CHAPTER 10
RF/MICROWAVE FILTERS
射頻微波濾波器

Lugwig, *RF Circuit Design: Theory & Applications*, Ch 5
Pozar, *Microwave & RF Design*, Ch 5
Pozar, *Microwave Engineering*, Ch 9
* J.-S. Hong & M. J. Lancaster, *Microstrip Filters for RF/Microwave Applications*

- Filter Configurations & Terms
- Periodic Structure
- Filter Design by the Image Parameter Method
  - Image Parameters for $T$ and $\pi$ Networks
  - Constant-$K$ Filter Sections
  - $m$-Derived Filter Sections
  - Composite Filters
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- Stepped-Impedance Low-Pass Filters
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Microstrip coupled line filter in a microwave mixer

LTCC Ceramic Bandpass filter for WLAN
Basic Filter Types

(a) Low-pass filter

(b) Bandpass filter

(c) High-pass filter

BPF Parameters:

- **Insertion Loss (IL):** \( IL = 10 \log(P_{in} / P_L) \)
- **Ripple; Bandwidth:** \( BW_{3dB} = f_U(3dB) - f_L(3dB) \)
- **Shape Factor:** describing filter sharpness
- **Rejection:** often specifying **60 dB as the rejection rate**
### Band-Pass Filter (BPF) 帶通濾波器

<table>
<thead>
<tr>
<th>Term 用語</th>
<th>定義 規定</th>
</tr>
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<tbody>
<tr>
<td>Nominal frequency</td>
<td>Specified Center Frequency. 規定的中心頻率</td>
</tr>
<tr>
<td>Passband width 通過帶域幅</td>
<td>The frequency band width in which the attenuation is same or less than a specified value A. Pass band width is specified by minimum value. 頻帶寬度的衰減是相同或低於規定的數值A。通帶（傳輸頻帶）寬度是以最小限度值設定。</td>
</tr>
<tr>
<td>Stopband width 減衰帶域幅</td>
<td>The frequency band width in which the attenuation is equal to B. B is specified by maximum value. 頻帶寬度的衰減是相等於B，B是最大限度值設定</td>
</tr>
<tr>
<td>Ripple 漣波</td>
<td>Within a pass band, the difference between maximum and minimum attenuation. 在通帶內，介於最大限度及最小限度衰減的不同</td>
</tr>
<tr>
<td>Insertion loss 插入損失 $S_{21}$</td>
<td>The transmitted power difference between a filter inserted or not. 傳輸功率的不同是在於是否有插入濾波器？</td>
</tr>
<tr>
<td>Attenuation guaranteed 保證減衰量 (Rejection)</td>
<td>The minimum attenuation guaranteed at stop band. 最低限度衰減保證是在停止通帶</td>
</tr>
<tr>
<td>Spurious response 贅餘響應</td>
<td>Minimum attenuation caused by unusual response in the stop band. 最低限度衰減是由停止通帶的不尋常反應所造成的</td>
</tr>
<tr>
<td>Terminal impedance 終端阻抗 $S_{11}$</td>
<td>A signal impedance and a load impedance of a filter. 信號阻抗及濾波器的負荷阻抗</td>
</tr>
</tbody>
</table>

![Band-Pass Filter Diagram](image-url)
**5.8GHz DR Bandpass Filter (BPF)**

- Center Frequency: 5.8GHz
- Bandwidth: 200MHz
- Insertion Loss: <2dB
- Return Loss: >10dB
• Special Filter Realization

The filter types are analyzed first in a normalized low-pass configuration. The low-pass behavior is frequency scaled to implement the remaining filter types through frequency transformation.

1. Butterworth-Type Filter (the maximally flat)

\[ IL = -\log(1 - |\Gamma_{in}|^2) = 10\log\{1 + a^2\Omega^{2N}\} \]

\(\Omega\) : the normalized frequency as introduced before.
N : denotes the order of the filter

2. Chebyshev-Type Filter (equi-ripple)

Chebyshev filter approach provides us with a steeper passband/stopband transition than Butterworth filter. But Chebyshev filter has ripple in passband/stopband.

\[ IL = 10\log\{1 + a^2T_N^2(\Omega)\} \]

\[ T_N(\Omega) = \cos\{N[\cos^{-1}(\Omega)]\} \text{, for } |\Omega| \leq 1 \]
\[ T_N(\Omega) = \cosh\{N[\cosh^{-1}(\Omega)]\} \text{, for } |\Omega| \geq 1 \]
**Kuroda's Identities**

It's important to be able to convert a partially difficult-to-implement design to a more suitable filter realized.
* (i.e., a **series** inductance implemented by a short-circuit transmission line is more complicated to realize than a **shunt** stub line.)

<table>
<thead>
<tr>
<th>Initial Circuit</th>
<th>Kuroda's Identity</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Initial Circuit Diagram" /></td>
<td><img src="image2.png" alt="Kuroda's Identity Diagram" /></td>
</tr>
<tr>
<td>$Y_C = S/Z_2$</td>
<td>$Z_{L} = SZ_1/N$</td>
</tr>
<tr>
<td><strong>Unit element</strong> $Z_1$</td>
<td><strong>Unit element</strong> $Z_2/N$</td>
</tr>
<tr>
<td><img src="image3.png" alt="Initial Circuit Diagram" /></td>
<td><img src="image4.png" alt="Kuroda's Identity Diagram" /></td>
</tr>
<tr>
<td><strong>Unit element</strong> $Z_2$</td>
<td><strong>Unit element</strong> $Z_1$</td>
</tr>
<tr>
<td>$Z_{L} = Z_1S$</td>
<td>$Z_{L} = SZ_1/N$</td>
</tr>
<tr>
<td><img src="image5.png" alt="Initial Circuit Diagram" /></td>
<td><img src="image6.png" alt="Kuroda's Identity Diagram" /></td>
</tr>
<tr>
<td>$Y_C = S/Z_2$</td>
<td>$Y_C = S/(NZ_2)$</td>
</tr>
<tr>
<td><strong>Unit element</strong> $Z_1$</td>
<td><strong>Unit element</strong> $NZ_1$</td>
</tr>
<tr>
<td><img src="image7.png" alt="Initial Circuit Diagram" /></td>
<td><img src="image8.png" alt="Kuroda's Identity Diagram" /></td>
</tr>
<tr>
<td>$Z_{L} = Z_1S$</td>
<td>$1 : N$</td>
</tr>
<tr>
<td><strong>Unit element</strong> $Z_2$</td>
<td><strong>Unit element</strong> $Z_2/N$</td>
</tr>
</tbody>
</table>

$$ N = 1 + Z_2/Z_1 $$
Example of Microstrip Filter Design

1. Select the normalized filter parameters to meet the design criteria
2. Replace the inductances and capacitances by equivalent $\lambda/8$ transmission line
3. Convert series stub lines to shunt stubs through Kuroda’s identities.
4. De-normalize and select equivalent microstrip lines (length, width, and dielectric constant)

Project 1:
Design a low-pass filter (LPF) whose input and output are matched to a 50 ohm impedance and that meets the following specification:
- cut-off frequency of 3GHz; equi-ripple of 0.5dB;
- rejection of at least 40dB at approximately twice the cut-off frequency.
(Assume a dielectric material in a phase velocity of 60% of the speed of light).

Step1:
Check the Chebyshev filter table. Find the order N=5 meet the specification:

\[ r_G = 1 \quad r_L = 1 \]
\[ C_1 = C_5 = 1.7058 \quad C_3 = 2.5408 \quad L_2 = L_4 = 1.2296 \]

Step2:
Apply Richard’s transformation

The characteristic line impedances and admittances are
\[ Y_1 = Y_5 = g_1 \quad Y_3 = g_3 \quad Z_2 = Z_4 = g_4 \]
Step 3:
Using Kuroda identities

The introduction of **unit elements** does not affect the filter performance since they are **match** to load and source impedances.
Step 4:  
Select the equivalent microstrip line

\[ v_p = 0.6c = 1.8 \times 10^8 \text{ m/s} \]

The length can be found to be 

\[ l = \frac{\lambda_c}{8} = \frac{v_p}{8f_c} = 7.5 \text{ mm} \]
Microstrip Stepped-Impedance Low-Pass Filters (Pozar MW P.470)

180° 3-dB hybrid balanced mixer with microstrip stepped-impedance LPF
Microstrip Line Coupled Filter
Microstrip Coupled Line Bandpass Filter (BPF) (Pozar MW P474)

9-9.5 GHz coupled microstrip-line BPF (FR-4 substrate)
insertion loss = 3.8 dB@9.24 GHz

*Note: This is only a simple test project which did not have a good performance due to using FR-4 substrate at 10-GHz range*