8.13 Design a low-pass, fourth-order, maximally flat filter using only shunt stubs. The cutoff frequency is 8 GHz and the impedance is 50 Ω. Use CAD to plot the insertion loss versus frequency.

a) Find and make fully-labeled sketch of low-pass filter prototype circuit (use form shown in Fig. 8.25b with Thevenin equivalent source). b) Use Richards' Transformation to implement low-pass filter prototype using stubs and draw fully-labeled sketch of resulting circuit. c) Add unit element to the lefthand side, sketch resulting circuit, apply Kuroda identity, & sketch resulting circuit. d) Add a unit element to the righthand side by load, sketch resulting circuit, apply Kuroda identity, & sketch resulting circuit. e) Add a unit element to the righthand side by load (again), sketch resulting circuit, apply Kuroda identity to each of the two resulting short-circuit stub & unit element combinations, and sketch resulting circuit. [Normalized design should now only have shunt open-circuit stubs.] f) Scale all impedances to a 50 Ω system and draw a fully-labeled sketch of final design. For all steps, the lengths ℓ may be left in terms of λ at f_c. CAD part is not required.

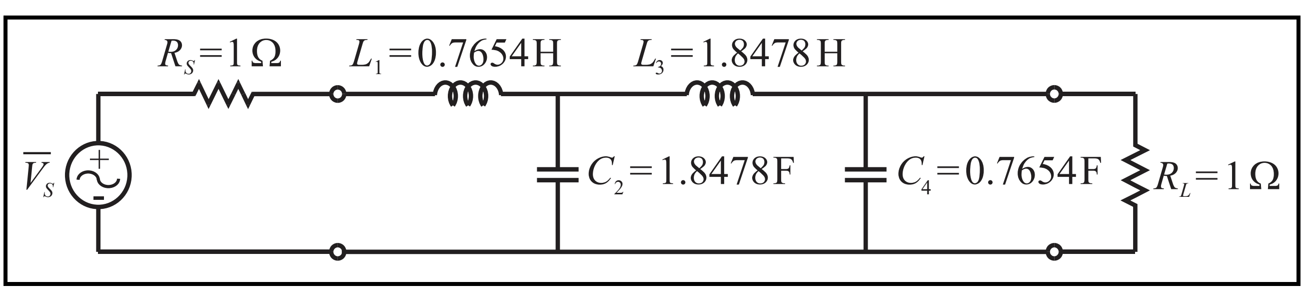
a) From Table 8.3, the immittances are **$g_1 = g_4 = 0.7654$**, **$g_2 = g_3 = 1.8478$**, & **$g_0 = g_5 = 1$** (matched).

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

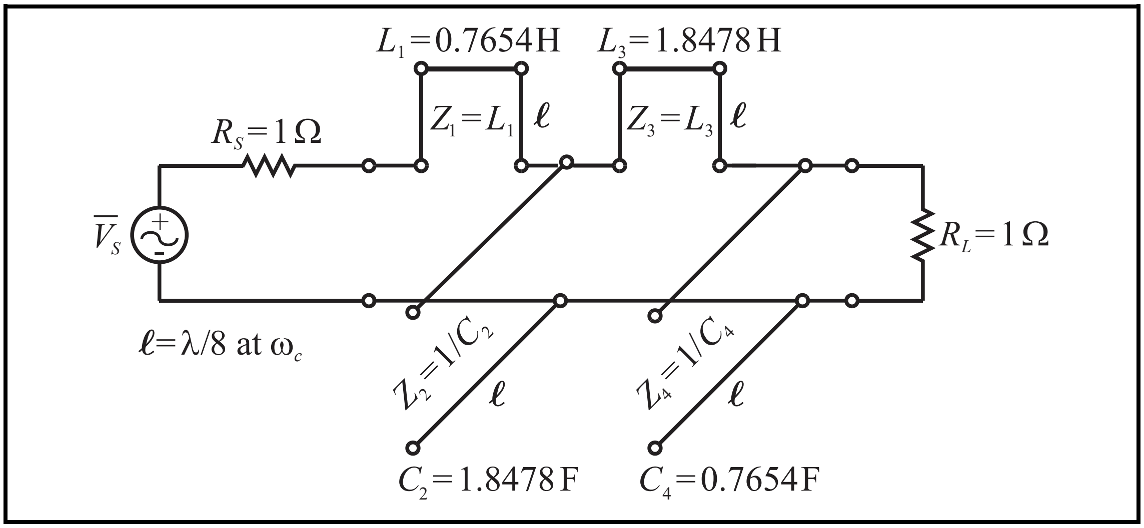
N	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}
1	2.0000	1.0000									
2	1.4142	1.4142	1.0000								
3	1.0000	2.0000	1.0000	1.0000							
4	0.7654	1.8478	1.8478	0.7654	1.0000						
5	0.6180	1.6180	2.0000	1.6180	0.6180	1.0000					
6	0.5176	1.4142	1.9318	1.9318	1.4142	0.5176	1.0000				
7	0.4450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

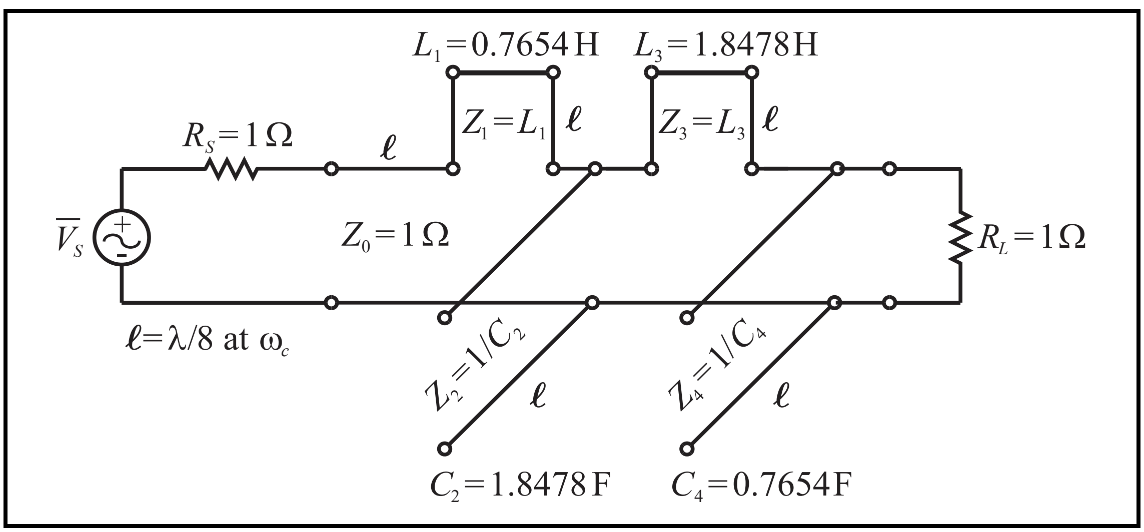
➢ For the filter architecture of Fig 8.25b, we get a LP prototype:



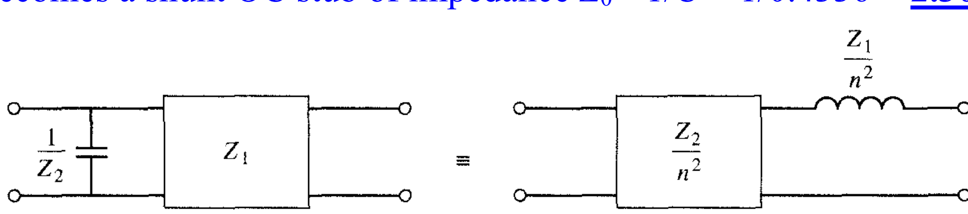
b) Using Richards' transformation (Fig. 8.34), we make the series inductors into series short circuit stubs & shunt capacitors into shunt open circuit stubs, both of length $\ell = \lambda/8$ @ ω_c.



c) Add unit element to the lefthand side, sketch resulting circuit, apply Kuroda identity, & sketch resulting circuit.

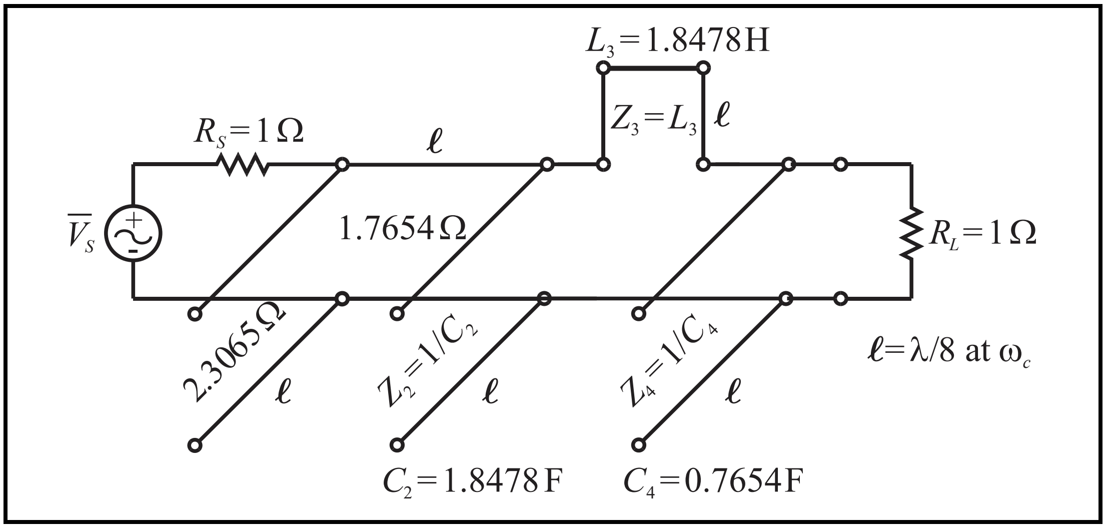


- For LH unit element w/ series inductive SC stub combination, use Kuroda identity (a), let $Z_1/n^2 = 0.7654\ \Omega$, $Z_2/n^2 = 1\ \Omega$, and $n^2 = 1 + Z_2/Z_1 = 1 + 1/0.7654 = 2.3065$. Therefore, we will get a TL section with impedance $Z_1 = n^2(Z_1/n^2) = 2.3065(0.7654) =$ **1.7654 Ω** and a shunt capacitor of $1/Z_2 = 1/[n^2\ (Z_2/n^2)] = 1/(2.3065*1) = 0.4336$ F. In turn, this shunt capacitor becomes a shunt OC stub of impedance $Z_0 = 1/C = 1/0.4336 =$ **2.3065 Ω**.

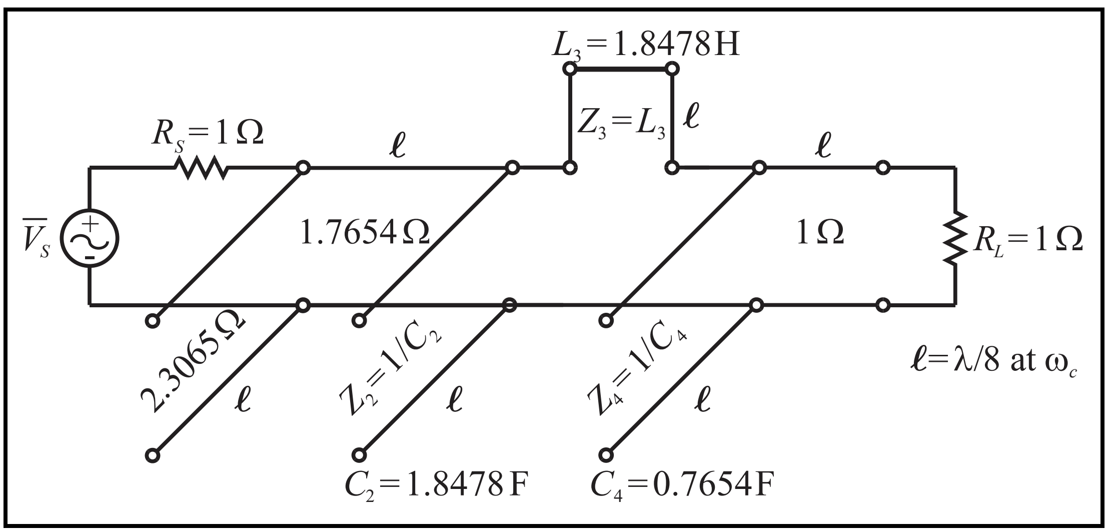


(a)

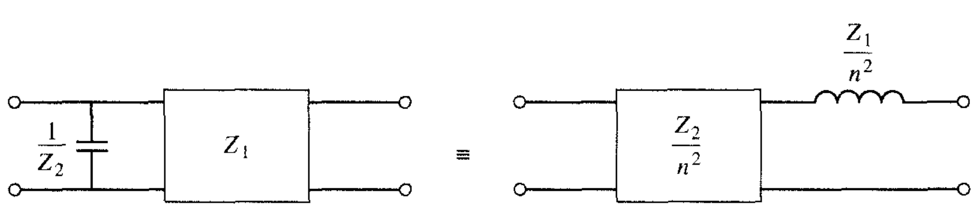
➢ This results in the circuit:



d) Add a unit element to the righthand side by load, sketch resulting circuit, apply Kuroda identity, & sketch resulting circuit.

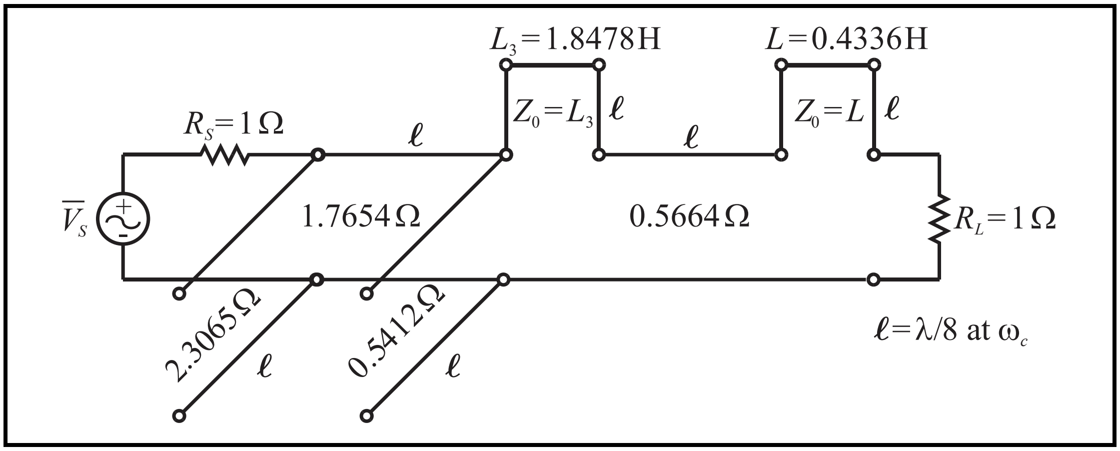


➢ For the RH shunt capacitive OC stub ($C_4 = 1/Z_4 = 0.7654$ F) w/ 1 Ω unit element combination, let $C_4 = 1/Z_2 = 0.7654$ F, $Z_1 = 1\,\Omega$, and $n^2 = 1 + Z_2/Z_1 = 1 + 0.7654^{-1}/1 = 2.3065$ for Kuroda identity (a). Therefore, we will get a TL section with impedance $Z_2/n^2 = 0.7654^{-1}/2.3065 =$ **0.5664 Ω** and a series inductor of $L = Z_1/n^2 = 1/2.3065 = 0.4336$ H. In turn, this series inductor becomes a series SC stub of impedance $Z_0 = L =$ **0.4336 Ω**.

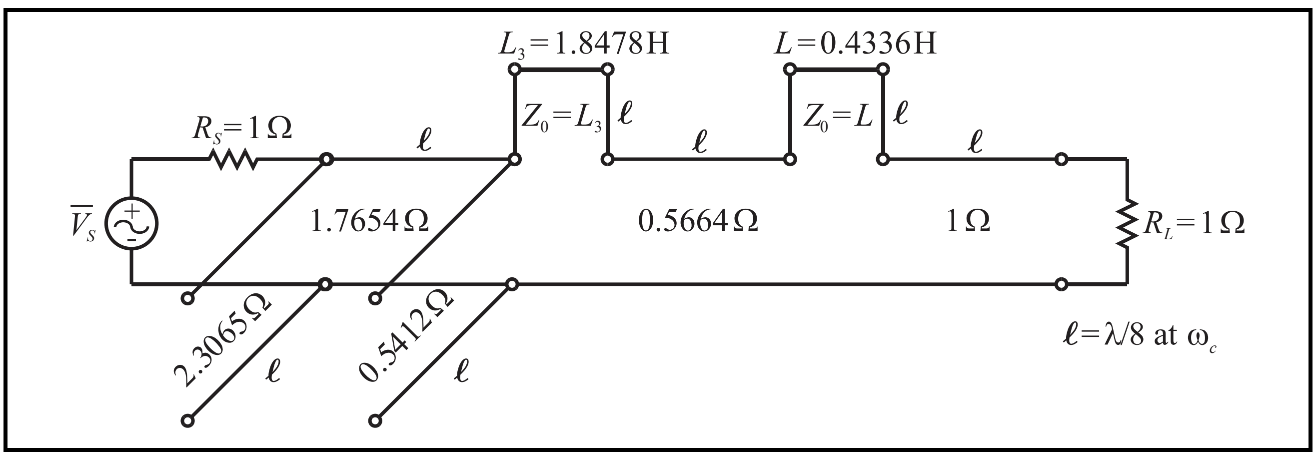


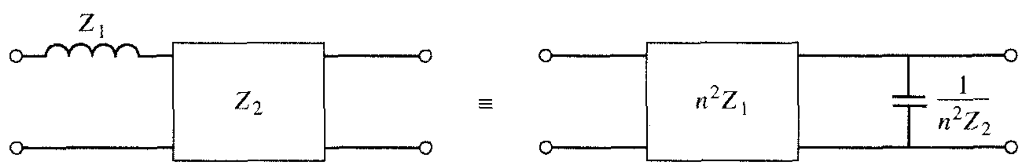
(a)

- This results in the circuit:



e) Add a unit element to the righthand side by load (again), sketch resulting circuit, apply Kuroda identity (b) to each of the two resulting short-circuit stub & unit element combinations, and sketch resulting circuit.



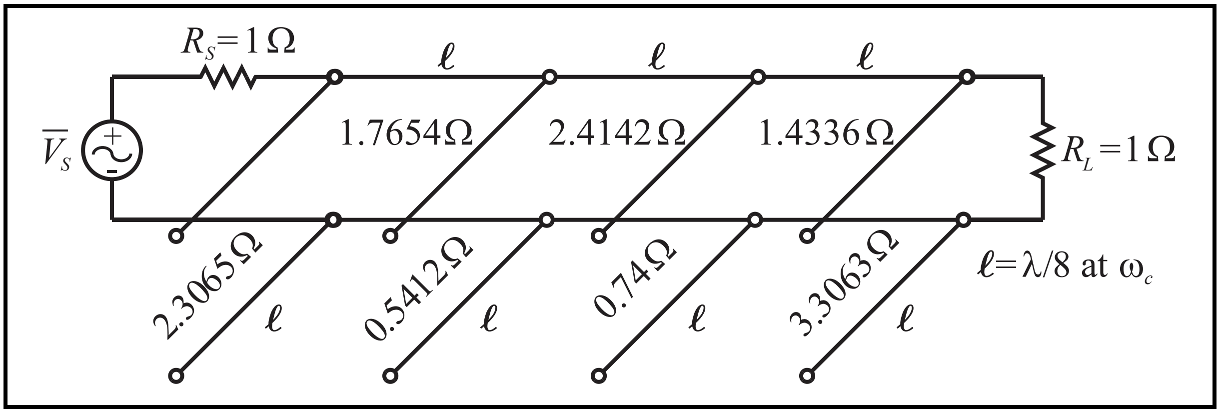


(b)

- For middle series inductive SC stub (L_3 = Z_0 = 1.8478 Ω) w/ 0.5664 Ω unit element combination, use Kuroda identity (b) with Z_1 = 1.8478 H, Z_2 = 0.5664 Ω, & $n^2 = 1 + Z_2/Z_1 = 1 + 0.5664/1.8478 = 1.3065$. Therefore, we get a TL section with impedance n^2Z_1 = 1.3065(1.8478) = **2.4142 Ω** and shunt capacitor $1/(n^2Z_2)$ = 1/(1.3065*0.5664) = 1.3513 F. This shunt capacitor becomes a shunt OC stub of impedance $Z_0 = 1/C$ = 1/1.3513 = **0.7400 Ω**.

- For RH series inductive SC stub ($L = Z_0$ = 0.4336 Ω) w/ 1 Ω unit element combination, use Kuroda identity (b) with Z_1 = 0.4336 H, Z_2 = 1 Ω, & $n^2 = 1 + Z_2/Z_1 = 1 + 1/0.4336 = 3.3063$. Therefore, we get a TL section w/ impedance n^2Z_1 = 3.3063(0.4336) = **1.4336 Ω** and shunt capacitor of $1/(n^2Z_2)$ = 1/(3.3063*1) = 0.30245 F. In turn, this shunt capacitor becomes a shunt OC stub of impedance $Z_0 = 1/C$ = 1/0.30245 = **3.3063 Ω**.

➢ This results in the circuit:



f) Scale all impedances to a 50 Ω system and draw a fully-labeled sketch of final design.

➢ Multiply all impedances by 50 to impedance scale. Added 50 Ω sections (no specified length) at both ends for connectivity.