Band-Pass Filter Design Example

Attenuation response of a third-order 3-dB ripple bandpass Chebyshev filter centered at 2.4 GHz. The lower cut-off frequency is $f_L = 2.16$GHz and the upper cut-off frequency is $f_U = 2.64$GHz.
RF/μW Stripline Filters

- Filter components become impractical at frequencies higher than 500 MHz
- Can apply the normalized low pass filter tables for lumped parameter filters to stripline filter design
- Richards Transformation and Kuroda’s Identities are used to convert lumped parameter filter designs to distributed filters
Richards Transformation: Lumped to Distributed Circuit Design

• Open- and short-circuit transmission line segments emulate inductive and capacitive behavior of discrete components

• Based on: \( Z_{in} = jZ_o \tan(\beta l) = jZ_o \tan(\theta) \)

• Set Electrical Length \( l = \lambda/8 \) so

\[
\theta = \beta l = \frac{\pi}{4} \frac{f}{f_o} = \frac{\pi}{4} \Omega
\]
Richards Transformation: Lumped to Distributed Circuit Design

• Richards Transform is:

\[ jX_L = j\omega L = jZ_o \tan \left( \frac{\pi}{4} \Omega \right) = SZ_o \]

and \[ jB_C = j\omega C = jY_o \tan \left( \frac{\pi}{4} \Omega \right) = SY_o \]

• For \( l = \lambda/8 \), \( S = j1 \) for \( f = f_o = f_c \)
Richards Transformation: Lumped to Distributed Circuit Design

\[ jX_L \rightarrow L \]

\[ jB_C \rightarrow C \]

\[ Z_o = 1/(j\omega C) \]

\[ Z_o = j\omega L \]

\[ \lambda/8 \text{ at } \omega_c \]
Unit Elements : UE

• Separation of transmission line elements achieved by using Unit Elements (UEs)
• UE electrical length: \( \theta = \pi \Omega /4 \)
• UE Characteristic Impedance \( Z_{UE} \)

\[
\begin{bmatrix}
A & B \\
C & D
\end{bmatrix}_{UE} = \begin{bmatrix}
cos\theta & jZ_{UE} \sin\theta \\
j Z_{UE} \sin\theta & cos\theta
\end{bmatrix} = \frac{1}{\sqrt{1+\Omega^2}} \begin{bmatrix}
1 & j\Omega Z_{UE} \\
j\Omega Z_{UE} & 1
\end{bmatrix}
\]
# The Four Kuroda’s Identities

<table>
<thead>
<tr>
<th>Initial Circuit</th>
<th>Kuroda’s Identity</th>
</tr>
</thead>
<tbody>
<tr>
<td>$Y_C = S/Z_2$</td>
<td>$Z_L = SZ_1/N$</td>
</tr>
<tr>
<td>Unit element $Z_1$</td>
<td>Unit element $Z_2/N$</td>
</tr>
<tr>
<td>$Z_L = Z_1S$</td>
<td>$Y_C = S/(NZ_2)$</td>
</tr>
<tr>
<td>Unit element $Z_2$</td>
<td>Unit element $NZ_1$</td>
</tr>
<tr>
<td>$Y_C = S/Z_2$</td>
<td>$Y_C = S/(NZ_2)$</td>
</tr>
<tr>
<td>Unit element $Z_1$</td>
<td>Unit element $NZ_1$</td>
</tr>
<tr>
<td>$Z_L = Z_1S$</td>
<td>$Z_L = SZ_1/N$</td>
</tr>
<tr>
<td>Unit element $Z_2$</td>
<td>Unit element $Z_2/N$</td>
</tr>
</tbody>
</table>

$V = 1 + Z_2/Z_1$
Kuroda’s Equivalent Circuit

\[ Z_2 = \frac{Z_1}{N} \]

- Short Circuit Series Stub
- Open Circuit Shunt Stub
- Unit Element

\[ Z_1 \]

\[ Z_2 \]

\[ l \]

\[ l \]
Realizations of Distributed Filters

• Kuroda’s Identities use redundant transmission line sections to achieve practical microwave filter implementations
• Physically separates line stubs
• Transforms series stubs to shunt stubs or vice versa
• Change practical characteristic impedances into realizable ones
Filter Realization Procedure

• Select normalized filter parameters to meet specifications
• Replace $L$’s and $C$’s by $\lambda_o /8$ transmission lines
• Convert series stubs to shunt stubs using Kuroda’s Identities
• Denormalize and select equivalent microstriplines
Filter Realization Example

• 5th order 0.5 dB ripple Chebyshev LPF
• $g_1 = g_5 = 1.7058$, $g_2 = g_4 = 1.2296$, $g_3 = 2.5408$, $g_6 = 1.0$
Filter Realization Example

• \( Y_1 = Y_5 = 1.7058, \ Z_2 = Z_4 = 1.2296, \ Y_3 = 2.5408; \) and \( Z_1 = Z_5 = 1/1.7058, \ Z_3 = 1/2.5408 \)
Filter Realization Example

- Utilizing Unit Elements to convert series stubs to shunt stubs
Filter Realization Example

- Apply Kuroda’s Identities to eliminate first shunt stub to series stub

\[ Z_1 = 0.6304 \text{ s.c.} \]
\[ Z_2 = 1.2296 \text{ s.c.} \]
\[ Z_4 = Z_2 \text{ s.c.} \]
\[ Z_5 = Z_1 \text{ s.c.} \]

\[ r_G = 1 \]
\[ Z_{UE1} = 0.3696 \]
\[ Z_{UE2} = Z_{UE1} \]

\[ r_L = 1 \]
\[ Z_3 = 0.3936 \]

\[ \text{o.c.} \]
Filter Realization Example

- Deploy second set of UE’s in preparation for converting all series stubs to shunt stubs
Filter Realization Example

- Apply Kuroda’s Identities to eliminate all series stubs to shunt stubs

- \( Z_1 = \frac{1}{Y_1} = NZ_2 = (1 + \frac{Z_2}{Z_1})Z_2 = 1 + (1/0.6304); \ Z_2 = 1 \) and \( Z_1 = 0.6304 \)
Filter Realization Example

• Final Implementation
Filter Realization Example

• Frequency Response of the Low Pass Filter