MICROWAVE ENGINEERING

Lecture 28:
Microwave
filters - part 2

INSERTION LOSS METHOD

Perfect filter:
- zero insertion loss in the passband
- infinite attenuation in the stopband
- linear phase response in passband to avoid distortion

ORDER OF THE FILTER = NUMBER OF REACTIVE ELEMENTS

Power Loss Ratio

$$P_{LR} = \frac{\text{Power at the source}}{\text{Power at the load}} = \frac{P_{INC}}{P_{LOAD}} = \frac{1}{1-|\Gamma(\omega)|^2}$$

The INSERTION LOSS:

$$IL = 10 \log P_{LR}$$

$$|\Gamma(\omega)|^2 = \frac{M(\omega^2)}{M(\omega^2)+N(\omega^2)} \Rightarrow \underbrace{P_{LR} = 1 + \frac{M(\omega^2)}{N(\omega^2)}}_{\text{ALL FILTERS FALL INTO THIS FORM}}$$

Typical Response is:

- **MAXIMALLY FLAT** (Binomial or Butterworth)

A low-pass filter of this type

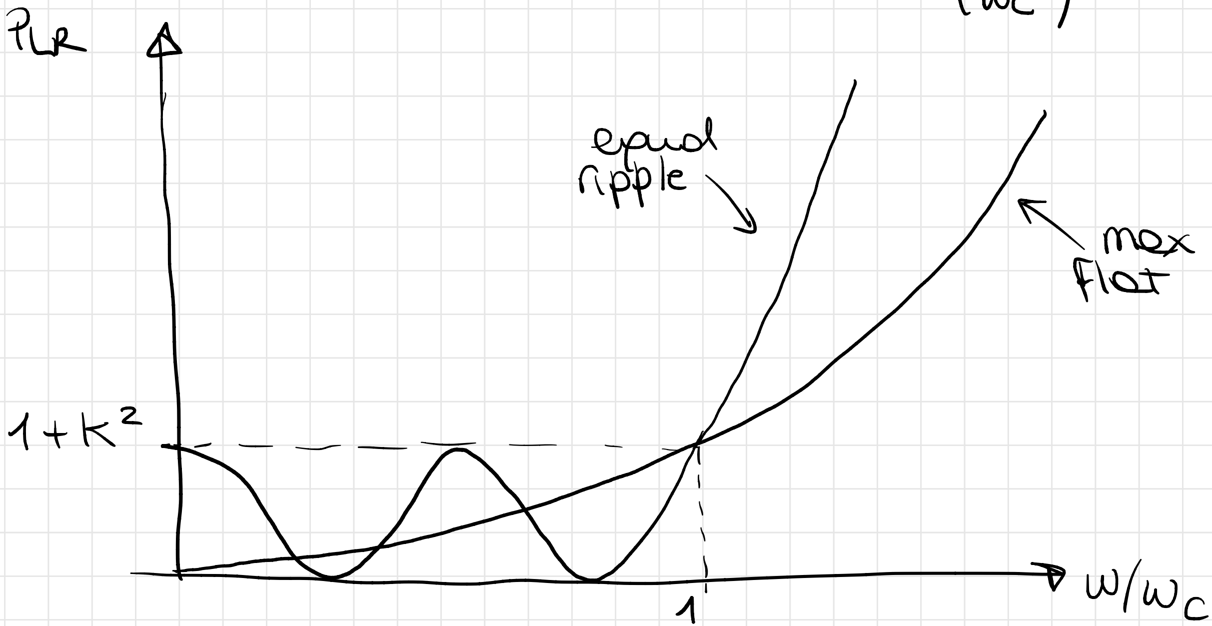
$$P_{LR} = 1 + k^2\left(\frac{\omega}{\omega_c}\right)^{2N}$$

N order of the filter

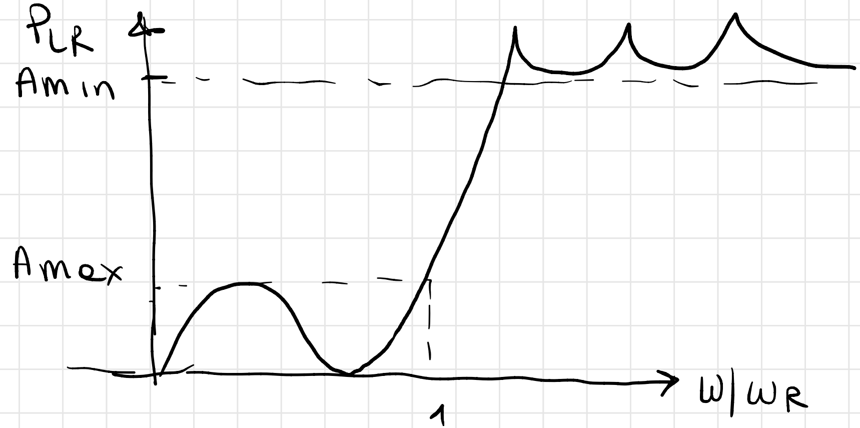
ω_c is cut-off frequency

- EQUAL RIPPLE (Chebyshev polynomial)

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



- <u>ELLIPTIC FUNCTION</u>



- <u>LINEAR PHASE FILTERS</u> → avoids distortion

  cons: less sharp cut-off

<u>DESIGN PROCESS</u>

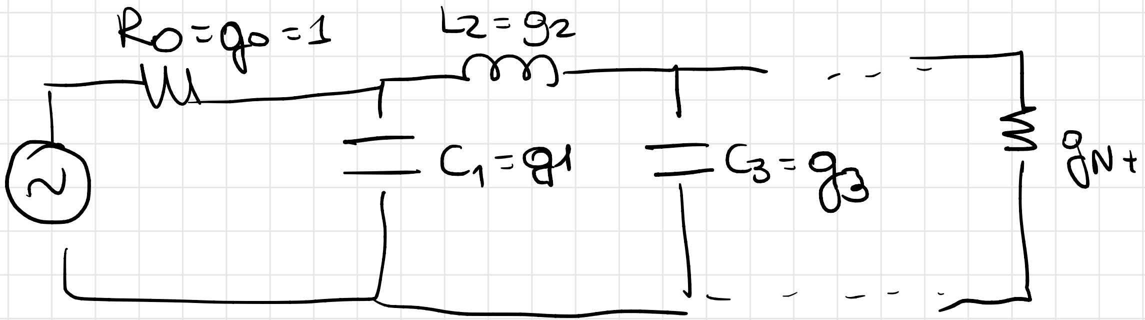
SPECIFICATION → LOW-PASS PROTOTYPE DESIGN → SCALING AND CONVERSION → IMPLEMENTATION

PROTOTYPES

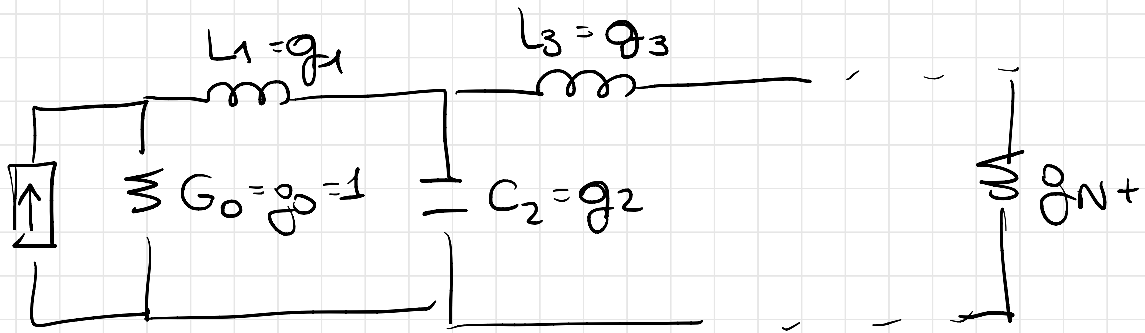
Designed with source impedance $R_S = 1\,\Omega$
Cut-off freq. $\omega_c = 1$

- Maximally flat prototypes:

① SHUNT ELEMENT START



② SERIES ELEMENT START



$g_0 = \begin{cases} \text{generator resistance} \rightarrow \text{shunt start} \\ \quad " \qquad \text{conductance} \rightarrow \text{series start} \end{cases}$

$\underset{K = 1:N}{g_K} = \begin{cases} \text{inductance} \rightarrow \text{series ind.} \\ \text{capacitance} \rightarrow \text{shunt cap.} \end{cases}$

$g_{N+1} = \begin{cases} \text{load resistance} \rightarrow \text{if } g_N \text{ is shunt cap.} \\ \quad " \qquad \text{conductance} \rightarrow \text{if } g_N \text{ is series ind.} \end{cases}$

- <u>Equal Ripple prototypes</u> → identical circuit as in max flat
Values of g are taken from a different table.

FILTER TRANSFORMATIONS

Impedance scaling

A source resistance R_0 can be obtained by scaling the filter components as follows:

$$L' = R_0 L$$

$$C' = \frac{C}{R_0}$$

$$R_S' = R_0$$

$$R_L' = R_L R_0$$

Frequency scaling To move the cut-off freq. from 1 to ω_c

$$P'_{LR}(\omega) = P_{LR}\left(\frac{\omega}{\omega_c}\right) \leftarrow \text{stretching the passband}$$

$$L_k' = \frac{L_k}{\omega_c}$$

$$C'_k = \frac{C_k}{\omega_c}$$

Scaling both impedance and freq.: $L_k' = \frac{R_0 L_k}{\omega_c}$ $C_k' = \frac{C_k}{R_0 \omega_c}$

low-pass to high-pass transformation: Replace ω with $\frac{\omega_c}{\omega}$

$$C_k' = \frac{1}{\omega_c L_k} \qquad L_k' = \frac{1}{\omega_c C_k}$$

with impedance scaling $C_k' = \dfrac{1}{R_0 \omega_c L_k}$ $L_k' = \dfrac{R_0}{\omega_c C_k}$

Band-pass and band-stop transformations

If we want a bandpass response between ω_1 and ω_2

fractional bandwidth $\Delta = \dfrac{\omega_2 - \omega_1}{\omega_0}$ $\omega_0 = \sqrt{\omega_1 \omega_2}$ center freq.

The new elements:

The single element L_k gets transformed into a series LC circuit

$$\begin{cases} L_k' = \dfrac{L_k}{\Delta \omega_0} \\[2ex] C_k' = \dfrac{\Delta}{\omega_0 L_k} \end{cases}$$

the shunt capacitors C_k are transformed in shunt LC circuit with elements

$$\begin{cases} L_k' = \dfrac{\Delta}{\omega_0 C_k} \\ \\ C_k' = \dfrac{C_k}{\Delta \omega_0} \end{cases}$$

If we want a stopband response between ω_1 and ω_2

series inductor will be replaced with shunt LC

$$\begin{cases} L_k' = \dfrac{\Delta L_k}{\omega_0} \\ C_k' = \dfrac{1}{\omega_0 \Delta L_k} \end{cases}$$

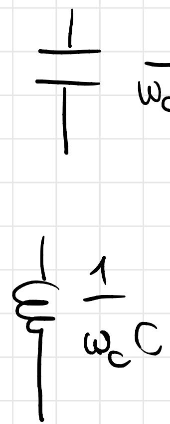
shunt capacitor becomes a series LC circuit

$$\begin{cases} L_k' = \dfrac{1}{\omega_0 \Delta C_k} \\ C_k' = \dfrac{\Delta C_k}{\omega_0} \end{cases}$$

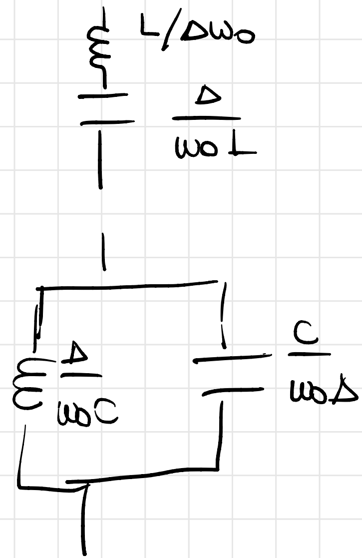
SUMMARY TRANSFORMATIONS

LOW-PASS

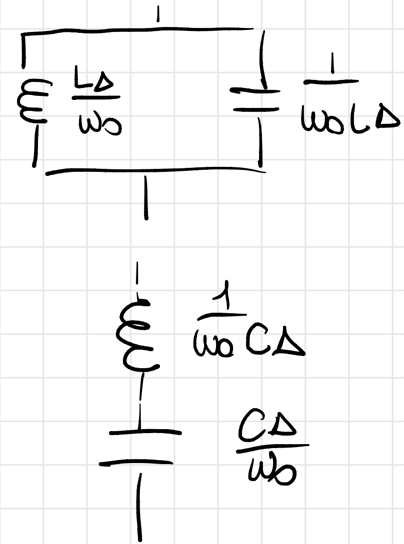
HIGH-PASS



BANDPASS



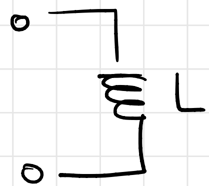
STOPBAND



FILTER IMPLEMENTATION

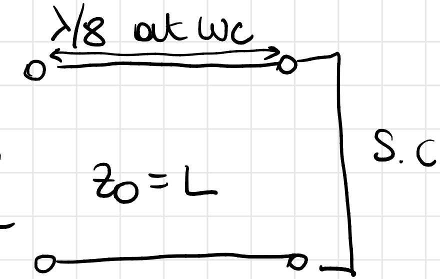
Richard's Transformations — Replace lumped elements with commensurate lines:

$jX_L \Rightarrow$

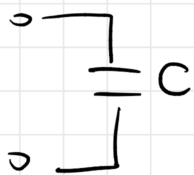


equivalent to

$\Rightarrow jX_L$

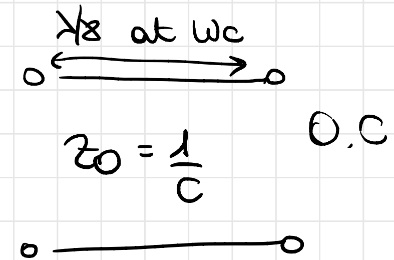


$jB_C \Rightarrow$



equivalent to

$\Rightarrow jB_C$



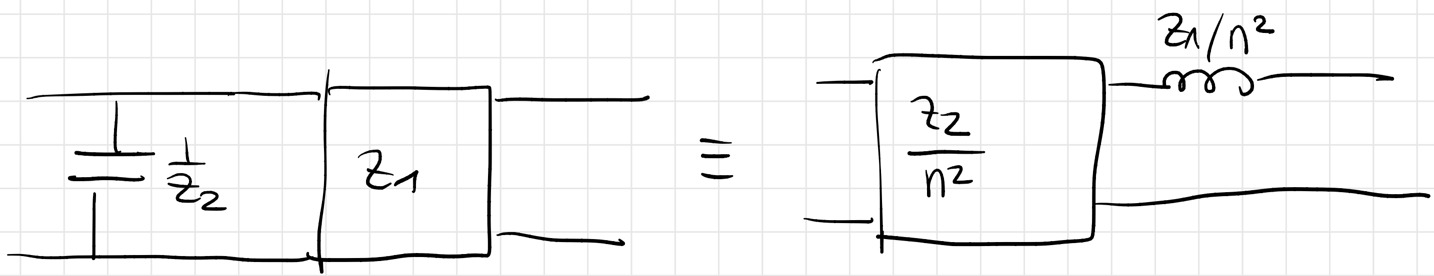
KURODA IDENTITIES

- Physically separate TL stubs
- Transform series stubs into shunt stubs and v.v.
- Change impractical charact. impedance into more practical ones

All T.L. are intended to be $\lambda/8$ at ω_c. Inductors and capacitors represent SC. and OC stubs

4 IDENTITIES

1



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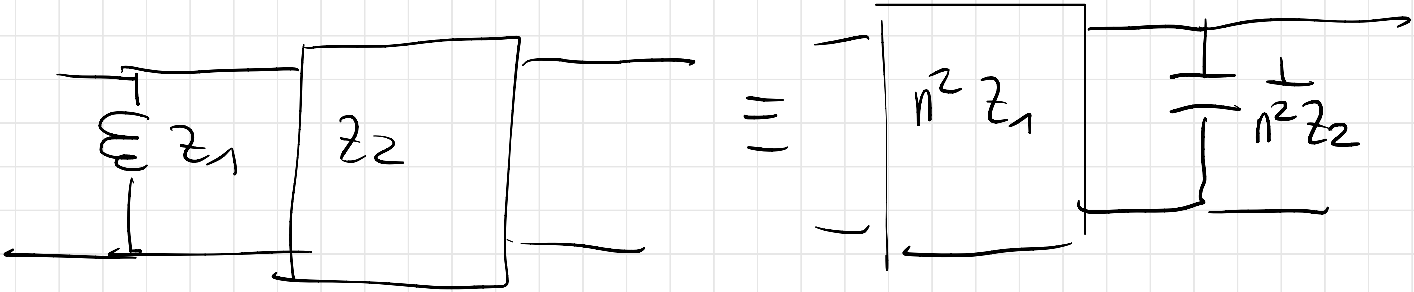
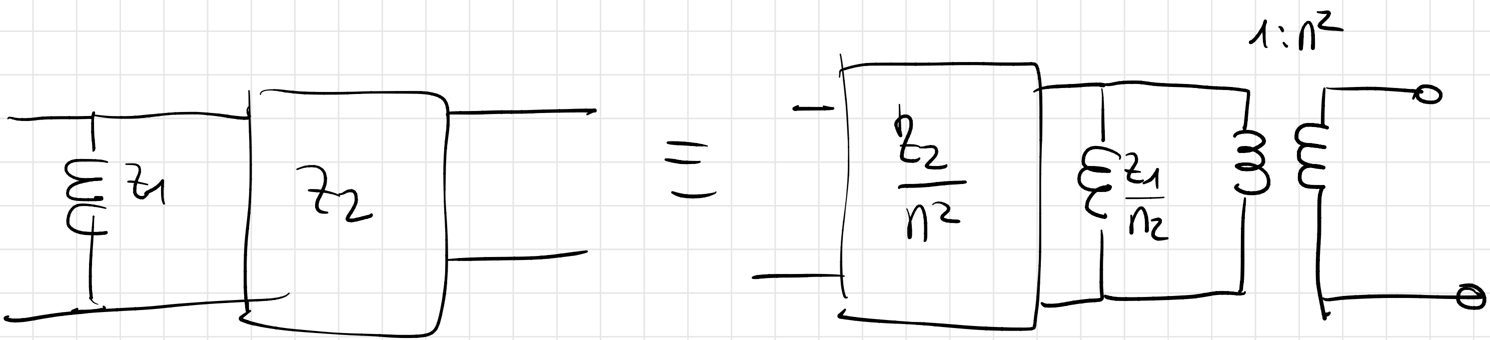


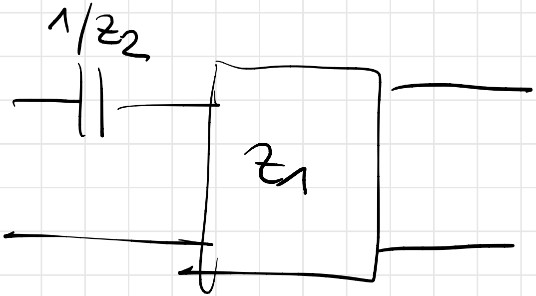
Z_1
Z_2
$\equiv$
$n^2 Z_1$
$\frac{1}{n^2 Z_2}$

3

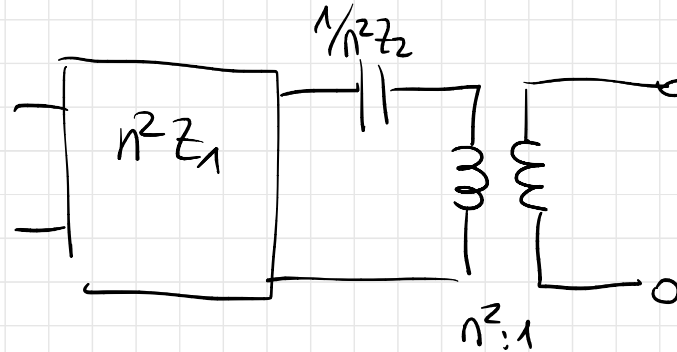


Z_1
Z_2
$\equiv$
$\frac{Z_2}{n^2}$
$\frac{Z_1}{n_2}$
$1:n^2$

4



$\equiv$



$$\boxed{n^2 = 1 + \frac{z_2}{z_1}}$$