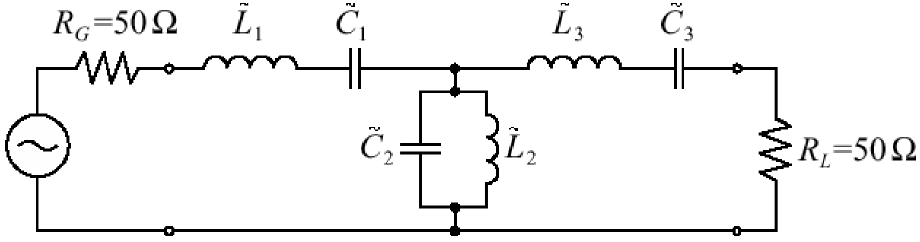
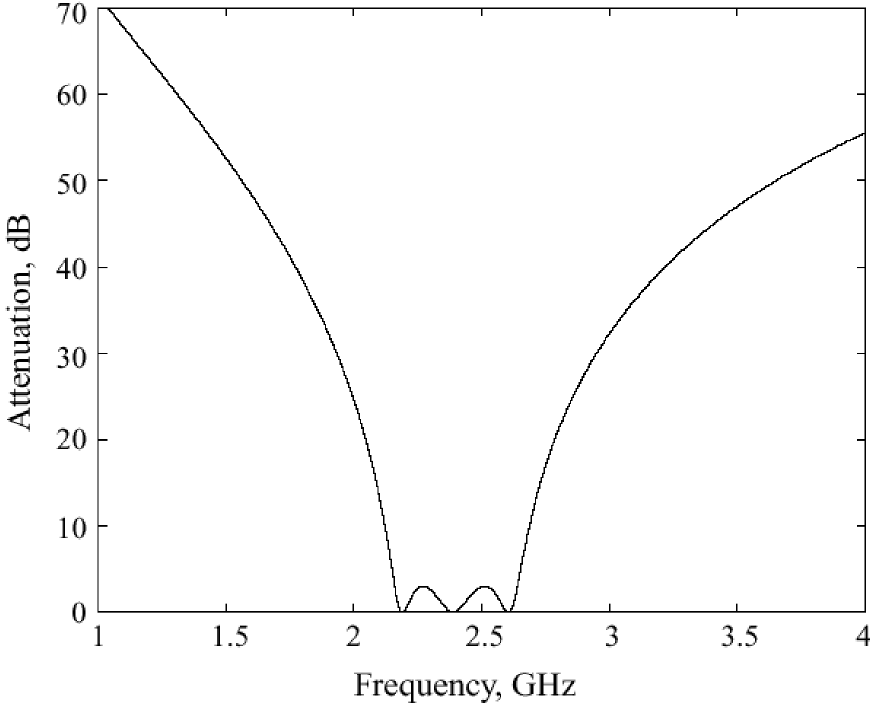
Band-Pass Filter Design Example





Attenuation response of a third-order 3-dB ripple bandpass Chebyshev filter centered at 2.4 GHz. The lower cut-off frequency is f_L = 2.16 GHz and the upper cut-off frequency is f_U = 2.64 GHz.

RF/μW Stripline Filters

- Filter components become impractical at frequencies higher than 500 MHz
- Can apply the normalized low pass filter tables for lumped parameter filters to stripline filter design
- Richards Transformation and Kuroda's Identities are used to convert lumped parameter filter designs to distributed filters

Richards Transformation: Lumped to Distributed Circuit Design

- Open- and short-circuit transmission line segments emulate inductive and capacitive behavior of discrete components
- Based on: $Z_{in} = jZ_o\, tan\left(\beta l\right) = jZ_o\, tan\left(\theta\right)$
- Set Electrical Length l = λ/8 so

$$\theta = \beta l = \frac{\pi}{4}\frac{f}{f_o} = \frac{\pi}{4}\Omega$$

Richards Transformation: Lumped to Distributed Circuit Design

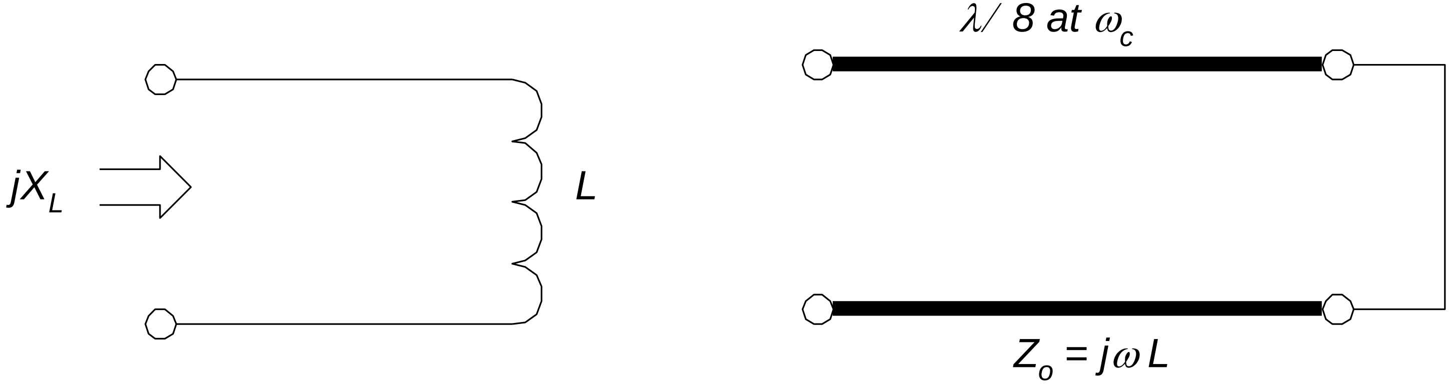
- Richards Transform is:

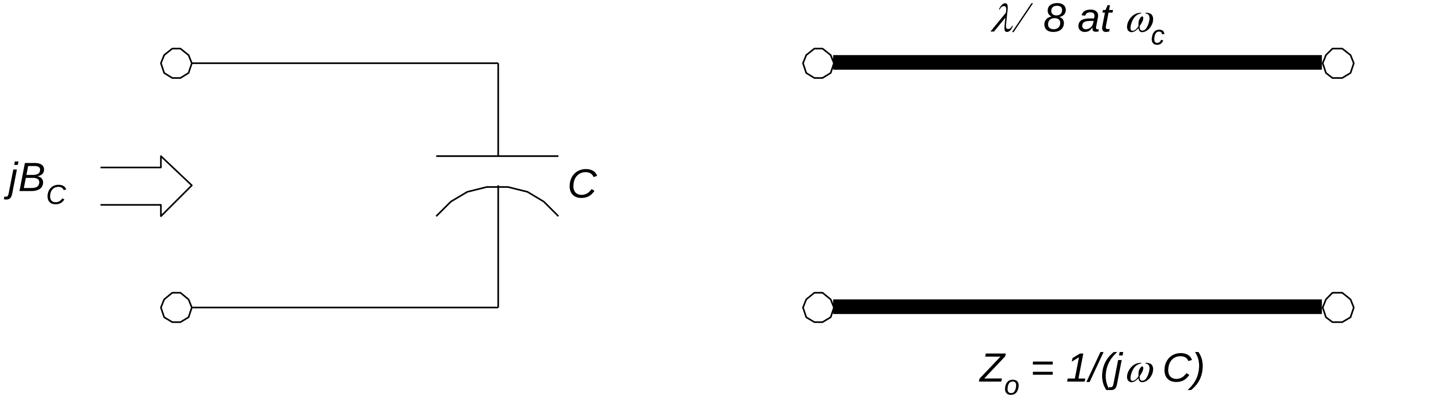
$$jX_L = j\omega L = jZ_o \tan\left(\frac{\pi}{4}\Omega\right) = SZ_o$$

and $$jB_C = j\omega C = jY_o \tan\left(\frac{\pi}{4}\Omega\right) = SY_o$$

- For $l = \lambda/8$, $S = j1$ for $f = f_o = f_c$

Richards Transformation:
Lumped to Distributed Circuit Design



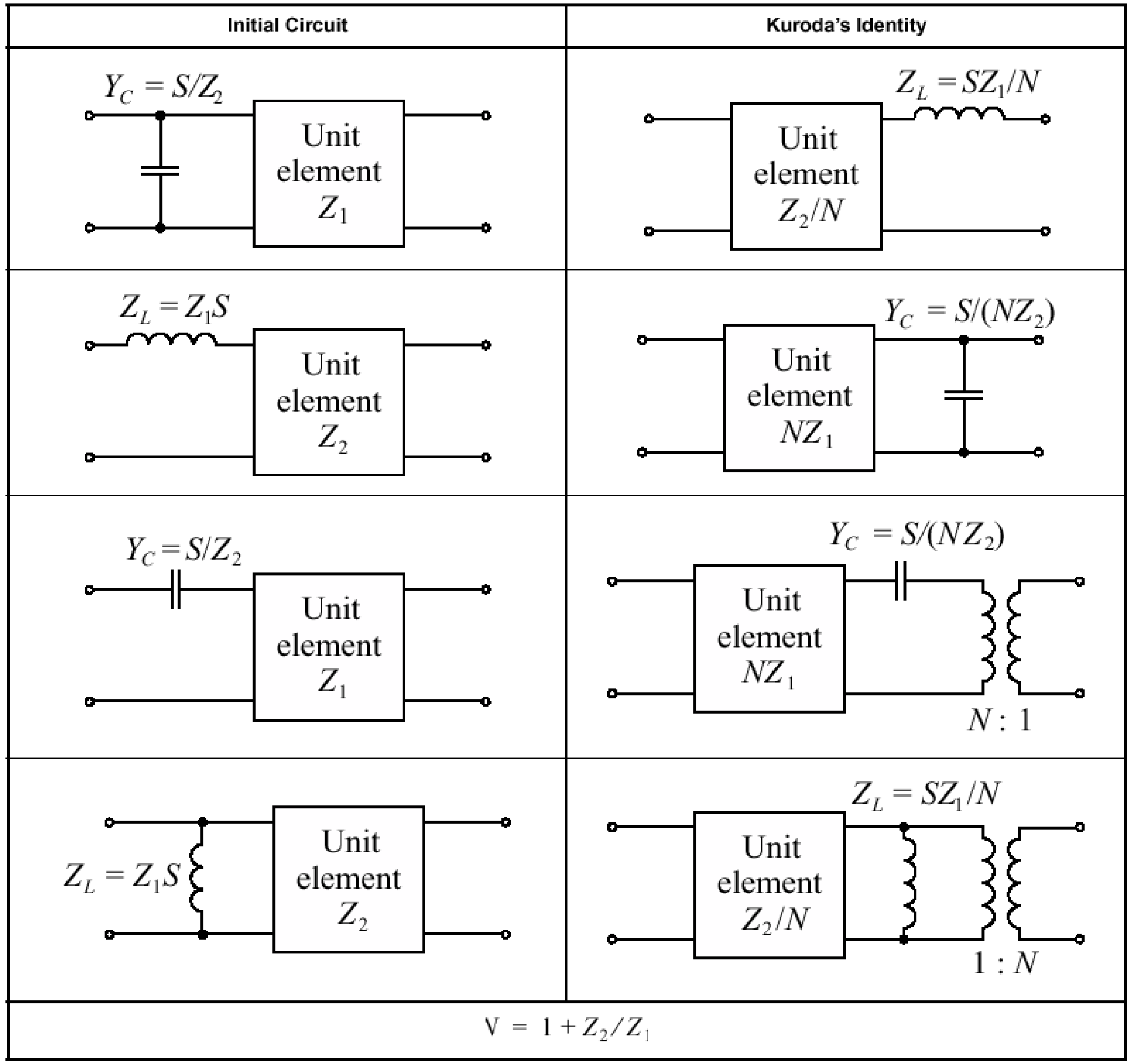


Unit Elements : UE

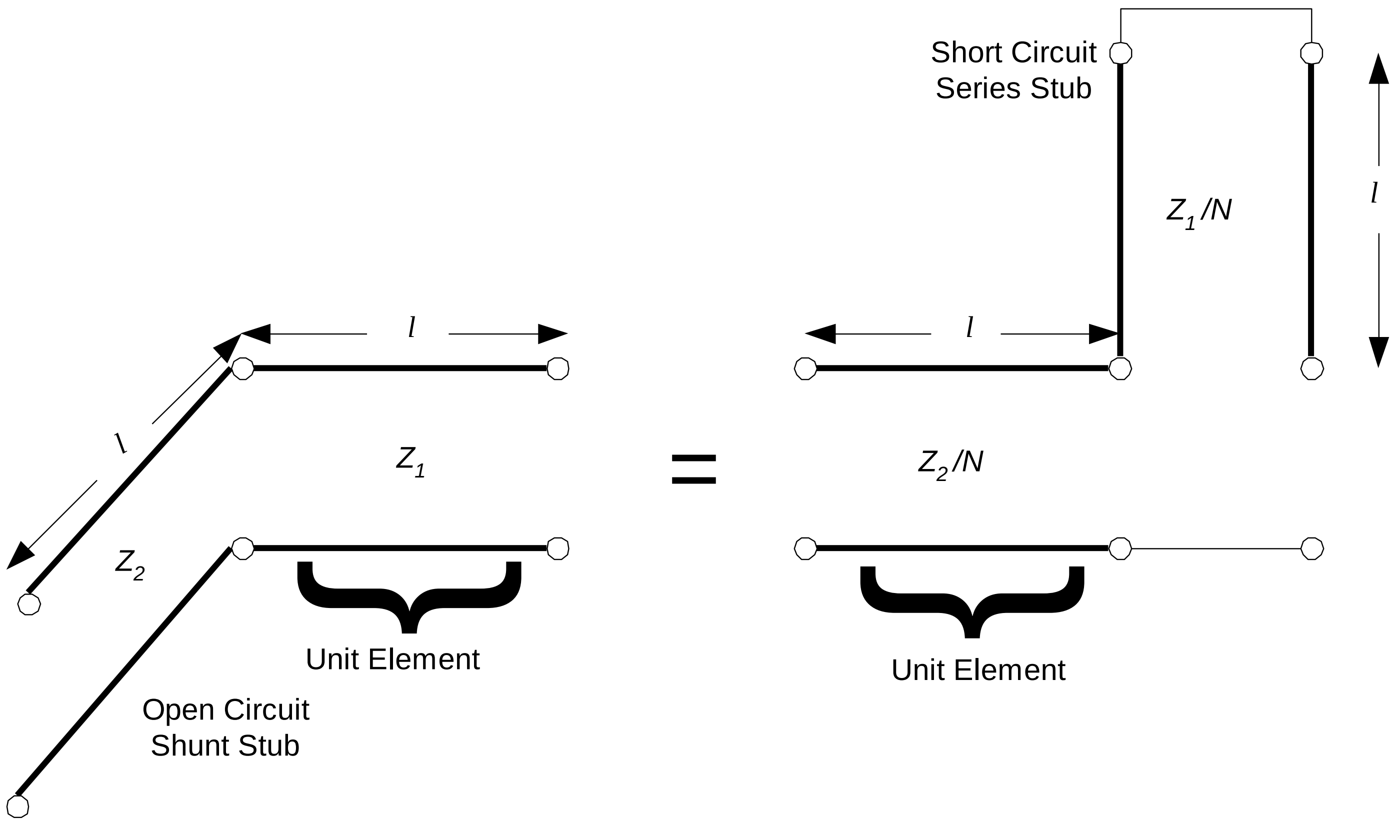
- Separation of transmission line elements achieved by using Unit Elements (UEs)
- UE electrical length: $\theta = \pi\Omega/4$
- UE Characteristic Impedance Z_{UE}

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix}_{UE} = \begin{bmatrix} \cos\theta & jZ_{UE}\sin\theta \\ \dfrac{j}{Z_{UE}}\sin\theta & \cos\theta \end{bmatrix} = \frac{1}{\sqrt{1+\Omega^2}} \begin{bmatrix} 1 & j\Omega Z_{UE} \\ \dfrac{j\Omega}{Z_{UE}} & 1 \end{bmatrix}$$

The Four Kuroda's Identities



Kuroda's Equivalent Circuit



Realizations of Distributed Filters

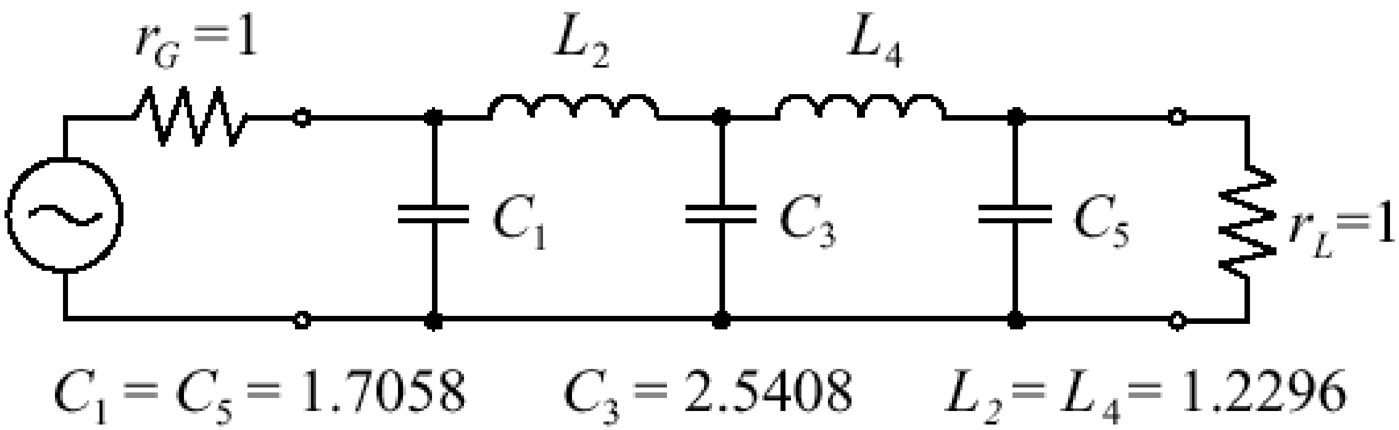
- Kuroda's Identities use redundant transmission line sections to achieve practical microwave filter implementations
- Physically separates line stubs
- Transforms series stubs to shunt stubs or vice versa
- Change practical characteristic impedances into realizable ones

Filter Realization Procedure

- Select normalized filter parameters to meet specifications
- Replace *L*'s and *C*'s by λ_o /8 transmission lines
- Convert series stubs to shunt stubs using Kuroda's Identities
- Denormalize and select equivalent microstriplines

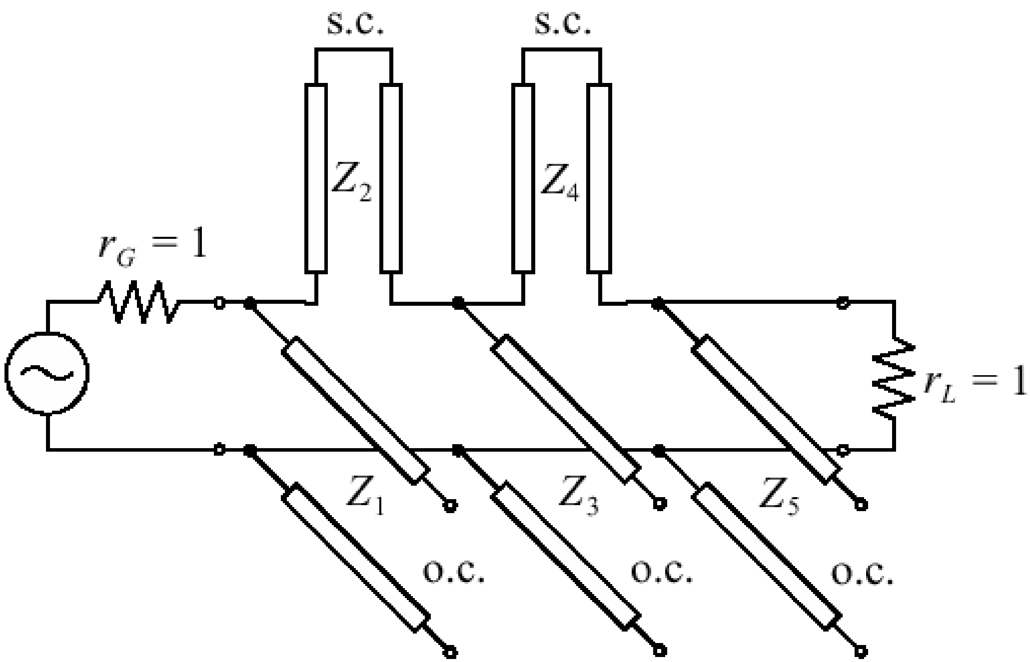
Filter Realization Example

- 5^{th} order 0.5 dB ripple Chebyshev LPF
- $g_1 = g_5 = 1.7058$, $g_2 = g_4 = 1.2296$, $g_3 = 2.5408$, $g_6 = 1.0$



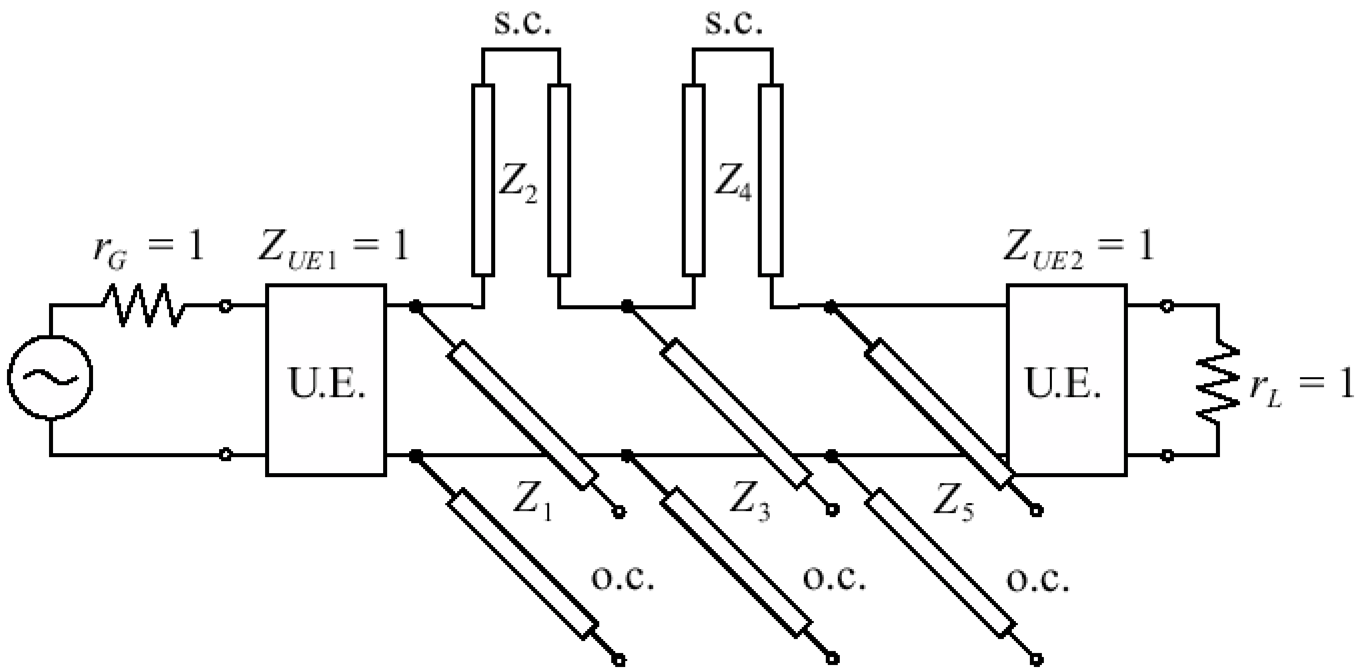
Filter Realization Example

- $Y_1 = Y_5 = 1.7058$, $Z_2 = Z_4 = 1.2296$, $Y_3 = 2.5408$; and $Z_1 = Z_5 = 1/1.7058$, $Z_3 = 1/2.5408$



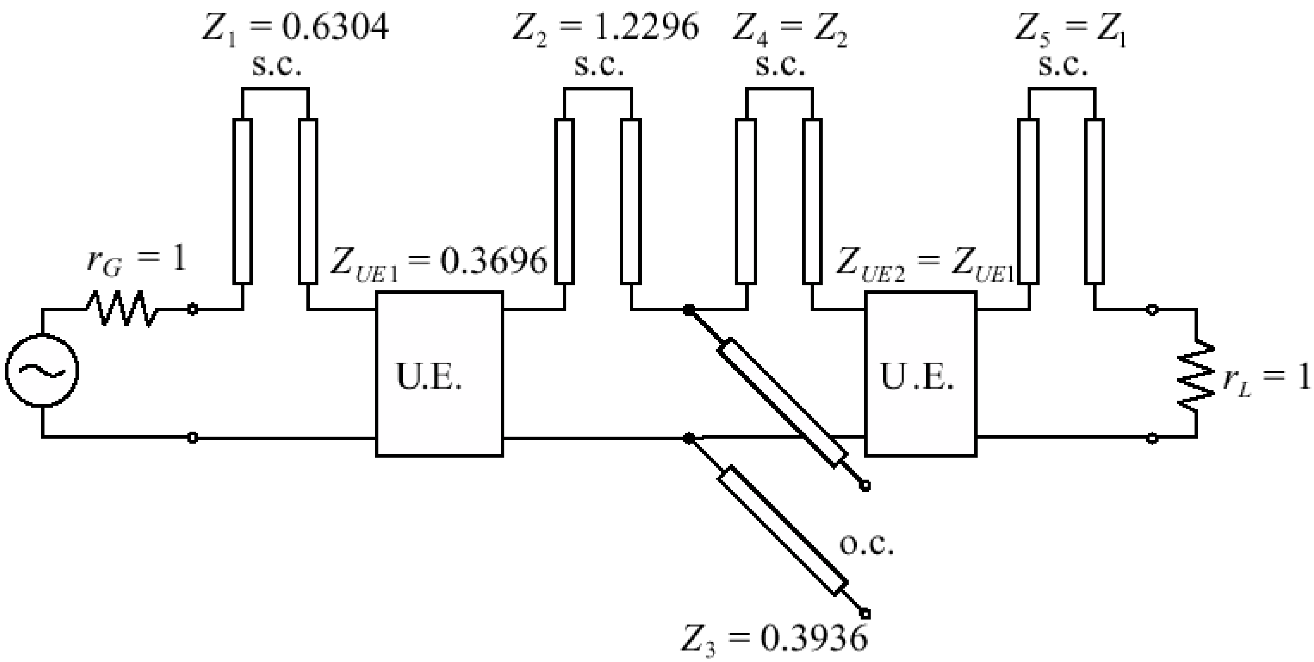
Filter Realization Example

- Utilizing Unit Elements to convert series stubs to shunt stubs



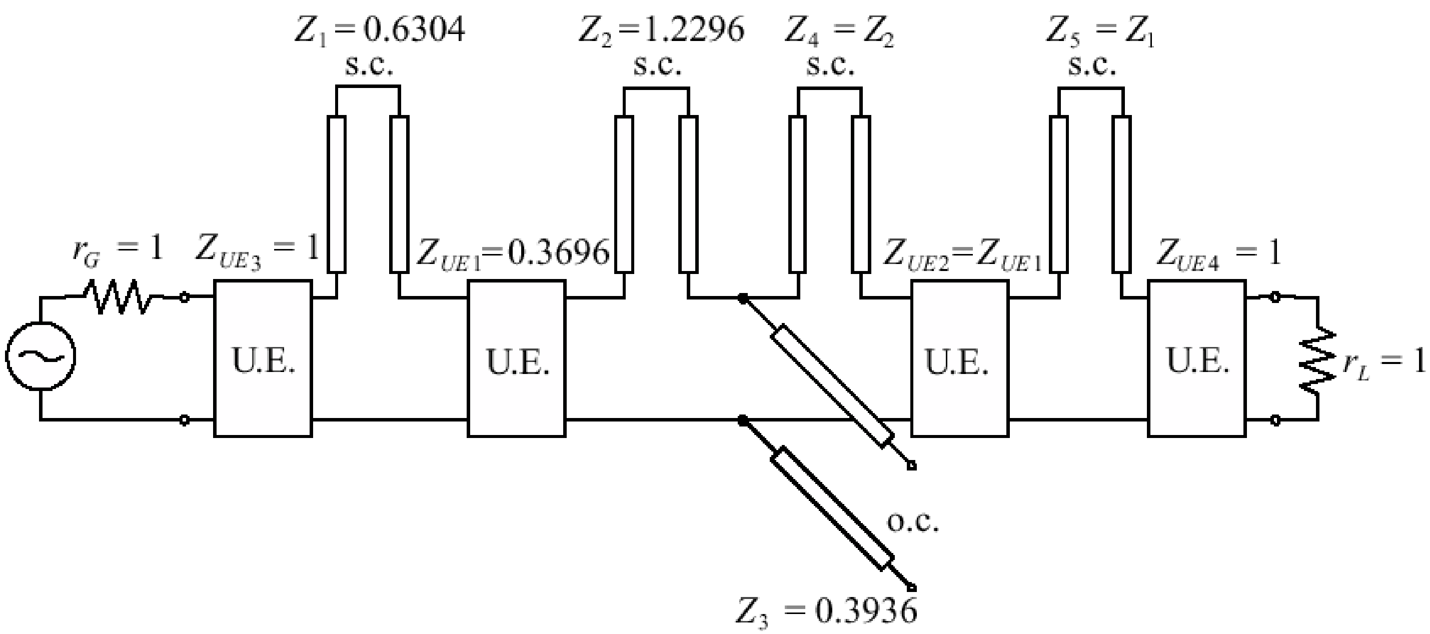
Filter Realization Example

- Apply Kuroda's Identities to eliminate first shunt stub to series stub



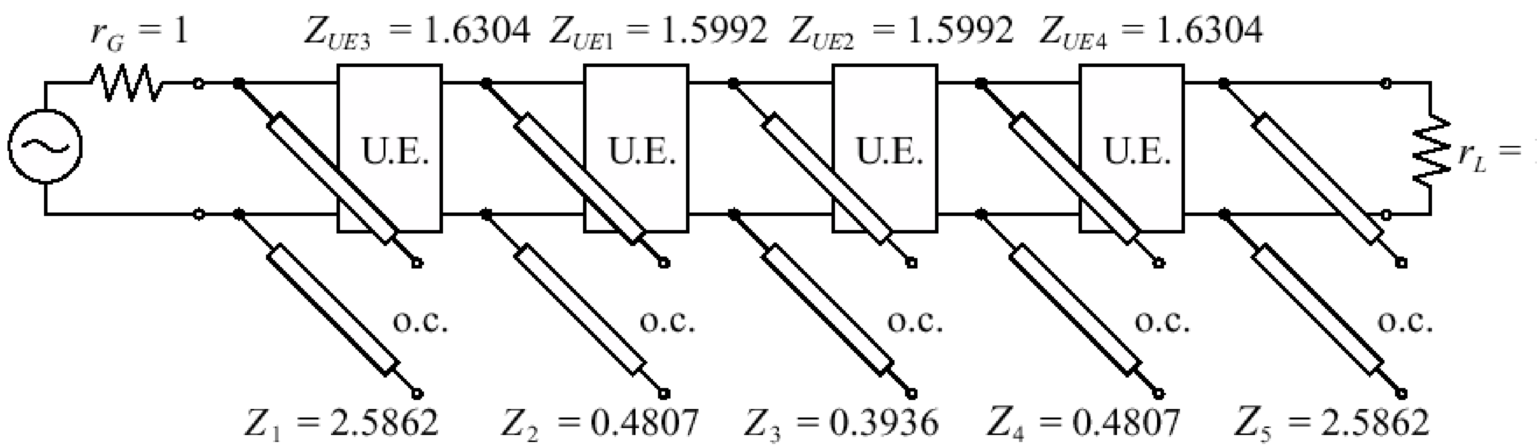
Filter Realization Example

- Deploy second set of UE's in preparation for converting all series stubs to shunt stubs



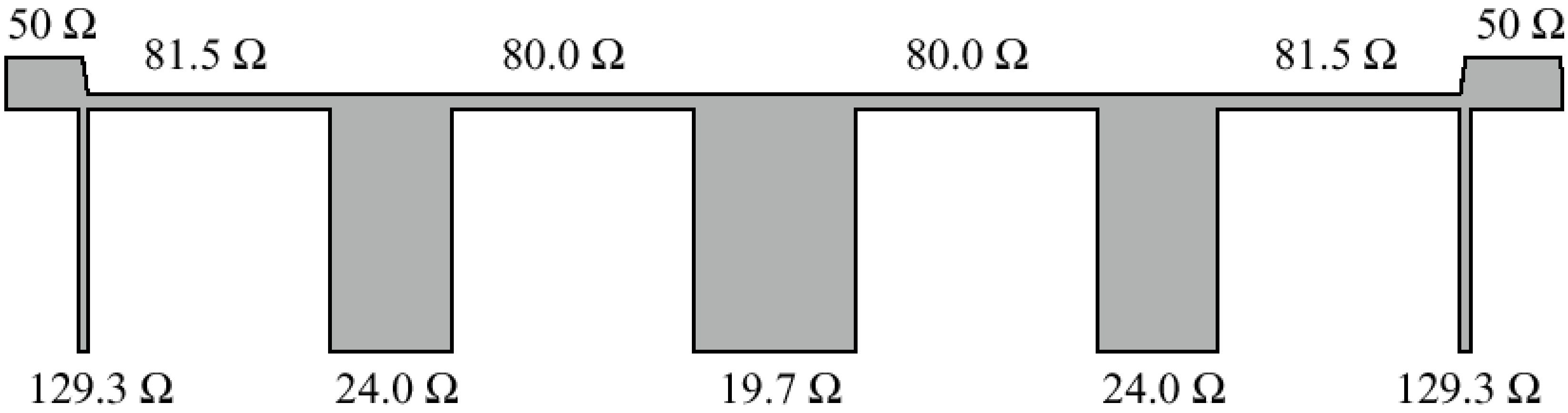
Filter Realization Example

- Apply Kuroda's Identities to eliminate all series stubs to shunt stubs
- $Z_1 = 1/Y_1 = NZ_2 = (1+Z_2/Z_1)Z_2$ $=1+(1/0.6304)$; $Z_2 = 1$ and $Z_1 = 0.6304$



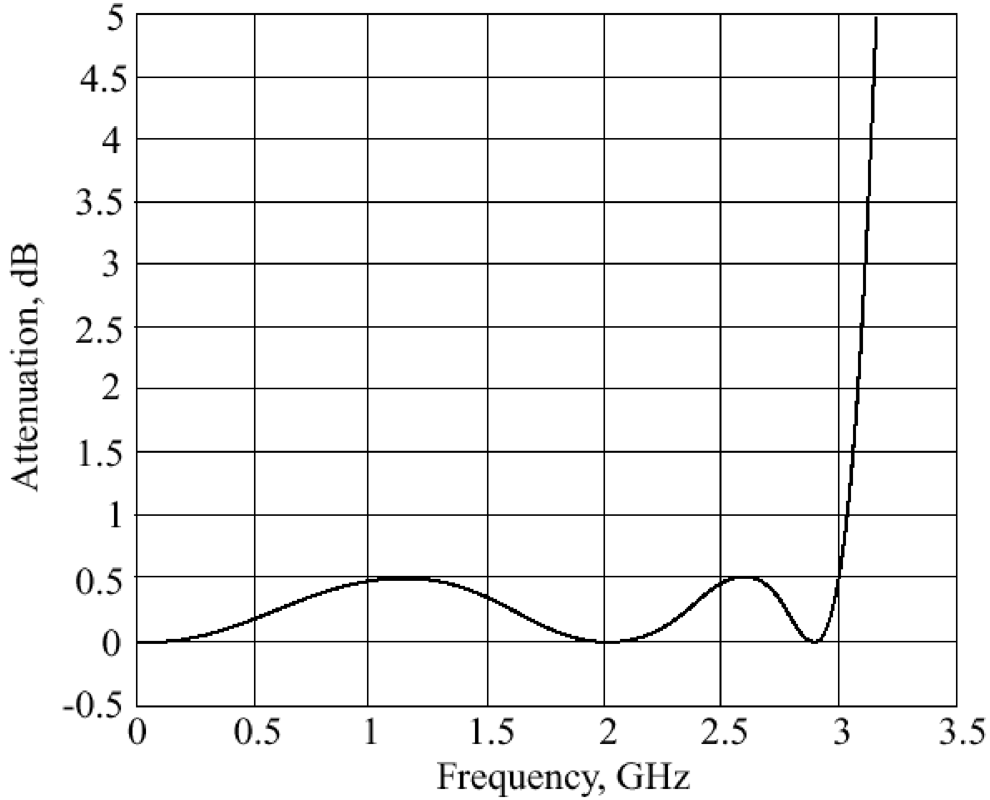
Filter Realization Example

- Final Implementation



Filter Realization Example

- **Frequency Response of the Low Pass Filte**



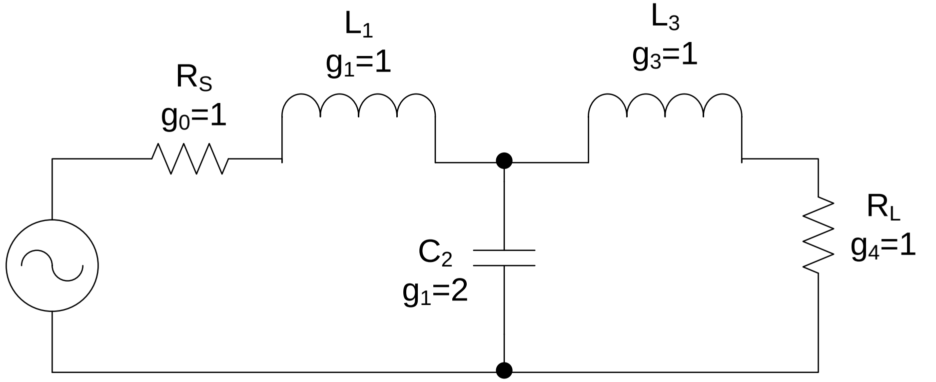
Lumped Parameter Band-Pass Filter Design

Design an N=3 band-pass maximally flat (Butterworth) filter with a center frequency of 900 MHz. The Bandwidth of the filter is 20% ; That is, BW = (0.20)(900 MHz) = 1.8 MHz or ±0.9 MHz.

From the Maximally Flat Low Pass Prototype Table 5-2,

$$g_0 = g_4 = 1,\ g_1 = g_3 = 1,\ g_2 = 2$$

Low Pass Prototype Filter



Where the normalized center frequency is

$\omega_c = 1$, $\omega_L = 1.1(2\pi\cdot 900\text{ MHz})$, and

$\omega_U = 0.9(2\pi\cdot 900\text{ MHz})$

So that $\omega_U - \omega_L = 1.13$Grad/s and

$$\omega_o = \sqrt{\omega_L \omega_U} = 5.627\,\text{Grad/s}$$

Finding the Filter Components

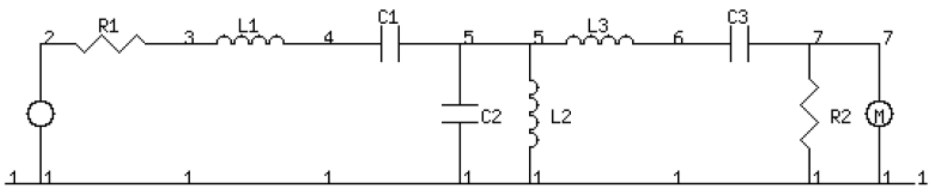
$$L_1 = L_3 = 50\left(\frac{g_1}{(\omega_U - \omega_L)}\right) = 44\text{nH}$$

$$C_1 = C_3 = \frac{1}{50}\left(\frac{\omega_U - \omega_L}{\omega_o^2 g_1}\right) = 0.713\text{pF}$$

$$L_2 = 50\left(\frac{\omega_U - \omega_L}{\omega_o^2 g_2}\right) = 0.892\text{nH}$$

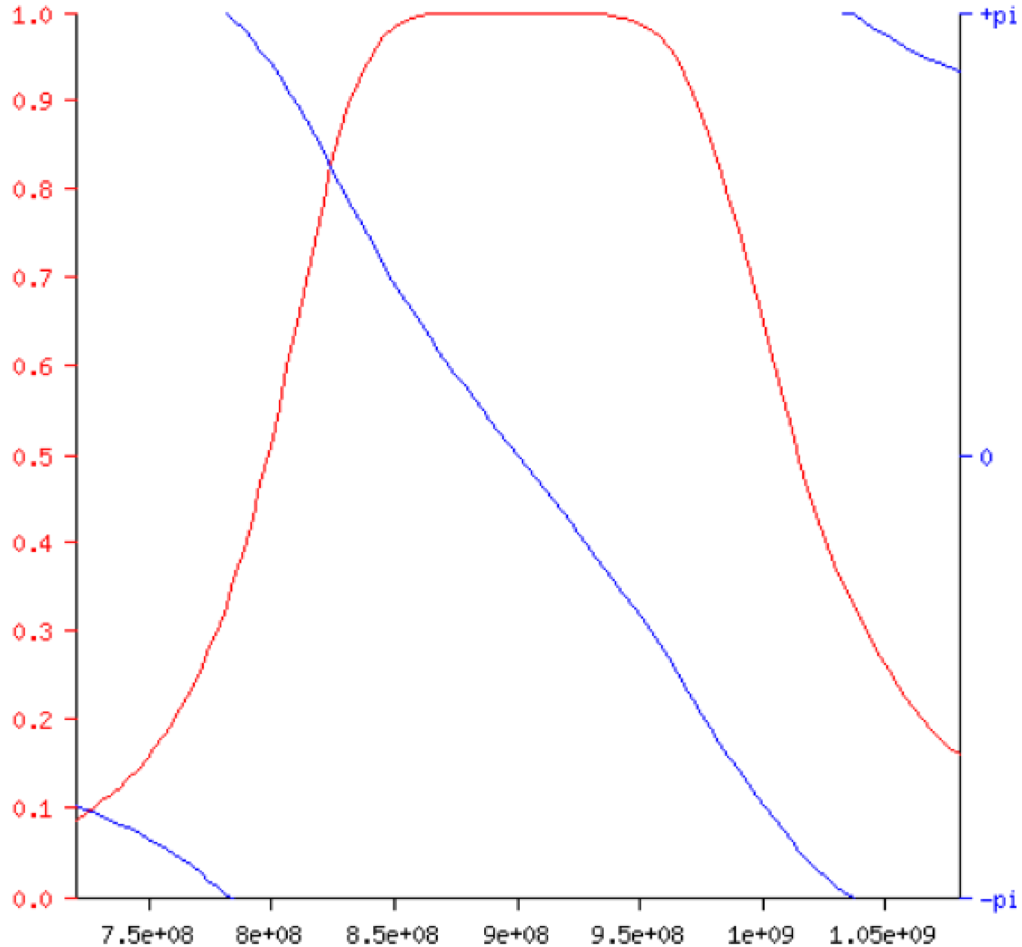
$$C_2 = \frac{1}{50}\left(\frac{g_2}{\omega_U - \omega_L}\right) = 35.2\text{pF}$$

Filter Simulation with Ansoft Designer



R1	50	50
L1	4.42097e-08	4.42097e-08
C1	7.07355e-13	7.07355e-13
C2	3.53678e-11	3.53678e-11
L2	8.84194e-10	8.84194e-10
L3	4.42097e-08	4.42097e-08
C3	7.07355e-13	7.07355e-13
R2	50	50

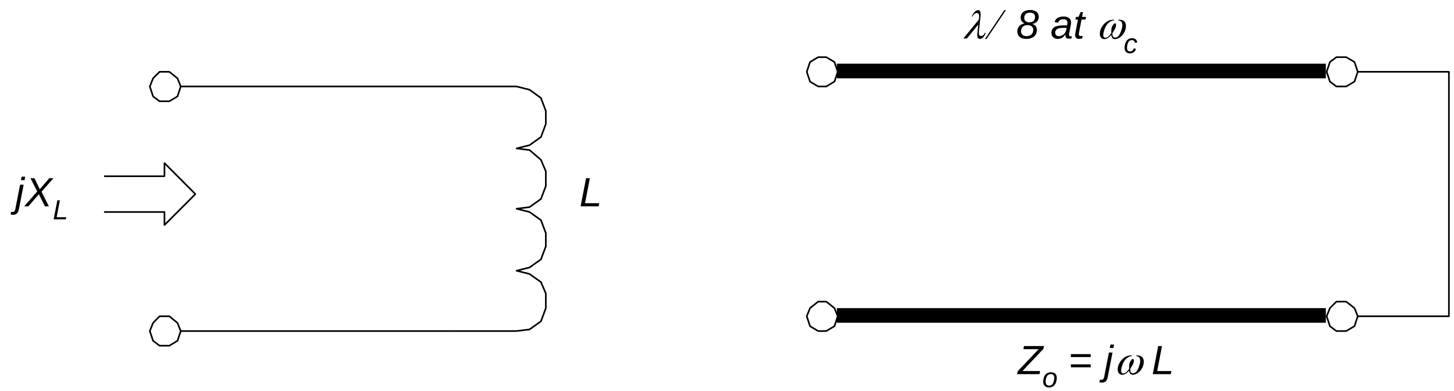
Filter Simulation with Ansoft Designer

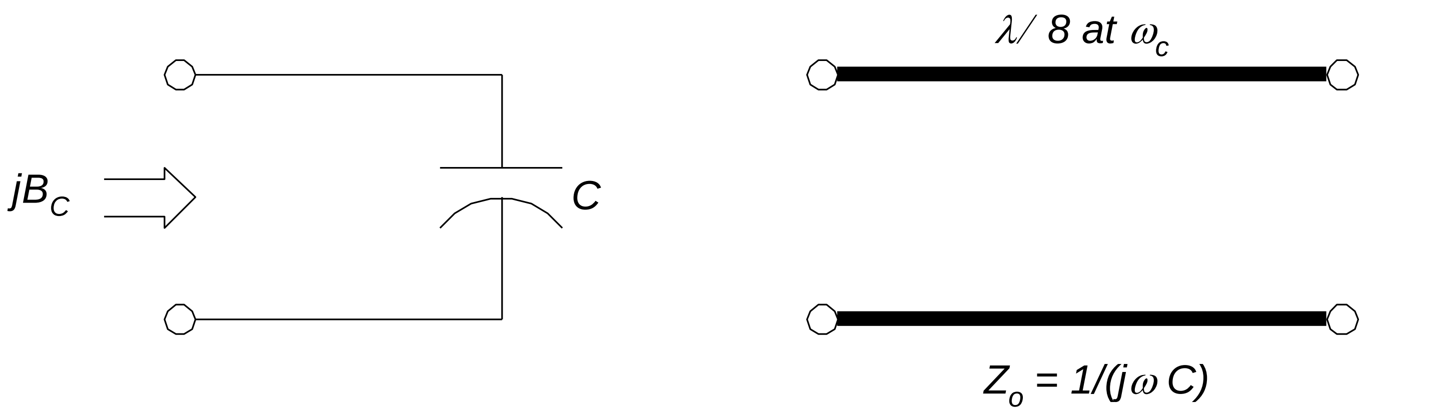


Some Observations On The Results

- Values of components are unreasonable
- Some other method for implementing the filter design goals must be found
- Solution: Use distributed filters using waveguides
- Richardson Transforms and Kuroda's Identities

Richards Transformation: Lumped to Distributed Circuit Design



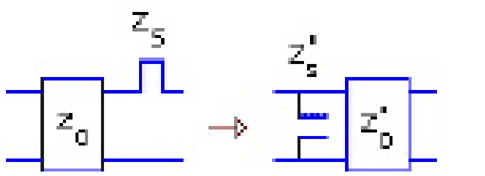


Kuroda Transforms

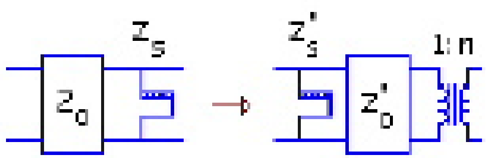
Kuroda Transformations

Kuroda transformation moves a transmission line over the other elements in a cascaded circuit and it is mostly used to separate distributed stub elements from each other. Having adjacent stubs is not practical for realization and inserting transmission line pieces in between is one way of overcoming this difficulty.

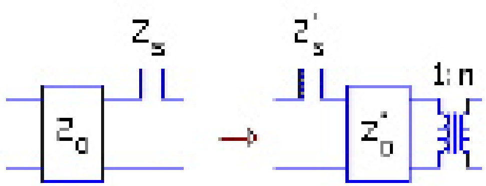
Although there are several other combinations, there are 3 basic Kuroda transformations:



$$n = \frac{Z_s + Z_0}{Z_0} \qquad Z_0' = n Z_0 \qquad Z_s' = n\left[\frac{Z_0}{Z_s}\right]^2$$



$$n = \frac{Z_s}{Z_s + Z_0} \qquad Z_0' = \frac{Z_0}{n} \qquad Z_s' = \frac{Z_s}{n}$$



$$n = \frac{Z_s + Z_0}{Z_0} \qquad Z_0' = n Z_0 \qquad Z_s' = n Z_s$$