a) Design a 4th-order, lumped-element, linear phase low-pass filter prototype using the architecture of Fig. 8.25b with a Thevenin equivalent source and draw a fully-labeled sketch. 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 (LH) side, sketch resulting circuit, apply a Kuroda identity to convert the LH series stub to a shunt stub, & sketch resulting circuit. d) Add a unit element to the righthand (RH) side by load, sketch resulting circuit, apply a Kuroda identity to convert the RH shunt stub to a series stub, & sketch resulting circuit. e) Add a unit element to the RH side by load (again), sketch resulting circuit, apply a Kuroda identity to each of the two short-circuit series stub & unit element combinations to convert them to shunt stubs, and sketch resulting circuit. [Note: 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 the final design [add 50 Ω sections (no specified length) at both ends for connectivity]. For all steps, lengths ℓ may be left in terms of λ at f_c.

a) From Table 8.5, the immittances are-

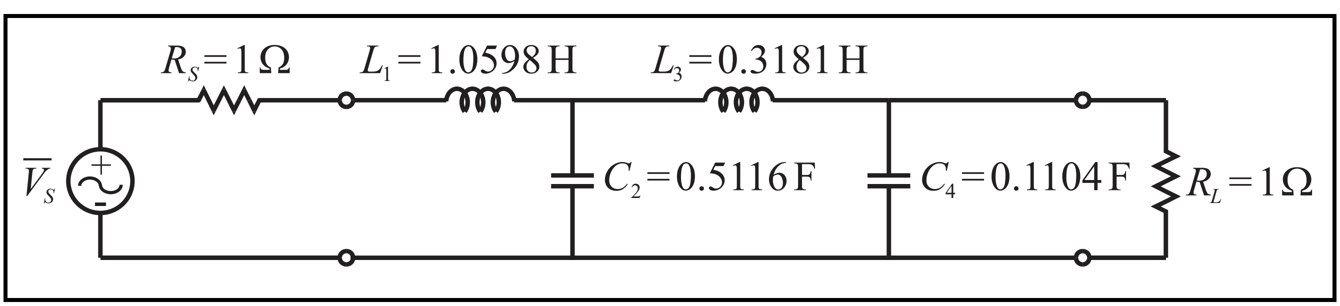
$g_0 = 1$ (matched), **$g_1 = 1.0598$**, **$g_2 = 0.5116$**, **$g_3 = 0.3181$**, **$g_4 = 0.1104$**, & **$g_5 = 1$** (matched).

TABLE 8.5 Element Values for Maximally Flat Time Delay Low-Pass Filter Prototypes ($g_0 = 1$, $\omega_c = 1$, $N = 1$ to 10)

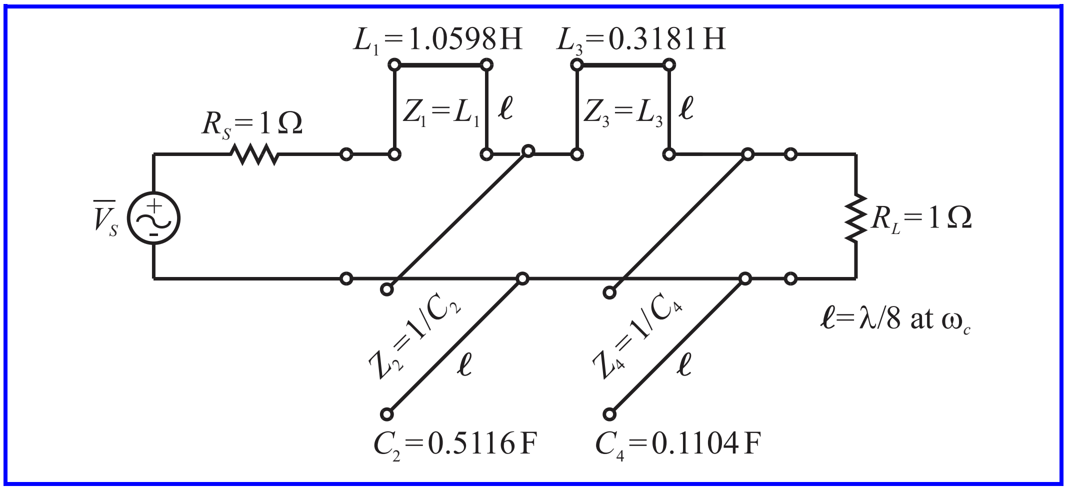
N	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}
1	2.0000	1.0000									
2	1.5774	0.4226	1.0000								
3	1.2550	0.5528	0.1922	1.0000							
4	1.0598	0.5116	0.3181	0.1104	1.0000						
5	0.9303	0.4577	0.3312	0.2090	0.0718	1.0000					
6	0.8377	0.4116	0.3158	0.2364	0.1480	0.0505	1.0000				
7	0.7677	0.3744	0.2944	0.2378	0.1778	0.1104	0.0375	1.0000			
8	0.7125	0.3446	0.2735	0.2297	0.1867	0.1387	0.0855	0.0289	1.0000		
9	0.6678	0.3203	0.2547	0.2184	0.1859	0.1506	0.1111	0.0682	0.0230	1.0000	
10	0.6305	0.3002	0.2384	0.2066	0.1808	0.1539	0.1240	0.0911	0.0557	0.0187	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.

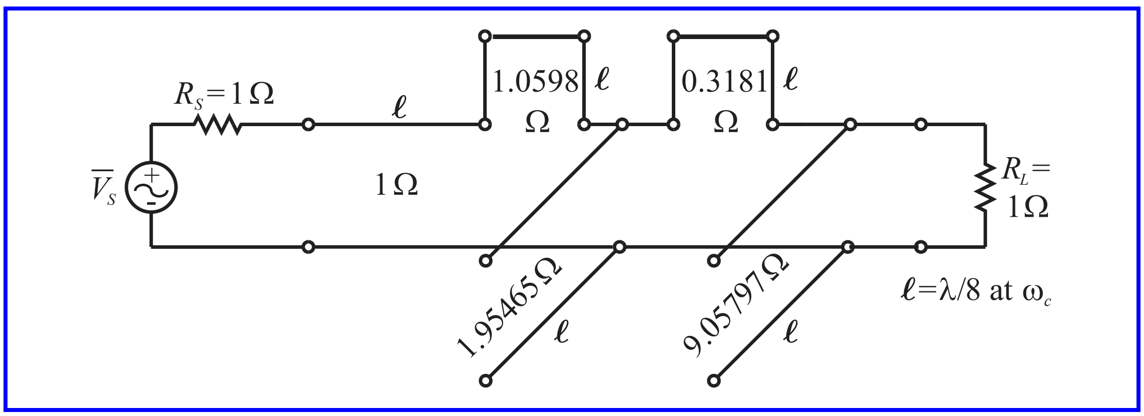
For the filter architecture of Fig 8.25b, we get a LPF prototype:



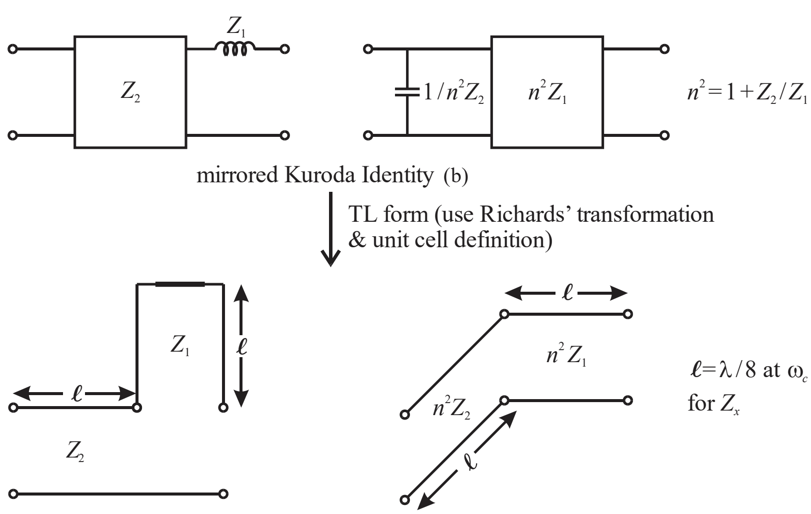
b) Using Richards' transformation (Fig. 8.34), the series inductors become series short circuit stubs & shunt capacitors become shunt open circuit stubs, all of length $\ell = \lambda/8$ at ω_c.



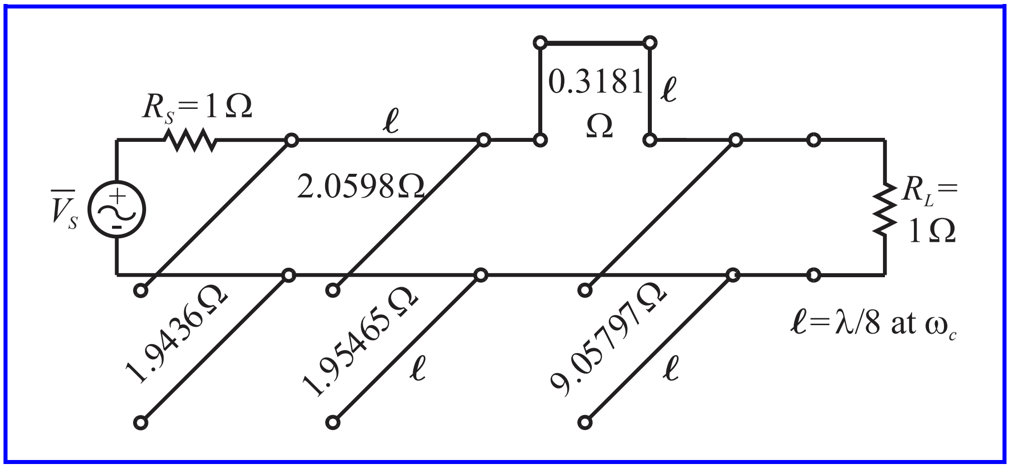
c) Add a matched (1 Ω) unit element to the left side, sketch resulting circuit …



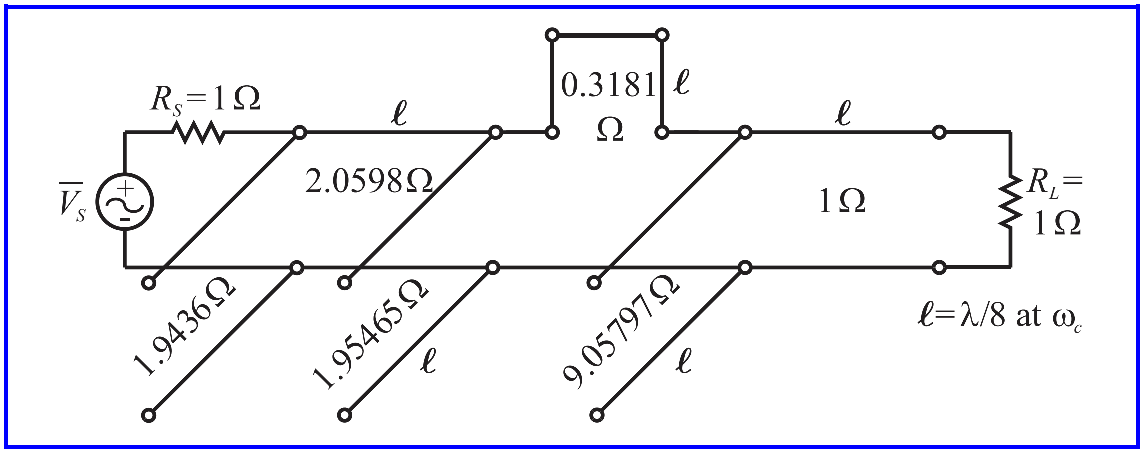
For LH unit element w/ series inductive SC stub combination, use mirrored Kuroda identity (b), shown below, where $Z_2 = 1\ \Omega$, $Z_1 = 1.0598\ \Omega$, and $n^2 = 1 + Z_2/Z_1 = 1 + 1/1.0598 = 1.94357$. Here, the shunt OC stub has impedance $n^2 Z_2 = 1.94357(1)$ = **1.94357 Ω** and the unit cell has impedance $n^2 Z_1 = 1.94357(1.0598)$ = **2.0598 Ω**.



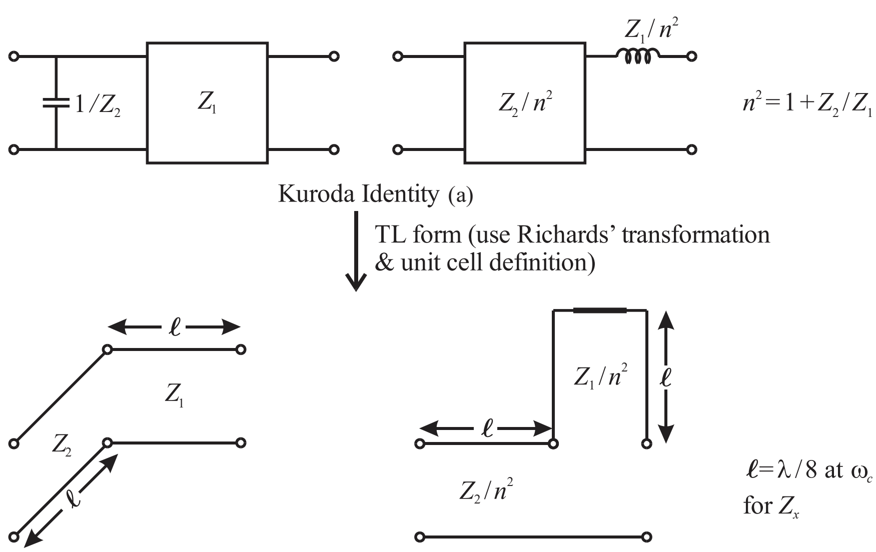
sketch resulting circuit



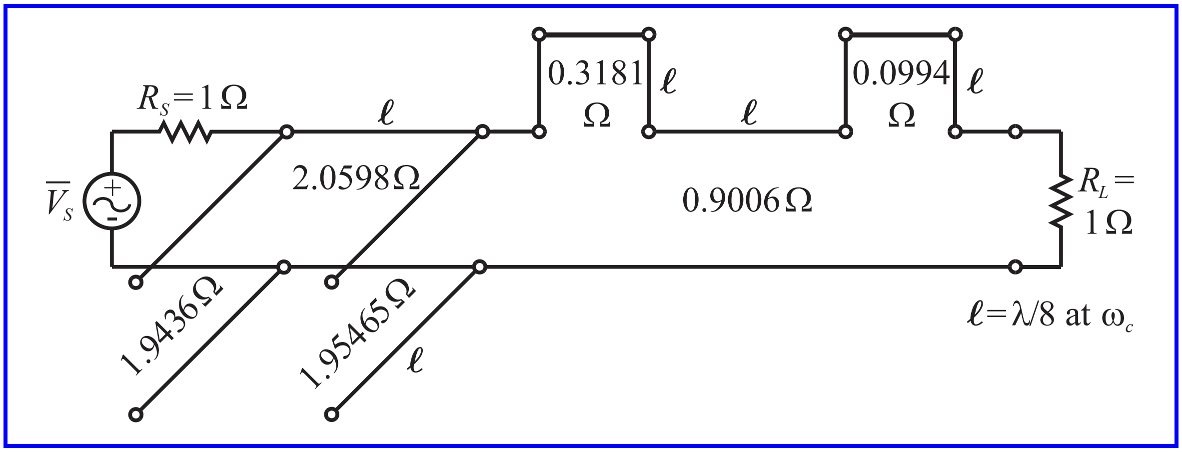
d) Add a unit element to the righthand (RH) side by load, sketch resulting circuit …



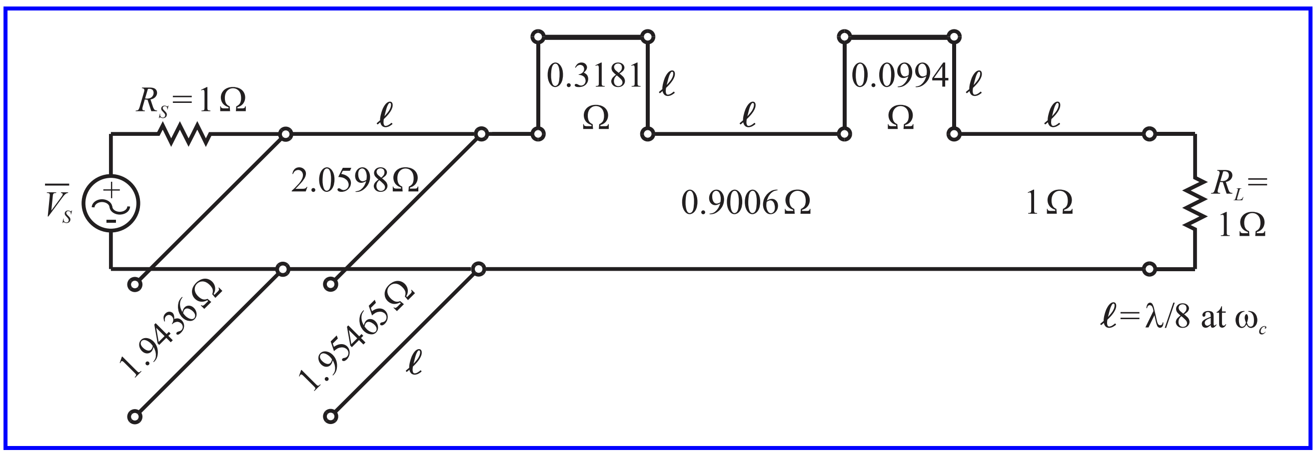
For RH unit element w/ shunt capacitive OC stub combination, use Kuroda identity (a), shown below, where $Z_1 = 1\ \Omega$, $Z_2 = 1/0.1104 = 9.05797\ \Omega$, and $n^2 = 1 + Z_2/Z_1 = 1 + 9.05797/1 = 10.05797$. Here, the series SC stub has impedance $Z_1 / n^2 = 1/10.058 =$ **0.0994236 Ω** and the unit cell has impedance $Z_2 / n^2 = 9.05797/10.05797 =$ **0.900576 Ω**.



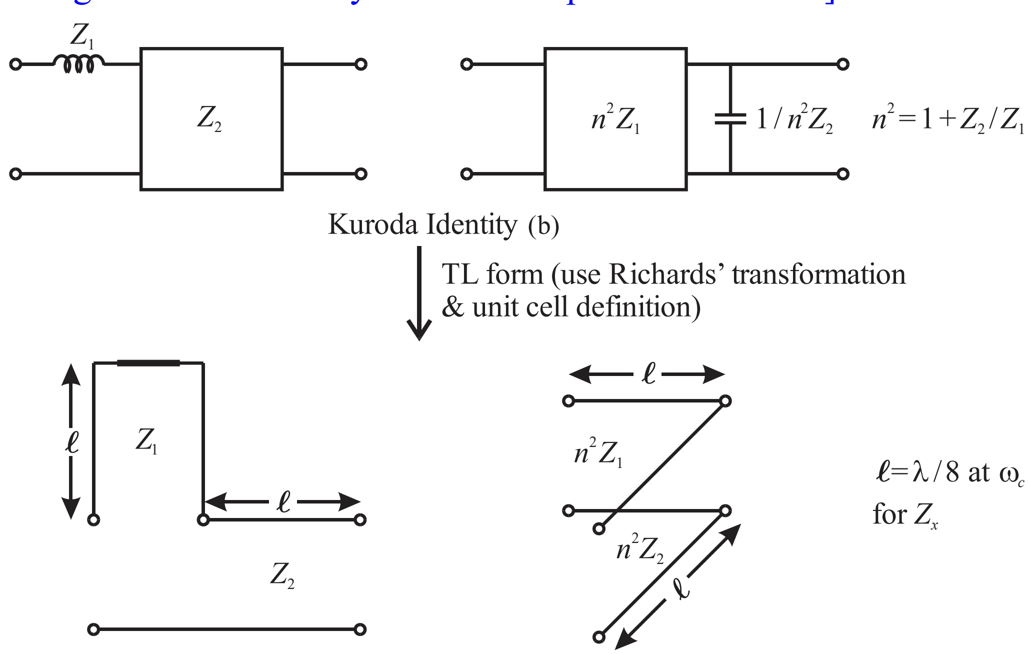
This results in the circuit:



e) Add a unit element to the RH side by load (again), sketch resulting circuit …



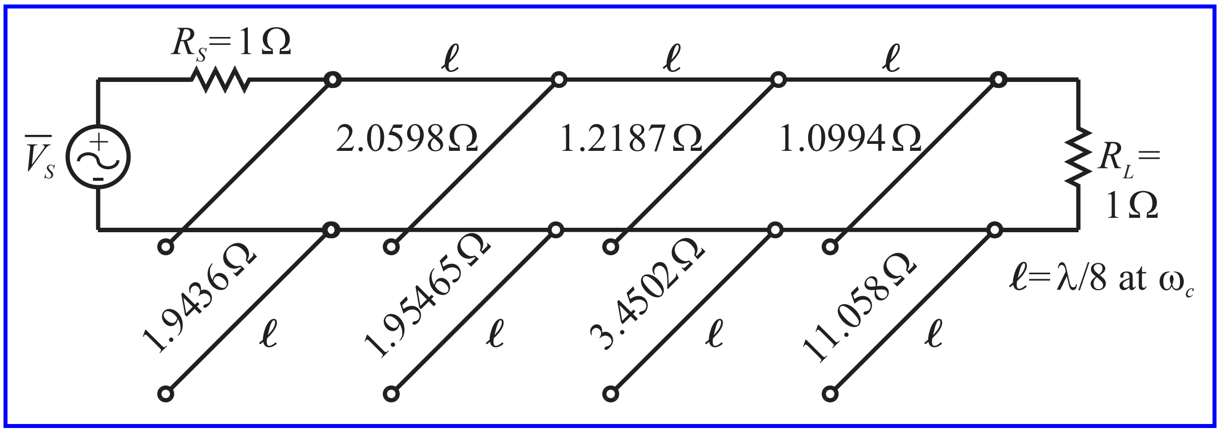
Apply Kuroda identity (b), shown below, to each of the two short-circuit series stub & unit element combinations to convert them to shunt stubs, and sketch resulting circuit. [Note: Normalized design should now only have shunt open-circuit stubs.]



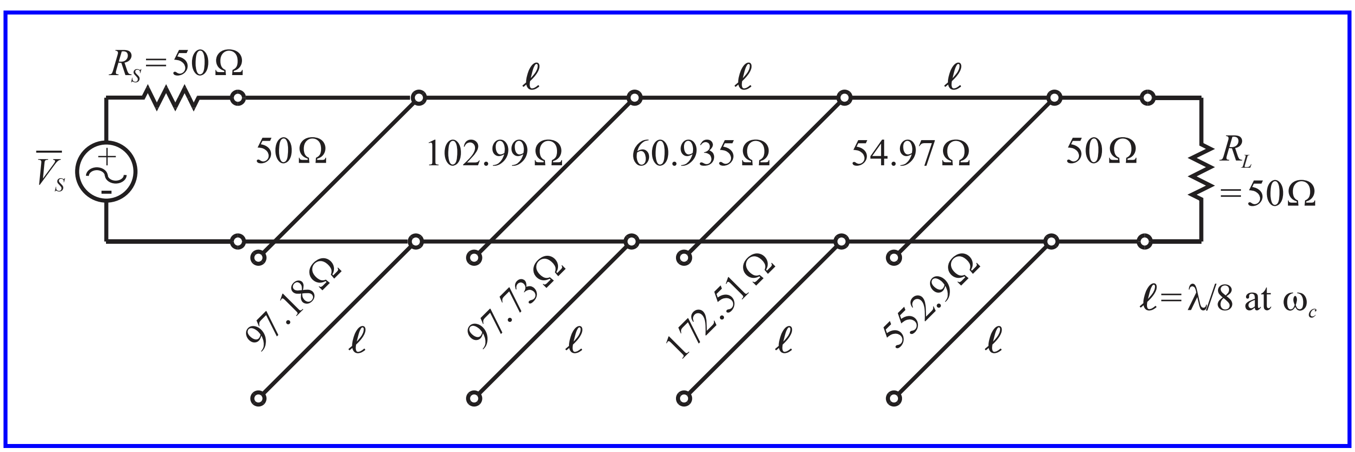
For the middle series inductive SC stub ($Z_1 = 0.3181\ \Omega$) with $Z_2 = 0.900576\ \Omega$ unit element combination, $n^2 = 1 + Z_2/Z_1 = 1 + 0.900576/0.3181 = 3.83111$. Therefore, we get a unit cell TL section with impedance $n^2 Z_1 = 3.83111(0.3181) =$ **1.21868 Ω** and a shunt OC stub of impedance $n^2 Z_2 = 3.83111(0.900576) =$ **3.4502 Ω**.

For the right series inductive SC stub ($Z_1 = 0.0994236\ \Omega$) with $Z_2 = 1\ \Omega$ unit element combination, $n^2 = 1 + Z_2/Z_1 = 1 + 1/0.0994236 = 11.05797$. Therefore, we get a unit cell TL section with impedance $n^2 Z_1 = 11.05797(0.0994236) =$ **1.0994 Ω** and a shunt OC stub of impedance $n^2 Z_2 = 11.05797(1) =$ **11.0580 Ω**.

This results in the circuit:



f) Scale all impedances to a 50 Ω system and draw a fully-labeled sketch of the final design [add 50 Ω sections (no specified length) at both ends for connectivity].



➢ **The last 553 Ω OC stub is NOT practical, and the 172.5 Ω OC stub is borderline.**