ECEN452: ULTRA HIGH FREQUENCY TECHNIQUE
LAB06
SAMBONG JANG
DR. HUFF

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

GIVEN:

Characteristic Impedance = 50 ohm
Thickness of substrate = 62 mil = 1.5748 mm
Dielectric constant of substrate = 4.1
Loss tangent of substrate = 0.01
Center Frequency = 2.5GHz
Minimum attenuation of 10dB at 3.25GHz

Background:

The insertion loss allows a high degree of control over the passband and stopband amplitude and the phase characteristics, with a systematic way to synthesize a desired response. Chebyshev response would satisfy a requirement for the sharpest cutoff. Chebyshev polynomials are useful in approximation. Maximally-flat is a characteristic that is also known as the binomial or Butterworth response, and is optimum in the sense that it provides the flattest possible point in the passband response for a given filter complexity, or order.

Load resistance will be normalized as 1 in maximally flat case whereas non-unity load resistance will be presented in equi-ripple filters with even N order.

The power loss ratio is given:

$$P_{LR} = \frac{\text{Power available from source}}{\text{Power delivered to load}} = \frac{P_{inc}}{P_{load}} = \frac{1}{1 - |\Gamma(\omega)|^2}.$$

Now, we obtain the power loss ratio expression for the maximally flat response:

$$P_{LR} = 1 + k^2 \left(\frac{\omega}{\omega_c}\right)^{2N}$$

Calculation:

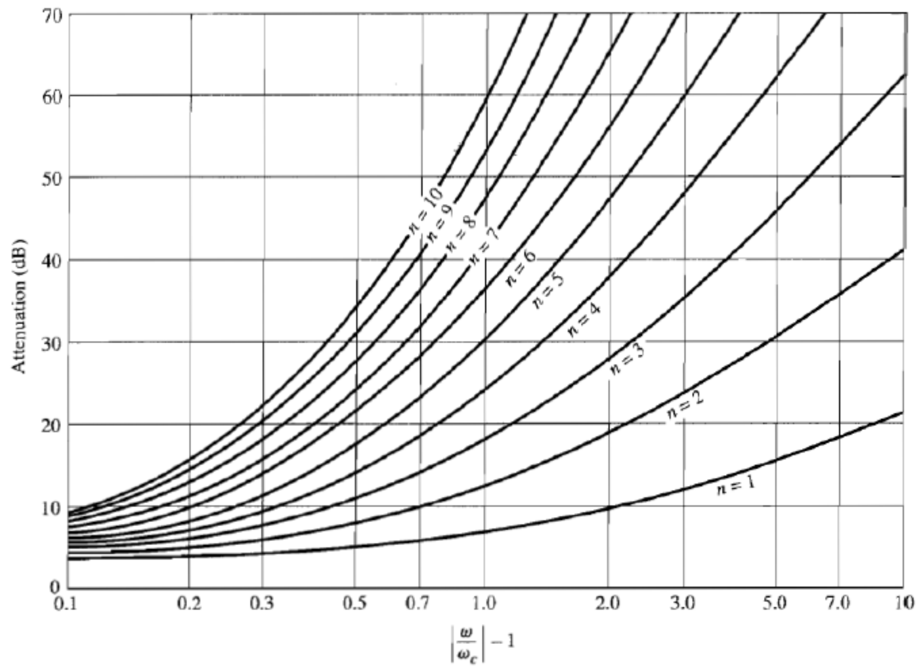


Figure. Attenuation [dB] in terms of frequency

$$\left|\frac{\omega}{\omega_c}\right| - 1 = \left|\frac{f_{10dB}}{f_c}\right| - 1 = 0.3$$

It seems N=4 curve doesn't really meet the point so we need the above curve (about 11dB, which is better) N=5 curve will do fine.

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

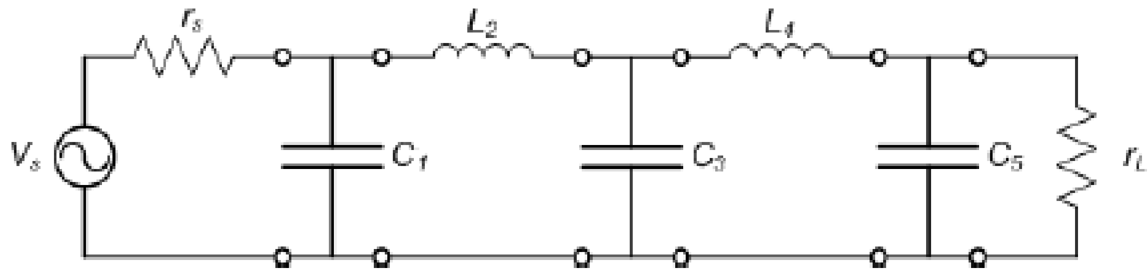
Element Values for Butterworth (Maximally Flat) Low-Pass Filter Prototypes
(g_o=1,w_c=1,N=1 to 10)

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

Figure

For $N = 5$,

$$g_1 = 0.6180$$
$$g_2 = 1.6180$$
$$g_3 = 2.0000$$
$$g_4 = 1.6180$$
$$g_5 = 0.6180$$
$$g_6 = 1.0000$$



Figure

Shunt	Series	Shunt	Series	Shunt
C	L	C	L	C
g1	g2	g3	g4	g5
0.61803	1.61803	2.00000	1.61803	0.61803

Figure

Shunt	Series	Shunt	Series	Shunt
OC	SC	OC	SC	OC
z1=1/g1	z2=g2	z3=1/g3	z4=g4	z5=1/g5
1.61804	1.61803	0.50000	1.61803	1.61804

Figure

Note that these values are normalized with the reference impedance Z_0
What we aim here is that we want to make all the elements in shunt; however, it requires multi-steps of calculations to achieve. The idea here is that we just add unit element and use it as a tool used in Kuroda's identity. After a couple of steps, we will be ended up with all elements in shunt.

Shunt	Unit	Shunt	Unit	Shunt	Unit	Shunt	Unit	Shunt
OC	Element	OC	Element	OC	Element	OC	Element	OC
z1''	ue3'	z2'	ue1''	z3	ue2''	z4'	ue4'	z5''
3.61804	1.38196	0.85410	2.23607	0.50000	2.23607	0.85410	1.38196	3.61804

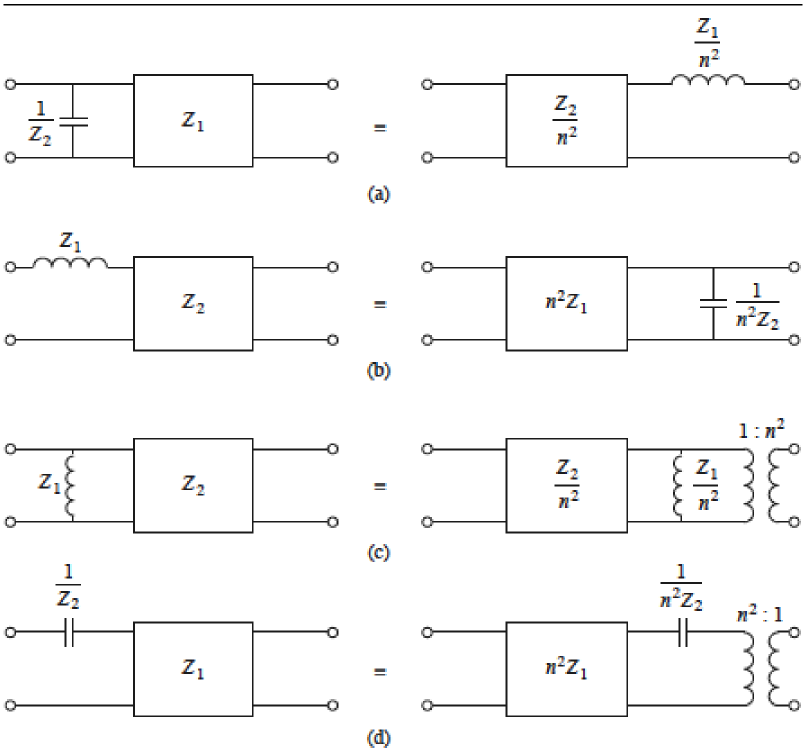
Shunt	Unit	Shunt	Unit	Shunt	Unit	Shunt	Unit	Shunt
OC	Element	OC	Element	OC	Element	OC	Element	OC
181	69	43	112	25	112	43	69	181
0.125λ	0.125λ	0.125λ	0.125λ	0.125λ	0.125λ	0.125λ	0.125λ	0.125λ

Figure

Width of UE1 = 1.761mm (69 ohm)
Length of UE1 = 8.633mm
Width of UE2 = 0.541mm (112 ohm)
Length of UE2 = 8.892mm

Width of 181 ohm = 0.0858mm
Length of 181 ohm = 9.076mm
Width of 43 ohm = 3.964mm
Length of 43 ohm = 8.349mm
Width of 25 ohm = 8.398mm
Length of 25 ohm = 8.042mm
Width of 50 ohm = 3.130mm

TABLE 8.7 The Four Kuroda Identities ($n^2 = 1 + Z_2/Z_1$)



Figure

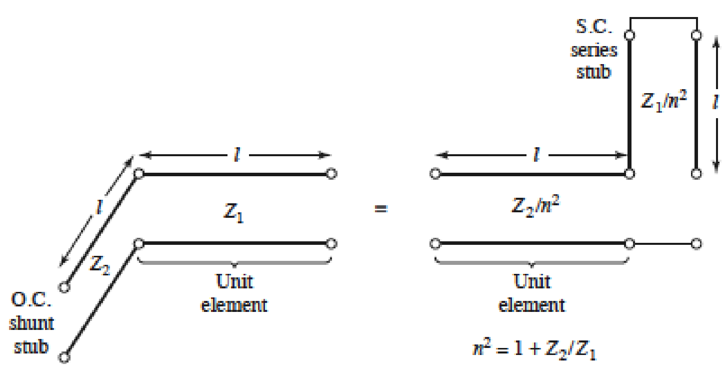


FIGURE 8.35 Equivalent circuits illustrating Kuroda identity (a) in Table 8.7.

Figure

Kuroda Identities are used for converting series stubs to shunt stubs whereas Richards Transformation is used for transforming capacitors to open stubs and inductors to short stubs. This is huge advantage because it allows some variation in design.

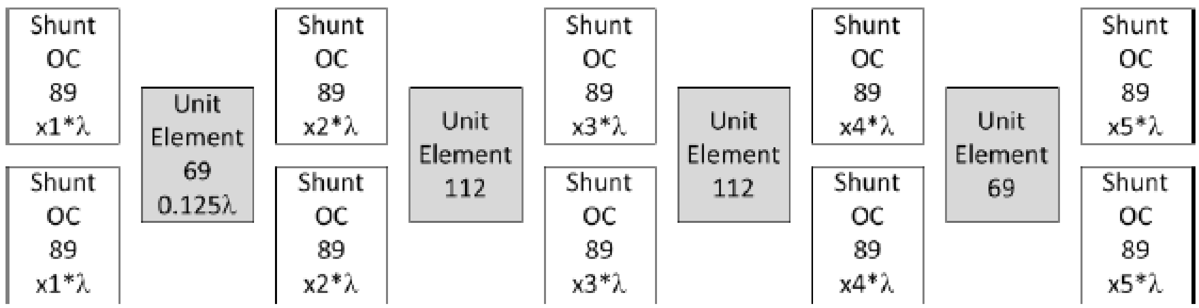


Figure. The final circuit after transformation

The input impedance of open circuit stub is given by:

$$Z_{OC} = -jZ_0 cot(\beta l)$$

$$\text{for } \frac{\lambda}{8}\ line, Z_{OC} = -jZ_0$$

since we are interested in easier implementation in practice, we fix the width of stub as 1mm, which corresponds to

$$Z_0 = 89\Omega$$

and the above figure shows 89 ohm stubs are in parallel with that being said,

$$Z_{OC} = Z_0||Z_0\cot(\frac{2\pi x_n}{\lambda})$$

also we know the following relation

$$cot^{-1}(y) = \frac{\pi}{2} - tan^{-1}(y)\ for\ any\ y$$

hence,

$$x_1 = x_5 = 0.038368\lambda = 2.694mm$$
$$x_2 = x_4 = 0.12773\lambda = 8.968mm$$
$$x_3 = 0.168536\lambda = 11.833mm$$
$$\text{with } \lambda = 70.212mm$$

Now, unit element calculations:

Width of UE1 = 1.761mm (69 ohm)
Width of UE2 = 0.541mm (112 ohm)
Length of UE1 = 8.633mm (69 ohm)
Length of UE2 = 8.892mm (112 ohm)

Width of 50 ohm = 3.13mm

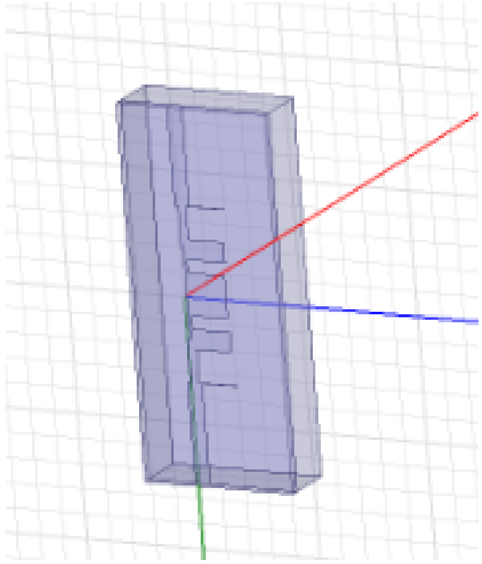


Figure. MaxFlat T line

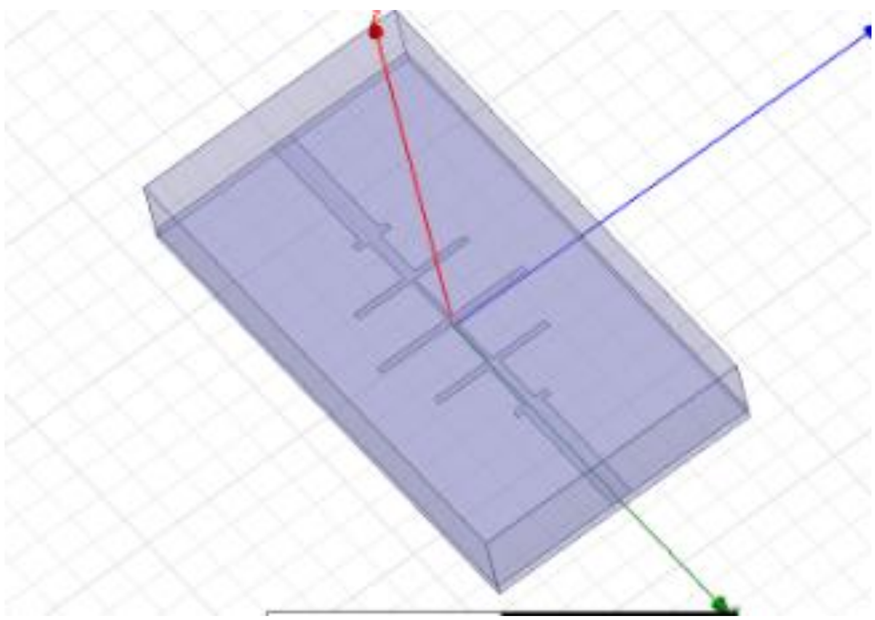
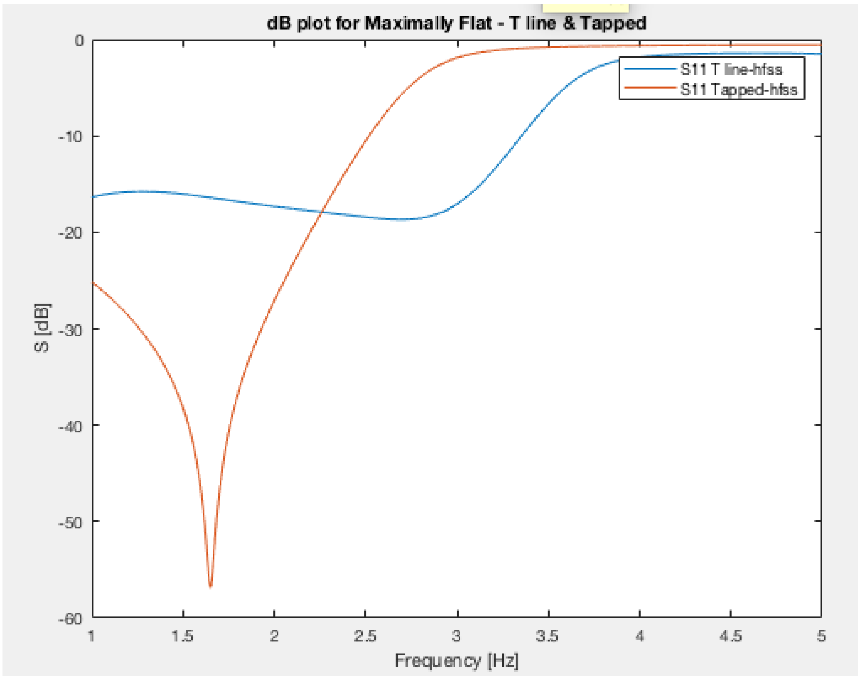
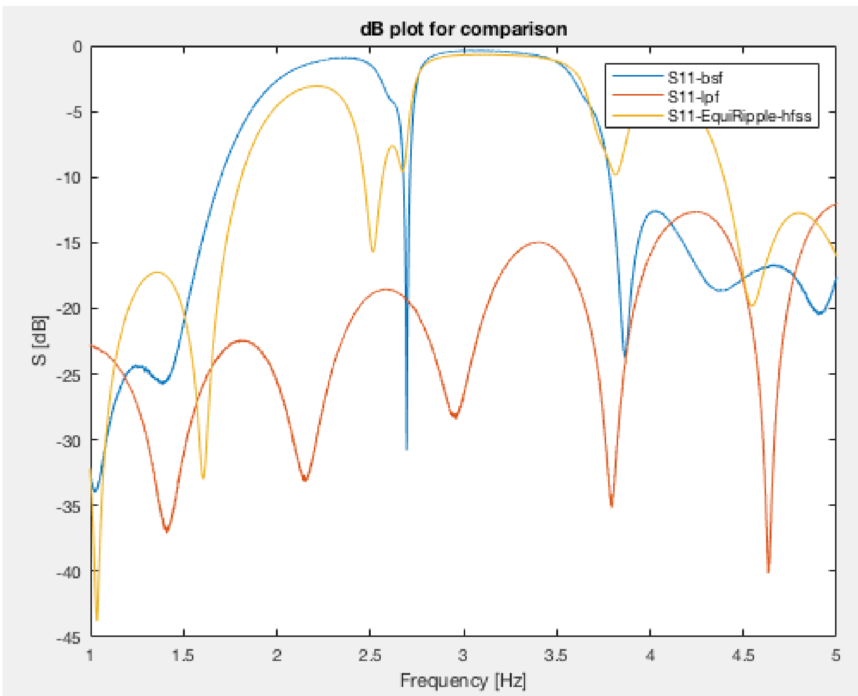


Figure. MaxFlat Tapped

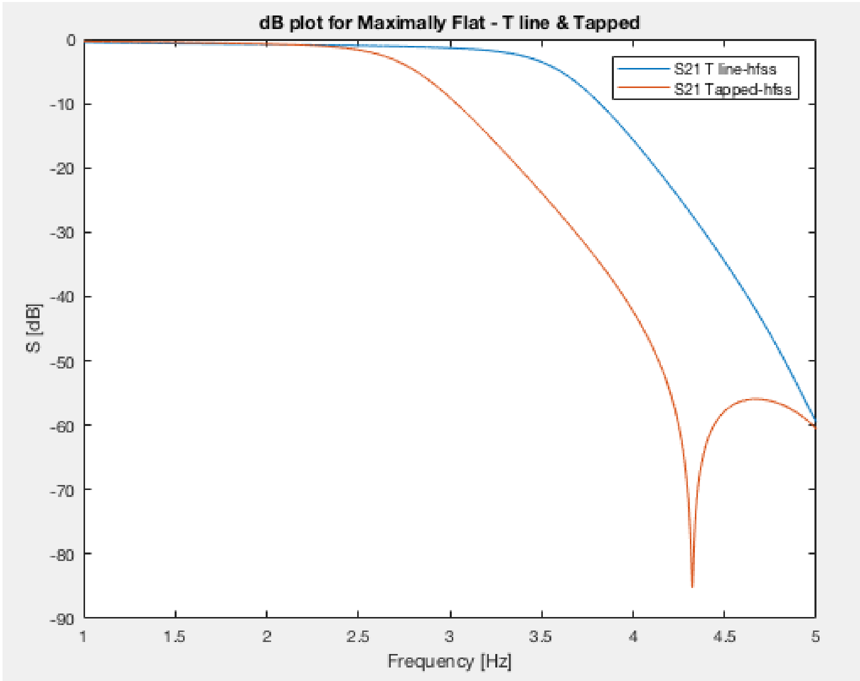


Figure

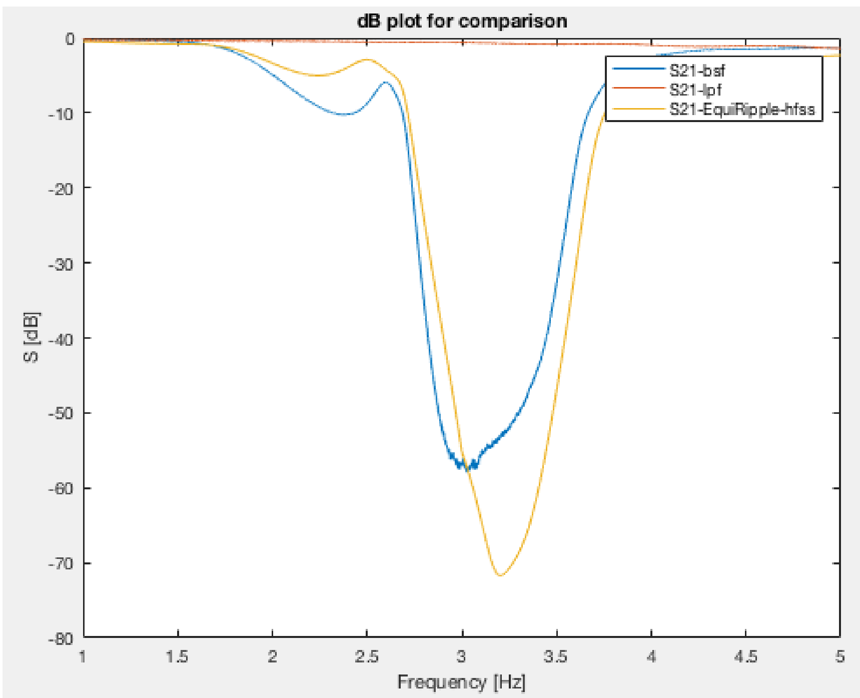


Figure

The band stop filter with range between approximately 2.7GHz and 3.9GHz



Figure



Figure

HFSS design for Equi-Ripple shows around -60dB at the center frequency.

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

Given:

Center Frequency = 3 GHz
Bandwidth of 2.25 GHz to 3.75 GHz
Microstrip line
Characteristic Impedance = 50 ohm
Thickness of substrate = 62 mil = 1.5748 mm
Dielectric Constant = 4.1
Loss Tangent = 0.01

Background:

If a Chebyshev polynomial is used to find the insertion loss of an Nth order low-pass filter,

$$P_{LR} = 1 + k^2 T_N^2 \left(\frac{\omega}{\omega_c} \right),$$

then a sharper cutoff will result, although the passband will have ripples of amplitude, $1 + k^2$, since $T_N(x)$ oscillates between ± 1 for x^2. ($T_N(x)$ is the Chebyshev polynomial of N th order)

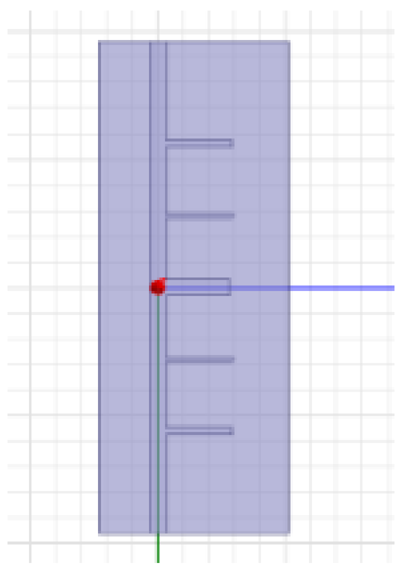


Figure. EquiRipple

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 and 3.0 dB ripple)

					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}
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
					3.0 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}
1	1.9953	1.0000									
2	3.1013	0.5339	5.8095								
3	3.3487	0.7117	3.3487	1.0000							
4	3.4389	0.7483	4.3471	0.5920	5.8095						
5	3.4817	0.7618	4.5381	0.7618	3.4817	1.0000					
6	3.5045	0.7685	4.6061	0.7929	4.4641	0.6033	5.8095				
7	3.5182	0.7723	4.6386	0.8039	4.6386	0.7723	3.5182	1.0000			
8	3.5277	0.7745	4.6575	0.8089	4.6990	0.8018	4.4990	0.6073	5.8095		
9	3.5340	0.7760	4.6692	0.8118	4.7272	0.8118	4.6692	0.7760	3.5340	1.0000	
10	3.5384	0.7771	4.6768	0.8136	4.7425	0.8164	4.7260	0.8051	4.5142	0.6091	5.8095

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 – Table 8.4

In order to determine 'N' for design, we need to know the ripple level and the following figure can help the determination.

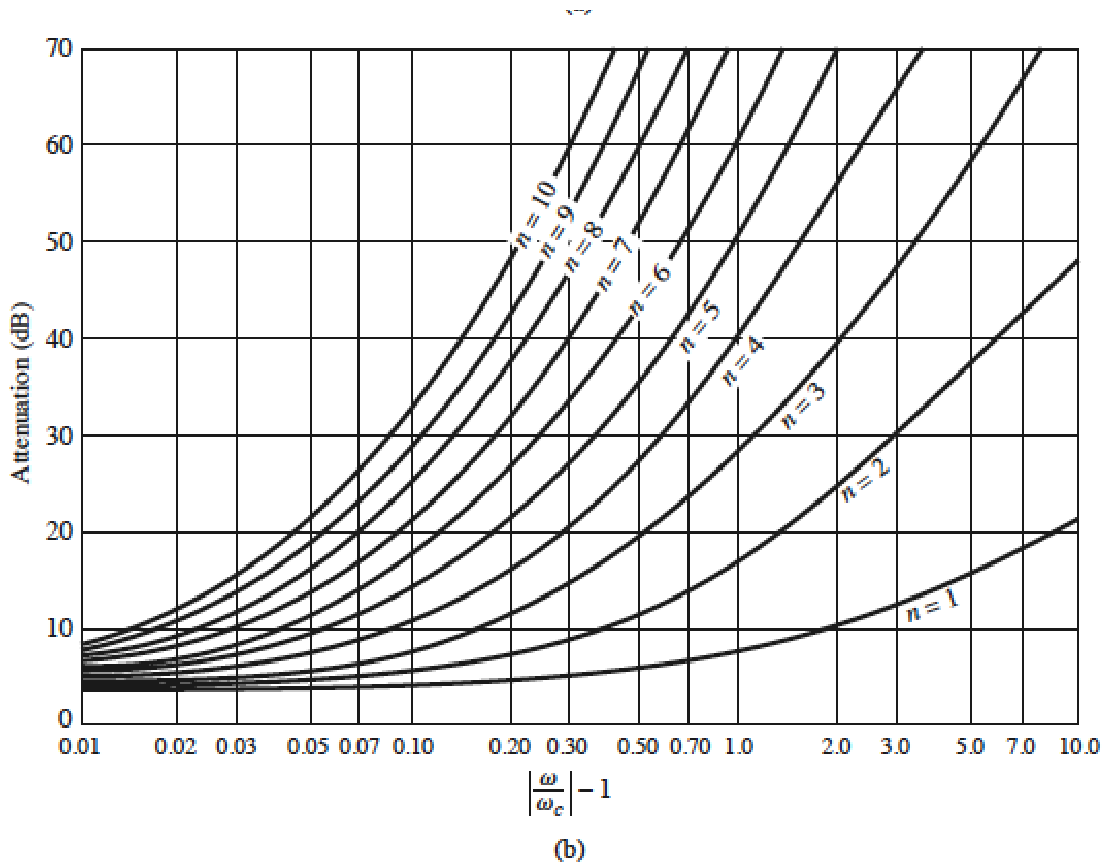


FIGURE 8.27 Attenuation versus normalized frequency for equal-ripple filter prototypes. (a) 0.5 dB ripple level. (b) 3.0 dB ripple level.

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.

Figure

$$g_1 = 1.7058$$
$$g_2 = 1.2296$$
$$g_3 = 2.5408$$
$$g_4 = 1.2296$$
$$g_5 = 1.7058$$
$$g_6 = 1.0000$$

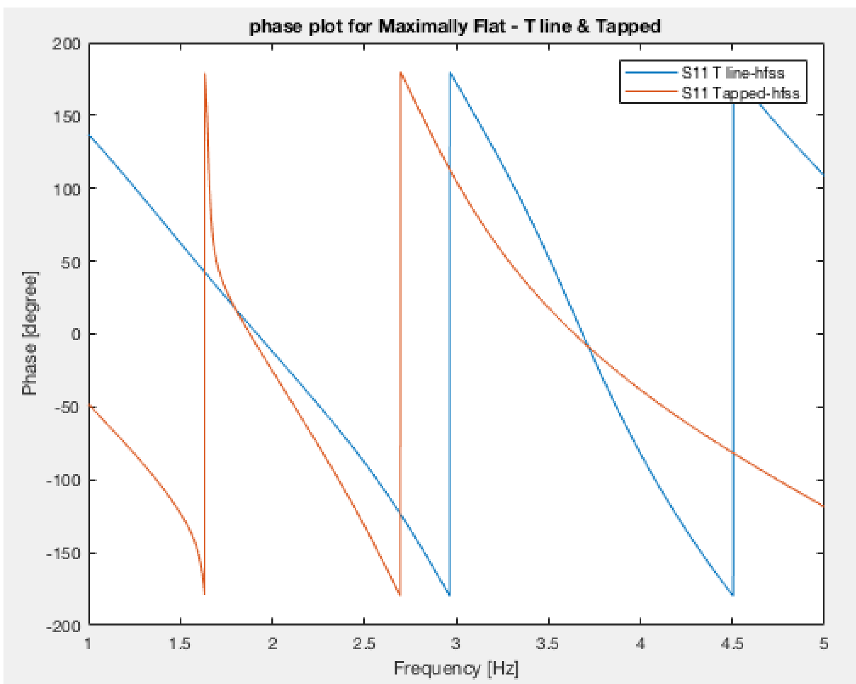
Scaled Impedance values of the equivalent open-circuit stubs using the following equation:

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

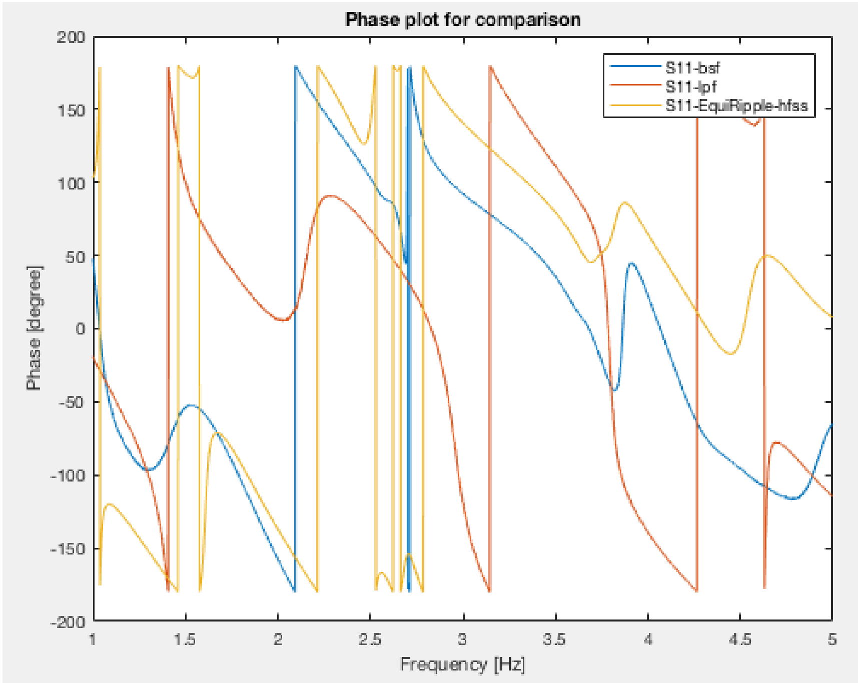
Shunt	Inverter	Shunt	Inverter	Shunt	Inverter	Shunt	Inverter	Shunt
OC	J1	OC	J2	OC	J3	OC	J4	OC
75	50	104	50	50	50	104	50	75
0.25λ	0.25λ	0.25λ	0.25λ	0.25λ	0.25λ	0.25λ	0.25λ	0.25λ

Figure

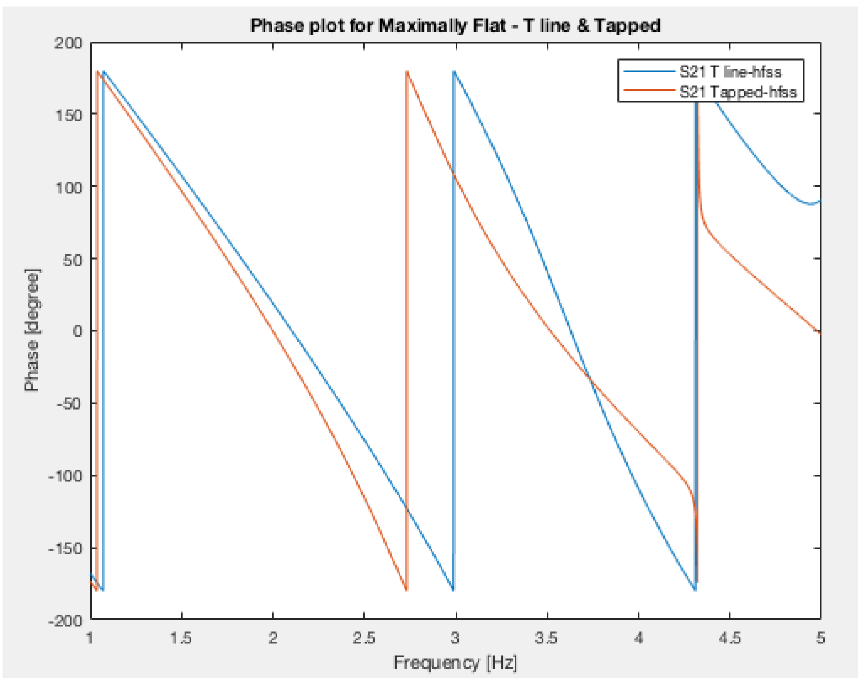
Length of 75 ohm = 14.446mm
Width of 75 ohm = 1.479mm
Length of 104 ohm = 14.743mm
Width of 104 ohm = 0.6685mm
Length of 50 ohm = 14.033mm
Width of 50 ohm = 3.117mm
length of UE = 14.033mm



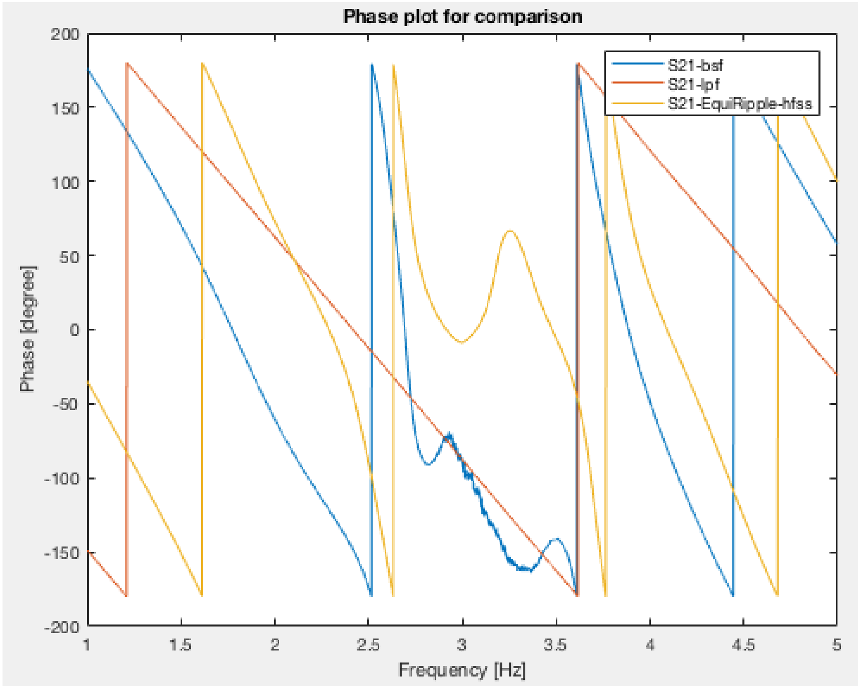
Figure



Figure



Figure


Phase plot for comparison
S21-bsf
S21-lpf
S21-EquiRipple-hfss
Phase [degree]
Frequency [Hz]
200
150
100
50
0
-50
-100
-150
-200
1
1.5
2
2.5
3
3.5
4
4.5
5

Figure

References:

[1] Microwave Engineering 4th Edition, David M. Pozar