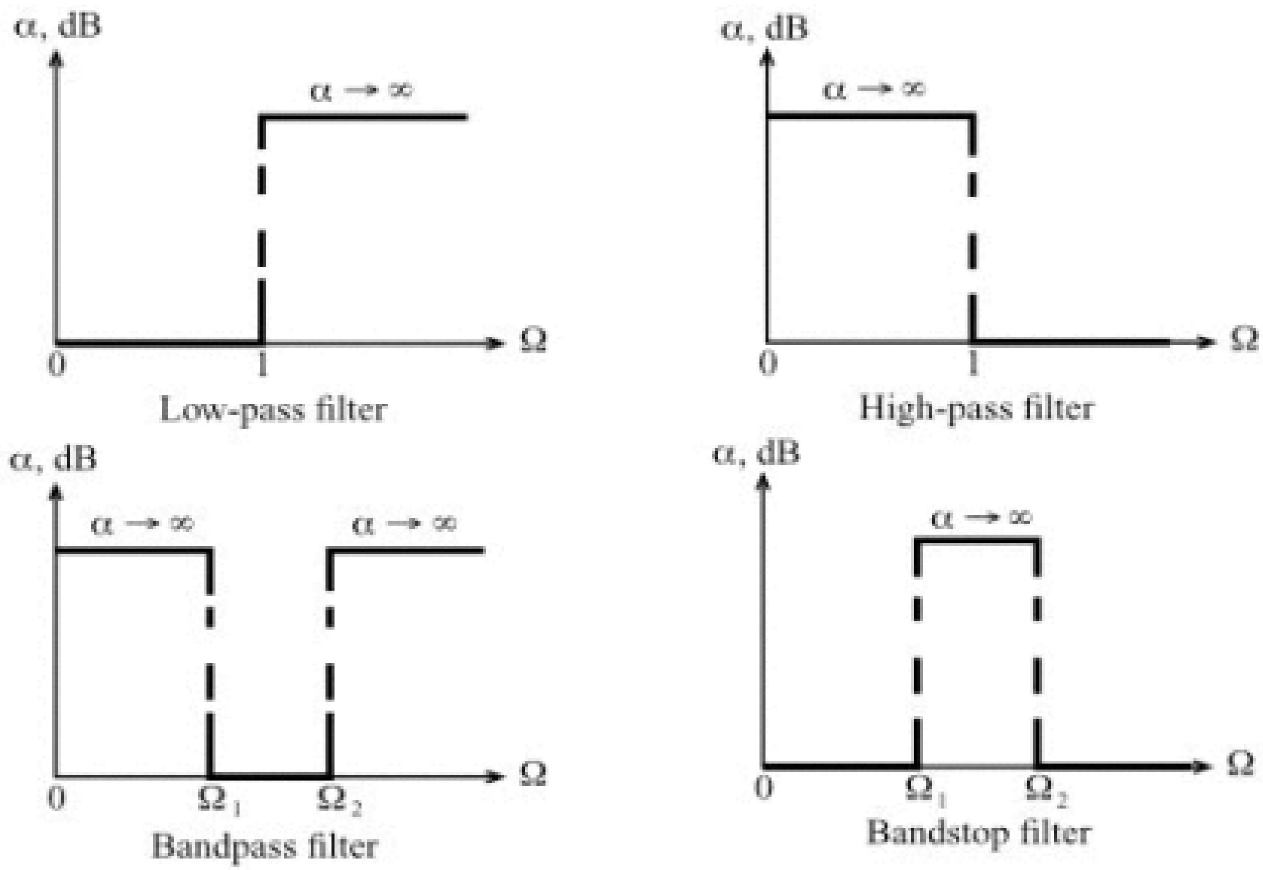
# Filter Design

# Filter Configuration




$$\Omega = \frac{\omega}{\omega_c}$$

**where $\omega_c$ is defined as the cutoff frequency for low-pass and high-pass filters and the center frequency for bandpass and bandstop filters.**

# Filter Frequency Response

A perfect filter would have zero insertion loss in the pass band, infinite attenuation in the stop band, and a linear phase response (to avoid signal distortion) in th pass band.

Binomial

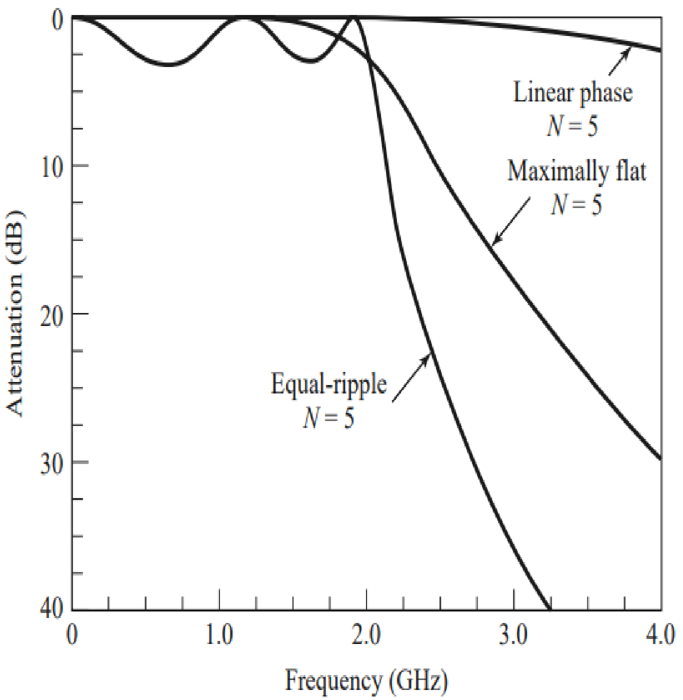
- easy to implement, monotonic profile, requires numerous elements

Chebyshev

- equal amplitude variations, steeper profile than Butterworth

Elliptic

- amplitude varies in both stopband anu passband, steepest profile, complicated design

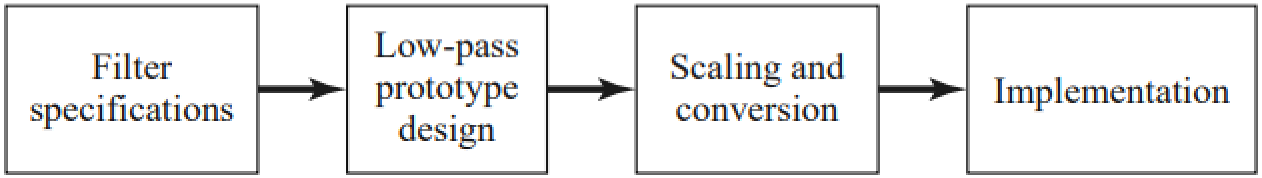


# Filter Definitions

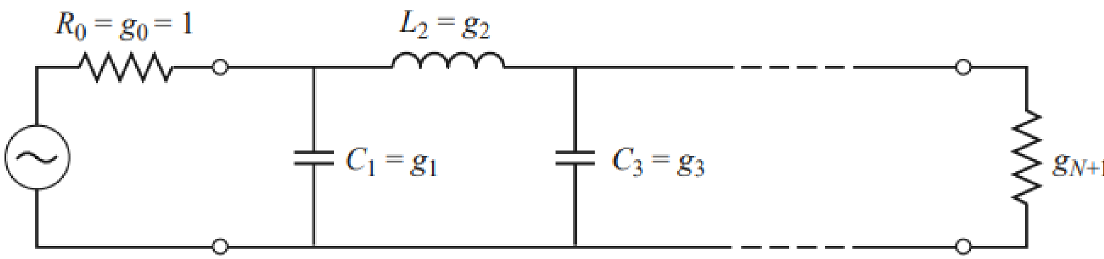
- Insertion loss - how much power is lost in going through the filter. IL = 10 log $P_{in}/P_L$

  IL quantity is the reciprocal of $|S_{12}|^2$
- Ripple - the flatness of the signal in the passband.
- Bandwidth - the width of the passband

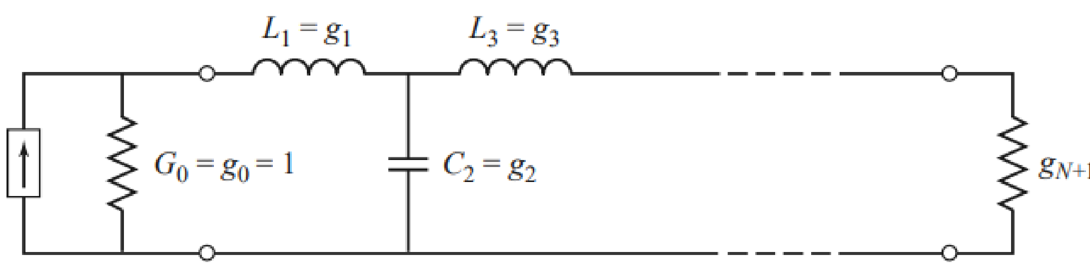
# Filter Design




## Filter Design Process




(a)




## Filter Design Prototype

# Maximally Flat LPF element Values

**TABLE 8.3** **Element Values for Maximally Flat Low-Pass Filter Prototypes ($g_0 = 1$, $\omega_c = 1$, $N = 1$ to 10)**

| $N$ | $g_1$ | $g_2$ | $g_3$ | $g_4$ | $g_5$ | $g_6$ | $g_7$ | $g_8$ | $g_9$ | $g_{10}$ | $g_{11}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2.0000 | 1.0000 | | | | | | | | | |
| 2 | 1.4142 | 1.4142 | 1.0000 | | | | | | | | |
| 3 | 1.0000 | 2.0000 | 1.0000 | 1.0000 | | | | | | | |
| 4 | 0.7654 | 1.8478 | 1.8478 | 0.7654 | 1.0000 | | | | | | |
| 5 | 0.6180 | 1.6180 | 2.0000 | 1.6180 | 0.6180 | 1.0000 | | | | | |
| 6 | 0.5176 | 1.4142 | 1.9318 | 1.9318 | 1.4142 | 0.5176 | 1.0000 | | | | |
| 7 | 0.4450 | 1.2470 | 1.8019 | 2.0000 | 1.8019 | 1.2470 | 0.4450 | 1.0000 | | | |
| 8 | 0.3902 | 1.1111 | 1.6629 | 1.9615 | 1.9615 | 1.6629 | 1.1111 | 0.3902 | 1.0000 | | |
| 9 | 0.3473 | 1.0000 | 1.5321 | 1.8794 | 2.0000 | 1.8794 | 1.5321 | 1.0000 | 0.3473 | 1.0000 | |
| 10 | 0.3129 | 0.9080 | 1.4142 | 1.7820 | 1.9754 | 1.9754 | 1.7820 | 1.4142 | 0.9080 | 0.3129 | 1.0000 |

*Source:* Reprinted from G. L. Matthaei, L. Young, and E. M. T. Jones, *Microwave Filters, Impedance-Matching Networks, and Coupling Structures*, Artech House, Dedham, Mass., 1980, with permission.

# Equiripple Filter element Values (0.5 dB Ripple)

**TABLE 8.4** **Element Values for Equal-Ripple Low-Pass Filter Prototypes ($g_0 = 1$, $\omega_c = 1$, $N = 1$ to 10, 0.5 dB and 3.0 dB ripple)**

| | | | | | 0.5 dB Ripple | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $N$ | $g_1$ | $g_2$ | $g_3$ | $g_4$ | $g_5$ | $g_6$ | $g_7$ | $g_8$ | $g_9$ | $g_{10}$ | $g_{11}$ |
| 1 | 0.6986 | 1.0000 | | | | | | | | | |
| 2 | 1.4029 | 0.7071 | 1.9841 | | | | | | | | |
| 3 | 1.5963 | 1.0967 | 1.5963 | 1.0000 | | | | | | | |
| 4 | 1.6703 | 1.1926 | 2.3661 | 0.8419 | 1.9841 | | | | | | |
| 5 | 1.7058 | 1.2296 | 2.5408 | 1.2296 | 1.7058 | 1.0000 | | | | | |
| 6 | 1.7254 | 1.2479 | 2.6064 | 1.3137 | 2.4758 | 0.8696 | 1.9841 | | | | |
| 7 | 1.7372 | 1.2583 | 2.6381 | 1.3444 | 2.6381 | 1.2583 | 1.7372 | 1.0000 | | | |
| 8 | 1.7451 | 1.2647 | 2.6564 | 1.3590 | 2.6964 | 1.3389 | 2.5093 | 0.8796 | 1.9841 | | |
| 9 | 1.7504 | 1.2690 | 2.6678 | 1.3673 | 2.7239 | 1.3673 | 2.6678 | 1.2690 | 1.7504 | 1.0000 | |
| 10 | 1.7543 | 1.2721 | 2.6754 | 1.3725 | 2.7392 | 1.3806 | 2.7231 | 1.3485 | 2.5239 | 0.8842 | 1.9841 |

# Equiripple Filter element Values (3 dB Ripple)

**3.0 dB Ripple**

| $N$ | $g_1$ | $g_2$ | $g_3$ | $g_4$ | $g_5$ | $g_6$ | $g_7$ | $g_8$ | $g_9$ | $g_{10}$ | $g_{11}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1.9953 | 1.0000 | | | | | | | | | |
| 2 | 3.1013 | 0.5339 | 5.8095 | | | | | | | | |
| 3 | 3.3487 | 0.7117 | 3.3487 | 1.0000 | | | | | | | |
| 4 | 3.4389 | 0.7483 | 4.3471 | 0.5920 | 5.8095 | | | | | | |
| 5 | 3.4817 | 0.7618 | 4.5381 | 0.7618 | 3.4817 | 1.0000 | | | | | |
| 6 | 3.5045 | 0.7685 | 4.6061 | 0.7929 | 4.4641 | 0.6033 | 5.8095 | | | | |
| 7 | 3.5182 | 0.7723 | 4.6386 | 0.8039 | 4.6386 | 0.7723 | 3.5182 | 1.0000 | | | |
| 8 | 3.5277 | 0.7745 | 4.6575 | 0.8089 | 4.6990 | 0.8018 | 4.4990 | 0.6073 | 5.8095 | | |
| 9 | 3.5340 | 0.7760 | 4.6692 | 0.8118 | 4.7272 | 0.8118 | 4.6692 | 0.7760 | 3.5340 | 1.0000 | |
| 10 | 3.5384 | 0.7771 | 4.6768 | 0.8136 | 4.7425 | 0.8164 | 4.7260 | 0.8051 | 4.5142 | 0.6091 | 5.8095 |

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# Filter Design by Richards Transformation and Kuroda's Identity

## Lumped element filter

- difficult to implement at MW frequency, as they are available at limited range
- Distance between filter components are not negligible

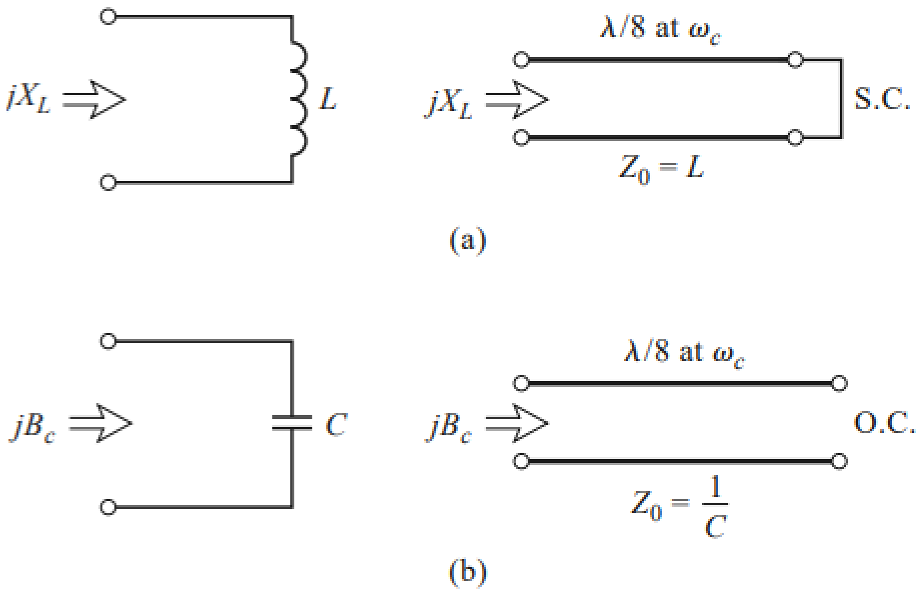
## Richards Transformation

- Lumped element converted to transmission line section

## Kuroda's identity

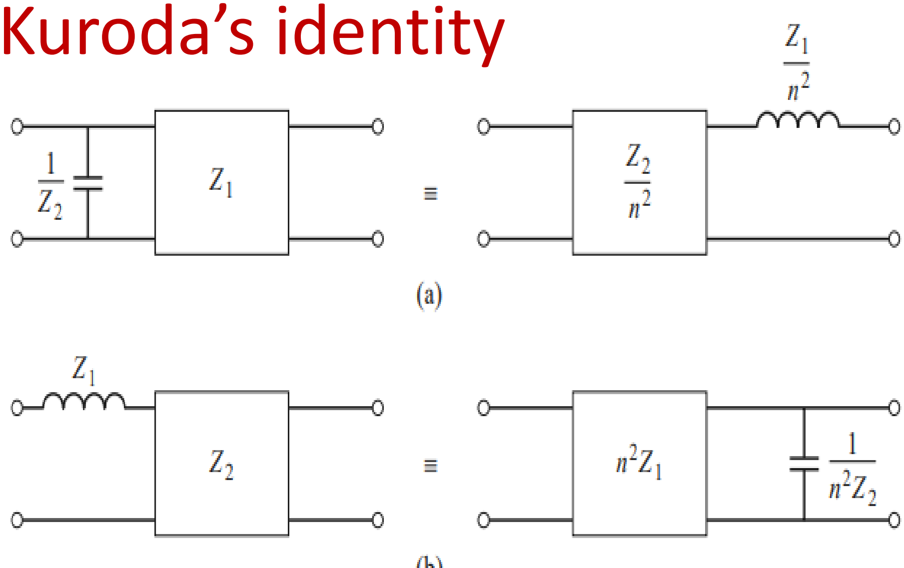
- Separate filter elements using transmission line structure
- Doesnot affect filter response, hence known as redundant filter

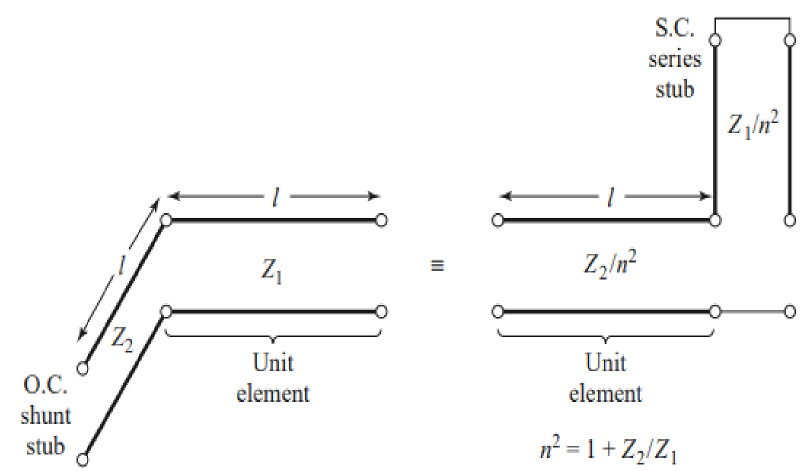
# Lumped element implementation in Transmissionline



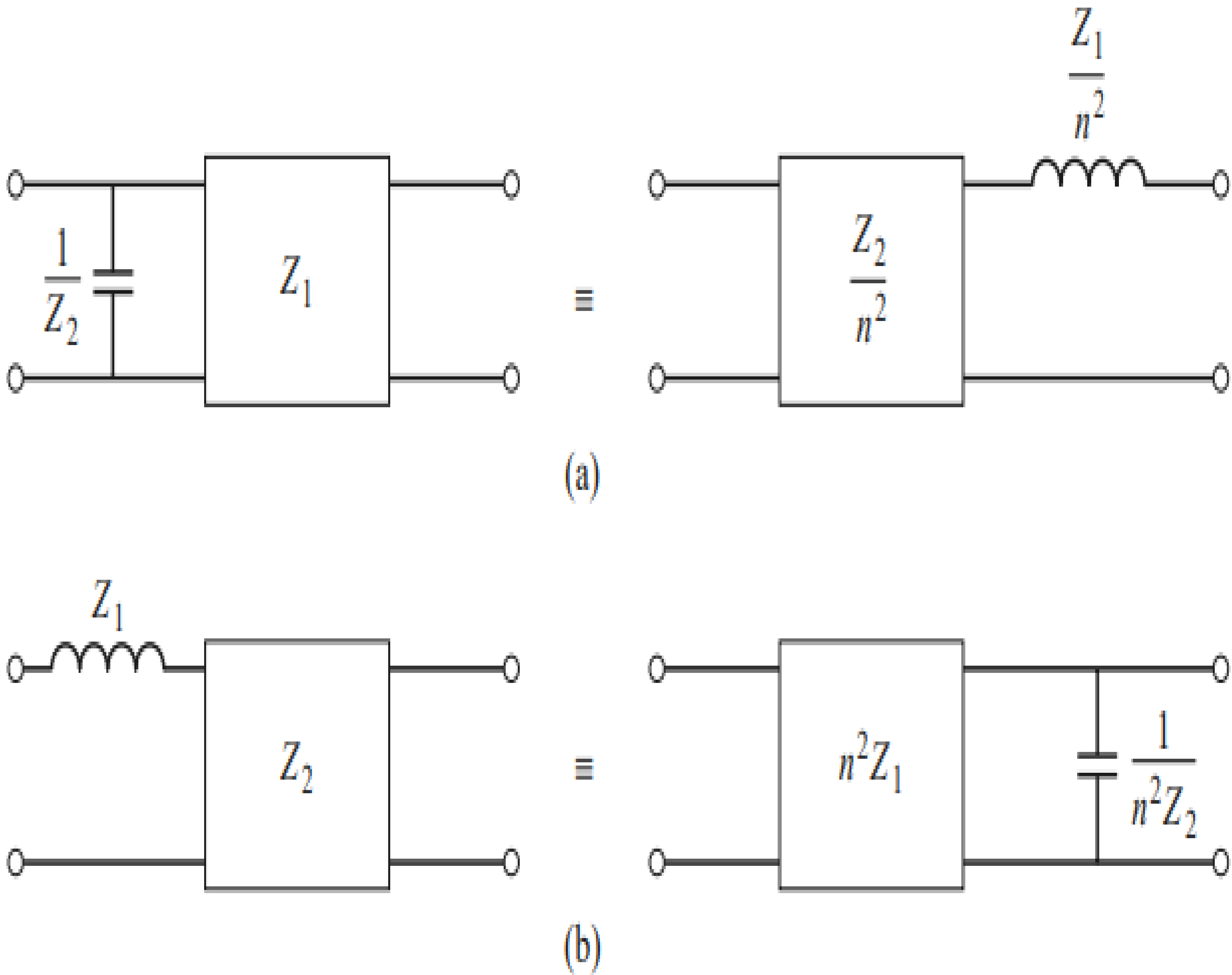

Richards' transformation. (a) For an inductor to a short-circuited stub. (b) For a capacitor to an open-circuited stub.

## Kuroda's identity




Equivalent circuits illustrating Kuroda identity (a) in Table 8.7



Z1
n2
1
Z2
Z1
≡
Z2
n2
(a)
Z1
Z2
≡
n2Z1
1
n2Z2
(b)

# Problems

3. Design a lowpass filter for 3dB equi-ripple response for following specifications: frequency of operation 4 GHz, 3rd order,, impedance 50$\Omega$. Consider a T section prototype and implement using shunt stub.

4. Design a lowpass filter for the following specifications: frequency of operation 4 GHz, 3rd order, maximally flat response, impedance 50$\Omega$. Consider a T section prototype and implement using shunt stub.

5. Design a low-pass, third-order, maximally flat filter using only series stubs. The cutoff frequency is 6 GHz and the impedance is $50\Omega$.

6. Design a low-pass, third-order, 3 dB ripple Chybyshev filter using series stubs only. The cutoff frequency is 6 GHz and the impedance is $50\Omega$.

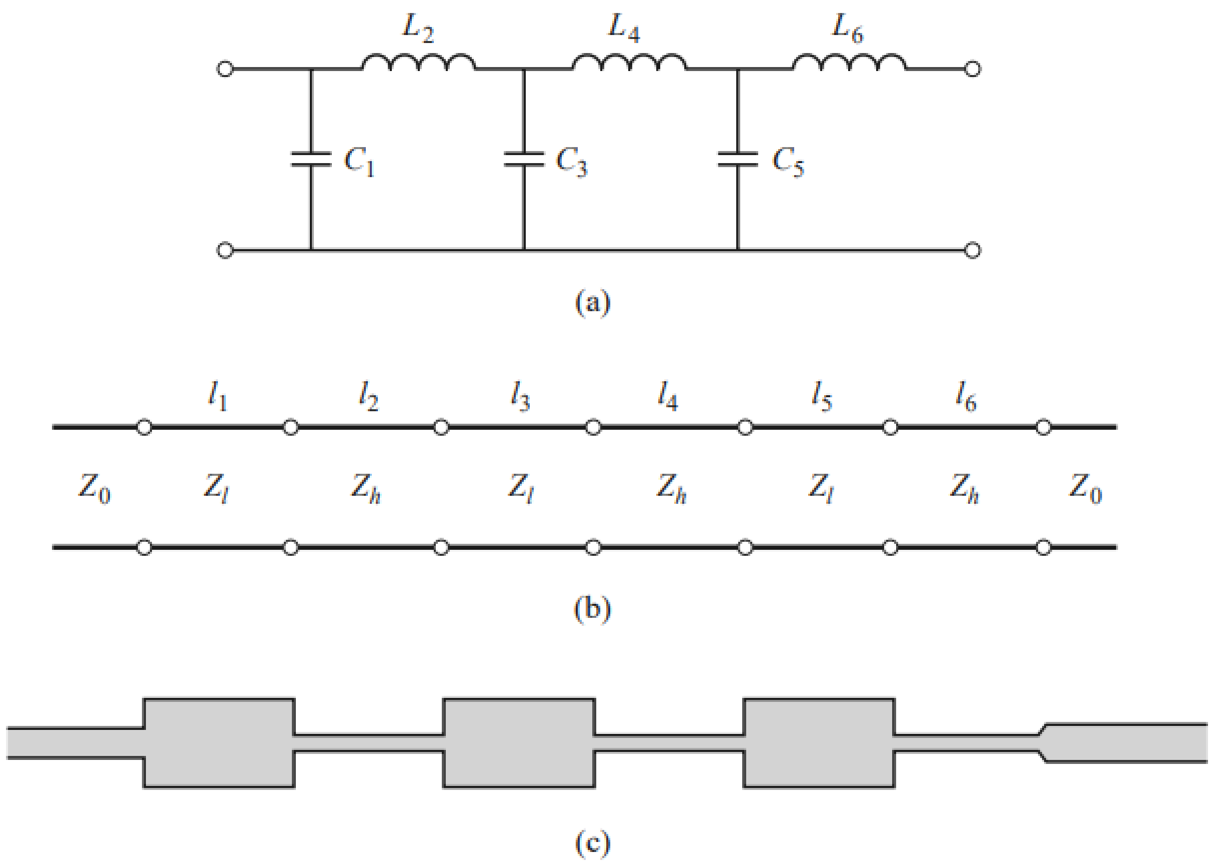
7. Design $4^{th}$ order maximally flat filter using shunt stubs at 8 GHz and the impedance is $50\Omega$.

# Stepped Impedance Filter

Stepped impedance filter

- Easiest method to implement LPF
- Use low and high impedances
- Popular because, less space than stubs
- Sharp cutoff not possible due to approximation

# Stepped Impedance Filter




Inductor

$$\beta l = \frac{LR_0}{Z_h}$$

Capacitor

$$\beta l = \frac{CZ_l}{R_0}$$

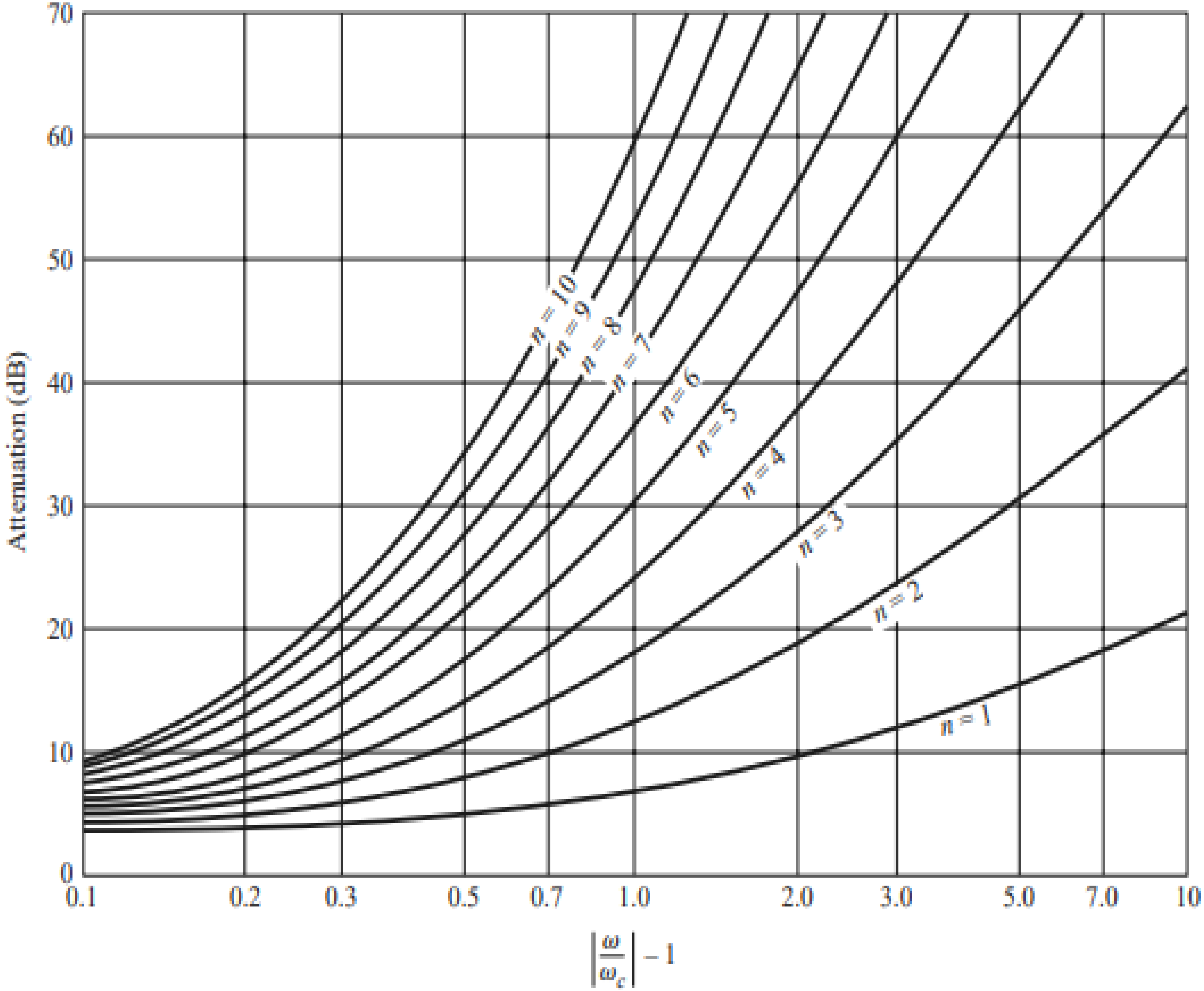
$R_0$ is the filter impedance; L, C are element values from the table.

a. LPF Prototype b. Stepped impedance implementation c. Microstrip Layout

# Filter Design

8. Design a stepped-impedance low-pass filter having maximally flat response and a cut off frequency of 2.5 GHz. It is necessary to have more than 20 dB insertion loss at 4 GHz. The filter impedance is 50 Ω. The highest practical line impedance is 150 Ω and the lowest is 10 Ω.

9. Design a stepped-impedance low-pass filter with fc = 2.0 GHz and $R_0$ = 50. Assume a maximally flat N = 5 response, and solve for the necessary line lengths and impedances if $Z_l$ = 10 Ω and $Z_h$ = 150 Ω




Attenuation versus normalized frequency for maximally flat filter prototypes a cutoff frequency of --- GHz and a fifth-order / 0.5 dB equal-ripple response. Assume $R_0 = 50\Omega$ , $Z_l = 15\ \Omega$ , and $Z_h = 120\ \Omega$ .

(a) Find the required electrical lengths of the five sections,

(b) Lay out the microstrip implementation of the filter on an substrate having $\varepsilon r = 4.4$, thickness h = 1.6 mm, with copper conductor of 0.5 mil thick. Use CAD to plot the insertion loss versus frequency in the passband of the filter

# Filter Response