Microwave Stepped Impedance Filter Design Sheet

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This sheet is used to design microwave stepped impedance filters. The real author of this sheet is **Lance Lasceri** of **tools.rfdude.com,** I have modified and annotated his original sheet to make it easier to understand, well at least for my application. The maths for this can be found at www.acusd.edu/~ekim/e194rfs01/iec19aek.pdf. I have also added some simulation results at the end.

There are three steps to this filter design:

Step 1, Get the filter g-values, this sheet calculated the g values according to the Chebychev polynomial, but these can be obtained in a variety of ways from books or from a program freely available from my web page. You will be pleased to know that these g-values agree with my program!!

Step 2, Calculate Zo and wavelength depending on the type of filter.
This MathCAD sheet stops at this point.

Step 3, Calculate length and width. One method is to use Linecalc which is part of ADS. For microstrip designs I have written a MathCAD sheet which is available from my wepage that works well for thin tracks, less well for thicker tracks. Also you can try **transcalc.sourceforge.net** for a Linecalc equivalent.

Yellow is user input, Green is output

Main user input area:

$\mu m := 10^{-6} \cdot m$ $\quad nH := 10^{-9} \cdot henry$

$L_{ar\_db} := 0.2$ passband ripple in dB

$N := 7$ order of the filter

$f_c := 10 \cdot GHz$ Cutoff frequency.

$Z_o := 50 \cdot \Omega$

LPF Frequency Response, for Chebychev Polynomials

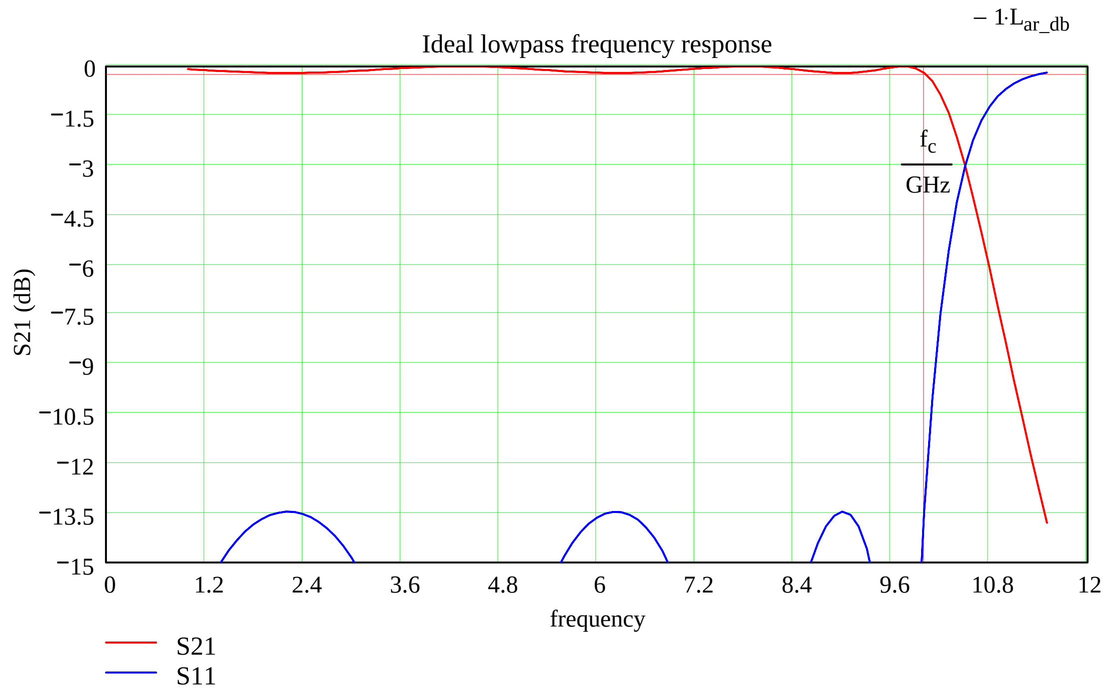
This section plots the frequency response assuming the Chebychev polynomial values calculated later. The frequency response is for the coupled BPF, the LPF response is later.

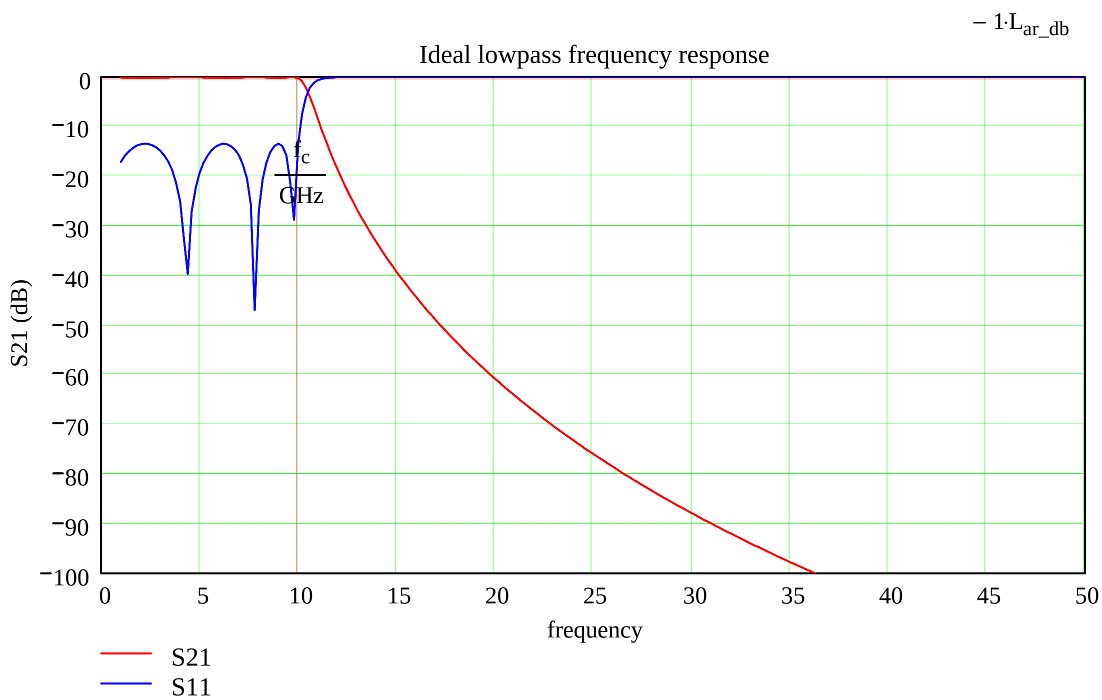
$$Y_o := \frac{1}{Z_o} \qquad \varepsilon := 10^{\frac{L_{ar\_db}}{10}} - 1 \qquad \varepsilon = 0.047$$

$$L_A(f, f_1) := \begin{cases} 10 \cdot \log\left[1 + \varepsilon \cdot \left[\cos\left(\left(N \cdot \text{acos}\left(\frac{f}{f_1}\right)\right)\right)\right]^2\right] & \text{if } f \le f_1 \\ 10 \cdot \log\left[\left[1 + \varepsilon \cdot \left[\cosh\left(\left(N \cdot \text{acosh}\left(\frac{f}{f_1}\right)\right)\right)\right]^2\right]\right] & \text{if } f > f_1 \end{cases}$$

$$S11_A(f, f_1) := 10 \cdot \log\left[1 - 10^{\left(\frac{-L_A(f, f_1)}{10}\right)}\right]$$

$$f_{lp\_hp\_sweep\_wide} := \frac{f_c}{10}, \frac{f_c}{10} + \frac{f_c}{50} .. f_c \cdot 5 \qquad f_{lp\_hp\_sweep\_narrow} := \frac{f_c}{10}, \frac{f_c}{10} + \frac{f_c}{100} .. f_c \cdot 1.15$$





Calculate the Chebychev (g) Polynomials

$k := 1..N$ $\beta := \ln\left(\coth\left(\frac{L_{ar\_db}}{17.37}\right)\right)$ $\gamma := \sinh\left(\frac{\beta}{2\cdot N}\right)$ $a_k := \sin\left[\frac{(2\cdot k-1)\cdot\pi}{2\cdot N}\right]$

$b_k := \gamma^2 + \left(\sin\left(\frac{k\cdot\pi}{N}\right)\right)^2$

$g_k := 0$

$g_0 := 1$

$g_{N+1} := 1$

g(0) and g(N+1) represent the input/output coupling for odd order filters, these are 1 representing the generator (and equal) load resistance

$$g_k := \begin{cases} \frac{2\cdot a_1}{\gamma} & \text{if } k = 1 \\ \frac{4\cdot a_{k-1}\cdot a_k}{b_{k-1}\cdot g_{k-1}} & \text{otherwise} \end{cases}$$

$$g = \begin{pmatrix} 1 \\ 1.372 \\ 1.378 \\ 2.276 \\ 1.5 \\ 2.276 \\ 1.378 \\ 1.372 \\ 1 \end{pmatrix}$$

The next step is to calculate Zo.

This next section converts the g-values to Zo-values. If you wish to use your own g-values, i.e not from the Chebychev polynomial then this is ok and you need to put them here as follows. User sets Zlow and Zhigh based on what is reasonable on the substrate.

$Z_{low} := 20$ $Z_{high} := 120$

$g_{100} := 2$

$angle\_L\_equiv_k := \operatorname{asin}\left(\frac{g_k\cdot\frac{Z_o}{\Omega}}{Z_{high}}\right)$ $angle\_C\_equiv_k := \operatorname{asin}\left[\frac{Z_{low}}{\frac{\left(\frac{Z_o}{\Omega}\right)}{g_k}}\right]$

$angle\_L\_equiv_k =$ (deg)	$angle\_C\_equiv_k =$ (deg)
34.875	33.293
35.047	33.455
71.478	65.543
38.687	36.874
71.478	65.543
35.047	33.455
34.875	33.293

There are a number of points to note:

1. The user needs to choose Zhigh/Zlow depending on the substrate.
2. If the angle exceeds 90 degrees then the ripple and N should be changed.
3. For max repeat frequency then the smaller the maximum angle is better.
4. The filter is designed by switching between the inductance/capacitance values in turn, hence two filters are possible from any given results.

Calculate dimensions

Now we can calculate the length of each section.

$\varepsilon_r := 4.5$ $\qquad \lambda_0 := \dfrac{3 \cdot 10^8 \cdot \frac{m}{s}}{f_c}$ $\qquad \lambda := \dfrac{\lambda_0}{\sqrt{\varepsilon_r}}$ $\qquad \lambda = 14.142\,mm$

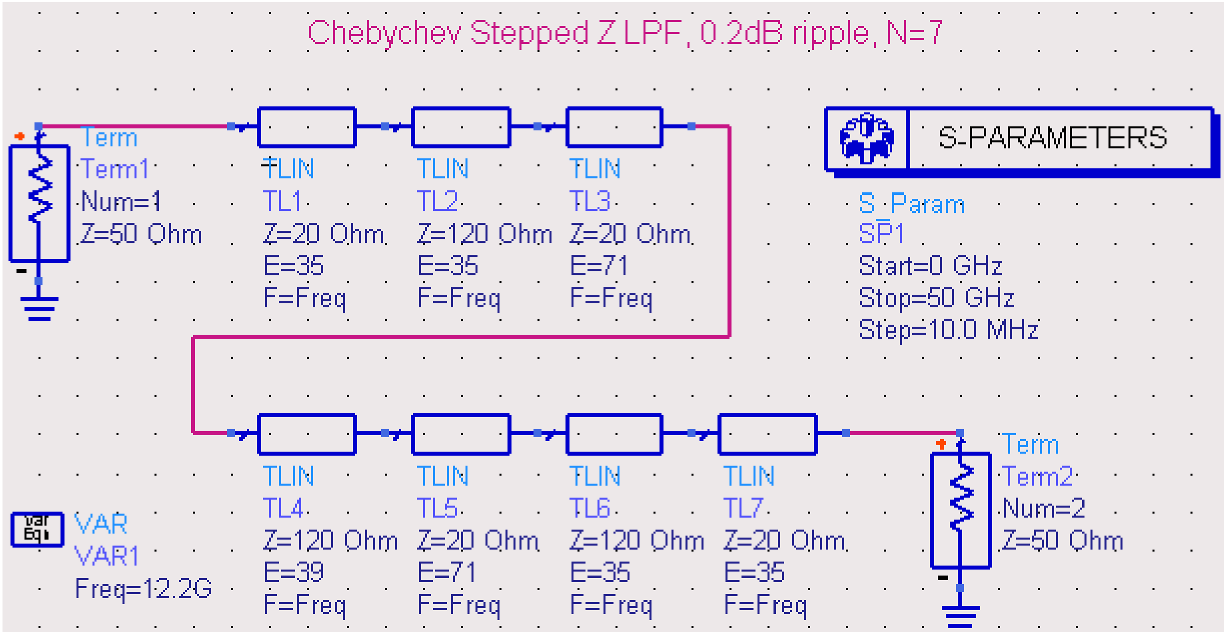
$$length\_L\_equiv_k := \lambda \cdot \frac{angle\_L\_equiv_k}{360 \cdot deg} \qquad length\_C\_equiv_k := \lambda \cdot \frac{angle\_C\_equiv_k}{360 \cdot deg}$$

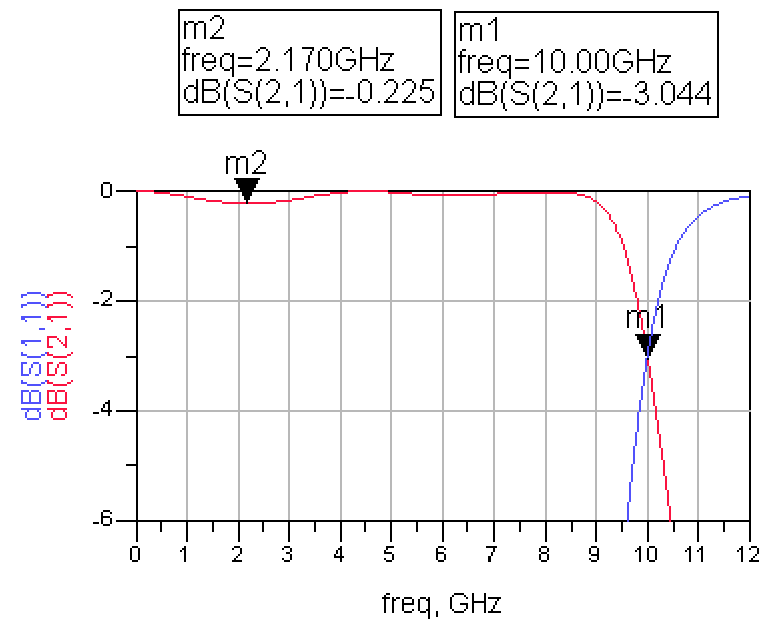
$length\_L\_equiv_k$ = (mm)	$length\_C\_equiv_k$ = (mm)
1.37	1.308
1.377	1.314
2.808	2.575
1.52	1.449
2.808	2.575
1.377	1.314
1.37	1.308

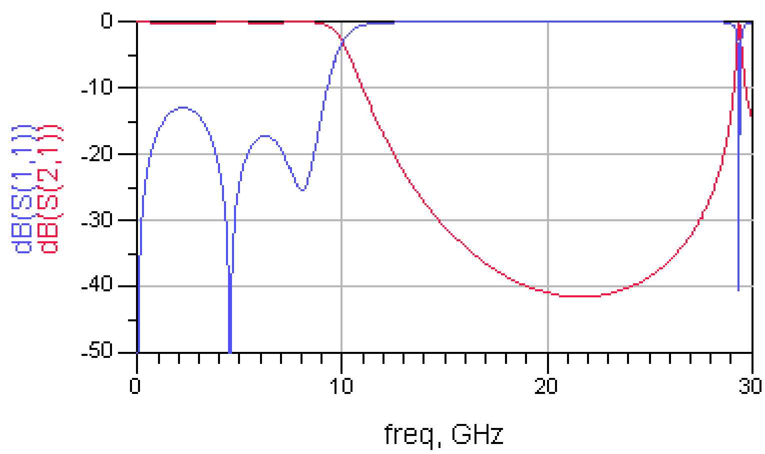
Simulation Results

To test these values I have run a simulation on ADS and as you can see the results are in good agreement. Both the ripple and return loss (S11) agree, but the cutoff frequency was out by 22% and I had to scale this. I'm not sure why this is.

You can see the downside of these filters that the frequency response repeats and the out of band attenuation is not a good we would like.


Chebychev Stepped Z LPF, 0.2dB ripple, N=7
Term
Term1
Num=1
Z=50 Ohm
TLIN
TL1
Z=20 Ohm
E=35
F=Freq
TLIN
TL2
Z=120 Ohm
E=35
F=Freq
TLIN
TL3
Z=20 Ohm
E=71
F=Freq
S-PARAMETERS
S_Param
SP1
Start=0 GHz
Stop=50 GHz
Step=10.0 MHz
VAR
VAR1
Freq=12.2G
TLIN
TL4
Z=120 Ohm
E=39
F=Freq
TLIN
TL5
Z=20 Ohm
E=71
F=Freq
TLIN
TL6
Z=120 Ohm
E=35
F=Freq
TLIN
TL7
Z=20 Ohm
E=35
F=Freq
Term
Term2
Num=2
Z=50 Ohm


m2
freq=2.170GHz
dB(S(2,1))=-0.225
m1
freq=10.00GHz
dB(S(2,1))=-3.044
m2
m1
dB(S(1,1))
dB(S(2,1))
0
-2
-4
-6
0 1 2 3 4 5 6 7 8 9 10 11 12
freq, GHz


dB(S(1,1))
dB(S(2,1))
0
-10
-20
-30
-40
-50
0 10 20 30
freq, GHz