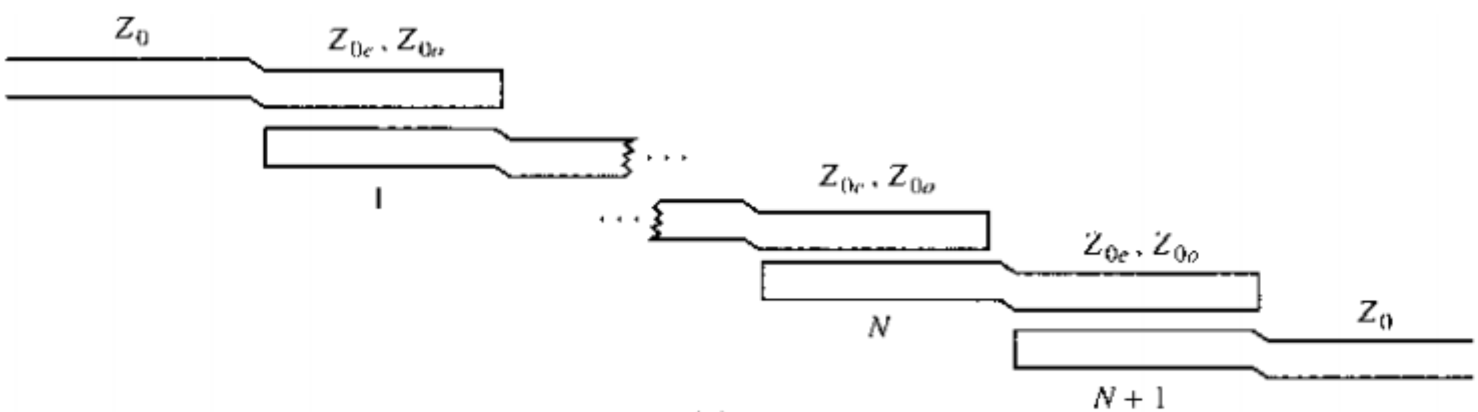
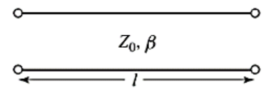
Design of Coupled Line Bandpass Filters



Design of a Coupled Line BPF

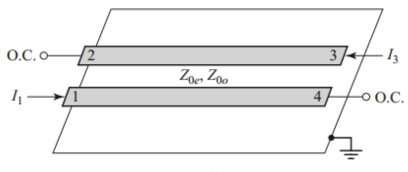
TX line ABCD Matrix

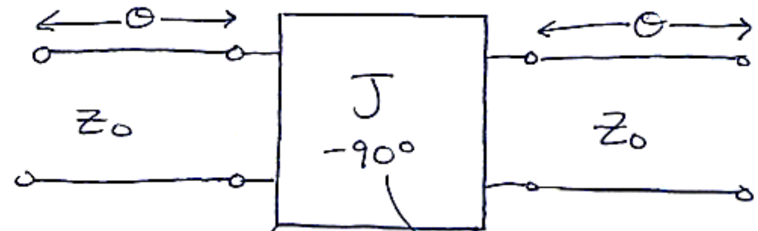


$A = \cos\beta\ell \qquad B = jZ_0\sin\beta\ell$

$C = jY_0\sin\beta\ell \qquad D = \cos\beta\ell$

- A single coupled line is approximated as:





$Z_o = \frac{1}{J}$

Admittance Inverter

90° phase shift due to $\frac{\lambda}{4}$ length

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \underbrace{\begin{bmatrix} \cos\theta & jZ_0\sin\theta \\ \frac{j\sin\theta}{Z_0} & \cos\theta \end{bmatrix}}_{\text{Transmission line}} \begin{bmatrix} 0 & -\frac{j}{J} \\ -jJ & 0 \end{bmatrix} \begin{bmatrix} \cos\theta & jZ_0\sin\theta \\ \frac{j\sin\theta}{Z_o} & \cos\theta \end{bmatrix}$$

Admittance inverter: A quarter – wave length of transmission of characteristic impedance, $\frac{1}{J} = \mathrm{Z_o}$

Design of a Coupled Line BPF

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \left(JZ_0 + \dfrac{1}{JZ_0}\right)\sin\theta\cos\theta & j\left(JZ_0^2\sin^2\theta - \dfrac{\cos^2\theta}{J}\right) \\ j\left(\dfrac{1}{JZ_0^2}\sin^2\theta - J\cos^2\theta\right) & \left(JZ_0 + \dfrac{1}{JZ_0}\right)\sin\theta\cos\theta \end{bmatrix}. \qquad (8.104)$$

The image impedance Z_i at the center frequency $(\theta = \frac{\pi}{2})$

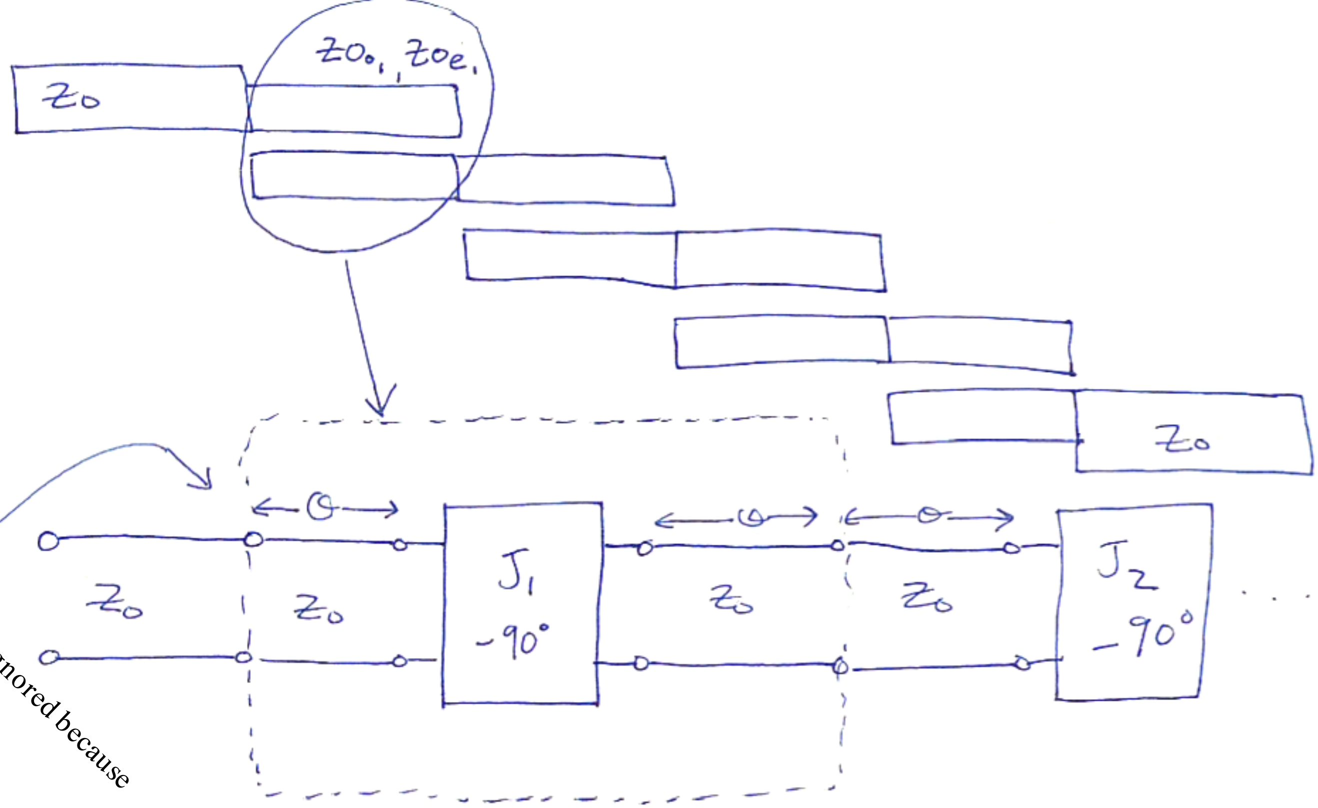
↓↓↓↓↓↓↓↓↓↓↓↓↓↓ (from $Z_i = \sqrt{\frac{AB}{CD}}$ and $\theta = \frac{\pi}{2}$)

The propagation constant:

$\cos\beta = A =$ ↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓↓

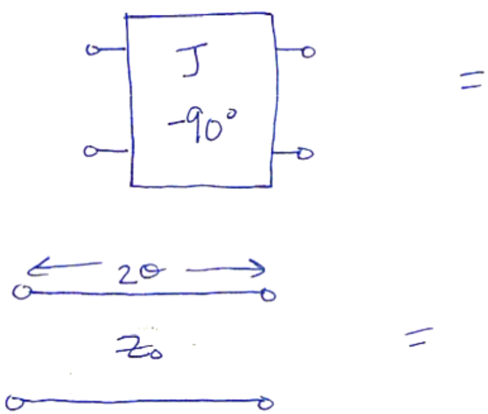
(from $e^{\gamma} = \sqrt{AD} - \sqrt{BC}$)

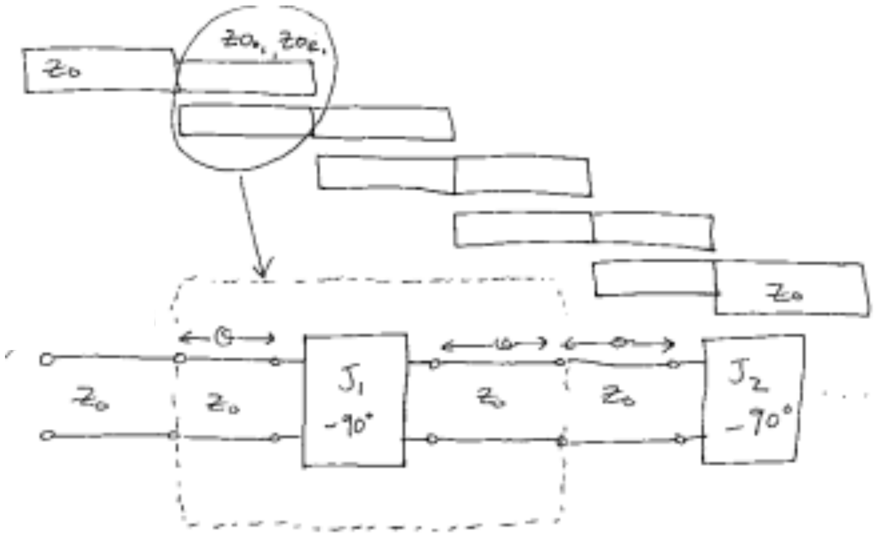
Now consider a BPF composed of a cascade of N+1 coupled line sections:

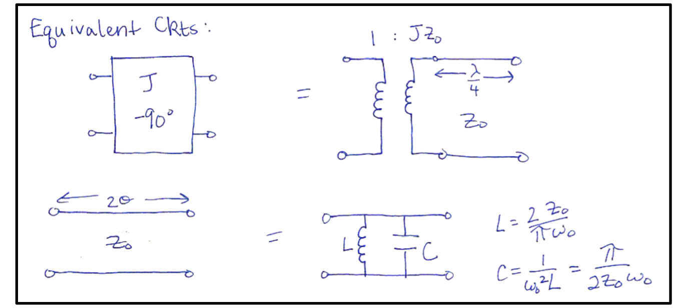


First section can be ignored because its matched to Zo

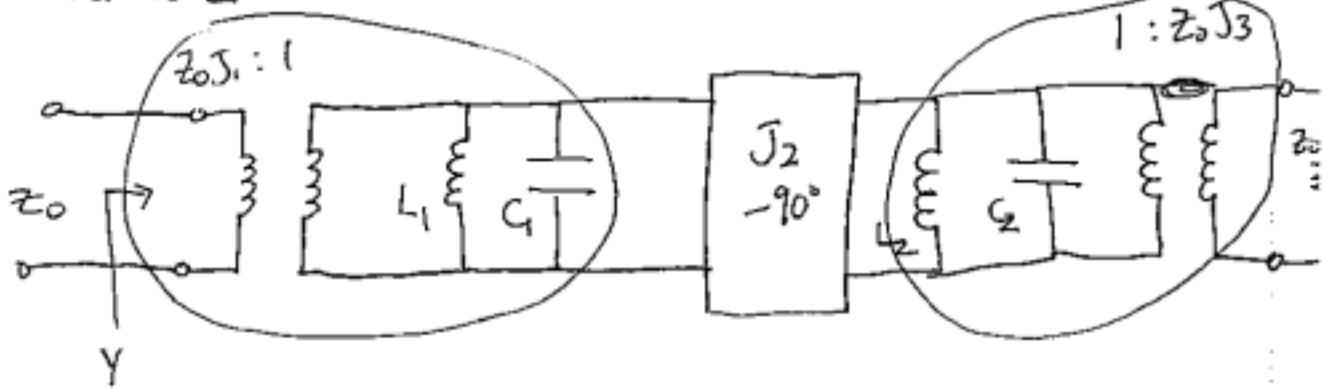
Equivalent Ckts:

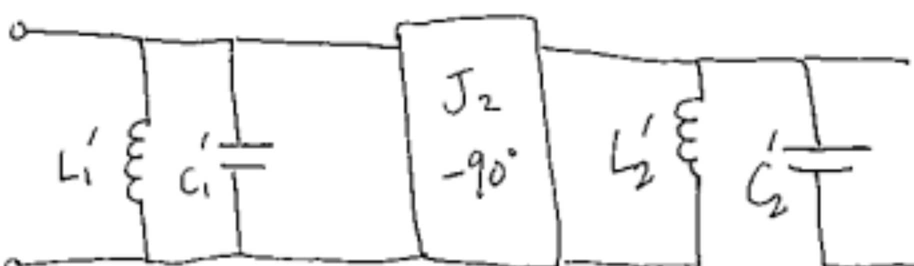



Z_{0o}, Z_{0e}
Z_0
θ
J_1
$-90°$
J_2
$-90°$

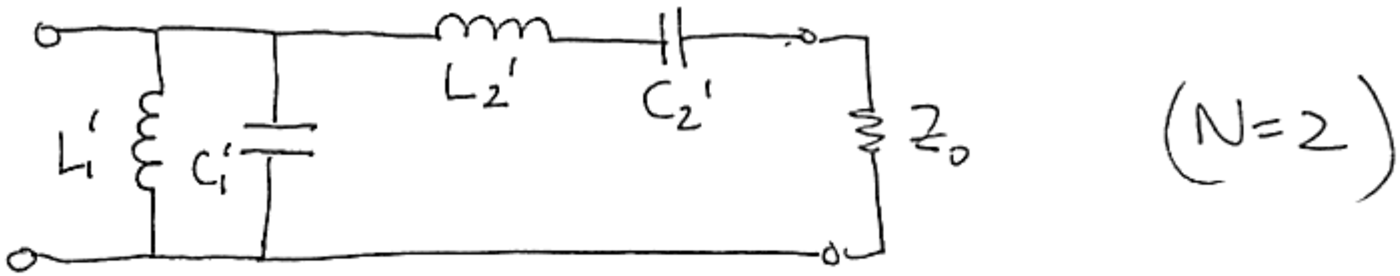

Equivalent Ckts:
$1 : JZ_0$
J
$-90°$
$\lambda/4$
Z_0
2θ
L
C
$L = \frac{2Z_0}{\pi\omega_0}$
$C = \frac{1}{\omega_0^2 L} = \frac{\pi}{2Z_0\omega_0}$

For N=2


$Z_0J_1 : 1$
Z_0
Y
L_1
C_1
J_2
$-90°$
L_2
C_2
$1 : Z_0J_3$


L_1'
C_1'
J_2
$-90°$
L_2'
C_2'

An admittance inverter will transform a shunt LC circuit to a series LC circuit



From here we can use the lumped element Lowpass prototype to determine values.

$L'_1 =$ ↓↓↓↓↓↓↓ $L'_2 =$ ↓↓↓↓↓↓↓

$C'_1 =$ ↓↓↓↓↓↓↓ $C'_2 =$ ↓↓↓↓↓↓↓↓

where $\Delta =$ ↓↓↓↓↓↓↓↓↓ (i.e. fractional bandwidth)

General Formulas are:

$$z_0 J_1 = \sqrt{\frac{\pi\Delta}{2g_1}}$$

$$z_0 J_n = \frac{\pi\Delta}{2\sqrt{g_{n-1}g_n}}$$

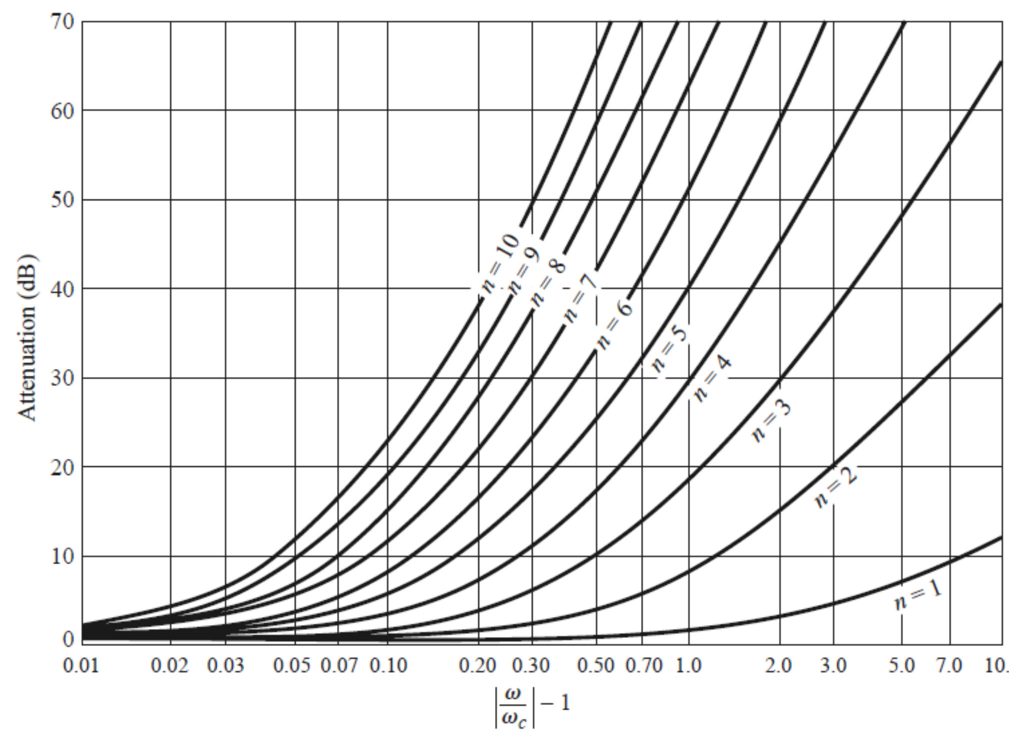
$$z_0 J_{N+1} = \sqrt{\frac{\pi\Delta}{2g_N g_{N+1}}}$$

$$z_{0_e} = z_0[1 + Jz_0 + (Jz_0)^2]$$

$$z_{0_0} = z_0[1 - Jz_0 + (Jz_0)^2]$$

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



Ex) Design a coupled line BPF with N=3 and 0.5 dB equal response. The center frequency is 2.0 GHz, the bandwidth is 10 % and Z_o= 50 Ω. Δ = 0.1 (given)

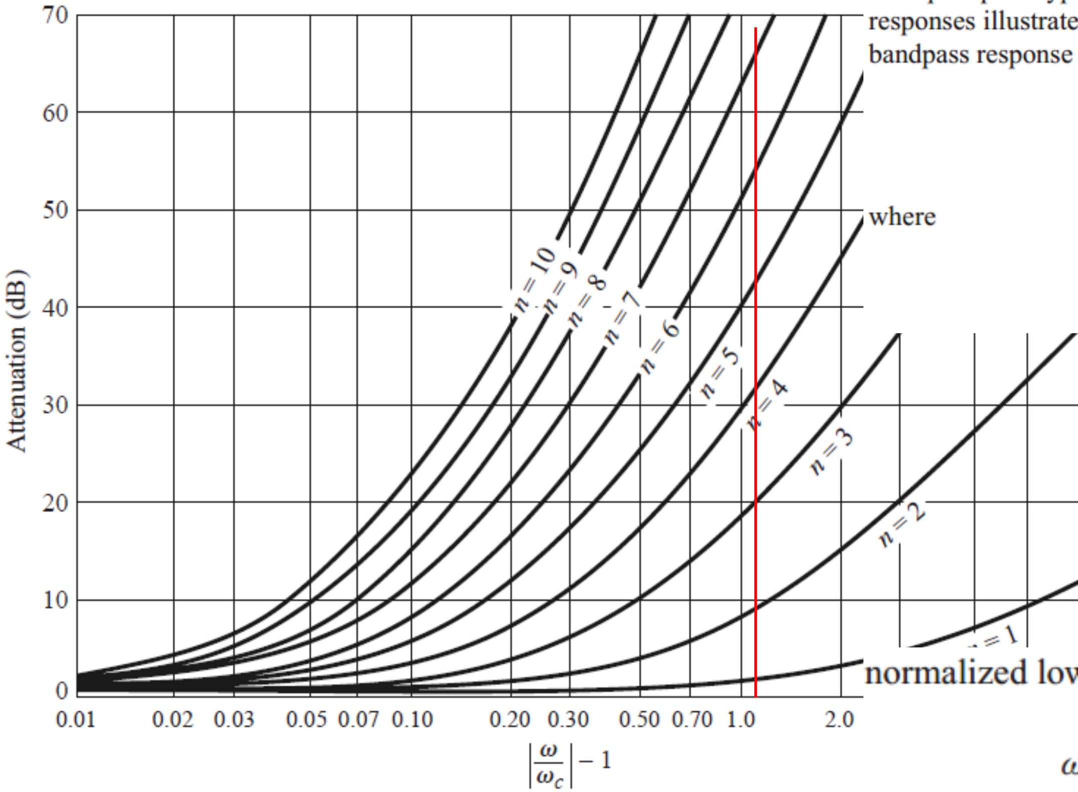
TABLE 8.4 Element Values for Equal-Ripple Low-Pass Filter Prototypes ($g_0 = 1$, $\omega_c = 1$, $N = 1$ to 10, 0.5 dB and 3.0 dB ripple)

					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

Ex) Design a coupled line BPF with N=3 and 0.5 dB equal response. The center frequency is 2.0 GHz, the bandwidth is 10 % and $Z_o = 50\ \Omega$. $\Delta = 0.1$ (given)

Ex) Design a coupled line BPF with N=3 and 0.5 dB equal response. The center frequency is 2.0 GHz, the bandwidth is 10 % and Z_o= 50 Ω. Δ = 0.1 (given)

What is the attenuation at 1.8 GHz?



Attenuation versus normalized frequency for equal-ripple (a) 0.5 dB ripple level.

Low-pass prototype filter designs can also be transformed to have the bandpass or bandstop responses illustrated in Figure 8.31. If ω_1 and ω_2 denote the edges of the passband, then a bandpass response can be obtained using the following frequency substitution:

$$\omega \leftarrow \frac{\omega_0}{\omega_2 - \omega_1}\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right) = \frac{1}{\Delta}\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right), \tag{8.71}$$

where

$$\Delta = \frac{\omega_2 - \omega_1}{\omega_0} \tag{8.72}$$

normalized low-pass form ($\omega_c = 1$):

$$\omega \leftarrow \frac{1}{\Delta}\left(\frac{\omega}{\omega_0} - \frac{\omega_0}{\omega}\right) = \frac{1}{0.1}\left(\frac{1.8}{2.0} - \frac{2.0}{1.8}\right) = -2.11.$$

Then the value on the horizontal scale of Figure 8.27a is

$$\left|\frac{\omega}{\omega_c}\right| - 1 = |-2.11| - 1 = 1.11,$$

which indicates an attenuation of about 20 dB for $N = 3$.

Design of Stepped Impedance Low Pass Filters

So the series inductors of a low-pass prototype can be replaced with high-impedance line sections ($Z_0 = Z_h$), and the shunt capacitors can be replaced with low-impedance line sections ($Z_0 = Z_\ell$).

Design of a Coupled Line BPF

Stepped Impedance Low Pass Filters

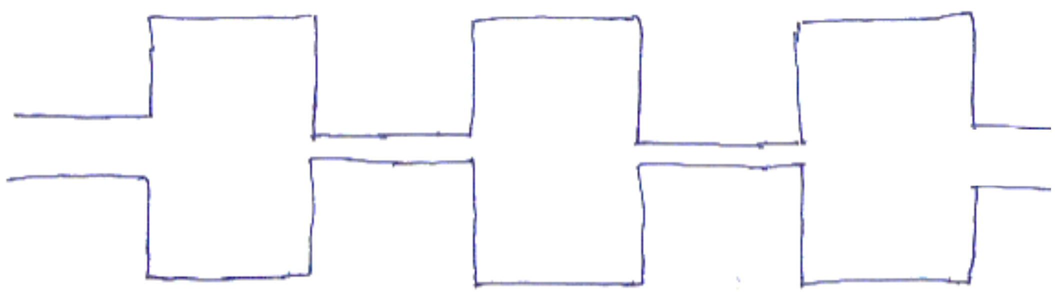
-Alternating sections of very high and very low characteristic impedances.

- Hi – z , Low – z filters

-Easy to design when compared to stubs

-Takes up less space

-Limited to applications where sharp cutoff is not required. (rejecting out – of – band mixer products)



How to design

1. Choose the highest & lowest impedances that are practical.

   Series inductor → high impedance line

   Shunt capacitor → low impedance line

2. Solve for electrical lengths

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

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

L and C: g values from prototype

R_0 = filter impedance > 50Ω

3. Solve for widths (material, ϵ_r, thickness, Impedance)

4. Solve for $l = \frac{2\pi}{\lambda_g} / \beta$

EXAMPLE 8.6 STEPPED-IMPEDANCE FILTER DESIGN

Design a stepped-impedance low-pass filter having a maximally flat response and a cutoff frequency of 2.5 GHz. It is desired to have more than 20 dB insertion loss at 4 GHz. The filter impedance is 50 Ω; the highest practical line impedance is 120 Ω, and the lowest is 20 Ω. Consider the effect of losses when this filter is implemented with a microstrip substrate having $d = 0.158$ cm, $\epsilon_r = 4.2$, $\tan\delta = 0.02$, and copper conductors of 0.5 mil thickness.

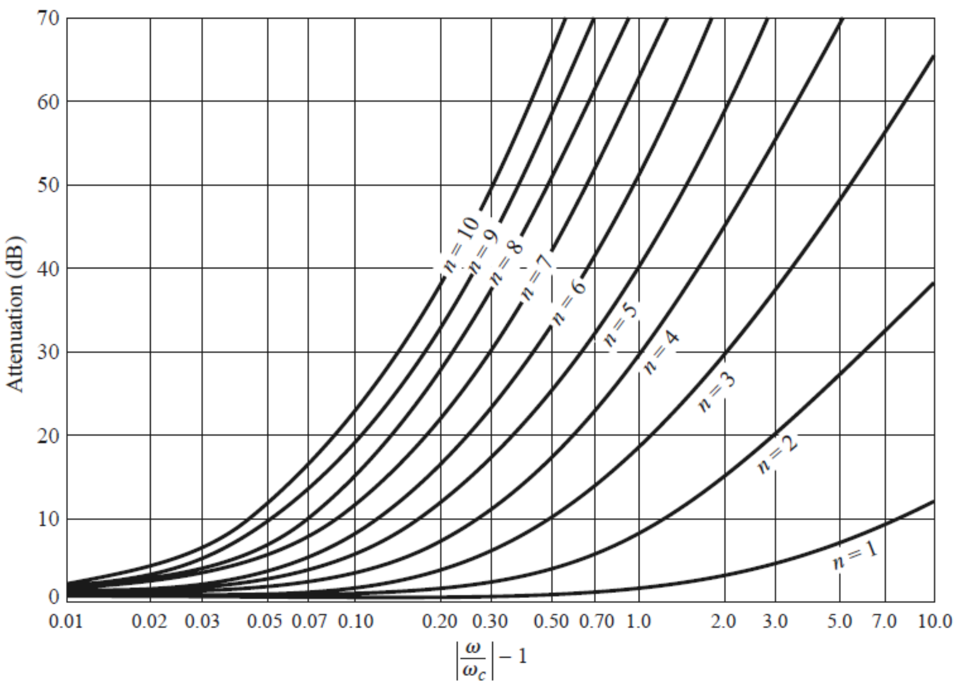


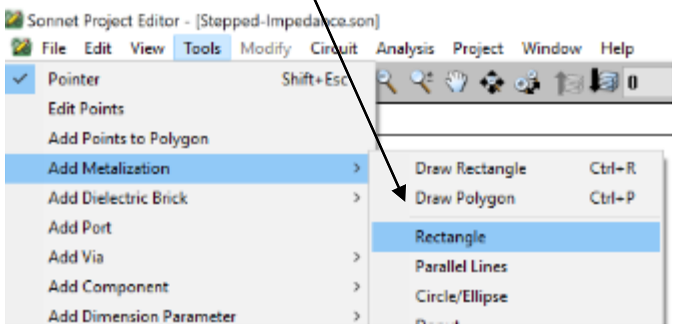
TABLE 8.3 Element Values for Maximally Flat Low-Pass Filter Prototypes ($g_0 = 1$, $\omega_c = 1$, $N = 1$ to 10)

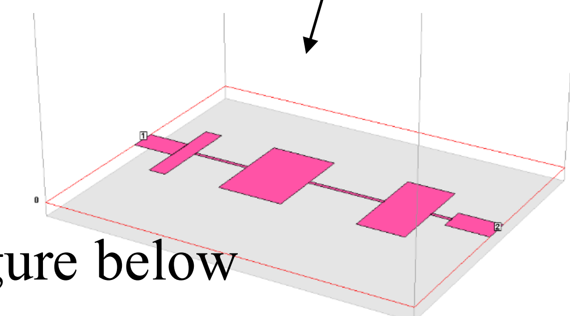
N	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}
1	2.0000	1.0000									
2	1.4142	1.4142	1.0000								
3	1.0000	2.0000	1.0000	1.0000							
4	0.7654	1.8478	1.8478	0.7654	1.0000						
5	0.6180	1.6180	2.0000	1.6180	0.6180	1.0000					
6	0.5176	1.4142	1.9318	1.9318	1.4142	0.5176	1.0000				
7	0.4450	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.

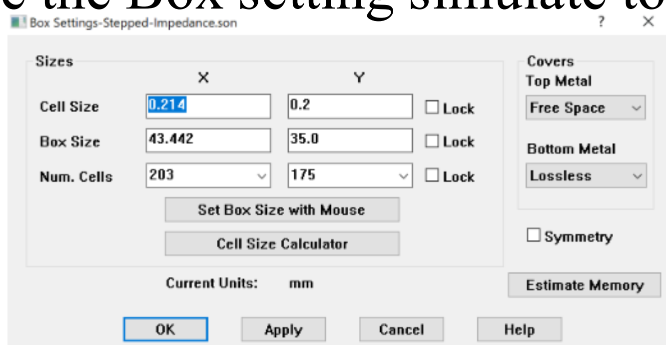
Lab 6

- Using the filter design in Example 8.6, obtain the S11 and S21 using Sonnet.
  - Use "Rectangle" function shown below to create the geometry





  - Use the Box setting simulate to the figure below



  - Run the simulation between 0.1 to 5.0 GHz

Stepped-Impedance Low-Pass Filter (Due April 13th Midnight Online Submission)

- Name:
- Geometry
- Simulation Results (S11 and S21)

Discuss the simulation results

1.
2.
3.