Introduction

Courtesy of Microdata Telecom Innovation

Courtesy of Powerwave Technologies

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The majority of modern microwave filters are designed by using the insertion-loss method, whereby the amplitude response of the filter is approximated by using network synthesis techniques that have been extended to accommodate microwave distributed circuit elements. A general four-step procedure is followed: determination of filter specifications, design of a low-pass prototype filter, scaling and transforming the filter, and implementation (conversion of lumped elements to distributed elements).
Introduction - Prototype Filter Networks

\[ K = \omega M \]

\[ \begin{align*}
  v_1 &= j\omega M \cdot i_2 \\
  v_2 &= j\omega M \cdot i_1 \\
  K &= \omega M = \omega L_0 k
\end{align*} \]
\[
\begin{align*}
 v_1 &= j \omega M_{01} \cdot i_1 \\
 0 &= j \omega M_{01} \cdot i_0 + j \omega L_0 \left( \delta_{01}(\omega) - j Q_0^{-1} \right) i_1 + j \omega M_{12} \cdot i_2 \\
 0 &= j \omega M_{12} \cdot i_1 + j \omega L_0 \left( \delta_{02}(\omega) - j Q_0^{-1} \right) i_2 + j \omega M_{23} \cdot i_3 \\
 0 &= j \omega M_{23} \cdot i_2 + j \omega L_0 \left( \delta_{03}(\omega) - j Q_0^{-1} \right) i_3 + j \omega M_{34} \cdot i_4 \\
 i_0 &= j \omega L_0 \cdot \mathbf{K} \cdot \mathbf{i}
\end{align*}
\]
\[
\delta_{w} = 1 - \frac{\omega_{0z}^2}{\omega^2}
\]

\[
u_1 \left(\begin{array}{c}
R_1 \\
R_2 \\
C_1 \\
L_1 \\
C_2 \\
L_2 \\
C_3 \\
L_3 \\
C_4 \\
L_4
\end{array}\right) \left(\begin{array}{c}
i_1 \\
i_2 \\
i_3 \\
i_4
\end{array}\right) = 0
\]

\[
\mathbf{u} = j\omega L_0 \cdot \mathbf{K} \cdot \mathbf{i}
\]

\[
\mathbf{K} = \begin{bmatrix}
0 & k_{01} & 0 & 0 & 0 \\
k_{01} & 0 & \delta_{01}(\omega) & k_{13} & 0 \\
0 & \delta_{02}(\omega) & 0 & k_{23} & 0 \\
0 & 0 & k_{23} & 0 & \delta_{03}(\omega) \\
0 & 0 & 0 & k_{34} & 0
\end{bmatrix}
\]

\[
\mathbf{Q} = \begin{bmatrix}
0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

Resonant frequency
Q-values
Coupling Matrix
Introduction – Modern Filter Synthesis (example)

Output from synthesis tool is the Coupling Matrix

A prototype filter network based on the synthesised coupling matrix is easy to build for use as a building block in a system simulation.
System Analysis – Optimisation

The filters can be optimised based on the cascaded system performance.
Filter Realisation – Coupling Extraction

The key to the realisation of a synthesised prototype network:

– How to extract the mutual couplings between resonators of an arbitrary 3D geometry?

Design variables v.s Coupling coefficients?
Coupling Extraction – Theory

Generalized bandpass filter circuit with admittance inverters

Coupling coefficients can be calculated from (MYJ)

\[ k_{j,j+1} = \frac{J_{j,j+1}}{\sqrt{b_j/b_{j+1}}}_{j=1}^{n-1} \]

\[ b_j = \frac{f_0}{2} \left| \frac{dB_j}{df} \right|_{f=f_0} \]

External Q-values can be calculated from (Ness)

\[ Q_e = \frac{\Gamma_d(\omega_0) \cdot \omega_0}{4} \]

\[ \Gamma_d(\omega) = -\frac{\partial \angle S_{11}}{\partial \omega} \]


Coupling Extraction – Implementation

1. Place lumped ports at every resonator

\[ J = -Y_{12} \]

\[ J_{i,j} = \text{im}(Y_{i,j}) \]

\[ b_j = \text{deriv}(\text{im}(Y_{j,j})) \]

\[ k_{j,j+1} = \left. \frac{J_{j,j+1}}{b_j b_{j+1}} \right|_{j=1}^{p-1} \]

\[ b_j = \left. \frac{f_0}{2} \cdot \frac{dB_j}{df} \right|_{f=f_0} \]
Coupling Extraction – Port Re-normalisation

Port 1
(Zp = 50 Ω)

Port 2
(Zp = 50 Ω)

Port 3
(Zp = 50 Ω)

Example:

Q = R / ω L

f_0 = 1 GHz
L = 1 nH
Q = 3000
R → 3000 * 2π

R = 50 ohm
Q → 50 / 2π

S_{11}

Z_{norm} = 10^{10} Ω
(open)

Z_{norm} = 10^{-10} Ω
(short)
Create Output Variables

(HFSS > Results > Output Variables)

\[ k_{BW,i,j} = 2 \cdot B_{i,j} \sqrt{\frac{dB_{i,j}}{df} \cdot \frac{dB_{j,j}}{df}} \]

\[ Q_e = \frac{\Gamma_d(\omega_0) \cdot \pi \cdot f_0}{2} \]

\[ 2 \cdot \text{im}(Y(1,2)) \cdot 10^{-6} / \sqrt{\text{deriv}(\text{im}(Y(1,1))) \cdot \text{deriv}(\text{im}(Y(2,2))))} \]

\[ \max(\text{GroupDelay}(0,0) \cdot \text{freq} \cdot \pi / 2) \]
Coupling Extraction

3 Extract Couplings for a given set of Design variables

Design variables

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<th>Value</th>
<th>Unit</th>
<th>Evaluated Value</th>
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<tr>
<td>IcL</td>
<td>7.4</td>
<td>mm</td>
<td>7.4 mm</td>
<td>Design</td>
</tr>
</tbody>
</table>

(Analytical derivatives*)

*) The estimated aperture heights from a single extraction using Analytical Derivatives and “Report Tuning” resulted in couplings within approx 5% from synthesis.
If making variants of the filter, getting the “designs curves” it’s probably more preferable to run a parametric sweep rather than multiple optimisations.
DynamicLink between AnsoftDesigner and HFSS

- Place capacitors at resonator ports
- Interpolate or Solve missing solutions

Good correspondence with synthesis apart from at the transmission zeros. WHY???
Coupling Extraction – *Parasitic Couplings*

How large impact does the parasitic couplings have on the ideal synthesised response?
Port Tuning

Modify the prototype network built from synthesis and include the spurious coupling.
Port Tuning
• A prototype filter network was built in Ansoft Designer based on a synthesised coupling matrix and used in a system simulation.

• Based on the system simulations, a modified coupling matrix was retrieved.

• An efficient method of coupling extraction was implemented in HFSS for the realisation of the coupling matrix.

• The results from HFSS was dynamically linked into Ansoft Designer and the filter was ”virtually tuned”.

• It was shown that parasitic couplings can have huge impact on the filter performance.
  – The method for coupling extraction makes it possible to calculate these parasitics. Therefore, it is possible to account for parasitics in an early stage of the design.
Thank You!