Filter Aktif

Elektronika
(TKE 4012)

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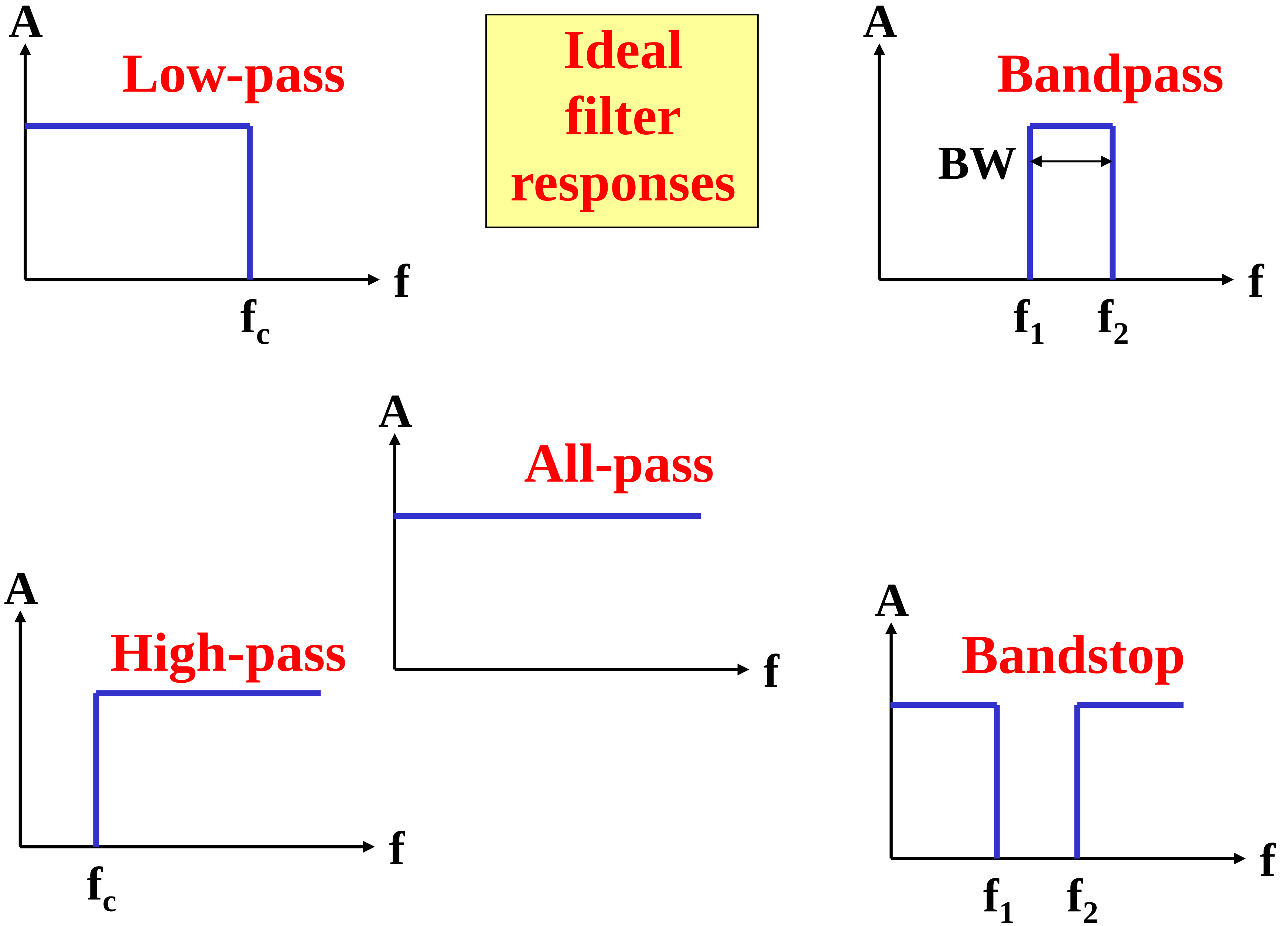

Ideal filter responses
A
Low-pass
f
fc
A
Bandpass
BW
f
f1
f2
A
All-pass
f
A
High-pass
f
fc
A
Bandstop
f
f1
f2

Real filter response

- **Ideal (*brickwall*) filters do not exist.**
- **Real filters have an approximate response.**
- **The attenuation of an ideal filter is ∞ in the stopband.**
- **Real filter attenuation is $v_{out}/v_{out(mid)}$:**

3 dB = 0.5

12 dB = 0.25

20 dB = 0.1

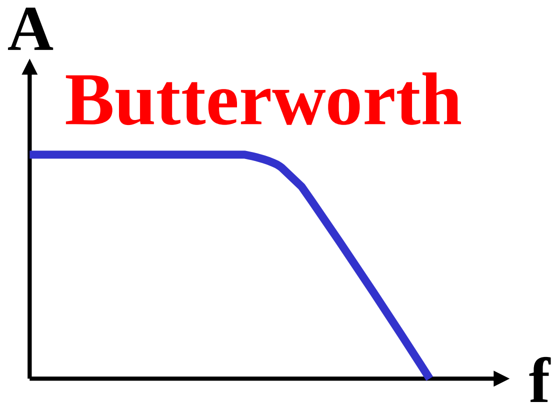
The order of a filter

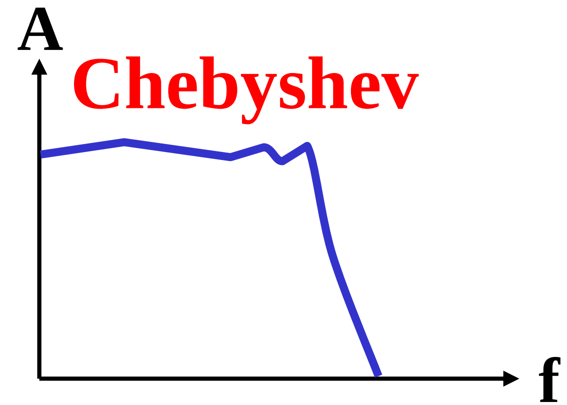
- **In an LC type, the order is equal to the number of inductors and capacitors in the filter.**
- **In an RC type, the order is equal to the number of capacitors in the filter.**
- **In an active type, the order is approximately equal to the number of capacitors in the filter.**

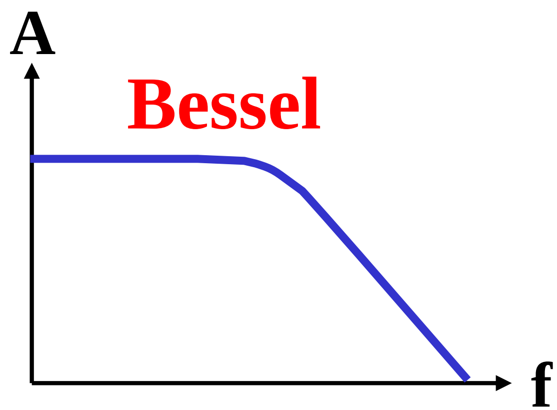
Filter approximations

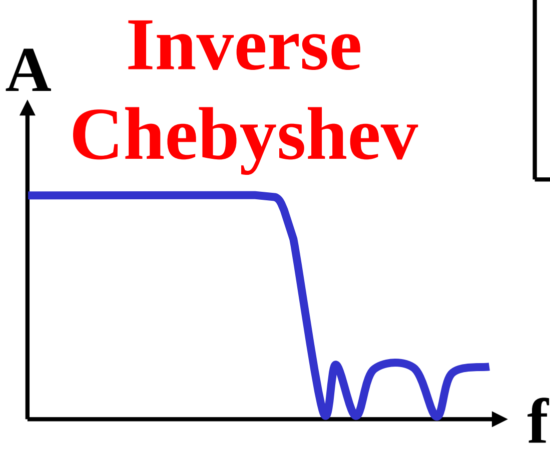
- Butterworth (maximally flat response): rolloff = 20n dB/decade where n is the order of the filter
- Chebyshev (equal ripple response): the number of ripples = n/2
- Inverse Chebyshev (rippled stopband).
- Elliptic (optimum transition)
- Bessel (linear phase shift)

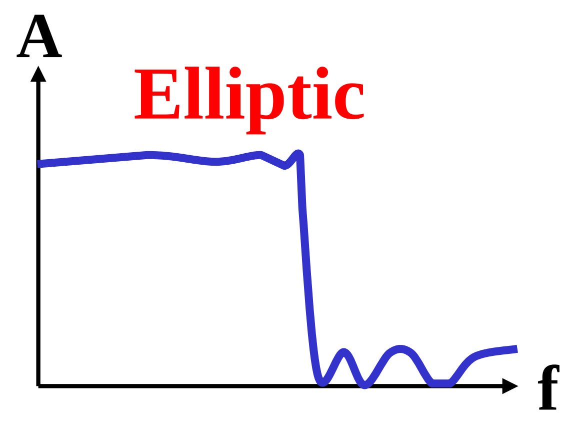
Real low-pass filter responses





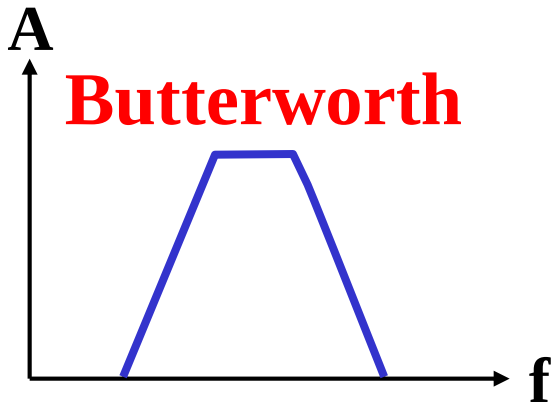


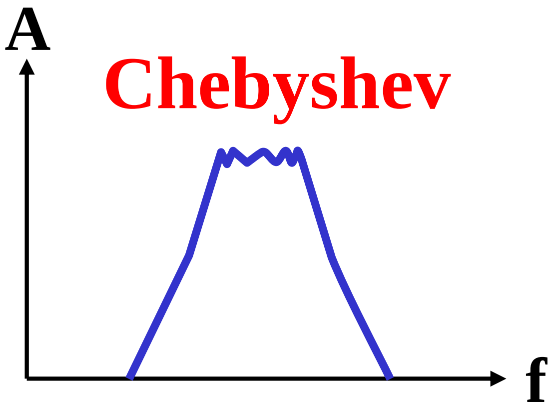


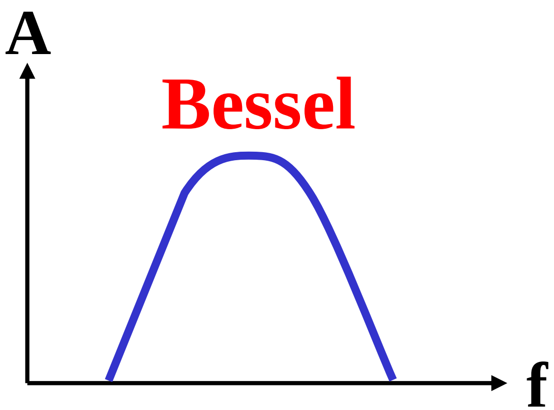


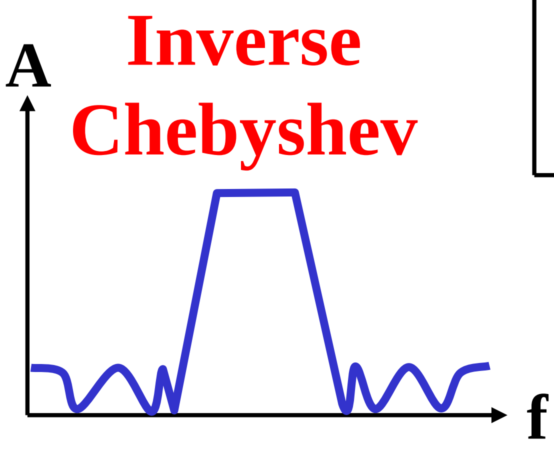
Note: monotonic filters have no ripple in the stopband.

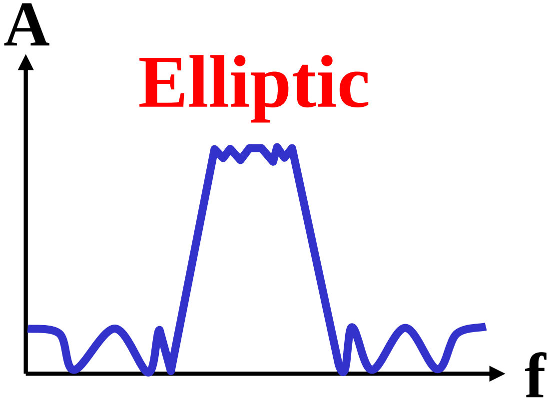
Real bandpass filter responses



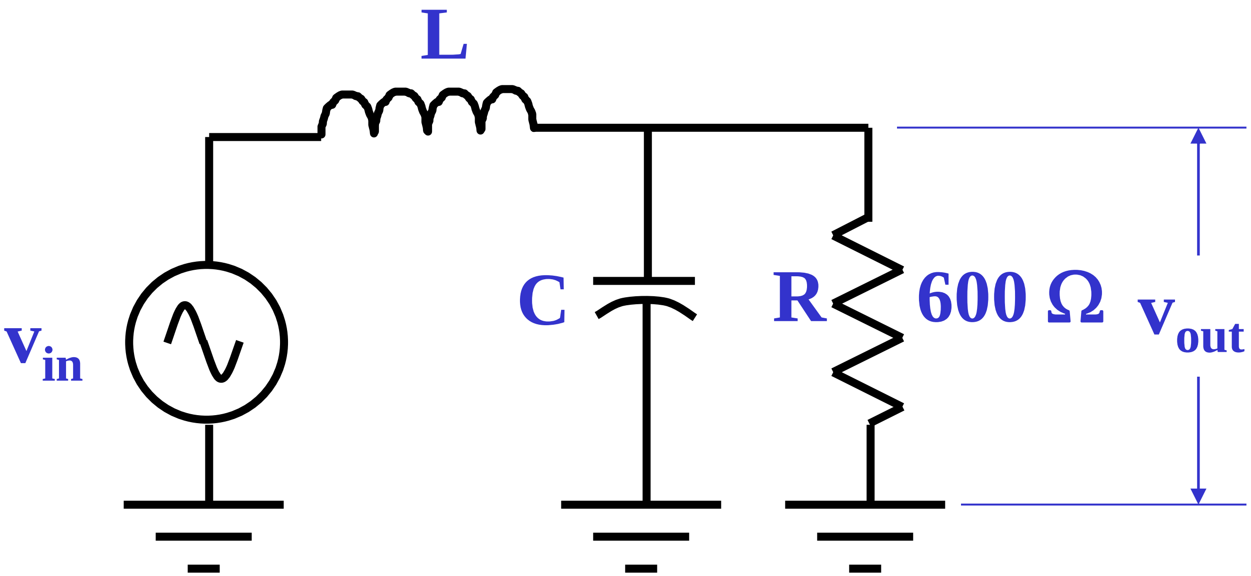








A second-order low-pass LC filter

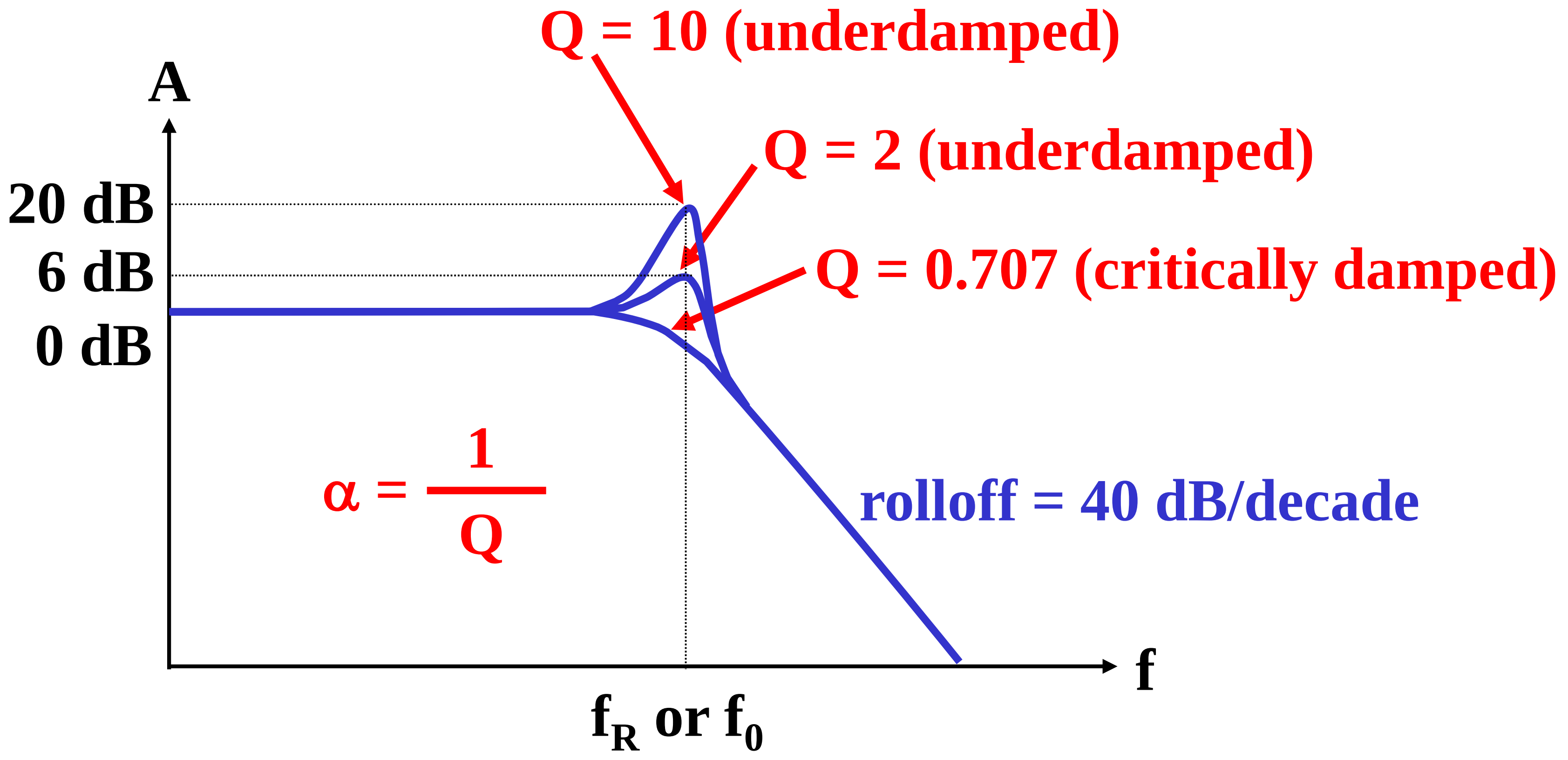


$$f_r = \frac{1}{2\pi\sqrt{LC}}$$

$$Q = \frac{R}{X_L}$$

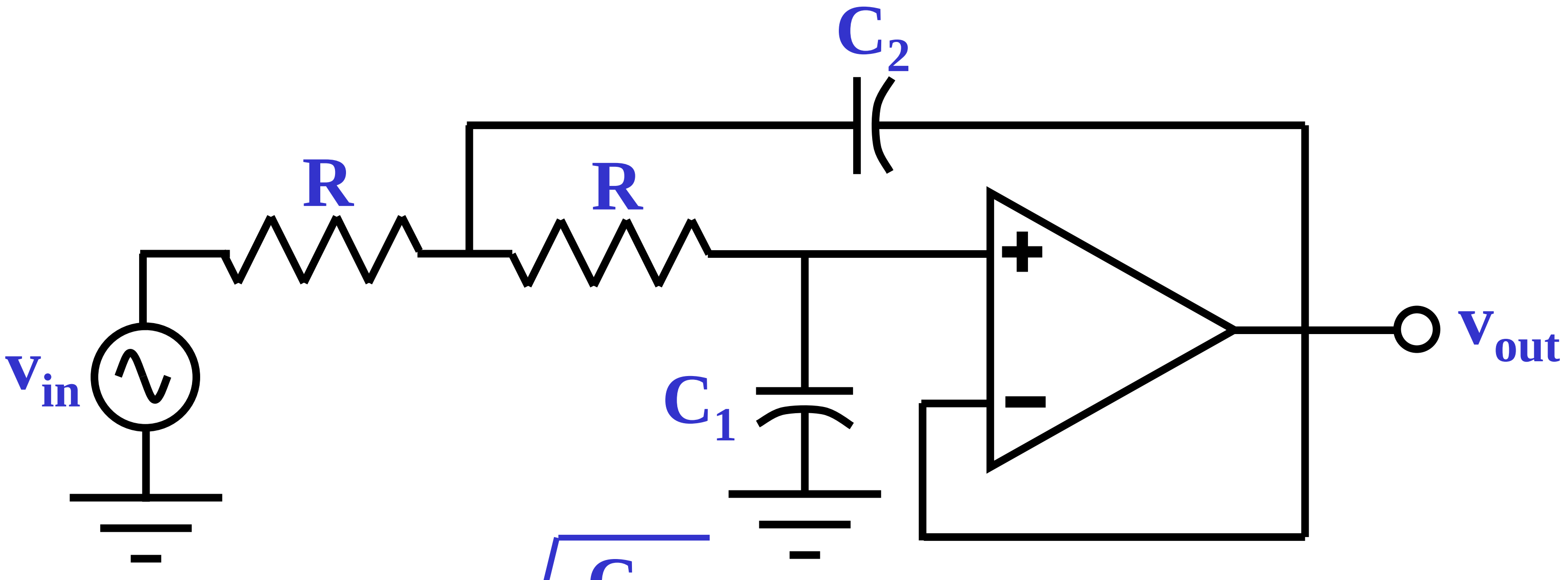
L	C	f_R	Q
9.55 mH	2.65 μF	1 kHz	10
47.7 mH	531 nF	1 kHz	2
135 mH	187 nF	1 kHz	0.707

The effect of Q on second-order response



The Butterworth response is critically damped.
The Bessel response is overdamped (Q = 0.577 … not graphed).
The damping factor is α.

Sallen-Key second-order low-pass filter



$$Q = 0.5\sqrt{\frac{C_2}{C_1}}$$

$$A_v = 1$$

$$f_p = \frac{1}{2\pi R\sqrt{C_1 C_2}} = \text{pole frequency}$$

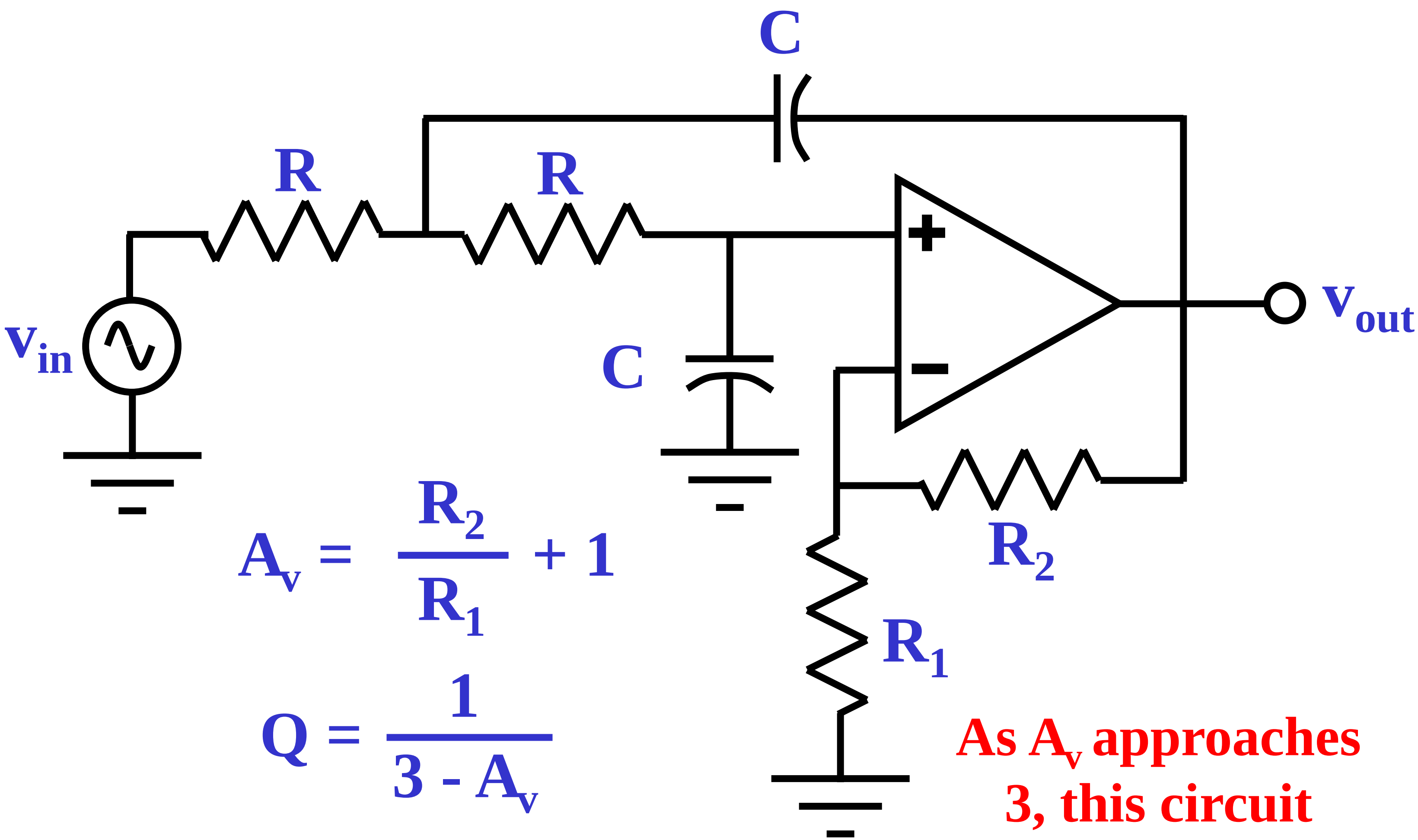
Second-order responses

- **Butterworth: $Q = 0.707$; $K_c = 1$**
- **Bessel: $Q = 0.577$; $K_c = 0.786$**
- **Cutoff frequency: $f_c = K_c f_p$**
- **Peaked response: $Q > 0.707$**
  - * $f_0 = K_0 f_p$ (the peaking frequency)
  - * $f_c = K_c f_p$ (the edge frequency)
  - * $f_{3dB} = K_3 f_p$

Higher-order filters

- Cascade second-order stages to obtain even-order response.
- Cascade second-order stages plus one first-order stage to obtain odd-order response.
- The dB attenuation is cumulative.
- Filter design can be tedious and complex.
- Tables and filter-design software are used.

Sallen-Key equal-component filter



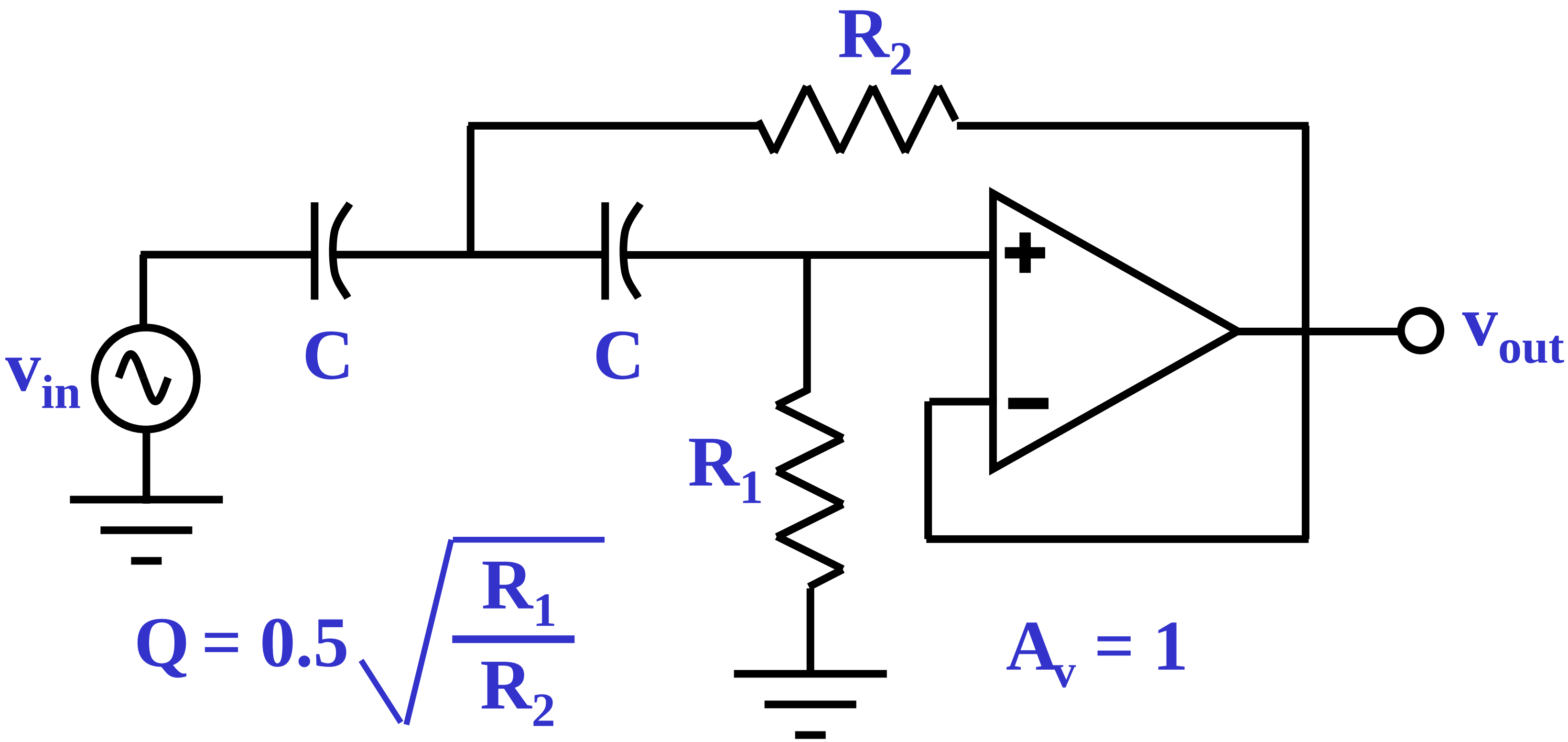
$$A_v = \frac{R_2}{R_1} + 1$$

$$Q = \frac{1}{3 - A_v}$$

$$f_p = \frac{1}{2\pi RC}$$

As A_v approaches 3, this circuit becomes impractical.

Sallen-Key second-order high-pass filter

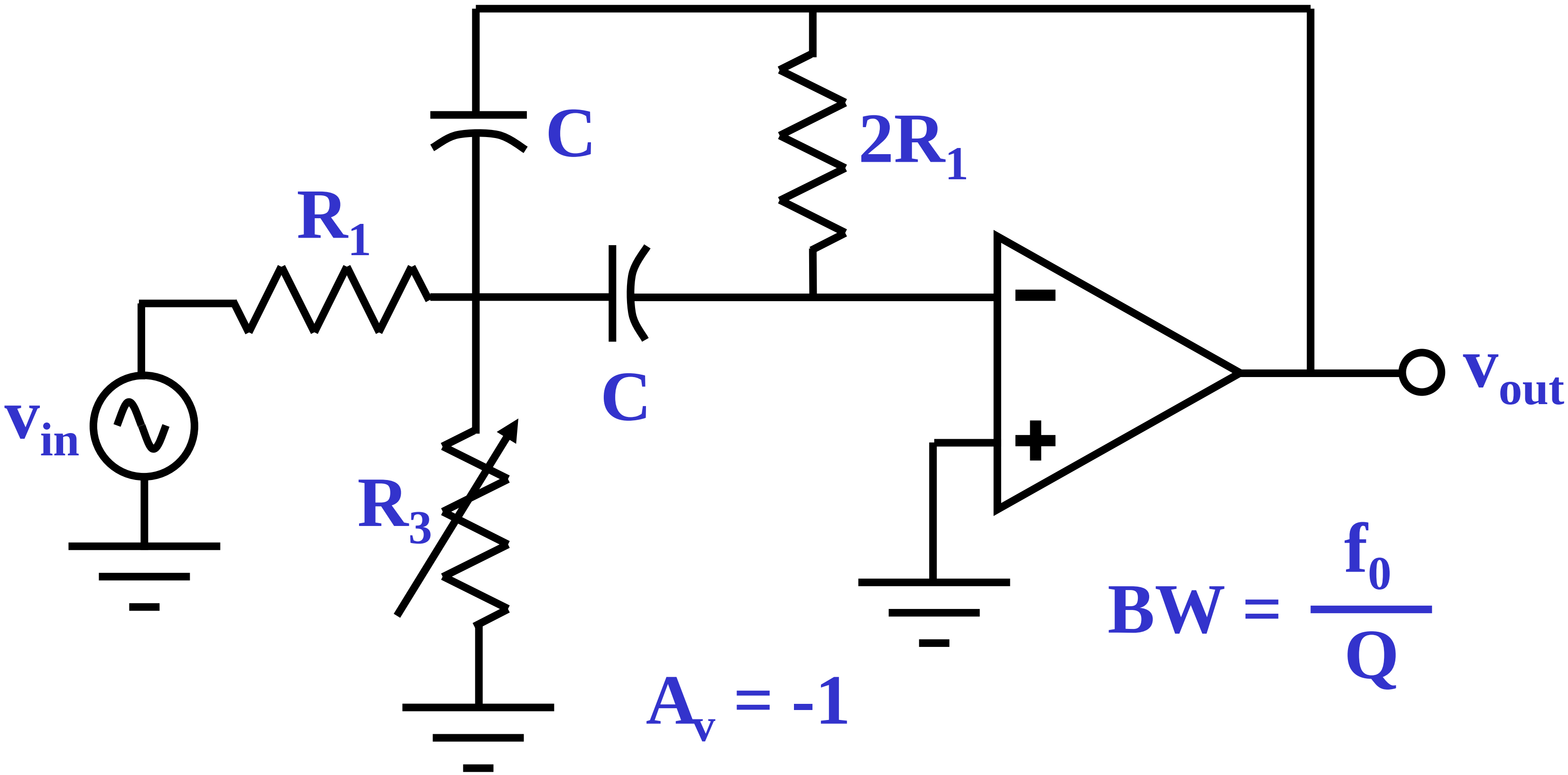


$$Q = 0.5\sqrt{\frac{R_1}{R_2}}$$

$$A_v = 1$$

$$f_p = \frac{1}{2\pi C\sqrt{R_1 R_2}}$$

Tunable MFB bandpass filter with constant bandwidth



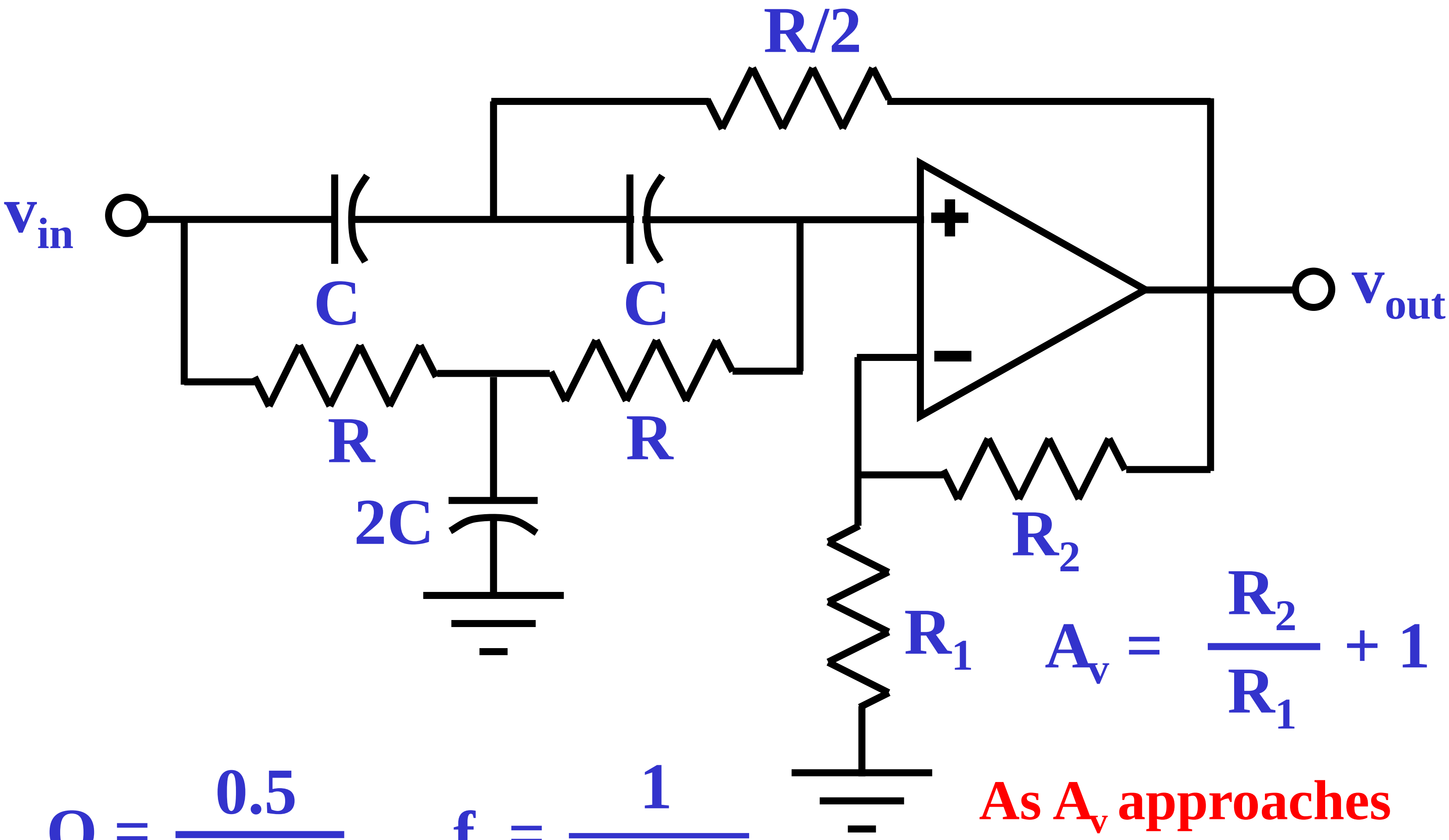
$$A_v = -1$$

$$BW = \frac{f_0}{Q}$$

$$f_0 = \frac{1}{2\pi C\sqrt{2R_1(R_1 \| R_3)}}$$

$$Q = 0.707\sqrt{\frac{R_1+R_3}{R_3}}$$

Sallen-Key second-order notch filter



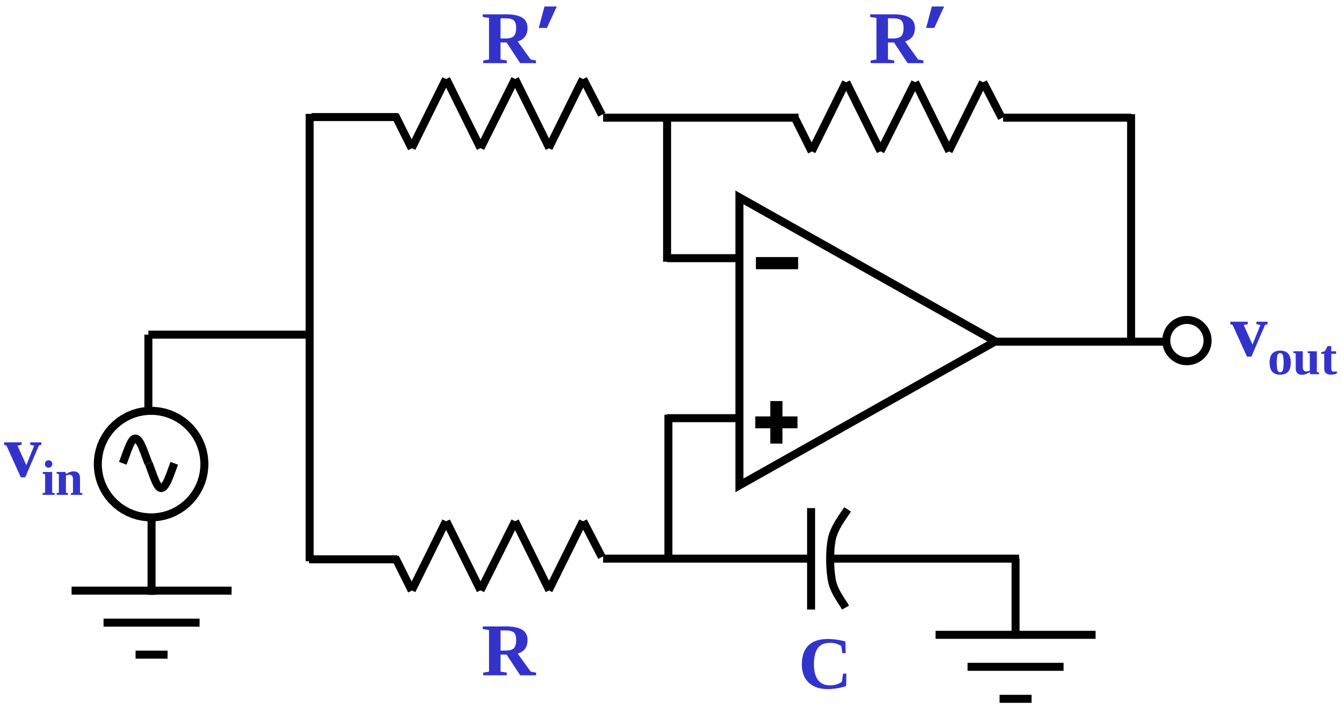
$$A_v = \frac{R_2}{R_1} + 1$$

$$Q = \frac{0.5}{2 - A_v}$$

$$f_0 = \frac{1}{2\pi RC}$$

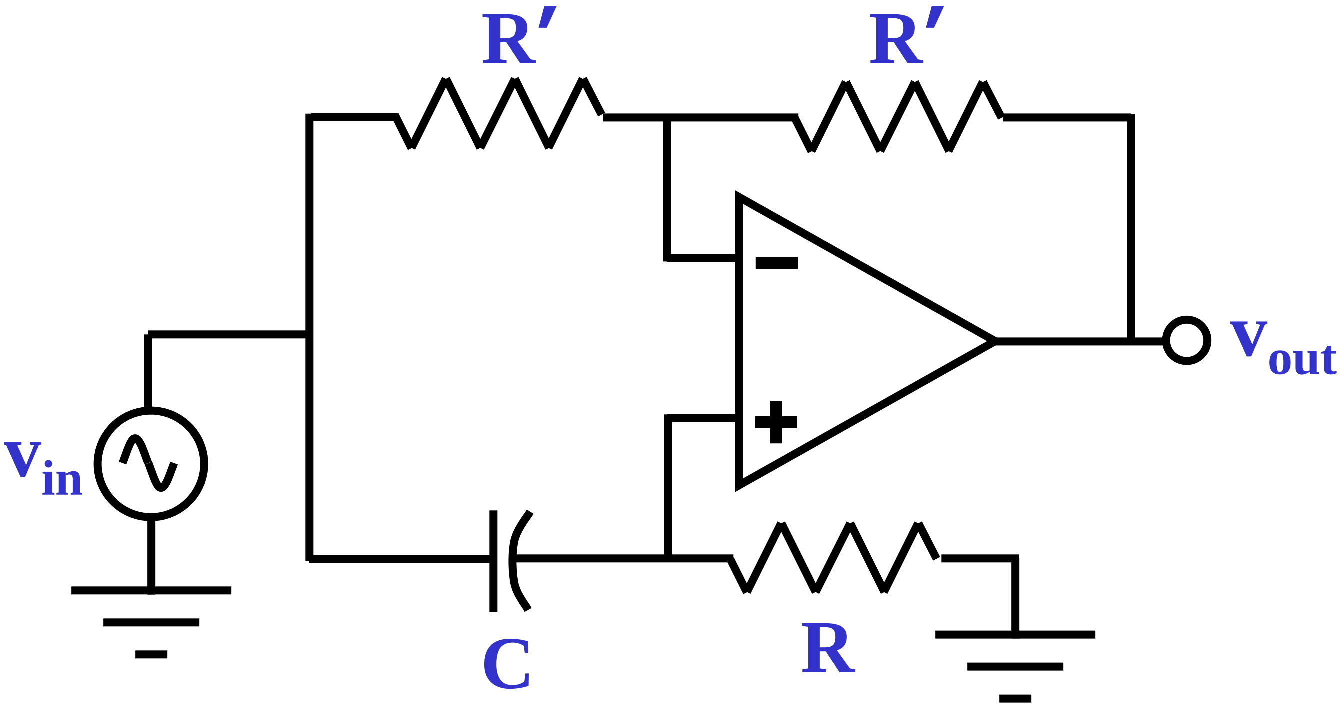
As A_v approaches 2, this circuit becomes impractical.

First-order all-pass lag filter



$$A_v = 1 \qquad f_0 = \frac{1}{2\pi RC} \qquad \phi = -2 \arctan \frac{f}{f_0}$$

First-order all-pass lead filter

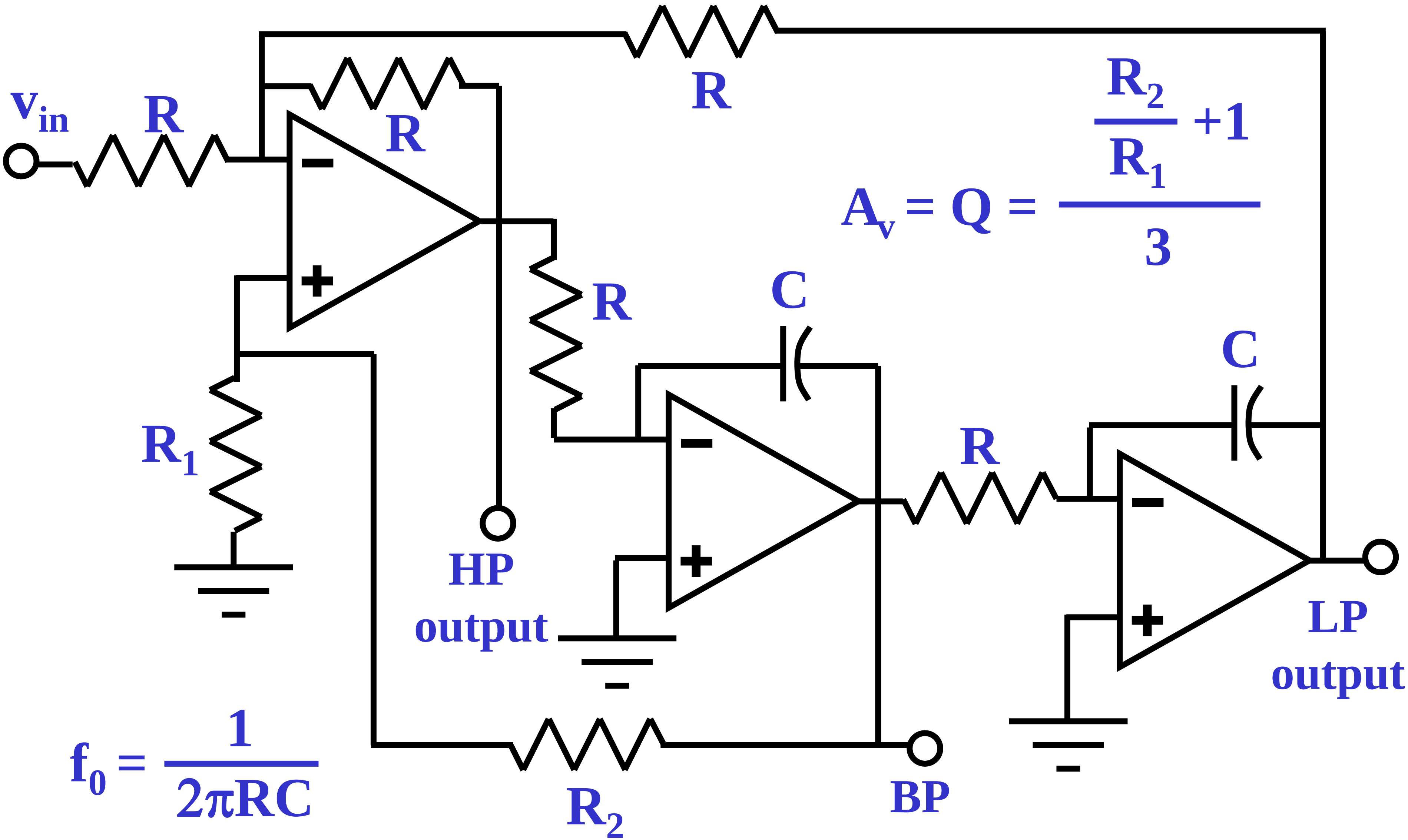


$A_v = -1$ $\qquad f_0 = \dfrac{1}{2\pi RC}$ $\qquad \phi = 2\arctan\dfrac{f_0}{f}$

Linear phase shift

- Required to prevent distortion of digital signals
- Constant delay for all frequencies in the passband
- Bessel design meets requirements but rolloff might not be adequate
- Designers sometimes use a non-Bessel design followed by an all-pass filter to correct the phase shift

State variable filter



$$A_v = Q = \frac{\frac{R_2}{R_1} + 1}{3}$$

$$f_0 = \frac{1}{2\pi RC}$$