EE 481/581 Microwave Engineering Examination #3 (Fall 2024)

Name Key

Instructions: Place answers in indicated spaces, use notation as given in class, and show/explain all work (including that on design figures/tables) for credit. Turn-in equation sheet(s) with exam.

1) For a 75 Ω system connected port 1, design a Wilkinson power divider to operate at 1.499 GHz where 3/5 of the power input into Port 1 goes to Port 2 and 2/5 of the power input into Port 1 goes to Port 3. First, assuming all the transmission lines use an air dielectric, find the phase velocity and wavelength. Then, find and fill-in all values indicated on the figure.

For air dielectric, $v_p = c = 2.9979 \times 10^8$ m/s

$\lambda = c/f = \frac{2.9979\times10^8}{1.499\times10^9} = 0.2000$ m

p. 332, $K^2 = P_3/P_2 = \frac{0.4P_1}{0.6P_1} = 2/3 = 0.\overline{66} \Rightarrow K = 0.8165$

(7.37a) $Z_{03} = Z_0\sqrt{\frac{1+K^2}{K^3}} = 75\sqrt{\frac{1+2/3}{0.8165^3}} = 131.2363\,\Omega$

(7.37b) $Z_{02} = K^2 Z_{03} = 2/3(131.2363) = 87.4909\,\Omega$

(7.37c) $R = Z_0(K + \frac{1}{K}) = 75(0.8165 + \frac{1}{0.8165}) = 153.0931\,\Omega$

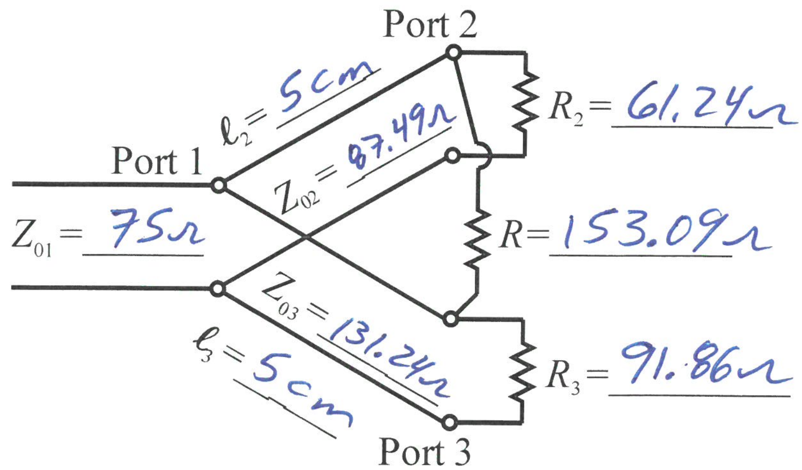
Per Fig 7.8, the arm lengths are $\lambda/4 \Rightarrow \ell_2 = \ell_3 = \frac{0.2}{4} = 0.05$ m

Per Fig 7.13, $Z_{01} = Z_0 = 75\,\Omega$

$R_2 = Z_0 K = 75(0.8165) = 61.2372\,\Omega$

$R_3 = Z_0/K = 75/0.8165 = 91.855865\,\Omega$

phase velocity = 2.9979×10^8 m/s wavelength = 0.2 m

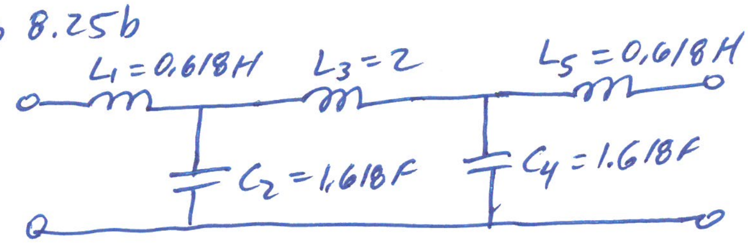


2) Design the lowest-order, maximally flat, lumped-element, **high-pass filter** (HPF) with a cutoff frequency of 2 GHz having at least 28 dB of attenuation at 1 GHz for use in a 75 Ω system. First, determine the order N and the low-pass prototype immittance values g_0 to g_{N+1}. Then, find the component values and draw a fully labeled sketch of the HPF. Minimize the use of inductors in the final design.

For LPF prototype, $\left|\frac{\omega}{\omega_c}\right|-1 = \left|\frac{2}{1}\right|-1 = 1$, Plot on Fig 8.26 along w/ 28 dB attenuation. Need $N=5$,

Per HPF transformation L→C and C→L. To minimize inductors in HPF, choose LPF architecture of Fig 8.25b

LPF



$R_0 = 75\,\Omega$ & $\omega_c = 2\pi(2\times10^9)$ rad/s

N= 5

immittances: $g_0=1$, $g_1=0.618$, $g_2=1.618$, $g_3=2$, $g_4=1.618$, $g_5=0.618$ & $g_6=1$

Per (8.70a), the series capacitors which replace the series inductors are $C_k' = \frac{1}{R_0\omega_c L_k}$

$$C_1' = C_5' = \frac{1}{75(2\pi)2\times10^9(0.618)} = 1.716882\,pF$$

$$C_3' = \frac{1}{75(2\pi)2\times10^9(2)} = 0.5305165\,pF$$

Per (8.70b), the shunt inductors which replace the shunt capacitors are $L_k' = \frac{R_0}{\omega_c C_k}$

$$L_2' = L_4' = \frac{75}{2\pi(2\times10^9)(1.618)} = 3.688696\,nH$$

$R_S = R_L = 75(1) = 75\,\Omega$ per (8.64c) & (8.64d)

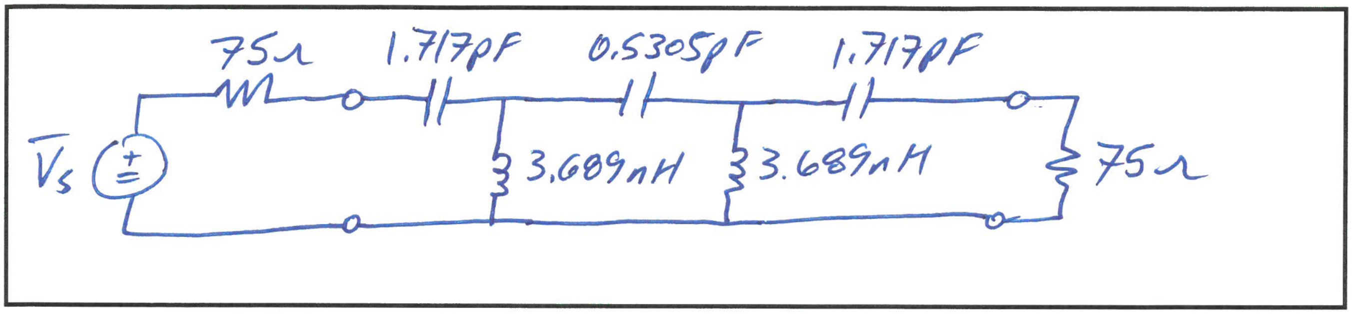


TABLE 8.3 Element Values for Maximally Flat Low-Pass Filter Prototypes ($g_0 = 1$, $\omega_c = 1$, $N = 1$ to 10)

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.

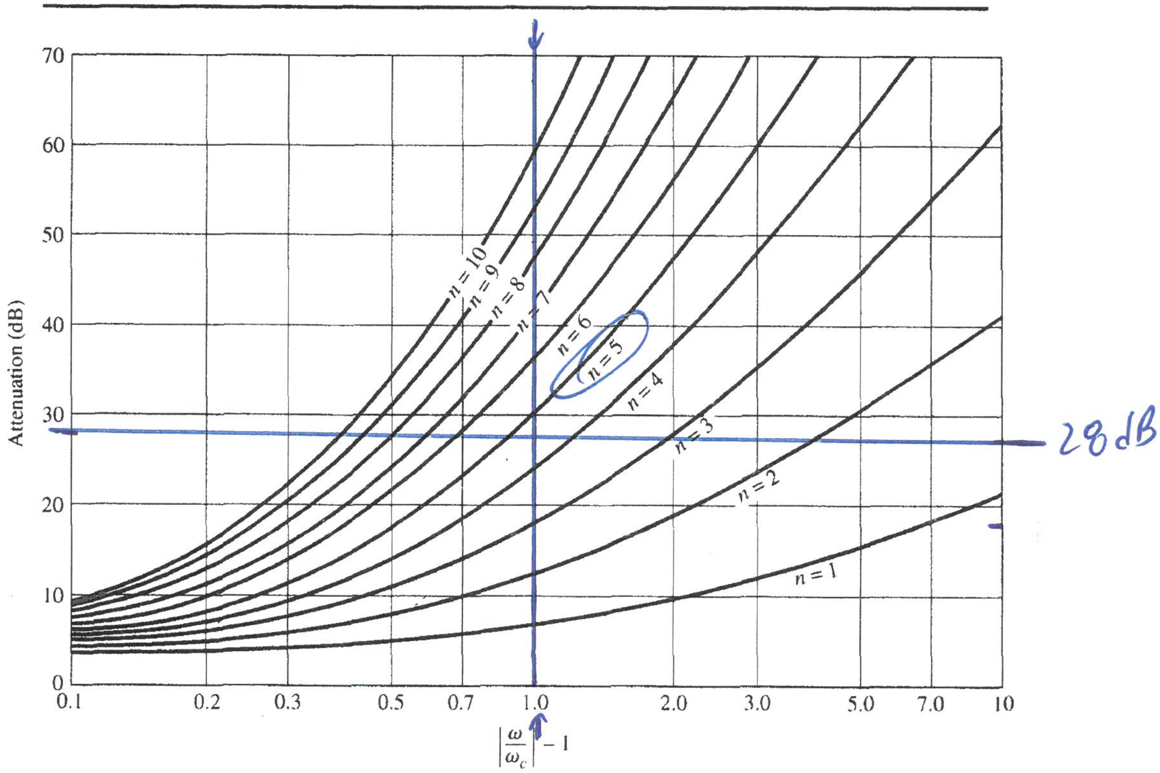


FIGURE 8.26 Attenuation versus normalized frequency for maximally flat filter prototypes.

Adapted 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.

3) A directional coupler has the [*S*]-matrix shown below. In **decibels**, determine the return loss, coupling factor, directivity, isolation, and insertion loss.

$$[S]=\begin{bmatrix} 0.08\angle 16^\circ & 0.96\angle 88^\circ & 0.2\angle 180^\circ & 0.006\angle 90^\circ \\ 0.96\angle 88^\circ & 0.08\angle 16^\circ & 0.006\angle 90^\circ & 0.2\angle 180^\circ \\ 0.2\angle 180^\circ & 0.006\angle 90^\circ & 0.08\angle 16^\circ & 0.96\angle 88^\circ \\ 0.006\angle 90^\circ & 0.2\angle 180^\circ & 0.96\angle 88^\circ & 0.08\angle 16^\circ \end{bmatrix}$$

Per (2.38), $RL = -20\log|\Gamma| = -20\log|S_{11}|$ $S_{11} = 0.08\angle 16^\circ$

$= -20\log(0.08) = 21.9382\text{ dB}$

Coupling (7.20a), $C = -20\log\beta = -20\log|S_{13}|$ $S_{13} = 0.2\angle 180^\circ$

$= -20\log 0.2 = 13.9794\text{ dB}$

Directivity (7.20b), $D = 20\log\frac{\beta}{|S_{14}|} = 20\log\frac{|S_{13}|}{|S_{14}|}$ $S_{14} = 0.006\angle 90^\circ$

$= 20\log\frac{0.2}{0.006} = 30.4576\text{ dB}$

Isolation (7.20c), $I = -20\log|S_{14}|$

$= -20\log 0.006 = 44.4375\text{ dB}$

Insertion loss (7.20d), $IL = -20\log|S_{12}|$ $S_{12} = 0.96\angle 88^\circ$

$= -20\log 0.96 = 0.3546\text{ dB}$

return loss = 21.938 dB   coupling factor = 13.979 dB   directivity = 30.458 dB

isolation = 44.437 dB   insertion loss = 0.355 dB

4) Design a third-order, 0.5 dB equal-ripple, lumped-element, **low-pass filter** prototype using the architecture of Figure 8.25b (use Thevenin equivalent source) and draw a fully labeled sketch in the appropriate box. Then, use Richards's transformation to implement the filter using series/shunt open/short-circuit stubs and draw a fully labeled sketch in the appropriate box. The lengths ℓ may be left in terms of λ at f_c.

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 ripple)

N	g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}
					0.5 dB Ripple						
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

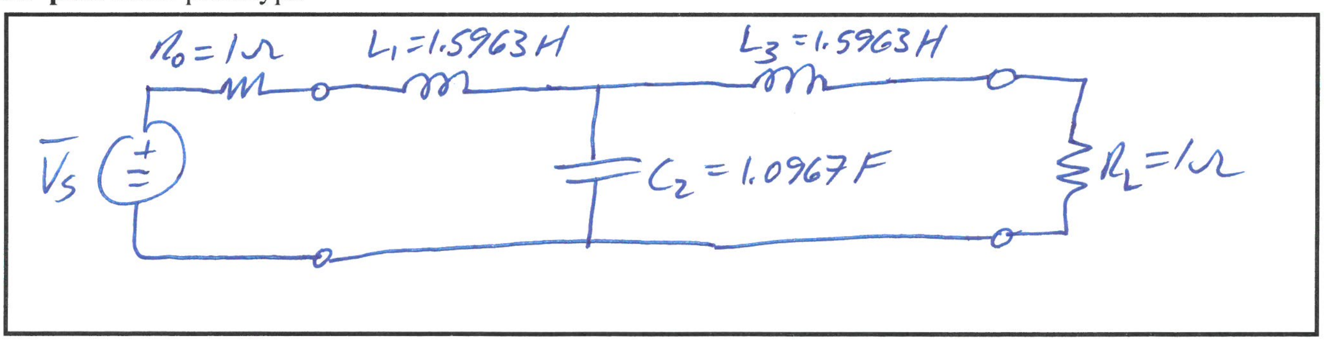
← 3rd order

$L_1 = g_1 = 1.5963\,H$ $\quad R_0 = g_0 = 1\Omega$

$C_2 = g_2 = 1.0967\,F$ $\quad R_L = g_4 = 1\Omega$

$L_3 = g_3 = 1.5963\,H$

low-pass filter prototype

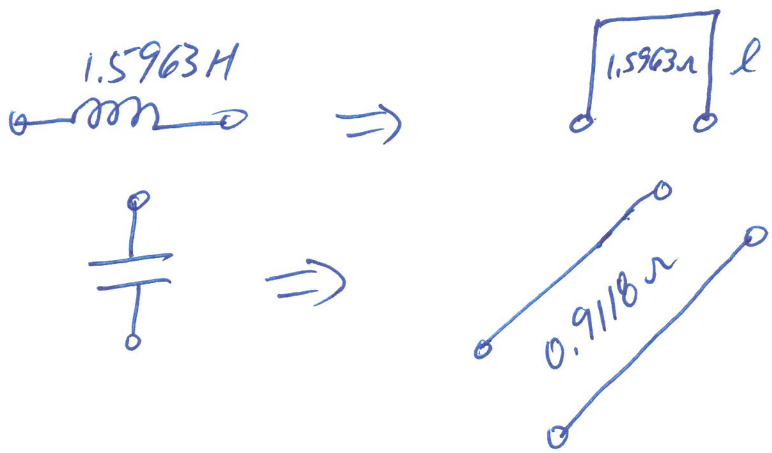


⇒ Not doing any freq. or impedance scaling.

* Per Fig 8.34a), the series inductors become series short-circuit stubs w/ $Z_0 = L$ and length $\ell = \lambda/8$ @ $\omega_c = 1$ rad/s

Here, $Z_0 = L = \underline{1.5963\,\Omega}$

★ Per Fig 8.34b), the shunt capacitor becomes a shunt open-circuit stub w/ $Z_0 = \frac{1}{C}$ and length $\ell = \lambda/8$ @ ω_c. $Z_0 = \frac{1}{1.0967} = 0.911826\Omega$



low-pass filter w/ stubs