Microwave Engineering

Microwave Filters

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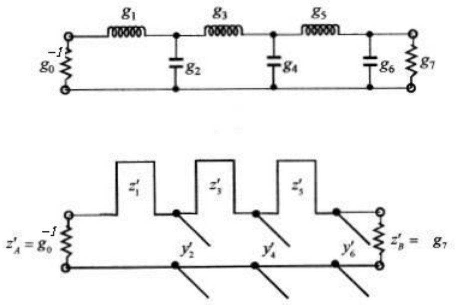
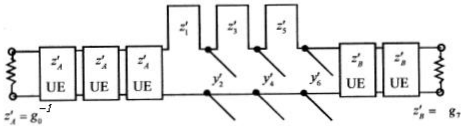
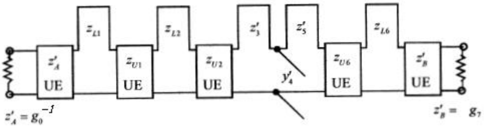
Topics Discussed

- Richard Transformation.
- Kuroda's Identities.
- Low Pass Filter Design using Stubs.

- $\Omega = 1 \quad \Rightarrow \quad$ stub lengths $\ell = \lambda_g/8$.
- A unity filter impedance is assumed.







- Odd number of UE's are added before the series stub, while even number of UE's are added before parallel stub.
- Total Number of UE's used on both sides is $N-1$, where N is the number of stubs used in the circuit.
- Finally we end up with parallel open circuits cascaded alternatively with UE's.

Example 8.5 (Pozar)

Design a low-pass filter for fabrication using microstrip lines. The specification are; cutoff frequency of 4 GHz, third order, impedance of 50 Ω, and a 3 dB equal-ripple characteristic.

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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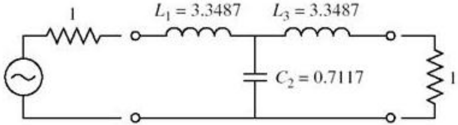
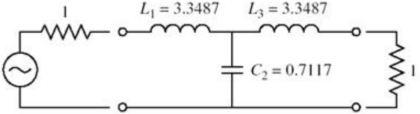
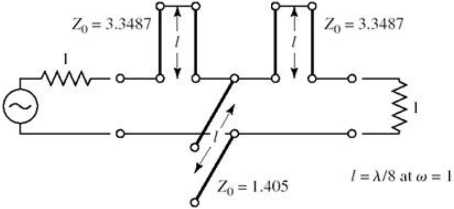




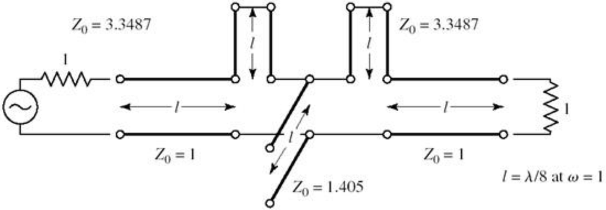
1
L1 = 3.3487
L3 = 3.3487
C2 = 0.7117
1

(a)



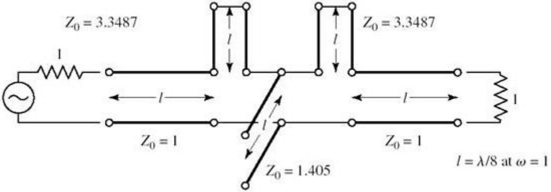
Z0 = 3.3487
Z0 = 3.3487
1
l
l
1
l
Z0 = 1.405
l = λ/8 at ω = 1

(b)

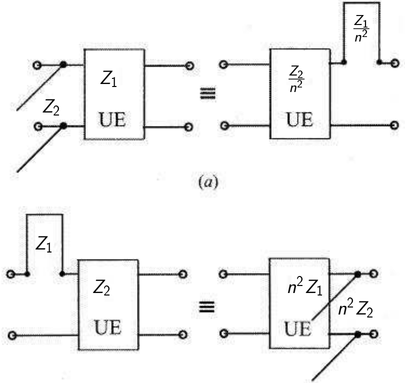


Z0 = 3.3487
Z0 = 3.3487
1
l
l
l
l
1
l
Z0 = 1
Z0 = 1
Z0 = 1.405
l = λ/8 at ω = 1

(c)

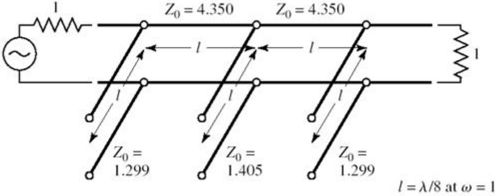


To convert series stubs into parallel stubs we use the first two Kuroda's identities, where $n^2 = 1 + Z_2/Z_1$.

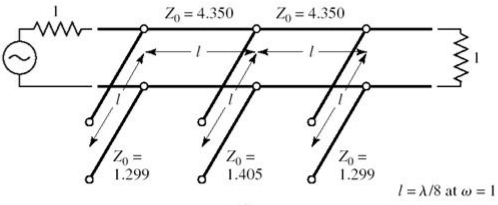


(a)

(b)



$$n^2 = 1 + \frac{Z_2}{Z_1} = 1 + \frac{1}{3.3487} = 1.299$$



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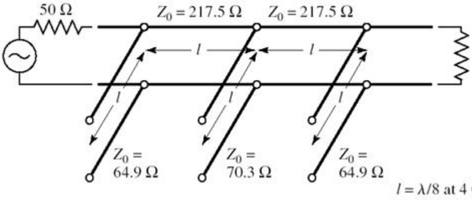
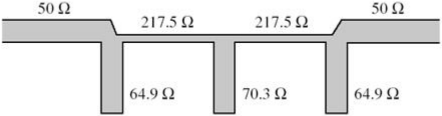
- Making Impedance scaling with $Z_0 = 50\,\Omega$ (figure (e)).
- Figure (f) show the realization using microstrip transmission lines.

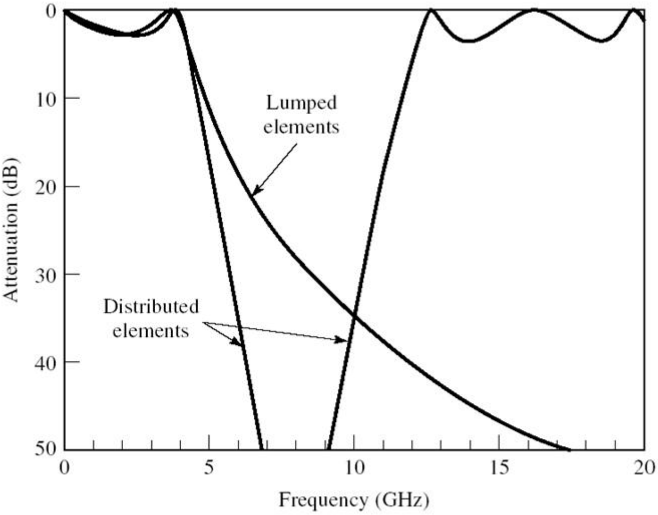


(e)



(f)

Amplitude responses of lumped-element and distributed-element low-pas filter of Example 8.5.

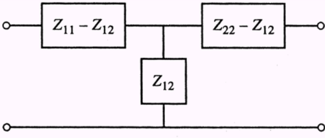


The $ABCD$ matrix for a TL with length ℓ,

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \cos(\beta\ell) & jZ_0 \sin(\beta\ell) \\ j\sin(\beta\ell)/Z_0 & \cos(\beta\ell) \end{bmatrix}$$

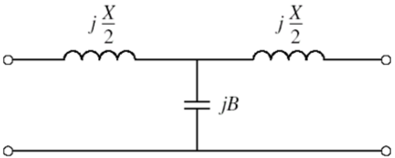
Transforming into Z matrix,

$$\begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} = \begin{bmatrix} -jZ_0 \cot(\beta\ell) & -jZ_0 \csc(\beta\ell) \\ -jZ_0 \csc(\beta\ell) & -jZ_0 \cot(\beta\ell) \end{bmatrix}$$



Series elemnets of the $\quad Z_{11} - Z_{12} = -jZ_0 \left[\dfrac{\cos(\beta\ell) - 1}{\sin(\beta\ell)}\right] = jZ_0 \tan\left(\dfrac{\beta\ell}{2}\right)$

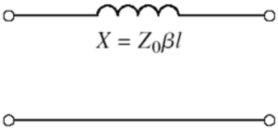
- If $\beta\ell < \pi/2$ the series arms act as inductors, while shunt arm Z_{12} acts as capacitor.



$$\frac{X}{2} = Z_0 \tan\left(\frac{\beta\ell}{2}\right), \qquad B = \sin(\beta\ell)/Z_0$$

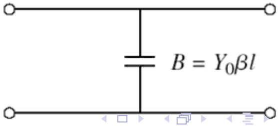
- For short line length ($\beta\ell < \pi/4$) and large characteristic impedance,

$$\left.\begin{array}{c} X \simeq Z_0\beta\ell \\ B \simeq 0 \end{array}\right\} \Longrightarrow$$



- For short line length ($\beta\ell < \pi/4$) and small characteristic impedance,

$$\left.\begin{array}{c} X \simeq 0 \\ B \simeq Y_0\beta\ell \end{array}\right\} \Longrightarrow$$



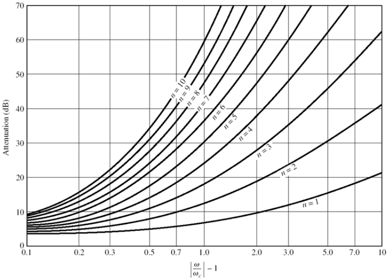
- To realize series inductance, a high impedance line Z_h is used.
- To realize shunt capacitance , a low impedance line Z_ℓ is used.
- Z_h/Z_ℓ should be as high as possible. Z_h and Z_ℓ are usually set the highest and lowest characteristic impedance that can be fabricated.
- After impedance scaling with reference impedance R_0, the electrical lengths at the desired cutoff frequency ω_c,

$$\beta\ell = \frac{LR_0}{Z_h} \qquad \text{(inductor)}$$

$$\beta\ell = \frac{CZ_\ell}{R_0} \qquad \text{(capacitor)}$$

(Example 8.6 Pozar) 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 necessary 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.



$$\frac{\omega}{\omega_c} - 1 = \frac{4}{2.5} - 1 = 0.6 \quad \Rightarrow \quad N = 6 \text{ gives the required attenuation at 4 GHz.}$$

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

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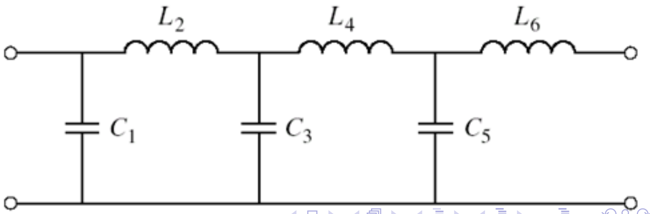
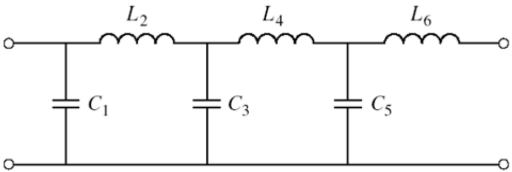
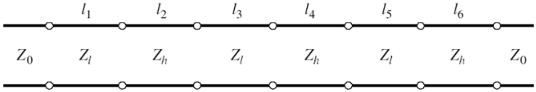
$C_1 = g_1 = 0.5176$
$L_2 = g_2 = 1.4142$
$C_3 = g_3 = 1.9318$
$L_4 = g_4 = 1.9318$
$C_5 = g_5 = 1.4142$
$L_6 = g_6 = 0.5176$



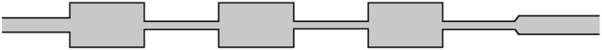
$C_1 = g_1 = 0.5176$
$L_2 = g_2 = 1.4142$
$C_3 = g_3 = 1.9318$
$L_4 = g_4 = 1.9318$
$C_5 = g_5 = 1.4142$
$L_6 = g_6 = 0.5176$

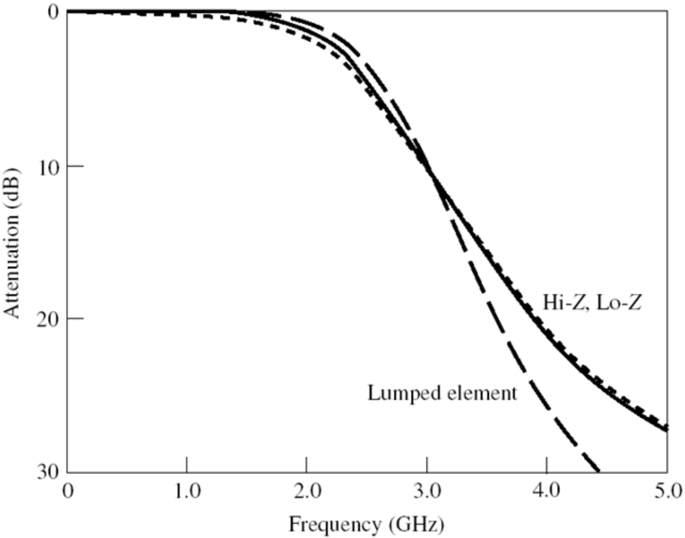


section	$Z_i = Z_\ell,$ or Z_h	$\beta\ell_i$	section	$Z_i = Z_\ell,$ or Z_h	$\beta\ell_i$
1	20 Ω	11.8°	4	120 Ω	46.1°
2	120 Ω	33.8°	5	20 Ω	32.4°
3	20 Ω	44.3°	6	120 Ω	12.3°



(b)





Amplitude response of the stepped-impedance low-pass filter of Example 8.6, with (dotted line) and without (solid line) losses. The response of the corresponding lumped-element filter is also shown.