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ECE-5341-001

7 December 2024

Final Project

My specifications were a Z_0 of 58 Ω and a f_0 of 2.8 GHz.

3rd Order Coupled-Line Bandpass Filter:

Using Table 8.3 from the textbook I found the necessary g_n for each section; equations of 8.121 I could find the normalized J_n values; and equations of 8.108 the even- and odd-mode impedances of each coupled line. π was 0.1 since my assigned bandwidth was 10% and N was 3.

$$Z_0 J_1 = \sqrt{\frac{\pi\Delta}{2g_1}} \qquad (8.121a)$$

$$Z_0 J_n = \frac{\pi\Delta}{2\sqrt{g_{(n-1)}g_n}} \qquad (8.121b)$$

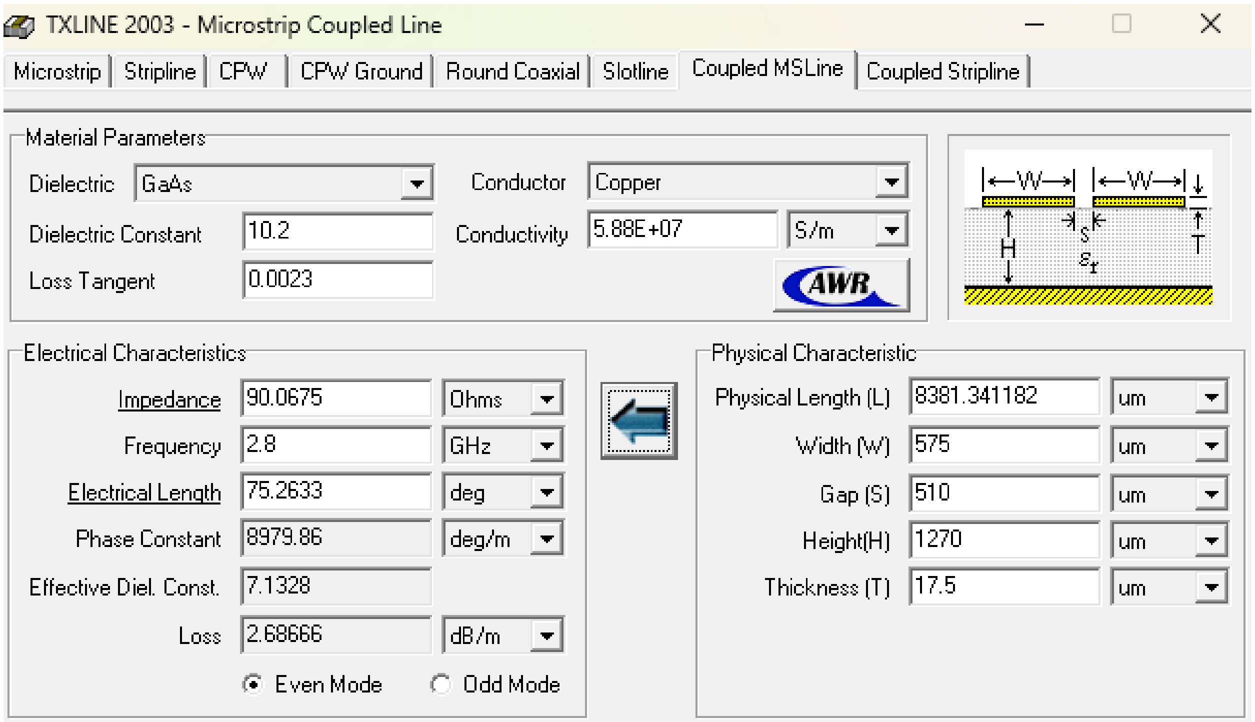
$$Z_0 J_{N+1} = \frac{\sqrt{\pi\Delta}}{2g_N g_{N+1}} \qquad (8.121c)$$

$$Z_{0e} = Z_0(1 + JZ_0 + (JZ_0)^2) \qquad (8.108a)$$

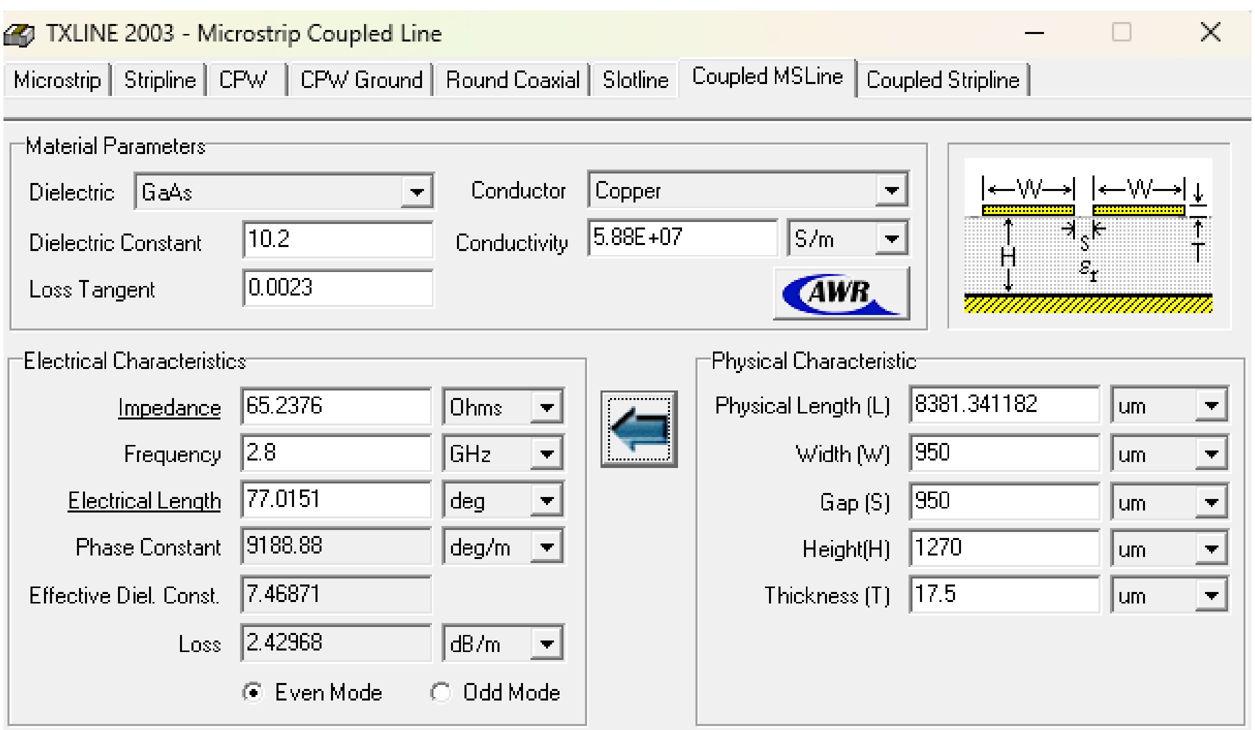
$$Z_{0o} = Z_0(1 - JZ_0 + (JZ_0)^2) \qquad (8.108b)$$

n	g_n	$Z_0 J_n$	Z_{0e} (Ω)	Z_{0o} (Ω)
1	1	0.396	90.1	44.1
2	2	0.111	65.2	52.3
3	1	0.111	65.2	52.3
4	1	0.396	90.1	44.1

Then, I ran the TXLine calculator until I managed the below values for the even-mode:

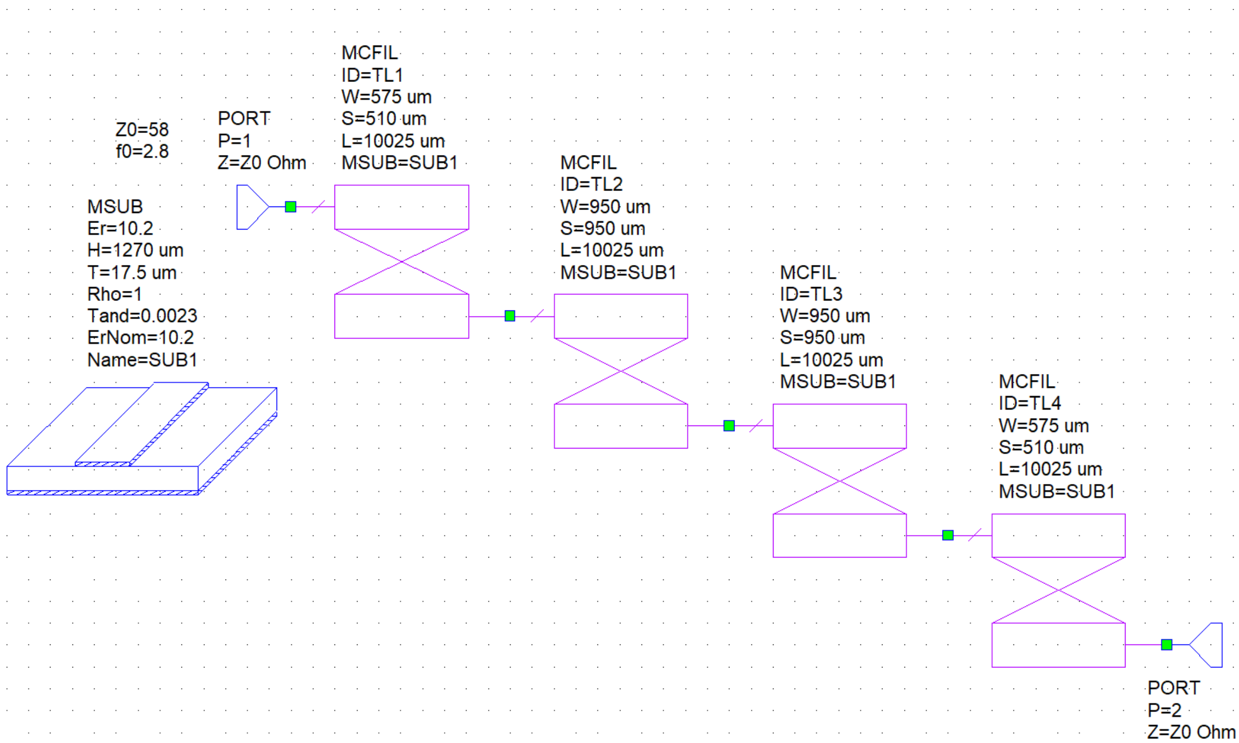


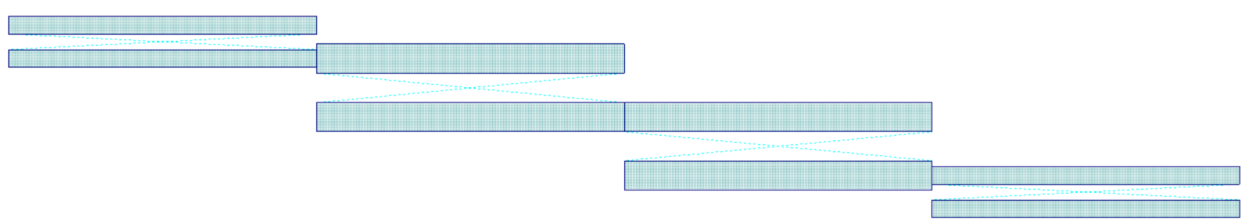
Output for sections $n = 1,4$

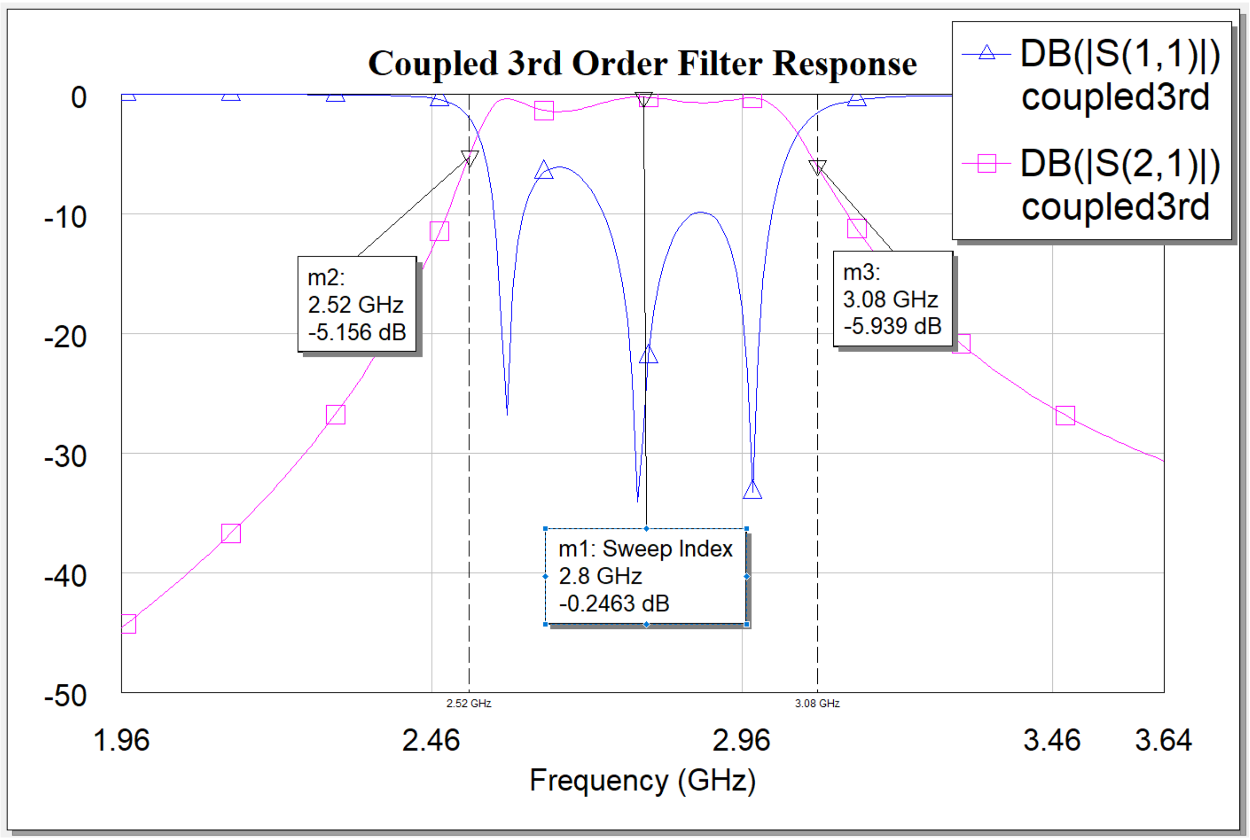


Output for sections $n = 2,3$

The calculated quarter-wavelength of f_0 shown in the above pictures did not produce the appropriate results, so the design was adjusted by first placing 90° in the "Electrical Length" textbox and then further adjusting the length until the desired results appeared.







Ceramic Resonator 4th Order Bandpass Filter:

The center frequency for this filter has been changed to $2f_0$, bandwidth is still 10%. Table 8.3 again provided the g_n values; equations of 8.136 the normalized J_n values; equations of 8.137 the capacitor values for every n; and equation 8.141 to find the stub length for every n (note in that one that ΔC_n is a single variable, as opposed to $\Delta * C_n$). The N is of course 4. For TXLine, I converted l_n to degrees, and ω_0 is the center frequency in radians/second.

$$Z_0 J_{01} = \sqrt{\frac{\pi\Delta}{2g_1}} \qquad (8.136a)$$

$$Z_0 J_{n,n+1} = \frac{\pi\Delta}{2\sqrt{g_{n-1}g_n}} \qquad (8.136b)$$

$$Z_0 J_{N+1} = \sqrt{\frac{\pi\Delta}{2g_N g_{N+1}}} \qquad (8.136c)$$

$$C_{01} = \frac{J_{01}}{\omega_0\sqrt{1-(Z_0 J_{01})^2}} \quad (8.137a)$$

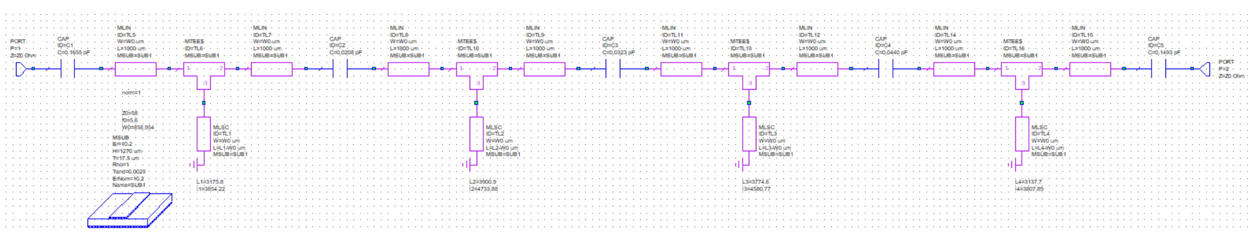
$$C_{n,n+1} = \frac{J_{n,n+1}}{\omega_0} \quad (8.137b)$$

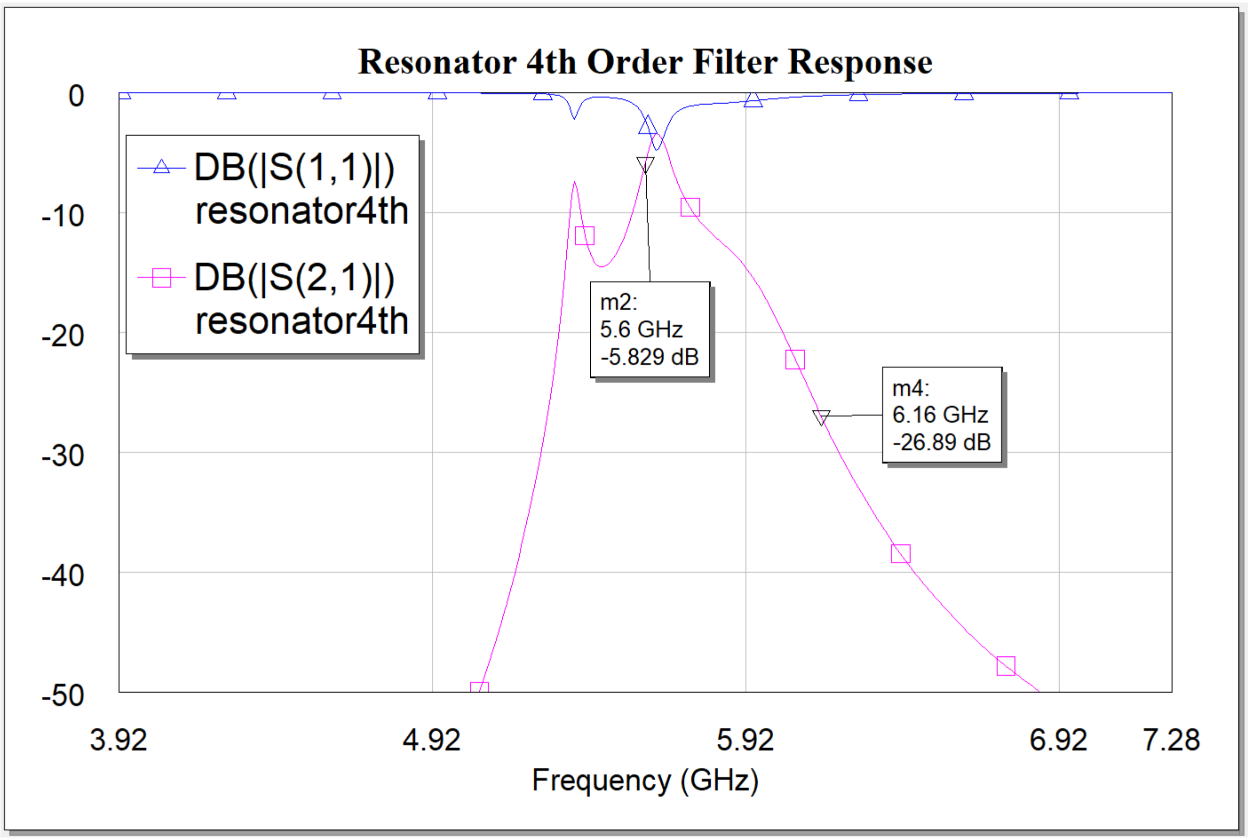
$$C_{N,N+1} = \frac{J_{N,N+1}}{\omega_0\sqrt{1-\left(Z_0 J_{N,N+1}\right)^2}} \quad (8.137c)$$

$$l_n = \lambda\left(\frac{1}{4} + \frac{Z_0\omega_0\Delta C_n}{2\pi}\right) \quad (8.141)$$

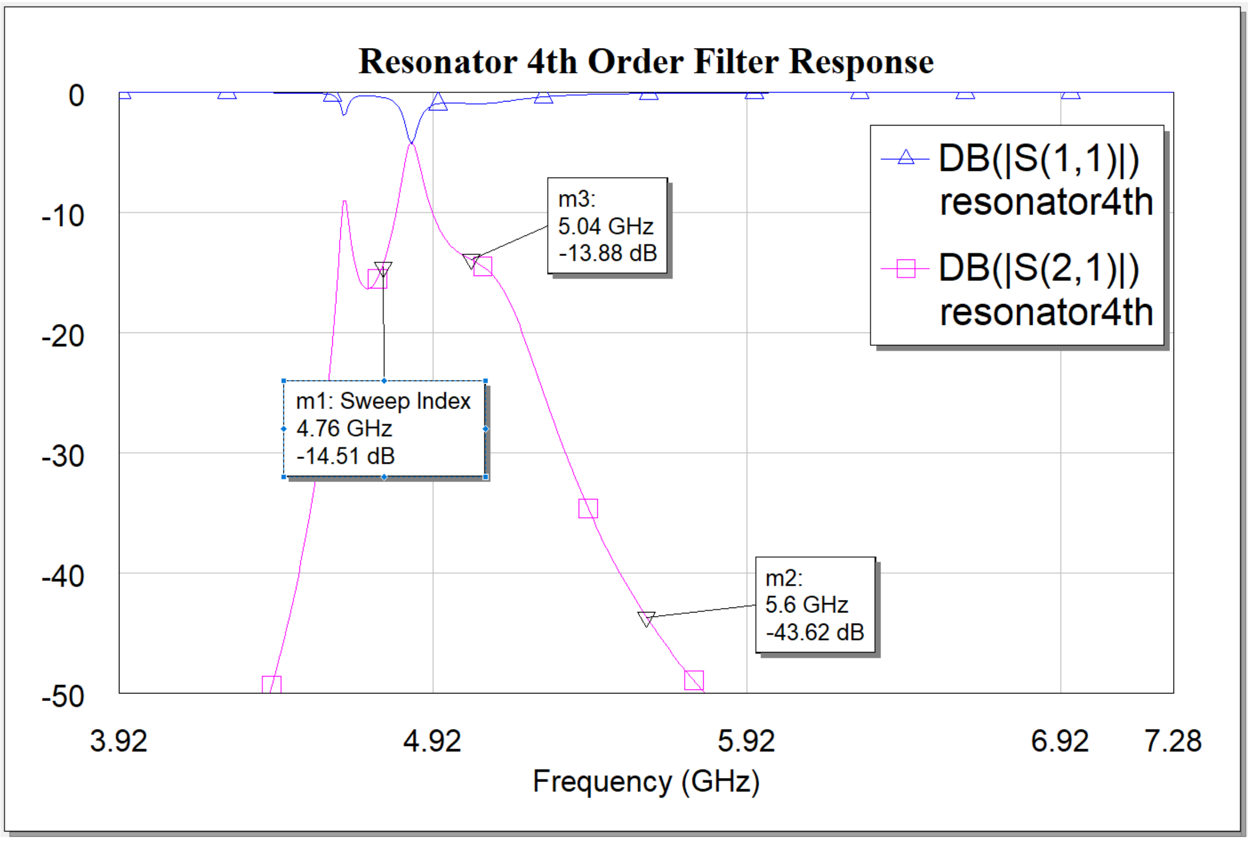
n	g_n	$Z_0 J_{n-1,n}$	$C_{n-1,n}$ (pF)	ΔC_n (pF)	l_n (mm)	l_n (°)
1	0.7654	0.320	0.1655	-0.1863	3.1758	68.22
2	1.8478	0.0425	0.0208	-0.0531	3.9009	83.79
3	1.8478	0.0660	0.0323	-0.0763	3.7746	81.08
4	0.7654	0.0898	0.0440	-0.1933	3.1377	67.40
5	1.0	0.320	0.1493	-	-	-

These mathematics work in an ideal scenario. To accommodate for the junctions, I had to subtract the width of the junctions from the stub length. Otherwise, the center frequency would be at 4.8 GHz.

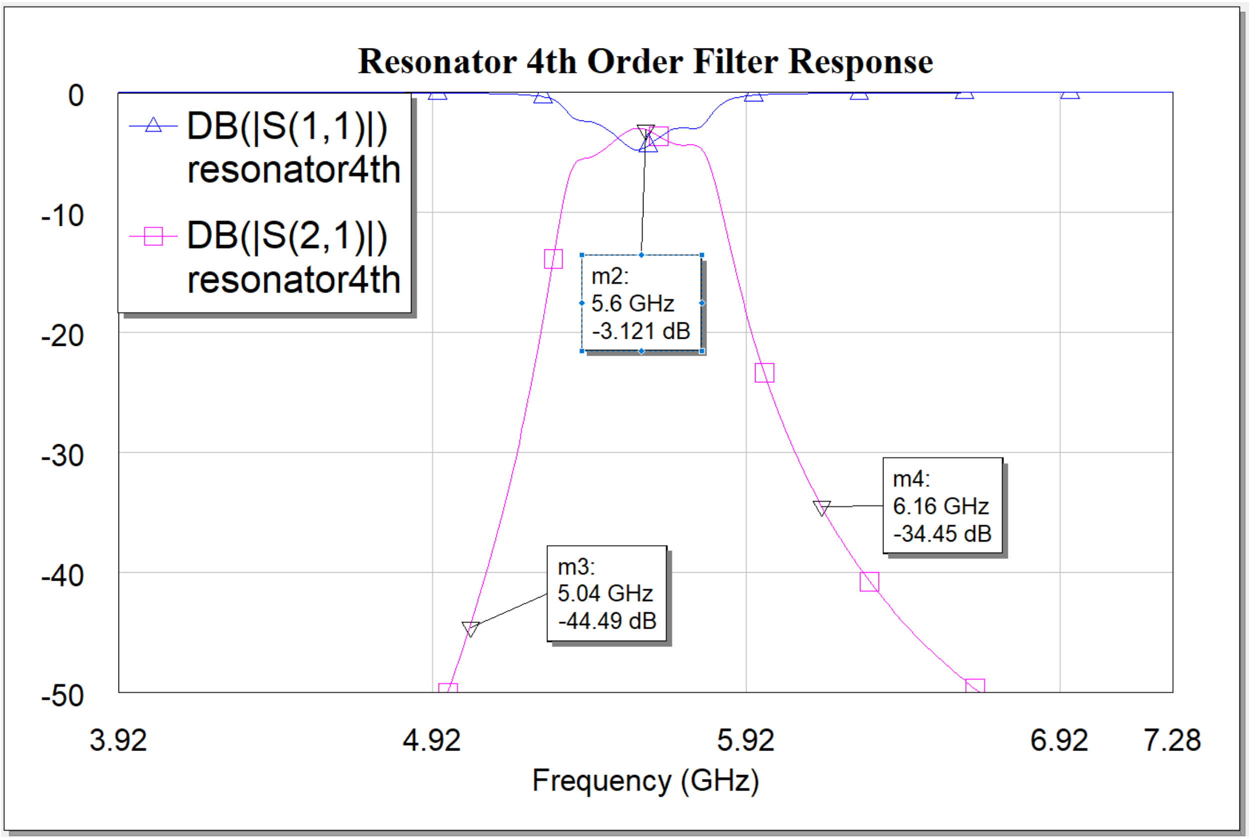




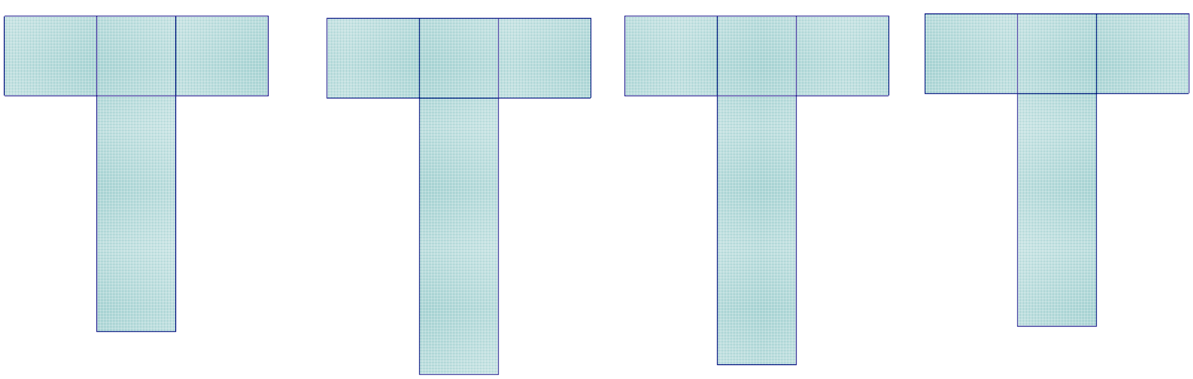
Notice on the schematic there are Ln and ln values. Ln means what was hand-calculated and ln is what TXLine calculates based on the electrical length I calculated. I tried to see if this would improve the filter response. It did not, as the graph below shows.



To fix the lumpy response, I tuned each stub length until I reached this result:



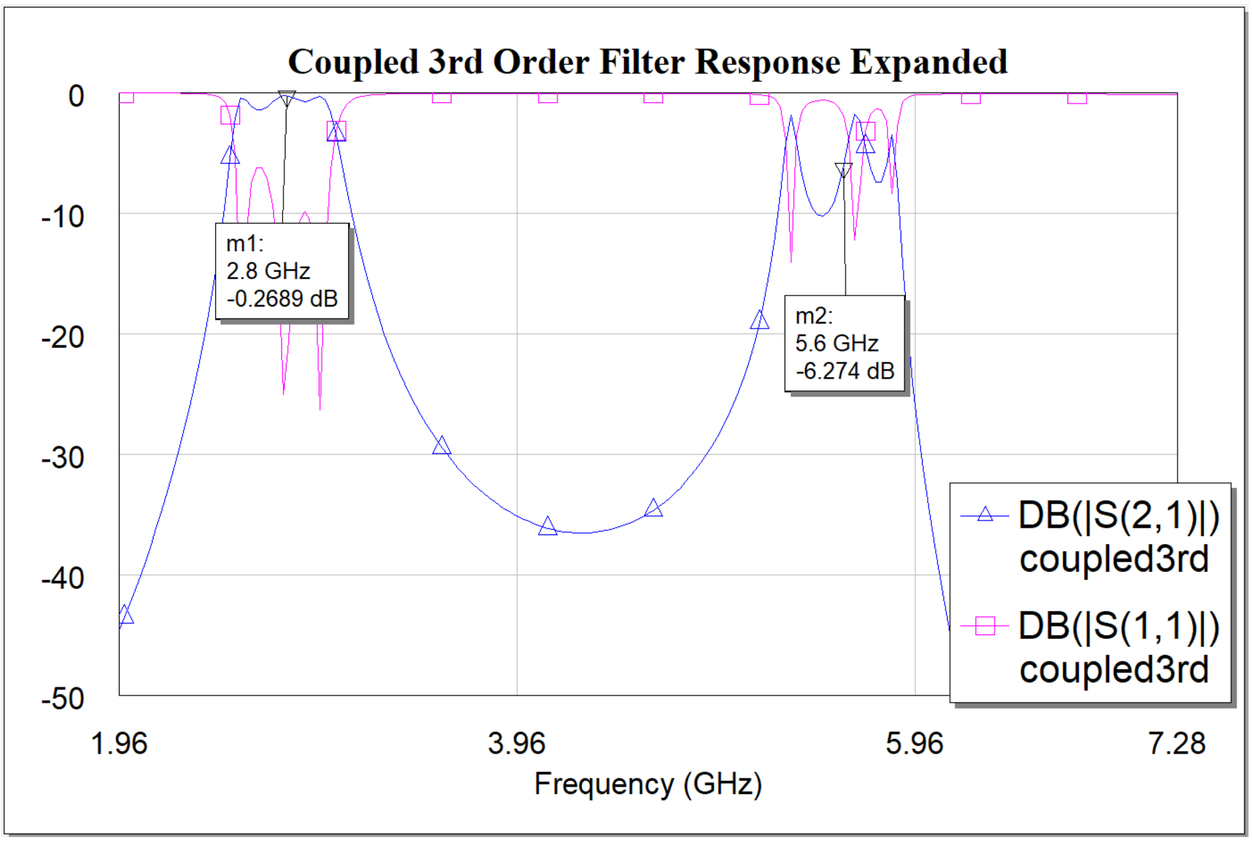
The bandwidth is not exceptional, however there is less loss at the center frequency and the passband is less lumpy.



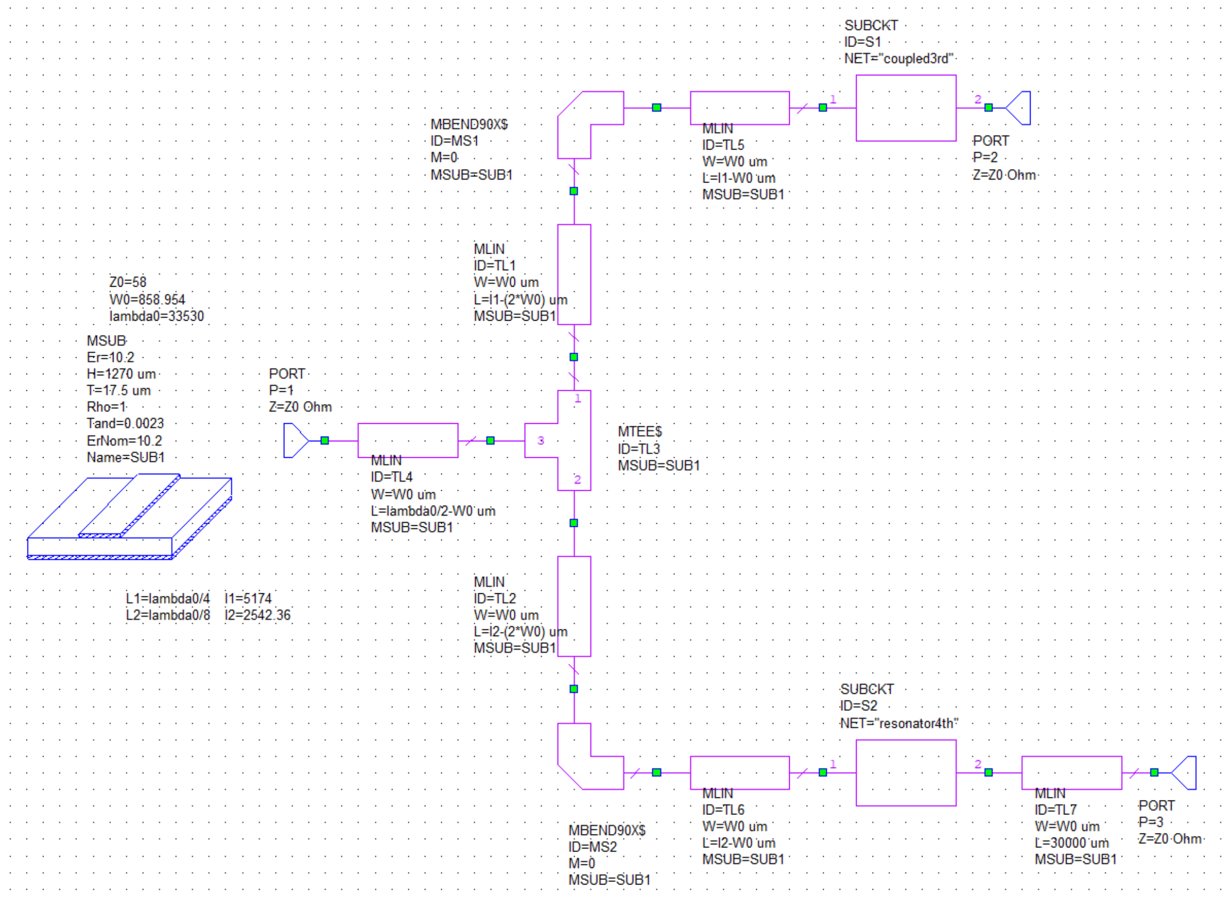
Note for the layout above that the gaps are to accommodate for the lumped-element capacitors.

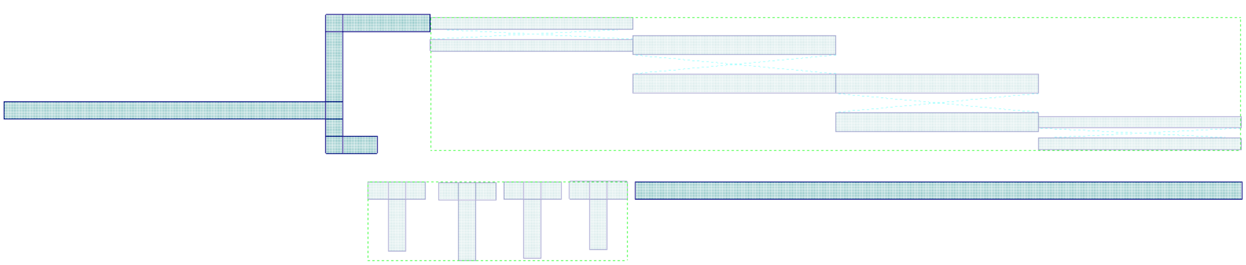
Diplexer:

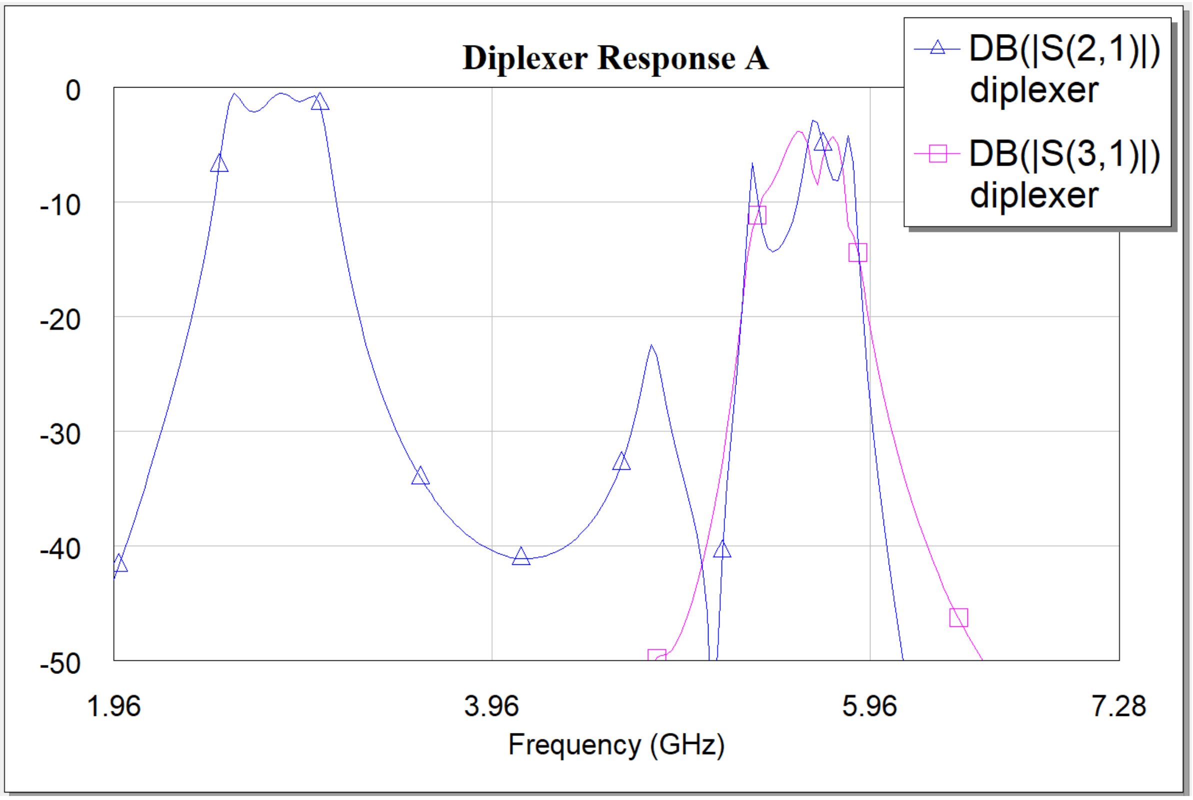
An effective Diplexer design does not allow the two I/O ports to suffer crosstalk. However, since at 5.6 GHz the 2.8 GHz filter exhibits a passband harmonic with a magnitude of -6 dB, the filter itself cannot deal with that issue. The graph below shows this behavior.

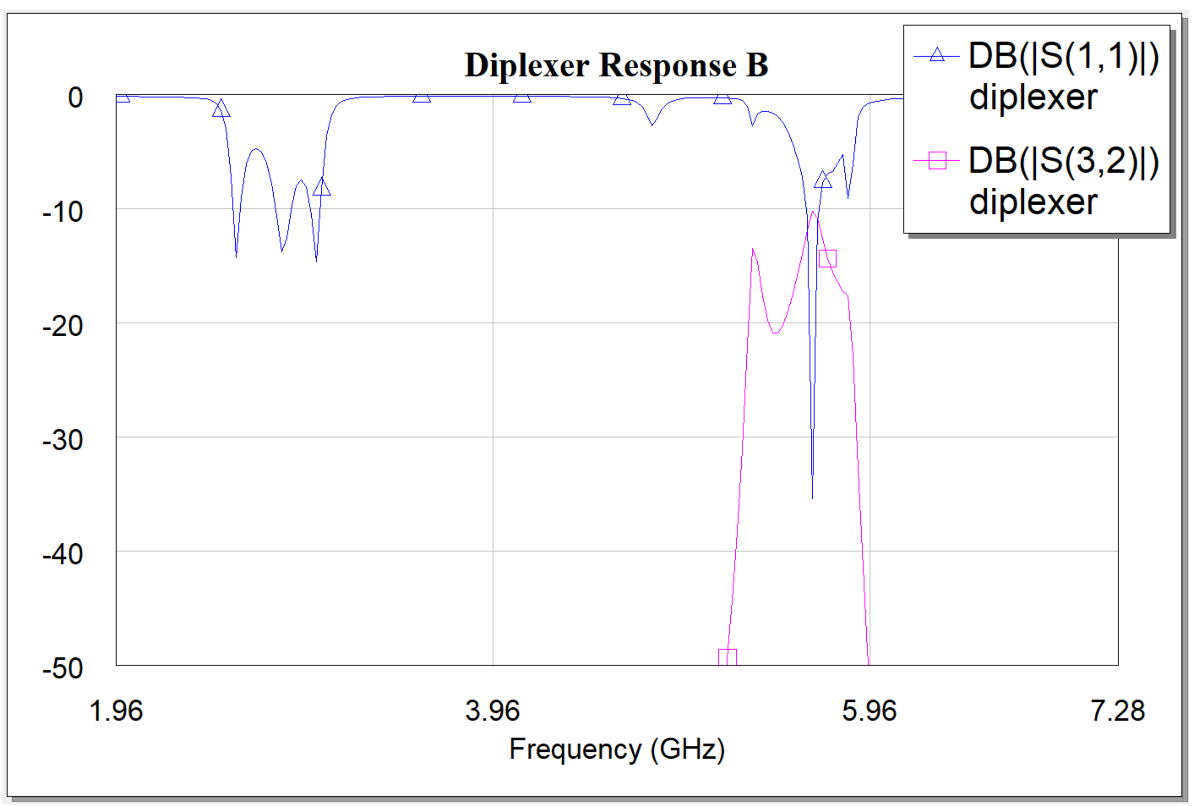


Further, because the frequencies are multiples of 2 to one another, designing the Diplexer itself to block out the 5.6 GHz signals into the 2.8 GHz filter is not feasible. A better specification for this would be to have the two signals possess center frequencies that are 1.5 times apart from one another, or perhaps nearly outside one another's passband.


SUBCKT
ID=S1
NET="coupled3rd"
MBEND90X$
ID=MS1
M=0
MSUB=SUB1
MLIN
ID=TL5
W=W0 um
L=l1-W0 um
MSUB=SUB1
PORT
P=2
Z=Z0 Ohm
MLIN
ID=TL1
W=W0 um
L=l1-(2*W0) um
MSUB=SUB1
Z0=58
W0=858.954
lambda0=33530
MSUB
Er=10.2
H=1270 um
T=17.5 um
Rho=1
Tand=0.0023
ErNom=10.2
Name=SUB1
PORT
P=1
Z=Z0 Ohm
MLIN
ID=TL4
W=W0 um
L=lambda0/2-W0 um
MSUB=SUB1
MTEE$
ID=TL3
MSUB=SUB1
L1=lambda0/4
L2=lambda0/8
l1=5174
l2=2542.36
MLIN
ID=TL2
W=W0 um
L=l2-(2*W0) um
MSUB=SUB1
SUBCKT
ID=S2
NET="resonator4th"
MLIN
ID=TL6
W=W0 um
L=l2-W0 um
MSUB=SUB1
MLIN
ID=TL7
W=W0 um
L=30000 um
MSUB=SUB1
PORT
P=3
Z=Z0 Ohm
MBEND90X$
ID=MS2
M=0
MSUB=SUB1




Diplexer Response A
DB(|S(2,1)|)
diplexer
DB(|S(3,1)|)
diplexer
0
-10
-20
-30
-40
-50
1.96
3.96
5.96
7.28
Frequency (GHz)

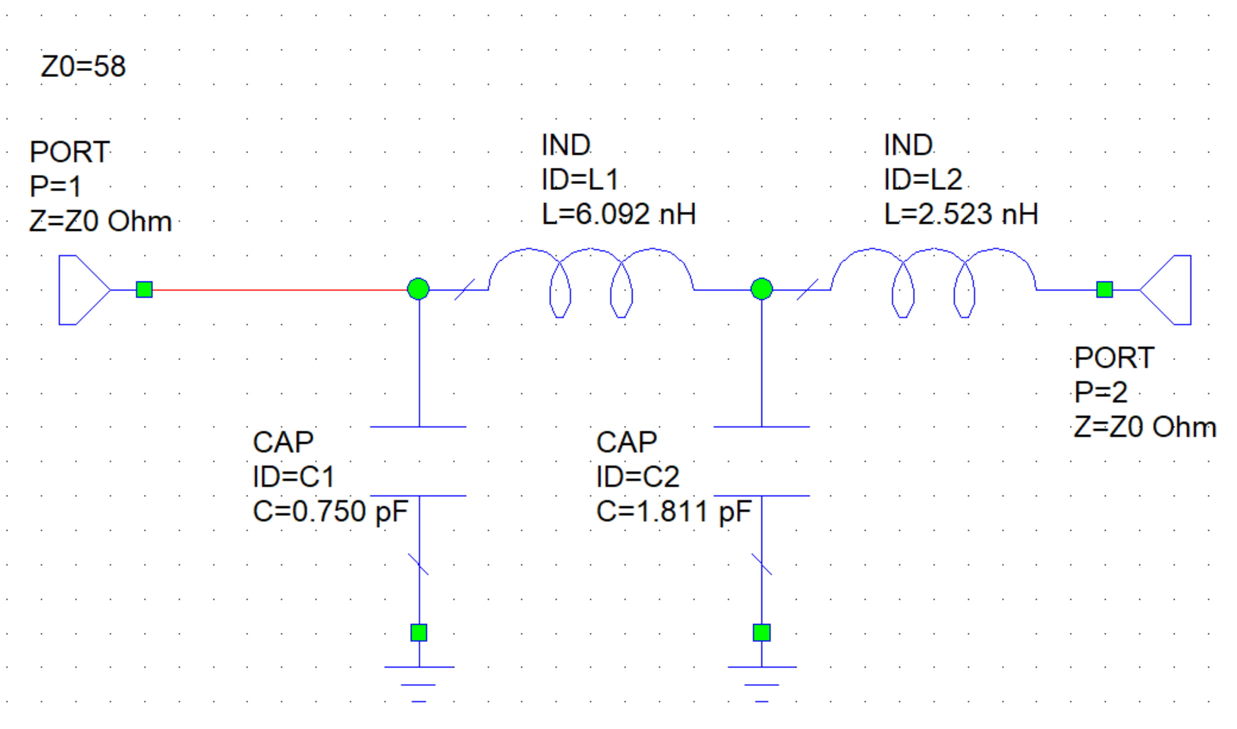

Diplexer Response B
DB(|S(1,1)|)
diplexer
DB(|S(3,2)|)
diplexer
0
-10
-20
-30
-40
-50
1.96
3.96
5.96
7.28
Frequency (GHz)

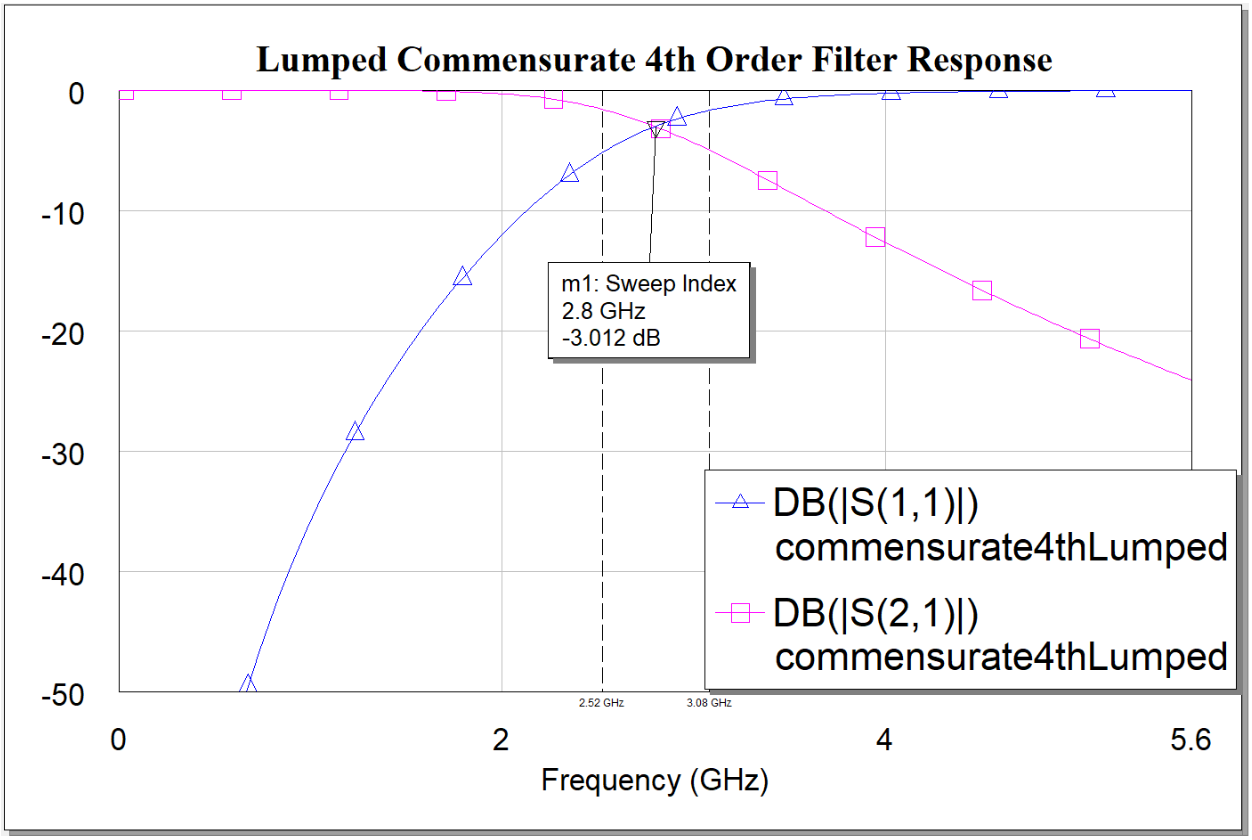
4th Order Commensurate-Line Low-Pass Filter.

I first prototyped this filter using lumped elements, calculating them by using the g_n values from Table 8.3 for an N of 4 (the same as the previous filter) and the equations of 8.67 to obtain the values seen in the schematic below.

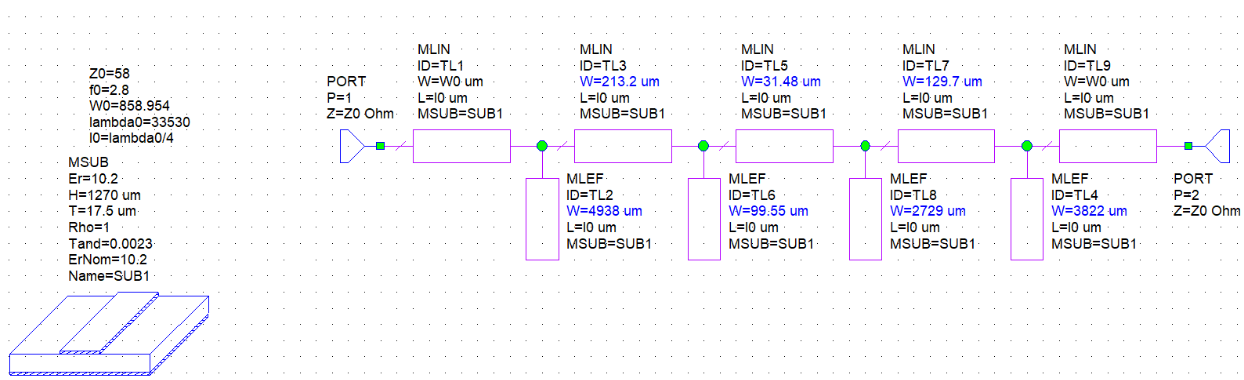
$$L'_k = \frac{R_0 L_k}{\omega_c} \qquad (8.67a)$$

$$C'_k = \frac{C_k}{R_0 \omega_c} \qquad (8.67b)$$

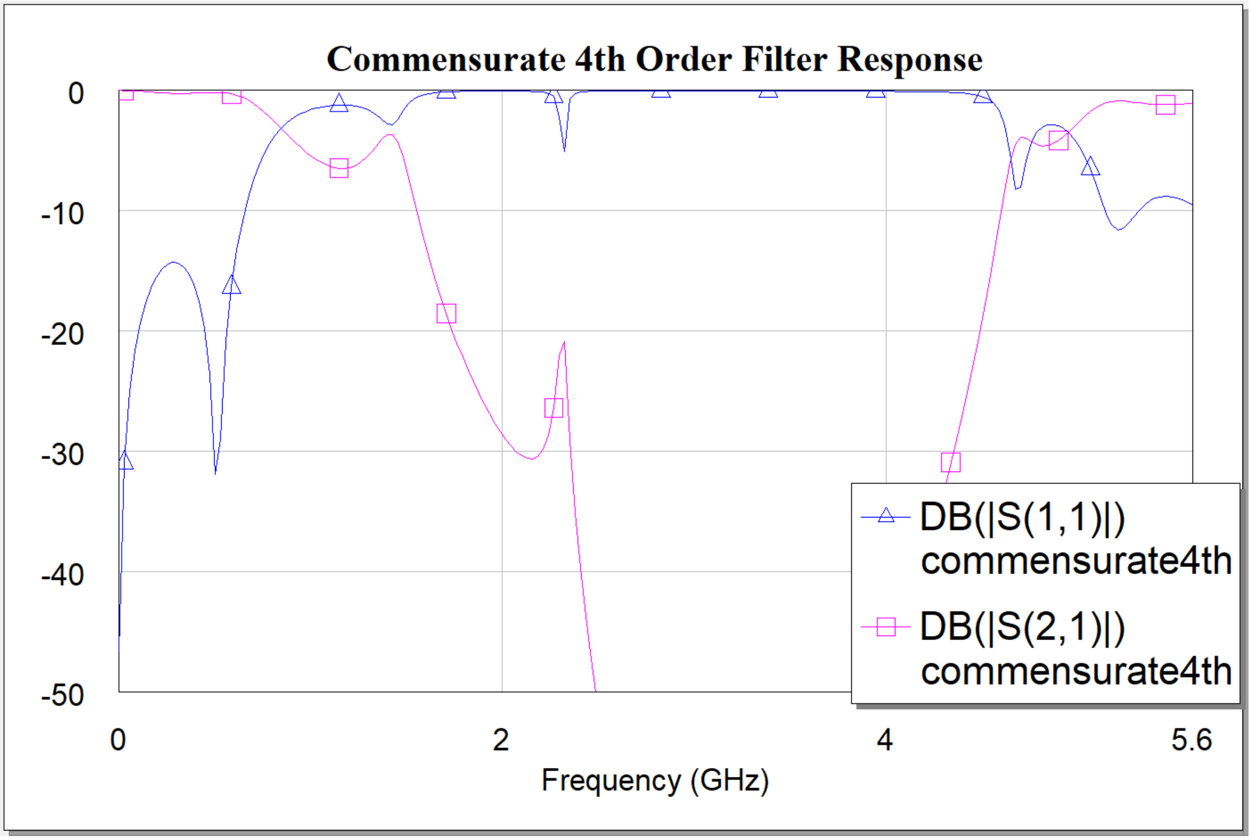




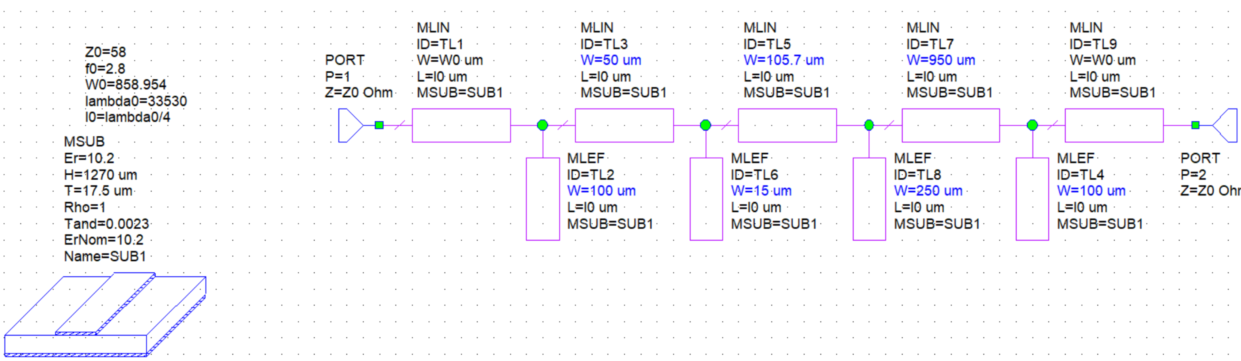
As seen in the graph above, this is precisely what we are looking for. From there, I applied Richard's transformations and the first two of Kuroda's identities until I got the desired circuit below (a scanned page of my hand-calculations is at the end of this summary).

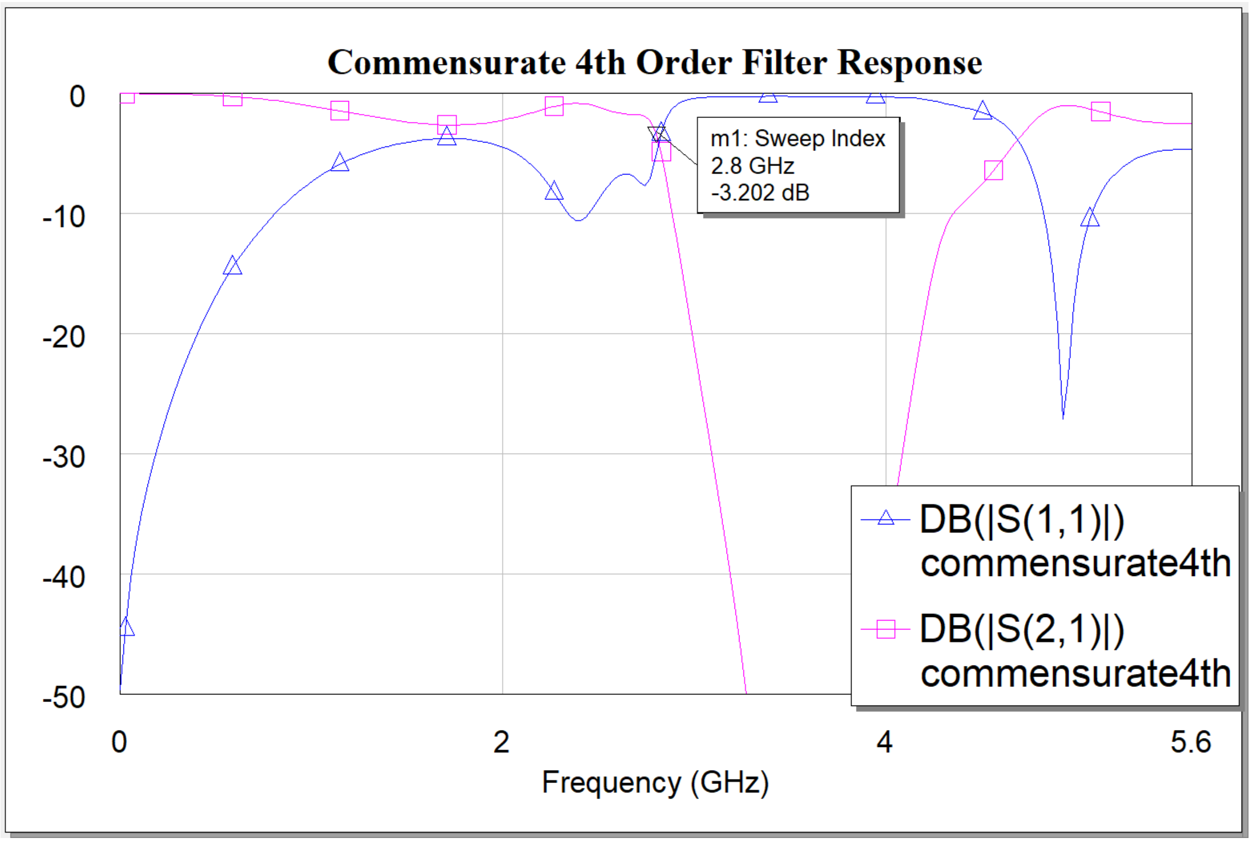


However, my hand-calculated values shown above did not produce a suitable filter, as seen below.



By tuning the values, however, I managed the below circuit and filter response.

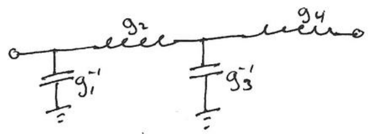




This result appears much more like what is expected, as per Figure 8.37 of the textbook, though the values assigned to manage this filter response is not scientifically robust.

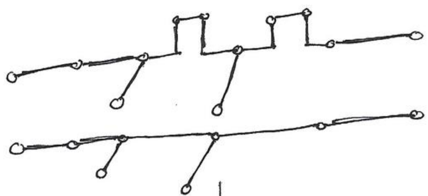
Commensurate 4th-order low-pass:

$g_1 = 0.7654$, $g_2 = 1.8478$, $g_3 = 1.8478$, $g_4 = 0.7654$, $g_5 = 1$



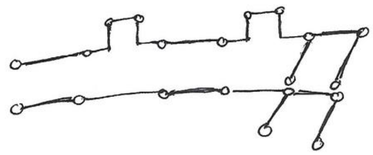
g_1^{-1}; g_2; g_3^{-1}; g_4

↓



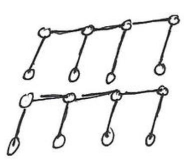
1; 1; g_1^{-1}; g_2; g_3^{-1}; g_4; 1

↓



$$1;\ \frac{1}{1+\frac{g_1}{1}};\ \frac{g_1}{1+\frac{g_1}{1}};\ g_2;\ \underbrace{g_3^{-1}}_{Z_3};\ \underbrace{\left(1+\frac{1}{g_4}\right)g_4}_{Z_{l_3}};\ \underbrace{\frac{1}{\left(1+\frac{1}{g_4}\right)\cdot 1}}_{Z_4}$$

↓



$$\underbrace{\frac{1}{\left(1+\frac{1}{\frac{1}{1+\frac{g_1}{1}}}\right)}\cdot 1}_{Z_1};\ \underbrace{\left(1+\frac{1}{\frac{1}{1+\frac{g_1}{1}}}\right)\frac{1}{1+\frac{g_1}{1}}}_{Z_{l_1}};\ \underbrace{\frac{1}{\left(1+\frac{\frac{g_1}{1+g_1/1}}{g_2}\right)}\frac{g_1}{1+g_1/1}}_{Z_2};\ \underbrace{\left(1+\frac{\frac{g_1}{1+g_1/1}}{g_2}\right)g_2}_{Z_{l_2}};\ \checkmark$$

	$\xrightarrow{Z_0}$
$Z_1 = 0.3616$	$= 20.9728\,\Omega$
$Z_{l_1} = 1.5664$	$= 90.8512$
$Z_2 = 1.8682$	$= 108.3556$
$Z_{l_2} = 2.2814$	$= 132.3212$
$Z_3 = 0.5412$	$= 31.3896$
$Z_{l_3} = 1.7654$	$= 102.3932$
$Z_4 = 0.4336$	$= 25.1488$