

ECEN 452-500: Ultra High Frequency Techniques
Spring 2016 – Prof. Huff
Lab 6

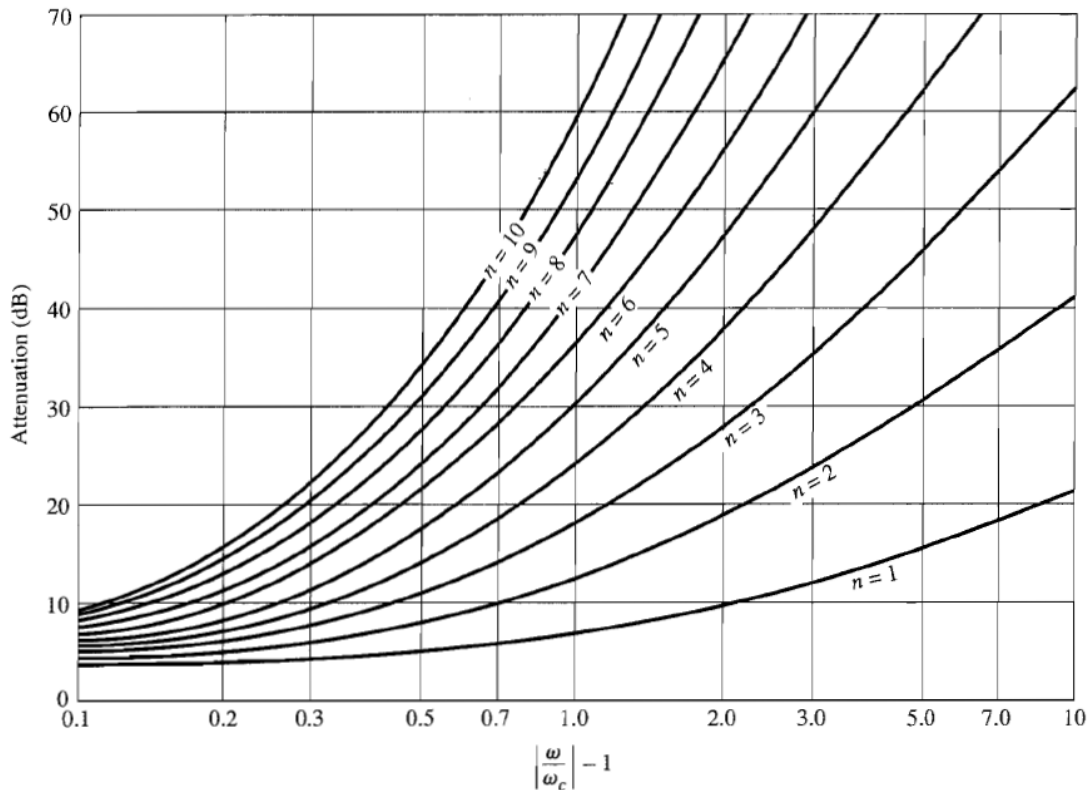
Pull the *Lab 6* subdirectory in the ECEN 452 GitHub directory *Labs* and locate the HFSS project files “*ECEN452_Lab6_Filters.hfss*”. Open each project file (File-Open...), then save them to the local drive of the computer you are running your simulations on and rename it by appending your team number to each file (e.g., “*ECEN452_LabX_TopicY_TeamZ*”).

In this lab you will be completing two designs of a low pass filter and the design of a band stop. These are found in your “*ECEN452_Lab6_Filters_GroupX.hfss*” project file. These design files are named “*N5_MaxFlat_LPF_T-Line*”, “*N5_MaxFlat_LPF_T-Line_Tapped*”, and “*N5_MaxFlat_BSF_T-Line*”. You will be designing these for a $Z_0 = 50\ \Omega$ reference impedance on the 62 mil thick FR4 ($\epsilon_r = 4.1$, $\tan \delta = 0.01$) substrate.

Task 1: Synthesis and implementation of a maximally-flat low-pass filter.

In this exercise you will synthesize a maximally-flat low-pass filter with a cut-off frequency $f_c = 2.5$ GHz and a minimum attenuation of 10 dB at 3.25 GHz.

Step 1: First, calculate the order N of the filter required to meet the specifications of providing 10 dB isolation at 3.25 GHz using $\left| \frac{\omega}{\omega_c} \right| - 1 = \left| \frac{f_{10dB}}{f_c} \right| - 1$ and the figure below.

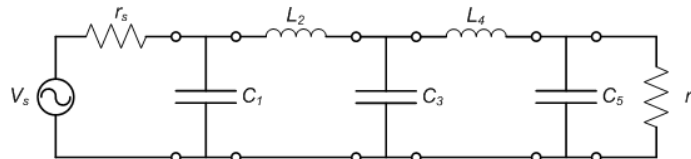


Step 2: Next, use the table on the following page to determine the filter coefficients for the (hint: five-element) low-pass prototype.

Element Values for Butterworth (Maximally Flat) Low-Pass Filter Prototypes
($g_0=1, w_c=1, N=1$ 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

Step 3: Assemble the prototype LC ladder network.



To simplify the analysis (visually), we will replace this ladder network with the table shown below.

Shunt C g_1 0.61803	Series L g_2 1.61803	Shunt C g_3 2.00000	Series L g_4 1.61803	Shunt C g_5 0.61803
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Step 4: Use Richard's Transformation to convert the capacitors into open circuit stubs and the inductors into short circuit stubs.

Shunt OC $z_1=1/g_1$ 1.61804	Series SC $z_2=g_2$ 1.61803	Shunt OC $z_3=1/g_3$ 0.50000	Series SC $z_4=g_4$ 1.61803	Shunt OC $z_5=1/g_5$ 1.61804
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Step 5: Use Kuroda's identities to convert series stubs to shunt stubs. This is a multi-step process, but the filter coefficients are symmetric in so we only need to transform one side of the filter and then capitalize on the symmetry. This will begin at the load and/or source side and work to the center of the filter (note: the center element is a shunt open-circuit stub, so it will remain untouched in this process).

Step 5.1 Insert unit elements source and load sides of the circuit to separate z_1 from z_2 and z_5 from z_4 .

Unit Element ue_1 1.00000	Shunt OC z_1 1.61804	Series SC z_2 1.61803	Shunt OC z_3 0.50000	Series SC z_4 1.61803	Shunt OC z_5 1.61804	Unit Element ue_2 1.00000
$N_1=1+ue_1/z_1$ $N_1=2.61304$			$N_2=1+ue_2/z_5$ $N_2=2.61304$			
Series SC z_1' ue_1/N_1	Unit Element ue_1' z_1/N_1	Series SC z_2 1.61803	Shunt OC z_3 0.50000	Series SC z_4 1.61803	Unit Element ue_2' z_5/N_1	Series SC z_5' ue_2/N_1

Step 5.2 Insert two more unit element source and load sides of the circuit. This will separate z_2 from z_3 and z_4 from z_3 , then separate z_4 from z_5 and z_1 from z_2 . This process will also convert z_1 , z_2 , z_4 , and z_5 into shunt OC stubs.

Unit Element ue3 1.00000	Series SC z1' 0.38194	Unit Element ue1' 0.61803	Series SC z2 1.61803	Shunt OC z3 0.50000	Series SC z4 1.61803	Unit Element ue2' 0.61803	Series SC z5' 0.38194	Unit Element ue4 1.00000
N3=1+z1'/ue3 N3=3.61804		N5=1+z2/ue1' N5=1.38197		N6=1+z4/ue2' N6=1.38197		N4=1+z5'/ue4 N4=3.61804		
Shunt OC z1'' ue3*N3	Unit Element ue3' z1'*N3	Shunt OC z2' ue1'*N5	Unit Element ue1'' z2*N5	Shunt OC z3 0.50000	Unit Element ue2'' z4*N5	Shunt OC z4' ue2'*N6	Unit Element ue4' z5'*N3	Shunt OC z5'' ue4*N4

Step 5.3 Perform impedance scaling for the transmission line.

Shunt OC z1'' 3.61804	Unit Element ue3' 1.38196	Shunt OC z2' 0.85410	Unit Element ue1'' 2.23607	Shunt OC z3 0.50000	Unit Element ue2'' 2.23607	Shunt OC z4' 0.85410	Unit Element ue4' 1.38196	Shunt OC z5'' 3.61804
Shunt OC 181 0.125λ	Unit Element 69 0.125λ	Shunt OC 43 0.125λ	Unit Element 112 0.125λ	Shunt OC 25 0.125λ	Unit Element 112 0.125λ	Shunt OC 43 0.125λ	Unit Element 69 0.125λ	Shunt OC 181 0.125λ

Step 6: Calculate the widths of the transmission lines and enter these into the design “N5_MaxFlat_LPF_T-Line” within the HFSS project “ECEN452_Lab6_Filters.hfss”. You will also need to enter this information into the “N5_MaxFlat_LPF_T-Line.zov” Z0lver assignment.

Step 7: Perform impedance and frequency scaling for the lumped element prototype you found in **Step 2** and enter these into the “N5_MaxFlat_LPF_LC.zov” Z0lver assignment.

Step 8: Calculate the values x_1 , x_2 , x_3 , x_4 , and x_5 (e.g., the electrical length of the stubs) for the modified low pass filter design “N5_MaxFlat_LPF_T-Line_Tapped_Stubs” that uses tapped stubs with a 1 mm width ($Z_0 = 89 \Omega$).

Shunt OC 89 $x_1*\lambda$	Unit Element 69 0.125λ	Shunt OC 89 $x_2*\lambda$	Unit Element 112	Shunt OC 89 $x_3*\lambda$	Unit Element 112	Shunt OC 89 $x_4*\lambda$	Unit Element 69	Shunt OC 89 $x_5*\lambda$
Shunt OC 89 $x_1*\lambda$		Shunt OC 89 $x_2*\lambda$		Shunt OC 89 $x_3*\lambda$		Shunt OC 89 $x_4*\lambda$		Shunt OC 89 $x_5*\lambda$

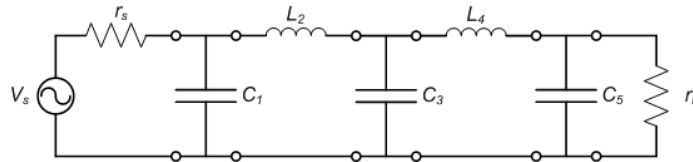
Task 2: Synthesis and implementation of an equi-ripple band-stop filter.

In this exercise you will synthesize a fifth-order 0.5 dB equi-ripple band-pass filter with a center frequency $f_c = 3.0$ GHz and a bandwidth of 2.25 GHz to 3.75 GHz (e.g., $\Delta = 0.5$), and then implement your design using microstrip transmission lines for a $Z_0 = 50 \Omega$ reference impedance on a 62 mil thick FR4 ($\epsilon_r = 4.1$, $\tan \delta = 0.01$).

Step 1: First, use the table on the following page to determine the element values of the low pass prototype.

N	0.5 dB Ripple										
	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

Step 2: Assemble the prototype LC ladder network.



To simplify the analysis (visually), we will replace this ladder network with the table shown below.

Shunt C g_1 1.7058	Series L g_2 1.2296	Shunt C g_3 2.5408	Series L g_4 1.2296	Shunt C g_5 1.7058
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Step 3: Convert this to a band-stop filter topology by replacing shunt elements with shunted LC series networks, and series LC parallel networks.

Shunt Series LC L_1', C_1'	Series Parallel LC L_2', C_2'	Shunt Series LC L_3', C_3'	Series Parallel LC L_4', C_4'	Shunt Series LC L_5', C_5'
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Step 4: Use inverters (e.g., quarter-wave transformers) to provide separation between the series elements and convert series stubs into shunt stubs.

Shunt Series LC L_1', C_1'	Inverter J1 1	Shunt Series LC L_2', C_2'	Inverter J2 1	Shunt Series LC L_3', C_3'	Inverter J3 1	Shunt Series LC L_4', C_4'	Inverter J4 1	Shunt Series LC L_5', C_5'
Shunt OC z_1 0.25λ	Inverter J1 1 0.25λ	Shunt OC z_2 0.25λ	Inverter J2 1 0.25λ	Shunt OC z_3 0.25λ	Inverter J3 1 0.25λ	Shunt OC z_4 0.25λ	Inverter J4 1 0.25λ	Shunt OC z_5 0.25λ

Step 5: Calculate the scaled impedance values of the equivalent open-circuit stubs using

$$Z_s = \frac{4Z_0}{\pi \times \Delta \times g_n}$$

[illegible]