A Design Technique for distributed Dual-band bandpass Filters

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Outline

- Motivations
- Different methods to design Dualband RF bandpass Filters
- Dualband Filter using Multiresonant Circuits
- Distributed Dual-band Bandpass Filter
- Results
- Conclusions

Motivations

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

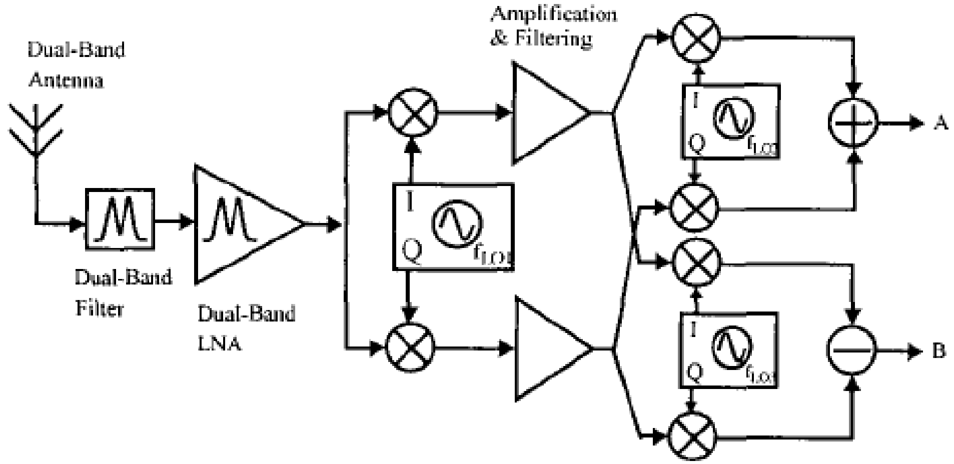
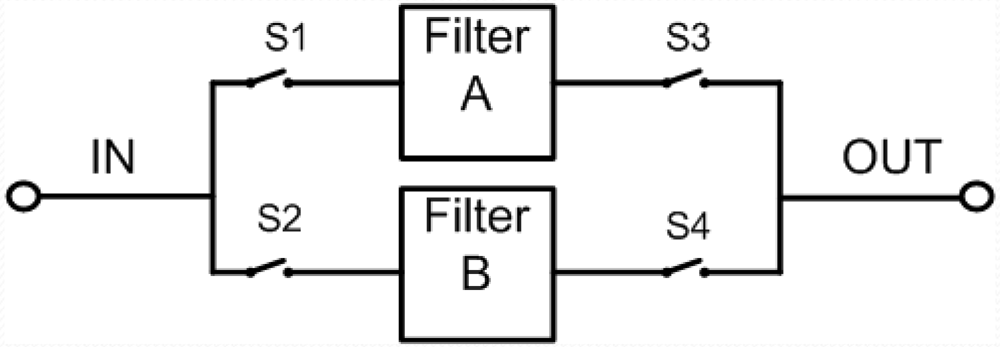


Fig. 1 : An architecture for concurrent dual-band receiver.

- 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?

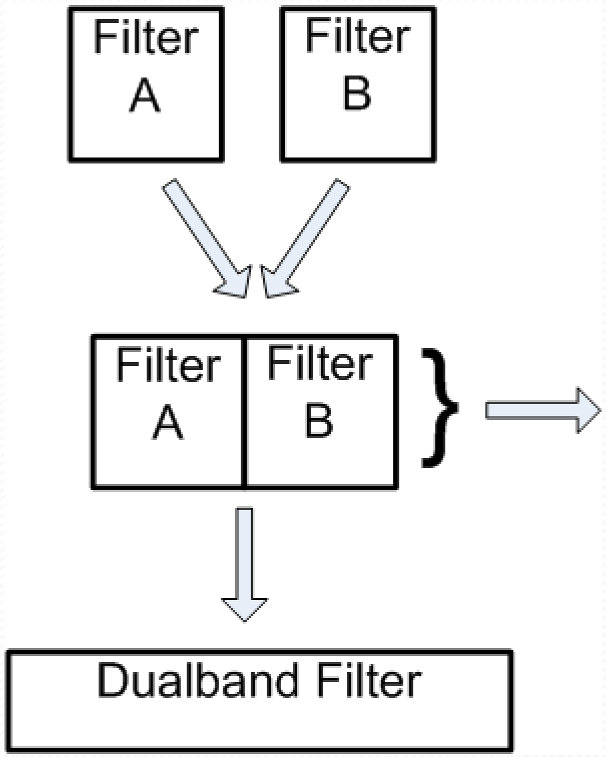
- There are several approaches to design a Dualband Filter, such as:
  - by combining two filters with different passbands and stopbands.



  - by using stepped impedance resonators.

  - by using Multi-Resonant Circuits (Our Proposal)

Design of Dualband Filter: Basic Design Principles



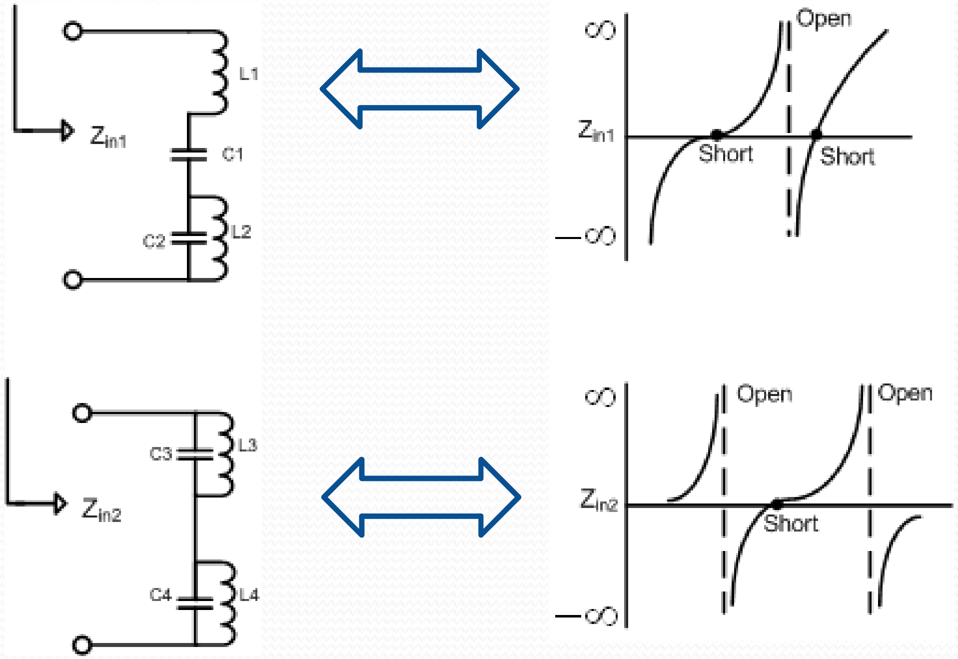
Filter A

Filter B

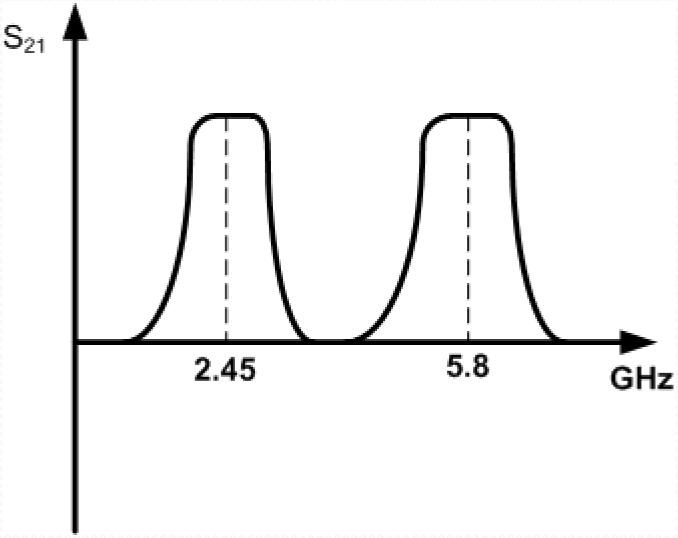
Filter A

Filter B

Dualband Filter



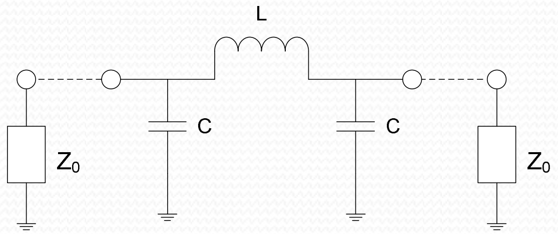
Design of Dualband Filter: Characteristics of filters



- 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

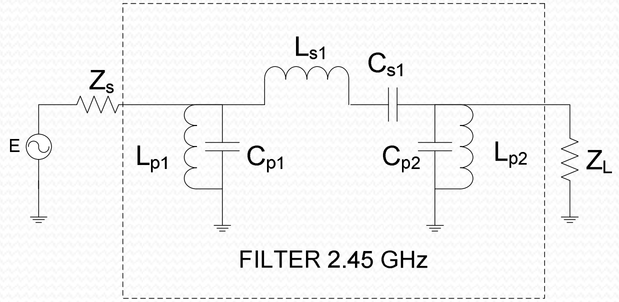
- Consider the first passband filter centered at 2.45 GHz and featuring 100 MHz bandwidth. $Z_{in} = Z_L = 50\Omega$.



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

Low pass to bandpass

filter transformation



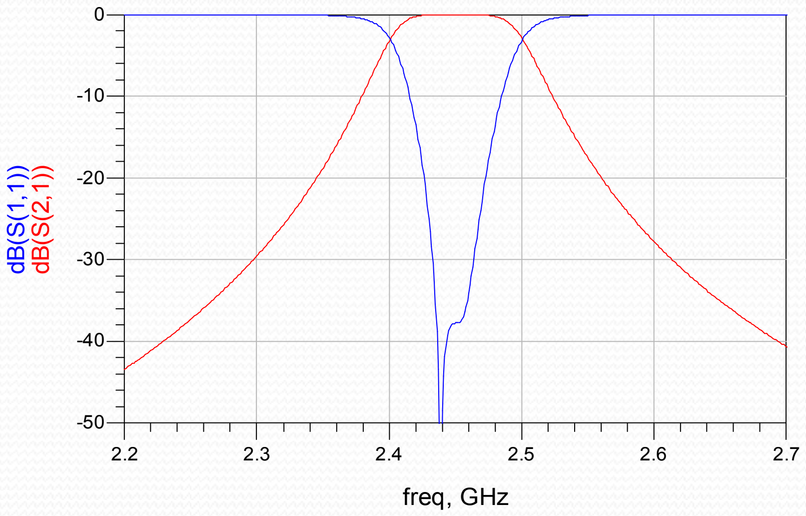
- With L_{p1} and L_{p2} = 0.1325 nH; C_{p1} and C_{p2} = 31.8309 pF; L_{s1} = 159.15 nH; C_{s1} = 26.5147 fF.

- Simulation Results

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

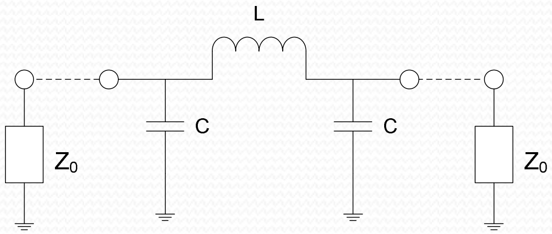
And

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



Second Passband Filter

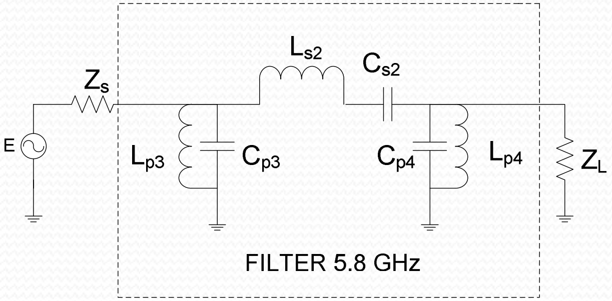
- Similarly, the second passband filter is designed and evaluated. So, a filter centered at 5.8 GHz and featuring 150 MHz of bandwidth is designed. $Z_{in} = Z_L = 50\Omega$.



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

Low pass to bandpass

filter transformation



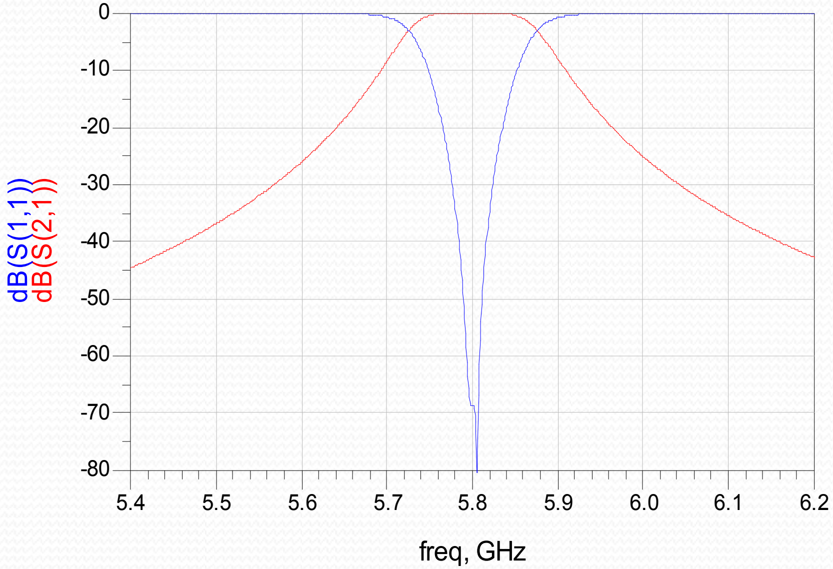
- With L_{p3} and L_{p4} = 35.4834 pH; C_{p3} and C_{p4} = 21.2206 pF; L_{s2} = 106.1032 nH; C_{s2} = 7.0966 fF.

- Simulation Results

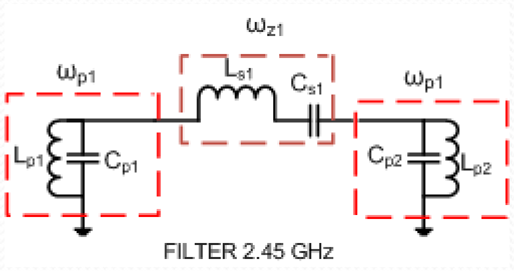
$S_{12} = S_{21}$
(by reciprocity features)

And

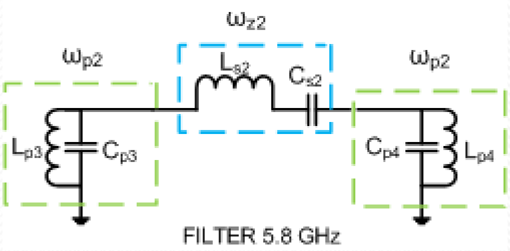
$S_{11} = S_{22}$
(by symmetry circuit)



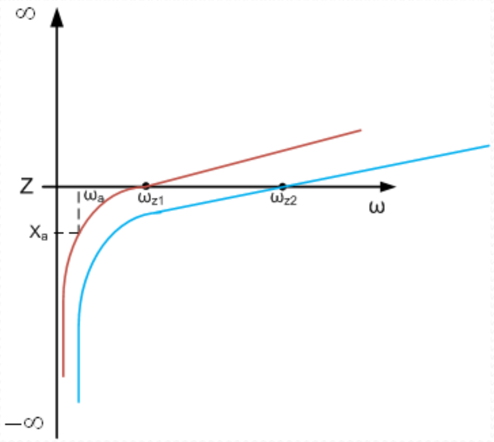
Combining the two Filters into just one

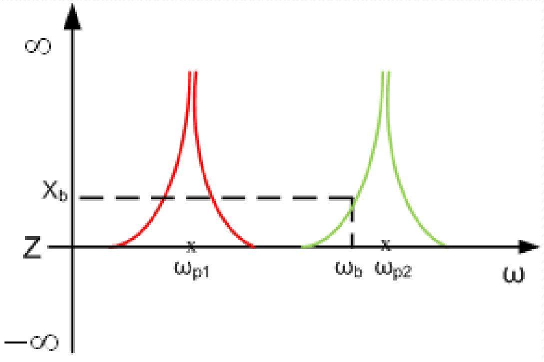


FILTER 2.45 GHz

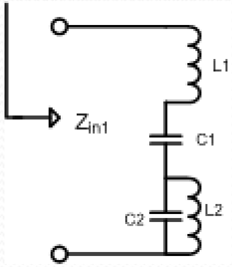


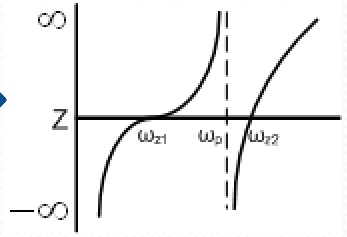
FILTER 5.8 GHz

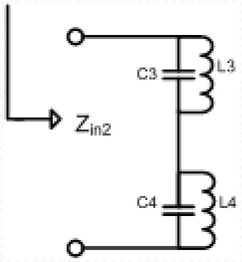


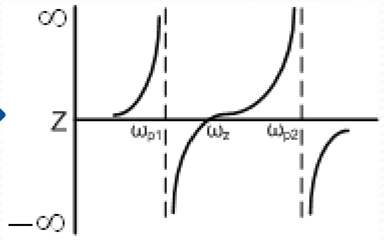


- Using Multi-Resonant circuits, we can get the same responses of filters.



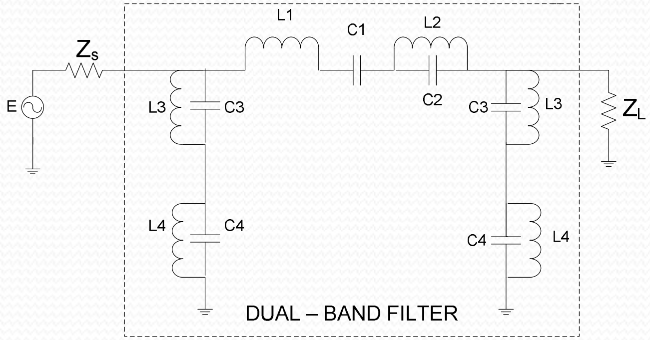






Dualband Filter using Multi-Resonant Circuits

- 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). $Z_{in} = Z_L = 50\Omega$.



$$Z_{in1} = \frac{s^4(L_1C_1L_2C_2) + s^2(L_1C_1 + L_2C_2 + L_2C_1) + 1}{s^3L_2C_1C_2 + sC_1}$$

$$\boldsymbol{C_1} = \frac{\omega_a^4 a - \omega_a^2 b + 1}{X\left(\omega_a - \frac{\omega_a^3}{\omega_p^2}\right)}$$

$$\boldsymbol{L_1} = \frac{a\omega_p^2}{C_1}$$

$$\boldsymbol{C_2} = \frac{-C_1}{a\omega_p^4 + 1 - b\omega_p^2}$$

$$\boldsymbol{L_2} = \frac{1}{\omega_p^2 C_2}$$

$$a = \frac{b\omega_{z1}^2 - 1}{\omega_{z1}^4};\ b = \frac{\omega_{z2}^4 - \omega_{z1}^4}{\omega_{z1}^2\omega_{z2}^4 - \omega_{z2}^2\omega_{z1}^4}$$

$$Z_{in2} = \frac{s^3(L_3L_4C_4 + L_3L_4C_3) + s(L_3 + L_4)}{s^4(L_3C_3L_4C_4) + s^2(L_3C_3 + L_4C_4) + 1}$$

$$\boldsymbol{C_4} = \frac{\left(f - \frac{v}{2}\right)2\omega_z^2 d - v\omega_z^2 d}{2\omega_z^2 dE - vE}$$

$$\boldsymbol{L_4} = \frac{d\omega_{p1}^2}{C_4}$$

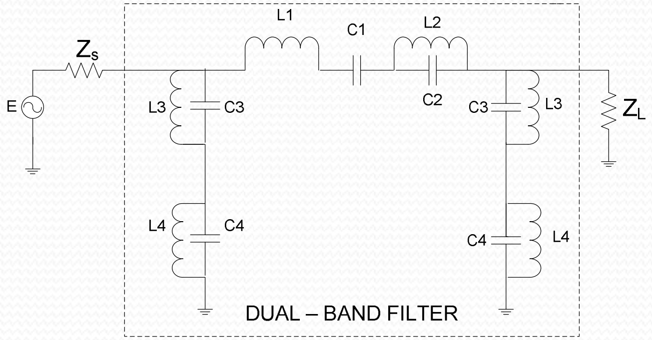
$$\boldsymbol{C_3} = \frac{-\omega_z^2 d C_4}{\omega_z^2 d - EC_4}$$

$$\boldsymbol{L_3} = \frac{d\omega_{p2}^2}{C_3}$$

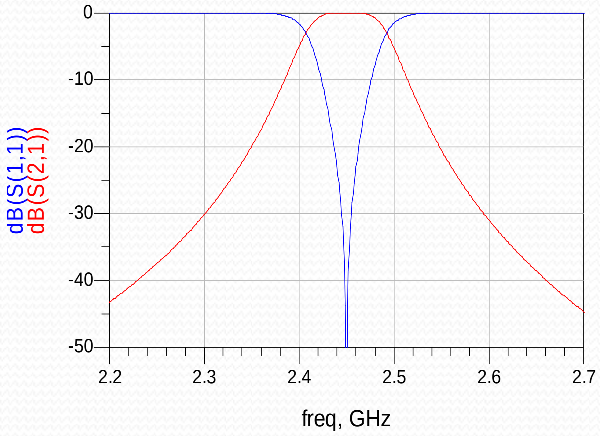
$$f = \frac{\omega_{p2}^4 - \omega_{p1}^4}{\omega_{p1}^2\omega_{p2}^4 - \omega_{p2}^2\omega_{p1}^4};\ d = \frac{f\omega_{p1}^2 - 1}{\omega_{p1}^4};\ v = \frac{f - \sqrt{f^2 - 4d}}{2};\ E = \frac{X\omega_z^2(\omega_b^4 d - \omega_b^2 f + 1)}{\omega_b\omega_z^2 - \omega_b^3}$$

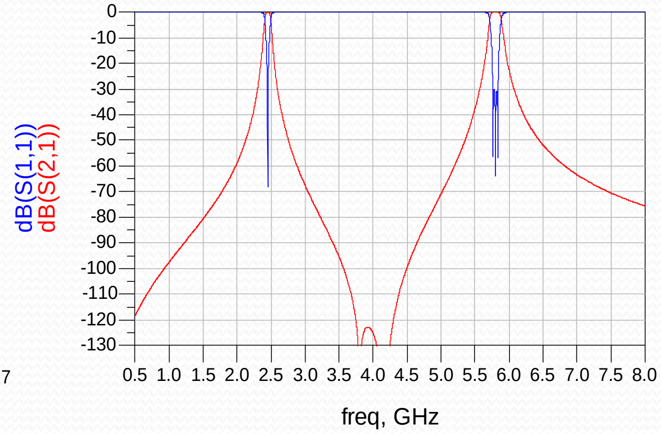
Dualband Filter using Multi-Resonant Circuits

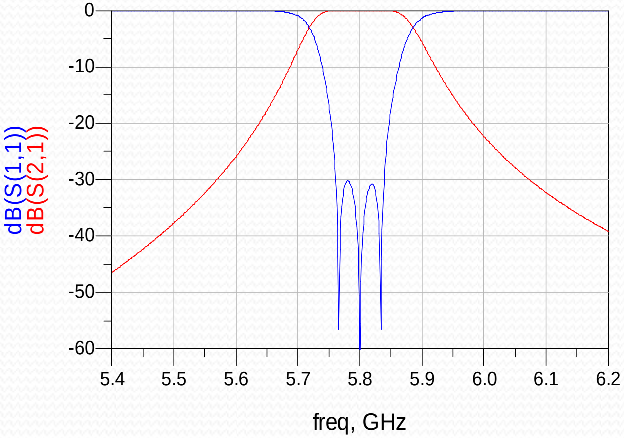
- Thus, using both multiresonant circuits (series and parallel ones), it was possible to create a single circuit that generates the two bandpass filters (2.45 GHz and 5.8 GHz). $Z_{in} = Z_L = 50\Omega$.



- With $\mathbf{L_1} = 61.808$ nH, $\mathbf{C_1} = 29.307$ fF, $\mathbf{L_2} = 48.020$ nH, $\mathbf{C_2} = 36.530$ fF, $\mathbf{L_3} = 35.074$ pH, $\mathbf{C_3} = 21.468$ pF, $\mathbf{L_4} = 0.13687$ nH and $\mathbf{C_4} = 30.832$ pF.



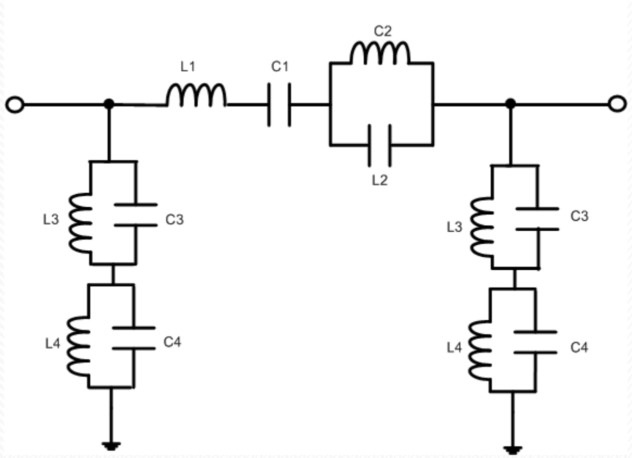




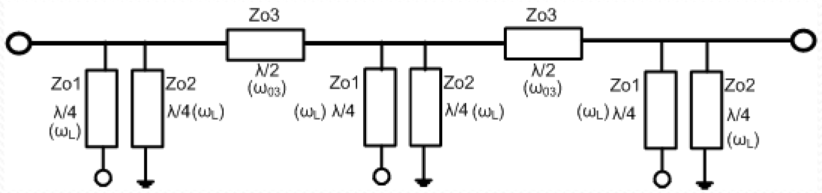
Distributed Dual-band Bandpass Filter

Distributed Dual-band Bandpass Filter

- The goal is to transform the lumped filter into a distributed ones, by using reciprocators.



Lumped Filter



Distributed Filter

Distributed Dual-band Bandpass Filter

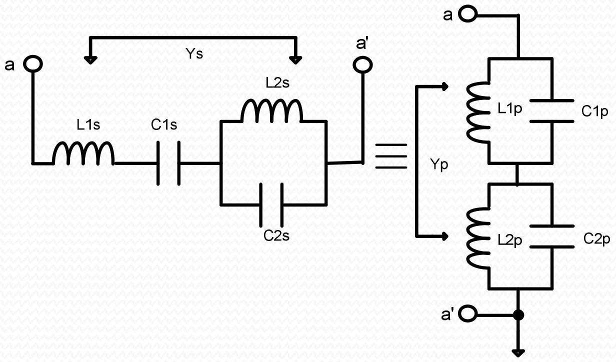
- To design a distributed dual passband filter, according to our technique, we consider the following steps:

  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.

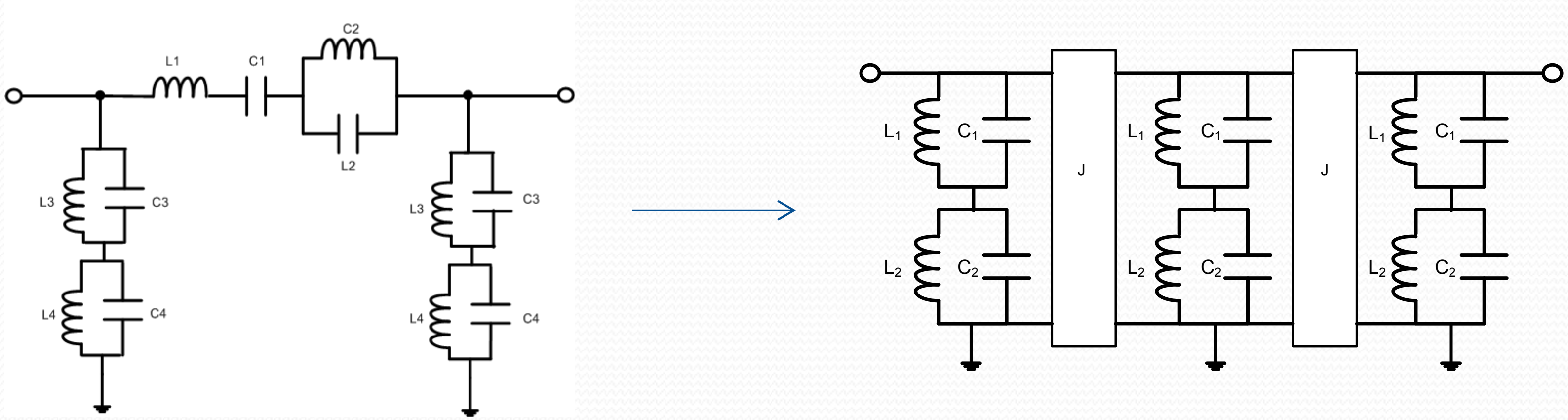


$$Y_s = \frac{s^4(L_{1s}C_{1s}L_{2s}C_{2s}) + s^2(L_{1s}C_{1s} + L_{1s}C_{2s} + L_{2s}C_{2s}) + 1}{s^3 L_{1s}L_{2s}C_{2s} + sL_{1s}}$$

$$Y_p = \frac{s^3(C_{1p}C_{2p}L_{2p} + C_{2p}C_{1p}L_{1p}) + s(C_{1p} + C_{2p})}{s^4(C_{1p}L_{1p}C_{2p}L_{2p}) + s^2(C_{1p}L_{1p} + C_{2p}L_{2p}) + 1}$$

$$\longrightarrow \quad Y_{eq} = \frac{J^2}{Y_s} = \frac{J^2\left[s^3(C_{1p}C_{2p}L_{2p} + C_{2p}C_{1p}L_{1p}) + s(C_{1p} + C_{2p})\right]}{s^4(C_{1p}L_{1p}C_{2p}L_{2p}) + s^2(C_{1p}L_{1p} + C_{2p}L_{2p}) + 1}$$

First Step:

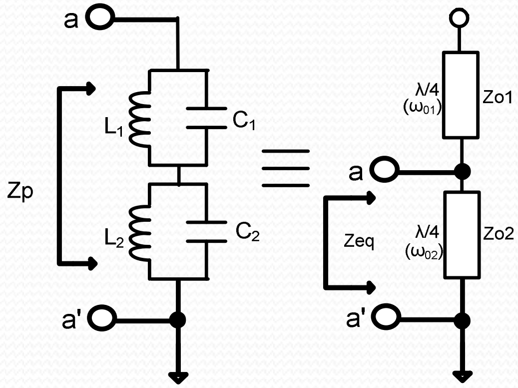


$$J_1 = \sqrt{\frac{C_{1p}C_{2p}(L_{1p}+L_{2p})}{L_{1s}L_{2s}C_{2s}}} \text{ and } J_2 = \sqrt{\frac{C_{1p}+C_{2p}}{L_{1s}}}$$

$$J_{eq} = \sqrt{J_1 J_2}$$

Second Step:

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



$$Z_{eq} = \frac{j\,Z_{01}Z_{02}}{Z_{01}\cot\frac{\pi\omega}{2\omega_L} - Z_{02}\tan\frac{\pi\omega}{2\omega_L}}$$

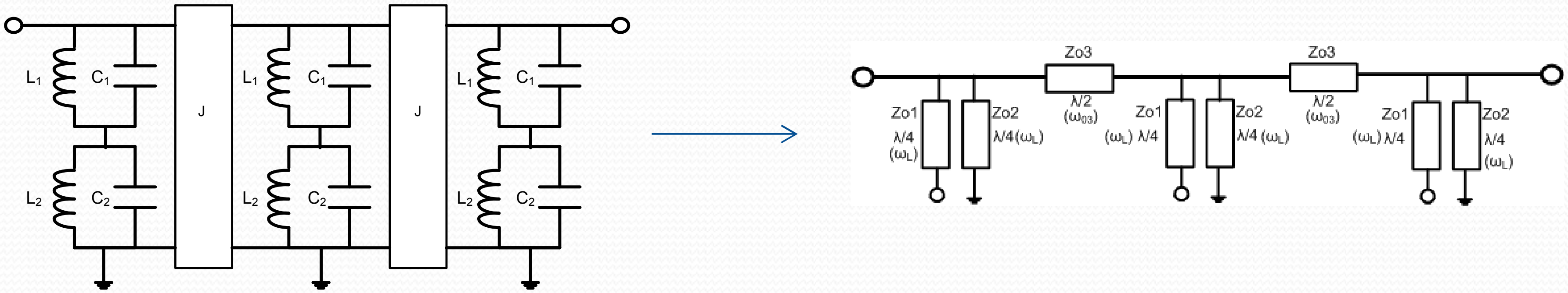
$$n = \left(\tan\frac{\pi\omega_{p1}}{\omega_{p2}+\omega_{p1}}\right)^2$$

$$\omega_L = \frac{\pi\omega_{p1}}{2\tan^{-1}\sqrt{n}}$$

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

$$Z_{01} = nZ_{02}$$

Second Step:



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

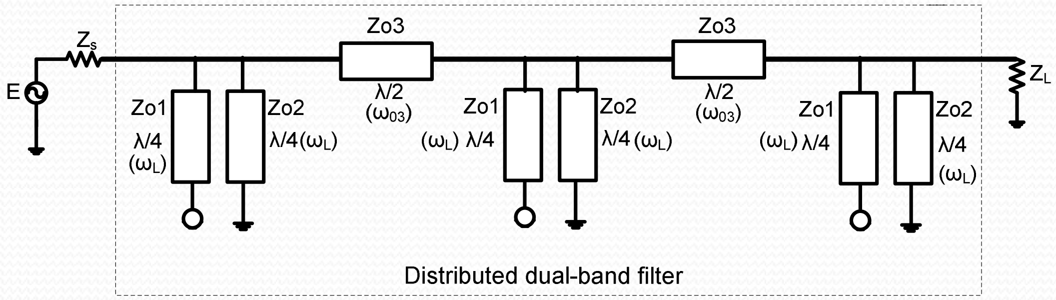
$$Z_{03} = \frac{2}{J_{eq}}$$

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

$$Z_{01} = nZ_{02}$$

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.



- The element values of the filter:

$Z_{01} = 5.5092\ \Omega$

$Z_{02} = 3.0265\ \Omega$

$Z_{03} = 65.23\ \Omega$

$\omega_L = 4.125\ \text{GHz}$

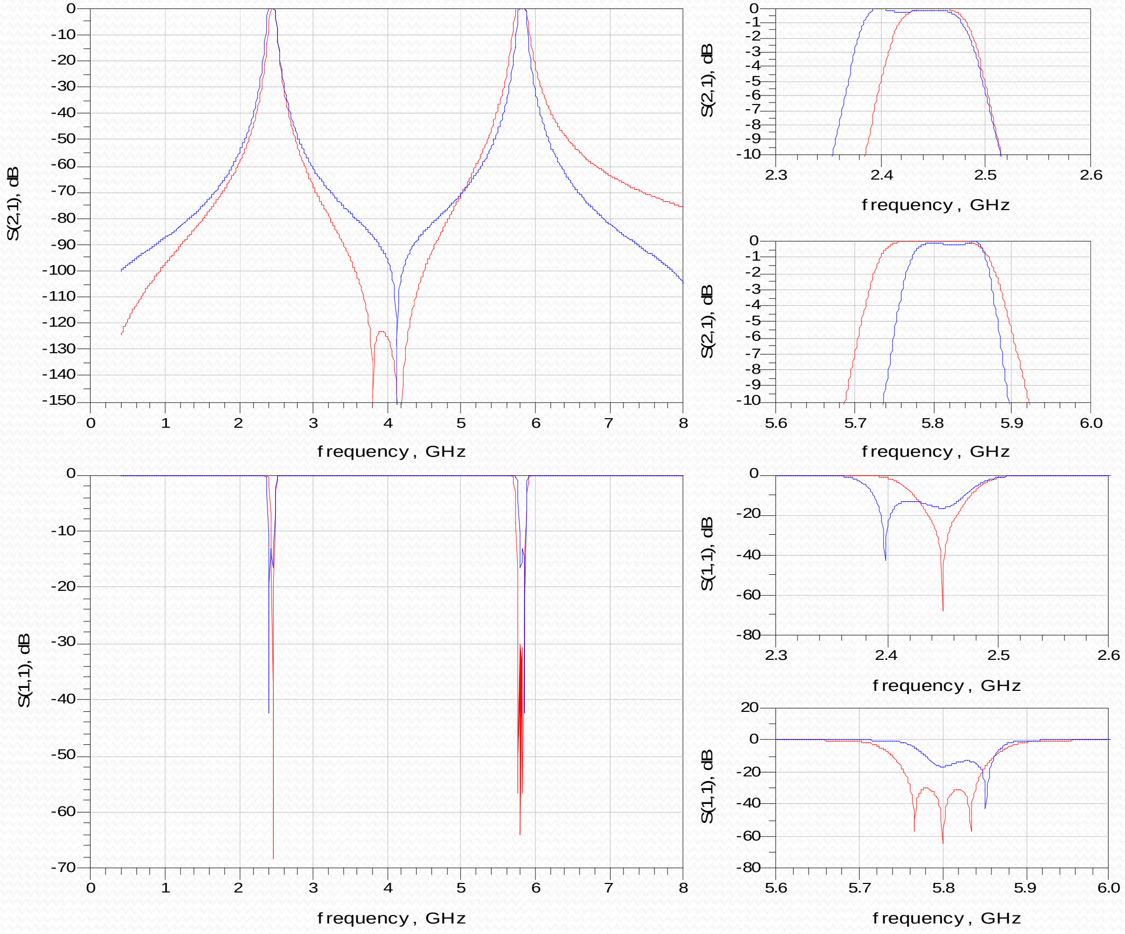
$\omega_{03} = 4.125\ \text{GHz}$

Results:

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

Lumped Filter (red)

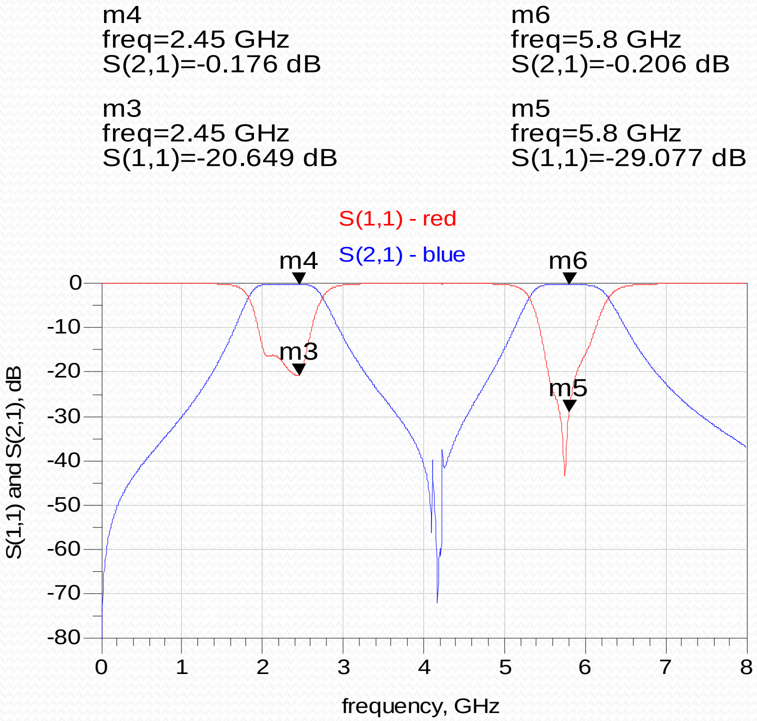
Distributed Filter (blue)



Results:

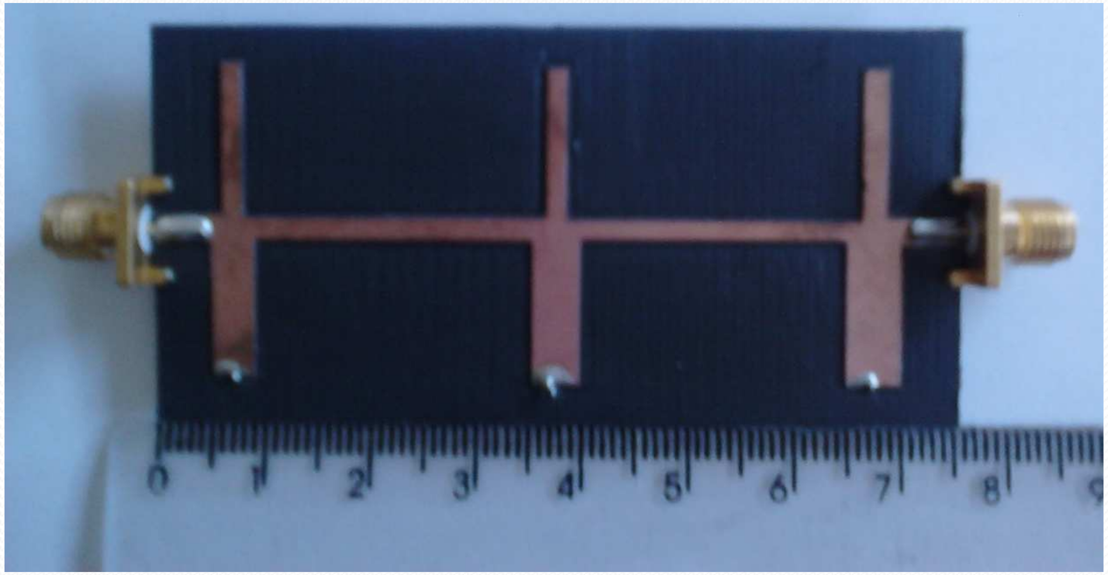
- To avoid low line characteristic impedances, the two filters are designed with wider bandwidth:
  - BW = 1 GHz, Z_{01} = 52 Ω, Z_{02} = 28 Ω and Z_{03} = 60.4 Ω

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



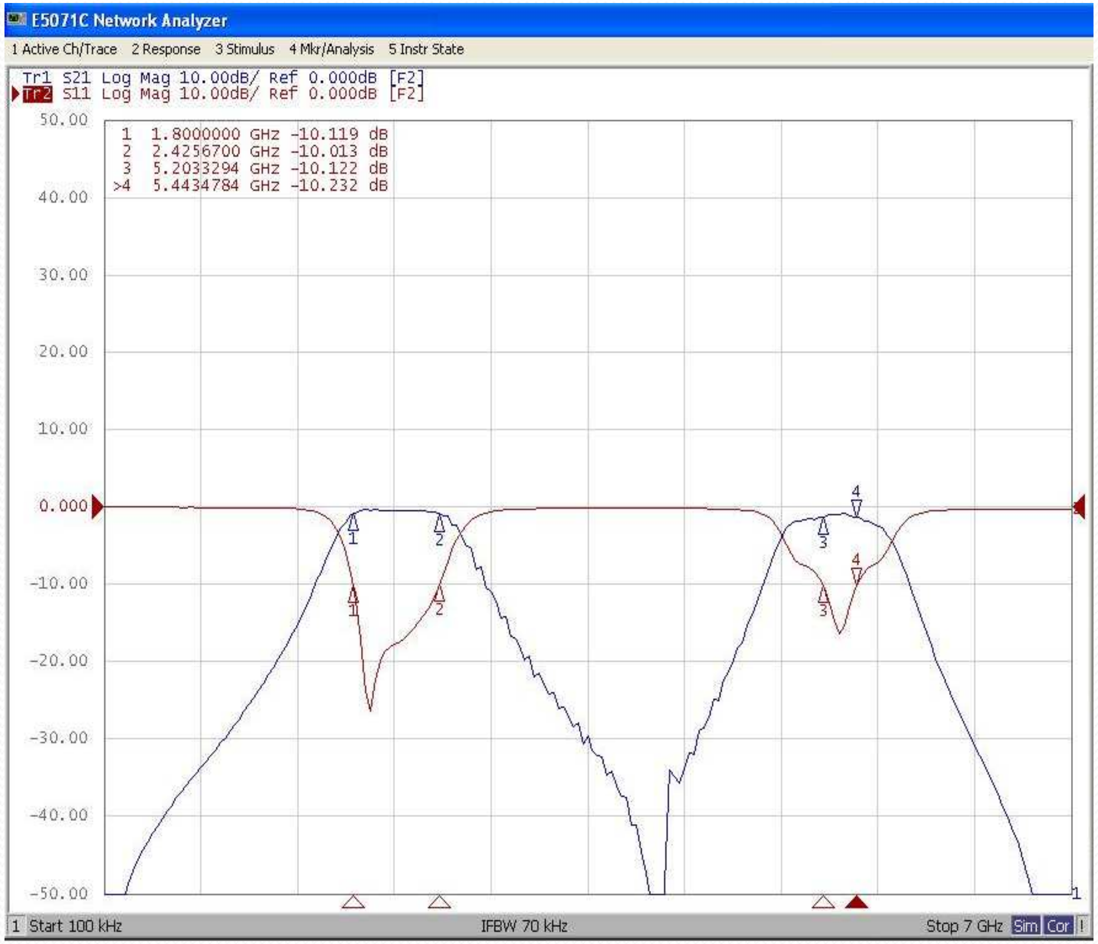
Results:

- 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:

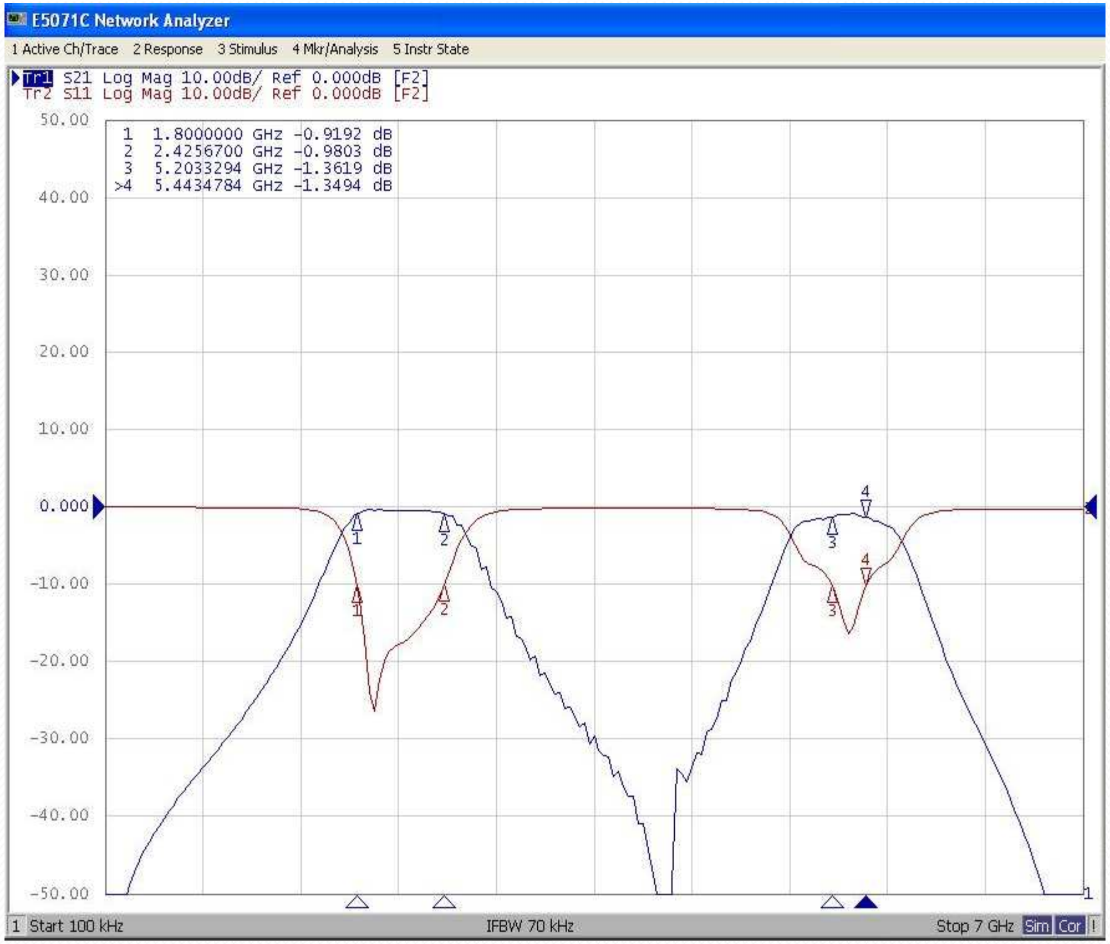


```
Tr1 S21 Log Mag 10.00dB/ Ref 0.000dB [F2]
Tr2 S11 Log Mag 10.00dB/ Ref 0.000dB [F2]
```

```
 1   1.8000000 GHz -10.119 dB
 2   2.4256700 GHz -10.013 dB
 3   5.2033294 GHz -10.122 dB
>4   5.4434784 GHz -10.232 dB
```

Results:

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



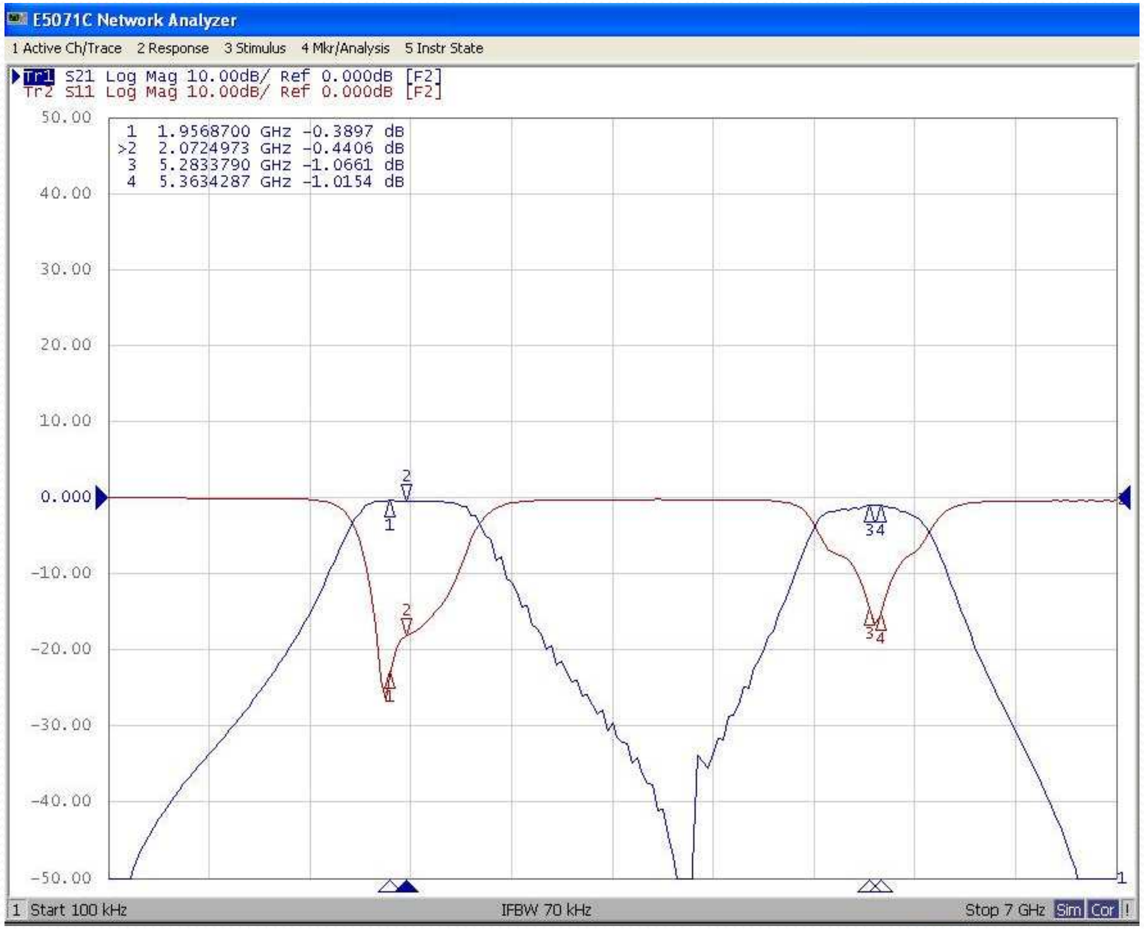
```
Tr1 S21 Log Mag 10.00dB/ Ref 0.000dB [F2]
Tr2 S11 Log Mag 10.00dB/ Ref 0.000dB [F2]
```

```
 1   1.8000000 GHz -0.9192 dB
 2   2.4256700 GHz -0.9803 dB
 3   5.2033294 GHz -1.3619 dB
>4   5.4434784 GHz -1.3494 dB
```

```
1 Start 100 kHz          IFBW 70 kHz          Stop 7 GHz
```

Results:

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

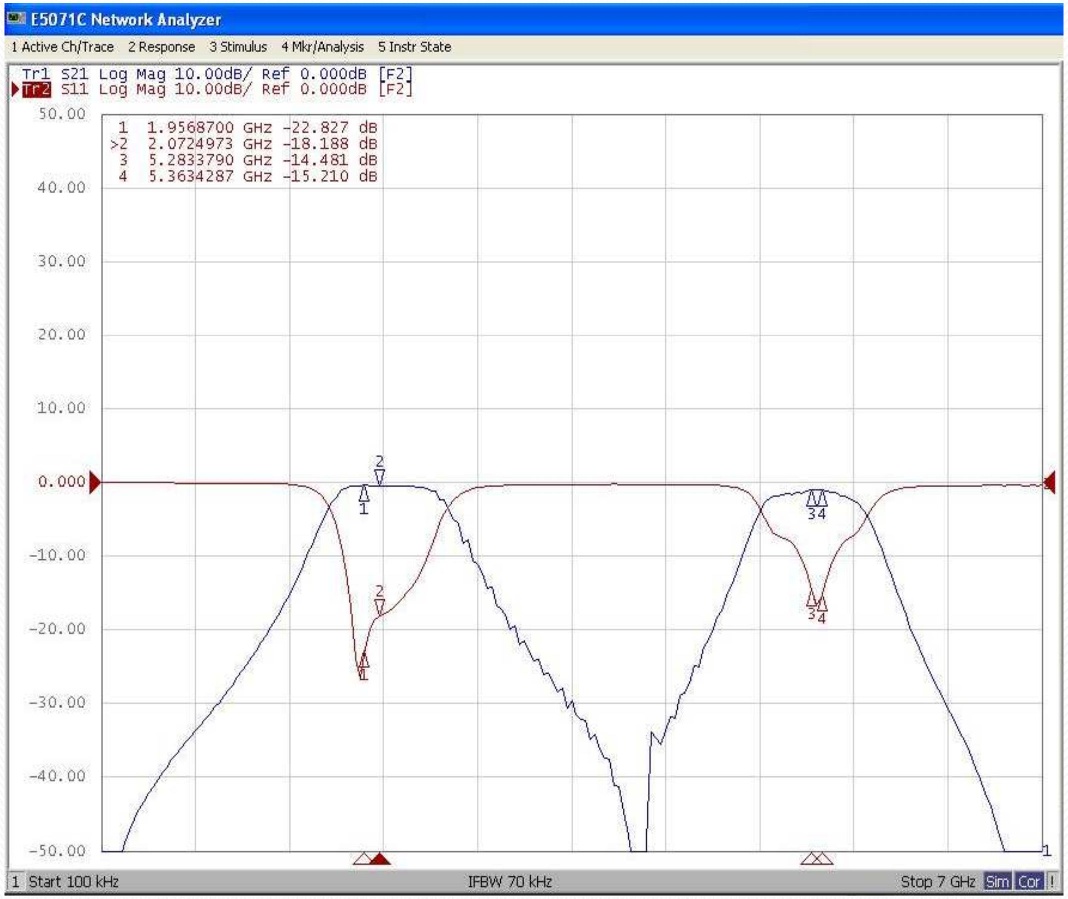


```
Tr1 S21 Log Mag 10.00dB/ Ref 0.000dB [F2]
Tr2 S11 Log Mag 10.00dB/ Ref 0.000dB [F2]
```

```
 1   1.9568700 GHz -0.3897 dB
>2   2.0724973 GHz -0.4406 dB
 3   5.2833790 GHz -1.0661 dB
 4   5.3634287 GHz -1.0154 dB
```

Results:

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

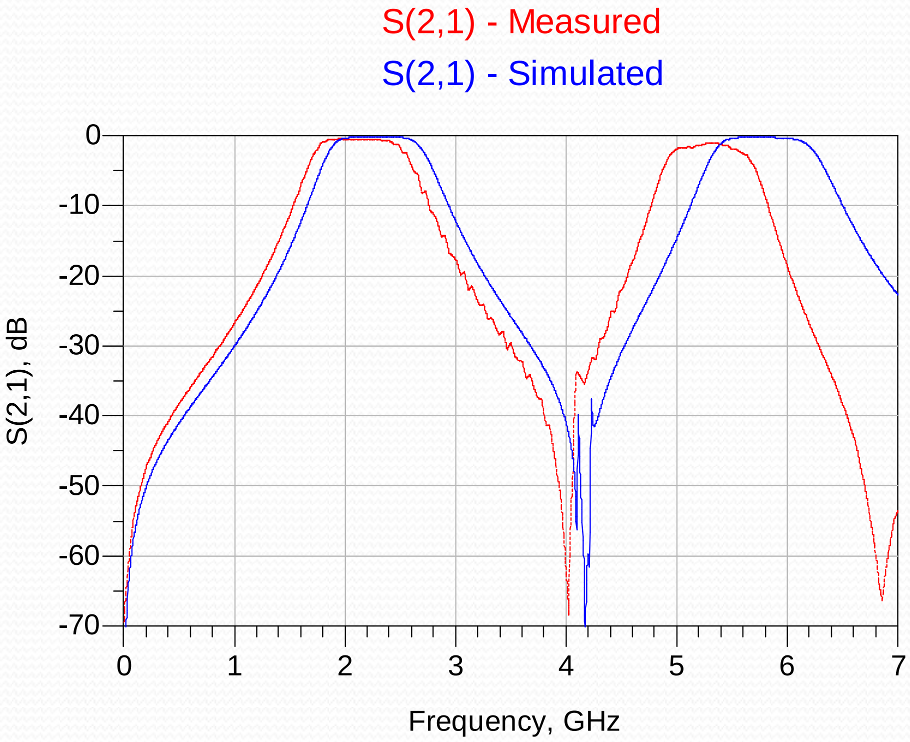


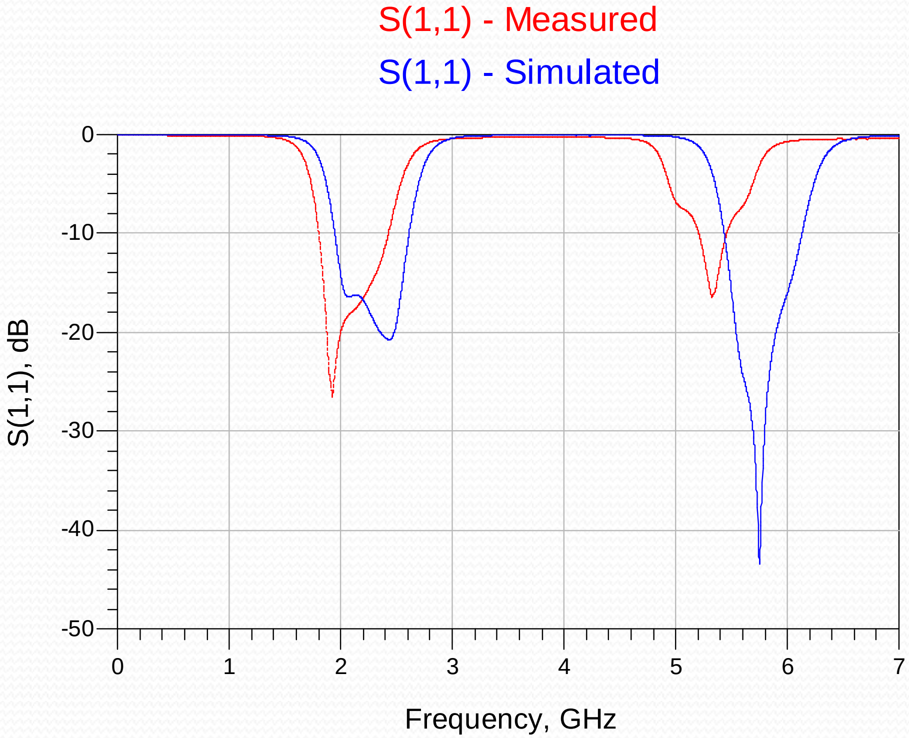
```
Tr1 S21 Log Mag 10.00dB/ Ref 0.000dB [F2]
Tr2 S11 Log Mag 10.00dB/ Ref 0.000dB [F2]
```

```
 1  1.9568700 GHz -22.827 dB
>2  2.0724973 GHz -18.188 dB
 3  5.2833790 GHz -14.481 dB
 4  5.3634287 GHz -15.210 dB
```

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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