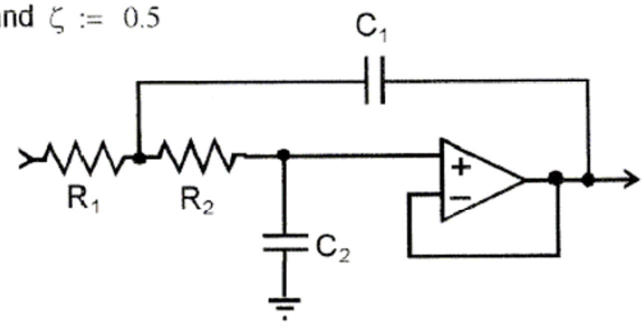
14-16 Low pass Sallen-Key with $\omega_0 := 2000$ rad/s and $\zeta := 0.5$



Use unity gain method: let $R := 10^4\ \Omega$, then

$C_1 := \dfrac{1}{\zeta \cdot \omega_0 \cdot R}$ $\quad C_2 := \zeta^2 \cdot C_1$ $\quad R_1 := R$ $\quad R_2 := R$

$R_1 = 1 \times 10^4\ \Omega$ $\quad R_2 = 1 \times 10^4\ \Omega$

$C_1 = 1 \times 10^{-7}$ F $\quad C_2 = 2.5 \times 10^{-8}$ F

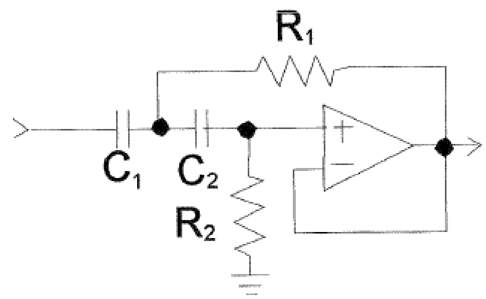
14-19 High pass with $\omega_0 := 2500$ rad/s and $\zeta := 0.75$

Use unity gain method: let $C := 200 \cdot 10^{-9}$, then

$$R_2 := \frac{1}{\zeta \cdot \omega_0 \cdot C} \qquad R_1 := \zeta^2 \cdot R_2 \qquad C_1 := C \qquad C_2 := C$$

$$R_1 = 1.5 \times 10^3 \ \Omega \qquad R_2 = 2.667 \times 10^3 \Omega$$

$$C_1 = 2 \times 10^{-7} \ \text{F} \qquad C_2 = 2 \times 10^{-7} \ \text{F}$$



14-31 First-order cascade poles for $\omega_C := 200$; $T_{MAX} := 10^{\frac{0}{20}}$; $T_{MIN} := 10^{\frac{-30}{20}}$; $\omega_{MIN} := 10^3$

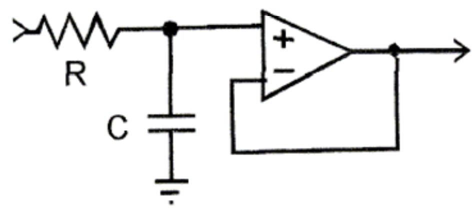
$$\alpha(n) := \frac{\omega_C}{\sqrt{2^{\frac{1}{n}} - 1}} \qquad T(s,n) := \frac{T_{MAX}}{\left(\frac{s}{\alpha(n)} + 1\right)^n}$$

Define $Gain_{dB}(\omega, n) := 20 \cdot \log(|T(j \cdot \omega, n)|)$

$n := 3 \quad Gain_{dB}(\omega_{MIN}, n) = -26.248$

$n := 4 \quad Gain_{dB}(\omega_{MIN}, n) = -30.327$ <--- n = 4 is the lowest order $\alpha(4) = 459.792$ $T_{MAX} = 1$

The required T(s) is $T(s) := \frac{1}{\left(\frac{s}{459.792} + 1\right)^4}$



Use a four-stage cascade of identical first-order low-pass voltage divider filters with K = 1 and

$R \cdot C = \frac{1}{459.792}$.

Let $R := 10^4 \Omega$ then $C := \frac{1}{R \cdot 459.792}$ $C = 2.175 \times 10^{-7}$ F

14-32 Butterworth poles for $\omega_C := 200$; $T_{MAX} := 10^{\frac{0}{20}}$; $T_{MIN} := 10^{\frac{-30}{20}}$; $\omega_{MIN} := 10^3$

$$\frac{1}{2}\cdot\frac{\ln\left[\left(\frac{T_{MAX}}{T_{MIN}}\right)^2 - 1\right]}{\ln\left(\frac{\omega_{MIN}}{\omega_C}\right)} = 2.146$$

<--- n = 3 is the lowest order

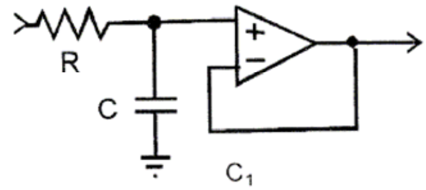
$$T(s) = \frac{T_{MAX}}{q3\left(\frac{s}{\omega_C}\right)}$$

The required transfer function is $q_3(s) = (s+1)\cdot\left(s^2+s+1\right)$ $\quad T_{MAX} = 1$

$$T(s) = \frac{1}{\left(\frac{s}{200}+1\right)\cdot\left[\left(\frac{s}{200}\right)^2 + \frac{s}{200} + 1\right]} = \left(\frac{1}{\frac{s}{200}+1}\right)\cdot\left[\frac{1}{\left[\left(\frac{s}{200}\right)^2 + \frac{s}{200} + 1\right]}\right] = T_1(s)\cdot T_2(s)$$

Use a two-stage cascade design

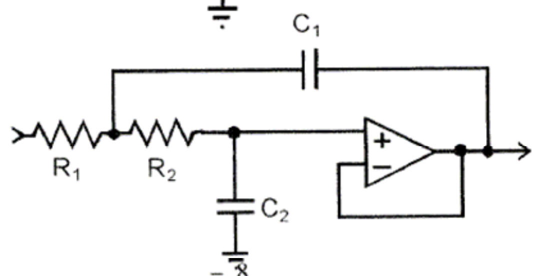
1st stage: Use a first-order low-pass voltage divider with



$$R\cdot C = \frac{1}{200}$$

Let $R := 10^4\ \Omega$ then $C := \frac{1}{200R}$ $\quad C = 5\times 10^{-7}$ F

2nd stage: Use a 2nd order unity gain S-K design with



$\omega_0 := 200 \quad \zeta := 0.5$ Let $\quad C_1 := 10^{-7} \quad C_2 := \zeta^2\cdot C_1$

$R := \left(\sqrt{C_1\cdot C_2}\cdot\omega_0\right)^{-1} \qquad R_1 := R \qquad R_2 := R$

$R_1 = 1\times 10^5\ \Omega \quad R_2 = 1\times 10^5\ \Omega \quad C_1 = 1\times 10^{-7}$ F $\quad C_2 = 2.5\times 10^{-8}$ F

14-40

$f_C := 25000 \quad T_{MAX} := 1 \quad T_{MIN} := 10^{-1.5} \quad f_{MIN} := 200 \cdot 10^3$

Butterworth

$$\frac{1}{2} \cdot \frac{\ln\left[\left(\frac{T_{MAX}}{T_{MIN}}\right)^2 - 1\right]}{\ln\left(\frac{f_{MIN}}{f_C}\right)} = 1.661 \quad \text{<--- n = 2}$$

Chebychev

$$\frac{\operatorname{acosh}\left[\sqrt{\left(\frac{T_{MAX}}{T_{MIN}}\right)^2 - 1}\right]}{\operatorname{acosh}\left(\frac{f_{MIN}}{f_C}\right)} = 1.498 \quad \text{<--- n = 2}$$

Since Butterworth & Chebychev both require n = 2, use Butterworth because of easier to design and similar parts

$\omega_C := 2 \cdot \pi \cdot f_C$

$$T(s) = \left[\frac{1}{\left(\frac{s}{\omega_C}\right)^2 + \left(\frac{s}{\omega_C}\right) + 1}\right] = \frac{1}{\left(\frac{s}{\omega_0}\right)^2 + 2 \cdot \zeta \cdot \left(\frac{s}{\omega_0}\right) + 1}$$

$\omega_0 := \omega_C \qquad \zeta := 0.5$

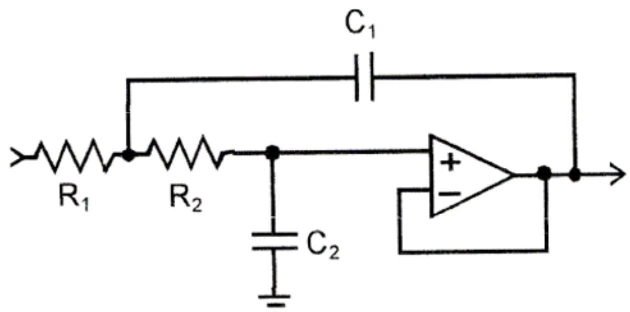
use a unity gain design with $\omega_0 = 1.571 \times 10^5$

and $\zeta = 0.5$ Let $C_1 := 10^{-8}$ then $C_2 := \zeta^2 \cdot C_1$

$R := \left[\left(\sqrt{C_1 \cdot C_2}\right) \cdot \omega_0\right]^{-1}$, $R_1 := R$, $R_2 := R$

$C_1 = 1 \times 10^{-8}$ F $\quad C_2 = 2.5 \times 10^{-9}$ F

$R_1 = 1.273 \times 10^3\ \Omega \quad R_2 = 1.273 \times 10^3\ \Omega.$



The element values calculated above can be used to verify the design.
Text eq. (14-3) gives the transfer function in terms of circuit elements. With $\mu = 1$ the transfer function is written as

$$T(s) := \frac{1}{R_1 \cdot R_2 \cdot C_1 \cdot C_2 \cdot s^2 + (R_1 \cdot C_1 + R_2 \cdot C_2 + R_1 \cdot C_2 - R_2 \cdot C_1) \cdot s + 1}$$

Testing the gain of the design at 25 kHz and 200 kHz yields

$20 \cdot \log\left(\left|T\left(j \cdot 2 \cdot \pi \cdot 25 \cdot 10^3\right)\right|\right) = 3.857 \times 10^{-15}$ <--- gain essentially unchanged at 25 kHz

$20 \cdot \log\left(\left|T\left(j \cdot 2 \cdot \pi \cdot 200\,10^3\right)\right|\right) = -36.056$ <--- less than -30 dB at 200 kHz as required