\omega T/2) + j\sin(\omega T/2) - \cos(\omega T/2) + j\sin(\omega T/2) \}} \\ &= \frac{-C_1 e^{-j\omega T/2}}{j2C_0 \sin(\omega T/2)} \approx \frac{-C_1}{j\omega C_0 T} \quad (\because \omega T \ll 1 \text{ のとき } \sin x \approx x) \end{aligned}$$

2-3-2 スイッチトキャパシタ積分回路の構成

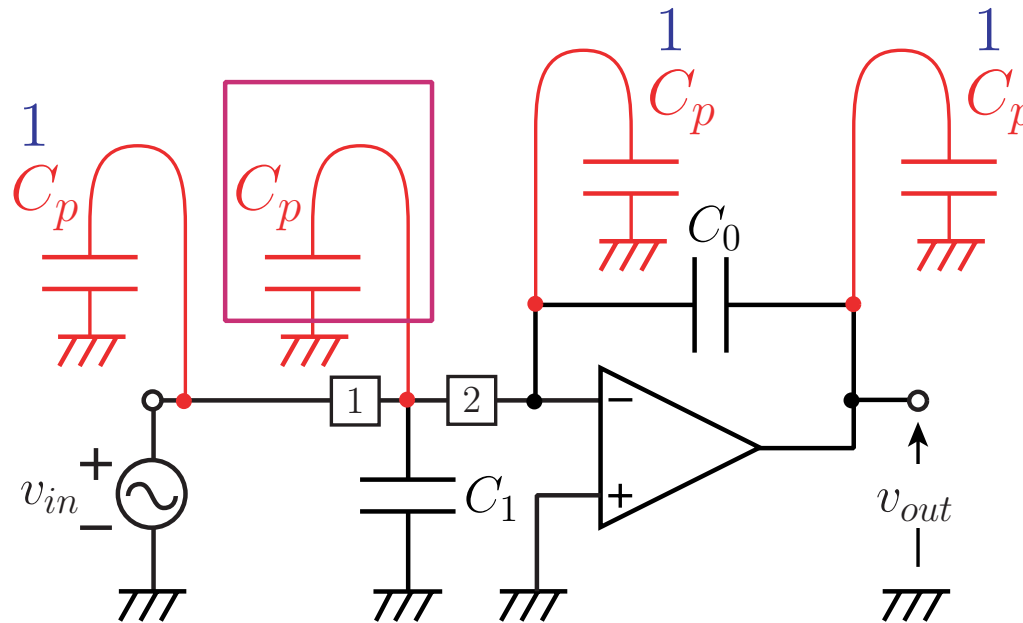
基本スイッチトキャパシタ積分回路の問題点

寄生容量



特性に影響を与えない寄生容量

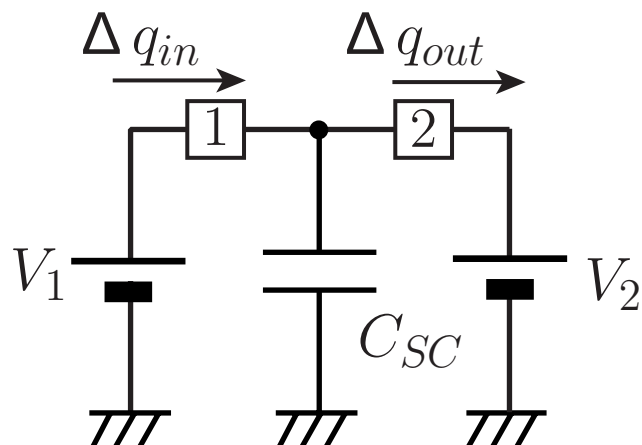
1. 常に電圧源または接地端子, 仮想接地端子のいずれかに接続されている寄生容量
2. 電圧源と接地端子に交互に接続される寄生容量
3. 仮想接地と接地端子に交互に接続される寄生容量



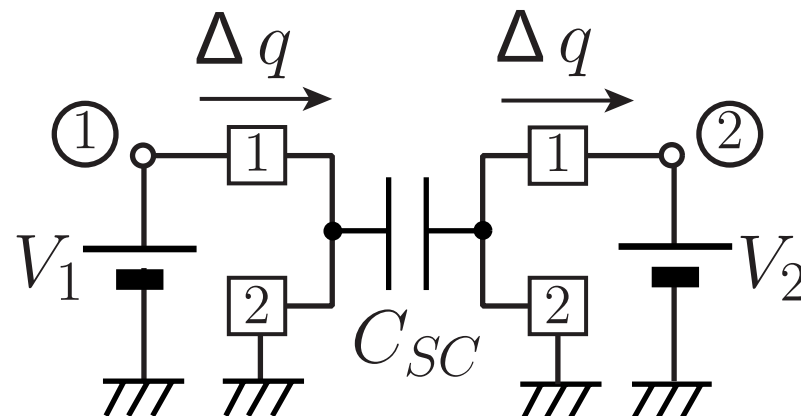
寄生容量に有感なスイッチトキャパシタ回路

1. 常に電圧源または接地端子，仮想接地端子のいずれかに接続されている寄生容量
2. 電圧源と接地端子に交互に接続される寄生容量
3. 仮想接地と接地端子に交互に接続される寄生容量

寄生容量への対策



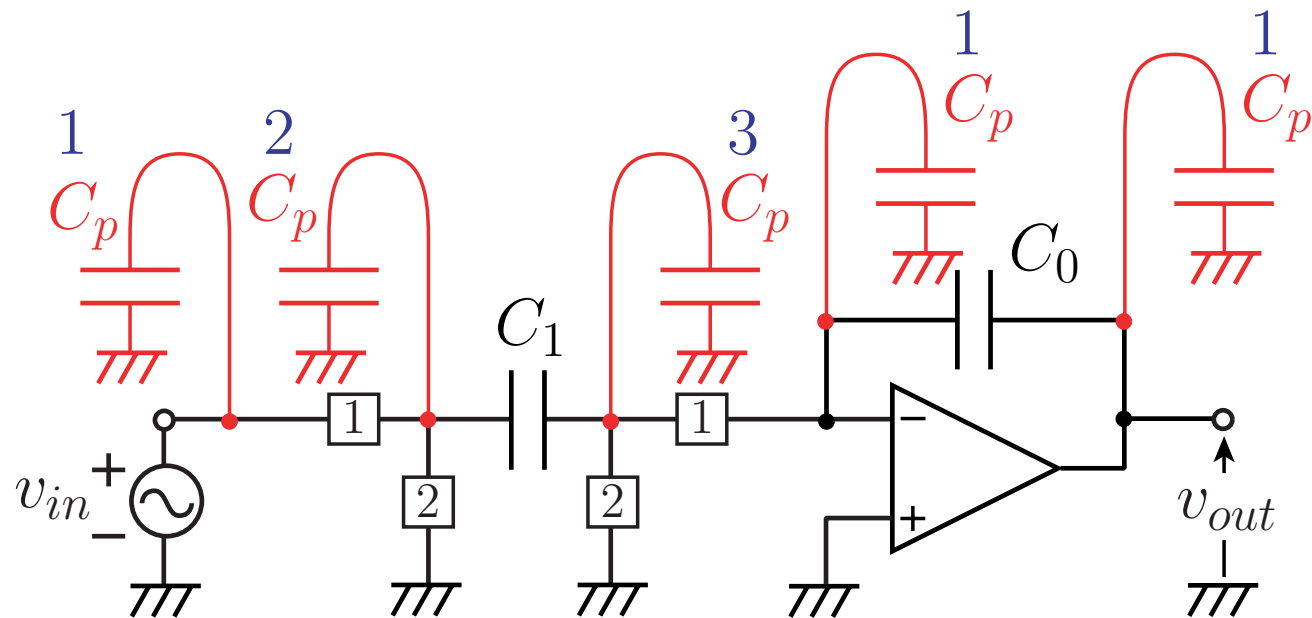
$$\Delta q_{out} = \Delta q_{in} = C_{SC} (V_1 - V_2)$$



$$\Delta q = C_{SC} (V_1 - V_2)$$

電荷の移動量: 同じ

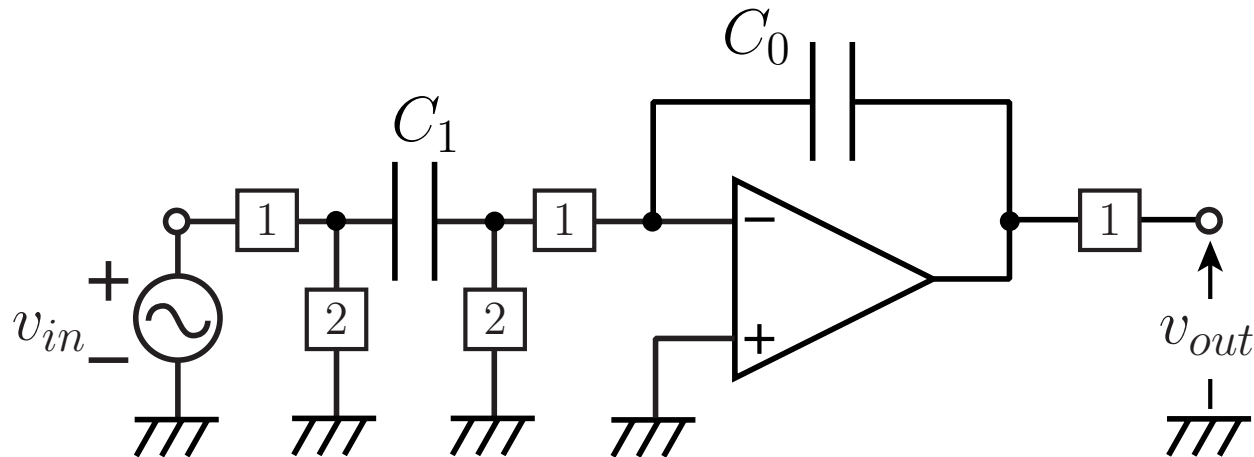
電荷の移動のタイミング:異なる



寄生容量に不感なスイッチトキャパシタ回路

1. 常に電圧源または接地端子，仮想接地端子のいずれかに接続されている寄生容量
2. 電圧源と接地端子に交互に接続される寄生容量
3. 仮想接地と接地端子に交互に接続される寄生容量

寄生容量に不感なスイッチトキャパシタ積分回路(1)

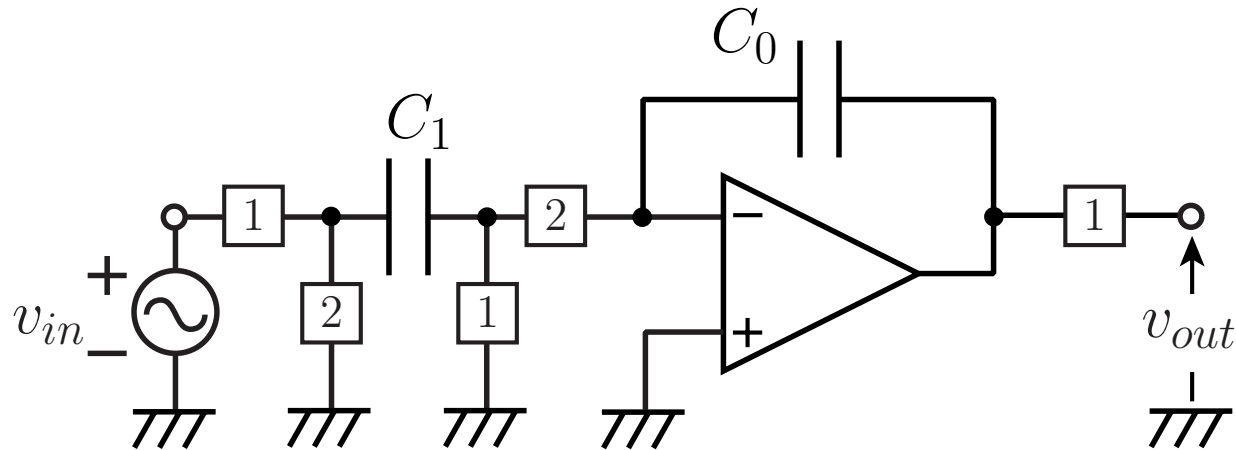


$$C_0 v_{out}(n) = C_0 v_{out}(n-1) - C_1 v_{in}(n)$$

$$C_0 V_{out}(z) = C_0 V_{out}(z) z^{-1} - C_1 V_{in}(z)$$

$$\boxed{\frac{V_{out}(z)}{V_{in}(z)} = \frac{-C_1}{C_0(1-z^{-1})}}$$

寄生容量に不感なスイッチトキャパシタ積分回路(2)

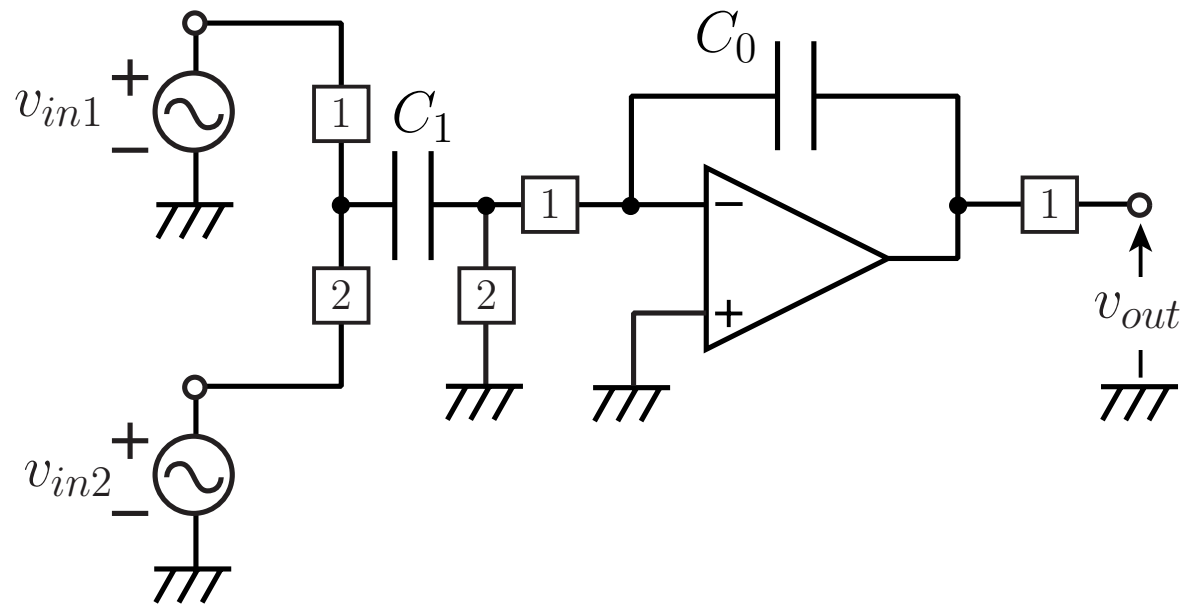


$$C_0 v_{out}(n) = C_0 v_{out}(n-1) + C_1 v_{in}(n-1)$$

$$C_0 V_{out}(z) = C_0 V_{out}(z) z^{-1} + C_1 V_{in}(z) z^{-1}$$

$$\frac{V_{out}(z)}{V_{in}(z)} = \frac{C_1 z^{-1}}{C_0 (1 - z^{-1})}$$

寄生容量に不感なスイッチトキャパシタ積分回路(3)



$$C_0 v_{out}(n) = C_0 v_{out}(n-1) - C_1 v_{in1}(n) + C_1 v_{in2}(n-1)$$

$$C_0 V_{out}(z) = C_0 V_{out}(z) z^{-1} - C_1 V_{in1}(z) + C_1 V_{in2}(z) z^{-1}$$

$$V_{out}(z) = \frac{C_1 \{ z^{-1} V_{in2}(z) - V_{in1}(z) \}}{C_0 (1 - z^{-1})}$$

2-3-3 スイッチトキャパシタフィルタの構成

双一次s-z変換

$$s \rightarrow \frac{2(1-z^{-1})}{T(1+z^{-1})}$$

$s=j\Omega$, $z=e^{j\omega T}$ を代入

$$\frac{2(1-z^{-1})}{T(1+z^{-1})} = \frac{2(1-e^{-j\omega T})}{T(1+e^{-j\omega T})} = \frac{2(e^{j\omega T/2}-e^{-j\omega T/2})}{T(e^{j\omega T/2}+e^{-j\omega T/2})}$$

$$= \frac{2\{\cos(\omega T/2)+j\sin(\omega T/2)-\cos(\omega T/2)+j\sin(\omega T/2)\}}{T\{\cos(\omega T/2)+j\sin(\omega T/2)+\cos(\omega T/2)-j\sin(\omega T/2)\}}$$

$$= \frac{4j\sin(\omega T/2)}{2T\cos(\omega T/2)} = j\frac{2}{T}\tan\frac{\omega T}{2}$$

$$\boxed{s \rightarrow \frac{2(1-z^{-1})}{T(1+z^{-1})}} \longrightarrow \boxed{\Omega \rightarrow \frac{2}{T} \tan\left(\frac{\omega T}{2}\right)}$$

$$\omega T \ll 1 \text{ のとき } \Omega = \frac{2}{T} \tan\left(\frac{\omega T}{2}\right) \approx \frac{2}{T} \times \frac{\omega T}{2} = \omega$$

LDI変換 (Lossless Discrete Integrator変換)

$$s \rightarrow \frac{z^{1/2} - z^{-1/2}}{T}$$

$s = j\Omega$, $z = e^{j\omega T}$ を代入

$$\begin{aligned} \frac{z^{1/2} + z^{-1/2}}{T} &= \frac{e^{j\omega T/2} - e^{-j\omega T/2}}{T} \\ &= \frac{\{\cos(\omega T/2) + j\sin(\omega T/2)\} - \{\cos(\omega T/2) - j\sin(\omega T/2)\}}{T} \end{aligned}$$

$$= j \frac{2}{T} \sin(\omega T/2)$$

$$\Omega \rightarrow \frac{2}{T} \sin\left(\frac{\omega T}{2}\right)$$

Ω の一部が ω へ写像

スイッチトキャパシタ2次区間回路

$$T_{second}(s) = \frac{N(s)}{s^2 + \frac{\omega_0}{Q}s + \omega_0^2}$$

↓
双一次s-z変換

$$T_{SC2}(z) = T_{second}\left(\frac{2}{T} \cdot \frac{1-z^{-1}}{1+z^{-1}}\right) = \frac{N\left(\frac{2}{T} \cdot \frac{1-z^{-1}}{1+z^{-1}}\right)}{\left(\frac{2}{T} \cdot \frac{1-z^{-1}}{1+z^{-1}}\right)^2 + \frac{\omega_0}{Q} \left(\frac{2}{T} \cdot \frac{1-z^{-1}}{1+z^{-1}}\right) + \omega_0^2}$$

低域通過型

$$N_{SC2}(z) \propto (1+z^{-1})^2$$

帶域通過型

$$N_{SC2}(z) \propto (1-z^{-2})$$

高域通過型

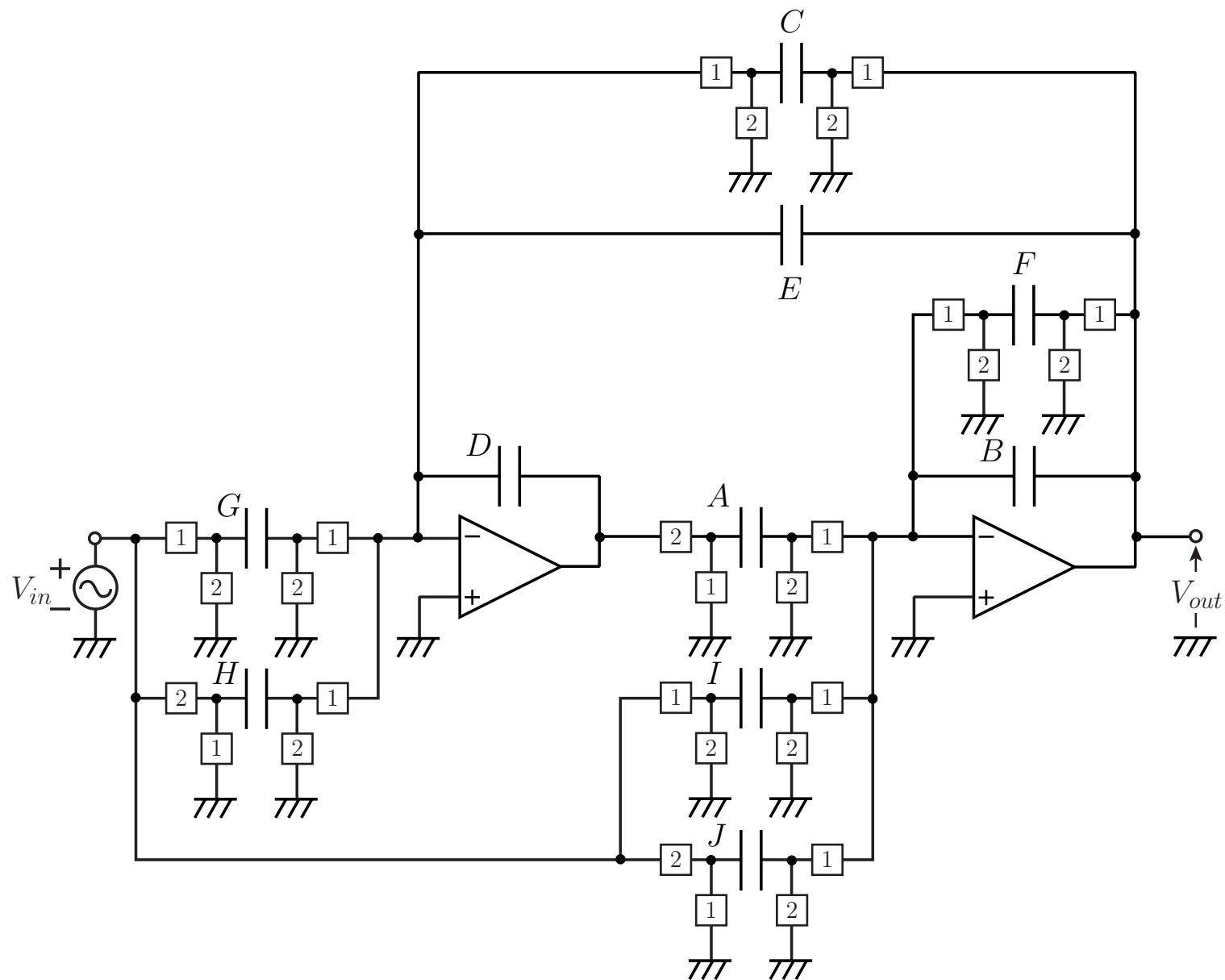
$$N_{SC2}(z) \propto (1-z^{-1})^2$$

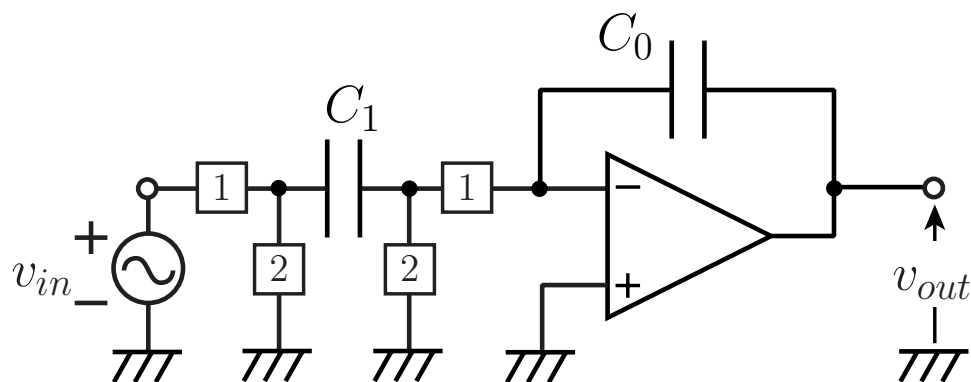
例：低域通過型伝達関数

$$T_{SC2}(z) = \frac{K\omega_0^2}{\left(\frac{2}{T} \frac{1-z^{-1}}{1+z^{-1}}\right)^2 + \frac{\omega_0}{Q} \left(\frac{2}{T} \frac{1-z^{-1}}{1+z^{-1}}\right) + \omega_0^2}$$

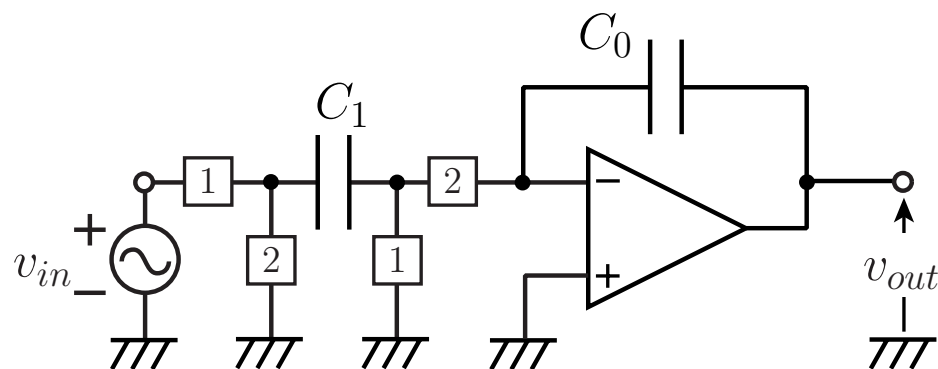
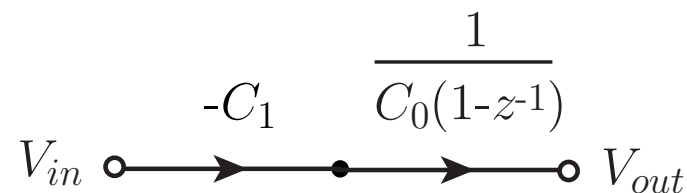
$$= \frac{\frac{K\omega_0^2}{\frac{4}{T^2} + \frac{2\omega_0}{TQ} + \omega_0^2} (1+z^{-1})^2}{1 - 2 \frac{\frac{4}{T^2} - \omega_0^2}{\frac{4}{T^2} + \frac{2\omega_0}{TQ} + \omega_0^2} z^{-1} + \frac{\frac{4}{T^2} - \frac{2\omega_0}{TQ} + \omega_0^2}{\frac{4}{T^2} + \frac{2\omega_0}{TQ} + \omega_0^2} z^{-2}}$$

FleischerとLakerの回路

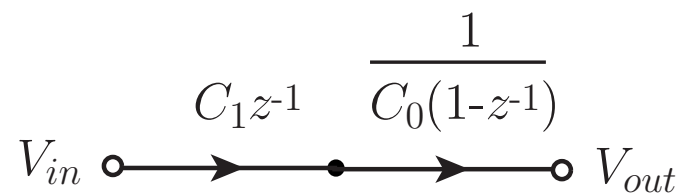


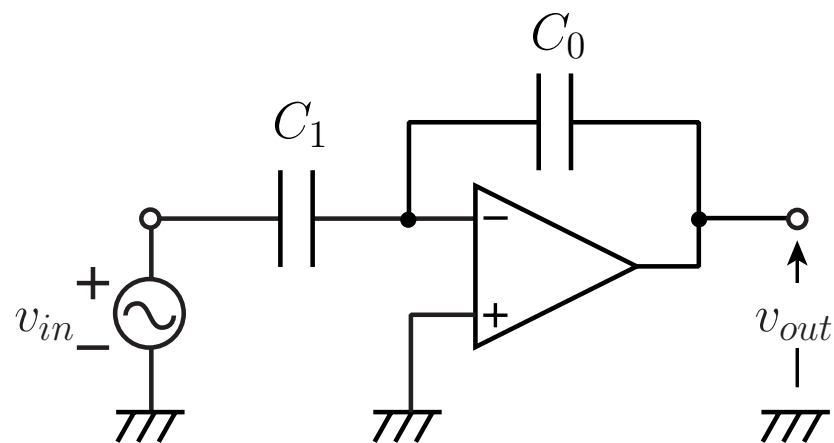


$$\frac{V_{out}(z)}{V_{in}(z)} = \frac{-C_1}{C_0(1-z^{-1})} = -C_1 \times \frac{1}{C_0(1-z^{-1})}$$

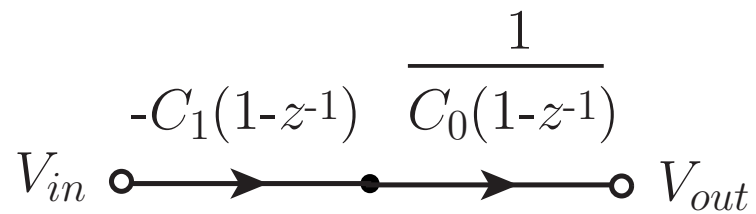


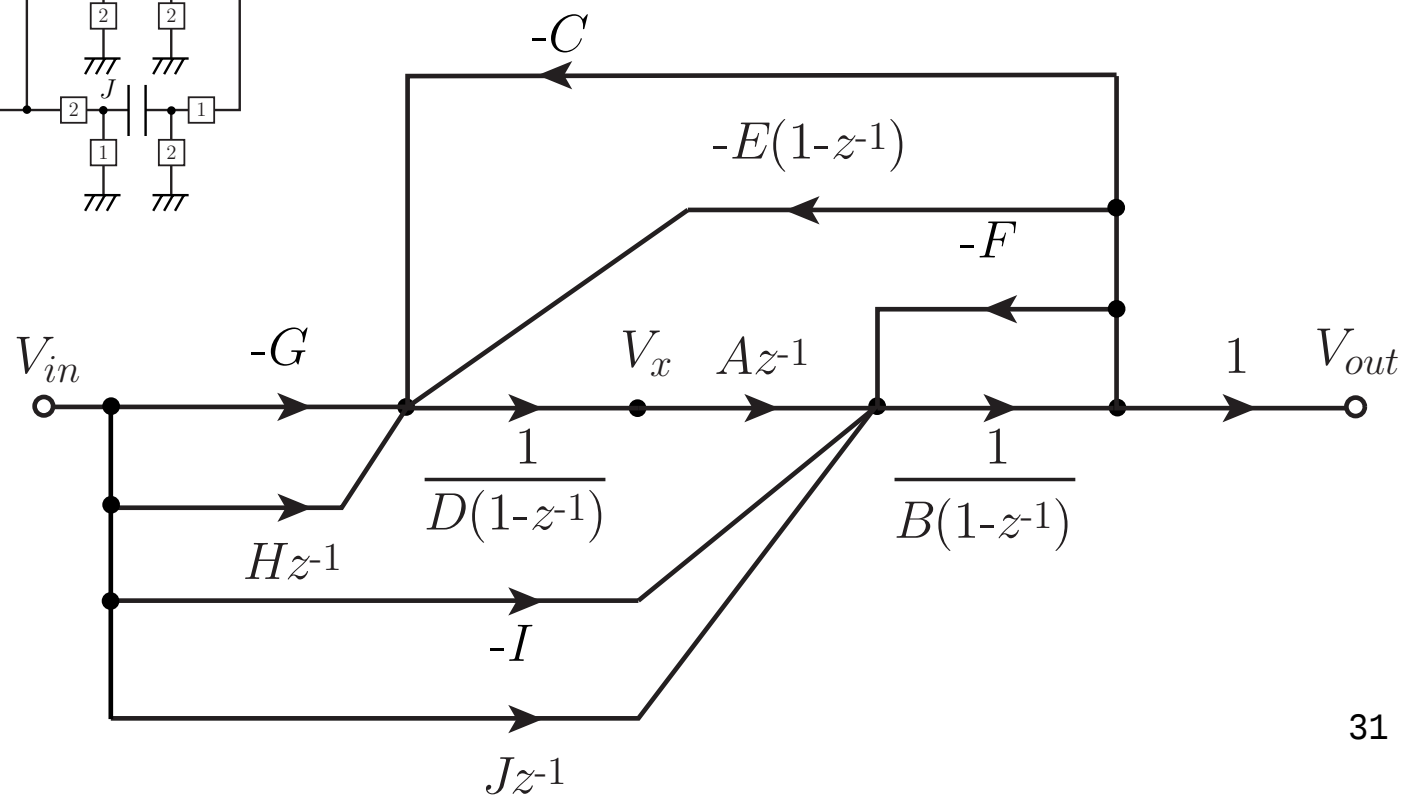
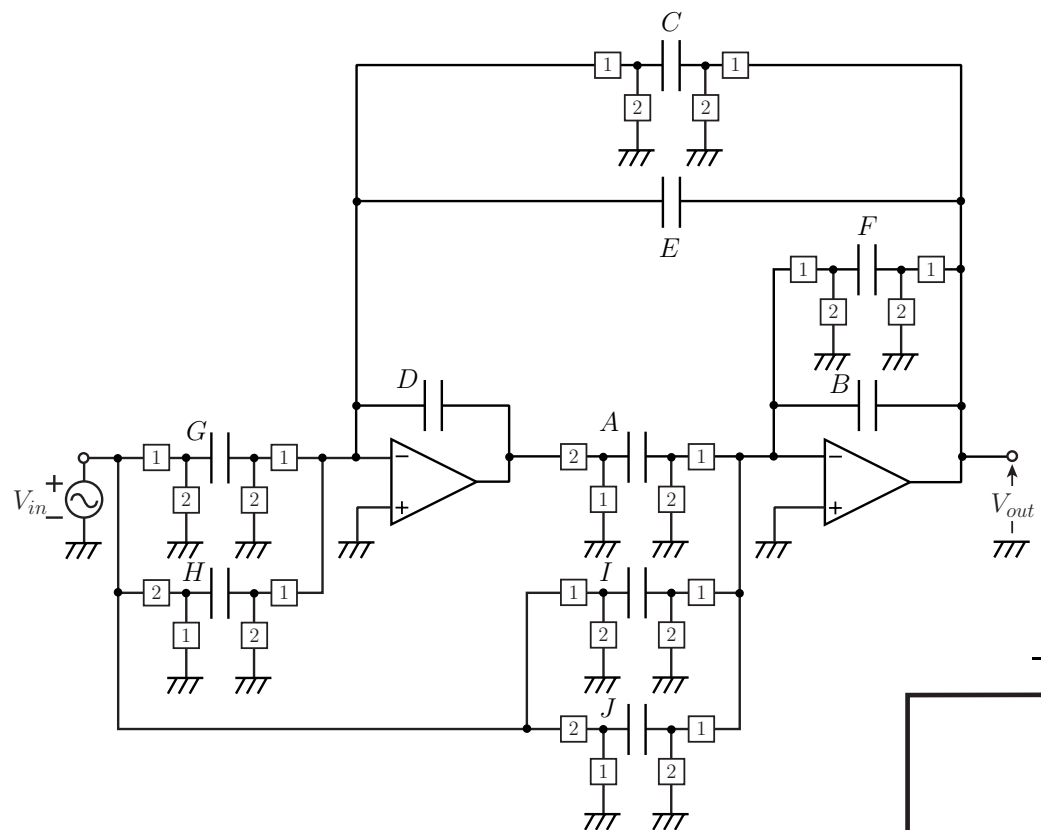
$$\frac{V_{out}(z)}{V_{in}(z)} = \frac{C_1 z^{-1}}{C_0(1-z^{-1})} = C_1 z^{-1} \times \frac{1}{C_0(1-z^{-1})}$$

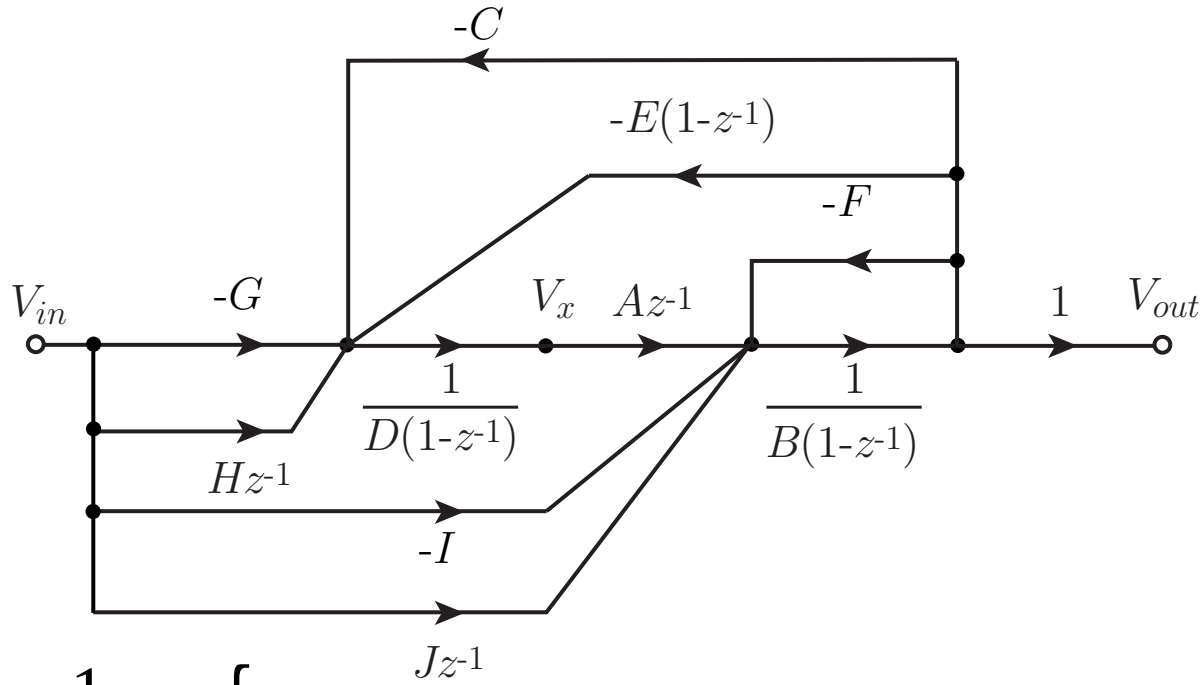




$$\frac{V_{out}(z)}{V_{in}(z)} = \frac{-C_1}{C_0} = -C_1(1-z^{-1}) \times \frac{1}{C_0(1-z^{-1})}$$





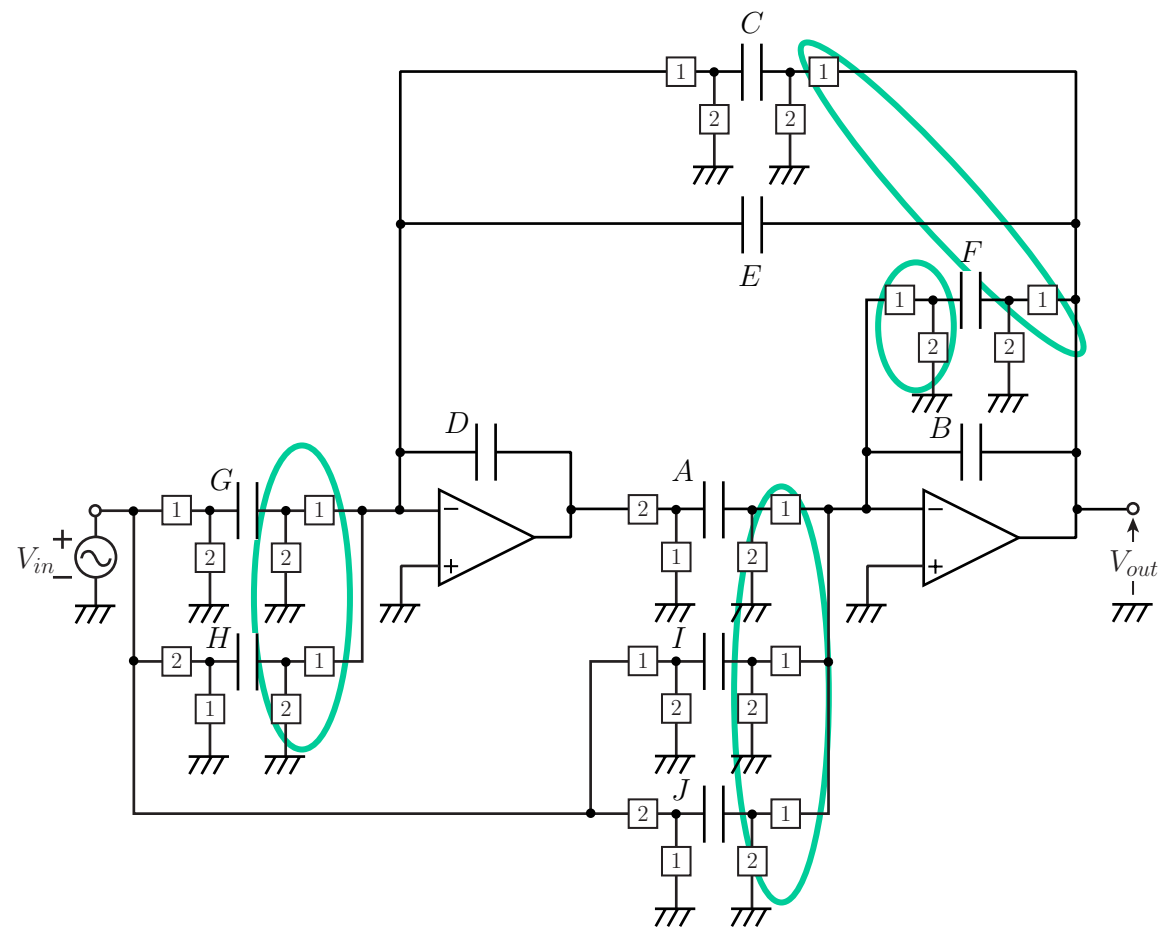


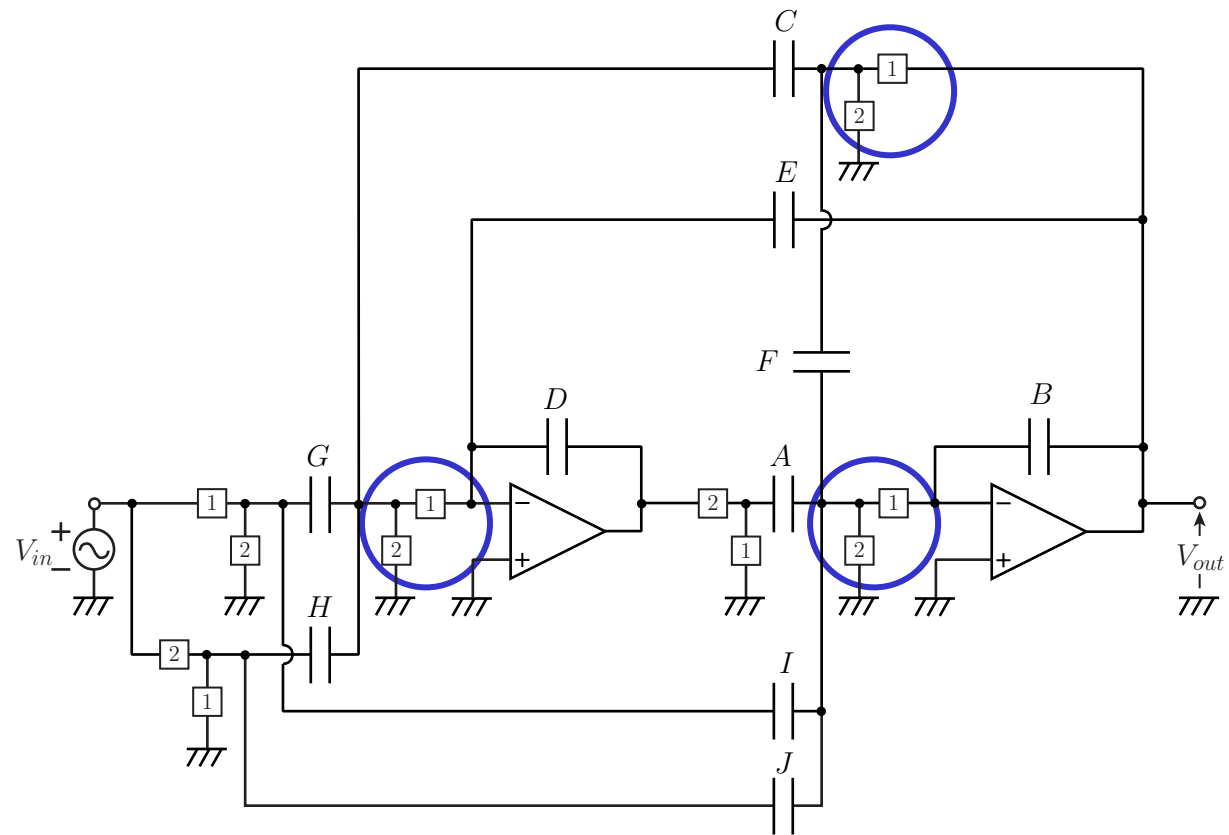
$$V_x = \frac{1}{D(1-z^{-1})} \left\{ -GV_{in} + Hz^{-1}V_{in} - CV_{out} - E(1-z^{-1})V_{out} \right\}$$

$$V_{out} = \frac{1}{B(1-z^{-1})} \left\{ Az^{-1}V_x - IV_{in} + Jz^{-1}V_{in} - FV_{out} \right\}$$

$$T_{FL}(z) = \frac{DI + (AG - DI - DJ)z^{-1} + (DJ - AH)z^{-2}}{D(B + F) + (AC + AE - DF - 2BD)z^{-1} + (BD - AE)z^{-2}}$$

スイッチの共有





$$T_{FL}(z) = \frac{DI + (AG - DI - DJ)z^{-1} + (DJ - AH)z^{-2}}{D(B + F) + (AC + AE - DF - 2BD)z^{-1} + (BD - AE)z^{-2}}$$

特性：容量比で決定



規格化



$$A = B = D = 1$$

$$T_{FL}(z) = \frac{I + (G - I - J)z^{-1} + (J - H)z^{-2}}{1 + F + (C + E - F - 2)z^{-1} + (1 - E)z^{-2}}$$

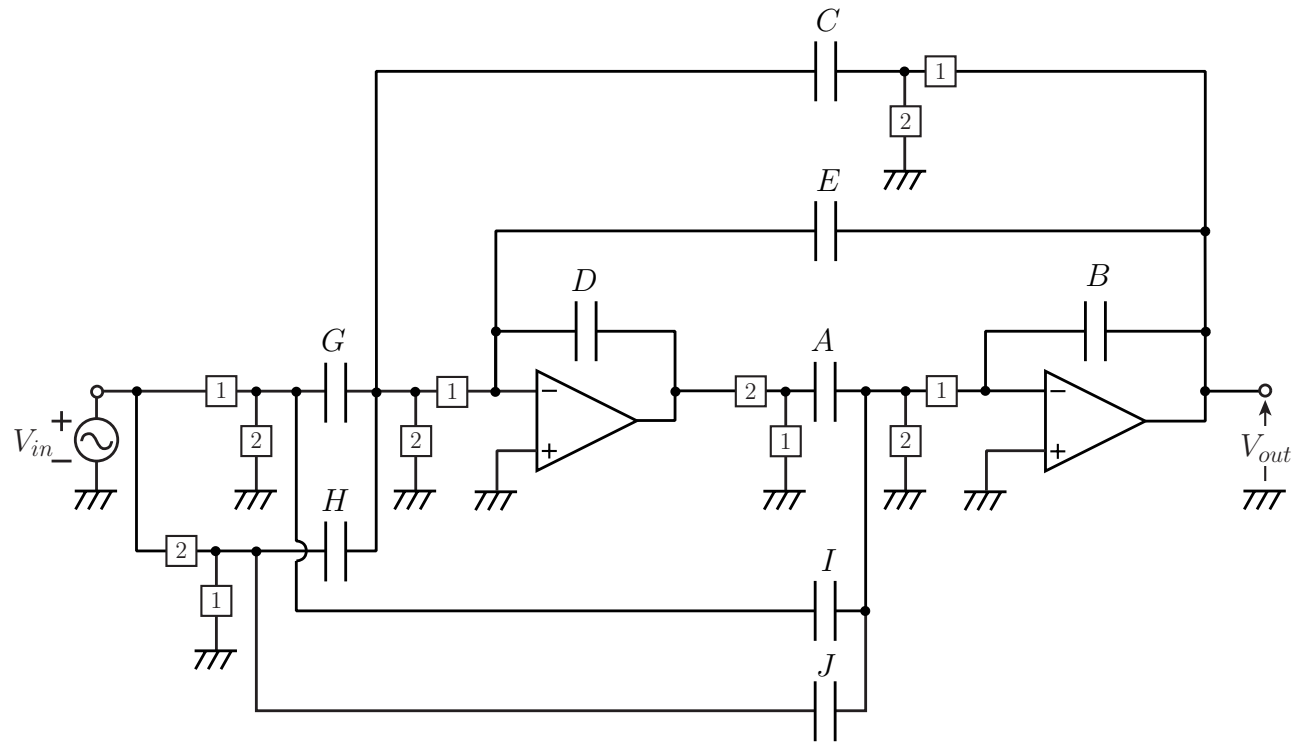
安定性：分母多項式の根は単位円内

$$1 + F > 1 - E$$

$$F = 0 \text{ or } E = 0$$

例: $F = 0$

$$T_{FL}(z) = \frac{I + (G - I - J)z^{-1} + (J - H)z^{-2}}{1 + (C + E - 2)z^{-1} + (1 - E)z^{-2}}$$



FleischerとLakerのE回路

$$T_{SC2}(z) = \frac{\frac{K\omega_0^2}{\frac{4}{T^2} + \frac{2\omega_0}{TQ} + \omega_0^2} (1+z^{-1})^2}{1 - 2 \frac{\frac{4}{T^2} - \omega_0^2}{\frac{4}{T^2} + \frac{2\omega_0}{TQ} + \omega_0^2} z^{-1} + \frac{\frac{4}{T^2} - \frac{2\omega_0}{TQ} + \omega_0^2}{\frac{4}{T^2} + \frac{2\omega_0}{TQ} + \omega_0^2} z^{-2}}$$

$$T_{FL}(z) = \frac{I + (G - I - J)z^{-1} + (J - H)z^{-2}}{1 + (C + E - 2)z^{-1} + (1 - E)z^{-2}}$$

$$E = \frac{\frac{4\omega_0}{TQ}}{\frac{4}{T^2} + \frac{2\omega_0}{TQ} + \omega_0^2}$$

$$C = \frac{4\omega_0^2}{\frac{4}{T^2} + \frac{2\omega_0}{TQ} + \omega_0^2}$$

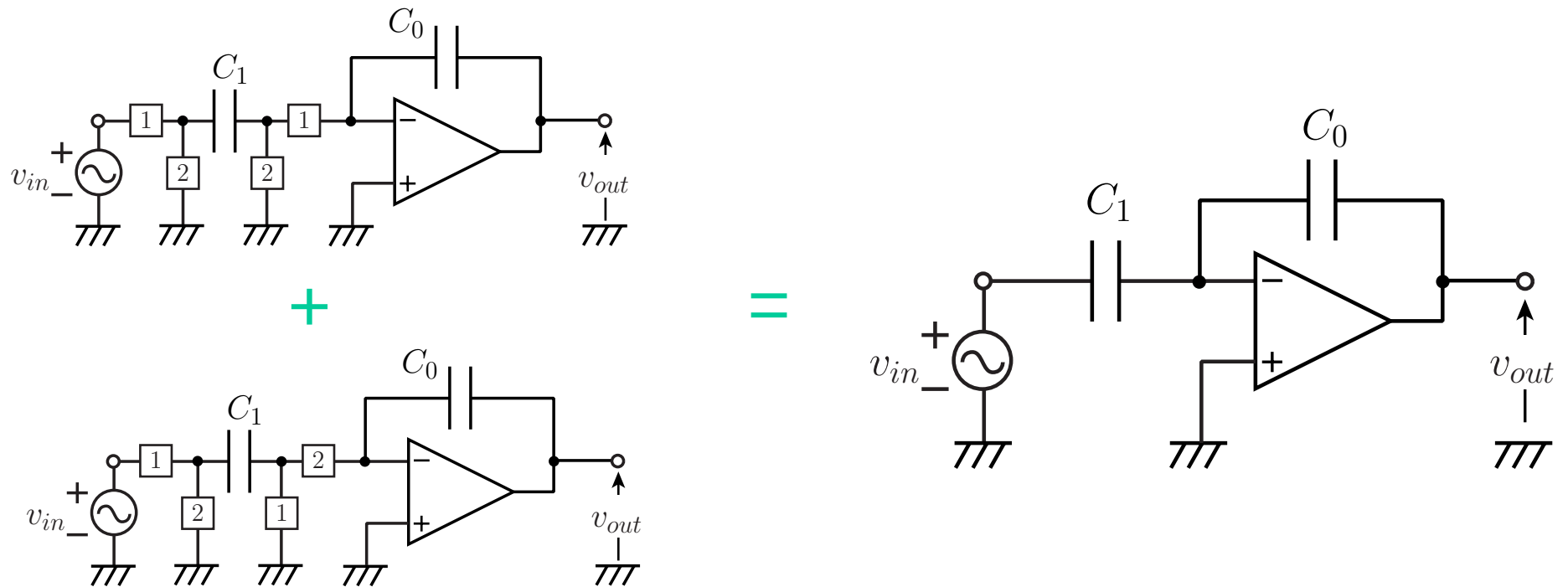
$$T_{FL}(z) = \frac{I + (G - I - J)z^{-1} + (J - H)z^{-2}}{1 + (C + E - 2)z^{-1} + (1 - E)z^{-2}}$$

$$T_{SC2}(z) = \frac{\frac{K\omega_0^2}{\frac{4}{T^2} + \frac{2\omega_0}{TQ} + \omega_0^2} (1 + 2z^{-1} + z^{-2})}{1 - 2 \frac{\frac{4}{T^2} - \omega_0^2}{\frac{4}{T^2} + \frac{2\omega_0}{TQ} + \omega_0^2} z^{-1} + \frac{\frac{4}{T^2} - \frac{2\omega_0}{TQ} + \omega_0^2}{\frac{4}{T^2} + \frac{2\omega_0}{TQ} + \omega_0^2} z^{-2}}$$

$$I = \frac{K\omega_0^2}{\frac{4}{T^2} + \frac{2\omega_0}{TQ} + \omega_0^2} \quad J = \frac{K\omega_0^2}{\frac{4}{T} + \frac{2\omega_0}{TQ} + \omega_0^2} \quad H = 0 \quad G = \frac{4K\omega_0^2}{\frac{4}{T^2} + \frac{2\omega_0}{TQ} + \omega_0^2}$$

$$A = B = D = 1 \quad C = \frac{4\omega_0^2}{\frac{4}{T^2} + \frac{2\omega_0}{TQ} + \omega_0^2} \quad E = \frac{\frac{4\omega_0}{TQ}}{\frac{4}{T^2} + \frac{2\omega_0}{TQ} + \omega_0^2}$$

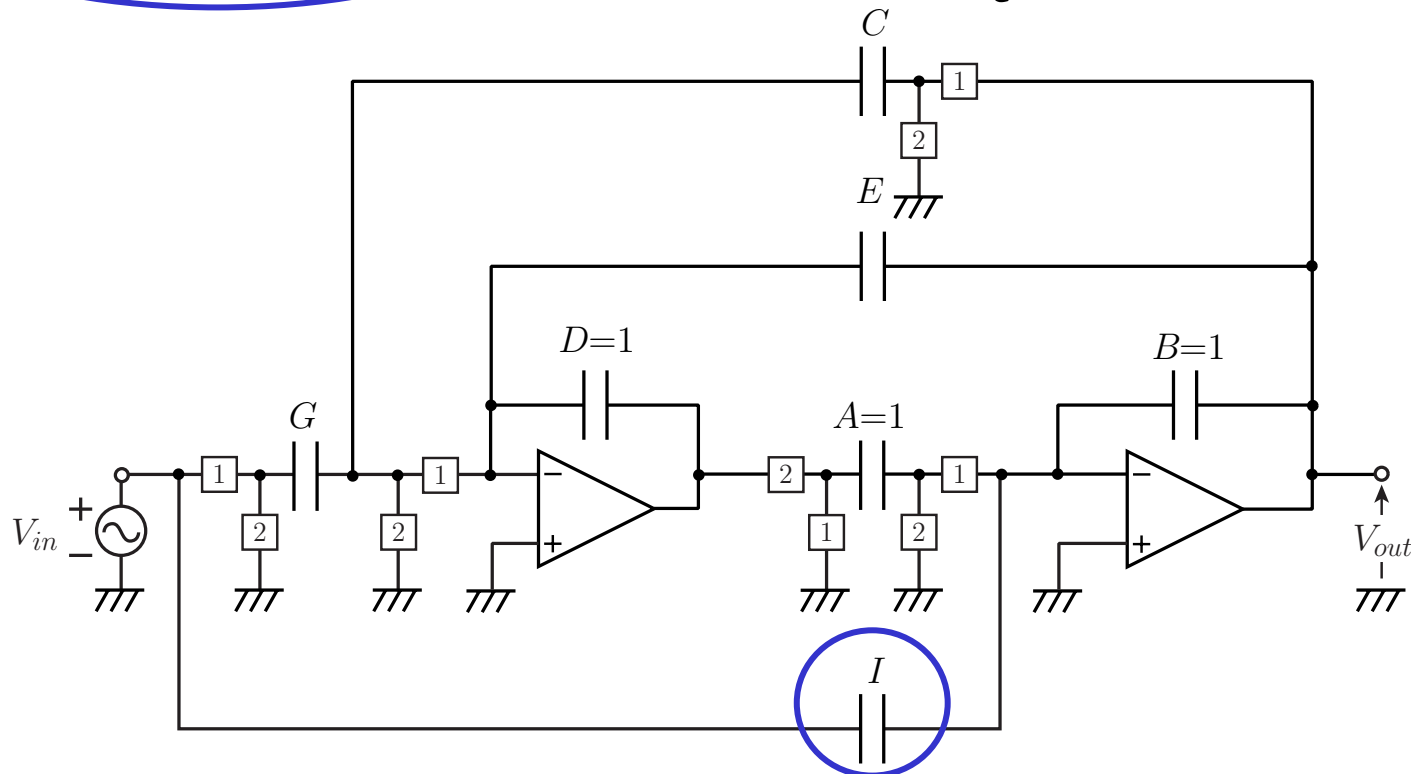
$$I = J = \frac{K\omega_0^2}{\frac{4}{T^2} + \frac{2\omega_0}{TQ} + \omega_0^2} \quad G = \frac{4K\omega_0^2}{\frac{4}{T^2} + \frac{2\omega_0}{TQ} + \omega_0^2} \quad H = 0$$



$$\frac{V_{out}(z)}{V_{in}(z)} = \frac{-C_1}{C_0(1-z^{-1})} + \frac{C_1 z^{-1}}{C_0(1-z^{-1})} = \frac{-C_1(1-z^{-1})}{C_0(1-z^{-1})} = \frac{-C_1}{C_0}$$

$$I = J = \frac{K\omega_0^2}{\frac{4}{T^2} + \frac{2\omega_0}{TQ} + \omega_0^2}$$

$$G = \frac{4K\omega_0^2}{\frac{4}{T^2} + \frac{2\omega_0}{TQ} + \omega_0^2} \quad H = 0$$



帯域通過型関数:

$$\begin{aligned}
 T_{SC2}(z) &= T_{second} \left(\frac{2}{T} \frac{1-z^{-1}}{1+z^{-1}} \right) = \frac{N \left(\frac{2}{T} \frac{1-z^{-1}}{1+z^{-1}} \right)}{\left(\frac{2}{T} \frac{1-z^{-1}}{1+z^{-1}} \right)^2 + \frac{\omega_0}{Q} \left(\frac{2}{T} \frac{1-z^{-1}}{1+z^{-1}} \right) + \omega_0^2} \\
 &= \frac{\frac{2K\omega_0}{TQ} (1+z^{-1})^2}{\frac{4}{T^2} + \frac{2\omega_0}{TQ} + \omega_0^2} \\
 &= \frac{1 - 2 \frac{\frac{4}{T^2} - \omega_0^2}{\frac{4}{T^2} + \frac{2\omega_0}{TQ} + \omega_0^2} z^{-1} + \frac{\frac{4}{T^2} - \frac{2\omega_0}{TQ} + \omega_0^2}{\frac{4}{T^2} + \frac{2\omega_0}{TQ} + \omega_0^2} z^{-2}}{1}
 \end{aligned}$$

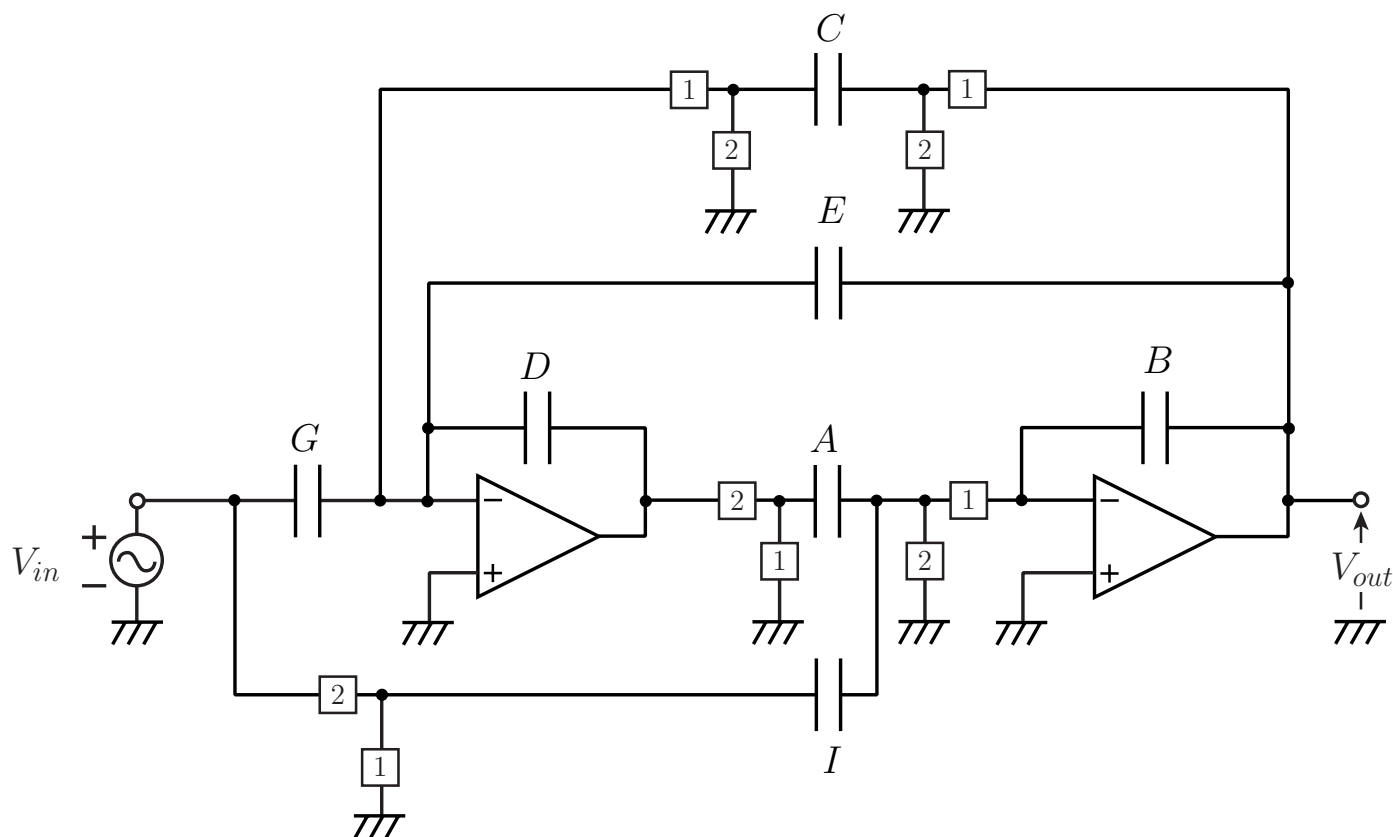
$$T_{SC2}(z) = \frac{\frac{2K\omega_0}{TQ} (1+z^{-1})^2}{1 - 2 \frac{\frac{4}{T^2} - \omega_0^2}{\frac{4}{T^2} + \frac{2\omega_0}{TQ} + \omega_0^2} z^{-1} + \frac{\frac{4}{T^2} - \frac{2\omega_0}{TQ} + \omega_0^2}{\frac{4}{T^2} + \frac{2\omega_0}{TQ} + \omega_0^2} z^{-2}}$$

$A=B=D=1$ とすると

$$T_{FL}(z) = \frac{I + (G - I - J)z^{-1} + (J - H)z^{-2}}{1 + (C + E - 2)z^{-1} + (1 - E)z^{-2}}$$

$$C = \frac{4\omega_0^2}{\frac{4}{T^2} + \frac{2\omega_0}{TQ} + \omega_0^2} \quad E = \frac{\frac{4\omega_0}{TQ}}{\frac{4}{T^2} + \frac{2\omega_0}{TQ} + \omega_0^2} \quad I = G = H = \frac{\frac{2K\omega_0}{TQ}}{\frac{4}{T^2} + \frac{2\omega_0}{TQ} + \omega_0^2} \quad J = 0$$

2次帯域通過フィルタ



例題

中心周波数1kHz , $Q=5$, $T=1/20000\text{s}$, $K=1$

$$\Omega \rightarrow \frac{2}{T} \tan\left(\frac{\omega T}{2}\right)$$

$$\omega_0 = 40000 \tan\left(\frac{2\pi \times 1000}{2} \times \frac{1}{20000}\right) = 2\pi \times 1008$$

$$\begin{aligned} T(z^{-1}) &= \frac{\frac{2K\omega_0}{TQ}(1-z^{-2})}{\left(\frac{4}{T^2} + \frac{2\omega_0}{TQ} + \omega_0^2\right) - 2\left(\frac{4}{T^2} - \omega_0^2\right)z^{-1} + \left(\frac{4}{T^2} + \frac{2\omega_0}{TQ} + \omega_0^2\right)z^{-2}} \\ &= \frac{0.0300(1-z^{-2})}{1-1.85z^{-1}+0.940z^{-2}} \end{aligned}$$

$$\omega_0=2\pi\times 1000, Q=5, T=1/20000\text{s}, K=1$$

$$A=B=D=1$$

$$\rightarrow 33.3\text{pF}$$

$$C=\frac{4\omega_0^2}{\frac{4}{T^2}+\frac{2\omega_0}{TQ}+\omega_0^2}=0.0950$$

$$\rightarrow 3.17\text{pF}$$

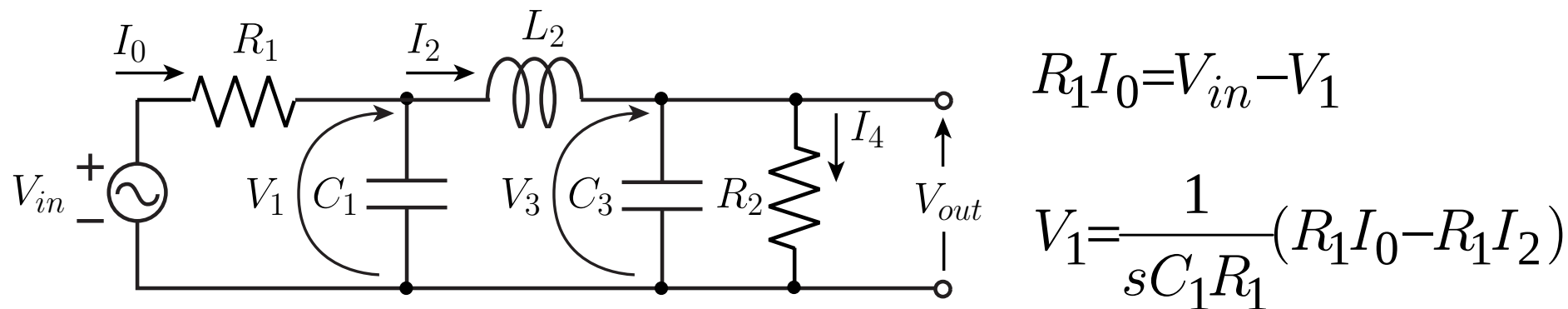
$$E=\frac{\frac{4\omega_0}{TQ}}{\frac{4}{T^2}+\frac{2\omega_0}{TQ}+\omega_0^2}=0.0600$$

$$\rightarrow 2.00\text{pF}$$

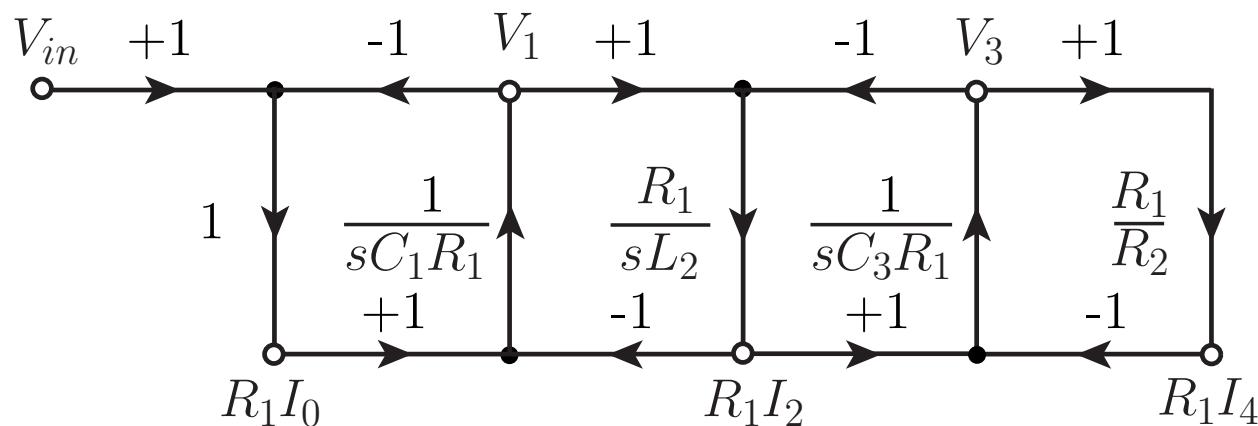
$$I=G=H=\frac{K\frac{2\omega_0}{TQ}}{\frac{4}{T^2}+\frac{2\omega_0}{TQ}+\omega_0^2}=0.0300$$

$$\rightarrow 1.00\text{pF}$$

スイッチトキャパシタ回路によるリープフログ・シミュレーション

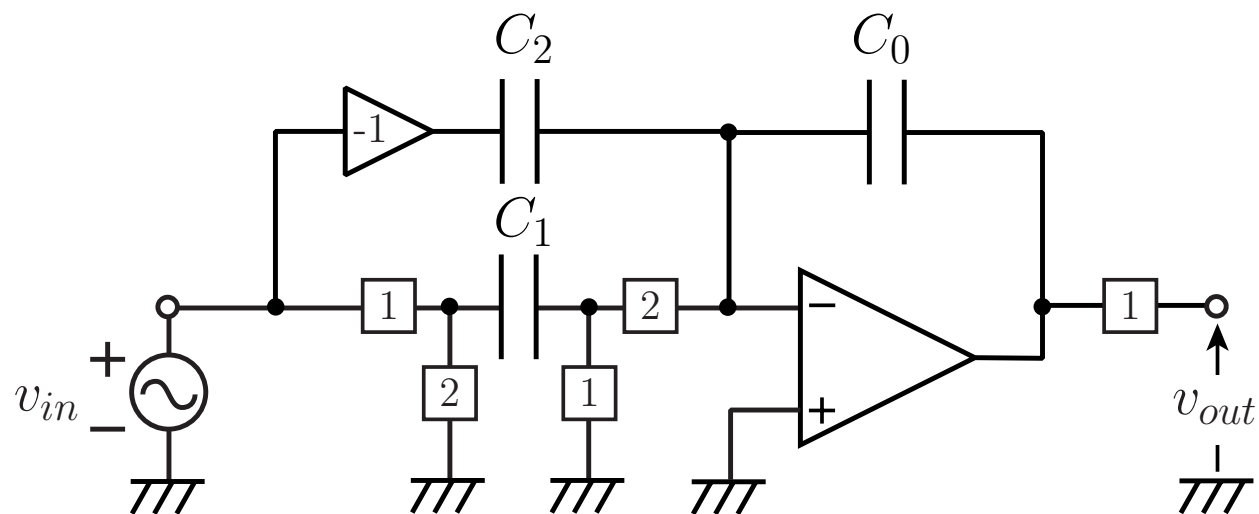


$$R_1 I_2 = \frac{R_1}{sL_2} (V_1 - V_3) \quad V_3 = \frac{1}{sC_3 R_1} (R_1 I_2 - R_1 I_4) \quad R_1 I_4 = \frac{R_1}{R_2} V_3$$



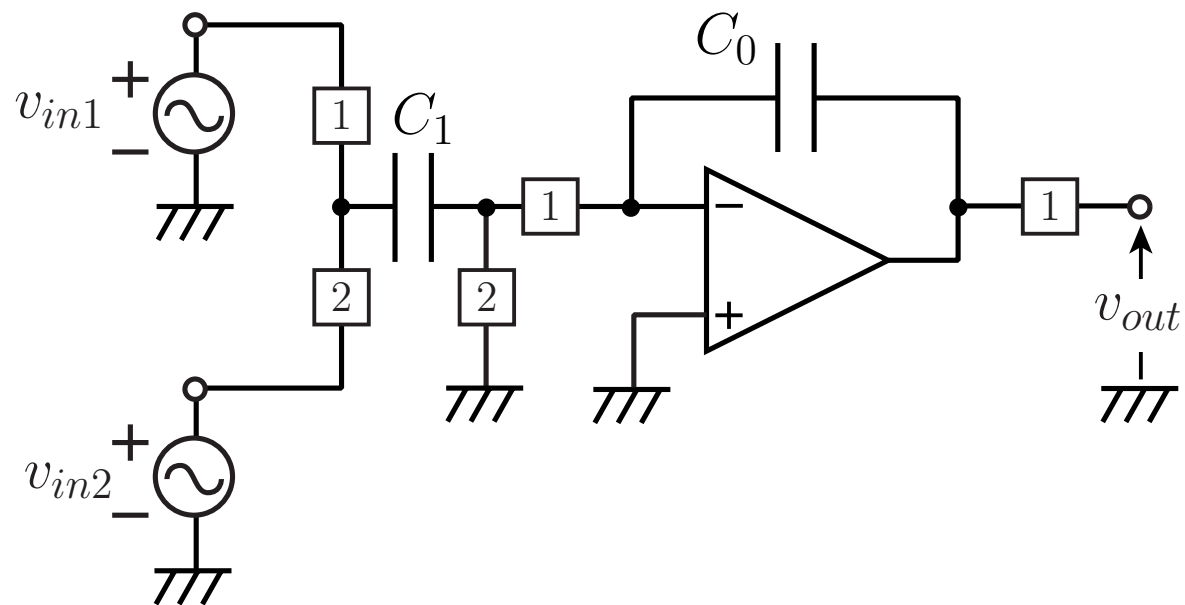
(a)

積分回路の選択

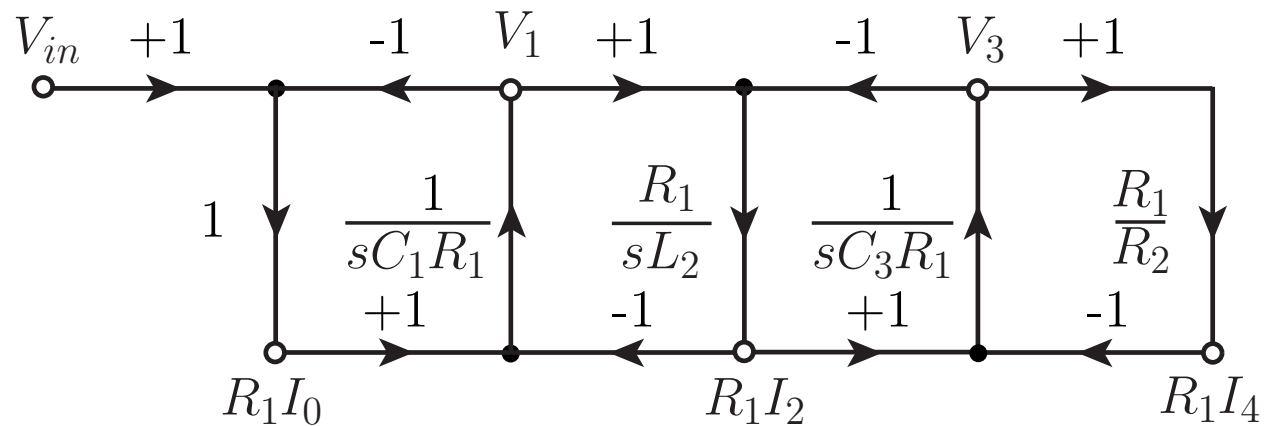


$C_1=2C_2$ のとき

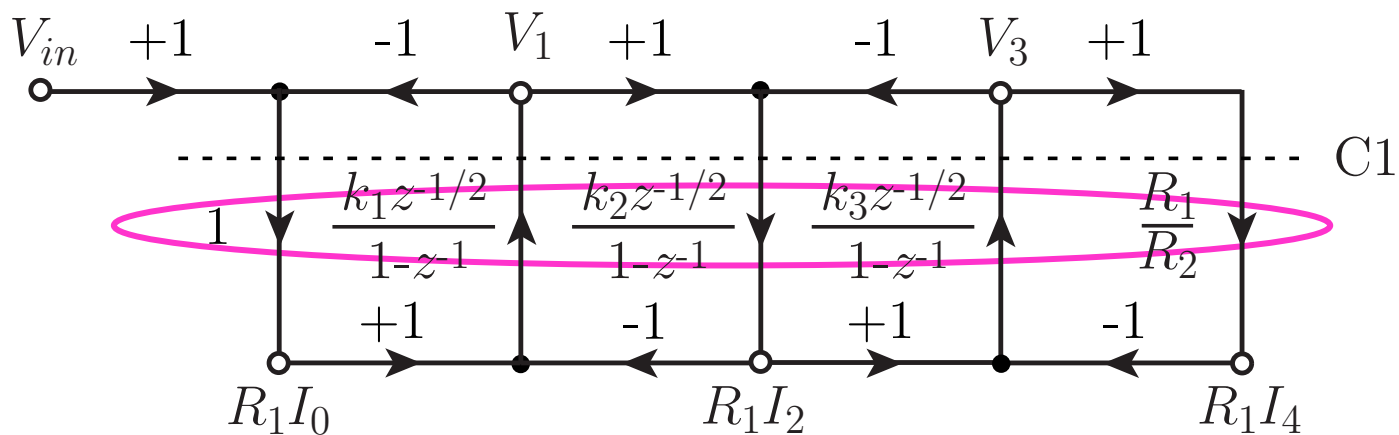
双一次積分回路
複雑



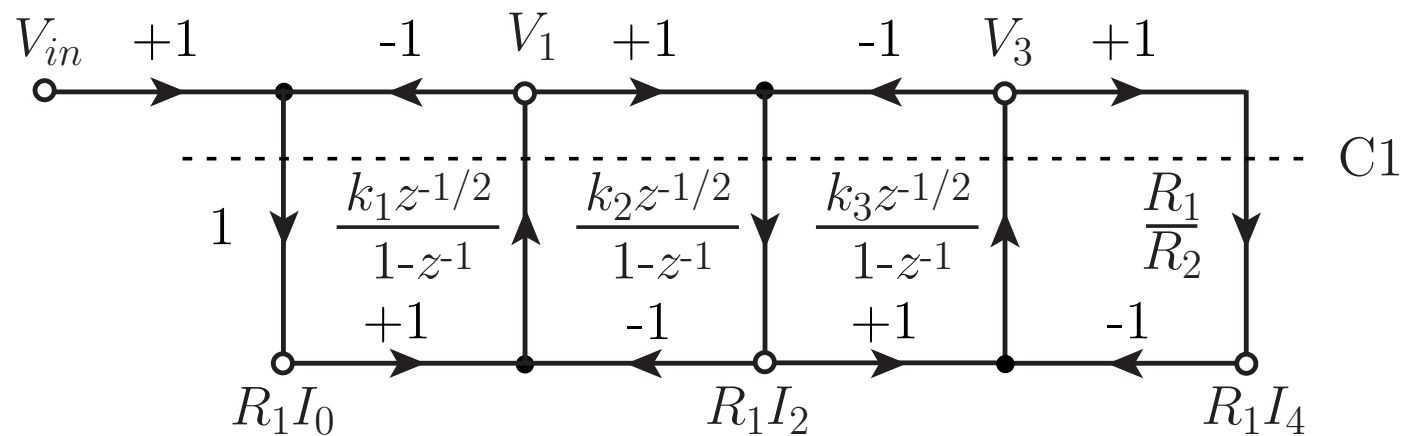
LDI積分回路
簡単



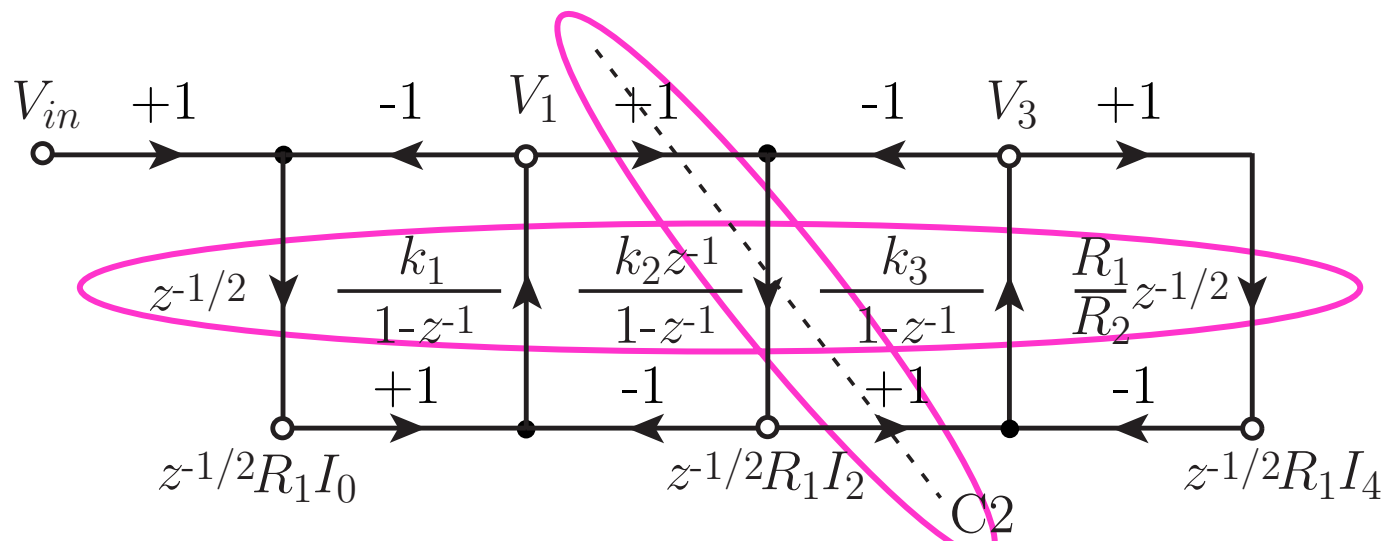
(a)



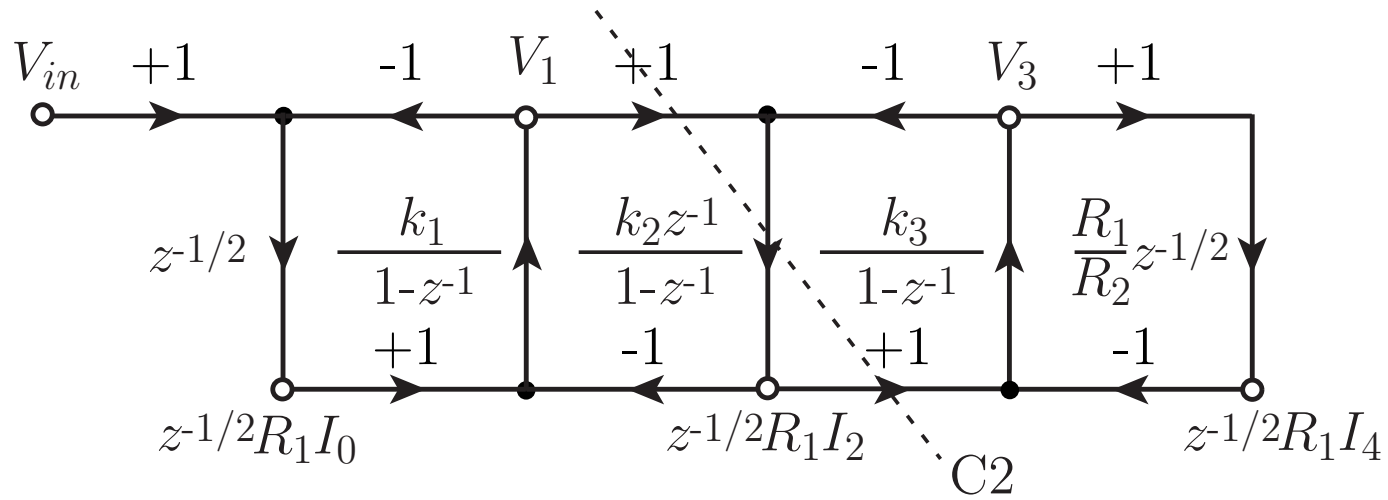
(b)



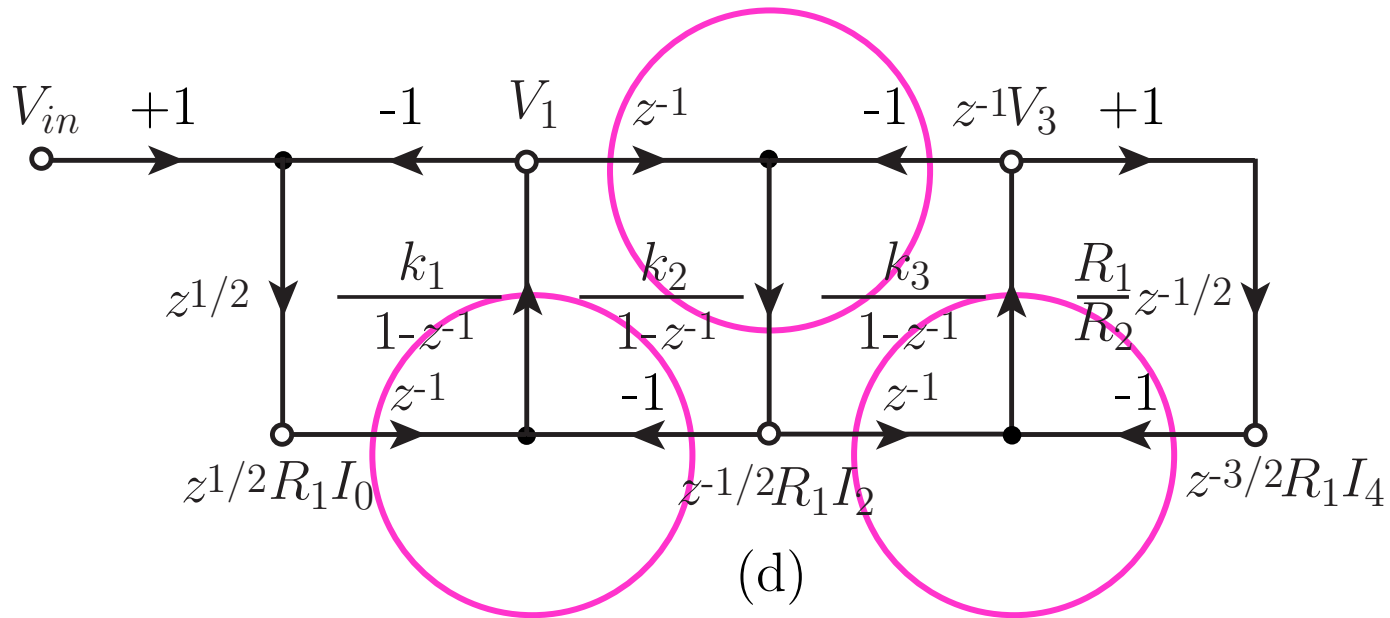
(b)



(c)

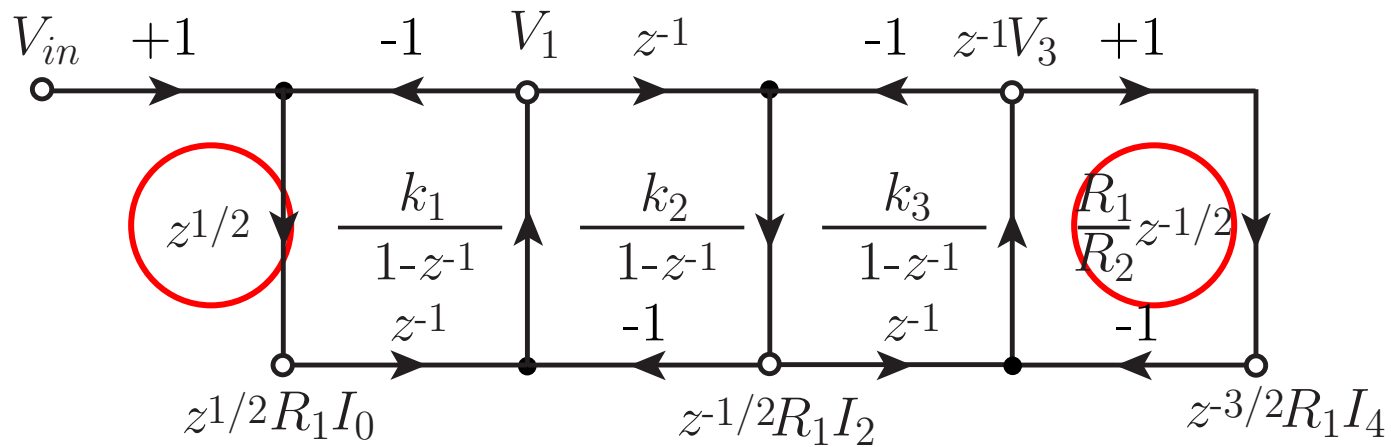


(c)



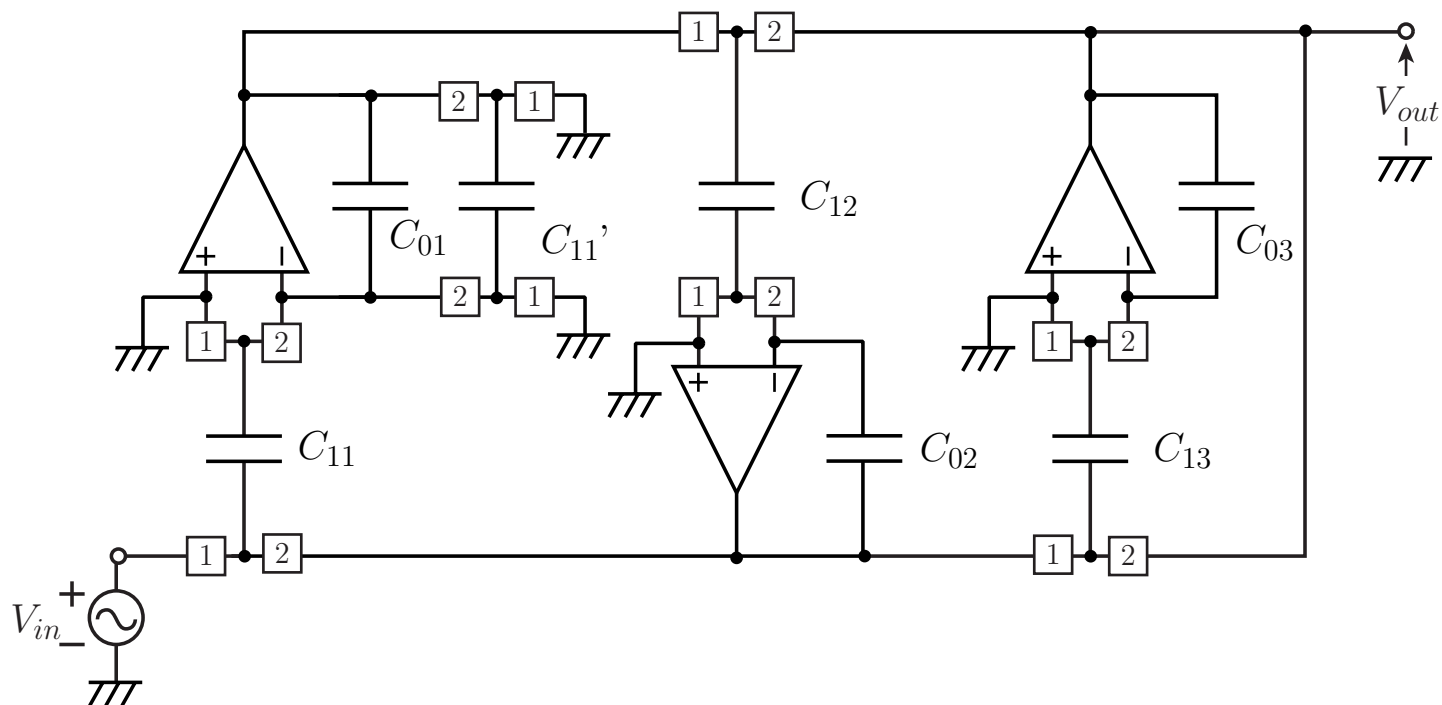
(d)

$$k_1 = \frac{T}{C_1 R_1} \quad k_2 = \frac{R_1 T}{L_2} \quad k_3 = \frac{T}{C_3 R_1}$$



(d)

$$k_1 = \frac{T}{C_1 R_1} \quad k_2 = \frac{R_1 T}{L_2} \quad k_3 = \frac{T}{C_3 R_1}$$



LDI変換の問題点

伝達関数 $T(s)$ の極:

$$s_i = \sigma_i + j\omega_i$$

$$s_i = \frac{z^{1/2} - z^{-1/2}}{T}$$



$$s_i^2 = \frac{z - 2 + z^{-1}}{T^2}$$

解:

$$z_i$$



$$z_i^{-1}$$

$$|z_i| < 1$$



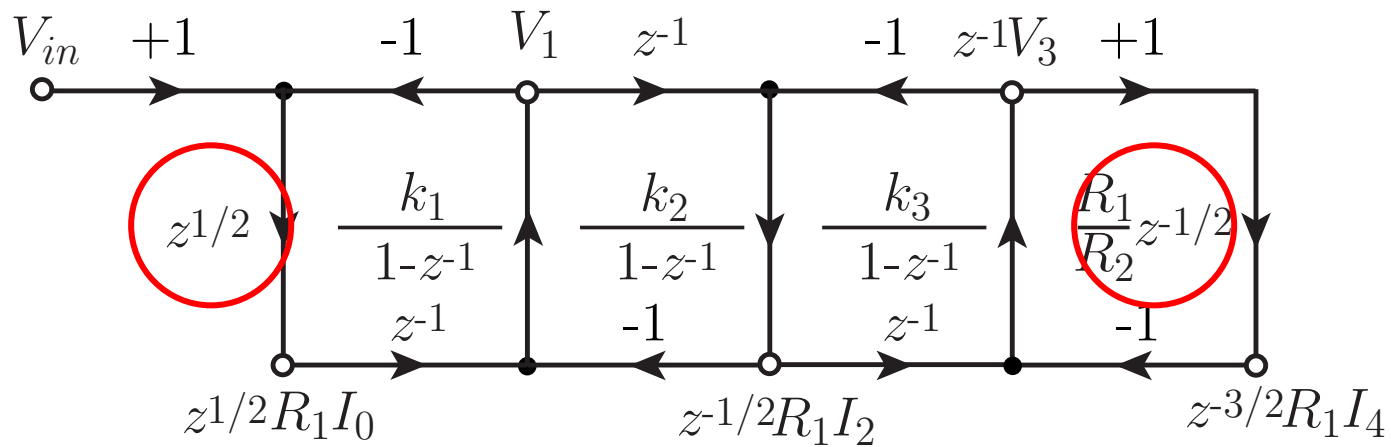
安定



$$|z_i^{-1}| > 1$$



不安定



(d)

$$k_1 = \frac{T}{C_1 R_1} \quad k_2 = \frac{R_1 T}{L_2} \quad k_3 = \frac{T}{C_3 R_1}$$

誤差要因

不安定性を除去

例題

遮断周波数1kHzの3次低域通過フィルタ

$$\Omega \rightarrow \frac{2}{T} \sin\left(\frac{\omega T}{2}\right)$$

$$T=1/20000\text{s}$$

$$\omega_0 = 40000 \sin\left(\frac{2\pi \times 1000}{2} \times \frac{1}{20000}\right) = 2\pi \times 996$$

$$R_1=R_2=1\text{k}\Omega \quad C_1=C_3=0.159\mu\text{F} \quad L_2=0.318\text{H}$$



$$R_1=R_2=1\text{k}\Omega \quad C_1=C_3=0.160\mu\text{F} \quad L_2=0.319\text{H}$$

$$k_1 = \frac{T}{C_1 R_1} = \frac{C_{11}}{C_{01}} = \frac{C'_{11}}{C_{01}} = 0.319$$

$$k_2 = \frac{TR_1}{L_2} = \frac{C_{12}}{C_{02}} = 0.160$$

$$k_3 = \frac{T}{C_3 R_1} = \frac{C_{13}}{C_{03}} = 0.319$$

$C_{01}=C_{02}=C_{03}=1$ とすれば

$$C_{11}=C'_{11}=C_{13}=0.319, C_{12}=0.160$$

$$C_{01}=C_{02}=C_{03}=6.25\text{pF}, C_{11}=C'_{11}=C_{13}=1.99\text{pF}, C_{12}=1.00\text{pF}$$

容量の総和 :25.7pF

$$k_1 = \frac{T}{C_1 R_1} = \frac{C_{11}}{C_{01}} = \frac{C'_{11}}{C_{01}} = 0.319$$

$$k_2 = \frac{TR_1}{L_2} = \frac{C_{12}}{C_{02}} = 0.160$$

$$k_3 = \frac{T}{C_3 R_1} = \frac{C_{13}}{C_{03}} = 0.319$$

$C_{01}=C_{03}=1$, $C_{02}=2$ とすれば

$$C_{11}=C'_{11}=C_{12}=C_{13}=0.319$$

$$C_{01}=C_{03}=3.13\text{pF} \text{ , } C_{02}=6.25\text{pF} \text{ , } C_{11}=C'_{11}=C_{12}=C_{13}=1.00\text{pF}$$

容量の総和 :13.4pF