A Design Technique for distributed Dual-band bandpass Filters

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• Different methods to design Dualband RF bandpass Filters
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Motivations

• The demand for the transceivers which can simultaneously support different standards.

Fig. 1 : An architecture for concurrent dual-band receiver.

• Instead of using a circuit for each communications standard, we can reuse blocks to be shared by different standards (potential for size and cost reduction).
How to Obtain Dualband Filter?

• There are several approaches to design a Dualband Filter, such as:
  ➢ by combining two filters with different passbands and stopbands.
  ➢ by using stepped impedance resonators.
  ➢ by using Multi-Resonant Circuits (Our Proposal)
Design of Dualband Filter: Basic Design Principles

Filter A  Filter B

Filter A  Filter B

Dualband Filter
Design of Dualband Filter: Characteristics of filters

- $f_{01} = 2.45$ GHz and featuring 100 MHZ of bandwidth.
- $f_{02} = 5.8$ GHz and featuring 150 MHZ of bandwidth.
- Third order Butterworth Filters
First Passband Filter

- Consider the first passband filter centered at 2.45 GHz and featuring 100 MHz bandwidth. $Z_{in} = Z_L = 50\Omega$.

Normalized third order Butterworth Filter, with

$L = 2\text{H}$ e $C = 1\text{F}$, $Z_0 = 1\Omega$ e $\omega_0 = 1\text{ rad/s}$.

- With $L_{p1}$ and $L_{p2} = 0.1325\text{ nH}$; $C_{p1}$ and $C_{p2} = 31.8309\text{ pF}$; $L_{s1} = 159.15\text{ nH}$; $C_{s1} = 26.5147\text{ fF}$.

- Simulation Results

$S_{12} = S_{21}$
(by reciprocity features)

And

$S_{11} = S_{22}$
(by symmetry circuit)
Second Passband Filter

- Similarly, the second passband filter is designed and evaluated. So, a filter centered at 5.8 GHz and featuring 150 MHz of bandwidth is designed. $Z_{in} = Z_L = 50 \Omega$.

![Normalized third order Butterworth Filter, with $L = 2H$ e $C = 1F$; $Z_0 = 1\Omega$ e $\omega_0 = 1$ rad/s.]

- With $L_{p3}$ and $L_{p4} = 35.4834 \text{ pH}$; $C_{p3}$ and $C_{p4} = 21.2206 \text{ pF}$; $L_{s2} = 106.1032 \text{ nH}$; $C_{s2} = 7.0966 \text{ fF}$.

- Simulation Results

  $S_{12} = S_{21}$
  (by reciprocity features)

  And

  $S_{11} = S_{22}$
  (by symmetry circuit)
Combining the two Filters into just one

- Using Multi-Resonant circuits, we can get the same responses of filters.
Dualband Filter using Multi-Resonant Circuits

- Thus, using both multiresonant circuits (series and parallel ones), it was possible to create a single circuit that generates the two bandpass filters (2.45 GHz and 5.8 GHz). $Z_{in} = Z_L = 50\Omega$.

\[
Z_{in1} = \frac{s^4(L_1C_1L_2C_2) + s^3(L_1C_1 + L_1C_2 + L_2C_2) + 1}{s^4L_1C_1C_2 + sC_1}
\]
\[
C_1 = \frac{\omega_2^2a - \omega_2^2b + 1}{\lambda^2(\omega_2 - \omega_3/\omega_2)}
\]
\[
L_1 = \frac{\lambda\omega_2^2}{C_1}
\]
\[
C_2 = \frac{-C_1}{\omega_2^2 + 1 - b\omega_2^2}
\]
\[
L_2 = \frac{1}{\omega_2^2C_2}
\]
\[
a = \frac{\omega_2^2 - \omega_2^2b}{\omega_2^2b}, \quad b = \frac{\omega_2^2 - \omega_2^2}{\omega_2^2\omega_2^2 - \omega_2^2\omega_2^2}
\]

\[
Z_{in2} = \frac{s^4(L_2C_3 + L_2L_3C_3) + s(L_2 + L_3)}{s^4(L_2C_3L_4C_3) + s^2(L_2C_2 + L_4C_4) + 1}
\]
\[
C_4 = \frac{(f - \frac{a}{b})2\omega_2^2d - v\omega_2^2d}{2\omega_2^2dE - vE}
\]
\[
L_4 = \frac{\omega_4^2}{C_4}
\]
\[
C_3 = \frac{-\omega_2^2dC_4}{\omega_2^2d - EC_4}
\]
\[
L_3 = \frac{\omega_3^2}{C_3}
\]
\[
f = \frac{\omega_2^2a - \omega_2^2b}{\omega_2^2\omega_2^2 - \omega_2^2\omega_2^2}; \quad d = \frac{\omega_2^2a - 1}{\omega_2^2b}; \quad E = \frac{\lambda\omega_2^2d - \omega_2^2d^2 + 1}{\omega_2^2\omega_2^2 - \omega_2^2d^2}; \quad V = \frac{\omega_2^2 - dE}{2}; \quad E = \frac{\lambda\omega_2^2d - \omega_2^2d^2 + 1}{\omega_2^2\omega_2^2 - \omega_2^2d^2}
\]
Dualband Filter using Multi-Resonant Circuits

- Thus, using both multiresonant circuits (series and parallel ones), it was possible to create a single circuit that generates the two bandpass filters (2.45 GHz and 5.8 GHz). \( Z_{\text{in}} = Z_L = 50\Omega \).

- With \( L_1 = 61.808 \text{ nH}, C_1 = 29.307 \text{ fF}, L_2 = 48.020 \text{ nH}, C_2 = 36.530 \text{ fF}, L_3 = 35.074 \text{ pH}, C_3 = 21.468 \text{ pF}, L_4 = 0.13687 \text{ nH} \) and \( C_4 = 30.832 \text{ pF} \).
Distributed Dual-band Bandpass Filter
Distributed Dual-band Bandpass Filter

- The goal is to transform the lumped filter into a distributed one, by using reciprocators.
Distributed Dual-band Bandpass Filter

To design a distributed dual passband filter, according to our technique, we consider the following steps:

1. We first perform an impedance transformation of the series multiresonant circuit to a parallel one, by using admittance inverters

2. We obtain the equivalence between the parallel multiresonant circuits and the transmission lines.
First Step:

- Transformation of the series multiresonant circuit to a parallel one.

\[ Y_s = \frac{s^4(C_{1s}L_{1s}C_{2s}L_{2s}C_{2s}) + s^2(C_{1s}L_{1s} + L_{1s}C_{2s} + L_{2s}C_{2s}) + 1}{s^3L_{1s}L_{2s}C_{2s} + sL_{1s}} \]

\[ Y_p = \frac{s^3(C_{1p}C_{2p}L_{2p}C_{1p}L_{1p} + C_{2p}C_{1p}L_{1p}) + s(C_{1p} + C_{2p})}{s^2(C_{1p}L_{1p}C_{2p}L_{2p}) + s^2(C_{1p}L_{1p} + C_{2p}L_{2p}) + 1} \]

\[ Y_{eq} = \frac{j^2}{Y_s} = \frac{j^2}{s^3(C_{1p}C_{2p}L_{2p}C_{1p}L_{1p} + C_{2p}C_{1p}L_{1p}) + s(C_{1p} + C_{2p})}{s^2(C_{1p}L_{1p}C_{2p}L_{2p}) + s^2(C_{1p}L_{1p} + C_{2p}L_{2p}) + 1} \]
First Step:

\[ J_1 = \sqrt{\frac{C_{1p}C_{2p}(L_{1p} + L_{2p})}{L_{13}L_{23}C_{2s}}} \text{ and } J_2 = \sqrt{\frac{C_{1p} + C_{2p}}{L_{13}}} \]

\[ I_{eq} = \sqrt{J_1J_2} \]
Second Step:

- Equivalence between the parallel multiresonant circuits and the transmission lines.

\[
Z_{eq} = \frac{j Z_{01} Z_{02}}{Z_{01} \cot \frac{\pi \omega}{2\omega_1} - Z_{02} \tan \frac{\pi \omega}{2\omega_1}}
\]

\[
n = \left( \tan \frac{\pi \omega_0}{\omega_{p2} + \omega_{p1}} \right)^2
\]

\[
\omega_L = \frac{\pi \omega_0}{2 \tan^{-1} \sqrt{n}}
\]

\[
Z_{02} = X_a \cot \frac{\pi \omega_a}{2\omega_L} - \frac{X_a}{n} \tan \frac{\pi \omega_a}{2\omega_L}
\]

\[
Z_{01} = n Z_{02}
\]
Second Step:

- Using the transmission lines like inverters, we obtain all-distributed filter.

\[ Z_{03} = \frac{2}{J_{eq}} \]

\[ Z_{02} = X_a \cot \frac{\pi \omega_a}{2 \omega_L} - \frac{X_a}{n} \tan \frac{\pi \omega_a}{2 \omega_L} \]

\[ Z_{01} = nZ_{02} \]
**Results:**

- In order to validate this technique, a distributed dual-band Butterworth passband filter, centered at 2.45 GHz and 5.8 GHz, is designed with transmission lines.

![Distributed dual-band filter diagram]

- The element values of the filter:

  \[ Z_{01} = 5.5092 \ \Omega \]
  \[ Z_{02} = 3.0265 \ \Omega \]
  \[ Z_{03} = 65.23 \ \Omega \]

  \[ \omega_L = 4.125 \ \text{GHz} \]
  \[ \omega_{03} = 4.125 \ \text{GHz} \]
Results:

- Simulation results (S21 and S11) of all-distributed and lumped dual-band bandpass filter
Results:

- To avoid low line characteristic impedances, the two filters are designed with wider bandwidth:
  - \( BW = 1 \text{ GHz} \), \( Z_{01} = 52 \Omega \), \( Z_{02} = 28 \Omega \) and \( Z_{03} = 60.4 \Omega \)

- Simulation assuming a realization on ROGERS RT/Duroid 5880 substrate.

\[
\begin{align*}
\text{m4} & \quad \text{freq}=2.45 \text{ GHz} \\
S(2,1) &= -0.176 \text{ dB} \\
\text{m6} & \quad \text{freq}=5.8 \text{ GHz} \\
S(2,1) &= -0.206 \text{ dB} \\
\text{m3} & \quad \text{freq}=2.45 \text{ GHz} \\
S(1,1) &= -20.649 \text{ dB} \\
\text{m5} & \quad \text{freq}=5.8 \text{ GHz} \\
S(1,1) &= -29.077 \text{ dB}
\end{align*}
\]
Results:

- Using the values obtained assuming a realization on ROGERS RT/Duroid 5880 substrate, was possible to manufacturing the filter, as show below:
Results:

- Measurement results of $S_{21}$ and $S_{11}$ using the Network Analyzer:
Results:

- Measurement results of $S_{21}$ and $S_{11}$ using the Network Analyzer:
Results:

- Measurement results of $S_{21}$ and $S_{11}$ using the Network Analyzer:
Results:

- Measurement results of $S_{21}$ and $S_{11}$ using the Network Analyzer:
Results:

- Comparison between the $S_{21}$ and $S_{11}$ simulated and measured:
Conclusions

• By using this technique, it is possible to previously specify the filter characteristics, once the filters are individually designed and then combined into just one. This is an advantage over the other methods.

• In order to validate this technique, a distributed dual-band Butterworth passband filter, centered at 2.45 GHz and 5.8 GHz, is designed with transmission lines and evaluated, whose results are in good agreement with those previously established for the filter.

• In conclusion, it is also possible to explore this technique to design a passband filter possessing more than two bands.
Thank You

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