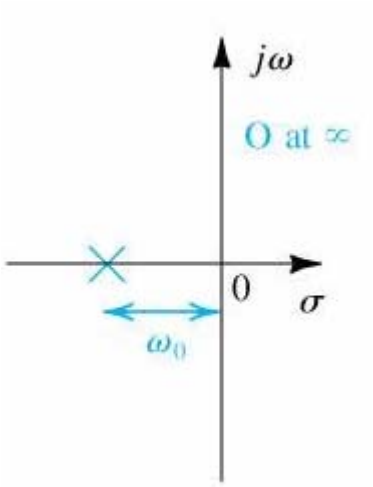
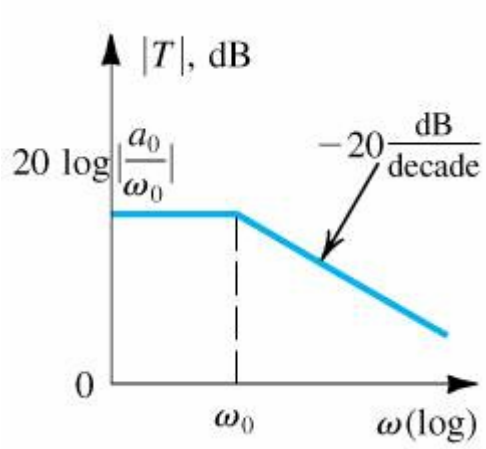
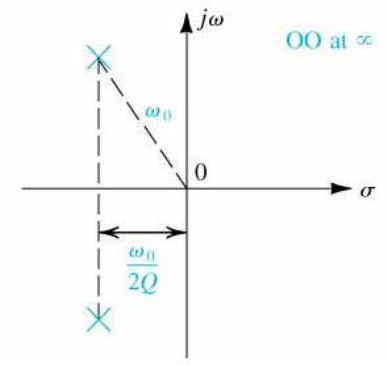
Lect. 18: Higher-Order Filters (S&S 12.1-3)

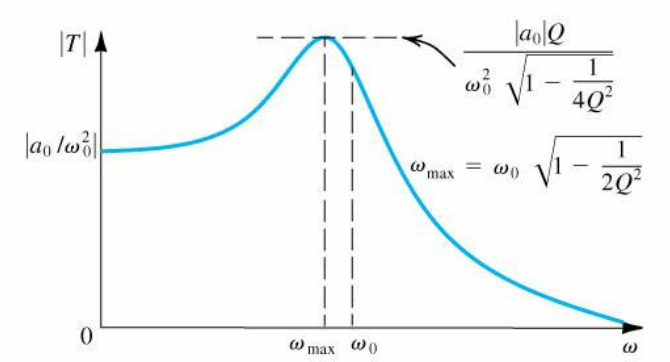
First-Order LP Filter

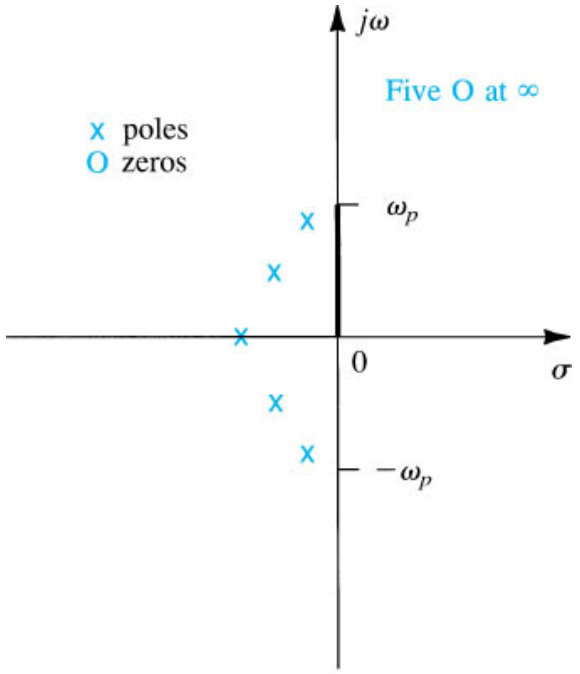




Second-Order LP Filter



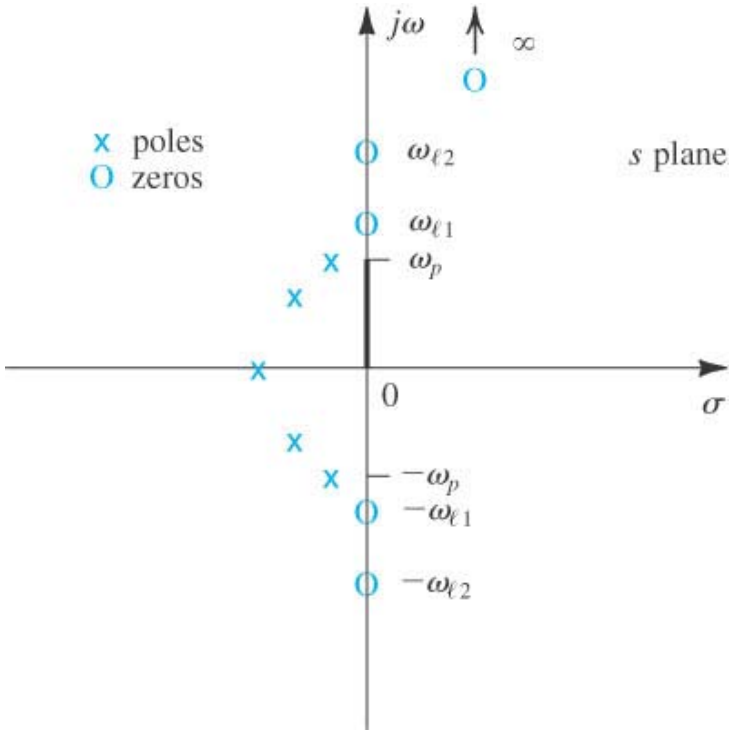




(b)

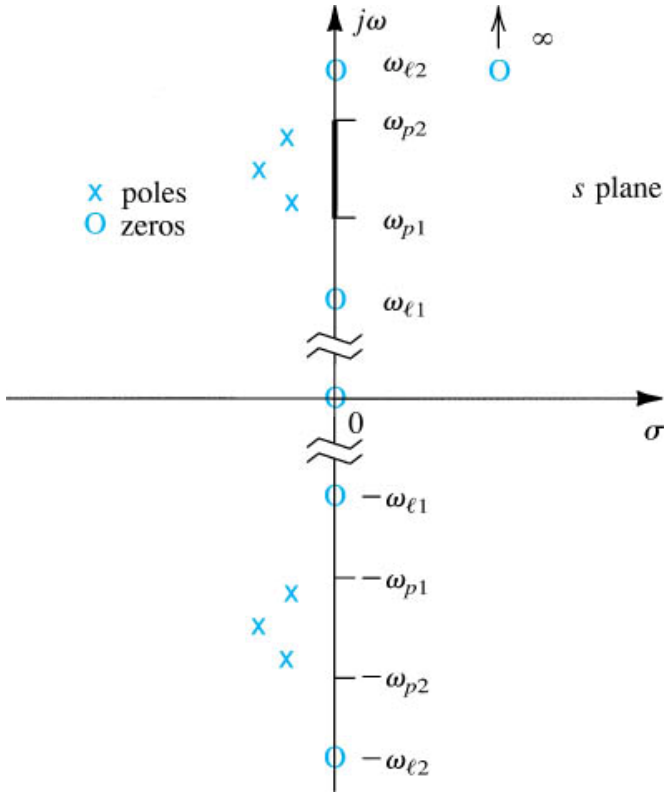
Order:

Lect. 18: Higher-Order Filters



Order:

Lect. 18: Higher-Order Filters

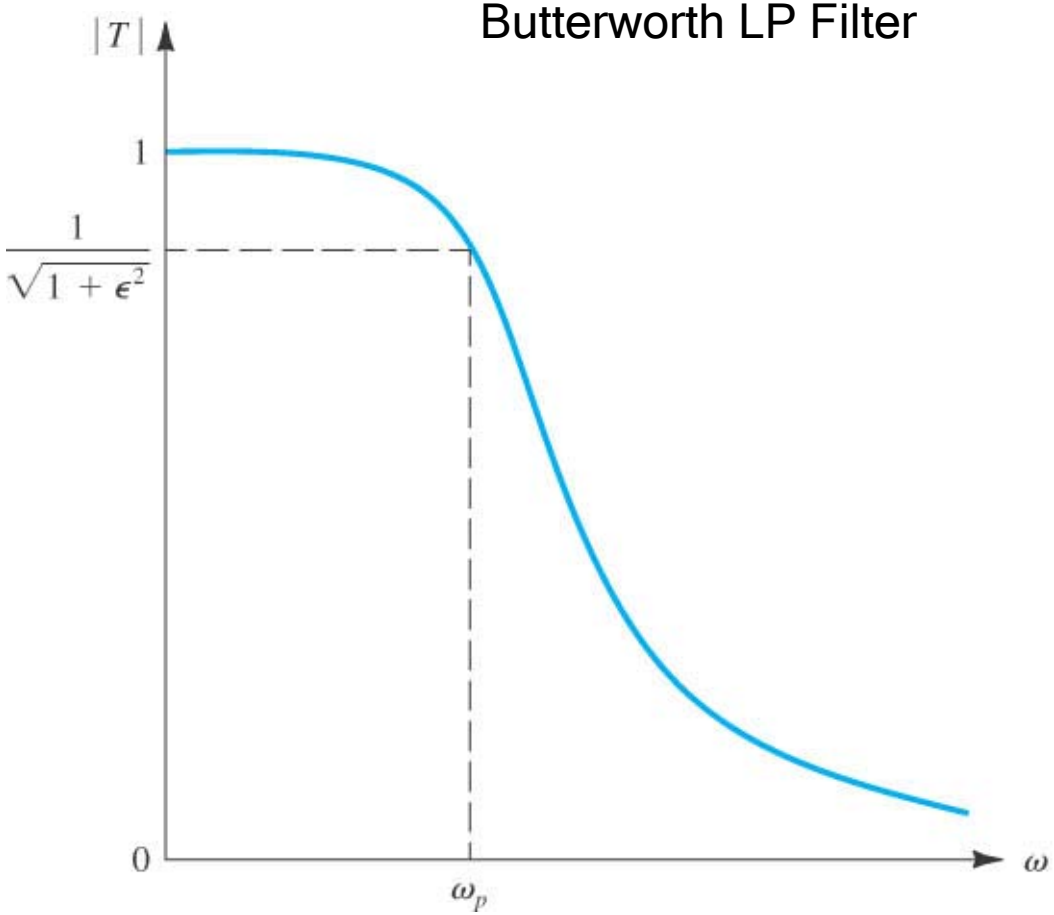


Filter design technique is an important issue in signal processing (analog and digital)

➔ Two types of LP filters: Butterworth and Chebyshev

Lect. 18: Higher-Order Filters

Butterworth LP Filter

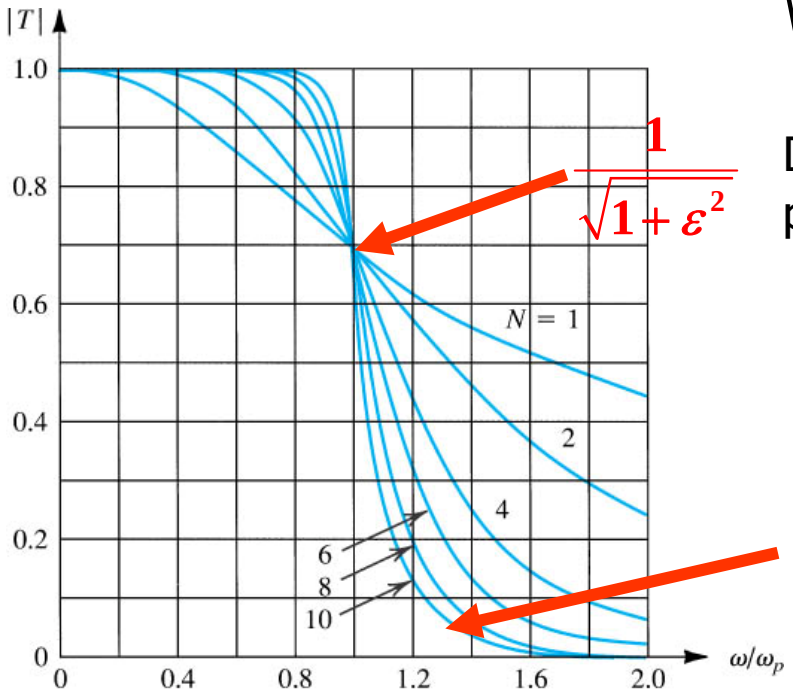


How many finite zeros?

$$\left|T(j\omega)\right| = \frac{1}{\sqrt{1+\varepsilon^2\left(\frac{\omega}{\omega_p}\right)^{2N}}}$$

Lect. 18: Higher-Order Filters

Butterworth LP Filter $$|T(j\omega)| = \frac{1}{\sqrt{1+\varepsilon^2\left(\frac{\omega}{\omega_p}\right)^{2N}}}$$



Determine ε so that A_{max} (maximum variation in pass band) is satisfied

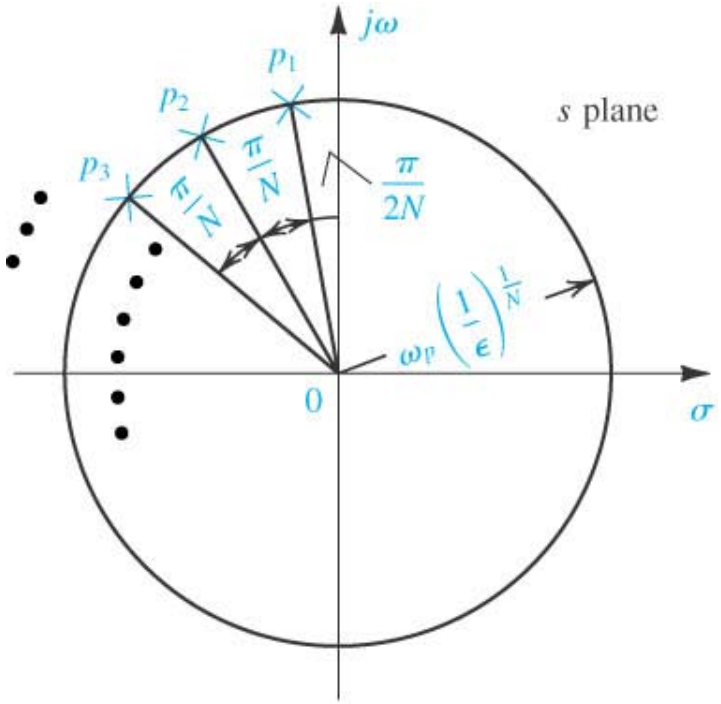
$$A_{max} = 20\log\sqrt{1+\varepsilon^2}$$

Determine N for the required stop-band attenuation

(ε =1)

Lect. 18: Higher-Order Filters

Butterworth Filter



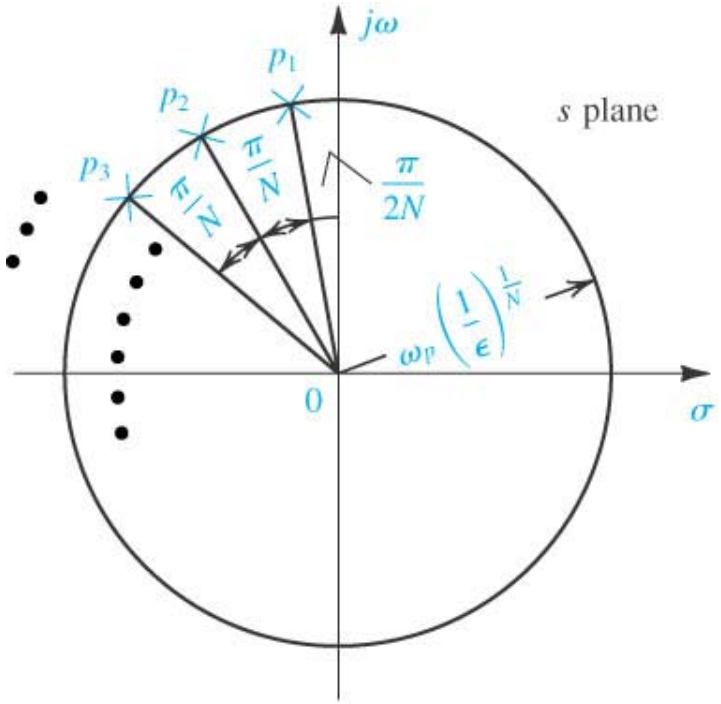
(a)

$$T(s) = K\frac{\omega_0^N}{(s-p_1)(s-p_2)\cdots(s-p_N)}$$

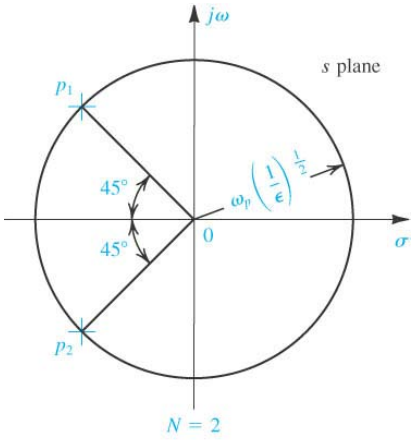
$$\omega_0 = \omega_p\left(\frac{1}{\varepsilon}\right)^{\frac{1}{N}}$$

Lect. 18: Higher-Order Filters

Pole-Zero diagrams for Butterworth Filter

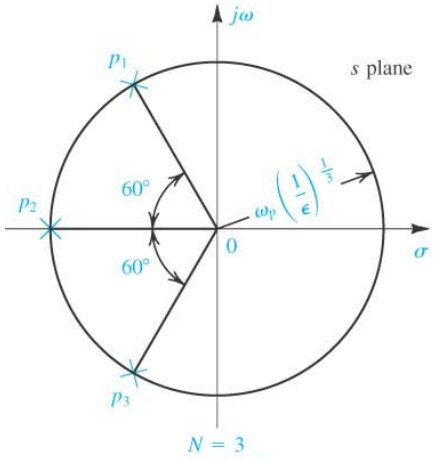


(a)



N = 2

(b)



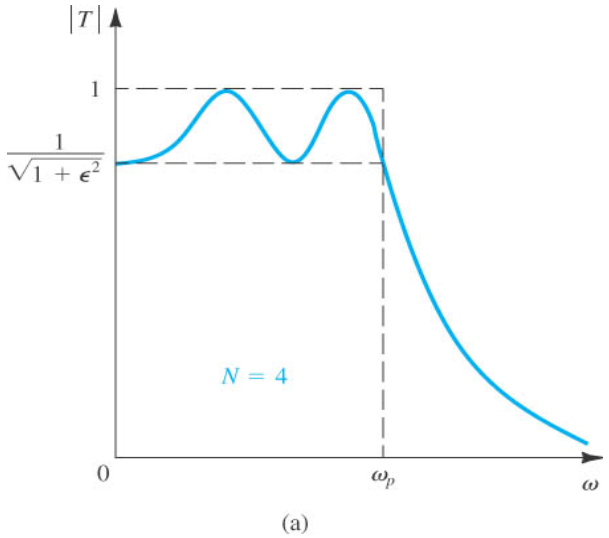
N = 3

(c)

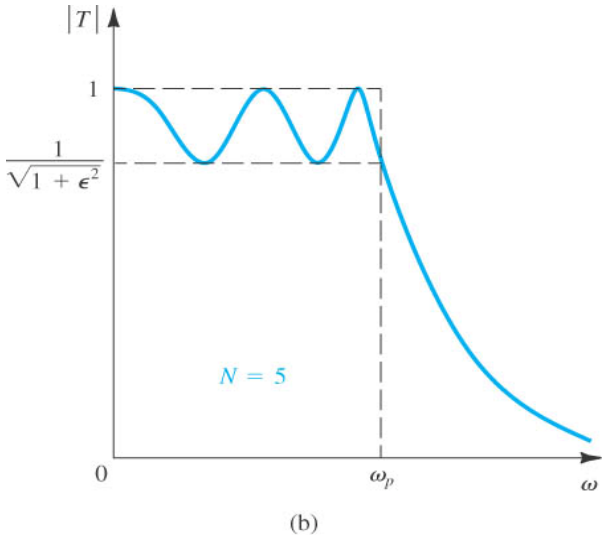
Lect. 18: Higher-Order Filters

Chevyshev Filter

$$T(s) = \frac{K\omega_p^N}{\varepsilon 2^{N-1}(s-p_1)(s-p_2)\cdots(s-p_N)}$$



(a)



(b)

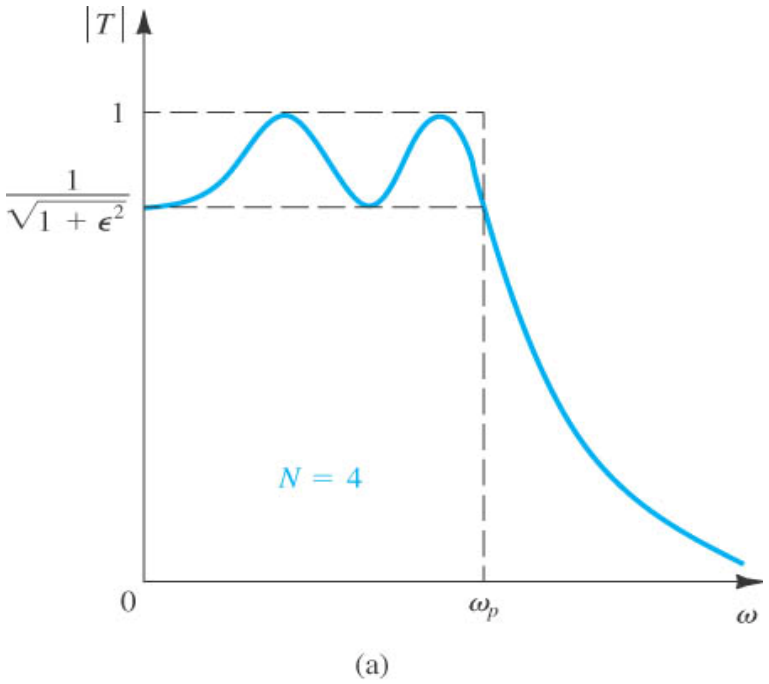
$$|T(j\omega)| = \frac{1}{\sqrt{1+\varepsilon^2\cos^2[N\cos^{-1}(\omega/\omega_p)]}} \quad \text{for } \omega \le \omega_p$$

$$|T(j\omega_p)| = \frac{1}{\sqrt{1+\varepsilon^2}} \quad \text{at } \omega = \omega_p$$

$$|T(j\omega)| = \frac{1}{\sqrt{1+\varepsilon^2\cosh^2[N\cosh^{-1}(\omega/\omega_p)]}} \quad \text{for } \omega \ge \omega_p$$

Lect. 18: Higher-Order Filters

Chevyshev Filter



(a)

$$A_{\max} = 10\log(1+\varepsilon^2)$$

$$\varepsilon = \sqrt{10^{A_{\max}/10} - 1}$$

Lect. 18: Higher-Order Filters

How to design higher-order filters with electronic circuits

1. Select the filter type with desired filter specifications.

2. Obtain the required transfer function.

3. Derive the corresponding block diagram

4. Design the circuit for the given block diagram

➔ Proejct #2