ECE 5180/6180 Microwave Filter Design

Lectures:

- Lumped element filters (also applies to low frequency filters)
- Stub Filters
- Stepped Impedance Filters
- Coupled Line Filters

Lumped Element Filters

Text Section 8.3

Portfolio Question: How do you design a lumped element filter using the Insertion Loss Method

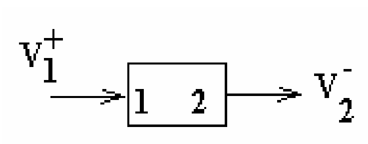
Power Loss Ratio

$$P_{LR} = \frac{Power\ \ Available\ \ from\ Source}{Power\ \ Delivered\ \ to\ \ Load} = \frac{P_{inc}}{P_{load}}$$

Insertion Loss

IL = 10 log P_{LR}

2-port network:



$$\begin{bmatrix} V_1^- \\ V_2^- \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} V_1^+ \\ V_2^+ \end{bmatrix}$$

$$Psource = \frac{\left(V_1^+\right)^2}{Z_{in}} \quad Pload = \frac{\left(V_2^-\right)^2}{Z_L}$$

$$For\ \ Matched\ \ System \quad Z_{in} = Z_L = Z_o$$

$$Then$$

$$\frac{Psource}{Pload} = \left(\frac{V_1^+}{V_2^-}\right)^2 = \frac{1}{\left|S_{21}\right|^2} = \frac{1}{\left|S_{12}\right|^2}$$

$$(For\ \ Reciprocal\ \ System \quad S_{21} = S_{12})$$

$$P_{LR} = \frac{1}{1-\left|\Gamma_{in}\right|^2} = \frac{1}{1-\left|\Gamma_{in}(\omega)\right|^2}$$

Filter Design by insertion loss method controls $\Gamma(\omega)$ to control passband and stopband of filter.

Filter parameters:

- Passband -- frequencies that are passed by filter
- Stopband -- frequencies that are rejected
- Insertion loss -- how much power is transferred to load in passband
- Attenuation -- how much power is rejected (not transferred to the load) in the stopband

Cutoff rate or attenuation rate -- how quickly the filter transitions from pass-to-stop or stop-to-passbands
Phase response -- Linear phase response in the passband means that signal will not be distorted.

Classes of Filters:
Determined by Γ.
We have not proven this yet, but a useful mathematical proof (section 4.1) shows that $|\Gamma(\omega)|^2$ is an even function of ω. So $|\Gamma(\omega)|^2$ can be written as a polynomial in ω^2 .

$$\left|\Gamma(\omega)\right|^2 = \frac{M(\omega^2)}{M(\omega^2)+N(\omega^2)}$$

$$P_{LR} = 1+\frac{M(\omega^2)}{N(\omega^2)}$$

The class of filter is controlled by the type of polynomial used.
Polynomials M and N can be

- Binomial (Butterworth) -- Maximally Flat
- Chebyshev -- Equal Ripple
- Elliptic -- Specified Minimum Stopband Attenuation (faster cutoff)
- Linear Phase

Binomial / Butterworth / Maximally Flat
Low Pass Filter Design:

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

N = Filter Order
ω = frequency of interest
ω_c = cutoff frequency

At ω_c , $P_{LR} = 1+k^2$
If the -3dB point is defined to be the cutoff point (common), k=1
For $\omega \gg \omega_c$ then $P_{LR} \approx k^2 (\omega/\omega_c)^{2N}$ which means Insertion Loss increases at a rate of 20N dB / decade.
(This allows us to increase the steepness of the cutoff by adding more sections.)

Chebyshev / Equal Ripple Filters

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

Where T_N are Chebyshev polynomials

Ripples are equal-in-size = $1+k^2$
Cutoff Rate is 20N dB/decade, same as binomial.
Insertion loss in the stopband is $(2^{2N})/4$ greater than binomial.

Elliptic and Linear Phase Filters
Other options, see textbook.

Filter Design Method
1. Design a LP filter for normalized Z,ω
2. Scale Z.

3. Convert from LP to HP or BP as desired.
4. Convert from lumped to distributed elements as desired.

1. Binomial Design of LP Filter for Normalized Z,ω

a. Determine how many elements are needed (N)

Find ω/ω_c and look at the figure for attenuation in the stopband (Fig.8.26, p.450)

Example: How many elements are required to design a maximally-flat filter with a cutoff frequency of 2 GHz if the filter must provide 20 dB of attenuation at 4 GHz?

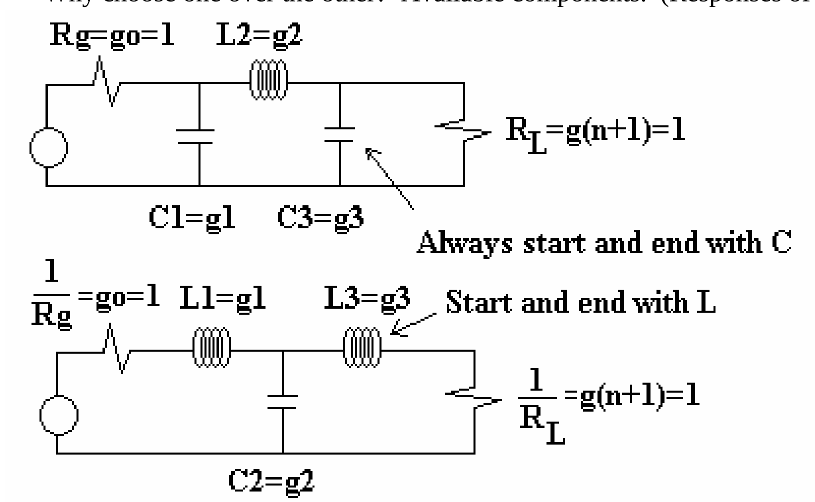
For this case, $|\omega/\omega_c|-1 = |4 / 2| -1 = 1.0$ (bottom axis). Find N line on filter that is ABOVE the desired attenuation. N=4.

b. Find resistance or conductance values from Table 8.3

Look at N=3.
g1 = 1.0; g2 = 2.0; g3 = 1.0; g4 = 1.0

c. Choose LP Filter Prototype

Why choose one over the other? Available components. (Responses of both are identical.)



Notes:
1) Rg and RL must be REAL. What if they aren't? (Add a length of line, resonate, or absorb imaginary part.)
2) The designs in our book always have Rg=RL. What if they are not equal? There are other tables… see handout. This is effectively matching and filtering simultaneously.
3) Design so far has considered normalized impedances Rg=RL=1 and normalized frequency (ω_c =1) … Use impedance and frequency scaling if they aren't 1.

1. **Chebyshev (Equal Ripple) Design of LP Filter for Normalized Z,ω**

Same steps as for binomial. There are only a few differences….

(a) Determine number of elements (N). This will always be less than or equal to binomial. Use Figure 8.27, with choice of size of ripple.
(b) Use table 8.4, with same choice of ripple as used in part a.
(c) Same as binomial.

2. Impedance and Frequency Scaling (normalization)

To build the same filter for Zo = Rg = RL and a given cutoff frequency ω_c
Use the same filter prototypes but scale the values:

(a) *Top filter prototype*
Rg=(Zo)(go)=
C1=g1 / (Zo ω_c)
L2=(Zo)(g2) / ω_c
C3=g3 / (Zo ω_c)
RL = (Zo)(g4)

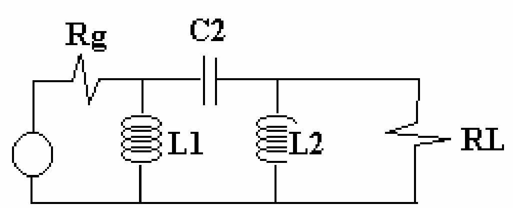
(b) *Bottom filter prototype*
Rg=1/(Zo go)
L1=(Zo)(g1) / ω_c
C2=g2 / (Zo ω_c)
L3=(Zo)(g3) / ω_c
RL=1/(Zo g4)

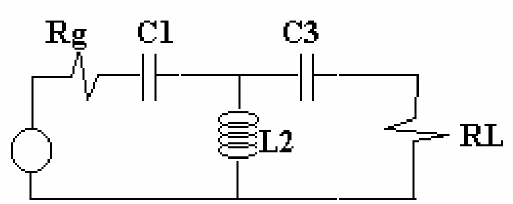
Binomial and Chebyshev are the same here, except for one difference:
RL for binomial is always matched.
RL for odd-order Chebyshev filters is NOT matched. Use a quarter-wave transformer to match.

Example:
For 0.5 dB ripple and N=3, g3=1.9841. For top prototype, RL=1.9841 Zo, which is not matched.
Quarterwave transformer would have Zq=($\sqrt{1.9841}$) Zo

3. Convert from LP to HP

High Pass Configurations





For both prototypes:
$C_k = 1/(Zo\ \omega_c\ g_k)$
$L_k = Zo/(\omega_c\ g_k)$
For top prototype:
Rg = Zo go
$R_L = Zo / g_{n+1}$
For bottom prototype:
Rg = 1 / (Zo go)
$R_L = 1/(Zo\ \ g_{n+1})$

3. Convert from LP to Bandpass or Bandstop

Normalized bandwidth

$$\Delta = \frac{\omega_2 - \omega_1}{\omega_o}$$

ω_1 = lower limit
ω_2 = upper limit
$\omega_o = \sqrt{\omega_1 \omega_2}$

See Table 8.6 p. 461 for conversions.

To use for unnormalized filters:
L → L Zo
C → C / Zo