Analog Filters

Filters can be used to attenuate unwanted signals such as interference or noise or to isolate desired signals from unwanted. They use the frequency response of a measuring system to alter the dynamic characteristics of a signal.

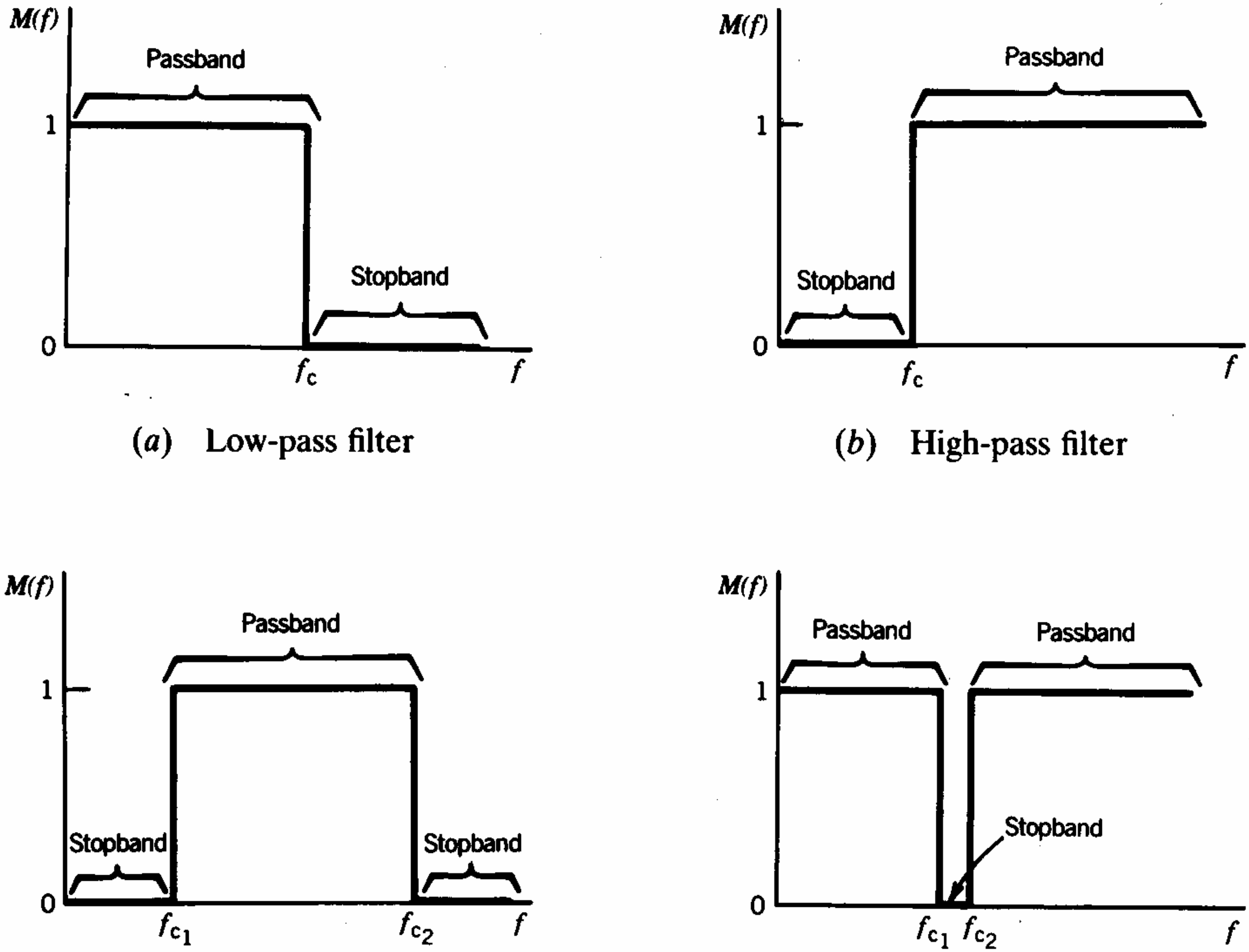
A common instrumentation filter application is the attenuation of high frequencies to avoid frequency aliasing in the sampled data.

Filters can be broadly classified as:

Low-pass	**eliminate high frequency components.**
High-pass	**eliminate low frequency components.**
Band-pass	**eliminate frequencies outside of a given range or band.**
Notch	**eliminate frequencies in a given range or band.**

Simple first-order systems can be used as low-pass filters because they attenuate higher frequencies more than lower frequencies. The thermocouples used in the lab would respond poorly to high frequency (> 1 Hz) temperature fluctuations.

FIGURE 6.25 Ideal filter characteristics.



(*a*) Low-pass filter

(*b*) High-pass filter

(*c*) Bandpass filter

(*d*) Notch filter

Some examples of low-pass filters are given below:

(Figure from Doebelin)

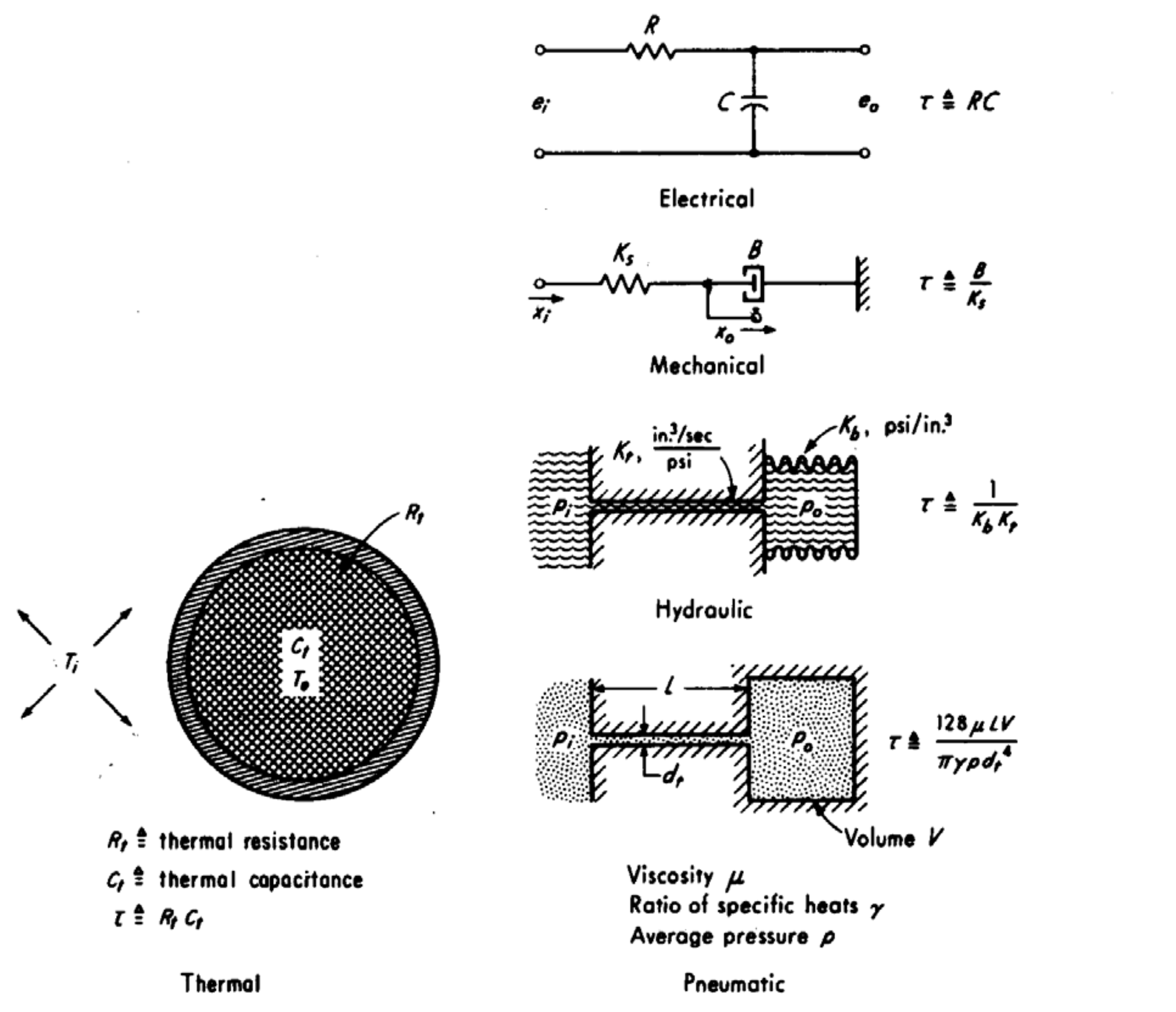


Figure 10.21 Low-pass filters.

$$M(\omega) = \frac{1}{[1+(\omega\tau)^2]^{1/2}} \quad (3.10)$$

$$\phi(\omega) = -\tan^{-1}\omega\tau \quad (3.9)$$

$$dB = 20 \log M(\omega) = 20 \log M(f)$$

We can improve the roll-off characteristics of a low-pass filter by cascading several stages:

FIGURE 6.28 Multistage or cascading *RC* filters.

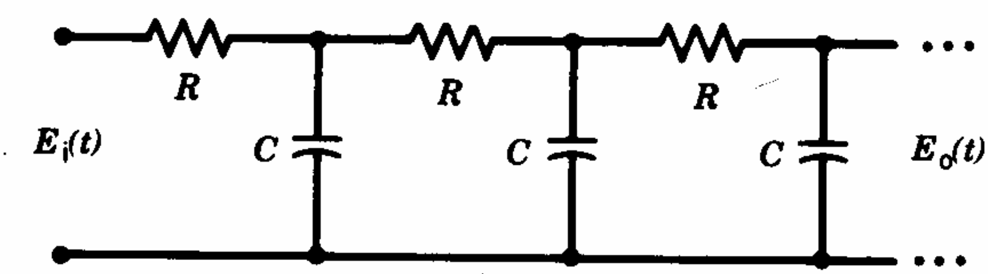


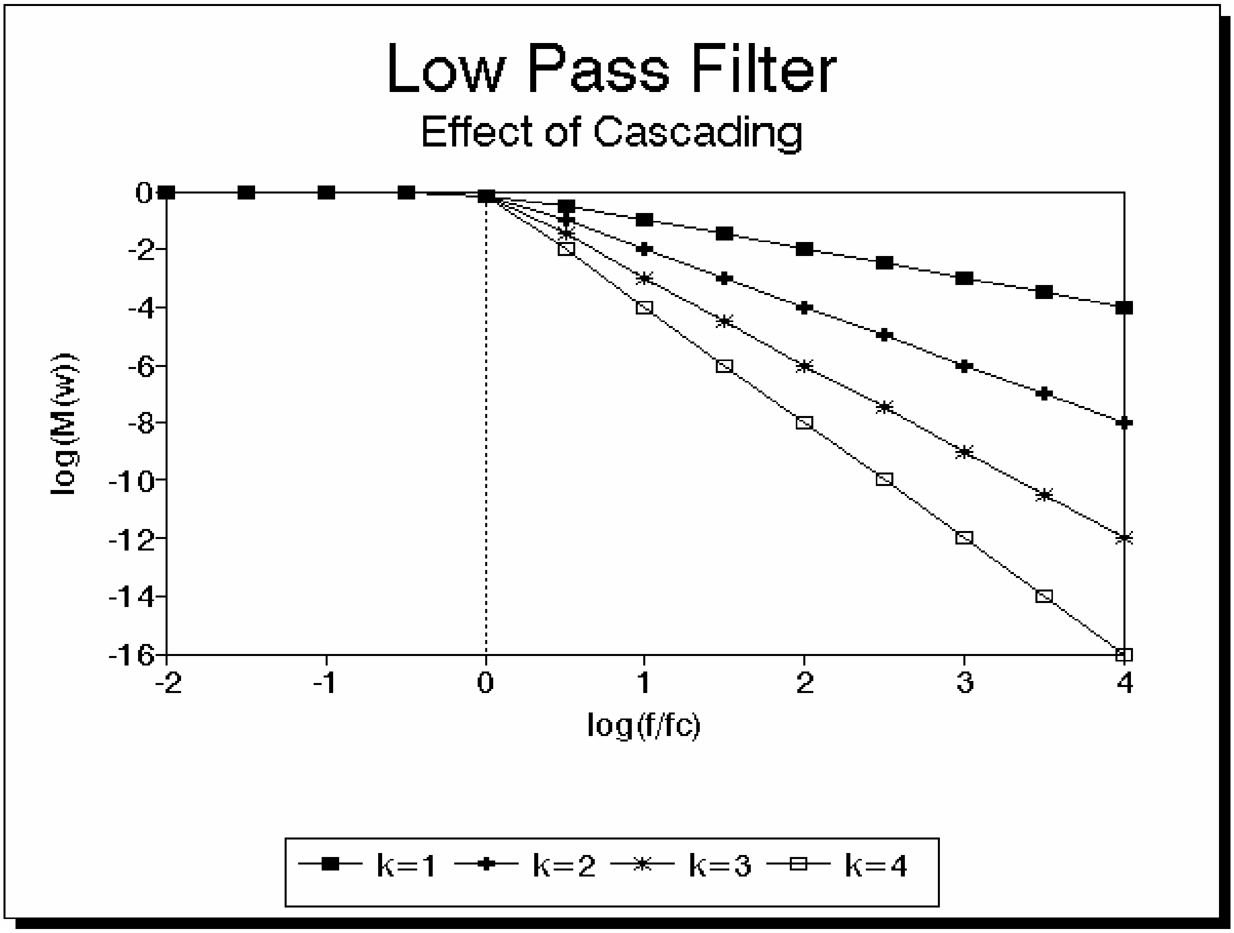
Figure 6.31 in 2nd and 3rd Edition

For the cascaded filter, the magnitude ratio and phase shift are:

$$M(f) = \frac{1}{[1+(f/f_c)^{2k}]^{1/2}}$$

$$\phi(f) = \sum_{i=1}^{k} \phi_i(f) \quad (6.57^1, 6.60^{2,3})$$

The magnitude ratio is plotted as a function of frequency for values of *k* = 1,2,3 and 4 below:



The phase shift is increased by the cascading, but that is usually not important.

Here are some examples of high pass filters, from Doebelin:

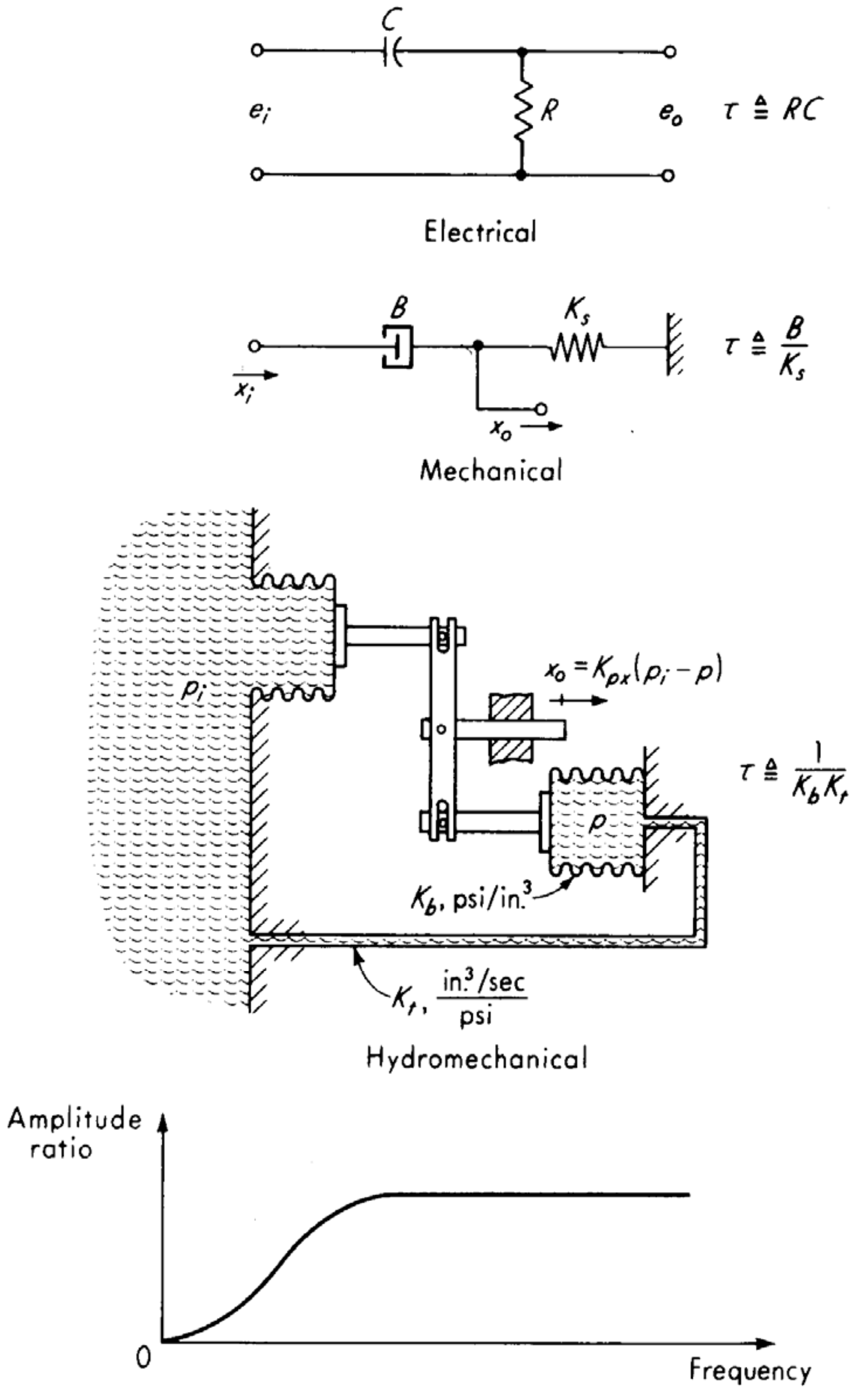


Figure 10.24 High-pass filters.

Cascading can also be used to improve the performance of high-pass filters:

FIGURE 6.29 Multistage high-pass *RC* Butterworth filter.

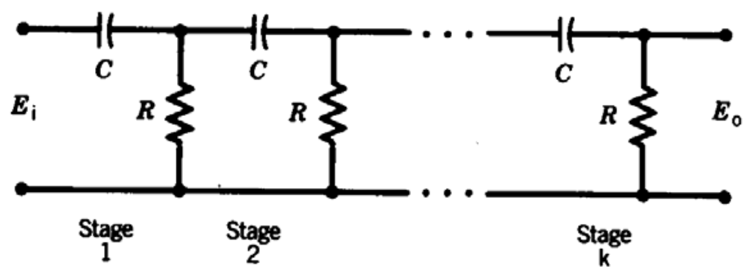
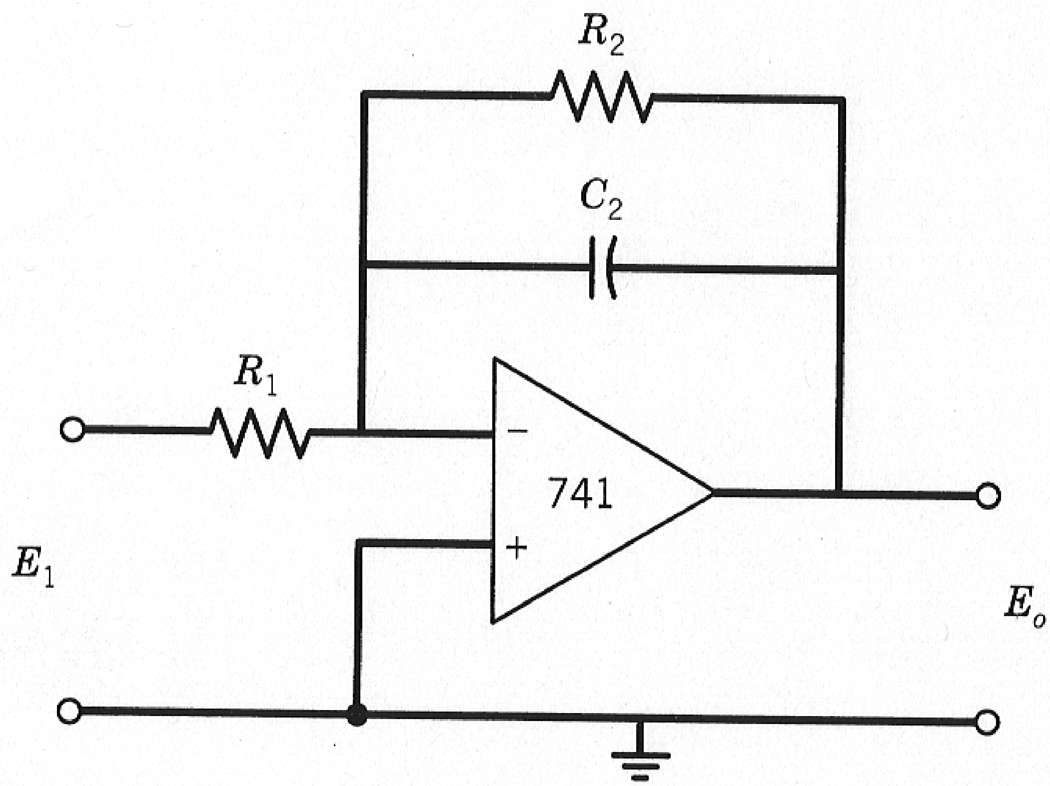
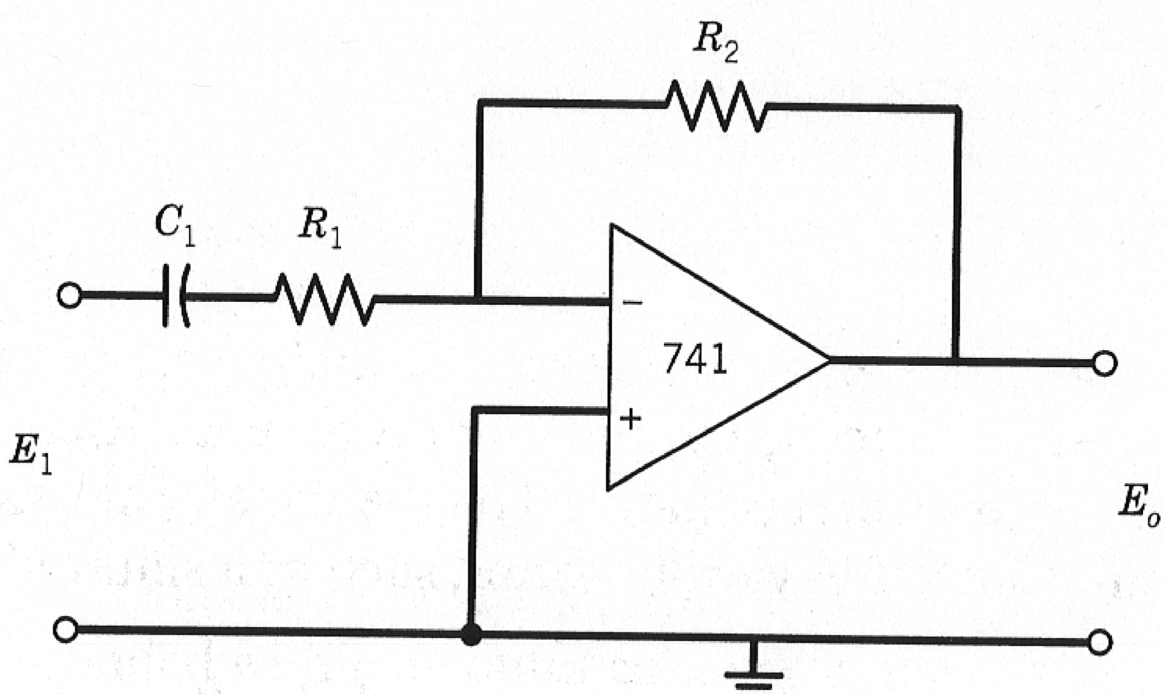


Figure 6.32 in 2nd and 3rd Edition

The filters described above are all passive, that is they involve no external power supply. Improved performance can be obtained from active filters, which use operational amplifiers. Some examples are shown below:



(a) Low-pass filter



(b) High-pass filter

Figure 6.34 Basic active filters.

Comparison of Common Low Pass Filter Types

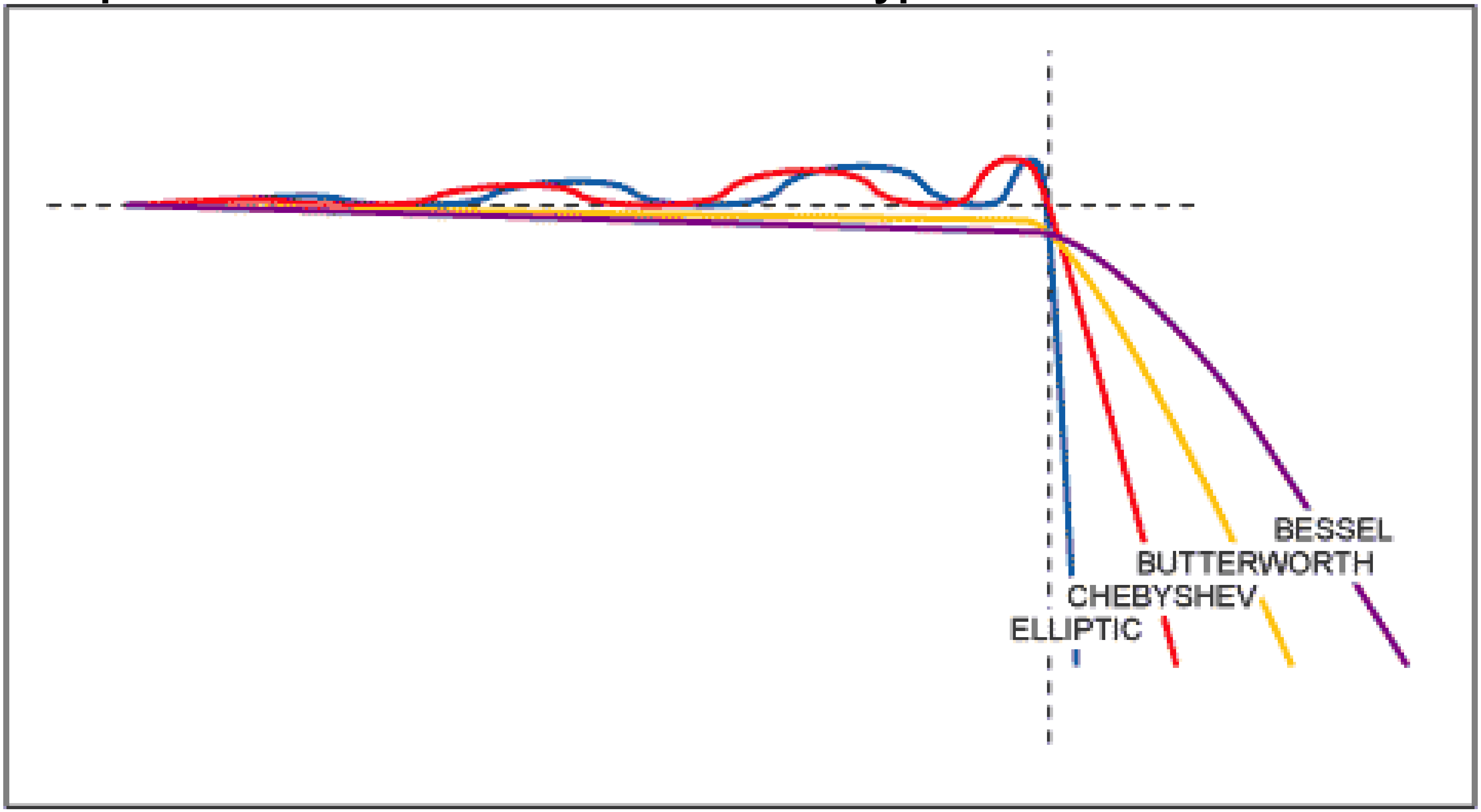


Figure 4 From www.maxim-ic.com Filter Basics: Anti-Aliasing

Key Features of Low Pass Filter Types

a. **Bessel: linear phase shift, gradual roll off**
b. **Butterworth: Steeper roll off, nonlinear phase shift**
c. **Chebyshev: Steep roll off, nonlinear phase shift, non-smooth pass band magnitude ratio**
d. **Elliptic: very steep roll off, nonlinear phase shift, non-smooth pass band magnitude ratio.**

Example 6.6

Design a one-stage Butterworth RC Low-pass filter with a cutoff frequency of -3 dB set at 100 Hz.

KNOWN

$f_c = 100$ **Hz,** $k = 1$

$M(100$ **Hz) = - 3 dB = .707**

FIND

R, C and δ

SOLUTION

Remember

$\tau = RC = 1/2\pi f_c$ **for a single pole** ***RC*** **filter!**

therefore: $f_c = 1/2\pi RC = 100\ Hz$

$RC = 1/200\pi = 0.00159$

EXAMPLE FINAL EXAM QUESTIONS:

1. Given a 1000 ohm resistor what size capacitor would be required to build a single pole Butterworth low pass filter with a cut off frequency of 100 Hz?

- **a. 1.59 uF**
- **b. 5 uF**
- **c. 2.5 uF**
- **d. 100 uF**

2. Which low pass filter type has the steepest magnitude ratio roll off?

- **a. Bessel**
- **b. Butterworth**
- **c. Chebyshev**
- **d. Elliptic**

3. Which low pass filter type has a linear phase shift?

- **a. Bessel**
- **b. Butterworth**
- **c. Chebyshev**
- **d. Elliptic**